French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load

Water Quality Study Design (Quality Assurance Project Plan)

August 2012

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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/1203114.html.

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Study Codes

Data for this project are available at Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim. Search User Study ID is TSWA0004.

Activity Tracker Code (Environmental Assessment Program) is 12-067.

TMDL Study Code (Water Quality Program) is FREP07MP.

Federal Clean Water Act 2008 303(d) Listings Addressed in this Study: See Table 1

Water Body Numbers:

Water body	River mile	WBID number
Pilchuck River	0-26.8	WA-07-1030
Pilchuck River	26.8-headwaters	WA-07-1040
French Creek	0-headwaters	WA-07-1052

Cover photo: Pilchuck River at Robe-Menzel Road.

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EAP: Washington State Department of Ecology Environmental Assessment Program
EIM: Washington State Department of Ecology Environmental Information Management database
EPA: U.S. Environmental Protection Agency
WQP: Washington State Department of Ecology Water Quality Program

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Abstract

Stream segments within the French Creek and Pilchuck River watersheds were included on the Washington State 2008 303(d) list of impaired water bodies for temperature, dissolved oxygen, and pH violations of water quality standards. The Washington State Department of Ecology (Ecology) is required under Section 303(d) of the federal Clean Water Act to develop and implement total maximum daily loads (TMDLs) for impaired waters of the state.

As a part of the TMDL for French Creek and the Pilchuck River (Snohomish County), this technical study will evaluate 303(d)-listed parameters in the watershed by:

- Conducting two critical-period (summer 2012) streamflow, dissolved oxygen, pH, and nutrient synoptic surface-water surveys.
- Installing surface-water thermistors from June to October, 2012.
- Conducting riparian habitat and channel geometry surveys.

Dissolved oxygen, pH, and temperature will be modeled by the contractor using a combined Shade-HSPF-QUAL2Kw modeling system. Modeling results will form the basis for allocating contaminant loads to pollutant sources.

The goal of the TMDL project is to ensure that French Creek and the Pilchuck River and their tributaries attain water quality standards for stream temperature, dissolved oxygen, and pH. After completion of the study, a Water Quality Improvement Report and Implementation Plan will be published, describing the results and corrective actions needed to attain 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 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 beneficial uses, such as for protection of cold water biota and drinking water supply, and (2) criteria, usually numeric limits, 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.

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

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

Category 2 – Waters of concern.

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

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

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

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

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. See Water Quality Program Policy 1-11, Ch. 2, "Ensuring Credible Data for Water Quality Management." (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf).

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 water quality standards.

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 and Implementation Plan* (WQIR/WQIP).

Who Should Participate in this TMDL?

This TMDL will set point and nonpoint source pollutant load targets in the area shown in Figure 1. Nonpoint pollution comes from diffuse sources and all upstream watershed areas have potential to affect downstream water quality. All potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. Therefore, all landowners with the potential to contribute nonpoint pollution should participate in this TMDL. Key representatives of landowners with potential nonpoint pollution sources include the Snohomish Conservation District and the French Slough Flood Control District (FSFCD).

Similarly, all point source dischargers in the watershed must also comply with the TMDL. Point source dischargers that must participate in this TMDL include the cities of Granite Falls, Snohomish, Lake Stevens, Monroe, and Marysville as well as Snohomish County, the Washington State Department of Transportation, and any other identified general or individual National Pollution Discharge Elimination System (NPDES) permittees that are identified as potential pollution sources. Granite Falls Wastewater Treatment Plant (WWTP) is the only individual NPDES permit holder identified as discharging into these watersheds at this time.

Ecology also anticipates strong participation by the Tulalip Tribes and a number of nonprofit organizations involved in instream and riparian restoration projects and possibly other stakeholder groups.

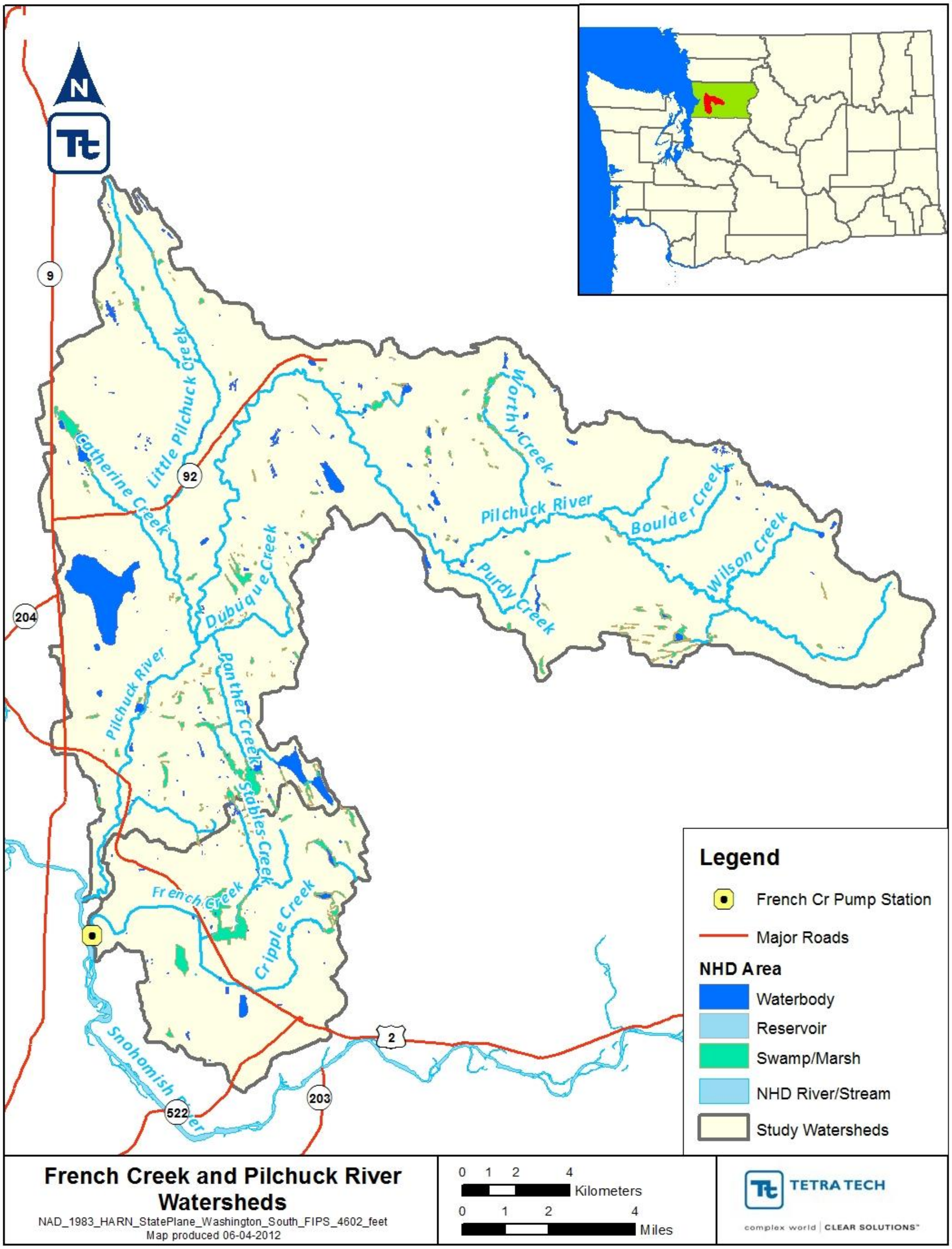

Figure 1. Study area for the French Creek and Pilchuck River Watersheds TMDL study.

Elements the Clean Water Act Requires in a TMDL

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

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

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

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

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

Why is Ecology Conducting a TMDL Study in This Watershed?

Background

The French Creek and Pilchuck River watersheds are impaired by high fecal coliform (FC) bacteria levels, high water temperatures, low pH levels, and low dissolved oxygen (DO) levels. Ecology addressed bacteria pollution problems in the Snohomish River Tributaries Fecal Coliform (FC) Bacteria TMDL (Wright et al., 2001) and its implementation plan (Svrjcek, 2003).

High water temperatures and low DO levels are both detrimental to fish and other native species that depend on cool, well-oxygenated water. These watersheds are at the upper end of the tidal portion of the Snohomish River Watershed and are valuable fishery resources. Data on high water temperatures and low DO levels in these watersheds became more available in the early 1990s (Tooley et al., 1990; Thornburgh et al., 1991) and expanded over the next decade (Thornburgh, 1997; Thornburgh and Williams, 2000). These data sources resulted in water segments within these two watersheds being included on the 303(d) list. In recent years, additional data have indicated more widespread impairments. In response to these listings and newer data, Ecology is initiating this TMDL study.

During the 2004 and 2009 WRIA 7 water quality scoping processes, Ecology consulted with watershed advisors and determined the existing bacteria TMDL should continue to be implemented in the French Creek and Pilchuck River watersheds to reduce both bacteria and nutrient loading problems that can lead to low DO levels. Grant applicants and Ecology looked for opportunities to improve riparian vegetation levels as part of proposed projects.

Ecology has provided funds for two Snohomish Conservation District projects for work in these basins. Ecology also provided funds to the cities of Monroe, Lake Stevens, and Marysville and the FSFCD to purchase DO meters and perform FC bacteria testing within their jurisdictions. More recently, Ecology placed the Adopt-A-Stream Foundation on its draft offer list for door-to-door outreach in the Little Pilchuck Creek basin.

In mid 2011, regional priorities for new TMDL starts were focused on other higher priority impaired areas. However, EPA made new funding available later in the year and Ecology chose to start the French Creek and Pilchuck River TMDLs ahead of schedule.

Improving water quality in the French Creek and Pilchuck River watersheds is necessary for the recovery of threatened cold water fish species that spawn, rear, or live there. The Pilchuck River supports Chinook, Coho, Sockeye, Chum, and Pink Salmon as well as bull trout and steelhead. French Creek supports Coho salmon and both resident and sea-run cutthroat trout. These fish species are highly valued by many state residents for cultural, recreational, or economic reasons.

The goal of this Quality Assurance Project Plan (QAPP) is to characterize water temperatures, DO, pH, and the watershed processes that affect those parameters, determine the TMDL of pollutants that will allow those parameters to meet the water quality standards, and to establish load and wasteload allocations for the heat and pollution sources that will comply with the TMDL.

The study outputs are designed to support the development of corrective actions needed to meet water quality standards for river water temperatures, DO concentrations, and pH levels, which will be detailed in a Water Quality Improvement Report and Implementation Plan (WQIR/ WQIP). The Improvement and Implementation Plan will help guide Ecology and other stakeholders in work to restore and protect aquatic life uses set forth in WAC 173-201A. This study will also contribute towards implementing the Puget Sound Action Agenda, the WRIA 7 Chinook Salmon Recovery Plan, and the anticipated Threatened Steelhead Trout Recovery Plan currently under development.

Study Area

The study area for this TMDL includes French Creek and the Pilchuck River and their tributaries upstream of the Snohomish River (Figure 1). Both of these subwatersheds fall within Water Resource Inventory Area (WRIA) 7.

Beneficial Uses

The main beneficial uses in French Creek and its tributaries to be protected by this TMDL include:

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

Similarly, the main beneficial uses in the Pilchuck River and its tributaries are:

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

Impairments Addressed by this TMDL

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

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

Water Body	Parameter	Listing ID
Pilchuck River	pH	7294
	Temperature	7295
Little Pilchuck Creek	pH	40817
Catherine Creek	Temperature	7395
Unnamed tributary to Pilchuck River	Dissolved Oxygen	47441
French Creek	Dissolved Oxygen	7272
		7276
		40743
	pH	7273
		7282
		40748
	Temperature	10640
		9273

This study will be looking at these watersheds more thoroughly and may find other impaired water bodies. Figure 2 shows 303(d) listed segments in the French Creek and Pilchuck River watersheds.

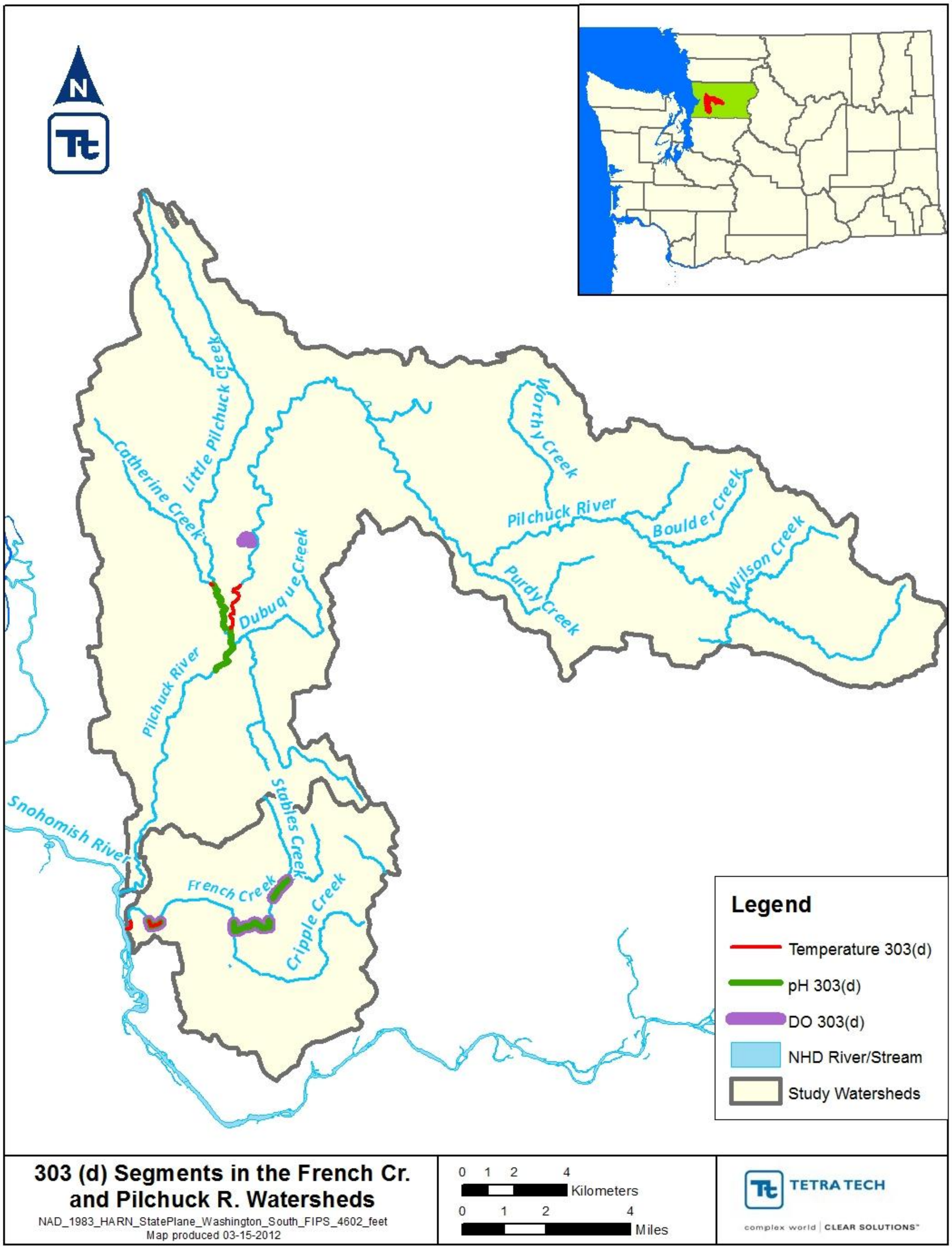

Figure 2. 303(d) listed segments in the French Creek and Pilchuck River watersheds.

How Will the Results of This Study be Used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve water quality standards. This is done by assessing the situation, identifying the practices needed to reduce pollution and, in some cases, 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 studies suggest areas for follow-up sampling to further pinpoint sources for cleanup.

Water Quality Standards and Numeric Targets

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state. This section provides information on the pH, DO, and temperature criteria in the standards that apply to the French Creek and Pilchuck River watersheds.

Segments of French Creek and the Pilchuck River and three of its tributaries were included on the Washington State 2008 303(d) list of impaired water bodies for temperature, DO, and pH. In this TMDL, the designated aquatic life uses to be protected are *core summer salmonid habitat, spawning, rearing, and migration* for both watersheds, and Boulder Creek and upstream in the Pilchuck River and in Cripple Creek, *char spawning and rearing*. The applicable water quality criteria for these parameters are summarized in Table 2.

Table 2. Washington State water quality criteria for impaired parameters in the French Creek and Pilchuck River watersheds.

Water Quality Parameter	2008 Use Classification	2008 Criteria
French Creek and all tributaries		
Temperature	Core summer salmonid habitat, spawning, rearing, and migration	<16°C 7-DADMax[1,3]
Dissolved Oxygen		>9.5 mg/L 1-DMin[2,3]
pH		6.5 to 8.5 units[3]
Pilchuck River and all tributaries below Boulder Creek		
Temperature	Core summer salmonid habitat, spawning, rearing, and migration	<16°C 7-DADMax(13°C Feb 15-June 15)[1,3]
Dissolved Oxygen		>9.5 mg/L 1-DMin[2,3]
pH		6.5 to 8.5 units[3]
Pilchuck River and all tributaries above Boulder Creek (including Boulder Creek)		
Temperature	Char spawning and rearing	<12°C 7-DADMax[1,3]
Dissolved Oxygen		>9.5 mg/L 1-DMin[2,3]
pH		6.5 to 8.5 units[3]

[1] 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
[2] 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the water body.
[3] A human-caused variation within the above range of less than 0.3°C for temperature, 0.2 mg/L for DO, and 0.2 units for pH is acceptable.

Dissolved Oxygen

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

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

Washington State's freshwater aquatic life use categories are described using key species (e.g., salmonid or char versus warm-water species) and life-stage conditions (e.g., spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

In the French Creek and Pilchuck River watersheds, the 1-DMin oxygen level must not fall below 9.5 milligrams per liter (mg/L) more than once every ten years on average.

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

The water quality standards allow Ecology to use natural conditions for TMDL and permitting purposes (WAC 173-201A-310(3)). Ecology considers the modeling approach used in this TMDL to be the best available scientific estimate of natural conditions in the French and Pilchuck watersheds.

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

pH

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

While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, the higher or lower pH goes, the more likely it is that lethal conditions can develop. For example, low pH values (<5.0) may liberate sufficient CO_2 from bicarbonate in the water to be directly lethal to fish.

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

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

To protect the applicable designated aquatic life use, pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities. Washington State Water Quality Standards reflect the importance of temperature to aquatic life by describing the temperature needs of key species (salmonid or char versus warm-water species) during critical life-stages (spawning versus rearing) [WAC 173-201A-200; 2003 edition].

Temperature levels fluctuate over the day and night in response to changes in weather conditions and river flows. Since the health of aquatic species is tied strongly 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.

The applicable criteria for the designated uses specify that the highest 7-DADMax temperature must not exceed 16°C more than once every ten years on average from the mouth of the Pilchuck River to Boulder Creek (with a supplemental spawning criterion of 13°C from February 15 to June 15) and in French Creek and its tributaries. In the Pilchuck River above Boulder Creek (including Boulder Creek), the highest 7-DADMax temperature must not exceed 12°C more than once every ten years on average.

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

Global Climate Change

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

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

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

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

Ecology is conducting this TMDL to meet Washington State's surface water quality standards based on current climatic patterns. Potential changes in stream temperatures associated with global climate change may require further modifications to human-source allocations at some future time.

Watershed Description

The French Creek and Pilchuck River watersheds are located in Snohomish County, Washington in Water Resource Inventory Area 7 (WRIA 7) (Figure 1). The French Creek watershed is approximately 29 square miles, and the Pilchuck River watershed is approximately 137 square miles. Both empty into the Snohomish River approximately 15 miles above where it enters Puget Sound.

The Pilchuck River watershed is dominated by low-density residential development and small farms, and also includes portions of the cities of Granite Falls, Snohomish, Lake Stevens, and Marysville. Approximately 49% of the watershed lies within unincorporated Snohomish County (Ecology, 2001) and a large portion of the Upper Pilchuck watershed is managed by the Department of Natural Resources (DNR) (Ecology, 2001).

A small portion of the French Creek watershed is located within the town of Monroe, leaving roughly 89% of the watershed within unincorporated Snohomish County. Land uses in the upper reaches of the French Creek drainage are primarily a mix of residential development, small farms and pastures, forested areas, and equestrian centers (Ecology, 2001). Commercial agriculture dominates the lower reaches.

Geographic Setting

Hydrology

The Pilchuck River is fed by numerous tributaries as it flows down from the Cascade Mountains. The drainage area is divided into the upper Pilchuck River, the lower Pilchuck River, and the Little Pilchuck Creek watersheds. Little Pilchuck Creek confluence is located at the division between the upper and lower Pilchuck River basins. This drainage includes Little Pilchuck Creek and its major tributaries, Star Creek and Catherine Creek. Tributaries to the Upper Pilchuck River include Purdy Creek, Boulder Creek, Wilson Creek, and Worthy Creek, while major tributaries to the Lower Pilchuck River include Dubuque Creek, Bunk Foss Creek, Sexton Creek, and Scott Creek. With an average annual discharge of 364 cubic feet per second (cfs), the Pilchuck River is the largest tributary to the Snohomish River below its confluence with the Skykomish and Snoqualmie Rivers.

French Creek drains a portion of south central Snohomish County, a northern portion of the city of Monroe, and a southeastern area of the city of Snohomish (Figure 1). It is fed by seven major tributaries, which include Chain Lake and Cripple, Golf Course, Richardson, Spada, Stables, and Trench Creeks. Discharge of French Creek to the Snohomish River near river-mile 15 is controlled by a pumping station with fish ladders, operated and maintained by the FSFCD.

Geology

The French Creek and Pilchuck River watersheds are located along the eastern margins of the Puget Lowland geologic region, which consists of a linear depression trending in a north-south direction between the Olympic Mountains to the west and the Cascade Mountains to the east. Along the eastern side of the Puget Lowland in the Cascade foothills, Tertiary- and Cenozoic-aged volcanic and sedimentary rocks (less than 70 million years old) underlie the glacially- derived surficial deposits (Bailey, 1998).

The majority of the surficial geologic units consist of "unconsolidated" (non-bedrock) glacial deposits. In the French Creek watershed, Vashon Glacial Till, Younger Alluvium, and Recessional Outwash are the primary glacially-derived geologic units (comprising over 88% of the watershed). Vashon Glacial Till is a relatively strong, stable structural geologic material consisting of a mixture of silt, sand, and gravel deposited in front of and below the advancing Vashon glacier. The Younger Alluvium deposits consist of organic rich, stream-laid clay, silt, and fine sands and lie in and around stream channels. The other significant geologic unit is Recessional Outwash, which consists of well-drained stratified outwash sand and gravel deposits (Bailey, 1998).

Land Use and Land Cover

Land use data for the French Creek and Pilchuck River watersheds were obtained from the Snohomish County's Assessor Office as parcel data that has been updated through 2012. The parcels depicted in the dataset are current real property parcel boundaries within Snohomish County, based on the legal descriptions contained in the assessment roll (Snohomish County Assessor, 2012). These data include 183 land cover types, which were consolidated into 23 categories for analysis purposes (Figure 3).

Other land use/land cover data reviewed include the *2010 Washington State Land use* and the *2006 National Land Cover Dataset* (NLCD) developed and maintained by the Multi-Resolution Land Characteristics Consortium (Fry et al., 2011). The *2010 Washington State land use* is based on the same tax parcel assessments that inform the Snohomish County parcel data, but includes only 83 land cover types. The *2006 NLCD* defines 20 land use cover types on a 30-meter gridded basis, which is of significantly lower resolution than the County parcel data. The County parcel data classifies land cover at scales of less than ten feet.

In addition, more detailed agricultural land spatial data will likely be obtained as TMDL development progresses. Potential data sources include U.S. Department of Agriculture (USDA) datasets, Washington State Department of Agriculture (WSDA) datasets, and Snohomish County agricultural data.

Tables 3 and 4 present the distribution of the grouped County land use categories in the French Creek and Pilchuck River watersheds, respectively. In addition, because the single family residential grouped land use makes up a significant area of the French Creek watershed and lower Pilchuck River watershed, the distribution of detailed County land uses for this category is presented. Vacant area is also a dominant land use category. Comparisons of aerial photos of vacant and open space parcels show that they are analogous to forested areas, with the County's differentiation between these categories likely related to tax classifications. Therefore, for the remainder of this document, "vacant" will be referred to as forested.

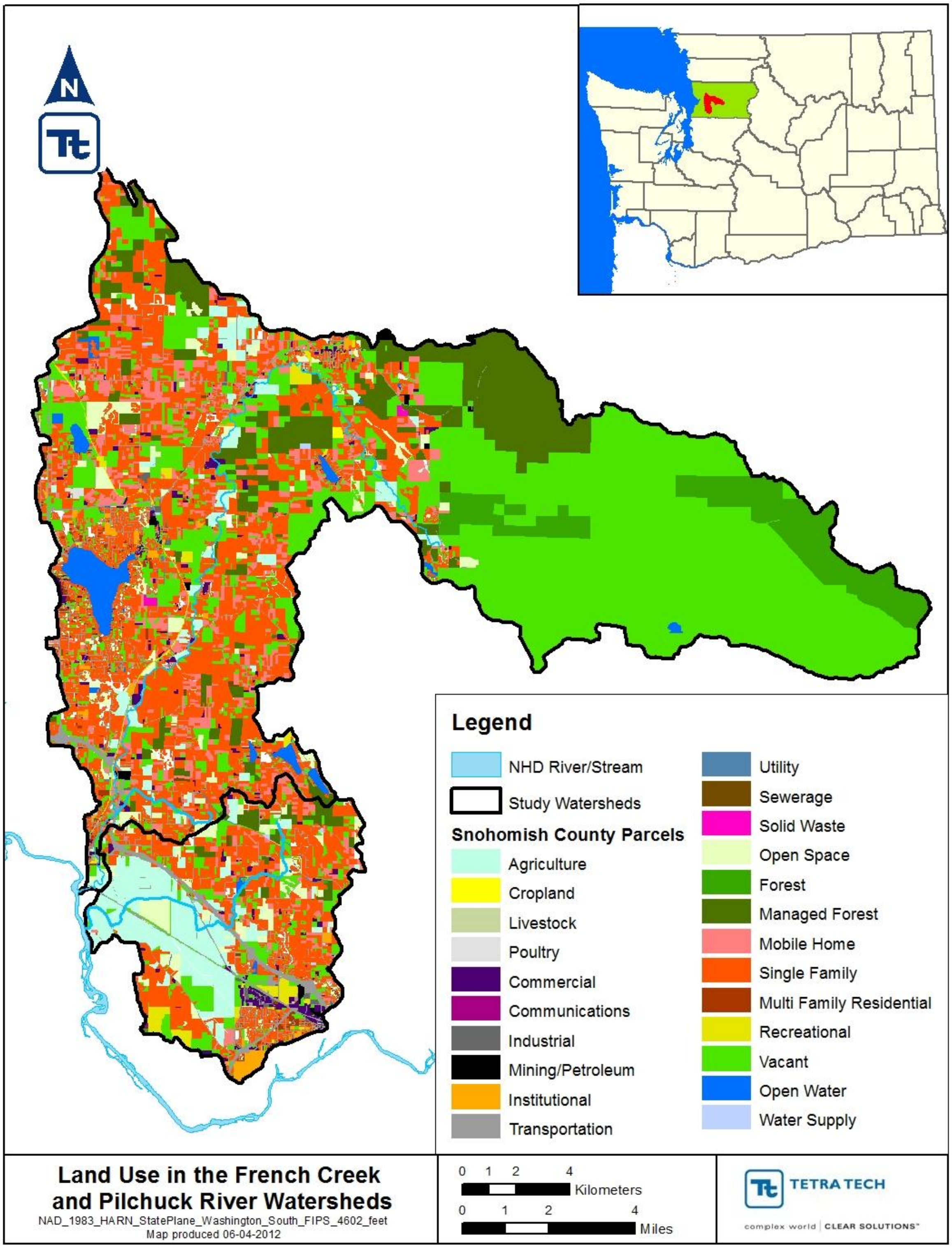

Figure 3. French Creek and Pilchuck River watersheds land use.

(Note: vacant is analogous to forested)

French Creek Watershed

The largest percent of area in the French Creek watershed is single family residential (33.3%) and a portion of the City of Monroe is in the southern part of the watershed (Table 3). The distribution of detailed County land uses included in the single family residential category shows that detached single family residences make up over 91% of these areas. Detached single family residences are the least intensive of the County residential land uses and based on analysis of aerial photography for the watershed, usually consist of a home on more than an acre of land.

The next largest land use within the basin is agriculture, covering 21.1% of the area. The French Creek watershed is known as an agricultural area. Forested areas also make up sizeable portions of the watershed (i.e., vacant: 12.9% and open space: 7.1%) as does transportation: 8.0%. Analysis of aerial photography in the watershed shows that even small vacant areas abutting single family parcels are generally forested areas.

Table 3. Land use/land cover area[a] and percent in the French Creek watershed

Grouped land use	Area (acres)	Percent area
Single Family Residential	6,169	33.3%
Agriculture	3,906	21.1%
Forested (Vacant)	2,396	12.9%
Transportation	1,490	8.0%
Forested (Open Space)	1,312	7.1%
Mobile Home	889	4.8%
Managed Forest	652	3.5%
Commercial	491	2.6%
Recreational	456	2.5%
Institutional	330	1.8%
Multi-Family Residential	115	0.6%
Industrial	71	0.4%
Mining/Petroleum	69	0.4%
Open Water	56	0.3%
Sewerage	36	0.2%
Water Supply	24	0.1%
Utility	24	0.1%
Forest	17	0.1%
Communications	13	0.1%
Livestock	11	0.1%
Total	**18,528**	**100.0%**

Single Family County Detail	Percent area
Single Family Residence - Detached	91.4%
2 Single Family Residences	5.9%
Senior Citizen Residences	2.3%
3 Single Family Residences	0.2%
Vacation Cabins	0.2%
Common Wall Single Family Residence	0.1%

[a]Areas calculated from Snohomish County property parcels (Snohomish County Assessor, 2012)

Pilchuck River Watershed

The Pilchuck River watershed also contains large areas of forested land: the largest percent (55%) of area in the Pilchuck River watershed is forested (vacant [39.3%], managed forest [10.2%], and forest [5.4%]) (Table 4). Like French Creek, single family residential also makes a sizeable portion of the watershed at 25.4% of the area, 91.7% of which is single family detached. Due to the large areas of forest and the rural character of single family residences, much of the Pilchuck River watershed remains in an undeveloped, forested state.

Table 4. Land use/land cover area[a] and percent in the Pilchuck River watershed

Grouped land use	Area (acres)	Percent area
Forested (Vacant)	35,069	39.3%
Single Family Residential	22,700	25.4%
Managed Forest	9,127	10.2%
Mobile Home	5,575	6.2%
Forest	4,851	5.4%
Transportation	2,580	2.9%
Forested (Open Space)	2,194	2.5%
Agriculture	2,150	2.4%
Open Water	1,592	1.8%
Commercial	1,022	1.1%
Recreational	874	1.0%
Multi-Family Residential	378	0.4%
Institutional	353	0.4%
Sewerage	247	0.3%
Mining/Petroleum	165	0.2%
Industrial	84	0.1%
Solid Waste	75	0.1%
Water Supply	60	0.1%
Poultry	48	0.1%
Utility	44	0.0%
Cropland	37	0.0%
Livestock	9	0.0%
Communications	5	0.0%
Total	89,240	100.0%

Single Family County Detail	Percent area
Single Family Residence - Detached	91.7%
2 Single Family Residences	4.6%
Senior Citizen Residences	3.3%
Vacation Cabins	0.1%
3 Single Family Residences	0.1%
4 Single Family Residences	0.1%
5+ Single Family Residences	0.0%
Common Wall Single Family Residence	0.0%

[a]Areas calculated from Snohomish County property parcels (Snohomish County Assessor, 2012)

Climate

The climate of the watersheds is greatly influenced by winds from the Pacific Ocean and Puget Sound. As a result, the area experiences relatively mild and wet winters with snow and freezing temperatures uncommon. Summers are moderately warm with few hot days and light rainfall. Average annual rainfall is just below 40 inches, with over two-thirds of this precipitation falling from October through March. During the wet season, rainfall is usually of light to moderate intensity. The wettest month is typically December, while July is normally the driest month (French Creek Watershed Management Committee, 2004).

Wildlife

Streams within the French Creek watershed support resident and sea-run cutthroat trout, spawning and juvenile Coho salmon, and steelhead trout. The Pilchuck River and its tributaries support spawning and juvenile Chinook, Coho, Sockeye, Chum, and Pink salmon as well as bull trout and steelhead trout.

These native species depend on cool water, pools and riffles, and off-channel wetlands during different parts of their life cycles (French Creek Watershed Management Committee, 2004). French Creek is also within the presumed distribution of the bull trout, which is listed as "threatened" under the Endangered Species Act.

Other fish observed in watershed streams include smallmouth bass, longnose sucker, brown bullhead, brook lamprey, sculpins, and stickleback. Cutthroat, eastern brook, and rainbow trout and bass have been introduced to lakes and ponds by the Snohomish Sportsman's Association and other parties (French Creek Watershed Management Committee, 2004).

The watersheds also provide habitat for many animal species, particularly along the riparian corridor and wetlands. Both resident and migratory birds rely on the area for food and raising their young. Many types of mammals, amphibians, and reptiles are abundant in the watershed. Several animals identified as priority by the Washington Department of Wildlife have been observed in the watersheds, including bald eagles, great blue herons, pileated woodpeckers, red-tailed hawks, cavity-nesting ducks, trumpeter swans, and other waterfowl (French Creek Watershed Management Committee, 2004).

Vegetation

Historically, the French Creek and Pilchuck River watersheds were large forested and scrub/shrub wetland areas. Mature and old growth stands of western hemlock and Douglas fir grew on the drier areas and mixed coniferous-deciduous forests in wetter areas (Franklin and Dyrness, 1973). The wetland areas were dominated by hardback spirea.

Currently, the vegetation is mainly red alder, vine maple, black cottonwoods, and western red cedar along the riparian corridor. Understory species in forested areas include salmonberry, sword ferns, and salal, while the forested swamps have skunk cabbage, salmonberry, and red-osier dogwood in their understory (French Creek Watershed Management Committee, 2004).

Considerable logging has occurred in the watersheds and some of the land near the lower French Creek was cleared for agricultural purposes in the late 1800s (French Creek Watershed Management Committee, 2004). Some of the cleared land has been replanted; however, much of the area will be or has been developed. Trees in the undeveloped forested areas generally revegetate on their own but have not reached an old growth stage. The agricultural floodplain of the lower French Creek watershed consists of several thousand acres of productive or fallow farmland, with hay as the major crop (French Creek Watershed Management Committee, 2004). These changes in landscape significantly impact the hydrology of the watersheds by increasing the amount of surface runoff and decreasing infiltration.

Hydromodifications

Historically, natural wetlands covered much of the western part of the watersheds. The Little Pilchuck Creek basin still has extensive wetlands (Ecology, 1997), while 90% of the French Creek floodplain wetlands have been drained for agriculture (French Creek Watershed Management Committee, 2004). A pump station and floodgates at the mouth of French Creek, operated by the FSFCD, control the water level to protect the surrounding agricultural land. These were constructed in the 1960s. Fish ladders were included in the design to provide anadromous species access to French Creek and its tributaries. In addition, there are several instream man-made structures and culverts in both watersheds that are full or partial barriers to upstream fish movement. On the Pilchuck River, these include the City of Snohomish Dam located upstream of the city of Granite Falls (if flows are high enough, fish can move upstream of the dam) (Savery and Hook, 2003). Other than the pump station, many of the structures in the French Creek watershed are small and can be readily repaired during maintenance operations (French Creek Watershed Management Committee, 2004).

Potential Sources of Contamination

Non-stormwater Point Source Pollutions

Permitted facility information was provided from the Ecology Permit and Reporting Information System database. When this report was published, there were 383 industrial/municipal wastewater discharge permitted facilities within the French Creek and Pilchuck River watersheds; however, only 207 of these are active (Figure 4 shows the spatial distribution of these facilities). Not all of these permits are applicable to the TMDL study. During TMDL development, the permits will be evaluated further to identify the permits of interest to the TMDL water bodies and pollutants. Phase I and Phase II stormwater permits are discussed separately in the following section.

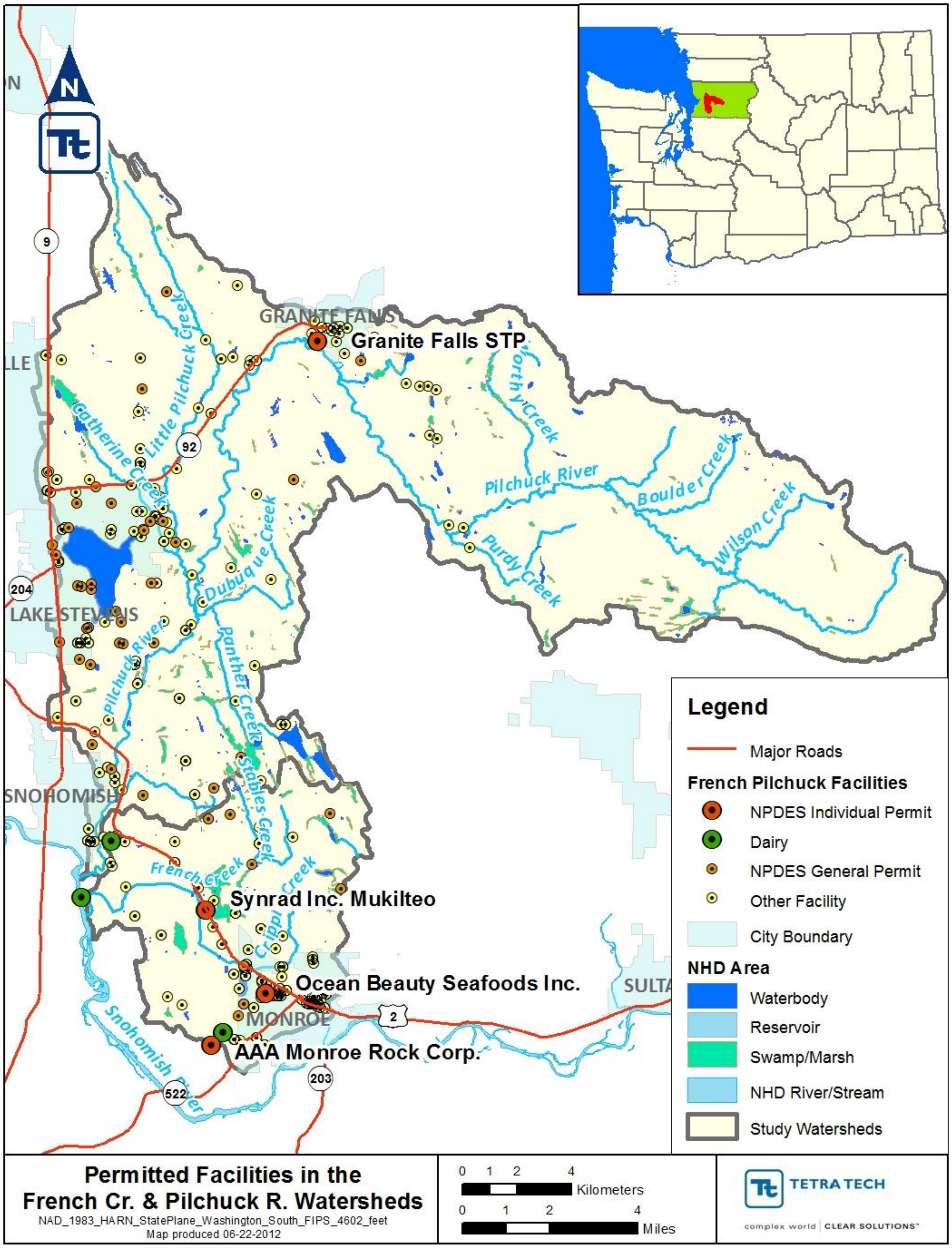

Figure 4. Permitted facility locations within the French Creek and Pilchuck River watersheds.

Table 5 summarizes permitted facility information by permit type (note: discharge monitoring report data have not yet been obtained for the applicable facilities) and identifies the number of facilities located along 303(d) listed stream segments. Locations were identified along an impaired segment when the facility was located adjacent to the segment and no other water body bisected the overland flow path from the facility to the impaired stream.

Table 5. Permitted discharger information in the French Creek and Pilchuck River watersheds.

Permit Type*	Number of Active Permits	Number of Inactive Permits	Total Number of Permits	Number of Permits on 303(d) Streams
401CZM Project Site	6	0	6	0
Air Qual Local Authority Reg	1	0	1	0
Air Qual Oper Permit Source	1	0	1	0
Biosolids	3	0	3	0
Construction SW GP	38	0	38	1
Dairy	1	2	3	0
Dam Site	8	0	8	0
Emergency/Haz Chem Rpt TIER2	23	13	36	0
Enforcement Draft	2	1	3	0
Enforcement Final	8	0	8	0
Haz Waste Management Activity	4	7	11	1
Hazardous Waste Generator	8	64	72	2
Hazardous Waste Planner	2	4	6	0
Independent Cleanup	0	1	1	0
Independent Remedial Actn Prg	0	4	4	0
Industrial IP	4	0	4	2
Industrial SW GP	5	0	5	0
Landfill	0	1	1	0
LUST Facility	8	15	23	1
Municipal IP	1	0	1	0
Non Enforcement Draft	2	0	2	0
Non Enforcement Final	7	0	7	0
Recycling	3	0	3	0
Revised Site Visit Program	7	0	7	0
Sand and Gravel GP	10	2	12	0
State Cleanup Site	14	9	23	1
Toxics Release Inventory	2	1	3	0
Underground Storage Tank	33	35	68	4
Voluntary Cleanup Sites	6	16	22	1
Total	**210**	**172**	**382**	**9**

*CZM: Coastal Zone Management; SW: Stormwater; GP: General Permit;
IP: Industrial Permit; LUST: Leaking Underground Storage Tank

Construction general stormwater, emergency/hazardous chemical, and underground storage tanks make up nearly half of the active permits with 38, 23, and 33 permits in each category, respectively. Available site information for the one active dairy located in the French Creek watershed and the Granite Falls WWTP within the Pilchuck River watershed are listed in Table 6.

Table 6. Permitted dairies and WWTPs in the French Creek and Pilchuck River watersheds.

Program ID	Facility Name	Facility Description	Status	Watershed
582646	Bartelheimer Brothers Inc.	Dairy	Active	French Creek
WA0021130	Granite Falls WWTP	Sewage Treatment Plant	Active	Pilchuck River

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

Point Source Stormwater Pollution

During rain events, rainwater washes the surface of the pavement, rooftops, and other impervious surfaces. This stormwater runoff accumulates and transports pollutants and contaminants via stormwater drains to receiving waters and can degrade water quality. Ecology issues NPDES permits to larger entities that operate municipal separate storm sewer systems (MS4s) responsible for collecting, treating, and discharging stormwater to local streams and rivers.

Snohomish County and the Washington State Department of Transportation (WSDOT) hold Phase I MS4 permits in the watershed. In addition, five communities (the cities of Granite Falls, Lake Stevens, Marysville, Snohomish, and Monroe) hold Phase II MS4 permits.

Snohomish County

Ecology issued an NPDES Phase I Municipal Stormwater Permit to Snohomish County and other western Washington jurisdictions in January 2007 and revised it in June 2009. Additional modifications were made in September 2010; however, they do not impact Snohomish County. Additional permit revisions have recently been made, with a reissuance date of August 1, 2012. This revision will address public comments received on the October 2011 draft permit and details associated with the revised permit will be captured in final TMDL report. Phase I permittees are cities and counties that operate large and medium MS4s. The permit regulates stormwater discharges to waters of Washington State from the permittees' MS4s in compliance with Washington Water Pollution Control Law (Chapter 90.48 RCW) and the federal Clean Water Act (Title 33 USC, Section 1251 et seq.).

Snohomish County has a Stormwater Management Plan (2010) that outlines the county's responsibilities to protect water through stormwater management. The Plan can be found at www.co.snohomish.wa.us/documents/Departments/Public_Works/surfacewatermanagement/water_quality/permit2010swmp.pdf.

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

Ecology's five-volume Stormwater Management Manual is available on the internet at www.ecy.wa.gov/programs/wq/stormwater/manual.html. A draft 2012 Stormwater Management Manual for Western Washington is currently released and will be finalized in summer 2012. The draft manual is available at www.ecy.wa.gov/programs/wq/stormwater/wwstormwatermanual/2012draft/2012draftSWMMWW.html.

Washington State Department of Transportation (WSDOT)

In March 2012, Ecology issued a new modified permit to WSDOT. This permit addresses stormwater discharges from WSDOT MS4s in areas covered by the Phase I Municipal Stormwater Permit, the Eastern Washington Phase II Municipal Stormwater Permit, and the Western Washington Phase II Municipal Stormwater permit. WSDOT highways, maintenance facilities, rest areas, park and ride lots, and ferry terminals are covered by this permit when a WSDOT-owned MS4 conveys the discharges. State highways in the French Creek and Pilchuck River watersheds include state route (SR) 2, SR 9, SR 522, SR 204, and SR 92.

More information on the WSDOT permit can be found at www.ecy.wa.gov/programs/wq/stormwater/municipal/wsdot.html

WSDOT has a 2011 Highway Runoff Manual that provides tools for designing stormwater collection, conveyance, and treatment systems for transportation-related facilities. This manual has been approved by Ecology as functionally equivalent to the Stormwater Management Manual for Western Washington and is available at www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm

Cities of Granite Falls, Marysville, Lake Stevens, Snohomish, and Monroe

Five cities located in the French Creek and Pilchuck River watersheds hold Phase II MS4 Permits (Granite Falls, Lake Stevens, Snohomish, and Monroe).

Ecology issued the Western Washington Phase II Municipal Stormwater Permit in January 2007 and modified it in June 2009. Additional permit revisions have recently been made, with a reissuance date of August 1, 2012. This revision will address public comments received on the October 2011 draft permit and details associated with the revised permit will be captured in final TMDL report. Under the Phase II permit, cities must follow prescribed guidelines to manage stormwater before it discharges to surface water. Permit requirements fall under five basic categories: public education and outreach, public involvement and participation, illicit discharge detection and elimination, the control of runoff from development, and pollution prevention. General information on the Phase II permit is available at www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIIww/wwphiipermit.html.

Outside of the city boundaries, Snohomish County must follow Phase I of the NPDES municipal stormwater guidelines to manage stormwater before it discharges to surface water.

Nonpoint Pollution Sources

Nonpoint pollution sources are dispersed and thus not controlled through discharge permits. Potential nonpoint sources within the French Creek and Pilchuck River watersheds include:

- Residential properties adjacent to the creeks
- Agricultural land
- Pet waste
- Human waste
- Failing onsite septic systems
- Excessive wildlife waste

While not an actual pollution source, the pump station on the French Creek also has a negative effect on the lower reach. The presence of this pump station alters the natural streamflow and slows the river down, creating a pool behind the pump. This affects temperature and DO (and possibly pH) and will be evaluated during the TMDL modeling.

Nonpoint source contributions are important to understand due to their impacts on stream water quality, and also as a major component of stormwater runoff. Nonpoint sources may contribute to changes in DO, pH, temperature, and other impairments and are discussed by water quality parameter below.

Pollution sources that affect dissolved oxygen levels

Decreased DO may result from increased nutrient loads that stimulate algae and plant growth, which is referred to as plant productivity. The actual plant productivity delivers oxygen to water through photosynthesis. Productivity may be limited by a specific nutrient (usually phosphorus in streams and lakes), by light to fuel photosynthesis, or by retention time in a water body. Excess nutrients can produce algae in large quantities. When these algae die, decomposition consumes DO, thereby lowering the DO.

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

- Septic systems.
- Stormwater runoff from both paved and pervious surfaces.
- Improper manure storage or disposal from commercial and non-commercial agriculture.
- Vegetation removal without erosion control from construction areas or forest harvest.
- Channel bank erosion or bed scour due to high flows or constrained reaches.
- Poor fertilizer and irrigation water management.

- Removal of riparian zone vegetation (riparian trees and other vegetation naturally filter nutrients and other pollutants and also reduce solar radiation reaching the stream surface, which may limit algal growth and also manages stream temperatures).

Some residences may have wastewater illegally piped to waterways or may have malfunctioning on-site septic systems where effluent seeps to nearby waterways. Pet waste concentrated in public parks, on creek-side trails, or private residences can be a source of contamination, particularly in urban areas. Swales, subsurface drains, and flooding through pastures and near homes can carry nutrients from sources and increase biochemical oxygen demand (BOD) in waterways.

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

Groundwater discharges can also affect DO levels and nutrient concentrations in streams. DO is often lower in groundwater. Relevant existing groundwater data will be researched to assess the potential influence of groundwater discharges on the impaired water bodies.

Pollution sources that affect pH levels

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

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

Decomposition in wetlands also can lower pH. The high residence time and high organic matter loading in wetlands, for example, produce low pH and DO levels. Some wetland complexes exist within the study systems and may contribute to the low levels recorded in the mainstems and the tributaries.

In addition, the pH of rain in western Washington is 4.8 to 5.1 (NADP, 2004). Therefore, stormwater and even groundwater may have a low pH due to regional atmospheric rather than local watershed conditions.

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

Pollution sources that affect water temperatures

Temperature is most directly impacted by the removal of riparian zone vegetation, which increases solar radiation reaching the stream surface. This reduction of riparian zone vegetation reduces the available shade, which increases sunlight to the stream surface and subsequently increases water temperature.

Groundwater influences, instream flows, water withdrawals, and stream channel geometry also influence stream temperature. Groundwater tends to maintain a constant temperature that can warm a stream in winter and cool it in the summer.

Other factors affecting water quality

Other natural factors and human activities can affect water quality. Areas of high groundwater input can in some locations result in DO levels that are lower than the criteria listed in our state standards. Similarly, the creation of isolated off-stream channels and pools sometimes have high temperatures and low DO levels during portions of the year.

The French Creek pump station and associated drainage system is an example of a major government infrastructure project that may be affecting water quality. This TMDL study hopes to better explain the effect of the pump station and the drainage system on water quality. Study results will help inform all involved parties about the limitations, and possibilities, for maximizing water quality in light of the competing societal needs for agricultural products and aquatic life benefits.

A variety of wildlife lives within the French Creek and Pilchuck River watersheds. Wildlife are a potential source of Biochemical Oxygen Demand (BOD) and nutrients, but are not considered pollution sources unless human activities have either concentrated the discharge of their wastes or caused a significant population increase resulting in higher nutrient loadings. Open fields, riparian areas, and wetlands provide feeding and roosting grounds for some birds whose waste products can increase BOD and nutrients in runoff. Concentrated wildlife (for example, nutria, raccoons, beaver, deer, and birds) in the watersheds will be noted during sampling surveys.

Historical Data Review

Water quality in the French Creek and Pilchuck River watersheds is monitored regularly by both Snohomish County and Ecology in certain locations. In addition, water quality monitoring has been conducted by the cities of Monroe, Snohomish, and Lake Stevens as well as the FSFCD and Snohomish Conservation District. Streamflow has been monitored by (USGS) and Snohomish County. Data were collected by these parties to support various purposes including ESA-related fisheries enhancement projects, existing TMDL implementation, water quality and quantity trend analysis, and flood control.

Pertinent data that can help describe existing water temperatures, nutrient levels, and river flows from these sources are described below. Data included in this QAPP are presented to characterize historical and recent flow and water quality conditions and general temporal and spatial resolution of available data. These data are assumed sufficient for this purpose and have not been subject to detailed QA/QC. QA/QC will be performed on all data before they are used in the TMDL analyses and report using Ecology's Credible Data Policy (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf).

Snohomish County Data

Snohomish County's Surface Water Management Division regularly monitors water quality in the French Creek and Pilchuck River watersheds under two monitoring studies: Snohomish County Surface Water Ambient Monitoring (Ambient Monitoring Study) and Snohomish County Surface Water Management FC Bacteria TMDL Monitoring (TMDL Monitoring Study). Though the TMDL Monitoring Study was originally designed for an FC bacteria TMDL, a range of water quality parameters were sampled, including those of concern for this study.

In an effort to make data available to the public, the County is currently migrating finalized monitoring data to the Ecology's Environmental Information Management (EIM) database. Prior to the development of EIM, County data were available through its online Surface Water Quality Database. Due to overlapping time periods when EIM came online and the Surface Water Quality Database was being decommissioned, some data are available through both systems. To simplify the following discussion, the monitoring data available from each resource are discussed separately.

Snohomish County Data in EIM Database

The Ambient Monitoring Study provides a record of discrete data collected by the County from 1995–2009, though data are only currently available in Ecology's EIM database from 2005 onward. Some of the earlier data are available through the County's Surface Water Quality Database, as discussed in the next subsection, and it is anticipated that all of the earlier data will be made available as development of the TMDLs progresses. Though the Ambient Monitoring Study includes several water quality monitoring stations throughout Snohomish County, only two of these are relevant to this TMDL: French Creek Long-Term Downstream (FCLD) and a station in the Pilchuck River (PILR) watersheds.

The TMDL Monitoring Study includes discrete monitoring data collected since 2010. These data represent the implementation of new monitoring practices, including uniform application of QA/QC procedures for collection of temperature data and other water quality parameters (Steve Britsch, personal communication, Snohomish County Surface Water Management Division).

Snohomish County has collected and analyzed water samples as part of the TMDL Monitoring Study at eight monitoring stations: four each in French Creek (CCLS, CCUS, FCLU, STABLES) and in Pilchuck River (PILOK, DUBQ, CATH, LPIL) watersheds (Figure 5).

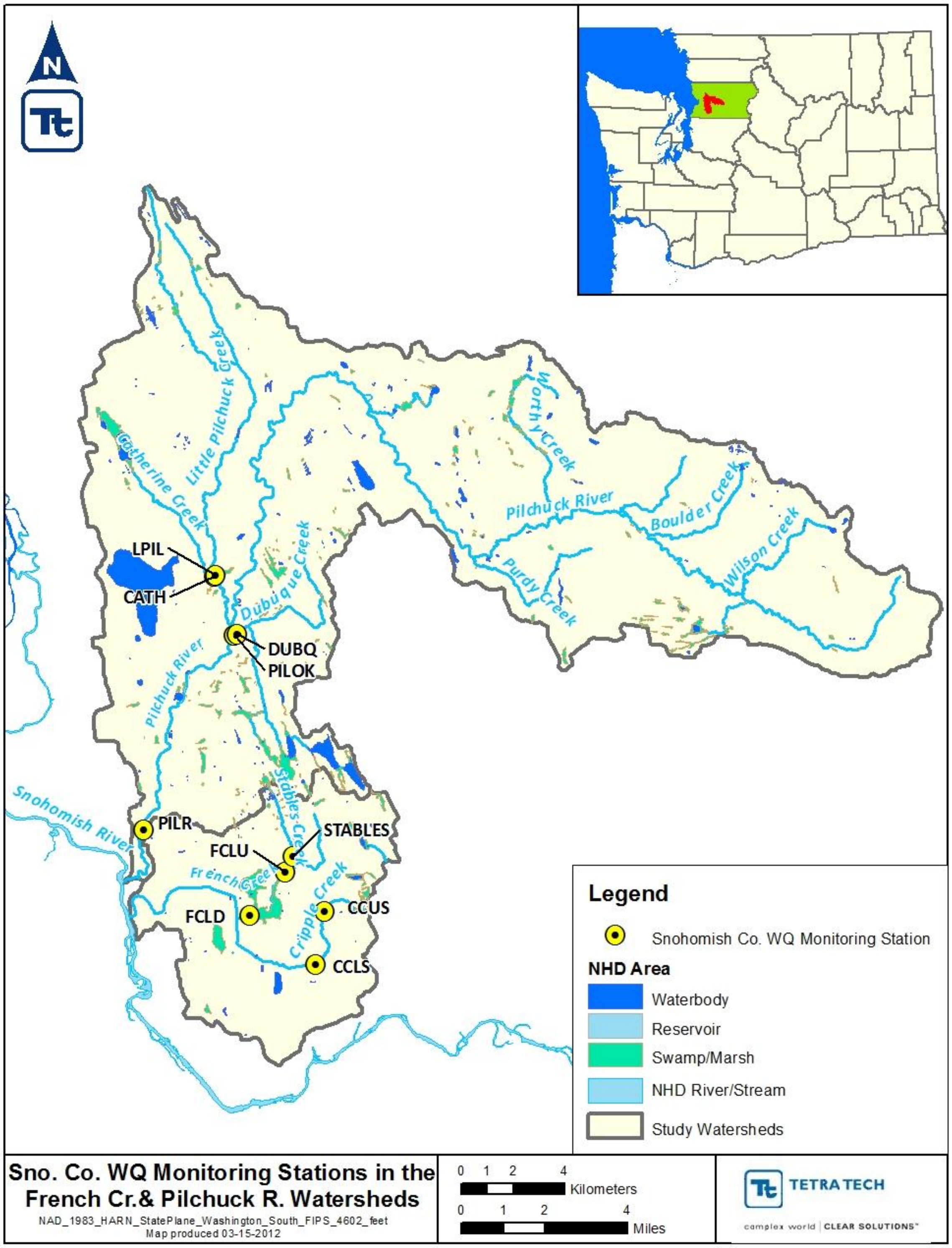

Figure 5. Snohomish County water quality monitoring stations cataloged in Ecology's EIM.

Tables 7 and 8 summarize the available DO, pH, temperature, nitrate-nitrite, total phosphorus, turbidity, and total suspended solids water quality results for both Snohomish County studies in the French Creek and the Pilchuck River watersheds, respectively. In addition to the TMDL parameters, nutrient data are of interest because they are related to DO and pH levels in the water bodies. All monitoring data are discrete samples collected at approximately monthly intervals. Note that minimum DO concentrations recorded at monitoring stations on Little Pilchuck Creek (LPIL) and FCLD are outliers for these datasets. The second lowest DO concentration at LPIL is 8.16 mg/L. However, DO concentrations do tend to be lower at FCLD. The second lowest DO concentration at FCLD is 3.72 mg/L. Considering all data, the median and 25th percentile concentrations at this location are 7.32 and 6.04 mg/L, respectively.

Table 7. Snohomish County French Creek watershed monitoring station water quality data summary (EIM).

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
CCLS	Cripple Creek Lower	1/25/2010	7/11/2011	Dissolved Oxygen	19	9.01	13.51	11.39	mg/L
				pH	19	6.51	7.65	7.21	pH
				Temperature, water	19	3.32	19.52	9.28	deg C
				Turbidity	19	0.80	5.24	2.02	NTU
		1/25/2010	6/8/2011	Total Suspended Solids	18	1.00	8.00	2.67	mg/L
CCUS	Cripple Creek Upper	1/25/2010	7/11/2011	Dissolved Oxygen	19	9.23	12.70	10.74	mg/L
				pH	19	6.47	7.31	6.99	pH
				Temperature, water	19	3.80	14.83	9.13	deg C
				Turbidity	18	1.29	5.22	2.87	NTU
		1/25/2010	6/8/2011	Total Suspended Solids	18	1.00	13.00	4.67	mg/L
FCLD	French Creek Long-Term Downstream	1/5/2004	12/8/2009	Dissolved Oxygen	70	1.76	12.33	7.25	mg/L
				pH	70	6.19	7.38	6.77	pH
				Temperature, water	70	1.90	21.61	11.72	deg C
				Turbidity	70	1.25	240.00	16.74	NTU
		10/4/2006	12/8/2009	Nitrite-Nitrate	38	0.11	3.50	0.78	mg/L
				Total Phosphorus	38	0.01	0.30	0.08	mg/L
				Total Suspended Solids	38	1.00	100.00	10.05	mg/L
FCLU	French Creek Upper	10/4/2006	7/11/2011	Dissolved Oxygen	58	9.25	15.13	11.25	mg/L
				pH	58	6.28	7.56	7.02	pH
				Temperature, water	58	0.00	16.05	9.14	deg C
				Turbidity	58	0.00	53.50	3.62	NTU
		10/4/2006	12/8/2009	Nitrite-Nitrate	39	0.06	1.30	0.58	mg/L
				Total Phosphorus	39	0.00	0.11	0.03	mg/L
		10/4/2006	6/8/2011	Total Suspended Solids	57	1.00	220.00	9.28	mg/L
STABLES	Stables Creek	1/25/2010	7/11/2011	Dissolved Oxygen	19	7.44	13.13	11.09	mg/L
				pH	19	6.20	7.20	6.88	pH
				Temperature, water	19	4.01	15.36	9.28	deg C
				Turbidity	19	1.25	4.40	2.27	NTU
		1/25/2010	6/8/2011	Total Suspended Solids	18	1.00	17.00	3.56	mg/L

Table 8. Snohomish County Pilchuck River watershed monitoring station water quality data summary (EIM).

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
CATH	Catherine Creek	1/8/2004	7/13/2011	Dissolved Oxygen	89	8.22	14.69	10.68	mg/L
CATH	Catherine Creek	1/8/2004	7/13/2011	pH	90	5.66	7.82	7.15	pH
CATH	Catherine Creek	1/8/2004	7/13/2011	Temperature, water	90	3.23	20.60	11.50	deg C
CATH	Catherine Creek	1/8/2004	7/13/2011	Turbidity	89	0.00	13.20	2.16	NTU
CATH	Catherine Creek	10/4/2006	12/7/2009	Nitrite-Nitrate	39	0.04	0.86	0.23	mg/L
CATH	Catherine Creek	10/4/2006	12/7/2009	Total Phosphorus	39	0.01	0.06	0.03	mg/L
CATH	Catherine Creek	10/4/2006	6/14/2011	Total Suspended Solids	57	1.00	22.00	4.44	mg/L
DUBQ	Dubuque Creek	1/8/2004	7/13/2011	Dissolved Oxygen	89	8.66	14.70	11.04	mg/L
DUBQ	Dubuque Creek	1/8/2004	7/13/2011	pH	89	6.09	7.97	7.19	pH
DUBQ	Dubuque Creek	1/8/2004	7/13/2011	Temperature, water	89	0.66	17.51	9.93	deg C
DUBQ	Dubuque Creek	1/8/2004	7/13/2011	Turbidity	90	0.00	8.38	2.03	NTU
DUBQ	Dubuque Creek	10/4/2006	12/7/2009	Nitrite-Nitrate	39	0.04	1.10	0.48	mg/L
DUBQ	Dubuque Creek	10/4/2006	12/7/2009	Total Phosphorus	39	0.01	0.05	0.02	mg/L
DUBQ	Dubuque Creek	10/4/2006	6/14/2011	Total Suspended Solids	57	1.00	21.00	3.28	mg/L
LPIL	Little Pilchuck Creek	1/8/2004	7/13/2011	Dissolved Oxygen	88	2.88	14.39	10.50	mg/L
LPIL	Little Pilchuck Creek	1/8/2004	7/13/2011	pH	90	6.37	7.67	7.06	pH
LPIL	Little Pilchuck Creek	1/8/2004	7/13/2011	Temperature, water	90	0.68	21.45	10.18	deg C
LPIL	Little Pilchuck Creek	1/8/2004	7/13/2011	Turbidity	90	0.00	46.40	2.19	NTU
LPIL	Little Pilchuck Creek	10/4/2006	12/7/2009	Nitrite-Nitrate	39	0.10	0.93	0.42	mg/L
LPIL	Little Pilchuck Creek	10/4/2006	12/7/2009	Total Phosphorus	39	0.01	0.08	0.02	mg/L
LPIL	Little Pilchuck Creek	10/4/2006	6/14/2011	Total Suspended Solids	57	1.00	17.00	2.46	mg/L
PILOK	Pilchuck River	1/21/2010	7/13/2011	Dissolved Oxygen	19	9.52	13.18	11.28	mg/L
PILOK	Pilchuck River	1/21/2010	7/13/2011	pH	19	6.27	7.74	7.22	pH
PILOK	Pilchuck River	1/21/2010	7/13/2011	Temperature, water	19	3.99	17.46	10.24	deg C
PILOK	Pilchuck River	1/21/2010	6/14/2011	Total Suspended Solids	18	1.00	290.00	34.78	mg/L
PILOK	Pilchuck River	1/21/2010	7/13/2011	Turbidity	19	0.84	194.00	20.44	NTU
PILR	Pilchuck River at Snohomish	1/8/2004	12/7/2009	Dissolved Oxygen	71	8.94	16.28	11.11	mg/L
PILR	Pilchuck River at Snohomish	1/8/2004	12/7/2009	pH	72	6.36	7.93	7.16	pH
PILR	Pilchuck River at Snohomish	1/8/2004	12/7/2009	Temperature, water	72	1.40	20.68	10.51	deg C
PILR	Pilchuck River at Snohomish	1/8/2004	12/7/2009	Turbidity	72	0.00	253.00	9.85	NTU
PILR	Pilchuck River at Snohomish	10/4/2006	12/7/2009	Nitrite-Nitrate	39	0.01	0.76	0.33	mg/L
PILR	Pilchuck River at Snohomish	10/4/2006	12/7/2009	Total Phosphorus	39	0.01	0.20	0.02	mg/L
PILR	Pilchuck River at Snohomish	10/4/2006	12/7/2009	Total Suspended Solids	39	1.00	240.00	17.28	mg/L

In addition, a general examination was made of how the discrete water quality data compare to applicable water quality criteria (see Water Quality Standards and Numeric Targets section). Water quality criteria for DO and temperature include a time component; therefore, instantaneous exceedances of the numeric component of the criteria do not necessarily represent a criterion violation. For example, for temperature, *point* measurements are compared to the 7-DADMax temperature criteria (continuous monitoring data are required to calculate the actual 7-DADMax for comparison with this standard). Instantaneous exceedances do represent a cause for concern and can give insight into water quality conditions. Exceedances of the numeric component water quality criteria for the TMDL parameters by month over the entire monitoring time period at each station are presented in Tables 9 and 10 for the French Creek and Pilchuck River watersheds, respectively.

The Snohomish County data for the French Creek watershed monitoring stations generally had wider ranges of exceedances than the Pilchuck River watershed. Specifically, the DO exceedances ranged from 5.3 to 90% (Table 9). pH exceeded the water quality criteria 0 to 22.9% of the time due to low pH and temperature exceedances ranged from 15.8 to 48.6 percent. Temperature exceedances were more frequent in the summer months; however, the other parameters did not show such a clear pattern. FCLD had the highest percent exceedance for all parameters and the largest total number of samples within the French Creek watershed (Table 9).

Table 9. Summary of Snohomish County discrete water quality data (EIM) exceedances of the numeric component of applicable water quality criteria in the French Creek watershed.

Station	Station name	Time period	Parameter	Sample Count	Number of Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
CCLS	Cripple Creek Lower	1/25/10–7/11/11	Dissolved Oxygen	19	0	0	0	0	0	0	0	1	0	0	0	0	5.3
			pH	19	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	19	0	0	0	0	0	0	1	1	1	0	0	0	15.8
CCUS	Cripple Creek Upper	1/25/10–7/11/11	Dissolved Oxygen	19	0	0	0	0	0	0	0	1	1	0	0	0	10.5
			pH	19	1	0	0	0	0	0	0	0	0	0	0	0	5.3
			Temperature, water	19	0	0	0	0	0	0	2	1	1	0	0	0	21.1
FCLD	French Creek Long-Term Downstream	1/5/04–12/8/09	Dissolved Oxygen	70	5	5	6	6	6	5	6	5	5	6	4	4	90.0
			pH	70	3	2	2	3	0	1	0	0	0	0	1	4	22.9
			Temperature, water	70	0	0	0	1	4	6	6	6	6	5	0	0	48.6
FCLU	French Creek Upper	10/4/06-7/11/11	Dissolved Oxygen	58	0	0	0	1	0	0	1	3	0	0	0	0	8.6
			pH	58	2	0	0	0	0	0	0	0	0	0	0	2	6.9
			Temperature, water	58	1	0	0	0	0	3	5	4	3	0	0	0	27.6
STABLES	Stables Creek	1/25/10-7/11/11	Dissolved Oxygen	19	0	0	0	0	0	0	0	1	0	0	0	0	5.3
			pH	19	1	1	0	0	0	0	0	0	0	0	0	0	10.5
			Temperature, water	19	0	0	0	0	0	0	2	1	1	0	0	0	21.1

In the Pilchuck River watershed, DO exceeded the criteria from 0 to 30.7% of the time, with the majority of exceedances occurring in the summer months (Table 10). The range of pH exceedances due to low pH at the same stations was extremely narrow (3.4 to 5.6%). Temperature criteria were exceeded more than the other parameters at Snohomish County monitoring stations in the Pilchuck River watershed (31.6 to 46.7% exceedances). As expected, these exceedances typically occurred in the summer months, especially in June and July. When compared to the other stations, the Pilchuck River station (PILOK) had the lowest percentage of exceedances for all three parameters (Table 10); however, it also had the fewest samples and data were only available for one complete summer season (Table 8).

Table 10. Summary of Snohomish County discrete water quality data (EIM) exceedances of the numeric component of applicable water quality criteria in the Pilchuck River watershed.

Station	Station name	Time period	Parameter	Sample Count	Number of Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
CATH	Catherine Creek	1/8/04–7/13/11	Dissolved Oxygen	89	0	0	0	1	1	5	6	6	5	0	0	0	27.0
			pH	90	1	0	0	1	0	0	1	0	0	0	0	1	4.4
			Temperature, water	90	0	0	0	1	7	8	8	7	7	4	0	0	46.7
DUBQ	Dubuque Creek	1/8/04–7/13/11	Dissolved Oxygen	89	0	0	0	1	1	0	2	3	1	1	0	0	10.1
			pH	89	1	0	0	1	0	0	0	0	0	0	0	1	3.4
			Temperature, water	89	0	0	0	0	4	7	8	6	7	0	0	0	36.0
LPIL	Little Pilchuck Creek	1/8/04–7/13/11	Dissolved Oxygen	88	0	0	0	1	1	5	8	6	6	0	0	0	30.7
			pH	90	2	0	0	0	0	0	0	0	1	0	1	1	5.6
			Temperature, water	90	0	0	0	0	4	8	8	7	7	0	0	0	37.8
PILOK	Pilchuck River	1/21/10–7/13/11	Dissolved Oxygen	19	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			pH	19	0	0	1	0	0	0	0	0	0	0	0	0	5.3
			Temperature, water	19	0	0	0	0	1	1	2	1	1	0	0	0	31.6
PILR	Pilchuck River at Snohomish	1/8/04–12/7/09	Dissolved Oxygen	71	0	0	0	1	1	0	2	2	0	0	0	0	8.5
			pH	72	1	0	1	0	0	0	0	0	0	1	0	1	5.6
			Temperature, water	72	0	0	0	0	3	4	6	6	6	2	0	0	37.5

Snohomish County Surface Water Quality Database Data

Prior to the development of Ecology's EIM database, Snohomish County water quality data were made accessible through the County's Surface Water Quality Database. These data are currently being migrated to EIM, but monitoring data collected prior to 2005 are still only available through the County database. Monitoring data for the French Creek and Pilchuck River watersheds currently available in the County Surface Water Quality Database were collected as part of the Ambient Monitoring Study, which ended in 2009. As a result, there is some overlap between data available in EIM and the County database where the data were collected at a monitoring station between 2005 and 2009. For the purposes of completeness, all County database data are presented as a separate dataset.

There are a total of twenty-four water quality monitoring stations in the French Creek and Pilchuck River watersheds with water quality data available in the County Surface Water Quality Database. Monitoring stations included in the EIM data, but not the County database are those where water quality monitoring was only collected after 2009 (PILOK and STABLES).

Tables 11 and 12 summarize the available DO, pH, temperature, nitrate-nitrite, total Kjeldahl nitrogen, ammonia, total phosphorus, turbidity, and total suspended solids water quality results for both Snohomish County studies in the French Creek and the Pilchuck River watersheds, respectively. All monitoring data other than water temperature are discrete samples collected at approximately monthly intervals. In addition, the data used to generate the summaries in Tables 11 and 12 should be considered estimates due to some limitations in transferring QA/QC flags and comments to the Surface Water Quality Database. Therefore, the usability of these data, particularly as model performance targets, will be further assessed at the time of model development. In most cases, the fully verified Snohomish County data migrated to the EIM database presented in the previous section will be used in lieu of data extracted from the Surface Water Quality Database.

Table 11. Snohomish County French Creek watershed water quality data summary (County Database).

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
CCH2	Cripple Cr at Hwy 2	5/23/1995	3/27/1996	Dissolved Oxygen	16	4.74	9.90	7.22	mg/L
				Nitrate-Nitrite	17	0.34	1.40	0.81	mg/L
				Temperature, water	16	4.00	14.70	9.54	deg C
				Total Phosphorus	17	0.02	0.13	0.06	mg/L
				Total Suspended Solids	14	2.00	14.00	6.36	mg/L
		7/20/1995	3/27/1996	pH	15	6.06	7.07	6.64	pH
CCLS	Cripple Cr at Robinhood Ln	5/25/1994	4/11/1995	Dissolved Oxygen	20	7.46	15.40	11.24	mg/L
				Nitrate-Nitrite	20	0.63	1.40	1.01	mg/L
				pH	20	6.50	7.80	7.18	pH
				Temperature, water	20	1.90	17.60	9.60	deg C
				Total Phosphorus	20	0.01	0.23	0.06	mg/L
		6/30/1994	4/11/1995	Total Suspended Solids	17	2.00	25.00	10.12	mg/L
CCUS	Cripple Cr at Trombley Rd	5/25/1994	4/11/1995	Dissolved Oxygen	20	3.81	13.91	10.27	mg/L
				Nitrate-Nitrite	20	0.27	1.60	0.83	mg/L
				pH	20	6.40	7.90	6.97	pH
				Temperature, water	20	2.70	14.40	9.20	deg C
				Total Phosphorus	20	0.01	0.06	0.04	mg/L
		6/14/1994	4/11/1995	Total Suspended Solids	15	2.00	18.00	6.40	mg/L
FCDD	French Cr at Old Sno-Monroe Hwy (short-term)	5/25/1994	4/12/1995	Dissolved Oxygen	19	1.59	9.87	5.89	mg/L
				Nitrate-Nitrite	20	0.21	5.40	1.66	mg/L
				pH	20	6.00	7.30	6.68	pH
				Temperature, water	20	5.00	21.30	11.59	deg C
				Total Phosphorus	20	0.02	0.16	0.07	mg/L
		5/25/1994	4/12/1995	Total Suspended Solids	19	2.00	16.00	8.53	mg/L
FCLD	French Cr at	9/15/1993	12/8/2009	Dissolved Oxygen	187	0.10	15.25	6.86	mg/L

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
	Old Sno-Monroe Hwy (long-term)			Nitrate-Nitrite	188	0.03	4.44	1.01	mg/L
				pH	189	5.94	9.14	6.72	pH
				Temperature, water	190	1.90	24.20	11.29	deg C
				Total Phosphorus	189	0.00	0.69	0.08	mg/L
				Total Suspended Solids	179	0.00	120.00	9.02	mg/L
		4/15/1998	12/8/2009	Turbidity	139	1.25	240.00	13.67	NTU
FCLU	French Cr at 167th Av	9/15/1993	12/8/2009	Dissolved Oxygen	189	7.34	15.48	11.31	mg/L
				Nitrate-Nitrite	190	0.06	2.30	0.67	mg/L
				pH	190	5.55	7.91	6.93	pH
				Temperature, water	191	0.00	16.60	9.38	deg C
				Total Phosphorus	188	0.00	0.13	0.02	mg/L
				Total Suspended Solids	171	0.00	220.00	6.00	mg/L
		4/15/1998	12/8/2009	Turbidity	140	0.00	53.50	2.59	NTU
FCMS	French Cr at Hwy 2	5/23/1995	3/27/1996	Dissolved Oxygen	15	1.16	11.00	6.79	mg/L
				Nitrate-Nitrite	17	0.05	2.30	0.73	mg/L
				Temperature, water	16	4.80	22.40	11.36	deg C
				Total Phosphorus	17	0.02	0.65	0.11	mg/L
				Total Suspended Solids	17	2.00	400.00	37.71	mg/L
		7/20/1995	3/27/1996	pH	15	6.04	6.91	6.49	pH
FL1	Fryelands at Fryelands Blvd (north)	5/23/1995	3/13/1996	Nitrate-Nitrite	16	0.04	0.95	0.41	mg/L
		5/23/1995	3/27/1996	Dissolved Oxygen	16	3.61	8.16	6.30	mg/L
				Temperature, water	16	5.60	16.50	11.46	deg C
				Total Phosphorus	17	0.01	0.13	0.06	mg/L
				Total Suspended Solids	16	2.00	110.00	22.63	mg/L
		7/20/1995	3/27/1996	pH	15	6.25	7.28	6.85	pH
FL2	Fryelands at Fryelands Blvd (middle)	5/23/1995	3/27/1996	Dissolved Oxygen	16	5.01	9.80	7.04	mg/L
				Nitrate-Nitrite	17	0.42	2.60	1.69	mg/L
				Temperature, water	16	6.50	16.20	11.74	deg C
				Total Phosphorus	17	0.01	0.10	0.03	mg/L
				Total Suspended Solids	14	1.00	180.00	19.00	mg/L
		7/20/1995	3/27/1996	pH	15	6.06	7.12	6.72	pH
FL3	Fryelands at Fryelands Blvd (south)	5/23/1995	3/27/1996	Dissolved Oxygen	16	2.01	12.09	7.66	mg/L
				Nitrate-Nitrite	17	0.20	2.90	1.88	mg/L
				pH	16	5.50	7.07	6.63	pH
				Temperature, water	16	6.40	16.70	11.39	deg C
				Total Phosphorus	17	0.00	0.12	0.05	mg/L
				Total Suspended Solids	17	2.00	200.00	35.53	mg/L
LH1	Lords Hill at Old Sno-Monroe Hwy (east)	5/23/1995	3/13/1996	Total Suspended Solids	13	1.00	170.00	23.77	mg/L
		5/23/1995	3/27/1996	Dissolved Oxygen	17	2.20	13.65	9.99	mg/L
				Nitrate-Nitrite	17	0.01	3.70	1.69	mg/L
				pH	16	6.39	7.30	6.73	pH
				Temperature, water	17	2.10	16.50	9.80	deg C
				Total Phosphorus	17	0.01	0.11	0.04	mg/L
LH2	Lords Hill at Old Sno-Monroe Hwy (west)	5/23/1995	3/27/1996	Dissolved Oxygen	16	8.45	14.61	11.15	mg/L
				Nitrate-Nitrite	17	0.64	4.10	2.13	mg/L
				pH	16	6.19	8.02	6.94	pH

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
				Temperature, water	17	2.60	16.90	9.61	deg C
				Total Phosphorus	17	0.01	0.13	0.04	mg/L
				Total Suspended Solids	16	2.00	290.00	24.88	mg/L
PUMP	French Cr at Pump station	5/23/1995	3/27/1996	Dissolved Oxygen	16	1.88	10.86	4.73	mg/L
				Nitrate-Nitrite	17	0.01	1.20	0.60	mg/L
				pH	16	5.78	7.11	6.45	pH
				Temperature, water	17	3.40	23.30	11.65	deg C
				Total Phosphorus	17	0.01	0.20	0.07	mg/L
				Total Suspended Solids	15	3.00	120.00	25.13	mg/L
SPLS	Spada Cr at Spada Rd	5/25/1994	4/12/1995	Dissolved Oxygen	19	7.72	14.11	11.51	mg/L
				Nitrate-Nitrite	20	0.13	1.10	0.61	mg/L
				Temperature, water	20	3.90	14.30	9.16	deg C
				Total Phosphorus	20	0.00	0.06	0.03	mg/L
		6/14/1994	4/12/1995	pH	19	6.70	7.60	7.11	pH
				Total Suspended Solids	14	2.00	26.00	7.86	mg/L
SPUS	Spada Cr at Storm Lk Rd	5/25/1994	4/12/1995	Dissolved Oxygen	19	1.02	13.04	8.09	mg/L
				Nitrate-Nitrite	20	0.02	1.10	0.42	mg/L
				pH	19	6.30	7.70	6.86	pH
				Temperature, water	20	3.20	23.20	11.04	deg C
				Total Phosphorus	19	0.00	0.09	0.04	mg/L
		6/30/1994	4/12/1995	Total Suspended Solids	11	2.00	110.00	23.18	mg/L
STLS	Stables Cr at Westwick Rd	5/26/1994	4/10/1995	Ammonia	15	0.01	0.23	0.04	mg/L
				Dissolved Oxygen	20	6.87	14.01	10.53	mg/L
				Nitrate-Nitrite	20	0.15	1.60	0.74	mg/L
				pH	19	6.70	7.30	6.99	pH
				Temperature, water	20	2.80	19.70	11.05	deg C
				Total Kjeldahl Nitrogen	16	0.05	1.80	0.81	mg/L
				Total Phosphorus	20	0.00	0.06	0.03	mg/L
				Total Suspended Solids	19	2.00	110.00	11.79	mg/L
STUS	Stables Cr at 93rd St SE	5/26/1994	4/10/1995	Ammonia	15	0.01	0.09	0.04	mg/L
				Dissolved Oxygen	20	6.18	15.73	10.32	mg/L
				Nitrate-Nitrite	20	0.18	1.30	0.79	mg/L
				pH	20	6.50	7.60	6.96	pH
				Temperature, water	20	2.90	16.10	10.22	deg C
				Total Kjeldahl Nitrogen	16	0.05	1.30	0.66	mg/L
				Total Phosphorus	20	0.01	0.05	0.03	mg/L
				Total Suspended Solids	19	2.00	56.00	11.16	mg/L
TRUS	Trench Cr at 139th Dr SE	5/25/1994	4/11/1995	Dissolved Oxygen	19	2.06	13.71	9.16	mg/L
				Nitrate-Nitrite	19	0.02	1.50	0.59	mg/L
				pH	19	5.80	7.60	6.65	pH
				Temperature, water	19	2.10	18.10	10.20	deg C
				Total Phosphorus	19	0.00	0.05	0.02	mg/L
		6/14/1994	3/1/1995	Total Suspended Solids	8	2.00	19.00	6.13	mg/L

Table 12. Snohomish County Pilchuck River watershed water quality data summary (County Database).

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
CATH	Catherine Cr at 12th St NE	10/21/1998	12/7/2009	Dissolved Oxygen	132	6.52	14.69	10.74	mg/L
				Nitrate-Nitrite	134	0.03	0.86	0.20	mg/L
				pH	134	5.66	7.82	7.11	pH
				Temperature, water	134	3.23	20.60	11.16	deg C
				Total Phosphorus	133	0.00	0.16	0.03	mg/L
				Total Suspended Solids	124	0.00	22.00	3.51	mg/L
				Turbidity	134	0.00	13.20	1.95	NTU
DUBQ	Dubuque Cr at OK Mill Rd	10/21/1998	12/7/2009	Dissolved Oxygen	132	8.66	14.70	11.24	mg/L
				Nitrate-Nitrite	134	0.04	1.74	0.54	mg/L
				pH	133	6.09	7.97	7.11	pH
				Temperature, water	133	0.66	17.51	9.54	deg C
				Total Phosphorus	130	0.00	0.08	0.02	mg/L
				Total Suspended Solids	119	0.00	21.00	2.84	mg/L
				Turbidity	134	0.00	12.48	1.96	NTU
GCLS	Golf Course Cr at 137th St NE	5/26/1994	4/10/1995	Dissolved Oxygen	20	4.58	14.86	9.88	mg/L
				Nitrate-Nitrite	20	0.02	1.60	0.67	mg/L
				pH	20	6.40	7.30	6.92	pH
				Temperature, water	20	1.90	16.90	9.74	deg C
				Total Phosphorus	20	0.01	0.09	0.03	mg/L
		6/27/1994	3/13/1995	Total Suspended Solids	14	2.00	43.00	8.00	mg/L
		2/27/1995	2/27/1995	Total Kjeldahl Nitrogen	1	0.41	0.41	0.41	mg/L
GCUS	Golf Course Cr at 147th Av SE	5/26/1994	3/28/1995	Total Suspended Solids	18	2.00	37.00	8.61	mg/L
				Dissolved Oxygen	20	3.74	14.21	9.16	mg/L
				Nitrate-Nitrite	20	0.01	1.40	0.50	mg/L
				pH	20	6.40	7.30	6.85	pH
				Temperature, water	20	2.80	24.50	11.16	deg C
				Total Phosphorus	19	0.01	0.11	0.04	mg/L
		2/27/1995	2/27/1995	Total Kjeldahl Nitrogen	1	0.41	0.41	0.41	mg/L
LPIL	Little Pilchuck Cr at 12th St NE	10/21/1998	12/7/2009	Dissolved Oxygen	131	2.88	14.39	10.75	mg/L
				Nitrate-Nitrite	134	0.02	1.36	0.45	mg/L
				pH	134	6.03	7.67	7.00	pH
				Temperature, water	134	0.68	21.45	9.76	deg C
				Total Phosphorus	131	0.00	0.24	0.03	mg/L
				Total Suspended Solids	124	0.00	20.00	2.50	mg/L
				Turbidity	134	0.00	46.40	1.95	NTU
PILR	Pilchuck R at 6th St	10/21/1998	12/7/2009	Dissolved Oxygen	133	8.85	16.28	11.23	mg/L
				Nitrate-Nitrite	135	0.01	1.00	0.37	mg/L
				pH	135	6.23	7.99	7.11	pH
				Temperature, water	135	1.40	20.68	10.24	deg C
				Total Phosphorus	130	0.00	0.20	0.02	mg/L
				Total Suspended Solids	123	0.00	240.00	10.32	mg/L
				Turbidity	135	0.00	253.00	7.15	NTU

Figure 6 illustrates Snohomish County water quality monitoring station locations from Tables 11 and 12, as well as the locations of continuous monitoring locations maintained by the county. Continuous monitoring data summaries are not included in this QAPP, however, because the data collected do not meet the definition of credible data in RCW 90.48.585 or conditions of Water Quality Program Policy 1-11 Chapter 4. .

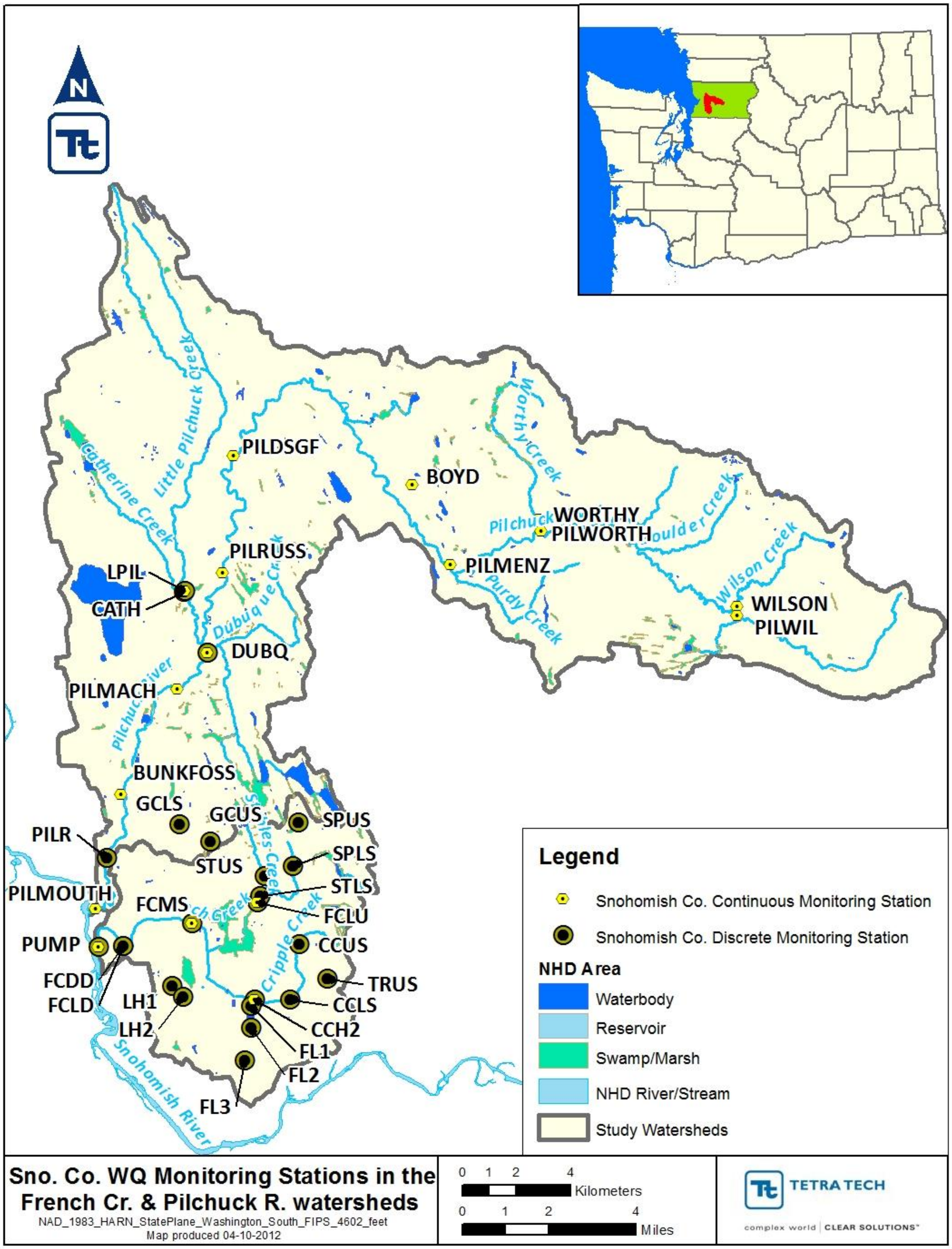

Figure 6. Snohomish County water quality monitoring stations cataloged in the Surface Water Quality Database.

A general examination was made of how the discrete water quality data compare to applicable water quality criteria (see Water Quality Standards and Numeric Criteria section above). Water quality criteria for DO and temperature include a time component; therefore, instantaneous exceedances of the numeric component of the criteria do not necessarily represent a criterion violation. Instantaneous exceedances do represent a cause for concern and can give insight into water quality conditions. Exceedances of the TMDL parameters by month over the entire monitoring time period at each discrete station are presented in Tables 13 and 14 for the French Creek and Pilchuck River watersheds, respectively.

The Snohomish County data for the French Creek watershed monitoring stations generally had wider ranges of exceedances than the Pilchuck River watershed. Specifically, the DO exceedances ranged from 5.3 to 100% in the French Creek watershed (Table 13). pH exceeded the water quality criteria 0 to 62.5% of the time generally due to low pH (FCLD had an exceedance due to high pH) and temperature exceedances ranged from 30 to 45%. Temperature and DO exceedances were more frequent in the summer months, with DO more likely to be exceeded in other months, as well. pH criteria were most often exceeded in the winter, late summer, and fall.

Of the two long-term monitoring locations, FCLD had the highest percent exceedance for all parameters. Of the short-term monitoring locations Fryelands (FL1) showed the highest percent exceedance for DO overall (100%) and also had a large percentage of temperature criteria exceedances (43.8%) (Table 13).

Table 13. Summary of Snohomish County discrete water quality data (County Database) exceedances of the numeric component of applicable water quality criteria in the French Creek watershed.

Station	Station name	Time period	Parameter	Sample count	Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
CCH2	Cripple Cr at Hwy 2	5/23/95–3/27/96	Dissolved Oxygen	16	1	1	2	--	1	1	1	2	1	2	1	2	93.8
		7/20/95–3/27/96	pH	15	1	0	0	--	--	--	0	1	1	0	0	0	20.0
		5/23/95–3/27/96	Temperature, water	16	0	0	0	--	1	1	1	2	1	0	0	0	37.5
CCLS	Cripple Cr at Robinhood Ln	5/25/94–4/11/95	Dissolved Oxygen	20	0	0	0	0	0	1	1	2	1	0	0	0	25.0
			pH	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	20	0	0	0	0	1	1	1	2	2	0	0	0	35.0
CCUS	Cripple Cr at Trombley Rd	5/25/94–4/11/95	Dissolved Oxygen	20	0	0	0	0	0	1	1	1	2	0	0	0	25.0
			pH	20	0	0	0	0	0	1	0	0	0	0	0	0	5.0
			Temperature, water	20	0	0	0	0	1	1	1	2	2	0	0	0	35.0
FCDD	French Cr at Old Sno-Monroe Hwy (short-term)	5/25/94–4/12/95	Dissolved Oxygen	19	1	2	1	1	1	2	1	2	2	2	2	1	94.7
			pH	20	2	1	0	0	0	0	0	1	0	0	0	1	25.0
			Temperature, water	20	0	0	0	0	1	2	1	2	2	0	0	0	40.0
FCLD	French Cr at Old Sno-Monroe Hwy (long-term)	9/15/93–12/8/09	Dissolved Oxygen	187	11	11	13	14	13	15	14	13	14	15	13	12	84.5
			pH	189	6	7	7	5	2	2	1	2	1	2	2	7	23.3
			Temperature, water	190	0	0	0	2	7	16	16	15	16	9	0	1	43.2
FCLU	French Cr at 167th Av	9/15/93–12/8/09	Dissolved Oxygen	189	0	0	1	1	0	1	4	5	5	0	0	0	9.0
			pH	190	4	2	3	3	3	1	0	0	1	3	3	8	16.3

Station	Station name	Time period	Parameter	Sample count	Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
			Temperature, water	191	0	0	0	0	2	12	16	15	11	2	0	0	30.4
FCMS	French Cr at Hwy 2	5/23/95–3/27/96	Dissolved Oxygen	15	1	0	2	--	1	1	--	2	1	2	1	2	86.7
		7/20/95–3/27/96	pH	15	1	1	1	--	--	--	0	1	1	1	1	0	46.7
		5/23/95–3/27/96	Temperature, water	16	0	0	0	--	1	1	1	2	1	0	0	0	37.5
FL1	Fryelands at Fryelands Blvd (north)	5/23/95–3/27/96	Dissolved Oxygen	16	1	2	2	--	1	1	1	2	1	2	1	2	100.0
		7/20/95–3/27/96	pH	15	0	0	0	--	--	--	0	1	1	0	0	0	13.3
		5/23/95–3/27/96	Temperature, water	16	0	0	0	--	1	1	1	2	1	1	0	0	43.8
FL2	Fryelands at Fryelands Blvd (middle)	5/23/95–3/27/96	Dissolved Oxygen	16	1	2	1	--	1	1	1	2	1	2	1	2	93.8
		7/20/95–3/27/96	pH	15	0	0	0	--	--	--	0	1	1	0	1	0	20.0
		5/23/95–3/27/96	Temperature, water	16	0	0	0	--	1	1	1	2	1	1	0	0	43.8
FL3	Fryelands at Fryelands Blvd (south)	5/23/95–3/27/96	Dissolved Oxygen	16	1	1	0	--	1	1	1	1	1	2	1	2	75.0
			pH	16	0	0	0	--	1	--	0	1	1	2	1	0	37.5
			Temperature, water	16	0	0	0	--	1	1	1	1	1	0	0	0	31.3
LH1	Lords Hill at Old Sno-Monroe Hwy (east)	5/23/95–3/27/96	Dissolved Oxygen	17	0	0	0	--	1	1	1	1	1	0	1	0	35.3
			pH	16	0	0	0	--	0	--	0	1	0	1	0	0	12.5
			Temperature, water	17	0	0	0	--	0	1	1	3	1	0	0	0	35.3
LH2	Lords Hill at Old Sno-Monroe Hwy (west)	5/23/95–3/27/96	Dissolved Oxygen	16	0	0	0	--	1	1	--	0	1	0	0	0	18.8
			pH	16	0	0	0	--	0	--	0	0	0	0	0	2	12.5
			Temperature, water	17	0	0	0	--	0	1	1	3	1	0	0	0	35.3
PUMP	French Cr at Pump station	5/23/95–3/27/96	Dissolved Oxygen	16	1	0	2	--	1	1	--	3	1	2	1	2	87.5
			pH	16	1	1	2	--	0	--	0	1	0	2	1	2	62.5
			Temperature, water	17	0	0	0	--	1	1	1	3	1	0	0	0	41.2
SPLS	Spada Cr at Spada Rd	5/25/94–4/12/95	Dissolved Oxygen	19	0	0	0	0	0	1	0	0	0	0	0	0	5.3
		6/14/94–4/12/95	pH	0	0	0	0	0	--	0	0	0	0	0	0	0	0.0
		5/25/94–4/12/95	Temperature, water	20	0	0	0	0	1	1	1	2	1	0	0	0	30.0
SPUS	Spada Cr at Storm Lk Rd	5/25/94–4/12/95	Dissolved Oxygen	19	0	0	0	0	1	2	1	2	2	2	0	0	52.6
			pH	19	1	1	0	0	0	0	0	0	0	0	0	0	10.5
			Temperature, water	20	0	0	0	0	1	2	1	2	2	1	0	0	45.0
STLS	Stables Cr at Westwick Rd	5/26/94–4/10/95	Dissolved Oxygen	20	0	0	0	0	0	1	1	2	2	0	0	0	30.0
			pH	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	20	0	0	0	0	1	2	1	2	2	0	0	0	40.0
STUS	Stables Cr at 93rd St SE	5/26/94–4/10/95	Dissolved Oxygen	20	0	0	0	0	0	1	1	2	2	1	0	0	35.0
			pH	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	20	0	0	0	0	1	2	1	2	2	0	0	0	40.0
TRUS	Trench Cr at 139th Dr SE	5/25/94–4/11/95	Dissolved Oxygen	19	0	0	0	0	1	2	--	2	2	1	0	0	42.1
			pH	19	1	2	3	0	0	0	--	0	0	0	1	1	42.1
			Temperature, water	19	0	0	0	0	1	1	--	2	2	1	0	0	36.8

Note: -- indicates no data collected

In the Pilchuck River watershed, DO exceeded the criteria 7.6 to 50% of the time, with the majority of exceedances occurring in the summer months (Table 14). The range of pH exceedances at the same stations was extremely narrow (5 to 9%). Temperature standards were exceeded 32.3 to 41% of the time. As expected, these exceedances typically occurred in the summer months. Monitoring stations on Golf Course Creek (GCLS and GCUS) showed the most frequent exceedances of the DO criteria and the second most frequent exceedances of the temperature criteria. Note that this station was sampled for only one year while the other stations have twenty-year records. Of the long-term monitoring stations, CATH located on Catherine Creek showed the most frequent exceedances for both DO and temperature criteria.

Table 14. Summary of Snohomish County discrete water quality data (County Database) exceedances of the numeric component of applicable water quality criteria in the Pilchuck River watershed.

Station	Station name	Time period	Parameter	Sample count	Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
CATH	Catherine Cr at 12th St NE	10/21/98–12/7/09	Dissolved Oxygen	132	0	0	0	1	1	6	8	8	8	1	0	0	25.0
			pH	134	2	0	1	1	0	0	1	0	0	1	0	1	5.2
			Temperature, water	134	0	0	0	1	5	11	11	11	11	5	0	0	41.0
DUBQ	Dubuque Cr at OK Mill Rd	10/21/98–12/7/09	Dissolved Oxygen	132	0	0	0	1	1	0	3	3	1	1	0	0	7.6
			pH	133	3	1	1	1	1	0	0	0	0	0	0	2	6.8
			Temperature, water	133	0	0	0	0	3	8	11	10	10	1	0	0	32.3
GCLS	Golf Course Cr at 137th St NE	5/26/94–4/10/95	Dissolved Oxygen	20	0	0	0	0	1	1	1	2	2	2	0	0	45.0
			pH	20	0	1	0	0	0	0	0	0	0	0	0	0	5.0
			Temperature, water	20	0	0	0	0	1	2	1	2	2	0	0	0	40.0
GCUS	Golf Course Cr at 147th Av SE	5/26/94–4/10/95	Dissolved Oxygen	20	0	0	0	0	1	2	1	2	2	2	0	0	50.0
			pH	20	0	0	1	0	0	0	0	0	0	0	0	0	5.0
			Temperature, water	20	0	0	0	0	1	1	1	2	2	0	0	0	35.0
LPIL	Little Pilchuck Cr at 12th St NE	10/21/98–12/7/09	Dissolved Oxygen	131	0	0	0	1	1	6	8	7	9	0	0	0	24.4
			pH	134	3	1	1	0	1	0	0	0	1	1	2	2	9.0
			Temperature, water	134	0	0	0	0	3	11	11	11	10	0	0	0	34.3
PILR	Pilchuck R at 6th St	10/21/98–12/7/09	Dissolved Oxygen	133	0	0	0	1	1	1	3	3	0	1	1	0	8.3
			pH	135	1	0	2	0	1	0	0	0	0	2	0	2	5.9
			Temperature, water	135	0	0	0	0	3	9	11	11	11	3	0	0	35.6

Washington State Department of Ecology Data

Ecology, in partnership with Snohomish County, has conducted water quality monitoring in the French Creek and Pilchuck River watersheds. Table 15 lists Ecology's current (07B075, 07R050) and historical (070B055, 07B090, 07B120, 07B150) water quality stations and their associated Water Quality Index (WQI). Ecology developed a WQI as a method to evaluate conventional water quality parameters including temperature, pH, FC bacteria, total suspended solids, DO, and nutrients during routine monitoring. Waters are rated as low, moderate, or high concern, where low concern represents good water quality, moderate concern represents marginal water quality, and high concern represents poor water quality. More information on Ecology's WQI can be found at
www.ecy.wa.gov/programs/eap/fw_riv/docs/WQIOverview.html.

French Creek, near the mouth, was identified as a water body of high concern based on its WQI. Most of the other water bodies were given a moderate ranking.

Table 15. Ecology water quality monitoring station descriptions.

Station ID	Station name	WQI[a] water quality	WQI rationale
07B055	Pilchuck River at Snohomish	Moderate	Based on WY 1996 WQ Summary
07B075	Pilchuck River at Russel Rd.	Moderate	Based on WY 2010 WQ Summary
07B090	Pilchuck River near Lake Stevens	None[b]	Historical data only
07B120	Pilchuck River at Robe-Menzel Rd.	Moderate	Based on WY 2006 WQ Summary
07B150	Pilchuck River at Menzel Lake Rd.	Moderate	Based on WY 2006 WQ Summary
07R050	French Creek near Mouth	High Concern	Based on WY 1996 WQ Summary

[a] Low concern represents good water quality, moderate concern represents marginal water quality, and high concern represents poor water quality.
[b] WQI value not available. The historic data (1976-1977) at this station are do not include all of the parameters used in WQI calculations.

Table 16 summarizes the water quality parameters of concern collected at the six Ecology monitoring stations and Figure 7 displays their locations in the watersheds.

Table 16. Ecology French Creek and Pilchuck River watersheds water quality data summary.

Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
07B055	Pilchuck River at Snohomish	12/1/1970	9/16/1996	Dissolved Oxygen	236	8.6	14	11.3	mg/L
				pH	230	6.4	8.6	7.2	pH
				Temperature, water	237	0.4	23.4	11.1	deg. C
07B075	Pilchuck River at Russel Rd.	10/20/2009	9/27/2010	Dissolved Oxygen	12	10.19	13.6	11.4	mg/L
				pH	12	6.96	7.67	7.3	pH
				Temperature, water	12	3.7	16.8	9.5	deg. C
07B090	Pilchuck River near Lake Stevens	10/11/1976	9/19/1977	Dissolved Oxygen	24	9.5	13.1	11.3	mg/L
				pH	24	6.8	8.9	7.3	pH
				Temperature, water	24	3.2	20.4	10.9	deg. C
07B120	Pilchuck River at Robe-Menzel Rd.	10/18/2005	9/19/2006	Dissolved Oxygen	12	10.5	13.3	11.9	mg/L
				pH	12	7.2	8.16	7.5	pH
				Temperature, water	12	4.5	14.4	9.1	deg. C
07B150	Pilchuck River at Menzel Lake Rd.	10/18/2005	9/19/2006	Dissolved Oxygen	12	10.7	13.3	12.0	mg/L
				pH	12	7.2	8.14	7.5	pH
				Temperature, water	12	3.9	12.8	8.2	deg. C
07R050	French Creek near Mouth	10/16/1995	12/14/2011	Dissolved Oxygen	14	3	8.9	6.8	mg/L
				pH	14	6.5	8.1	7.0	pH
				Temperature, water	14	4.2	17.6	10.7	deg. C

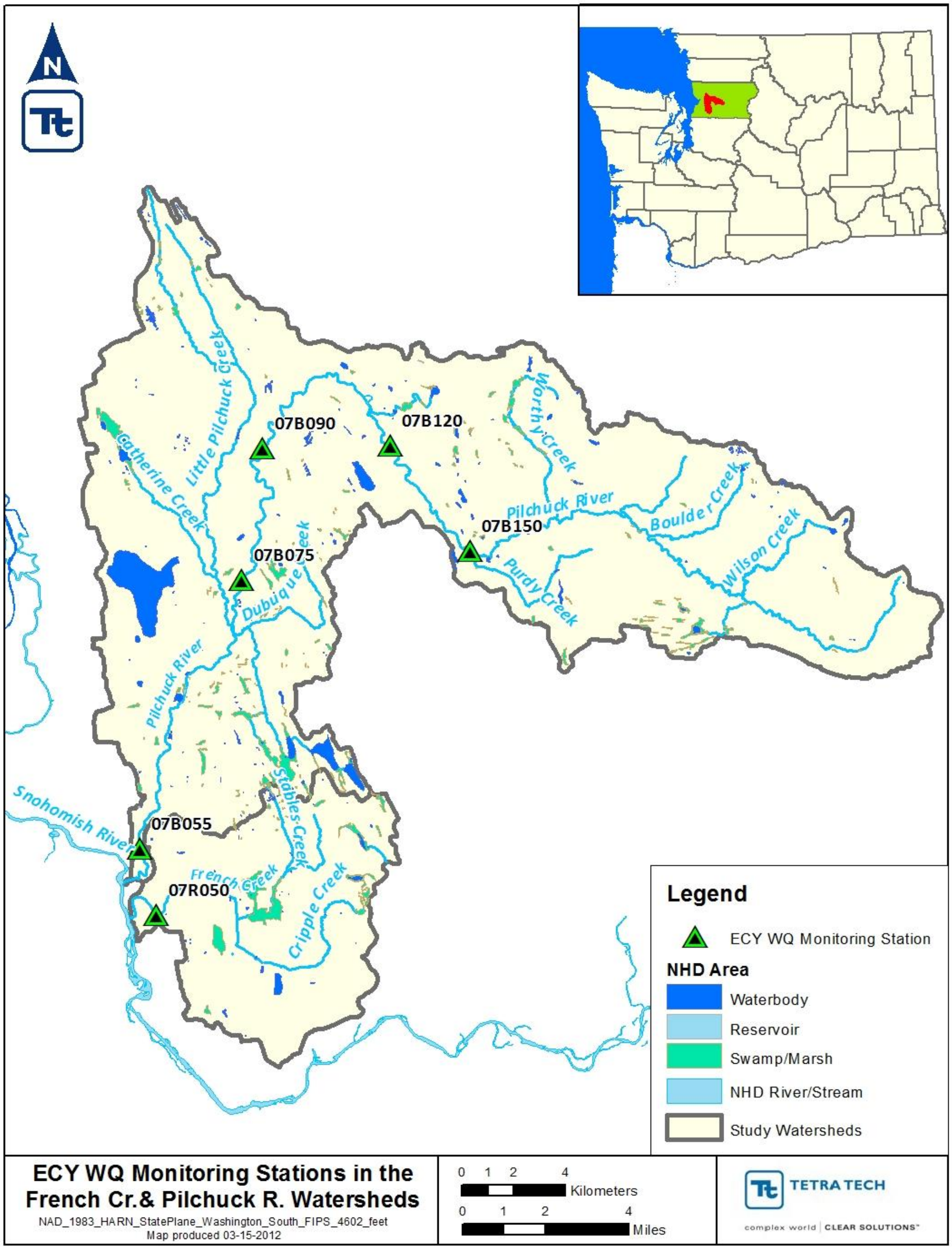

Figure 7. Washington Department of Ecology water quality monitoring stations.

Table 17 presents a summary of exceedances for the numeric component of water quality criteria by month over the monitoring time period at each Ecology station for DO, pH, and temperature. Water quality criteria for DO and temperature also include a time component; therefore, instantaneous exceedances of the numeric component of the criteria do not necessarily represent a criterion violation. Instantaneous exceedances do represent a cause for concern and can give insight into water quality conditions. When evaluating the Pilchuck River stations, DO exceeded the water quality criteria 0% of the time at all stations except the Pilchuck River at Snohomish (07B055), which had an exceedance frequency of 5.9% (as noted above, this given that the DO criteria has a time component, additional evaluation is required to accurately characterize impairments; if samples are collected mid-day they may not characterize the early morning critical DO conditions). In contrast, the French Creek station near the mouth (07R050) exceeded DO criteria 100% of the time.

pH exceeded the criteria at the Pilchuck River stations 0 to 4.2% of the time (only two stations had exceedances—07B055 and 07B090). The Ecology French Creek station (07R050) did not have any pH exceedances.

Temperature exceeded the criteria 16.7 to 41.7% of the time at the Pilchuck River stations and 42.9% of the daily temperature measurements at the French Creek station exceeded the water quality criteria (Table 17). As expected, these exceedances generally occurred during the summer critical period.

Table 17. Ecology French Creek and Pilchuck River watershed monitoring exceedance summary for discrete data.

Station	Station name	Time period	Parameter	Sample count	Exceedances												
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	%
07B055	Pilchuck River at Snohomish	12/1/70–9/16/96	Dissolved Oxygen	236	0	0	0	0	0	0	6	7	1	0	0	0	5.9
			pH	230	0	0	1	0	1	0	0	0	0	0	0	1	1.3
			Temperature, water	237	0	0	0	2	13	20	20	20	19	3	0	0	40.9
07B075	Pilchuck River at Russell Rd.	10/20/09–9/27/10	Dissolved Oxygen	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			pH	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	12	0	0	0	0	1	0	1	1	1	0	0	0	33.3
07B090	Pilchuck River near Lake Stevens	10/11/76–9/19/77	Dissolved Oxygen	24	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			pH	24	0	0	1	0	0	0	0	0	0	0	0	0	4.2
			Temperature, water	24	0	0	0	0	1	2	2	2	2	1	0	0	41.7
07B120	Pilchuck River at Robe-Menzel Rd.	10/18/05–9/19/06	Dissolved Oxygen	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			pH	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	12	0	0	0	0	1	1	1	1	0	0	0	0	33.3
07B150	Pilchuck River at Menzel Lake Rd.	10/18/05–9/19/06	Dissolved Oxygen	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			pH	12	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	12	0	0	0	0	0	0	1	1	0	0	0	0	16.7
07R050	French Creek near Mouth	10/16/95–12/14/11	Dissolved Oxygen	14	1	--	1	1	1	1	1	1	1	2	2	2	100.0
			pH	14	0	--	0	0	0	0	0	0	0	0	0	0	0.0
			Temperature, water	14	0	--	0	0	1	1	1	1	1	1	0	0	42.9

Note: -- indicates no data collected

Other Water Quality Monitoring Data

The city of Monroe and the FSFCD have also collected monitoring data in the French Creek watershed. These data are summarized in Table 18 and the monitoring locations are shown in Figure 8.

Table 18. City of Monroe and FSFCD water quality monitoring data summaries.

Agency	Station	Station name	Begin date	End date	Parameter	Sample count	Min	Max	Avg	Unit
City of Monroe	FC-Frye	French Creek near Fryelands	3/11/2008	7/11/2011	Dissolved Oxygen	41	4.8	16.1	8.6	mg/L
					Temperature, water	41	2.6	15.4	9.6	deg C
	FC-LTye	Lake Tye Outfall	3/11/2008	7/11/2011	Dissolved Oxygen	41	7.6	15.3	10.6	mg/L
					Temperature, water	41	4.3	22.9	13.5	deg C
	FC-Crp	Lower Cripple Crk at 179th	3/11/2008	7/11/2011	Dissolved Oxygen	37	7.4	15.2	11.8	mg/L
					Temperature, water	38	0.3	15.6	8.7	deg C
French Slough Flood Control District	Site 1	Airport Bridge	9/30/2003	11/17/2009	Dissolved Oxygen	68	4.2	11.6	6.8	mg/L
	Site 2	Lateral Ditch A	9/30/2003	11/17/2009	Dissolved Oxygen	68	1.5	7.8	4.4	mg/L
	Site 3	French Creek by Hwy 2	9/30/2003	11/17/2009	Dissolved Oxygen	68	4.5	12.8	9.2	mg/L
	Site 4	Cripple Creek	9/30/2003	11/17/2009	Dissolved Oxygen	68	5.5	10.8	7.9	mg/L
	Site 5	Tye Lake Creek	9/30/2003	11/17/2009	Dissolved Oxygen	66	5.2	12.5	9.2	mg/L
	Site 6	Pump Station	3/20/2006	11/17/2009	Dissolved Oxygen	40	3.1	8.6	5.4	mg/L

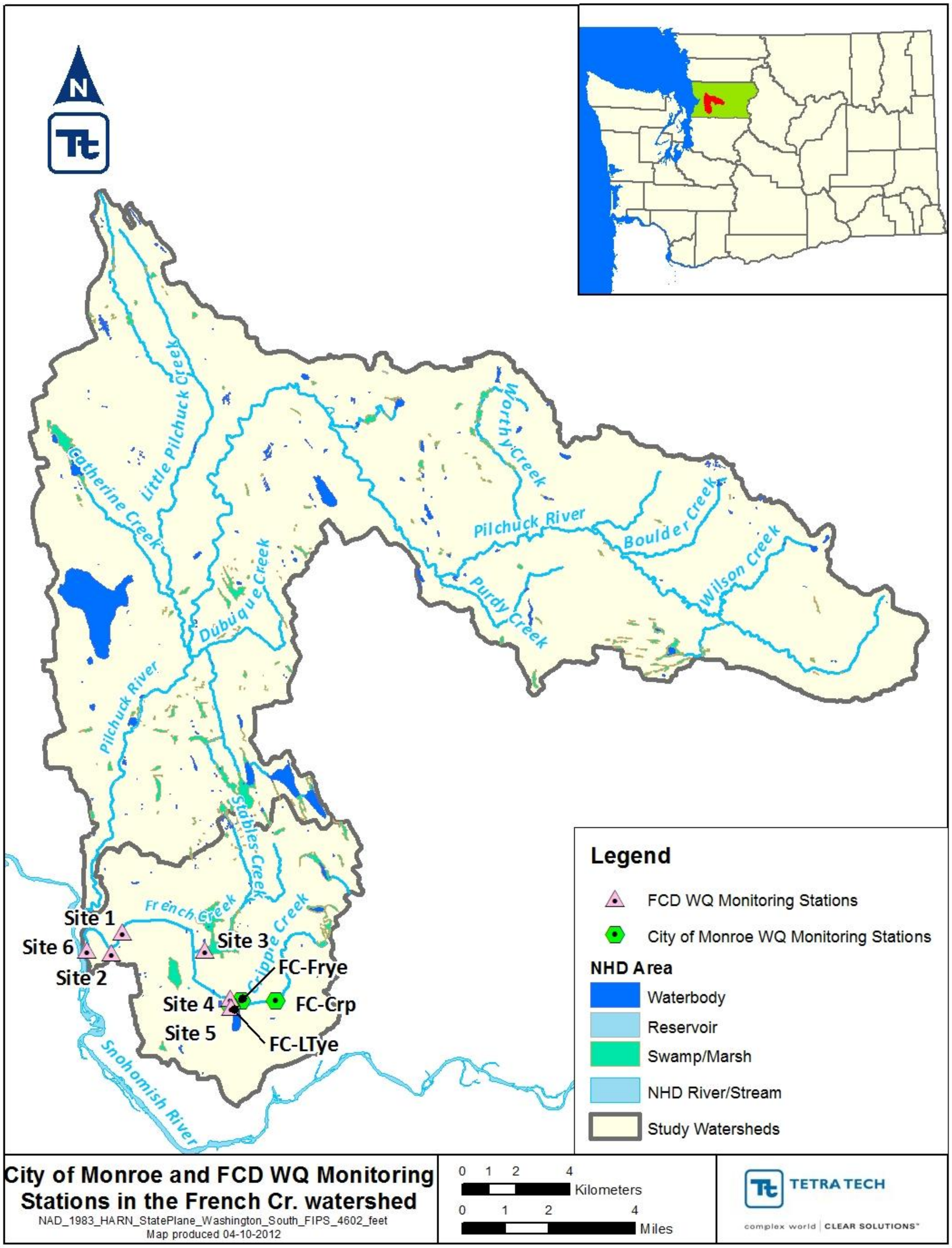

Figure 8. City of Monroe and FSFCD water quality monitoring station locations.

Streamflow Data

Snohomish County's Surface Water Management Division conducts field monitoring of streamflow in the Pilchuck River watershed. The County has monitored nine stations, including six locations along the Pilchuck River and a single location on three tributaries to the Pilchuck River: Catherine Creek, Dubuque Creek, and Little Pilchuck Creek. The County also collects continuous flow data at one station in the upper reaches of French Creek, which has been used to summarize the daily average flow for the purposes of this study. Discharge data for water releases at the pump station located on the mouth of French Creek (Figure 1) are not maintained by the FSFCD. To support TMDL model development, a time-series of water withdrawals due to pump activity will be developed during Hydrologic Simulation Program – Fortran modeling (HSPF) to maintain the water level set by the FSFCD.

There is one long-term continuous USGS flow gage (USGS 12155300) co-located with the county station PR4.2 on the Pilchuck River mainstem near the city of Snohomish. Flow monitoring station locations are shown in Figure 9. Table 19 lists streamflow monitoring stations in the study area and summarizes the available data.

During the TMDL development process it may be necessary to expand the available flow record. This can be done by establishing relationships between flows at long-term flow monitoring stations (07B055, FCLU, and USGS 12155300) and flows at the other monitoring stations with shorter flow records.

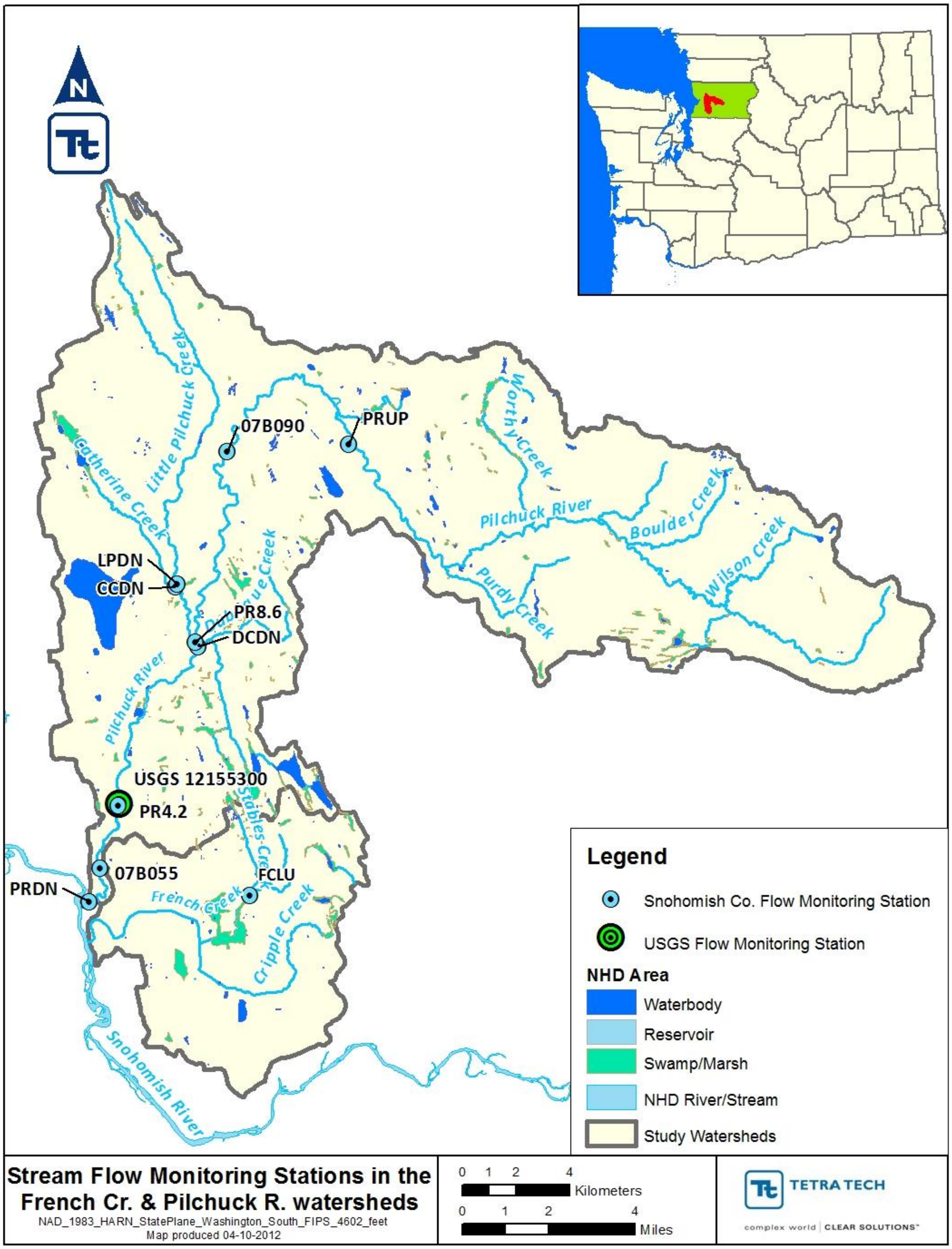

Figure 9. Snohomish County and USGS streamflow monitoring stations.

Table 19. Streamflow monitoring stations in the Pilchuck River watershed.

Agency	Station ID	Station name (measurement type)	Begin date	End date	Sample count	Min (cfs)	Max (cfs)	Avg (cfs)
Snohomish County Surface Water Management Division	07B055	Pilchuck River at Snohomish (instantaneous)	7/12/1971	9/16/1996	217	40.0	2,950.0	484.0
	07B090	Pilchuck River near Lake Stevens (instantaneous)	10/11/1976	9/19/1977	23	62	545.0	200.3
	CCDN	Catherine Creek at Little Pilchuck Creek (instantaneous)	2/13/1996	4/9/1996	5	10.7	48.9	33.6
	DCDN	Dubuque Creek at mouth (instantaneous)	2/13/1996	4/9/1996	5	11.1	51.5	34.7
	LPDN	Little Pilchuck Creek a mouth (instantaneous)	2/13/1996	4/9/1996	6	11.5	54.3	34.4
	PR4.2	Pilchuck River near Snohomish, WA (instantaneous)	2/13/1996	4/9/1996	6	236.0	900.0	552.5
	PR8.6	Pilchuck River at Dubuque Creek (instantaneous)	2/13/1996	4/9/1996	5	193.0	693.0	479.2
	PRDN	Pilchuck River at mouth (instantaneous)	2/13/1996	4/9/1996	6	236.0	900.0	659.3
	PRUP	Pilchuck River above Coon Creek (instantaneous)	2/13/1996	4/9/1996	5	148.0	520.0	360.6
	FCLU	French Cr at 167th Av (long-term continuous)	3/27/1995	1/13/2012	5,735	0.0	505.7	14.2
USGS	12155300	Pilchuck River near Snohomish, WA (long-term continuous)	5/5/1992	2/27/2012	7,238	36	12,100	476.7

Goals and Objectives

Project Goal

The goal of the proposed TMDL study is to evaluate compliance with state water quality standards for temperature, DO, and pH in the French Creek and Pilchuck River watersheds and to support development of a Water Quality Improvement Report and Implementation Plan.

Study Objectives

Objectives of the TMDL study are as follows:

- Collect high quality data during field surveys from June 2012 to September 2012.
- Characterize stream temperatures and processes governing the thermal regime in French Creek and the Pilchuck River and major tributaries. This includes the influence of tributaries and groundwater/surface water interactions on the heat budget.
- Develop a predictive temperature model for French Creek and the Pilchuck River and major tributaries. Using critical conditions in the model, determine the streams' capacities to assimilate heat. Evaluate the system potential temperature (approximate natural temperature conditions) for both streams.
- Characterize processes governing DO and pH in French Creek and the Pilchuck River and major tributaries, including the influence of tributaries, nonpoint sources, and groundwater.
- Develop a model to simulate watershed processes, instream biochemical processes and productivity, DO, and pH in French Creek and the Pilchuck River and major tributaries. Evaluate natural conditions with the model by removing human pollutant sources and hydromodifications to the extent feasible. Using critical conditions in the model, determine the capacity to assimilate biochemical oxygen demand and nutrients.
- Determine the loading capacity of pollutants that meets temperature, pH, and DO water quality criteria and protect beneficial uses.
- Present potential alternative pollutant allocation scenarios for point and nonpoint sources that meet the loading capacity.
- Use the calibrated models to evaluate future water quality management decisions for the French Creek and Pilchuck River watersheds.

Study Design

Overview

TMDL study objectives will be supported by data collected by Ecology during field monitoring surveys during the summer of 2012. The study may also be supported with pertinent existing data collected by Snohomish County, Ecology, USGS, city of Monroe, FSFCD, and others. Any water quality data collected and used in the TMDL analysis will meet the requirements of Ecology's credible data policy (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf.).

In situ DO, pH, temperature, conductivity, and associated conventional parameters will be monitored during the summer critical season. Sites include locations at the mouths of tributaries, significant drainage/discharges, and key locations along French Creek and the Pilchuck River as detailed later in the "Water Quality Sampling Plan" subsection of this report.

Streamflow will be measured or calculated at all sites at the time of sampling. In addition, a continuous flow gage will be installed in French Creek – downstream of Cripple Creek and before the impounded area – at the Old Snohomish Monroe Rd. Bridge to characterize critical season flow from the upper watershed.

In addition to the diurnal surveys, one continuously recording (DO, temperature, pH, and conductivity) Hydrolab® DataSonde® will be installed with Ecology's flow gage on French Creek, which will record throughout the course of the summer.

The watershed and water quality models will be calibrated to these field data. The calibrated models will be used to evaluate the water quality in response to various alternative scenarios of pollutant loading and calculate the loading capacity of French Creek and the Pilchuck River.

Load allocations for nonpoint sources and wasteload allocations for point sources will also be evaluated. The models will be used to determine (1) how much nutrients and biochemical oxygen demand need to be reduced to meet DO and pH water quality criteria and (2) how much effective shade is necessary to bring stream temperature into compliance with water quality criteria. Components and descriptions of the models are summarized in the Modeling and Analysis Framework section. In addition, potential best management practices (BMPs) will be evaluated with the selected models to determine implementation opportunities to achieve the required load reductions.

Modeling and Analysis Framework

Addressing the principal study questions requires a modeling framework that can provide an interactive simulation of flow, upland nutrient and thermal loading, instream oxygen demand, and carbon and alkalinity balance processes. To predict thermal, DO, and pH conditions throughout the French Creek and Pilchuck River watersheds systems and to assess relationships with riparian vegetation characteristics and topography, a combined Shade-HSPF-QUAL2Kw modeling system will be applied.

This modeling system is composed of a geographical information system (GIS)-based Shade model linked to the QUAL2Kw water quality model and the HSPF watershed model to develop watershed management options. Figure 10 illustrates how the models interact and work together to develop prescriptive TMDL allocations. The selected models are based on data that are already available or can be collected during the summer 2012 sampling included in this QAPP, and on the analysis needed to meet study objectives.

QUAL2Kw serves as the model to perform instream water quality simulations. The steady-state QUAL2Kw model is appropriate for evaluating impairments and determining specific conditions during the summer low flow period. The HSPF model performs watershed simulations and provides hydrology and water quality boundary conditions, i.e., inputs, to the instream QUAL2Kw model. In addition, because HSPF is a process-based model, it will be used to simulate the impact of BMP implementation on runoff quantity and pollutant inputs. The GIS-based Shade model will simulate shading factors based on topography and riparian vegetation coverage, which will feed into the QUAL2Kw instream model.

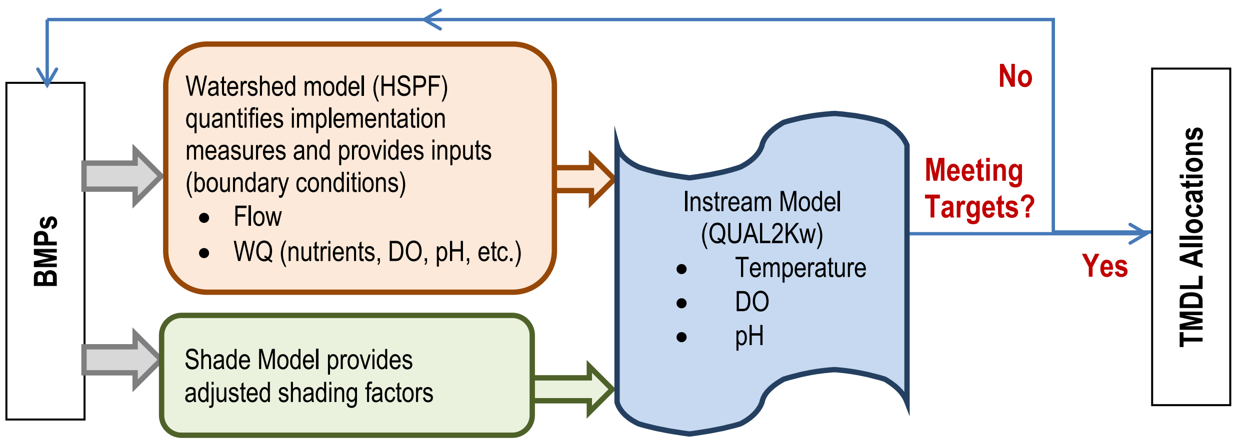

Figure 10. Shade-HSPF-QUAL2Kw Modeling System

In addition to the overall modeling framework, non-stormwater point sources will be evaluated using a mass balance equation to calculate effluent discharge (Ecology, 2007). This calculation ensures that the discharge will not raise the river temperature by more than 0.3ºC at the edge of the mixing zone under all but the most extreme – 1 in 10 years – conditions. Provisions in the Washington State Water Quality Standards allow mixing zones of up to 25% by volume of the streamflow.

Model Selection

The work described in this QAPP does not involve creating new simulation modeling software. Rather, it involves developing a base conceptual model and data collection for the watersheds and applying that information to existing models: Shade.xls, QUAL2Kw, and HSPF. The rationale for selecting proposed modeling framework components is described below in the model-specific sections.

Shade Model

The Shade model was selected to evaluate solar radiation along the streams using watershed specific GIS-based data derived with the TTools ArcView extension developed by the Oregon Department of Environmental Quality (ODEQ). It was designed to develop GIS-based data from acquired polygon and grids coverages. It specifically used these coverages to develop vegetation and topography data perpendicular to the stream channel and longitudinal stream channel characteristics such as the near-stream disturbance zone and elevation. Typical inputs into TTools are LiDAR data, digital elevation models (DEMs) and aerial imagery (digital orthophoto quadrangles and rectified aerial photos). Stream width, aspect, topographic shade angles, elevation, and riparian vegetation will be sampled with TTools for incorporation into the Shade model. The riparian vegetation coverage will contain four specific attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density of the riparian vegetation.

Ecology's Shade model (Shade.xls—a Microsoft Excel spreadsheet available for download at www.ecy.wa.gov/programs/eap/models.html (Ecology, 2003a) was adapted from a program that ODEQ developed as part of version 6 of its HeatSource model. Shade.xls calculates effective shade using one of two methods. The first is Chen's method, based on the Fortran program, HSPF SHADE. Y.D. Chen developed it for his 1996 Ph.D. dissertation at the University of Georgia (Chen, 1996), and it is further documented in the Journal of Environmental Engineering (Chen 1998a, 1998b). The second method is ODEQ's original method from the HeatSource model version 6. Documentation of ODEQ's HeatSource model is at www.heatsource.info and www.deq.state.or.us/wq/TMDLs/TMDLs.htm. The Shade model quantifies the potential daily solar load and generates the percent effective shade. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because vegetative cover and topography intercept it. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics, such as height, width, overhang, and density.

The Shade model requires physical and vegetation parameters such as stream width, aspect, topographic shade angles, elevation, and riparian vegetation that will be determined using the TTools GIS extension. Most data inputs for the Shade Model are easily available through aerial imagery and digital elevation models. Additional field data will be collected to characterize riparian shade (to compare observed shade to model-predicted shade) and vegetation. TTools output will be used as input for the Shade model to generate longitudinal effective shade profiles. Riparian vegetation, stream aspect, topographic shade angles, and latitude/longitude will be used to estimate effective shade. Reach-averaged integrated hourly effective shade, i.e., the fraction of potential solar radiation blocked by topography and vegetation, will be used as input into the QUAL2Kw model, which is discussed below.

HSPF Model

HSPF is a comprehensive, basin-scale watershed and stream reach model that is capable of simulating hydrology, pollutant load generation, and fate and transport of pollutants instream channels. It allows the integrated simulation of runoff processes and instream interactions and is capable of simulating sub-daily dynamic time series of runoff and pollutant loads and concentrations. HSPF represents subsurface interactions, vegetation, topography, and natural storage in hydrology simulations. The required data for HSPF modeling are already available from existing sources, discussed below, or are anticipated to be collected during the summer 2012 sampling addressed by this QAPP. These data can be categorized into three groups.

- Input/execution data, including precipitation and meteorology data (potential evapotranspiration, air temperature, dew point, solar radiation, wind speed, and cloud cover), diversions and point sources, atmosphere deposition.
- Watershed characteristic data, including land use/cover, soils, DEM, and channel information, i.e., hydraulics and geometry.
- Calibration/validation data, including observed flow and water quality measurements such as temperature, pH, DO, nutrients, and biochemical oxygen demand.

The original HSPF model (hydrology only) for the French Creek watershed was developed by the French Creek Watershed Management Committee and Snohomish County (Beyerlein and Brascher, 1998). HSPF modeling efforts will build on the available hydrology simulation since the available modeling report includes some of the modeling parameters. However, the original HSPF model will be updated with more recent French Creek watershed characteristics. The Pilchuck River watershed will be added to this model. The two watersheds will be combined into a single input file for ease of model configuration, but output can be provided for individual reaches throughout the system. Also, the hydrology parameterization will be refined through comparison with available flow data. This additional review, calibration, and validation (model corroboration) will ensure that the original HSPF hydrology model meets the specifications in this QAPP and covers the entire TMDL study area. Additional detail on the calibration and validation process is included later in this report.

After hydrology simulations are complete, water quality simulations will be completed to support predictions of temperature, DO, and pH in the French Creek and Pilchuck River watersheds, using the RQUAL functions in HSPF. The DO simulation could also require simulation of nutrients and algal growth, if the monitoring data of the segments simulated in HSPF show significant diurnal DO swing, which indicates that low DO is caused by eutrophication. The pH simulation requires simulation of carbon dioxide, total inorganic carbon, and alkalinity. The HSPF water quality model will be calibrated using observed instream data (nutrients, DO, carbon dioxide, total inorganic carbon, alkalinity, pH, temperature). Output from the HSPF model will be used to provide boundary conditions, i.e., model inputs, such as altered hydrology and pollutant runoff data, to the QUAL2Kw water quality model.

The HSPF model will also be used to evaluate different BMP implementation scenarios. Specifically, most of the structural BMPs (e.g., infiltration BMPs, detention/retention, etc.) can be represented in the model directly to simulate the potential impact on instream water quality. HSPF can also be used to simulate stream conditions without the French Creek pump station. Representation of existing and potential BMPs is dependent on available data and information; therefore, the specific simulations will be determined once data are obtained and reviewed for TMDL analyses. For some of the non-structural BMPs, such as nutrient management and pasture management, an efficiency-based approach will be used to estimate impacts and land simulation parameters such as reduced nutrient inputs from specific land uses. Estimates will be adjusted to reflect the assumed efficiencies. The contractor will explore various options to identify appropriate removal efficiencies, including similar modeling and monitoring efforts in Washington and elsewhere and also in the Western Washington Hydrology Model.

The contractor will calibrate the HSPF and QUAL2Kw water quality models in tandem. Parameter values obtained by calibrating and validating the QUAL2Kw model to short-term monitoring events will be used to refine the temperature, pH, and DO representation in HSPF. The updated HSPF model will be used to further refine the inputs for QUAL2Kw to achieve the best fit to support TMDL calculations.

QUAL2Kw Model

The steady-state QUAL2Kw model will be used for detailed evaluation of temperature and water quality impacts under critical flow and weather conditions in French Creek and the Pilchuck River. These two watersheds will be represented by separate QUAL2Kw models since they are not connected. QUAL2Kw is a quasi-steady state model and is Ecology's preferred tool for DO TMDLs. It is the primary water quality model that has been used in past TMDLs and will be used in this TMDL as well. The model uses steady-state flow conditions and simulates water temperature and water quality parameters with diurnal variations. QUAL2Kw is well matched to the short-period, intensive/continuous monitoring work conducted by local agencies. QUAL2Kw will be used to address specific specialized processes such as hyporheic flow.

Meteorological conditions have strong influences on water temperature. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, and headwater temperature. Some of these parameters, such as effective shade from Shade model, are calculated, and others are obtained from weather station information. Stream temperature is also affected by point source effluent temperatures. It will be obtained from discharge monitoring report (DMR) data, where available. Additional water quality parameters, including nutrients, will also be obtained for simulation of pH and DO. These factors will be specified or simulated as time-varying functions. These point sources will be incorporated into the model based on available data. They will also be evaluated separately using a mass balance equation to calculate effluent discharge to ensure the point source meets temperature Water Quality Standards at the edge of the mixing zone (Ecology, 2007).

QUAL2Kw will be applied to conduct focused analysis of critical conditions such as low flow and high temperature that impact all three impairments, pH, DO, and temperature, from which TMDL targets can be determined directly. Model input will include flow, temperature, DO, nutrient, BOD, alkalinity, and/or total inorganic carbon boundary conditions from the basin-scale HSPF model. The QUAL2Kw model will be used for evaluating TMDL loading capacity and developing allocations under critical conditions. As described above, calibration of the QUAL2Kw model to short-term events with continuous monitoring data will also be used to refine parameters for the heat, pH, and DO simulations in the watershed-scale HSPF water quality model.

Summary of the Modeling Framework

The Shade-HSPF-QUAL2Kw modeling system provides a dynamic simulation of flow, upland nutrient and thermal loading, steady-state instream thermal balance, oxygen demand, and carbon and alkalinity balance processes under critical conditions. HSPF will be run continuously for a long period of time to capture various environmental conditions at an hourly time scale. The anticipated modeling period is 1996-2012. The model may be run sub-hourly if data are available for calibration. QUAL2Kw will be run hourly for shorter date ranges during the 2012 critical summer period, coinciding with the best available data for calibration. The complete modeling system will be used to develop prescriptive TMDLs in French Creek and the Pilchuck River for temperature, DO, and pH, including various scenarios and evaluations of land use and the effect of the pump station on the lower reach of French Creek. Table 20 summarizes the modeling components and their role in the proposed technical approach.

Table 20. Shade-HSPF-QUAL2Kw Modeling Components

Model Component	Function
Shade Model	Calculates effective shade based on riparian topography and vegetation for input to QUAL2Kw stream model.
HSPF	Simulates watershed hydrology, pollutant load generation, provides loading and boundary conditions (input) to QUAL2Kw stream model, and predicts impact of future land use changes and BMP implementation.
QUAL2Kw	Simulates instream DO, pH, and temperature under low flow and high temperature steady-state critical conditions.

Careful consideration was given to model selection. Both models have some disadvantages. Specifically, HSPF needs intensive input data and its instream water quality simulation module is not as rigorous as QUAL2Kw because it does not consider some specialized processes, such as hyporheic flow. Disadvantages of QUAL2Kw are that it does not consider the land use-based processes required to perform scenarios for prescriptive TMDL development. However, when combined, both models have strong advantages for French Creek and the Pilchuck River TMDL development.

An HSPF model is needed to provide loading and boundary conditions to the stream and to address land use changes and BMP implementations under future scenarios for prescriptive TMDL development. The advantages of using HSPF include:

- HSPF is a well-known public domain model that has comprehensive representation of watershed land and stream processes, as well as watershed pollutant sources, including nonpoint sources by multiple land uses, point sources, and atmospheric deposition.
- HSPF has the capability to simulate temperature, DO, and pH.
- Existing and anticipated data are sufficient to support development and calibration of an HSPF model.
- HSPF is a process-based model that can be used to simulate the effectiveness of structural and non-structural BMPs, thereby supporting development of prescriptive TMDL allocations.
- HSPF is flexible and can be adapted to a wide range of watershed conditions.
- HSPF has a robust subsurface hydrology component that can simulate baseflow.

There are also strong advantages for including a QUAL2Kw model to address impairments associated with low flow critical conditions:

- QUAL2Kw is Ecology's standard tool for low flow critical condition TMDLs and has a high degree of familiarity for both Ecology staff and stakeholders.
- QUAL2Kw enables a focused analysis of critical conditions from which TMDL targets can be determined directly, rather than through analysis of dynamic time series, which is often not necessary and is resource intensive.
- QUAL2Kw is well matched to the short-period intensive/continuous monitoring work that will be conducted on the creeks.
- QUAL2Kw addresses some specialized processes such as hyporheic flow that are not normally addressed in HSPF and can be used to test the relevance and importance of such processes.
- A QUAL2Kw application can provide important information on parameter values for both heat and DO that can be carried over to the HSPF model to refine the calibration.
- Because QUAL2Kw can be run quickly it is a useful tool for efficient assessment of the sensitivity of model results to boundary conditions and parameters.

Model Calibration and Assessment

Environmental simulation models are simplified mathematical representations of complex real-world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigating how a system would likely respond to a perturbation from its current state. To provide a credible basis for predicting and evaluating mitigation options, the ability of the model to represent real-world conditions should be demonstrated through a process of model calibration and corroboration (CREM, 2009).

Objectives of Model Calibration Activities

Model calibration is designed to ensure that the model is adequate to provide appropriate input to answer the study questions. The objective of this TMDL is to develop innovative temperature, pH, and DO TMDLs, which include BMP implementation strategies to address the required load reductions. The principal study questions to be addressed by modeling in this project are:

1. What are the sources of decreased DO and pH and increased temperature in the French Creek and Pilchuck River watersheds during critical summer low flow conditions?
2. What are the TMDL allocations—such as riparian shade, nutrients, or impervious area—needed in the French Creek and Pilchuck River watersheds to meet temperature, pH, and DO standards?

To address those questions, the models must be able to provide credible representations of the movement of water, and the generation and transport of thermal and pollutant loads.

In addition, the model can also be used to assess other management actions such as enhanced groundwater interactions, changes in the flow regime, etc. A more refined list of potential scenarios to evaluate will be determined during TMDL development.

Model Calibration/Assessment Procedures

Calibration consists of the process of adjusting model parameters to provide a match to observed conditions. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the water body of interest. Calibration tunes the models to represent conditions appropriate to the water body and watershed being studied.

However, calibration alone is not sufficient to evaluate the predictive capability of the model or to determine whether the model developed via calibration contains a valid representation of cause and effect relationships. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a quality assessment step often referred to as validation. In the assessment step, the quality of the model performance is assessed on a set of data separate from that used in calibration. Details associated with these processes for the HSPF and QUAL2Kw models are described in the following sections. Also, to verify accuracy of the Shade model, available data including field measurements of effective shade and vegetation and hemisphere photographs will be used.

HSPF Model

The French Creek and Pilchuck River model HSPF will be calibrated and assessed through a sequential process, beginning with hydrodynamics, followed by the water quality. The model time period will overlap with the available flow and water quality data. Based on data reviewed and received to date, it is anticipated that 1995-2012 will be the HSPF modeling period to ensure that all hydrologic and seasonal conditions are covered. Hydrologic calibration will use standard operating procedures described for the HSPF model in BASINS Technical Note 6 on *Estimating Hydrology and Hydraulic Parameters for HSPF* (EPA, 2000). HSPF modeling will build on work conducted by the French Creek Watershed Management Committee and Snohomish County (Beyerlein and Brascher, 1998). However, significant refinements will be made to update the conditions in the French Creek watershed with more recent geographic and meteorological data as well as to incorporate the Pilchuck River watershed.

The contractor will calibrate the hydrology modeling for HSPF. During this process, all model inputs will be verified as within acceptable ranges of measured data specific to the basin or literature values. Model output will be compared to the annual water balance, low/high flow distribution, storm peaks, and hydrograph shape, among other things. During hydrology calibration, land segment hydrology parameters are adjusted iteratively to achieve agreement between simulated and observed streamflows at specified locations throughout the basin. Agreement between observed and simulated streamflow data are evaluated on annual and seasonal bases using quantitative and qualitative measures. Quantitative measures and performance targets are described below in the *Quality Objectives for Modeling* section.

Specifically, annual water balance, groundwater volumes and recession rates, and surface runoff and interflow volumes and timing are evaluated, along with composite comparisons, e.g., average monthly streamflow values over the period of record. Given that impairments are associated with low-flow critical conditions, the calibration and validation process will focus on achieving a strong fit during these periods; however, the contractor will also try to accurately capture high flow events. Specific attention will be paid to model fit on individual dates used as boundary conditions for the QUAL2Kw model simulations.

After calibration for hydrology, the contractor will calibrate the models for water quality. In the development of the French Creek and Pilchuck River model carried out under this work assignment, rigorous calibration will be undertaken for temperature, pH, and DO. The model will be set up to provide a mass balance representation of pollutant loading, e.g., total nitrogen, total phosphorus. It will also provide a representation of instream kinetics of algal growth for the segments with DO swings caused by eutrophication. For those segments, this study will also investigate whether DO swings are simulated within acceptable ranges in other parts of the river to ensure the model is performing well in different contexts. While emphasis will be placed on model fit associated with the QUAL2Kw simulation period, the longer HSPF simulation will consider processes that span multiple days or weeks such as algal growth, thereby representing antecedent conditions which can affect the boundary conditions to QUAL2Kw.

Unlike flow, many water quality parameters are not observed continuously. In many cases, the calibration must rely on comparison of continuous model output to point-in-time-and-space observations. As a result, it is not possible to fully separate error in the model from variability inherent in the observations. For example, a model could provide an accurate representation of an event mean or daily average concentration in a reach, but an individual observation at one time and one point in a reach itself could differ significantly from the average. The calibration and assessment will focus on matching the average or minimum/maximum water quality standards for the parameters of interest. When evaluating model performance in matching multiple measurements, it is important to use statistical tests that compare modeled and measured values as part of a weight-of-evidence evaluation of the water quality calibration. By using statistical tests between observed and simulated concentrations, supplemented by analyzing consistency between simulated loads and loads determined from observed data, meaningful calibration of the water quality parameters can be performed. When continuous water quality data are available, continuous model output will be compared using the QUAL2Kw model, as described below.

As another example using DO, it is unreasonable to propose that the model predict all temporal variations in concentrations. Unavoidable deviations between the model predictions and observations will result from all of the following:

- unmonitored changes in point source loading
- loading from groundwater or activities associated with high nutrient loads
- precipitation events that are not adequately represented by the available rain gauge network
- analytical uncertainty in observed water quality

The model should, however, provide an acceptable representation of long-term and seasonal trends in concentration, the minimum values that represent impairment, and correctly represent the relationship between flow and load.

In this project, a two-phased approach will be used for water quality calibration. In the first phase, the model will be calibrated, guided by a visual comparison approach aimed at reproducing the trend and overall dynamics of the system. The second phase involves fine tuning the parameters and then calculating various error statistics. Evaluation of these statistics will identify the most appropriate calibrated parameters. The results are subsequently evaluated visually to ensure the trend and overall dynamics of the system are maintained after the phase two refinements.

After the model is adequately calibrated, the quality of the calibration will be assessed through tests on a separate data set. This process is often referred to as model validation, defined as “subsequent testing of a pre-calibrated model to additional field data, usually under different external conditions, to further examine the model’s ability to predict future conditions” (EPA 1997). Its purpose is to determine how the calibrated model assesses the variables and conditions that can affect model results. The process also demonstrates the ability to predict field observations for periods separate from the calibration effort, without changing model parameters from the calibration step. This step helps to ensure that the calibration is robust. This step also ensures that the quality of the calibration is not an artifact of over-fitting to a specific set of observations; this can occur because of the persistence of the effects of high-precipitation events on water storage in the model. Assessment also provides a direct measure of the degree of uncertainty that can be expected when the model is applied to conditions outside the calibration series.

QUAL2Kw Model

The QUAL2Kw model (Chapra and Pelletier, 2003; Ecology, 2003b) will be used to simulate both observed and critical conditions. Critical conditions are characterized by a period of low flows and high water and air temperatures which affect temperature, DO, and pH due to plant productivity. pH changes are also associated with soil, precipitation, and snowmelt pH. Sensitivity analyses will be run to assess the variability of the model results.

Temperature

The QUAL2Kw model will be used to evaluate the system potential temperature in segments along the main stem of the Pilchuck River and major tributaries downstream of Purdy Creek and along the main major reaches of the French Creek watershed. The model will be used to evaluate various heat budget scenarios for future water quality management decisions in the French Creek and Pilchuck River watersheds.

Data collected during this TMDL effort will allow the development of a temperature simulation methodology that is both spatially continuous and spans full-day lengths. The model will be calibrated to observed summer 2012 conditions measured by this study design. The GIS and modeling analysis will be conducted using specialized software tools:

- The Ttools extension for ArcView will be used to sample and process GIS data for input to the shade and temperature models.
- Ecology's Shade Model (Ecology, 2003a) will be used to estimate effective shade along the watershed segments. Effective shade will be calculated at 50- to 100-meter intervals along the streams, and then averaged over 500- to 1000-meter intervals for input to the temperature model. The Shade Model will be calibrated by comparing field measurements to model-estimated effective shade. This will ensure the model is accurately representing the parameters impacting shade.
- The QUAL2Kw model will be used to calculate the components of the heat budget and to simulate water temperatures. The temperature model simulates diurnal variations in-stream temperature using the kinetic formulations for the components of the surface water heat budget that are described in Chapra (1997).

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

Dissolved oxygen and pH

Water quality modeling for DO and pH will also be conducted using QUAL2Kw. The water quality model will use kinetic formulations for simulating DO and pH in the water column. The model will be calibrated and corroborated using data collected during the synoptic[1] surveys and available historical data.

Existing Data and Data Gaps

The HSPF model will be run for a long time to account for various watershed conditions. The anticipated time period is 1995-2012, based on a review of available data. Existing data as well as data collected under this QAPP will be used in model development, calibration, and assessment. Input time series of meteorological and point source data will be compiled that correspond to the HSPF modeling period. The QUAL2Kw model simulations will be calibrated using the new water quality, flow, and air temperature/relative humidity data to be collected under this QAPP. The HSPF model simulations will be calibrated for the same time period for boundary conditions.

Data to support these modeling efforts include both existing data for the HSPF model and new data to be collected for the HSPF and QUAL2Kw models. Existing discrete and continuous temperature and streamflow monitoring conducted throughout the watershed were examined and are described below. Data gaps have been identified based on a review of these existing monitoring data and the plan to address these gaps is discussed in the Water Quality Sampling Plan section.

Discrete Monitoring Data

Stream segments listed as impaired for DO, pH, and temperature in the French Creek and Pilchuck River watersheds are detailed in Table 21 along with the monitoring stations located on each segment. See Figure 11 for map. While other stream segments in the watersheds are also important and are included in this study, this table identifies some of the data likely used for the 303(d) listing decision that prompted this study.

[1] All stations sampled over a short period of time.

Table 21. Monitoring sites located on 303(d) impaired segments (Category 5).

Stream	303(d) Segment Ecology ID	River Mile		303(d) Listing			Data Source*	Station	Location
		DS	US	Temp	pH	DO			
French Creek	1220872478883	0.00	0.58	x			FCD	Site 6	On
							SnoCo	PUMP	On
	1220872478883	1.97	2.63	x	x	x	FCD	Site 2	Upstream
							FCD	Site 1	Upstream
							SnoCo	FCDD	On
							SnoCo	FCLD	On
							EIM	FCLD	On
							ECY	07R050	On
	1220872478883	6.45	8.60		x	x	FCD	Site 3	On
							SnoCo	FCMS	Downstream
	1220872478883	9.66	10.57		x	x	SnoCo	FCLU	On
							SnoCo	STLS	Upstream
							EIM	FCLU	On
							EIM	STABLES	Upstream
Pilchuck River	1220899479044	12.08	14.19		x		SnoCo	DUBQ	Upstream
							EIM	DUBQ	Upstream
							EIM	PILOK	On
	1220899479044	14.19	16.46	x			ECY	07B075	On
Little Pilchuck Creek	1220358479889	0.64	2.83		x		SnoCo	LPIL	On
							SnoCo	CATH	Upstream
							EIM	LPIL	On
							EIM	CATH	Upstream
Catherine Creek	1220455480080	0.00	0.13	x			SnoCo	CATH	Upstream
							EIM	CATH	Upstream
Unnamed Trib to Pilchuck R.	1220248480200	0.37	0.90			x	No Data		

* FCD: Flood Control District.
SnoCo: Snohomish County – Historical.
EIM: Snohomish County – Recent.
ECY: Washington State Department of Ecology.

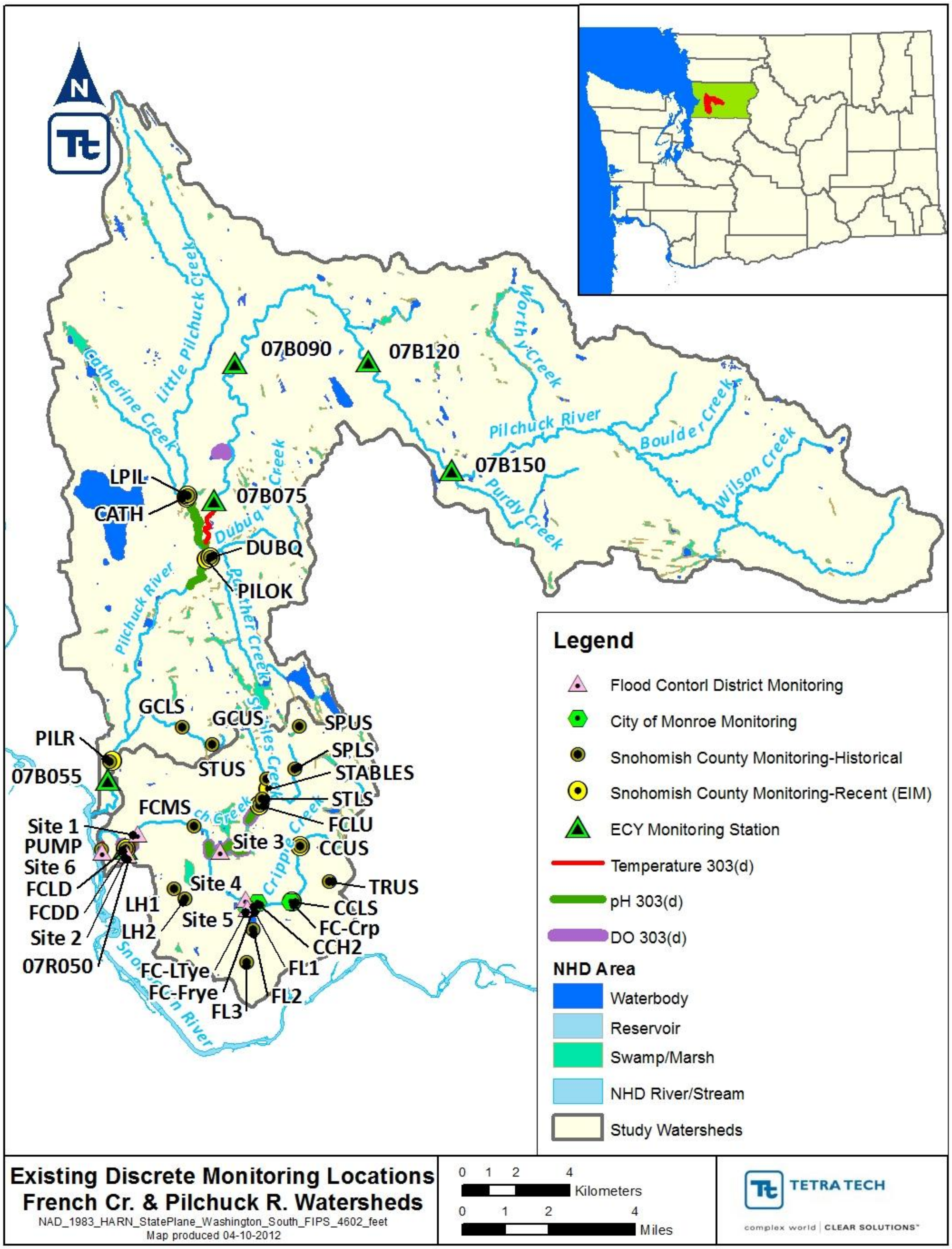

Figure 11. Discrete water quality monitoring sites in the French and Pilchuck watersheds.

Table 22 lists the water quality parameters and associated abbreviations referenced in the subsequent data summary tables. These parameters are required for developing QUAL2Kw and HSPF models that will be used to determine TMDLs for the watersheds.

Table 22. Surface water quality monitoring parameters

Water Quality Parameter	Abbreviation
Turbidity	Turb
Total Suspended Solids + Total Nonvolatile Suspended Solids	TSS + TNVSS
Alkalinity	Alk
Chloride	Cl
Chlorophyll-*a* (lab filtered)	Chl-a
Ammonia	NH_3
Nitrite-Nitrate	NO_2+NO_3
Total Persulfate Nitrogen	TPN
Orthophosphate	OP
Total Phosphorus	TP
Periphyton (biovolume)	Perphy
Dissolved Organic Carbon	DOC
Total Organic Carbon	TOC
Temperature	Temp
Dissolved Oxygen	DO
pH	pH

Summary of the discrete water quality monitoring data collected in the French Creek and Pilchuck River watersheds are presented in Table 23 and Table 24, respectively. All discrete data were collected at roughly monthly intervals over the period of record. They are generally part of synoptic studies where multiple, though not necessarily all, sites within the same dataset were sampled on the same day. Data quality for each source will be reviewed before use in the TMDL. See *External Data Usability* section below.

Table 23. Discrete data summary for the French Creek watershed

Station ID	Data Source*	Stream Location	Time Period	Sample Count[a]									
				DO	pH	Temp	NO_2 + NO_3	NH_3	TKN	TP	OP	TSS	Turb
Site 6	FCD	French Creek	3/20/06–11/17/09	40	--	--	--	--	--	--	--	--	--
PUMP	SnoCo	French Creek	5/23/95–3/27/96	16	16	17	17	--	--	17	--	15	--
Site 2	FCD	French Creek	9/30/03–11/17/09	68	--	--	--	--	--	--	--	--	--
Site 1	FCD	French Creek	9/30/03–11/17/09	68	--	--	--	--	--	--	--	--	--
FCDD	SnoCo	French Creek	5/25/94–4/12/95	19	20	20	20	--	--	20	--	19	--
FCLD	SnoCo	French Creek	9/15/93–12/8/09	187	189	190	188	--	--	189	--	179	139
FCLD	EIM	French Creek	1/5/04–12/8/09	70	70	70	38	--	--	38	--	38	70

Station ID	Data Source*	Stream Location	Time Period	Sample Count[a]									
				DO	pH	Temp	NO_2 + NO_3	NH_3	TKN	TP	OP	TSS	Turb
07R050	ECY	French Creek	10/16/95–12/14/11	14	14	14	14	14	--	14	14	--	14
Site 3	FCD	French Creek	9/30/03–11/17/09	68	--	--	--	--	--	--	--	--	--
FCMS	SnoCo	French Creek	5/23/95–3/27/96	15	15	16	17	--	--	17	--	17	--
FCLU	SnoCo	French Creek	9/15/93–12/8/09	189	190	191	190	--	--	188	--	171	140
STLS	SnoCo	Stables Creek	5/26/94–4/10/95	20	19	20	20	15	16	20	--	19	--
FCLU	EIM	French Creek	10/4/06–7/11/11	58	58	58	39	--	--	39	--	57	58
STABLES	EIM	Stables Creek	1/25/10–7/11/11	19	19	19	--	--	--	--	--	18	19
CCH2	SnoCo	Cripple Creek	5/23/95–3/27/96	16	15	16	17	--	--	17	--	14	--
CCLS	EIM	Cripple Creek	1/25/10–7/11/11	19	19	19	--	--	--	--	--	18	18
CCLS	SnoCo	Cripple Creek	5/23/94–4/11/95	20	20	20	20	--	--	20	--	17	--
CCUS	EIM	Cripple Creek	1/25/10–7/11/11	19	19	19	--	--	--	--	--	18	18
CCUS	SnoCo	Cripple Creek	5/25/94–4/11/95	20	20	20	20	--	--	20	--	15	--
FC-Crp	City of Monroe	Cripple Creek	3/11/08–7/11/11	37	38	--	--	--	--	--	--	--	--
FC-Frye	City of Monroe	Cripple Creek	3/11/08–7/11/11	41	41	--	--	--	--	--	--	--	--
FC-Ltye	City of Monroe	Cripple Creek	3/11/08–7/11/11	41	41	--	--	--	--	--	--	--	--
Site 4	FCD	Cripple Creek	9/30/03–11/17/09	68	--	--	--	--	--	--	--	--	--
Site 5	FCD	Cripple Creek	9/30/03–11/17/09	66	--	--	--	--	--	--	--	--	--
FL1	SnoCo	Unnamed Trib to Cripple Cr.	5/23/95–3/27/96	16	15	16	16	--	--	17	--	16	--
FL2	SnoCo	Unnamed Trib to Cripple Cr.	5/23/95–3/27/96	16	15	16	17	--	--	17	--	14	--
FL3	SnoCo	Unnamed Trib to Cripple Cr.	5/23/95–3/27/96	16	16	16	17	--	--	17	--	17	--
SPLS	SnoCo	Spada Creek	5/25/94–4/12/95	19	19	20	20	--	--	20	--	14	--
SPUS	SnoCo	Spada Creek	5/25/94–4/12/95	19	19	20	20	--	--	19	--	11	--
STUS	SnoCo	Stables Creek	5/26/94–4/10/95	20	19	20	20	15	16	20	--	19	--
TRUS	SnoCo	Trench Creek	5/25/94–4/11/95	19	19	19	19	--	--	19	--	8	--
LH1	SnoCo	Unnamed Trib to French Cr.	5/23/95–3/27/96	17	16	17	17	--	--	17	--	13	--
LH2	SnoCo	Unnamed Trib to French Cr.	5/23/95–3/27/96	16	16	17	17	--	--	17	--	16	--

* FCD: Flood Control District; SnoCo: Snohomish County – Historical;
EIM: Snohomish County – Recent; ECY: Washington State Department of Ecology
[a] There is likely some overlap between the EIM and SnoCo monitoring datasets for the same stations and time periods. Sample totals in these cases are estimates.
Note: -- indicates no data collected

Table 24. Discrete data summary for the Pilchuck River watershed

Station ID	Data Source*	Stream Location	Time Period	Sample Count[a]									
				DO	pH	Temp	NO_2 + NO_3	NH_3	TKN	TP	OP	TSS	Turb
DUBQ	SnoCo	Dubuque Creek	10/21/98–12/7/09	132	133	133	134	--	--	130	--	119	134
DUBQ	EIM	Dubuque Creek	1/8/04–7/13/11	89	89	89	39	--	--	39	--	57	90
PILOK	EIM	Pilchuck River	1/21/10–7/13/11	19	19	19	--	--	--	--	--	18	19
07B075	SnoCo	Pilchuck River	10/20/09–9/27/10	12	11	12	12	12	--	12	12	--	12
LPIL	EIM	Little Pilchuck Cr.	10/21/98–12/7/09	131	134	134	134	--	--	131	--	124	134
LPIL	SnoCo	Little Pilchuck Cr.	1/8/04–7/13/11	88	90	90	39	--	--	39	--	57	90
CATH	SnoCo	Catherine Creek	10/21/98–12/7/09	132	134	134	134	--	--	133	--	124	134
GCLS	SnoCo	Golf Course Creek	5/26/94–4/10/95	20	20	20	20	--	1	20	--	14	--
GCUS	SnoCo	Golf Course Creek	5/26/94–3/28/95	20	20	20	20	--	1	19	--	18	--
07B055	ECY	Pilchuck River	12/1/70–9/16/96	236	230	237	108	230	17	226	229	--	181
07B090	ECY	Pilchuck River	10/11/76–9/19/77	24	24	24	--	24	--	24	24	--	24
07B120	ECY	Pilchuck River	10/18/05–9/19/06	12	12	12	12	12	--	--	12	--	12
07B150	ECY	Pilchuck River	10/18/05–9/19/06	12	12	12	12	12	--	--	12	--	12
PILR	EIM	Pilchuck River	1/8/04–12/7/09	71	72	72	39	--	--	39	--	39	72
PILR	SnoCo	Pilchuck River	10/21/98–12/7/09	133	135	135	135	--	--	130	--	123	135
CATH	EIM	Catherine Creek	1/8/04–7/13/11	89	90	90	39	--	--	39	--	57	89

* SnoCo: Snohomish County – Historical.
EIM: Snohomish County – Recent.
ECY: Washington State Department of Ecology
[a] There is likely some overlap between the EIM and SnoCo monitoring datasets for the same stations and time periods. Sample totals in these cases are estimates.
Note: -- indicates no data collected

Data for the TMDL pollutants under investigation (DO, pH, and temperature) are present throughout the watersheds. In addition to the impaired pollutants, additional data are available that support the development of TMDLs, including nutrient data and data for suspended sediments and turbidity. The available data will be used for development, calibration, and assessment of the HSPF model. Data gaps in the study area were assessed based on the existing spatial resolution of monitoring and the locations of major tributaries. New data collected under this QAPP will be used to fill data gaps and support development of the QUAL2Kw and HSPF models.

From spatial and temporal review of the data summaries it appears that most of the segments have sufficient data collected for modeling the impaired parameters with HSPF. Some data gaps do exist. Specifically, it is recommended that DO, pH, and temperature data be collected at the existing stations PUMP and 07B075 on French Creek and Pilchuck, respectively, as well as at a new station located on the impaired unnamed tributary from Connor Lake to the Pilchuck River. In addition, because of its unique location downstream of a listed segment, DO, pH, and temperature monitoring are also recommended at station FCMS. Additional nutrient data, including the parameters identified in Table 22, would also be useful at stations PUMP, FCLD, FCMS, Site 3, FCLU, PILOK, 07B075, and LPIL. Detailed reviews of the data in each watershed are provided below along with recommended monitoring on specific tributaries to address identified data gaps. These data monitoring recommendations are summarized in the *Water Quality Sampling Plan* section.

Major tributaries to French Creek include Cripple Creek, Stables Creek, and Spada Creek. Multiple existing water quality monitoring has been located on each of these tributaries over the past 18 years. Cripple Creek has the highest number of monitored stations (thirteen), including recent data collected at stations CCLS, CCUS and all locations monitored by the city of Monroe and the Flood Control District (Figure 11).

Recent data include monitoring of DO, pH, Temp, NO_2 + NO_3, and TP, but not for other nutrient constituents. Therefore, it is recommended that monitoring of missing nutrient parameters [nitrite (NO_2), nitrate (NO_3), dissolved nitrite (NO_2 Dis), NH_3, TKN, and OP Dis] be collected at existing stations CCLS, CCUS, and a new location at the French Creek confluence where all water quality parameters should be collected.

Three monitoring stations (STLS, STABLES, and STUS) are on Stables Creek (Figure 11). Of the three locations, only STABLES has recent monitoring data, which include measurements of the TMDL parameters and TSS. No recent nutrient data have been collected on this tributary and no DO, temperature, or pH data have been collected in the upper reaches. Therefore, it is recommended that nutrient data be collected near the confluence with French Creek at station STLS and all constituents be collected at the upstream station STUS.

Historical monitoring data exist for two locations (SPLS and SPUS) on Spada Creek (Figure 11). Therefore, monitoring of all parameters is recommended at a new station near the Spada Creek confluence with French Creek (see *Water Quality Sampling Plan* section).

Pilchuck River Watershed

Unlike the French Creek watershed, the Pilchuck River drainage does not have multiple monitoring locations on each major tributary. In addition, large segments along the mainstem have no monitoring data, though monitoring is not thought to be necessary above station 07B150 at the Purdy Creek confluence. Even though temperature data in this portion of the watershed show exceedances, the area is almost entirely forested and undeveloped above this point and is managed by the Washington State Department of Natural Resources (WDNR). There are also no 303(d) listings above this area, even though there were exceedances in the past. Major tributaries to the Pilchuck River include Panther Creek, Dubuque Creek, Catherine Creek, and Little Pilchuck Creek. Golf Course Creek is also a tributary of interest.

No monitoring stations are currently located on Panther Creek. A new monitoring station at its confluence with Dubuque Creek is recommended where all water quality parameters should be monitored.

Historical monitoring data exist for each of the other major tributaries to the Pilchuck River, Dubuque Creek (DUBQ), Catherine Creek (CATH), and Little Pilchuck Creek (LPIL). Only one additional monitoring site is recommended for LPIL to characterize tributary inputs. Existing monitoring at the other locations is up-to-date and has been done at the confluence with the Pilchuck River.

Historic monitoring data exist for two locations in Golf Course Creek (GCLS and GCUS). To supplement these data it is recommended that all water quality parameters be collected at a new station near the confluence with the Pilchuck River and at the existing station GCLS, located approximately at the midpoint along the stream’s length near the golf course.

Water quality monitoring has been conducted along the Pilchuck River mainstem at seven locations, 07B055, PILR, PILOK, 07B075, 07B090, 07B120, and 07B150. Stations with recent monitoring data include PILR, PILOK, 07B120, and 07B150. Station PILR has a good record of $NO_2 + NO_3$, and TP but not of other nutrient data. Stations 07B120 and 07B150 each have twelve samples of the TMDL constituents, as well as $NO_2 + NO_3$, NH3, and OP. Additional nutrient data should be collected at station PILR and all constituents should be collected at stations 07B090, 07B120, and 07B150. In addition, a new monitoring station on the Pilchuck River mainstem between stations PILR and PILOK is recommended to fill gaps in the spatial coverage of monitoring locations.

Continuous Temperature and Streamflow Monitoring Data

Monitoring stations where continuous temperature and flow data were collected or are currently being collected in the French Creek and Pilchuck River watersheds are shown in Figure 12. Continuous temperature data have been summarized in Table 25 and continuous flow data have been summarized in Table 26.

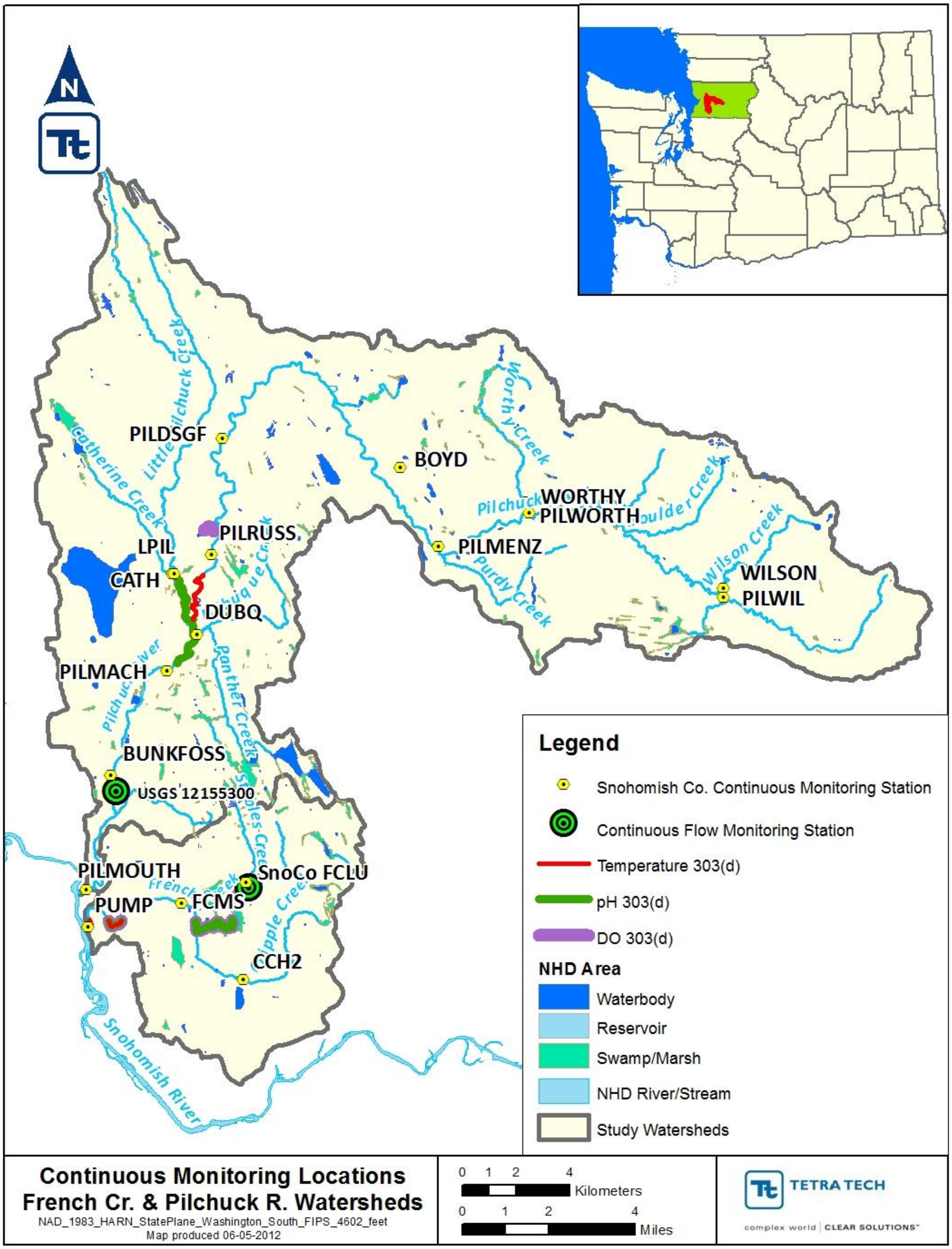

Figure 12. Continuous temperature (Snohomish County) and streamflow (Snohomish County and USGS) monitoring locations in the French Creek and Pilchuck River watersheds.

Table 25. Snohomish County continuous temperature monitoring data

Station ID	Station Name	Historical		Recent (EIM)*	
		Begin Date	End Date	Begin Date	End Date
BOYD	Boyd Cr at Pilchuck R confluence	6/14/1999	11/4/1999	--	--
BUNKFOSS	Bunk Foss Cr at Machias Rd	6/18/1999	9/20/1999	--	--
CATH	Catherine Cr at 12th St NE	6/18/1999	9/20/1999	2008	2009
CCH2	Cripple Cr at Hwy 2	5/17/1995	12/20/1995	2010	2010
CCUS	Cripple Cr @ Trombley Rd	--	--	2010	2010
DUBQ	Dubuque Cr at OK Mill Rd	6/18/1999	9/20/1999	2008	2009
FCLU	French Cr at 167th Av	3/27/1995	5/24/2005	2008	2011
FCDD	French Cr @ Old Sno-Monroe Hwy (short-term)	--	--	2008	2010
FCMS	French Cr at Hwy 2	5/9/1995	12/20/1995	2008	2010
LPIL	Little Pilchuck Cr at 12th St NE	6/18/1999	9/21/2000	2008	2010
PILDSGF	Pilchuck R at 152nd Av NE	6/23/1999	9/20/1999	--	--
PILMACH	Pilchuck R at Machias Rd	6/23/1999	9/20/1999	--	--
PILMENZ	Pilchuck R at Menzel Lk Rd	6/23/1999	9/20/1999	--	--
PILMOUTH	Pilchuck R at east of Lincoln Av	7/6/2000	9/29/2000	--	--
PILRLOW	Pilchuck R @ Snohomish city park	--	--	2010	2010
PILRUSS	Pilchuck R at Russell Rd	7/6/2000	9/25/2000	--	--
PILWIL	Pilchuck R at Wilson Cr	6/9/1999	10/4/1999	--	--
PILWORTH	Pilchuck R at Worthy Cr	6/9/1999	10/4/1999	--	--
PUMP	French Cr at Pump station	5/9/1995	12/20/1995	--	--
STABLES	Stables Cr @ 96th St SE	--	--	2010	2010
WILSON	Wilson C at Pilchuck R	6/11/1999	9/27/1999	--	--
WORTHY	Worthy Cr at Pilchuck R	6/10/1999	9/27/1999	--	--

* The station naming convention is different from the one used for historical data. Station assignments to historical data stations were made using best judgment.

Continuous temperature monitoring stations are located throughout the watersheds; however, additional locations would be helpful to characterize more of the watershed areas as well as inputs to the models.

Currently neither continuous DO nor pH monitoring has been collected in the study watersheds. Recommended continuous DO and pH monitoring locations include PUMP, FCLD, Site 3, FCLU, PILOK, LPIL, 07B075, 07B150, and new locations on the unnamed tributary from Connor Lake to Pilchuck River and on Pilchuck River at Dubuque Road.

Two continuous streamflow monitoring locations, one each in the French Creek and Pilchuck River watersheds are currently being monitored (Figure 12 and Table 26). The location on the Pilchuck River is near the mouth and should be sufficient to characterize flow throughout the watershed. The location on French Creek is below the Stables Creek confluence. This gage, should allow for a good characterization of flow conditions at the north eastern portion of the

French Creek watershed. In addition, a time-series of water withdrawals due to pump activity will be developed during HSPF modeling to maintain the water level set by the FSFCD.

To bolster understanding of the hydrology in lower French Creek, one additional continuous flow monitoring gage will be installed downstream of FCMS, under the Old Snohomish Monroe Rd. Bridge, before sampling begins.

Table 26. Continuous streamflow monitoring in the French Creek and Pilchuck River watersheds

Station	Station Name	Begin Date	End Date	Sample Count
FCLU	French Cr at 167th Av	3/27/1995	1/13/2012	5,735
12155300	Pilchuck River near Snohomish, WA	5/5/1992	2/27/2012	7,238

Meteorological Data

Meteorological data are also an important component of model simulation. In addition to the available external meteorological data described below (see *Data Quality* section), air temperature data will be collected with the water quality and flow monitoring to accurately represent concurrent weather conditions.

Water Quality Sampling Plan

The following describes the monitoring study design for Section 303(d)-listed parameters and related constituents covered by this TMDL, as well as streamflow monitoring. Stations were selected based on 303(d) listings, historical data, spatial resolution, locations of tributaries, and identified data gaps.

Figure 13 and Table 27 show proposed water quality sampling locations and surveys to fulfill the data needs for QUAL2Kw and HSPF modeling to complete the TMDL analyses. Table 28 shows the proposed survey schedule. The HSPF model will be used to model both the entire French Creek and Pilchuck River watersheds. The QUAL2Kw model will cover the major reaches of the entire French Creek watershed, while the Pilchuck River QUAL2Kw model will begin just downstream of the confluence of Purdy Creek, monitoring site 22 in Figure 13. Specifically, monitoring site 22 will be used to characterize the uppermost boundary condition for the Pilchuck River watershed QUAL2Kw model.

In addition to the monitoring outlined in Table 27, field data will be collected at each water thermistor location. Specific field data include channel cross section, bank full depth and width, and vegetation heights, for ground truthing the LiDAR data. In the cases where existing infrastructure inhibit the collection of field data at a location, a suitable site as close as practicable, but within 1,000 feet of the monitoring location, will be identified for field data collection. Sites may be added or removed from the sampling plan depending on access and new information provided during the field observation and preliminary data analysis.

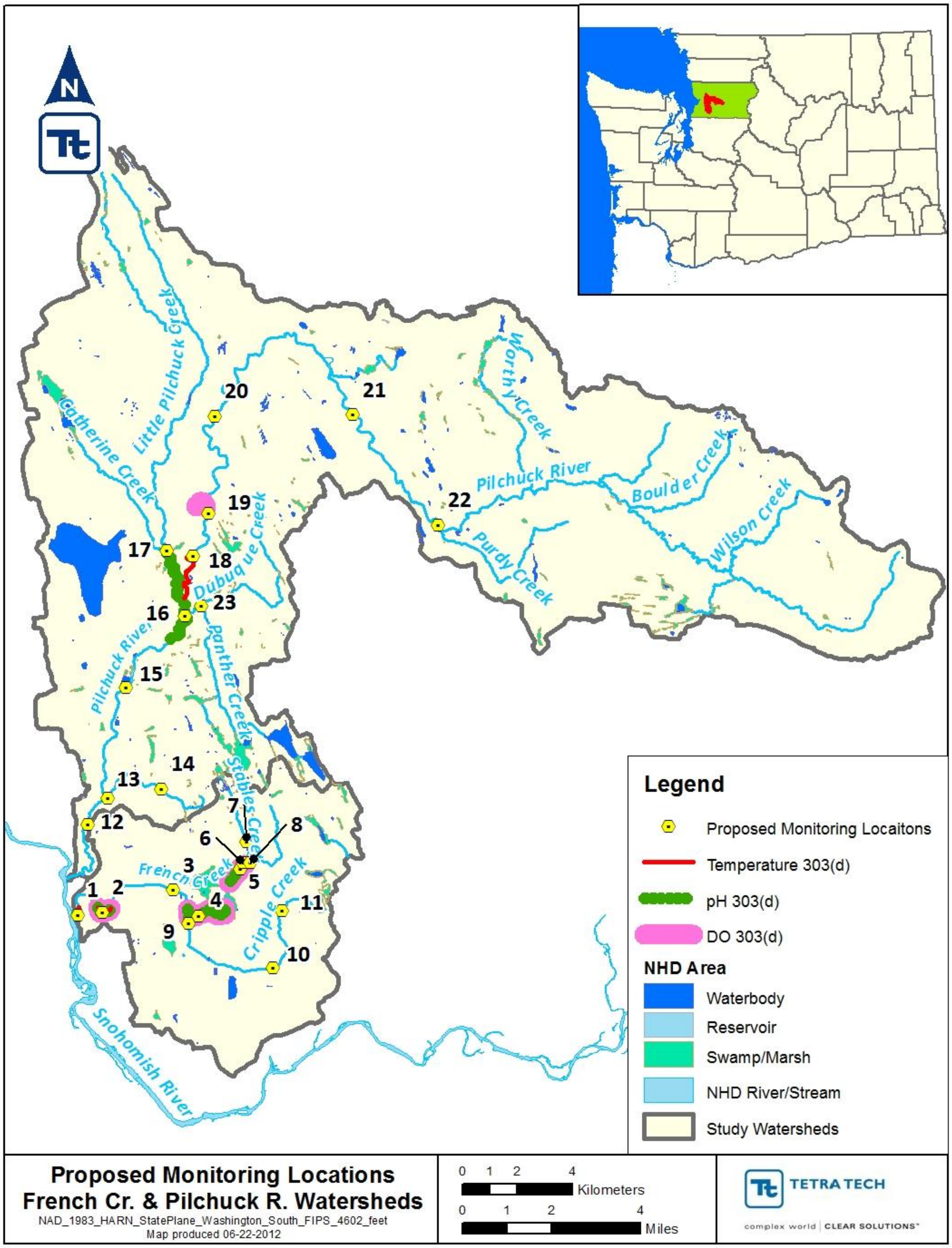

Figure 13. Proposed monitoring locations in the French Creek and Pilchuck River watersheds.

Table 27. Proposed Ecology monitoring locations in the French Creek and Pilchuck River watersheds.

Map ID	Existing Station ID	Ecology ID	Mainstem or Tributary Location	Synoptic Survey [1]	H_2O and Air Thermistor	In Situ Hydrolab Measurements [2]	Continuous Diurnal Monitoring [2]	Streamflow	Location Description	NAD 83 Latitude	NAD 83 Longitude
1	PUMP	07-FRE-0.1	Mainstem	X	X	X	X	X	French Cr at Pump station	47.889	-122.086
2	FCLD	07-FRE-1.3	Mainstem	X	X	X	X	X [3]	French Cr at Old Sno-Monroe Hwy (long-term)	47.89	-122.074
3	FCMS	07-FRE-3.7	Mainstem	X	X	X		X	French Cr above Cripple Ck, near HWY 2	47.889	-122.027
4	Site 3	07-FRE-4.4	Mainstem	X	X	X	X	X	French Cr at Hwy 2	47.898	-122.039
5	FCLU	07-FRE-6.9	Mainstem	X	X	X	X	X	French Cr at 167th Av	47.905	-122.007
6	STLS	07-STA-0.1	Tributary	X	X	X		X	Stables Cr at Westwick Rd	47.907	-122.006
7	STUS	07-STA-0.6	Tributary			X		X	Stables Cr at 93rd St SE	47.914	-122.005
8	New location	07-SPA-0.3	Tributary	X	X	X		X	Spada Creek at 100th St SE	47.907	-122.002
9	New location	07-CRI-0.0	Tributary	X	X	X		X	Cripple Creek at French Creek confluence	47.895	-122.068
10	CCLS	07-CRI-2.8	Tributary			X		X	Cripple Cr at 179th/ Robinhood Ln	47.873	-121.99
11	CCUS	07-CRI-4.3	Tributary			X		X	Cripple Cr at most downstream Trombley Rd crossing	47.891	-121.987
12	PILR	07-PIL-2.0	Mainstem	X	X	X		X	Pilchuck R at 86th / 6th St	47.918	-122.081
13	New location	07-GOL-0.0	Tributary	X	X	X		X	Golfcourse Creek at Sexton Rd.	47.927	-122.072
14	GCLS	07-GOL-2.0	Tributary	X	X	X		X	Golf Course Cr at 137th St NE	47.93	-122.046
15	New location	07-PIL-5.7	Mainstem	X	X	X	X	X	Pilchuck River at Dubuque Rd	47.963	-122.064
16	PILOK	07-PIL-8.5	Mainstem	X	X	X	X	X	Pilchuck River at OK Mill Rd.	47.987	-122.037
17	LPIL	07-LIT-1.8	Tributary	X	X	X	X	X	Little Pilchuck Cr at 12th St NE	48.008	-122.046
18	07B075	07-PIL-10.4	Mainstem	X	X	X	X	X	Pilchuck River at Russel Rd	48.006	-122.033
19	New location	07-CON-0.0	Tributary	X	X	X	X	X	Unnamed tributary from Connor Lk to Pilchuck R off Russell Rd	48.02	-122.026
20	07B090	07-PIL-15.1	Mainstem	X	X	X		X	Pilchuck River at 64th St NE	48.052	-122.024
21	07B120	07-PIL-21.5	Mainstem	X	X	X		X	Pilchuck River at Robe-Menzel Rd	48.053	-121.957
22	07B150	07-PIL-25.5	Mainstem	X	X	X	X	X	Pilchuck River at Menzel Lake Rd	48.018	-121.915
23	New location	07-DUB-0.0	Tributary	X	X	X		X	Dubuque Creek at OK Mill Rd	47.99	-122.029
NA	New location	07-GRA-WWTP	Facility on mainstem	X	X [4]	X			City of Granite Falls Wastewater Treatment Plant on Pilchuck River	NA	NA

[1] Includes sampling all parameters in Table 22.
[2] Parameters monitored include DO, pH, conductivity, and temperature.
[3] Ecology will install a continuous flow gage at this location.
[4] H_2O thermistor only.

Table 28. Proposed survey schedule for the 2012 French Creek and Pilchuck River study.

Survey type and frequency	Jun	Jul	Aug	Sep	Oct
Air and surface water thermistor installs	X				
Air and surface water thermistor downloads	X	X	X	X	X
Air and surface water thermistor removals					X
Dissolved oxygen, pH, and nutrient synoptic surface water sampling		X		X	
Habitat and channel geometry		X	X		
Periphyton sampling				X	

Dissolved oxygen, pH, and synoptic surveys

DO, pH, and associated conventional field parameter data will be collected in the early morning and late afternoon. Field teams will record in situ parameters (temperature, DO, pH, and conductivity) and will collect representative grab samples for laboratory analysis. Synoptic surveys will be conducted to support model calibration processes.

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

Continuous diurnal monitoring for pH, DO, conductivity, and temperature will be conducted at 10 sites using Hydrolab DataSondes® or MiniSondes® following Ecology's standard operating procedures (Swanson, 2010). Once deployed, Winkler DO grab samples will be taken at dawn and dusk. Periphyton sampling will occur at each synoptic survey sampling site to determine biomass and chlorophyll-*a* levels. Periphyton field sampling protocols are adapted from USGS protocols (Moulton et al., 2002).

Temperature

Continuous temperature dataloggers (thermistors) will be deployed at several sites shown in Figure 13 and Table 27, following continuous temperature monitoring protocols (Bilhimer and Stohr, 2009). Each site will have two thermistors: one to measure water temperature and another to measure air temperature. The thermistors will measure temperature at 30-minute intervals. Instream thermistors are deployed with a shade device in the thalweg of a stream, suspended off the stream bottom and in a well-mixed area, typically in riffles or swift glides. Air thermistors

[2] Winkler dissolved oxygen samples for lab check of field measurements.

are deployed with a shade device near the instream thermistor in a shaded area such as in a bush or tree.

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

Heat loads to the stream will be calculated using a heat budget that accounts for surface heat flux and mass transfer processes. Heat load data are of limited value in guiding management activities needed to solve identified water quality problems. Shade will be used as a surrogate to heat load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR § 130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and heat load upon the affected stream section. Other factors influencing the effect of the solar heat load on stream temperatures will also be assessed if identified during the field investigations, including human-caused changes, instream morphology, streamflow, and groundwater interactions.

Riparian habitat and channel geometry surveys

Effective shade inputs to the QUAL2Kw model require an estimate of the aerial density of vegetation shading the stream. Ground truthing is necessary, so a hemispherical lens and digital camera will be used to take 360° pictures of the sky to calculate the shade provided by vegetation and topography at the center of the stream. These photographs will be taken at each site to verify existing riparian vegetation compared to aerial photos. They will be processed using specialized software to calculate effective shade, which can be used to verify against the Shade model results.

Ecology will follow Timber-Fish-Wildlife stream temperature survey methods for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted in July and August of 2012. Depending on stream access, field measurements will be taken at one or two locations per site, or as necessary for accurate ground truthing. Measurements will consist of bank full depth and width, and vegetation heights.

Practical Constraints and Logistical Problems

Although rare, logistical problems such as excessive precipitation during typically dry periods, scheduling conflicts, sample bottle delivery errors, vehicle or equipment problems, or the limited availability of personnel or equipment may interfere with sampling. Any problems that interfere with data collection and quality will be noted and discussed in the final report.

Sampling Procedures

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

Grab samples will be collected directly into pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL) and described in their *Lab Users Manual* (MEL, 2008). Samples will be collected according to the standard operating procedures (SOPs) for surface water sampling (Joy, 2006; Mathieu, 2006). DO sampling (Winkler method) will follow the SOP for measuring DO in surface waters (Ward and Mathieu, 2011). Sample parameters, containers, volumes, preservation requirements, and holding times are listed in Table 29. All samples for laboratory analysis will be labeled, stored on ice, and delivered to MEL within 24 hours of collection via FedEx or Ecology courier.

All samples taken to MEL will follow MEL chain-of-custody procedures (MEL, 2008). However, Ecology will not follow sample security procedures because samples will never leave Ecology's possession.

A minimum of 10% of the samples will be field replicates used to assess total (field and lab) variability. Samples will be collected in the thalweg, below the water's surface.

Ecology's periphyton field sampling protocols are adapted from the revised USGS protocols (Moulton et al., 2002). Periphyton biomass samples will be collected by scraping material from a measured surface area on representative rocks. Three samples will be collected at each site. Periphyton biomass samples are collected for laboratory analysis of chlorophyll-a and ash-free dry weight. Samples will not be collected for species verification. Benthic area coverage by periphyton or macrophytes will be estimated for each site using a grid and random sampling technique. Notes on general periphyton and macrophyte types will be taken (e.g., filamentous, diatoms, reed canary grass, emergent weeds).

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

- Global Positioning System (GPS) coordinates and a sketch of the site (during installation only).
- Depth of the instream thermistor under the water surface and height off the stream bottom.
- Stream temperature with a thermometer or temperature probe checked for accuracy against a National Institute of Standards and Technology (NIST) certified thermometer.
- Serial number of each thermistor and the action taken with the thermistor (e.g., downloaded data, replaced thermistor, or noted any movement of the thermistor location to keep it submerged in the stream).

- The date and time before the dataloggers are installed/removed or downloaded, and the date and time after they have been returned to their location. All timepieces and computer clocks should be synchronized to an atomic clock using Pacific Daylight Savings Time. Pacific Standard Time will be reported if thermistors are still in place during the time change.

Table 29. Containers, preservation requirements, and holding times for surface water samples (MEL, 2008).

Parameter	Container	Preservative	Holding Time
Dissolved Oxygen	300 mL BOD bottle & stopper	2 mL manganous sulfate reagent + 2 mL alkaline-azide reagent	4 days
Chloride	500 mL poly (HDPE[1])	Cool to 0°C to 6°C	28 days
Total Suspended Solids; TNVSS[2]	1000 mL poly	Cool to 0°C to 6°C	7 days
Turbidity	500 mL poly	Cool to 0°C to 6°C	48 hours
Alkalinity	500 mL poly – No Headspace	Cool to 0°C to 6°C; Fill bottle *completely*; Don't agitate sample	14 days
Ammonia	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0°C to 6°C	28 days
Dissolved Organic Carbon	60 mL poly with: Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; 1:1 HCl to pH<2; Cool to 0°C to 6°C	28 days
Nitrate/Nitrite	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0°C to 6°C	28 days
Total Persulfate Nitrogen	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0°C to 6°C	28 days
Orthophosphate	125 mL amber poly w/ Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; Cool to 0°C to 6°C	48 hours
Total Phosphorous	60 mL clear poly	1:1 HCl to pH<2; Cool to 0°C to 6°C	28 days
Total Organic Carbon	60 mL clear poly	1:1 HCl to pH<2; Cool to 0°C to 6°C	28 days
Chlorophyll-*a*	1000 mL amber poly	Cool to 0°C to 6°C;	24 hrs to filtration; 28 days after filtration (frozen)
Periphyton	1000 mL amber poly	Cool to 0°C to 6°C	24 hrs to filtration; 28 days after filtration (frozen)

HDPE[1] : High-density polyethylene.

TNVSS[2]: Total Nonvolatile Suspended Solids.

Measurement Procedures

Field measurements will include conductivity, temperature, pH, and DO using a calibrated Hydrolab DataSonde® or MiniSonde® (Swanson, 2010). DO will also be collected and analyzed using the Winkler titration method (Ward and Mathieu, 2011).

Temperature dataloggers will be downloaded monthly or bi-monthly using Ecology SOP protocols (Bilhimer and Stohr, 2009).

During the field surveys, streamflow will be measured when practical. Instantaneous flow measurements will follow Ecology SOP protocol (Sullivan, 2007).

Continuous flow volumes at Ecology gages will be calculated from stage height records and rating curves developed during the project at a station just below Cripple Creek on French Creek. Stage height will be measured by pressure transducer and recorded by a datalogger every 15 minutes.

A continuously recording Hydrolab® DataSonde® will also be installed with Ecology's flow gage on French Creek. The DataSonde will record DO, temperature, pH, and conductivity every 15 minutes throughout the course of the summer.

All dataloggers will be downloaded monthly to reduce potential data loss due to vandalism, theft, or equipment malfunction.

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

Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet 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

Field sampling procedures and laboratory analyses inherently have associated uncertainty which results in data variability. Measurement quality objectives (MQO) state the acceptable data variability for a project. *Precision* and *bias* are data quality criteria used to indicate conformance with measurement quality objectives. The term *accuracy* refers to the combined effects of precision and bias (Lombard and Kirchmer, 2004).

Precision is a measure of the variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for laboratory duplicate samples will be expressed as relative percent difference (RPD). Precision for field replicate samples will be expressed as the relative standard deviation (RSD) for the group of duplicate pairs (Table 30).

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 Ecology's measurement, sampling, and handling protocols.

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

Table 30 outlines analytical methods, expected precision of sample duplicates, and method reporting limits. The targets for precision of field replicates are based on historical performance by MEL for environmental samples taken around the state by EAP (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives. The laboratory's measurement quality objectives and quality control procedures are documented in the MEL *Lab Users Manual* (MEL, 2008).

Table 30. Measurement quality objectives for laboratory analysis parameters.

Analysis	Method	Method Lower Reporting Limit[1]	Lab Blank Limit	Check Standard (% recovery limits)	Matrix Spikes (% recovery limits)	Precision – Lab Duplicates (RPD)	Precision – Field Replicates (mean)[2]
Total Alkalinity	SM2320B	5 mg/L	<½ RL	80-120%	n/a	20%	10% RSD
Chloride	EPA 300.0	0.1 mg/L	<MDL	90-110%	75-125%	20%	5% RSD
Chlorophyll *a* – water	SM10200H3M	0.05 ug/L	n/a	n/a	n/a	20%	20% RSD
Chlorophyll *a* – periphyton	SM10200H3M	0.05 ug/L	n/a	n/a	n/a	20%	50% RSD
Biomass (Ash Free Dry Weight) – periphyton	SM10300C(5)	0.05 ug/L	n/a	n/a	n/a	20%	50% RSD
Dissolved Oxygen (Winkler)	SM4500OC	0.05 mg/L	n/a	n/a	n/a	n/a	± 0.1 mg/L
Dissolved Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Persulfate Nitrogen	SM4500NB	0.025 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Ammonia	SM4500NH3H	0.01 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Nitrate/Nitrite	SM4500NO3I	0.01 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Orthophosphate	SM4500PG	0.003 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Phosphorus	SM4500PF	0.005 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Turbidity	SM2130	0.5 NTU	< 1/10th RL	90-105%	n/a	20%	15% RSD
Total Suspended Solids	SM2540D	1 mg/L	±0.3 mg	80-120%	n/a	20%	15% RSD

RL: reporting limit
MDL: method detection limit
RSD: relative standard deviation
[1] reporting limit may vary depending on dilutions
[2] field replicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately

Table 31 summarizes field measurement MQO for precision and bias, as well as the manufacturer's stated accuracy, resolution, and range for the equipment used in this study.

Table 31. Measurement quality objectives and resolution for field measurements and equipment.

Parameter	Equipment/ Method	Bias	Precision– Field Replicates (mean)	Equipment Accuracy	Equipment Resolution	Equipment Range	Expected Range
Water Quality Measurements							
Water Temperature	Hydrolab®	See Table 32	± 0.2°C	± 0.1°C	0.01° C	-5 to 50° C	0 to 30° C
Specific Conductance	Hydrolab®	See Table 32	5% RSD	± (0.5% + 1 uS/cm)	1 uS/cm	0 to 100,000 uS/cm	20 to 500 uS/cm
pH	Hydrolab®	See Table 32	± 0.2 s.u.	± 0.2 units	0.01 s.u.	0 to 14 s.u.	6 to 10 s.u.
Dissolved Oxygen – Luminescent (LDO)	Hydrolab®	See Table 32	5% RSD	± 0.1 mg/L at <8 mg/L; ± 0.2 mg/L at 8 to <20 mg/L[a]	0.01 mg/L	0 to 60[b] mg/L	0.1 to 15 mg/L
Dissolved Oxygen – Clark Cell	Hydrolab®	See Table 32	5% RSD	± 0.2 mg/L at <20mg/L[a]	0.01 mg/L	0 to 50[b] mg/L	0.1 to 15 mg/L
Flow Measurements							
Streamflow	EAP SOP	n/a	10% RSD	n/a	n/a	n/a	0.01 to 2,000 cfs
Velocity	Marsh McBirney	±0.05 ft/s[c]	n/a	±2% + zero stability[c]	0.01 ft/s	-0.5 to +20 ft/s	0.01 to 10 ft/s
Velocity	StreamPro ADCP	n/a	n/a	±1.0% or ±0.007 ft/sc	0.003 ft/s	-16 to +16 ft/s	0.01 to 10 ft/s
Continuous Temperature Monitoring							
Water Temperature	Hobo Water Temp Pro v2	n/a	n/a	±0.2°C at 0° to 50°C[ad]	0.02°C at 25°C	-40° to +50°C	0 to 30°C
Air Temperature	Hobo Water Temp Pro v2 or v1	n/a	n/a	±0.2°C at 0° to 50°C[ad]	0.02°C at 25°C	-40° to 70°C	-5 to 40°C

[a] accuracy is diminished outside of listed range
[b] greater than natural range
[c] zero stability check criteria, not a measurement of bias
[d] also the MQO for accuracy assessed by pre and post deployment water bath checks

Table 32 contains the data quality bias objectives for both instrument drift and fouling checks.

Table 32. Measurement quality objectives for Hydrolab post-deployment and fouling checks.

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

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

Representative Sampling

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

Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for the French Creek and Pilchuck River TMDL is to correctly collect and analyze 100% of the samples for each of the sites. However, problems occasionally arise during sample collection that cannot be controlled; thus a completeness of 95% is acceptable. Examples of problems are: flooding, site access problems, and sample container shortages.

Investigatory samples may be collected at sites not included in this QAPP. If necessary, a site may be added to further characterize obvious problems in an area.

Quality Objectives for Modeling

To help guide the interpretation of the technical information provided by the water quality models, several methods can be used to compare observed measurement and model results. These methods include:

- Graphical comparison for visual inspection
- Statistical methods quantifying the comparison

This section presents options for evaluating model performance that may be used in the TMDL analysis. In addition, performance target ranges associated with some of the statistical tests are presented. The performance targets are based on generally accepted values from the literature and experience with previous projects. Numeric acceptance criteria are not specified for the model; rather *performance target ranges* are identified. These ranges provide a guide and a goal for model evaluation; however, several factors will be considered when determining overall model acceptance. Modeling will not be disqualified based on any single departure. Appropriate uses of the model will be determined by the project team after assessing the types of decisions to be made, the model performance, and the available resources.

Acceptance Criteria for Model Calibration

The intended uses of the model focus on the effectiveness of different implementation strategies, which may consider existing BMPs if data are available for representation in the model. As such, the ability of the models to represent the relative contributions of different source areas and the relative performance of different management measures is of greatest importance, while obtaining a precise estimate of loading time series is of less direct interest. Ideally, the models should attain tight calibration to observed data; however, a less precise calibration can still be useful.

In light of these uses of the models, it is most informative to specify performance target ranges of precision that characterize the model results as *very good*, *good*, *fair*, or *poor*. See Table 33 and Table 34 for the quantitative values defining these categories for hydrology and water quality, respectively. These characterizations inform appropriate uses of the model: where a model achieves an excellent fit it can generally assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit it should assume a much less prominent role in the overall weight-of-evidence evaluation of management options.

The general acceptance criterion for models to be applied in this project is *to achieve a quality of fit of good or better*. If that level of quality is not achieved on some or all measures, the model might still be useful. A detailed description of its potential range of applicability will be provided in the draft TMDL.

Model Performance Measurements

To conduct the calibration process described in the Study Design section above, a visual comparison along with a set of basic statistical methods will be used to compare model predictions and observations. These methods are presented below for the HSPF and QUAL2Kw models.

Visual Comparisons of Model Results

Model results (hydrology and water quality) will be compared with associated observed measurements using graphical presentations. Such visual comparisons are extremely useful in evaluating model performance over the appropriate temporal range. For example, continuous monitoring data can be compared with continuous modeling results to ensure diurnal variation and minimum/maximum values are well represented. Model performance is ultimately determined through best professional judgment and experience with previous projects.

Statistical Tests of Model Results

Model performance can also be evaluated using statistical tests. This section presents a suite of tests that may be used during calibration of the HSPF and QUAL2Kw models. The exact statistical tests will be determined during model calibration and may include any of the following. In addition, if determined necessary and appropriate, additional tests of model fit may also be applied.

HSPF Model

Statistical methods that may be used during the HSPF calibration process include the mean error statistic, the absolute mean error, the root-mean-square error, the relative error, the coefficient of determination, and the Nash-Sutcliffe coefficient of model fit efficiency for time series data. These statistical tests are defined below. While each of those statistics may be reported, model acceptance criteria are only defined for a specific subset of these measures, as described in the "Model Performance Targets" section below.

Mean Error Statistic. The mean error between model predictions and observations is defined as

$$E = \frac{\sum(O - P)}{n},$$

where

E = mean error
O = observations
P = model prediction at the same time as the observations
n = number of observed-predicted pairs

A mean error of zero is ideal. A non-zero value is an indication that the model might be biased toward either over- or under-prediction. However, an important consideration of the mean error approach is that it can severely penalize the model for small phase shifts in timing. One approach that can be used to address this is to establish a time window, calculate the range of model predictions for the time window, then count a deviation from prediction only if the observation falls outside this range within this time window.

Absolute Mean Error Statistic. The absolute mean error between model predictions and observations is defined as

$$E_{abs} = \frac{\sum |(O-P)|}{n},$$

where

E_{abs} = absolute mean error

O, *P*, and *n* are as defined above

An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a value less than zero.

Root-Mean-Square Error Statistic. The root-mean-square error (E_{rms}) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O-P)^2}{n}}.$$

A root-mean-square error of zero is ideal. The root-mean-square error is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error.

Relative Error Statistics. The relative error statistics (*RE*) between model predictions and observations is calculated by dividing the mean error (*E*) and absolute mean error (E_{abs}) statistics by the mean of the observations. A relative error statistic of zero is ideal. When it is non-zero, it represents the percentage of deviation between the model prediction and observation.

Coefficient of Determination. The coefficient of determination (R^2) is defined as

$$R^2 = \frac{\sum_{i=1}^{n} \left(P_i - \overline{O}\right)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O}\right)^2},$$

where the overbar indicates the mean of the *n* observed values. The coefficient of determination varies between 0 and 1 and indicates the proportion of the total variation in observations explained by the model.

Nash-Sutcliffe Coefficient of Model Fit Efficiency. The coefficient of model fit efficiency or Nash-Sutcliffe coefficient (E_{NS}) is particularly useful for evaluating model fit to continuous data, taking into account both the difference between model and observed values and the variance of the observations. The statistic is defined as

$$E_{NS} = 1.0 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O}\right)^2}.$$

The resulting coefficient ranges from minus infinity to 1.0, with higher values indicating better agreement. At a value of zero, the test indicates that the model is a good predictor of the observed mean, while negative values indicate that the model is a better predictor of the observed mean.

QUAL2Kw Model

QUAL2Kw model resolution and performance will be measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986) that is defined above for the HSPF model.

Model bias will be assessed both mathematically and graphically as described above. Bias is the systematic deviation between a measured (i.e., observed) and a computed (i.e., modeled) value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration.

Mathematically, bias is calculated as the relative percent difference (RPD). This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

$$RPD = (| P_i – O_i | *2) / (O_i + P_i),$$

where

P_i = ith prediction
O_i = ith observation

QUAL2Kw graphically represents observed and measured values along the length of the modeled stream segment. Therefore, bias will also be evaluated by observing modeled trends and over- or under-prediction between computed vs. measured values.

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

Model Performance Targets for Select Statistical Tests

For HSPF hydrologic models, a variety of performance targets have been specified, including Donigian et al. (1984), Lumb et al. (1994), and Donigian (2000). On the basis of these publications and previous experience with the model, potential HSPF performance targets to guide simulation of the water balance components are summarized in Table 33. As noted above, model performance will be deemed acceptable where a performance evaluation of *good* or *very good* is attained; however, several factors will be considered when determining overall model acceptance.

Various factors can contribute to poor statistics. For hydrology simulation, precipitation and evapotranspiration are the major driving forces. Yet the spatial variations can be high, especially for precipitation. Other factors such as unique geology and groundwater system can also contribute to poor calibration. The statistics should be used with visual inspection to evaluate the model performance.

Because QUAL2Kw uses steady-state flow, only one flow condition can be considered for one model run. For model flow calibration and validation, two modeled results will be output. The flow balance of QUAL2Kw is mainly governed by specified boundary inflows, which will be calibrated using HSPF. For other parameters such as velocity, statistics can be calculated if data are available. Statistics become meaningful when sufficient data are available. It is not expected that sufficient data will be available for the QUAL2Kw hydrology calibration; therefore, it is anticipated that statistics will not be calculated on QUAL2Kw flow simulations. Any statistics that are calculated must be used cautiously in combination with visual inspection.

Table 33. Performance targets for HSPF hydrologic simulation (magnitude of annual and seasonal relative mean error (RE); daily and monthly R^2)

Model component	Very good	Good	Fair	Poor
1. Error in total volume	≤ 5%	5%–10%	10%–15%	> 15%
2. Error in 50% lowest flow volumes	≤ 10%	10%–15%	15%–25%	> 25%
3. Error in 10% highest flow volumes	≤ 10%	10%–15%	15%–25%	> 25%
4. Error in storm volume	≤ 10%	10%–15%	15%–25%	> 25%
5. Winter volume error (January-March)	≤ 15%	15%–30%	30%–50%	> 50%
6. Spring volume error (April-June)	≤ 15%	15%–30%	30%–50%	> 50%
7. Summer volume error (July-September)	≤ 15%	15%–30%	30%–50%	> 50%
8. Fall volume error (October-December)	≤ 15%	15%–30%	30%–50%	> 50%
9. R^2 daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
10. R^2 monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

Sources: Donigian et al., 1984; Lumb et al., 1994, and Donigian, 2000

As noted above, these performance targets are compiled from available literature values and these may be used to guide calibration. These targets are only associated with a subset of the statistical tests described in the *Model Performance Measurements* section because of the availability of literature values. In addition to using these targets as a calibration guide, it is important to consider the TMDL objectives and critical conditions. Therefore, summer and low flow hydrology statistics are more important and may be held to a higher standard, i.e., lower relative mean error. In addition to the hydrology components described above, the error in 7-day low flow volume will also be evaluated as this is the critical period assessed in the TMDL.

It is important to clarify that the tolerance ranges are intended to be applied to mean values and that individual events or observations can show larger differences and still be acceptable (Donigian, 2000).

General performance targets for water quality simulation with HSPF are also provided by Donigian (2000) and are shown in Table 34. These are calculated from observed and simulated daily values, and should be applied only in cases with a minimum of 20 observations. Unlike flow, water quality parameters are not always observed continuously. For discrete observed samples, the HSPF calibration must therefore rely on comparison of continuous model output to point-in-time-and-space observations. This creates a situation in which it is not possible to fully separate error in the model from variability inherent in the observations. For example, a model could provide an accurate representation of an event mean or daily average concentration in a reach, but an individual observation at one time and one point in a reach itself could differ significantly from the average.

For continuous observed water quality data, the HSPF model results can be directly compared; however, any uncertainty present in the hydrologic calibration will also propagate into the water quality simulation. Data collection itself often cannot capture the peak values. Loading information can also consist of average values, for example, monthly data from DMR. Therefore, capturing all the observed instream data right at the exact date by the model can become unachievable. Statistics should be used cautiously in combination with visual inspection of graphical comparisons of model results and data.

The QUAL2Kw model runs under steady-state flow conditions. The water quality in that selected day can vary. Statistics will be calculated using continuous data for comparison in addition to the visual comparison described above. The statistics described for the QUAL2Kw model include RMSE and RPD. As a general evaluation of model performance, the criteria in Table 34 may be applied to the QUAL2Kw model; however, these performance targets were originally developed for assessing relative error (RE) for conventional water quality parameters.

For the RMSE comparisons, the statistics will be expressed in actual units, i.e., degrees Celsius, mg/L, etc. and may be performed not just on average values but also on minimum and maximum of daily values to capture diurnal variation in the continuous data. Several statistical tests should be used cautiously in combination with visual inspections to assess model performance.

Table 34. Performance targets for HSPF water quality simulation (magnitude of annual and seasonal relative average error (RE) on daily values)

Model component	Very good	Good	Fair	Poor
Dissolved oxygen	≤ 15%	15%–25%	25%–35%	> 35%
Nutrients	≤ 15%	15%–25%	25%–35%	> 35%
Temperature	≤ 15%	15%–25%	25%–35%	> 35%
pH	≤ 15%	15%–25%	25%–35%	> 35%

Quality Control

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

Laboratory

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

Field

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

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

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

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

Hydrolab MiniSonde® and DataSonde® DO, pH, and conductivity sensors will be calibrated according to manufacturer's recommendations and the Hydrolab SOP (Swanson, 2010). The temperature sensor on these probes is factory-calibrated. Hydrolabs will be calibrated before each sampling survey and checked afterward using certified standards and reference solutions. Hydrolab results will be accepted, qualified, rejected, or corrected, as appropriate.

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

Corrective Actions

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

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

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

Data Management Procedures

Ecology's Management of Environmental Data

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

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

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

An EIM user study ID (TSWA0004) has been created for this TMDL. All monitoring data will be available via the internet once the project data have been validated. The URL address for this geospatial database is: http://apps.ecy.wa.gov/eimreporting/search.asp. After reviewing project data for quality and finalizing the review, the EIM data engineer will upload the data.

All final spreadsheet files, paper field notes, and final products created as part of the data collection and data quality assessment process will be kept with the project data files.

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

Contractor's Management of Modeling Data

The modeling software to be used for this project consists primarily of the HSPF model and the QUAL2Kw model. Code and executables for HSPF are publicly available from EPA as part of the BASINS4 package (http://water.epa.gov/scitech/datait/models/basins/index.cfm), and executables for the QUAL2Kw and Shade models are available as part of Ecology's Environmental Assessment Program Models for Total Maximum Daily Load Studies (www.ecy.wa.gov/programs/eap/models.html).

The contractor will maintain and provide the final version of the model, including input, output, and executables, to Ecology and EPA for archiving at the completion of the task. Electronic copies of the data, GIS, and other supporting documentation (including records documenting model development) will be supplied to Region 10 with the final report. The contractor will maintain copies in a task subdirectory, subject to regular system backups, and on disk for a maximum period of 3 years after task termination, unless otherwise directed by EPA.

Most work conducted by the contractor for this task requires the maintenance of computer resources. The contractor's computers are either covered by on-site service agreements or serviced by in-house specialists. When a problem with a microcomputer occurs, in-house computer specialists diagnose the problem and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. For other computer equipment requiring outside repair and not covered by a service contract, local computer service companies are used on a time-and-materials basis.

Routine maintenance of microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes.

All contractor computer users have been instructed on the importance of routinely archiving work assignment data files from hard drive to compact disc or server storage. The office network server is backed up on tape nightly during the week. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems have been placed on all contractor computer systems and are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software is performed to keep up with evolutionary changes in computer storage, media, and programs.

Audits and Reports

After field work is completed, sample results are received from MEL, and data have undergone a quality assurance review, Ecology's project manager will write a memo to the EPA selected contractor presenting the data. Subsequent reports will follow technical direction from EPA (EP-C-08-004, Task Order 88).

Data Verification and Validation

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

Field notebooks will be checked for missing or improbable measurements before leaving each site. The project 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 Ecology project manager for consultation. Validated data will be moved to a separate file labeled "Final."

The field lead will check data received through LIMS for omissions against the Request for Analysis forms. Data can be in spreadsheets or downloadable tables from EIM. These tables and spreadsheets will be located in a file labeled "Draft" until data verification and validation is completed. Field replicate sample results will be compared to quality objectives in Table 30. The Ecology project manager will review data requiring additional qualifiers.

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

Data Quality (Usability Assessment)

Study Data Usability

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

Usability of Results from Modeling

From a decision context, the primary function of the calibrated water quality model is to predict the response of pollutant loads to changes in management. As such, an important input to the decision-making process is information on the degree of uncertainty that is associated with model predictions. In some cases, the risks or *costs* of not meeting water quality standards could be substantially greater than the costs of over-protection, creating an asymmetric decision problem in which there is a strong motivation for risk avoidance. Further, if two scenarios produce equivalent predicted results, the scenario with the smaller uncertainty is often preferable. Therefore, an uncertainty analysis of model predictions is essential.

As with any mathematical approximation of reality, a water quality model is subject to significant uncertainties. Direct information on the aggregate prediction uncertainty will arise from the model corroboration exercise; however, further diagnostics are needed to understand the sources and implications of uncertainty.

The major sources of model uncertainty include the mathematical formulation, boundary conditions data uncertainty, calibration data uncertainty, and parameter specification. In many cases, a significant amount of the overall prediction uncertainty is due to boundary conditions. Examples of this are: uncertainty in estimation of rainfall from point gage measurements, uncertainty in specifying point source loading time series, and uncertainty in the observed data used for calibration and validation. These sources of uncertainty are largely unavoidable, but they do not invalidate the use of the model for decision purposes. Uncertainties in the mathematical formulation and model parameters are usually of greater concern for decision purposes because they describe the relationships in the calibrated model.

For the French Creek and Pilchuck River TMDL project, the model code for the two primary models, HSPF and QUAL2Kw, have a history of testing and application, so outright errors in the coding of the models are unlikely. A simulation model, however, is only a simplified representation of the complexities of the real world. The question is not whether the model is *right* in the sense that it represents all processes, but rather whether it is useful, in the sense that it represents the important processes to a sufficiently correct degree to be useful in answering the principal study questions.

Additional aspects of model quality assessment are described below, including model development, software development, surveillance of project activities, and overall model output assessment and model usability.

Model Development Quality Assessment

This QAPP and other supporting materials will be distributed to all personnel involved in the work assignment. The designated contractor Modeling QC Officer, shown in Table 36, will ensure that all tasks described in the work plan are carried out in accordance with the QAPP. The contractor will review staff performance throughout each development phase of each case study to ensure adherence to task protocols.

Quality assessment is defined as the process by which QC is implemented in the model development task. All modelers will conform to the following guidelines:

- All modeling activities including data interpretation, load calculations, or other related computational activities are subject to audit or peer review. Thus, the modelers are instructed to maintain careful written and electronic records for all aspects of model development.
- If historical data are used, a written record on where the data were obtained and any information on their quality will be documented in the final report. A written record on where this information is on a computer or backup media will be maintained in the task files.
- If new theory is incorporated into the model framework, references for the theory and how it is implemented in any computer code will be documented and peer-reviewed.
- Any modified computer codes will be documented, including internal documentation, e.g., revision notes in the source code, and external documentation, e.g., user's guides and technical memoranda supplements.

The QC Officer will periodically conduct surveillance of each modeler's work. Modelers will be asked to provide verbal status reports of their work at periodic internal modeling work group meetings. The contractor Task Order Leader (TOL) (see Table 36. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Ralph Svrjcek Ecology, WQP, NWRO Phone: (425) 649-7165 rsvr461@ecy.wa.gov	Ecology 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, assists with field work.
Dave Garland Ecology, WQP, NWRO Phone: (425) 649-7031 dgar461@ecy.wa.gov	Unit Supervisor of Project Lead	Approves the QAPP and assists with project scoping.
Trevor Swanson Ecology, EAP, HQ Phone: (360) 407-6685 trsw461@ecy.wa.gov	QAPP Author, Project Manager/ Field Lead/EIM Data Engineer	Helps define project objectives, scope, and study design. Writes sections of the QAPP. Manages the data collection program. Leads, coordinates, and conducts field surveys.
Teizeen Mohamedali	Modeling and	Provides modeling and technical expertise for the project.

Staff	Title	Responsibilities
Ecology, EAP, NWRO Phone: (360) 715-5209 tmoh461@ecy.wa.gov	technical support	Reviews the QAPP.
Chuck Springer Ecology, EAP, HQ Phone: (360) 407-6997 cspr461@ecy.wa.gov	Hydrogeologist	Deploys and maintains continuous flow gages and staff gages. Produces records of streamflow data at sites selected for this study.
George Onwumere Ecology, EAP, HQ Phone: (360) 407-6730 ogeo461@ecy.wa.gov	Unit Supervisor of Project Manager	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the QAPP.
Robert F. Cusimano Ecology, EAP, HQ Phone: (360) 407-6596 bcus461@ecy.wa.gov	Section Manager of Project Manager	Approves the QAPP.
Dean Momohara Ecology, EAP, MEL Phone: (360) 871-8801 dmom461@ecy.wa.gov	Acting Lab Director	Provides laboratory staff and resources, sample processing, analytical results, laboratory contract services, and quality assurance/quality control (QA/QC) data. Approves the QAPP.
William Kammin Ecology, EAP, HQ Phone: (360) 407-6964 wkam461@ecy.wa.gov	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.
Amy King Tetra Tech, Inc. Phone: (720) 881-5874 amy.king@tetratech.com	Tetra Tech Task Order Leader/ QAPP Author/ Project Manager	Primary contact for project management and liaison for communication between EPA/Ecology and the Tetra Tech team. Writes sections of the QAPP. Leads, coordinates, and conducts technical analyses to support TMDL development for temperature, DO, and pH, including TMDL report development.
Jonathan Butcher Tetra Tech, Inc. Phone: (919) 485-8278 jon.butcher@tetratech.com	Tetra Tech Modeling Quality Control Officer	Provides oversight and quality control on technical aspects of the project, including modeling and data analyses. Approves the final QAPP.
John O'Donnell Tetra Tech, Inc. Phone: (703) 385-6000 john.odonnell@tetratech.com	Tetra Tech Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.
Jayne Carlin EPA Region 10 Watersheds Unit Phone: (206) 553-8512 Carlin.Jayne@epa.gov	Task Order Manager	Developed technical direction and task overview for project. Coordinates review of QAPP with EPA QA officers. Approves the QAPP.
Gina Grepo-Grove EPA Region 10 Environmental Characterization Unit Phone: 206-553-1632 Grepo-Grove.Gina@epa.gov	Quality Assurance Manager	Provides QA/QC oversight for project and approves the QAPP.

EAP: Environmental Assessment Program.
MEL: Manchester Environmental Laboratory.
QAPP: Quality Assurance Project Plan.
NWRO: Northwest Regional Office.
HQ: Headquarters.

WQP: Water Quality Program.

) or his/her designee will make monthly detailed modeling documentation available to members of the modeling work group.

Software Development Quality Assessment

New software development is not anticipated for this project. If any such development is required, the QC Officer or designee will conduct surveillance on software development activities to ensure that all tasks are carried out in accordance with the QAPP and satisfy user requirements.

Surveillance of Project Activities

Internal peer reviews within the contractor's organization will be documented in the project file and QAPP file. Documentation will include the names, titles, and positions of the peer reviewers; their report findings; and the project management's documented responses to their findings. The contractor TOL could replace a staff member if it is in the best interest of the task to do so.

Performance audits are quantitative checks on different segments of task activities. The contractor QC Officer or designee will be responsible for overseeing work as it is performed and for periodically conducting internal assessments during the data entry and analysis phases of the task. The contractor TOL will perform surveillance activities throughout the duration of the task to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in the data review and technical approach documentation. These surveillance activities will include assessing how task milestones are achieved and documented; corrective actions are implemented; budgets are adhered to; peer reviews are performed; data are managed; and whether computers, software, and data are acquired in a timely manner.

Output Assessment and Model Usability

Departures from Acceptance Criteria

The model developed for the project will be used to assess a series of study objectives, as summarized in the *Goals and Objectives* section above. Acceptance criteria for the model are described in the *Quality Objectives for Modeling* section.

Written documentation will be prepared under the direction of the relevant QC officer addressing the calibrated model's ability to meet the specified acceptance criteria and provided to the TOL and QA officer for review. If a model does not meet acceptance criteria, the QC officer will first direct efforts to bring the model into compliance. If, after such efforts, the model still fails to meet acceptance criteria, the contractor will conduct a thorough exposition of the problem and potential corrective actions, e.g., by collecting additional data or modifying model code, and provide them to Ecology and EPA. The contractor will also provide an analysis of the degree to which any model that does not fully meet acceptance criteria might still be useful for addressing study questions.

Reconciliation with User Requirements

In the *Quality Objectives for Modeling* described above, acceptable performance target ranges – but not specific numeric acceptance criteria – for the models are presented. Appropriate uses of the model will be determined by the project team on the basis of an assessment of the types of decisions to be made, the model performance, and the available resources.

If the project team determines that the quality of the model calibration is insufficient to address the project goal and study objectives, the contractor will consult with Ecology, EPA, and other team members, as appropriate, as to whether the levels of uncertainty present in the models can allow user requirements to be met, and, if not, the actions needed to address the issue.

A detailed evaluation of the ability of the modeling tools to meet user requirements will be provided in either the TMDL report or in internal technical memoranda between the contractor and Ecology, which may ultimately be included as an appendix to the TMDL report.

External Data Usability

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

External data (also referred to as secondary data) are data previously collected under an effort outside the 2012 study that are used for water body assessment as well as model development and calibration. Other secondary data will be assembled from other sources. Table 35 lists the secondary sources that are anticipated to be used as part of this project. The sections below provide details regarding how such secondary data will be identified, acquired, and used for this task.

Table 35. Sources of key secondary data.

Data type	Source
Flow data	U.S. Geological Survey gaging station (National Water Information System); Snohomish County Surface Water Management Division
Meteorology data	National Climatic Data Center (NCDC); Snohomish County (one station available in French Creek and two in Pilchuck River watersheds)
Water quality observations	Snohomish County Surface Water Management Division; Ecology; French Slough Flood Control District; city of Monroe; USGS
Reach hydraulics	French Creek Watershed Management Committee and Snohomish County HSPF; Snohomish County Surface Water Management Division; USGS
Point source data	Discharge Monitoring Reports (Ecology)

Flow Data

Reliable streamflow data are important to model development and calibration and validation. The USGS maintains a streamflow gage on the Pilchuck River near Snohomish, Washington. Data from the gage are readily available through the USGS National Water Information System, accompanied by related QC information.

Additional flow measurements in the Pilchuck River watershed have been collected and are available through the Snohomish County Surface Water Management Division. Nine monitoring locations throughout the watershed have collected instantaneous flow samples from 1971 through 1996. Most records are from 1996. See Figure 3 and Table 3. These data have already been loaded into Ecology's EIM System and are accessible at https://fortress.wa.gov/ecy/eimreporting/search.asp. All data are stored with associated QC information including detection limit, data qualifier and flag, sample ID, analysis lab identifier, result method, and validation method.

In addition, continuous flow data are currently being compiled from the Snohomish County Surface Water Management Division for a station located on French Creek, at 167th Avenue. It is anticipated that an Ecology flow station will also be installed in French Creek at the Old Snohomish Monroe Road Bridge by the time data collection begins. These data will also have associated QC information when they are made available. When flow data from sources other than Ecology, USGS, and Snohomish County gaging and field measurements are used, the project team will review the relevant QA protocols and document the results in the final TMDL report.

Meteorological Data

HSPF requires input time series of precipitation, temperature, and potential evapotranspiration at a minimum. All relevant precipitation and temperature stations will be reviewed for applicability to the model. Detailed data for hourly air temperature and other inputs potentially needed to estimate potential evapotranspiration such as dew point temperature, wind speed, and cloud cover will be obtained from NOAA's National Climatic Data Center (NCDC). NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States.

COOP stations record hourly or daily rainfall data. Airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover. All data compiled and maintained by NCDC are stored with associated QC tags that identify data quality and missing intervals. Additional precipitation data are also available from Snohomish County at three locations: one in the French Creek watershed, and two in the Pilchuck River watershed. County data includes quality tags for each record. All climactic data are available at one hour intervals and can be used to support the development of the Shade and QUAL2Kw models.

Water Quality Observations

Water quality observations are required for calibration of the HSPF and QUAL2Kw models in addition to overall water body assessment (see *Historical Data Review* section). Parameters of interest include, but are not necessarily limited to, temperature, DO, pH, BOD, nitrogen, phosphorous, total inorganic carbon, carbon dioxide, and alkalinity.

Tetra Tech, Inc., EPA contractor for QAPP development, has compiled and reviewed water quality monitoring data for French Creek and Pilchuck River watersheds collected by the Snohomish County Surface Water Management Division, Ecology, the French Creek Flood Control District, and the city of Monroe. Specifically, as noted in the Historical Data Review, monitoring included in situ continuous data and instantaneous values as well as grab samples collected for laboratory analysis.

Monitoring parameters include those identified in the impairment listings of the two watersheds (DO, pH, and temperature), as well as the related nutrient parameters, alkalinity, total organic carbon, NH_3, NO_3, NO_2, TKN, ortho-phosphorus, total dissolved phosphorus, and TP.

Data available from Snohomish County were downloaded from Ecology's EIM system and from the County's Surface Water Online Database (http://198.238.192.103/spw_swhydro/index.asp). Water quality data collected by the French Creek Flood Control District, and the city of Monroe were made available through Ecology (Ralph Svrjcek, personal communication, Washington State Department of Ecology, 2012). All data obtained have associated data quality codes for QC purposes.

It is assumed that data collected and provided by Ecology, Snohomish County, and others have undergone appropriate QA/QC procedures, but if data from other sources are used, the project team will review the relevant QA protocols and document the results in the final TMDL report. This ensures that the data for the TMDL analyses can be combined, compared, and analyzed comprehensively, resulting in a complete suite of data and information to characterize the study area.

Reach Hydraulics

Stream geometry information is a required input to both the HSPF and QUAL2Kw models. This information includes stream channel width, depth, and available cross-section estimates. This information is necessary to best represent the physical system in the models. Basic stream geometry data will be collected at the monitoring stations during the summer 2012 sampling described in this QAPP. These data will be the primary source of stream geometry information as it is being collected at the same time as the water quality data used for model calibration. Other data sources will be investigated, as necessary. For example, details on the French Creek watershed stream reach segments simulated using HSPF by the French Creek Watershed Management Committee and Snohomish County are provided in the modeling report by Beyerlein and Brascher (1998). This information will be utilized and refined, as necessary, based on more recent data. Other stream geometry information will be compiled from available reports and will be used as a secondary source of information, if necessary.

Point Source Discharges

Several types of NPDES permitted facilities or activities exist in the French Creek and Pilchuck River watersheds, as described above in the Watershed Description section. The most numerous type is the construction stormwater general permit, with 38 active construction permits throughout the watersheds. Construction permits primarily address the release of total suspended solids into surface waters and associated increases in turbidity; however, the permits can also include limits on pH, nutrients, or other pollutant parameters. Emergency/hazardous chemical and underground storage tank permits are also prevalent (23 and 33 permits in each category, respectively).

The Granite Falls WWTP is also an active point source in the Pilchuck River watershed. The facility's outfall will be sampled once during each synoptic survey and data will be incorporated into the models. Ecology will incorporate any NPDES permit reporting data indicating that an effluent discharge, or category of dischargers, contributes nutrients or other relevant pollutants that affect temperature or DO levels during a critical period. If the data are determined not to be representative of a discharger or category of dischargers, Ecology may choose not to incorporate that data into its models.

Snohomish County and WSDOT hold Phase I MS4 permits in the watershed. In addition, four communities (Granite Falls, Marysville, Lake Stevens, Snohomish, and Monroe) hold Phase II MS4 permits. These permits do not stipulate limits for temperature, DO, pH, or flow. During this project, all available monitoring data from EPA Region 10 and Ecology will be assembled. When data from other sources are used, the project team will review the relevant QA protocols and document the results in the final TMDL report.

Quality Control for Secondary Measurements

The majority of the secondary measurements will be obtained from quality-assured sources. Secondary measurements are collected outside of the 2012 study and will be used in the long-term HSPF modeling effort. Associated water quality data will be verified using Ecology's Credible Data Policy before inclusion in TMDL analyses. For non-water quality data, the project team will determine how much effort should be made to find reports or metadata that might contain measurement performance criteria information. The team will perform general quality checks on the transfer of data from any source databases to another database, spreadsheet, or document.

Where non-water quality data are obtained from sources lacking an associated quality report, the contractor Project Manager will evaluate data quality of such secondary data before using it. Additional methods that might be used to determine the quality of secondary data are:

- Verifying values and extracting statements of data quality from the raw data, metadata, or original report
- Comparing data to a checklist of required factors, e.g., analyzed by an approved laboratory, used a specific method, met specified data quality objectives, validated

If it is determined that such searches are not necessary or that no quality requirements exist or can be established, but the non-water quality data must be used in the task, a statement will be included in the final report indicating that the quality of the specified secondary data is unknown.

Project Organization

Table 36 describes the roles and responsibilities of Ecology and selected EPA contractor staff.

Table 36. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Ralph Svrjcek Ecology, WQP, NWRO Phone: (425) 649-7165 rsvr461@ecy.wa.gov	Ecology 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, assists with field work.
Dave Garland Ecology, WQP, NWRO Phone: (425) 649-7031 dgar461@ecy.wa.gov	Unit Supervisor of Project Lead	Approves the QAPP and assists with project scoping.
Trevor Swanson Ecology, EAP, HQ Phone: (360) 407-6685 trsw461@ecy.wa.gov	QAPP Author, Project Manager/ Field Lead/EIM Data Engineer	Helps define project objectives, scope, and study design. Writes sections of the QAPP. Manages the data collection program. Leads, coordinates, and conducts field surveys.
Teizeen Mohamedali Ecology, EAP, NWRO Phone: (360) 715-5209 tmoh461@ecy.wa.gov	Modeling and technical support	Provides modeling and technical expertise for the project. Reviews the QAPP.
Chuck Springer Ecology, EAP, HQ Phone: (360) 407-6997 cspr461@ecy.wa.gov	Hydrogeologist	Deploys and maintains continuous flow gages and staff gages. Produces records of streamflow data at sites selected for this study.
George Onwumere Ecology, EAP, HQ Phone: (360) 407-6730 ogeo461@ecy.wa.gov	Unit Supervisor of Project Manager	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the QAPP.
Robert F. Cusimano Ecology, EAP, HQ Phone: (360) 407-6596 bcus461@ecy.wa.gov	Section Manager of Project Manager	Approves the QAPP.
Dean Momohara Ecology, EAP, MEL Phone: (360) 871-8801 dmom461@ecy.wa.gov	Acting Lab Director	Provides laboratory staff and resources, sample processing, analytical results, laboratory contract services, and quality assurance/quality control (QA/QC) data. Approves the QAPP.
William Kammin Ecology, EAP, HQ Phone: (360) 407-6964 wkam461@ecy.wa.gov	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.
Amy King Tetra Tech, Inc. Phone: (720) 881-5874 amy.king@tetratech.com	Tetra Tech Task Order Leader/ QAPP Author/ Project Manager	Primary contact for project management and liaison for communication between EPA/Ecology and the Tetra Tech team. Writes sections of the QAPP. Leads, coordinates, and conducts technical analyses to support TMDL development for temperature, DO, and pH, including TMDL report development.
Jonathan Butcher Tetra Tech, Inc. Phone: (919) 485-8278 jon.butcher@tetratech.com	Tetra Tech Modeling Quality Control Officer	Provides oversight and quality control on technical aspects of the project, including modeling and data analyses. Approves the final QAPP.

Staff	Title	Responsibilities
John O'Donnell Tetra Tech, Inc. Phone: (703) 385-6000 john.odonnell@tetratech.com	Tetra Tech Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.
Jayne Carlin EPA Region 10 Watersheds Unit Phone: (206) 553-8512 Carlin.Jayne@epa.gov	Task Order Manager	Developed technical direction and task overview for project. Coordinates review of QAPP with EPA QA officers. Approves the QAPP.
Gina Grepo-Grove EPA Region 10 Environmental Characterization Unit Phone: 206-553-1632 Grepo-Grove.Gina@epa.gov	Quality Assurance Manager	Provides QA/QC oversight for project and approves the QAPP.

EAP: Environmental Assessment Program.
MEL: Manchester Environmental Laboratory.
QAPP: Quality Assurance Project Plan.
NWRO: Northwest Regional Office.
HQ: Headquarters.
WQP: Water Quality Program.

Project Schedule

Table 37 shows the anticipated project schedule for the French Creek/Pilchuck River TMDL project.

Table 37. 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	October 2012	Trevor Swanson
Laboratory analyses completed	October 2012	
Environmental Information System (EIM) database		
EIM user study ID	TSWA0004	
Product	Due date	Lead staff
EIM data loaded	November 2012	Trevor Swanson
EIM quality assurance	December 2012	To be declared
EIM complete	January 2013	Trevor Swanson
Final TMDL (WQIR) report: To be declared by EPA and the contractor.		

Laboratory Budget

Table 38 presents the estimated laboratory budget for this study. The budget and lab sample load are based on:

1. One periphyton assessment.
2. Two synoptic surface-water surveys.

The greatest uncertainty in the laboratory workload and cost estimate is whether any sites will be added for investigation purposes, e.g., to further pinpoint pollution sources or bracketing stream reaches. However, efforts will be made to keep the submitted number of samples within the estimate provided here.

Table 38. Laboratory budget.

Parameter	Cost[1] per sample (dollars)	# of sites	Times sampled per day	# of samples (including field QA)	# of surveys	Total # of samples	Total cost (dollars)
Turbidity	11.92	20	2	44	2	88	$1049
Total Suspended (TSS) + TNVSS[2]	26.02	20	2	44	2	88	$2290
Alkalinity	18.43	20	2	44	2	88	$1621
Chloride	14.09	20	2	44	2	88	$1240
Chlorophyll-*a* (lab filtered)	59.61	20	2	44	2	88	$5246
Ammonia (NH_3)	14.09	20	2	44	2	88	$1240
Nitrite-Nitrate (NO_2/NO_3)	14.09	20	2	44	2	88	$1240
Total Persulfate Nitrogen (TPN)	18.43	20	2	44	2	88	$1621
Orthophosphate (OP)	16.26	20	2	44	2	88	$1431
Total Phosphorus (TP)	19.50	20	2	44	2	88	$1716
Periphyton (biomass and chl. *a* levels)	82.00[3]	20	3[4]	66	1	66	$5412
Dissolved Organic Carbon	38.98	20	2	44	2	88	$3431
Total Organic Carbon	35.77	20	2	44	2	88	$3148
						Total	**$30,685**

[1] Costs include 50% discount for Manchester Laboratory
[2] Total nonvolatile suspended solids
[3] Estimate
[4] Number of samples at each site. Periphyton will only be sampled once during study.

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

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.

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.

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.

1-DMin or 1-day minimum temperature: The lowest 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.

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

Anthropogenic: Human-caused.

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

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

Critical 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.

Diurnal: Occurring on a 24-hour cycle, as opposed to diurnal (day) or nocturnal (night) occurrences.

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

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

Eutrophication: The process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.

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).

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

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.

Near-stream disturbance zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars.

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).

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

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

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.

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.

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 thermal potential: See system-potential temperature.

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

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

BMP	Best management practice
BOD	Biochemical Oxygen Demand
COOP	Cooperative Observer Network
CREM	Council for Regulatory Environmental Modeling
DEM	Digital elevation models
DMR	Discharge monitoring report
DNR	Washington State Department of Natural Resources
DW	Dry weight
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
ECY	Washington State Department of Ecology
EIM	Environmental Information Management
EPA	U.S. Environmental Protection Agency
FCLD	French Creek Long-Term Downstream (monitoring station)
FSFCD	French Slough Flood Control District
GIS	Geographic Information System software
HDPE	High-density polyethylene plastic
HSPF	Hydrological Simulation Program—Fortran modeling software
LDO	Luminescent dissolved oxygen
LiDAR	Light Detection and Ranging
MDL	Method detection limit
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objectives
MS4	(See Glossary above.)
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Dataset
NPDES	(See Glossary above)
ODEQ	Oregon Department of Environmental Quality
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
QUAL2Kw	Modeling software for dissolved oxygen
RCW	Revised Code of Washington
RE	Relative error
RL	Reporting limit
RM	River mile
RPD	Relative percent difference
RQUAL	A one-dimensional finite difference water quality model
RSD	Relative standard deviation
SnoCo	Snohomish County
SOP	Standard Operating Procedure
SR	State Route

TMDL	(See Glossary above)
TNVSS	Total nonvolatile suspended solids
TOL	Task Order Leader
USC	United States Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WBAN	Weather Bureau Army-Navy
WQA	Water Quality Assessment
WQI	Water Quality Index
WQIP	Water Quality Implementation Plan
WQIR	Water Quality Improvement Report
WQP	Water Quality Program
WRIA	Water Resource Inventory Area
WSDA	Washington State Department of Agriculture
WSDOT	Washington State Department of Transportation
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft/s	feet per second
mg	milligrams
mg/L	milligrams per liter (parts per million)
mL	milliliters
NTU	nephelometric turbidity units
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
uS/cm	microsiemens per centimeter, a unit of conductivity