DEPARTMENT OF ECOLOGY
State of Washington

Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

December 2020

Publication 20-10-035

Publication Information

This report is available on the Department of Ecology's website at:
https://apps.wa.gov/ecy/publications/SummaryPages/2010035.html.

Data for this project are available in Ecology's EIM Database. Study ID: TSWA0004.

The Activity Tracker Code for this study is 12-067.

Suggested Citation:

Mathieu, N., and H. Khan. 2020. Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load, Water Quality Improvement Report and Implementation Plan. Publication 20-10-035. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/2010035.html.

Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area: WRIA 7; HUC number 17110011 - Snohomish.

Contact Information

Publications Coordinator
Water Quality Program
Washington State Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360 407-6600

Washington State Department of Ecology – https://ecology.wa.gov

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

Cover photo: Eroding bank on the Middle Pilchuck River in need of riparian restoration. Photo taken by Nuri Mathieu, summer 2014.

Pilchuck River
Temperature and Dissolved Oxygen
Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

By

Nuri Mathieu
Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington

And

Heather Khan
Water Quality Program
Washington State Department of Ecology
Bellevue, Washington

Table of Contents

List of Appendices

The Appendices are available as a Supplemental file to this report at:
https://apps.ecology.wa.gov/publications/summarypages/2010035.html

List of Figures

List of Tables

Acknowledgements

The authors of this report thank the following people for their contributions to this study:

- Laurie Mann, Christopher Zell, and Lisa Kusnierz, U.S. Environmental Protection Agency
- Peter Verhey, Washington Department of Fish and Wildlife
- Frank Leonetti and Mike Rustay, Snohomish County Surface Water Management
- Cindy Dittbrenner, Kristin Marshall, and Carson Moscoso, Snohomish Conservation District
- Brett Gaddis, Snohomish County Public Works
- Reid Camp, Cramer Fish Sciences
- Frederick Goetz, U.S. Army Corps of Engineers
- Morgan Ruff, Tulalip Tribes
- Washington State Department of Ecology:
  - Ralph Svrjcek
  - Marty Jacobson
  - Laura Fricke
  - Cristiana Figueroa-Kaminsky
  - John Rose and Jay Cook
  - Christopher Martin
  - Cleo Neculae
  - Scott Collyard, Danielle DeVoe, Kevin Leung, Robert Nolan, Meghan Rosewood-Thurman and Jessica Schwing
  - Nancy Rosenbower, Leon Weiks, and Dean Momohara, Manchester Environmental Lab
  - Former Ecology staff: Dave Garland, Joan Nolan, Lazaro Eleuterio, Paul Cracknell, and Trevor Swanson

The authors also thank the Pilchuck River Technical Advisory Group for its guidance and dedication:

- Kurt Nelson and Colin Wahl, Tulalip Tribes
- Laurie Mann, U.S. Environmental Protection Agency
- Jamie Bails, Washington Department of Fish and Wildlife
- Elsa Pond, Washington Department of Transportation
- Steve Britsch, Snohomish County Surface Water Management
- Kristin Marshall, Thomas Bulthuis, and Jay Luce Nelson, Snohomish Conservation District
- Brent Kirk, City of Granite Falls
- Stacy Clear, Gray and Osborne (for City of Granite Falls)
- Jon Stevens, City of Lake Stevens
- Jessie Balbiani, City of Marysville
- Andrew Sics, City of Snohomish
- Rodney Pond, Sound Salmon Solutions
- Mary Lou White, Wild Fish Conservancy
- Christopher Martin, Washington Department of Ecology

Chapter 1: Introduction

Overview

Improving water quality in the Pilchuck River watershed is needed to support the recovery of threatened cold water fish species that spawn, rear, or live there. Chinook, coho, sockeye, chum, and pink salmon, as well as bull trout and steelhead trout, call the Pilchuck River home. These fish species are highly valued by the many state residents that depend on them for cultural, recreational, or economic reasons. The Pilchuck River mainstem has been targeted for restoration of endangered Chinook salmon (Snohomish Basin Salmon Recovery Forum, 2005).

The Pilchuck River drains a 137-square-mile watershed located in Snohomish County in Water Resource Inventory Area (WRIA) 7. The watershed drains into the upper end of the tidally influenced portion of the Snohomish River.

Data collected over two decades (Tooley et al., 1990; Thornburgh et al., 1991; Thornburgh and Williams, 2000) revealed high water temperatures and low dissolved oxygen (DO) levels. These levels do not protect fish and other native species that depend on cool, clean water (Figure 1). As a result, multiple water segments in the Pilchuck River were included on the 303(d) list of impaired water bodies (Table 1). In recent years, much more data have become available indicating more widespread impairment.

In response to these listings, Ecology collected data from 2012 to 2016 to characterize temperature and DO in the river. Ecology used these data to develop a water quality model to help determine the causes of impairment and develop management scenarios to improve water quality. Using these monitoring and modeling results, Ecology determined the wasteload and load allocations needed to meet water quality standards for the Pilchuck River and its tributaries. Ecology then used this information to develop this report, Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load, Water Quality Improvement Report and Implementation Plan.

The Pilchuck River and its tributaries are also impaired by high bacteria levels. This report does not address bacteria pollution because Ecology previously addressed bacteria pollution problems in the Snohomish River Tributaries Fecal Coliform (FC) Bacteria TMDL (Wright et al., 2001) and its implementation plan (Svrjcek, 2003).

Even before this TMDL was fully developed, local organizations used Ecology grant funds to start early implementation actions. The Snohomish Conservation District started by working with the City of Snohomish on education/outreach and a low-impact development project. They included the Pilchuck River in their National Estuary Program (NEP) funded Easement Pilot program activities and recently received an Ecology grant to promote instream restoration activities. The Adopt-A-Stream Foundation carried out door-to-door outreach and riparian plantings in the Little Pilchuck Creek basin and later added more riparian restoration projects in the Little Pilchuck in partnership with the City of Lake Stevens. Ecology also helped facilitate a streamside restoration project in Dubuque Creek.

Figure 1. Dead fish found in isolated low oxygen habitat in the Pilchuck River.

Much more on-the-ground work is needed to restore water quality in the Pilchuck Watershed. This TMDL supports that future work by establishing a firm scientific understanding of water temperatures, DO levels, and the processes that affect those parameters. The TMDL's implementation plan further describes the riparian and riverine improvements needed to make the Pilchuck River a healthy place for fish and supporting biota.

Scope

This TMDL addresses temperature and DO issues in the entire Pilchuck River watershed (Figure 2). To support on-the-ground implementation and planning, the TMDL divided the Pilchuck River watershed into the following three sections to summarize water quality information:

- **Upper Pilchuck River** (~ RM 26 to headwaters) –upstream of Purdy Creek. There are no 303(d) listings in the upper Pilchuck River. Ecology did not conduct modeling analysis in this section; however, a load allocation was assigned.
- **Middle Pilchuck River** (~ RM 8.6 to 26) –between the confluences with Little Pilchuck Creek and the Purdy Creek. The upstream end of the middle Pilchuck River (RM 26) marks the start of the model boundary. Only the mouths of the tributaries in this section were included in the modeling analysis.
- **Lower Pilchuck River** (mouth to ~RM 8.6) –from the confluence with the Snohomish River to the OK Mill Road bridge. Only the mouths of the tributaries in this section were included in the modeling analysis.

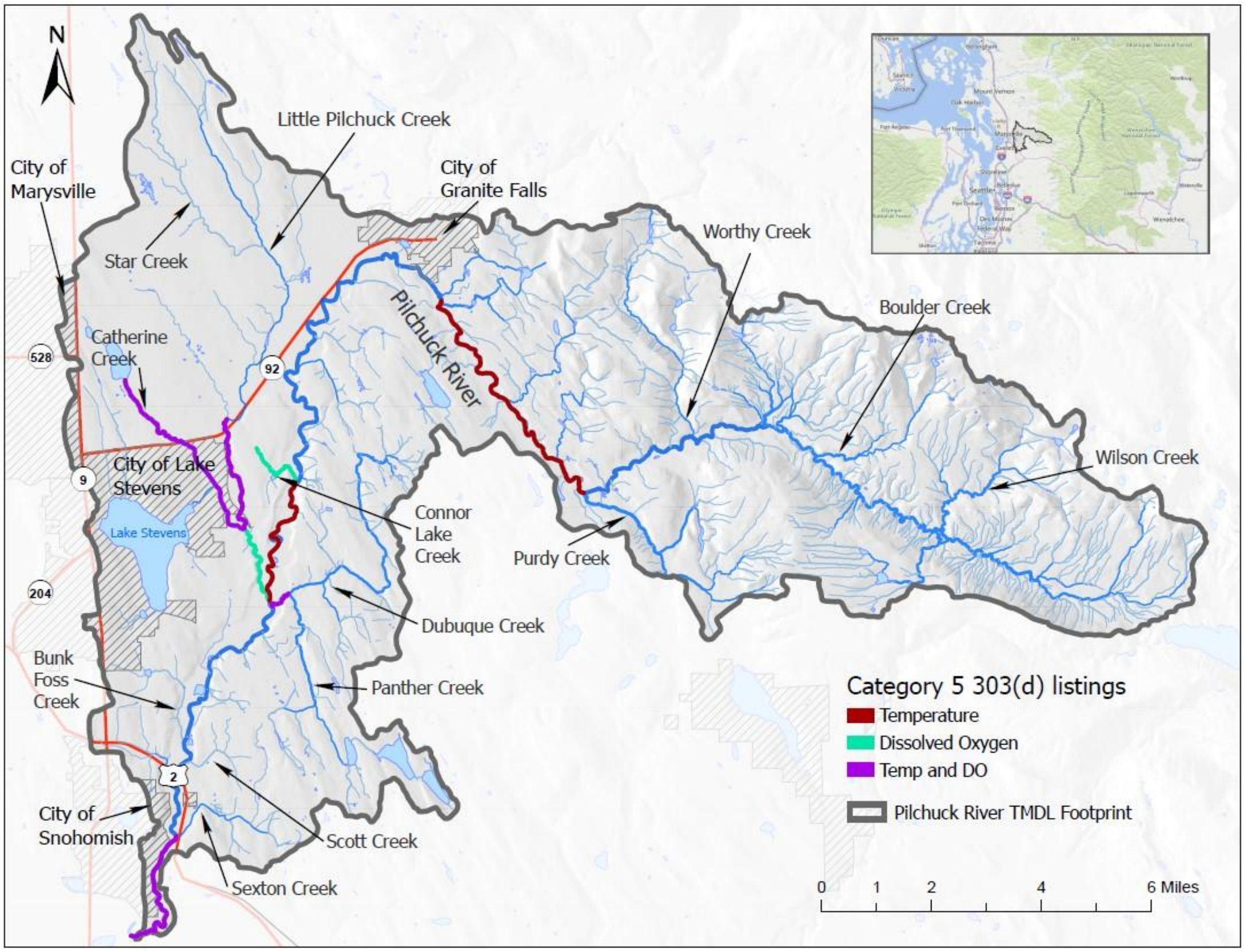

Figure 2: Pilchuck River watershed and TMDL study area with 303(d) impaired water bodies.

The primary use to be protected by this TMDL is the aquatic life use of Char spawning and rearing for the upper watershed above Boulder Creek and Core Summer Salmonid Habitat below Boulder Creek. Portions of the Pilchuck River have applicable supplemental spawning and incubation criteria of 13˚C from February 15 to June 15. Tables 4 and 5 in the "Uses of Water Bodies" section provide more information about beneficial uses and the water quality criteria for temperature and DO in this watershed.

Table 1 and Figure 2 provide a summary of 303(d) impaired water bodies that are addressed by this TMDL. In recent years, much more data have become available indicating more widespread impairment. As described in the Appendix A, Water Quality Issues section, DO and temperature are important to the health and vitality of fish.

Table 1. Water bodies on the 2014 303(d) list addressed by TMDL.

Listing ID	Water-body Name	Section of Pilchuck (or trib ultimately discharges to)	Pollutant	Reach Code (Assessment Unit ID)
10621	Pilchuck River	Lower (~RM 0-3)	Dissolved Oxygen	17110011000048
10620	Pilchuck River	Lower (~RM 0-3)	Temperature	17110011000048**
7295	Pilchuck River	Middle (~RM 9-12)	Temperature	17110011000061**
14725	Pilchuck River	Middle (~RM 20-23)	Temperature	17110011000064**
72567	Pilchuck River	Middle (~RM 23-26)	Temperature	17110011000065**
7394	Catherine Creek	Little Pilchuck Creek	Dissolved Oxygen	17110011000073
7395	Catherine Creek	Little Pilchuck Creek	Temperature	17110011000073**
7400	Dubuque Creek	Middle (RM 8.6)	Dissolved Oxygen	17110011000054
7401	Dubuque Creek	Middle (RM 8.6)	Temperature	17110011000054**
9274	Little Pilchuck Creek	Middle (RM 8.6)	Dissolved Oxygen	17110011000188
9275	Little Pilchuck Creek	Middle (RM 8.6)	Temperature	17110011000188**
40911	Little Pilchuck Creek	Middle (RM 8.6)	Dissolved Oxygen	17110011000072
47441	Unnamed Creek (Tributary to Pilchuck R)*	Middle (~RM 12)	Dissolved Oxygen	17110011000180

*Referred to as Connor Lake Creek throughout document (see Figure 2 for location)
** Supplemental Spawning Criteria also apply to this segment, in addition to the Core Summer Salmonid Use Criteria. See Table 5 and Ecology Publication 06-10-038 for further detail.

As a result of the data collected in 2012 and 2016 by Ecology for this TMDL study, additional water-body segments were found that do not meet state water quality standards (Table 2). These impaired segments are also addressed by this TMDL. All the impaired reaches identified in Tables 1 and 2 occur in the Pilchuck watershed below Boulder Creek, therefore the beneficial uses and criteria identified as “below Boulder Creek” in Table 4 and 5 apply.

Table 2. Additional water-body segments of the Pilchuck River addressed by this TMDL that were found to not meet WQ standards (not currently on the 303(d) list).
Station locations (PIL XX) refer to river mile from the mouth of the Pilchuck.

Water Body	Parameter	NHD Reach Code/ Assessment Unit ID	Basis
Pilchuck River	Dissolved Oxygen	17110011000049	2016: 3 of 3 daily min excursions at PIL3.6
Pilchuck River	Dissolved Oxygen	17110011000052	2016: 3 of 3 daily min excursions at PIL5.7 2012: 6 of 6 daily min excursions at PIL5.7
Pilchuck River	Dissolved Oxygen	17110011000053	2012: 6 of 6 daily min excursions at PIL8.5
Pilchuck River	Dissolved Oxygen	17110011000061	2012: 3 of 3 daily min excursions at PIL10.4
Pilchuck River	Dissolved Oxygen	17110011000062	2016: 3 of 3 daily min excursions at PIL11.6
Pilchuck River	Dissolved Oxygen	17110011000063	2016: 3 of 3 daily min excursions at PIL15.1 & PIL18.7
Pilchuck River	Dissolved Oxygen	17110011000064	2016: 3 of 3 daily min excursions at PIL21.5
Pilchuck River	Temperature	17110011000052*	2012: 7-DADMax excursions at PIL5.7
Pilchuck River	Temperature	17110011000053*	2016: 3 of 3 daily max excursions at PIL8.2
Pilchuck River	Temperature	17110011000062*	2016: 3 of 3 daily max excursions at PIL11.6
Pilchuck River	Temperature	17110011000063*	2012: 7-DADMax excursions at PIL15.1
Unnamed Creek (Connor Lake Creek)	Temperature	17110011000180	2012: 7-DADMax excursion at CON-0.0
Unnamed Creek (Sexton Creek)	Temperature	17110011000244	2012: 7-DADMax excursion at GOL-0.0**

*Supplemental Spawning Criteria also apply to this segment, in addition to the Core Summer Salmonid Use Criteria. See Table 5 and Ecology Publication 06-10-038 for further detail.
**Original study referred to this creek as Golf Course Creek, but local partners call it Sexton Creek.

Table 3 lists pollutants that are not addressed by this TMDL. All the pH listings in Table 3 are derived from data showing low values measured during the wet season. Low pH can be the result of natural wetland flushing or acidic rainfall events in naturally poorly buffered systems (Mathieu, 2011). Therefore, the pH listings are unlikely to be tied to the sources of impairment causing temperature and DO problems associated with low flows.

Table 3. 2012 303(d) or Category 2 segments not addressed by this report.

Water body	Listing ID	Parameter	NHD Reach Code/ Assessment Unit ID	2014 Category
Pilchuck River	7291	pH	17110011000048	5
Little Pilchuck Creek	40817	pH	17110011000188	5
Little Pilchuck Creek	40912	Temperature	17110011000072	2
Dubuque Creek	40816	pH	17110011000054	2
Catherine Creek	40930	pH	17110011000073	5
Unnamed Creek (Trib to Pilchuck River)	71217	pH	17110011000217	5
Unnamed Creek (Trib to Pilchuck River)	73910	Temperature	17110011000217	2

Uses of the Water Bodies

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, water-body classifications, and numeric and narrative water quality criteria for surface waters of the state. The beneficial uses of the Pilchuck River and its tributaries are summarized in Table 4.

The State Water Quality Standards describe aquatic life use categories using key species (cold-water versus warm-water species) and life-stage conditions (spawning versus rearing). In this TMDL, the designated aquatic life uses to be protected are core summer salmonid habitat below Boulder Creek and char spawning and rearing above Boulder Creek.

Table 4. Beneficial uses for the Pilchuck River.

Geographic Area	Aquatic Life Uses	Other Uses
Confluence with the Snohomish River up to Boulder Creek	Core summer salmonid habitat	Primary Contact Recreation Water supply Miscellaneous uses
All waters above Boulder Creek	Char spawning and rearing	Primary Contact Recreation Water supply Miscellaneous uses

Downstream Uses

Downstream uses include both freshwater uses in the Snohomish River and marine uses in the Snohomish Estuary and the Salish Sea as described in Table 602 and Table 600 of the Water

Quality Standards (see also the state Water Quality Atlas[1]). Appendix A contains a detailed discussion of how the allocations in this TMDL could impact downstream uses. The next section discusses the water quality criteria that will protect beneficial uses as applied to the Pilchuck River.

Water Quality Criteria

Each beneficial use designation described above has associated numeric and narrative water quality criteria. The temperature and dissolved oxygen (DO) criteria for Pilchuck River are described below.

State Standards Protect Fish and Other Aquatic Life

Washington's numeric water quality criteria are based on the needs of the most sensitive fish species in the water body. In the Pilchuck River, temperature is expressed as the highest allowable 7-day average daily maximum (7-DADMax) temperatures. The metric includes an adequate magnitude and duration (averaging period) to protect salmonids and represents conditions in the thalweg or main stream channel.

Special consideration is also required to protect the spawning and incubation season of salmonid species throughout the mainstem Pilchuck River and many of its tributary streams.[2] In these areas the 7-DADMax should not exceed 13°C (55.4°F) during the period February 15 to June 15 every year.

DO criteria are also designed to protect fish for spawning, rearing, and migration periods in the case of salmon. DO levels also fluctuate throughout the day based on the photosynthesis of aquatic plants and respiration of both plants and other organisms. DO is evaluated using a 1-day minimum level.

Both parameters affect the physiology and behavior of fish and other aquatic life. For example, a warmer stream has less oxygen available for the fish and other organisms it supports. Therefore, temperature and DO levels are influential factors that can affect the distribution and health of aquatic life. Temperature and DO levels in streams fluctuate over the day and year in response to changes in solar energy inputs, meteorological conditions, river flows, groundwater input, and other factors.

Table 5 summarizes the applicable water quality criteria for temperature and DO.

[1] https://fortress.wa.gov/ecy/waterqualityatlas/StartPage.aspx
[2] Best viewed in Ecology's Water Quality Atlas (https://fortress.wa.gov/ecy/waterqualityatlas/StartPage.aspx)

Table 5. Washington State Water Quality Criteria for temperature and DO in the Pilchuck River.

Applicable Reach	Water Quality Parameter	Criteria
Below Boulder Creek	Temperature	<16°C 7-DADMax* (13°C, February 15-June 15)**
Below Boulder Creek	Dissolved Oxygen	>9.5 mg/L 1-DMin***
Above Boulder Creek	Temperature	<12°C 7-DADMax
Above Boulder Creek	Dissolved Oxygen	>9.5 mg/L 1-DMin

*7-DADMax: the highest annual running 7-day average of daily maximum temperatures.
** Supplemental Spawning Criteria apply to all of the mainstem Pilchuck River in this reach, but for the Pilchuck tributaries they only apply to the lower portions of Little Pilchuck, Catherine, Dubuque, and Panther Creeks. See Ecology Publication Number 06-10-038 for detailed maps.
***1-DMin: the lowest annual daily minimum oxygen concentration occurring in the water body.

Natural Water Body Variation

While state standards apply throughout a water body, there may be site-specific features, including shallow, stagnant, and eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that measurements be taken from well-mixed portions of rivers and streams. For similar reasons, samples are not to be taken from anomalously cold areas such as at discrete points where cold groundwater flows into the water body.

Washington State uses the criteria described above to ensure full protection for its designated aquatic life uses. The standards recognize, however, that some waterbodies are naturally cooler and hold more oxygen, and some are naturally warmer and hold less oxygen. When a water body is naturally warmer than the above-described numeric criteria, the state limits the allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally warmer temperature condition. When a water body's DO is lower than the criteria in (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L.

How Are Fish Affected?

Because state standards for temperature and DO are designed to sustain healthy fish populations, it is helpful to know how high temperatures and in turn low DO levels affect fish with respect to their geographic distribution during the critical period (June 16-September 30). Detailed information is provided in Appendix A under Temperature and Dissolved Oxygen Water Quality Issues.

What Fish Are Present During the Summer Critical Period?

The main populations of fish presence in the Pilchuck River include Skykomish Chinook, Pilchuck Winter Steelhead, Snohomish Coho, Snohomish Odd-Year Pink, and Snohomish

Coastal Cutthroat. Coho salmon rear throughout the mainstem and spawn mostly in the tributaries including Little Pilchuck Creek and Dubuque Creek. Fall Chinook spawn from southeast of City of Snohomish to downstream of Pilchuck Tree Farm Road and rear from downstream of Pilchuck Tree Farm Road to upstream of Purdy Creek. August flows in the Pilchuck River are too low for spawning adult Chinook, who typically spawn in September (Verhey, P. Personal communication. 2017); however their use of the Pilchuck River is relatively low when compared to steelhead. Tulalip Tribes noted observations of Chinook spawning up to Worthy Creek in 2020 for the first time in 100 years (Nelson, K. Public Communications, November 13, 2020). Visit WDFW's SalmonScape[3] website for more information.

Winter Steelhead, on the other hand, typically start to spawn in mid-March and rarely spawn into late June (Verhey, P. Personal communication. 2017; Verhey, P. Personal communication. June 3, 2020) through the Pilchuck River mainstem and in the tributaries including Little Pilchuck, Dubuque, Catherine and Panther creeks. Bull trout, although not listed as one of the main populations, have been shown to rear throughout the mainstem and in the tributaries including Little Pilchuck, Dubuque, Catherine, and Panther creeks. Tulalip Tribes noted observations of Bull trout roughly where Purdy Creek enters the mainstem near the old Pilchuck Diversion Dam site (Nelson, K. Public communications, November 13, 2020). Fall chum also are listed as spawning from Machias up to Granite Falls.

Snohomish Odd-Year Pink have documented presence from the mouth up to Granite Falls. According to WDFW's Species in Washington web page,[4] pink salmon typically like to spawn in large river mainstems (e.g. Snohomish River) and tributaries that are relatively close to saltwater. No further information was found to indicate Pink salmon spawn or rear in the Pilchuck River watershed.

Figure 3 illustrates the life cycles of these salmonids as it relates to temperature criteria and the critical period. High temperatures during the critical period may decrease or block migration, decrease salmonid growth and kill salmon. Decreases in summer flows contribute to increased temperatures during the critical period, which affects rearing habitat capacity for juveniles and affect spawning availability and access. Bull trout activity is largely unknown due to high variability of their movements in this system. The grayed out boxes for cutthroat represent general information related to Puget Sound; however, no further information was found about these life cycle activities specific to the Pilchuck River or the Snohomish River basins (Trotter, 1989; Johnson et al., 1999; Blakely, Leland and Ames, 2000; Anderson, Year Unknown; Goetz, Baker, Buehrens, and Quinn, 2013; Losee et al., 2017).

[3] http://apps.wdfw.wa.gov/salmonscape/
[4] https://wdfw.wa.gov/species-habitats/species/oncorhynchus-gorbuscha#desc-range

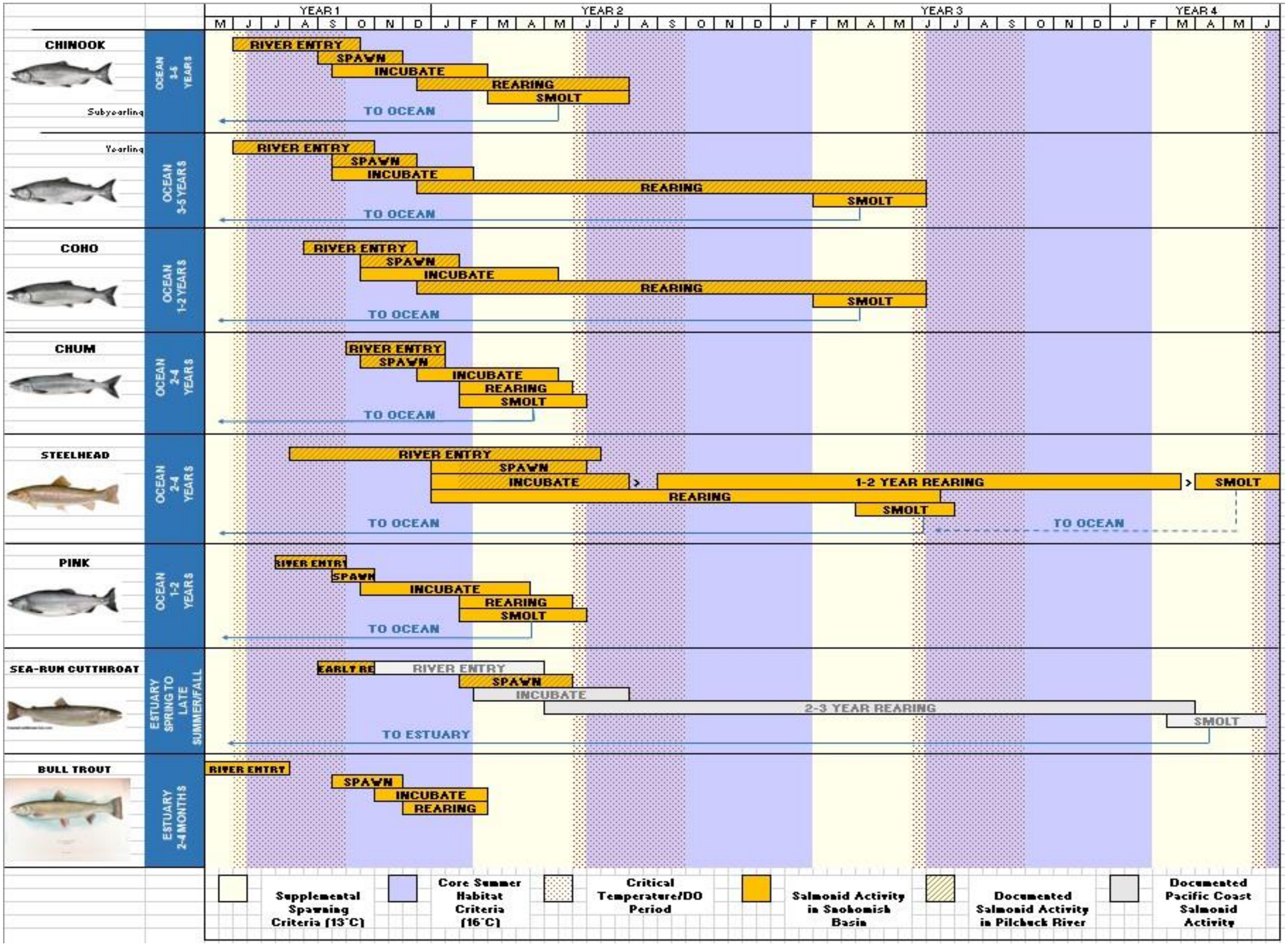

Figure 3. Temperature criteria impacts on salmonid activity.

Figure adapted from leDoux et al. 2017 and Beechie et al. 2013.

Both the TMDL study and other accepted scientific research on stream temperatures tell us that a substantial increase in shading over Pilchuck watercourses will result in cooler water temperatures and higher DO. The scientific literature also confirms that many factors, including air temperature; shading; elevation; surface hydrology; channel shape and complexity; and connectivity to groundwater, combine to influence stream temperature (Poole and Berman, 2000). This report's implementation plan relies on several core methods for improving stream temperatures.

Targets

The Pilchuck River TMDL sets out a combination of control and correction measures needed to ensure the water body meets the state standards for temperature and DO. Those measures may be specific criteria established in state standards or other surrogate values that relate directly with the pollutant of concern. The TMDL describes that range of control actions and limitations as "targets."

Ecology used the QUAL2Kw (Pelletier and Chapra, 2008) water quality model to evaluate the effect of shade, nutrients, organic matter, and several other factors on DO and temperature in the Pilchuck River. We present the modeling and analytical procedure in the **Temperature and DO TMDL Analysis** sections.

We found that even under natural conditions, the Pilchuck River watershed will not meet numeric water quality criteria for DO and temperature during the periods with high air temperatures and low flows. Therefore, the shade/heat, phosphorus, and BOD targets in this TMDL are based on the 0.2 mg/L human allowance for DO and the 0.3 allowance for temperature. Ecology also used the model to confirm that these targets did not result in excursions of water quality criteria when air temperatures are cooler, flows are higher, and natural conditions meet numeric water quality criteria.

Temperature

Several human influenced factors significantly impact temperature in the river including riparian shade, permitted discharges, instream baseflow loss, and hyporheic connectivity. Temperature allocations for pollutant sources are presented in load of therms per day.

Ecology has determined that the most important factor that will lead to streams within the Pilchuck River watershed meeting DO and temperature standards is the establishment of system potential shade. System potential shade will reduce water temperatures, allowing water to hold more dissolved oxygen. It will also reduce the amount of light reaching the water surface, which will help moderate algae growth.

Because shade is a key surrogate measure for improving both temperature and DO, this TMDL establishes explicit shade targets. We present these targets in Chapter 2 in the load capacity and load allocations sections. The need for shade targets, as well as other surrogated targets, is discussed further in the 'Detailed Temperature Analysis and Allocations' section.

The TMDL includes the various temperature targets needed to meet allocations and state standards including:

- Effective Shade in percent shade (0% means all direct solar radiation is reaching the river; 100% means no direct solar radiation is reaching the river).
    - The effective shade target is system potential shade in both the mainstem and tributaries (see Chapter 2).
    - Numeric targets, based on the system potential shade, were calculated for specific mainstem river reaches to measure implementation progress and site-specific compliance.
    - The effective shade curves (Figure 56) is used to calculate the target in areas without specific numeric targets.
- Bank/floodplain improvements in feet of restoration.
    - Bank improvements such as levee setbacks, softening, or armor removal to increase hyporheic flow exchange.
- Baseflow restoration in cubic feet per second restored.
    - Subbasin-specific baseflow restoration to increase depth and reduce river temperatures.

Dissolved Oxygen

The QUAL2Kw model and study results determined that phosphorus loading results in increased bottom algae growth. As algae levels increase, they consume more oxygen (respiration) as part of the photosynthesis daily cycle. The model also demonstrated that increases in the levels of organic matter and ammonia instream can result in additional oxygen depletion, as the organisms that break down this organic matter consume oxygen. The breakdown of carbon-based organic matter and ammonia is measured as BOD. See Chapter 4 and Appendices A and F for detailed discussion.

Temperature increases in the Pilchuck River also significantly reduce DO levels; therefore, the temperature targets also apply to DO. In addition, further impacts to DO are addressed by providing pollutant load targets for both point and nonpoint sources throughout the watershed including:

- Biochemical oxygen demand (BOD) in lbs/day.
- BOD allocations are expressed as the uninhibited 5-Day biochemical oxygen demand (BOD_5). Uninhibited BOD_5 represents the combined oxygen demand from biological use of carbon, ammonia, and organic nitrogen over a 5-day period following sample collection. Soluble reactive phosphorus (SRP) in lbs/day.
    - Phosphorus load allocations are expressed as soluble reactive phosphorus (SRP). Soluble reactive phosphorus is sometimes referred to as inorganic phosphorus or ortho-phosphate.

Note that meeting the assigned phosphorus and BOD allocations will not entirely solve the low DO problem; temperature improvements are also needed.

Basis for Targets

These temperature, phosphorus, and carbon loads are based on two different parts of the state standards:

1. First, when air temperatures are at their warmest and flows are at their lowest, stream temperatures are predicted to naturally exceed numeric criteria. During these conditions, the natural conditions provisions of the standards are used to set targets. Specifically, the allowable human impact must be not be greater than 0.3°C (for temperature) and less than 0.2 mg/L (for DO).
2. Second, at certain times when air temperatures are cooler and flows are higher, natural stream temperatures are predicted to be below numeric criteria. During these conditions, targets are tested and in some cases adjusted, to meet the applicable numeric criteria.

The following summarizes what criteria were used to develop the TMDL (targets/loading capacity) by season:

Temperature Summary

- **Fall-Winter Season (October 1-February 14)** – 7-DADMax temperature less than 16°C applies and is used to develop the TMDL (targets/loading capacity). Temperatures are predicted to be below this numeric criteria during this period.
- **Supplemental Spawning Season (February 15 to June 15)** – 7-DADMax temperature less than 13°C applies. Typically early June is when temperatures are predicted to naturally exceed numeric criteria, triggering natural conditions provisions described above. Both the numeric criteria and the natural conditions provisions were used to develop the TMDL (targets/loading capacity) during this period.
- **Critical Summer Season (June 16 to September 30)** – 7-DADMax temperature less than 16°C applies, but is frequently exceeded during this period. Typically August is when temperatures are predicted to naturally exceed numeric criteria; triggering the natural conditions provisions stated above. Early September may exceed due to extenuating low streamflows. Both the numeric criteria and the natural conditions provisions were used to develop the TMDL (targets/loading capacity).

Dissolved Oxygen (DO) Summary

- **Fall-Winter Season (October 1 – May 31)** - 1-day minimum DO greater than 9.5 mg/L applies and is used to develop the TMDL (targets/loading capacity). DO levels are predicted to be above this numeric criteria during this period.
- **Critical Summer Season (June 1 – September 30)** – 1-day minimum DO greater than 9.5 mg/L applies. Under critical streamflows, DO levels are frequently lower than 9.5 mg/L during this time period; triggering the natural conditions provisions stated above. Under runoff conditions, the 9.5 mg/L criteria is met more often, but occasionally is not achieved... Both the numeric criteria and the natural conditions provisions were used to develop the TMDL (targets/loading capacity).

The TMDL Allocations and Detailed TMDL Study Results sections of this report further describe how seasonal variation and critical conditions are addressed through this TMDL.

Sources of Impairment

Temperature

Temperature can be elevated in surface water as the result of both point and nonpoint sources of heat. Potential nonpoint sources within the watershed that cause warmer temperatures include loss of vegetation in the riparian zone along the mainstem and tributaries. Riparian vegetation loss is caused by permanent clearing for numerous land uses and temporary forest practices including harvest roads. This reduction of riparian vegetation reduces the available shade, which increases sunlight to the stream surface and subsequently increases water temperature.

Temperature is also affected by other human activities which change the amount of flow and physical characteristics of the river channel including:

- Reduced Flow – Water use and land use changes (such as increased impervious surfaces) can lead to a reduction of in-stream water volume (larger, deeper waterbodies are more resilient to heating) and cool groundwater inflows.
- Altered Shape – Activities such as straightening, dredging, armoring, or removing vegetation from a channel or riparian area can change stream channel morphology and geometry.
- Altered Sediment – Land use activities that increase sediment delivery or deposition patterns can lead to a decrease in the connection between the river and cooler subsurface flow paths (hyporheic flow).

Potential point sources of heat loads include wastewater, stormwater, and industrial process waters. In the Pilchuck River watershed the Granite Falls WWTP discharges treated wastewater and effluent temperatures can often exceed surface water receiving temperatures in summer months.

During storm events, rainwater can scour 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. However, rainfall in the critical period is rare, and when rainfall occurs the temperature drops. Stormwater from point sources generally does not contribute to thermal impairments.

Sand and Gravel facilities are generally considered to have minimal impact to surface water temperatures (Ecology, 2010). Appendix I discusses NDPES permitted facilities within the watershed in greater detail and Tables 50 to 53 summarize the types of permits and names of facilities.

Dissolved Oxygen

Dissolved oxygen can be depressed in surface water as the result of both point and nonpoint sources of organic matter and nutrients, as well as the direct contribution of water with low DO concentrations. Increased organic matter from decaying vegetation, in addition to other nutrient and sediment loading, leads to increased biological activity and depletion of DO. Landscape changes also contribute indirectly to low DO. For example, loss of riparian vegetation decreases shading, increases aquatic vegetation, increases stream temperatures, and results in lower DO concentrations.

Phosphorus

Granite Falls Wastewater treatment plant currently utilizes secondary effluent treatment practices that result in SRP concentrations in the range of 3-5 mg/L, which is ~100-1,000 times greater than the concentrations in the Pilchuck River. The existing SRP load from the WWTP represents ~160% of the estimated load capacity under low flow conditions. The TMDL allocates an SRP load of ~7% of the estimated overall load capacity and maintains a less than 0.2 mg/L downstream impact to DO.

Permitted stormwater sources can contribute SRP via a number of mechanisms; however, runoff based P is not predicted to be a significant source driving impairment as most of this flushed out of the watershed during times when algae are less active.

Sand and Gravel could potentially provide a source of phosphorus when discharging to surface waters; however, this discharge typically occurs during runoff events. Process water discharges also have some potential impact, but there currently appears to be no direct discharge under baseflow conditions in the study area.

Data collection for the TMDL did not reveal significant nonpoint sources of phosphorus in the watershed. Potential nonpoint sources of phosphorus in watershed include:

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

Biochemical Oxygen Demand

In general, the sources of excess biochemical oxygen demand (BOD) within the Pilchuck River watershed are similar to the sources of phosphorus including the wastewater treatment plant, stormwater, on-site septic systems, animal manure, etc.

BOD is elevated in human and animal waste and can be very high from sources of decaying vegetation and other organic matter, including natural sources such as wetlands. Activities such as dumping grass clippings in a waterbody can lead to elevated levels of BOD.

Climate Change

While climate change was not included within the scope of this study, this plan recognizes the potential impacts of climate change on stream temperature and DO. When compared with the 1980s, the Pacific Northwest is projected to see average summer air temperature increases of 1.7°C by the 2020s, 2.7°C by the 2040s and 4.7°C by the 2080s based on multi-model averages (Manthua, Tohver and Hamlet 2010). Furthermore, summer air temperatures greater than 18°C would become the norm for western WA by the 2040s and only higher elevations of the Cascades and Olympics would resemble the average lowland air temperatures of the 1980s (Manthua, Tohver and Hamlet, 2010). Manthua et al. (2010) also projected a sustained duration of water temperatures greater than 21˚C across Washington State during the summer. For example, in warmer eastern WA, water temperatures of 21˚C that typically lasted for 1 to 5 weeks (mid-July to early August) in the 1980s may persist for 10 to 12 weeks (mid-June to early September) by the end of the 21st century.

Streamflow is projected to increase in winter and decrease in spring and summer for all basin types, with the greatest changes occurring in mixed rain and snow watersheds (Mauger et al, 2015). The Snohomish River Basin is projected to transition from snow/rain mix to a rain dominant basin (Figure 4). A loss of spring-melt may decrease or eliminate spawning opportunities for steelhead, alter egg-fry survival for other salmon species, cause early dewatering of side channel and off-channel habitats, and reduce floodplain connectivity (Beechie 2013). A decrease in the volume of summer low flows and longer duration of low summer flows may contribute to increased stream temperatures, reduce access or availability of spawning and rearing habitat, hinder summer salmon migration, and cause fish to shift their migration period to avoid unfavorable temperature and DO conditions. More information about global climate change may be found in Appendix A.

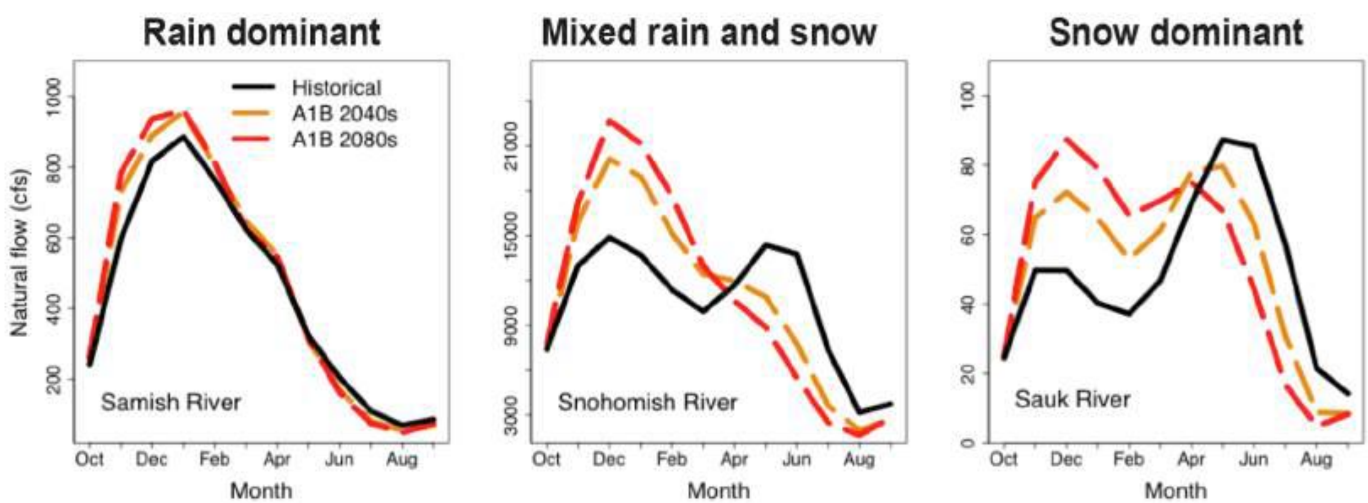

Figure 4. Streamflow projections: Samish River, a warm water basin (left); Sauk River, a cold water basin with source waters at high elevations (right); and Snohomish River, a middle-elevation basin with substantial area near the current snowline (middle) (Mauger et al., 2015).

Actions such as restoring floodplain connectivity, streamflow regimes, and incised channels, as well as removing barriers, are most likely to decrease stream temperatures, increase baseflows, and decrease peak flows, thereby increasing salmon resilience (Beechie, 2013). Under climate change, pests are expected to emerge earlier in the year due to shorter cold seasons that would otherwise keep them dormant. Tree pests may wreak havoc on an otherwise healthy riparian buffers. Dead and diseased trees may pose a greater fire risk under climate change. Tree protection and maintenance may include the following:

- An Integrated Pest Management Plan[5] (IPM) to monitor trees that are more susceptible to pests (e.g. weeds, insects, disease agents, pathogens). An IPM focuses on pest prevention and using chemicals only when needed to minimize environmental impacts such as destroying a beneficial species that might prey on the pest.
- A tree program to monitor, thin and replace diseased, deformed or dead trees that might serve as kindle for fire. Disease-free wood should be retained for large woody material (also known as large woody debris) placement projects.

Climate change should be a consideration during the adaptive management of this TMDL.

[5] https://www.epa.gov/managing-pests-schools/introduction-integrated-pest-management

Chapter 2: TMDL Allocations

This chapter presents TMDL allocations derived from Ecology's 2012-2016 data collection, subsequent water quality model development and calibration, and analysis of numerous modeling scenario predictions including system potential conditions and impacts from variable magnitude and timing of loading from point and nonpoint sources. The 'Detailed TMDL Study Results and Analysis' section of this report and Appendices D-I contain a detailed description of these efforts. The following presents the final results of the detailed TMDL analysis.

TMDL Formula

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

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

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

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity. The short-hand formula that describes the TMDL is:

$$LC=\sum WLA+\sum LA+MOS+RS$$

Loading Capacity (LC) equals sum of Wasteload Allocations (WLA) plus sum of Load Allocations (LA) plus Margin of Safety (MOS) and Reserve Capacity (RS).

The Pilchuck River Temperature and Dissolved Oxygen TMDL uses all the allocations shown in the equation above.

Seasonal Variation and Critical Conditions

This TMDL considered seasonality and identified critical conditions, which are described in greater detail in 'Detailed TMDL Study Results and Analysis' sections for temperature and DO analysis.

For temperature there are three seasons and two critical conditions:

- **Fall-Winter Season: October 1 to February 14**
    - No critical condition
- **Supplemental Spawning Season: February 15 to June 15**
    - Criterion is 7-DADMax< 13°C
    - Critical condition = lowest flows and highest air temperatures (typically June)
- **Core Summer Habitat Season: June 16 to September 30**
    - Criterion is 7-DADMax< 16°C
    - Critical condition = highest air temperatures (typically August) and low flows

The Core Summer Habitat season was determined to be the most critical season because air temperatures are at their greatest, solar radiation is at its strongest, water use is at its peak, and flows are at their lowest; therefore, Ecology based TMDL allocations and estimated loading capacity on this season and its most critical condition. The one exception involved Granite Falls WWTP, which has separate WLAs to ensure compliance with both core summer habitat and supplemental spawning criteria. For all other allocations, Ecology determined that the allocations and implementation actions derived for the Core Summer Habitat season will protect Pilchuck River water quality during the supplemental spawning season, as well as the remainder of the year.

For dissolved oxygen (DO), there are two seasons, one critical and one non-critical, and two conditions within the critical season:

- **Fall-Winter-Spring Season: October 1 to May 31**
    - No critical condition.
- **Summer Season: June 1 to September 30; Baseflow (<=75 cfs) critical condition**
    - Criterion is DO daily min > 9.5 mg/L.
    - Critical condition = highest air temperatures (typically August) combined with low flows.
- **Summer Season: June 1 to September 30; Runoff (>75 cfs) condition**
    - Not a critical condition, but increased phosphorus loading from runoff can be stored by bottom algae.
    - Bottom algae can use this stored phosphorus later, to a degree, during periods of increased productivity, so phosphorus allocations are necessary.

The summer season was determined to be the most critical condition; however, Ecology created two sets of TMDL allocations based on different baseflow conditions (for less than or equal to and greater than 75 cfs) because:

- The loading capacity is significantly different between the two conditions.
- It is not necessary or practical to meet the reduced allocations required at baseflow condition during periods of stormwater and nonpoint runoff, given the impact is less during these events.

Loading Capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards.

Temperature

Loading capacities (Table 6) for the Pilchuck River are the solar radiation (nonpoint sources) and NPDES permitted (point sources) heat loads that (1) allow stream temperatures to stay below the numeric criteria or (2) do not exceed the natural condition by more than 0.3°C. The 'Detailed TMDL Study Results and Analysis – Temperature Analysis and Allocations' section of the report contains details on determination of the temperature loading capacity and allocations in this TMDL. The allocations developed for the summer critical season are also protective of supplemental spawning criteria (with the exception of the two separate wasteload allocations for Granite Falls WWTP). Ecology tested this in the QUAL2Kw model during the early June critical supplemental period to ensure compliance.

The Temperature TMDL Analysis and Allocations section contains more detail supplemental spawning compliance (see figures 49 and 50).

Table 6. Estimated loading capacity for temperature.

Water-body Name	Sub-basin Name	Reach (RM= River Mile)	Applicable Assessment Unit ID 17110011000xxx	Effective Shade Target	Total Heat Load Capacity (therms/ day)
Pilchuck River	Entire Watershed	Headwaters to ~RM1	n/a	See below	219,878
Pilchuck River	Upper Pilchuck	Headwaters to Menzel Lake Rd (~RM26)	065	SPS*	89,707
Pilchuck River	Menzel	Menzel Lake Rd to Robe Menzel Rd (~RM21)	064	45.3% (SPS)	21,056
Pilchuck River	Granite Falls	Robe Menzel Rd to GF-WWTP outfall (~RM19)	n/a	45.8% (SPS)	12,571
Pilchuck River	SR92	Granite Falls WWTP outfall to 64th St NE (~RM15)	n/a	49.5% (SPS)	17,137
Pilchuck River	Lochsloy	64th St NE to 28th Pl NE (~RM 12)	062	48.0% (SPS)	13,235
Pilchuck River	Russell Rd	28th Pl NE to Little Pilchuck Creek (~RM9)	061	46.1% (SPS)	13,388
Pilchuck River	Machias	Little Pilchuck Creek to Dubuque Rd (~RM6)	n/a	46.8% (SPS)	14,905
Pilchuck River	Three Lakes	Dubuque Rd to Three Lakes Road (~RM3)	048	50.3% (SPS)	10,761
Pilchuck River	Snohomish	Three Lakes Road to (~RM1)	048	57.4% (SPS)	8,281
Little Pilchuck Creek	Entire Basin	Headwaters to mouth	072; 188	SPS*	15,889
Dubuque Creek	Entire Basin	Headwaters to mouth	054	SPS*	2,947
Catherine Creek	Entire Basin	Headwaters to mouth	073	SPS*	7,121
Connor Lake Creek	Entire Basin	Headwaters to mouth	180	SPS*	168
Sexton Creek	Entire Basin	Headwaters to mouth	244	SPS*	493

***Effective shade target is the system potential shade, which should be calculated for each planting project or evaluated reach using channel width, stream aspect, and the effective shade curves (Figure 56) in the detailed load allocations in Chapter 4.**

Dissolved Oxygen

Loading capacities (Table 7) for the Pilchuck River are set in lbs/day of SRP and BOD5 and represent the tributary/groundwater loads (nonpoint sources) and NPDES permitted (point sources) loads that (1) allow stream DO to stay above the numeric criteria or (2) do not exceed the natural condition by more than 0.2 mg/L. '*Detailed TMDL Study Results and Analysis – Dissolved Oxygen Analysis and Allocations*' section of this report contains details on determination of the DO loading capacity and allocations in this TMDL.

Table 7. Estimated loading capacity for soluble reactive phosphorus (SRP) and biochemical oxygen demand (BOD). Load capacities apply to the period of June 1 to September 30. Note: temperature capacities in Table 6 also apply to Dissolved Oxygen.

Water-body Name	Sub-basin Name	Reach	Applicable Assessment Unit ID 17110011000xxx	Baseflow SRP LC (lbs/day)	Runoff SRP LC (lbs/day)	Baseflow BOD5 LC (lbs/day)	Runoff BOD5 LC (lbs/day)
Pilchuck River	Entire Watershed	Headwaters to mouth		4.2066	9.6569	210.11	362.64
Pilchuck River	Upper Pilchuck	Headwaters to Menzel Lake Rd (~RM26)		2.4782	4.2504	36.50	110.60
Pilchuck River	Menzel	Menzel Lake Rd to Robe Menzel Rd (~RM21)	064	0.1229	0.4493	2.72	6.66
Pilchuck River	Granite Falls	Robe Menzel Rd to GF-WWTP outfall (~RM19)		0.1766	0.4206	6.61	13.69
Pilchuck River	SR92	Granite Falls WWTP outfall to 64th St NE (~RM15)	063	0.1815	0.4115	4.21	8.62
Pilchuck River	Lochsloy	64th St NE to 28th Pl NE (~RM 12)	062	0.1224	0.3082	1.97	3.95
Pilchuck River	Russell Rd	28th Pl NE to Little Pilchuck Creek (~RM9)	061	0.1007	0.2151	1.11	2.17
Pilchuck River	Machias	Little Pilchuck Creek to Dubuque Rd (~RM6)	052/053	0.1463	0.3835	1.95	4.76
Pilchuck River	Three Lakes	Dubuque Rd to Three Lakes Road (~RM3)	049	0.0501	0.1965	1.38	4.45
Pilchuck River	Snohomish	Three Lakes Road to mouth	048	0.1086	0.2682	2.20	5.10
Little Pilchuck Creek	Entire Basin	Headwaters to mouth	188	0.3685	1.9551	11.29	53.44
Dubuque Creek	Entire Basin	Headwaters to mouth	054	0.0282	0.4391	0.88	10.73
Catherine Creek	Entire Basin	Headwaters to mouth	073	0.1649	0.8749	5.05	23.92
Connor Lake Creek	Entire Basin	Headwaters to mouth	180	0.0323	0.0689	0.36	0.70

Wasteload Allocations

Tables 8 through 16 present the temperature, phosphorus, and BOD wasteload allocations (WLAs) for the Pilchuck River Temperature and Dissolved Oxygen TMDL. The 'Detailed TMDL Study Results and Analysis – Temperature and Dissolved Oxygen Analysis and Allocations' sections of this report detail how Ecology developed these WLAs.

Temperature WLAs for the mainstem and tributaries to the Pilchuck River are evaluated within the cumulative 0.3°C change on the scale of the entire watershed, with loads distributed throughout each sub-basin input based on land area. In this context, due to dispersion (mixing) and the non-conservative nature of temperature in a waterbody, the impact of the WLAs at any one point in the Pilchuck river mainstem is a relatively small portion of the cumulative 0.3°C. The majority of the cumulative 0.3°C is assigned to the impact of lost baseflow.

Limited stormwater temperature data for Little Pilchuck Creek suggests minimal temperature loading, which is consistent with modeled temperature predictions in the mainstem (see Chapter 4 for additional discussion). The TMDL assumes the cumulative impact from stormwater WLAs in the tributaries will be relatively minor and result in tributary temperatures significantly less than a 0.3°C increase to the numeric criteria.

Ecology determined there was not significant stormwater SRP or BOD loading during the critical period (see Chapter 4 for detail). The Pilchuck River mainstem and tributary general permit WLAs are based on existing BOD concentrations and an assumed increase in SRP concentrations during runoff periods. It is important to note that the DO WLAs for the tributaries also include the thermal allocations resulting from system potential shade.

The TMDL assumes the effects of stormwater SRP and BOD loads in the tributaries will be within the range of allowable change given that they are generally flushed through the tributaries and into the mainstem during runoff events.

For BOD, short retention times and slow decay rates should result in minimal change, in a manner similar to the predicted stormwater BOD loading effects in the mainstem model.

For SRP, algae growth in the tributaries is not expected to be significant during overcast periods of rain and net algae loss can even occur due to scour, in a manner similar to algal growth predictions in the mainstem model. In addition, given that narrower channels in the tributaries lead to very high system potential effective shade percentages, algal productivity would likely be entirely limited by available light, rather than nutrient concentrations, under system potential shade conditions.

City of Granite Falls Wastewater Treatment Plant (WWTP)

Permittee Name: City of Granite Falls STP

Permit Number: WA0021130

Permit Type: Municipal NPDES Individual Permit

Water-body Names: Pilchuck River

Listing ID/s of Receiving Water: 10621, 7295, 10620 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 8. Wasteload allocations for the city of Granite Falls WWTP.

Pollutant	WLA	Unit	Applicable Period	Additional Information
Temperature	893	Therms / day	June 16 to Sept 30	Effluent flow <=0.4 cfs
Temperature	1092	Therms / day	June 16 to Sept 30	Effluent flow 0.41- 0.5 cfs
Temperature	1253	Therms / day	June 16 to Sept 30	Effluent flow 0.51- 0.6 cfs
Temperature	1,414	Therms / day	June 16 to Sept 30	Effluent flow 0.61- 0.7 cfs
Temperature	1,117	Therms / day	Feb 15 to June 15	Effluent flow <=0.5 cfs
Temperature	1223	Therms / day	Feb 15 to June 15	Effluent flow 0.51- 0.6 cfs
Temperature	1359	Therms / day	Feb 15 to June 15	Effluent flow 0.61- 0.7 cfs
Temperature	1,476	Therms / day	Feb 15 to June 15	Effluent flow 0.71- 0.8 cfs
SRP	0.31	Pounds / day	June 1 to Sept 30	Seasonal Average
BOD5	139	Pounds / day	June 1 to Sept 30	Monthly average

Other Requirements:

- The TMDL recommends SRP effluent samples be collected and analyzed on a routine basis. The expected sampling frequency will likely be within the range of 1-3 samples per week. Sample collection should occur routinely on the same days of the week (for example, Mondays and Thursdays). Sample collection should not occur on two consecutive days.
- The TMDL recommends that Ecology's permit writer recalculate the effluent flow each permit cycle based on the method described in the 'Detailed TMDL Study Results and Analysis – Temperature Analysis and Allocations' section of this report.

Snohomish County – Phase 1 Municipal Stormwater

Permittee Name: Snohomish County

Permit Number: WAR044502

Permit Type: Municipal Stormwater General Permit – Phase 1

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing IDs of Receiving Water: 10621, 7295, 10620, 14725, 72567, 7394, 7395, 7400, 7401, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 9. Wasteload allocations for Snohomish County.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP LC (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 LC (lbs/day)
Pilchuck River	Entire Watershed	8759	0.1169	1.4294	4.09	29.13
Pilchuck River	Upper Pilchuck	0	0	0	0.00	0.00
Pilchuck River	Menzel	1118	0.0057	0.2172	0.51	3.64
Pilchuck River	Granite Falls	594	0.0029	0.0776	0.27	1.93
Pilchuck River	SR92	505	0.0053	0.0562	0.23	1.64
Pilchuck River	Lochsloy	382	0.0056	0.0541	0.17	1.24
Pilchuck River	Russell Rd	228	0.0033	0.0241	0.10	0.74
Pilchuck River	Machias	409	0.0060	0.0760	0.19	1.33
Pilchuck River	Three Lakes	603	0.0088	0.0890	0.27	1.96
Pilchuck River	Snohomish	251	0.0112	0.0765	0.25	1.47
Little Pilchuck Creek	Entire Basin	3179	0.0464	0.5168	1.43	10.34
Dubuque Creek	Entire Basin	1489	0.0217	0.2420	0.67	4.84
Catherine Creek	Entire Basin	1430	0.0209	0.2326	0.65	4.65
Connor Lake Creek	Entire Basin	73	0.0011	0.0077	0.03	0.24

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications...
- Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.

- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

City of Granite Falls – Phase 2 Municipal Stormwater

Permittee Name: City of Granite Falls

Permit Number: WAR045517

Permit Type: Municipal Stormwater General Permit – Phase 2 Western Washington

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 10. Wasteload allocations for the City of Granite Falls.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	96	0.0007	0.0116	0.043	0.311
Pilchuck River	Granite Falls	52	0.0003	0.0067	0.023	0.168
Pilchuck River	SR92	44	0.0005	0.0049	0.020	0.143

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications.
- Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

City of Lake Stevens – Phase 2 Municipal Stormwater

Permittee Name: City of Lake Stevens

Permit Number: WAR0021130

Permit Type: Municipal Stormwater General Permit – Phase 2 Western Washington

Water-body Names: Pilchuck River; Little Pilchuck Creek, Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 10620, 7394, 7395, 9274, 9275, 40911 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 11. Wasteload allocations for the City of Lake Stevens.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	630	0.0092	0.1015	0.284	2.048
Pilchuck River	Machias	5	0.0001	0.0009	0.002	0.015
Pilchuck River	Three Lakes	64	0.0009	0.0095	0.029	0.209
Little Pilchuck Creek	Entire Basin	561	0.0082	0.0912	0.253	1.824
Catherine Creek	Entire Basin	252	0.0037	0.0410	0.114	0.821

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications.
- Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

City of Snohomish – Phase 2 Municipal Stormwater

Permittee Name: City of Snohomish

Permit Number: WAR045543

Permit Type: Municipal Stormwater General Permit – Phase 2 Western Washington

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 10620 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 12. Wasteload allocations for the City of Snohomish.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	66	0.0010	0.0087	0.030	0.215
Pilchuck River	Three Lakes	24	0.0004	0.0036	0.011	0.079
Pilchuck River	Snohomish	42	0.0006	0.0052	0.019	0.136

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications.
- Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Construction Stormwater General Permit

Permittee Name: All active Construction Stormwater General Permittees within study area

Permit Number: multiple/transient

Permit Type: Construction Stormwater General Permit

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620, 14725, 72567, 7394, 7395, 7400, 7401, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 13. Wasteload allocations for construction stormwater permittees.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	275	0.0035	0.0431	0.124	0.893
Pilchuck River	Upper Pilchuck	0	0	0	0.000	0.000
Pilchuck River	Menzel	31	0.0002	0.0060	0.014	0.101
Pilchuck River	Granite Falls	18	0.0001	0.0024	0.008	0.060
Pilchuck River	SR92	16	0.0002	0.0017	0.007	0.051
Pilchuck River	Lochsloy	11	0.0002	0.0015	0.005	0.036
Pilchuck River	Russell Rd	6	0.0001	0.0007	0.003	0.021
Pilchuck River	Machias	11	0.0002	0.0021	0.005	0.037
Pilchuck River	Three Lakes	20	0.0003	0.0029	0.009	0.064
Pilchuck River	Snohomish	13	0.0002	0.0016	0.006	0.042
Little Pilchuck Creek	Entire Basin	107	0.0016	0.0174	0.048	0.347
Dubuque Creek	Entire Basin	41	0.0006	0.0067	0.019	0.134
Catherine Creek	Entire Basin	48	0.0007	0.0078	0.022	0.156
Connor Lake Creek	Entire Basin	2	0.00003	0.0002	0.001	0.007

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications. Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Industrial Stormwater General Permit

Permittee Name: All active Industrial Stormwater General Permittees within the study area.

Permit Number: multiple/transient

Permit Type: Industrial Stormwater General Permit

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620, 14725, 72567, 7394, 7395, 7400, 7401, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 14. Wasteload allocations for industrial general stormwater permittees.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	275	0.0035	0.0431	0.124	0.893
Pilchuck River	Upper Pilchuck	0	0	0	0.000	0.000
Pilchuck River	Menzel	31	0.0002	0.0060	0.014	0.101
Pilchuck River	Granite Falls	18	0.0001	0.0024	0.008	0.060
Pilchuck River	SR92	16	0.0002	0.0017	0.007	0.051
Pilchuck River	Lochsloy	11	0.0002	0.0015	0.005	0.036
Pilchuck River	Russell Rd	6	0.0001	0.0007	0.003	0.021
Pilchuck River	Machias	11	0.0002	0.0021	0.005	0.037
Pilchuck River	Three Lakes	20	0.0003	0.0029	0.009	0.064
Pilchuck River	Snohomish	13	0.0002	0.0016	0.006	0.042
Little Pilchuck Creek	Entire Basin	107	0.0016	0.0174	0.048	0.347
Dubuque Creek	Entire Basin	41	0.0006	0.0067	0.019	0.134
Catherine Creek	Entire Basin	48	0.0007	0.0078	0.022	0.156
Connor Lake Creek	Entire Basin	2	0.00003	0.0002	0.001	0.007

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff: > 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications. Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.

- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Sand and Gravel General Permit

Permittee Name: All active Sand and Gravel General Permittees within study area.

Permit Number: multiple/transient

Permit Type: Industrial Stormwater General Permit

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620, 14725, 72567, 7394, 7395, 7400, 7401, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 15. Wasteload allocations for sand and gravel permittees.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	275	0.0035	0.0431	0.124	0.893
Pilchuck River	Upper Pilchuck	0	0	0	0.000	0.000
Pilchuck River	Menzel	31	0.0002	0.0060	0.014	0.101
Pilchuck River	Granite Falls	18	0.0001	0.0024	0.008	0.060
Pilchuck River	SR92	16	0.0002	0.0017	0.007	0.051
Pilchuck River	Lochsloy	11	0.0002	0.0015	0.005	0.036
Pilchuck River	Russell Rd	6	0.0001	0.0007	0.003	0.021
Pilchuck River	Machias	11	0.0002	0.0021	0.005	0.037
Pilchuck River	Three Lakes	20	0.0003	0.0029	0.009	0.064
Pilchuck River	Snohomish	13	0.0002	0.0016	0.006	0.042
Little Pilchuck Creek	Entire Basin	107	0.0016	0.0174	0.048	0.347
Dubuque Creek	Entire Basin	41	0.0006	0.0067	0.019	0.134
Catherine Creek	Entire Basin	48	0.0007	0.0078	0.022	0.156
Connor Lake Creek	Entire Basin	2	0.00003	0.0002	0.001	0.007

Other Requirements:

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff :> 75 cfs.
- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications.

Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.

- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Washington State Department of Transportation Stormwater

Permittee Name: Washington State Department of Transportation Stormwater

Permit Number: WAR043000

Permit Type: Stormwater General Permit

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620, 7394, 7395, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

- Temperature allocations apply from June 16 to September 30.
- SRP and BOD5 allocations apply from June 1 to September 30.
- Baseflow = Daily Average River Flow is <= 75 cfs; Runoff :> 75 cfs.

Table 16. Wasteload allocations for Washington State Department of Transportation.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	172	0.0023	0.0260	0.077	0.558
Pilchuck River	Granite Falls	18	0.0001	0.0024	0.008	0.060
Pilchuck River	SR92	16	0.0002	0.0017	0.007	0.051
Pilchuck River	Lochsloy	11	0.0002	0.0015	0.005	0.036
Pilchuck River	Three Lakes	20	0.0003	0.0029	0.009	0.064
Little Pilchuck Creek	Entire Basin	107	0.0016	0.0174	0.048	0.347
Catherine Creek	Entire Basin	48	0.0007	0.0078	0.022	0.156

Other Requirements:

- Best management practices (BMPs) are required in all stormwater permits to protect designated aquatic life uses. TMDLs may identify additional actions to protect water quality, which will be considered as part of permit renewals or permit modifications. Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees.
- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Reserve for Future Growth

Permittee Name: Future NPDES Permits

Permit Number: N/A

Permit Type: Various

Water-body Names: Pilchuck River; Tributaries to Pilchuck River

Listing ID of Receiving Water: 10621, 7295, 10620, 14725, 72567, 7394, 7395, 7400, 7401, 9274, 9275, 40911, 47441 (includes listings within TMDL boundary downstream of direct receiving segment).

Table 17. Reserve wasteload allocations for future NPDES permittees.

Water-body Name	Sub-basin Name	Temperature (therms/day)	Baseflow SRP (lbs/day)	Runoff SRP (lbs/day)	Baseflow BOD5 (lbs/day)	Runoff BOD5 (lbs/day)
Pilchuck River	Entire Watershed	275	0.0035	0.0431	0.124	0.893
Pilchuck River	Upper Pilchuck	0	0	0	0.000	0.000
Pilchuck River	Menzel	31	0.0002	0.0060	0.014	0.101
Pilchuck River	Granite Falls	18	0.0001	0.0024	0.008	0.060
Pilchuck River	SR92	16	0.0002	0.0017	0.007	0.051
Pilchuck River	Lochsloy	11	0.0002	0.0015	0.005	0.036
Pilchuck River	Russell Rd	6	0.0001	0.0007	0.003	0.021
Pilchuck River	Machias	11	0.0002	0.0021	0.005	0.037
Pilchuck River	Three Lakes	20	0.0003	0.0029	0.009	0.064
Pilchuck River	Snohomish	13	0.0002	0.0016	0.006	0.042
Little Pilchuck Creek	Entire Basin	107	0.0016	0.0174	0.048	0.347
Dubuque Creek	Entire Basin	41	0.0006	0.0067	0.019	0.134
Catherine Creek	Entire Basin	48	0.0007	0.0078	0.022	0.156
Connor Lake Creek	Entire Basin	2	0.00003	0.0002	0.001	0.007

Other Requirements:

- Temperature allocation represents daily average for season including runoff and non-runoff conditions.
- Daily average river flows should be obtained from gage USGS 12155300 Pilchuck River near Snohomish, WA.

Load Allocations

The following tables present load allocations for temperature (Table 18), phosphorus (Table 19), and BOD (Table 20) in the Pilchuck River TMDL study area. The ‘Detailed TMDL Study Results and Analysis – Temperature and Dissolved Oxygen Analysis and Allocations’ sections of the report describes the methodology and calculation of these values.

Table 18. Temperature load allocations. The allocations apply from June 16 to September 30.

Water-body Name	Sub-basin Name	Effective Shade Target	Solar Radiation Heat Load (therms/day)	Tributaries and Groundwater (therms/day)	Total Load Allocation (therms/ day)
Pilchuck River	Entire Watershed	See below	73927	45423	209,057
Pilchuck River	Upper Pilchuck	SPS*	n/a	n/a	89,707
Pilchuck River	Menzel	45.3% (SPS)	15949	3864	19,813
Pilchuck River	Granite Falls	45.8% (SPS)	5451	6383	11,834
Pilchuck River	SR92	49.5% (SPS)	10754	5756	16,510
Pilchuck River	Lochsloy	48.0% (SPS)	8588	4210	12,798
Pilchuck River	Russell Rd	46.1% (SPS)	9866	3181	13,134
Pilchuck River	Machias	46.8% (SPS)	10104	4341	14,445
Pilchuck River	Three Lakes	50.3% (SPS)	8719	1252	9,971
Pilchuck River	Snohomish	57.4% (SPS)	4496	3268	7,936
Little Pilchuck Creek	Entire Basin	SPS*	n/a	6,417	11,615
Dubuque Creek	Entire Basin	SPS*	n/a	1,293	1,293
Catherine Creek	Entire Basin	SPS*	n/a	5,198	5,198
Connor Lake Creek	Entire Basin	SPS*	n/a	87	87
Sexton Creek	Entire Basin	SPS*	n/a	172	172

The load allocations in Tables 19 and 20 are based on existing measured loads in 2012. The need for nonpoint reductions in localized areas may be identified in the future. The load allocation for Little Pilchuck Creek includes Catherine Creek, its temperature impaired tributary (Listing IDs 7394 and 7395). In a similar fashion the diffuse load allocation for the Pilchuck River includes the unnamed creek (tributary to the Pilchuck river), also known as Connor Lake tributary (Listing ID 47441).

Table 19. Soluble reactive phosphorus (SRP) load allocations. The allocations apply from June 1 to September 30.

Water body	Applicable Area	Baseflow SRP LA (lbs/day)	Runoff SRP LA (lbs/day)
Pilchuck River	Entire Watershed	3.7479	7.5719
Pilchuck River	Upper Pilchuck	2.4782	4.2504

Pilchuck River	Menzel	0.1167	0.208
Pilchuck River	Granite Falls	0.1731	0.3242
Pilchuck River	SR92	0.1751	0.3417
Pilchuck River	Lochsloy	0.1161	0.2464
Pilchuck River	Russell Rd	0.0971	0.1883
Pilchuck River	Machias	0.1397	0.2981
Pilchuck River	Three Lakes	0.0388	0.0799
Pilchuck River	Snohomish	0.1012	0.2044
Little Pilchuck Creek	Entire Basin	0.3074	1.2602
Dubuque Creek	Entire Basin	0.0045	0.1702
Catherine Creek	Entire Basin	0.1376	0.5640
Connor Lake Creek	Entire Basin	0.0311	0.0603

Table 20. BOD5 load allocations. The allocations apply from June 1 to September 30.

Water body	Applicable Area	Baseflow BOD5 LA (lbs/day)	Runoff BOD5 LA (lbs/day)
Pilchuck River	Entire Watershed	66.03	187.0
Pilchuck River	Upper Pilchuck	36.50	110.6
Pilchuck River	Menzel	2.16	2.62
Pilchuck River	Granite Falls	6.28	11.29
Pilchuck River	SR92	3.93	6.58
Pilchuck River	Lochsloy	1.78	2.53
Pilchuck River	Russell Rd	1.00	1.35
Pilchuck River	Machias	1.75	3.26
Pilchuck River	Three Lakes	1.02	1.88
Pilchuck River	Snohomish	1.97	3.42
Little Pilchuck Creek	Entire Basin	9.36	39.5
Dubuque Creek	Entire Basin	0.14	5.36
Catherine Creek	Entire Basin	4.19	17.7
Connor Lake Creek	Entire Basin	0.32	0.4

Margin of Safety

The margin of safety accounts for uncertainty about the pollutant loading and water-body response and must be included in all TMDLs to ensure water quality standards are met, despite these uncertainties. In this TMDL, the margin of safety is implicit.

- Critical air temperatures (90th percentile of annual 7-day averages of daily maximum) were combined with the critical low flows (lowest 7-day average flows with recurrence intervals of 10 years; 7Q10) to represent a reasonable worst-case condition for water temperatures and DO in the Pilchuck River. The combination inherently represents a recurrence interval of greater than one in every 10 years, which provides additional margin of safety.
- The 7Q10 flow was used to evaluate reasonable worst-case conditions for discharge of point-source effluent.
- The 7Q10 flow used to calculate temperature WLAs for the Granite Falls WWTP outfall at ~RM 19 was scaled down by a factor of 0.85 from the downstream USGS gage located at RM 3.6. This factor is conservative given that the two low-flow measurements available to compare these locations had ratios of 0.86 and 0.95.
- Implementation will include additional measures beyond riparian shade that should contribute to lower stream temperatures, such as instream structures creating pools that connect with hyporheic flow, and wetland restoration creating improved groundwater connection.
- The calibrated model slightly over-predicts phosphorus uptake downstream of the WWTP and thus slightly under-predicts phosphorus loading capacity.

The calibrated model displayed relatively low uncertainty and bias, which suggests the implicit margin of safety does not need to be overly conservative:

- Model uncertainty assessment for prediction of water temperature in existing conditions compared to system potential conditions revealed a variance between scenarios of 0.16°C root mean square error (RMSE). This is less than the 0.3°C allowable change from natural conditions.
- Model uncertainty assessment for prediction of DO in existing conditions compared to system potential conditions revealed a variance between scenarios of 0.08 mg/L root mean square error (RMSE). This is less than the 0.2 mg/L allowable change from natural conditions.
- Model bias evaluation shows no evidence of systematic over- or under-prediction of temperature or DO. There also is no evidence of a trend in error over the length of the river.

TMDL Calculation

Table 21 presents a summary of all temperature allocations (in therms/day) used in calculating the TMDL load capacity.

Table 21. Temperature TMDL calculations expressed in therms/day.

Water body	Applicable Area	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	Entire Watershed	209,057	10,547	275	Implicit	219,878
Pilchuck River	Upper Pilchuck	89,707	0	0	Implicit	89,707
Pilchuck River	Menzel	19,813	1212	31	Implicit	21,056

Water body	Applicable Area	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	Granite Falls	11,834	719	18	Implicit	12,571
Pilchuck River	SR92	16,510	612	16	Implicit	17,137
Pilchuck River	Lochsloy	12,798	426	11	Implicit	13,235
Pilchuck River	Russell Rd	13,134	247	6	Implicit	13,388
Pilchuck River	Machias	14,445	448	11	Implicit	14,905
Pilchuck River	Three Lakes	9,971	771	20	Implicit	10,761
Pilchuck River	Snohomish	7,936	332	13	Implicit	8,281
Little Pilchuck Creek	Entire Basin	11,615	4167	107	Implicit	15,889
Dubuque Creek	Entire Basin	1,293	1613	41	Implicit	2,947
Catherine Creek	Entire Basin	5,198	1875	48	Implicit	7,121
Connor Lake Creek	Entire Basin	87	79	2	Implicit	168
Sexton Creek	Entire Basin	172	309	12	Implicit	493

Table 22 presents a summary of all soluble reactive phosphorus (SRP) allocations (in lbs/day) used in calculating the TMDL load capacity.

Table 22. SRP TMDL calculations expressed in lbs/day.

Water body	Applicable Area	Condition	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	Entire Watershed	Baseflow	3.7479	0.4552	0.0035	Implicit	4.2066
Pilchuck River	Upper Pilchuck	Baseflow	2.4782	0	0	Implicit	2.4782
Pilchuck River	Menzel	Baseflow	0.1167	0.0060	0.0002	Implicit	0.1229
Pilchuck River	Granite Falls	Baseflow	0.1731	0.0034	0.0001	Implicit	0.1766
Pilchuck River	SR92	Baseflow	0.1751	0.0062	0.0002	Implicit	0.1815
Pilchuck River	Lochsloy	Baseflow	0.1161	0.0061	0.0002	Implicit	0.1224
Pilchuck River	Russell Rd	Baseflow	0.0971	0.0035	0.0001	Implicit	0.1007
Pilchuck River	Machias	Baseflow	0.1397	0.0064	0.0002	Implicit	0.1463
Pilchuck River	Three Lakes	Baseflow	0.0388	0.011	0.0003	Implicit	0.0501
Pilchuck River	Snohomish	Baseflow	0.1012	0.0072	0.0002	Implicit	0.1086
Little Pilchuck Creek	Entire Basin	Baseflow	0.3074	0.0596	0.0015	Implicit	0.3685
Dubuque Creek	Entire Basin	Baseflow	0.0045	0.0231	0.0006	Implicit	0.0282
Catherine Creek	Entire Basin	Baseflow	0.1376	0.0267	0.0007	Implicit	0.1649
Connor Lake Creek	Entire Basin	Baseflow	0.0311	0.0011	0.0000	Implicit	0.0323
Pilchuck River	Entire Watershed	Runoff	7.5719	2.0419	0.0431	Implicit	9.6569
Pilchuck River	Upper Pilchuck	Runoff	4.2504	0	0	Implicit	4.2504
Pilchuck River	Menzel	Runoff	0.208	0.2353	0.006	Implicit	0.4493
Pilchuck River	Granite Falls	Runoff	0.3242	0.094	0.0024	Implicit	0.4206

Water body	Applicable Area	Condition	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	SR92	Runoff	0.3417	0.0681	0.0017	Implicit	0.4115
Pilchuck River	Lochsloy	Runoff	0.2464	0.0603	0.0015	Implicit	0.3082
Pilchuck River	Russell Rd	Runoff	0.1883	0.0261	0.0007	Implicit	0.2151
Pilchuck River	Machias	Runoff	0.2981	0.0833	0.0021	Implicit	0.3835
Pilchuck River	Three Lakes	Runoff	0.0799	0.1137	0.0029	Implicit	0.1965
Pilchuck River	Snohomish	Runoff	0.2044	0.0622	0.0016	Implicit	0.2682
Little Pilchuck Creek	Entire Basin	Runoff	1.2602	0.6775	0.0174	Implicit	1.9551
Dubuque Creek	Entire Basin	Runoff	0.1702	0.2622	0.0067	Implicit	0.4391
Catherine Creek	Entire Basin	Runoff	0.5640	0.3032	0.0078	Implicit	0.8749
Connor Lake Creek	Entire Basin	Runoff	0.0603	0.0084	0.0002	Implicit	0.0689

Table 23 presents a summary of all 5-day biochemical oxygen demand (BOD5) allocations (in lbs/day) used in calculating the TMDL load capacity.

Table 23. BOD5 TMDL calculations expressed in lbs/day.

Water body	Applicable Area	Condition	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	Entire Watershed	Baseflow	66.03	144.0	0.1	Implicit	210.1110
Pilchuck River	Upper Pilchuck	Baseflow	36.50	0	0	Implicit	36.5000
Pilchuck River	Menzel	Baseflow	2.16	0.5470	0.014	Implicit	2.7200
Pilchuck River	Granite Falls	Baseflow	6.28	0.3250	0.008	Implicit	6.6120
Pilchuck River	SR92	Baseflow	3.93	0.2760	0.007	Implicit	4.2130
Pilchuck River	Lochsloy	Baseflow	1.78	0.1920	0.005	Implicit	1.9730
Pilchuck River	Russell Rd	Baseflow	1.00	0.1120	0.003	Implicit	1.1120
Pilchuck River	Machias	Baseflow	1.75	0.2020	0.005	Implicit	1.9520
Pilchuck River	Three Lakes	Baseflow	1.02	0.3480	0.009	Implicit	1.3780
Pilchuck River	Snohomish	Baseflow	1.97	0.2270	0.006	Implicit	2.2040
Little Pilchuck Creek	Entire Basin	Baseflow	9.36	1.8800	0.048	Implicit	11.2880
Dubuque Creek	Entire Basin	Baseflow	0.14	0.7270	0.019	Implicit	0.8840
Catherine Creek	Entire Basin	Baseflow	4.19	0.8413	0.0215	Implicit	5.0516
Connor Lake Creek	Entire Basin	Baseflow	0.32	0.0359	0.0010	Implicit	0.3561
Pilchuck River	Entire Watershed	Runoff	187.0	174.7500	0.8900	Implicit	362.6400
Pilchuck River	Upper Pilchuck	Runoff	110.6	0	0	Implicit	110.6000
Pilchuck River	Menzel	Runoff	2.62	3.9400	0.101	Implicit	6.6610
Pilchuck River	Granite Falls	Runoff	11.29	2.3380	0.06	Implicit	13.6920
Pilchuck River	SR92	Runoff	6.58	1.9900	0.051	Implicit	8.6230

Water body	Applicable Area	Condition	LA	WLA	Future Growth	MOS	TMDL
Pilchuck River	Lochsloy	Runoff	2.53	1.3850	0.036	Implicit	3.9490
Pilchuck River	Russell Rd	Runoff	1.35	0.8040	0.021	Implicit	2.1720
Pilchuck River	Machias	Runoff	3.3	1.4590	0.037	Implicit	4.7600
Pilchuck River	Three Lakes	Runoff	1.9	2.5060	0.064	Implicit	4.4510
Pilchuck River	Snohomish	Runoff	3.4	1.6360	0.042	Implicit	5.0970
Little Pilchuck Creek	Entire Basin	Runoff	39.5	13.5510	0.347	Implicit	53.4390
Dubuque Creek	Entire Basin	Runoff	5.4	5.2440	0.134	Implicit	10.7330
Catherine Creek	Entire Basin	Runoff	17.7	6.0643	0.1553	Implicit	23.9150
Connor Lake Creek	Entire Basin	Runoff	0.4	0.2575	0.0067	Implicit	0.6956

Chapter 3: Implementation Plan

Introduction

This implementation plan was developed jointly by Ecology and interested and responsible parties. It describes recommended actions to improve water quality in the Pilchuck River watershed. It explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, mission, or direct responsibility for cleanup), along with the programs or other means through which they will address these water quality issues. The plan also describes a wide range of specific actions required to improve water quality and achieve state standards. These include riparian plantings, increasing summer baseflows, and improving instream habitat, as well as limiting nutrient inputs from individual properties, stormwater, and the Granite Falls Wastewater Treatment Plant (WWTP).

In this chapter of the Pilchuck TMDL, Ecology describes how temperature and DO pollutant levels will be reduced to meet state standards. Temperature and DO TMDL reductions should be achieved by year 2081 in the Pilchuck River and its tributaries. The success of this TMDL project will be assessed using monitoring data from streams in the watershed and adaptive monitoring will be implemented to adjust and ensure pollution reduction measures are effective.

Land Distribution

Ecology used 2016 land-use data from the Snohomish County's Assessor Office (Snohomish County Assessor, 2012) to evaluate broad-scale pollution stress on the Pilchuck Watershed. We consolidated the 183 land use types into 13 categories for analysis purposes (Figure 5). A large majority of the Pilchuck River watershed (55%) is forested.[6] Single family residential takes up about 25% of the total watershed area, most of which is concentrated in the lower and middle watershed. Undeveloped land takes up about 19%. Agriculture makes up about 0.3% of the total watershed area. The remaining acreage consists of other land use categories such as commercial, mining, manufacturing, transportation, recreation, open space and open water.

---

[6] County data showed a large part of the watershed as being "vacant" or "open space" categories. Comparison with aerial photos they are analogous to forested areas. For the purposes of pollution stress analysis, land defined by the County as "vacant" will be referred to as forested.

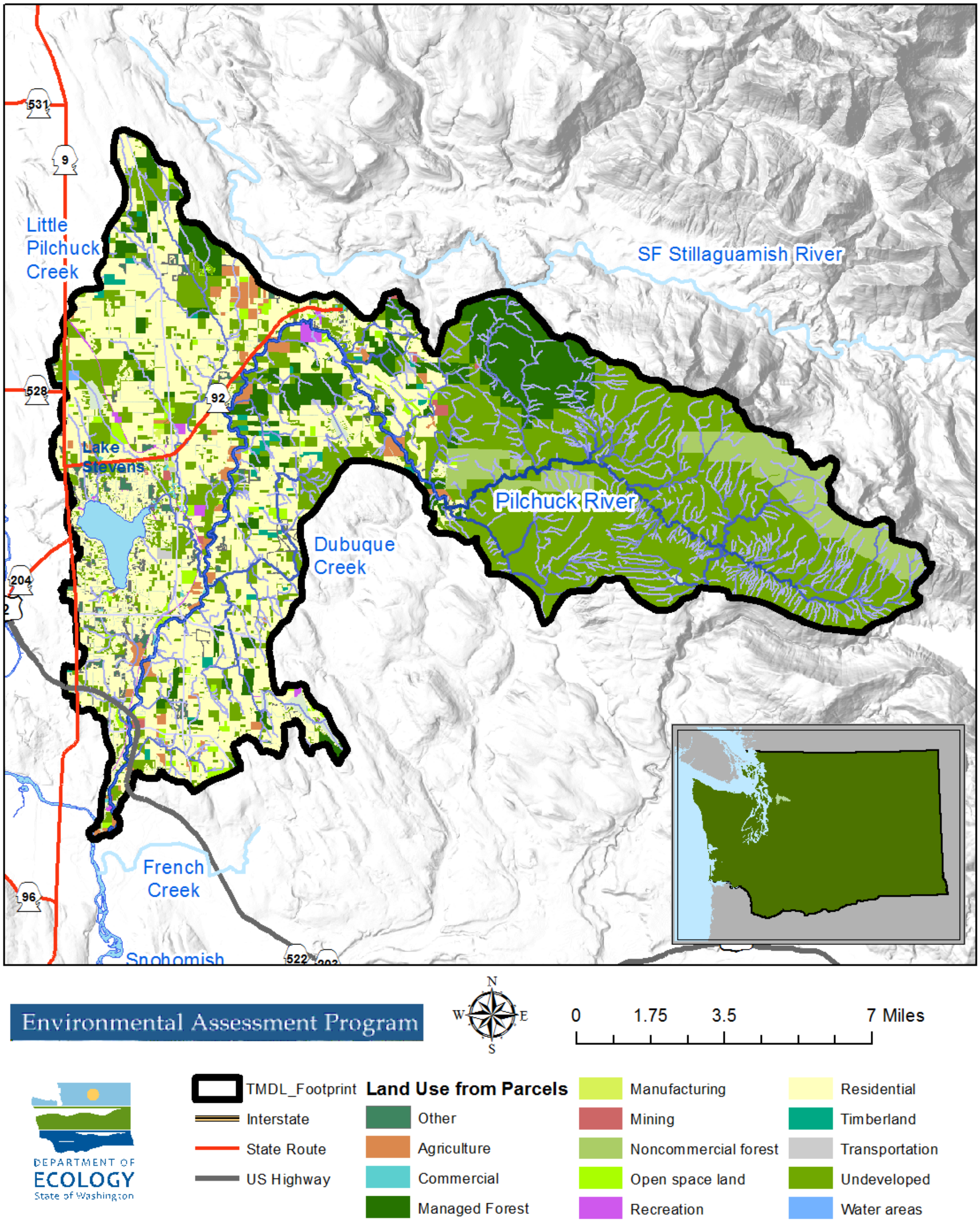

Figure 5. Land use in the Pilchuck River watershed.

Point Sources of Pollution

Point source wasteload allocations (WLAs) will be largely self-implementing through the administration of the National Pollutant Discharge Elimination System (NPDES) Program. However, the Pilchuck River Watershed Implementation Lead is tasked to working with permit managers to ensure that new TMDL-related requirements become permit conditions when permits are renewed. No additional TMDL-related conditions are anticipated for general permittees as part of WLAs in this TMDL. WLAs for the Granite Falls WWTP will be expressed as effluent limits by the permit manager.

Nonpoint Sources of Pollution

The Pilchuck River watershed is home to rural residential living, forestry activities, and four urban centers. Those actions and activities, which we describe below, are essential to decreasing temperature and increasing dissolved oxygen levels. Each general set of actions in Table 24 is discussed below followed by a detailed discussion of improvement opportunities identified in our study.

Table 24. Key strategies for reducing critical season water temperatures and increasing DO in the Pilchuck River.

Key Strategies
Riparian Restoration • Restore riparian shading to 180' on mainstem and to Ecology Riparian Buffer Map widths on tributaries. • Conduct community-based social marketing to determine most effective outreach and education efforts to landowners.
Restoring and Enhancing Natural River Processes • Create cold water refuges with large woody material (LWM) and other instream structure. • Install LWM and implement other BMPs to create edge habitat. • Restore forested wetlands and off-channel habitat to increase hyporheic function. • Reconnect floodplains and side channels. • Assess salmon thermoregulation behavior to better understand habitat needs. • Assess existing beaver activities including local salmon/beaver/human interactions, and beaver management practices. • Install beaver dam analogs and post-assisted log structures (PALs). • Conduct community-based social marketing to determine most effective outreach and education efforts to landowners.
Water Conservation and Streamflow Augmentation • Reduce surface and groundwater use during late-summer, low flow conditions. • Remove and/or modify bank armoring to increase hyporheic cooling processes.

Key Strategies
• Setback/remove levees to restore natural processes that create cooler water. • Evaluate using imported water from Spada Lake Reservoir for new development in place of new exempt wells. Assess dry season impacts of added water withdrawals to the reservoir and Sultan River and added exported water to the Pilchuck River. • Implement low-flow irrigation BMPs to improve irrigation timing and efficiency. • Evaluate and install impoundment BMPs (e.g., beaver dam analogs, PALs) to retain water for use during the summer where feasible. • Implement stormwater retrofits that increase groundwater levels utilizing low impact development (LID). • Conduct community-based social marketing to determine most effective education & outreach efforts encouraging landowners to adopt water conservation practices.
Nutrient, Sedimentation and Erosion Control • Implement stormwater retrofit BMPs including LID. • Apply nutrients using the proper rates and timing. • Install LWM, vertical arrays, coir logs and other bank stabilization BMPs. • Install livestock exclusion fencing and off-channel water facilities. • Implement erosion and sediment control BMPs during construction. • Investigate and repair possible sewer leaks and failing onsite septic systems. • Conduct community-based social marketing to determine most effective outreach and education efforts to landowners.

Key Strategies for Reducing Water Temperatures and Nutrient Inputs

Restore Riparian Vegetation

Planting native vegetation where buffers are lacking is a priority. Trees provide a direct temperature benefit by creating shade. In some locations, they provide indirect benefits related to air cooling, supplying woody material, and eventual narrowing and deepening of the stream channel. Big trees in riparian areas eventually fall down and improve stream processes that help keep water cooler. Tree height and density work together to prevent solar radiation from reaching the water. As illustrated in Figure 50 of this TMDL, large buffers will significantly lower air temperatures around a stream and provide an added dimension of cooling. Some added benefits of riparian restoration include: (1) trees acting as flood fences that trap flood-borne debris, which would reduce the cost of removing flood control debris after a flood event; and (2) trees help stabilize the river's location and may prevent excessive bank erosion and loss of farmland. Planting tributaries areas is essential since narrower streams are easier to shade than wider streams.

Implementation partners (discussed later in this document) should encourage landowners to establish 180-foot riparian buffers on each side of the mainstem Pilchuck River and buffers consistent with Ecology's Riparian Buffer Width Map[7] along tributary streams in order to effectively achieve microclimate gains needed to decrease water temperatures. All watercourses with flowing waters should have complete shade at the maximum density feasible. Implementation partners should consult with an Ecology Water Cleanup specialist to discuss phasing riparian planting designs along the mainstem Pilchuck River in order to maximize funding opportunities. Planting sites should be properly prepared based on local soil, topography, and location within the channel migration zone. The need for annual plant maintenance for a period of at least 5 years following plantings should be evaluated and always be included where the previous dominant vegetation was composed of blackberries, reed canary grass, Japanese knotweed, and other invasive or noxious weeds. Restoration specialists should regularly review the success of techniques to ensure that planting, watering, weed management, and outreach techniques are the most effective ones available. In the face of climate change, other potential tree protection and maintenance activities discussed in Chapter 1, Climate Change Section should also be assessed.

Establish good riparian vegetation on public and private properties: All landowners with riparian areas on their property are part of the solution to reducing water temperatures in the Pilchuck River. Outreach programs that inform and motivate private landowners are essential to achieve this TMDL requirement. Publically-owned riparian areas that do not have treed buffer widths consistent with this TMDL should be identified and scheduled for planting at the earliest date and no later than five years from the date this TMDL is approved.

Enforce local ordinances and refine as needed: Protecting existing wooded riparian areas is especially important because of the long time it takes to establish new mature growth. Regulations must be enforced in order to derive both deterrent and corrective action benefits. Ecology's Pilchuck River Temperature and Dissolved Oxygen TMDL meets the requirements for best available science and should be consulted when updating shoreline and critical areas ordinances, clearing and grading ordinances, and other regulations.

State Environmental Policy Act and land use planning: Consider TMDLs during State Environmental Policy Act (SEPA) and other local land use planning reviews. If the land use action under review is known to potentially impact temperature and dissolved oxygen (DO) as addressed by this TMDL project, then the project may have a significant adverse environmental impact. SEPA lead agencies and reviewers are required to look at potentially significant environmental impacts and alternatives and to document that the necessary environmental analyses have been made. Land-use planners and project managers should consider findings and actions in this TMDL plan to prevent new land uses from violating water quality standards. Local authorities should consider this TMDL in the issuance of land use permits.

---

[7] http://www.arcgis.com/home/webmap/viewer.html?webmap=d5478a4aaf704d81bac63ffc934e1549&extent=-123.0388,47.109,-122.5317,47.2963

Figure 6. Riparian restoration photo.

Restoring and Enhancing Natural River Processes

Enhance Cold Water Refuges using LWM: Enhancing and protecting cold water refuges is vital to salmon recovery. Cold water refuges (CWRs) are generally defined as water that is 2°C cooler than the surrounding waters (Torgensen, Ebersole and Keenan, 2012). While trees take many years to reach their full potential to protect streams from excessive heating, CWRs provide immediate assistance to salmon and other cold water species during the warmest times of the year. They are preferred areas for fish and invertebrates when water temperatures get too warm for them to tolerate. Observations of fish using CWRs provide direct evidence of the importance CWRs usage for salmon migration. Fish are able to detect <0.1°C temperature difference and respond to this fine-scale difference both spatially and temporally by moving to more favorable water (Torgersen, Ebersole, and Keenan, 2012). Streams with healthy natural processes can contain a wide variety of these relatively cooler areas. Many types of hydrological processes including tributary junctions, side channels, alcoves, stratified pools, groundwater seeps, hyporheic exchange (i.e., laterally through point bars and meander bends; or vertically through a pool and riffle system) can create CWRs (Leonetti et al., 2015).

Figure 7. Potential cold water refuge (CWR) spot with large woody material (LWM) for fish along the Pilchuck River

For example, where groundwater from wetlands and other sources is available near a stream, the presence of large wood structures can connect that cooler groundwater to a stream or river. Scour pools created by large wood structures create cooler, deeper pools that can tap into groundwater. Large wood just upstream of where a cooler tributary enters the mainstem can increase the size of the resulting downstream CWR. In some stream reaches, warm water temporarily leaves a stream only to emerge downstream after being cooled during its subsurface travel. Fish and invertebrates can have a dynamic relationship with CWRs during periods where stream temperatures are high.

Control Excessive Erosion and Sedimentation: Excessive sediment loading can affect local waters and aquatic life by covering salmon eggs and filling streams so that they become wider and shallower. Making a stream wider and shallower can also affect water temperatures and DO levels. This problem happens in parts of the stream where water velocities decrease and sediment falls to the bottom of the stream. The settled sediment causes the stream to spread out and become wider. When the stream is wider, more water comes into contact with air and sunlight making the water warmer. The warmer water also holds less oxygen to support fish and other aquatic life.

Sediment deposition can also smother salmon eggs and "cement" the redds where salmon deposit their eggs. Cemented redds get clogged with fine sediment, causing poor water flow through the gravel. Without good water flow, oxygen levels needed by developing eggs can become too low, causing them to die. Moreover, as fine sediments clog the spaces between gravel, cobble, and other finer substrates, the rate of hyporheic exchange is also reduced.

Bank erosion in streams and rivers is part of a water body's evolution. When it occurs at natural levels, erosion brings in fresh gravel to support healthy aquatic invertebrate communities as well as provide good salmon spawning substrates. However, when human activities change stream hydrology and increase water flows, the force of the higher flows accelerates this process. Increased storm intensity and precipitation are additional factors that can also induce these higher flows especially in the face of climate change. When trees and native vegetation are cleared from riparian areas, the loss of roots make banks more susceptible to erosion and can cause both a destruction of fish habitat and significant property loss.

Although a sediment budget was not created as a part of this TMDL, the most common sources of sediment and altered stream processes typically include 1) landslides; 2) erosion resulting from poor forestry management practices; 3) construction site runoff; 4) alteration of natural stream channels and riparian areas; and 5) hydraulic scouring following urban and rural development. Actions to control sediment released from forest roads, control hydraulic scouring through stormwater infiltration, and control damage to riparian areas are discussed throughout this chapter. This implementation plan supports the following additional actions aimed at reducing sediment buildup and improving natural processes that contribute to improved water temperatures:

- Control erosion during construction activities
- Restore riverbank stability with riparian vegetation
- Maintain forest access roads
- Restore natural river processes

Water Conservation and Streamflow Augmentation

This TMDL shows that reducing the amount of water flowing in the Pilchuck River increases stream temperatures and reduces DO levels. Adding water back into the river results in cooler water with more DO. For that reason, increasing summer baseflow levels through water conservation and streamflow augmentation is an important objective of this TMDL. Water conservation techniques are well established and not individually detailed below. However, streamflow augmentation is a relatively new field of environmental restoration. The Pilchuck River's wide variety of land uses and geography is an excellent watershed in which to pilot new flow augmentation techniques. Implementation actions required to improve streamflows are discussed below.

Infiltrate stormwater where feasible and to the maximum extent practicable: Impervious surfaces such as roofs, roads, and parking lots increase the potential for adverse impacts by preventing rainwater from infiltrating into the ground. Infiltrating stormwater helps maintain or restore natural hydrologic processes such as groundwater recharge that support streamflows during summer. The proper infiltration of stormwater also helps remove pollutants and help minimize flood frequencies.

Property owners can use a suite of Low Impact Development (LID) tools, including harvesting and infiltrating rain water with rain barrels, installing bio-swales, replacing lawn grass with native species or a rain garden, augmenting lawn soils to improve water absorption, and replacing paved areas with gravel or permeable pavers. Riparian buffers also infiltrate and slow down stormwater. Information on these different LID options is available through Snohomish Conservation District's Urban Stormwater Program.[8] This plan recommends that state and local governments work together to advance the use of Low Impact Development (LID) practices in new development, redevelopment and retrofit projects. Low impact development is a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions (PSAT and WSU, 2005). Ideally, site planning and stormwater management are integrated at the initial design phases of a project to maintain a more hydrologically functional landscape.

Ecology's groundwater velocity table (illustrated in Appendix J) may serve as an example of a useful tool for the site planning of infiltration facilities. After inputting the elevation of the infiltration facility, stream elevation and distance to the stream, this table automatically calculates the following based on soil type:

- Hydraulic gradient (slope)
- Linear velocity (rate of change)
- Travel time (in days and years)

Ecology provides a detailed example on how to estimate groundwater volume, groundwater velocity, travel time, and drainage area for infiltration facilities (Appendix J). Since this watershed has a permeable soil layer as well as a restrictive soil layer (seasonal high water table, bedrock, or other impervious layer), Ecology also examined the feasibility to site infiltration facilities based on the soil characteristics described in Ecology's 2019 Stormwater Management Manual for Western Washington.[9] Ecology found infiltration to be feasible for the Pilchuck River watershed (refer to Appendix J). The analysis in Appendix J is meant to provide a starting point for identifying where water might be strategically added back to the Pilchuck River mainstem and Little Pilchuck Creek. This TMDL recommends conducting site planning and field verification during a stormwater project's initial design phases, and assessing site conditions throughout the life of the project.

Restore or enhance wetlands where feasible: Wetlands store water and slowly charge groundwater supplies during dry weather periods. This TMDL recommends additional research to identify marginal forestry and agricultural lands where wetland restoration could improve summer baseflows.

[8] https://snohomishcd.org/sound-homes

[9] https://fortress.wa.gov/ecy/ezshare/wq/Permits/Flare/2019SWMMWW/2019SWMMWW.htm

Figure 8. Example bioretention facility.

Use imported water for new development: Where feasible, supplying new homes and development with carefully managed water sources outside of the Pilchuck River watershed can help increase summer streamflows. Imported water is currently estimated to contribute up to ~ 4 cfs in summer baseflow gain.

It is important to note that the Washington State Legislature passed the 2018 Streamflow Restoration Act (ESSB 6091) to provide actions that offset impacts to instream flows associated with permit exempt domestic water use and achieve net ecological benefit. While these actions are not expected to directly contribute to water quality improvement, this program is expected to prevent future degradation to instream flows. It will also provide essential guidance on increasing stream baseflows. This implementation plan recommends tracking and keeping up with streamflow restoration guidance developed by Ecology's Water Resources Program resulting from this new law.

This plan also recommends that state and local governments work together to plan for the use of imported water for new development from outside the basin (e.g., Spada Reservoir) to limit new exempt wells where feasible. It is important to note that the Little Pilchuck Creek is a closed basin to new water right applications.

Prevent illegal water withdrawals: On a localized basis, illegal water withdrawals have the potential to affect water temperatures and should be reported to Ecology by contacting (425) 649-7000. All surface water diversions must be authorized through a water rights permit. Ecology's Northwest Regional Office, Water Resources Program will work with local landowners that need water for crop irrigation and can be contacted at the telephone number above.

Improve efficiency and timing of irrigation: Dry Pacific Northwest summer climate conditions lead to increased irrigation needs and therefore more water withdrawals. Landowners should water fields, gardens and lawns during the cooler times of the day in the morning or in the evening during the critical summer months. Irrigation timers can be used to improve convenience of watering in the early morning. Using efficient irrigation devices, such as soaker hoses and drip irrigation, conserves water in gardens and fields by (1) delivering water slowly close to the plant roots where it is most needed and (2) avoiding overspraying and evaporation. See smart watering techniques.[10]

Additionally, installing water control valves on drainage tiles to control water flow rather than draining open year-round, may help conserve the amount of water withdrawal from Pilchuck River itself during the summer. This TMDL recommends additional research to determine how much of an effect valve drain tiles have in water conservation during the summer. Agricultural water users should consult with the Snohomish Conservation District Farm Planning Program[11] to develop a water management plan that maximizes watering efficiency.

Ecology supports conservation efforts that optimize irrigation and soil health practices. While irrigation audits are currently not regulated by Ecology, this TMDL also recommends voluntary irrigation audits to manage natural soil moisture and texture. Incentive programs should be considered to encourage landowners to conduct a voluntary irrigation audit.

Streamflow Augmentation through Beaver Management

Beaver dams have the potential to increase summer baseflows through an expansion in both surface and subsurface water storage due to water ponding and infiltration, (Dittbrenner, 2019; Pollock, Castro, and Lewallan, 2018; Bouwes et al., 2016; Rosell et al., 2005). Dittbrenner (2019) found that beaver relocations to headwater streams in the Skykomish watershed created 243 m^3 of surface water storage and 581 m^3 of subsurface water storage per 100 m of stream reach in the first year following relocation. Adding surface water features and increasing subsurface storage is expected to increase downstream flows.

While beaver management was not included within the scope of this study, this plan recognizes the beneficial impacts beavers bring to stream restoration and salmon recovery (Figure 9). Beavers are currently present in both the Little Pilchuck and Dubuque subbasins (Snohomish County. verbal communication. November 16, 2017) and are thought to potentially have widespread presence throughout the rest of watershed. Several sources indicate beavers have the ability to recharge groundwater by elevating water tables, reconnect and expand floodplains, increase hyporheic exchange, increase summer baseflows, expand wetlands and cold water refuges, create sediment traps and improve water quality (Pollock, Castro, and Lewallen, 2018; Bouwes et al., 2016; Weber et al., 2017; Rosell et al., 2005).

---

[10] https://snohomishcountywa.gov/DocumentCenter/View/7261/Smart-Watering?bidId
[11] https://snohomishcd.org/sound-farms

As illustrated in Figure 9, beaver-made dams and beaver dam analogs (i.e., structures that mimic beaver dams) slow and increase surface water levels upstream of the dam (Bouwes et al., 2016). Pools above and below dams increase bed channel complexity and provide resting and foraging opportunities for fish. Deeper pools allow the water temperature to stratify and increase hydraulic pressures, which force cooler groundwater to disperse and upwell further downstream creating an expansion of CWRs. Gravel bars may form at the tail of a beaver pond and just downstream from the scour of the dam, which creates spawning habitat and provides fish places to hide. Frequent inundation of inset floodplains creates side channels and rearing habitat for juvenile salmonids and increases riparian vegetation recruitment. An increase in riparian vegetation and pond complexes translates to more food supply and refuges for beavers leading to higher survival and persistent beaver colonies. Beavers maintain the dam and associated geomorphic, hydrologic and biotic processes continue to create complex fish habitat (Bouwes et al., 2016).

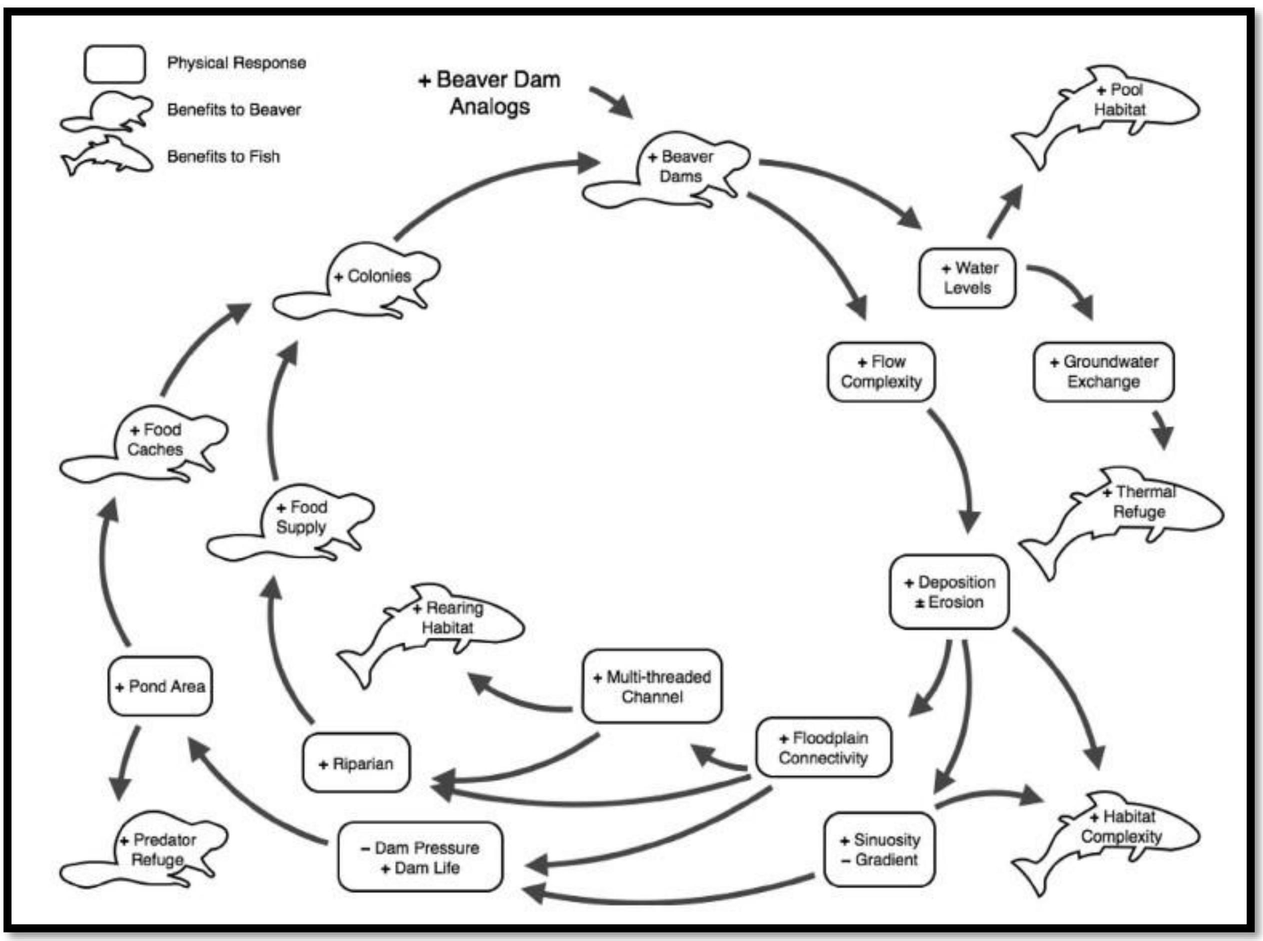

Figure 9. Changes expected from beaver dam analog installation and the benefits to beaver and fish (Bouwes et al., 2016).

Weber et al. (2017) studied beaver impacts on stream temperature and found that even though beaver colonies are viewed negatively for reducing shade, their data suggested that the increase in solar radiation was offset by the buffering effect caused by an increase in surface water storage. Furthermore, summer stream temperature maximums decreased for stream reaches located downstream of active beaver dams, with Dittbrenner (2019) finding a cooling effect average of 2.3°C in stream temperatures during summer baseflow conditions in the Skykomish River watershed. Areas with the greatest longitudinal increases in maximum summer stream temperature occurred during times when no beaver dams or beaver dam analogs existed. When evaluating the potential of beaver ponds to supplement summer hydrology as a total percentage of summer precipitation, Dittbrenner (2019) states beaver complexes have the potential to supplement summer precipitation by 2.4% in mixed basins such as the Snohomish River basin (see Figure 5 in the Climate Change section of this report).

The extent to which beaver dams and beaver dam analogs (BDAs) raise groundwater levels and example BDA calculations based on the August baseflow restoration targets from 'Load Allocations' section are discussed in Appendix J. Example BDA calculations are meant as a starting point and do not reflect the entire suite of BMPs that can used to return water to the Pilchuck River. Careful site planning is a must when considering BDA construction. Snohomish County noted that any constructed BDAs in the Pilchuck River watershed are likely to be shortly occupied by beavers (Rustay, M. public communications, November 13, 2020). By increasing groundwater storage, beaver dams and BDAs can shift slightly losing stream reaches to gaining reaches (Majerova et al., 2015), shorten the non-flowing duration of intermittent streams (Woo and Waddington, 1990), and even convert intermittent streams into perennial streams (Snodgrass, 1997; Pollock et al., 2003).

Extensive planning must be undertaken in places where beavers and humans interact or in places where beaver relocation or reintroduction may be under consideration. Where necessary, property acquisition or easements should be considered where conditions are suitable for beaver colonization and water storage. Active outreach and education to inform landowners about beavers and how to live with beavers (including the challenges) should be explored. Known and potential challenges between humans and beavers include:

- Impacts to roads and other transportation infrastructure through plugging of road culverts and/or backwatering of water behind beaver dams.
- Flooding of private property including dwellings and septic drain fields.
- Unwanted beaver browse of crops and ornamental plants.
- Potential reduction of fish passage in confined streams, especially those associated with built infrastructure.

When considering beaver restoration, refer to "The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains"[12], Beavers Northwest[13] and Washington State Department of Fish and Wildlife's (WDFW) website[14] for more information. This TMDL

[12] https://www.fws.gov/oregonfwo/Documents/2018BRGv.2.01.pdf
[13] http://www.beaversnw.org/home.html
[14] https://wdfw.wa.gov/species-habitats/species/castor-canadensis

recommends consulting with WDFW wildlife biologists early and often during the planning of beaver management projects. This TMDL also recommends conducting beaver assessments to better determine the extent of beaver family populations to help guide future beaver management and public outreach projects within this watershed.

Nutrient, Sediment, and Erosion Control

Practice natural yard care techniques: The summer season is when plants and lawns need the most water and a time when streamflows are at their lowest. Landowners can purchase native plants for their yard that are already acclimated to the local climate and require less maintenance than lawns. Selecting drought-tolerant native plants that require less irrigation will help leave more water in the stream. Adding mulch or compost helps retain moisture in the soil for plants and also conserves water. Applying a slow-release fertilizer at the proper rate and time will reduce the amount of nutrients that runoff during storm events by releasing nutrients more slowly. Grass-cycling, is also a good technique to retain grass clippings on the lawn for soil organisms to break down as free nutrients. See Snohomish County's natural yard care website[15] for more information or resources about natural yard care.

Add protections where livestock are present: Livestock owners have a special challenge in establishing and protecting vegetation, preventing erosion, and controlling nutrient discharges in riparian areas. Grazing animals have the potential to destroy riparian areas as well as discharge bacterial pollutants and nutrients to local waters if proper management practices are not followed. Proper best management practices (BMPs) for livestock rearing include fencing to keep animals out of waterways and riparian areas, off-stream watering facilities, and the proper combination of tree coverage and filter strips outside of the fencing—all of which are needed to protect local surface waters.

[15] https://snohomishcountywa.gov/1097/Natural-Yard-Care

Figure 10. Livestock grazing.

Continuous grazing can cause soils to become compacted and reduce infiltration of stormwater to recharge groundwater supplies. It also weakens plants and offers an opportunity for invasive plants to become established and makes it easier for bacteria and other pollutants to drain off the land and into a wetland or stream. Healthy grass promotes the infiltration of stormwater and is better for livestock. Grass forage has its best nutrient value between 3” and 8” of height. Grazing below 3” depletes the plants’ energy reserves, which it needs throughout its dormant period. Remove animals when grass height reaches 3” and return them when the height reaches 6” or more.

The Snohomish County Water Pollution Ordinance[16] (Snohomish County Code 7.53) prohibits discharges that contain contaminants, including sediments. The ordinance may allow or require best management practices (BMPs) described in appropriate stormwater prevention plans. Snohomish County’s Critical Areas Ordinance[17] (Chapter 30.62A.620-640) specifically addresses standards and conditions relating to commercial agriculture. The ordinance requires the use of agricultural BMP’s to protect the functions and values of wetlands and fish and wildlife conservation areas. Although the need to plant trees in riparian areas is not specifically discussed in the ordinance, landowners should include planting trees as an appropriate BMP in the design of animal grazing areas near critical areas or buffers.

Farms that spread nutrients on a field should be sure to apply nutrients at agronomic rates. Due to high seasonal rainfall, the appropriate timing and amount of nutrient application is critical (Carey and Harrison, 2014). If nutrients are applied during a rainy period and/or too heavily, then plant uptake may be limited, resulting in excess nutrients washing off the field and polluting nearby water bodies. Refer to Ecology’s Voluntary Clean Water Guidance for Agriculture[18] and contact Snohomish Conservation District for further information and recommendations on BMPs that address nutrients.

Small farms should receive periodic technical assistance visits from the Snohomish Conservation District’s Farm Planning Program[19] to ensure BMPs are being followed. Technical assistance visits to new landowners are especially important when livestock properties change ownership.

Where Do We Have Opportunities for Improvement?

Many reaches of the mainstem Pilchuck and its tributaries need large riparian planting and restoration. Shade is needed along major river segments and all major tributaries in order to cool not only the water temperature, but create a microclimate that decreases the air temperature. The larger the buffer, the greater the air temperature decrease.

[16] https://snohomish.county.codes/SCC/7.53
[17] https://snohomish.county.codes/SCC/30.62A_Part600
[18] https://fortress.wa.gov/ecy/publications/documents/2010008.pdf
[19] https://snohomishcd.org/sound-farms

A wide tree canopy buffer can help cool soil and subsurface temperatures, which may translate to cooler groundwater and hyporheic flows.

As part of this implementation plan, Ecology reviewed orthophotography from ArcGIS in 2017 and 2018. The following analysis divides Pilchuck River watershed into three segments:

- Upper Pilchuck (River Mile 26.4 and above)
- Middle Pilchuck (River Mile 8.6 to 26.4)
- Lower Pilchuck (confluence with Snohomish River to River Mile 8.6)

River metrics and corresponding maps used to delineate the reaches in these segments can be found in Appendix K.

During the 2014 and 2016 surveys, Ecology identified several areas while evaluating seeps and small tributaries along the mainstem that might function as potential cold water refuge (CWR) areas. The temperature differences between the seeps and tributaries and the mainstem averaged 5.6°C. These CWR areas are discussed throughout the Middle and Lower Pilchuck subbasin reaches. A full list of potential CWRs may be found in Table 40 and Figure 24. Siting of actual CWR projects will require additional study. Ecology's direct observations of cold water inputs and flow balancing work is intended to show both the potential for creating CWRs and the general areas where that potential exists. This TMDL recommends additional geomorphic and hydrologic assessment to identify and prioritize CWR creation and augmentation in the mainstem and all major tributaries.

The strategic placement of large woody material (LWM) also known as large woody debris (LWD) or engineered log jams to improve the amount of cool water inputs and localized fish refuges is highly encouraged as a means of implementing this TMDL. Placing LWM in stream channels creates channel complexity and forms scour pools, improving fish habitat as well as enhancing groundwater inflow to the stream (Booth, 1997; Drury, 1999). This TMDL recognizes that for projects to install LWM as envisioned in this TMDL will require additional field research and community outreach. Project managers should include an analysis demonstrating a high likelihood of creating new or increased groundwater inputs as a prioritization criterion. Public safety should also be weighed as a factor during LWM project design. Grant authorities are encouraged to recognize the complexity of the additional analysis, community outreach, and design challenges when examining how they can structure their funding guidelines to help facilitate this important but complex aspect of implementing this TMDL.

Increasing the number of pools is another key component towards providing more CWRs that can act as stepping stones for fish when temperatures are too high. Pools also provide habitat for fish rearing. Table 25 shows average near stream disturbance zone (NSDZ) channel widths, wetted to NSDZ channel width conversion ratios, approximate wetted channel widths, average frequency of pools per mile targets based on the Matrix of Pathways and Indicators (NMFS, 1996) and average frequency of pools per kilometer targets within the Middle Pilchuck and the Lower Pilchuck reaches.

Ecology estimated the wetted channel width by multiplying the NSDZ channel width by the wetted to NSDZ ratio. From NMFS (1996), Ecology used linear interpolation or regression ($y = 572.65x^{-0.764}$) to estimate approximate pools per mile target. Further information on where additional pools are needed is discussed later in the Middle and Lower Pilchuck subbasin sections.

Table 25. Pilchuck River channel widths and average pool targets.

River Miles	Average NSDZ Channel Width (m)	Wetted to NSDZ ratio	Approx. wetted width (m) at low flow	~pool/mi target (1996 matrix)	~pool/km target
Middle Pilchuck (RM 8.70-RM 25.48)	48.52	0.54	26.20	19.1	11.8
Lower Pilchuck (RM 1.24 to RM 8.08)	41.37	0.63	26.06	19.1	11.9
Total Study Area (Middle +Lower Pilchuck)	46.37	0.57	26.43	18.9	11.8

Upper Pilchuck Mainstem and Subbasins

Most of the Upper Pilchuck from RM 42 to about RM 26 is forested lands managed by Washington State Department of Natural Resources (Figure 11). Actions that can be taken to minimize temperature and DO impacts are discussed below.

In August 2020, Tulalip Tribes and City of Snohomish completely removed the City of Snohomish Diversion Dam (built in 1932) on the Pilchuck River, which impeded upstream fish migration. The Pilchuck River Dam Removal Restoration project restored unimpeded fish access to 37 miles of high quality habitat. During the course of this project, a second smaller dam (built in 1912) was also removed.

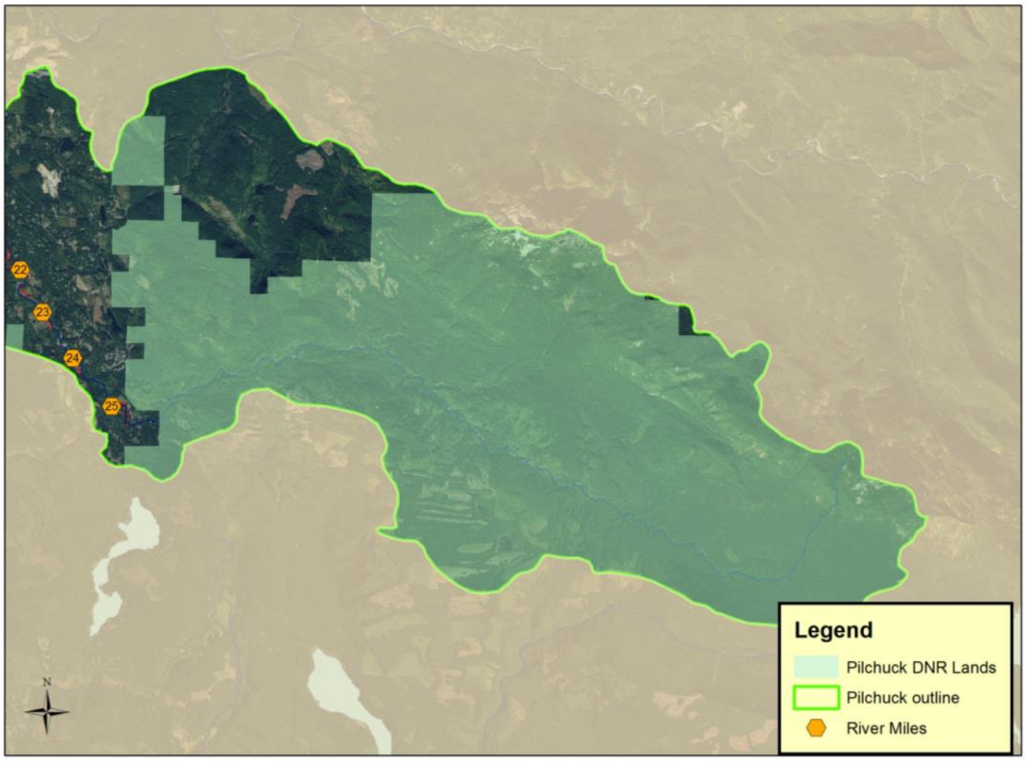

Figure 11. Upper Pilchuck subbasin

The state's forest practices regulations will be relied upon to bring waters into compliance with the load allocations established in this TMDL on private and state forest lands. This strategy, referred to as the Clean Water Act Assurances, was established as a formal agreement to the 1999 Forests and Fish Report.[20]

The state's forest practices rules were developed with the expectation that the stream buffers and harvest management prescriptions were stringent enough to meet state standards for temperature and turbidity, and provide protection equal to what would be required under a TMDL. As part of the 1999 agreement, new forest practices rules for roads were also established. These new road construction and maintenance standards are intended to provide better control of road-related sediments, provide better stream bank stability protection, and meet current best management practices.

To ensure the rules are as effective as assumed, a formal adaptive management program was established to assess and revise the forest practices rules, as needed. The agreement to rely on the forest practices rules in lieu of developing separate TMDL load allocations or implementation

[20] https://www.dnr.wa.gov/Publications/fp_rules_forestsandfish.pdf

requirements for forestry is conditioned on maintaining an effective adaptive management program.

Consistent with the directives of the 1999 Forests and Fish agreement, Ecology conducted a formal 10-year review of the forest practices and adaptive management programs in 2009[21]. Ecology noted numerous areas where improvements were needed, but also recognized the state's forest practices program provides a substantial framework for bringing the forest practices rules and activities into full compliance with the state standards. Therefore, Ecology decided to conditionally extend the CWA assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific milestones for program accomplishment and improvement. These milestones were designed to provide Ecology and the public with confidence that forest practices in the state will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

This TMDL study did not analyze the effect of clearcutting and other forest management practices on basin hydrology and resulting temperature effects. However, the adaptive management process for the Forest Practices Rules includes research being conducted by the Cooperative Monitoring, Evaluation and Research Committee (CMER)[22] a committee established by the Forest Practices Board. Among their work is research on the effect of forest management strategies on stream temperature, sedimentation and hydrology.

The regulations for private forests and State Trust Lands are discussed below:

- **Private forests and state trust land*s:*** Private forest landowners must follow the Forest Practices Rules (FPRs, Chapter 76.09 RCW). The FPRs are regulations adopted by the Forest Practices Board that establish minimum guidelines for timber harvesting and riparian forest management. Riparian Management Zones (RMZ) are established along all perennial streams where silvicultural activities are restricted to protect shade and large woody material (LWM; also known as large woody debris) at levels that meet the water quality standards and protect the stream's ecological functions.[23] The widths of RMZ are based on the soil site class (its ability to grow trees), and varies from 90-200 feet. Management within the RMZ is strictly controlled by a complex set of forestry prescriptions established in the state forest practices rules. Although the rules will allow management (thinning) to within 50 feet of the water, along most fish-bearing streams a 101 to 118 foot wide no-entry buffer is established.

The specific allowance for harvest within the RMZs depends on how dense the stand is and how well it protects stream shade and the supply of LWM to the streams. The width is also conditioned on the size of the stream, whether or not it contains fish, and whether or not it flows year-round (perennial). Private landowners must follow either the state forest practices rules established in conformance with the *Final Forest Practices Habitat Conservation Plan* (FPHCP)

---

[21] https://fortress.wa.gov/ecy/publications/SummaryPages/0910101.html

[22] https://www.dnr.wa.gov/about/boards-and-councils/forest-practices-board/cooperative-monitoring-evaluation-and-research/

[23] More information about Western Riparian Management Zones is available online (WAC Chapter 222-30-021) at: https://apps.leg.wa.gov/wac/default.aspx?cite=222-30-021.

or follow alternative prescriptions established in a HCP developed and approved specifically for their ownership.

State Trust Lands are subject to the *State Lands Habitat Conservation Plan* (HCP). The State Lands HCP is an agreement covering multi-species that ensures management activities on State Trust lands will not result in degradation of habitats that are important for federally listed species. This agreement establishes alternative harvesting prescriptions for State Trust lands that are believed to provide equal or greater protection than those required for private forestry operations. Buffer widths along watercourses depend on the stream type.[24] Fish bearing streams have a site index buffer applied. The width of a site index buffer depends on the productivity of the soil, and is equal to the height the site dominant tree species is expected to get in 100 years.

Currently, under the HCP, some silvicultural activities are allowed within the riparian management zones if the stand does not meet the desired future condition. Where riparian zones will be entered, a core zone of 25 feet on each side of the stream is considered a no touch area, and is not subject to any management practices. Within the remaining buffer area, thinning can occur, as well as creation of downed woody debris and snags. These activities are to be designed based on site specific conditions so as to have a positive influence on the stream itself, as well as on the riparian ecosystem and the species, which rely on it.

Although state and private forest lands are managed under other authorities, this TMDL has the following general recommendations for forest managers to promote the improvement of water temperatures and DO in the Upper Pilchuck River subbasin:

- **Establish or maintain good riparian vegetation:** Where significant portions of riparian buffers are found to be poorly vegetated (such as with grasses, shrubs, or invasive species), riparian restoration and replanting with the appropriate plant species are needed.
- **Provide treatment for logging road systems:** Proper attention to the state of logging roads and their drainage facilities is needed to prevent sediment delivery to the watershed. Older roads, sediment control structures, and stormwater conveyance systems should be evaluated for maintenance, removal, or decommissioning.
- **Evaluate large scale land use changes from forestry activities:** Large scale land use changes from forestry activities affect watershed hydrology. Changes in interflow, groundwater storage, and surface runoff can occur from the construction of roads and clearing of land associated with forestry activities. It is expected that existing forestry management rules and plans will consider this impact on water quality as they are revised.
- **Augment streamflow:** Assess whether wetland restoration, beaver dam analogs (or other impoundment BMPs) and other beaver management practices are feasible. Consult with WDFW wildlife biologists early and often during the planning of beaver management projects.

[24] Stream type descriptions are available online under "Riparian management zone" (WAC Chapter 222-16-010) **at:** https://apps.leg.wa.gov/wac/default.aspx?cite=222-16-010. Additional definitions are available online at: (WAC Chapter 222-16-030) **at:** https://apps.leg.wa.gov/WAC/default.aspx?cite=222-16-030.

Middle Pilchuck Mainstem and Subbasins

As illustrated in Figures 12 and 13, the Middle Pilchuck River encompasses about 18 miles of channel extending upstream from the confluence with Dubuque Creek at Ok Mill Road (RM 8.6) to RM 26.4 (where the diversion dam used to be). The Middle Pilchuck mainstem contains several riverine (riparian wetlands along rivers, streams) and freshwater forested/shrub wetlands. Little Pilchuck Creek subbasin contains more wetlands than Dubuque Creek (Figures 15 and 16). Refer to Appendix K for more detailed maps and information about the stream reaches discussed later in this section.

During August 2012, the daily maximum water temperature in the Middle Pilchuck mainstem peaked at 22.87°C and in mid-August 2012, the 7-DADMax water temperatures peaked at about 22.5°C, well exceeding the state standard of 16°C. On August 18, 2016, the minimum water temperatures in the mainstem were just above state standards, peaking at 16.85°C, while the maximum water temperatures peaked at about 22.6°C. Modeling scenarios characterized later in this document in Chapter 4, 'System potential conditions' section, show that the Middle Pilchuck is unable to meet the numeric criteria part of the state standards, even under system potential conditions. Despite being unable to meet the numeric criteria, the management scenarios are shown to:

- Reduce 7-DADMax water temperatures below the adult fish lethality of 22˚C (Figure 44);
- Reduce the 1-day maximum temperatures below the adult fish lethality criteria of 23˚C (Figure 45); and
- Meet the narrative 0.3°C human impact part of the state standards.

The addition of streamflow restoration and increased hyporheic exchange show a noticeable difference with reducing temperatures below 22˚C, especially in the lower reaches. System potential shade plus microclimate continue to show a substantial difference compared to a no action scenario when moving from upstream (RM 26) to downstream through the mainstem Pilchuck River.

The city of Lake Stevens partnered with the Adopt-A-Stream Foundation, who planted trees and installed LWM with many private landowners in the Little Pilchuck Watershed (see Figure 13). Snohomish Conservation District is currently working with landowners to restore riparian buffers in both the Middle and Lower Pilchuck segments with Ecology funding.

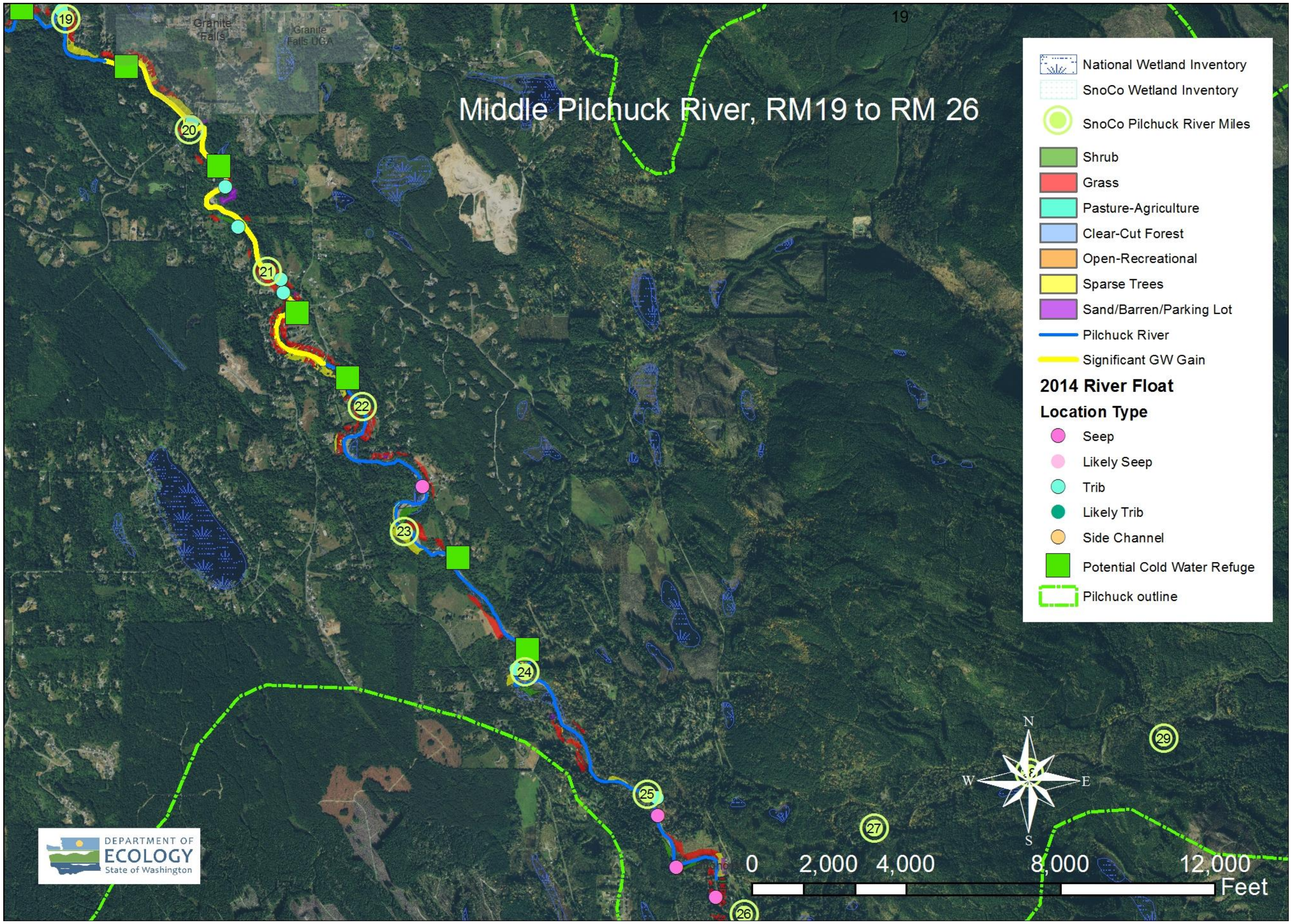

Figure 12. Middle Pilchuck implementation opportunities

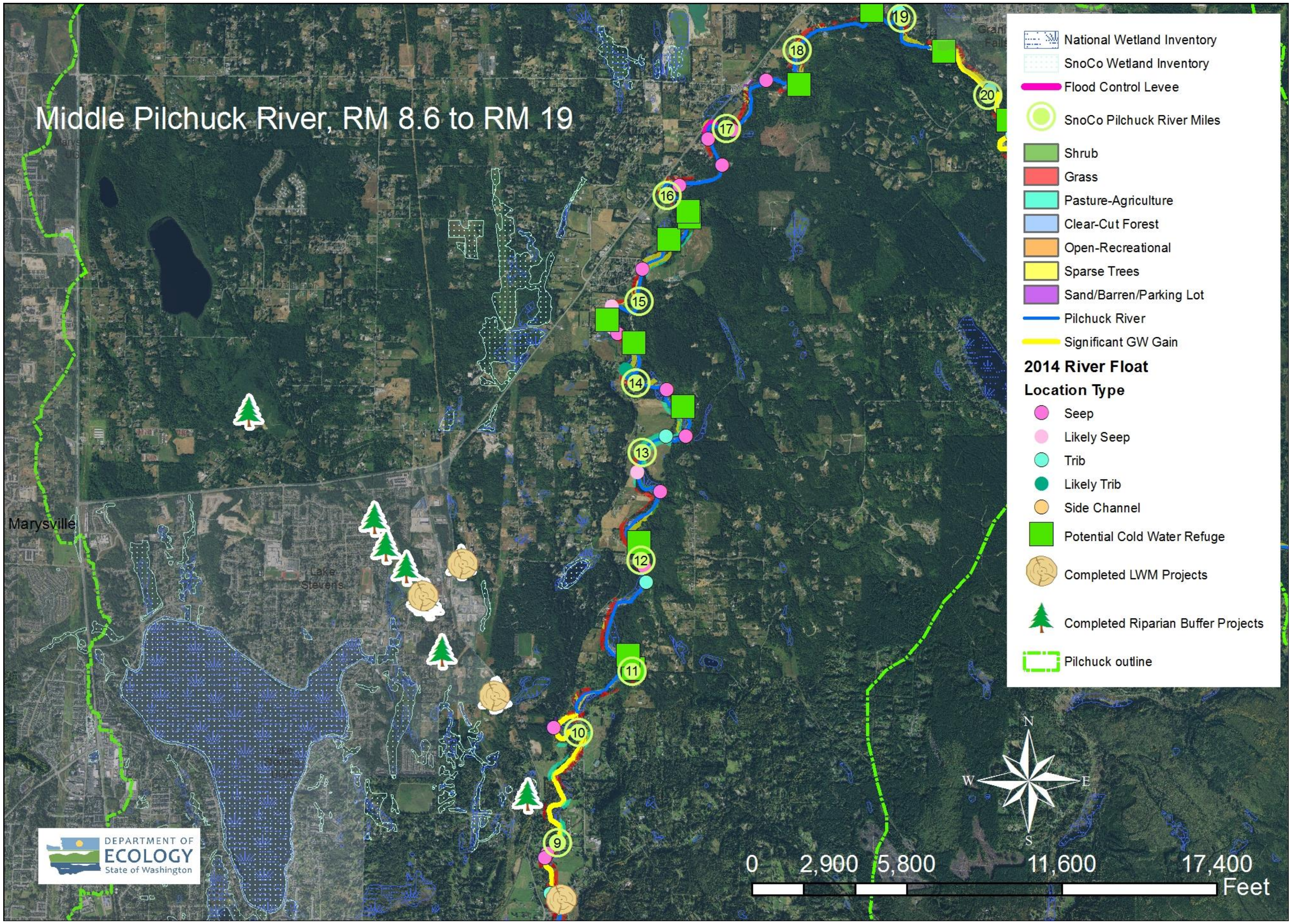

Figure 13. Middle Pilchuck RM 8.6-19 implementation opportunities

Ecology examined the 180-foot riparian buffer on each side of the mainstem Middle Pilchuck River from OK Mill Road to the diversion dam to determine the number of acres that need planting, and the number of acres that already have tree coverage or have little to no planting potential. As shown in Table 26, Ecology calculated a total riparian area of 769 acres along the Middle Pilchuck mainstem. Of this 769 acres, 204.2 acres or 27% of the total riparian area needs to be planted with trees. Over half of the total riparian area or 440.2 acres already has large-sized trees. About 13% or 101.9 acres had trees considered small or medium in height. We expect these small to medium trees to provide more shade as they increase in size over the coming decades. About 21.4 acres were comprised of roads and infrastructure that had little to no planting potential.

Table 26. Middle Pilchuck mainstem riparian areas (OK Mill Rd to diversion dam).

Land Use	Acres	% of Total Riparian Area
Total riparian area	769	100%
Areas in need of riparian planting		
Barren acres	6.3	1%
Pasture/grass/clear-cut	182.6	24%
Shrub-scrub	15.3	2%
Areas with existing tree coverage		
Medium sized trees	70.7	9%
Small sized trees	31.2	4%
Large sized trees	440.2	57%
Areas with little/no planting possibility		
Water	0.8	0%
Industrial/Power line/House	11.1	1%
Road	10.3	1%

Ecology also examined pool targets in the Middle Pilchuck and compared these targets with Snohomish County's assessment (SCSWM, 2012a)± – see Table 27. Reaches 1, 2, 3, 5, 6, 7 all meet the average pool target of 11.8 pools/km as shown in Table 25. Reaches that did not meet the average targets are discussed in the following section.

Table 27. Existing pool frequencies by Middle Pilchuck reach, as identified by Snohomish County.

Reach	Pool Frequency (pools/km)±	Difference from estimated pool target (pools/km)*
1	15.0	-3.2
2	15.2	-3.4
3	15.8	-4.0
4	10.4	1.4

Reach	Pool Frequency (pools/km)[±]	Difference from estimated pool target (pools/km)*
5	25.0	-13.2
6	13.1	-1.3
7	16.7	-4.9
8	7.2	4.6

*Estimated frequency of pools target is 11.8 pools per km (Table 25).

Reaches 8 and 7 (collectively RM 26.44 to 22.52)

Water temperatures measured about 20 feet downstream of the bridge at Menzel Lake Road went just above 16˚C early to mid-August 2012. During this same timeframe, temperatures would dip down to about 12-13˚C. Dissolved oxygen levels at RM 25.5 were lowest in August 2012, when they dipped to just above 9.5 mg/L. See Appendix D, Figure D.1 for further details.

A wider riparian buffer might be achieved between RM 25 and RM 26 (Reach 8) on the right bank between privately-owned and municipal parcels. According to ArcGIS, it appears there may be a couple of unnamed tributaries (with a seep noted at each tributary) coming in on the left bank side. This might be an area to explore for potential CWR areas for fish in concert with planting.

According to Snohomish County's Habitat Report (SCSWM, 2012a), Reach 8 contains a frequency of 7.2 pools per kilometer (Table 26) and is characterized as having few high quality pools. After further calculation, the frequency of pools target for the Middle Pilchuck segment (RM 8.70 to 25.48) is 11.8 pools per kilometer. Additional information about how the frequency of pools were calculated may be found in a preceding section in Table 25. As part of the CWR strategy, further study will be needed to determine the feasibility and prioritization of pool creation. Since Reach 8 is relatively cooler than other reaches, pool creation or enhancement might be less of a priority in this reach; however, the opportunity to assess and prioritize pools within this reach should not be overlooked, especially in the face of climate change.

In Reaches 7 and 8, there is quite a bit of large woody material (LWM) and gravel bars found downstream from RM 25 to about RM 23 that may be able to provide CWR habitat and should be explored for CWR expansion. From about RM 24 to about RM 23 (Reach 7), there are sizable and intermittent planting opportunities along the left bank as well as a couple of potential CWR spots along the right bank. Planting opportunities also exist around a meander at RM 23.

Reaches 4, 5, and 6 (collectively RM 18.32 to 22.52)

Water temperatures measured upstream of the bridge at Robe Menzel Road in Reach 6 went above 16˚C from early July to early September 2012, peaking at about 20˚C in mid-August 2012. Water temperatures peaked at 21˚C on August 18, 2016. In the morning hours, water temperatures would dip below 16˚C with the lowest water temperature measured at 15.27˚C on August 17, 2016 at 8:30 am at Robe Menzel Road. Observed temperatures fluctuated over the course of 24 hours, potentially affecting fish life during the day, less so at night... No DO results were recorded at the Robe Menzel Road in 2012; however, DO measurements taken during mid-August 2016 range from about 8.7 mg/L to nearly 10.6 mg/L.

Significant groundwater gain start from Robe Menzel Road (Reach 6) and end near City of Granite Falls (between RM 19 and RM 20 in Reach 4). Part of this gain may be due to permeable glacial outwash soils in the area. Gaining reaches are characterized as one of the hydrologic processes that create CWRs. This TMDL recommends prioritizing this gaining reach area for CWR expansion and riparian restoration opportunities. From Robe Menzel Rd to around RM 21, there may be intermittent parcels to plant both on the left and right banks. In Reach 6, there are two potential CWR sites between RM 22 and RM 21. Around RM 21.29, there are two tributaries downstream from one of the potential CWR sites in Reach 6.

About a quarter mile upstream from RM 20 in Reach 5, planting opportunities along the right bank and a potential CWR between an unnamed tributary and a riverine wetland should be explored. Bare/sparse patches were observed beyond the 180' riparian buffer on a municipal parcel that might benefit from planting to prevent erosion and promote a cooler microclimate in Reach 4. Within Reach 4, there are three intermittent clusters of small parcels that might be planting opportunities depending on landowner willingness. In between two of the parcel clusters is a potential CWR site near a seep. Downstream of RM 19, there may be small intermittent planting opportunities and a potential CWR site along the right bank. Along the left bank across from the potential CWR site is a riverine wetland. The left bank along Reach 4 generally seems to be well-vegetated with trees and should be protected.

Reach 4 is characterized in the Snohomish County habitat report (SCSWM, 2012a) as having a low frequency of pools per river kilometer at 10.4 pools per river kilometer as well as few high quality rearing pools (Table 27). High quality pools were defined in the report as pool locations within the mainstem that are ≥1.0 m in residual depth and have ≥10% cover (i.e. wood debris, boulder, riprap, brushy/overhanging vegetation). Reach 6 is also characterized as having a low frequency of pools and few high quality rearing pools by comparison to the other reaches in the Middle Pilchuck segment. However, Reach 6 has a frequency of 13.1 pools per river kilometer, which meets the Middle Pilchuck target of 11.8 pools per river kilometer (Table 27). This TMDL recommends further study to assess and prioritize pool enhancement and/or creation in both reaches.

Reach 3 (RM 14.45 to 18.32)

Intermittent planting or wetland restoration opportunities should be explored along the right bank near RM 18 to RM 17 and just downstream on the left bank. With an unnamed tributary entering the left bank, there may also be potential for a CWR and/or off-channel habitat. Downstream of RM 17 at the meander, the potential for engineered side channel creation (where a side channel could be formed in an area that is already shaded) along the left bank should be assessed.

At the meander at RM 16, WSDOT completed a project in 2016 to divert the river from SR 92 and planted the area, which will need time to grow. Downstream of RM 16, there are two areas for potential CWRs, and a sizeable opportunity for planting along the left bank to reduce bank erosion, which aligns with the priority matrix in Snohomish County's Middle Pilchuck Final Report (SCSWM, 2012c). On the right bank, a potential CWR may be fed by freshwater forested/shrub wetland and may be a source of groundwater recharge to the river. This area should be explored for expanding and connecting off-channel habitat and upland wetlands to the north where glacial outwash soil and alluvium exist, so the water being held in the wetland remains cooler for a longer time in order to increase the likelihood of groundwater/surface water exchange in the summer months when it is most needed.

At the meander upstream of RM 16 (Figure 14), a feasibility assessment for side channel or starter channel creation to the east (where there is existing tree cover) should be explored. Snohomish County noted there is mid-floodplain dike (placed in the 1940s) that fills wetland areas and alters channel processes within this reach. Dike removal should also be explored to restore wetlands and channel processes as part of a feasibility assessment (Leonetti, F. public communications. November 13, 2020).

During August 17-18 2016, DO levels above 9.5 mg/L were measured in the late morning into the afternoon about 100 feet upstream of the bridge at 64th Street (herein referred to as 64th Street). By late afternoon, DO levels begin to decrease. Water temperatures during this same time frame at 64th Street range from 16.28˚C to 21.46˚C.

After Ecology's field study in 2016, the mainstem river moved from its main channel into a side channel upstream of RM 14.45 (in Figure 14, this area is just downstream of RM 15), which is now a prime area to be protected. Since the river now appears to have good tree cover on both sides within this newly occupied side channel, this TMDL recommends review of most current orthophotography in combination with field verification to determine the channel complexity and CWR potential, including but not limited to off channel habitat or back water channel habitat connections, side channel and/or braided channel creation, as well as CWR expansion with instream structures such as LWM. A gravel bar on the tail of an island formed by the abandoned mainstem and the newly occupied side channel upstream of RM 14.45 might be a source of hyporheic cooling that should also be explored for potential CWR and BDA feasibility.

The potential to connect and restore three wetland complexes (two forested/shrub and one forested emergent) on the right bank as off-channel habitat should be explored. Riparian planting is needed on the right bank, which aligns with Snohomish County's project matrix (SCSWM, 2012c). Glacial outwash and alluvium soils are present through the abandoned meander, which may foster cooler hyporheic function. One forested/shrub wetland on the left bank that might be feeding a seep is also adjacent to a potential CWR site.

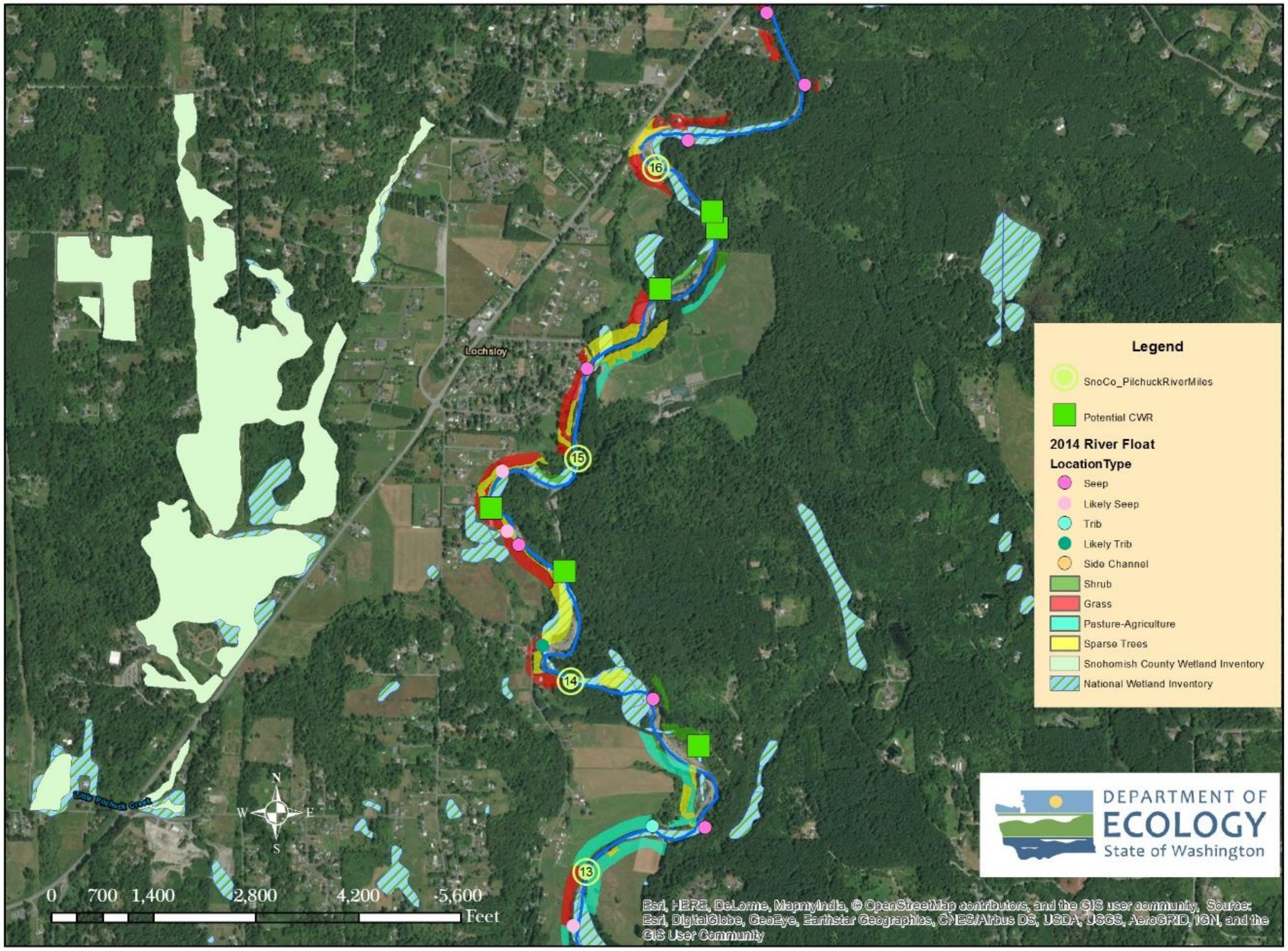

Figure 14: Middle Pilchuck wetland complex example

Reach 2 (RM 11.38 to 14.45)

Starting at about 0.3 mile from RM 14 to past RM 13, ample opportunities should be explored for planting buffers on both the right and left bank. As part of a FY 2020 Ecology grant, restoration work is currently proposed along the right bank of the large meander between RM 14 and RM 13 by Snohomish Conservation District. About 0.2 to 0.3 miles upstream, there is a tributary on the right bank and a seep on the left bank respectively. From temperature probe data, Snohomish County (Leonetti, F. Personal communication. Nov. 16, 2017 and July 28, 2020) indicated the area around RM 13 was one of the colder spots they monitored, which is thought to be due to floodplain hyporheic exchange or reach-scale flow gain in this more-confined Pilchuck river segment just downstream from the Pilchuck-Little Pilchuck outwash plain. An opportunity to shade the tributary may help bring cooler water into the Pilchuck.

Downstream of RM 13 to the next meander, intermittent opportunities should be explored to extend riparian buffers to increase the amount of cooling, mostly on the right bank, but also some spots on the left bank just before the meander. Upstream of RM 12 after the meander, we observed a seep with a potential for a CWR site. The left bank forested area around this CWR site (upstream of RM 12) should be explored for adding channel complexity such as creating side channels or back water channel habitat and adding LWM.

Left bank areas that already contain tree cover around RM 11.38 should also be explored for off-channel habitat potential. Adding more habitat complexity with well-engineered side or back water channels will help slow down flashier streamflows in the winter (lessening flood risk to nearby property owners, stream bank erosion and the need for bank armoring) and provide complex fish habitat and further cooling during the summer.

Reach 1 (RM 8.60 to 11.38)

Roughly a quarter mile upstream, riparian planting opportunities should be explored along the right bank. Just upstream of RM 11, three seeps were observed and a likely tributary. These areas contain a couple of potential CWR sites as temperatures were found to be fairly low with a series of nearby forested/shrub and riverine wetlands. There may be a few intermittent spots for riparian planting on both sides upstream of Russell Road, which require field verification.

About 30 feet upstream of the bridge at Russell Road, DO levels range from 8.5 mg/L to about 10.2 mg/L in late August 2012. Water temperature measurements were incomplete for 2012; however, in mid-August the minimum water temperatures were at or above 16˚C, peaking well above 20˚C.

From Russell Road to just downstream of OK Mill Road is a significant segment of groundwater gain. Around RM 10, Russell Road is adjacent to the river for part of the river’s meander, which might become an area of concern should the river continue towards the road and potentially impact nearby homes. The right bank appears to have more space and there may be potential to widen the buffer if the landowner goals permit. Upstream of RM 10 is a meander that appears to be newly abandoned due to channel migration; there may be an opportunity to restore this meander as a side channel or create deep backwater pools for off-channel habitat. This TMDL recommends exploring how to increase CWRs within this segment into the downstream reaches.

Little Pilchuck Creek: Water temperature measurements taken in 2012 about 200 feet downstream of bridge at 12th Street in Little Pilchuck Creek showed the following:

- Water temperatures (including 7-DADMin temperatures) exceed the supplemental spawning criteria of 13˚C in early June.
- From late June to early September, water temperatures exceed 16˚C, peaking well above 20˚C in mid-August.
- The 7-DADMin temperature exceeds 16˚C during early July to late-August.

This subbasin was observed to be dry during the subsequent 2014 and 2016 surveys. In late August 2012, DO levels never went above 9.5 mg/L, but instead appeared to remain between 8.5 to 9.0 mg/L.

Using the land-use/land-cover dataset from the USDA's National Agricultural Statistics Service,[25] Ecology examined riparian areas in the Little Pilchuck subbasin (Figure 15). Estimates indicate that 56.5% of the land cover is forested at 630 acres, followed by 21.4% development at about 239 acres and 10% wetland at 113 acres. Shrubland comprised about 94 acres and agricultural use areas about 28 acres. Ecology estimated about 361 acres of riparian area needs shade, the majority in the lower part of the subbasin around Lake Stevens. This calculation was derived by taking the sum of the barren, agriculture, shrubland and developed land use areas. Based on Ecology's Riparian Buffer Width Map,[26] most of these riparian areas are at 100-ft buffer widths; however, some areas are less than 100 ft. Ecology's analysis shows there are plenty of areas where riparian planting is needed in Little Pilchuck. This TMDL recommends review of most current orthophotography in combination with field verification to develop targeted riparian planting projects.

[25] https://nassgeodata.gmu.edu/CropScape/
[26] https://waecy.maps.arcgis.com/home/webmap/viewer.html?webmap=d5478a4aaf704d81bac63ffc934e1549

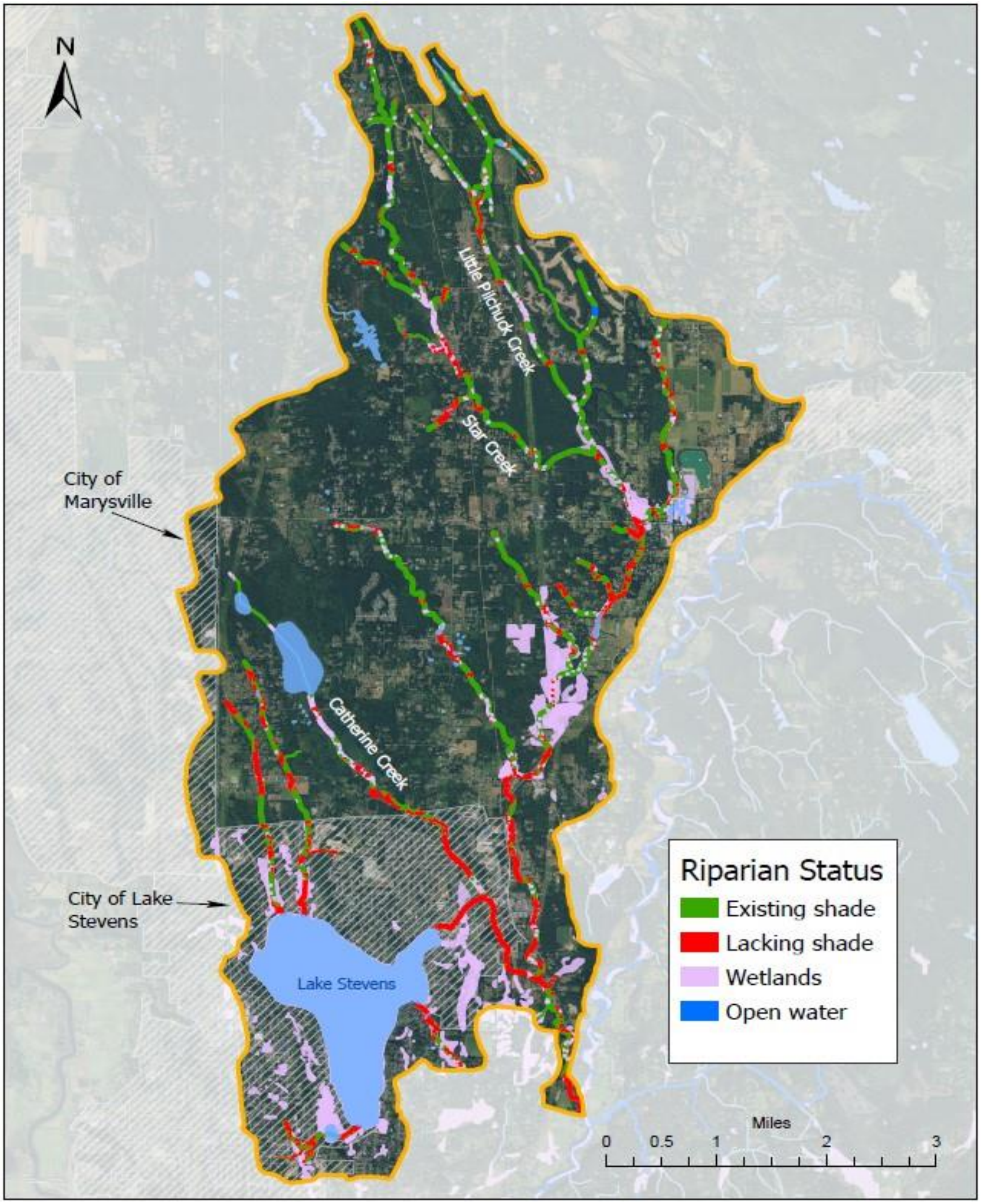

Figure 15. Little Pilchuck Creek subbasin riparian area map.

There are intermittent areas about a quarter mile upstream from RM 9 to just upstream of Little Pilchuck Creek (Sites 1-1 and 1-2) where planting is either needed or may be extended along the left bank. Planting is also needed around the confluence of Little Pilchuck Creek with the mainstem Pilchuck River on the right bank within Site 1-1. Since Reach 1, Sites 1-1 through 1-5 were found to have significant groundwater gain, further analysis should be considered for potential CWR sites or wetland expansion or restoration (Figure 16). For example, about 7 parcels northeast of Lake Stevens contain a wetland complex that may offer an opportunity to plant trees to shade the wetland and increase wetland value. Education and outreach opportunities may exist along the northeastern corner reach (see Figure 15) of the subbasin on water conservation BMPs. This TMDL also recommends exploring the feasibility for beaver management opportunities throughout this subbasin in consultation with WDFW wildlife biologists.

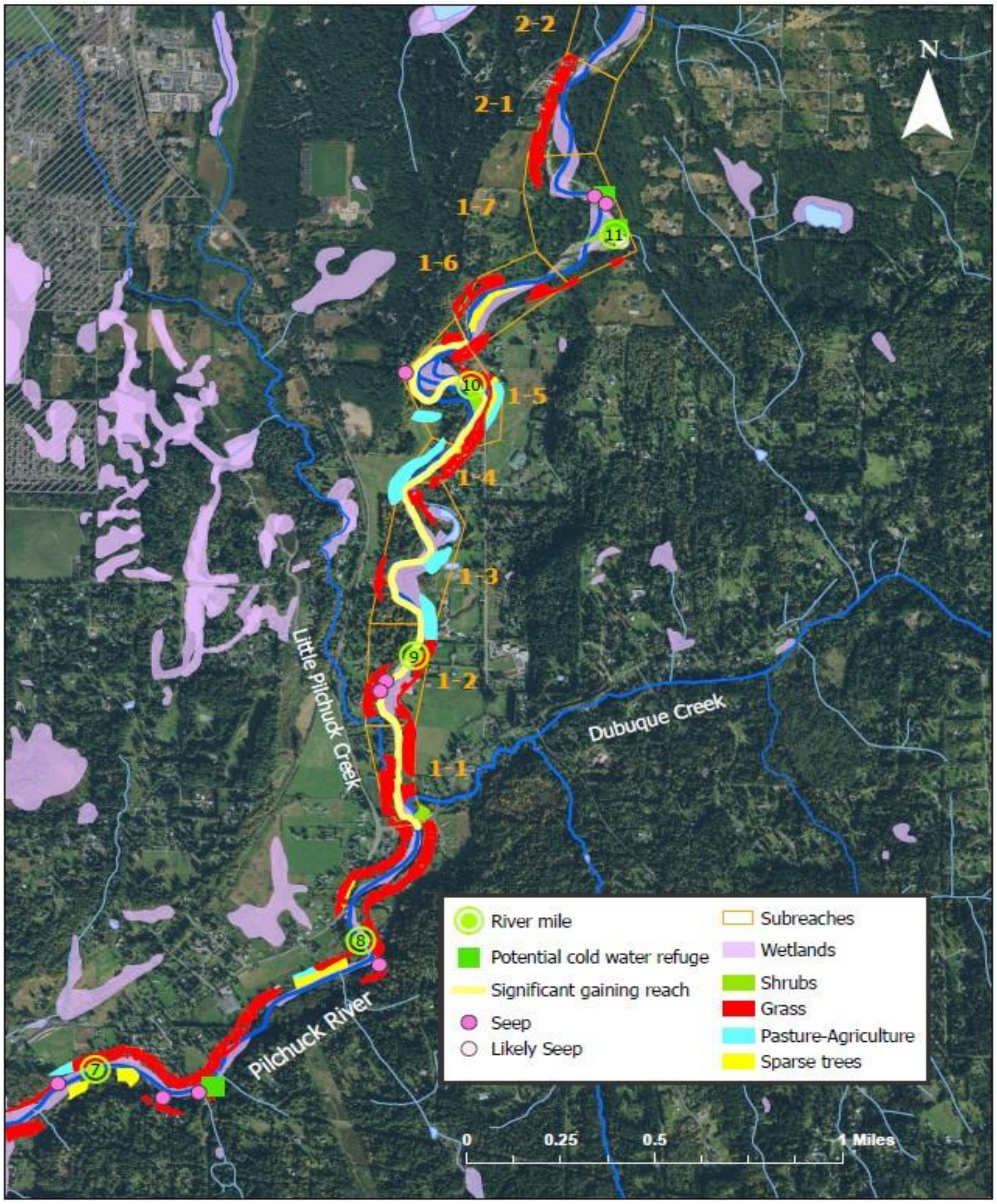

Figure 16. Sub-reach sites 1-1 through 1-5 implementation actions.

Dubuque Creek: According to the Lower Pilchuck River Assessment: Habitat Technical Report (Appendix A), water temperatures measured on Dubuque Creek showed a 7-DADMax of 19.65°C, whereas the mainstem water temperatures measured 22.45˚C in 2016 (Cardno, 2018). Even though this value exceeds the state temperature numeric criterion, this tributary was found to be 2.8˚C cooler than the mainstem; and therefore, would be a valuable CWR area for salmonids. At the mouth of Dubuque Creek, water temperatures (7-DADMax) peaked at 20˚C in early to mid-August 2012. Temperatures were at or above 16˚C from early July to about mid-September. This tributary needs to be protected as a cold-water input into the mainstem Pilchuck. Restoration and CWR opportunities for this tributary should be considered as part of this implementation plan.

Using the same land-cover/land-use dataset mentioned earlier for Little Pilchuck Creek, Ecology examined riparian areas in the Dubuque subbasin (Figure 17) comprising about 915 acres. Estimates indicate that 73% of the land cover is forested at 665.5 acres, followed by 16.5% development at about 151 acres and 5.8% shrubland at 53.4 acres. Wetlands comprised 37.4 acres and agricultural use areas about 4 acres. Ecology estimated nearly 209 acres of the riparian area needs shade. This calculation was derived by taking the sum of the barren, agriculture, shrubland, and developed land use areas. Based on Ecology's Riparian Buffer Width Map,[27] most of these riparian areas are at 100-ft buffer widths; however, some areas are less than 100 ft. Ecology's analysis shows some areas where riparian planting is needed in Dubuque Creek. This TMDL recommends review of most current orthophotography in combination with field verification to develop targeted riparian planting projects.

[27] https://waecy.maps.arcgis.com/home/webmap/viewer.html?webmap=d5478a4aaf704d81bac63ffc934e1549

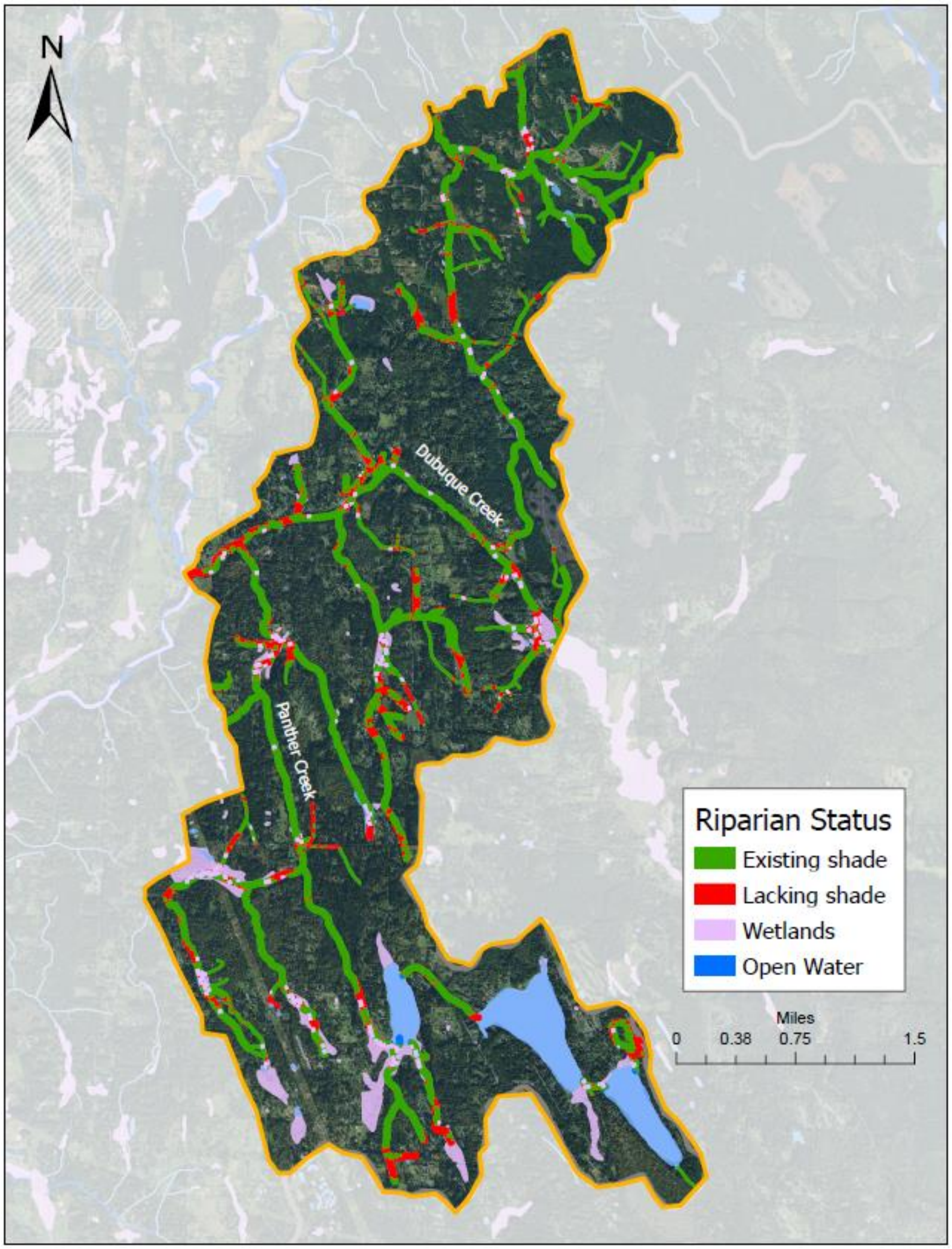

Figure 17. Dubuque Creek subbasin riparian area map

Lower Pilchuck Mainstem and Subbasins

The Lower Pilchuck River is characterized as 8.6 miles of channel from OK Mill Road to the mouth of the Pilchuck River at its confluence with the Snohomish River (Figure 18). Lower Pilchuck mainstem contains several riverine and freshwater forested/shrub wetlands with the exception of Southeast of City of Snohomish (west of Hwy 2) and south of the confluence with Snohomish River where freshwater emergent wetlands exist. The wetlands in this segment were classified as degraded (SBSRTC, 2002). Refer to Appendix K for more detailed maps and information about the stream reaches discussed later in this section.

Existing temperature conditions indicate temperatures reach acute levels for salmon just before mid-August in the lower reaches around RM 5. This emphasizes the need to prioritize the Lower Pilchuck for planting trees and other measures to cool the water.

Ecology examined the 180-foot riparian buffer on each side of the mainstem Lower Pilchuck River from OK Mill Road to the mouth to determine the number of acres that need planting, and the number of acres that already have tree coverage or have little to no planting potential. As shown in Table 28, Ecology calculated a total riparian area of 371 acres along the Lower Pilchuck mainstem. Of this 371 acres, nearly 177 acres or just under half of the total riparian area needs to be planted with trees. About 32% of the total riparian area or 118 acres in the Lower Pilchuck mainstem already has large-sized trees. About 10% of the total riparian area had trees considered small and medium in height. We expect these small and medium trees to provide more shade as they increase in size in the coming decades. About 38.1 acres were comprised of roads and infrastructure with little or no planting potential. Figure 18 illustrates the implementation opportunities including: areas needing planting, potential CWR locations and areas with existing flood control levees.

Table 28. Lower Pilchuck mainstem (below OK Mill Road) riparian areas.

Land Use	Acres	% of Total Riparian Area
Total riparian area	371	100%
Areas in need of riparian planting		
Barren acres	2.9	1%
Pasture/grass/sedge/rush	166.2	45%
Shrub-scrub	7.5	2%
Areas with existing tree coverage		
Medium sized trees	18.1	5%
Small sized trees	17.1	5%
Large sized trees	118.0	32%
Areas with little/no planting possibility		
Water	2.9	1%
Industrial/Power line/House	19.0	5%
Road	16.2	4%

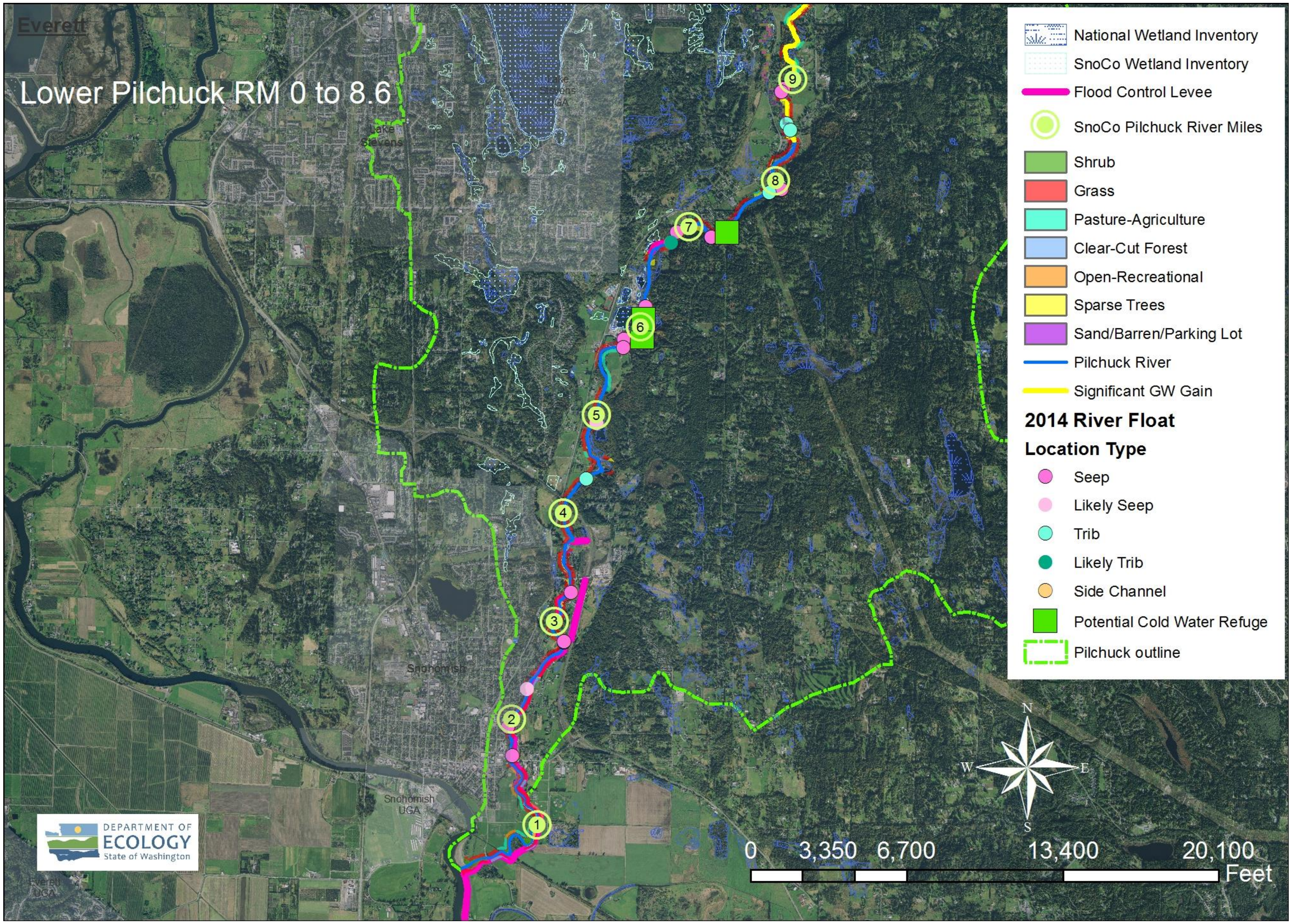

Figure 18. Lower Pilchuck River implementation opportunities.

Ecology also calculated average pool targets in the Lower Pilchuck and cross-referenced this information with Snohomish County's assessment (Cardno, 2018)± – see Table 29. With an average pool target of 19.1 pools/mile for Lower Pilchuck (Table 29), Reaches 4, 6, 7 and 8 in the Lower Pilchuck need to increase quantity of pools as part of the CWR strategy. This TMDL recommends further study to assess and prioritize pool enhancement and/or creation in these four reaches.

Table 29. Existing pool frequencies by Lower Pilchuck reach, as identified by Snohomish County.

Reach	Pool Frequency (pools/mile)±	Difference from estimated pool target (pools/mile)*
1	19.1	0.0
2	19.9	-0.8
3	21.1	-2.0
4	11.5	7.6
5	19.0	0.1
6	13.4	5.7
7	11.7	7.4
8	12.1	7.0

*Estimated frequency of pools target is 19.1 pools per mile (Table 25).

Reach 8 (RM 7.23 to 8.60): Water temperatures measured about 25 feet downstream of the OK Mill Road bridge exceed 16˚C from early July to mid-September, with the 7-DADMax peaking at 21.36˚C on August 15, 2012. The 7-DADMin well-exceeded 16˚C in mid-August 2012. On August 18, 2016, the water temperature peaked to just above 22.5˚C, which nearly exceeding the one-day maximum temperature adult lethality criteria of 23˚C.

Downstream of OK Mill Road Bridge, a planting opportunity should be explored on about 5 parcels along the right bank. About three parcels on the left bank have residential homes within about 75 to 80 feet from the river, so planting opportunities may be intermittent until the meander after RM 8. Another five postage stamp parcels along the right bank near RM 8 have structures too close to the river to warrant planting. Where sand/barren/parking lots were observed along some of these parcels on the right bank, stormwater BMPs might be explored.

Before RM 8 on the right bank (within Reach 8), a considerable opportunity to plant on about five parcels should be explored as well as provide technical assistance to reduce barren areas. Intact riparian vegetation communities will help reduce loose sediment that may find its way to the river. For the most part, the left bank seems to have adequate buffers between RM 8 and RM 7 with about five isolated parcels that either have no tall vegetation or have sparse trees. Four tributaries were observed along this stretch as well as a few seeps.

Reaches 6 and 7 (collectively RM 5.83 to 7.23): Roughly 0.3 miles after RM 7 is a potential cold water refuge between two observed tributaries and upstream from an observed seep. At least 20 parcels along the right bank have building structures within about 50 feet of the river after RM 7 with limited buffer possibilities.

From about RM 7 in Reach 7 to Dubuque Road, there are several freshwater forest/shrub and riverine wetland; and freshwater pond complexes on both the right and left banks, which might contribute cooler water as seeps and associated tributaries. Just before and after RM 6 on the left bank are two potential cold water refuge areas (Figure 19). Areas near both Reaches 6 and 7 should be investigated for potential wetland restoration and cold water refuge expansion opportunities. Extensive wetland and freshwater pond complexes may bring in cooler water in the form of observed seeps that create potential cold water refuge areas and enhance hyporheic function as well as possible off-channel habitat connection. There were observed barren areas along the right bank adjacent to wetland complexes that might benefit from potential technical assistance if landowner goals permit.

According to the Lower Pilchuck assessment, there are levees that were used for gravel mining. Although active gravel mining still exists, there might be opportunities to explore levee setback, removal or modification depending on current use and landowner willingness. The assessment also noted Reach 6 as the highest priority reach for small scale LWM or engineered log jam enhancement (Cardno, 2018).

Reaches 3, 4, and 5 (collectively RM 2.90 to 5.83): Water temperatures measured 150 feet downstream of Dubuque Road bridge show temperatures (including 7-DADMin) exceeding 16˚C in mid-August 2012. Temperatures remain above state standards until mid-September 2012. Data taken on August 18, 2016, indicates the highest water temperature at 22.45˚C, and coming close to exceeding the 1-day maximum temperature adult lethality criteria of 23˚C.

Along the left bank downstream from Dubuque Road, there might be a planting opportunity. Reach 5 also has a few parcels with potential planting opportunities after RM 5.

Before RM 5, there was a potential seep observed that is likely coming from a couple of freshwater ponds on the left bank. Between RM 5 and Hwy 2, there are about 8 parcels that appear to need more riparian shading along the right bank. Near RM 4 (south of Hwy 2 to Three Lakes Rd), there are a mix of private and municipal parcels that need to be planted. There are about 11 residential parcels that may be limited in planting possibility along the left bank.

Water temperatures measured about 25 feet upstream of the Three Lakes road bridge show the highest temperature at 22.63˚C on August 18, 2016, nearly exceeding the 1-day maximum temperature adult lethality criteria of 23˚C. South of Three Lakes Road, residential properties are in close proximity to the river, which limit planting opportunities. At about RM 3, a few intermittent opportunities for planting should be investigated. State Highway 2 and Orchard Avenue are protected by flood control levees in this stretch. There is a meander upstream of Old Snohomish/Monroe Road that should be explored for engineered side channels in order to create a potential CWR spot for fish on the south-east side.

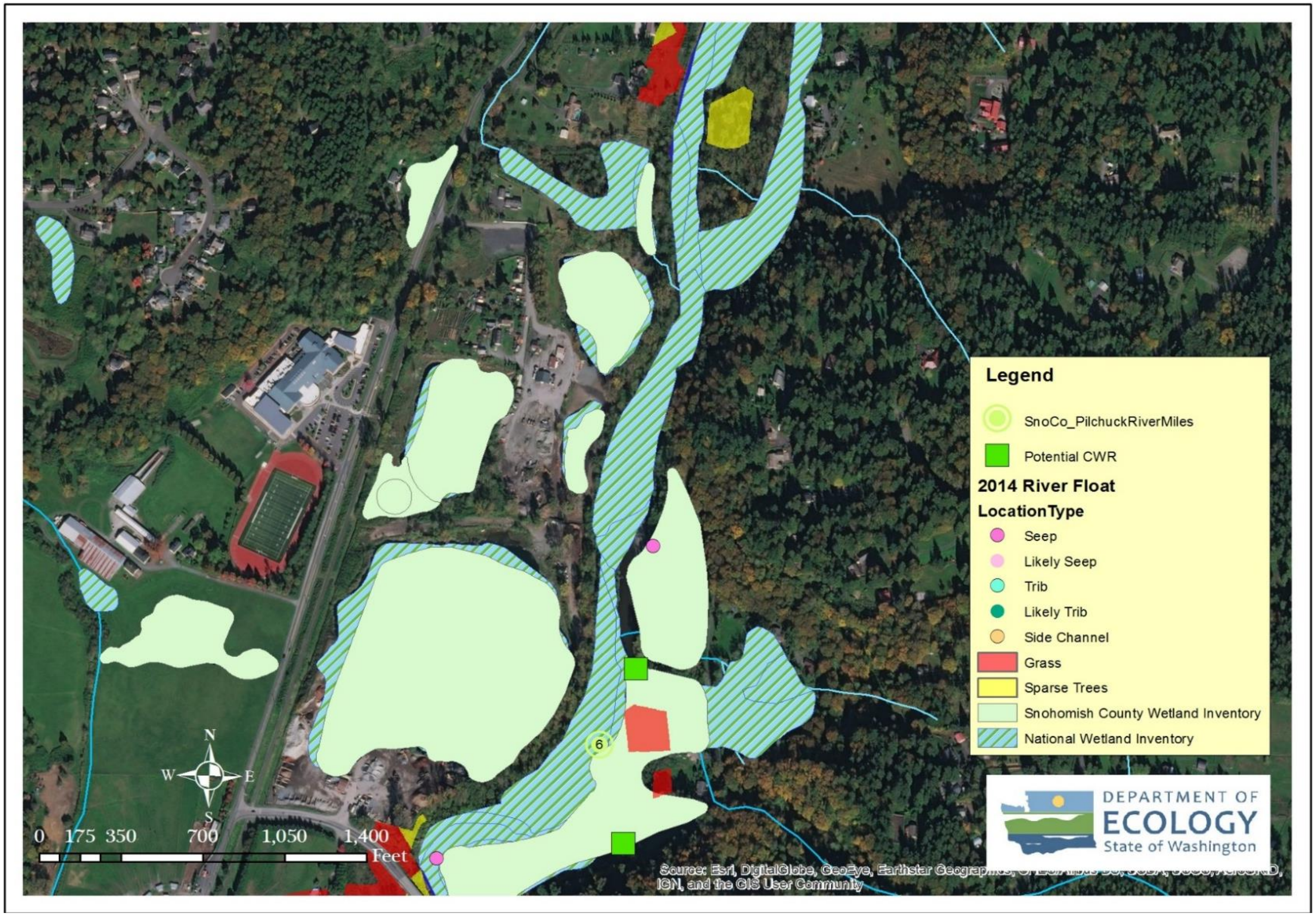

Figure 19: Lower Pilchuck wetland complex example

Reaches 1 and 2 (collectively RM 0 to RM 2.90): Water temperatures measured about 80 feet upstream of the 6th Street bridge show temperatures (including 7-DADMin) exceeding 16˚C in mid-August 2012. Temperatures continue to exceed state standards into mid-to-late September 2012.

There is a long stretch of flood control levee downstream from an unnamed tributary out to the confluence with Snohomish River. The levee continues south down Snohomish River protecting agricultural land. There is little to no tree cover the whole stretch down on both left and right banks. South of Hwy 2, the technical report (Chapter 4, Section 4.5, Figure 49) shows a shade deficit starting at 20-30% and up. On the right bank near RM 2 (south of 6th Street bridge), there may be little opportunity for planting due to the proximity of about 14 residential postage stamp parcels to the river. Around the RM 2, there are about 4 parcels along the left bank that appear to be a Snohomish County park area that was called out in the Lower Pilchuck assessment for levee setback and floodplain reconnection. Riparian restoration should be considered in concert with floodplain reconnection.

As shown in Table 57 and Figure 58, RM 2 through 5 (roughly Reaches 2 through 5) is a priority area cited as most in need of shade with RM 2, RM 4, and RM 5 showing the three highest percentages of shade increase needs along the mainstem Pilchuck River. This area should be investigated for riparian shading and LWM opportunities as well as the feasibility for levee setbacks. The Lower Pilchuck assessment calls out a Snohomish County parcel in Reach 1 upstream of Old-Snohomish Monroe Rd that should be explored for levee setback feasibility in concert with riparian restoration (Cardno, 2018).

Organizations that Implement TMDLs

U.S. Environmental Protection Agency

The 1997 Memorandum of Agreement between the U.S. Environmental Protection Agency (EPA) Region 10 and Ecology requires that EPA and Ecology jointly evaluate the implementation of TMDLs in Washington State. These evaluations will address whether interim targets are being met, whether implementation measures such as BMPs have been put into effect, and whether NPDES permits are consistent with TMDL wasteload allocations (WLAs). EPA provides technical assistance and funding to states and tribes to implement the Clean Water Act (CWA). For example, EPA’s CWA Section 319 grants are combined with Ecology’s grant and loan funds and are made available to stakeholders through Ecology’s annual Water Quality Combined Financial Assistance process. On occasion, the EPA also has other grant monies available (CWA 104(b) (3)) to address stormwater pollution problems.

Tulalip Tribes

The Tulalip Tribes is a federally recognized Indian Tribe with tribal lands located near the mouth of the Snohomish River. As signatories of the Treaty of Point Elliott of 1855, the Tulalip Tribes' adjudicated usual and accustomed area extends from the Canadian border south to Vashon Island and includes the Snohomish/Snoqualmie/Skykomish watersheds. The Tribe has a continuous interest in activities taking place outside of the reservation, particularly those that might affect the Tribes' cultural and archaeological resources and treaty-protected fishery resources.

The Tulalip Tribes share a common interest in and responsibility for the protection and enhancement of the environment as well as the protection of cultural and archaeological resources. The Tribe focuses its resources in the Pilchuck River watershed on activities related to salmon recovery including pollution source identification and control, and salmon recovery implementation.

Washington State Department of Ecology

Ecology performs the following three activities that help to control thermal pollution inputs to the Pilchuck River watershed:

- Issues National Pollutant Discharge Elimination System (NPDES) permits for wastewater treatment plants and other point source discharges. These permits will implement the wasteload allocations (WLAs) set for the Granite Falls WWTP in the Pilchuck River watershed.
- Administers the total maximum daily load (TMDL) program, which prepares studies, reports, and provides technical assistance to organizations implementing water improvement activities.
- Provides competitive grant funding to correct point and nonpoint pollution problems through the Combined Financial Assistance, Terry Husseman Account and Streamflow Restoration Implementation grant programs.

Washington Department of Fish and Wildlife

The mission of the Washington Department of Fish and Wildlife (WDFW) is to provide sound stewardship of fish and wildlife. The health and well-being of fish and wildlife is important not only to the species themselves, but to humans as well. Often, when fish and wildlife populations are threatened, their decline can predict environmental hazards or patterns that also may have a negative impact on people.

The WDFW provides technical assistance regarding the design of restoration projects, prepares hydraulic permit approvals (HPAs), and participates in various watershed activities to help craft and implement sound watershed management policies.

Washington State Department of Natural Resources

The Washington State Department of Natural Resources (DNR) manages activities on private and State Trust forestlands in the Pilchuck River watershed. Regulations administered by DNR protect existing mature riparian vegetation and allow for creation of intact riparian forests where they do not currently exist.

DNR provides a number of valuable services to public and private forestry professionals. Relatively new tools designed to help foresters to identify areas where road building and harvesting can create a high risk to the environment include their Landslide Inventory and Landslide Hazard Zone analyses. Technical assistance to forest owners of all sizes is also available.

An important DNR program aimed at controlling sediment discharges from large private and State Trust forest lands is the Road Maintenance and Abandonment Program (RMAP). Under RMAP, all large industrial landowners, including DNR State Lands, were required to have submitted an inventory and rehabilitation plan for all roads within their ownership by December 31, 2005. These landowners had 15 years from that date to fix all identified issues. The issues specifically targeted by this program include road-related fish blockages and road segments on unstable slopes. To help address fish passage and protections in smaller forest parcels, small forest landowners can take advantage of programs including:

- The Family Forest Fish Passage Program[28] is a cost-share program designed to assist private forestland owners with removing culverts and other stream crossing structures related to forest roads.
- The Forestry Riparian Easement Program[29] is a voluntary program that reimburses landowners for the value of trees they are required to leave to protect fish habitat.

[28] https://www.dnr.wa.gov/node/570
[29] https://www.dnr.wa.gov/programs-and-services/forest-practices/small-forest-landowners/forestry-riparian-easement-program

Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) permit covers stormwater discharges from WSDOT's MS4 in areas covered by the Phase I Municipal Stormwater Permit[30], the Eastern Washington Phase II Municipal Stormwater Permit, and the Western Washington Phase II Municipal Stormwater permit, and EPA-approved TMDLs in which WSDOT has a wasteload allocation. WSDOT implements a Stormwater Management Program Plan and submits annual compliance reports and monitoring data to Ecology. Data is also available for WSDOT-led research and research in which WSDOT was a partner.

WSDOT has an Implementing Agreement[31] with Ecology to apply the Highway Runoff Manual[32] (HRM) statewide, which provides design requirements stormwater for WSDOT's stormwater facilities. The HRM has been approved by Ecology as functionally equivalent to the Stormwater Management Manual for Western Washington.

Currently, WSDOT is in the process of working on fish barriers that are partially or fully blocked. Four fish barriers along State Route 2 are scheduled for design during 2021-2023 to improve fish passage. Also, WSDOT places great importance on protecting wetlands and have 5 designated compensatory mitigation sites within the Pilchuck River watershed.

Puget Sound Partnership

The Puget Sound Partnership (the Partnership) works to restore and protect the biological health and diversity of Puget Sound by restoring habitat functions and values; reducing the level of toxic chemicals, nutrients, and pathogens entering Puget Sound fresh and marine waters; improving water quality and habitat by managing stormwater runoff; ensuring adequate instream flows; protecting ecosystem biodiversity; and building and sustaining the capacity for taking action. The Partnership works with several boards and councils to guide and oversee progress in cleaning up Puget Sound and carry out the 2007-2009 Puget Sound Conservation and Recovery Plan and the Puget Sound Action Agenda.

Partnership staff specialize in many important areas such as stormwater management, salmon recovery, and education and outreach to the public. These staff work directly with tribal and local governments, community groups, citizens and businesses, and state and federal agencies.

[30] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Stormwater-general-permits/Municipal-stormwater-general-permits/WSDOT-Municipal-Stormwater-Permit
[31] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Stormwater-general-permits/Municipal-stormwater-general-permits/WSDOT-Municipal-Stormwater-Permit
[32] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Stormwater-general-permits/Municipal-stormwater-general-permits/WSDOT-Municipal-Stormwater-Permit

Snohomish Conservation District

The Snohomish Conservation District (SCD) works with landowners and livestock owners throughout Snohomish County to develop resource management plans. A principal focus of their work is surface water protection. The SCD provides information and services including, but not limited to, riparian and instream restoration, soils, water quality, livestock husbandry, backyard conservation, pasture management, nutrient management, and residential low impact development (LID) retrofits.

The SCD provides technical assistance, farm plans, and cost-share funds to help implement BMPs using county, state, and federal funds. BMPs that can contribute to reducing local water temperatures include fencing livestock out of streams and planting riparian buffers.

Snohomish County

The activities of several branches of Snohomish County Government can affect the overall water quality in the Snohomish watershed. Many water quality related activities are carried out by Snohomish County Public Works—Surface Water Management, which performs pollution identification, prevention, and control activities as well as salmon recovery efforts. Snohomish County Planning and Development Services are also very important as the department oversees building and land development activities and performs enforcement. Each organization is discussed in more detail below.

Snohomish County Public Works--Surface Water Management:

Surface Water Management (SWM) is involved in a wide range of water pollution control activities including education, water quality monitoring, riparian restoration, salmon recovery, and NPDES permit administration. SWM activities in the Pilchuck River watershed are largely coordinated through their salmon recovery efforts. The County also has the following programs and projects in place to improve water quality in the Pilchuck River watershed:

- Education, conducted through targeted programs as well as through the activities of Watershed Stewards.
- A Water Pollution Control Ordinance (Chapter 7.53 Snohomish County Code), which prohibits the discharge of pollutants to County streams.
- Coordination and support for the Snohomish Basin Salmon Recovery Forum and Snohomish Basin Salmon Recovery Technical Committee and their goals of increasing salmonid populations and improving habitat quality and quantity throughout the basin.
- Riparian restoration, instream restoration and stormwater BMP work through discretionary and grant funding.
- State of Our Waters – chemical, physical and biological monitoring of randomly selected rivers, streams and lakes. Continuous temperature monitoring, conducted in accordance with Ecology protocols in receiving waters across unincorporated Snohomish County.

- Implements County's NPDES municipal stormwater permit requirements related to drainage facility operation, water quality issues and education and outreach programs.

Snohomish County Planning and Development Services:

Snohomish County Planning and Development Services (PDS) develop and administer county regulations for commercial and residential development as well as public projects. PDS also enforces the Snohomish County Code as it relates to protection of water quality, implements the Critical Areas Regulations, its Shoreline Master Program and other development regulations, and works closely with the agricultural community through its agricultural liaison and the Agricultural Advisory Board.

Along with other parts of Snohomish County Government, PDS is promoting LID principles and has folded LID provisions into its drainage code where the use of LID facilities and BMPs are required where functionally feasible (Ordinance 30.63A). The county helps sponsor the Sustainable Development Task Force, which is a public/private partnership dedicated to the adoption of strategies that protect the environment by promoting the wise use of building materials, energy efficiency, and the reduction or elimination of stormwater. PDS and SWM are working with the agricultural community to develop and implement the Sustainable Lands Strategy (SLS), which seeks to reconcile the land-based needs of agriculture and habitat restoration activities in Snohomish County and find net gains for both of these county needs.

Under requirements of the Growth Management Act (GMA) and the Shoreline Management Act (SMA), Snohomish County protects sensitive areas through its Critical Areas Regulations (CAR) and Shoreline Master Program (SMP), respectively. The CAR became effective in 2007 and include protections for riparian buffers and wildlife habitat along streams and areas of groundwater recharge, such as wetlands, that can influence streamflow and temperature. Critical areas within shoreline jurisdiction are protected by incorporating CAR into the SMP by reference. Through these regulations, the County continues to protect and enhance wetlands and fish and wildlife conservation areas; and includes monitoring and adaptive management amongst a suite of strategies in its plans and programs. Under the GMA, the County is required to update its CAR every seven years, and under the SMA, the county is required to update the SMP every eight years.

Snohomish County adopted a Critical Areas Ordinance (Chapter 30.62A.620-640) that specifically addresses standards and conditions relating to commercial agriculture. The ordinance requires the use of agricultural BMP’s to protect the functions and values of wetlands and fish and wildlife conservation areas. When reviewing critical areas pertaining to aquatic habitat, the County must consider this TMDL, and subsequently the pronounced impacts of lack of shade on water temperature, DO and the state water quality standards, as best available science.

Snohomish Basin Salmon Recovery Forum

Formed in 1998, the Snohomish Basin Salmon Recovery Forum is a 40+ member voluntary, non-partisan coalition of local government representatives, tribal representatives, non-governmental organization representatives, citizens, business representatives and representatives from special purpose districts and interest groups who guide conservation efforts in the Snohomish River basin. The Forum's mission is to protect and restore the ecological health of the Snohomish River Basin including biodiversity, hydrology and water quality to enhance the productivity and diversity of all wild salmon stocks in the Snohomish River basin by putting the Snohomish River Basin Salmon Recovery Conservation Plan (Conservation Plan) into action. Initially, the Forum focused on salmon recovery planning and early implementation actions to help restore Chinook populations. With the completion of the Conservation Plan in June 2005, the Forum's role evolved to the following:

- Serve as the Snohomish Basin lead entity citizens' committee.
- Promote implementation of the Conservation Plan by participation agencies, organizations, and interests.
- Monitor implementation and adaptively manage the Conservation Plan over time.
- Advocate for continued funding and identify new sources of funding to implement the Conservation Plan.
- Provide a forum for local governments and organizations to coordinate and communicate about watershed issues. This includes discussing differing viewpoints and identifying common ground about watershed topics, as well as providing policy guidance and basin-level context and strategies.
- Respond to Endangered Species Act listings at the local level.
- Actively engage with the Puget Sound Partnership and Stillaguamish-Snohomish Local Integrating Organization to implement the Action Agenda for Puget Sound.

City of Granite Falls

CITY OF GRANITE FALLS

The City of Granite Falls operates a wastewater treatment plant (WWTP) and stormwater management system. The Granite Falls WWTP National Pollutant Discharge Elimination System (NPDES) permit is discussed earlier in the report in the Wasteload Allocation section. Since the primary source of DO impairment is predicted to come from periphyton (bottom algae) due to an increased loading of soluble reactive phosphorus (SRP), Granite Falls will be required to meet a seasonal (from June 1 to September 30) wasteload allocation (WLA) for SRP to address DO. In addition, Granite Falls will continue to be required to meet a seasonal WLA for BOD5. Granite Falls will also be required to meet WWTP discharge tiered temperature WLAs (year-round). Granite Falls will be required to conduct WQ monitoring of their outfalls near the WWTP to ensure they meet these allocations. All aforementioned WLAs established in this TMDL will be expressed as needed in their NPDES permit.

In September 2016, Granite Falls completed a Phase I project to install pervious pavement in its downtown area to treat stormwater runoff from about 1.43 acres for total suspended solids, dissolved copper, dissolved zinc and total phosphorus before discharging to Lake Gardner and eventually to Pilchuck and Snohomish river systems. The City completed an adjacent Phase II pervious pavement project on about 0.48 acres in February 2019.

Under the GMA and the SMA, the City is required to update its Critical Areas Ordinance (CAO) on a periodic basis to protect critical areas. When reviewing development regulations and the CAO pertaining to aquatic habitat, the city must consider this TMDL, and subsequently the pronounced impacts of lack of shade on water temperature, and the state water quality standards, as best available science. This TMDL meets and exceeds the criteria for best available science for water temperature and dissolved oxygen impairments of the Pilchuck River watershed provided under WAC 365-195-905.

The City should review development codes to make sure that LID approaches can be incorporated into development designs.

City of Lake Stevens

The City of Lake Stevens operates a stormwater management system. The City and Snohomish County developed a phosphorus management plan for Lake Stevens in 2013 to identify how it plans to control high nutrient loading resulting in unwanted algal blooms. The City partnered with Adopt-A-Stream Foundation to implement several riparian restoration projects from 2013 to 2015.

Under the GMA and the SMA, the City is required to update its Critical Areas Ordinance (CAO) on a periodic basis to protect critical areas. When reviewing development regulations and the CAO pertaining to aquatic habitat, the City must consider this TMDL, and subsequently the pronounced impacts of lack of shade on water temperature, and the water quality standards, as best available science. This TMDL meets and exceeds the criteria for best available science for water temperature and dissolved oxygen impairments of the Pilchuck River watershed provided under WAC 365-195-905.

City of Marysville

The City of Marysville borders the Pilchuck River watershed on the west with a sliver of jurisdiction within the watershed. The City does not currently operate any stormwater systems within the watershed. In the event that growth management planning expands their jurisdiction further into the Pilchuck River watershed, the City must consider this TMDL and subsequently the pronounced impacts of lack of shade on water temperature, and the water quality standards, as best available science. This TMDL meets and exceeds the criteria for best available science for water temperature and dissolved oxygen impairments of the Pilchuck River watershed provided under WAC 365-195-905.

City of Snohomish

The City of Snohomish operates a stormwater management system. In 2017, the City partnered with Snohomish County and Environmental Coalition of South Seattle on public outreach programs related to pet waste, natural yard care, and septic system operation and maintenance as part of their NPDES Phase II permit. The City of Snohomish requires the Stormwater Management Manual for Western Washington to be used for new construction and redevelopment projects as part of their stormwater management regulations. In 2009 and 2016, the City of Snohomish adopted ordinances to promote the use of low impact development best management practices (BMPs) (Ordinance No. 2173 and Ordinance No. 2315).Under the GMA and SMA, the City is required to update its Critical Areas Ordinance (CAO) on a periodic basis to protect critical areas. When reviewing development regulations and the CAO pertaining to aquatic habitat, the City must consider this TMDL, and subsequently the pronounced impacts of lack of shade and decreased baseflow on water temperature, and the water quality standards, as best available science. This TMDL meets and exceeds the criteria for best available science for water temperature and dissolved oxygen impairments of the Pilchuck River watershed provided under WAC 365-195-905.

Adopt-A-Stream Foundation

ADOPT A STREAM FOUNDATION & NORTHWEST STREAM CENTER

The Adopt-A-Stream Foundation (AASF) is a private 501(c)(3) nonprofit organization based in south Everett, Washington. Evolving from the Adopt-A-Stream Program created in 1980, AASF's mission is to "teach people how to become better stewards of their watersheds" including the importance of 3,000 miles of creeks, streams and rivers in Snohomish County.

AASF carries out its mission by producing and distributing environmental education materials nationally and internationally, conducting Streamkeeper Academy™ events for school and community groups throughout the Pacific Northwest, and providing local communities with stream and wetland restoration assistance. In addition, AASF developed the Northwest Stream Center, a regional environmental learning facility that has stream and wetland ecology and fish and wildlife habitat as its central themes. AASF's long-term goal is to stimulate everyone to become a Streamkeeper™, taking actions necessary to protect and enhance their home watersheds.

AASF conducted several restoration projects with Ecology grant funding within the Pilchuck River watershed, all within the City of Lake Stevens. From 2013 to 2015, AASF conducted a suite of restoration projects referred to as Little Pilchuck Streamkeepers. These projects ranged from 2,000 square feet to just over an acre at 12 private properties and 2 public properties along Catherine Creek and Little Pilchuck Creek. From 2014 to 2017, AASF planted 12 acres along Catherine Creek. AASF completed a project in Upper Catherine Creek to restore 8.2 acres in 2019. About 30% of total stream length of Catherine Creek has riparian restoration projects with buffer widths ranging from 35-foot to 100-foot implemented by AASF.

Ducks Unlimited

DUCKS UNLIMITED

Ducks Unlimited (DU), a 501 (c)(3) nonprofit, is considered a world leader in waterfowl and wetland conservation. DU got its start from a small group of sportsmen in 1937 during the dust bowl era when droughts plunged waterfowl populations into all-time lows. Since then, DU has conserved more than 14 million acres in North American including 69,000 acres in Washington State. In Western Washington, DU is focused on wetland conservation activities and on sustaining wildlife-friendly farming practices.

On working farmlands, DU improves infrastructure to make water management more dependable and economical, while also mimicking natural wetland functions such as wildlife habitat and water quality benefits. DU also restores natural processes to conserve wetland, stream, beaver, oak and prairie, and estuarine habitats. With a staff of biologists, engineers, regulatory specialists and fundraisers, DU provides funding, technical expertise, and implementation support to project partners and proponents. DU is also one of the nation's largest accredited land trusts, holding conservation easements on more than 400,000 acres.

Sound Salmon Solutions

SOUND SALMON SOLUTIONS

Sound Salmon Solutions (originally known as Stilly Snohomish Fisheries Enhancement Task Force) is a 501 (c)(3) nonprofit regional fisheries enhancement group that supports salmon recovery in Stillaguamish, Snohomish, and south Island Counties. Base funding for Regional Fisheries Enhancement Group activities comes from a grant from US Fish and Wildlife Service's Partners for Fish and Wildlife Program and fee-for-service and sales programs administered by Washington Department of Fish and Wildlife.

Sound Salmon Solutions connects people to their watershed through interactive education, hands-on stewardship, and stream habitat restoration.

Washington Water Trust

WASHINGTON WATER TRUST
Working to restore our state's rivers and streams.

Washington Water Trust (WWT) works to improve and protect streamflows and water quality throughout Washington State that benefit agriculture, fisheries, and wildlife by using innovative, market-based transactions and cooperative partnerships to create balanced solutions. Since 1998, WWT has worked successfully to restore streamflows that sustain the fisheries, water quality and recreational resources vital to our quality of life in the Northwest. WWT has been a leader in river restoration with 30 years of collective experience in water rights due diligence and water management alternatives. This agency was added here as an additional resource for partnerships, project sponsorship and consultation as it relates to streamflow augmentation actions cited in this TMDL.

Wild Fish Conservancy

The Wild Fish Conservancy (WFC) is a nonprofit, conservation-ecology organization dedicated to the preservation and recovery of the Northwest's native fish and ecosystems. The WFC seeks to improve conditions for all of the Northwest's wild fish by conducting important research on populations and habitats; advocating for better land-use, salmon-harvest, and hatchery management; and developing model habitat-restoration projects. The WFC has performed stream relocation and restoration projects.

Priorities and Timeline

Important TMDL priorities and reach-specific actions are described in greater detail in the previous "Nonpoint Sources of Pollution and Opportunities for Improvement" section.

General priorities and reaches include:

- Riparian plantings in the Lower Pilchuck River and the tributaries. The hottest summer temperatures occur in Lower Pilchuck, can exceed acute lethality criteria guidance, and present a potential thermal barrier to migrating salmon. Tributaries more narrow than the mainstem will likely be easier to shade.
- Cold water refuge enhancement in the lower half of Pilchuck River and in the tributaries.
- Baseflow restoration in the Little Pilchuck Creek subbasin. Restoring cold natural baseflow to this important tributary will not only cool the mainstem Pilchuck, but also restore summer connectivity and create a valuable cold water refuge.

Riparian Restoration

To achieve clean water in the Pilchuck River, meet water quality standards, and support aquatic life uses, it is necessary to restore riparian forest areas and implement restoration projects that benefit streamflow, stream temperatures and DO. Riparian forest restoration should target areas with shade deficits greater than 30%, especially in Lower Pilchuck from about RM 0 to RM 12.

While there are relatively few agricultural lands in this watershed, Ecology recognizes planting a large riparian buffer may be impractical and pose a significant challenge to small farms, who are conflicted between the need to shade local waters versus the need to maximize sunlight and growing area on their land. Local regulators are also conflicted because activities that assist farmers (e.g., draining groundwater through ditches and drain tiles and tree removal) can result in a loss or degradation of fish habitat. This TMDL encourages exploration towards balancing agrarian values with environmental needs by incorporating landowner parcel-specific knowledge into riparian restoration design and fostering educational opportunities between local regulators and farms alike. Holistic collaboration may help boost creative win-win solutions that elevate landowner willingness and participation (Chapman, Satterfield, and Chan, 2019).

This TMDL recommends that farmers plant the largest reasonable buffer possible. The USDA Conservation Reserve Enhancement Program provides payments to farmers to assist in the financial impact of losing arable land when improving riparian vegetation.

Farms managing much smaller watercourses that drain to tributaries should provide high density shade because mature trees along tributaries can make a difference in the downstream temperatures. Planting tributary areas is a high priority since narrower streams are easier to shade than wider streams.

Table 30. Riparian restoration activities and implementation partners.

Activity	Active Partner
Restore riparian shading to 180-foot buffers on either side of mainstem and to Ecology Riparian Buffer Map widths on tributaries.	Tulalip Tribes, Snohomish County SWM, Snohomish Conservation District, Adopt-A-Stream Foundation, Ducks Unlimited, Sound Salmon Solutions, Wild Fish Conservancy

Activity	Active Partner
Complete field shade deficit analysis on Pilchuck River tributaries to identify tree-planting opportunities.	Snohomish County SWM, Tulalip Tribes, Ecology
Promote the benefits/effects of riparian buffers through community-based social marketing (CBSM).	All Partners (ongoing)

Due to limited resources (and as noted in Chapter 1), only the mouths of the tributaries were included as part of the modeling analysis of this TMDL. In the preceding “Where do we have opportunities for improvement” section, Ecology estimated about 361 acres need planting in Little Pilchuck Creek and about 209 acres need planting in Dubuque Creek for a total of about 570 acres in these two subbasins. This does not account for potential riparian planting needs of tributaries in other subbasins.

Implementation partners should take note that riparian restoration in the mainstem and the tributaries should be happening concurrently at a pace of about 16 acres/year at minimum; however, since the total estimated acreage for Dubuque and Little Pilchuck Creek subbasins requires field verification, Ecology created two separate tables to show the entire timeframe needed to plant 951 acres at this pace (Tables 31 and 32). These tables are meant to show an example of how long planting 951 acres in the Pilchuck River watershed will take if partners plant at a pace of about 16 acres per year.

Table 31. Riparian planting progress timeline for Pilchuck River mainstem.

Year	Total Acres planted goal	% complete
2031	96	25
2041	192	50
2051	288	75
2061	381	100

This suggests a riparian planting project pace of ~9.5 acres/year on the Pilchuck River mainstem.

Table 32. Estimated riparian planting progress timeline for Little Pilchuck and Dubuque Creeks.

Year	Total Acres planted goal	% complete
2031	70 (451*)	12% (47%**)
2041	140 (521*)	25% (55%**)
2051	210 (591*)	37% (62%**)
2061	280 (661*)	49% (70%**)
2071	425 (806*)	75% (85%**)
2081	570 (951*)	100%

*Total number of planted acres when added with mainstem Pilchuck River.
** Total percentage of planted acres completed when added with mainstem Pilchuck River.

This suggests a riparian planting project pace of 7 acres/year in the Little Pilchuck and Dubuque Creek subbasins from 2031 to 2061 and a planting project pace of 14.5 acres/year from 2071 to 2081.

Cold Water Refuge Enhancement

Enhancing and protecting cold water refuges (CWRs) is vital to salmon recovery. CWRs are generally defined as water that is 2°C cooler than the surrounding waters. While trees take many years to reach their full potential to protect streams from excessive heating, CWRs fed by groundwater, tributaries, seeps and springs, among other sources provide immediate assistance to salmon and other cold water species during the warmest times of the year. Initial CWR assessment work outlined below should be completed by 2026 (Table 33). Additional future assessments may be conducted as resources allow on an as needed basis.

Table 33. CWR activities, implementation partners, and estimated timeline.

Activities	Active Partners	Estimated Target Year
Evaluate 21 potential Cold Water Refuge locations on the mainstem. Enhance feasible CWR locations with LWM, boulders or other instream structures.	Tulalip Tribes, Snohomish County SWM, Snohomish Conservation District, Adopt-A-Stream Foundation, Sound Salmon Solutions, Wild Fish Conservancy, Ecology	2066
Measure temperatures to assess potential CWR locations at least 2˚C cooler in the tributaries.	Snohomish County SWM, Tulalip Tribes, Ecology	2026 and as needed
Enhance feasible CWR locations with LWM, boulders or other instream structures in the tributaries. Promote benefits of CWR through CBSM.	Tulalip Tribes, Snohomish County SWM, Snohomish Conservation District, Adopt-A-Stream Foundation, Sound Salmon Solutions, Wild Fish Conservancy, Ecology	2066
Assess pool creation feasibility and prioritization in the mainstem and tributaries.	Snohomish County SWM, Tulalip Tribes, Snohomish Conservation District, Ecology	2026 and as needed

Activities	Active Partners	Estimated Target Year
Add pools in designated reaches of the Lower and Middle Pilchuck where feasible.	Tulalip Tribes, Snohomish County SWM, Snohomish Conservation District, Adopt-A-Stream Foundation, Sound Salmon Solutions, Wild Fish Conservancy, Ecology	2066

Streamflow Augmentation and Water Conservation

Growing populations need clean drinking water. Outside of urban areas, groundwater is a key source of water for new development. Ecology set minimum instream flows and allowable groundwater withdrawal rates to protect those instream flows. Visit the instream flow rule for the Snohomish River basin, Chapter 173-507 WAC[33] web page for more information.

This TMDL determined regulated water withdrawals in large quantities such as irrigation were a significant contributor to temperature problems in the mainstem Pilchuck River, especially where Little Pilchuck Creek enters the mainstem. Less water is available in the stream during the summer and stream levels drop even lower with increased water use such as irrigation of lawns, gardens, pastures and agricultural fields. Solar radiation heats the water up more quickly and as temperatures increases, DO levels decrease.

Implementing water conservation and stream augmentation actions (Table 34) to restore water back into Pilchuck River with a particular focus on Little Pilchuck subbasin should be a priority as part of this implementation plan.

Table 34. Streamflow augmentation and water conservation activities, implementation partners, and estimated timeline.

Activity	Active Partner	Estimated Target Year
Remove/modify bank armoring.	Tulalip Tribes, Municipal stormwater permittees, Snohomish County SWM, Snohomish Conservation District, Adopt-A-Stream Foundation, Sound Salmon Solutions, Wild Fish Conservancy	2066
Evaluate use of imported water for new development.	City of Lake Stevens, Snohomish County Surface Water Management, Snohomish County Planning and Development	2026 and as needed
Implement stormwater retrofits that increase groundwater levels utilizing low impact development (LID).	Phase I and Phase II Municipal stormwater permittees, Ecology	2066

[33] https://apps.leg.wa.gov/wac/default.aspx?cite=173-507

Activity	Active Partner	Estimated Target Year
Evaluate and install impoundment BMPs (e.g., beaver dam analogs, wetland restoration). Conduct beaver management assessments.	Tulalip Tribes, Snohomish County SWM, Snohomish Conservation District, WDFW, Ecology and more	2066
Implement low-flow irrigation BMPs to improve irrigation timing and efficiency.	Snohomish Conservation District, Washington Water Trust	2066
Promote water conservation, irrigation efficiency, natural yard care, and LID BMPs through CBSM and incentives.	Phase I and Phase II Municipal stormwater permittees, Snohomish County SWM, Snohomish County Planning and Development, Snohomish Conservation District, Washington Water Trust, Ecology	ongoing

Granite Falls Compliance Timeline

Compliance timelines for the Granite Falls WWTP will be established as part of the NPDES permit in accordance with WAC 173-201A-510(4).[34] Under the current NPDES permit, design plans and specifications for the proposed WWTP improvements are expected in 2022.

Technical Feasibility

Returning the Pilchuck River to good health requires a combination of actions for both point sources and nonpoint sources. Some of implementation approaches are well-established, others use existing principles and approaches and apply them in new ways. Refer to Chapter 2, TMDL Formula Section for details on how point source pollutants and nonpoint source pollutants are defined.

In the case of point sources, an engineering assessment has been completed for the Granite Falls Wastewater Treatment Plant (WWTP) and the proposed phosphorus reductions are technically feasible (Gray and Osborne, 2018).

The Phase 1 and Phase 2 Municipal Stormwater permit requires the development, implementation, and management of source control programs to prevent and reduce the discharge of point and nonpoint source pollutants to stormwater systems. Source Control programs often include the implementation of operational, structural, and treatment BMPs at pollution generating land use types, businesses, and activities. The Municipal Stormwater Permit requires implementation of source control BMPs. Structural and non-structural BMPs outlined in Ecology's Stormwater Management Manual for Western Washington (SMMWW) can help

[34] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-510

control nutrient discharge and moderate temperature discharge. Visit Ecology's Stormwater Manuals[35] web page to access the SMMWW, LID guidance manuals and other related resources. Implementation partners should keep in mind that the costs derived for stormwater facilities are rough estimates from very few projects and can vary based on design and location.

For nonpoint sources of thermal pollution, there is extensive experience re-establishing riparian vegetation. The Skagit River System Cooperative[36] achieved a pace of ~20 acres/year of riparian plantings between the period of 2001-2015. Although it is important to note that these plantings were spread out among many creeks and sloughs. There are many other impaired riparian areas outside of the Pilchuck River watershed in need of plantings and limited resources/funding to address all of them. Fortunately, there are many experienced restoration partners working on a variety of fronts to return the Pilchuck River to good health. Where additional research is needed, Ecology expects several highly-qualified entities to engage in restoring in-water habitat and instream flows.

Costs

The costs associated with implementation are important because they:

- Give a sense of how realistic load reduction goals are (see Technical Feasibility section below).
- Help implementers develop sound budgets and/or ensure that funding requests are accounted for.
- May help prioritize grant funding resources in future.

What follows is an attempt to provide cost estimates for the actions described previously. However, implementers should note that there are inherent assumptions, compounding estimates, and unknowns associated with this work that prohibit accurate analysis. While this TMDL tried to approach this exercise with rigor, implementers are advised to use what follows with caution and a certain degree of circumspection. As this TMDL did not attempt to provide detailed analysis or recommendations regarding long-term actions, cost estimates are developed only for short-term actions. Estimated costs are summarized in Table 35. Organizational operating costs (e.g. salaries, travel costs) and supporting resources costs (e.g. effectiveness monitoring) were not included in the estimates unless otherwise stated.

---

[35] https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals
[36] http://skagitcoop.org/programs/restoration/riparian-planting/

Table 35. TMDL implementation cost estimates.

Nonpoint Source BMPs	Cost per unit	# of units	Total
Riparian Planting (mainstem Pilchuck River)	$20,000/acre	381 acres	$7,620,000
Riparian Planting (Dubuque and Little Pilchuck Creeks)	$20,000/acre	570 acres	$11,400,000
Small Large Woody Material (composed of 3 to 4 pieces)	$12,000/each	50*	$600,000
Engineered Log Jams	$62,937/each	25	$1,573,425
Post-assisted log structures	$600/each	50*	$30,000
Beaver dam analogs	$4,100/each	50*	$205,000
Subtotal			$21,428,425
Stormwater BMPs	**Cost per unit**	**# of units**	**Total**
Treatment facilities	$250,000/acre	4,632 acres	$1.16 billion
Flow control facilities	$546,000/acre	4,632 acres	$2.53 billion

*Chose 50 units only for illustrative purposes. Costs vary greatly depending on many factors: stream width and location, log size, material and associated mobilization costs, and who installs. Further assessments will be needed to determine actual number of units and associated cost in the mainstem and the tributaries.

From the White River TMDL, nonpoint BMP cost estimates were calculated using a combination of NRCS Environmental Quality Incentives Program (EQIP) fiscal year 2019 rates. These calculations ranged from $1287.04-$6272.08 per acre (NRCS EQIP). Costs for BMPs are often provided in ranges, and in these cases the upper value was used for costing calculations. Acreage data were derived from GIS analysis or consultant vegetation analysis. The following is a summary of input data and assumptions:

- Riparian Planting
  - Acreage assumes 180-foot buffers along each side of the entire mainstem
  - Acreage assumes 100-foot buffers along each side of water courses in Dubuque and Little Pilchuck subbasins.
  - Acreage = 381 acres (Middle + Lower Pilchuck River) and 486 acres (Dubuque and Little Pilchuck Creek subbasins) - see “Where do we have Opportunities for Improvement?” section.
- Engineered log jams: the number of units assumes 21 potential CWR on the mainstem, rounded up to 25. This number is expected to increase as the number of potential CWR is assessed in the tributaries.

Since the NRCS EQIP range is too low for this region, we calculated a rough riparian buffer estimate based on feedback from the Snohomish Conservation District (Marshall, K. Personal communication. November 4, 2019). The $20,000 estimate was based on at least one year of site preparation, at least one year of planting, and at least three years of site maintenance and management including replanting, invasive vegetation control, and vegetation monitoring (survival, vigor) for a total of at least 5 years of activity per acre.

Engineered log jams were calculated using feedback collected from the Nooksack Indian Tribe (Coe, T. Personal communication. July 16, 2019), which correlated to feedback provided by Sound Salmon Solutions (Pond, R. Personal communication. June 18, 2019), where a 46 piece engineered log jam was priced at about $60,000 (including tax). Costs provided by the Nooksack Indian Tribe were itemized for log jam construction and related activities: wood supply, other construction supplies, permits, engineering, staff, and indirect rate. Pricing generally ranged from about $50,000 to about $65,000 per jam and may depend on the nature of the site being restored as well as log dimensions. For example, if a stream system is unconfined, dynamic, and braided, then restoration design would dictate the placement of log jams in a higher density across the floodplain. Based on feedback from Snohomish County (Gaddis, B. Personal communication. June 18, 2019), smaller log jams (3-4 pieces) ranged in price from about $10,000 to $12,000 per jam including mobilization and associated site work in 2014.

Beaver dam analogs (BDAs) and post-assisted log structures (PALS) are low technology and relatively low cost restoration practices. Table 35 displays upper cost estimates on a per structure basis for BDAs and PALs. Costs can vary greatly depending on a number of factors such as stream width and location, cost of materials, and who is installing the structures. Once the proper permits (e.g. Hydraulic Project Approval) are obtained, BDAs and PALS can be installed cheaply and quickly if a stream is small and easily accessible, materials (e.g. posts) can be harvested on-site, and volunteers or AmeriCorps or Washington Conservation Corps crews install them. Ecology received a detailed range of costs from Cramer Fish Sciences (Camp, R. Personal Communication. September 17, 2020) as follows:

- BDAs
  - Total project cost: $4,000 - $150,000
  - Per structure: $600 - $4,100
  - Per mile: $38,000 - $115,000
  - Per linear foot of structure (width): $28 - $43
- PALs
  - Total project cost: $2,000 - $220,000
  - Per structure: $120 - $600
  - Per mile: $31,000 - $68,000
  - Per linear foot of structure (width): $14 - $35

Ecology also estimated the average cost per acre to retrofit to permit standards for stormwater facilities in Western Washington based on feedback from FMS (Schwing, J. personal communication, September 23, 2020). Acreage was calculated using the land-use/land-cover dataset from the USDA's National Agricultural Statistics Service[37] and assumes medium and high impervious areas within the watershed. Flow control facilities were found to cost over twice as much as treatment facilities during this analysis. Implementation partners should keep in mind that the costs derived for stormwater facilities are rough estimates from very few projects and can vary based on design, location, and site conditions. Further assessments are needed to

[37] https://nassgeodata.gmu.edu/CropScape/

determine the actual surface area (in acres) contributing to the facility or BMP type and the associated cost.

Funding Opportunities

Funding is available from several agencies mentioned in this document. The most popular funds used in our area are discussed below. There are many other funding sources, especially for projects that benefit both water quality and salmon. EPA's Funding Resources for Watershed Protection and Restoration[38] website provides additional funding source information including The Water Financial Clearing House,[39] a searchable database of financial assistance sources (grants, loans, and cost-sharing) available to fund a variety of watershed protection projects. The following is a partial list of funding opportunities that are popular in western Washington.

U.S. Environmental Protection Agency

National Estuary Program

EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national importance. In the Puget Sound and surrounding watersheds, this includes protection of fish, shellfish, wildlife, and recreational activities and requires the control of point and nonpoint sources of pollution. Using a collaborative, consensus-building approach, the Management Conference (a collective of governments, organizations, businesses and individuals convened by the Puget Sound Partnership[40]) engages in developing and implementing the Puget Sound Action Agenda. Local and regional experts in habitat restoration, shellfish bed protection and recovery, stormwater pollution, and salmon recovery came together to review and rank Near Term Actions for inclusion in the 2018-2022 Action Agenda. One of the near-term actions adopted into the 2018-2022 action agenda included the removal of the Pilchuck Diversion Dam,[41] which estimated costs of $2.5 million. The EPA provides funding to Washington state agencies as Strategic Initiative Leads and to the Northwest Indian Fisheries Commission to implement the Puget Sound Action Agenda. Interested parties should reference the Puget Sound Partnership's NEP Solicitation and Grants[42] web page for specific information on how to apply for these funds.

Environmental Education Grants

Education institutions; state, local, and tribal environmental and educational public agencies; and nonprofit organizations described as 501(c)(3) of the Internal Revenue Code are eligible for this funding, which supports environmental education projects that promote environmental awareness and stewardship. These grants require non-federal matching funds for at least 25% of the total

[38] https://www.epa.gov/nps/funding-resources-watershed-protection-and-restoration
[39] https://ofmpub.epa.gov/apex/wfc/f?p=165:1
[40] https://www.psp.wa.gov/
[41] https://actionagenda.pugetsoundinfo.wa.gov/Project/FactSheet/13039
[42] https://www.psp.wa.gov/NEP-solicitation-and-grants.php

cost of the project. For more information, e-mail EEgrants@epa.gov or visit EPA's Environmental Education[43] web page.

Washington State Department of Ecology

Water Quality Combined Financial Assistance Program

Ecology's Water Quality Program administers the following four main funding programs under an integrated annual funding cycle. Ecology awards grants and loans on a competitive basis to eligible public entities for high priority water quality projects throughout Washington State. Applicants use one integrated financial assistance application to apply for funds from the four funding sources simultaneously. Ecology typically kicks off its annual cycle in August with applicant training workshops. Grants typically require 25% match.

Centennial Clean Water Program: Centennial is a state funded program created by the Washington State Legislature in the mid-1980s. Under this program, grants are available to public entities for wastewater infrastructure (limited to hardship communities) and nonpoint source pollution control projects including but not limited to: on-the-ground restoration, agricultural best management practices (BMPs), off-stream watering provisions, onsite septic repair and replacement, stormwater activities, and drinking water source protection.

Clean Water Act Section 319 Nonpoint Source Grant Program (Section 319): The United States Congress established Section 319 as part of the Clean Water Act amendments of 1987 to address nonpoint sources of water pollution. Under this program, grants are available to public entities for projects including but not limited to: on-the-ground restoration, watershed planning, technical assistance, BMP implementation, off-stream watering provisions, water quality monitoring, and education and outreach.

Clean Water State Revolving Fund (CWSRF): The United States Congress established the CWSRF as part of the Clean Water Act Amendments of 1987. Under this program, low-interest loans are available to public entities for projects including but not limited to: facilities, nonpoint source planning and implementation, local stormwater regulation review, low impact development planning and implementation, and education and outreach. Low interest loans have also been used as "pass through" to homeowners for projects such as onsite septic repair and replacement or agricultural BMP implementation. Loans may be used for a wider range of improvements on private property.

Stormwater Financial Assistance Program (SFAP): The SFAP is designed to fund stormwater projects and activities that have been proven effective at reducing impacts from existing infrastructure and development and enhance existing stormwater programs. Grants are available to counties, cities, towns and port districts for retrofit projects including but not limited to:

[43] https://www.epa.gov/education

stormwater treatment facilities, detention facilities, infiltration systems, low impact development planning and BMP implementation, and a limited suite of stormwater activities.

Refer to Ecology's Find A Grant or Loan[44] web page and/or the Water Quality Combined Funding Program[45] web page for more information.

Coastal Protection Fund: Since July 1998, water quality penalties issued under Chapter 90.48 RCW have been deposited into a sub-account of the Coastal Protection Fund known as Terry Husseman Account. A portion of this fund is made available to regional Ecology offices to support on-the-ground environmental restoration and enhancement projects. Local governments, tribes, and state agencies must propose projects through Ecology staff. Contact an Ecology Water Cleanup specialist to investigate fund availability and to determine if your project is a good candidate or visit the Coastal Protection Fund - Terry Husseman Account Grants[46] web page for more information.

Floodplains-By-Design: Ecology's Floodplain Management Program administers the Floodplains by Design grant program under a biennial funding cycle. Ecology awards grants on a competitive basis to eligible entities (e.g., local governments, tribes, diking and drainage districts, port districts, nonprofit agencies) for collaborative and innovative projects throughout Washington State that support the integration of flood hazard reduction with ecological preservation and restoration. Proposed projects may also address other community needs, such as preservation of agriculture, improvements in water quality, or increased recreational opportunities provided they are part of a larger strategy to restore ecological functions and reduce flood hazards. Visit the Floodplains by Design[47] web page for more information.

Streamflow Restoration Implementation Grants: The 2018 Streamflow Restoration Act (ESSB 6091) provides for actions in watersheds to offset potential impacts to instream flows associated with permit exempt domestic water use and achieve net ecological benefit. The purpose of this Streamflow Restoration Grant program is to provide funding for those actions ("projects"). Ecology's Water Resources Program administers the Streamflow Restoration Grants program and awards grants on a competitive basis for projects throughout the state that improve streamflows and instream resources, as directed under the new law. Visit the Streamflow Restoration[48] web page for more information.

[44] https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan
[45] https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan/Water-Quality-Combined-Funding-Program
[46] https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan/Coastal-protection-fund
[47] https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Hazards/Floods-floodplain-planning/Floodplains-by-Design
[48] https://ecology.wa.gov/Water-Shorelines/Water-supply/Streamflow-restoration

Washington State Recreation and Conservation Office and Washington Department of Fish and Wildlife

Aquatic Lands Enhancement (ALEA) Program

The Aquatic Lands Enhancement Account (ALEA) Grant Program provides grant-in-aid support for the purchase, improvement, or protection of aquatic lands for public purposes, and for providing and improving access to such lands. It is guided by concepts originally developed by DNR, including re-establishment of naturally self-sustaining ecological functions related to aquatic lands, providing or restoring public access to the water, and increasing public awareness of aquatic lands as a finite natural resource and irreplaceable public heritage.

Local and state governments, as well as Native American Tribes, are eligible to apply if legally authorized to acquire and develop public open space, habitat, or recreation facilities. Federal agencies, nonprofit organizations, and private entities are not eligible, but are encouraged to seek a partnership with an eligible entity in order to pursue the public benefits the ALEA Grant Program supports. ALEA Grant Program funds may be used for the purchase, restoration, or improvement of aquatic lands for public purposes, and for providing and improving public access to aquatic lands and associated waters.

All projects must be consistent with the local shoreline master program and must be located on lands adjoining a water body that meets the definition of "navigable." Projects intended primarily to protect or restore salmonid habitat must be consistent with the appropriate lead entity strategy or regional salmon recovery plan. Recipients must provide at least 50% match. For more information, view the WDFW's Aquatic Lands Enhancement Account Volunteer Cooperative Grant Program[49] and/or RCO's Aquatic Lands Enhancement Account[50] web pages.

Salmon Recovery Funding Board

This board was created in 1999 by the State Legislature to provide salmon recovery grants that protect existing high quality salmon habitat, restore degraded habitat, and assess the feasibility of future projects and other salmon-related activities. Part of the funding comes from the state Puget Sound Acquisition and Restoration Fund, which supports projects in Puget Sound watersheds. Local and state governments, Native American Tribes, as well as special purpose districts, private landowners, nonprofit organizations and regional fisheries enhancement groups are all eligible to apply. View RCO's Salmon Recovery and Puget Sound Acquisition and Restoration[51] web page for more information.

Visit RCO's grant programs[52] web page to learn about additional grant opportunities (including the two mentioned above).

---

[49] https://wdfw.wa.gov/species-habitats/habitat-recovery/alea
[50] https://rco.wa.gov/grant/aquatic-lands-enhancement-account/
[51] https://rco.wa.gov/grant/salmon-recovery/
[52] https://rco.wa.gov/recreation-and-conservation-office-grants/find-a-grant/

US Department of Agriculture

Conservation Reserve Enhancement Program (CREP)

The CREP is a voluntary program to establish forested buffers along streams where streamside habitat is a significant limiting factor for salmonids. It is a great way to help landowners implement conservation practices on their property while also offsetting the burden of property taxes through land rental payments. In addition to providing habitat, the buffers improve water quality and increase stream stability. Land must be on a salmon or steelhead stream to be eligible.

Land enrolled in CREP is removed from production and grazing under 10-15 year contracts. In return, landowners receive annual rental, incentive, maintenance, and cost share payments.

Other program highlights include:

- Annual payments can equal 100% of the weighted average soil rental rate (incentive is 110% in areas designated by Growth Management Act).
- Annual soil rental rates in Snohomish County for 2019 are about $110/acre and with incentive about $220/acre (Moscoso, C. personal communication. August 6, 2020).

Landowners can enter a 10-15 year rental agreement with the United States Department of Agriculture. Additional incentives offered through the program include a signing bonus, fencing cost-share for livestock owners, watering facilities, and other land improvements for qualifying landowners. CREP is administered by Snohomish Conservation District in cooperation with the USDA Farm Service Agency.

Conservation Reserve Program (CRP)

The CRP is a voluntary program that offers annual rental payments, incentive payments for certain activities, and cost-share assistance to establish approved cover on eligible cropland. Administered by the Snohomish Conservation District, assistance is available in an amount equal to not more than 50% of the participant's costs in establishing approved practices; contract duration is between 10-15 years.

Environmental Quality Incentives Program (EQIP)

This federally funded program is managed by the Natural Resources Conservation Service (NRCS). The EQIP program has the following features:

Provides technical assistance, cost share payments and incentive payments to assist crop and livestock producers with environmental and conservation improvements on the farm.

- 75% cost sharing but allows 90% if producer is a limited resource or beginning farmer or rancher.
- Program funding divided 60% for livestock-related practices, 40% for crop land.
- Contracts are for 1 to 10 years.
- No annual payment limitation; sum not to exceed $450,000 per individual/entity.

There is no single source of funding to make the Pilchuck River watershed clean and cool again. Ecology TMDL staff will work with stakeholders to develop strategies for funding water quality improvement projects and prepare appropriate scopes of work that will help implement this implementation plan. Funding agencies should be evaluating the effectiveness of existing programs to meet the needs of this and other TMDLs and modifying their programs to ensure continued riparian improvements leading to the completion of TMDL goals.

Wetland Reserve Enhancement Partnership

The Wetland Reserve Enhancement Partnership[53] (WREP) is a voluntary NRCS easement program, which is part of the Agricultural Conservation Easement Program, a Farm Bill Conservation Program. State agencies, county and local governments, non-governmental organizations and American Indian Tribes collaborate with NRCS through partnership agreements. These partners work directly with tribal and private landowners, who voluntarily enroll eligible land through the purchase of an NRCS Wetland Reserve Easement in order to protect, restore and enhance wetlands. With this funding, easements enable landowners to adopt conservation practices that improve wetland functions and conditions. Eligible lands (e.g. farmed or converted wetland habitat that can be restored), may be enrolled under permanent easements, 30-year easements, or 30-year contracts (for acreage owned by tribal landowners). Partners are required to contribute a financial or technical assistance match of at least 10 percent. Proposals that provide match greater than 10 percent receive higher consideration in the selection process.

Other Funding Opportunities

This TMDL recommends creating funding opportunities to build and maintain incentive programs essential towards encouraging landowners to install BMPs on their property (e.g. riparian buffers, irrigation efficiencies, etc.). King County's Small Habitat Restoration Program[54] is one example incentive program that builds low-cost projects to enhance and restore streams and wetlands. This program might be modeled when creating new incentive programs or expanding on existing programs.

In addition, this TMDL encourages the creation of incentive programs, not just for landowners, but also for developers in order to promote stormwater BMPs, LID and irrigation efficiency systems. Incentive programs may also double as important tools in the outreach toolbox and are also listed in the Outreach section.

---

[53] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/acep/?cid=nrcseprd1459249

[54] https://www.kingcounty.gov/services/environment/animals-and-plants/restoration-projects/small-habitat-restoration-program.aspx

Outreach

Public education and outreach efforts are a fundamental component of the Pilchuck River TMDL. These efforts help raise general awareness, create stewardship opportunities, and effect behavior change to improve water quality. It is important to educate residents and visitors in the Pilchuck River watershed, on how their individual and collective actions can help improve water quality. Targeted education and outreach efforts are needed to promote voluntary implementation of water quality BMPs.

Ecology has several procedures and general practices built into the Washington State TMDL process that encourage outreach to external parties. These parties may include:

- Local government, federal government, and sister state agencies
  - e.g., counties, cities, local health districts, EPA, NRCS (USDA), WSDA, DOH, Conservation Commission
- NPDES permittees
- Local, stream-side landowners
- Watershed citizens
- Non-profit groups

Collaborative Relationships

Relationship building is a key component of TMDL outreach and overall TMDL implementation success. Ecology has already begun to develop collaborative relationships with key stakeholders and hopes to build on and leverage these as TMDL implementation intensifies. Here are some examples of these relationships:

- Snohomish Conservation District
- Adopt-A-Stream Foundation
- Sound Salmon Solutions
- Snohomish County
- Tulalip Tribes

Education

While the outreach to governments and agencies described above is a useful and necessary component of TMDL implementation, outreach to private landowners and the general public is critical to TMDL success. Local partners should identify which communities in the project area have more than 5% or 1,000 people that speak English less than very well using EPA's Environmental Justice (EJ) screening tool[55] or other similar EJ tools. If the Linguistically Isolated Population number is above 5%, use the United States Census Bureau[56] database to determine which languages are spoken and how many individuals speak English less than very well.

[55] https://ejscreen.epa.gov/mapper/
[56] https://data.census.gov/cedsci/

Partners should then translate education and outreach materials that are produced for the general public in the non-English language(s).

In lieu of a permit system to regulate nonpoint pollution sources, many of the actions described in this TMDL rely on the voluntary participation of private citizens.

This TMDL recommends a community-based social marketing approach to determine the most effective education/outreach strategy to reach the target audience. Using community-based social marketing (CBSM) is strategically important for understanding how to influence behavior of a target audience in complex economic, political, and social climates with limited resources.

The following details a general CBSM approach Ecology will take to implement this TMDL:

- Coordinate with key stakeholders to develop a collaborative, detailed education/outreach strategy
  - Key stakeholders include: Snohomish County, cities, Snohomish Conservation District, Adopt-A-Stream Foundation, Ducks Unlimited, Sound Salmon Solutions, Washington Water Trust, Wild Fish Conservancy
  - Be sure to include staff with communication/outreach training/expertise
- Analyze the situation and identify behaviors
- Select target audience
  - Landowners with property adjacent to surface water
  - Identify geographic areas to focus outreach efforts
  - Focus on implementation priorities, working through ranked reach priorities sequentially
- Identify barriers, motivators and benefits to implementation
  - Brainstorm from an audience perspective about what is in it for them
- Design strategies to address barriers
  - Develop messaging
  - Concentrate on the TMDL compliance BMPs
  - Emphasize funding assistance opportunities
  - Ensure messaging consistency amongst partners/stakeholders across media and events to the extent possible
- Pilot test strategies, then refine based on lessons learned
- Implement strategies - general methods include, but are not limited to:
  - Produce education materials to support messaging (e.g., leaflets, brochures, utility inserts, post cards, door hangers)
    - Restoration project and creek signage
  - Use social media/mass media (e.g., Facebook, Twitter, Instagram, Nextdoor)
    - Messages should be short, targeted to audience
    - Spread the word about local programs and advertise upcoming workshops or other education events
    - Use blogs, local TV and newspapers to spread messaging (e.g. short videos, written articles)
  - Use education events and tools
    - Develop new public events or make use of existing education events to present messaging and answer questions

        - Use Ecology's 'Enviroscape' model[57] and other such tools to teach basic riparian ecology and BMP function
        - Use the Stormwater Messaging Toolkit[58] and Stormwater Outreach for Regional Municipalities (STORM's) Resource Reservoir[59] to teach basics on stormwater-related topics.
    - Promote citizen science monitoring efforts and incorporate messaging into training as far as possible
    - Partner with local schools to further spread messaging
    - Conduct door-to-door canvassing in priority neighborhoods
    - Engage community in neighborhood social events and project tours
    - Promote community volunteer groups
    - Create incentives for landowners to install riparian buffers and other BMPs through incentive programs
    - Create incentives for developers to promote LID and stormwater BMPs; and irrigation efficiency BMPs through incentive programs
- Evaluate how the strategies worked (i.e. lessons learned), update and continue to implement

Tracking Progress

Monitoring

Tulalip Tribes, Snohomish County Surface Water Management, WDFW, Ecology and other organizations have completed monitoring in the Pilchuck River watershed for many years (Table 31). Monitoring efforts have been completed to assess watershed health, water and habitat quality, and the status of fish populations. The following information summarizes past monitoring efforts completed in the Pilchuck River watershed.

Ecology first completed ambient monitoring in the Pilchuck Watershed as early as 1976, and more recently from 2005-2006 and 2009-2010. To assess temperature and DO impacts for this TMDL, Ecology worked with the EPA and a scientific consulting firm to do a watershed assessment during the summer of 2012. Ecology determined that further flow and groundwater data was needed and collected that data during the summers of 2014 and 2016.

Tulalip Tribes Natural Resources Department completed habitat surveys in 2002, which included woody debris and riparian zone surveys; and spawner surveys in 1999, 2001 and 2002. Water temperature monitoring was also conducted throughout the mainstem 2001-2002 as part of their work to address data gaps around salmonid habitat in the Pilchuck River.

Snohomish County Surface Water Management (SCSWM) built upon work done by Tulalip Tribes Natural Resources Department and completed several assessments in the Pilchuck River watershed. The Snohomish River Basin Salmon Conservation Plan identified the Middle Pilchuck subbasin as a restoration priority. It became clear this subbasin did not have a completed watershed

---

[57] https://www.enviroscapes.com/
[58] https://www.pugetsoundstormgroup.org/Toolkit.aspx?no=521&DocID=QO69z02P5AQ%3d
[59] https://pugetsoundstormgroup.org/

assessment to guide recovery efforts, so SCSWM completed habitat and geomorphic assessments in phases from 2010 to 2012. More recently in 2018, SCSWM completed an assessment for the Lower Pilchuck segment to identify salmon impairments and potential project types and locations.

Effectiveness Monitoring

Effectiveness monitoring is the primary tool that will be used to assess if implementation actions result in water quality improvement. Monitoring the effectiveness of projects helps ensure that the time and effort of public, private, and citizen resources are put to the best use. Most project managers have some level of effectiveness they are required to meet as part of their duties. Ecology will encourage project partners to measure implementation project performance in order to help assess the success of this TMDL. Forestry management, city and county mitigation plantings, and even voluntary riparian plantings are examples of different projects subject to different rules. Federal (EPA Clean Water Act 319 fund program), state (Joint Legislative Audit and Review Committee), and local authorities are demanding additional data regarding accountability. All project managers should consider including an effectiveness monitoring component that is representative of the work they are doing and its success contributing to TMDL goals and objectives.

Monitoring of project effectiveness can be done in many ways and should help improve the quality of restoration projects over time. All relevant aspects of a project should be considered for effectiveness assessment. Initially, the efficiency of outreach efforts (e.g., changes in stakeholder behavior, number and percentage of watershed residents participating) can be evaluated. After plants are in the ground, it is important to establish good baseline numbers and plan for additional monitoring at about 5 year intervals up to 15 years. Plant type and survival rates should be calculated for representative projects. This TMDL recommends continuous water temperature monitoring during the critical summer season at 'USGS 12155300 Pilchuck River near Snohomish, WA' streamflow gage at Three Lakes Road or other representative location in the Middle Pilchuck subbasin. Dissolved oxygen monitoring should be evaluated when a system-wide effectiveness monitoring study is performed.

All monitoring efforts should be coordinated to reduce duplication of effort. The evolving condition of riparian areas throughout the watershed should also be evaluated periodically. Factors that should be analyzed through GIS analysis and associated field verification include trends in riparian vegetation composition and stream width. This TMDL recommends riparian vegetation analysis every 10 years using Light Detection and Ranging (LiDAR) data that can be used to identify existing vegetation types, heights and densities.

Municipalities and other general permittees will be responsible for making sure they meet all of the requirements of their permits and permit language may be reviewed if site specific concerns are found. Ecology's permit manager will track progress on the Granite Falls WWTP through DMR compliance. Permits that receive a WLA are generally managed by permit managers, who will be tracking progress through inspections and annual reporting. Compliance with existing general permit conditions constitutes compliance with this TMDL.

Following are examples of implementation activities that can be tracked for this TMDL:

- number and size of LWM or instream structure installations
- number and size of pools created or enhanced
- water temperature measurements between CWRs and adjacent stream channel
- use of CWR by holding adult and rearing juvenile salmon
- number and size of LID or stormwater BMPs installed/retrofitted
- number of BDAs installed
- number of irrigation efficiency BMPs installed/retrofitted
- acres of riparian buffer planted
- acres of wetlands restored
- linear feet of side channel reconnected
- acres of floodplain reconnected
- linear feet of levee and/or bank armoring removed or setback
- number of community outreach events conducted and the topic(s) covered
- number of property owners under conservation easements

A major goal of this TMDL is to implement water quality improvement projects that will cumulatively meet the effective shade and streamflow restoration targets established in this TMDL. Completing a new shade deficit analyses as early as 2031, would provide the most detailed measure of progress towards meeting riparian forest restoration goals in the Pilchuck River watershed. The system potential riparian vegetation for the watershed is 85 percent canopy cover.

As resources allow, some level of effectiveness monitoring should be completed every 10 years starting in 2031 until water quality standards are attained. Other efforts that can support effectiveness monitoring include desktop land use and land cover assessments, qualitatively viewing aerial photography, and implementing regular implementation tracking in the watershed through the Pilchuck River watershed.

Ecology effectiveness monitoring should consider the following elements:

- Water temperature, DO and flow monitoring of Pilchuck River to track trends.
  - Request a basin station (coupled with a flow station) for two years.
- Shade canopy/habitat assessments to evaluate progress towards system potential shade targets as outlined in Chapter 4, System Potential Conditions, Table 57 and habitat quality.
  - Establish baseline hemispherical photography of watershed, then take hemispherical photographs every 10 years to evaluate effective shade and tree canopy height (Table 36).
- Baseflow monitoring to evaluate progress towards restoring water to the river system (Chapter 4, Summer Baseflow Restoration Targets section, Table 58).
  - Request additional flow stations as needed.
  - Calculate amount of water (in cfs) added to the river every 10 years as resources allow.
  - Calculate 10^{th} percentile of historical monthly minimums at USGS 12155300 Pilchuck River near Snohomish, WA streamflow gage at Three Lakes Road.

When water quality standards are met, Ecology will delist category 5 waters in accordance with Policy 1-11.

Table 36. Monitoring schedule in the Pilchuck River watershed.

Monitoring Project	Organization	Year
TMDL Study	Department of Ecology	2012, 2014, 2016
Ambient WQ Monitoring	Department of Ecology	2005-2006, 2009-2010
Streamflow Gauge	United States Geologic Survey	Ongoing
Stage Gauge (at Menzel Lake Road)	Snohomish County Surface Water Management	2008-ongoing
"Habitat Conditions and Chinook Use in the Pilchuck River"	Tulalip Tribes Natural Resources Department	1999, 2001, 2002
"Middle Pilchuck River Assessment: Habitat Report"	Snohomish County Surface Water Management	2010, 2012
"Middle Pilchuck River Assessment: Geomorphic Report"	Snohomish County Surface Water Management	2010-2012
"Lower Pilchuck River Assessment"	Snohomish County Surface Water Management	2016-2018
Shade Deficit Analysis (LiDAR)	Ecology or local partner	2031, 2041, 2051, 2061, 2071, 2081, 2091
Baseflow Restoration Analysis	Ecology or local partner	2018, 2031, 2041, 2051, 2061, 2071
Continuous Water Temperature Monitoring	Ecology or local partner	Annually during critical period
Salmon Recovery Plan Review and Status and Trends Monitoring	Snohomish Basin Salmon Recovery Technical Committee	Ongoing as recovery review occurs

Adaptive Management

Natural systems are complex and dynamic. The way a system will respond to human management activities is often unknown and can only be described as probabilities or possibilities. Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. In the case of TMDLs, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. As we implement these actions, the system will respond, and it will also change. Adaptive management allows us to fine-tune our actions to make them more effective, and to try new strategies if we have evidence that a new approach could help us to achieve compliance.

TMDL reductions should be achieved by year 2081. Partners will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the implementation strategy as needed. Ecology will use adaptive management when water monitoring data show that the TMDL targets are not being met or implementation activities are not producing the desired result. If state standards are achieved, but wasteload and load allocations are not, the TMDL will be considered satisfied.

Ecology will use adaptive management when water monitoring data show that the TMDL targets are not being met or implementation activities are not producing the desired result. A feedback loop (Figure 20) consisting of the following steps will be implemented:

Step 1. The activities in the water quality implementation plan are put into practice.

Step 2. Programs and BMPs are evaluated for technical adequacy of design and installation.

Step 3. The effectiveness of the activities is evaluated by assessing new monitoring data and comparing it to the data used to set the TMDL targets.

- **Step 3a.** If the goals and objectives are achieved, the implementation efforts are adequate as designed, installed, and maintained. Project success and accomplishments should be publicized and reported to continue project implementation and increase public support.
- **Step 3b.** If not, BMPs and the implementation plan will be modified or new actions identified. The new or modified activities are then applied as in Step 1.

It is ultimately Ecology's responsibility to assure that implementation is being actively pursued and water standards are achieved. See the Effectiveness Monitoring section in this report.

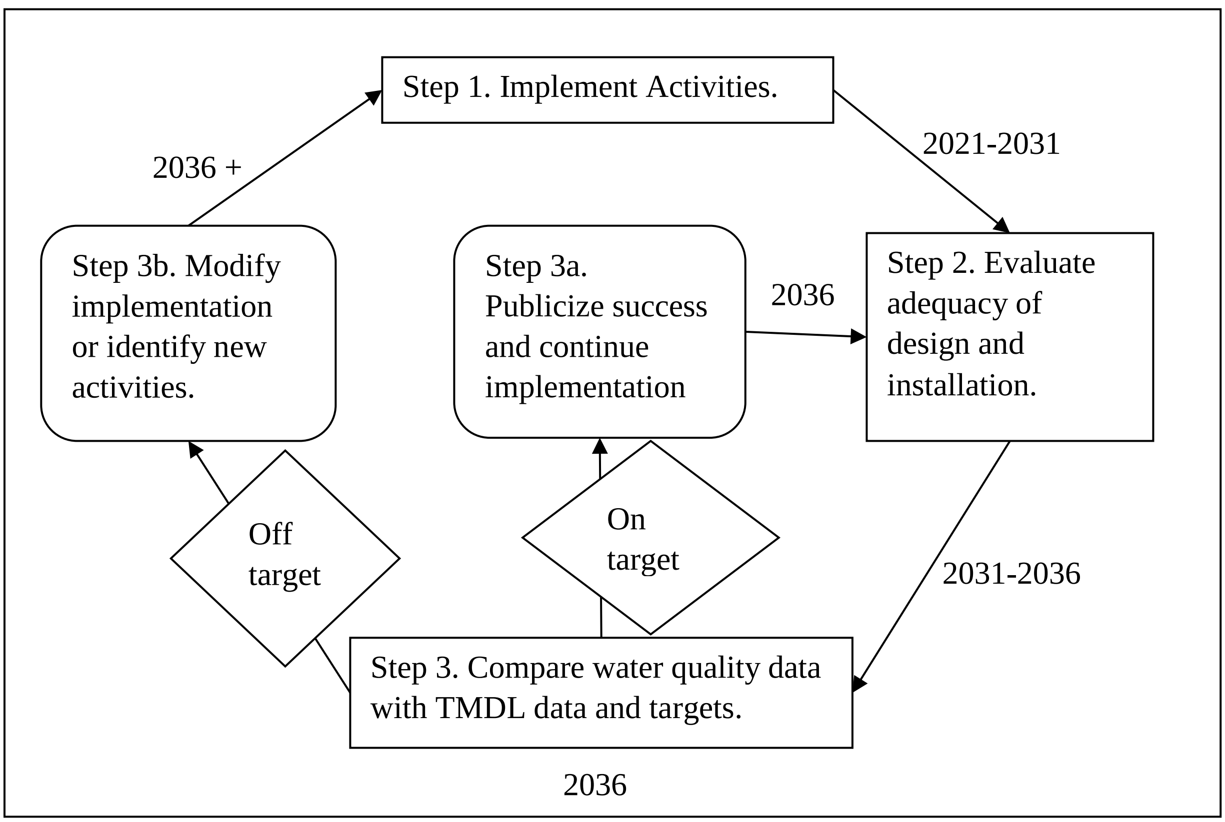

Figure 20. Feedback loop for determining need for adaptive management.
Dates are estimates and may change depending on resources and implementation status.

Reasonable Assurance

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. For the Pilchuck River Temperature and Dissolved Oxygen TMDL, both point and nonpoint sources exist. TMDL projects (and related implementation plans) must show “reasonable assurance” that these sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance; permit administration, and enforcement will all be used to ensure that the goals of this TMDL project are met.

The goal of the TMDL is to help the waters of the basin meet the State’s water quality standards. The following rationale helps provide reasonable assurance that the Pilchuck River TMDL goals will be met by 2081 if implementation happens immediately. Implementation should happen as soon as possible to minimize how rapidly water temperatures will be rising due to climate change.

Ecology has formed working relationships with implementation partners such as Tulalip Tribes, Snohomish Conservation District, and Adopt-A-Stream Foundation, who began and continue to implement early on-the-ground restoration. Examples of these efforts include Little Pilchuck Streamkeepers, the 2020 removal of the Pilchuck Diversion Dam, and the funding of tree planting through the Terry Husseman Account as well as Ecology’s Combined Financial Assistance Program.

Ecology and EPA will control point source thermal loadings from NPDES-permitted facilities as part of engineering plan review and approval as well as basic permit administration activities. There is also considerable interest and local involvement in riparian and instream restoration actions that will help reduce stream temperatures in the watershed. Ecology believes that the following activities already support this TMDL and add to the assurance that water temperatures, from nonpoint sources, will meet conditions provided by Washington State water quality standards. This assumes that the identified activities are continued and maintained.

The following rationale helps provide reasonable assurance that the Pilchuck River nonpoint-source TMDL goals will be met by 2081. Since trees will need at least 50 years to reach maturity, achieving full system potential is expected to take more time.

- Tulalip Tribes: technical assistance, research and problem identification, special project support for riparian and instream improvement projects, streamflow restoration, instream restoration, riparian restoration
- Ecology: technical assistance, project development and coordination, Combined Financial Assistance Program, wetland protection, regulation of NPDES permitted discharges and regulation of nonpoint pollutant discharges including, but not limited to nutrient discharges
- City of Granite Falls: control of stormwater and wastewater treatment plant discharges
- City of Marysville: control of stormwater discharges
- City of Lake Stevens: streamflow restoration, control of stormwater discharges
- City of Snohomish: control of stormwater discharges

- Adopt-A-Stream Foundation: education and outreach; riparian planting and maintenance; instream restoration
- Sound Salmon Solutions: riparian planting and maintenance; instream restoration, education and outreach
- Ducks Unlimited: wetland restoration, water conservation
- Snohomish Conservation District: technical and financial assistance, project coordination, riparian restoration, instream restoration, water conservation, education and outreach
- Wild Fish Conservancy: landowner outreach, project development and implementation for riparian plantings and instream restoration
- Snohomish Basin Salmon Recovery Forum and Technical Committee: technical assistance and funding for riparian restoration and instream improvements
- Snohomish County: regulatory authority, funding assistance, riparian restoration, streamflow restoration, instream restoration, control of stormwater discharges
- Washington Water Trust: project sponsor, water conservation, instream restoration, streamflow restoration
- Washington State Department of Transportation: control of stormwater discharges, wetland mitigation, fish passage improvements

The monitoring and adaptive management process described in the Tracking Progress section of this report is designed to provide information in a feedback loop (Figure 20) to encourage more landowner participation in BMP implementation and restoration projects. If the monitoring results indicate that the approaches being used are not working, the organizations involved in monitoring and implementation will re-convene to determine whether different approaches should be used.

Education, outreach, technical and financial assistance, and enforcement all will be used to ensure that the goals of this Water Quality Improvement Report are met. Ecology will seek funding resources to increase the number of compliance staff to investigate water use and develop appropriate compliance actions.

Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards. However, it is the goal of all participants in the TMDL process to achieve clean water through cooperative efforts.

Chapter 4: Detailed TMDL Study Results and Analysis

Project Goal

The goal of this water quality improvement report and implementation plan is to address temperature and dissolved oxygen (DO) problems in the Pilchuck River in order to improve water quality and restore beneficial uses. More specifically, the goal is for the Pilchuck River to meet Washington State temperature and DO water quality standards.

Project Objectives

Data Collection Objectives

- Collect high quality data during field surveys from June to September 2012.
- Refine understanding of Pilchuck River through follow-up data collection in 2014 and 2016.
- Characterize stream temperatures and processes governing the thermal regime in the Pilchuck River and major tributaries. This includes the influence of tributaries and groundwater/surface water interactions on the heat budget.
- Characterize processes governing DO and pH in the Pilchuck River and major tributaries, including the influence of tributaries, point and nonpoint sources, and groundwater.

TMDL Analysis Objectives

- Develop a predictive temperature model for the Pilchuck River. Using critical conditions in the model, determine the streams' capacities to assimilate heat loads. Evaluate the system potential temperature (approximate natural temperature conditions).
- Develop a model to simulate instream biochemical processes and productivity, DO, and pH in the Pilchuck River. Evaluate system potential conditions with the model by removing human pollutant sources and hydromodifications to the extent feasible.
- Using critical conditions in the model, determine the loading capacity of pollutants needed to meet temperature, pH, and DO water quality criteria and protect beneficial uses.
- Present potential pollutant allocation scenarios for point and nonpoint sources in order to meet the loading capacity.
- Use the calibrated models to evaluate scenarios for future water quality management of the Pilchuck River watershed.

Methods

Ecology's study design, data collection, and data quality methods are described in detail in the Quality Assurance Project Plan (QAPP) for this study (Swanson et al., 2012) and addendums to the QAPP (Mathieu, 2014; Mathieu, 2016).

Final study area, locations, data quality, data collection, and modeling methods are described briefly here and in greater detail in Appendices D through H.

Study Area and Sampling Locations

The study area for this project extends from about river mile (RM) 25.5 between Menzel Lake Rd and the Snohomish diversion dam to ~RM 1.5 at the 2^{nd} Street Bridge in the city of Snohomish (Figure 21).

Ecology collected samples and measurements from 14 key locations on the mainstem Pilchuck River, one point source (two locations), and two significant tributaries (Tables 37 and 38). Appendix D details additional locations that were sampled in a more limited capacity for the TMDL, including 5 additional mainstem sites, 17 minor tributaries, 9 seeps, and 5 piezometers.

Table 37. Core mainstem study locations on the Pilchuck River.

Location ID	Map#	Location Description	Latitude	Longitude
07-PIL-25.5	1	Pilchuck River at Menzel Lake Rd, ~20 ft. d/s of bridge	48.01872	-121.91504
07-PIL-21.5	2	Pilchuck River at Robe-Menzel Rd, just u/s of bridge	48.05479	-121.95703
07-PIL-18.9	3	Pilchuck River ~200 ft upstream of Granite Falls WWTP outfall	48.07601	-121.97758
07-PIL-18.7	4	Pilchuck River at WDFW access at end of Ray Gray Rd	48.07632	-121.98303
07-PIL-15.1	5	Pilchuck River at 64th St, ~100 ft. u/s of bridge near RB	48.05355	-122.02357
07-PIL-11.6	6	Pilchuck River just u/s of 28th Pl NE access to river	48.02309	-122.02401
07-PIL-10.4	7	Pilchuck River at Russell Rd, ~30 ft. u/s of bridge	48.00740	-122.03333
07-PIL-8.6	8	Pilchuck River u/s of confluence with Little Pilchuck Creek	47.98907	-122.03681
07-PIL-8.5	9	Pilchuck River at OK Mill Rd, ~25 ft. d/s of bridge	47.98675	-122.03550
07-PIL-8.2	10	Pilchuck River ~1,000 ft d/s of OK Mill Rd	47.98498	-122.03672
07-PIL-5.8	11	Pilchuck River ~900 ft u/s of Dubuque Rd; u/s of spring/ tributary on left bank	47.96309	-122.06328
07-PIL-5.7	12	Pilchuck River at Dubuque Rd, ~150 ft. d/s of bridge	47.96207	-122.06569
07-PIL-3.6	13	Pilchuck River at Three Lakes Rd, ~25 ft. u/s of bridge	47.93756	-122.07466
07-PIL-2.0	14	Pilchuck River at 6th St, ~80 ft. u/s of bridge	47.91883	-122.08253

d/s: downstream; u/s: upstream; RB: right bank

Table 38. Core tributary and point source study locations on the Pilchuck River.

Location ID	Map#	Location Description	Latitude	Longitude
07-GRA-EFF	P1	Granite Falls WWTP effluent at plant after UV treatment	48.07899	-121.97520
07-GRA-STP	P2	Granite Falls WWTP manhole near outfall to Pilchuck R	48.07605	-121.97971
07-DUB-0.0	T1	Dubuque Creek ~50 ft. u/s of confluence with Pilchuck R	47.98791	-122.03630
07-LIT-1.8	T2	Little Pilchuck Creek at 12th St, ~200 ft. d/s of bridge	48.00707	-122.04557

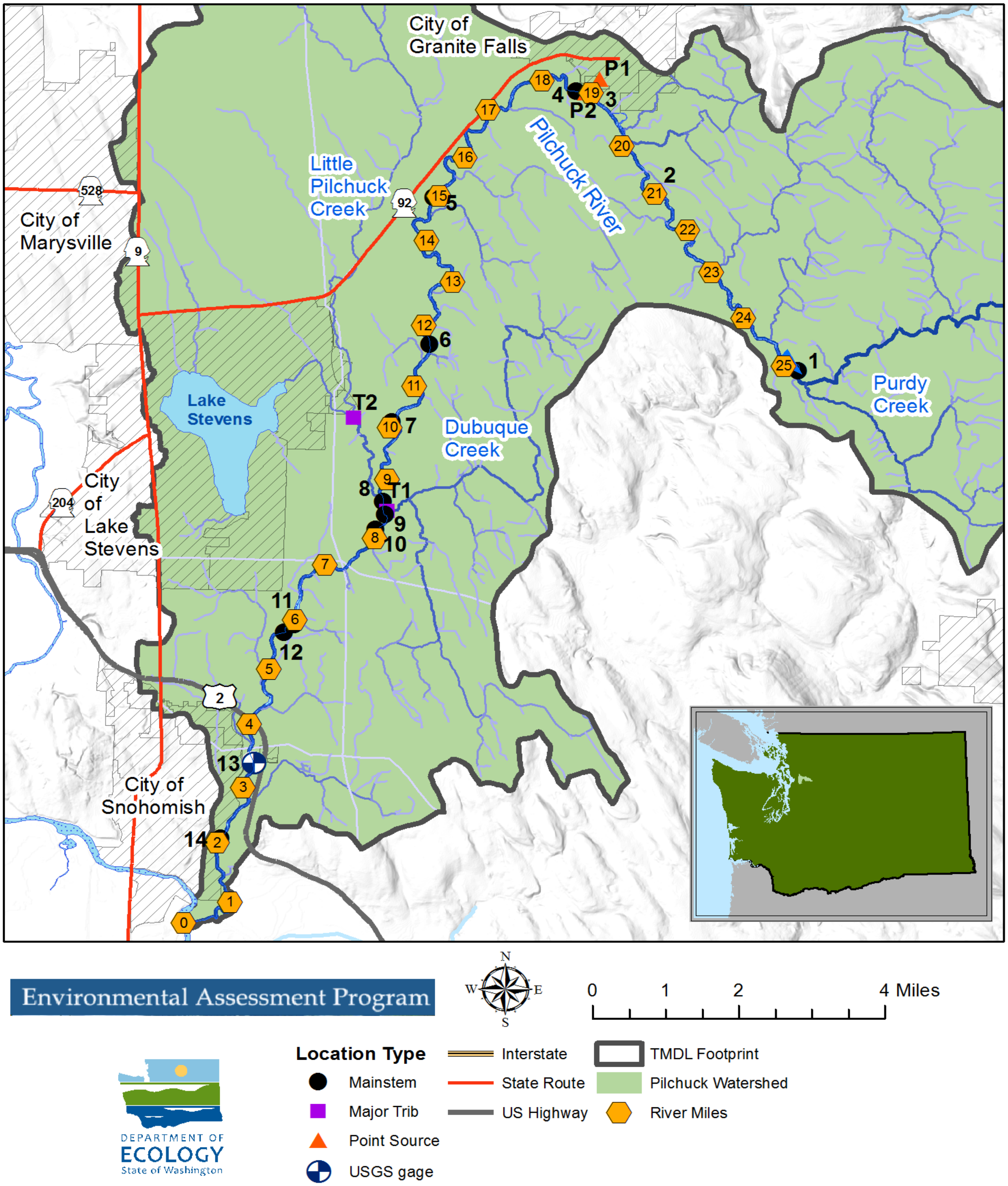

Figure 21. Pilchuck TMDL study area and sampling locations.

Data Quality Methods

Data quality assurance methods included:

- Field quality assurance (QA) methods:
  - Duplicate samples for streamflow, periphyton, and water quality measurements.
  - Calibration of water quality instruments (including sondes and thermistors), prior to use or deployment, using NIST-certified standards and manufacturer or Ecology procedures. Deployed sondes were also post-checked using the same procedures.
- Lab QA methods:
  - Ecology's Manchester Environmental Laboratory analyzed duplicates, blanks, matrix spikes, and laboratory control samples for each batch of samples analyzed, following routine laboratory procedures (MEL 2016).

See Appendix E for more information on data quality.

Data Collection Methods

In general, data collection followed the plan outlined in the QAPP and addendums, with a few notable exceptions:

- During the 2012 study, several thermistors were lost or stolen. As a result several locations did not have complete temperature records from June to October. These stations were redeployed in early August and captured the 7-DADMax peak for the year, but not the peak daily maxima.
- The 2016 study planned to install 8-12 piezometers along the course of the river. Piezometer installation was attempted at multiple locations in the upper watershed, but failed due to underlying glacial till, cobbles, or bedrock. As a result, only five piezometers were successfully installed in the mid to lower river. Additional seeps were sampled to compensate for the reduced number of groundwater samples.

Information and Data from Sources Outside of Ecology

Information from the U.S. Geological Survey (USGS) flow gage 12155300 (Pilchuck River near Snohomish, WA) was used for model development and calibration, as well as general validation of Ecology data. Streamflow and stage data from the USGS station were used (USGS, 2017).

Modeling Framework

Ecology used the recently updated QUAL2Kw 6.0 modeling framework[60] (Pelletier and Chapra, 2008) to develop the loading capacity for nutrients and temperature and to make predictions about water quality under various scenarios.

Appendix F describes the modeling framework in greater detail. In general Ecology:

- Used the TTools extension for ArcView (Ecology, 2015) to process GIS data for input to the Shade model.

[60] https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs

- Used Ecology's Shade.xlsm model (version 40b04a06; Pelletier, 2015) to estimate effective shade along the mainstem of the Pilchuck River.
- Collected/compiled time series data and developed time series records from discrete data using linear interpolation or regression.
- Populated the QUAL2Kw model with channel geometry, model segmentation, and reach information.
- Populated the QUAL2Kw model with meteorology, water quality, and shade data.

Figure 22 depicts a conceptual diagram of the modeling inputs and framework.

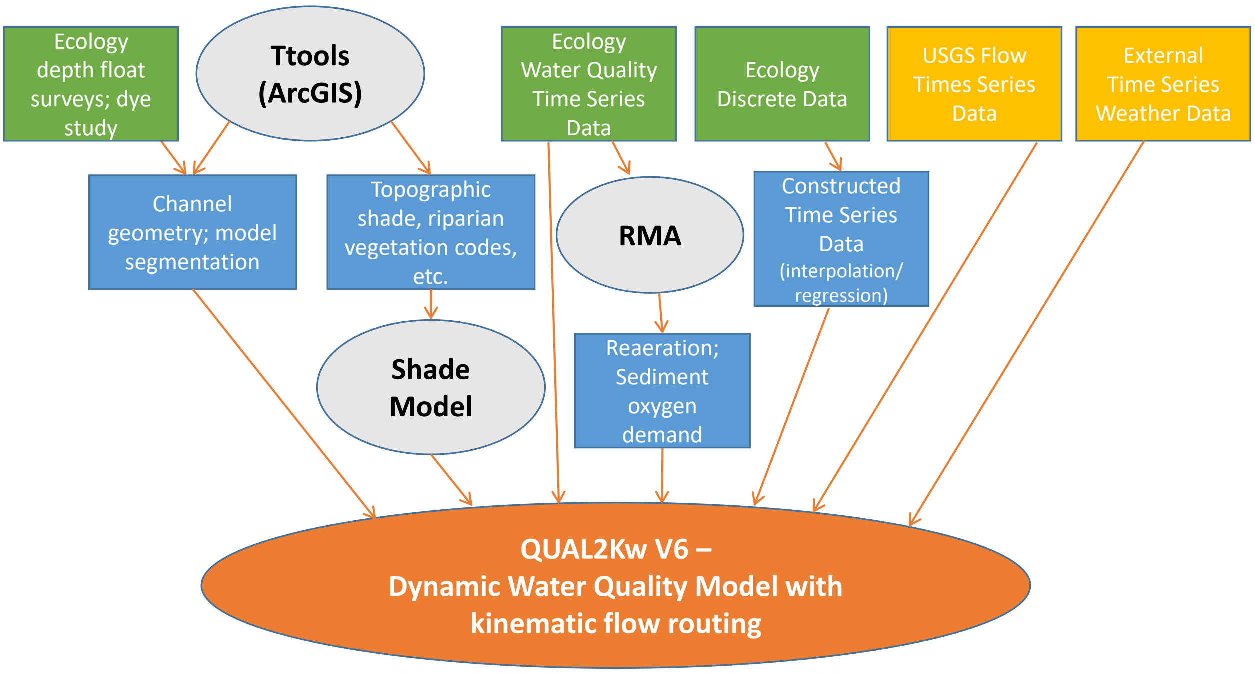

Figure 22. Conceptual diagram of the model inputs and framework.

The QUAL2Kw water quality model was first developed for the temperature analysis and then expanded to simulate the effects of nutrients, periphyton growth, carbonaceous biochemical oxygen demand (CBOD), and hyporheic biofilm growth on DO in the Pilchuck River.

There are several important concepts for modeling the effect of primary productivity in running waters. Among the most important are:

- Within the model, only one nutrient can limit algal growth at a time. The limiting nutrient will be the least available relative to its demand. This principle is known as Liebig's law of the minimum (Chapra, 2008).
- For river modeling, it is important to correctly limit the growth rate to predict algal biomass yield. The growth rate is limited by the concentration of the most limiting nutrient (i.e., the supply rate of the limiting nutrient), by the amount of available light, and by temperature. In some situations, other factors limit growth instead of nutrients, such as scour or sloughing, space available for attachment, or grazing by macroinvertebrates.

- It is appropriate to use the dissolved-fraction concentration of the limiting nutrient, such as soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN), as the basis for modeling periphyton growth. This is because the nutrient must be in a readily-available form for biological uptake and growth to occur during solute transport (Jacoby and Welch, 2004).
- Total phosphorus and nitrogen are important to model since the particulate and organic fractions can be transformed into the dissolved fractions through various instream and hyporheic processes.

Ecology's River Metabolism Analyzer (RMA) was also used to derive estimates of respiration, productivity, reaeration, and sediment oxygen demand (SOD) using the diel water quality data and whole stream metabolism analysis techniques.

Detailed documentation of the modeling framework is provided in Appendix F (Model Documentation).

Model Calibration Methods

Appendix F (Model Documentation) provides a detailed description of the model calibration. The general approach was:

1. Evaluating the quality of the geometry rating curves, and associated longitudinal depth and width data, by comparing to observed time of travel data within the QUAL2Kw model.
2. Calibrating to observed temperature data by making several adjustments to rates, constants, and input data, based on review of the data quality and adjustment of light and heat model parameters.
3. Using continuous temperature data from all stations in the 2012 study to evaluate the balance of error between sites and minimize overall bias.
4. Using the calibrated temperature model (QUAL2Kw) as a starting point for DO and nutrients.
5. Calibrating to observed suspended solids data by adjusting the inorganic suspended solids (ISS) and chlorophyll input data to optimize goodness of fit to observed data during critical conditions. While DO in the model was generally insensitive to the concentrations of these parameters, having realistic levels in the model is important to accurately account for light limitation factors.
6. Calibrating productivity of the hyporheic biofilm to generate a SOD comparable to estimates derived from whole stream metabolism analysis using RMA. The diffuse/groundwater CBOD input concentrations were increased to match this level of productivity.
7. Researching rates used in calibrated QUAL2Kw models in the western U.S. and using the 25^{th} and 75^{th} percentiles of these rates as the ranges for the initial adjustment of model parameters. Several rates were ultimately adjusted beyond this interquartile, but remained within the bounds of literature and previous studies.
8. Relying on diel DO data collected during the late August 2012 survey as the primary tool for visual evaluation during calibration of DO. Data from this survey was generally of higher quality, had more stations, and were collected during more stable flow conditions than during the late July/early August 2012 survey.
9. Using additional nutrient and diel water quality data from 2016 to help guide calibration.

Results and Discussion

During the 2012 field study, Ecology collected flow, temperature, DO, pH, periphyton, and nutrient data. The goal of this effort was to characterize and model the response of temperature, DO, and pH in the water column. Ecology extended the study during the summers of 2014 and 2016 by collecting additional data and groundwater samples in order to calibrate the model and understand groundwater input and instream processes.

Complete data tables and time series plots for the project are located in Appendix D.

Data Quality Assurance Results

Ecology Sources

In 2004, Washington State enacted a law entitled the Water Quality Data Act. The law requires that the data used in certain water quality activities meet its credible data principles. As required by this law, Ecology developed a policy regarding the use and collection of water quality data. Ecology's policy "Ensuring Credible Data for Water Quality Management", also known as Chapter 2, is available online.[61]

The three main goals of the policy are to:

- Explain how data are used to inform decisions about water quality and water quality improvement projects.
- Describe criteria to establish data credibility.
- Recommend appropriate training and experience for data collection.

Overall, Ecology found the study data to be of acceptable quality and useable based on the above policy and the study objectives. Some results were qualified or rejected based on failure to meet measurement quality objectives or other issues. Appendix E provides more detailed data quality results.

Sources Outside of Ecology

Ecology reviewed the data quality methods and results from USGS and determined the data used were of acceptable quality. A description of USGS data quality methods and results is included in Appendix E.

Model Quality Assessment Results

Appendix F provides a detailed description of the model quality evaluation including an error and sensitivity analysis.

[61] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11

In general the calibrated model performed well for temperature under a dynamic set of conditions over the course of the modeling period. Performance was measured by the ability to predict important spatial and temporal patterns of these variables.

Performance was also assessed through goodness of fit to observed data, via statistics for error and bias. In this respect, the model calibration was comparable in fitness to similar applications of QUAL2Kw (Sanderson and Pickett, 2014):

For all hourly predictions during the most critical period of 7/8/12 to 9/8/12:
- Average RMSE = 0.65°C
- Average Bias = -0.10°C
- Error was worst during early July (higher flows) and early September (lower temperatures).

For observed vs. predicted 7-DADMax values from 7/8/12 to 9/8/12:
- Average RMSE = 0.46°C
- Average Bias = -0.02°C

The temperature model was most sensitive to factors affecting either:
- Solar shortwave radiation, including observed (or modeled) solar radiation, effective shade, and cloud cover inputs.
- Longwave radiation, which is influenced by the chosen emissivity model.

The calibrated model also performed well for key water quality variables including DO, pH, and nutrients, under a dynamic set of conditions over the course of the modeling period. Performance was measured by the ability to predict important spatial and temporal patterns of these variables, particularly diel DO at higher levels of primary productivity.

Performance was also assessed through goodness of fit to observed data using statistics for error and bias. In this respect, the model calibration for DO was comparable in fitness to similar applications of QUAL2Kw (Sanderson and Pickett, 2014):

For all hourly predictions during the most critical period of 7/8/12 to 9/8/12:
- Average RMSE = 0.23 mg/L
- Average Bias = 0.02 mg/L

The model was most sensitive to parameters and inputs that affect bottom algae primary productivity and biomass, particularly maximum growth rate and respiration rates.

Hydrology

Based on USGS gage data, streamflows in the Pilchuck River followed a relatively typical pattern (near historical median for 1992-2016) in August and early September of 2012, but were well above the median in June and July and below the median in late September and October (Figure 22). Flows steadily receded from July through September, dropping to a baseflow of 50 to 70 cfs. Data collection also occurred in 2014 and 2016, which were more typical flow years (near median flow).

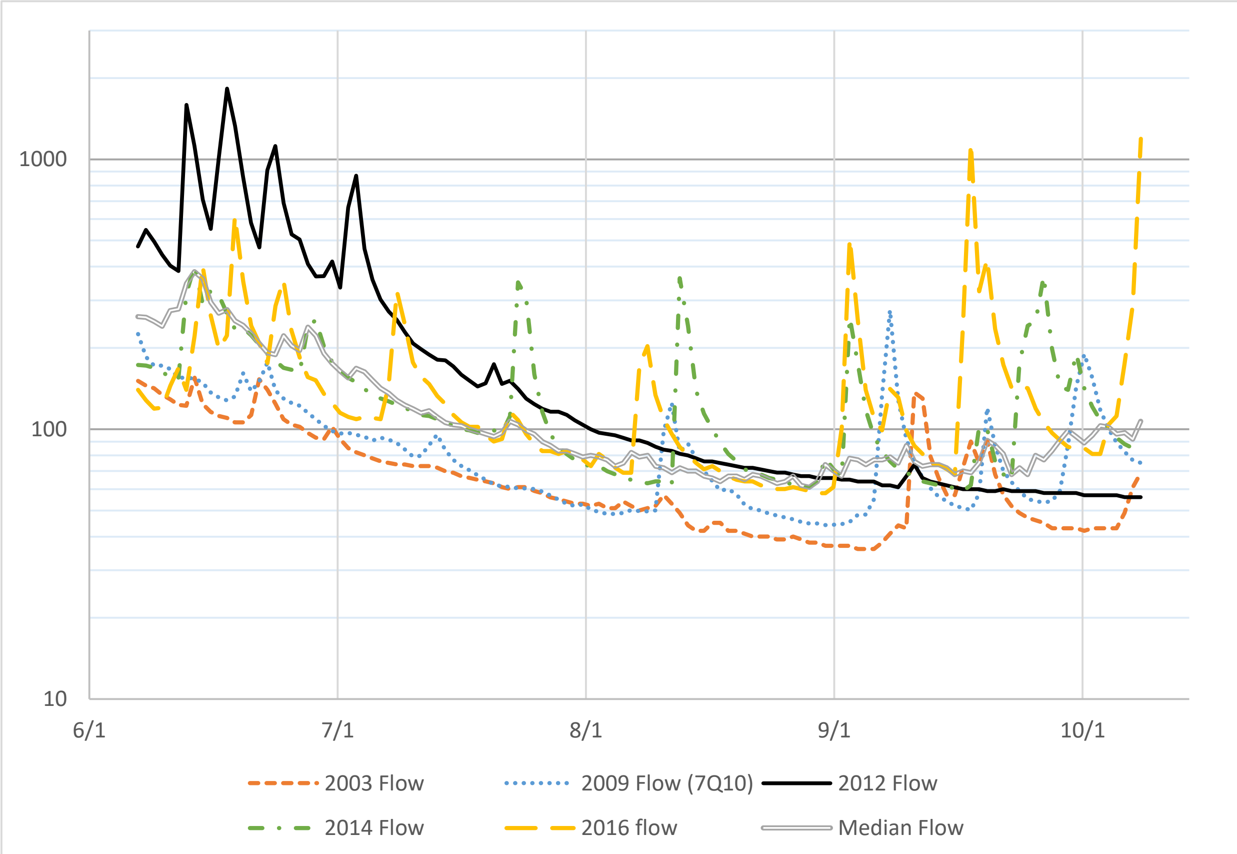

Figure 23. Pilchuck River summer flows for the study years (2012, 2014, and 2016), two low-flow years (2003 and 2009), and historical median daily flow.

The most significant hydrologic inputs to the Pilchuck River within the study area are groundwater (see discussion below), Little Pilchuck Creek, and Dubuque Creek. These two tributaries range from a combined input of 0.1 cfs (or 0.2 % of mainstem flow) in the late summer or early fall of 2014 to 14 cfs (or 14% of mainstem) in July 2012.

Flow measurements at the USGS gage extend only back to 1992, so a long-term flow record was not available to determine more reliable flow statistics. Based on the 25-year record from 1992 to 2016, the lowest 7-day average flows with 10-year recurrence interval (7Q10) low flow is ~41.8 cfs and the 7Q2 low flow is ~57.6 cfs. Low-flow years depicted in Figure 22 include 2003 (the lowest annual 7-day flow on record) and 2009 (7-day low flow near 7Q10).

Groundwater and Cold Water Refuge

Groundwater

The localized effect of groundwater entering a water body can significantly affect water quality and the associated fish habitat. Ecology observed numerous locations in the study area (Table 34 and Figure 24) where the following types of subsurface discharge occurred:

- **Lateral discharge from shallow surficial aquifers** to the mainstem Pilchuck or hydrologically connected tributary, which can occur when an underlying confining layer prevents vertical migration of groundwater. This type of discharge was observed throughout the watershed and typically occurred where the river channel intersected or was adjacent to a confining Vashon till layer. A similar type of discharge was observed in an area where an intersection with confining bedrock resulted in concentrated groundwater discharge near the outfall to the Granite Falls WWTP and the Washington Department of Fish and Wildlife (WDFW) access at Ray Gray Rd.

- **Vertical upwelling of groundwater,** which occurs when groundwater enters the river in a relatively porous area of a streambed. Ecology observed this condition in the piezometer downstream of Dubuque Rd. It is unclear whether the source of this upwelling water was a break in the confining layer and connection to a deeper aquifer unit or a thicker layer of alluvium that was connected to the surficial aquifer layer (i.e., depth to Vashon till was greater). Water quality results, temperature monitoring, and vertical hydraulic gradients suggest this was not a shallow or recent hyporheic discharge (for example, from a riffle/pool sequence or gravel bar in the active channel).
- **Off-stream wetlands, ponds, lakes, or tributaries**, which can have a hydrologic subsurface connection with the Pilchuck River channel. Based on aerial photography and digital elevation models, there are numerous areas where this is a possibility. Notable wetlands, ponds, and lake areas include the pond wetland complexes at ~RM 13, the Connor Lake tributary, and ~RM 25. Notable tributary channels with potential subsurface flow are Little Pilchuck and Dubuque Creeks.
- **Alluvial floodplain aquifers (hyporheic flow).** These can have locations where streamflows go subsurface then return to the river as cooler water. The time water spends subsurface and the distance it travels can be very short or very long, affecting the amount of cooling that occurs. Areas where this may occur include the major side channel at RM 14. These areas were identified by springs and seeps with conductivities similar to river water. More discussion on the effect of hyporheic flows on river DO and temperature levels is provided in the implementation section of this report.

Ecology developed multiple flow balances based on seepage surveys conducted in 2012 and 2014 (Table 39). An uncertainty analysis was performed on the seepage flow balance for each reach. The reach seepage gain or loss was deemed significant if it exceeded the 95% confidence interval of the combined measurement error for each flow site.

The net significant gain was calculated as the sum of all significant gains and losses (bold numbers in Table 39), while “net gain – all” is the sum of all gains and losses, including those that were not statistically significant.

The majority of the surveys showed a consistent significant overall gain of about 8 to 14 cfs, equating to about 10% to 20% of river flow. A large “gain” (a positive difference from upstream to downstream) of 45 cfs was measured during the July 2012 survey when flows were above 100 cfs. However, only five mainstem measurement locations were surveyed, and boundary flows were dropping over the course of the survey. This suggests that this difference may be partially due to dynamic flow changes.

Table 39. Flow gains and losses in cubic feet per second, with significance, from the 2012 and 2014 seepage surveys.

Date	RM 20.9	RM 18.7	RM 15.1	RM 10.4	RM 8.6	RM 8.4	RM 5.7	RM 2	Net Signif. Gain	Net Gain All
7/31/12	Nm	nm	**22.88**[g]	-5.6	nm	**13.8**[g]	nm	**8.22**[g]	**44.9**[g]	39.3
8/28/12	Nm	nm	**4.73**[g]	-0.73	nm	**3.84**[g]	**5.27**[g]	-1.52	**13.84**[g]	11.59
7/9/14	2.3	**10.58**[g]	***-5.98*** [l]	***-6.3*** [l]	nm	**8.39**[g]	**3.05**[g]	1.29	**9.74**[g]	13.33
8/7/14	0.7	**4.35**[g]	3.25	nm	**4.59** [g]	1.09	-3.61	0.57	**8.94**[g]	10.94
8/28/14	***-3.81*** [l]	**17.4**[g]	***-10.12***[l]	-1.54	nm	**4.85**[g]	-0.14	1.69	**8.32**[g]	8.33
Median =	0.7	**10.58**[g]	n/a	-3.57	n/a	n/a	-0.28	0.93	**9.74**[g]	11.59

[g] = significant gain; [l] = *significant loss*; nm = no measurement; all other values not significant

The 2014 surveys identified two areas of consistent and substantial gains:

- The reach between Robe-Menzel Rd (PIL20.9) and Ray Gray Rd (PIL18.7).
    - As mentioned above, groundwater discharge was observed at the bedrock outcropping near the Granite Falls WWTP.
    - In 2010, Snohomish County documented a 0.9°C decrease in 7-DADMax temperature between ~RM 20.6 and ~RM 18.5 (SCSWM, 2012a).
- The reach between Russell Rd (PIL10.1) and OK Mill Rd (PIL8.4).
    - Given that the mouths of Little Pilchuck Creek and Dubuque Creek enter in this stretch, it is possible that the two tributaries are contributing significant subsurface flow to the Pilchuck River at lower flows.
    - The 8/7/14 seepage survey suggested much of this gain was happening before the confluence of the two tributaries; however, seepage was observed along the right bank just upstream of the Little Pilchuck, which parallels the mainstem in this stretch, indicating a possible subsurface connection prior to the confluence.

Cold Water Refuges

Ecology also looked for seeps and small tributaries, and made other observations during the 2014 and 2016 surveys to identify areas that could potentially serve as cold water refuges (CWR), or areas that are hydrologically connected to and 2°C or more cooler than the main river channel (Table 40). Measured temperatures in these seeps and tributaries ranged from 9.8 to 17.1°C (14.2°C average) and were between 2.7 and 13.1°C cooler than the adjacent mainstem temperature. The temperature differences between the seeps and tributaries and the mainstem averaged 5.6°C.

Longitudinal temperature profiles collected in 2014 were not as useful as field surveys in identifying CWR because short-term cooling effects were generally limited to less than 0.2°C in the main channel. Significant reductions in temperature were only observed in poorly mixed or off-channel locations which were not measured by these profiles. Profiles were collected during the 2014 floats with temperature recorded every 30 seconds.

Many of these potential CWR locations appear to currently lack the channel structure or habitat features to adequately provide refuge to fish. This information, along with extensive habitat information provided by Snohomish County's *Middle Pilchuck River Assessment Habitat Report* (SCSWM, 2012a), should be used to prioritize potential instream restoration projects.

Field staff also collected water quality measurements of apparent groundwater seepage during surveys conducted in 2014 and 2016 (Figure 24). Given that measurements were collected from day-lighted sources, the temperature, DO, and pH results are likely higher than subsurface groundwater.

Table 40. Potential cold water refuge (CWR) locations identified in the Pilchuck River.

Site ID	~RM	Bank	Temperature (°C)	Difference from mainstem temperature (°C)	Description/comments
Seep23.1	23.1	Right	10.8	-7.2	Large log jam and pools immediately upstream
Trib22.5	22.5	Right	12.5	-5.4	Tributary with some large woody material (LWM) and side channels
Seep21.1	21.1	Right	16.43	-2.7	Reed canary grass around seep, needs riparian restoration
Seep20.5	20.5	Right	12.48	-5.2	Near Skinner Road side channel monitored by Snohomish County
Trib19.6	19.6	Right	17.1	-3.5	Tributary with pools, log jams, braids, and seeps within 0.5 km
Seep18.9	18.9	Left	13.9	-6.4	Groundwater seep upstream of WWTP outfall
Seep18.1	18.1	Right	14.68	-3.6	Seep on bank ~10' above water surface
Trib17.2	17.2	Left	15.1	-1.8	Tributary with pools, log jams, and seeps within 0.5 km
Seep15.3	15.3	Left	13.49	-7.1	Seep; possibly fed by upland wetlands ~500' to NE
Trib15.3	15.3	Left	15.39	-3.8	Tributary; possibly fed by upland wetlands ~500' to NE
Seep15.1	15.1	Right	17.5	-2.9	Off-channel wetlands likely fed by groundwater and hyporheic flow
Seep14.3	14.3	Right	14.9	-5.7	Series of three culverts in armored bank
Side Channel	14.3	Left	n/a	n/a	Major side channel
Seep13.3	13.3	Left	15	-6.1	Multiple seeps from RM 12.8 to 13.5; off-channel habitat potential
Seep11.7	11.7	Left	12	-10.5	Off-channel habitat potential, needs LWD/cover
Seep10.7	10.7	Left	14.66	-8.3	Multiple seeps, likely fed by large wetlands complex to E/SE
Trib10.6	10.6	Left	9.81	-13.1	Tributary, likely fed by groundwater and wetlands complex to E/SE
Trib7.3	7.3	Left	12.21	-4.9	Tributary channel/culvert and multiple seeps
Trib6	6.0	Left	13.86	-4.5	Tributary channel fed by wetlands to the east
Seep5.8	5.8	Left	14.9	-5.6	Seep just upstream of Dubuque Rd
Average =	n/a	n/a	14.2	-5.6	n/a

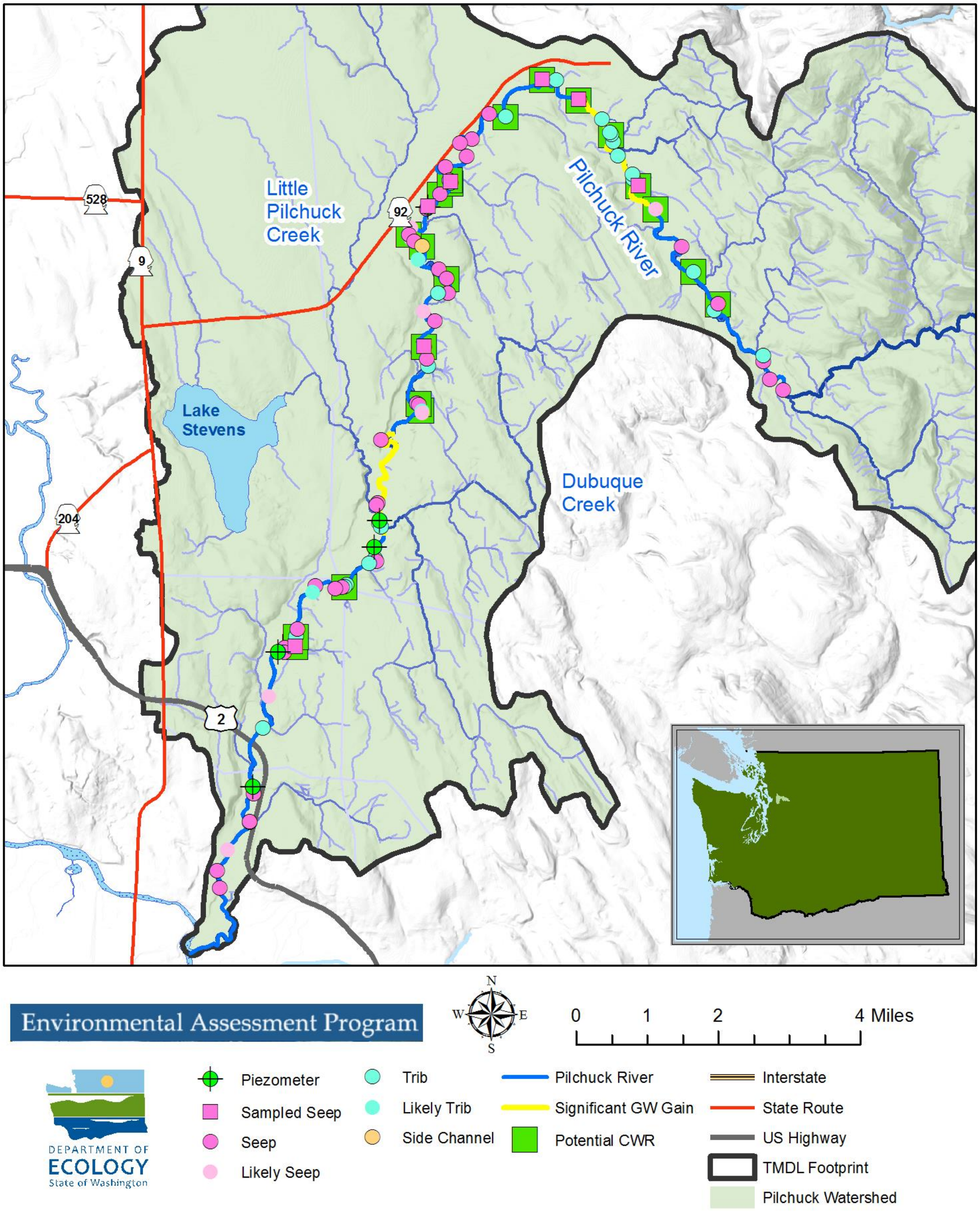

Figure 24. Locations of observed and sampled seeps, piezometers, potential cold water refuge (CWR), and reaches with significant flow gains.

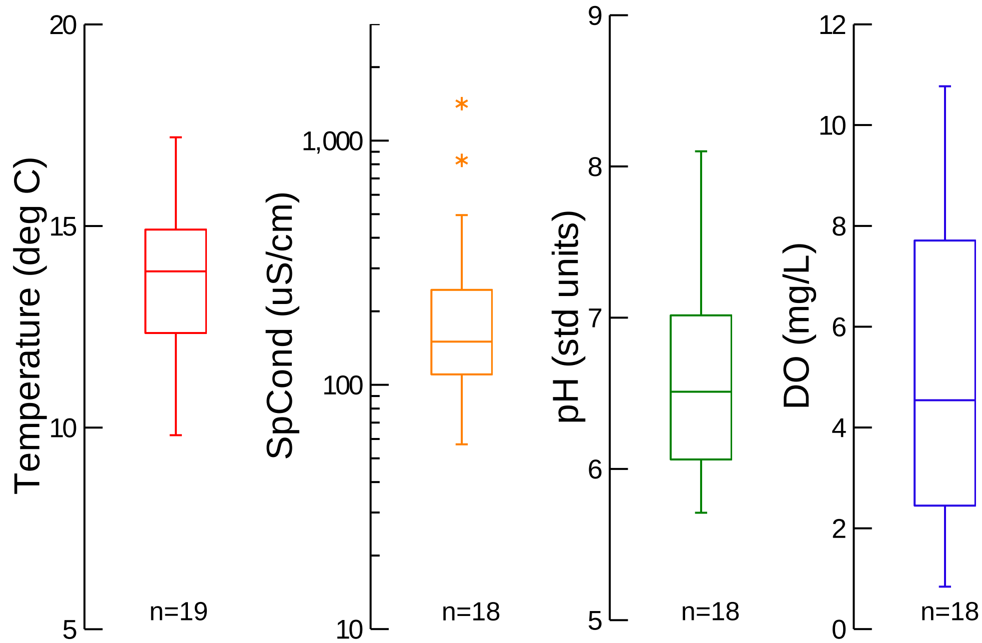

Figure 25. Boxplots of groundwater seep measurement results for 2014 and 2016.

In 2016, the mainstem river bottom was instrumented with five instream piezometers to measure groundwater characteristics at or just below the river bed. Four of the piezometers were instrumented with temperature loggers at multiple depths and deployed in the river for two months. The fifth piezometer was installed at 64th Ave bridge (PIL15.1) and left in for only one day and then sampled, due to impending site access restriction related to removal and replacement of the existing bridge. This piezometer did not have a temperature logger installed.

Based on positive vertical hydraulic gradients, water quality characteristics, and temperature profiles, Ecology identified the 64th Ave bridge (PIL15.1) and Dubuque Rd (PIL5.7) piezometers as likely areas where the river was gaining flow. There is less certainty at PIL15.1, given the piezometer was only installed for one day; however, field staff observed evidence of groundwater seepage along banks which supports the likelihood of groundwater upwelling at this site. The remaining piezometers upstream of Little Pilchuck (PIL8.6), downstream of OK Mill Rd (PIL8.3), and at Three Lakes Rd (PIL3.6) were identified as likely losing flow.

Temperature results for the piezometers are depicted in Figure 25. The gaining piezometer at Dubuque Rd shows a relatively stable, cool temperature of ~13°C at the deepest temperature logger (~3.5 feet below streambed). In the other three piezometers, temperatures below the streambed mimic stream temperature patterns, but daily variations are muted at deeper depths. As an example, on 9/10/16 the daily maximum temperature ~1 foot below the streambed was 2 to 2.5°C less than the stream temperature, highlighting the potential importance of the hyporheic zone in regulating stream temperatures.

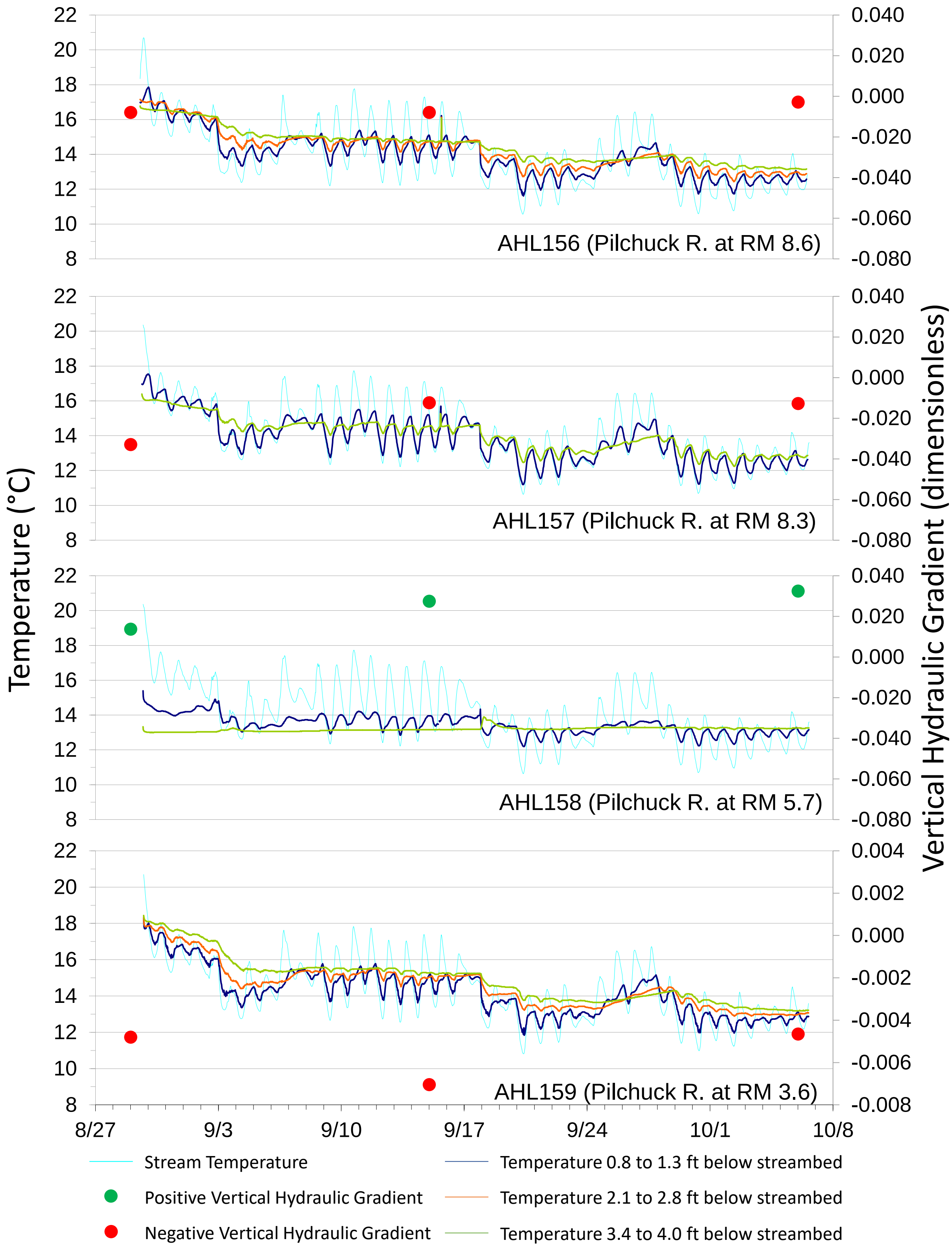

Figure 26. Piezometer temperature monitoring results for 2016.

Figure 27. Selected groundwater seepage areas observed within the Pilchuck River channel during 2014 surveys.

Hyporheic Zone

The hyporheic zone of a stream refers to the saturated interstitial spaces below the streambed and adjacent stream banks that contain some proportion of channel water (White, 1993). It plays an important role in buffering stream temperatures, providing habitat, cycling nutrients, and buffering pollutants. Hyporheic areas have been described as “giant trickling filters” (Danielopol, 1989).

Biological productivity within the hyporheic zone can be a significant contributor to whole-stream productivity (Mulholland et al., 1997; Fellows et al., 2001) and affect both localized and overall DO levels. Even systems with significant primary productivity from aquatic plant life can be net-heterotrophic due to hyporheic activity (Grimm and Fisher, 1984). Streams with hyporheic productivity tend to be net sinks for organic matter and DO (Mulholland et al., 2001) due to the presence and growth of heterotrophic organisms (invertebrates and microbes).

The hyporheic zone can be either a net source (from decomposition of particulate organic matter) or a net sink (due to microbial assimilation) of dissolved organic carbon (DOC) (Brugger et al., 2001; Battin et al., 2003; Crenshaw et al., 2002). Forest/riparian soils in the floodplain terrace can represent a significant source of DOC to the hyporheic zone (Clinton et al., 2002; Mei et al., 2012).

The potential for several different hyporheic exchange processes was observed in the Pilchuck River during the study (Figure 28), including:

- Downwelling/upwelling flow in riffle/pool sequences with coarse alluvial substrate. Downwelling typically occurs at the beginning of a riffle, with upwelling occurring in the downstream pool. This is most prevalent in the upper and mid sections of the study area.
- Flow through large alluvial deposits (gravel/sand bars or islands) in the active channel. This type of hyporheic flow was observed throughout the study area.
- Flow through alluvial floodplain aquifers (historic river channel) adjacent to active stream channel. This is most prevalent in the middle to lower sections of the study area.

Figure 28 demonstrates the model-simulated effect of hyporheic flow on predicted daily maximum temperatures for the Pilchuck River on August 5, 2012. Without hyporheic flow in the model, temperatures would increase by up to 0.9°C and an average of 0.4°C. A large increase in the model for all reaches in hyporheic zone thickness (to 100 cm) and flow fraction (to 25%) would decrease daily maximum temperature by up to 1.0°C and an average of 0.6°C.

Modeling analysis also found that the current level of hyporheic activity provides on average 8% decrease in inorganic phosphorus concentrations in the river, with a maximum of up to 18% (compared to no hyporheic activity).

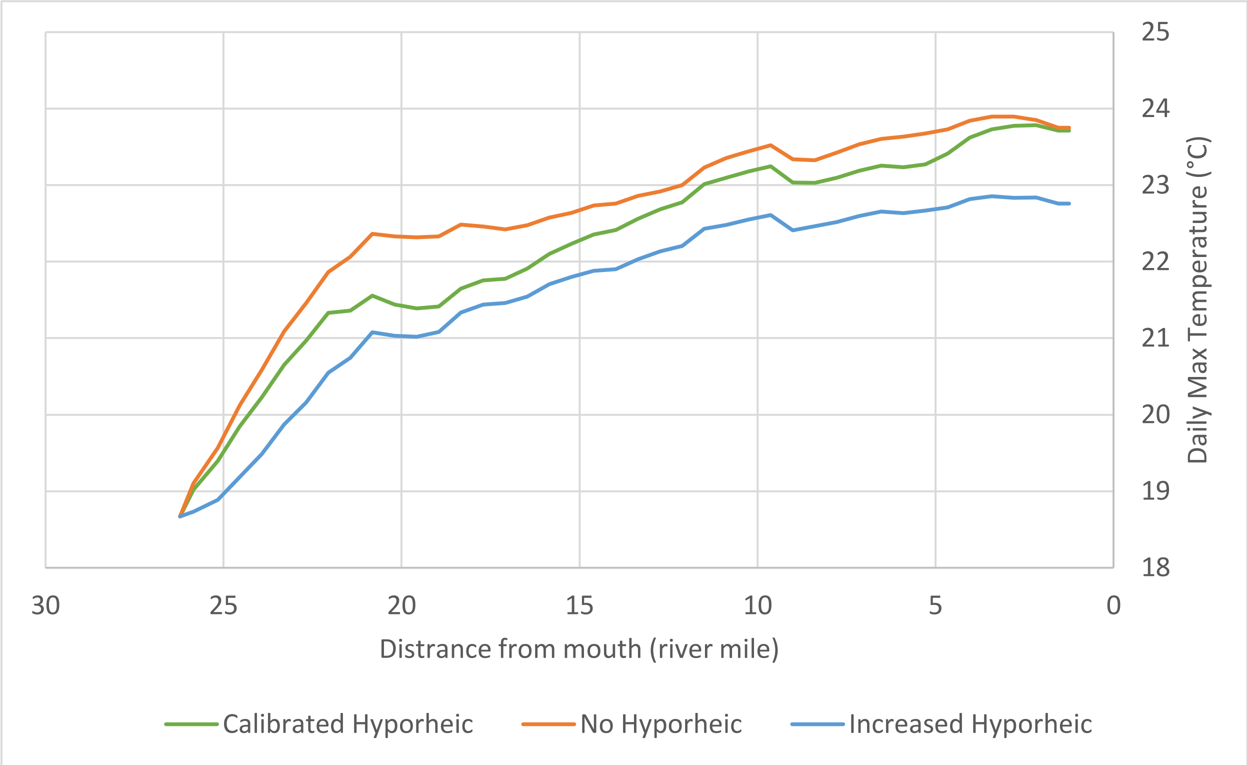

Figure 28. Model-simulated effect of hyporheic flow on Pilchuck River daily maximum temperatures for 8/5/12.

Meteorology

Hourly air temperature, humidity, wind speed, solar radiation, and cloud cover data were used from the locations identified in Table 41. In addition to these stations, Ecology installed a network of data loggers to continuously monitor near-stream air temperature at 11 stations in 2012.

The Snohomish AgWeatherNet station and the National Weather Service site at the Everett Paine Field Airport provided the dew point, solar radiation, wind, and cloud cover data.

Figure 29. Examples of observed hyporheic flow in the Pilchuck River.

Table 41. Weather data used in the 2012 model.

Agency	Station	Frequency	Air Temp	Dew Point/RH	Solar Rad	Wind	Cloud Cover
WA Ecology	07-PIL-2.0	30 minutes	X				
WA Ecology	07-PIL-5.7	30 minutes	X				
WA Ecology	07-PIL-8.5	30 minutes	X				
WA Ecology	07-PIL-10.4	30 minutes	X				
WA Ecology	07-PIL-15.1	30 minutes	X				
WA Ecology	07-PIL-21.5	30 minutes	X				
WA Ecology	07-PIL-25.5	30 minutes	X				
WA Ecology	07-CON-0.0	30 minutes	X				
WA Ecology	07-DUB-0.0	30 minutes	X				
WA Ecology	07-LIT-1.8	30 minutes	X				
WA Ecology	05A105	15 minutes	X				
WSU AgWeatherNet	Snohomish	15 minutes	X	X	X	X	
NCDC Coop SOD	Monroe 455525	Daily	X				
NCDC Surf. Airways	Arlington Municipal Airport	Hourly	X	X	X	X	X
NCDC Surf. Airways	Everett Snohomish Airport	Hourly	X	X	X	X	X

NCDC: National Climatic Data Center; SOD: Summary of the Day

After reviewing monitoring stations in the vicinity of the Pilchuck River watershed, the National Climate Data Center (NCDC) Cooperative Summary of the Day station, Monroe 455525, was selected as the closest station with a long period of record (50+ years) for calculating a distribution of annual hottest 7-day period air temperatures. Distribution of the highest annual 7-DADMax values from this station is shown in Figure 30. Distribution of the highest annual 1-DADMax values from this station is shown in Figure 31.

For 2012, the 7-day maximum air temperature occurred on 8/15/12 at 81.7°F (27.6°C) and fell at the 26th percentile of historical results. The highest daily maximum air temperature occurred on 8/5/12 at 89°F (31.7°C) and fell at the 45th percentile of historical results.

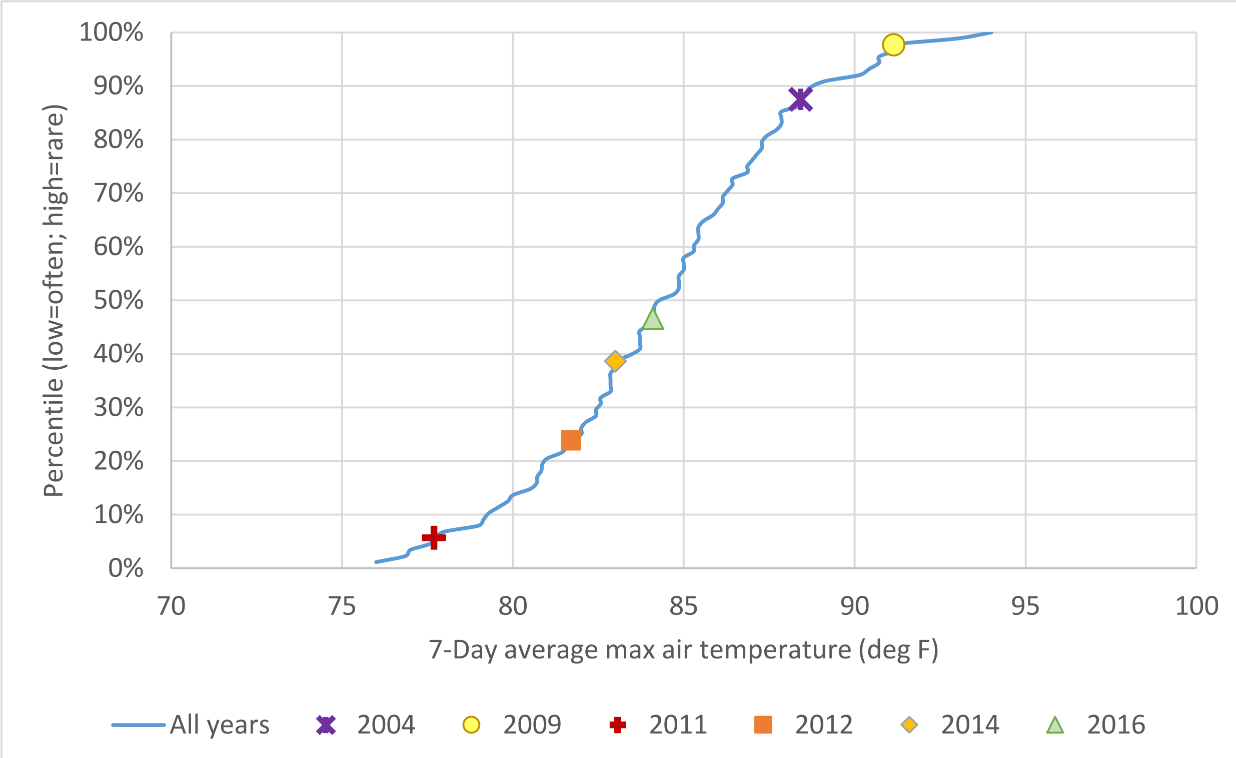

Figure 30. Cumulative frequency distribution of 7-day average maximum air temperatures at Monroe.

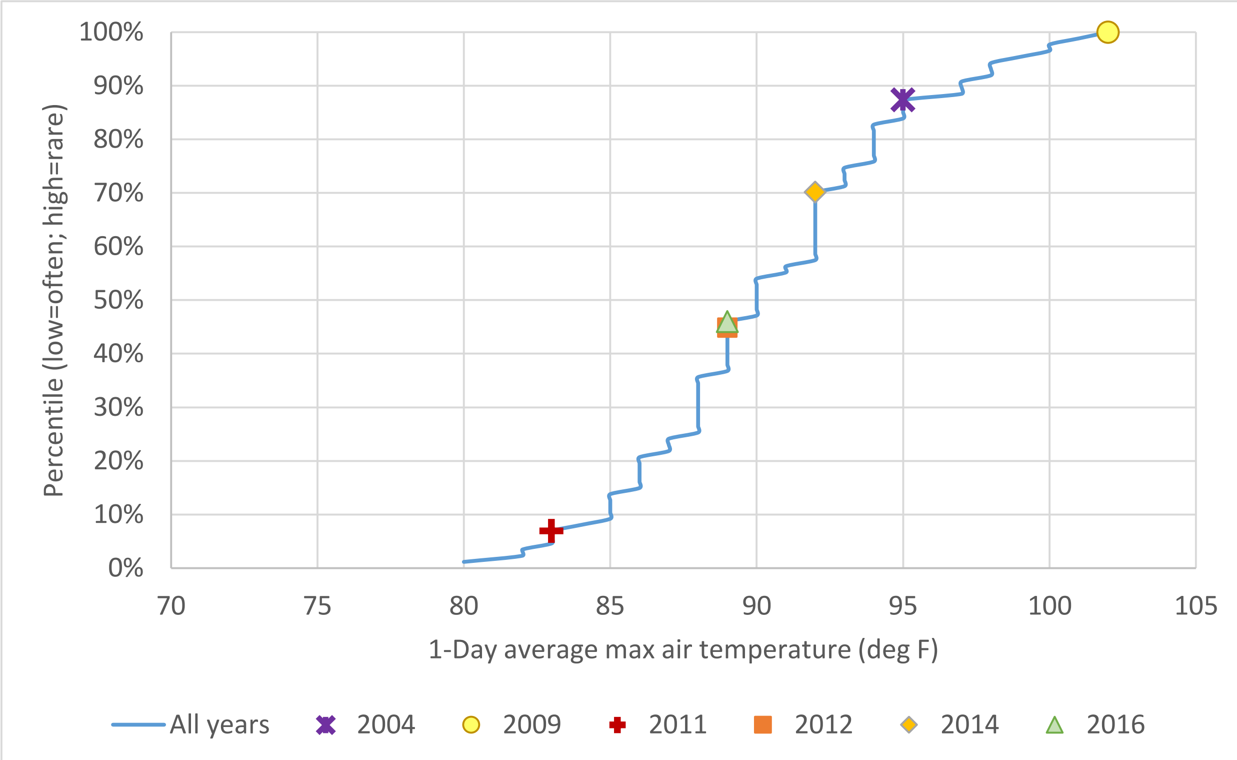

Figure 31. Cumulative frequency distribution of highest daily maximum air temperatures at Monroe.

Effective Shade

Effective shade is measured as the difference between solar radiation above the canopy and the solar radiation that ends up making it to the stream.

Effective shade produced from riparian vegetation and topographic features was estimated using the Shade model. The model quantifies the solar radiation received along each reach of the channel for each hour of the day, taking into account shading provided by vegetation canopy and topographic features.

Effective shade estimates from the Shade model were checked using hemispherical photography. Hemispherical canopy pictures were taken at or near each water temperature monitoring location along the mainstem Pilchuck River. Ecology processed the images using both HemiView and Gap Light Analyzer (GLA) software (Frazer et al., 1999) to provide field estimates of effective shade to compare to the shade model results. The HemiView and GLA calculations were made for August 14, 2012 to represent critical conditions (peak 7-DADMax).

Figure 32 illustrates an effective shade profile for August 15, 2012. Effective shade ranged from near 0% to greater than 90%, but was typically less than 50%, with the majority of the effective shade ranging between 10% and 40%.

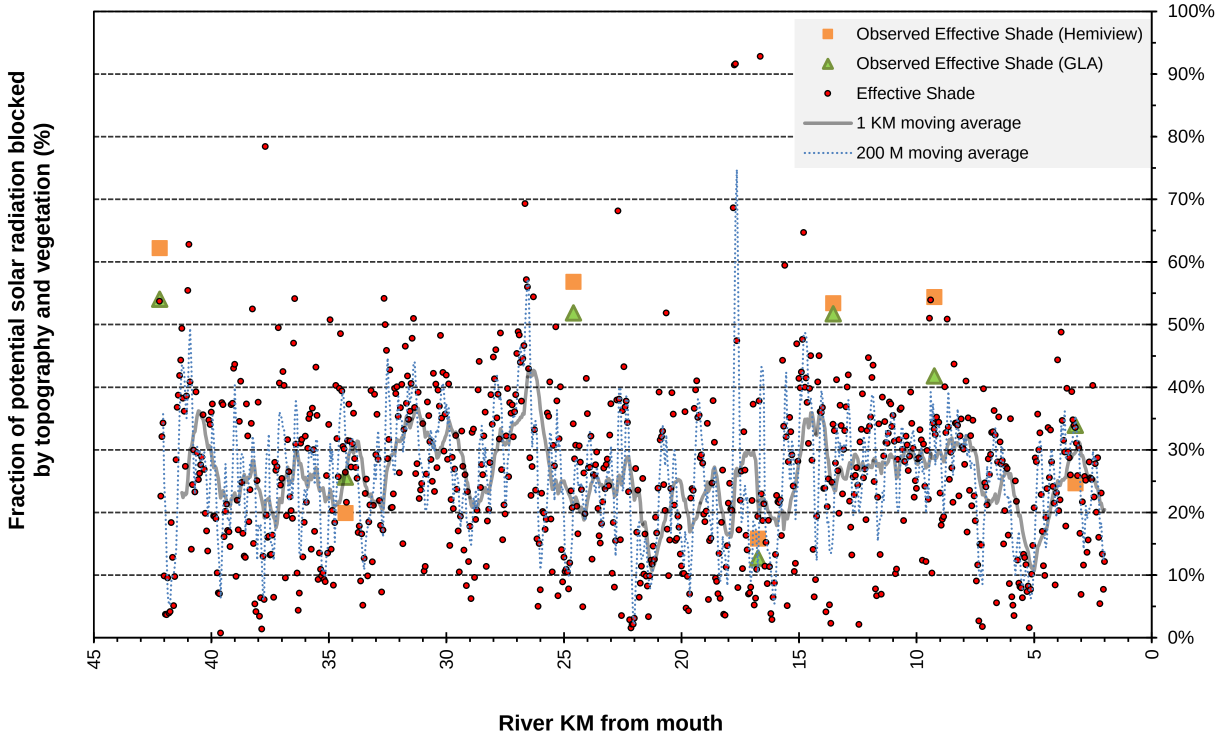

Figure 32. Modeled effective shade along the Pilchuck River for existing vegetation on 8/15/12.

Water Temperature

In 2012, Ecology monitored water temperature using data loggers at numerous sites along the Pilchuck River mainstem and at key tributaries. Tables 42 and 43 summarize the peak daily maximum and 7-day average daily maximum (7-DADMax) values at these sites. The peak 7-DADMax (22.05°C) and daily maximum (22.87°C) temperatures were recorded at the Russell Rd site (PIL10.4) on August 14 and August 16 (data before August 7 were lost at this site, so this may not represent peak annual temperatures). These results were consistent with 2010 temperature monitoring by Snohomish County where the peak 7-DADMax of 22.9°C occurred at Russel Rd (SCSWM, 2012a).

For sites with a full period of record (June through October), the hottest stream temperatures occurred on August 5, 2012. All of these 2012 dates correspond to periods where the 7-day maximum air temperatures were greater than the historical 90th percentiles (see Meteorology section).

Table 42. Peak daily maximum and 7-day average daily maximum (7-DADMax) values for the mainstem Pilchuck River from the 2012 data.

Station	Deployment Dates	Peak 7-DADMax °C	Peak Day 7-DADMax	Peak Daily Max °C	Peak Day
PIL25.5	6/6/12 - 10/9/12	17.62	8/15/12	18.70	8/5/12
PIL21.5	6/6/12 - 10/9/12	20.36	8/15/12	21.22	8/5/12
PIL15.1	8/8/12 - 10/9/12	20.52	8/15/12	21.24	8/16/12
PIL10.4	8/7/12 - 10/9/12	22.05	8/14/12	22.87	8/16/12
PIL8.5	6/6/12 - 10/8/12	21.39	8/14/12	22.56	8/5/12
PIL5.7	8/7/12 - 10/8/12	21.74	8/14/12	22.49	8/17/12
PIL2.0	8/7/12 - 10/8/12	21.64	8/14/12	22.45	8/17/12

Gray shading indicates the annual peak temperature was likely not captured due to data gaps.

Table 43. Peak daily maximum and 7-day average daily maximum (7-DADMax) values for tributary and point sources from the 2012 data.

Station	Deployment	Peak 7-DADMax °C	Peak Day 7-DADMax	Peak Daily Max °C	Peak Day
GRA-STP	7/11/12 - 8/21/12; 8/29/12 - 10/9/12	19.57	9/7/12	20.43	8/5/12
LIT-1.8	6/6/12 - 10/9/12	21.35	8/15/12	22.61	8/5/12
DUB-0.0	6/6/12 - 10/8/12	19.85	8/15/12	21.22	8/5/12
CON-0.0	6/6/12 - 8/6/12	21.23	7/9/12	21.99	8/5/12

Gray shading indicates the annual peak temperature was likely not captured due to data gaps.

Water temperatures were monitored by Ecology in a similar way during August 2016. This survey provided greater spatial resolution over a shorter period of time. The results (Table 44) show rapid stream heating from RM 25.5 to 21.5 and RM 15 to 11.6, with stable or cooling daily maximum temperatures from RM 21.5 to 18.7, RM 11.6 to 5.7, and RM 3.6 to 2.0. This is generally consistent with previous temperature monitoring (SCSWM, 2012a) and estimates of groundwater flow gains (see Groundwater Results section).

Table 44. Temperature statistics and calculated change rates for 8/18/16.

~RM	Temp. Min. (°C)	Temp. Average (°C)	Temp. Max. (°C)	Daily Min. change rate (°C/mile)	Daily Avg. change rate (°C/mile)	Daily Max. change rate (°C/mile)
25.5	13.74	n/a	18.41	n/a	n/a	n/a
21.5	15.46	17.98	21	0.43	n/a	0.65
18.7	15.92	18.45	21.14	0.16	0.17	0.05
15.0	16.69	18.93	21.46	0.21	0.13	0.09
11.6	16.81	19.47	22.63	0.04	0.16	0.34
8.5	16.85	19.55	22.56	0.01	0.03	-0.02
5.7	16.91	19.57	22.45	0.02	0.01	-0.04
3.6	17.13	19.68	22.63	0.10	0.05	0.09

Blue/negative values indicate cooling trend; red/positive values indicate warming trend; light shading/color represents smaller change, darker shading/color represents larger change.

The calibrated temperature model suggests solar shortwave and longwave radiation are the dominant physical processes influencing instream temperatures (Figure 33). However, hyporheic flow does have a measureable impact on lowering peak afternoon temperatures (see Hyporheic Results and Discussion section).

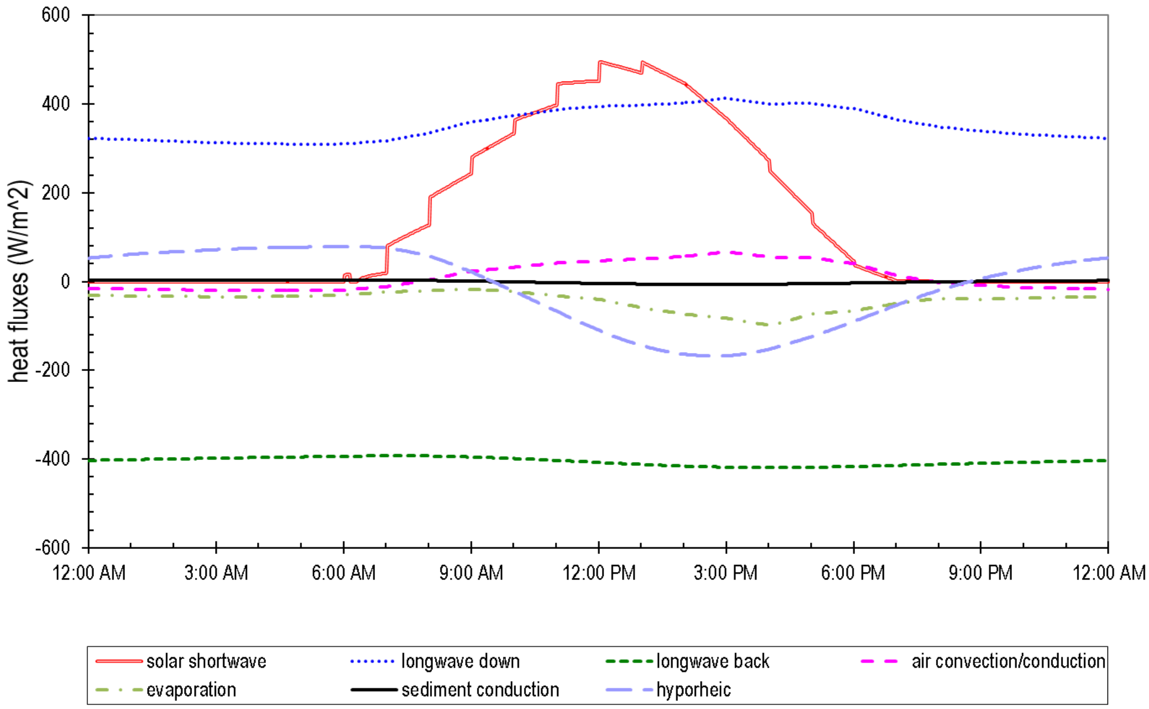

Figure 33. Diel predicted heat fluxes in the Pilchuck River in model reach 29 for 8/17/12.

Nutrients

Nutrient concentrations in the Pilchuck River are important because they influence the amount of biological productivity, which in turn influences the DO in the river.

Ecology collected nutrient samples along the mainstem Pilchuck River during the two synoptic surveys in 2012, as well as during a synoptic survey on August 17, 2016. The 2016 synoptic survey was conducted to provide additional information about nutrient concentrations and water quality below the WWTP and added sampling locations at RM 19, 18.7, 17.4, and 11.6.

Figure 34 depicts longitudinal nitrogen concentrations for the three synoptic surveys. The data illustrate several observed patterns:

- Ammonia was typically below the reporting limit (10 ug/L), so it was not plotted.
- Nitrate and total nitrogen decreased from RM 25 to 19 and RM 15 to 10.
- Nitrate and total nitrogen increased steeply from RM 19 to 15 and gradually from RM 10 to 2.
- Morning (AM) total nitrogen was significantly higher than afternoon (PM) levels in 2012, particularly on 7/31/2012.

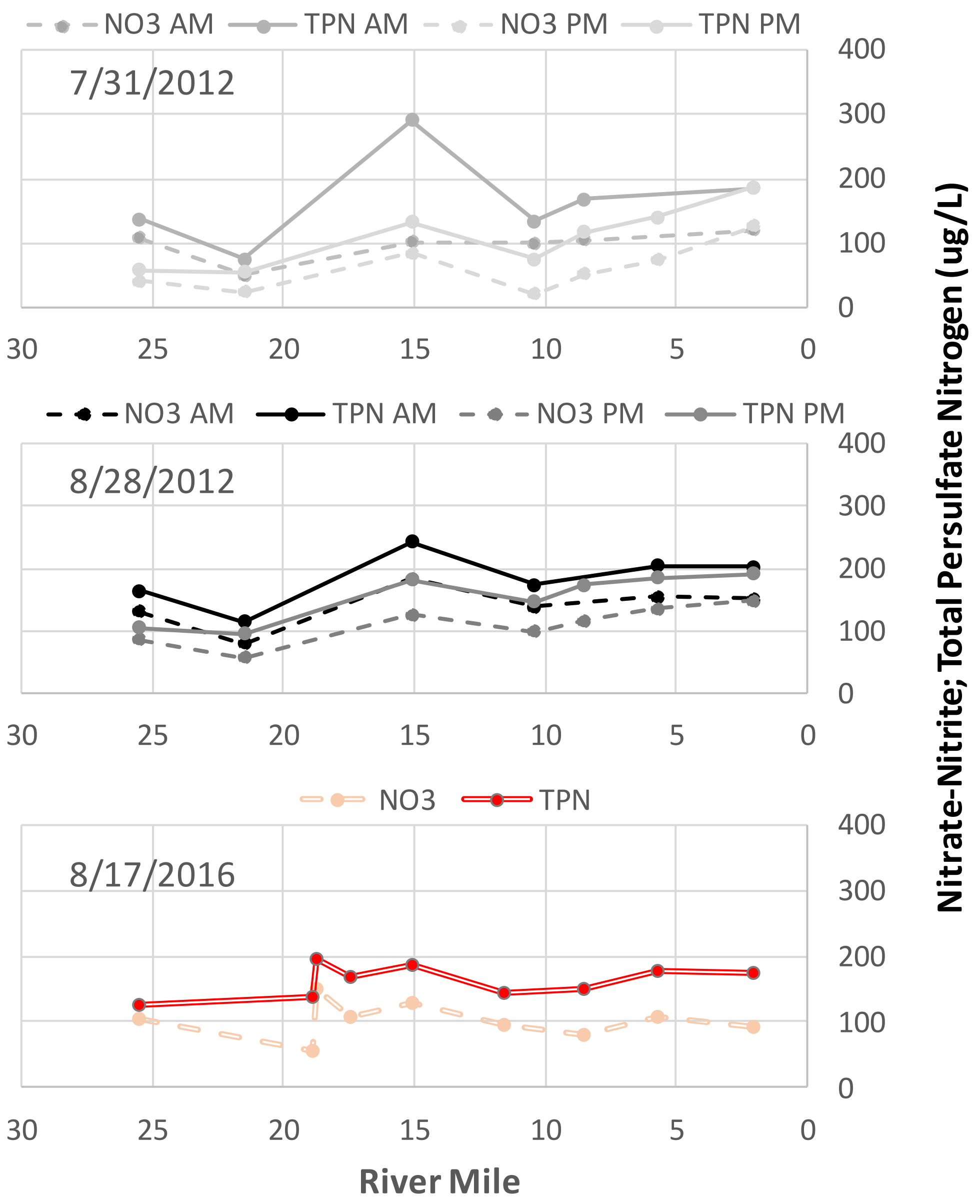

Figure 34. Longitudinal nitrogen concentrations in the Pilchuck River in 2012 and 2016.

Figure 35 depicts longitudinal phosphorus concentrations for the three synoptic surveys. The data illustrate several observed patterns:

- Orthophosphate and total phosphorus decreased from RM 25 to 19 and RM 15 to 2.
- Orthophosphate and total phosphorus increased steeply from RM 19 to 15. This pattern is only evident in 2016 data, when samples were taken closer to the WWTP.
- Mass balance analysis and the calibrated model show that the Granite Falls WWTP is the primary source of phosphorus and nitrogen inputs within the Pilchuck TMDL study area.

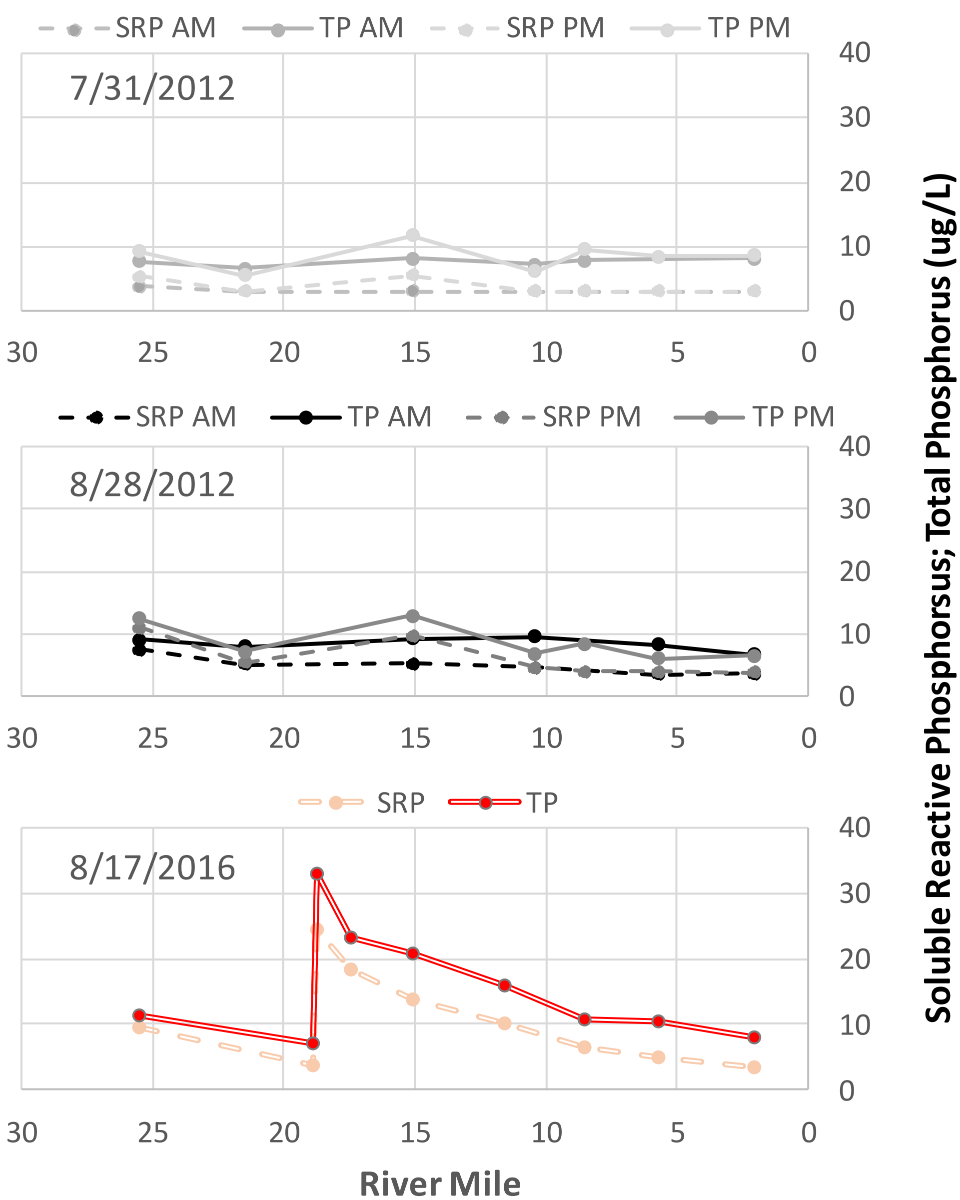

Figure 35. Longitudinal phosphorus concentrations in the Pilchuck River in 2012 and 2016.
SRP: soluble reactive phosphorus; TP: total phosphorus

Periphyton

Periphyton refers to the biofilm that accumulates on the stream bottom, which is primarily composed of attached algae. Periphyton can significantly influence the DO levels of a stream through photosynthesis and respiration; this is particularly true in wide and shallow rivers such as the Pilchuck.

Biomass

Table 45 contains the periphyton (bottom algae) biomass results from the 2012 field surveys. The average values represent the average of three samples collected at each location, one from the left side of channel, one from the center of the channel, and one from the right side of the channel. The ratio of chlorophyll *a* to ash-free dry weight (AFDW) provides a very general indicator of the relative amount of autotrophic vs. heterotrophic productivity, with higher ratios indicating more primary production.

Ecology used the chlorophyll *a* and AFDW content to characterize the range and magnitude of periphyton biomass for use in the model. Site averaged chlorophyll *a* biomass ranged from 3.7 to 23.7 mg/m^2, with a median of 14 mg/m^2. Nuisance levels of algae growth are typically an order of magnitude higher at 100-200 mg/m^2 (Horner et al., 1983; Welch et al., 1988; Quinn, 1991); however, the QUAL2Kw model indicates the potential effects on DO and pH can be significant in the context of water quality criteria (see Dissolved Oxygen discussion).

Table 45. Periphyton results for the Pilchuck River 2012 surveys.

Statistic/ Parameter	RM 25.5	RM 21.5	RM 15.1	RM 10.4	RM 10.4	RM 8.5	RM 5.7	RM 2.0
Median chlorophyll *a* (mg/m2)	3.1	19.7	5	17.3	16.3	17.1	19.6	14.3
Median AFDW (g/m2)	1.2	2.9	1.9	2.9	2.3	2.6	3.2	2.1
Median Ratio of CHL*a* (mg) to AFDW (g)	3	5.5	3.3	5.8	6.2	3.9	4.6	6.7

Figure 36 depicts the observed vs. model-predicted periphyton biomass throughout the Pilchuck River on August 28, 2012. The relatively large range in observed values reflects the variability of both the matrix and spatial distribution in the river.

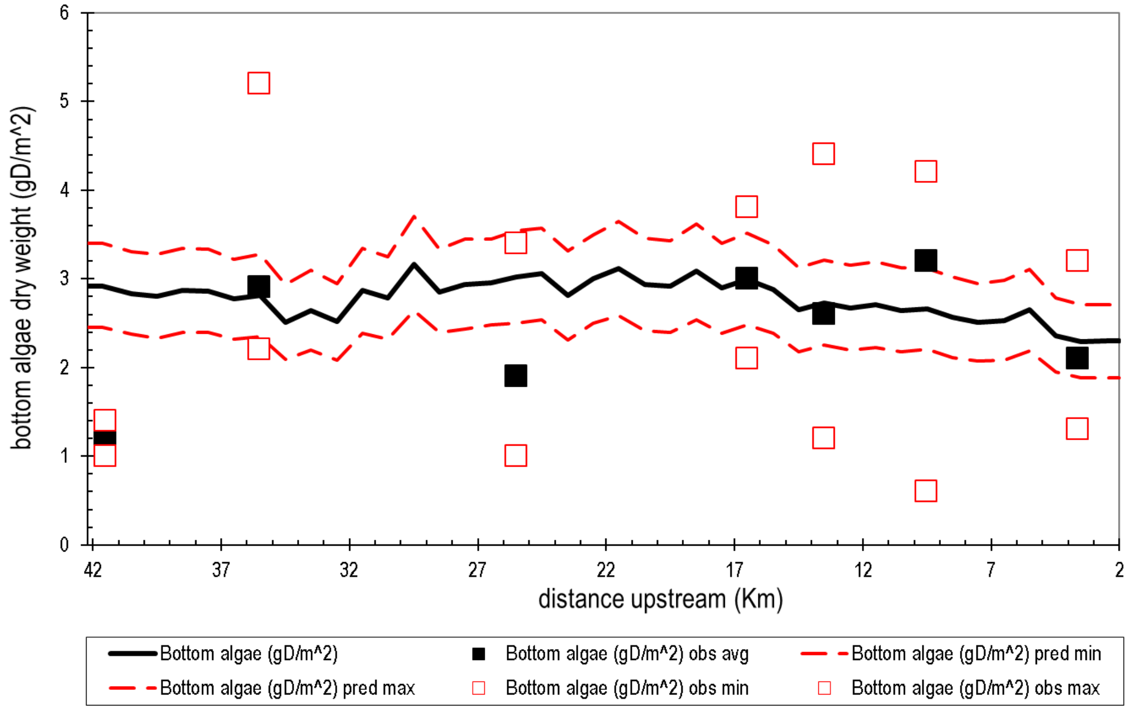

Figure 36. Predicted and observed periphyton biomass levels in the Pilchuck River, August 28, 2012.

Figure 37 illustrates the variability of growth and types of bottom algae within both a single substrate (36b) and throughout different reaches (36 a, c, d).

Figure 37. Observed variability in periphyton growth in the Pilchuck River.

Limitation

Numerous factors can limit or stimulate growth of periphyton in rivers and streams, including: available light and nutrient supply; temperature, grazing and excretion from primary consumers; and scour from changes in velocity or mobilization of substrate (Larned, 2010). When nutrient limitation is evident, one theory is that periphyton growth follows Liebig's Law of the Minimum which states that the nutrient in shortest supply controls growth, typically either nitrogen or phosphorus, although carbon, silica, iron, and other micronutrients can potentially also limit growth (De Baar, 1994).

Cellular and instream nutrient concentration ratios are often used as indicators of which nutrient is limiting growth. Nutrient ratios are frequently compared to the Redfield Ratio of 106C:16N:1P, a molar ratio derived from an empirical study of average composition of marine organic matter (Redfield, 1934; Redfield, 1958). In general, if the molar nitrogen:phosphorus (N:P) ratio is greater than 16:1, it is assumed that P is the limiting nutrient and less than that ratio is N-limited. Others have modified the rule to: > 20:1 indicates P-limitation, <10:1 indicates N-limitation, and between 10:1 and 20:1 indicates either nutrient could be limiting (Schanz and Juon, 1983; Borchardt, 1996).

Figure 38 illustrates the relationship of both total and dissolved nitrogen to phosphorus in the Pilchuck River. The results suggest that the river is likely phosphorus-limited. The only sections of the river where the ratio is in the ambiguous range (10-20) is immediately below the WWTP (~RM 18.9) where a large influx of phosphorus occurs and, to a lesser degree, at the upstream boundary of the study area. The nutrient ratio data indicate that the river becomes increasingly phosphorus-limited downstream of the WWTP, as phosphorus uptake/loss occurs.

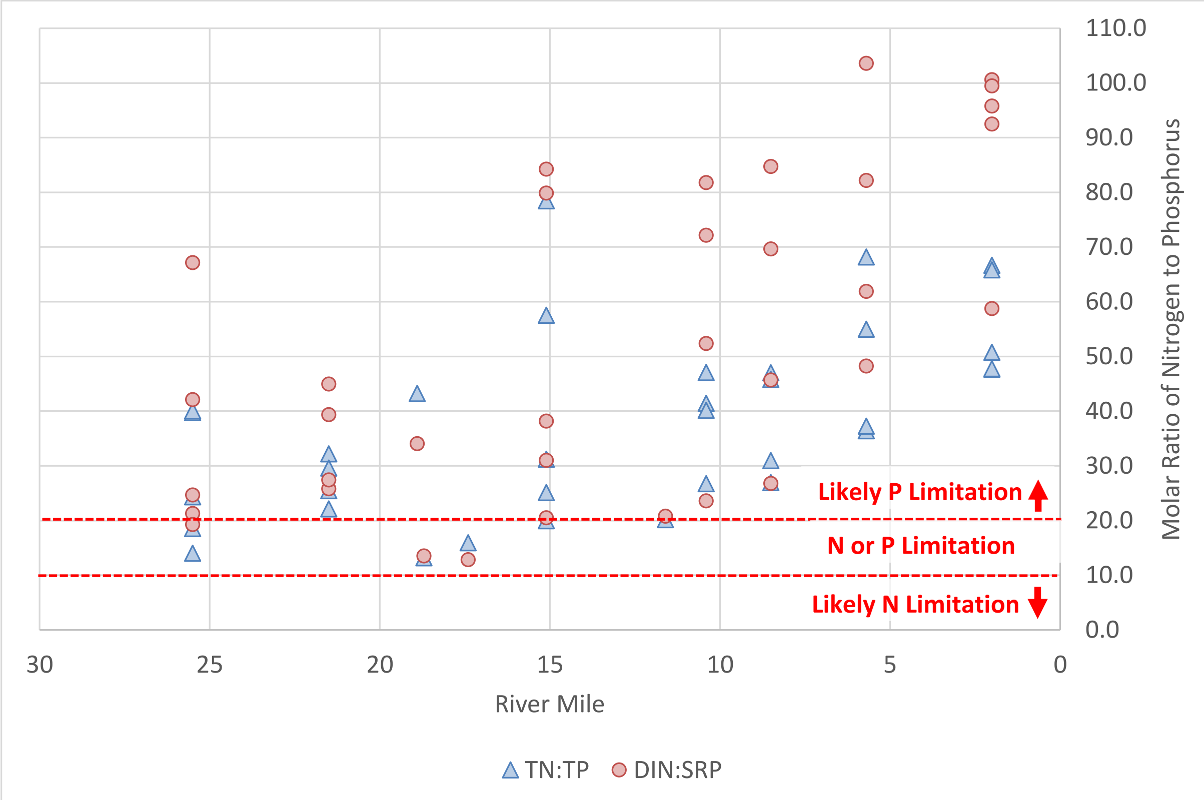

Figure 38. Molar ratio of nitrogen to phosphorus in the Pilchuck River.
TN:TP = total nitrogen : total phosphorus
DIN:SRP = dissolved inorganic nitrogen : soluble reactive phosphorus

A sensitivity analysis of periphyton scour shows that removing the scour function for the entire modeling period would result in a ~10 to 12% increase in periphyton biomass throughout the river on August 28, 2012 and a corresponding decrease in minimum DO of 0.02 to 0.05 mg/L, depending on the reach.

Figure 39 illustrates the relative effects of the various limiting factors in the model. Over the course of a full day, light has the strongest limiting effect; however, on clear days during the hours of peak solar radiation, phosphorus has the greatest limiting effect. Since the model uses singular nutrient limitation, nitrogen and carbon have no effect. Temperature has a minor limiting effect.

Increased shade and water depth, and decreased phosphorus concentrations are predicted to be the primary controls for decreasing periphyton growth and productivity in the Pilchuck River.

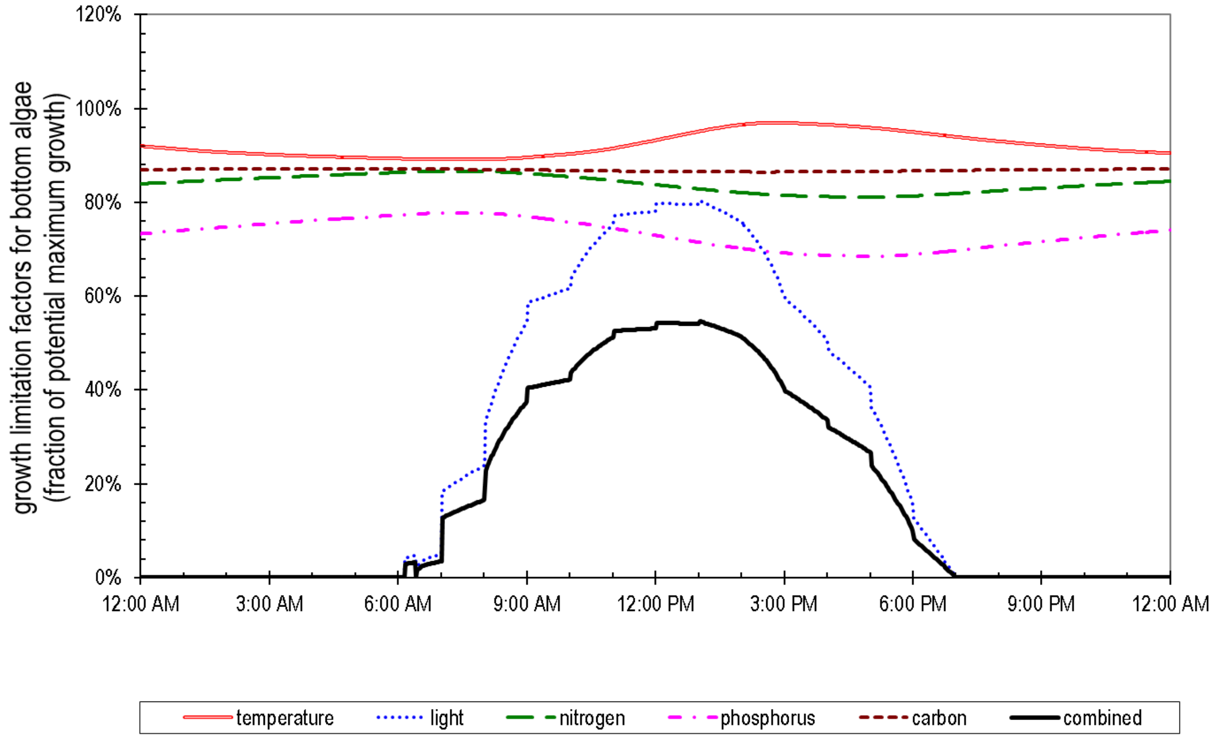

Figure 39. Simulated periphyton growth limitation factors for the Pilchuck River at OK Mill Rd (~RM 8.5)

Combined = The cumulative growth limitation effect of all limiting factors (nutrient limitation in combination with light limitation and temperature limitation).

Biochemical Oxygen Demand and Carbon

Biochemical oxygen demand (BOD) can be an important influence in a stream's metabolism and is typically derived from two primary sources:

- **Carbonaceous (CBOD)** – the oxygen consumed from organisms breaking down organic carbon in the water.
- **Nitrogenous (NBOD)** – the oxygen consumed during nitrification when ammonia is converted to nitrate. The amount of organic nitrogen in the stream also influences the NBOD, as it can provide a fresh source of ammonia via hydrolysis.

For BOD analysis, the laboratory can modify the method to inhibit nitrifying bacteria and provide an estimate of CBOD only. This TMDL uses **uninhibited** BOD, which represents the combined BOD from both CBOD and NBOD sources.

The TMDL also refers to three types of BOD in the discussion of samples, modeling, and allocations:

- **5-Day BOD (BOD5)** – the total BOD measured in a laboratory bottle test after 5 days. The TMDL uses BOD5 to determine allocations because it is the most practical to measure and represents the majority of potential impact on the Pilchuck River (travel time is less than 5 days).

- **Ultimate theoretical BOD (BODuT)** – the total BOD that could potentially be exerted given unlimited time if all organic carbon, organic nitrogen, and ammonia in the water sample were consumed. This model includes the ultimate theoretical CBOD as two distinct variables:
    - Fast CBODu- organic matter that is more readily decomposed. Sometimes referred to as labile organic matter.
    - Slow CBODu- organic matter that is not easily broken down. Sometimes referred to as refractory, or recalcitrant, organic matter.
- **Ultimate practical BOD (BODuP)** – the total BOD measured in a laboratory bottle test after an extended period (typically 20-60 days) where little or no change in the BOD is measureable on a daily basis. This measurement is roughly comparable to the amount of fast CBODu in the sample, but likely will not capture the potential BOD from the more difficult to decompose organic carbon. This type of BOD is not directly used in this TMDL, except to compare to practical CBODu allocations set by the Snohomish Estuary DO TMDL (see Appendix A: Protection of Designated and Downstream Uses for details).

Finally, dissolved organic carbon (DOC) data can provide a surrogate for BOD, as it can be related to BODu based on the amount molar mass ratio of oxygen consumed per unit of carbon.

Ecology collected limited BOD5 samples from the river during the August 2016 survey. In addition, the Granite Falls WWTP collects three composite BOD5 samples per week from their treated effluent (Table 46).

Table 46. Statistics for Granite Falls WWTP BOD5 sample results between 6/6/12 and 10/11/12.

Parameter	n	Min	Mean	Median	Max	Monthly Mean Permit Limit	Standard Deviation	Coefficient of Variance
BOD5 (mg/L)	38	2.3	7.2	6.6	15.7	30	3.3	0.5
Theoretical ultimate CBOD estimate (mg/L)	n/a	7.0	21.7	20.0	47.6	n/a*	n/a	n/a

* The BOD5 limit of 30 mg/L translated to a theoretical CBODu of ~91 mg/L.

For use in the water quality model, BOD5 measurement results were extrapolated to estimates of ultimate CBODuT using the formula:

$$CBODuT = \frac{CBOD5}{1 - e^{-k_1 5}}$$

where CBODuT = the theoretical ultimate carbonaceous BOD [mgO_2/L], CBOD5 = the 5-day dissolved carbonaceous BOD [mgO_2/L], and k_1 = the CBOD decomposition rate [/d].

The reported Granite Falls WWTP BOD5 result for August 29, 2012 was 15.1 mg/L; using this equation, the CBODu estimate equals 45.8 mg/L. This estimate is consistent with an alternate estimate of the CBODu of 42.5 mg/L derived using the DOC result from August 28, 2012 of

15.9 mg/L and the molar mas ratio of oxygen consumed during carbon oxidation of 2.67 $mg0_2$/mgC.

During the 2012 synoptic surveys, total organic carbon and DOC levels were typically fairly low in the river, with DOC often below the reporting limit of 1 mg/L (Figure 40). The calibrated model suggests there is a significant source of organic carbon and CBOD that was not captured by the study data collection (see Appendix F – Model Documentation for further discussion).

Organic carbon and CBOD were not measured in groundwater or minor tributaries for the study, so this value is unknown. The additional source of carbon fueling heterotrophic productivity in the sediments is unknown but could reasonably be contributed by some combination of groundwater (particularly from off-stream wetlands), buried particulate organic matter from storm events during the winter/spring, or settling organic matter during the 2012 model period.

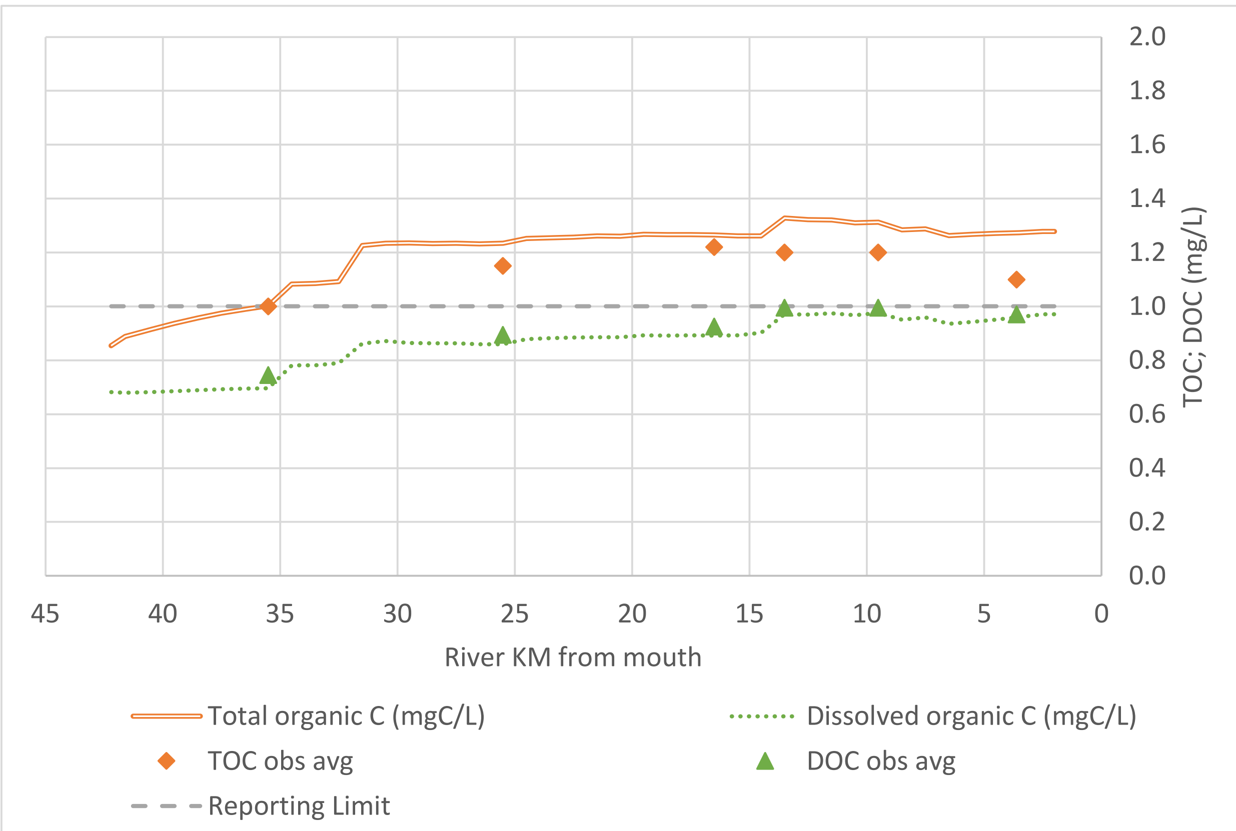

Figure 40. Model-simulated vs. observed total and dissolved organic carbon in the Pilchuck River on 8/28/12.

Dissolved Oxygen and pH

Ecology collected continuous DO and pH data during two surveys in July and August of 2012, and one survey in August 2016. Observed DO minima consistently fell below water quality criterion during all three surveys (Table 47). In general, DO was lowest between RM 12 and 2, in the downstream reaches; however, values below the criterion were observed at the upstream stations as well.

Observed pH fell within the criteria during all surveys (Table 48); however, PIL25.5 reached the upper limit of 8.5 on one day in July 2012. pH values were typically highest in the upstream reaches and lowest in the downstream reaches.

Table 47. Observed DO minimums and maximums during the 2012 and 2016 surveys.

Location ID	July 30 - Aug 2, 2012 DO Max.	July 30 - Aug 2, 2012 DO Min.	Aug 27 - 30, 2012 DO Max.	Aug 27 - 30, 2012 DO Min.	Aug 16 - 19, 2016 DO Max.	Aug 16 - 19, 2016 DO Min.	DO criterion
07-PIL-25.5	11.41	9.55	11.07	9.58	10.68	**9.04**	> 9.5 mg/L
07-PIL-21.5					10.59	**8.7**	> 9.5 mg/L
07-PIL-18.7					10.14	**8.39**	> 9.5 mg/L
07-PIL-15.1					9.65	**7.88**	> 9.5 mg/L
07-PIL-11.6					10.32	**8.13**	> 9.5 mg/L
07-PIL-10.4			10.33	**8.51**			> 9.5 mg/L
07-PIL-8.5	10.6	**8.60**	10.33	**8.49**			> 9.5 mg/L
07-PIL-8.2					9.98	**8.37**	> 9.5 mg/L
07-PIL-5.7	10.12	**8.59**	10.39	**8.71**	10.27	**8.11**	> 9.5 mg/L
07-PIL-3.6					10.03	**7.98**	> 9.5 mg/L
07-PIL-2.0					10.02	**8.15**	> 9.5 mg/L
07-LIT-1.8			**9.39**	**8.47**			> 9.5 mg/L

Bold numbers denote values below the minimum DO criterion.

Table 48. Observed pH minimums and maximums during the 2012 and 2016 surveys.

Location ID	July 30 - Aug 2, 2012 pH Max.	July 30 - Aug 2, 2012 pH Min.	Aug 27 - 30, 2012 pH Max.	Aug 27 - 30, 2012 pH Min.	Aug 16 - 19, 2016 pH Max.	Aug 16 - 19, 2016 pH Min.	pH criteria
07-PIL-25.5	8.50	7.50	8.14	7.53	7.86	7.36	6.5 to 8.5
07-PIL-21.5					7.91	6.98	6.5 to 8.5
07-PIL-18.7					7.89	7.35	6.5 to 8.5
07-PIL-15.1					7.39	7.04	6.5 to 8.5
07-PIL-11.6					7.78	7.07	6.5 to 8.5
07-PIL-10.4			8.06	7.45			6.5 to 8.5
07-PIL-8.5			7.72	7.26			6.5 to 8.5
ri07-PIL-8.2					7.79	7.36	6.5 to 8.5
07-PIL-5.7	7.76	7.33	7.78	7.42	7.85	7.26	6.5 to 8.5
07-PIL-3.6					7.72	7.18	6.5 to 8.5
07-PIL-2.0					7.59	7.11	6.5 to 8.5
07-LIT-1.8			7.68	7.42			6.5 to 8.5
07-CON-0.0	7.64	7.50					6.5 to 8.5

Ecology calibrated the QUAL2Kw model to the DO and pH data collected in 2012, and used the 2016 data to help determine the relative impact of inputs and patterns in-between the 2012 locations. The calibrated QUAL2Kw model (Figure 41) indicates that the important factors influencing the flux of DO in the Pilchuck River include:

- Periphyton photosynthesis (daylight) and
- Reaeration (nighttime)
    - Both of them are primary sources of increased DO
- Periphyton respiration, and
- Hyporheic sediment oxygen demand (SOD) (driven by CBOD inputs to hyporheic zone).
    - Both of them are primary sources of decreased DO minimums (night/early morning)
- Phytoplankton (floating algae) photosynthesis/respiration,
- CBOD in the water column, and
- Nitrification in the water column
    - All these three sources are predicted to have minimal impact on DO

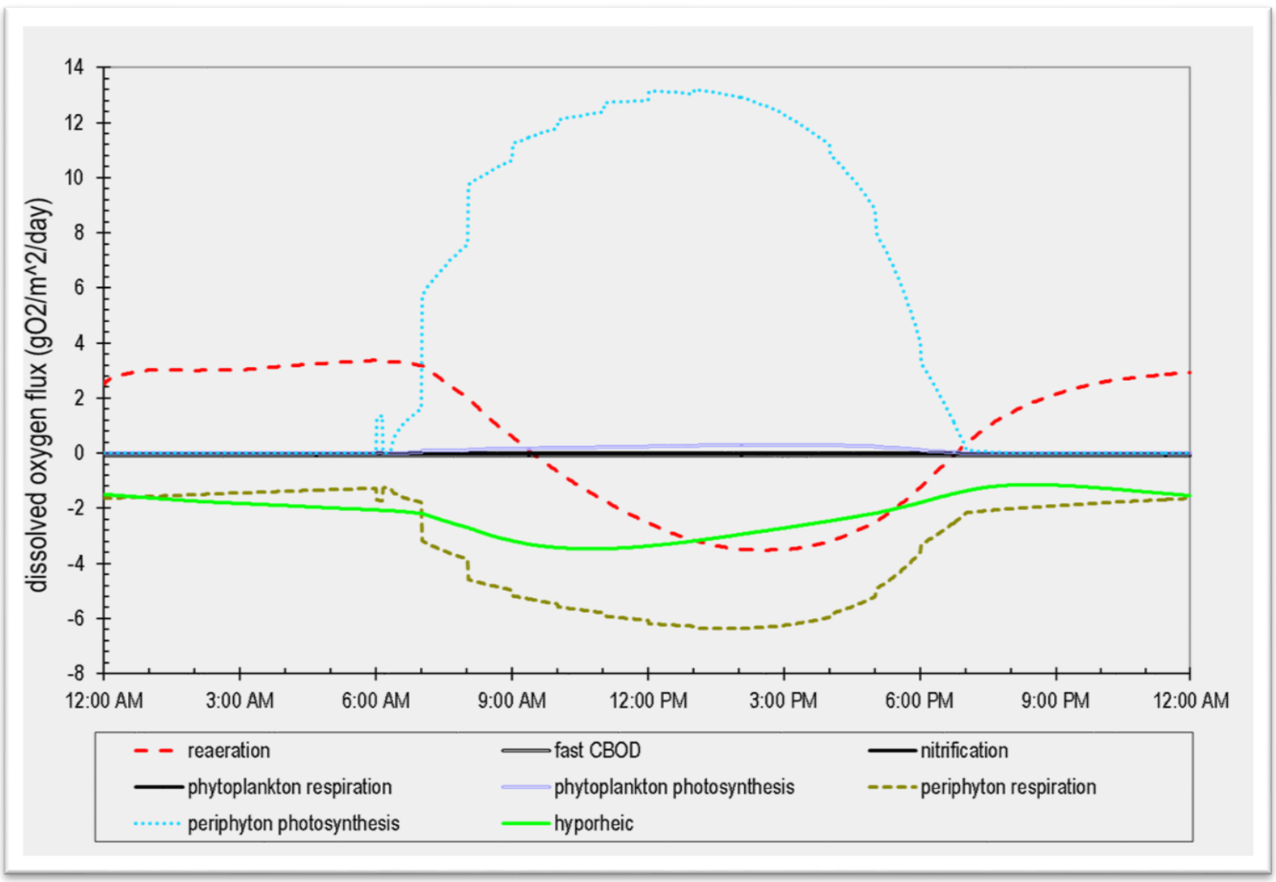

Figure 41. Predicted influences on diel DO fluxes for the Pilchuck River at OK Mill Rd on 8/17/12.

Temperature TMDL Analysis and Allocations

Ecology used the data collected in 2012 and 2016 and the calibrated 2012 model to develop several modeling scenarios for the TMDL analysis. Ecology used these modeling scenarios to assess compliance with the water quality standards and develop load (for nonpoint pollution sources) and wasteload (for point sources) allocations. Table 49 summarizes the modeling scenarios developed for the TMDL. Model documentation included in Appendix F describes inputs used to develop these scenarios in greater detail.

Table 49. Modeling scenarios used in the TMDL analysis.

Scenario Name	Streamflow	Air Temp	Other Conditions and Modifications
Existing 2012	2012 USGS & ECY	2012 ECY & AWN*	Primarily ECY data with some weather data from NWS & AWN
No action- Critical	Adjusted 2009 USGS (7Q10)	Increased to 2009 max	Same as above but with critical flow and air temperatures
System Potential-Critical	Adjusted 2009 USGS (7Q10)	Increased to 2009 max	Estimated changes in shade, microclimate, and other factors
System Potential-Average	2016 USGS	Increased to 2016 max	Same changes as above scenario with 2016 flow and weather
TMDL- Critical	Adjusted 2009 (7Q10)	Increased to 2009 max	Added point sources at WLAs & partially restored baseflow & hyporheic function
TMDL- Average	2016 USGS	Increased to 2016 max	Same as above scenario but with 2016 flows and weather

*2012 represents a relatively cool year for air temperatures with a 7-day average maximum in the 24th percentile and a relatively typical year for flow (46th percentile).

Compliance with Standards

The existing 2012 (Figure 42) and no action critical conditions (Figure 42) model scenarios predict that the entire river would fail to meet the 7-DADMax criterion for Core Summer Salmonid Habitat (16°C) during the warmest temperatures in August. Much of the river also failed to meet the 16°C criterion from July to early September. These model scenarios predict the river would meet the 16°C criterion at times in late June and from late September to early October.

The lower river failed to meet the Supplemental Spawning criterion (13°C) in early to mid-June in the existing 2012 model.

Observed data confirms the magnitude and timing of these predicted violations (see Temperature Results section and Appendix F – Model Documentation).

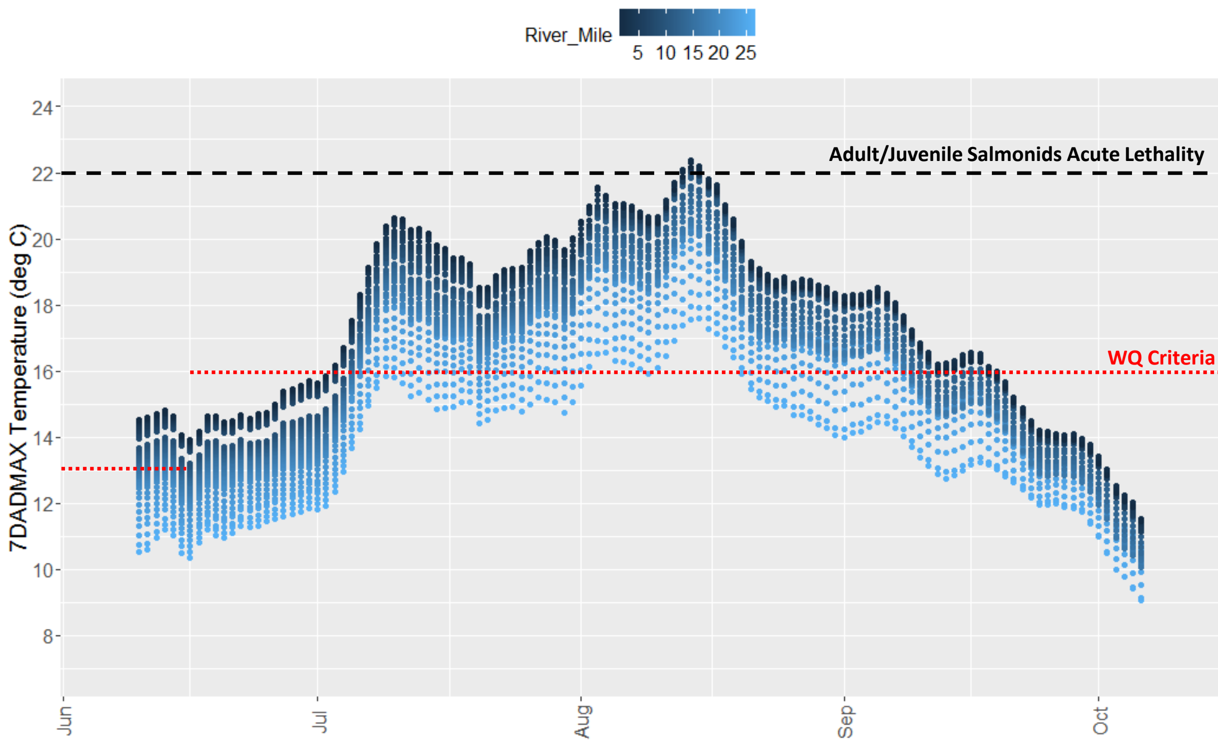

Figure 42. Existing 2012 model-predicted 7-DADMax temperature compared to WQ criteria.

When critical low-flow and increased air temperatures are added to existing conditions (no-action critical scenario), the model predicts that the highest temperatures would increase to a 7-DADMax of greater than 24°C (Figure 43) and a daily maximum of greater than 25°C. Most of the river failed to meet the Supplemental Spawning criterion (13°C) in early to mid-June in the no-action critical conditions scenario.

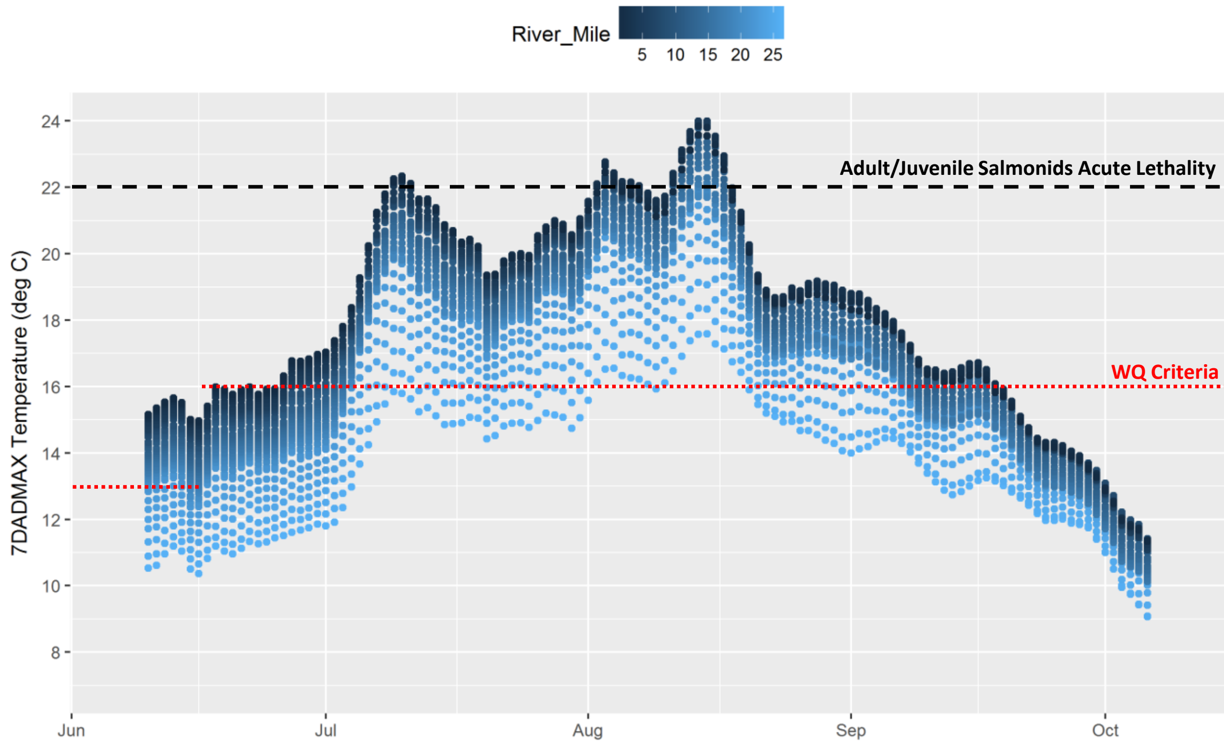

Figure 43. No action critical conditions model-predicted 7-DADMax temperature compared to WQ criteria.

System Potential Conditions

The TMDL uses a modified version of the calibrated QUAL2Kw model to estimate the temperatures that would be expected to occur under system potential conditions. System potential conditions are conditions that do not include human modifications to riparian vegetation, channel modifications, and summer baseflow. The system potential condition serves as an estimate of natural conditions, as defined by Washington State water quality standards.

Ecology has created a checklist to ensure that modeling and TMDL development staff consider and document the most important elements of a model designed to represent natural conditions. Appendix G contains complete documentation of development of system potential conditions and the associated checklist. In summary, Ecology made the following modifications to estimate system potential temperature conditions:

- System potential shade (SPS)
  - Set a composite system potential tree height of 125 ft (38 m) based on site-specific soil index percentages within the riparian zone.
  - Increased canopy density to 85% and riparian overhang to 12.5 ft (3.8 m).
  - Re-ran shade model and updated QUAL2Kw with system potential effective shade.
  - Assumed 180-ft-wide buffers of system potential riparian vegetation along each bank.
- Microclimate (MC)
  - Reduced hourly air temperatures by 5%.

  - Increased dew point by 3%, except for when already >97% relative humidity (RH).
  - Resulted in an average RH increase of 5.1%.
  - Assumed system potential riparian vegetation will produce microclimate effects.
- Reduced headwater and tributary temperatures (BC)
  - Reduced temperatures so that 7-DADMax was below 16°C and scaled remaining values (above 10°C) by the same percentage.
  - This reduction assumes inflowing headwaters and tributaries do not exceed the water quality criterion of 16°C under un-impacted conditions.
  - Recalculated (increased) DO based on the decreased temperatures.
- Baseflow restored (WR)
  - Added restored baseflow based on estimates of consumptive water use and net baseflow loss in the TMDL study area (see Appendix H).
- Channel morphology changes/Hyporheic exchange (H)
  - Increased hyporheic flow fraction in each model reach based on percent of banks with hardening/armoring.
- Point source effluent
  - Removed Granite Falls WWTP as a model input.
- SPS+MC+BC+BF+H
  - Represents Ecology's best estimate of system potential under critical 7-day low flow and high air temperature conditions.

Figure 44 depicts the longitudinal 7-DADMax temperature results of these modeling scenarios for critical June, August, and September conditions. Figure 45 depicts the longitudinal daily maximum temperature results of these modeling scenarios for critical June, August, and September conditions. The scenario 'SPS+MC+BC+BF+H' represents Ecology's best estimate of system potential under critical 7-day low flow and high air temperature conditions.

Although not equivalent, daily maximum values are highly correlated to 7-DADMax values. The results show the river would meet the applicable 1-day max thresholds identified in the water quality standards of 23°C (acute adult/juvenile lethality) during August critical conditions and 17.5°C (fish embryo lethality) during September Chinook spawning.

The TMDL deliberately did not alter some parameters or river features based on historical analysis or lack of available evidence (see Appendix H for additional detail):

- Turbidity, chlorophyll *a*, and carbon inputs were not altered due to existing low levels and complexity of processes that could impact these parameters.
- Channel slope, sinuosity, and width were not altered due to analysis of historic GLO surveys and academic literature suggesting little or no impact.

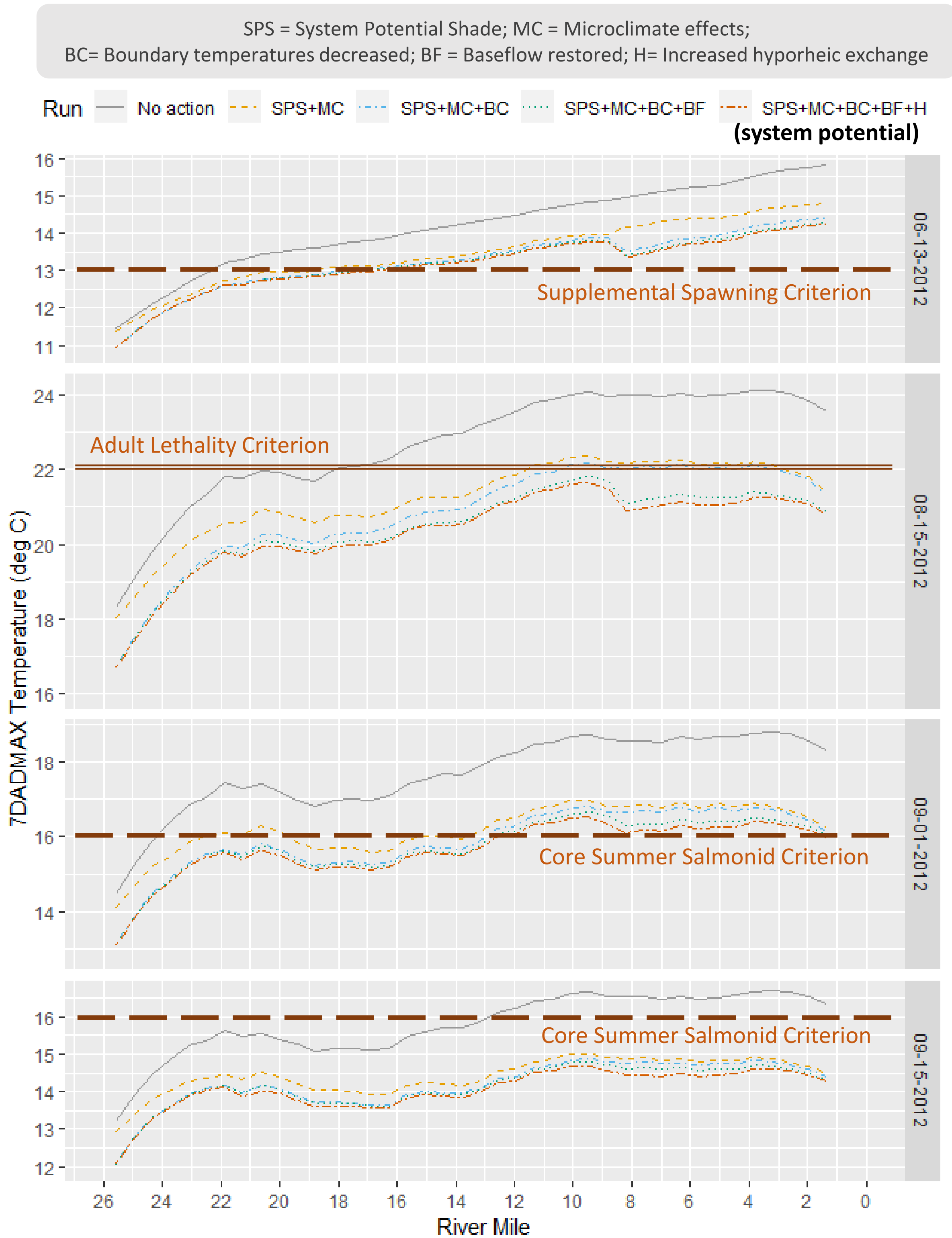

Figure 44. 7-DADMax water temperatures for no action and system potential scenario under critical conditions.

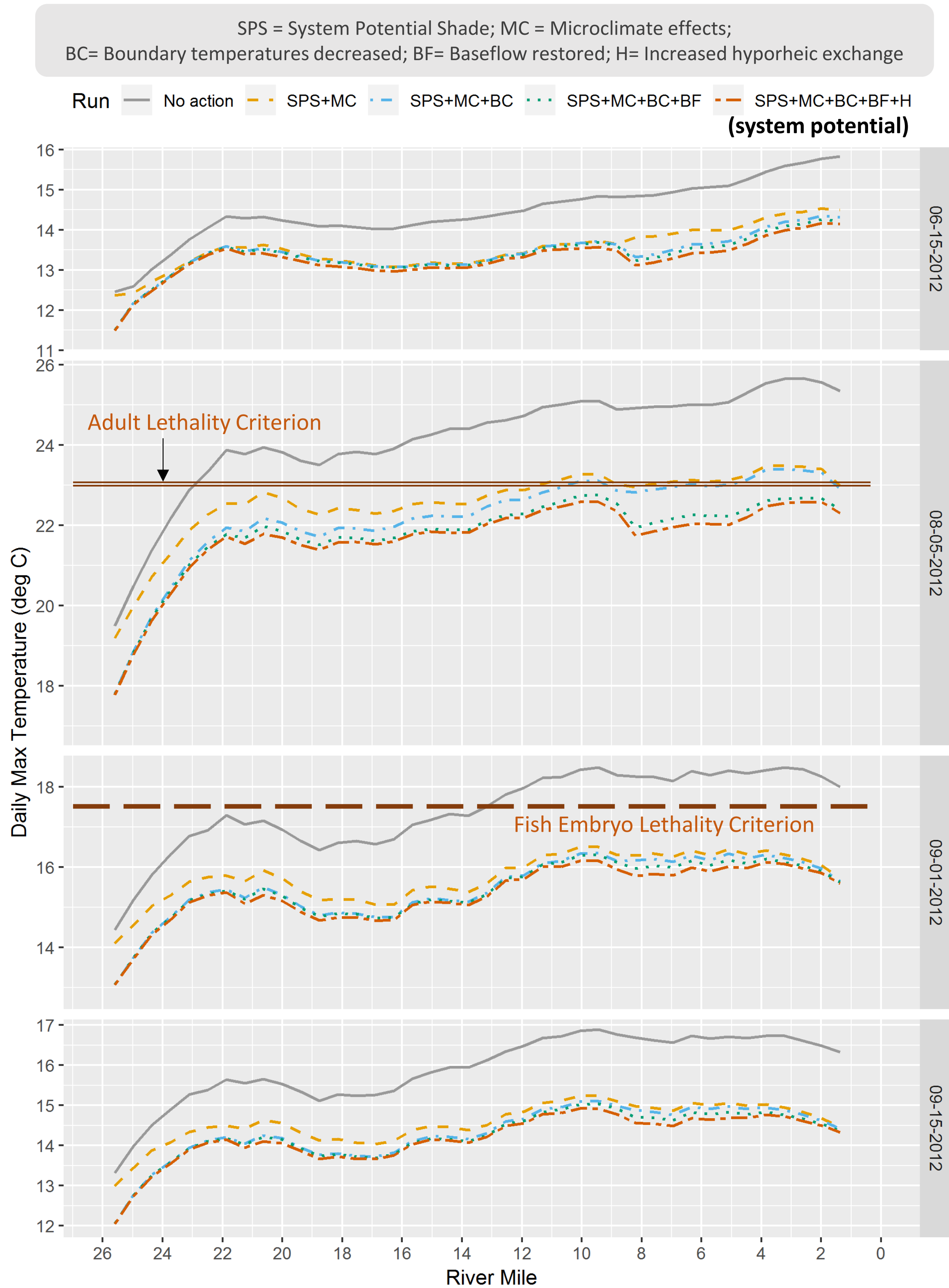

Figure 45. Daily maximum water temperatures for no action and system potential scenarios under critical conditions.

Ecology used the QUAL2Kw model to simulate system potential critical conditions continuously from June 7 to October 9. The system potential model primarily used 2012 conditions and inputs (with the system potential modifications described above) and modifications to represent critical conditions including:

- Air temperatures increased by 3.89°C degrees during the period of highest 7-DADMax water temperatures (from August 12 to 18) to represent critical conditions.
- Used 2009 streamflows, which were adjusted/decreased to represent 7Q10 low flow conditions by subtracting 3 cfs.

Figure 46 presents the simulation results for system potential critical conditions in the Pilchuck River across the complete spatial and temporal model domain. Figure 47 shows that under un-impacted conditions only a small portion of the lower river fails to meet the 13°C criterion in June and the river would meet the 16°C criterion from early September to early October. The larger improvement in September compared to July and August is mostly due to the increased influence of riparian shade later in the year, as the angle of the sun becomes lower and ambient air temperatures decrease.

In the system potential critical model, 7-DADMax values in the river would also be reduced below the threshold for acute lethality in moderately acclimated adult and juvenile salmon of 22°C identified by the water quality standards (WAC 173-201A-200(1)(c)(vii)(A)).

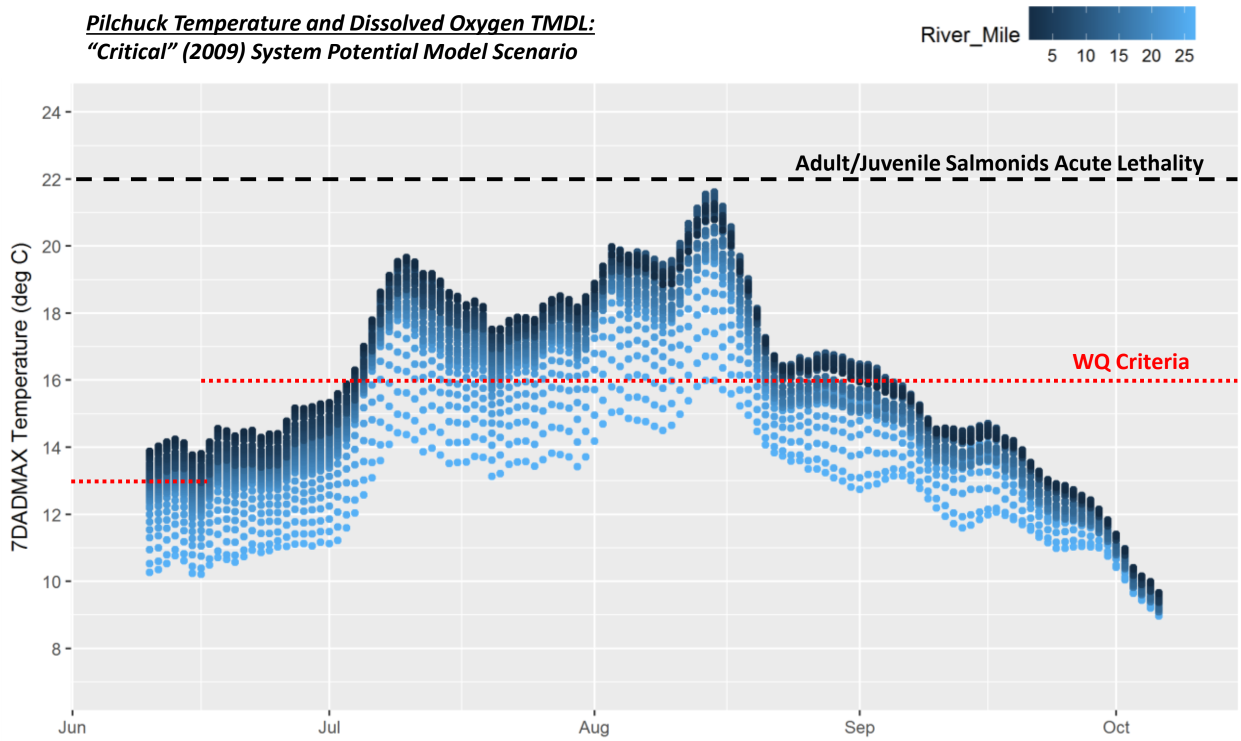

Figure 46. System potential model-predicted critical 7-DADMax temperature with 7Q10 (2009) flows.

Ecology also evaluated how system potential conditions might change under a year with relatively typical flow and air temperature conditions. The year 2016 was selected because:

- The 7-day low flow (59.4 cfs) represented a 58% exceedance probability (1.7 year recurrence interval).
- The 7-day average maximum air temperatures at Monroe of 28.9°C (~84°F) represent a ~55% exceedance probability.

The 2016 scenario is referred to as the "average conditions" scenario in this document. Appendix F contains details of how 2016 inputs were developed. Figure 47 depicts the results of the 2016 system potential scenario. The highest 7-DADMax values for the 2016 "average" system potential scenario were ~0.9°C less than in the critical system potential scenario.

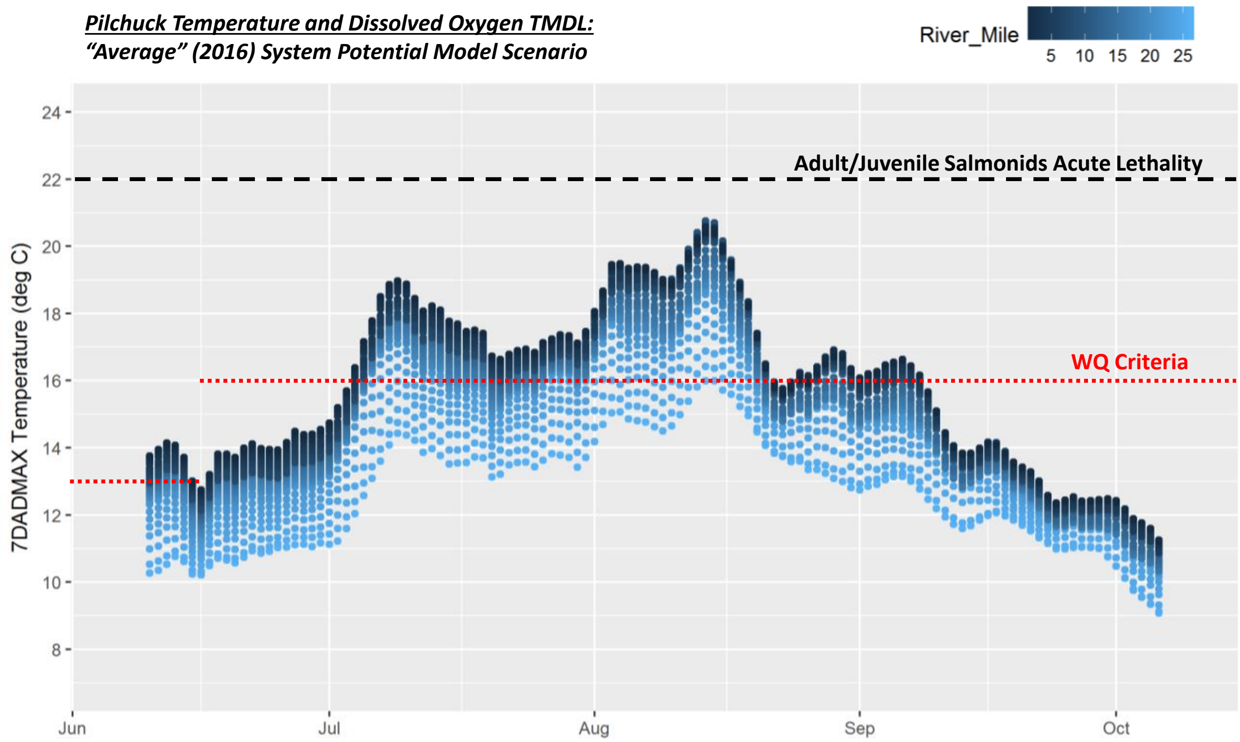

Figure 47. Predicted system potential temperatures under 2016 "average" conditions scenario.

Evaluating Further Potential Reductions to Temperature Beyond the Estimated System Potential Condition

Given that the predicted highest 7-DADMax for the system potential model was greater than 5°C above the numeric criterion of 16°C, Ecology explored several additional scenarios to evaluate the potential upper bounds of restoration actions.

Ecology performed sensitivity tests on the system potential temperature and explored how additional improvements beyond the estimated system potential would affect temperature in the Pilchuck River. Ecology tested three additional scenarios to evaluate these improvements:

1. **Natural-88m shade:** System potential conditions (identified as SPS+MC+BC+BF+H) with the system potential tree height increased from 38m (125 ft) to 88m (290 ft; this value is based on old-growth conifers and was tested in the South Fork Nooksack Temperature TMDL (Kennedy et al. 2020)).
2. **Natural-88m+12BC:** The same as #1, plus the boundary conditions (headwater at RM 25) temperatures are decreased so they do not exceed 12°C (maximum is 4°C lower than in #1).
3. **Natural-88m+12BC+MaxH:** The same as #2, except the amount of natural hyporheic exchange is increased to the maximum end of the ranges for hyporheic parameters.

Figure 48 illustrates that the combined impact of these three scenarios results in 7-DADMax temperatures above 20°C on August 15, which still exceeds the numeric criterion by greater than 4°C.

Given this disparity, Ecology based the TMDL load capacity and allocations on allowing no more than a cumulative 0.3°C human impact, using the system potential critical temperature as a baseline. This is not intended to establish a new numeric criterion for the Pilchuck River, but rather a point of reference to determine the allowable impacts as specified in the water quality standards during naturally warm critical conditions. The numeric criterion of 16°C still applies under naturally cooler times and conditions, particularly at higher flows, cooler air temperatures, and during late June and the month of September.

When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the standards state that the natural conditions constitute the water quality criteria (WAC 173-201A-260 (1)(a)). This provision of the water quality standards is implemented by using the modeled natural condition as the TMDL target. Ecology will consider a formal rule change to adopt site-specific criteria, as provided by WAC 173-201A-430. This will happen after significant implementation of the measures outlined in this TMDL; at which point the natural condition, determined by empirical and modeled data, could be used to set new water quality criteria through a public rule making process. This process would involve updated analysis of natural conditions and legacy impacts, and all measures that facilitate bringing the river into water quality compliance.

The TMDL is also designed to allow the Pilchuck River to:

- Largely meet the numeric criterion of 16°C later in the month of September when Chinook migration and spawning are at peak levels in the Pilchuck River.
- Meet acute lethality criteria for moderately acclimated adult and juvenile salmonids at all times.

The TMDL also addresses a wide range of human impacts to Pilchuck River temperatures, beyond riparian shade, including impacts to baseflows and hyporheic connectivity.

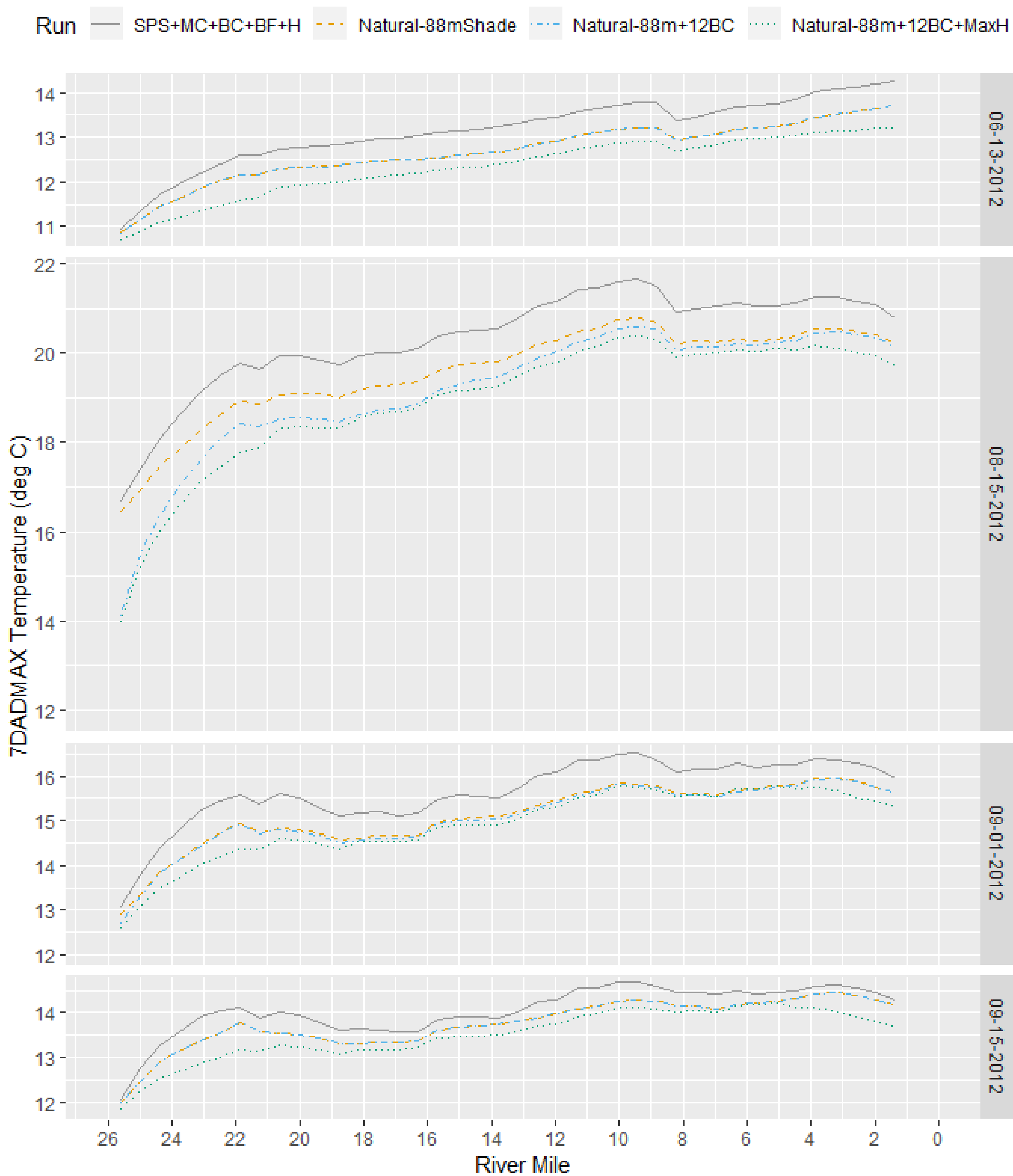

Figure 48. Additional temperature improvement scenarios[62] beyond system potential conditions.

Loading Capacity

EPA's current regulation defines loading capacity as "the greatest amount of loading that a water can receive without violating water quality standards" (40 CFR § 130.2(f)). The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. Loading capacities for the Pilchuck River are the solar radiation (nonpoint sources) and NPDES permitted (point sources) heat loads that (1) allow stream temperatures to stay below the numeric criteria or (2) do not exceed the natural condition by more than 0.3°C.

The TMDL analysis used the calibrated QUAL2Kw model and the Shade model to estimate the assimilative load capacity for temperature in the Pilchuck River, which is the basis for the load and wasteload allocations (WLAs) assigned in this TMDL. Loading capacity was determined based on prediction of water temperatures under low-flow (7Q10) and critical climate (90th percentile air temperature) conditions combined with a range of effective shade conditions. For the tributaries to the Pilchuck River and the headwaters (upper Pilchuck), the load capacity was calculated using the numeric criteria and the TMDL critical scenario flows. The load capacity and allocations for the impaired tributaries were set based on the percentage they occupied within their parent sub-basins: Catherine 45% of Little Pilchuck, Connor Lake 32% of Russell Rd, and Sexton 93% of Snohomish.

This TMDL uses the modeled system potential temperature as an approximation of the natural temperature **during critical high air temperatures and low-flow conditions**. TMDL load allocations are supposed to be set for the critical condition in order to be protective of the stream during the rest of the year. The modeled system potential condition uses best estimates of potential mature riparian vegetation, riparian microclimate, baseflow loss, and other impacts. The TMDL design condition is the system potential condition with "minimized human disturbance."

This TMDL is designed to protect against temperature impairments during the entire critical season of June through September. While the most critical conditions occur at lower flows and peak air temperatures during late July to mid-August, the temperature WLAs are also designed to be protective during other conditions, including summer storms, early June Steelhead spawning, and September Chinook spawning.

The system potential critical model scenario (i.e., 7Q10 critical low-flows and high air temperature) was used to compare the system potential 7-DADMax temperature to TMDL critical scenario (Figure 49). At times and locations where the system potential 7-DADMax temperature is predicted to be greater than 15.7°C, the loading capacity is determined to be the

---

[62] 1. Natural-88m shade: System potential conditions (identified as SPS+MC+BC+BF+H) with the system potential tree height increased from 38m (125 ft) to 88m (290 ft).
2. Natural-88m+12BC: The same as #1, plus the boundary conditions (headwater at RM25) temperatures are decreased so they do not exceed 12°C (maximum is 4°C lower).
3. Natural-88m+12BC+MaxH: The same as #2 except the amount of natural hyporheic exchange is increased to the maximum end of the ranges for hyporheic parameters.

system potential 7-DADMax + 0.3°C. The difference between the system potential and TMDL models is used to determine whether the TMDL is below the load capacity (0.3°C increase). Figure 50 shows the difference between the system potential and TMDL models under "average" 2016 conditions, compared to the loading capacity.

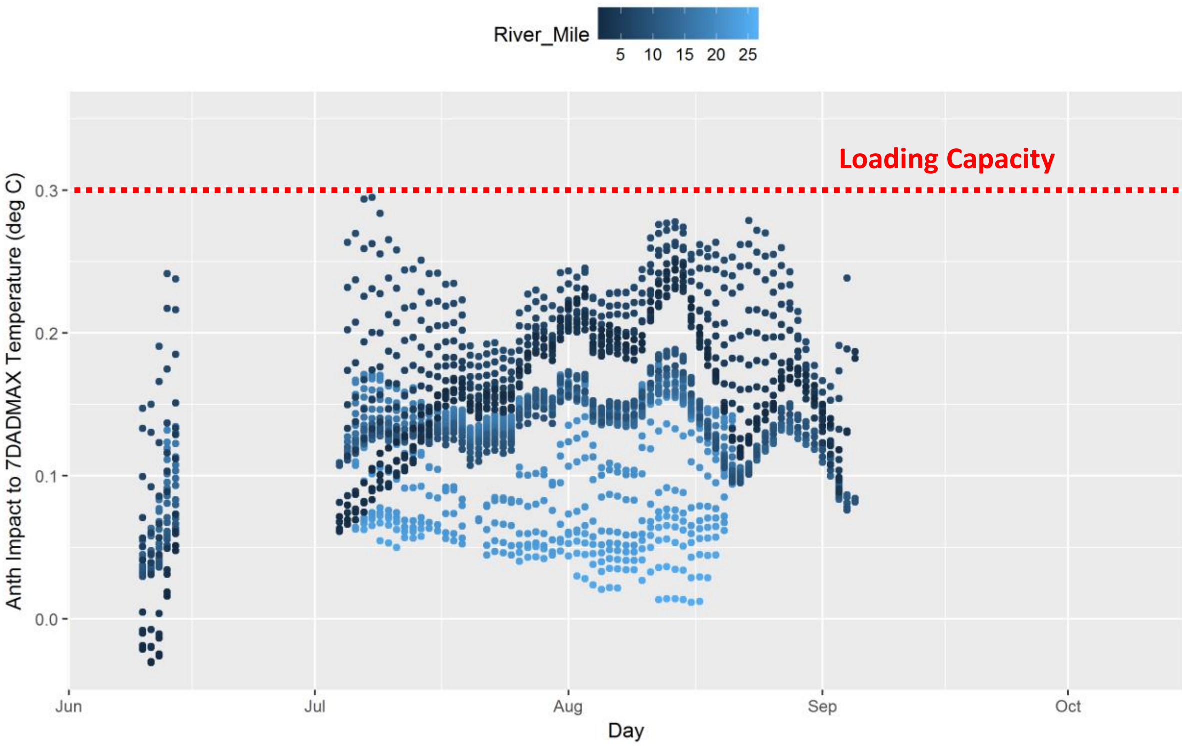

Figure 49. Predicted human-induced change to water temperatures in the Pilchuck River for TMDL

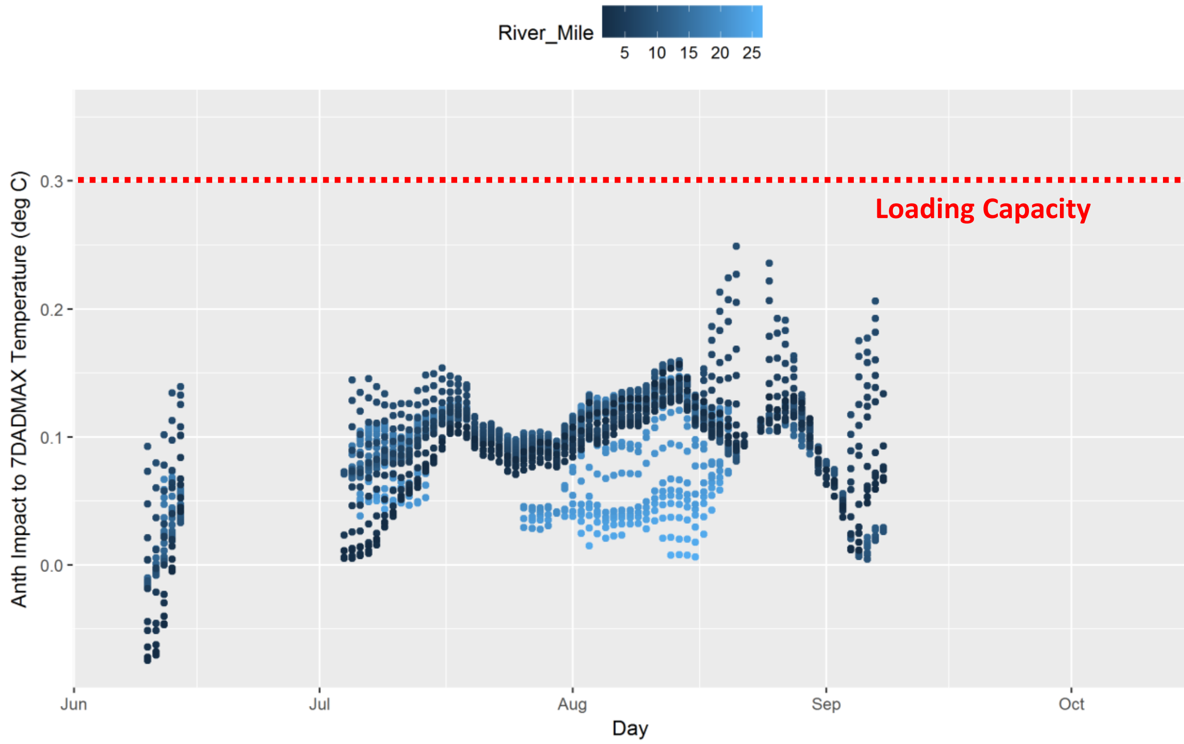

Figure 50. Predicted human-induced change to water temperatures in the Pilchuck River for TMDL "average" (2016) conditions.

Wasteload Allocations

Table 50 summarizes the types of major NPDES permits and categories in the Pilchuck TMDL study area. Tables 51 to 53 list the specific permittees within the general permit categories. Appendix I provides a more detailed accounting of individual permittees within the watershed, including current activity level and potential to discharge to surface water.

Table 50. Summary of NPDES permits in the TMDL study area.

Permit Type	Receiving Water body	Permittee	Permit #
Municipal NPDES individual	Pilchuck River	Granite Falls WWTP	WA0021130
Transportation general	Pilchuck Watershed	WSDOT	WAR043000
Construction general	Pilchuck Watershed	Multiple; transient	Multiple
Sand and gravel general	Pilchuck Watershed	Multiple	Multiple
Industrial general	Pilchuck Watershed	Multiple	Multiple
Municipal general	Pilchuck Watershed	Multiple	Multiple

Table 51. Sand and Gravel permits

Receiving Water body	Permittee	Permit #
Tributary of Pilchuck	Pilchuck Sand & Gravel Inc.	WAG503379
Groundwater	Riverside Sand & Gravel	WAG503086
Groundwater	Lake Industries Menzel Lake Gravel	WAG503312
Unknown	Jaxico Real Estate Investment Group LLC	WAG994258
Ditch to Little Pilchuck	Thomco Aggregate LLC	WAG503027
Pond	Premier Pacific Properties	WAG503327
East Fork Little Pilchuck	Concrete Norwest Getchell Pit	WAG503166
Pond next to Pilchuck R.	Great Western Transport, Inc.	WAG503046
Ditch to Pilchuck River	Green Dot Concrete	WAG994446

Table 52. Municipal Stormwater general permits

Receiving Water body	Permittee	Permit #
Pilchuck Watershed	Snohomish County- Phase 1	WAR044502
Pilchuck Watershed	City of Granite Falls- Phase 2	WAR045517
Pilchuck Watershed	City of Lake Stevens- Phase 2	WAR0021130
Pilchuck Watershed	City of Snohomish- Phase 2	WAR045543

Table 53. Industrial Stormwater general permits

Receiving Water body	Permittee	Permit #
Little Pilchuck	Central Steel	WAR012091
Little Pilchuck	Northwest Auto Recyclers	WAR303981
Pilchuck River	UPF Washington LLC	WAR000752

Discharges to state waters are regulated through permits as part of the NPDES program. A facility with an NPDES permit is considered a “point source” of pollution. The Washington State water quality standards (WAC 173-201A) restrict the amount of warming that point sources can cause when river or stream temperatures are cooler than the numeric criteria:

> Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge).

Maximum effluent temperatures should also be no greater than 33˚C to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life.

At times and locations where the model predicts the assigned numeric criteria cannot be attained even under estimated natural conditions:

> When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

The TMDL applies the “less than 0.3˚C impact” at the edge of the mixing zone (near-field) to set the wasteload allocations (WLA) for the one individual permitted point source discharge in the TMDL, the Granite Falls WWTP.

The TMDL also applies the less than 0.3˚C impact to the cumulative impact (far-field) of all temperature impacts to set WLAs for general permitted point source discharges. This cumulative impact analysis considers the combined temperature impacts of all sources (point, nonpoint, and non-pollutant) in all reaches of the river. The TMDL uses the model scenarios for the cumulative analysis (see loading capacity section).

The load allocations (see effective shade targets) for the nonpoint sources of incoming solar radiation result in shade levels that are equivalent to the estimated natural, system potential shade conditions. However, there are projected temperature impacts from other non-pollutant sources, including loss of baseflow and hyporheic that exceed the allowable 0.3˚C warming under existing conditions.

With load allocations of system potential shade and some mitigation of non-pollutant impacts, a portion of the 0.3˚C may be assigned to point sources, in order to establish WLAs. However, point sources must still be regulated to meet the incremental warming restrictions established in the standards to protect cool water periods.

Wasteload allocation for Granite Falls Wastewater Treatment Plant (WWTP)

In Washington State, the months likely to exceed the water temperature criteria are June through September, with most occurrences in July and August. June and September generally are cooler, but June has a lower aquatic life temperature criterion to be protective of spawning salmonids (7-DADMax <13°C). Because streamflow is lower during July and August when stream temperature is at its highest, a WLA generated with the flows that correspond to that period is protective of the aquatic life standard and is appropriate.

The Granite Falls WWTP NPDES discharge is assigned a daily maximum temperature WLA, based on thermal loading and a maximum allowable effluent temperature (T_{NPDES}). The maximum allowable thermal loading (WLA) and maximum allowable effluent temperature (T_{NPDES}) for Granite Falls were determined by testing variable effluent temperatures at future effluent flows in the TMDL model scenarios, along with the combined impact from other sources, and comparing to the system potential model scenarios to determine if the 7-DADMax impact was less than 0.3°C.

The WLAs and temperature targets from the cumulative impacts (far-field) analysis in the model were verified by calculating the change to 7-DADMax temperatures at the edge of the mixing zone (near-field) for the Granite Falls WWTP. The mixing zone was defined as 25% of the flow in the Pilchuck River. Ecology calculated daily maximum temperatures at the edge of the mixing zones as:

$$DMT_{emz} = \frac{\left(DMT_{eff} + \left(DF_{davg} - 1\right) \times DMT_{nat}\right)}{DF_{davg}}$$

where:

DMT = Daily Maximum Temperature; emz = edge of the mixing zone; eff = effluent;
nat = receiving water segment in the system potential model; DF_{davg} = Daily Average Dilution Factor

Where:

$$Daily\ Average\ Dilution\ Factor = \frac{(Daily\ Avg\ River\ Flow \times 0.25) + Daily\ Avg\ Effluent\ Flow}{Daily\ Avg\ Effluent\ Flow}$$

The daily maximum temperatures at the edge of the mixing zones were then used to calculate the 7-day average daily maximum (7-DADMax) temperatures at the edge of the mixing zone.

Figure 51 depicts the predicted 7-DADMax temperatures at the edge of the mixing zone (orange/solid line) for four levels of average effluent flow (a range from current to future buildout). Figure 51 also shows predicted compliance with each applicable water quality criteria and tier of effluent flow:

1. When {[System Potential] > [Numeric Criterion - 0.3°C]}:
    a. The <0.3°C criterion applies (double red line).
    b. Blue bars depict the increase in 7-DADMax temperatures from system potential at the edge of the mixing zone (secondary axis). Where they are present, they represent the measure of compliance.
2. When {[System Potential] < [Numeric Criterion - 0.3°C]}:
    a. {[Background + 28/(T+7)] > [Numeric Criterion]}:
    b. The biologically based numeric criteria apply (black dashed lines).
    c. The 7-DADMax temperatures at the edge of the mixing zone (orange/solid line) are compared to these criteria. Where 1b (blue bars) and 3a (green dotted line) are NOT present, the numeric criterion represents the measure of compliance.
3. When {[Background + 28/(T+7)] < [Numeric Criterion]}:
    a. The incremental increase criterion applies (Background + 28/(T+7); depicted as green dotted lines). Where the green dotted lines are present, they represent the measure of compliance.
    b. The 7-DADMax temperatures at the edge of the mixing zone (orange/solid line) are compared to these criteria.

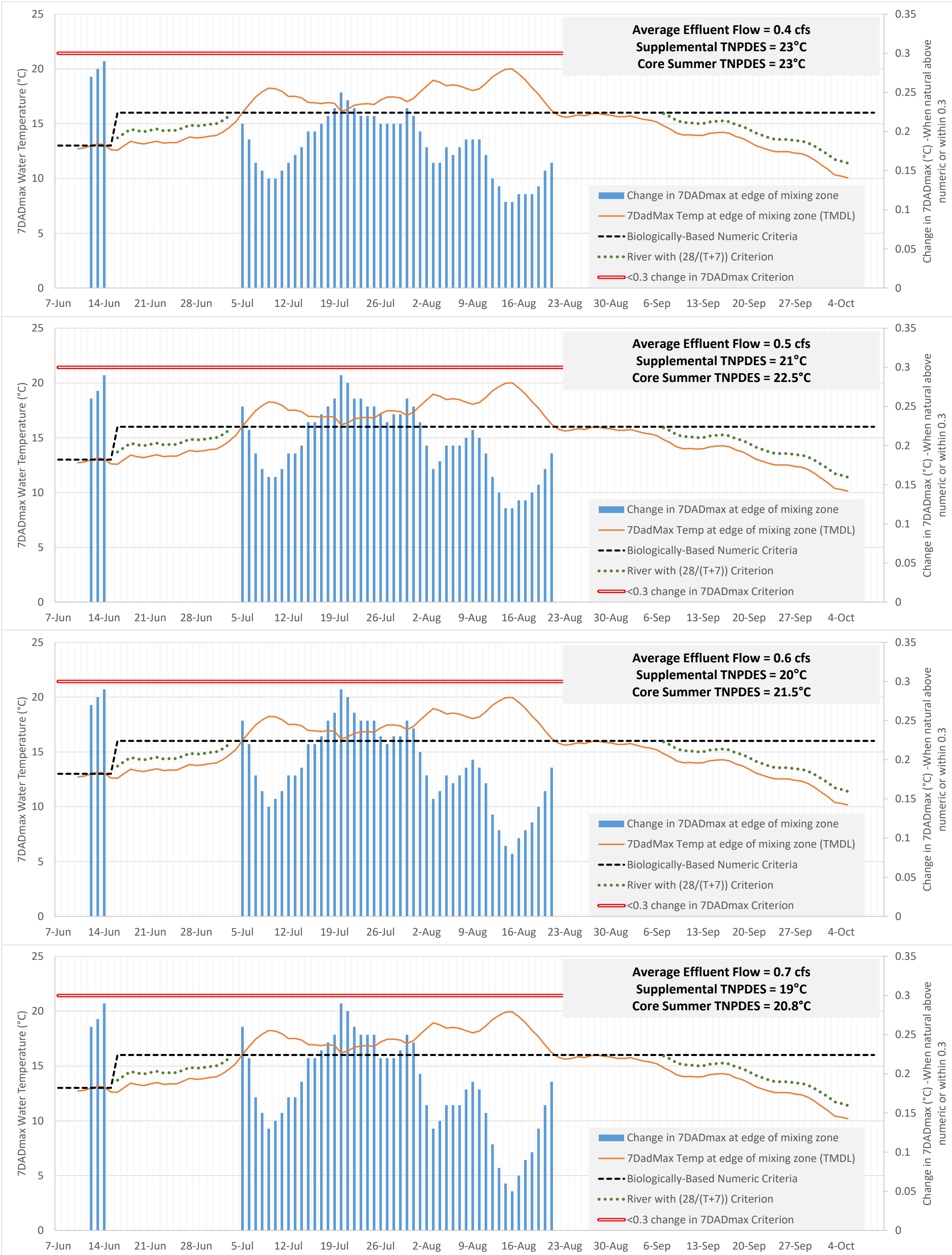

Figure 51. Predicted 7-DADMax temperatures at the edge of the Granite Falls WWTP mixing zone for variable effluent flows and comparison to applicable water quality criteria.

From June 16 to October 1 (critical period for Core Summer Habitat criterion), the Granite Falls WWTP must meet the WLAs listed in Table 54.

Table 54. Tiered wasteload allocations for Granite Falls WWTP from June 16 to October 1

Effluent Flow Range for WLA tier at permit update*	Average Effluent Flow Tested (June – Sept) (cfs)	Core Summer T_{NPDES} Limit (°C)	Flow Scale Factor (from 2012 flows)	Core Summer WLA (therms/day)
<=0.4 cfs	0.4	23.0	1.10	893
0.41 to 0.5 cfs	0.5	22.5	1.37	1,092
0.51 to 0.6 cfs	0.6	21.5	1.65	1,253
0.61 to 0.7 cfs	0.7	20.8	1.93	1,414

* Based on average daily effluent flow from June 16 - October 1 for the most recent 4 years, with 5-year population growth applied at a 2% growth rate. For 2015 – 2018, the average was 0.32 cfs; 0.35 cfs with 5-year growth.

During the Supplemental Spawning period, February 15 to June 15, the Granite Falls WWTP must meet the WLAs listed in Table 55.

Table 55. Tiered wasteload allocations for Granite Falls WWTP from February 15 to June 15

Effluent Flow Range for WLA tier at permit update*	Average Early June Effluent Flow Tested (cfs)	Supplemental T_{NPDES} Limit (°C)	Early June Scale factor (from 2012 flows)	Supplemental WLA (therms/day)
<=0.5 cfs	0.5	23	1.00	1,117
0.51 to 0.6 cfs	0.6	21	1.21	1,223
0.61 to 0.7 cfs	0.7	20	1.41	1,359
0.71 to 0.8 cfs	0.8	19	1.61	1,476

* Based on average daily effluent flow from June 1 - June 15 for the most recent 4 years, with 5-year population growth applied at a 2% growth rate. For 2015 – 2018, the average was 0.36 cfs; 0.4 cfs with 5 year growth.

The WLA (in therms/day) for the Granite Falls WWTP is determined by the temperature limit and effluent flow using the following equation:

$$WLA = TNPDES * future\ effluent\ flow\ (cfs) * 97.1$$

where:

97.1 equals a conversion factor to therms/day (therm / (cfs * degC)).

T_{NPDES} = temperature limit criterion in °C.

Note: 1 therm = 100,000 BTU = 105,506 kilojoules = 25,200 kilocalories = 29,307 Watt/hr.

Tiered WLAs are set based on the Granite Falls WWTP predicted effluent flow for the end of a permit cycle. The WLAs apply based on the average daily effluent flow from the most recent 4 years for the applicable period, with 2% population growth applied over a 5-year period (multiplier =1.104). The TMDL recommends the T_{NPDES} Targets from Tables 47 and 48 be used in the permit at the time of update, based on effluent flows determined by this method.

Stormwater and General Permit Wasteload Allocations

Wasteload allocations are required for permitted stormwater discharges if they are a source of pollutant loading to the stream when receiving water temperatures are impaired. The Pilchuck River watershed has permitted stormwater sources discharging into its mainstem and tributaries. Although Ecology expects thermal loadings from permitted stormwater to be of minimal size during critical low-flow conditions, the TMDL must assign WLAs to all NPDES-permitted thermal discharges within the TMDL study area that could contribute to the impairment. It is important to note that runoff in Western Washington typically cools rapidly during long rain events and is not expected to cause a 0.3°C increase of the 7-day average daily maximum temperature. The Snoqualmie River Temperature TMDL (Svrjcek and Stohr, 2011) provides good additional discussion of local instream and air temperature response to summer storm events.

Temperature monitoring from the 2012 study indicates that stream temperatures are likely to decrease during significant runoff events. A simulation of June 2012 storms shows that runoff in the Little Pilchuck Creek watershed does not appear to increase water temperatures and is instead correlated with cooler temperatures in the stream (Figure 52). The smallest of these storms, occurring during late June, resulted in an approximate doubling of the flow in the river and a greater than 2°C decrease in water temperatures in the creek, with the temperature falling below 16°C. Relative to other basins in the Pilchuck River watershed, Little Pilchuck Creek, which includes much of Lake Stevens, has the largest drainage area and highest percentage of impervious surfaces.

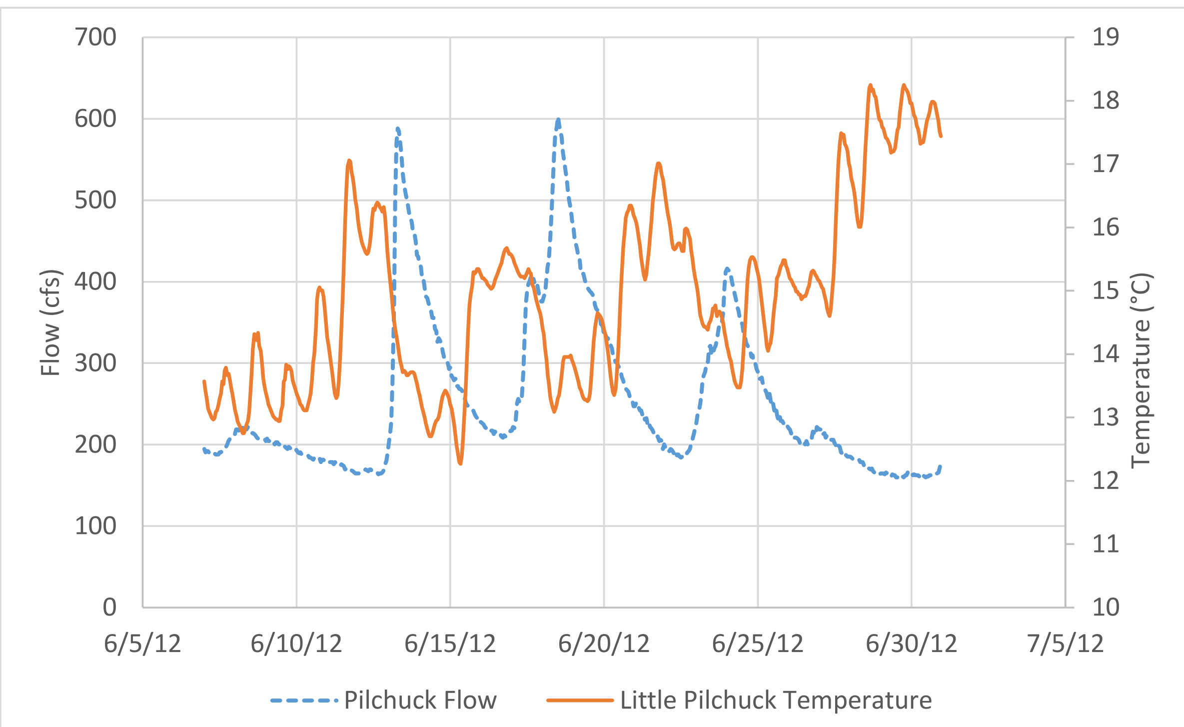

Figure 52. Relationship between June flow peaks (storms) and Little Pilchuck Creek temperatures.

During these summer storms, the river flow can increase due to runoff and the loading capacity can increase. In order to test the loading capacity of potential stormwater discharges under various summer conditions, Ecology tested hypothetical stormwater loading in the model.

Ecology developed hypothetical stormwater inflows for the TMDL by:

- Using the modified 2009 flow record as a basis for developing flows. This flow record was found to be most representative of a 7Q10 critical year (see other sections) and includes runoff events in each month within the study period.
- Assuming that 20% of the increase in flow during runoff events originates from within the TMDL study area. According to an analysis conducted using USGS Streamstats, for a 2-year peak flow event, 80% of the increase in discharge originates upstream of the study area (Mastin et al., 2016).
- Assuming that all 20% of the increase in flow during runoff originates from a permitted source (e.g., municipal stormwater infrastructure, state highways).
  - Assuming all 20% originates from NPDES permitted sources is overly conservative, as much of the watershed is rural and runoff from these areas likely originates from natural drainage features and shallow groundwater flow paths.
  - However, this evaluates a maximum stormwater flow scenario and accommodates the possibility of future development of permeable lands into impervious surface.
- Dividing the total hypothetical permitted runoff and distributing to each model reach based on the percentage of total land area that drains to that reach.
- Including a small "baseflow" from permitted stormwater infrastructure to accommodate the possibility of discharge from NPDES permitted sources during non-runoff conditions.
  - The total permitted "baseflow" equals less 1.5 cubic feet per second, so it does not have a large effect on critical low flow in the TMDL model.

Figure 53 illustrates the hypothetical permitted stormwater inflows developed using this method.

Ecology then developed a maximum daily temperature limit for permitted stormwater sources using the following process:

- Setting hypothetical permitted stormwater input of hourly temperatures equal to the critical conditions air temperature used at the downstream end of the model.
- Reducing any hourly temperatures above a certain threshold (daily maximum limit) to the threshold value.
- Testing different daily maximum targets to find a value that resulted in less than 0.3°C cumulative impact from all sources. This testing occurred in concert with other management actions (riparian shade, baseflow restoration, Granite Falls WWTP target).

This process resulted in a daily maximum temperature limit of 21°C for all NPDES permitted sources (except for the Granite Falls WWTP). Ecology determined this value appropriate for the TMDL because it is:

- Within the range of the Granite Falls WWTP municipal wastewater limit (20.8°C to 23°C, depending on effluent flow), and thus equitable to other points source targets.
- Below the acute daily maximum criterion in the water quality standards (23°C).
- Similar to the estimated maximum system potential 7-DADMax temperature (~21.5°C).

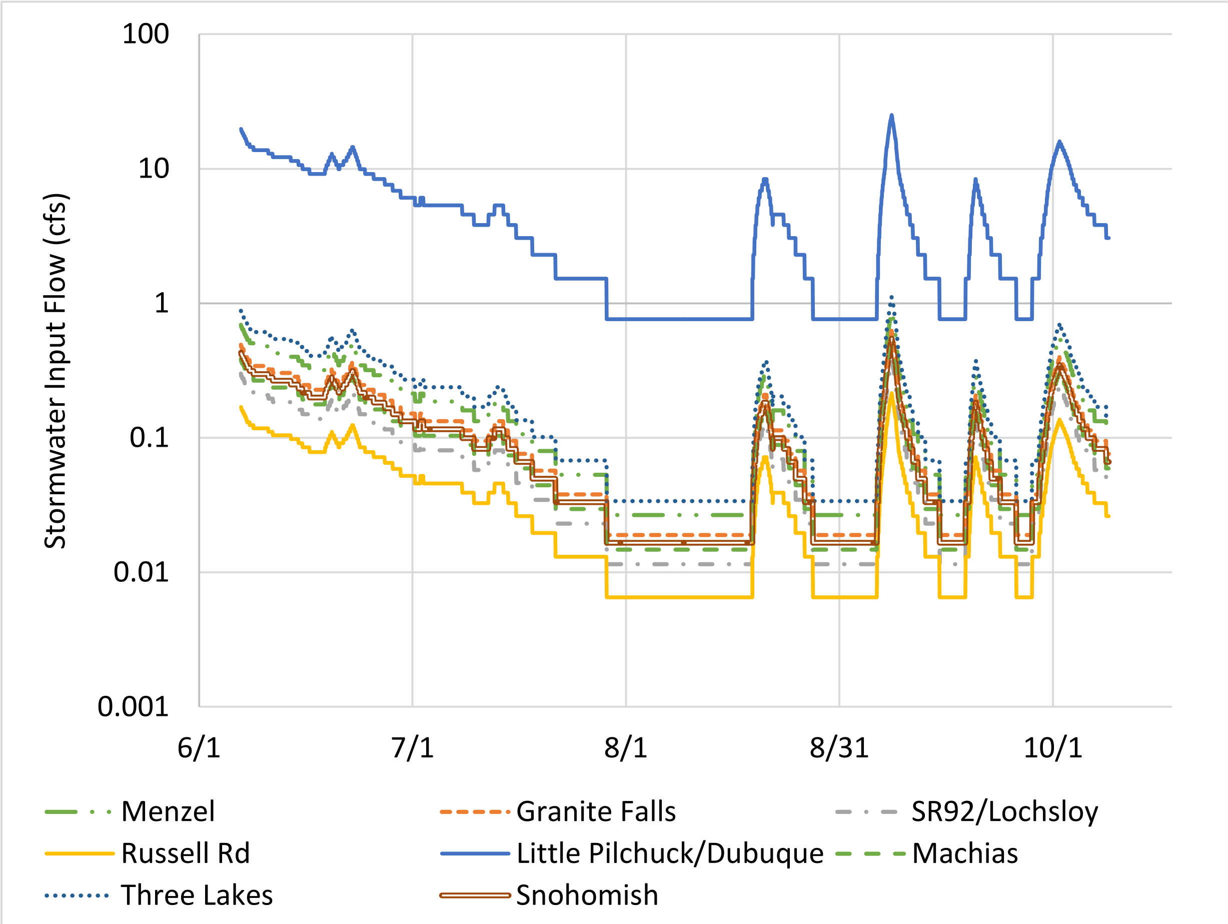

Figure 53. Hypothetical stormwater inflows used to develop stormwater wasteload allocations.

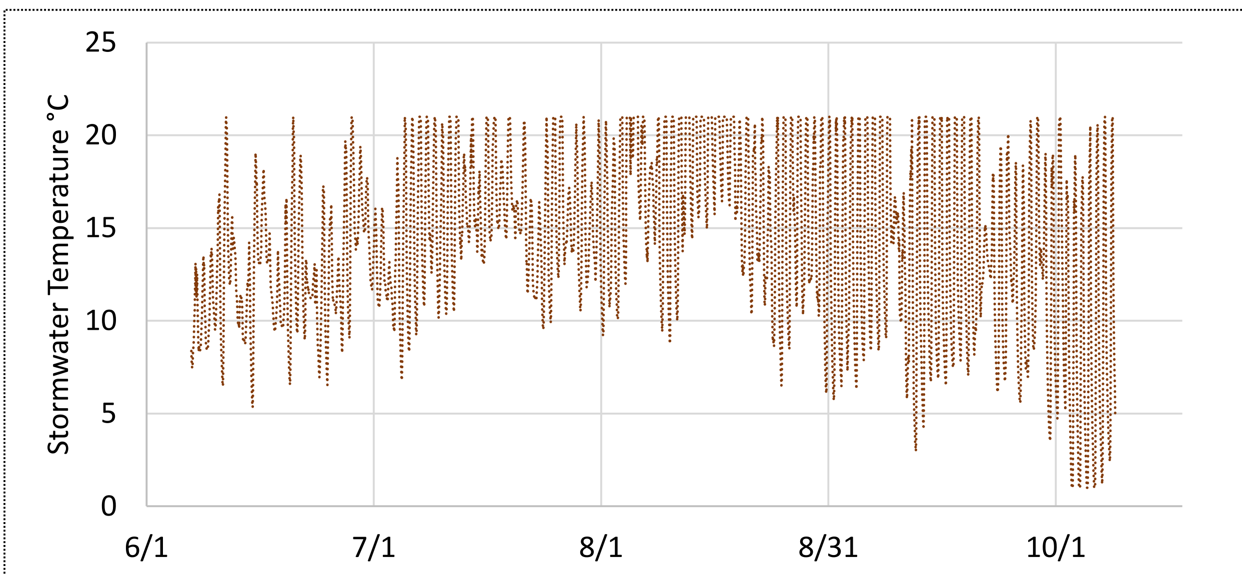

Figure 54. Stormwater temperature inputs tested in the model.

Once Ecology tested stormwater loading in the model and determined compliance with the water quality standards (less than 0.3°C anthropogenic change to 7-DADMax; 7-DADMax <22°C; Daily max <23°C), then the total stormwater load was allocated by reach to accommodate all NPDES permittees within the study area. The majority of the load (87.5-90%) within each reach was allocated to the municipal stormwater permit holders and distributed amongst municipalities based on the percentage of land base within the subbasin that corresponds to the allocation reach. The remaining load (10-12.5%) was distributed by giving 2.5% of the available capacity to each applicable general permit category within the reach. Figure 55 illustrates the TMDL subbasins used to divide allocations by reach. Table 56 provides a summary of these WLAs.

Table 56. NPDES permit wasteload allocations for each reach and permit in therms per day.

Subbasin/Reach	Snohomish County Phase 1	City of Granite Falls Phase 2	City of Lake Stevens Phase 2	City of Snohomish Phase 2	WSDOT	Construction Stormwater General	Industrial Stormwater General	Sand and Gravel General	Future Individual Permits	Total Reach Allocation
Menzel	1118	NA	NA	NA	NA	31	31	31	31	1243
Granite Falls	594	52	NA	NA	18	18	18	18	18	738
SR 92	505	44	NA	NA	16	16	16	16	16	628
Lochsloy	382	NA	NA	NA	11	11	11	11	11	437
Russell Rd	228	NA	NA	NA	NA	6	6	6	6	254
Machias	409	NA	5	NA	NA	11	11	11	11	460
Three Lakes	603	NA	64	24	20	20	20	20	20	790
Snohomish	251	NA	NA	42	NA	13	13	13	13	516
Little Pilchuck	3179	NA	561	NA	107	107	107	107	107	4274
Dubuque Creek	1489	NA	NA	NA	NA	41	41	41	41	1654
Total	8759	96	630	66	172	275	275	275	275	10993

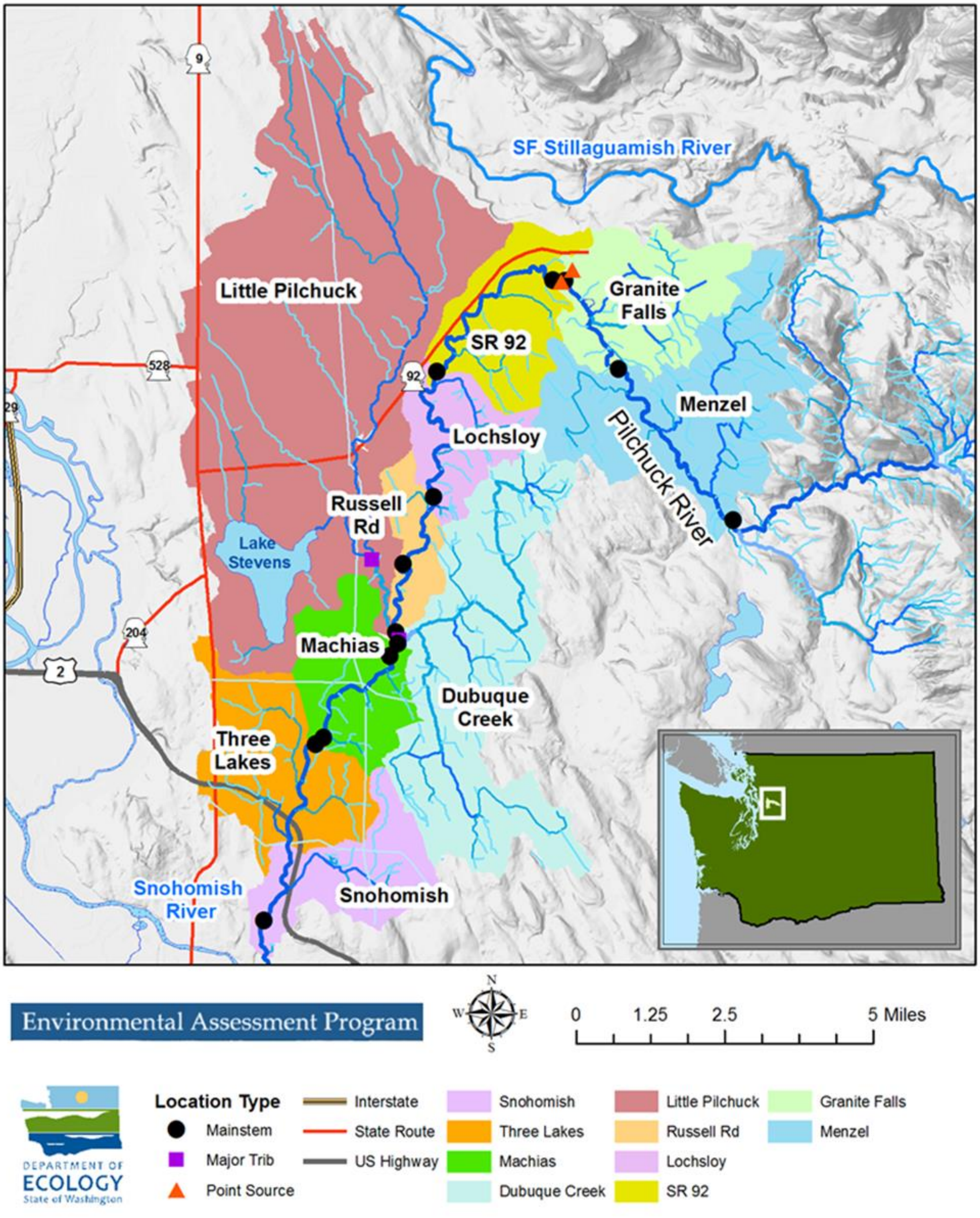

Figure 55. TMDL subbasins used to assign reach specific stormwater wasteload allocations.

Load Allocations

This TMDL establishes load allocations for nonpoint sources. Nonpoint sources must meet these allocations in order to meet both the numeric threshold criteria and the allowances for human-caused warming under conditions that are naturally warmer than those criteria.

Predicted system potential temperatures do not meet numeric temperature criteria during the hottest period of the year throughout the Pilchuck River watershed; therefore, there is a widespread need to achieve maximum protection from direct solar radiation. All tributaries likely also need system potential vegetation to meet water quality standards; however, the lower two miles of each tributary are particularly important to the Pilchuck River achieving water quality standards.

The load allocation for the mainstem Pilchuck River and each tributary with a temperature impairment, is the potential shade that would occur from system potential mature riparian vegetation. The TMDL defines system potential mature riparian vegetation as that vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

Table 56 contains numeric load allocations for effective shade for the Pilchuck River and for each tributary in the watershed. The TMDL bases the load allocations on the estimated relationship between shade, channel width, and stream aspect at the maximum riparian vegetation condition (shown in Figure 56). The effectiveness of shade to cool stream temperatures decreases as the width of the channel increases.

Table 57 also presents predicted system potential and current effective shade on the Pilchuck River. Figure 58 shows the shade deficit, or difference between system potential and current shade, for the Pilchuck River within the study area.

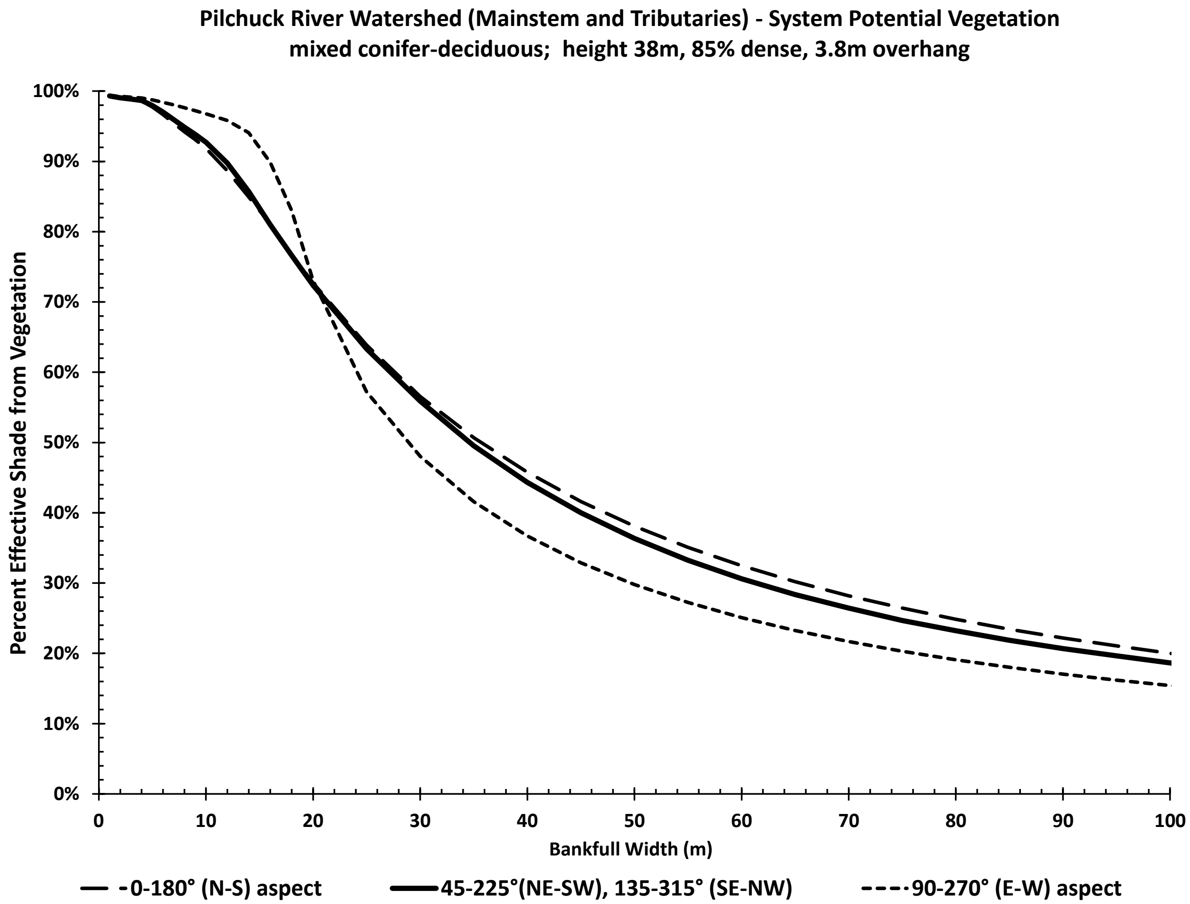

Figure 56. Effective shade vs. bankfull width for system potential vegetation in the Pilchuck River.

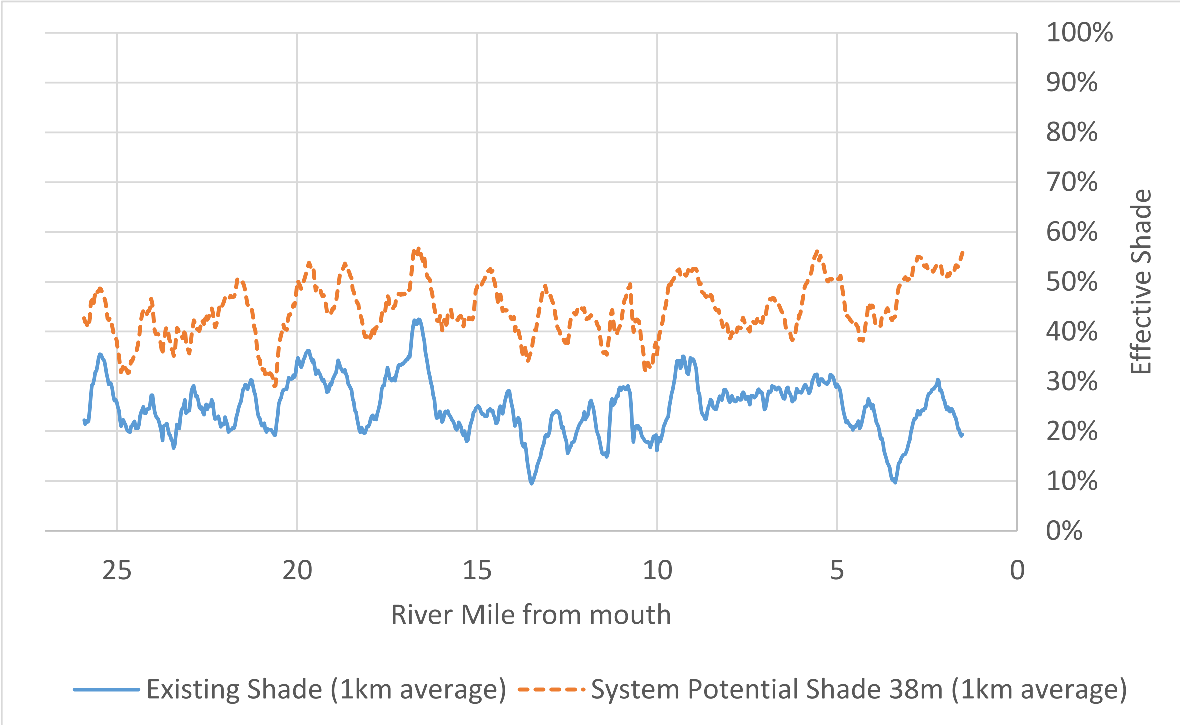

Figure 57. System potential shade on the Pilchuck River for August 15.

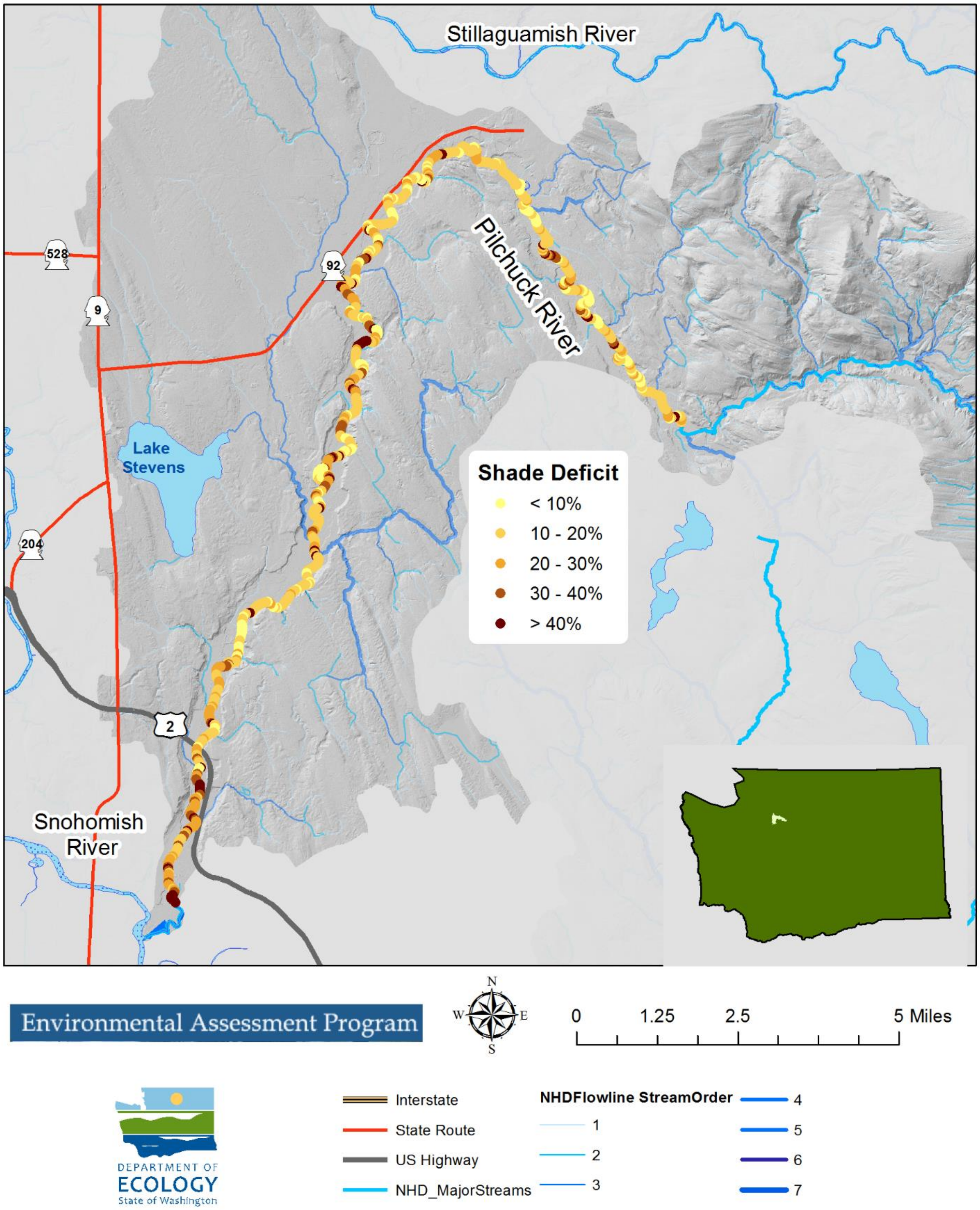

Figure 58. Shade deficit (system potential shade minus existing shade) for the Pilchuck River.

Table 57. Load allocations for thermal loading from shortwave solar radiation to the Pilchuck River.

Downstream River Mile	Current Shade	System Potential Shade	% Shade Deficit	LA solar (w/sec/m^2)	Length (m)	Width (m)	LA solar (Therms/ day)
25	33.3%	46.4%	13.1%	148.3	1931	16.03	3759
24	27.8%	42.6%	14.8%	158.7	1609	14.92	3120
23	27.1%	41.9%	14.8%	160.7	1609	15.38	3259
22	29.4%	45.7%	16.2%	150.3	1609	15.36	3043
21	30.0%	50.0%	19.9%	138.3	1609	15.18	2768
20	28.6%	39.3%	10.8%	167.7	1609	14.38	3179
19	37.0%	52.2%	15.2%	132.0	1609	13.06	2272
18	30.9%	50.0%	19.1%	138.1	1609	15.89	2893
17	34.2%	48.2%	14.0%	142.9	1609	14.07	2650
16	37.9%	53.2%	15.4%	129.2	1609	14.41	2453
15	27.4%	46.4%	19.1%	147.8	1609	14.15	2758
14	30.3%	52.2%	21.9%	131.9	1609	13.86	2411
13	21.8%	46.2%	24.4%	148.4	1609	15.34	3001
12	26.5%	45.7%	19.2%	149.7	1609	16.09	3176
11	27.7%	43.8%	16.1%	154.9	1609	16.35	3340
10	23.6%	40.1%	16.5%	165.1	1609	16.51	3592
9	34.4%	54.3%	19.8%	126.0	1609	17.66	2934
8	31.0%	49.8%	18.8%	138.4	1609	16.76	3057
7	30.5%	43.7%	13.2%	155.0	1609	17.35	3545
6	32.6%	46.8%	14.1%	146.7	1609	18.11	3502
5	34.9%	55.3%	20.4%	123.3	1609	16.25	2640
4	28.7%	47.0%	18.3%	145.8	1609	16.95	3259
3	20.7%	48.6%	27.9%	141.5	1609	15.11	2820
2	31.4%	56.5%	25.0%	119.9	1609	15.36	2428
1	24.6%	58.2%	33.6%	115.1	1609	13.64	2068

These load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural shade conditions. Because anthropogenic changes to stream temperature can result from causes other than permitted discharges or the removal of shade, the Implementation Plan for this TMDL also includes a variety of measures to address channel structure, hyporheic flow, and other factors. Implementation of these measures, as well as system potential vegetation, will help ensure that water temperatures will approach natural conditions and allow for cold-water refuge to more fully support the aquatic life uses in the river.

The Pilchuck River Temperature and Dissolved Oxygen TMDL identified four additional areas of restoration that are needed to meet water quality standards and allow for the aquatic life beneficial use of Core Summer Salmonid Habitat:

- Restore summer baseflow throughout the watershed.
- Extend riparian buffer width to 180 feet on each side of the river channel in order to
  - Create a microclimate with cooler air temperature and increased humidity,
  - Retain some working buffer and effective shade after channel migration events,
  - Provide large woody material (LWM) to recharge wood recruitment,
  - Shade the alluvial floodplain to cool hyporheic flow.
- Design actions to increase hyporheic connectivity and flow including restoring banks and floodplains to pre-development conditions where feasible.
- Strategically place LWM and other engineered habitat projects to increase frequency of pools, hyporheic flow connectivity, and cold-water refuge (see Implementation section).

Summer Baseflow Restoration Targets

Ecology estimated the amount of potential baseflow loss within the TMDL study area at up to 15-20 cfs during the peak outdoor water-use months of July and August. Appendix H contains a detailed description of the methodology for water use estimates.

Baseflow restoration is needed in the watershed in order to achieve a less than 0.3°C cumulative anthropogenic impact to temperature. This can be achieved if 75% of baseflow loss is restored in the Little Pilchuck subbasin and 60% is restored in the remaining subbasins. Table 58 contains estimates of the baseflow restoration needed, in cubic feet per second.

Table 58. Estimates of baseflow restoration needed, in cubic feet per second, to meet temperature water quality standards.

Subbasin	June	July	August	September
Menzel	1.0	1.4	1.0	0.3
Granite Falls	1.6	2.3	1.7	0.6
Lochsloy	0.6	0.9	0.6	0.2
Machias	0.5	0.8	0.6	0.1
Little Pilchuck	4.2	6.0	4.5	1.6
Dubuque	0.0	0.1	0.0	0.0
Three Lakes	0.4	0.7	0.5	0.1
Snohomish	0.6	0.8	0.6	0.2
Total	8.9	12.9	9.6	3.1

Compliance with baseflow restoration targets is measured at the USGS 12155300 Pilchuck River Near Snohomish, WA streamflow gage at Three Lakes Road. Table 59 contains the 1 in 10 year monthly minimum flow for the USGS gage, upstream restoration targets, and the target monthly minimum flow. Ecology set the target as a monthly minimum because this is representative of the critical condition and a simple way to assess whether the target has been met, compared to an annual 7Q10 flow or other calculated metric.

It is important to note that the Pilchuck River would not be expected to meet these targets in an abnormally low-flow year (greater than 1 in 10 year occurrence).

Table 59. Historical and target minimum monthly flows for USGS 12155300 Pilchuck River Near Snohomish, WA gage.

Metric/Target	June	July	August	September
10th percentile of historical monthly minimums	73.1	52.8	41.8	40
Upstream restoration target*	8.3	12.1	9	2.9
Target monthly minimum flow	81.4	64.9	50.8	42.9

*The upstream restoration targets do not include the streamflow restoration target for the Snohomish Basin, which is located downstream of the USGS gage.

Wide Riparian Buffer Widths

The TMDL analysis extended the riparian buffer width to 180 feet on each side of the river channel in order to maximize the thermal and aquatic life benefits and restore the stream temperature regime to near system potential conditions.

Wide riparian buffers make sense for the Pilchuck River as a long-term goal for the following reasons:

- The Pilchuck River has a relatively large and active channel migration zone.
  - A geomorphic assessment conducted by Snohomish County (SCSWM, 2012b) on the Middle Pilchuck River determined that ~20% of the banks had a channel migration rate of 6 feet per year or greater (for the period of 1991-2009).
  - Mature vegetation reduces bank erosion, but new plantings within ~50 feet of the stream would be at risk of not surviving in these quickly eroding areas.
  - Planting or protecting a wide buffer retains some functional buffer and effective shade following large channel migration events.
  - Channel migration through mature, wide vegetated buffers can result in well-shaded side channels that reduce stream temperature and provide CWR (see example in Figure 58).
- Several studies have documented a microclimate effect that occurs at the edge conditions of a riparian buffer or forest (see Appendix G for detailed discussion and references).
  - Beneficial microclimate effects include cooler air temperatures and increased relative humidity, as well as reduced wind speed and decreased soil temperatures.
  - Larger riparian forest areas (wider buffers) can potentially magnify microclimate effects.

- Maintaining a wide buffer creates a recharging wood buffer area adjacent to the active wood buffer (area within a tree height of the active channel).
    - Recharging wood buffers increases large woody material (LWM) recruitment by destabilizing trees in the active wood buffer (when a tree or stand falls) and by supplying LWM to the active wood buffer or channel during mass wasting or other erosion events, particularly on hillslopes >40% (Mazzorana et al, 2009).
- Wide buffers shade more of the crucial areas adjacent and hydraulically connected to the river including side channels, wetlands, tributary confluences, and floodplain hyporheic flow paths.
    - Extending the buffer widths includes trees that shade the alluvial floodplain and potentially cool shallow hyporheic flow. Figure 59 provides a hypothetical example.
    - Figure 60 contains an example on the Pilchuck River at an important side channel at ~RM 14. Applying a 180-foot buffer to the main channel provides a shade buffer to ~31% of this side channel, whereas a 75 foot buffer would only cover ~13% of the side channel.

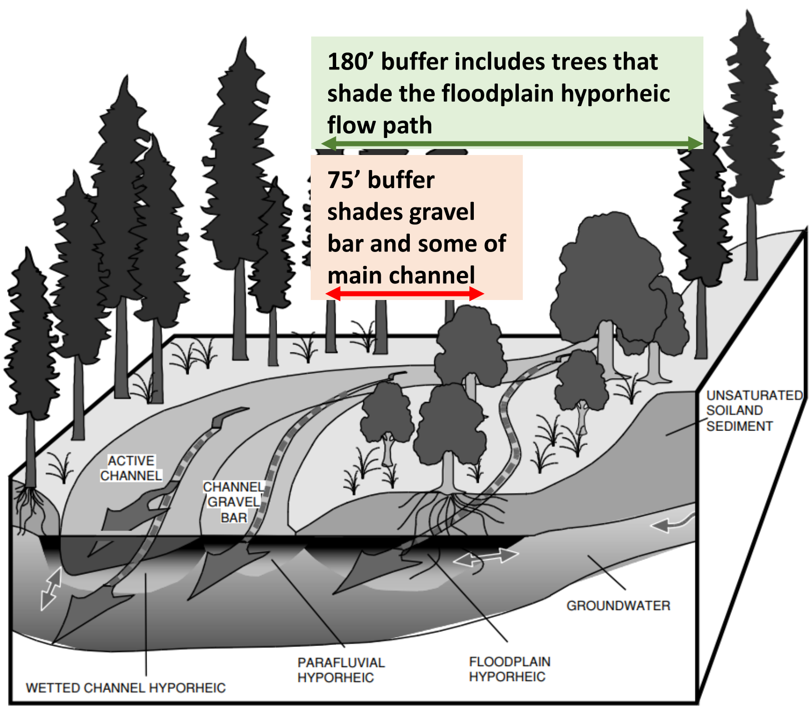

Figure 59. Hypothetical example of a wide buffer shading hyporheic floodplain flow. Figure adapted from Naiman et al., 2000).

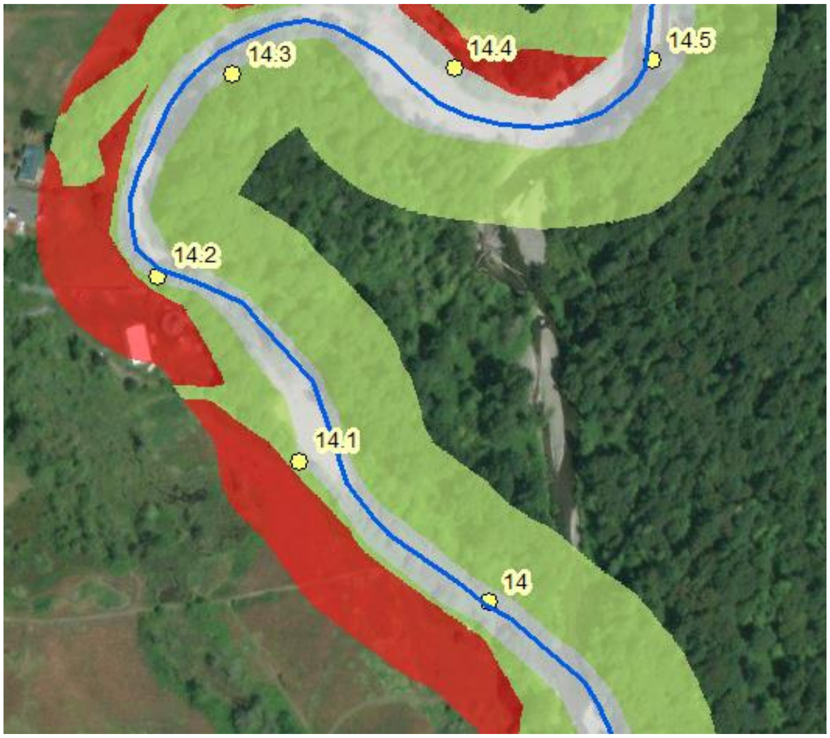

Figure 60. Digitized 180-foot buffer on the Pilchuck River (green shaded area) overlaps with 31% of a side channel at RM 14.

Restoring Hyporheic Connectivity through Bank, Floodplain, and In-Channel Modifications

As described under "System Potential Conditions" and in Appendix G, the system potential model assumed that the fraction of hyporheic flow has decreased by the percentage that the river banks have been hardened or modified. For example in reach 33 of the model (Snohomish County Reach L6), 22% of the bank length has been modified (78% of the bank length remains natural). In the 2012 model, the calibrated hyporheic flow fraction was 0.15 (or 15% of the main channel flow) for reach 33. In the system potential model, the hyporheic flow fraction was increased by dividing the existing hyporheic fraction of 0.15 by 0.78 for an estimated natural hyporheic flow fraction of 0.1923.

Using this method for the entire modeled river length, the average system potential hyporheic flow fraction was estimated at ~18%, compared to an average existing hyporheic flow fraction estimated at ~13%. It is important to note that there is not a measurable quantitative link between percent of bank modified and hyporheic flow fraction; however, it does provide a qualitative assessment of the relative potential impacts based on the strong conceptual relationship between bank armoring and hyporheic connectivity. Appendix G discusses this relationship in greater detail, including references, under the 'Channel Morphology Changes: Bank and Floodplain Modifications' section.

Bank restoration, floodplain connectivity, and in-channel addition of large wood debris would likely improve the hyporheic flow fraction (how much of the Pilchuck River flow is interacting with the hyporheic zone) and contribute to achieving a less than 0.3°C cumulative anthropogenic impact to temperature. The target level of restoration is a 2% increase in hyporheic connectivity which would result in an average hyporheic flow fraction of ~15%.

Comparison of TMDL Scenarios to Numeric Criteria

Table 60 summarizes the percent of model reaches and days that fail to meet numeric criteria for the TMDL model scenarios. A model reach day represents the result for each of the 41 model reaches (includes headwater) for each of the 119 days where a 7-DADMax value was calculated.

Under critical conditions, the total percent of reach days that fail to meet the numeric criteria improves by 18% in the TMDL scenario. The TMDL scenario represents compliance that is within 1% of the system potential scenario.

Under "average" 2016 conditions, the system potential model scenario compliance with numeric criteria improves (compared to critical conditions) by 5%.

The largest overall improvement in compliance (30%) from the TMDL occurs in the month of September, when existing conditions are closer to the numeric criteria and shade is more effective.

Table 60. Percent of model reaches and days that fail to meet numeric criteria for the TMDL model scenarios.

Run Name	Total Reach Days Fail	Total Reach Days	Total % Fail	June % Fail	July % Fail	Aug. % Fail	Sept. % Fail
Existing-2012	2,832	4,879	58%	17%	80%	96%	36%
No Action- Critical	3,054	4,879	63%	28%	89%	97%	36%
System Potential- Critical	2,135	4,879	44%	15%	75%	79%	4%
TMDL- Critical	2,187	4,879	45%	16%	76%	80%	6%
System Potential- 2016	1,914	4,879	39%	13%	64%	70%	8%
TMDL-2016	1,996	4,879	41%	14%	67%	72%	9%

Seasonal Variation

The Clean Water Act (CWA) section 303(d)(1) requires that TMDLs "be established at the level necessary to implement the applicable water quality standards with seasonal variations." The current regulation also states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(2)]. Finally, section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The Pilchuck River watershed experiences seasonal variation with cooler temperatures occurring in the winter and warmer temperatures in the summer. The highest temperatures typically occur from mid-July through late-August. However, a more stringent criterion applies from February 15 to June 15 (13°C), and critical Chinook spawning typically occurs in September, when flows are at their lowest. For this reason, the critical season is defined as June 1 to September 30 to cover these shoulder season conditions. This timeframe is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The model was calibrated to a date from the period of June 7 to October 9, 2012, which captured the warmest time of year and critical periods for both core summer salmonid and supplemental spawning. The calibrated model was modified to represent critical streamflows (i.e., lowest 7-day average flows with 10-year recurrence interval or 7Q10) and air temperatures (90^{th} percentile) in order to develop load allocations and WLAs.

Load allocations from the summer model runs resulted in requiring the maximum riparian protection to the stream. The dynamic model confirmed that allocations would be protective throughout the summer season and during the hottest part of the supplemental spawning period. For point sources, seasonal variation is taken into account, as described in the Wasteload Allocation section, through the use of dynamic WLAs.

In summary, there are three seasons and two critical conditions for temperature:

- **Fall-winter season—October 1 to February 14—no critical condition**
  - Reduced air temperature and solar radiation, coupled with increased flow, lead to significantly lower stream temperatures and compliance with water quality criteria.
- **Supplemental Spawning Season—February 15 to June 15—early June critical condition**
  - Increasing seasonal air temperatures and declining baseflows result in the end of this season typically providing the most critical condition.
  - More stringent 7-DADMax criterion of 13°C applies.
  - Criterion is frequently exceeded in June during tail end of Steelhead spawning window even under predicted system potential conditions.
- **Core Summer Habitat season—June 16 to September 30—August critical condition**
  - Peak annual air temperatures, typically in August, are the largest driver of critical conditions. Minimum annual flows, typically occurring in late August or early September, are also an important driver.
  - 7-DADMax criterion of 16 °C applies, but is frequently exceeded for much of the season even under predicted system potential conditions.

The Core Summer Habitat season was determined to be the most critical condition; thus Ecology based TMDL allocations and estimated loading capacity on this season and its critical condition, with the exception of the Granite Falls WWTP, which has separate WLAs to ensure compliance with different criteria between the two critical seasons. For all other allocations, Ecology determined, through the technical analysis, that the targets and implementation actions derived from the Core Summer Habitat season will be protective during the supplemental spawning season.

Reserve Capacity for Future Growth

Given that temperatures exceed criteria, even under system potential conditions, there is very small capacity for future growth. However, future growth may occur under one of three conditions:

- The temperature discharge occurs at or below the water quality criteria.
  - Daily allocation for future growth in therms/day is determined by the formula:

$$Allocation_{future\ growth} = T_{crit} \times Q \times 97.1$$

where,

T_{crit} = The applicable temperature criterion either 13 or 16°C
Q = future discharge in cubic feet per second
97.1 = conversion factor to transform the units to therms/day

- By replacing a permitted heat load source that was assigned an allocation in this TMDL.
- If the new discharge is within one of the general permit categories assigned a WLA in this TMDL.

Table 56 also includes a very small amount of capacity reserved for future individual permits. This quantity represents the explicit reserve for future growth and is summarized in Chapter 2: TMDL Allocations.

Conclusions and Model Findings

- Under the current riparian status, the Pilchuck River 7-DADMax water temperature is expected to reach up to 24.1°C, exceeding the 22°C lethal threshold to salmonids, during critical low-flow (7Q10) and 90th percentile climate conditions.
- A buffer of mature riparian vegetation along the banks of the Pilchuck River is expected to decrease the average daily maximum and 7-DADMax temperatures. The most critical 7-DADMax temperature could be decreased by up to 1.6°C (°F) compared to the no action scenario.
- The changes in microclimate associated with mature riparian vegetation could further lower the highest 7-DADMax water temperature by about 0.8°C.
- If restoration activities in the tributaries and headwater result in waters that meet the numeric temperature standards, a further reduction of 0.3°C is expected to the highest 7-DADMax.
- Additional hyporheic cooling can reduce water temperatures by 0.1°C on the hottest day.
- Full restoration of baseflow can cool water temperatures by 0.3°C on the hottest day.
- With all management scenarios in place, temperatures are expected to remain below the lethal threshold, with a 7-DADMax of up to 21.1°C during critical conditions. These temperatures are well above the numeric water quality criterion (16°C).
- With all management scenarios in place, the overall decrease in the average maximum stream temperature for the simulated critical condition is expected to be 3.1°C for the highest 7-DADMax. While the river would still reach temperatures in late July or August above the maximum values established in the numeric water quality criteria, the cooling will be significant for the designated beneficial uses of these waterbodies.

- With all management scenarios in place, the overall decrease in the average maximum stream temperature for the simulated supplemental spawning is expected to be 1.2°C (6/13/12). For conditions in September, this decrease is expected to be 1.9°C (9/1/12). With these reductions, the river would remain below the fish embryo lethality threshold (17.5°C) and meet the respective 7-DADMax criteria (13°C and 16°C) in almost all of the river, with the exception of the lowest reaches.
- Overall, Ecology found the study data to be of acceptable quality and useable based on Ecology's credible data policy and the study objectives.
- The summer of 2012 exhibited warmer than average air temperatures (95^{th} percentile for 7-day average maximum) and relatively average river low-flow levels.
- The 7-DADMax temperatures during 2012 did not meet (were above) water quality criteria at all sites monitored in the watershed, including the upstream boundary and tributaries.
- The steepest increase in longitudinal temperature on the river occurred at the upstream end of the study area between Menzel Lake Rd (~RM 25) and Robe Menzel Rd (~RM 21). This increase represents about 2.7°C over about 4 river miles. This steep increase is attributed to increasing air temperatures at decreasing elevations, increased channel widths, and decreasing shade. This is a relatively common and natural effect when transitioning from narrower upland canyon topography to a more open valley and floodplain.
- Significant groundwater discharge to the Pilchuck River was inferred from results of flow balance surveys and was observed in the field, primarily as diffuse seepage from banks, particularly where the river channel intersects the top of the glacial till.
- Hyporheic flow of river water through bottom sediments and gravel bars was observed throughout the Pilchuck River watershed study area. The estimated amount of hyporheic flow in the Pilchuck River is predicted to be a significant mitigating factor for temperature.
- The primary source of heat loading is direct solar shortwave radiation. Shade from riparian vegetation is the largest mitigating factor for reducing stream temperatures.

Recommendations

- Increasing shade to the lower half of the Pilchuck River (~RM 0 to 12) should be the top priority. These improvements are particularly important for avoiding the lethal threshold (23°C) at peak temperatures and the fish embryo lethality threshold (17.5 °C) during the critical Chinook spawning month of September.
- Increasing riparian shade along the rest of the river is also very important for improving thermal habitat and avoiding lethal conditions for fish.
- Riparian restoration of tributaries that are high value for salmonid use should also be a priority. It is often easier and faster to establish vegetation to shade narrower tributary streams.
- Hyporheic exchange flows and groundwater discharges are important in maintaining the current temperature regime and reducing maximum daily instream temperatures.
    - Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the hydraulic conductivity of streambed sediments.
    - Activities that reduce the hydraulic conductivity of streambed sediments could increase stream temperatures.

- Management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.
  - Quantify hyporheic flow fraction, depth, and thermal properties to refine our understanding of the impact of hyporheic restoration over multiple scales.
- Protecting and restoring channel structure and habitat features at or near cold water refuges is necessary to provide thermal relief during peak summer temperatures.
- Preserve/restore groundwater baseflow, off-channel wetlands, and areas with hyporheic function. These features are important for mitigating high instream temperatures.
- Establish/continue long-term temperature monitoring in the Pilchuck River to track trends over time.
- Using continuous temperature monitoring, confirm cooling trends between the Granite Falls WWTP facility and outfall to the Pilchuck River.

Dissolved Oxygen TMDL Analysis and Allocations

Ecology used the same modeling scenarios developed for the temperature TMDL analysis as the basis for developing the dissolved oxygen (DO) TMDL. Ecology used these modeling scenarios to assess compliance with the water quality standards and develop load (for nonpoint pollution sources) and wasteload (for point sources) allocations for phosphorus and biochemical oxygen demand (BOD). Table 61 summarizes the modeling scenarios developed for the TMDL. Model documentation in Appendices F and G describes these scenarios in detail.

Table 61. Modeling scenarios used in the TMDL analysis.

Scenario Name	Streamflow	Air Temp	Other Conditions and Modifications
Existing 2012	2012 USGS & ECY	2012 ECY & AWN*	Primarily ECY data with some weather data from NWS & AWN
No action- Critical	Adjusted 2009 USGS (7Q10)	Increased to 2009 max	Same as above but with critical flow and air temperatures
System Potential- Critical	Adjusted 2009 USGS (7Q10)	Increased to 2009 max	Estimated changes in shade, microclimate, and other factors
System Potential- Average	2016 USGS	Increased to 2016 max	Same changes as above scenario with 2016 flow and weather
TMDL- Critical	Adjusted 2009 USGS (7Q10)	Increased to 2009 max	Added point sources at WLAs & partially restored baseflow & hyporheic function
TMDL- Average	2016 USGS	Increased to 2016 max	Same as above scenario but with 2016 flows and weather

*2012 represents a relatively cool year for air temperatures with a 7-day average maximum in the 24^{th} percentile and a relatively typical year for flow (46^{th} percentile).

Current Compliance with Standards

The existing 2012 (Figure 61) and no action critical (Figure 62) model scenarios predict that the entire river would fail to meet the daily minimum criterion for Core Summer Salmonid Habitat (9.5 mg/L) during the lowest oxygen levels (<8 mg/L) in early August. Much of the river also failed to meet the 9.5 mg/L criterion from July to early September. These model scenarios predict the river would meet the 9.5 mg/L criterion at times in June and from late September to early October (Figure 60).

Observed data confirms the magnitude and timing of these predicted violations (see Dissolved Oxygen Results section and Appendix F – Model Documentation).

When critical low-flow and increased air temperatures are added to existing conditions (no-action critical scenario), the model predicts that the lowest DO levels would decrease to a daily minimum of less than 7.5 mg/L (Figure 61).

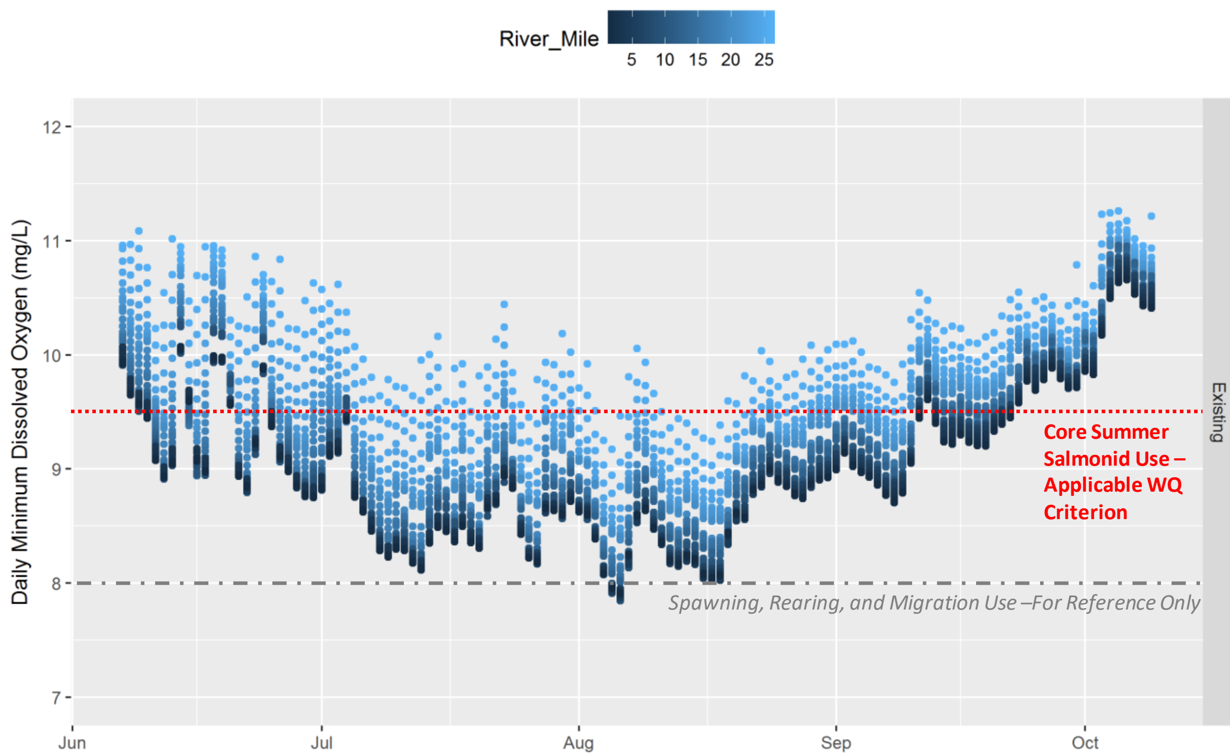

Figure 61. Existing 2012 model-predicted daily minimum DO compared to WQ criteria.

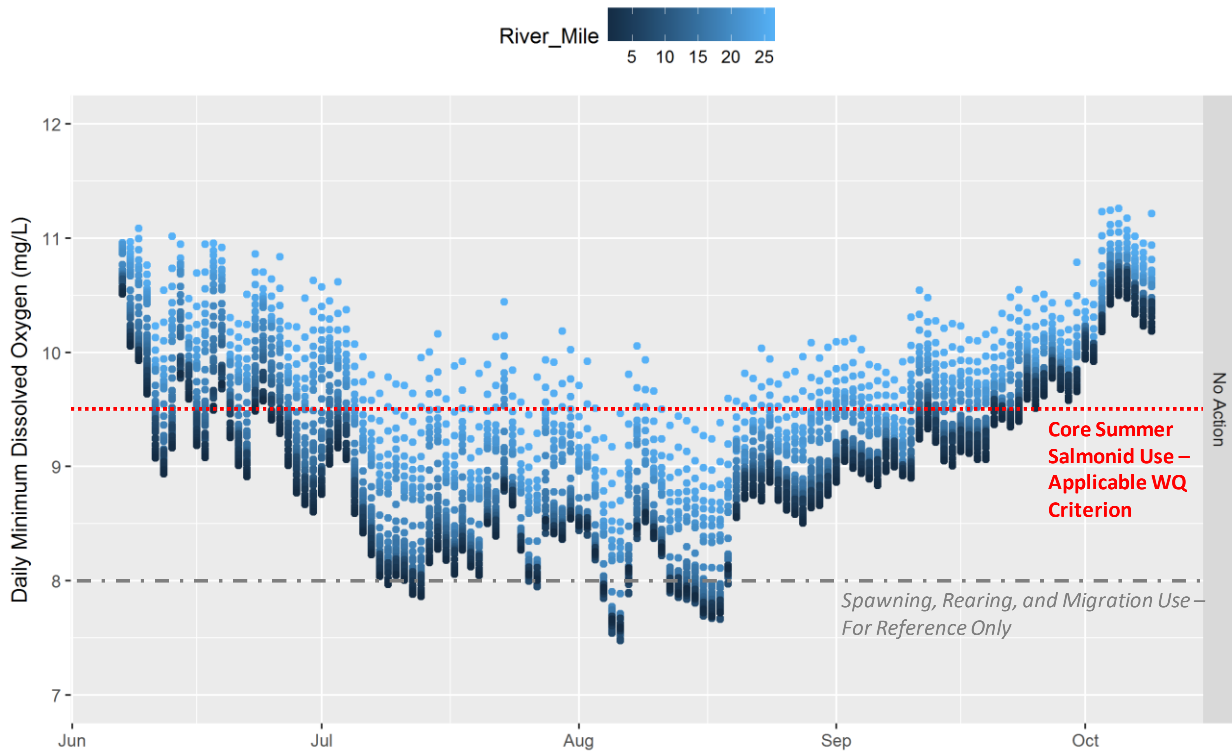

Figure 62. No action critical conditions 2012 model-predicted daily minimum DO compared to WQ criteria.

System Potential Conditions

The TMDL uses a modified version of the calibrated QUAL2Kw model to estimate the DO levels that would be expected to occur under system potential conditions. System potential conditions are conditions that do not include human modifications to riparian vegetation, channel modifications, and summer baseflow. The system potential condition serves as an estimate of natural conditions, as defined by Washington State water quality standards.

Ecology has created a checklist to ensure that modeling and TMDL development staff consider and document the most important elements of a model designed to represent natural conditions. Appendix G contains complete documentation of the development of system potential conditions and the associated checklist. The temperature TMDL analysis section contains more information about the major changes to the model to represent system potential conditions.

Figure 63 presents the simulation results for system potential critical conditions in the Pilchuck River across the complete spatial and temporal model domain. Figure 62 shows that under un-impacted conditions only a small portion of the lower river fails to meet the 9.5 mg/L criterion in June and September; much of the river does not meet the 9.5 mg/L criterion in July and August.

In the system potential critical model, all daily minimum DO levels would be increased above 8 mg/L (compared to no action scenario).

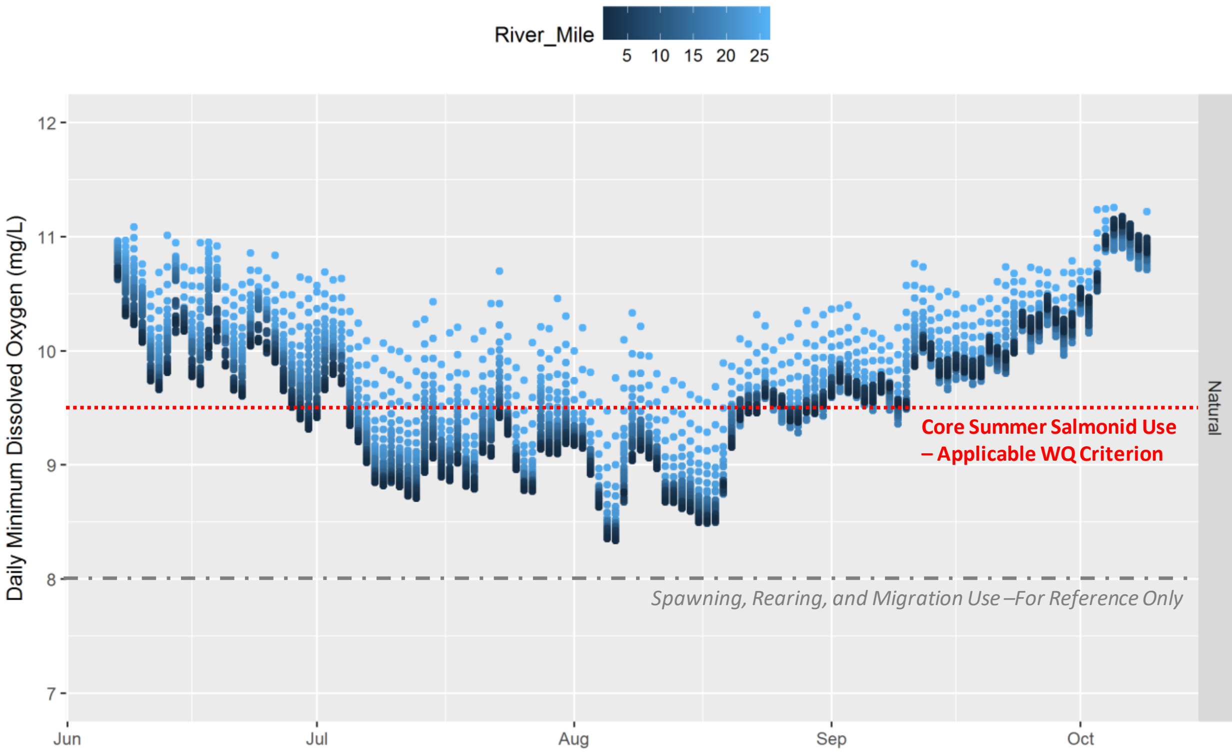

Figure 63. System potential model-predicted critical daily minimum DO with 7Q10 (2009) flows.

Ecology also evaluated how system potential conditions might change under a year with relatively typical flow and air temperature conditions. The year 2016 was selected because:

- The 7-day low flow (59.4 cfs) represented a 58% exceedance probability (1.7 year recurrence interval).
- The 7-day average maximum air temperatures at Monroe of 28.9°C (~84°F) represent a ~55% exceedance probability.

The 2016 scenario is referred to as the “average conditions” scenario in this document. Appendix F contains details of how 2016 inputs were developed. Figure 64 depicts the results of the 2016 system potential scenario. The lowest daily minimum values for the 2016 “average” system potential scenario were only ~0.2 mg/L greater than in the critical system potential scenario.

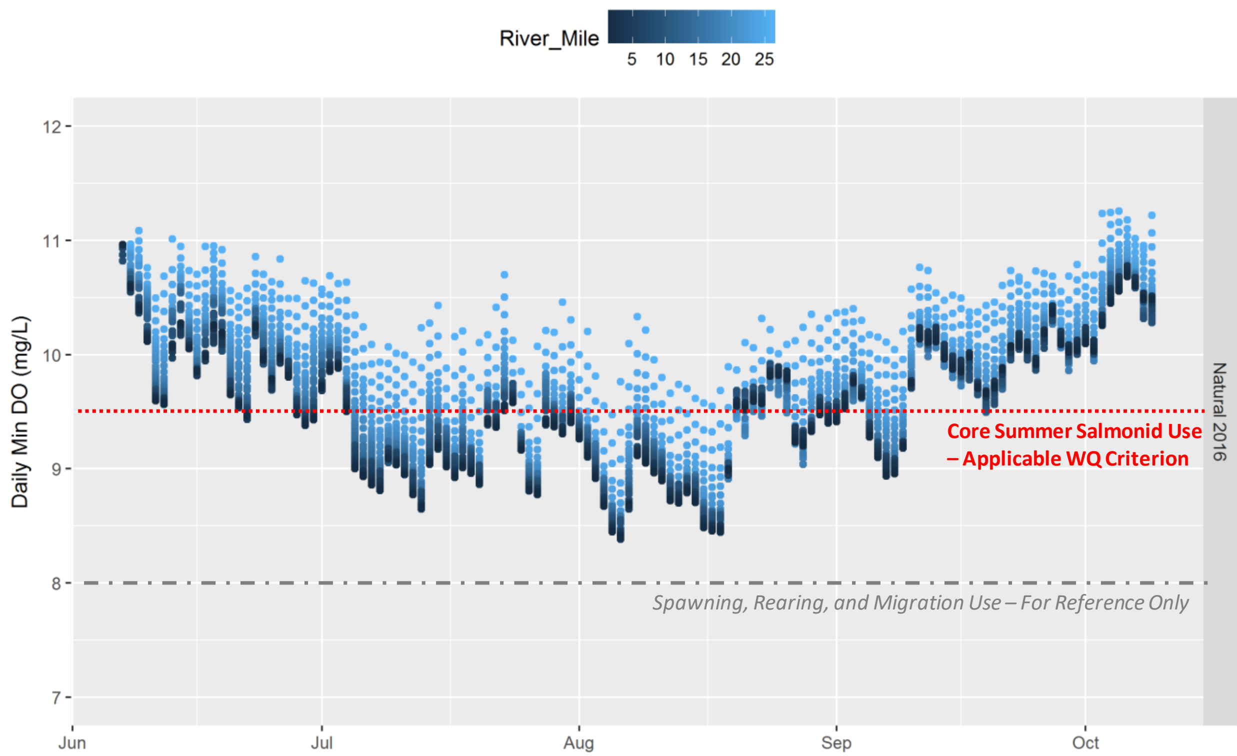

Figure 64. Predicted system potential DO under 2016 “average” conditions scenario.

Loading Capacity

The loading capacity of a river system is defined as the amount of a pollutant that can be added to the river without causing an exceedance of the water quality standards. Because dissolved oxygen (DO) is predicted to drop below the numeric criterion of 9.5 mg/L during the critical season even under system potential conditions, the loading capacity for DO in this TMDL is based on:

- WAC 173-201A-200(1)(d)(i):

  “When a water body's DO is lower than the criteria in Table 200 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L.”
- When system potential DO is above or equal to 9.7 mg/L, ensuring the total human impact does not result in DO below 9.5 mg/L.
- When system potential DO is below 9.7 mg/L, ensuring that the total human impact does not exceed 0.2 mg/L change compared to system potential DO.

The calibrated QUAL2Kw model was used to estimate the assimilative load capacity for phosphorus and BOD in the Pilchuck River, which is the basis for the load and wasteload allocations assigned in this TMDL. For phosphorus, the allocations are provided in soluble reactive phosphorus (SRP) and not total phosphorus. The basis for using SRP in this TMDL is:

- Travel times are relatively fast in the system (<1.5 days) and the calibrated hydrolysis rate of organic/particulate phosphorus appears to be relatively slow (10%/day). This results in relatively little particulate phosphorus being converted to SRP in the river. In the TMDL model, the river is at ~2 ug/L of organic phosphorus downstream of the Granite Falls Wastewater Treatment Plant (WWTP), which means <0.3 ug/L of SRP are added diffusely over the course of ~19 river miles.
- The WWTP effluent (primary source of phosphorus loading) contained almost entirely SRP, with very little organic phosphorus in the samples analyzed.
- The TMDL model is conservative in that it assumes ~30% particulate phosphorus, even though sample results have been much less with current treatment.
- A sensitivity analysis (Figure 65) was run to test the impact of SRP vs organic phosphorus:
    - In the TMDL model, with the WWTP is set as (DO TMDL):
        - 60 ug/L organic phosphorus
        - 125 ug/L soluble reactive phosphorus
        - 185 ug/L total phosphorus
    - For the high TP scenario (a), the WWTP is set as:
        - 120 ug/L organic phosphorus
        - 125 ug/L soluble reactive phosphorus
        - 245 ug/L total phosphorus
    - For the high SRP scenario (b), the WWTP is set as:
        - 0 ug/L organic phosphorus
        - 185 ug/L soluble reactive phosphorus
        - 185 ug/L total phosphorus
- The sensitivity analysis (Figure 65) shows that:
    - DO in the Pilchuck River is not impacted by an increase in organic phosphorus and total phosphorus from the WWTP (with SRP held constant).
    - DO is significantly impacted by an increase in SRP from the WWTP (with total phosphorus held constant).

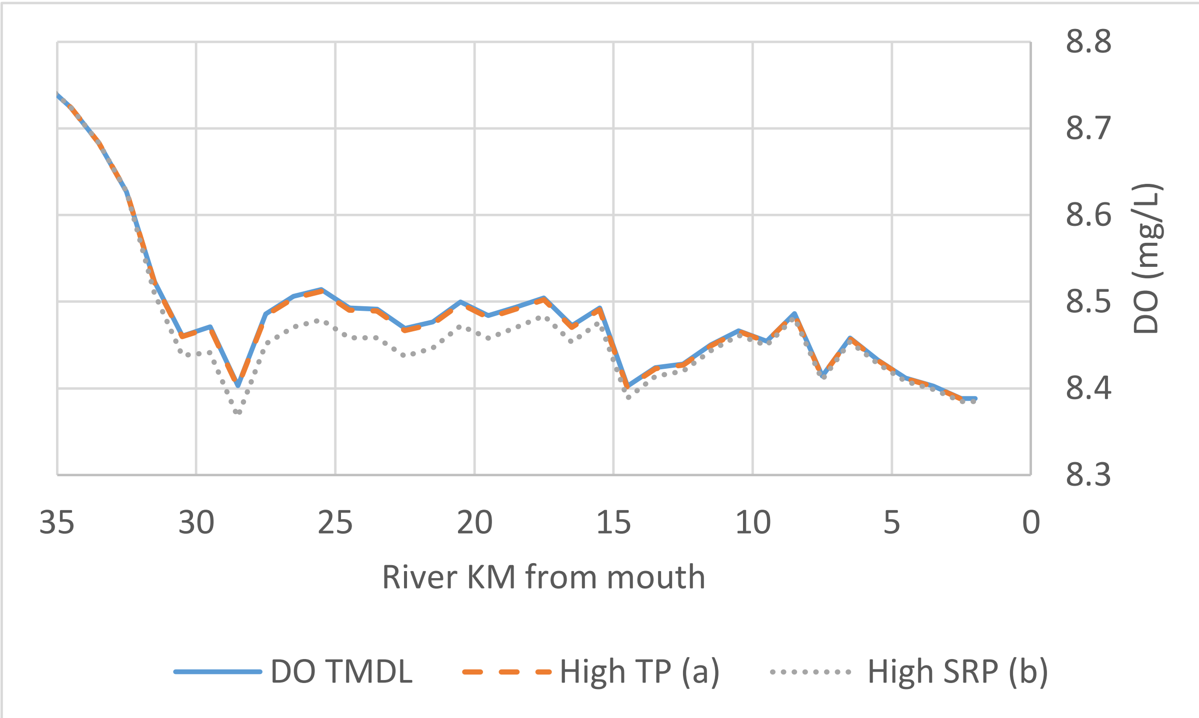

Figure 65. Plot showing sensitivity of DO in the TMDL model to increases in total phosphorus and SRP from the Granite Falls WWTP.

The Pilchuck River typically has low concentrations of SRP during the critical period. Because DO is tied to algal productivity, and because productivity is limited by SRP availability, any input of SRP during these conditions will likely have an impact on DO and pH.

To protect DO, loading capacities have been evaluated for BOD as well as for SRP. The load capacities for both BOD and SRP rely on the loading of the other. In the Pilchuck River model, SRP loading has a greater impact on DO compared to BOD, so the load capacity for the purposes of the TMDL is set as the existing estimated BOD loading and a reduction in SRP loading to meet water quality standards (Figure 66).

The load capacity and allocations for the impaired tributaries were set based on the percentage they occupied within their parent sub-basins: Catherine 45% of Little Pilchuck and Connor Lake 32% of Russell Rd.

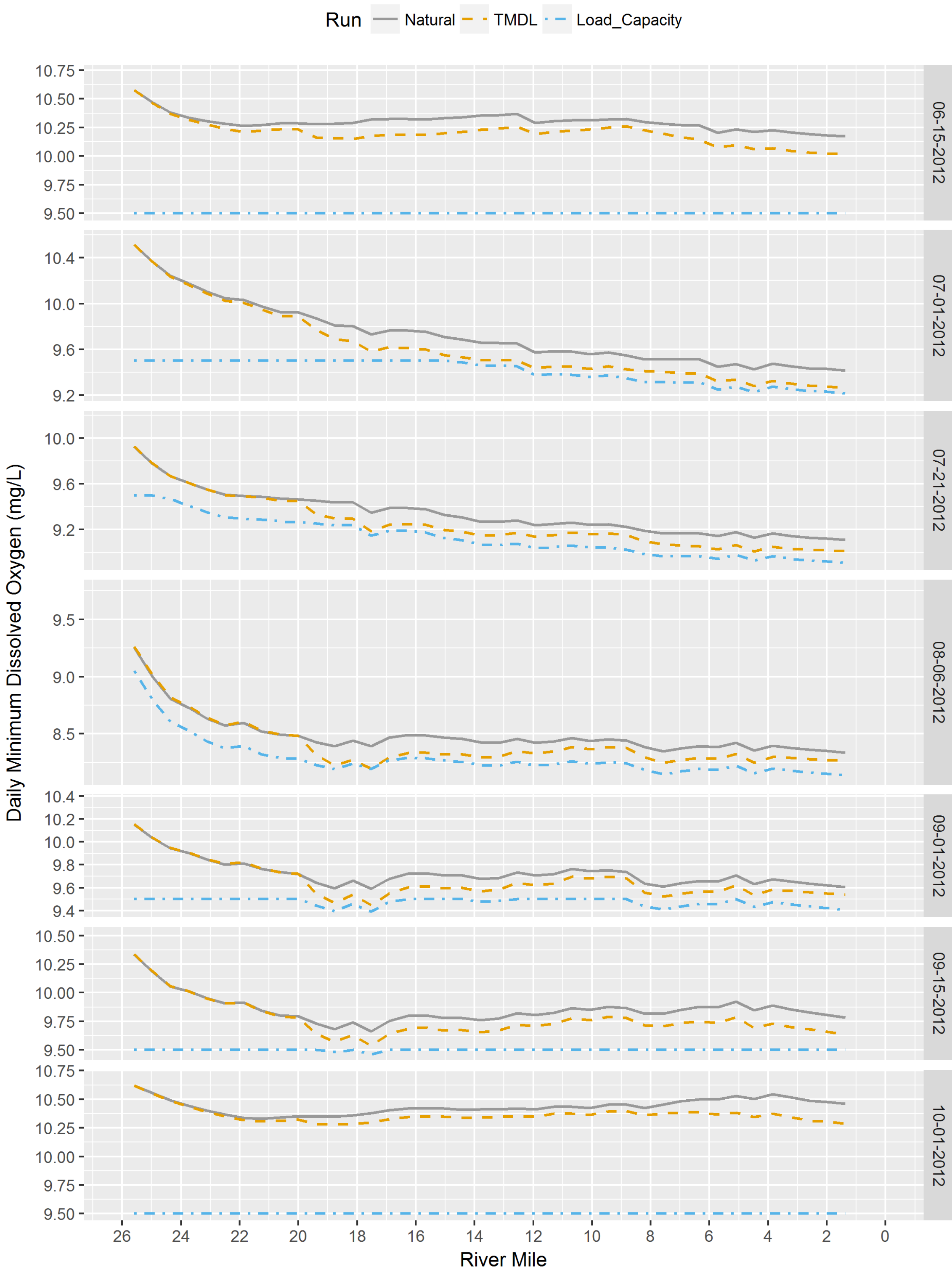

Figure 66. Longitudinal DO profiles illustrating loading capacity and maximum allowable loading from the Granite Falls WWTP (impact to DO starting between river miles 19-20).

The TMDL assesses loading capacity for two different river flow conditions and assigns two separate sets of allocations for each source based on the flow in the Pilchuck River, as described in Table 62.

Table 62. Description and threshold for "baseflow" and "runoff" conditions in the Pilchuck River as defined for the TMDL allocations.

River Flow (Pilchuck River at USGS gage 12155300)	Label	Description
Less than or equal to 75 cfs	Baseflow	Flow is low and relatively stable; little to no surface runoff occurs; soluble phosphorus has more immediate and dramatic impact on instream productivity.
Greater than 75 cfs	Runoff	Flow is less stable and typically either rapidly changing due to runoff influence or steadily declining in response to last precipitation event; surface runoff occurs more frequently; soluble phosphorus has a less immediate and dramatic impact on instream productivity.

The loading capacity for this TMDL was evaluated within the critical conditions model based on WWTP reductions needed to meet the 0.2 mg/L criterion, and existing and potential discharges from point and nonpoint sources.

The system potential critical model scenario (with 7Q10 critical low-flows) was used to compare the system potential daily minimum DO to TMDL critical scenario (Figure 65). At times and locations where the system potential daily minimum DO is predicted to be less than 9.7 mg/L, the loading capacity is determined to be the system potential daily minimum DO minus 0.2 mg/L (Figure 67 for critical conditions and Figure 68 for average conditions). The difference between the system potential and TMDL models is used to determine whether the decrease due to the TMDL is below the load capacity (<0.2 mg/L decrease).

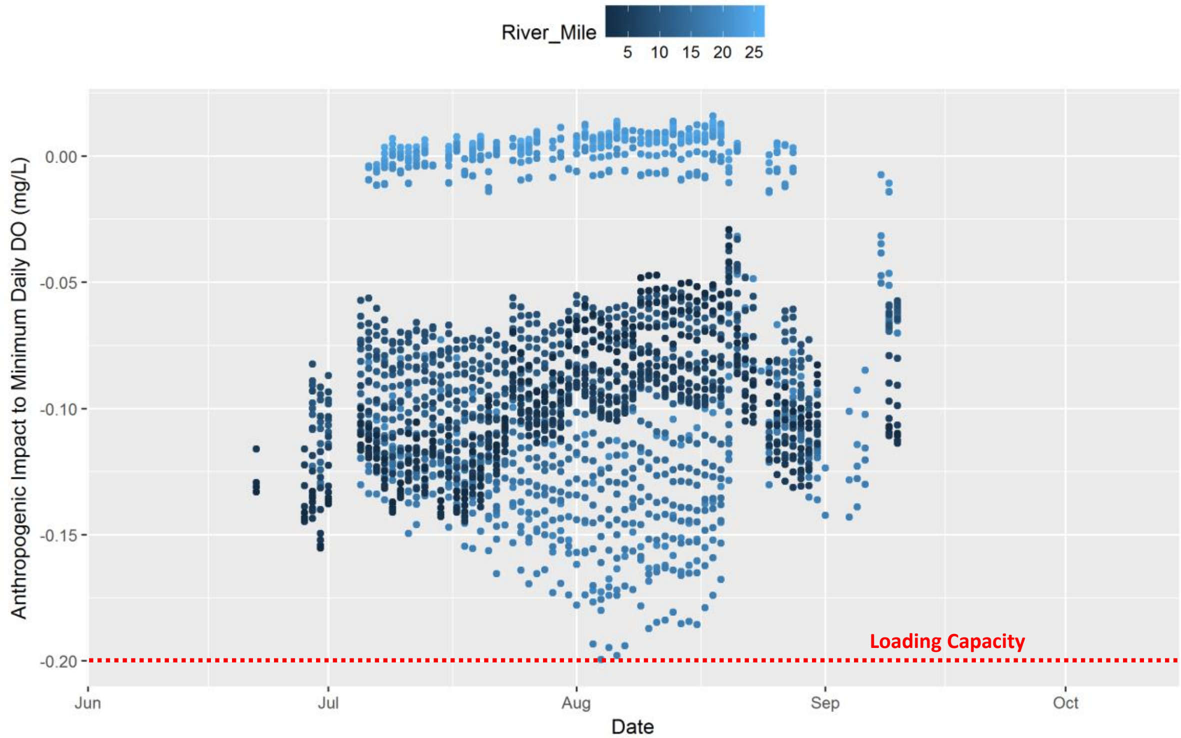

Figure 67. Difference between the predicted system potential and TMDL scenario daily minimum DO under critical low flow and high air temperature conditions.

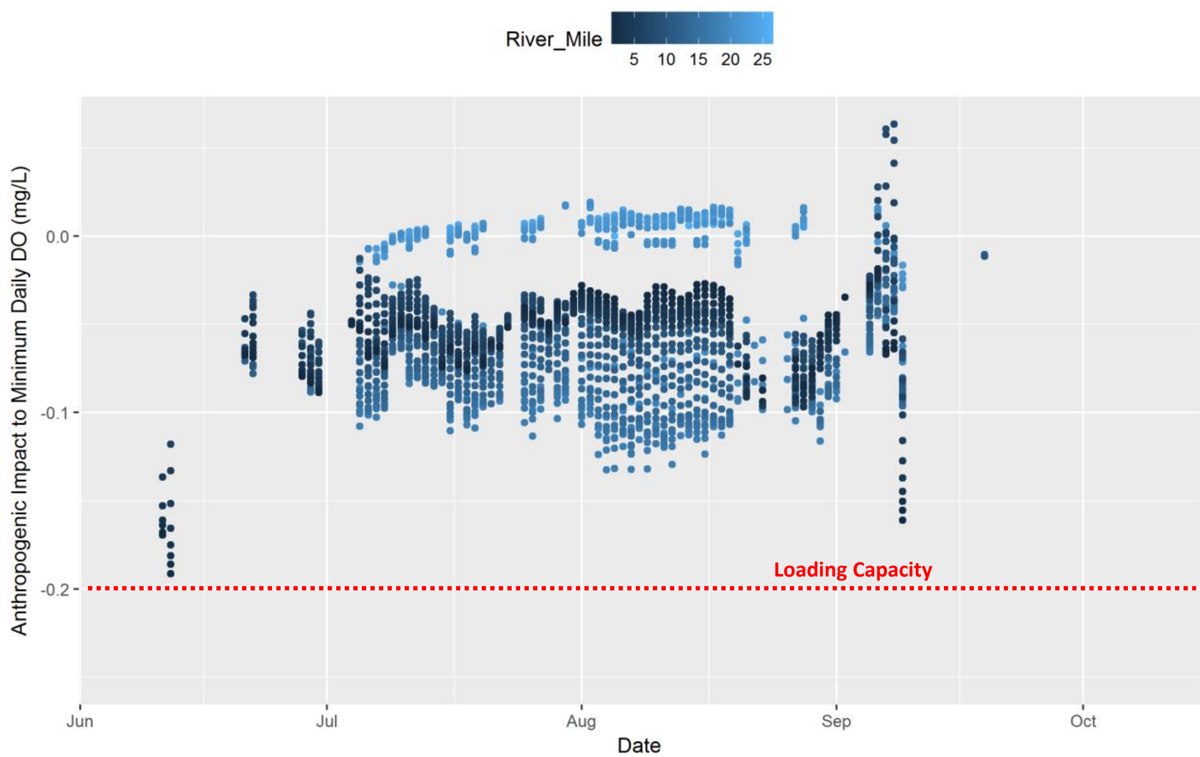

Figure 68. Difference between the predicted system potential and TMDL scenario daily minimum DO under "average" (2016) summer flow and air temperature conditions.

Wasteload allocations

Tables 50 to 53 in the Temperature TMDL Analysis section list the types, names, and permit numbers of discharges in the Pilchuck River Temperature and DO TMDL study area that have National Pollutant Discharge Elimination System (NPDES) permits. Appendix I provides a more detailed accounting of individual permittees within the watershed, including current activity level and potential to discharge to surface water.

The primary point source of nutrient loading to the Pilchuck River is the Granite Falls WWTP, which is the only constant permitted individual discharge. The WWTP commonly discharges nitrogen and phosphorus levels greater than one hundred times the concentration in the river, although the current summer effluent flow is relatively small (typically less than 0.5 cfs).

Because the DO impact of nutrient and BOD loading dissipates downstream of the source, the loading capacity in the Pilchuck River TMDL can be assigned to successive sources on downstream segments of the river without impairing DO. Table 63 and Figure 69 describe and illustrate the loading segments used in the TMDL.

Table 63. Load allocation segmentation of the Pilchuck River used for this TMDL.

Reach Name	Upstream End of Reach	Downstream End of Reach	Downstream Description/ Location
Menzel	42 km (Menzel Lake Rd)	35.5 km	Robe Menzel Rd; PIL21.5
Granite Falls	35.5 km	31.8 km	Granite Falls WWTP outfall
SR 92	31.8 km	24.8 km	64th St NE
Lochsloy	24.8 km	19.5 km	28th Pl NE
Russell Rd	19.5 km	14 km	Upstream of Little Pilchuck
Little Pilchuck Cr	Entire basin	Entire basin	Pilchuck River Confluence
Dubuque Creek	Entire basin	Entire basin	Pilchuck River Confluence
Machias	19.5 km	10 km	Dubuque Rd
Three Lakes	10 km	6.6 km	Three Lakes Rd
Snohomish	6.6 km	2 km	Pilchuck Recreation Area

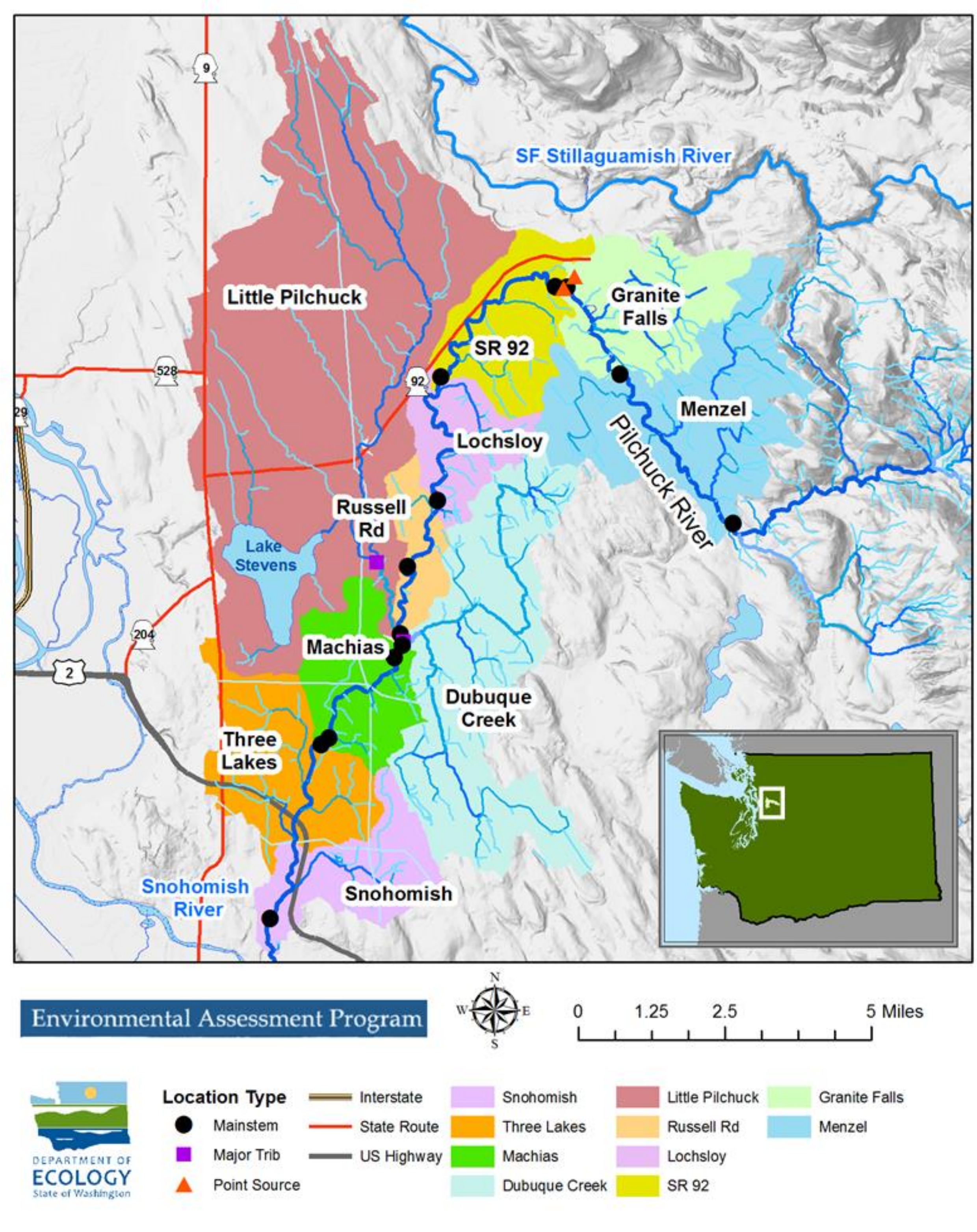

Figure 69. TMDL allocation segmentation within the Pilchuck River watershed

This TMDL assigns daily phosphorus wasteload allocations (WLAs), in lbs. of SRP/day, during summer baseflow conditions (river flow of less than 75 cfs). These daily allocations were designed using the following process:

- Leave the Granite Falls WWTP BOD loading at the current permit load limits.
- Set the Granite Falls WWTP phosphorus at loading that causes no greater than 0.2 mg/L cumulative change to downstream DO levels in the Pilchuck River.
- Set stormwater and general permit WLAs upstream of Granite Falls WWTP at very low loading so as not to increase cumulative impact near the WWTP.
- Allocate "renewed" loading capacity to downstream segments based on size of drainage area and distance downstream from WWTP outfall.
- Within each segment, the "renewed" loading capacity is allocated to the municipal stormwater permittees, based on the size of drainage area.

The "renewed" baseflow capacity is allocated to municipal stormwater and other NPDES permittees to allow for stormwater infrastructure that discharges at baseflow, in-between runoff events. In some situations, infiltrated or treated stormwater can be discharged gradually or in batches via a pump station or other control structure. These types of discharges can add cooler baseflow to the river, depending on storage method and retention time. Since a steady increase in baseflow and decrease in temperature is beneficial to aquatic life, some phosphorus allocation is provided to allow for this option, assuming the temperature WLAs outlined in this TMDL are also met.

A value of 75 cfs was selected for the baseflow threshold based on the calculated median July and August baseflow (73 cfs) at the USGS gage 12155300. Daily estimated baseflow values were based on the baseflow index (BFI) modified method of baseflow separation using the USGS Groundwater Toolbox Software (Barlow et al., 2017).

The TMDL sets different daily phosphorus and BOD load allocations for permitted sources when river flows are greater than 75 cfs, given that flow conditions, runoff loading, and daily load capacity are dynamic under these conditions. This higher flow condition is referred to in the report as the "runoff" condition. The runoff WLAs limit the amount of algae growth over the course of the season due to phosphorus uptake during both baseflow and storm events.

The dynamic 124-day QUAL2Kw model of the Pilchuck River allows for analysis of the impact of variable phosphorus and BOD loading over the course of the summer. For phosphorus, both the daily and seasonal allocations apply only during the critical season from June 1 to September 30 (see *Seasonal Variation*). Chapter 2 contains the final SRP and BOD5 WLA.

SRP effluent samples should be collected and analyzed on a routine basis. The expected sampling frequency will likely be within the range of 1-3 samples per week. Sample collection should occur routinely on the same days of the week (for example, Mondays and Thursdays). Sample collection should not occur on two consecutive days.

Daily average river flows should be obtained for the Pilchuck River at USGS gage 12155300 Pilchuck River near Snohomish, WA.

Figure 70 illustrates how the assigned daily SRP load of 0.31 lbs/day for the Granite Falls WWTP would translate to effluent SRP concentration, based on effluent flow levels encompassing current to future buildout.

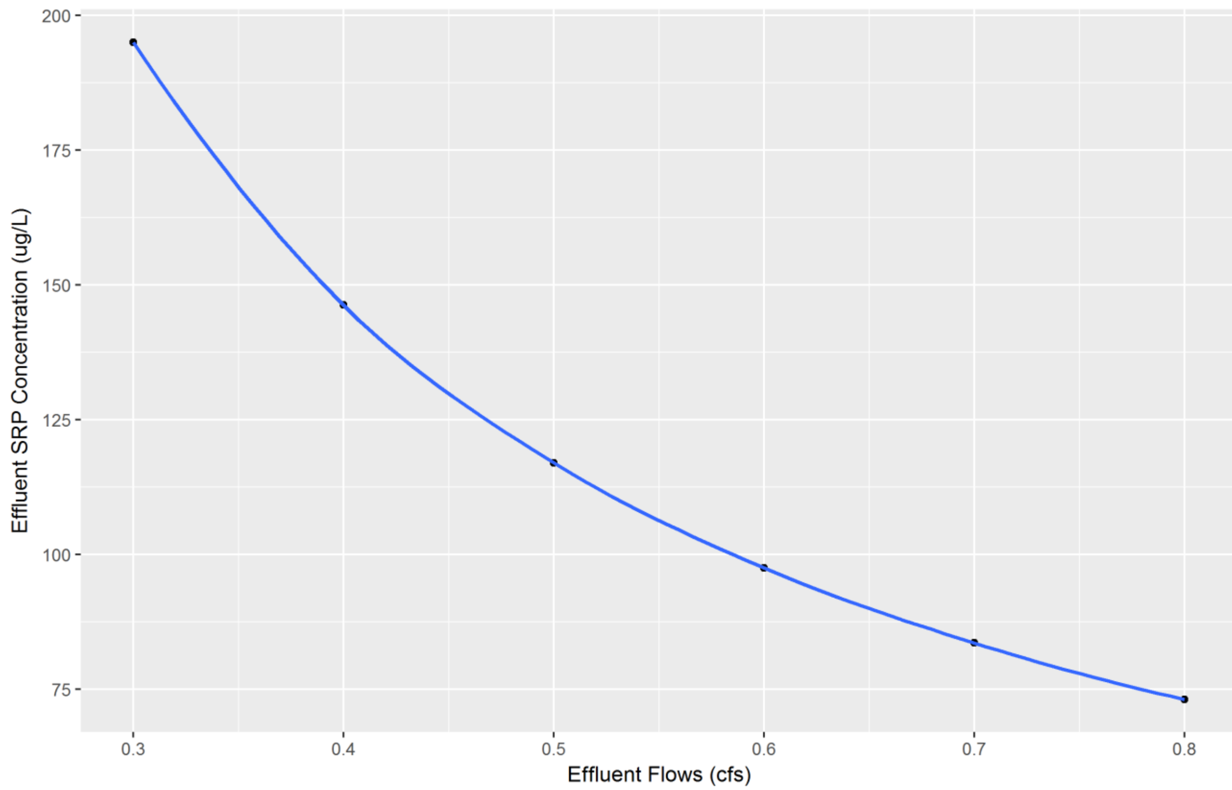

Figure 70. Estimated effluent SRP concentration needed for the Granite Falls WWTP to meet assigned wasteload allocation, based on a range of effluent flow levels.

Stormwater and General Permit Wasteload Allocations

Wasteload allocations (WLAs) are required for permitted stormwater discharges if they are a source of phosphorus or BOD loading to the stream when receiving water DO levels are impaired. The Pilchuck River watershed has permitted stormwater sources discharging into its mainstem and tributaries. Although Ecology expects phosphorus and BOD loadings from permitted stormwater to be of minimal size during critical low-flow conditions, the TMDL must assign WLAs to all NPDES-permitted entities within the TMDL study area that could discharge pollutant loads and contribute to the impairment.

During summer rainstorms, the river flow can increase due to runoff and with it, the loading capacity can increase. In order to test the loading capacity of potential stormwater discharges under various summer conditions, Ecology tested hypothetical stormwater loading in the model.

Ecology first developed hypothetical stormwater inflows for the TMDL (see temperature TMDL analysis). Ecology then developed a maximum daily phosphorus concentrations for permitted stormwater sources by testing different concentrations to find a value that resulted in less than 0.2 mg/L cumulative impact from all sources. The final SRP concentrations used varied by model reach, but fell between the range of sample results from a recent Western Washington stormwater monitoring study (Hobbs et al., 2015). This testing occurred in concert with other management actions (riparian shade, baseflow restoration, Granite Falls WWTP limit).

Once Ecology tested stormwater loading in the model and determined compliance with the water quality standards (less than 0.2 mg/L anthropogenic change to daily minimum DO), then the total stormwater load was allocated by reach to accommodate all NPDES permittees within the study area. The majority of the load (87.5-90%) allocated within each reach was allocated to the municipal stormwater permit holders and distributed amongst municipalities based on the percentage of land base within the subbasin that corresponds to the allocation reach. The remaining load (10-12.5%) was distributed by giving 2.5% of the available capacity to each applicable general permit category within the reach.

Tables 64 and 65 provide a summary of these WLAs for both baseflow conditions and the entire growing season. The two tables include both daily baseflow and seasonal phosphorus WLAs for the remaining NPDES permits within the TMDL study area. Because construction stormwater, industrial stormwater, and sand and gravel general permits can be short term for an individual permittee (construction is completed or facility becomes inactive), one aggregate WLA is assigned to each general permit, and not to individual facilities/permittees.

Table 64Table 64. Daily wasteload allocations for each reach and permit in pounds of SRP/day (apply only when river flow is less than or equal to 75 cfs).

Subbasin	Snohomish County P1	City of Granite Falls P2	City of Lake Stevens P2	City of Snohomish P2	WSDOT	Construction Stormwater	Industrial Stormwater	Sand and Gravel	Future Individual Permits	Total Reach Allocation
Menzel	0.0057	NA	NA	NA	NA	0.0002	0.0002	0.0002	0.0002	0.0063
Granite Falls	0.0029	0.0003	NA	NA	0.0001	0.0001	0.0001	0.0001	0.0001	0.0036
SR92	0.0053	0.0005	NA	NA	0.0002	0.0002	0.0002	0.0002	0.0002	0.0065
Lochsloy	0.0056	NA	NA	NA	0.0002	0.0002	0.0002	0.0002	0.0002	0.0064
Russell	0.0033	NA	NA	NA	NA	0.0001	0.0001	0.0001	0.0001	0.0037
LittlePilchuck	0.0464	NA	0.0082	NA	0.0016	0.0016	0.0016	0.0016	0.0016	0.0624
Dubuque	0.0217	NA	NA	NA	NA	0.0006	0.0006	0.0006	0.0006	0.0242
Machias	0.0060	NA	0.0001	NA	NA	0.0002	0.0002	0.0002	0.0002	0.0067
Three Lakes	0.0088	NA	0.0009	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0116
Snohomish	0.0112	NA	NA	0.0006	NA	0.0002	0.0002	0.0002	0.0002	0.0075
Total	0.1169	0.0007	0.0092	0.0010	0.0023	0.0035	0.0035	0.0035	0.0035	0.1390

Table 65. Daily wasteload allocations for each reach and permit in pounds of SRP/day (apply only when river flow is greater than 75 cfs).

Subbasin	Snohomish County P1	City of Granite Falls P2	City of Lake Stevens P2	City of Snohomish P2	WSDOT	Construction Stormwater	Industrial Stormwater	Sand and Gravel	Future Individual Permits	Total Reach Allocation
Menzel	0.2172	NA	NA	NA	NA	0.0060	0.0060	0.0060	0.0060	0.2413
Granite Falls	0.0776	0.0067	NA	NA	0.0024	0.0024	0.0024	0.0024	0.0024	0.0964
SR92	0.0562	0.0049	NA	NA	0.0017	0.0017	0.0017	0.0017	0.0017	0.0698
Lochsloy	0.0541	NA	NA	NA	0.0015	0.0015	0.0015	0.0015	0.0015	0.0618
Russell	0.0241	NA	NA	NA	NA	0.0007	0.0007	0.0007	0.0007	0.0268
Little Pilchuck	0.5168	NA	0.0912	NA	0.0174	0.0174	0.0174	0.0174	0.0174	0.6949
Dubuque	0.2420	NA	NA	NA	NA	0.0067	0.0067	0.0067	0.0067	0.2689
Machias	0.0760	NA	0.0009	NA	NA	0.0021	0.0021	0.0021	0.0021	0.0854
Three Lakes	0.0890	NA	0.0095	0.0036	0.0029	0.0029	0.0029	0.0029	0.0029	0.1166
Snohomish	0.0765	NA	NA	0.0052	NA	0.0016	0.0016	0.0016	0.0016	0.0638
Total	1.4294	0.0116	0.1015	0.0087	0.0260	0.0431	0.0431	0.0431	0.0431	1.7256

Ecology used the same method to allocated BOD5 loading in the TMDL study area. Tables 66 and 67 include both daily baseflow and seasonal phosphorus WLAs for the remaining NPDES permits within the TMDL study area.

Ecology set the BOD allocations as a BOD5 (a 5-day analysis) load to allow for a more affordable sample method (compare to ultimate BOD) that is comparable to current permit limits. In determining the allocations for BOD, the combined impact of nitrogenous (NBOD) and carbonaceous BOD (CBOD) were included based on Total Kjeldahl Nitrogen (TKN) loads (for NBOD) and CBOD loads in the QUAL2Kw model. Thus, an uninhibited BOD method is acceptable for compliance monitoring, as the effect of NBOD is included in the allocations.

Table 66. Daily wasteload allocations for each reach and permit in pounds of BOD5/day (apply only when river flow is less than 75 cfs).

Subbasin	Snohomish County P1	City of Granite Falls P2	City of Lake Stevens P2	City of Snohomish P2	WSDOT	Construction Stormwater GP	Industrial Stormwater GP	Sand and Gravel GP	Future Individual Permits	Total Reach Allocation
Menzel	0.505					0.014	0.014	0.014	0.014	**0.561**
Granite Falls	0.268	0.023			0.008	0.008	0.008	0.008	0.008	**0.333**
SR92	0.228	0.020			0.007	0.007	0.007	0.007	0.007	**0.283**
Lochsloy	0.173				0.005	0.005	0.005	0.005	0.005	**0.197**
Russell	0.103					0.003	0.003	0.003	0.003	**0.115**
Little Pilchuck	1.434		0.253		0.048	0.048	0.048	0.048	0.048	**1.928**
Dubuque	0.672					0.019	0.019	0.019	0.019	**0.746**
Machias	0.185		0.002			0.005	0.005	0.005	0.005	**0.207**
Three Lakes	0.272		0.029	0.011	0.009	0.009	0.009	0.009	0.009	**0.357**
Snohomish	0.248			0.019		0.006	0.006	0.006	0.006	**0.233**
Total	**4.086**	**0.043**	**0.284**	**0.030**	**0.077**	**0.124**	**0.124**	**0.124**	**0.124**	**4.960**

Table 67. Daily wasteload allocations for each reach and permit in pounds of BOD5/ day (apply only when river flow is greater than 75 cfs).

Subbasin	Snohomish County P1	City of Granite Falls P2	City of Lake Stevens P2	City of Snohomish P2	WSDOT	Construction Stormwater GP	Industrial Stormwater GP	Sand and Gravel GP	Future Individual Permits	Total Reach Allocation
Menzel	3.637					0.101	0.101	0.101	0.101	**4.041**
Granite Falls	1.931	0.168			0.060	0.060	0.060	0.060	0.060	**2.398**
SR92	1.643	0.143			0.051	0.051	0.051	0.051	0.051	**2.041**
Lochsloy	1.243				0.036	0.036	0.036	0.036	0.036	**1.421**
Russell	0.743					0.021	0.021	0.021	0.021	**0.825**
Little Pilchuck	10.337		1.824		0.347	0.347	0.347	0.347	0.347	**13.898**
Dubuque	4.840					0.134	0.134	0.134	0.134	**5.378**
Machias	1.331		0.015			0.037	0.037	0.037	0.037	**1.496**
Three Lakes	1.961		0.209	0.079	0.064	0.064	0.064	0.064	0.064	**2.570**
Snohomish	1.466			0.136		0.042	0.042	0.042	0.042	**1.678**
Total	**29.132**	**0.311**	**2.048**	**0.215**	**0.558**	**0.894**	**0.894**	**0.894**	**0.894**	**35.746**

Appropriate best management practices (BMPs) required through stormwater permits for controlling pollutant loadings to surface waters are applied to each stormwater discharge to protect designated aquatic life uses. Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees. Stormwater discharges may be considered for mixing zones as specified in WAC 173-201A-400, which should be applied in conjunction with the WLA in the previous paragraphs.

Load Allocations

This TMDL establishes load allocations for nonpoint sources; in order to meet both the numeric threshold criteria and the allowances for human impact under DO conditions that are naturally below those criteria, nonpoint sources must meet these allocations.

Predicted system potential DO does not meet numeric DO criteria during the hottest period of the year throughout the Pilchuck River watershed. In order to achieve near system potential DO levels, there is a widespread need to achieve maximum protection from direct solar radiation.

The load allocation for the mainstem Pilchuck River below Menzel Lake Rd. and the two miles of each study-area tributary nearest its mouth, includes the potential shade that would occur from system potential mature riparian vegetation, as discussed in the Temperature TMDL analysis section. Thus, the temperature load allocations are needed to achieve compliance with DO criteria.

Tables 68 and 69 contain the baseflow and seasonal phosphorus loading allocations assigned by the TMDL for nonpoint sources.

Table 68. Daily load allocations for each reach and nonpoint source category in pounds of SRP/day (apply only when river flow is less than or equal to 75 cfs).

Subbasin	Groundwater	Tributaries	Restored Baseflow	Total Nonpoint
Menzel	0.0864	0.0000	0.0303	0.1167
Granite Falls	0.0720	0.0752	0.0259	0.1731
SR92	0.1036	0.0349	0.0366	0.1751
Lochsloy	0.0908	0.0034	0.0219	0.1161
Russell	0.0864	0.0014	0.0093	0.0971
Little Pilchuck		0.3074		0.3074
Dubuque		0.0045		0.0045
Machias	0.0908	0.0247	0.0242	0.1397
Three Lakes	0.0173	0.0101	0.0114	0.0388
Snohomish	0.0691	0.0071	0.0250	0.1012
Total	0.6162	0.4686	0.1847	1.2696

Table 69. Seasonal load allocations for each reach and nonpoint source in pounds of SRP/day (apply only when river flow is greater than 75 cfs).

Subbasin	Groundwater	Tributaries	Restored Baseflow	Total Nonpoint
Menzel	0.1739	0.0000	0.0342	0.2080
Granite Falls	0.1449	0.1501	0.0292	0.3242
SR92	0.2087	0.0918	0.0412	0.3417
Lochsloy	0.2133	0.0085	0.0246	0.2464
Russell	0.1739	0.0036	0.0108	0.1883
Little Pilchuck		1.2602		1.2602
Dubuque		0.1702		0.1702
Machias	0.2133	0.0569	0.0279	0.2981
Three Lakes	0.0348	0.0318	0.0134	0.0799
Snohomish	0.1391	0.0369	0.0284	0.2044
Total	1.3018	1.8101	0.2096	3.3216

Tables 70 and 71 contain the baseflow and seasonal BOD5 loading allocations assigned by the TMDL for nonpoint sources.

Table 70. Daily load allocations for each reach and nonpoint source category in pounds of BOD5/day (apply only when river flow is less than or equal to 75 cfs).

Subbasin	Groundwater	Tributaries	Restored Baseflow	Total Load Allocation
Menzel	51.1		13.1	64.3
Granite Falls	42.6	32.6	11.2	86.5
SR92	61.4	9.8	15.8	87.0
Lochsloy	53.7	0.8	9.5	64.0
Russell	51.1	0.3	4.0	55.5
Little Pilchuck		71.9		71.9
Dubuque		1.0		1.0
Machias	53.7	5.6	4.0	63.4
Three Lakes	10.2	2.3	4.9	17.4
Snohomish	40.9	1.7	10.8	53.5
Total	364.9	126.0	73.6	564.4

Table 71. Daily load allocations for each reach and nonpoint source category in pounds of BOD5/day (apply only when river flow is greater than 75 cfs).

Subbasin	Groundwater	Tributaries	Restored Baseflow	Total Load Allocation
Menzel	204.3	0.0	28.6	232.8
Granite Falls	170.2	125.5	24.4	320.2
SR92	245.1	47.6	34.4	327.1
Lochsloy	250.6	3.7	20.6	274.9
Russell	204.3	1.6	9.0	214.9
Little Pilchuck		547.8		547.8
Dubuque		74.0		74.0
Machias	250.6	24.7	9.0	284.4
Three Lakes	40.9	13.8	11.2	65.8
Snohomish	163.4	16.0	23.7	203.2
Total	1,529.5	854.7	160.9	2,545.1

These load allocations are expected to result in DO levels that are equivalent to those that would occur under natural shade conditions and only slightly elevated nutrient and BOD loading. Because anthropogenic changes to DO can result from causes other than those described above, the Implementation Plan for this TMDL also includes a variety of measures to address channel structure, hyporheic flow, and other factors. Implementation of these measures, as well as system potential vegetation, will help ensure that water temperatures will approach natural conditions and allow for cold-water refuge to more fully support the aquatic life uses in the river.

The Pilchuck River Temperature and Dissolved Oxygen TMDL identified four additional areas of restoration that are needed to meet water quality standards and allow for the aquatic life beneficial use of Core Summer Salmonid Habitat:

- Restore summer baseflow throughout the watershed.
- Extend riparian buffer width to 180 feet on each side of the river channel in order to:
    - Create a microclimate with cooler air temperature and increased humidity,
    - Retain some working buffer and effective shade after channel migration events,
    - Provide large woody material (LWM) to recharge wood recruitment, and
    - Shade the alluvial floodplain to cool hyporheic flow.
- Design actions to increase hyporheic connectivity and flow including restoring banks and floodplains to pre-development conditions where feasible.
- Strategically place LWM and other engineered habitat projects to increase frequency of pools, hyporheic flow connectivity, and cold-water refuge (see Implementation section).

The Temperature TMDL Analysis section contains more detailed information on these additional areas of restoration.

Comparison of Model Scenarios to Numeric Criteria

Table 72 summarizes the percent of model reaches and days that fail to meet numeric criteria for the TMDL model scenarios. A model reach day represents the result for each of the 41 model reaches (includes headwater) for each of the 125 days where a daily minimum value was calculated.

Table 72. Percent of model reaches and days that fail to meet numeric DO criteria for the TMDL model scenarios.

Run Name	Total Reach Days Fail	Total Reach Days	Total % Fail	June % Fail	July % Fail	Aug % Fail	Sept % Fail
Existing-2012	3359	5125	66%	47%	90%	96%	43%
No Action- Critical	3343	5125	65%	34%	90%	96%	52%
System Potential- Critical	1913	5125	37%	2%	74%	73%	2%
TMDL- Critical	2173	5125	42%	7%	77%	83%	7%
System Potential- 2016	1879	5125	37%	4%	61%	69%	15%
TMDL-2016	2172	5125	41%	9%	66%	75%	16%

Under critical conditions, the total percent of reach days that fail to meet the numeric criteria improves by 23% in the TMDL scenario (compared to no action scenario). The TMDL scenario represents overall compliance that is within 5% of the system potential scenario.

Under "average" 2016 conditions, the system potential model scenario compliance with numeric criteria improved under steady, low flows (compared to critical conditions) by 13% in July and 4% in August.

In June and September when flows were dynamic and much higher, the average conditions system potential scenario had worse compliance compared to critical system potential conditions, by 2% in June and 13% in September. This negative change, which is somewhat counterintuitive, was due to an assumed increase in hyporheic flow and greater carbon/BOD and SRP loading from more storm/high-flow events under the average-condition flow year. In the model, this resulted in more hyporheic productivity and oxygen demand and more periphyton respiration from increased SRP. It is important to note that BOD and SRP inputs during dynamic flows carry greater uncertainty, compared to steady baseflow conditions, as they were not the focus of the original study.

The largest overall improvement in critical conditions compliance (45%) from the TMDL occurs in the month of September, when existing conditions are closer to the numeric criteria (thus a smaller change can result in more compliance) and riparian shade is more effective due to the reduced solar angle in late summer.

Seasonal Variation

Clean Water Act (CWA) section 303(d)(1) requires that TMDLs "be established at the level necessary to implement the applicable water quality standards with seasonal variations."

The current regulation also states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(2)]. Finally, section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The Pilchuck River watershed experiences seasonal variation that impacts dissolved oxygen (DO) levels. In the winter, DO levels are significantly higher as the cooler water can hold more oxygen, more upstream flow allows for a greater loading capacity of phosphorus, and deeper water coupled with weaker solar radiation leads to very little periphyton growth. In the summer, warm water holds less oxygen, flow is low, the loading capacity is reduced, and shallow water coupled with peak solar radiation can lead to rapid periphyton growth.

The combination of lowest flows and highest temperatures typically occurs in July and August. However spawning can occur in June and September, and these months can sometimes have lower flows and higher temperatures. For this reason, the critical season is defined as June 1 to September 30 to cover these shoulder-season conditions. This timeframe is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The model was calibrated for a period of June 7 to October 9, 2012, which captured the warmest time of year, lowest flows, and lowest DO. The calibrated model was modified to represent critical streamflows (i.e., lowest 7-day average flows with 10-year recurrence interval or 7Q10) and air temperatures (90^{th} percentile) in order to develop load allocations and wasteload allocations.

For DO there are two seasons, one critical and one non-critical, and two conditions within the critical season:

- **Fall-Winter-Spring season—October 1 to May 31—no critical condition**
  - Reduced stream temperatures and biological productivity result in higher DO levels and compliance with water quality criteria.
- **Summer season—June 1 to September 30—baseflow critical condition**
  - Annual minimum flows and increased solar radiation result in more light reaching bottom algae and less dilution of effluent phosphorus loads, which increases algal productivity and lowers DO. Increased temperatures lower DO.
  - Daily minimum criterion of 9.5 mg/L applies.
  - Criterion frequently exceeded under this condition even under predicted system potential conditions.
- **Summer season—June 1 to September 30—runoff condition**
  - Increased flows, reduced solar radiation due to cloud cover, and cooler air temperatures increase DO levels in the river and loading capacity.
  - Daily minimum criterion is less frequently exceeded.
  - Increased phosphorus loading from runoff can be stored by bottom algae, to a degree, and utilized later during periods of increased productivity, so phosphorus allocations are necessary.

The summer season baseflow condition was determined to be the most critical condition; however, Ecology created two sets of TMDL allocations and estimated loading capacity because:

- The loading capacity is significantly different between the two conditions.
- It is not feasible to meet the reduced allocations necessary at baseflow condition during periods of stormwater and nonpoint runoff.

It is still necessary to provide some level of allocation during runoff conditions to control algal growth during baseflow conditions.

Reserve Capacity for Future Growth

Given that DO levels are below (do not meet) criteria, even under system potential conditions, there is a very small capacity for future growth. However, future growth may occur under one of two conditions:

- By replacing a phosphorus load source that was assigned an allocation in this TMDL.
- By using some of the reserve allocation for individual discharge permits, provided there is no discharge of phosphorus to the Pilchuck River at baseflow (< 75 cfs).

Conclusions and Model Findings

- DO in the Pilchuck River is sensitive to soluble reactive phosphorus (SRP). Small inputs of SRP can have significant impacts to DO.
- The SRP discharged by the Granite Falls WWTP has an impact of up to 0.73 mg/L on daily minimum DO in the downstream reaches of the river. If the wasteload allocations are met, daily minimum DO values would improve by up to 0.53 mg/L.
- The shade produced by system potential mature riparian vegetation is expected to improve daily minimum DO values by up to 0.35 mg/L. Microclimate effects from full shade are expecting to improve daily minimum DO by up to an additional 0.06 mg/L.
- Improvements in boundary conditions DO levels (due to boundary temperature improvements) are expected to improve daily minimum DO values by up to 0.31 mg/L.
- Baseflow restoration targets (Table 58) are expected to improve daily minimum DO values by up to 0.11 mg/L.
- Hyporheic flow restoration goals are expected to improve daily minimum DO values by up to 0.06 mg/L.
- Background dissolved nutrient concentrations are relatively low in the river (<10 ug/L orthophosphate; <100 ug/L dissolved inorganic nitrogen).
- The analysis of nitrogen:phosphorus ratios indicates that the limiting nutrient for primary productivity in the Pilchuck River is likely inorganic phosphorus in the water.
- The Granite Falls WWTP was the primary source of phosphorus loading within the Pilchuck River watershed study area.
- Results of stream metabolism analysis suggest the river is likely a net heterotrophic system, with significant oxygen demand likely coming from organisms that do not obtain food from sunlight (e.g., microbes, aquatic insects).
- Overall, Ecology found the study data to be of acceptable quality and useable based on Ecology's credible data policy and the study objectives.

- DO daily minimums do not meet (are below) the water quality criterion of 9.5 mg/L for all sites monitored in the watershed.
- The results of modeled daily DO levels and changes show:
  - Warm stream temperatures, periphyton (attached bottom algae) respiration, and hyporheic sediment oxygen demand (driven by nutrient inputs to the hyporheic zone) are the primary factors decreasing DO minimums.
  - Phytoplankton (floating algae) photosynthesis/respiration, biochemical oxygen demand (BOD) in the water column, and nitrification are all predicted to have a negligible effect on DO levels.

Recommendations

- Wasteload allocations for the Granite Falls WWTP are needed to control SRP and BOD from June through September. These WLAs are expected to eliminate the largest negative impacts to DO that are observed in the river downstream of the Granite Falls WWTP outfall.
- Load and wasteload allocations are needed for WSDOT stormwater, general stormwater permit holders, tributaries, and other nonpoint sources. These load and wasteload allocations will prevent DO impairments throughout the Pilchuck River.
- Full implementation of the temperature allocations in this TMDL are necessary to reach the maximum improvement for DO concentrations.
- Quantify dissolved organic carbon (DOC) or carbonaceous BOD loading from groundwater, small tributaries, and off-stream wetlands and lakes.

References

Ahmed, A., G. Pelletier, M. Roberts, and A. Kolosseus. 2014. South Puget Sound Dissolved Oxygen Study, Water Quality Model Calibration and Scenarios. Publication 14-03-004. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/1403004.html.

Ahmed, A., C. Figueroa-Kaminsky, J. Gala, T. Mohamedali, G. Pelletier, and S. McCarthy. 2019. Puget Sound Nutrient Source Reduction Project. Volume 1: Model Updates and Bounding Scenarios. Washington Department of Ecology, Publication 19-03-001. https://apps.wa.gov/ecy/publications/SummaryPages/1903001.html.

Albertson, S.L., K. Erickson, J.A. Newton, G. Pelletier, R.A. Reynolds, and M.L. Roberts. 2002. South Puget Sound Water Quality Study, Phase 1. Publication 02-03-021. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/0203021.html.

Anderson, J.D. Year Unknown. Coastal Cutthroat Trout in Washington State: Status and Management, Washington State Department of Fish and Wildlife, 600 Capitol Way N. Olympia Washington 98502, pp. 1-25.

Bailey, K.R. 1998. French Creek Watershed Geologic Report. Prepared for The French Creek Watershed Management Committee and Snohomish County Surface Water Management. June 1998.

Barlow, P.M., Cunningham, W.L., Zhai, Tong, and Gray, Mark. 2017. U.S. Geological Survey Groundwater Toolbox version 1.3.1, a graphical and mapping interface for analysis of hydrologic data: U.S. Geological Survey Software Release, 26 May 2017. http://dx.doi.org/10.5066/F7R78C9G

Battin, T.J., L.A. Kaplan, J.D. Newbold, and S.P. Hendricks. 2003. A mixing model analysis of stream solute dynamics and the contribution of a hyporheic zone to ecosystem function. Freshwater Biology, 48(6), pp. 995-1014.

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. *River research and applications*, *29*(8), pp. 939-960.

Blakely, A., B. Leland, and J. Ames. 2000. 2000 Washington State Salmonid Stock Inventory: Coastal Cutthroat Trout. Washington Department of Fish and Wildlife, 600 Capitol Way N. Olympia, WA 98502.

Booth, D. B., 1997. Geology and Geomorphology of Stream Channels, Course Manual by D.B. Booth with B. Collins, D. Montgomery, and S. Perkins, University of Washington Center for Urban Water Resources Management, January 1997, 282 pp.

Borchardt, M. 1996. 'Nutrients' in Stevenson, R., M. Bothwell, and R. Lowe (eds.). Algal Ecology: Freshwater Benthic Ecosystems. San Diego, CA: Academic Press.

Bouwes, N., N. Weber, C.E. Jordan, W.C. Saunders, I.A. Tattam, C. Volk, J.M. Wheaton, and M. Pollock. 2016. Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (Oncorhynchus mykiss). Sci. Rep. 6, 28581; doi: 10.1038/srep28581.

Brett, J.R., M. Hollands, and D.F. Alderdice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. Journal of the Fisheries Board of Canada, 15(4), pp. 587-605.

Brown, C. and D. Hallock. 2009. Washington State dissolved oxygen standard: a review and discussion of freshwater intragravel criteria development. Washington State Department of Ecology.

Brugger, A., B. Wett, I. Kolar, B. Reitner, and G.J. Herndl. 2001. Immobilization and bacterial utilization of dissolved organic carbon entering the riparian zone of the alpine Enns River, Austria. Aquatic Microbial Ecology, 24(2), pp. 129-142.

Butkus, S.R., B. Cusimano, D.E. Wright. 1999. Snohomish River Estuary Total Maximum Daily Load – Submittal Report, Publication. 99-57-WQ. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/documents/9957.pdf

Cardno. 2018. Lower Pilchuck River Assessment. Prepared by Cardno for Snohomish County Surface Water Management. 61 pp.

Carey, B.M., and J.H. Harrison, PhD. 2014. Nitrogen Dynamics at a Manured Grass Field Overlying the Sumas-Blaine Aquifer in Whatcom County, Washington State Department of Ecology Environmental Assessment Program, Olympia, WA Publication 14-03-001. https://apps.wa.gov/ecy/publications/documents/1403001.pdf

Chapman, M., T. Satterfield and K.M.A. Chan. 2019. When value conflicts are barriers: Can relational values help explain farmer participation in conservation incentive programs?. Land Use Policy, 82, pp.464-475. https://doi.org/10.1016/j.landusepol.2018.11.017

Chapra, S.C., 2008. Surface water-quality modeling. Waveland press.

Clinton, S.M., R.T. Edwards, and R.J. Naiman. 2002. Forest-River Interactions: Influence on Hyporheic Dissolved Organic Carbon Concentrations in a Floodplain Terrace. JAWRA Journal of the American Water Resources Association, 38(3), pp. 619-631.

Crenshaw, C.L., H.M. Valett, and J.R. Webster. 2002. Effects of augmentation of coarse particulate organic matter on metabolism and nutrient retention in hyporheic sediments. Freshwater Biology, 47(10), pp. 1820-1831.

Cusimano, B. 1995. Snohomish River Estuary Dry Season TMDL Study Phase I – Water Quality Model Calibration, Publication 95-338. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/95338.html.

Cusimano, B. 1997. Snohomish River Estuary Dry Season TMDL Study Phase II – Water Quality Model Confirmation and Pollutant Loading Capacity Recommendations, Publication 97-325. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/97325.html.

Danielopol, D.L. 1989. Groundwater fauna associated with riverine aquifers. Journal of the North American Benthological Society, pp. 18-35.

De Baar, H.J.W. 1994. von Liebig's law of the minimum and plankton ecology (1899–1991). Progress in Oceanography, 33(4), pp. 347-386.

Dittbrenner, B. 2019. Restoration potential of beaver for hydrological resilience in a changing climate. PhD Dissertation. University of Washington. 152 pp.

Drury, T.A., 1999. Stability and Pool Scour of Engineered Log Jams in the North Fork Stillaguamish River, Washington. Civil Engineering Master of Science thesis, University of Washington Dept. of Civil and Environmental Engineering, 62 pp

Ecology. 1997. Water Quality Assessment of Tributaries to the Snohomish River and Nonpoint Source Pollution TMDL Study. September 1997. Publication 97-334. https://apps.wa.gov/ecy/publications/SummaryPages/97334.html

Ecology. 2010. Fact Sheet Sand and Gravel General Permit. Washington State Department of Ecology, Olympia, WA.

Ecology. 2015. TTools for ArcGIS. Washington State Department of Ecology, Olympia, WA. https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs.

Fellows, C.S., M.H. Valett, and C.N. Dahm. 2001. Whole stream metabolism in two montane streams: Contribution of the hyporheic zone. Limnology and Oceanography, 46(3), pp. 523-531.

Frazer, G.W., C.D. Canham, and K.P. Lertzman. 1999. Gap Light Analyzer (GLA): Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, user's manual and program documentation. Copyright © 1999: Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

Goetz, F.A., B. Baker, T. Buehrens, and T. P. Quinn. 2013. Diversity of movements by individual anadromous coastal cutthroat trout *Oncorhynchus clarkii clarkia*. Journal of Fish Biology, 83, pp. 1161-1182.

Gray and Osborne Incorporated Consulting Engineers. 2018. City of Granite Falls Wastewater Facilities Plan. G&O Publication 17560.

Grimm, N.B. and S.G. Fisher. 1984. Exchange between interstitial and surface water: implications for stream metabolism and nutrient cycling. Hydrobiologia, 111(3), pp. 219-228.

Hannah, D.M., I.A. Malcolm, and C. Bradley. 2009. Seasonal hyporheic temperature dynamics over riffle bedforms. Hydrological Processes, 23(15), pp. 2178-2194.

Hicks, M., 2002. Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards – Temperature Criteria – Draft Discussion Paper and Literature Summary. Washington State Department of Ecology, Olympia, WA. Publication 00-10-070. https://apps.wa.gov/ecy/publications/SummaryPages/0010070.html.

Hicks, M., 2000. Evaluating Criteria for the Protection Aquatic Life in Washington's Surface Water Quality Standards – Dissolved Oxygen – Draft Discussion Paper and Literature Summary. Washington State Department of Ecology, Olympia, WA. Publication 00-10-071. https://apps.wa.gov/ecy/publications/SummaryPages/0010071.html.

Hobbs, W., B. Lubliner, N. Kale, and E. Newell, 2015. Western Washington NPDES Phase 1 Stormwater Permit: Final S8.D Data Characterization, 2009-2013. Washington State Department of Ecology Water Quality Program and Environmental Assessment Program, Olympia, WA. Publication 15-03-001. https://apps.ecology.wa.gov/publications/SummaryPages/1503001.html

Horner, R.R., E.B. Welch, and R.B. Veenstra. 1983. Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity. In Periphyton of freshwater ecosystems (pp. 121-134). Springer Netherlands.

Jacoby, J. and E. Welch. 2004. Pollutant effects in freshwater: applied limnology. CRC Press.

Johnson, O.W., M. H. Ruckelshaus, W. S. Grant, F.W. Waknitz, A. M. Garrett, G. J. Bryant, K. Neely, and J. J. Hard. Status Review of Coastal Cutthroat Trout from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-37.

Kennedy, J.T., H. Nicholas, S. Job, J. Butcher, S. Hood, and T. Mohamedali. 2020. South Fork Nooksack River Temperature Total Maximum Daily Load Water Quality Improvement Report and Implementation Plan. Tetra Tech and Washington State Department of Ecology Water Quality Program and Environmental Assessment Program, Olympia, WA. Publication 20-10-007. https://apps.wa.gov/ecy/publications/SummaryPages/2010007.html

Larned, S.T. 2010. A prospectus for periphyton: recent and future ecological research. Journal of the North American Benthological Society, 29(1), pp. 182-206.

leDoux B., J. Engle, M. Ruff, C. Wahl. 2017. WRIA 7 Climate Change Impacts to Salmon Issue Paper. Final Draft, January 2017, Prepared for Snohomish Basin Salmon Recovery Technical Committee. https://snohomishcountywa.gov/DocumentCenter/View/41032

Leonetti, F.E., K.J. Terpstra, and B. Dittbrenner. 2015. Temperature Anomalies in the Stillaguamish River Mapped from 2001 Thermal Infrared Aerial Imagery. Snohomish County Public Works, Surface Water Management. Everett, WA. Prepared for Washington State Department of Ecology (Grant Agreement G1000349).

Losee, J., G. Madel, H. Faulkner, A. Claiborne, T. Seamons, and W. Young. 2017. Cutthroat Trout in Saltwater: Spawn Timing, Migration Patterns and Abundance of Anadromous Coastal Cutthroat Trout. Washington State Department of Fish and Wildlife, 600 Capitol Way N. Olympia Washington 98502, Wild Trout Symposium XII—Science, Politics, and Wild Trout Management: Who's Driving and Where Are We Going?

Majerova, M., B.T. Neilson, N.M. Schmadel, J.M. Wheaton, and C.J. Snow. 2015. Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream. Hydrol. Earth Syst. Sci., 19, pp. 3541–3556.

Manchester Environmental Laboratory (MEL). 2016. Laboratory Users Manual, 9th ed. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester.

Manchester Environmental Laboratory (MEL). 2016. Quality Assurance Manual. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change*, Vol. 102, Nos. 1-2, September 2010.

Mathieu, N. 2011. Salmon Creek Watershed Low Dissolved Oxygen and pH Characterization Study. Washington State Department of Ecology Environmental Assessment Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication 13-03-013. https://apps.wa.gov/ecy/publications/SummaryPages/1303013.html

Mathieu, N. 2014. Addendum to Quality Assurance Project Plan: French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load. Washington State Department of Ecology Environmental Assessment Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication 14-03-112. https://apps.wa.gov/ecy/publications/SummaryPages/1403112.html

Mathieu, N. 2016. Addendum 2 to Quality Assurance Project Plan: French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load. Washington State Department of Ecology Environmental Assessment, P.O. Box 47600, Olympia, WA, 98504-7600 Publication 16-03-115. https://apps.wa.gov/ecy/publications/SummaryPages/1603115.html

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. *State of Knowledge: Climate Change in Puget Sound.* Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

Mazzorana, B., A. Zischg, A. Largiader, and J. Hübl. 2009. Hazard index maps for woody material recruitment and transport in alpine catchments. Natural Hazards and Earth System Sciences, 9(1), pp. 197-209.

Mei, Y., G.M. Hornberger, L.A. Kaplan, J.D. Newbold, and A.K. Aufdenkampe. 2012. Estimation of dissolved organic carbon contribution from hillslope soils to a headwater stream. Water Resources Research, 48(9).

Mote, P.W., A.K. Snover, S.M. Capalbo, S. Eigenbrode, P. Glick, J.S. Littell, R. Raymondi, S. Reeder. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program.

Mulholland, P.J., E.R. Marzolf, J.R. Webster, D.R. Hart, and S.P. Hendricks. 1997. Evidence that hyporheic zones increase heterotrophic metabolism and phosphorus uptake in forest streams. Limnology and Oceanography, 42(3), pp. 443-451.

Mulholland, P.J., C.S. Fellows, J.L.Tank, N.B. Grimm, J.R. Webster, S.K. Hamilton, E. Martí, L. Ashkenas, W.B. Bowden, W.K. Dodds, and W.H. McDowell. 2001. Inter-biome comparison of factors controlling stream metabolism. Freshwater Biology, 46(11), pp. 1503-1517.

Naiman, R.J., R.E. Bilby, and P.A. Bisson. 2000. Riparian ecology and management in the Pacific coastal rain forest. BioScience, 50(11), pp. 996-1011.

Pelletier, 2015. Shade.xls: a tool for estimating shade from riparian vegetation. Washington State Department of Ecology, Olympia, WA. https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs

Pelletier, G. and S. Chapra, 2008. QUAL2Kw: a modeling framework for simulating river and stream water quality. User's Manual, Theory and documentation. https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs

Pollock, M. M., M. Heim, and D. Werner. 2003. Hydrologic and geomorphic effects of beaver dams and their influence on fishes. Pages 213-233 in S. V. Gregory, K. Boyer, and A. Gurnell, editors. The ecology and management of wood in world rivers. American Fisheries Society, Bethesda, Maryland.

Pollock, M.M., G.M. Lewallen, K. Woodruff, C.E. Jordan and J.M. Castro (Editors) 2018. The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Version 2.01. United States Fish and Wildlife Service, Portland, Oregon. 189 pp. Online at: http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Beaver.asp

Poole, G.C. and C.H. Berman, 2000. Pathways of Human Influence on Water Temperature Dynamics in Stream Channels. U.S. Environmental Protection Agency, Region 10, Seattle, WA. 20 p. www.krisweb.com/biblio/gen_usepa_pooleetal_2000_pathways.pdf.

Puget Sound Action Team (PSAT) and Washington State University (WSU), Pierce County Extension. 2005. Low Impact Development: Technical Guidance Manual for Puget Sound. 256 pp. Publication Number PSAT 05-03. https://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

Quinn, J. M. 1991. Guidelines for the control of undesirable biological growths in water. Consultancy Report No. 6213/2. National Institute of Water and Atmospheric Research, Hamilton, New Zealand.

Redfield, A. C. (1934). On the proportions of organic derivatives in sea water and their relation to the composition of plankton (pp. 176-92). Liverpool, UK: university press of liverpool.

Redfield, A. C. 1958. The biological control of chemical factors in the environment. American scientist, 230A-221.

Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long. 2014. Puget Sound and the Straits Dissolved Oxygen Assessment Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Publication 14-03-007. Washington State Department of Ecology, Olympia. https://apps.wa.gov/ecy/publications/SummaryPages/1403007.html.

Rosell, F., O. Bozsér, P. Collen, and H. Parker. 2005. Ecological impact of beavers Castor fiber and Castor canadensis and their ability to modify ecosystems. Mammal Review. 35(3&4), pp. 248-276.

Sanderson, T.L. and P.J. Pickett, 2014. A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies. Washington State Department of Ecology, Olympia, WA. Publication 14-03-042. https://apps.wa.gov/ecy/publications/SummaryPages/1403042.html

Savery, A. and A. Hook. 2003. Habitat Conditions and Chinook Use in the Pilchuck River. Tulalip Tribes Natural Resources Department, Marysville, Washington, USA.

Schanz, F. and H. Juon. 1983. Two different methods of evaluating nutrient limitations of periphyton bioassays, using water from the River Rhine and eight of its tributaries. Hydrobiologia, 102(3), 187-195.

Snodgrass, J.W. 1997. Temporal and spatial dynamics of beaver-created patches as influenced by management practices in a South-Eastern North American Landscape. The Journal of Applied Ecology. 34(4), pp. 1043-1056.

Snohomish County Assessor. 2012. https://snohomishcountywa.gov/2934/Assessor.

Snohomish Basin Salmon Recovery Forum (SBSRF). 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA. https://snohomishcountywa.gov/ArchiveCenter/ViewFile/Item/2153

Snohomish River Basin Salmonid Recovery Technical Committee (SBSRTC). 2002. Snohomish River Basin Salmonid Habitat Conditions Review. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Snohomish County Surface Water Management (SCSWM). 2012a. Middle Pilchuck River assessment - habitat report. Prepared by Snohomish County, for the Salmon Recovery Funding Board. 61 pp.

Snohomish County Surface Water Management (SCSWM). 2012b. Middle Pilchuck River assessment - geomorphic report. Prepared by Snohomish County, for the Salmon Recovery Funding Board. 34 pp.

Snohomish County Surface Water Management (SCSWM). 2012c. Middle Pilchuck River assessment – final report. Prepared by Snohomish County, for the Salmon Recovery Funding Board. 35 pp.

Snover, A.K., G.S. Mauger, L.C. Whitely Binder, M. Krosby, and I. Tohver. 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle, WA.

Stohr, A., J. Kardouni, and R. Svrjcek. 2011. Snoqualmie River Basin Temperature Total Maximum Daily Load: Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Olympia, WA. Publication 11-10-041. https://apps.wa.gov/ecy/publications/SummaryPages/1110041.html

Svrjcek, R. 2003. Lower Snohomish River Tributaries Fecal Coliform Total Maximum Daily Load Detailed Implementation Plan. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication 03-10-031. https://apps.wa.gov/ecy/publications/SummaryPages/0310031.html.

Swanson, T., A. King, N. Gurdian, and J. Zhen. 2012. French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load Water Quality Study Design (Quality Assurance Project Plan). Washington State Department of Ecology, Olympia, WA. Publication 12-03-114. https://apps.wa.gov/ecy/publications/SummaryPages/1203114.html

Thornburgh, K. and G. Williams. 2000. The State of the Waters, Water Quality in Snohomish County's Rivers, Stream, and Lakes. Snohomish County Department of Public Works, Surface Water Management, Everett, WA.

Thornburgh, K., K. Nelson, K. Rawson, and G Lucchetti. 1991. Snohomish System Water Quality Study 1987-90. Tulalip Fisheries Department Progress Report. Tulalip Fisheries Department, Marysville, WA 98270.

Tooley, et al., 1990. Data Appendix: Timber-Fish-Wildlife - Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington. https://apps.wa.gov/ecy/publications/SummaryPages/90e75.html.

Torgersen, C., J. Ebersole, and D. Keenan. 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes - EPA 910-C-12-001. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/038.

Trotter, P. 1989. Coastal Cutthroat Trout: A Life History Compendium. Transactions of the American Fisheries Society. 118, pp. 463-473.

USGS, 2017. USGS Real-Time Water Data for Washington: Streamflow. Snoqualmie/Snohomish River Basin station: 12155300. National Water Information System: Web Interface. United States Geological Survey. https://waterdata.usgs.gov/wa/nwis/uv/?site_no=12155300&PARAmeter_cd=00060,00065

WAC 173-201A. Water Quality Standards for Surface Waters in the State of Washington. Washington State Department of Ecology, Olympia, WA. https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A.

Weber N., N. Bouwes, M.M. Pollock, C. Volk, J. M. Wheaton, G. Wathen. J. Wirtz and C. Jordan. 2017. Alteration of stream temperature by natural and artificial beaver dams. PLoS ONE 12(5): e0176313. https://doi.org/10.1371/journal.pone.0176313

Welch, E.B., J.M. Jacoby, R.R. Horner, and M.R. Seeley. 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiologia, 157(2), pp. 161-168.

White, D.S. 1993. Perspectives on defining and delineating hyporheic zones. Journal of the North American Benthological Society, pp. 61-69.

Woo, M.K., and J.M. Waddington. 1990. Effects of Beaver Dams on Subarctic Wetland Hydrology. Arctic 43(3), pp. 223-230.

Wright, Robert, J, Randy Coots, and Robert F. Cusimano. 2001. Lower Snohomish River Tributaries Fecal Coliform Total Maximum Daily Submittal Report. Washington State Department of Ecology Water Quality Program, Olympia, WA. Publication 00-10-087. https://apps.wa.gov/ecy/publications/SummaryPages/0010087.html.

Appendices

The Appendices are available as a Supplemental file to this report at:
https://apps.ecology.wa.gov/publications/summarypages/2010035.html

Appendix A: Background

Appendix B: Public Participation

Appendix C: Glossary and Acronyms

Appendix D: Data Summary

Appendix E: Data Quality Results

Appendix F: Model Documentation

Appendix G: Natural Conditions Checklist

Appendix H: Baseflow Loss Analysis

Appendix I: NPDES Facility Analysis

Appendix J: Streamflow Augmentation Analysis

Appendix K: Reach Metrics