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Appendices A-K

Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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

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Temperature and Dissolved Oxygen
Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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Appendix A. Background

Clean Water Act and TMDLs

What is a Total Maximum Daily Load (TMDL)?

A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Federal Clean Water Act Requirements

The Clean Water Act (CWA) established a process to identify and clean up polluted waters. The CWA requires each state to develop and maintain water quality standards that protect, restore, and preserve water quality. Water quality standards consist of (1) a set of designated uses for all water bodies, such as salmon spawning, swimming, and fish and shellfish harvesting; (2) numeric and narrative criteria to achieve those uses; and (3) an antidegradation policy to protect high quality waters that surpass these conditions.

The Water Quality Assessment and the 303(d) List

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

To develop the WQA, Ecology compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The WQA divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list.

Category 1 — Meets standards for parameter(s) for which it has been tested.

Category 2 — Waters of concern.

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

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

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

Further information is available at Ecology's Water Quality Assessment website: ecology.wa.gov/303d.

The CWA requires that a TMDL be developed for each of the water bodies on the 303(d) list.

TMDL Process Overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed, and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community, then develops a plan to control and reduce pollution sources, as well as a monitoring plan to assess effectiveness of the water quality improvement activities. The implementation plan identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

After the public comment period, Ecology addresses the comments. Then, Ecology submits the TMDL to EPA for approval.

Watershed Hydrology

Hydrology and hydrography

With an average annual discharge of 364 cubic feet per second (cfs), the Pilchuck River is the largest tributary to the Snohomish River below its confluence with the Skykomish and Snoqualmie Rivers.

Notable tributaries within the watershed include:

- **Upper Pilchuck River** - Purdy, Boulder, Wilson, and Worthy Creeks
- **Middle Pilchuck River** -
  - Little Pilchuck Creek – including Star and Catherine Creek
  - Dubuque Creek – including Panther Creek
  - Connor Lake Creek
- **Lower Pilchuck River** - Bunk Foss, Sexton, and Scott Creeks

The hydrology of the Pilchuck River is discussed further in the *Results and Discussion* section of the report.

Geology

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

The majority of the surficial geologic units consist of "unconsolidated" (non-bedrock) glacial deposits. In the Pilchuck River watershed, Vashon Glacial Till, Younger Alluvium, and Recessional Outwash are the primary glacially-derived geologic units (comprising over 88% of the watershed):

- **Vashon Glacial Till** is a relatively strong, stable geologic material consisting of a mixture of silt, sand, and gravel deposited in front of and below the advancing Vashon glacier.
- **Younger Alluvium** deposits consist of organic rich, stream-laid, clay, silt, and fine sands and lie in and around stream channels. It also encompasses the well-rounded river gravels and cobbles that make up much of the main stem channel bottom.
- **Recessional Outwash** consists of well-drained stratified outwash sand and gravel deposits (Bailey, 1998).

Figure A-1 illustrates an example of geology in the Pilchuck River valley within the study area. The dark gray band in middle of the picture is the wetted, top portion of the confining Vashon till layer present throughout the study area.

Figure A-1. Vertical cross-section of geology at exposed bluff near Russell Road bridge crossing.

Hydromodifications

Historically, natural wetlands covered much of the western part of the Pilchuck River watershed. Extensive wetlands have been documented in the Little Pilchuck Creek basin (Ecology, 1997). In addition, several instream man-made structures and culverts in the watershed are full or partial barriers to upstream fish movement. On the Pilchuck River, these include the City of Snohomish Dam located upstream of the city of Granite Falls and Menzel Lake Road. Note that if flows are high enough, fish can move upstream of the dam (Savery and Hook, 2003).

Water Use

A description and estimates of water use from domestic, industrial, and agricultural water use in the TMDL study area is described in detail in Appendix H - Baseflow Loss.

Water Quality Issues

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

High water temperatures and low DO levels are both detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. The Pilchuck watershed is at the upper end of the tidal portion of the Snohomish River Watershed and contains valuable fishery resources. Data on high water temperatures and low DO levels in these watersheds became more available in the early 1990s (Tooley et al., 1990, Thornburgh et al., 1991) and expanded over the next decade (Thornburgh, 1997, Thornburgh and Williams 2000). These data sources resulted in water segments being included on the 303(d) list.

During past WRIA 7 water quality scoping processes, Ecology consulted with watershed stakeholders and determined that implementing the existing bacteria TMDL should continue in the Pilchuck River watershed to reduce both bacteria and nutrient loading problems that can lead to low DO levels. Those implementation efforts would focus on riparian plantings as well to more directly support salmon recovery efforts. However, in late 2011, EPA made new TMDL funding available and Ecology chose to start the Pilchuck River temperature and DO TMDL ahead of schedule to complement local salmon recovery efforts.

Temperature

Ecology reviewed the effect of high temperatures on spawning and rearing salmonids and found that reduced fish survival can occur in many ways (Hicks, 2002). In the weeks immediately preceding spawning, temperatures above 14-16°C can reduce the health of the eggs and sperm in adult fish. Various studies showed reduced survival of eggs when prespawn Chinook and steelhead experience holding temperatures above state standards. Migration can be impaired when average temperatures exceed 15°C and maximum temperatures exceed 18-20°C. Temperatures above 21-22°C block migration completely. Single day peak temperature of 24-25°C is capable of killing salmonids that have not been well acclimated. Warm water diseases increase the risk of losses to both migrating adults and rearing juveniles when temperatures rise above 17-18°C. Special consideration is also required to protect spawning and incubation of salmonid species. Constant temperature in the range of 8-10°C and a daily maximum temperature below 13-15°C are necessary to ensure fertilized eggs have high survival success and the embryos develop properly (Hicks, 2002). Warmer water also is correlated to slower swimming speeds of juvenile salmon and a higher metabolism of predator fish, resulting in higher predation of juvenile salmonids (Figure A-2; Brett et al., 1958).

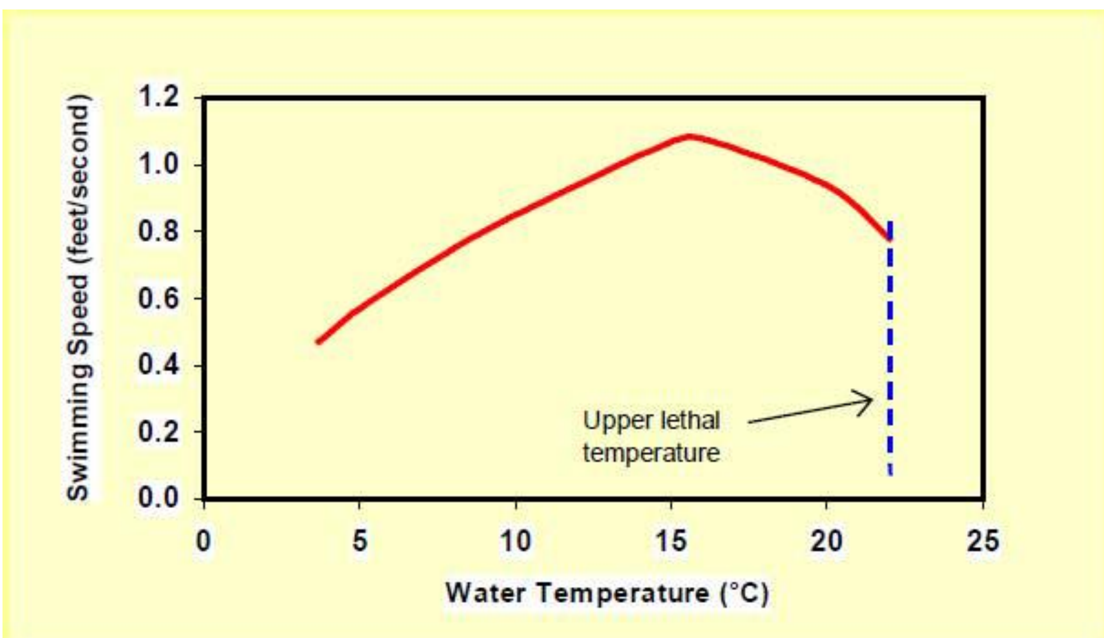

Figure A-2. Water temperatures above 15°C slow down juvenile salmon making them vulnerable to predation.

Henry's Law states the solubility of gases in water decreases with increasing temperature and decreasing pressure; therefore, temperature has the largest impact on equilibrium oxygen concentration. Higher temperatures result in lower oxygen carrying capacity of water (Brown and Hallock, 2009). A decrease in oxygen levels for fish affects their growth rates, swimming ability, disrupts their metabolism and ability to endure stressors and other toxins; and increases their susceptibility to disease and predation.

Dissolved Oxygen

Ecology reviewed literature on the effects of DO on salmonids and found they require more DO during spawning and incubation than during rearing. Growth rates in salmonids are influenced by temperature, food availability and DO (Hicks, 2000). Food consumption has a direct relationship to the DO requirements of fish. The metabolic rates of fish are elevated at the time of feeding and for some hours afterwards. Where there is high food availability at warmer temperatures, depressions in oxygen reduce the ability of fish to metabolize food, potentially resulting in lower growth rates. An average oxygen concentration of 9.0 mg/L would be the lowest that would have a negligible (5% or less) effect on growth rates. Daily oxygen levels should be maintained at 8 to 8.5 mg/L to fully optimize salmonid growth potential.

Lower levels of DO can also impact the ability of salmon to move in their natural environment. Upstream migration of spawning adult salmon was found to be the most costly sustained energy expenditure since spawning adults do not feed in freshwaters. When coupled with predation avoidance, this may increase lethal stress in fish in the absence of adequate oxygen levels. In coho and Chinook salmon, Davis et al. (1975) made the following projections: at 9 mg/L, maximum sustained swimming speed would be reduced by less than 2%; at 8 mg/L, expect minor decreases in swimming speed of 3-7% and at 7 mg/L, swimming performance is likely reduced by 5-10%. The swimming fitness of salmonids is maximized when DO levels are above 8-9 mg/L.

Maintaining oxygen levels greater than 8.5 mg/L provides added protection from the effects of several very common pollutants such as the addition of organic matter or nutrients. Low oxygen coupled with the mixing of lower oxygen waters such as wastewater, groundwater and some wetland seeps can significantly increase detrimental effects. Respiration and cooling are more pronounced in the morning whereas photosynthesis and warming are more pronounced in the afternoon. Exposing eggs just before hatching to restricted oxygen supply below 9.0 mg/L can translate to reduced embryonic growth. Later in their development, juvenile salmonids will actively avoid DO concentrations that are 5.0-6.0 mg/L or lower, so these levels should be considered a barrier to the movement and habitat selection of salmonids. Hicks (2000) indicated much of the literature supports the conclusion that since fish are so efficient in their use of oxygen, little room can be spared for activities that drive down the levels of oxygen. Minimum and maximum DO levels should be considered when evaluating fish habitat.

Protection of Designated and Downstream Uses

Ecology's analysis found that allocations for heat, phosphorus, and BOD loads prescribed in the Pilchuck River Temperature and Dissolved Oxygen TMDL are expected to have an acceptable level of impact on all designated and downstream uses. In summary:

- Predicted Pilchuck River DO levels are greater than (meet) less stringent downstream criteria on the Snohomish River and have a very small overall impact.

- Predicted Pilchuck River temperature levels are estimated to be naturally above (do not meet) numeric downstream criteria on the Snohomish River; however the predicted impact to the Snohomish is minimal, ~3% (0.01°C) of what the water quality standards considers as a measureable change (0.3°C).
- Water supply, toxics, aesthetics, and miscellaneous uses are not expected to be negatively impacted. Pilchuck River algae levels are currently below nuisance levels and will be further reduced by the TMDL, which should improve the aesthetic value of the river.
- BOD5 allocations set in this TMDL for the Pilchuck River are compatible with ultimate BOD allocations for the Pilchuck River assigned in the Snohomish River Estuary DO TMDL (Butkus and Cusimano, 1999).
- The Pilchuck TMDL allocations are not expected to significantly impact downstream uses/impairments in the Salish Sea, beyond the Snohomish River estuary; however the Puget Sound Nutrient Reduction Project may identify future BOD or carbon reductions necessary in the Pilchuck River watershed below the load allocations identified in the Pilchuck River or Snohomish Estuary TMDLs.

Downstream Uses

Washington water quality standards require upstream actions to be conducted in manners that meet downstream water-body criteria. The standards also require that the most stringent water quality criteria apply where multiple criteria for the same water quality parameter are assigned to a water body to protect different uses and at the boundary between water bodies protected for different uses.

The water quality standards language in WAC 173-201A-260(3)(b)-(d) states:

> "(b) Upstream actions must be conducted in manners that meet downstream water body criteria. Except where and to the extent described otherwise in this chapter, the criteria associated with the most upstream uses designated for a water body are to be applied to headwaters to protect nonfish aquatic species and the designated downstream uses.
>
> "(c) Where multiple criteria for the same water quality parameter are assigned to a water body to protect different uses, the most stringent criterion for each parameter is to be applied.
>
> (d) At the boundary between water bodies protected for different uses, the more stringent criteria apply."

In developing TMDLs, Ecology routinely identifies and considers all designated uses (also described as beneficial uses) of the impaired water body and waterbodies directly downstream of the impairment. This is done to ensure the chosen TMDL target and associated allocations will protect all designated uses and downstream designated uses.

The Waterbody Uses section of the TMDL report lists all designated uses that apply to the Pilchuck River. Of those uses, only the aquatic life uses have specific criteria for temperature and DO. Table A.1 lists the uses and criteria that apply within and immediately downstream of the TMDL study area, and include the aquatic life uses of Core Summer Salmonid Habitat (which applies to the Pilchuck River from Mouth to approximately river mile (RM) 31, at the confluence with Boulder Creek).

Table A.1. Stringency comparison of designated uses and criteria for TMDL reach and the immediate downstream reach.

	TMDL Reach	Downstream Reach
Reach Description	Pilchuck River – mouth to ~RM 26 at Menzel Lake Rd bridge.	Snohomish River: Upstream of the southern tip of Ebey Island (latitude 47.942, longitude -122.1719) to below Pilchuck Creek at (latitude 47.9005, longitude -122.0925).
Designated Use	Freshwater Aquatic Life – Core Summer Salmonid Habitat	Aquatic Life – Spawning Rearing and Migration Habitat
Temperature Quality Criteria	7-DADMax < 16°C* Anthropogenic increase allowance of <0.3°C, when natural condition above 16°C	7-DADMax < 17.5°C Anthropogenic increase allowance of <0.3°C, when natural condition below 17.5°C
Dissolved Oxygen Water Quality Criteria	Daily minimum DO > 9.5 mg/L* Anthropogenic increase allowance of <0.2 mg/L, when natural condition below 9.5 mg/L	Daily minimum DO > 8.0 mg/L Anthropogenic increase allowance of <0.2 mg/L, when natural condition below 8.0 mg/L

*Denotes most stringent criteria for a parameter.

In addition to protecting the designated uses of the impaired water bodies addressed by the TMDL, Ecology evaluated and confirmed that the TMDL was protective of downstream waters. The Pilchuck River flows into the Snohomish River, which is designated for Spawning Rearing and Migration Habitat. Natural temperatures and DO concentrations within the TMDL reach are predicted to not meet respective numeric criteria, therefore the anthropogenic increase allowance applies to both parameters. Sections 4.5 and 4.6 contain a more detailed discussion of TMDL impacts compared to human allowance criteria. In the reach of the Pilchuck River right above the confluence with the Snohomish River:

- For Dissolved Oxygen, the TMDL is protective of downstream uses for the following reasons:
  - The TMDL model scenario predicts minimum DO at critical conditions of 8.1 mg/L, which meets the downstream numeric criterion of 8.0 mg/L.
  - The difference between the lowest TMDL scenario DO and the lowest estimated natural DO in the Pilchuck River is less than 0.2 mg/L, consistent with the natural conditions provision. After mixing with the larger Snohomish River the TMDL impact, relative to the estimated natural impact, of the Pilchuck River is much smaller than 0.2 mg/L, ~0.01 mg/L or less at current 7Q10 flows and Snohomish River DO between 5 and 8 mg/L.
  - The predicted Pilchuck River carbonaceous biochemical oxygen demand (CBOD) loading used to develop this TMDL is within the allowable allocated level determined by the Snohomish Estuary Dissolved Oxygen TMDL (Butkus and Cusimano, 1999), see section below for additional detail.
  - There are no downstream TMDLs for the Snohomish River that specifically limit the Pilchuck River phosphorus loading. The TMDL model scenario predicted phosphorus concentrations at the mouth of the Pilchuck River are low (<5 ug/L SRP) during baseflow conditions.

- For Temperature:
  - The TMDL model predicts 7-DADMax temperatures at critical conditions of greater than 21°C, which does not meet the downstream numeric criterion of 17.5°C; however:
  - The difference between the highest TMDL 7-DADMax temperatures and the estimated natural 7-DADMax temperatures in the Pilchuck River is less than 0.3°C, consistent with the natural conditions provision. After mixing with the larger Snohomish River, the TMDL impact, relative to the estimated natural impact of the Pilchuck River, is much smaller than 0.3°C, ~0.01 °C at 7Q10 flows and Snohomish River temperatures between 17 and 20°C (see Chapter 4: Temperature TMDL Analysis and Allocations for detail).
  - There are no downstream temperature TMDLs for the Snohomish River that specifically limit the Pilchuck River temperature loading.

Protection of Other, Non-Aquatic Life Uses

Washington water quality standards (WAC-173-201A-200) also requires the protection of water supply and miscellaneous uses:

> *(3) **Water supply uses.** The water supply uses are domestic, agricultural, industrial, and stock watering.*
>
> ***General criteria.** General criteria that apply to the water supply uses are described in WAC **173-201A-260** (2)(a) and (b), and are for:*
>
> *(a) Toxic, radioactive, and deleterious materials; and*
>
> *(b) Aesthetic values.*
>
> *(4) **Miscellaneous uses.** The miscellaneous fresh water uses are wildlife habitat, harvesting, commerce and navigation, boating, and aesthetics.*
>
> ***General criteria.** General criteria that apply to miscellaneous fresh water uses are described in WAC **173-201A-260** (2)(a) and (b), and are for:*
>
> *(a) Toxic, radioactive, and deleterious materials; and*
>
> *(b) Aesthetic values.*

The general criteria that apply (described in WAC173-201A-200) for protection of these uses are:

> *(2) **Toxics and aesthetics criteria.** The following narrative criteria apply to all existing and designated uses for fresh and marine water:*
>
> *(a) Toxic, radioactive, or deleterious material concentrations must be below those which have the potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health (see WAC **173-201A-240**, toxic substances, and **173-201A-250**, radioactive substances).*
>
> *(b) Aesthetic values must not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste (see WAC **173-201A-230** for guidance on establishing lake nutrient standards to protect aesthetics).*

The allocations for temperature, BOD, and phosphorus represent reductions in overall loading for these parameters, which would be expected to have either no effect or improve the general criteria listed above. Current bottom algae (periphyton) biomass levels (<50 mg Chl a/m2) are well below the aesthetic nuisance levels (100-150 mg Chl a/m2) identified by Horner et al. (1983). The TMDL reductions in phosphorus in particular are designed to further decrease algae growth in the river, which should protect and improve the aesthetic value of the river. In addition, the TMDL includes recommendations and associated implementation actions designed to increase baseflows and infiltrate stormwater to increase the quantity and improve the quality of water in the river. This increase in flow would generally be expected to decrease the concentrations of any toxic, radioactive, or deleterious materials that may be present in the river.

Snohomish River Estuary DO TMDL

The BOD loading allocated in this TMDL achieves the allocation given to the Pilchuck River during development of the Snohomish River Estuary DO TMDL, for reasons explained below.

The Snohomish River Estuary DO TMDL (Cusimano, 1997; Butkus and Cusimano, 1999) sets an allocation for the mouth of the Pilchuck River based on an Ultimate Carbonaceous Biochemical Oxygen Demand (CBODu) concentration of 1.2 mg/L and critical low flow of 55.8 cfs (the TMDL's estimate of Pilchuck 7Q10 at the mouth). This results in the allocation value of 361 lbs/day of CBODu for the Pilchuck River. The Snohomish Estuary DO TMDL states this allocation represents existing conditions and does not include a prescribed reduction of Pilchuck River CBOD. It is unclear from the Snohomish estuary project reports (Cusimano, 1995; Cusimano, 1997; Butkus and Cusimano, 1999) how a value of 1.2 mg/L CBODu was derived, but this value was used in all locations where a 5-day BOD (BOD5) value below the reporting limit (2-3 mg/L, dilution dependent) was measured in the TMDL, including for the upstream Snohomish River background (discussed below).

Since CBODu may be calculated in various ways and Ecology does not have historical CBOD data for the Pilchuck River, several methods were used to estimate the basis for the 361 lbs/day allocation to ensure consistency with the Snohomish River Estuary DO TMDL. Factors considered in these methods include 5-day BOD values, organic carbon levels, and decay rates.

The only Pilchuck BOD sample data from the Snohomish Estuary TMDL study in the 1990s is unhelpful, as BOD5 values were all below a relatively high reporting limit of 3 mg/L. Theoretically, if the value was actually 2 mg/L or more the ultimate CBOD value could be 6 mg/L or more.

Therefore, BOD5 sample data is not particularly useful in this range due to the high reporting limit. In these cases soluble CBODu can be roughly estimated from dissolved organic carbon (DOC) data by multiplying the DOC value by the stoichiometric ratio of oxygen demand to organic carbon (2.67 is typically used as a default). Total CBODu, which includes the influence of any algal and detrital carbon in the sample, can be roughly estimated by multiplying the total organic carbon (TOC) by 2.67.

By this method, 0.99 mg/L, the average DOC value at low flow from the 2012 study, yields an estimated soluble CBODu of 2.6 mg/L, greater than 2X the value used in the Snohomish TMDL. This converts to an estimated 782 lbs/day of soluble CBODu. This level of DOC is relatively low compared to dry season DOC results in WRIA 7 in Ecology's Environmental Information Management (EIM) database (Figure A-3) and it is unlikely that CBODu loading has doubled since the 1990s in the Pilchuck watershed.

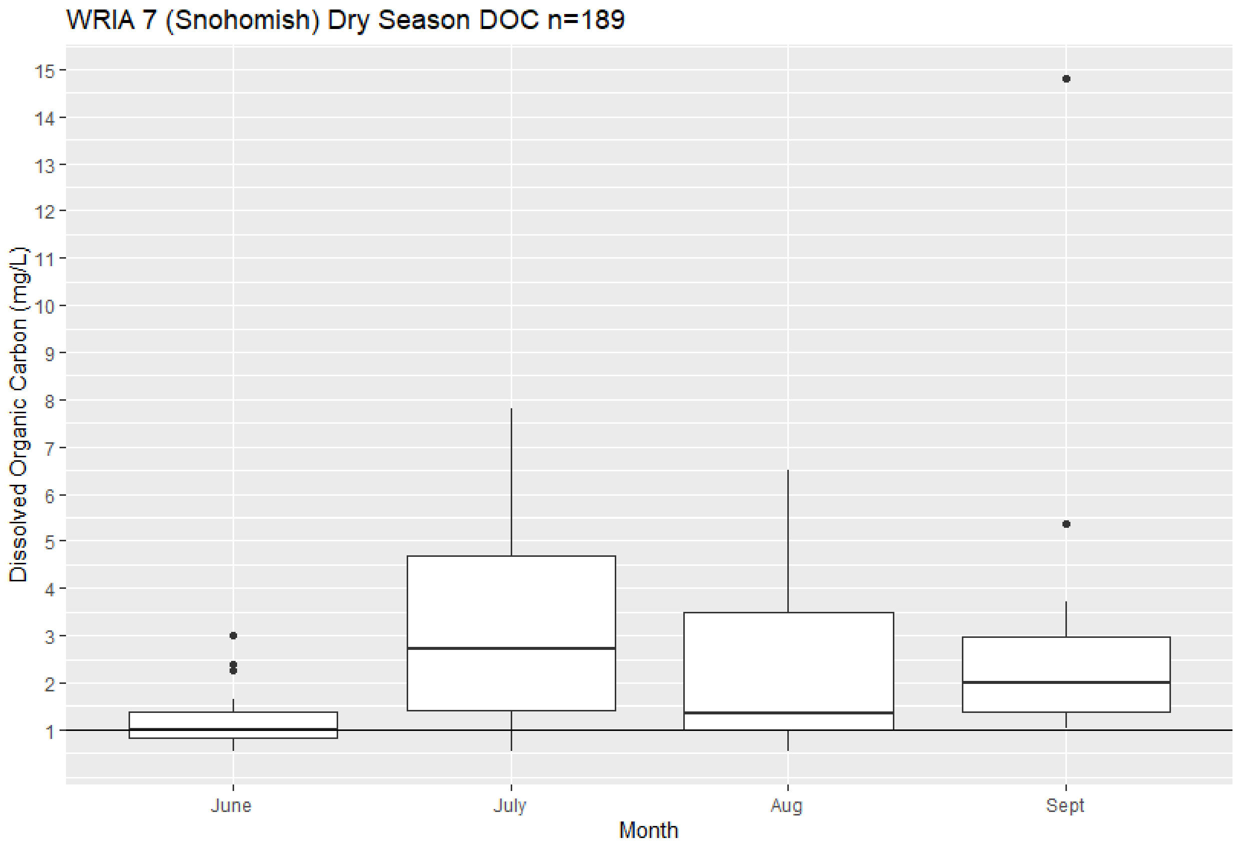

Figure A-3. Dry Season Dissolved Organic Carbon results in WRIA 7 – Snohomish downloaded from EIM on 2/11/2020.

Furthermore, Phase 1 (Cusimano, 1995) notes that "Generally, the water quality of the Pilchuck River was found to be good, some loading of organic matter is suggested by the measured 2-3 mg/L of TOC." Multiplied by the 2.67 ratio, this represents a total CBODu of 6.34 to 8.01 mg/L. Using a ratio of DOC/TOC of 0.85 (from 2012 Pilchuck data) that converts to 1.7 to 2.55 mg/L of DOC (i.e., 85% of 2 and 3 mg/L, respectively). Multiplying the DOC values by 2.67 translates to 4.54 to 6.81 mg/L of soluble CBODu. This converts to an estimated 1366 to 2050 lbs/day of soluble CBODu. These TOC values were likely not obtained at critical low flow, but do demonstrate that organic carbon loading from the Pilchuck River was not strikingly low in the 1990s. Clearly, this estimate of CBODu loading based on the TOC values is not compatible with the allocation in the TMDL, which calls for no reduction of CBODu loading.

There is some discrepancy as to what constitutes "ultimate" CBOD. Models and TMDLs could consider several different ways to approach ultimate CBOD, including these two common versions:

1. **The theoretical ultimate CBOD** once all dissolved organic carbon has been degraded and the associated oxygen demand has been exerted. This number is very hypothetical and could take months or years to actually be realized, if at all. This is the number approximated above using TOC or DOC and the 2.67 ratio, to estimate total and soluble CBODu respectively. This theoretical value is comparable to CBODu outputs from the QUAL2Kw model. See section 4.4 for additional discussion.
2. **The practical "ultimate" CBOD** which is the oxygen demand exerted by "readily-degraded" carbon after ~20-60 days in a bottle test. This could represent either total or soluble/dissolved CBOD, depending on whether the sample is filtered or not. This is essentially the point where little or no additional oxygen demand is measured in the bottle between measurements. This number can be significantly less than #1 because the most recalcitrant organic carbon may be degraded very slowly in the environment (and possibly not at all in the laboratory bottle test). These values are NOT comparable to theoretical CBODu outputs from the QUAL2Kw model.

Recently Ecology's ambient monitoring program has started collecting CBOD samples at major rivers draining to Puget Sound and analyzing CBOD results after 2, 5, 10, 15, 20, 30, and 60 days. For the Snohomish River in October 2018 (low flows) the dissolved CBOD after 30 days was measured as 1.2 mg/L and as 1.5 mg/L after 60 days (ultimate version #2, practical CBODu) whereas the DOC on this date was 1.35 mg/L which equates to a theoretical soluble CBODu of 3.6 mg/L (ultimate version #1, theoretical CBODu). This illustrates how much higher theoretical CBODu tends to be compared to practical CBODu. The calculated BOD decay rate based on this 60-day result is 0.009/day.

Based on the above information, particularly the measured organic carbon, it is likely that the Snohomish Estuary DO TMDL allocation represents an ultimate CBOD value closer to a 60-day practical CBOD result. The Pilchuck TMDL calculates CBODu as a 60-day value (version #2, practical) in order to be comparable to the results of the Snohomish Estuary DO TMDL. Using this method Ecology determined the Pilchuck BOD allocations were in compliance with the downstream allocation of 361 CBODu lbs/day.

Because the QUAL2Kw model does not output 60-day CBOD results, an estimate can be obtained using the DOC output (0.94 mg/L at 7Q10 flow) and the 60-day decay rate from the Snohomish River of 0.009/day. This method yields a calculated 60-day CBODu at the mouth of the Pilchuck of 1.05 mg/L. This equals 283 lbs/day of practical 60-day CBODu at the critical flow for the Pilchuck used in the Snohomish TMDL (55.8 cfs) or 256 lbs/day at the critical flow at the downstream end of the Pilchuck TMDL model (50.5 cfs). This DOC level is comparable to levels measured in 3 samples collected in August 2012 at summer low flows in the Pilchuck River (0.94, 1.00, and 1.03 mg/L all on 8/28/2012). Based on the higher flow rate (55.8) from the Snohomish Estuary TMDL, a DOC value of 1.1 mg/L or less corresponds to a 60-day CBODu load of less than 361 lbs/day, using the method described above, which will protect downstream uses because it is consistent with the allocation from the downstream estuary TMDL.

Downstream impacts to the Salish Sea

The Pilchuck River flows to the Snohomish River, which ultimately flows to Possession Sound and the Salish Sea. Extensive research including water quality modeling (Ahmed et al., 2019, Ahmed et al., 2014; Albertson et al., 2002; Roberts et al., 2014) show that DO in the Salish Sea is depleted below natural conditions by human-caused nitrogen and carbon loading from point sources and watersheds, including the Snohomish River watershed.

The Pilchuck River TMDL does not allocate nitrogen loading, but rather phosphorus loading, which is not considered to be a limiting nutrient that promotes depletion of oxygen in the Salish Sea. However, carbon allocations assigned in the Pilchuck River TMDL could potentially impact DO in the Salish Sea.

The Pilchuck TMDL carbon allocations are not expected to significantly impact downstream uses/impairments in the Salish Sea, beyond the Snohomish River estuary; however it is possible that the Puget Sound Nutrient Reduction Project may identify future BOD or carbon reductions necessary in the Pilchuck River watershed below the load allocations identified in the Pilchuck River or Snohomish Estuary TMDLs.

The Pilchuck TMDL allocations for BOD apply only to the dry season (June to September) when the average flow and volume of runoff are significantly reduced compared to the wet season (October to May). The TMDL allocates relatively minor BOD loads including:

- Nonpoint loads at estimated existing levels.
- Granite Falls WWTP, the largest point source load of carbon, at existing permit levels.
- A small accommodation for dry season "runoff" conditions of ~33 lbs/day BOD5 for current and future stormwater or other NPDES permitted discharges.

Given the reduction in runoff volume and peak flow events in the dry season, less of the organic carbon load from the Pilchuck River is rapidly flushed out to marine waters and a significant portion of this load is likely attenuated in the Snohomish River before reaching the Salish Sea.

Global Climate Change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Snover et al., 2013; Mote et al., 2014). Factors affecting these changes include natural climate variability, which influences regional climate on annual and decadal scales, and long-term increases in air temperature due to rising greenhouse gas emissions. Chapter 21 of the U.S. National Climate Assessment report *Climate Change Impacts in the United States* (Mote et al., 2014) described observed and projected changes in air temperatures across the region:

> *"Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F.*
>
> *An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099 (compared to the period 1970 to 1999), depending largely on total global emissions of heat-trapping gases. The increases are projected to be largest in summer.*

A warming climate affects snowpack and hydrology in important ways. Washington's spring snowpack is projected to decline by 38% to 46% by the 2040s and by 56% to 70% by the 2080s under low and moderate warming scenarios (Snover et al., 2013). The impact of this snow loss on hydrology will vary by basin, as noted in Mote et al., 2014:

> *Hydrologic response to climate change will depend upon the dominant form of precipitation in a particular watershed, as well as other local characteristics including elevation, aspect, geology, vegetation, and changing land use. The largest responses are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt. By 2050, snowmelt is projected to shift three to four*

> *weeks earlier than the 20th century average, and summer flows are projected to be substantially lower, even for an emissions scenario that assumes substantial emissions reductions (B1).*

By the 2040s, summer flows are projected to decrease by 30% to over 50% in the rivers draining the Cascade Mountains, Olympic Mountains, and western front of the Rocky Mountains in Washington. These lower flows, combined with rising air temperatures, are expected to cause increased summer stream temperatures. Mantua et al. (2010) presented climate change modeling scenarios that projected annual maximum weekly average water temperatures that by the 2080s are from 1 to 6°C higher than 1980s conditions. Higher stream temperatures degrade or eliminate habitat for salmonids and can increase disease and predation. Increased water temperatures can also decrease DO levels and increase the impacts of pollutants on receiving waters.

Water quality can also be affected by an expected increase in extreme precipitation events. According to Mote et al., 2014:

> *Averaged over the region, the number of days with more than one inch of precipitation is projected to increase 13% in 2041 to 2070 compared with 1971 to 2000 under a scenario that assumes a continuation of current rising emissions trends (A2), though these projections are not consistent across models.*

More extreme precipitation events, combined with warming winter temperatures, increase the risk of winter flooding in mixed rain-snow and rain-dominant watersheds. This will likely increase stormwater management challenges in urban areas. Increased erosion and pollutant runoff is also an expected consequence of more intense storms.

Other climate change impacts identified by Mote et al. (2014) that may result in degraded water quality in rivers and streams include:

- Increasing wildfires, resulting in increased post-fire erosion and pollutant loading
- Changes to watershed vegetation from changes to temperature, moisture, and fire regimes
- Increased agricultural pesticide use to control increased disease, pests, and weeds

In 2015, the University of Washington Climate Impacts Group published *State of Knowledge: Climate Change in Puget Sound* (Mauger et al., 2015). This report summarized current research on the impacts of climate change in the Puget Sound region for issues ranging from snowpack to human health. It identified numerous likely changes in freshwater and marine water quality. These changes include:

- Decreased summer freshwater flows
- Increased sediment loads in winter and spring
- Warmer freshwater and marine water temperatures
- Decreased DO levels
- Changes in estuarine circulation
- Increased harmful algal blooms
- Increased acidification (lower marine pH levels)
- Rising sea levels and increased coastal erosion

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool and provide thermal refugia for fish. Growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help offset the changes expected from global climate change by increasing stream temperature resiliency. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our freshwater and estuarine resources.

In summary, increased rainfall intensity and changes to watershed vegetation and land uses may increase storm event pollutants. The cumulative impact of climate change is likely to increase the vulnerability of receiving waters to pollutant runoff. This emphasizes the importance of increasing receiving water resiliency and reducing pollutant sources.

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

Information on climate change in Washington State is available from the [University of Washington Climate Impacts Group website](https://cig.uw.edu/)[1] and from Ecology's [Climate Change website](https://ecology.wa.gov/ClimateChange)[2].

[1] https://cig.uw.edu/
[2] https://ecology.wa.gov/ClimateChange

Appendix B. Public Participation

Public Comments

Ecology held a 30-day public comment period for this TMDL from October 15, 2020 through November 15, 2020. Ecology sent an online news release[3] to all local media in the watershed on October 15. Ecology placed announcements through the water quality improvement listserv, the Pilchuck and French watersheds web page[4] and Twitter.[5]

Ecology interviewed for an Everett Herald news article,[6] and a King 5 TV interview and article.[7] The Everett Herald released the news article on October 29, 2020 and King 5 released a TV interview and article later that same day.

Ecology held a virtual public workshop on October 29, 2020 at 5 pm (Figure B-1). The presentation from the workshop was posted to the Pilchuck and French watersheds web page. Ecology also made a virtual presentation to the Sustainable Lands Strategy group at a special session meeting on November 4, 2020 at 1 pm (Figure B-2).

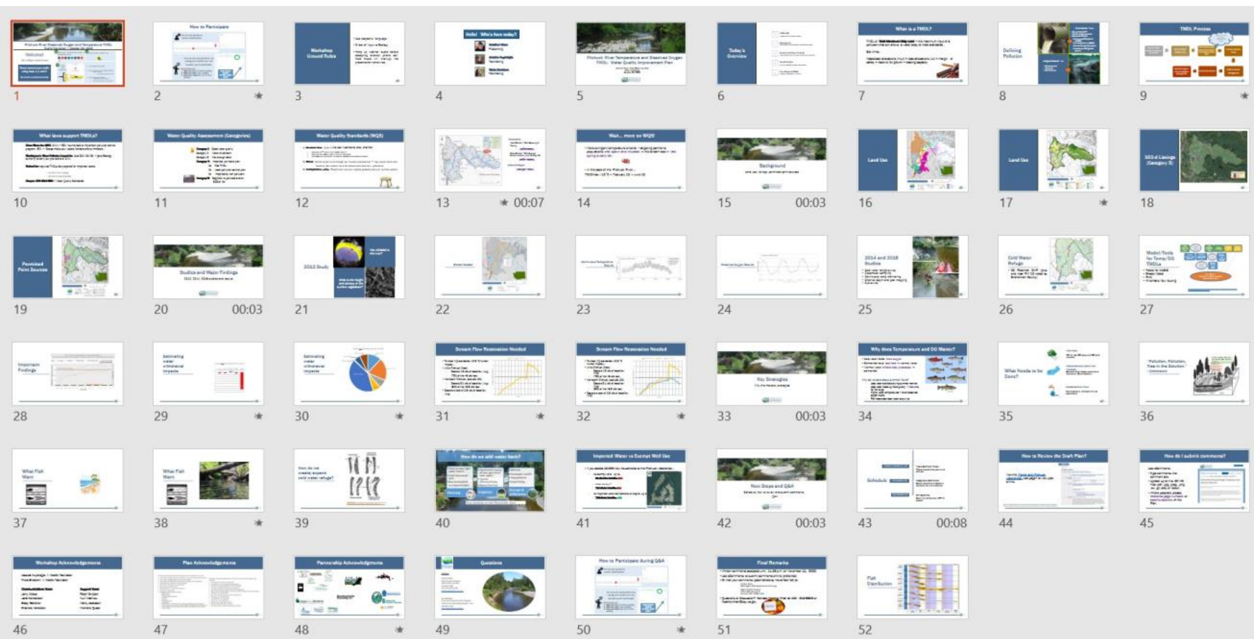

Figure B-1: Pilchuck River TMDL Public Workshop – Copy of presentation slides

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[3] https://ecology.wa.gov/About-us/Get-to-know-us/News/2020/Oct-15-Pilchuck-Watershed

[4] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Total-Maximum-Daily-Load-process/Directory-of-improvement-projects/French-Creek-Pilchuck-watersheds

[5] https://twitter.com/ecyseattle/status/1317103009717891072?s=20

[6] https://www.heraldnet.com/news/development-has-made-the-pilchuck-river-warmer-harming-fish/

[7] https://www.king5.com/article/tech/science/environment/pilchuck-river-is-5-degrees-too-warm-and-threatening-salmon-runs/281-3a1a744a-3c89-481f-8f76-b880514c7161

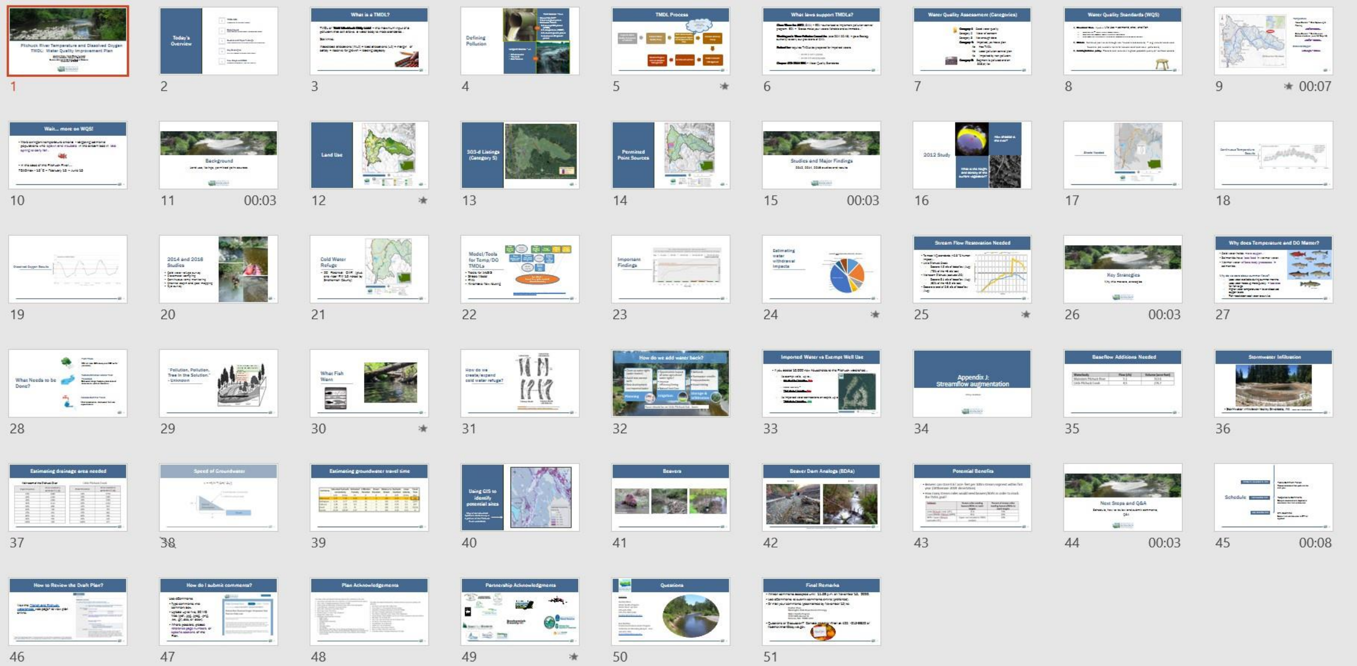

Figure B-2: Sustainable Lands Strategy – Copy of Presentation Slides

Comments and Response

Ecology received comments from 8 individuals, the Tulalip Tribe, the Snoqualmie Tribe, the City of Granite Falls, Snohomish County, and EPA Region 10. The full text of most of the comments are reproduced below. Where Ecology made only minor revisions in response to suggested document edits, Ecology did not include a response below. Salutations and closings have been removed and formatting where appropriate has been reproduced. Ecology's response follows the comment.

Comment From: Andrew Reyes- Individual (I-1-1)

Aren't you the same Folks that Approve or Desapprove of Building Sites/Permits, if it does not meet the Standards for Fish & Wild Animals ? Why did you then approve for Mass Building in this areas if It is Concerning to the Enviroment ? Now your Telling Us your Crying Wolf !!! When i purchase my Property in Granite They Did a Mass Study for Wild life And Salmon. Makes me Wonder who's doing the INSP ??? Anyway More Tax payers Money going out. What is the Plan ??? I Like to KNow . ACR 10-29-2020

Response To: Andrew Reyes – Individual (I-1-1)

The local jurisdiction (city or county) performs the typical building permit approval and inspection processes. Numerous state and local agencies are involved in the larger growth management planning process which is dictated by state law under Chapter 36.70A RCW, GROWTH MANAGEMENT—PLANNING BY SELECTED COUNTIES AND CITIES. The comprehensive plan for Snohomish County can be found at: https://snohomishcountywa.gov/2139/Comprehensive-Plan. This TMDL report constitutes the plan for meeting temperature and dissolved oxygen criteria in the Pilchuck River watershed.

Comment From: Richard Quint- Individual (I-2-1)

Well.....if one of the problems is from trees not shading the river, then stop allowing removal of trees within a range that allows sun to reach the river and start planting all along open areas next to the river. This won't affect the recreational use of the river but it will stop people from clear cutting right up to the river. And it will also help preserve the existing river channel. That means less new homes being built! YAY!! Go build your new house back in California! No sense in destroying Washington any more than it already has been!!!!!! And stop paving everything over!!!

Response To: Richard Quint- Individual (I-2-1)

Ecology agrees that trees should not be removed within the riparian buffer widths identified within this plan. Much of that buffer width is protected by Snohomish County Critical Areas Regulations, which can be found at https://snohomishcountywa.gov/2925/Critical-Area-Requirements. The TMDL specifies that tall mature trees should be established within these buffers wherever there is not an existing building or road. No new buildings or impervious surfaces should be established within these buffers, otherwise the TMDL allocations cannot be achieved.

Comment From: Joe- Individual (I-3-1)

Sounds like if you want the water to cool the river needs to be dredged. Along with creating cooling rest pockets. Change the depth and and this will allow the water to not be able to warm up in shallow stretches. Add riff Raff and these will help from erosion and act as an insulator to keep cool if done right.

Response To: Joe- Individual (I-3-1)

Ecology agrees that increasing depth and narrowing the river channel is an effective way of cooling the water. However, dredging can have serious negative ecological impacts including altering the sediment quality needed for salmon spawning. A dredged river section will also generally drastically lower the river's velocity and ability to reaerate with new oxygen from the atmosphere. It can also cause increased oxygen demand from organisms in the sediments and result in growth of oxygen consuming aquatic plants, all of which will lead to lower oxygen levels in the water. Although large rock (rip rap) can prevent erosion, it decreases the amount of higher quality fish habitat and prevents natural processes from maintaining a balanced environment that supports fish throughout their entire life cycle in a river.

Comment From: Chrystal Baird- Individual (I-4-1)

Please follow the tribes and scientists and do what we need to do to save our water, our fish, and the ecosystems. Water is life, without it we all die.

Response To: Chrystal Baird- Individual (I-4-1)

Ecology agrees that the best available science, along with input from tribal governments and other stakeholders, should be used to address water quality impairments.

Comment From: Aubria Boynton- Individual (I-5-1)

Throw dead logs in to river. Salmon love the shade.

Response To: Aubria Boynton- Individual (I-5-1)

Ecology agrees that large woody material should be added to the river. The implementation plan for this TMDL includes detailed information in support of this action.

Comment From: Benjamin Price- Individual (I-6-1)

Short Term - Cooling cores injected into the river gravels in slow moving portions of the river. Coolers could be powered by solar panels or small micro hydro generators in areas where non salmon bearing tributaries flow in.

Artificial Shade trees could be placed along the stream banks to help cool the banks until live plants can establish themselves

Long Term - More LWD to increase flow dynamics which, when coupled with a steady flow of new LWD from plants, would help to lower temperature over time.

Funding - Carbon sequestration credit bank all areas where vegetation is planted to create a financial input that could last many decades. Could possibly be worked in as a land owner partnership.

Response To: Benjamin Price- Individual (I-6-1)

Ecology appreciates the creative solutions proposed to this complex problem and encourages local partners to explore feasible options for cooling the river. It should be noted these short term solutions would require significant engineering, funding, and environmental impact review process. Ecology agrees that large woody debris should be added to the river strategically to help create cold water refuges. The implementation plan for this TMDL includes detailed information in support of this action.

Comment From: J S- Individual (I-7-1)

You guys ever float the Pilchuck river and see how many people are pumping water out of the river to water thier grass there are dozens of these home made irrigation systems from the old dam site down river to the machias area. Keeping the water in the river would help with flows temperatures and oxygen levels

Response To: J S- Individual (I-7-1)

Yes, field staff have floated the river during the course of the study and have observed what appear to be withdrawal/irrigation systems. Ecology's Water Resources Program staff have been notified of this activity and will work with local entities as appropriate to address water withdrawal problems.

Comment From: Bruce A. Straughn (Councilmember, City of Granite Falls, Position #2)- Individual (I-8-1)

Thank you for the efforts of yourself and others in the development of the proposed Temperature and Dissolved Oxygen Total Maximum Daily Load Water Quality Improvement Report and Implementation Plan (TMDL) for the Pilchuck River located in Snohomish County. It is clear that the Pilchuck River is in need of protective and corrective measures to enhance the viability of migrating salmonids and other species.

I have read the proposed TMDL and supporting appendices, took copious notes, and intended to comment on many items that I felt could be worded differently or perhaps supported with additional data. In the end I have realized that the sum total of those comments would lead to very similar if not identical conclusions. So I will instead direct my comments on one statement which I believe is not accurate based on currently available information and a concern I have regarding financial equity.

First, Table 35 on page 96 indicates that effluent from the City of Granite Falls wastewater treatment plant could be percolated thru soil to reduce phosphorous discharges at an estimated cost of $619,000. The city hired a consultant to investigate that option approximately 18-24 months ago. It is my understanding that the results of the study were that the option was not feasible due to existing soil conditions. Unfortunately that likely means that other, more costly, means of phosphorous removal would need to be implemented.

My main concern with the proposed TMDL is with the statement on page 95 that "The Granite Falls WWTP should be allowed two full permit cycles (~10 years) to complete the necessary treatment upgrades and optimize operations for phosphorus removal." I am unaware of any regulatory framework for this statement or financial analysis regarding the feasibility of completion within that timeframe.

The TMDL identifies approximately $40.2 million in proposed watershed enhancements, with approximately one-half of that total ($20.4 million) applied to upgrades at the city's wastewater treatment plant (WWTP). Table 34 on page 95 identifies timeframe goals for the water shed enhancements unrelated to the WWTP. These enhancements are proposed to occur over 45+ years, with completion in 2066. It is also noted in the TMDL plan that the total benefits of those enhancements would not occur until possibly 50 years afterwards, correlating with the time for seedling trees to reach full canopy height.

Absent grants or legislative appropriation, costs for the treatment plant upgrade are borne by residents of the city, with a population of roughly 4,000. Costs for the other watershed enhancements are proposed to be borne by combinations of county wide funding sources (county population approximately 800,000) and state funding sources. The WWTP enhancements represent a burden on city residents of approximately $5000 per capita. If we assume all the non-WWTP costs are paid by Snohomish County residents the total would be $25 per capita. Compounding this enormous inequity is the proposed timeline of 10 years for completion of the WWTP upgrades, and 45+ years for all other watershed enhancements.

These inequities in total costs and drastically varying timelines are further exasperated by the realities of economic demographics. The annual median household income in Granite Falls is approximately $60,259, approximately 69% of the median for Snohomish County as a whole. Additionally, the poverty rate in Granite Falls is in the neighborhood of 11.5%, some 42% greater than the rate for Snohomish County.

It is also important to reflect on how the city has arrived in the position it now finds itself with regards to wastewater treatment. Our treatment plant is not an archaic relic from the days of the industrial revolution when treatment consisted of piping wastes to the nearest water body. It was constructed to produce effluent complying with the standards within WAC 173-221. That work, and subsequent upgrades, was completed with the review and approval of Ecology. In recent years Ecology has repeatedly recognized the city for the outstanding operation of the WWTP. The city now finds itself in a financially precarious situation after accommodating unprecedented growth as dictated by policy makers tasked with implementing legislated growth management requirements. In a nutshell, we build the WWTP we are required to build, operate it nearly flawlessly, accept more growth that many (likely most) residents desire, have that growth increase the pollutant levels from the WWTP, and then get hammered financially for the quantity of pollutants being released.

None of this is intended to argue that the upgrades and enhancements in the TMDL plan are not warranted. However, the city is not solely responsible for the current state of the Pilchuck River and should not bear a disproportionate burden on the proposed corrective actions. Absent very significant, and at this time unidentified, sources of funding the proposed WWTP upgrades cannot occur in the timeline proposed.

I ask that the timeframe for required WWTP upgrades be revised to treat the residents of Granite Falls more equitably. Perhaps having a trigger that begins a timeline for WWTP upgrade completion once an agreed percentage of design and construction costs have been secured. There are likely legislative actions the city council could undertake to commit the city to pursuing funding for WWTP upgrades and to ensure that the proverbial "ball" is not dropped.

Response To: Bruce A. Straughn (Councilmember, City of Granite Falls, Postion #2)- Individual (I-8-1)

Ecology understands that both the Clean Water Act and the GMA can place demands on communities. Ecology appreciates the financial and growth pressures on the City of Granite Falls.

All references to construction and other WWTP costs, including the $20.4 million, have been removed from the report for clarity. The $20.4 million costs include upgrades related to both population growth and nutrient removal, as well as baseline and new O&M costs. Not all of these costs are attributable to this TMDL.

The WWTP improvements would qualify for a low interest loan through Ecology's Water Quality Combined Financial Assistance Program. Additional funding sources for water and wastewater projects are available through the Infrastructure Assistance Coordinating Council at: https://deptofcommerce.app.box.com/v/sciwaterfundingsummary.

Ecology also removed the reference to a 10-year compliance schedule from the report. Ecology will work with the City to establish reasonable compliance schedules to meet the TMDL allocations through the NPDES permit process. Compliance timelines for the Granite Falls WWTP will be established as part of the NPDES permit in accordance with WAC 173-201-510(4).

The following language from WAC 173-201A-510(4) pertains to compliance schedules and TMDLs:

"(b) Schedules of compliance shall be developed to ensure final compliance with all water quality-based effluent limits and the water quality standards as soon as possible." ...
"(e) When an approved total maximum daily load has established waste load allocations for permitted dischargers, the department may authorize a compliance schedule longer than ten years if:

(i) The permittee is not able to meet its waste load allocation in the TMDL solely by controlling and treating its own effluent;

(ii) The permittee has made significant progress to reduce pollutant loading during the term of the permit;

(iii) The permittee is meeting all of its requirements under the TMDL as soon as possible; and

(iv) Actions specified in the compliance schedule are sufficient to achieve water quality standards as soon as possible."

Ecology revised the statement you referenced in your letter (page 1, paragraph 4), and it now reads: "Compliance timelines for the Granite Falls WWTP will be established as part of the NPDES permit in accordance with WAC 173-201A-510(4)."

Comments From: Snohomish County- Agency (A-1-1)

Comments #1 and #2 (Campbell):

1. It seems peculiar that the SRP loading from nonpoint source does not factor in the loading from decaying organic material from the forested areas along the river and tributaries. How can the list not include that? And how does that loading compare to the other nonpoint sources that are listed? Over time as shade is provided, even more decaying organic material will create loading. If SRP is a key factor, then the entire source loading needs to be considered, weighed and then factored into the implementation plan.
2. Add failing sewer systems as a source of phosphorus.

Ecology Response to Comment #1 and #2 (Campbell):

1. The water quality model does account for SRP loading from decaying organic material in the water and sediment. However, it was beyond the scope and resources of the study to attempt to accurately quantify the difference in organic matter loading in areas that currently have no vegetation versus full system potential vegetation. In general, organic matter from mature vegetation tends to break down more slowly and contribute less to DO problems then more easily broken down sources such as grass clippings or animal waste. In addition, as the natural riparian condition for the Pilchuck was forested, SRP loading would be considered natural background under this condition.
2. Noted. A bullet has been added to this section.

Comment #3 through #10 on Climate Change (Leonetti):

3. Please cite the source for values referenced in the sentence “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”.
4. Why reference Eastern WA? In the following sentence. “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”.
5. As it relates to the sentence “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)”. Since summer low flows have already been decreasing over the course of data availability, 1992-2020, what does that suggest about the risk of temperature increases due to natural causes. Doesn’t this suggest that increases assigned to human causes are less?
6. As it relates to the sentence “A loss of spring-melt may decrease or eliminate spawning opportunities for steelhead, alter egg survival and emergent fry for other salmon species, cause early dewatering of side channel and off-channel habitats, and reduce floodplain connectivity”. Is this true for Pilchuck – wouldn’t it be more rain dominated already since lower elevation and farther west?
7. As it relates to highlighted section the sentence below – it seems as though timing of emergence is missing here. “A loss of spring-melt may decrease or eliminate spawning opportunities for steelhead, alter egg survival and emergent fry for other salmon species, cause early dewatering of side channel and off-channel habitats, and reduce floodplain connectivity”.
8. Figure caption should be on same page as figure if possible.

9. Does the sentence here belong in section 3? “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)”.
10. As it relates to the sentences below – should there be an adaptive management chapter? “An Integrated Pest Management Plan4 (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”.

Response to Comments #3 through #10 on Climate Change (Leonetti):

3. Cited and added language.
4. Ecology received a comment to explain what the sustained duration of water temperatures in relation to the 1980s means. Eastern WA provided the clearest example to help illustrate. This same research indicated Stillaguamish River at Arlington is projected to have water temperatures greater than 21 degrees Celsius for 13 weeks by 2100 centered on the first week of August. However, it was unclear what Stillaguamish conditions were like in the 1980s, so a comparison could not be drawn. Changed the wording of "increased timing" to "sustained duration" to improve clarity.
5. Ecology found water temperatures and dissolved oxygen levels in August to be due to natural conditions. The watershed is (and will continue to be) sensitive to human impacts during the summer months.
6. According to the closest Snotel station (Alpine Meadows at 3,500 ft elevation - https://www.nrcs.usda.gov/wps/portal/nrcs/detail/or/snow/products/?cid=nrcs142p2_046266), the snow-water equivalent normally reaches a peak of about 50 inches in April and does not completely disappear until late June. Ecology reviewed the steep topography along the upper watershed boundary where Mount Pilchuck is located and found the peak elevation within the watershed to be nearly 5,300 ft. Given this is a higher elevation than the Alpine Meadows station, the effects of snow-water equivalency would be expected to be greater; and therefore, loss of spring melt is expected to be likely under climate change.
7. Ecology revised to "egg-fry survival" and cited source.
8. Comment noted.
9. Originally, this climate change section was in Chapter 3. Ecology felt the Climate Change section better fit the intent of Chapter 1 and being more upfront.
10. The TMDL has a specific adaptive management discussion in Chapter 3 and strived to include that topic where appropriate in other areas of the TMDL. Ecology added a sentence in Chapter 3, Restore Riparian Vegetation as follows: "In the face of climate change, other potential tree protection and maintenance activities discussed in Chapter 1, Climate Change Section should also be assessed."

Comments #11 through #15 on Load Allocations and TMDL (Britsch and Leonetti):

11. The first and second bullets under other loading limits and requirements contradict one another. Suggest removing the 1st bullet as BMPs are not expected to be required through municipal stormwater permits.

12. The third bullet under other loading limits and requirements suggests that municipal stormwater permittees may have mixing zones applied to stormwater discharges. Suggest clarifying that this applies to industrial stormwater permittees.
13. As it relates to the last sentence below - What is the proportion of the load allocation to Catherine Creek which drains Lake Stevens? No mention of warmwater discharge off of surface of stratified lake in summer? Is the diffuse load allocation solely assigned or due to Connor Lake? 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).
14. Is the statement below because 100% shading will not achieve temperature targets? "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".
15. Is there a comparison between these WLA values and current actual loading estimates?

Response to Comment #11 through #15 on Load Allocations and TMDL (Britsch and Leonetti):

11. Ecology has modified text in the first bullet to improve clarity to: "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."
12. Ecology decided this language is unnecessary and removed this bullet where it appears in this draft TMDL. Nothing in this TMDL affects how WAC 173-201A-400 is applied.
13. Ecology has revised the load capacity and allocation tables to clearly delineate the portion of loading assigned to Catherine Creek, Connor Lake Tributary, and Sexton Creek. Ecology recognizes that summer stratification in Star Lake and Connor Lake contribute to warmer temperatures in Catherine Creek and Connor Lake Trib. As the lakes are considered a natural or non-pollutant source of heat load, the goal in both of these smaller tributaries remains to create system potential vegetation and shade along the length of each stream. If these goals are met the anthropogenic/pollutant source of the impairment (loss of shade) will be addressed.
14. Correct. While Ecology found that shade is the most significant factor in lowering stream temperatures, other measures were shown through modeling to contribute to even more decreases to stream temperature. Thus the TMDL includes baseflow restoration and hyporheic exchange targets.
15. This TMDL does not directly compare current and future WLAs. However, the TMDL does include numerous elements to compare the impacts between the current and allocated loads including the modeling scenarios presented in chapter 4. For temperature, the TMDL compares existing vs system potential shade, existing vs recommend baseflow levels, and existing vs recommended hyporheic flow. For DO, Chapter 1 compares existing vs allocated phosphorus loads for the primary source, the Granite Falls WWTP.

Comment #17 on Chapter 3 Point Sources (Leonetti):

Suggest moving "Point sources of pollution" to the beginning of section 3.

Response to Comment #17 on Chapter 3 Point Sources (Leonetti):

Thank you for the good suggestion. Since this is a section that is part of the new Ecology TMDL document template, Ecology decided to retain the section without changes to avoid repetition.

Comment #19 through #25 on Chapter 3 Nonpoint Sources (Multiple Commenters):

19. 180ft is greater than County code for protection of buffers when developing. The added benefit of 30 feet from 150 to 180 feet away from a stream channel must have marginal/asymptotic improvement. Is it feasible to show what the differences are in terms of allocation between these?
20. As it relates to the sentence below - These widths are commonly not an option or reality. Need sliding scale for buffer widths, some is better than none. “Restore riparian shading to 180’ on mainstem and to Ecology Riparian Buffer Map widths on tributaries.”
21. Community-based social marketing (CBSM) is a proprietary method. Revise to say "Use a social marketing process to determine most effective outreach and education efforts to landowners." Funding needed for this process and inclusion of all key stakeholders needed. Priority audience should be inclusive of all residents, not just landowners.
22. Feedback from the Salmon Recovery Funding Board review of the Middle Pilchuck project was that boulders were not a preferred element. This type of element might be difficult to fund.
23. How does installing LWM to create edge habitat improve temperature or DO?
24. Include funding an incentive program (easements, buffer plantings, etc.) to encourage landowners to install BMPs on their property.
25. Include application of nutrients at agronomic rates under the BMPs for nutrient, sedimentation and erosion control.

Response to Comment #19 through #24 on Chapter 3 Table 24 (Multiple Commenters):

19. Unfortunately, the difference in temperature between 150 vs 180 buffers is difficult to quantify because it includes the more subtle microclimate and hyporheic floodplain shading effects. While it is feasible to show the difference of impact due solely to shade between these two widths, Ecology does not plan to conduct this additional analysis at this time, given that the study has determined the need for 180 foot widths to express full microclimate benefits.
20. Although some riparian buffer is better than none with regard to decreasing solar inputs to streams, Ecology temperature TMDLs are designed to show how to be fully protective of water quality in an impaired waterbody. The science from our study shows us 180 feet is what is needed on the mainstem to represent the thermal impact of vegetation in the watershed's original undeveloped state. In the long term, large buffers also contribute to reestablishing natural processes, associated especially with the Pilchuck River's actively migrating channel. For water quality improvement purposes, this TMDL encourages the largest buffer (up to 180 ft) be planted. Besides site-specific limitations and landowner willingness considerations, individual funding sources and restoration practitioners must decide what size buffer on a particular stream constitutes an acceptable benefit from that investment.
21. Ecology e-mailed Doug Makenzie-Mohr (the founder of community-based social marketing) on November 17, 2020, and he confirmed that neither the phrase nor the methodology is patented. Existing language will remain. Ecology agrees with the commenter that funding is needed for this process. Although this TMDL envisions outreach to a targeted audience due to the resource limitations, we do not want to discount a broader effort that would also capture community support.

22. Ecology removed "boulders" from table 24 to be more consistent with Salmon Recovery Board preferences.
23. Some cool water inputs observed during our study resulted from small surface water inputs on side banks. Because rearing salmonids are known to use these areas, we wanted to document the potential need for this BMP and fully support restoration specialists that may wish to maximize habitat benefits in these small but important microhabitats.
24. Ecology agrees that incentive programs are essential tools to encourage installation BMPs. To avoid redundancies in Table 24, we will stress this tool to help implement our "Key Strategies" in the Cost and Outreach sections. See text in the new "Other Funding Opportunities" subsection.
25. Ecology added this important best management practice in Table 24 and in the text under "Nutrient, Sediment and Erosion Control" section.

Comment #26 through #28 on Chapter 3- Key strategies for reducing water temp and nutrient inputs (Leonetti and Jackson):

26. As it relates to the sentence below – narrower and deeper channels are not demonstrated in unimpaired riparian zones. narrower and deeper is associated with channelization and impaired vegetation. “In some locations, they provide indirect benefits related to air cooling, supplying woody material, and eventual narrowing and deepening of the stream channel”.
27. The riparian buffer widths map tool does not show 180ft buffer width of the Pilchuck, rather a maximum of 100ft. Need to resolve discrepancy.
28. Consider referencing the King County Small habitat restoration program as a model incentive program.

Response to Comment #26 through #28 on Chapter 3- Key strategies for reducing water temp and nutrient inputs (Leonetti and Jackson):

26. Ecology agrees with the observation made in this comment. Our intent in this sentence is to support the reestablishment of vegetation that 1) returns sidebank erosion to natural levels reducing the likelihood of excessive sediment deposition downstream that reduces stream depths and 2) prevents stream widening due to accelerated sidebank erosion and exposes a waterbody to more contact with warm air temperatures and additional solar radiation.
27. The GIS mapping tool was not developed as part of this TMDL study. It was developed to show the minimum buffer widths that can be funded through Ecology's Combined Funding Program. Since our TMDL focused on modeling of the mainstem Pilchuck River and considered tributary interactions as single-point inputs, we felt that buffer widths set in the mapping tool set a good restoration goal for the tributaries. Buffer widths in the mapping tool are highly likely to restore tributary temperatures to the maximum allowable level shown in the Water Quality Standards, or better, even though those widths were not specifically modeled in the TMDL. Thus, they would be highly protective of these smaller streams and be a good investment of both public and private funds.
28. Noted and added. See comment 24 discussion and King County Small Habitat Restoration at https://green2.kingcounty.gov/small-habitat-restoration/default.aspx.

29-37: Ecology made minor edits.

Comment #38 through #46 on Chapter 3 Water Conservation and Streamflow Augmentation (Multiple Commentors):

38. As it relates to the sentence below – The phrase "adding water back" suggests it has been taken out. Was this already established somewhere else in doc? “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 goal of this TMDL”.
40. As it relates to the sentence below – How are the actions required? “Implementation actions required to improve stream flows are discussed below”.
41. As it relates to the sentence below – Using HSPF geology soils data via GIS analysis, it became apparent that the spatial distribution of outwash soils combined with the % of outwash soils capable of infiltration is a barrier to infiltration of stormwater. The percentage of outwash soils within each analyzed basin are as follows: Dubuque = 2%, Lake Stevens = 1%, Little Pilchuck Creek = 9%, Lower Pilchuck River = 9%, Middle Pilchuck River = 25% and Upper Pilchuck River = 20%. Please recognize these limitations in the TMDL.
42. Please recognize the need for and/or identify incentive programs to facilitate use of Low Impact Development.
43. As it relates to the paragraph below - Do we know where groundwater flows either to Little Pilchuck or Pilchuck River? Is there a groundwater divide? “Ecology provides a detailed example on how to estimate groundwater volume, groundwater velocity, travel time, and drainage area for infiltration facilities (Appendix J). This analysis 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”.
44. I don’t think it’s feasible in most cases for new homes in the basin to use imported water. The county does not have regulatory tools to require that all new homes in the basin import their water from outside the basin. We can require hook-up to existing water systems where available, but some of the water systems could be using supply obtained in the basin.
45. Help us understand how having new development obtain water from outside the basin, increases flow in the Pilchuck. Wouldn’t there be just as much water taken out by users as there is now? Seems like it could ensure that stream flows aren’t reduced further.
46. Requiring irrigation audits could perhaps have the greatest impact on conservation measures. It revolutionizes irrigation practices and makes sure that every drop counts. This is critical for large-scale irrigation as well as smaller scale. Conservation measures must be fully endorsed and supported by local water purveyor(s) - public, community or private. Funding of incentives may likely be necessary to create the greatest impact. WATER CONSERVATION PRACTICES: A key impact is made when natural soil moisture and soil texture are taken into consideration before plants are selected, and when mulching is applied to bare soil areas.

Response to Comments #38 through #46 on Chapter 3 Water Conservation and Streamflow Augmentation (Multiple Commenters):

38. While evaluating water withdrawal impacts to summer baseflow, Ecology found that over 15 cfs of net baseflow loss occurred due to pasture/turf irrigation in August. This is discussed briefly in summer baseflow targets section in Chapter 4. For greater context into the water use estimates, please see Appendix H: Baseflow Loss and Water Use.
40. Ecology acknowledges use of the word "required" in this TMDL even where there is no regulatory mechanism in place to ensure implementation occurs. It was a conscious choice to

stress the importance of accomplishing each restoration action. Although some actions are not specifically required by law, they are required – or are necessary – to return the waterbody to good health.

41. Ecology examined soil depth and feasibility and added language in the "Water Conservation and Streamflow Augmentation Section" and Appendix J. See Appendix J, Streamflow Augmentation Analysis - "Feasibility of Stormwater Infiltration Practices" for a detailed analysis.
42. Ecology mentioned creating incentives for LID in the Outreach Section in the last bullet "Create incentives for developers to promote LID and stormwater BMPs; and irrigation efficiency BMPs through incentive programs." Ecology added "through incentive programs" to make more clear. See comment # 24.
43. Ecology did not have detailed enough groundwater information to determine where a subsurface divide might exist between the Little Pilchuck and Pilchuck. As described in the baseflow loss appendix, Ecology used the assumption that all groundwater stays within the subbasins delineated based on surface water features.
44. The TMDL does not require new homes to use imported water, merely recommends it, and Ecology recognizes that it may not be feasible in some locations. Ecology believes the feasibility of imported water use will likely improve over the relatively long TMDL implementation period as infrastructure expands.
45. Imported water does generally result in a net increase in flow to a system as a portion of outdoor irrigation and indoor use routed to septic systems recharge local groundwater levels. In addition, imported water users in Granite Falls add flow to the river via discharge through the treated WWTP effluent.
46. Ecology's Water Resources Program supports conservation efforts including optimization of irrigation practices, but irrigation auditing is not a practice that is regulated or required. Ecology added the following language: "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."

Comment #47 through #54 on Chapter 3 Streamflow Augmentation through Beaver Management (Multiple Commenters):

47. As it relates to the paragraph below - Provide a citation for streamflow augmentation. It's not clear that this has been demonstrated in western Washington. "Beaver dams can significantly increase summer baseflows by increasing both surface and subsurface water storage by causing water to pond and infiltrate".
48. As it relates to the sentence below - I would be cautious about equating storage with downstream flow improvement? Dittbrenner (2019) found that beaver relocations to headwater streams in the Skykomish watershed created 243 m3 of surface water storage and 581 m3 of subsurface water storage per 100 m of stream reach in the first year following relocation.
49. As it relates to the sentence below - I'm sure they are much more widespread. Would it be useful to have an assessment of beaver occupancy? Beavers are currently present in both the Little Pilchuck and Dubuque subbasins (Snohomish County, verbal communication 11/16/17).
50. Beavers do great things for water quality and fish and wildlife, but we know a lot about some of the impact's beavers have on human activity and infrastructure. These are known and should be

briefly mentioned in the section that talks about needed planning and human/beaver interactions. Modify language to say: Known and potential conflicts between beavers and humans 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.

51. Landowner outreach for beaver restoration is critical but may also want to mention/consider acquisition (fee simple, easement, other) of properties (or portion) with characteristics suitable for beaver colonization and water storage.
52. Agree that further beaver population should be assessed, but my experience tells me it is likely that there are enough animals in the Pilchuck basin that we should assume any constructed BDA constructed will shortly be occupied by beavers.
53. Throughout the document pertaining to beaver planning (ex. see pg 74) text says "a" WDFW biologist should be consulted. This should be changed to WDFW wildlife biologists or something similar.
54. As it relates to the sentence below - I would be cautious about the applicability to Pilchuck from observations in eastern WA or elsewhere in the country. Maybe use more cautious language. "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)".

Response to Comment #47 through #54 on Chapter 3 Streamflow Augmentation through Beaver Management (Multiple Commenters):

47. Ecology modified this sentence to: "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)."
48. Comment noted. Ecology added the following sentence to clarify: "Adding surface water features and increasing subsurface storage is expected to increase downstream flows."
49. Ecology agrees it would be useful to have a beaver assessment. In the last sentence in "Streamflow Augmentation through Beaver Management" section, Ecology states: "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." Ecology also modified the sentence to read: "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 watershed."
50. Noted. Added suggested language.
51. Ecology added a sentence: "Where necessary, property acquisition or easements should be considered where conditions are suitable for beaver colonization and water storage."
52. Noted. Ecology added the following language: "Careful site planning is a must when considering BDAs. Snohomish County noted any BDAs constructed in the Pilchuck River watershed are likely to be shortly occupied by beavers (Rustay, M. public communication, November 13, 2020)."

53. Noted. Changed all WDFW habitat biologist references to "WDFW wildlife biologists" to be consistent.
54. Comment noted. Ecology acknowledges that more experience is needed in the area of flow augmentation, especially as the techniques apply to Western Washington. This TMDL encourages research and pilot projects to study the placement, construction, and detailed monitoring of flow augmentation projects in Western Washington.

Comment #56 and #57 on Chapter 3 Nutrient Sediment, and Erosion Control (Multiple Commenters):

56. As it relates to the sentence below – I think it would be more appropriate to say that 7.53 prohibits discharges that contain contaminants, including sediment. Regardless of whether a stormwater prevention plan exists, which they don't for rural residential/hobby farms, they are still prohibited from discharging pollution. Also – edit to include highlighted language below. The Snohomish County Water Pollution Ordinance14 (Snohomish County Code 7.53) may allow or require best management practices (BMPs) described in appropriate stormwater prevention plans. The need to plant trees in riparian areas is not specifically discussed in the ordinance, so landowners must be sure to include this in the design of animal grazing areas.
57. Include Snohomish County Critical Areas regulations and required use of best management practices for agriculture.

Response to Comment #56 and #57 on Chapter 3 Nutrient Sediment, and Erosion Control (Multiple Commenters):

56. Noted and added suggested language. Further edits were made in this section (see comment 57 for the revisions).
57. Ecology modified text regarding SCC 7.53 and Chapter 30.62A Part 600 (agricultural activities) as follows: "The Snohomish County Water Pollution Ordinance (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 (Chapter 30.62A.620-640) specifically addresses standards and conditions relating to commercial agriculture. The ordinance requires the use of agricultural BMPs 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."

Comment #61 and #62 on Chapter Where do we have opportunities for improvement (Leonetti):

61. As it relates to the sentence below - Summary of NSDZ, pool frequency and targets needs to be revised. The pers. comm referenced is incorrect. Snohomish County has never used NSDZ for channel width measurement, nor for pool frequency calculation. Please reference the source for pool target estimates. “The frequency of pools was calculated by multiplying the NSDZ channel widths by 1.9 channel width/pool (Leonetti, F. Personal communication. April 2018). Further information on where additional pools are needed is discussed later in the Middle and Lower Pilchuck subbasin sections”.
62. It would be useful to highlight the gap between existing and target pool frequency. Also – Include units (meters) and source. Are these Ecology measurements or from SnoCo 2012?

Response to Comment #61 and #62 on Chapter Where do we have opportunities for improvement (Leonetti):

61. The Snohomish County citation was solely meant to note where the channel width/pool information was originally derived. The Snohomish County reference no longer applies as Table 25 was modified based on another comment and now references the 1996 Matrix of Pathways and Indicators.
62. Comment noted. Ecology added columns to Tables 27 and 29 to show the differential between the existing pool frequency and the estimated targets address this comment. Ecology added units to the NSDZ channel width column. Sources are cited within the text.

63-76 – Ecology made minor edits. For comments 67 and 68, Ecology added reach maps to Appendix K.

Comment #77 Chapter 3- Reach 3 (RM 14.45 to 18.32) (Leonetti):

77. As it relates to the sentence below - Sentence doesn't make sense as far as explaining the logic for hyporheic cooling. Also please expand on the potential that the abandoned mainstem (now effectively an oxbow channel) is a new CWR due to groundwater inflow, improved shading, and possible beaver colonization. Beaver dam analogs may also be appropriate.

Response Comment #77 Chapter 3- Reach 3 (RM 14.45 to 18.32) (Leonetti):

77. Revised to: "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."

78-88 – Ecology made minor edits.

Comment #89 and #90 Chapter 3- Snohomish County Planning and Development Services (Byline):

89. When discussing the Critical Areas regulations, consider adding that they require the use of best management practices on agricultural lands to protect functions and values of habitat.
90. In reference to ESHB 1886, Snohomish County did not choose to implement the alternative and voluntary process for addressing the Growth Management Act to address critical areas in agricultural areas.

Response to Comment #89 and #90 Chapter 3- Snohomish County Planning and Development Services (Bylin):

89. Ecology added the following text: "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 BMPs to protect the functions and values of wetlands and fish and wildlife conservation areas."
90. Ecology removed the discussion of ESHB 1886 in the TMDL.

91-98, 100, 103-104 – Ecology made minor edits.

Comment #99 Chapter 3- Technical Feasibility (Majewski):

99. As it relates to the sentence below - It might be helpful for readers to understand that much of this area and any area that discharges straight to the river or tribs is not regulated by the NPDES permit. Also – suggest making the following edits. 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.

Response to Comment #99 Chapter 3- Technical Feasibility (Majewski):

99. Comment noted. Ecology has rewritten the Technical Feasibility section to address this comment. Ecology also included a reference to Chapter 2, TMDL Formula section, which defines point source and nonpoint source pollutants in terms of the NPDES permit. Other sentence edits were accepted.

Comment #101 and #102 Chapter 3- Costs and Education (Majewski):

101. As it relates to the sentence below - I don't think most BDAs could be installed quickly as they will require an HPA. 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.
102. As it relates to the sentence below – Please remove this reference (Environmental Justice screening tool) as organizations use other tools to do this work. This includes Title VI related compliance datasets, datasets from WA DOH (Environmental Health Disparities Map), etc.

Response to Comment #101 and #102 Chapter 3- Costs and Education (Majewski):

101. Added: "Once the proper permitting (e.g. Hydraulic Project Approval - HPA) is obtained, BDAs and PALs can be installed…"
102. Ecology retained reference to this screening tool since this tool is recommended for use during management of Ecology Water Quality Program grants. Ecology modified language to: "...using EPA's Environmental Justice screening tool or other similar EJ tools."

Comment #105 through #110 Chapter 3- Effectiveness Monitoring and Tracking Progress (Multiple Commenters):

105. As it relates to the sentence below - I don't think this is a true statement "Most project managers have some level of effectiveness they are required to meet as part of their planning projects."
106. In addition to pools created and enhanced, need to also specify effectiveness to form cold water refuge or improvement. A lot of the justification for LWM and pool formation is predicted on a CWR response. Need to monitor for that.
107. As it relates to the sentence below - Is the effective shade target simply 100% of potential? Is this stated somewhere? "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".
108. As it relates to the sentence below - I don't recall seeing a specific streamflow restoration target? 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.
109. As it relates to the sentence below – Shouldn't the effective shading and improvement just be modeled, using hemispherical data as a calibration input? "Establish baseline hemispherical photography of watershed, then take hemispherical photographs every 10 years to evaluate whether shade deficit target of 85% has been met (Table 36)".

110. As it relates to the bullets under the sentence below - Can this set of bullets reference the streamflow restoration target mentioned in the previous paragraph? Baseflow monitoring to evaluate progress towards restoring water to the river system.

Response to Comment #105 through #110 Chapter 3- Effectiveness Monitoring and Tracking Progress (Multiple Commenters):

105. Ecology modified the text as follows: "Many project managers have some level of effectiveness they are required to meet as part of their duties and Ecology will encourage our partners to measure implementation project performance in order to help measure the success of this TMDL. Ecology also modified the last sentence to: "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."

106. Ecology added two bullets as follows: 1) “water temperature measurements between CWRs and adjacent stream channel to note CWR effectiveness” and 2) “use of CWR by holding adult and rearing juvenile salmon.”

107. The effective shade target is the system potential shade which is defined in several places throughout the document. This is near 100%, but in some places slightly less as we do not assume vegetation in areas of existing roads and houses. Chapter 4 contains effective shade targets which can be measured. These targets have also now been summarized by reach in Chapter 2. Ecology added a definition of effective shade to the glossary in Appendix C.

108. Streamflow Restoration targets may be found in Chapter 4, Summer Baseflow Restoration Targets, Table 58.

109. Effective shade can be calculated from the hemi photos using the HemiView or GLA software. Assuming it is done in a representative way, this approach provides % effective shade that can be directly compared to the reach shade targets in the TMDL or the shade curve (Figure 56) at a site or project scale. This provides a more cost effective way of evaluating shade progress compared to performing extensive shade modeling.

110. Noted. Ecology added information to indicate where summer baseflow restoration target table may be found (Chapter 4, Summer Baseflow Restoration Targets section, Table 58).

Comment #111 Chapter 3- Reasonable Assurance (Majewski):

111. Should regulatory authority be added the Ecology’s list of bulleted items?

Response to Comment #111 Chapter 3- Reasonable Assurance (Majewski):

111. Ecology has expanded the rationale as it relates to Ecology's regulatory authority.

Comment #113 through #120 Chapter 4 (Leonetti and Britsch):

113. As it relates to the sentence below – It looked like groundwater flow gains ended near Dubuque Creek. Can you explain the apparent cooling present downstream from RM 8.5. Flow gain from seepage was reported in the reach above this. Is this a downstream effect from that or a possible undetected seepage that continues down river? There are few to none cool surface inputs downstream from Dubuque Cr. “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)”.

114. Does Ecology consider all TMDL analysis to constitute a "reasonable potential analysis" under 40 CFR 122.44(d)(1)(i), which aids in determining that MS4 discharges have the reasonable potential to cause or contribute to an in-stream excursion above a narrative or numeric criteria? If so - does Ecology expect EPA may approve this as a stormwater TMDL - whereby Ecology would then require implementation of programmatic actions under municipal stormwater permits?

115. Please help the County understand why a Wasteload Allocation for temperature has been assigned, when stormwater has not been found to be a source of temperature loading to the stream when receiving water temperatures are impaired. In fact, temperature monitoring from the 2012 study indicates that stream temperatures are likely to decrease during significant runoff events.

116. As it relates to the sentence below - Change "working" buffer to functional. In some cases, "working buffers" refers to agricultural uses within wider buffers. “Planting or protecting a wide buffer retains some working buffer and effective shade following large channel migration events”.

117. As it relates to the sentence below - Please provide a reference to the "strong conceptual relationship" “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”.

118. As it relates to the sentence below - Given peak annual air temps are the largest driver, how is climate change expected play into load allocations or strategies? “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”.

119. As it relates to the sentence below - Can a brief reminder be added here to explain the steep increase in temperature - shading?, losing reach?, air temp increase?, withdrawals, point discharge?? “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.”

120. As it relates to the sentence below – Shouldn’t this bullet be a sub-bullet of the previous bullet point. “Quantify hyporheic flow fraction, depth, and thermal properties to refine our understanding of the impact of hyporheic restoration over multiple scales”.

Response to Comment #113 through #120 Chapter 4 (Leonetti and Britsch):

113. It should be noted that this language states "stable or cooling" and in this case the magnitude of the change is not large below RM 8.5 (~0.1 deg C). Based on observations and analysis, Ecology does not believe this is attributable to undetected seepage. The model suggests this change is largely attributable to changes in channel geometry, as the river generally becomes a bit deeper and narrower in the lower stretch.

114. Ecology does not prepare stormwater and non-stormwater TMDLs. All TMDLs consider and address all relevant pollutant sources; the approach is not the same as a reasonable potential analysis used in water quality permitting. Where municipal stormwater is determined in a TMDL to contribute to impairment, the TMDL can serve as a reference for documenting that contribution to impairment. Ecology assesses if a municipal stormwater permittee’s WLA

reflects a major reduction from the current estimated loading. Some TMDL WLAs do not require additional actions beyond the existing permit requirements. Where existing MS4 permit conditions do not adequately ensure compliance with a wasteload allocation, Ecology may add requirements to MS4 permits to complement other permit requirements and ensure water body improvements.

115. Although limited data from the mouth of the Little Pilchuck suggests temperatures are likely to decrease during significant runoff events, this is not definitive proof. Thermal loading from stormwater can still carry pollutant heat load and Ecology is required to set WLAs for any potential permitted discharges of a pollutant. The WLAs are set at levels that are demonstrated within the model to be protective of water quality. Ecology recognizes that current stormwater management practices appear protective and the TMDL has not recommended any additional actions beyond those in the current permits.
116. Noted and changed.
117. A reference to Appendix G (Natural Conditions Documentation) has been added to the main document. In the appendix this conceptual relationship is discussed in greater detail with citations from the literature.
118. Ecology recognizes that climate change provides a shifting baseline that makes natural resource planning particularly challenging, including in TMDLs. While it is very important to plan for, climate change represents a non-pollutant impact that is not typically factored into TMDL allocations. However, climate change does play heavily into the TMDL implementation strategy in the Pilchuck River, which has elevated the priority/importance of implementation measures that support cold water refuge and near term mitigation of increasing temperatures.
119. Noted and a brief reminder has been added. The steep increase is attributed to changes in air temperature and elevation, as well as channel width and shading. This is a relatively common and natural effect when transitioning from narrower upland canyon topography to a more open valley and floodplain.
120. Noted and Changed.

Comment #124 (Glaub):

124. Ch3/Organizations: "Habitat" more inclusive of all projects SnoCo supports, including riparian restoration. Suggested Language: Habitat restoration work through discretionary and grant funding.

Response to Comment #124 (Glaub):

124. Ecology decided retain the existing language in order to be consistent with language throughout the document. Instream restoration was added per an earlier comment.

Comments #16, 18, 29-37, 63-76, 78-88, 91-98, 100, 103-104, 121-123, 125-129 (Multiple Commenters):

Various suggestions for wording, grammar, spelling, formatting, and organization.

Response to Comments #16, 18, 29-37, 63-76, 78-88, 91-98, 100, 103-104, 121-123, 125-129 (Multiple Commenters):

Noted and minor changes made where applicable.

Comments From: Lisa Kusnierz -EPA Region 10- Agency (A-2-1)

Comment #1:

EPA recommends that the assessment units (AUs) indicated in Tables 1 and 2 be denoted in Figure 2 or another figure to visually show where all AUs addressed by the TMDLs are located. Additionally, the designated uses and applicable criteria in Tables 4 and 5 primarily reference upstream and downstream of Boulder Creek on the Pilchuck River, and without the AUs being identified in a figure or the water quality standards tables, it is difficult to discern what uses and criteria apply to all tributaries and AU segments; EPA requests that the document more clearly identify the uses and criteria applicable to each AU.

Response to Comment #1:

Ecology recognizes the need for clarity around the location of the AUs. We have added a column to Table 1 referencing the general location of the AU and a sentence between Table 1 and 2 clarifying that all currently identified impaired units are located below Boulder Creek. We have also added 303(d) listings to Figure 2.

Comment #2:

In the Targets discussion on p. 20, EPA requests that Ecology explain the basis for the surrogate targets/TMDLs. Although the potential factors influencing temperature and dissolved oxygen are discussed generally on p. 22/23 and in depth in Section 4 and Appendix F, the surrogate approach being used and its basis is not clearly presented.

Ecology Response to Comment #2:

Ecology edited the targets discussion to include information on how the model and study results demonstrate the connection between the surrogates and their impact on temperature and DO.

Comment #3:

Wasteload allocations for temperature, phosphorus, and biochemical oxygen demand are commonly referenced in the document as limits versus allocations. Because TMDL wasteload allocations must be incorporated into a permit before they are an enforceable limit and this terminology could be confusing, EPA recommends consistent usage of the term wasteload allocation.

Response to Comment #3:

Ecology recognizes the use of the term limit is confusing, given its specific meaning in NPDES permits. All references to limits have been changed to 'targets' or 'allocation' depending on the context.

Comment #4:

In Chapter 2, Loading Capacity, please also include (or reference, if they are clearly identified elsewhere in the document) loading capacities for the tributaries for which temperature and dissolved oxygen TMDLs are being developed: Catherine Creek, Dubuque Creek, Little Pilchuck Creek and Unnamed Creek. Although Unnamed Creek is not impaired for temperature, if there is a thermal loading capacity that Ecology has identified is needed to address the dissolved oxygen impairment, that should be identified. Additionally, please identify the listing ID(s) and impairment addressed by each TMDL/loading capacity.

Response to Comment #4:

Ecology has added the tributaries and sub reaches to the loading capacity and TMDL tables in Chapter 2 to clearly identify the capacity related to each listing/impairment. Ecology also added cross references to listings and assessment units.

Comment #5:

The target and allocation for effective shade is not presented consistently within the document. EPA's understanding matches with most of the references in the document, which describe the allocation as being site potential vegetation on the entire length of the tributaries. However, in the load allocation discussion on p. 177 (2nd and 3rd paragraphs), Ecology notes shade allocations have been established for the lower two miles of each tributary, and the temperature target discussion on p. 20 implies allocation to natural conditions is only in certain places where it says effective shade is "Assigned to specific river reaches to measure implementation progress and site-specific compliance."

Response to Comment #5:

The reference to "the lower two miles of each tributary" was a remnant of an earlier draft of the document. This language has been removed and both Chapter 2 and 4 now clearly identify that the allocation is system potential shade for the entire length of the impaired tributaries.

Comment #6:

If Figure 56 also illustrates the effective shade for the tributaries, please indicate that in the title of the Figure, and in the text (where appropriate). If Figure 56 does not indicate the effective shade for the tributaries, EPA requests those be identified.

Response to Comment #6:

Ecology edited the title of Figure 56 and associated in-text references to clearly state that the shade curve applies to the mainstem and tributaries. In addition, Ecology added a footnote to Chapter 2 load capacity table that points to Figure 56 as effective shade targets for tributaries.

Comment #7:

It appears that several assumptions associated with the wasteload allocations, including the reserve wasteload allocation, are described in Section 4 but not included or referenced in Section 2 where the wasteload allocation tables and requirements are presented. EPA requests that all associated assumptions regarding wasteload allocations be included or referenced in Section 2.

Response to Comment #7:

The "future individual permits" section in Chapter 2 contains the reserve wasteload allocation. Ecology edited this section, heading name, and heading level to make it clear that this is the reserve allocation. Ecology made additional edits to Chapter 2 to improve clarity and clearly reference Chapter 4 for detailed assumptions.

Comments From: Brent Kirk (City Manager, City of Granite Falls)-Agency (A-3-1)

I know that there have been concerns about reduce flows in the Pilchuck due to individual property owners drilling wells, so I thought you would like to know the DOE in the past 2 months has approved 2 wells to be drilled less on riverfront lots on Paradise Lane without any notification to the city. I was told by Sno Co Health District that these are being permitted for "irrigation purposes" by

DOE and the District, which is BS because I know that the people are using them down there for potable water and living on these lots with blackballed septic systems, but I can't prove it once they bury the septics. And the city evidently is not being looped in on the permit issuance for these wells from DOE. So you may want to talk to someone in your organization about banning well permits in that area because everyone down there knows how to work the system now and I expect others to apply and be granted permits from DOE in the future. I don't understand why DOE would permit these wells so easily within 200-300 ft from the river when the TMDL clearly shows that these actions are detrimental to temperature and stream flows.

Response to Brent Kirk Comment (A-3-1):

Ecology’s Water Resources Program has not approved any water right permit in the vicinity of Paradise Lane, Granite Falls, in 2019 or 2020. However, small uses of groundwater are generally legal without a water right under the groundwater permit exemption (RCW 90.44.050), with further limitations under the Streamflow Restoration law (RCW 90.94.030). Please be advised that Ecology has not “approved 2 wells to be drilled” as suggested by Mr. Kirk. Ecology does not approve/deny drilling of wells; we simply receive notification that a well is proposed and that it has been completed. If it requires a water right, then a permitting decision may be made.

Ecology does regulate whether wells are constructed properly. Recent records of well drilling submitted to Ecology (Well Reports and Notices of Intent) in the vicinity of Paradise Lane, Granite Falls have been identified and reviewed by the well construction coordinator for well construction code violations. The minimum standards in the well construction code specify requirements for well construction, but do not establish covenants or setbacks from wells for other infrastructure development. As such, it is likely there is no administrative authority Ecology can wield regarding anything constructed within setbacks after the fact. However, degradation of the groundwater resource is always taken to be non-compliant behavior.

Comment (Brent Kirk comments via e-mail):

We have reviewed the Draft TMDL Plan referenced above. The City agrees that the water quality of the Pilchuck River should support a robust and diverse aquatic ecosystem. To achieve that diversity, the Pilchuck River needs help as indicated in the draft plan.

The Draft TMDL Plan proposes riparian improvements, stormwater controls and upgrades to the Granite Falls wastewater treatment plant, the sole municipal wastewater discharge on the river. The Draft TMDL indicates that two new parameters will be added to the Granite Falls Wastewater Treatment Plant NPDES permit - phosphorus (SRP) and temperature. In addition to the increased treatment requirements being proposed, the City will not be given any increase in BOD_5 loading relative to its current permit.

The 2018 Wastewater Facilities Plan anticipated these permit requirements: 0.31 lb/day SPR (approximately 0.1 mg/L), 139 lb/day BOD_5 and new seasonal temperature limits. Various new facilities at the treatment plant are recommended in the Facilities Plan to meet the anticipated requirements. However, the cost of the recommended upgrades is daunting, estimated at approximately $20,000,000.

At the same time that new wastewater permit discharge limits for the City are being proposed, regulations related to Growth Management are requiring the City to accommodate a population target more than double its current population, with another increase in population allocation projected for the next comprehensive planning update. This effectively results in a “squeeze play” being imposed upon the City by numerous outside forces.

The City does not have the financial resources to implement the necessary water quality improvements at the wastewater treatment plant in the recommended 10-year time period. Using the current population as a base, the necessary upgrades may cost approximately $15,000 per household.

If Ecology pushes forward with the TMDL, we sincerely hope that Ecology recognizes the financial impact on the citizens of Granite Falls and makes funding available to the City so that the City may proceed with the upgrades to benefit the Pilchuck River system. We support improving the water quality of the Pilchuck River as it will benefit all who live in or visit the watershed.

Response to Brent Kirk comments via e-mail:

See response to Bruce A. Straughn’s comments (Comment #I-8-1).

Comments From: Kelsey Taylor- Snoqualmie Indian Tribe (T-1-1)

Comment #1:

I can't tell the difference between the 100ft buffer and the 75ft buffer. I recommend either making the 75ft buffer a different color/thickness or removing 100ft entirely, with just 75+, 50, and 35ft.

Response to Comment #1:

Comment acknowledged. The GIS mapping tool was not developed as part of this TMDL study. It was developed to show the minimum buffer widths that can be funded through Ecology's Combined Funding Program. Since our TMDL focused on modeling of the mainstem Pilchuck River and considered tributary interactions as single-point inputs, we felt that buffer widths set in the mapping tool set a good restoration goal for the tributaries. Buffer widths in the mapping tool are highly likely to restore tributary temperatures to the maximum allowable level shown in the Water Quality Standards, or better, even though those widths were not specifically modeled in the TMDL. Thus, they would be highly protective of these smaller streams and be a good investment of both public and private funds.

Comment #2:

The link would be more effective if it went to the buffer widths required for each stream type. The list of definitions that the link goes to does not include stream type as a definition.

Response to Comment #2:

Stream types and associated buffer widths are described under "Riparian management zones" at the link provided. Ecology revised the footnote to improve clarity.

Comment #3:

Wetlands difficult to see on map, consider revising.

Response to Comment #3:

Comment acknowledged.

Comment #4:

Significant adding error in subtotal for point source costs.

Response to Comment #4:

Ecology removed the Point Source costs since the WWTP has not yet completed the design phase.

Comment #5:

Broken links that say “Error! Reference Source Not Found.”

Response to Comment #5:

Noted. Ecology thought we fixed this, but it somehow occurred again right before publication. We will attempt to correct this in the final version.

Comments From: Kurt Nelson- Tulalip Tribes (T-2-1)

Comment #1:

Table 1. Can the river mile be added to the reach code or add an additional column

Response to Comment #1:

Ecology recognizes the need for clarity around the location of the AUs. We have added a column to Table 1 referencing the general location of the AU.

Comment #2 through #6 Chapter 1- Fish Distribution:

2. Table 4. We observed bull trout at the old Pilchuck Dam site at roughly the Purdy Creek junction.
3. “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 of the daily maximum temperatures (7-DADMax). The metric includes an adequate magnitude and duration (averaging period) to protect salmonids and represents conditions in the thalweg or main stream channel. In setting this standard, it is assumed that aquatic fish species have access to cold water refuge where they can reside in water that is cooler than the 7-DADMax temperatures and that colder temperatures are available to protect fish at night.” I do not understand this assumption, is this part of a criteria? Do you have assumptions like this for spawning or incubation? Plays down the impact.
4. Chinook have been observed spawning up to Worthy Creek this year. The first time in a 100 years.
5. Do you want to mention Pink Salmon? A principle issue maybe adult migration which would include Pink Salmon.
6. Does spawning availability mean access?

Response to Comment #2 through #6 Chapter 1- Fish Distribution:

2. Ecology added text to note this observation.
3. This series of statements was meant to both explain the temperature criteria in state standards and provide more detail on how fish experience thermal stress. Because stream characteristics vary throughout a waterbody both spatially and throughout the day, the purpose was to support the importance of natural processes and features in creating cold water refuges. However, the reference for the last sentence could not be found during the review of public comments and Ecology decided to remove that text in the final TMDL.
4. Ecology added text to note this observation.

5. Ecology added the following text about pink salmon: "Snohomish Odd-Year Pink have documented presence from the mouth to Granite Falls. According to WDFW's Species in Washington web page, 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."
6. Ecology added language to improve clarity, so the sentence now reads: "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."

Comment #7 through #11 Chapter 1- Other:

7. Bank improvements also improve shade or effective shade.
8. In the first sentence carbon load is mentioned. This is the first time I am seeing this, may need to be brought up sooner.
9. DO Summary - may also apply to Temp Summary too.- Second paragraph - is exceeded the right term to use?
10. Climate Change Last Paragraph: Third sentence does not make sense. The way I am reading it, are you talking about survival of emergent fry. Just remove emergent fry from sentence.
11. Climate Change Last Paragraph: Is the information in this paragraph based on a particular reference or many references, you may want to add them?

Response to Comment #7 through #11 Chapter 1- Other:

7. Ecology agrees that bank improvements can also improve effective shade. The TMDL analysis did not have information to try and quantify these effects. Ecology hopes that with this additional benefit the stream temperature is reduced further.
8. Ecology believes this 'basis for targets' section, which is part of Chapter 1 - Introduction, is the appropriate place to introduce how carbon/BOD loads relate to the DO impairment. Additional language has been added to this section to further clarify the relationship.
9. Although the use of the term "exceeded" may be technically correct, Ecology agrees that rewording as follows will improve reader comprehension: "Under critical streamflows, DO levels are frequently lower than 9.5 mg/L triggering the natural conditions provisions stated above. Under runoff conditions, the 9.5 mg/L criteria is met more often but occasionally not achieved."
10. Ecology revised to "egg-fry survival" and cited source.
11. Ecology added a reference for the second sentence in this paragraph.

Comment #12 Chapter 2- Wasteload Allocations:

12. Topic: Stormwater in reference to: "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." This probably outside this TMDL, but monitoring requirements at least at a couple of designated sites need to be included in order to verify levels. This comment applies to all stormwater sections.

Response Comment #12 Chapter 2- Wasteload Allocations:

12. There are an extremely large number of regulated stormwater outfalls and challenges achieving representative sampling. Therefore, the implementation plan for this TMDL recommends local

ambient monitoring programs, and future effectiveness monitoring including sampling for orthophosphates (also called soluble reactive phosphorus) and periodic measurements of periphyton to verify control of in-stream phosphorus levels.

Comment #13 and #14 Chapter 3- Introduction and Land Distribution:

13. Is the date of 2111 new, I do not remember that date mentioned. This needs to be much sooner, especially since it is involving ESA listed species. Is this date ok with NMFS? Something like 2050 would be better.
14. What is the remaining 20% in land distribution?

Response to Comment #13 and #14 Chapter 3- Introduction and Land Distribution:

13. Ecology significantly revised the estimated targets on the tributaries before this draft went to public comment. Most implementation activities target 2066; however, depending on planting pace, field verification and the potential for work in other tributaries --some tree planting is now estimated to continue until 2081.
14. Ecology added language to clarify the remaining 20%.

Comment #15 through #26 Chapter 3- Key Strategies for Reducing Water Temperatures and Nutrient Inputs:

15. May want to mention microclimate in this paragraph because you bring it up later.
16. Table 24. 7th bullet. Are you saying that there are thermoregulatory behaviors unique to the Pilchuck. You should have a reference. How is this restoring processes?
17. Table 24. 11th bullet. What about removing direct surface withdrawals, through connections to water purveyors or source switching to deeper regional aquifers?
18. Table 24. 19th bullet - does this include bringing up old public and private stormwater facilities up to current standards - hope so.
19. Table 24. 20th bullet. What is a vertical array?
20. Does NPDES fall under either of these sections? What about the Shoreline Master Program or FEMA regulations?
21. Does the TMDL have any teeth? If this is provided to a hearing examiner (HE) will it have more weight than the opinion of County or City staff who HE's always defer to.
22. Is this 2 degree level based on a study, a reference is needed to support this.
23. Maintaining forest access roads - it is my understanding forest road management includes trying to disconnect road drainage from stream drainage.
24. LID comments - I believe LID is just encouraged and is not accepted by engineers and design professionals. If it is required they may have to accept it.
25. Redevelopment should also be required to bring out dated stormwater infrastructure up to standards. State and local agencies should develop a process to identify and update outdated private stormwater facilities to current standards.
26. I do not see any SCD or NRCS references in these sections, they would help here?

Response to Comment #15 through #26 Chapter 3- Key Strategies for Reducing Water Temperatures and Nutrient Inputs:

15. An existing sentence in this paragraph, which refers to microclimate in plainer language reads: "As illustrated in Figure 59 of this TMDL, large buffers will significantly lower air temperatures around a stream and provide an added dimension of cooling."
16. If we have a better understanding of the thermoregulatory behaviors in salmon, this might guide CWR creation/expansion to better suit the needs and preferences of salmon species under a given set of water conditions.
17. If a water user is diverting and using water from a surface water source as authorized by a water right certificate or permit, or in the manner described in a water right claim, Ecology cannot force the water user to change their water source or connect to a purveyor. Additionally, under current water law, there can be difficulties with changing a surface water source to a deep aquifer due to the potential for new/different impacts on streams.

    Ecology's Water Resources Program continues the pursuit of identifying potentially non-compliant water users who may need targeted technical assistance. Getting water users into compliance, and keeping these users in compliance, is a major part of the program's work. For questions about specific water uses in local communities, please contact Ecology's Water Resources Program.
18. Ecology understands the value and need to bring all stormwater facilities up to current standards. We also recognize the need to prioritize that retrofit work. This Pilchuck River TMDL defers to the watershed planning and retrofit requirements in current and future Phase I and Phase II Municipal Stormwater Permits to guide that work. While acknowledging the importance of taking a statewide approach regarding the retrofit of all substandard stormwater treatment facilities, this TMDL does call for strategic stormwater retrofitting as a best management practice to improve summer baseflows. As part of implementation, Ecology will be reaching out to municipal stakeholders in 2021 to encourage research and a pilot project to begin this work.
19. Ecology is aware that salmon recovery specialists have been experimenting with the installation of large wood directly into streambeds and banks in order to create islands and capture large wood travelling downstream. Because the design and placement of appropriate in-water and streamside structures is so site specific, we wanted to acknowledge the full range of tools they might employ. For this reason, Ecology added the use of coir logs.
20. Ecology added language about the Shoreline Master Program where critical areas are discussed in greater detail under "Organizations that Implement the TMDL." Also added "shoreline" in paragraph where critical areas are discussed.

    As it pertains to FEMA regulations, the National Flood Insurance Program (NFIP) does not address water quality. However, floodplain development in the Pilchuck River Basin is subject to the Puget Sound Biological Opinion for the NFIP (BiOp). Meeting BiOp requirements should help to preserve riparian vegetation. However, there are not specific NFIP regulatory requirements associated with the BiOp.

    NPDES permits are done under the Clean Water Act, a separate regulatory program from the Shoreline Management Act and from FEMA regulations.
21. Although the TMDL is considered best available science and should be considered in the development of planning documents and environmental regulation, it is not in itself a regulatory document. Where appropriate in the evaluation of environmental issues, we encourage local

decision-makers at all levels to use this TMDL to inform their decisions. From a regulatory perspective, the WLAs derived in the report do get translated by permit writers into wastewater discharge permit requirements. Further information about which permits are assigned WLAs may be found in Chapter 2.

22. Ecology added a citation to improve clarity. This criterion came from EPA's "Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes."
23. Ecology agrees that forest road management includes disconnecting road drainage from stream drainage. This practice is paramount towards reducing the amount of fine sediment that enters the stream.
24. LID practices are now widely accepted and understood by stormwater engineers nationwide. Washington State's municipal stormwater permits have extensive requirements regarding the integration of LID practices in new construction and redevelopment. As a result, Ecology expects the use of LID practices to increase over time. Among the related permit language is the following text:

    "Permittees shall continue to require LID Principles and LID BMPs when updating, revising, and developing new local development-related codes, rules, standards, or other enforceable documents, as needed. The intent shall be to make LID the preferred and commonly-used approach to site development. The local development-related codes, rules, standards, or other enforceable documents shall be designed to minimize impervious surfaces, native vegetation loss, and stormwater runoff in all types of development situations, where feasible."
25. Ecology requires stormwater infrastructure be brought up to current standards in both new development and redevelopment projects in areas covered by our Phase I and Phase II Municipal Stormwater General Permits. Many private systems discharge into public storm sewers and those facilities must be constructed and maintained in accordance with permit conditions. The Snohomish Conservation District may be a good resource for private stormwater system owners to consult regarding retrofitting their treatment facilities as they have worked with a number of local municipalities in this area. See also the response to comment # 18.
26. Snohomish Conservation District is referenced towards the end of the section in the following sentences: "Small farms should receive periodic technical assistance visits from the Snohomish Conservation District's Farm Planning Program to ensure BMPs are being followed. Technical assistance visits to new landowners are especially important when livestock properties change ownership." Ecology also provides a link to SCD's Farm Planning Program.

Comment #27 through #40 Chapter 3- Where Do We have Opportunities for Improvement- Pools and Middle Pilchuck:

27. Shouldn't current conditions versus targets be discussed here?
28. I think there needs to be references with this table. Not sure where these targets came from, they are inconsistent with NMFS targets. At the size of river mentioned the pool frequency per mile should be 26 not 23.6.
29. Second to last sentence. What are you saying - even with the proposed actions temperatures will still exceed standards?
30. So how much of the buffer width does not meet this buffer width - about 70%?

31. Last sentence - not sure what this means. There is LWD in the reach but it is not functioning to provide pool habitat. What do gravel bars have to do with pool habitat? These appear to be simply observations of habitat availability.
32. First full paragraph. I think I would remove of the third sentence and say something like Observed temperatures fluctuated over the course of 24 hours, potentially effecting fish life during the day, less so at night.
33. Is this correct - a residual pool depth of 30 meters?
34. Frank considers riprap as cover, I am not sure what his basis is.
35. There appears to be groundwater contributions to the river above RM 19. Does the river largely lose flow from RM 19 to RM 10?
36. Suggest changing goals of permit to - if landowner permission allows.
37. Check language in these sections to make sure this does not sound like a survey crews report - I see we used frequently.
38. What stream mile is 12th Street?
39. Last sentence - I think you are referring to a location here not the whole basin.
40. Why a different buffer width on streams - you used 180 feet earlier?

Response to Comment #27 through #40 Chapter 3- Where Do We have Opportunities for Improvement- Pools and Middle Pilchuck:

27. Ecology added a column to Tables 27 and 29 to address the gap between current conditions and targets.
28. Ecology's estimates used near-stream disturbance zone (NSDZ) channel widths, which would be nearly equivalent to bank full channel width. The 1996 matrix and the 1994 Section 7 Fish Habitat Monitoring Protocol for the Upper Columbia Basin (June 1994) use wetted channel width. Ecology modified the table to convert from NSDZ to wetted channel width and used regression to estimate the frequency of pools per mile at 19.1.
29. Ecology edited the text to read: 'the numeric criteria part of the state standards', changed 'state standard' to 'numeric criteria', and added a 3rd bullet item describing that the narrative portion of the standard is met (which applies when above numeric criteria). Please see the 'System Potential Conditions' section in Chapter 4 under 'Temperature TMDL Analysis and Allocations' for a detailed discussion for how the temperature impacts under the TMDL compares to both parts of the state standards.
30. This is outside the scope of this TMDL study to assess whether the buffer width is achieved since the scale can vary depending on location. Ecology is willing to provide riparian buffer data to others wishing to explore buffer widths in greater detail.
31. This sentence is split between two pages and in its entirety reads: "In Reaches 7 and 8, there is quite a bit of large woody material and gravel bars found downstream from RM 25 to about RM 23 that may be able to provide cold water refuge habitat and might be expanded."
    Gravel bars can be areas of surface to ground exchange where cooler water might be coming in. Ecology is suggesting that these existing areas might be expanded to increase the size of the potential CWR area. This sentence is also meant to be the start of a new paragraph, not a continuation of the previous information about pool habitat.
32. Ecology replaced sentence with suggested language.
33. Ecology corrected the typo. The residual pool depth is 1.0 meters.

34. Ecology attempted to clarify the cited author's criteria for defining percent cover for reference by other salmon recovery specialists. We defer to local recovery specialists on defining appropriate criteria for high quality pools for individual waterbodies. While recognizing their may be a unique use for riprap in limited situations, this TMDL supports the restoration of natural processes that will ultimately better support beneficial uses in the Pilchuck River.
35. In general yes, there appears to be some flow loss in that stretch. Table 39 contains detailed information on flow gains and losses.
36. Removed language.
37. Comment acknowledged. Ecology attempted to replace the word "we" with Ecology where instances occurred.
38. River miles have not been delineated for the Little Pilchuck system. This road crossing would be ~1.5 miles upstream of the confluence with the Pilchuck River.
39. Ecology changed the word "reach" to "segment" to improve clarity.
40. This TMDL indicates that a 180-ft buffer is necessary only for the Pilchuck River mainstem. For tributary streams, which were modeled as inputs at the confluence with the mainstem Pilchuck River, Ecology believes the buffer widths shown in Ecology's Riparian Buffer map will be fully protective of the stream's beneficial uses. Ecology revised references to 100-ft buffer widths in the text to acknowledge areas that require less than 100-ft. For example, most Little Pilchuck Creek riparian areas require 100-ft buffer widths; however, a few small areas within the subbasin only require 50-ft or 35-ft riparian buffer widths.

Comment #41 through #44 Chapter 3- Where Do We have Opportunities for Improvement- Lower Pilchuck and Organizations that Implement the TMDL:

41. Figure 17. I think the figure may be incorrect, the southwestern boundary appears in error.
42. Is it 371 or 381 in second sentence?
43. It is a little confusing in that you describe reach attributes in downstream direction. Looking at location based on a downstream direction is a standard way of describing banks?
44. Tulalip Tribes- Second paragraph - To follow from the previous paragraph I would suggest adding protection of cultural and archaeological resources here too.

Response to Comment #41 through #44 Chapter 3- Where Do We have Opportunities for Improvement- Lower Pilchuck and Organizations that Implement the TMDL:

41. Ecology revised the Dubuque Creek map and as a result, also revised the amount of areas that need to be planted in the in the corresponding text as well as for Cost and Timeline Sections.
42. For the Middle Pilchuck, the total acreage is 371, so the sentences in this section are correct as is. The 381 acres you see referenced later in the document refers to the sum of the areas that need to be planted in both the Middle and Lower Pilchuck. It actually comes out to 380.8 acres and Ecology rounded it up to 381 acres.
43. Comment noted. According to several sources, left bank and right bank refers to the bank of a stream that is to the observer's left and right respectively while facing in the direction of the flow or in a downstream direction.
44. Ecology modified the sentence to read: "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."

Comment #45 through #51 Chapter 3- Priorities and Timelines and Costs:

45. What is the 85% based on - may want a reference.
46. Table 30. Are these current actions by partners?
47. The area between the Pilchuck and Little Pilchuck (rm 9 -10) - where they run parallel maybe an area that is needed for further study. They may be sharing a shallow aquifer linking them.
48. Granite Falls WWTP. First sentence on page appears out of place.
49. Table 35. Were there alternatives for the WWTP upgrades and was this the most expensive?
50. Table 35. Stormwater BMP's - Why per acre? Why not per facility? Sometimes these facilities handle both treatment and control. These numbers look way over blown.
51. Table 35. We have found EQIP estimates to be too low in this region.

Response to Comment #45 through #51 Chapter 3- Priorities and Timelines and Costs:

45. Ecology revised wording in this section and provided a reference to Chapter 4 to improve clarity.
46. This table represents the actions required in order to restore beneficial uses to the Pilchuck River. The table outlines who among the implementation partners would likely be involved or active with the activity. The table may also capture activities that are ongoing.
47. Noted. Ecology will consider additional study of river mile 9 to 10 during implementation and adaptive management work, however the work will depend on availability of additional resources.
48. Added a heading called "Granite Falls Compliance Timeline."
49. Ecology removed Granite Falls WWTP costs from the table for improved clarity.
50. Since stormwater facilities vary by size, type, and site conditions, it was far simpler to look at this in terms of the amount of impervious area that could be improved. Ecology did not have the resources to analyze each facility type more deeply; however, over time we expect this new costing process to evolve and become more refined with future TMDLs. Ecology moved a sentence that states: "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." and added the following: "Further assessments are needed to determine the actual surface area (in acres) contributing to the facility or BMP type and the associated cost."
51. Based on this feedback, Ecology revised the sentence from "seemed" to "is" to read: "Since the NRCS EQIP range is too low for this region…"

Comment #52 through #59 Chapter 3- Other:

52. USDA: What about their Wetland Reserve Program or Wetland Reserve Enhancement Program?
53. Effectiveness Monitoring: This is implementation monitoring not effectiveness monitoring
54. Monitoring: Might consider, salmon spawning locations and numbers. Ultimately that is a benefit you are protecting with this TMDL.
55. We do not agree with a 2111 target.
56. Maybe I missed it, but other than the 2111 target are there others. Don't recall seeing interim targets or short term targets to make sure it is trending in the right direction.
57. Tulalip Tribes will likely implement restoration projects as well as provide support.

58. What about the responsibilities the cities and county has with NPDES, permitting, permitting compliance, stormwater upgrades?
59. I hope the focus is just not on restoration projects.

Response to Comment #52 through #59 Chapter 3- Other:

52. Ecology added language about the Wetland Reserve Enhancement Program for USDA in the Costs Section, under the Funding Opportunities subsection.
53. When Ecology starts effectiveness monitoring, we collect implementation information from stakeholders. Ecology is currently working through the effectiveness monitoring process for Snohomish Tributaries Fecal Coliform TMDL. It soon became clear that providing partners with examples of implementation items to track within the TMDL itself would be beneficial to everyone involved in the effectiveness monitoring process, including Ecology staff.
54. Ecology does not anticipate having the resources to do this work when we do effectiveness monitoring. However, we will consult with the Snohomish Salmon Recovery Forum and other partners to incorporate this information if it is available. Ecology added "use of CWR by holding adult and rearing juvenile salmon" to implementation tracking bulleted list.
55. See comment # 13 above.
56. Ecology has interim dates in the Priorities and Timeline Section. Please see Tables 31-34.
57. Noted and added. Ecology is looking forward to working with and supporting partners on their implementation efforts.
58. Ecology added cities to the bulleted list and added "control of stormwater discharges" where applicable for cities and county.
59. Ecology modified the sentence, so it now reads: "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."

Comment #60 through #66 Chapter 4:

60. Where does this 2 degree criteria come from?
61. Taking measurements only at monitoring sites, does not sound sufficient for determining effective shade.
62. Is scenario 2 supposed to be a climate change scenario, if not why was a climate change scenario not included?
63. WLA Table 52. Why is Marysville not included in this table?
64. First sentence on page mentions table 54 - is this correct?
65. Is full restoration of baseflow realistic?
66. May want to study this between river miles 9 and 10.

Response to Comment #60 through #66 Chapter 4:

60. Added a citation in Chapter 3, where Ecology first talks about CWR to clarify. This criterion came from EPA's "Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes."
61. Ecology agrees that this would not be a sufficient approach to determine effective shade. Hemiview photos collected during the study are only taken as a general check on effective shade

modeling results; Effective shade was calculated using Ttools and the shade model every 50 meters for the entire length of the model.

62. No, scenario 2 is not a climate change scenario. A climate change scenario was not included in this TMDL due to time and resource constraints. Ecology recognizes the importance of climate change and is striving to include climate impacts in as many projects as possible given finite resources. If significant interest exists and resources are available, climate change scenario modeling in the Pilchuck River could be conducted as a separate project using the existing model.
63. Marysville does not currently operate any stormwater systems within in the Pilchuck River watershed; therefore, the city does not receive a WLA.
64. This was an artifact of an earlier draft. The current version has correct table references throughout the document.
65. Our lack of experience in restoring baseflows over time makes it difficult to answer this question. Regardless, the TMDL needs to provide the audience with the full range and volume of corrective actions needed to maximize restoration of beneficial uses. Ecology anticipates that the 60-75% restoration targets do represent a significant amount of work and will not be easily achieved.
66. Noted. Ecology recognizes the need for additional research to support implementation activities. We will consider additional study of river mile 9 to 10 during implementation and adaptive management work; however, the work will depend on availability of additional resources.

Comment #67 through #70 Appendix A:

67. When are the carbon additions from the river most problematic or beneficial in the estuary or Port Gardner. I think we need a better understanding of carbon processes throughout the year.
68. In light of this comment, why a target of 2111? I would think your target dates should line up with climate change target dates.
69. This is why improvements to stormwater facilities are so critical. Maybe not from a temperature perspective, but definitely for SRP, nitrogen and other pollutants.
70. Also provides options for the future.

Response to Comment #67 through #70 Appendix A:

67. For further information on marine impacts of freshwater carbon loading, please visit Ecology's webpages on Salish Sea Modeling: https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Salish-Sea-modeling and Puget Sound Nutrient Reduction: https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients/Puget-Sound-Nutrient-Reduction-Project.
68. See comment #13 above.
69. Comment acknowledged.
70. Ecology agrees.

Appendix C. Glossary and Acronyms

Glossary

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum and minimum thermometers or continuous monitoring probes having sampling intervals of 30 minutes or less.

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

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

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every 10 years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

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

Anthropogenic: Human-caused.

Best management practices (BMPs): Physical, structural, or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

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

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

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

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

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

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

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

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

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

Load: The mass of a constituent transported by a stream in a given amount of time, usually expressed in units such as kg/day or lbs/day. It is calculated by multiplying constituent concentration times streamflow.

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

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

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

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

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

"Natural conditions" or "natural background levels": Natural conditions means surface water quality that was present before any human-caused pollution. When estimating natural conditions in the headwaters of a disturbed watershed it may be necessary to use the less disturbed conditions of a neighboring or similar watershed as a reference condition. (See also WAC 173-201A-260(1).)

Near-stream disturbance zone (NSDZ): The active channel area without established, shade-producing riparian vegetation that includes features such as gravel bars. Unwetted channel area is either bare or contains non-shade producing vegetation in recently disturbed areas.

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

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms. Nutrients can be transported from groundwater to surface water.

Orthophoto: An aerial photograph from which distortions owing to camera tilt and ground relief have been removed, so that it has the same scale throughout and can be used as a map.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

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

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

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

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

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

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

Reach: A specific portion or segment of a stream.

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

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

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

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

System potential: The design condition used for TMDL analysis.

System potential channel morphology: The more stable configuration that would occur with less human disturbance.

S**ystem potential mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System potential riparian microclimate can also include expected changes to wind speed and relative humidity.

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

Thalweg: The line of lowest elevation within a river.

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

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

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

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

Acronyms and Abbreviations

A-C	
AASF	Adopt-A-Stream Foundation
AFDW	ash-free dry weight
ALEA	Aquatic Lands Enhancement Account
BC	boundary conditions
BDA	beaver dam analog
BLM	Bureau of Land Management
BMP	best management practice
BOD	biochemical oxygen demand
CAO	Critical Areas Ordinance
CAR	Critical Areas Regulations
CBSM	community-based social marketing
CFR	Code of Federal Regulations
CIR	crop irrigation requirement
CMER	Cooperative Monitoring, Evaluation, and Research Committee
CREP	Conservation Reserve Enhancement Program
CWA	Clean Water Act
CWR	cold water refuge
D-E	
DEM	digital elevation model
DEQ	Department of Environmental Quality
DIN	dissolved inorganic nitrogen
DNR	Washington State Department of Natural Resources
DO	dissolved oxygen
DOC	dissolved organic carbon
DOH	Washington State Department of Health
DU	Ducks Unlimited
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EJ	environmental justice
EPA	United States Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
ER	ecosystem respiration
F-I	
FC	fecal coliform (bacteria)
FPR	Forest Practice Rule
GIS	Geographic Information System software
GLA	Gap Light Analyzer
GLO	General Land Office (related to Bureau of Land Management)
GMA	Growth Management Act
GPP	gross primary productivity
HCP	Habitat Conservation Plan
HPA	hydraulic permit approval
IPM	integrated pest management
ISS	inorganic suspended solids

K-N

KW	kinematic wave (flow routing modeling method)
LA	load allocation
LID	low impact development
LiDAR	Light Detection and Ranging data
LWM	large woody material (also known as LWD or large woody debris)
MC	microclimate
MEL	Manchester Environmental Laboratory
MOS	margin of safety
MQO	measurement quality objective
MS4	municipal separate storm sewer system
NAIP	National Agriculture Imagery Program
NASS	National Agricultural Statistics Service
NEP	National Estuary Program
NHD	National Hydrography Dataset
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System (see glossary)
NRCS	Natural Resources Conservation Service
NSDZ	near-stream disturbance zone (see glossary)
NWS	National Weather Service

P-R

PAL	post-assisted log structure
PDS	Snohomish County Planning and Development Services
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RCO	Washington State Recreation and Conservation Office
RCW	Revised Code of Washington
RH	relative humidity
RM	river mile
RMA	River Metabolism Analyzer modeling tool
RMSE	root mean squared error
RPD	relative percent difference
RPZ	riparian management zone
RS	reserve capacity
RSD	relative standard deviation

S-U

SBSRTC	Snohomish River Basin Salmon Recovery Technical Committee
SCD	Snohomish Conservation District
SEPA	State Environmental Policy Act
SFAP	Stormwater Financial Assistance Program
SLS	Sustainable Lands Strategy
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SNOTEL	SNOwpack and TELemetry
SOD	sediment oxygen demand

SOP	standard operating procedures
SPS	system potential shade
SRP	soluable reactive phosphorus
SSURGO	Soil Survey Geographic database
SCSWM	Snohomish County Surface Water Management
TMDL	Total Maximum Daily Load (see glossary)
TN	total nitrogen
TP	total phosphorus
TPN	total persulfate nitrogen
TSS	total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
W-Z	
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WFC	Wild Fish Conservancy
WLA	wasteload allocation
WQA	Water Quality Assessment
WREP	Wetland Reserve Enhancement Partnership
WRIA	Water Resource Inventory Area
WSDA	Washington State Department of Agriculture
WSDOT	Washington State Department of Transportation
WWT	Washington Water Trust
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow
dw	dry weight
ft	feet
g	gram, a unit of mass
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mgd	million gallons per day
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
NTU	nephelometric turbidity units
s.u.	standard units
µg/L	micrograms per liter (parts per billion)
µS/cm	microsiemens per centimeter, a unit of conductivity

Appendix D. Data Tables and Plots

This appendix summarizes the data that were collected specifically for the Pilchuck Temperature and Dissolved Oxygen TMDL, including continuous water quality deployments, synoptic surveys, and nutrient and flow monitoring.

Sample and Measurement Locations

Tables D-1 through D-4 contain location details for the 2012 study.

Table D-1. Mainstem Pilchuck River location details for the 2012, 2014, and 2016 studies.

Location ID	Location Description	Latitude	Longitude
07-PIL-26	Pilchuck River immediately downstream of diversion dam		
07-PIL-25.5	Pilchuck River at Menzel Lake Rd., ~20 ft. downstream of bridge	48.01872	-121.91504
07-PIL-22.6	Pilchuck River ~2,000 ft SE of S end of Scherrer Rd	48.03681	-121.93842
07-PIL-21.5	Pilchuck River at Robe-Menzel Rd., just upstream of bridge	48.05479	-121.95703
07-PIL-18.9	Pilchuck River ~200 ft upstream of Granite Falls WWTP outfall	48.07601	-121.97758
07-PIL-18.7	Pilchuck River at WDFW access at the end of Ray Gray Rd	48.07632	-121.98303
07-PIL-17.4	Pilchuck River ~1/4 mile below private bridge off Crooked Mile Rd	48.07600	-122.00076
07-PIL-16.8	Pilchuck River ~600 ft SE of intersection of SR92 and 84th St NE	48.07059	-122.00840
07-PIL-15.1	Pilchuck River at 64th St., ~100 ft. upstream of bridge near RB	48.05355	-122.02357
07-PIL-11.6	Pilchuck River just upstream of 28th Pl NE access to river	48.02309	-122.02401
07-PIL-10.4	Pilchuck River at Russell Rd., ~30 ft. upstream of bridge	48.00740	-122.03333
07-PIL-8.6	Pilchuck River upstream of confluence with Little Pilchuck River	47.98907	-122.03681
07-PIL-8.5	Pilchuck River at OK Mill Rd., ~25 ft. downstream of bridge	47.98675	-122.03550
07-PIL-8.2	Pilchuck River ~1,000 ft downstream of OK Mill Rd	47.98498	-122.03672
07-PIL-7.0	Pilchuck River ~300 ft SW of W end of Meadow Dr	47.97654	-122.05308
07-PIL-5.8	Pilchuck River ~900 ft upstream of Dubuque Rd; upstream of spring/trib on left bank	47.96309	-122.06328
07-PIL-5.7	Pilchuck River at Dubuque Rd., ~150 ft. downstream of bridge	47.96207	-122.06569
07-PIL-3.6	Pilchuck River at Three Lakes Rd, ~25 ft. upstream of bridge	47.93756	-122.07466
07-PIL-2.0	Pilchuck River at 6th St., ~80 ft. upstream of bridge	47.91883	-122.08253

Table D-2. Point source and major tributary location details for the 2012, 2014, and 2016 studies.

Location ID	Location Description	Latitude	Longitude
07-GRA-EFF	Granite Falls WWTP effluent at plant immediately after UV treatment	48.07899	-121.97520
07-GRA-STP	Granite Falls WWTP manhole near outfall to Pilchuck River	48.07605	-121.97971
07-DUB-0.0	Dubuque Creek ~50 ft. upstream of mouth	47.98791	-122.03630
07-LIT-1.8	Little Pilchuck Creek at 12th St., ~200 ft. downstream of bridge	48.00707	-122.04557

Table D-3. Minor Tributary location details for the 2012, 2014, and 2016 studies.

Location_ID	Location Description	Latitude	Longitude
7-Pur-0.0	Purdy Creek at mouth	48.01600	-121.91280
7-Pil-Trib-20.0	Tributary to LB of Pilchuck at ~RM20	48.06450	-121.96664
7-Pil-Trib-19.7	GNIS Name Coon Creek. Flows from Milard Lake outlet	48.06731	-121.96804
7-Pil-Trib19.6N	North branch of trib to RB of Pilchuck at ~RM19.6; 3rd-order tributary at Robe-Menzel Rd	48.06876	-121.96871
7-Pil-Trib19.6S	South branch of trib to RB of Pilchuck at ~RM19.6; 1st-order tributary at Robe-Menzel Rd	48.06873	-121.96875
7-Pil-Trib19.3	1st-order trib to RB of Pilchuck at ~RM19.3	48.07202	-121.97233
7-PIL-Trib18.2	Trib to RB of PIL at ~RM18.2; outlet from Gardner Lake	48.07972	-121.98568
7-Pil-Trib17.2	2nd-order trib to LB of PIL at ~RM17.2; ~2000 ft E of SR92 & 84 St NE	48.07253	-122.00216
7-Pil-Trib15.3	2nd-order trib to LB of PIL at ~RM15.3; ~0.5 mi u/s of 64th St bridge	48.05833	-122.01781
07-CON-0.0	Trib from Connor Lake to PIL River, off Russell Rd.; ~50 ft. upstream of mouth	48.01907	-122.02719
7-Pil-Trib11.5	3rd-order trib to LB of PIL at ~RM11.5; ~750’ d/s of 28th Pl NE access	48.02139	-122.02402
7-Pil-Trib10.7	1st-order trib to LB of PIL at ~RM10.7; ~500 ft W of 14th St and 155th Ave NE	48.01179	-122.02456
7-Pil-Trib7.8	1st-order trib to LB of PIL at ~RM7.9; ~1/4 E of Division St & Machias Rd	47.98053	-122.03979
7-Pil-Trib7.3	2nd-order trib to LB of PIL at ~RM7.3; ~500 ft S of Pilchuck Way & Riviera Blvd	47.97597	-122.04728
7-Pil-Trib6	2nd-order trib to LB of PIL at ~RM6; ~1/3 mi u/s of Dubuque Rd	47.96545	-122.06190
7-Scott-0.6	2nd-order trib aka Scott Creek to LB of Pilchuck at ~RM4.4	47.94653	-122.07096
7-Sext-0.0	3rd-order trib aka Sexton Creek to LB of Pilchuck at ~RM2.8	47.92730	-122.07471

Table D-4. Seep and piezometer location details for the 2014 and 2016 studies.

Location_ID	Location Description	Latitude	Longitude
07-PIL-Seep20.5	Seepage to Pilchuck R on RB ~1/2 mile d/s of Robe Menzel Rd	48.05845	-121.96024
07-PIL-Seep18.9	Seepage to Pilchuck R on LB just u/s of Granite Falls WWTP	48.07562	-121.97879
07-PIL-Seep18.1	Seepage to Pilchuck R on RB ~3/4 mile d/s of Granite Falls WWTP	48.07979	-121.98990
07-PIL-Seep15.3	Seepage to Pilchuck R on LB ~1/2 mile u/s of 64th St NE	48.05849	-122.01701
07-PIL-Seep14.8	Seepage to Pilchuck R on RB immediately u/s of 64th St NE	48.05344	-122.02390
7-Pil-Seep14.3	Seepage to Pilchuck R on LB ~1/4 mi NW of end of 54th St NE	48.04877	-122.02879
7-Pil-Seep14.2	Seepage to Pilchuck R on LB ~1/4 mi NW of end of 54th St NE	48.04751	-122.02943
07-PIL-Seep11.7	Seepage to Pilchuck R on LB ~700 feet u/s of 28th Pl NE access	48.02469	-122.02412
07-PIL-Seep5.9	Seepage to Pilchuck R on LB ~1,000 u/s of Dubuque Rd	47.96335	-122.06149
07-PIL-Piez14.8	Piezometer in Pilchuck R on RB immediately u/s of 64th St NE	48.05340	-122.02390
AHL156	Piezometer in Pilchuck R on RB just u/s of Little Pilchuck River	47.98940	-122.03687
AHL157	Piezometer in Pilchuck R on LB ~1,000 ft d/s of OK Mill Rd	47.98397	-122.03833
AHL158	Piezometer in Pilchuck R on RB ~500 d/s of Dubuque Rd	47.96214	-122.06686
AHL159	Piezometer in Pilchuck R on RB just d/s of Three Lakes Rd	47.93455	-122.07370

Sample Laboratory Data

Table D-5 contains parameter abbreviations used commonly in this report. Table D-6 contains laboratory sample results for the 2012 study. Table D-7 and D-8 contain laboratory sample results for the 2016 study.

Table D-5. Parameter abbreviations and units of measurements.

Abbreviation	Parameter	Unit of Measurement
Alk	Alkalinity, Total as CaCO3	mg/L
BOD	Biological Oxygen Demand	mg/L
Cl	Chloride	mg/L
NH4	Ammonia Nitrogen	ug/L
NO2-NO3	Nitrite-Nitrate Nitrogen	ug/L
TPN	Total Persulfate Nitrogen	ug/L
SRP	Orthophosphate (Referred to in the TMDL as Soluble Reactive Phosphorus)	ug/L
TP	Total Phosphorus	ug/L
DOC	Dissolved Organic Carbon	mg/L
TOC	Total Organic Carbon	mg/L
TSS	Total Suspended Solids	mg/L
TNVSS	Total Non-volatile Suspended Solids	mg/L
Turb	Turbidity	NTU
Chl a	Chlorophyll a	ug/L

Table D-6. Sample results for the 2012 study.
Dark shaded cells with U qualifier indicate analyte was not detected at or above the reported result.
Highlighted cells with J qualifier indicate the associated numerical result is an estimate.

EIM Location ID	Date	Time	Sample ID	TNVSS	TSS	NO2-NO3	SRP	Turb	Alk	Cl	NH3	DOC	TOC	TPN	Chl a	TP
07-PIL-25.5	7/31/2012	7:45	1207085-42	1 U	1 U	0.086	0.0048	0.6	29.3	1.07	0.01 U	1 U	1 U	0.086 J	2.7 J	0.0083
07-PIL-25.5	7/31/2012	18:45	1207085-19	1 U	1 U	0.042	0.0054	0.7	28.9	1.17	0.01 U	1 U	1 U	0.059	3.2	0.0093
07-PIL-25.5	8/28/2012	8:10	1209063-19	1 U	1 U	0.122	0.0107	0.6	35.5	1.24	0.01 U	1 U	1 U	0.143	0.8 J	0.0106
07-PIL-25.5	8/28/2012	18:00	1209063-42	4	5	0.086	0.011	0.5 U	34.7	1.27	0.01 U	1 U	1 U	0.105	0.8	0.0125
07-PIL-21.5	7/31/2012	7:10	1207085-41	1 U	1	0.051	0.003 U	0.6	30.2	1.28	0.01 U	1 U	1	0.076 J	4 J	0.0066
07-PIL-21.5	7/31/2012	18:15	1207085-18	1 U	2	0.025	0.003 U	0.6	29.1	1.22	0.01 U	1 U	1.2	0.055	2.5	0.0055
07-PIL-21.5	8/28/2012	7:47	1209063-18	1 U	1 U	0.079	0.005	0.7	35.7	1.42	0.01 U	1 U	1 U	0.115	1.2 J	0.0079
07-PIL-21.5	8/28/2012	17:40	1209063-41	1 U	1 U	0.057	0.0054	0.5 U	34.2	1.34	0.01 U	1 U	1	0.095	1.2	0.0071
07-PIL-15.1	7/31/2012	6:26	1207085-40	2	2	0.102	0.003 U	0.8	30.8	2.3	0.01 U	1.2	1.2	0.159 J	8.5 J	0.0082
07-PIL-15.1	7/31/2012	6:26	1207085-45	1	2	0.102	0.0032	0.8	30.9	2.44	0.01 U	1	1.2		8.6 J	0.0082
07-PIL-15.1	7/31/2012	16:55	1207085-17	2	3	0.085	0.0055	0.8	29.5	2.4	0.01 U	1.4	1.6	0.133	5.9	0.0117
07-PIL-15.1	8/28/2012	7:19	1209063-17	1 U	2	0.184	0.0053	0.6	35.8	3.17	0.018	1 U	1.1	0.242	3.2 J	0.0093
07-PIL-15.1	8/28/2012	16:30	1209063-40	1 U	2	0.126	0.0097	0.7	34.2	3.31	0.01 U	1 U	1.2	0.182	7.5	0.0129
07-PIL-10.4	7/31/2012	5:25	1207085-38	2	3	0.101	0.003 U	1.2	32.4	2.44	0.01 U	1.4	1.5	0.135	7.6 J	0.0072
07-PIL-10.4	7/31/2012	15:55	1207085-15	2	4	0.022	0.003 U	0.9	30.8	2.38	0.01 U	1.3	1.6	0.075	5.6	0.0062
07-PIL-10.4	8/28/2012	6:20	1209063-15	2	3	0.138	0.0044	1.4	37.4	3.06	0.01 U	1 U	1.2	0.171	2.4 J	0.0105
07-PIL-10.4	8/28/2012	6:20	1209063-23	2	3	0.139	0.0047	1.6	37.7	3.06	0.01 U	1 U	1.1	0.176	2.6 J	0.0086
07-PIL-10.4	8/28/2012	15:45	1209063-38	1 U	1	0.099	0.0046	0.7	36.1	3.08	0.01 U	1 U	1.3	0.147	2	0.0069
07-PIL-8.5	7/31/2012	8:15	1207085-36	2	3	0.105	0.003 U	1	33.5	2.69	0.01 U	2	3	0.168	6.1 J	0.0079
07-PIL-8.5	7/31/2012	18:35	1207085-13	3	4	0.052	0.003 U	1.1	32.6	2.53	0.01 U	1.6	2	0.117	6.7	0.0096
07-PIL-8.5	8/28/2012	8:10	1209063-13	1 U	1	0.14	0.0041	0.7	38.9	3.18	0.01 U	1	1.2	0.185	1.8 J	0.0075
07-PIL-8.5	8/28/2012	17:15	1209063-36	1 U	2	0.116	0.004	0.7	36.8	3.15	0.01 U	1 U	1.2	0.174	1.9	0.0084
07-PIL-5.7	7/31/2012	7:35	1207085-35	2	4	0.131	0.003 U	1	34.1	2.71	0.01 U	1.9	2.3	0.189	5.7 J	0.007
07-PIL-5.7	7/31/2012	17:55	1207085-12	2	3	0.074	0.003 U	0.8	33.5	2.58	0.01 U	1.7	1.9	0.14	2.8	0.0085
07-PIL-5.7	8/28/2012	7:45	1209063-12	1 U	2	0.154	0.0035	0.8	39.6	3.18	0.01 U	1	1.2	0.204	1.8 J	0.0082

EIM Location ID	Date	Time	Sample ID	TNVSS	TSS	NO2-NO3	SRP	Turb	Alk	Cl	NH3	DOC	TOC	TPN	Chl a	TP
07-PIL-5.7	8/28/2012	16:50	1209063-35	1 U	2	0.135	0.0039	0.6	38.7	3.22	0.01 U	1 U	1.2	0.185	1.6	0.006
07-PIL-2.0	7/31/2012	5:30	1207085-32	2	3	0.12	0.003 U	1.2	35.5	2.76	0.01 U	1.9	2.4	0.186	4.7 J	0.0081
07-PIL-2.0	7/31/2012	16:00	1207085-09	1	2	0.128	0.003 U	1.1	34.2	2.81	0.01 U	1.8	2.3	0.183	1.3	0.0097
07-PIL-2.0	7/31/2012	16:00	1207085-22	2	2	0.125	0.003 U	0.7	34.8	2.78	0.01 U	2	2.1	0.19	2	0.0076
07-PIL-2.0	8/28/2012	6:10	1209063-09	1	2	0.152	0.0036	0.8	40.4	3.21	0.01 U	1	1.1	0.202	1.6 J	0.0067
07-PIL-2.0	8/28/2012	15:35	1209063-32	1 U	1	0.149	0.0038	0.6	39.8	3.29	0.01 U	1 U	1.1	0.195	1.1	0.0055
07-PIL-2.0	8/28/2012	15:35	1209063-44	1 U	1	0.149	0.0038	0.7	40.4	3.33	0.01 U	1	1.1	0.189	1.1	0.0074
07-GRA-STP	7/31/2012	17:35	1207085-21	2 U	8	19.5	3.02	4.6	34.4	31.7	0.597	10.3	13.7	20.5	2.3	3.32
07-GRA-STP	7/31/2012	17:35	1207085-23	2 U	8	19.5	3.1	4.2	33.7	31.7	0.583	10.2	12.6	20.9	2.1	3.36
07-GRA-STP	8/28/2012	17:00	1209063-21	2 U	10	0.48	3.88	8.2	158	38	24.1	15.8	19.5	27.3	2.5	3.9
07-GRA-STP	8/28/2012	17:00	1209063-45	2 U	10	0.658	3.9	8	156	39	24.3	16	19.5	31.6	2.4	3.83
07-CON-0.0	7/31/2012	6:00	1207085-39	5	6	0.29	0.0065	4.3	29.5	3.3	0.018	3.3	3.7	0.137	0.6 J	0.0217
07-CON-0.0	7/31/2012	16:15	1207085-16	2	3	0.288	0.0071	1.7	29.2	3.28	0.015	3.9	3.4	0.418	0.6	0.0192
07-LIT-1.8	7/31/2012	9:00	1207085-37	2 U	3	0.141	0.0109	1.4	37.3	3.71	0.01 U	7.2	7.3	0.335	1.6 J	0.0248
07-LIT-1.8	7/31/2012	19:10	1207085-14	1 U	2	0.142	0.0107	1.3	39	3.7	0.01 U	6.2	6.6	0.334	0.7	0.0247
07-LIT-1.8	8/28/2012	6:53	1209063-14	1 U	2	0.111	0.0084	1.3	46.7	4.04	0.01 U	3	3.5	0.253	1 J	0.0179
07-LIT-1.8	8/28/2012	16:08	1209063-37	1 U	1	0.089	0.0088	1	44.9	4.05	0.01 U	3.1	3.4	0.238	1	0.0171
07-DUB-0.0	7/31/2012	8:00	1207085-43	1 U	1 U	0.264	0.0054	0.8	38.1	3.03	0.01	3.9	4.2	0.365	0.8 J	0.0123
07-DUB-0.0	7/31/2012	18:20	1207085-20	1 U	1 U	0.224	0.0054	0.6	37.3	3	0.011	4.7	4.2	0.312	0.7	0.0106
07-DUB-0.0	8/28/2012	8:20	1209063-20	1 U	1 U	0.225	0.0057	0.5 U	45.6	3.14	0.01 U	2.5	2.5	0.296	0.9 J	0.0073
07-DUB-0.0	8/28/2012	17:30	1209063-43	1 U	1 U	0.193	0.0052	0.5 U	43.6	3.01	0.01 U	2.3	2.5	0.271	0.7	0.0072

Table D-7. Surface water sample results for the 2016 study.

Dark shaded cells with U qualifier indicate analyte was not detected at or above the reported result.

EIM Location ID	Date	Time	Sample ID	NO2-NO3	OP	Alk	NH3	TPN	TP	BOD5
07-GRA-EFF	8/17/2016	8:40	1608040-04	10.6	4.24		0.977	13	4.34	
07-GRA-EFF	8/18/2016	8:50	1608040-17	12.6	4.22		0.708	14.8	4.25	
07-PIL-11.6	8/18/2016	17:15	1608040-19	0.095	0.0101	34.5	0.01 U	0.145	0.0159	2 U
07-PIL-15.1	8/17/2016	17:46	1608040-07	0.129	0.0139	34.2	0.01 U	0.187	0.0207	2 U
07-PIL-17.4	8/18/2016	13:00	1608040-02	0.107	0.0184		0.011	0.168	0.0233	
07-PIL-18.7	8/18/2016	11:35	1608040-05	0.149	0.0243		0.01 U	0.196	0.0329	2 U
07-PIL-18.9	8/17/2016	15:53	1608040-03	0.057	0.0037	33.4	0.01 U	0.137	0.007	2 U
07-PIL-2.0	8/18/2016	18:50	1608040-23	0.093	0.0035	37.9	0.01 U	0.175	0.0081	2 U
07-PIL-25.5	8/17/2016	17:30	1608040-01	0.103	0.0094	33.3	0.01 U	0.14	0.0117	2 U
07-PIL-25.5	8/17/2016	17:30	1608040-14	0.107	0.0096		0.01 U	0.125	0.011	2 U
07-PIL-5.8	8/18/2016	18:20	1608040-22	0.107	0.0049		0.01 U	0.177	0.0105	2 U
07-PIL-8.2	9/15/2016	16:00	1609033-01	0.105	0.0058	34.4	0.01 U	0.149	0.0086	
07-PIL-8.6	8/18/2016	17:45	1608040-20	0.08	0.0066		0.014	0.15	0.0107	
07-PIL-8.6	9/15/2016	17:20	1609033-06	0.089	0.0065	34.9	0.01 U	0.107	0.0082	
07-PIL-8.6	10/6/2016	12:40	1610026-03	0.082	0.0038	30.2	0.015	0.116	0.0071	
PR4.2	10/6/2016	17:15	1610026-08	0.066	0.003 U	31.9	0.01 U	0.113	0.0095	

Table D-8. Piezometer and seep sample results for the 2016 study.
Dark shaded cells with U qualifier indicate analyte was not detected at or above the reported result.

EIM Location ID	Date	Time	Sample ID	NO2-NO3	OP	Alk	NH3	TPN	TP
07-PIL-PIEZ14.8	8/18/2016	10:12	1608040-24	0.037	0.0118	101	0.072	0.135	0.0439
07-PIL-SEEP11.7	8/18/2016	17:30	1608040-26	0.01 U	0.16	255	0.282	0.329	0.166
07-PIL-SEEP15.3	8/18/2016	14:55	1608040-25	0.01 U	0.0058	29.7	0.01 U	0.072	0.0116
07-PIL-SEEP18.1	8/18/2016	12:30	1608040-29	0.651	0.0153		0.01 U	0.668	0.0158
07-PIL-SEEP18.9	8/17/2016	15:40	1608040-10	0.036	0.0036	47.2	0.01 U	0.044	0.005 U
07-PIL-SEEP20.5	8/17/2016	13:14	1608040-09	0.239	0.0066	55.5	0.01 U	0.231	0.0084
07-PIL-SEEP5.8	8/18/2016	18:41	1608040-28	0.025	0.0383	78.9	0.092	0.184	0.0842
07-PIL-SEEP5.8	8/18/2016	18:47	1608040-31	0.024	0.035	79.3	0.096	0.177	0.0766
07-PIL-SEEP5.8	9/15/2016	14:10	1609033-04	0.011	0.0508	82.3	0.09	0.155	0.0844
AHL156	9/15/2016	17:10	1609033-02	0.312	0.572	33.3	0.01 U	0.377	0.0106
AHL156	10/6/2016	12:40	1610026-02	0.77	0.0083	31.2	0.01 U	0.826	0.0102
AHL157	9/15/2016	15:50	1609033-03	0.257	0.0079	31.7	0.01 U	0.284	0.0077
AHL157	10/6/2016	14:23	1610026-04	0.274	0.0067	30.2	0.01 U	0.29	0.0066
AHL158	9/15/2016	13:10	1609033-05	0.271	0.0105	66.6	0.012	0.332	0.008
AHL158	10/6/2016	15:50	1610026-06	0.39	0.0101	69.5	0.01 U	0.405	0.0097
AHL159	10/6/2016	17:10	1610026-07	0.182	0.0082	33.9	0.011	0.203	0.0072
AHL159	10/6/2016	17:30	1610026-09	0.171	0.008	34.3	0.01 U	0.189	0.0121

Field Measurement Data

Tables D-9 through D-12 contains discrete measurement results for the study. Figures D-1 and D-2 depict continuous temperature data results for the 2012 study. Figures D-3 to D-8 depict continuous water quality sonde results for the 2012 synoptic surveys. Figure D-9 depicts longitudinal depth results for the 2014 float surveys.

Table D-9. Discrete measurement results for the 2012 study.

EIM Location ID	Date	Time	Temperature, water	Specific Conductivity (at 25 °C)	pH	Dissolved Oxygen	Flow
07-CON-0.0	7/31/2012	6:00	14.95	73.9	7.53	9.53	
07-CON-0.0	7/31/2012	16:15	18.16	74.7	7.58	9.3	
07-CON-0.0	7/31/2012	16:20					0.03
07-DUB-0.0	7/31/2012	8:00	14.29	85.5	7.6	10.1	
07-DUB-0.0	7/31/2012	10:10					2.15
07-DUB-0.0	7/31/2012	18:20	17.73	85.6	7.63	9.33	
07-DUB-0.0	8/28/2012	8:20	13.97	97.2	7.82	9.6	
07-DUB-0.0	8/28/2012	8:45					0.25
07-DUB-0.0	8/28/2012	17:30	16.77	95.6	8.21	9.44	
07-GRA-STP	7/31/2012	18:00	19.17	386	6.78	6.92	
07-GRA-STP	8/28/2012	17:14	19.53	498	7.48	5.65	
07-LIT-1.8	7/31/2012	9:00	17.15	84.6	7.23	8.96	
07-LIT-1.8	7/31/2012	9:45					11.9
07-LIT-1.8	7/31/2012	19:10	19.47	89.7	7.26	8.51	
07-LIT-1.8	8/28/2012	7:00	16.14	107	7.36	8.6	
07-LIT-1.8	8/28/2012	10:40					4.31
07-LIT-1.8	8/28/2012	16:08	18.37	107	7.62	8.82	
07-PIL-10.4	7/31/2012	5:25	14.72	73.4	7.33	9.2	
07-PIL-10.4	7/31/2012	12:15					89.6
07-PIL-10.4	7/31/2012	15:55	19.09	72.2	8.57	11.08	
07-PIL-10.4	8/28/2012	6:20	15.48	86	7.31	9.02	
07-PIL-10.4	8/28/2012	11:15					50.6
07-PIL-10.4	8/28/2012	15:45	18.88	84.8	8.01	10.1	
07-PIL-15.1	7/31/2012	6:26	14.13	70.1	7.2	9.11	
07-PIL-15.1	7/31/2012	10:57					93.3
07-PIL-15.1	7/31/2012	11:27					97.1
07-PIL-15.1	7/31/2012	16:55	18.07	69.8	8.43	11.38	
07-PIL-15.1	8/28/2012	7:26	14.92	88.7	7.05	8.43	
07-PIL-15.1	8/28/2012	7:28	15.23	82.7	7.18	9.01	
07-PIL-15.1	8/28/2012	10:05					51.3
07-PIL-15.1	8/28/2012	16:29	17.81	79.9	8.81	11.73	
07-PIL-15.1	8/28/2012	16:30	17.49	86.7	7.82	11.11	
07-PIL-2.0	7/31/2012	5:30	15.21	80.8	7.16	9.19	

EIM Location ID	Date	Time	Temperature, water	Specific Conductivity (at 25 °C)	pH	Dissolved Oxygen	Flow
07-PIL-2.0	7/31/2012	12:10					126
07-PIL-2.0	7/31/2012	16:00	19	81.4	7.25	9.31	
07-PIL-2.0	8/28/2012	6:10	15.48	88.1	7.38	8.61	
07-PIL-2.0	8/28/2012	12:00					62.7
07-PIL-2.0	8/28/2012	15:35	18.81	89.8	7.59	9.31	
07-PIL-21.5	7/31/2012	7:10	12.68	64.2	7.51	10.36	
07-PIL-21.5	7/31/2012	9:36					76.7
07-PIL-21.5	7/31/2012	9:45	12.97	63.1	7.8	11.14	
07-PIL-21.5	7/31/2012	18:15	16.11	63.1	8.07	10.51	
07-PIL-21.5	8/28/2012	7:47	13.68	74.7	7.51	10.16	
07-PIL-21.5	8/28/2012	9:05					45.7
07-PIL-21.5	8/28/2012	17:40	16.71	73.7	8.19	10.48	
07-PIL-25.5	7/31/2012	7:45	11.57	62.4	7.65	11.06	
07-PIL-25.5	7/31/2012	8:06					71.7
07-PIL-25.5	7/31/2012	9:10	11.66	61.9	7.85	11.35	
07-PIL-25.5	7/31/2012	18:45	14.59	62.5	8.11	10.22	
07-PIL-25.5	8/28/2012	8:10	12.05	74.4	7.63	10.65	
07-PIL-25.5	8/28/2012	8:20					46
07-PIL-25.5	8/28/2012	18:00	14.62	74.3	8.07	10.46	
07-PIL-5.7	7/31/2012	7:35	14.78	78.6	7.14	9.35	
07-PIL-5.7	7/31/2012	17:55	19.4	78	7.34	9.32	
07-PIL-5.7	8/28/2012	7:45	15.12	85.2	7.36	9.4	
07-PIL-5.7	8/28/2012	10:14					64.3
07-PIL-5.7	8/28/2012	16:50	18.2	86.3	7.68	9.95	
07-PIL-8.5	7/31/2012	8:15	14.65	75.2	7.24	10.11	
07-PIL-8.5	7/31/2012	10:30					117
07-PIL-8.5	7/31/2012	18:35	18.6	75.2	7.4	9.45	
07-PIL-8.5	8/28/2012	8:10	15.05	83.1	7.34	8.77	
07-PIL-8.5	8/28/2012	9:09					59
07-PIL-8.5	8/28/2012	17:15	18.06	83.1	7.58	10	

Table D-10. Flow, depth, velocity, and width data for the 2014 and 2016 surveys.
Highlighted cells with J qualifier indicate the associated numerical result is an estimate.

EIM Location ID	Date	Time	Average Depth	Average Velocity	Wetted Width	Flow
07-BFC-0.0	8/7/2014	16:30	0.2	0.16	2.7	0.11
07-BFC-0.0	8/28/2014	12:40	0.3	0.12	4.1	0.14
07-DUB-0.0	7/9/2014	13:07	0.3	0.43	11.8	1.3
07-DUB-0.0	8/6/2014	11:23	0.2	0.16	10.6	0.32
07-DUB-0.0	8/27/2014	15:00	0.2	0.07	9.8	0.14
07-GOL-0.0	7/10/2014					0.1
07-LIT-1.8	7/9/2014	15:30	0.3	0.12	9.5	0.31
07-LIT-1.8	8/6/2014	11:02	0.3	0.2	10.2	0.59
07-PIL-10.4	7/9/2014	9:10	1.9	0.69	65.8	86
07-PIL-10.4	8/27/2014	14:57	1.3	0.62	65.1	51
07-PIL-11.6	7/9/2014	10:30	1.1	1.8	46.6	92
07-PIL-11.6	8/6/2014	15:05	0.9	1.4	47.5	60
07-PIL-11.6	8/27/2014	15:58	0.9	1.3	46.2	54
07-PIL-15.1	7/9/2014	11:15	1	1.5	57.9	91
07-PIL-15.1	7/9/2014	12:00	1	1.5	58.9	92
07-PIL-15.1	8/6/2014	14:07	0.9	1.2	51.8	61
07-PIL-15.1	8/27/2014	12:23	1	0.98	52.5	54
07-PIL-15.1	8/27/2014	12:45	1	0.94	52.8	51
07-PIL-16.8	7/9/2014	11:10	1	1.5	60.5	91
07-PIL-16.8	8/27/2014	11:30	0.8	1.1	61.5	57
07-PIL-18.7	7/8/2014		1.4	1.1	65	96
07-PIL-18.7	8/5/2014	10:30	1.1	0.84	62.4	57
07-PIL-18.7	8/26/2014	17:20	1	0.99	61	62
07-PIL-2.0	7/10/2014	12:40	1.2	1.2	71.5	102
07-PIL-2.0	8/7/2014	9:45	0.9	0.97	71.9	66
07-PIL-2.0	8/28/2014	10:10	0.9	0.87	71.2	58
07-PIL-21.5	7/8/2014		1.7	0.84	57.9	82
07-PIL-21.5	8/5/2014	12:32	1.4	0.65	55	50
07-PIL-21.5	8/26/2014	15:40	1.4	0.56	56	43
07-PIL22.6	8/26/2014	12:30	1.4	0.45	63.4	40
07-PIL-26.0	7/8/2014	8:30	1	1.1	67.7	73
07-PIL-26.0	7/8/2014	9:00	1	1.1	67.8	76
07-PIL-26.0	8/5/2014	8:30	0.7	0.95	69.4	49
07-PIL-26.0	8/5/2014	8:50	0.8	0.82	69.5	45
07-PIL-26.0	8/26/2014	8:49	0.7	1	68	49
07-PIL-5.7	7/10/2014	14:15	1.4	1.1	60.9	99
07-PIL-5.7	7/10/2014	14:50	1.4	1.2	60.9	102
07-PIL-5.7	8/6/2014	14:29	1.3	0.83	61.2	65
07-PIL-5.7	8/6/2014	15:07	1.3	0.83	60.6	65
07-PIL-5.7	8/28/2014	14:27	1.3	0.68	60.8	56

EIM Location ID	Date	Time	Average Depth	Average Velocity	Wetted Width	Flow
07-PIL-7.0	7/10/2014	10:55	0.8	1.5	83.8	98
07-PIL-7.0	8/28/2014	11:28	0.9	0.89	75.8	58
07-PIL-8.5	7/9/2014	13:00	1.6	0.96	63	96
07-PIL-8.5	8/6/2014	12:30	0.7	1.6	58	68
07-PIL-8.5	8/27/2014	11:16	1.4	0.66	58	56
07-PIL-8.6	7/9/2014		0.9	1.2	80.1	87
07-PIL-8.6	8/6/2014	10:15	0.7	1.1	80.2	66
07-PIL-8.6	8/27/2014	10:21	0.7	1.3	66	60
07-PIL-SEEP14.2	7/9/2014	14:12				0.5 J
07-PIL-SEEP14.2	8/6/2014	14:21				0.2 J
07-PIL-SEEP14.3	7/9/2014	14:15				0.2 J
07-PIL-SEEP14.3	8/6/2014	14:19				0.2 J
07-PIL-TRIB10.6	8/27/2014	17:22				0.02 J
07-PIL-TRIB11.5	7/9/2014	16:07				0.1 J
07-PIL-TRIB15.3	7/9/2014	12:03				0.8 J
07-PIL-TRIB15.3	8/6/2014	12:30				0.03 J
07-PIL-TRIB17.2	7/9/2014	10:03				0.2 J
07-PIL-TRIB17.2	8/6/2014					0.05 J
07-PIL-TRIB18.2	7/8/2014		0.2	0.16	5.9	0.17
07-PIL-TRIB18.2	8/5/2014	11:20	0.2	0.2	8.5	0.36
07-PIL-TRIB18.2	8/27/2014	12:00	0.2	0.65	2.9	0.29
07-PIL-TRIB19.3	7/8/2014		0.1	0.44	1.7	0.07
07-PIL-TRIB19.3	8/5/2014		0.1	0.43	1.3	0.04
07-PIL-TRIB19.3	8/26/2014	16:45	0.1	0.73	3.5	0.26 J
07-PIL-TRIB19.7	7/8/2014		0.3	0.36	4.4	0.52
07-PIL-TRIB19.7	8/5/2014	15:30	0.3	0.38	5.2	0.62
07-PIL-TRIB19.7	8/26/2014	13:21	0.2	0.98	3.8	0.56
07-PIL-TRIB20.0	7/8/2014		0.2	0.27	11.2	0.72
07-PIL-TRIB20.0	8/5/2014	13:58	0.7	0.44	3.4	1
07-PIL-TRIB20.0	8/26/2014	15:42	0.6	0.3	3.6	0.69
07-PIL-TRIB6	7/10/2014	11:33				0.4 J
07-PIL-TRIB6	8/6/2014	12:34				0.1 J
07-PIL-TRIB6	8/27/2014	12:18	0.1	1.2	1	0.12 J
07-PIL-TRIB7.3	7/10/2014	10:22				1 J
07-PIL-TRIB7.3	8/6/2014	11:40				0.5 J
07-PIL-TRIB7.8	7/10/2014	10:03				0.05 J
07-PUR-0.0	7/8/2014	10:00	0.4	0.94	9	3.7
07-PUR-0.0	8/5/2014		0.4	0.79	8	2.3
07-PUR-0.0	8/26/2014	9:30	0.3	0.89	7.6	2.2
07-SCOTT-0.6	7/10/2014	10:40	0.4	0.16	1.8	0.11
07-SCOTT-0.6	8/7/2014	12:30	0.4	0.19	6.2	0.42
07-SCOTT-0.6	8/28/2014	12:00	0.4	0.12	6.4	0.3

EIM Location ID	Date	Time	Average Depth	Average Velocity	Wetted Width	Flow
7-PIL-TRIB19.6S	7/8/2014		0.8	0.45	3.6	1.2
7-PIL-TRIB19.6S	8/5/2014	16:22	0.2	0.12	11.2	0.28
PR4.2	8/7/2014	11:00	0.9	1.4	56.2	67
PR4.2	8/7/2014	11:28	0.9	1.5	55.9	74
PR4.2	8/28/2014	11:13	0.9	1.3	52.4	62
SNOCO_SWLKRM	7/8/2014		0.3	1.3	2.5	0.91
SNOCO_SWLKRM	8/5/2014	15:50	0.2	1.3	3	0.71
SNOCO_SWLKRM	8/26/2014	16:29	0.2	0.04	11.2	0.08

Table D-11. Discrete surface water measurement results for the 2014 and 2016 surveys.

EIM Location ID	Date	Time	Temperature, water	pH	Specific Conductivity (at 25 °C)	Dissolved Oxygen
07-PIL-11.6	8/16/2016	21:09	20.42		74.8	
07-PIL-11.6	8/19/2016	8:08	16.96	7.25	80.4	8.99
07-PIL-15.1	8/16/2016	20:45	20.03		76.6	
07-PIL-15.1	8/17/2016	9:32	16.4		77.3	
07-PIL-15.1	8/17/2016	17:26	20.89	7.34	81.6	9.11
07-PIL-15.1	8/19/2016	8:30	16.87	7.17	80.3	8.7
07-PIL-18.7	8/16/2016	19:11	20.54		72.8	
07-PIL-18.7	8/17/2016	16:08	20.52	7.43	77	9.43
07-PIL-18.7	8/19/2016	9:00	16.02	7.17	75.7	9.66
07-PIL-2.0	8/16/2016	16:45	21.76		85.3	
07-PIL-2.0	8/19/2016	11:04	17.99	7.42	89	9.64
07-PIL-21.5	8/16/2016	19:30	19.46		70.3	
07-PIL-21.5	8/17/2016	11:30	17.31	7.61	74.5	
07-PIL-21.5	8/18/2016	8:14	15.47	7.54	71.8	9.64
07-PIL-21.5	8/19/2016	9:30	15.89	7.42	71.6	10.03
07-PIL-25.5	8/18/2016	7:52	13.82	7.56	70.3	10.28
07-PIL-25.5	8/19/2016	10:00	14.15	7.53	70.8	10.55
07-PIL-3.6	8/16/2016	17:15	22.19		85.2	
07-PIL-5.7	8/16/2016	17:47	22.1		83.3	
07-PIL-5.7	8/18/2016	18:30	22.28	7.74	86.2	9.13
07-PIL-5.7	8/19/2016	7:05	17.25	7.01	87.6	9
07-PIL-5.7	9/15/2016	12:52	15.33		83.4	11.98
07-PIL-8.2	8/16/2016	18:30	21.98		80.4	
07-PIL-8.2	8/19/2016	7:38	17.03	7.07	84.2	9.11
07-PIL-8.2	9/15/2016	15:10	16.49		80.7	10.64
07-PIL-8.6	9/15/2016	16:57	17.14		80.1	10.22
07-PIL-TRIB10.6	8/27/2014	17:22	9.81	8.1	289	4.73
07-PIL-TRIB15.3	8/27/2014	13:01	15.39	6.91	74	4.6
07-PIL-TRIB17.2	7/9/2014	9:51	14.63	7.43	84.5	9.68
07-PIL-TRIB17.2	8/27/2014	10:55	15.53	7.92	96	9.77
07-PIL-TRIB17.2	8/18/2016	13:23	16.74	7.32	94.8	9.56
07-PIL-TRIB18.2	8/6/2014	9:40	20.5			
07-PIL-TRIB19.6	8/26/2014	16:24	17.1			
07-PIL-TRIB22.5	8/26/2014	13:16	12.5	5.9	68	2.36
07-PIL-TRIB24.3	8/5/2014	11:41	17.06	6.8	71.8	7.87
07-PIL-TRIB24.3	8/26/2014	10:34	15.86	7.06	70.5	8.34
07-PIL-TRIB6	8/28/2014	12:21	13.86	8.03	156.9	10.36
07-PIL-TRIB7.3	7/10/2014	10:20	12.21	7.52	165	10.13

Table D-12. Discrete piezometer and seep measurement results for the 2014 and 2016 surveys.

EIM Location ID	Date	Time	Temperature, water	pH	Specific Conductivity (at 25 °C)	Dissolved Oxygen	Temperature, hyporheic
07-PIL-PIEZ14.8	8/18/2016	10:00		6.15	207.3	5.6	13.82
07-PIL-PIEZ14.8	8/18/2016	10:30		6.21	207.4	5.3	13.82
07-PIL-SEEP1.7	8/28/2014	16:21	17.2				
07-PIL-SEEP10.7	8/27/2014	17:06	14.66	7.58	401.8	9.97	
07-PIL-SEEP11.7	8/6/2014	16:33	12				
07-PIL-SEEP11.7	8/18/2016	17:39	11.63	6.7	495.7	4.41	
07-PIL-SEEP13.3	8/6/2014	15:16	15				
07-PIL-SEEP14.2	8/27/2014	14:41	14.95	6.98	150.3	4.01	
07-PIL-SEEP14.3	8/6/2014	14:20	14.8				
07-PIL-SEEP14.8	8/17/2016	18:24	15.13	7.21	136.4	9	
07-PIL-SEEP15.1	7/9/2014	12:48	16.89	6.19	118	2.21	
07-PIL-SEEP15.1	8/27/2014	13:23	18.3	6.87	132.4	2.72	
07-PIL-SEEP15.1	8/27/2014	13:34	17.2	6.49	108	2.22	
07-PIL-SEEP15.3	8/18/2016	14:43	13.51	6.36	57	4.44	
07-PIL-SEEP15.3	8/18/2016	14:55	13.47	6.4	57.1	3.79	
07-PIL-SEEP18.1	8/18/2016	12:30	14.68	7.05	154	9.94	
07-PIL-SEEP18.9	8/17/2016	14:49	13.61	6.07	830	0.84	
07-PIL-SEEP18.9	8/17/2016	15:40	14.12	5.71	1417	4.57	
07-PIL-SEEP20.5	8/17/2016	11:52	12.48	6.51	148.1	4.54	
07-PIL-SEEP21.1	8/26/2014	14:20	16.43		189	7.48	
07-PIL-SEEP23.1	8/5/2014	13:08	10.25	6.96	93.2	10.77	
07-PIL-SEEP23.1	8/26/2014	12:19	11.4				
07-PIL-SEEP5.8	7/10/2014	12:04	11.38	6.24	250	6.45	
07-PIL-SEEP5.8	8/18/2016	18:41	18.48	6.59	169.3	1.63	
07-PIL-SEEP5.8	9/15/2016	14:13	14.87	6.53	27	1.14	
7-PIL-SEEP14.25	8/27/2014	14:38	18.53	7.57	77.2	5.71	
AHL156	9/15/2016	17:08		6.57	76.9	1.4	15.39
AHL156	9/15/2016	17:10		6.57	75	1.42	15.39
AHL156	10/6/2016	12:35		6.53	78.7	2.11	13.46
AHL156	10/6/2016	12:38		6.49	78.1	2.17	13.46
AHL157	9/15/2016	15:46		6.39	75.7	0.03	15.05
AHL157	9/15/2016	15:47		6.35	75.6	0	15.05
AHL157	10/6/2016	14:17		6.43	72.5	0	13.42
AHL157	10/6/2016	14:20		6.39	72.8	0	13.36
AHL158	9/15/2016	13:04		6.07	145.2	1.35	13.96
AHL158	9/15/2016	13:16		6.04	145.6	1.12	13.9
AHL158	10/6/2016	15:43		6.15	152.6	1.08	13.52
AHL158	10/6/2016	15:46		6.16	152	1.05	13.48
AHL159	10/6/2016	17:00		6.63	80.4	1.83	13.32
AHL159	10/6/2016	17:03		6.61	79.9	1.89	13.31

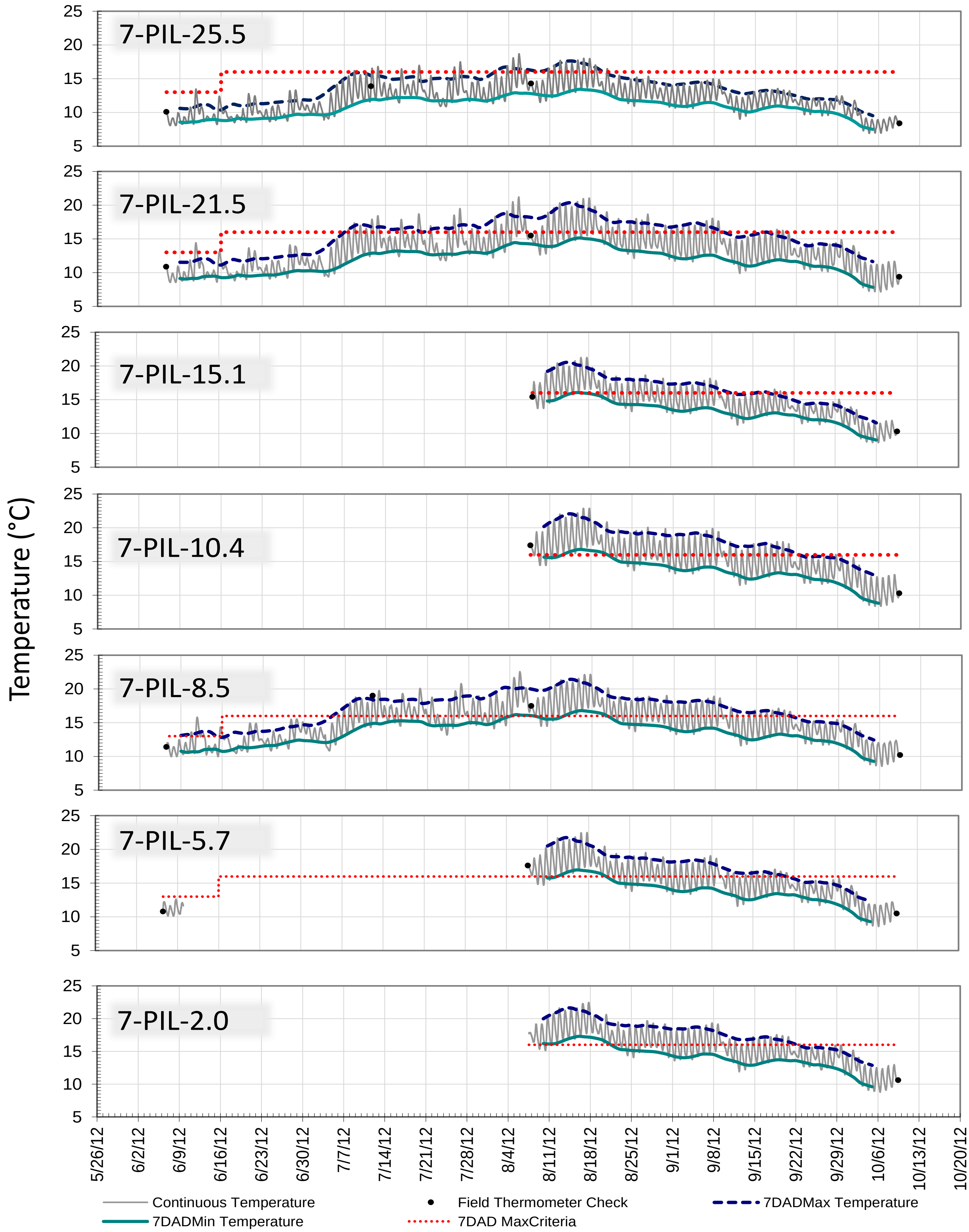

Figure D-1. Continuous temperature results for Pilchuck River mainstem.

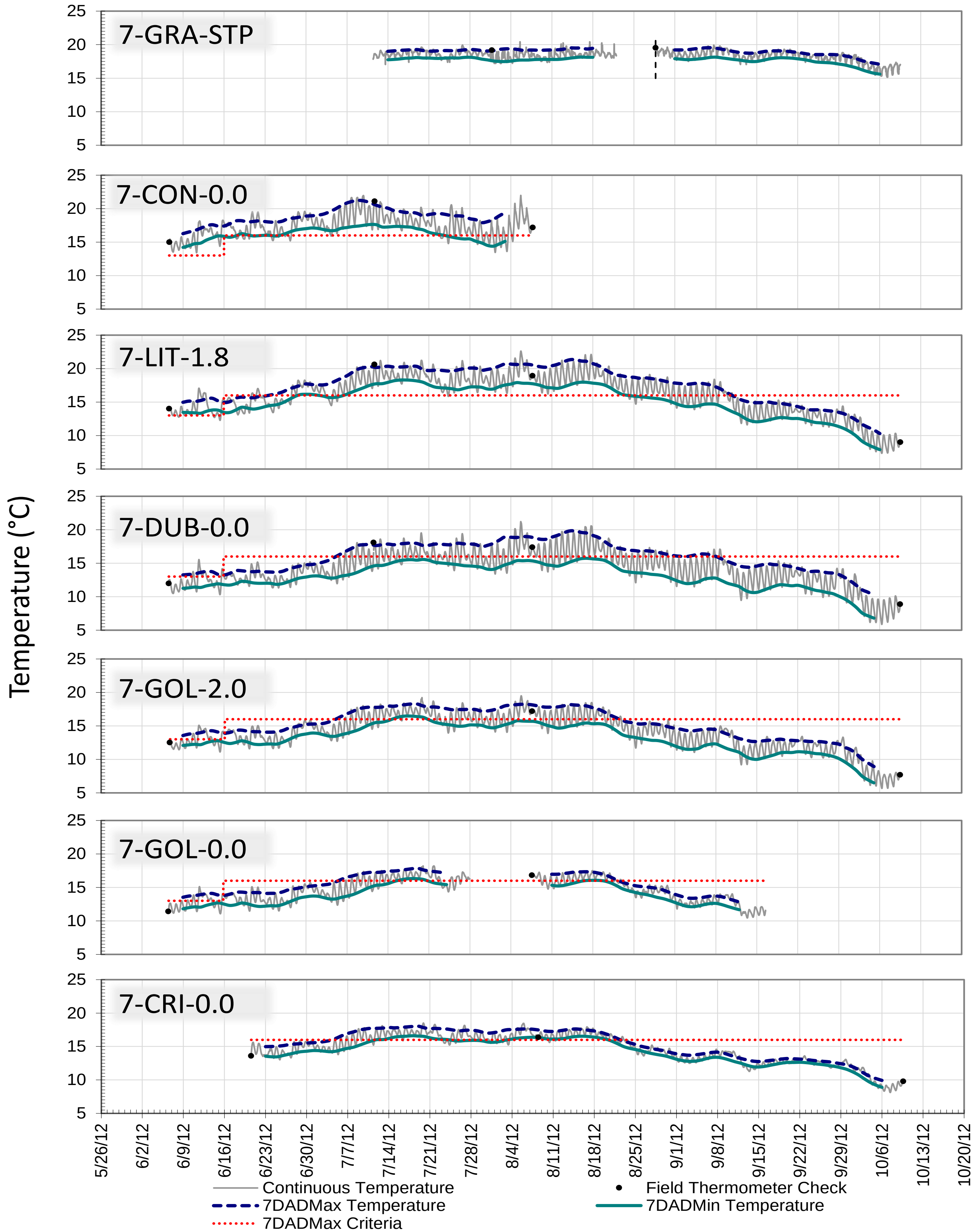

Figure D-2. Continuous temperature results for Pilchuck tributaries and Granite Falls WWTP.

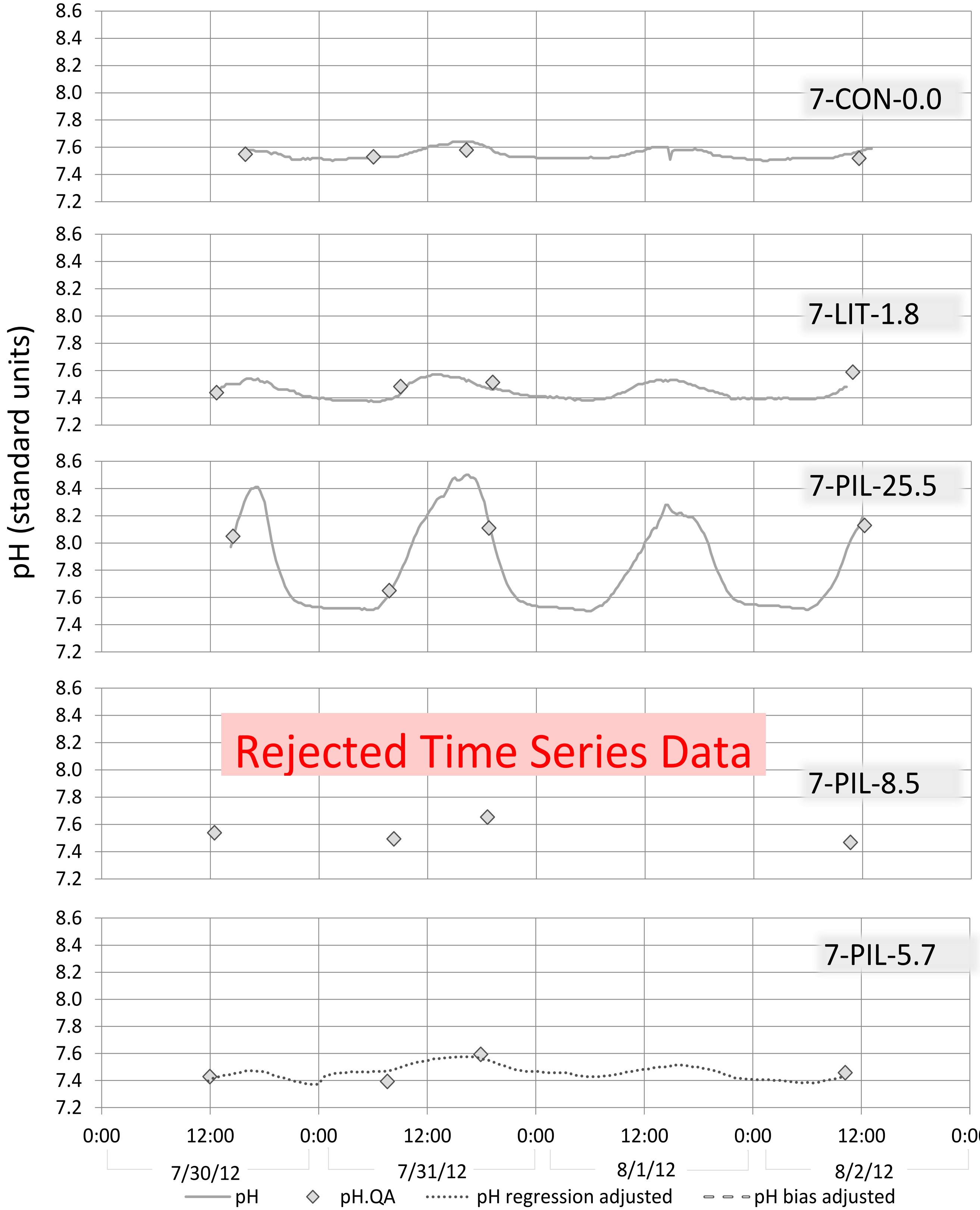

Figure D-3. Diel pH results for late July/ early August 2012 deployment.

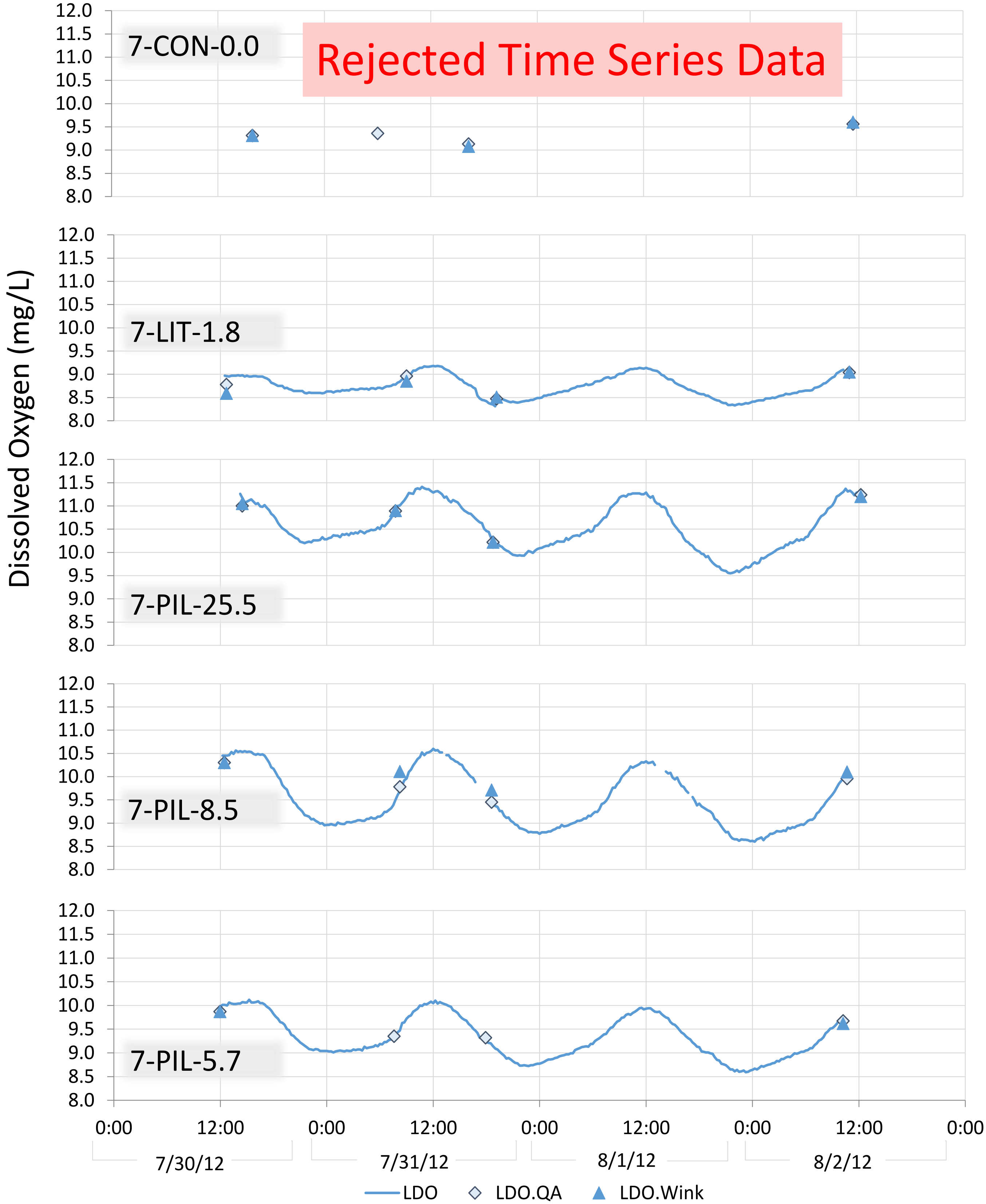

Figure D-4. Diel dissolved oxygen results for late July/ early August 2012 deployment.

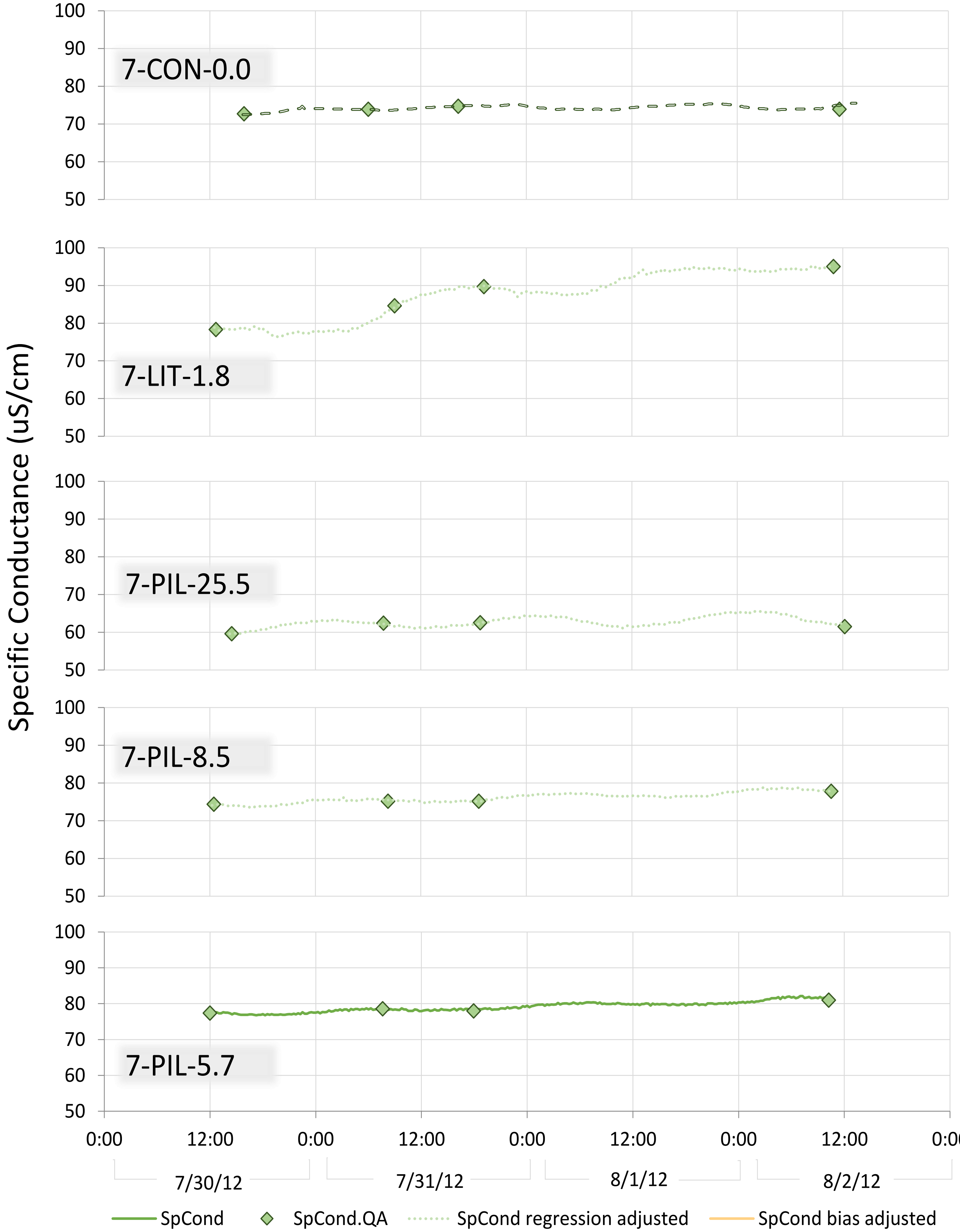

Figure D-5. Diel specific conductance results for late July/ early August 2012 deployment.

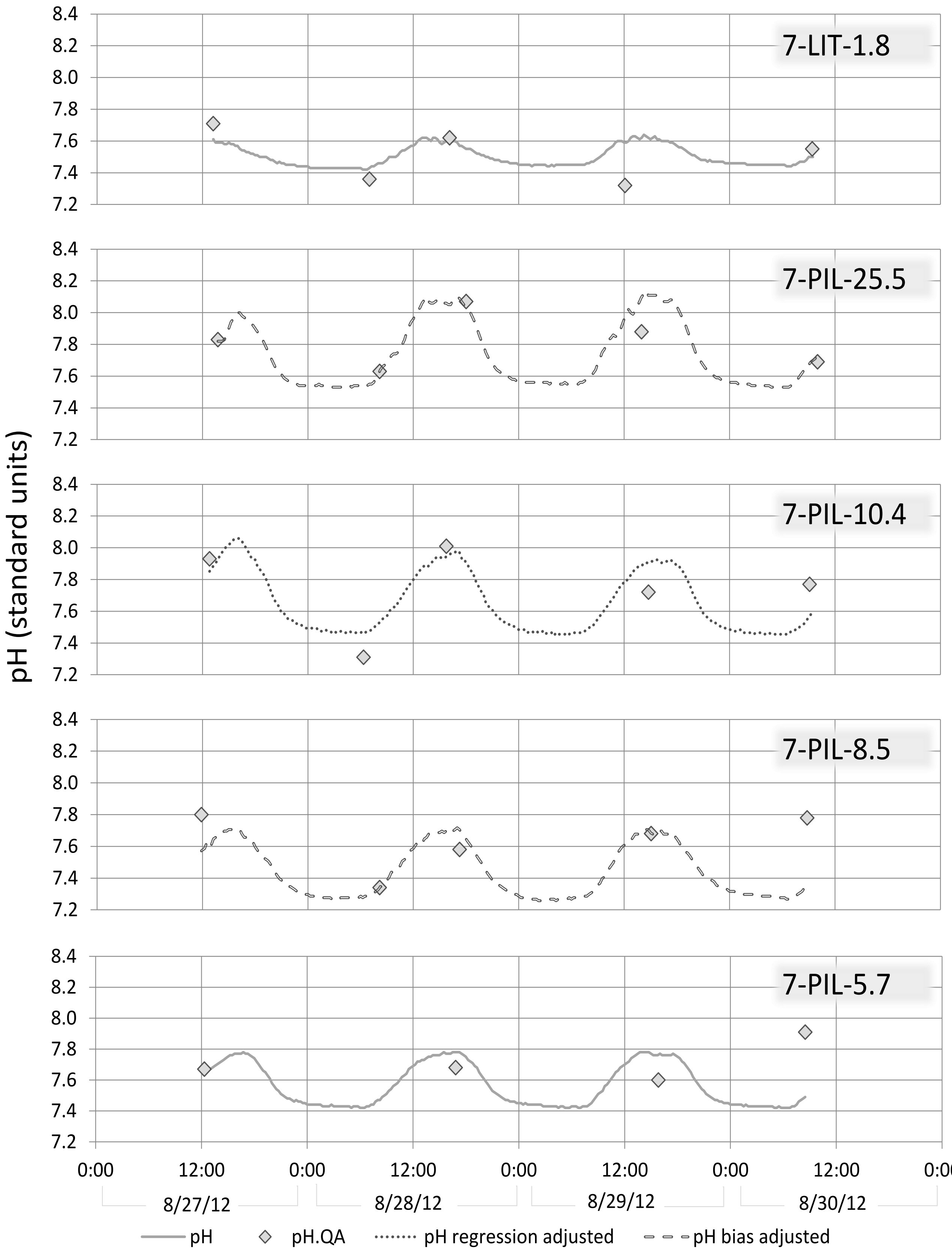

Figure D-6. Diel pH results for late August 2012 deployment.

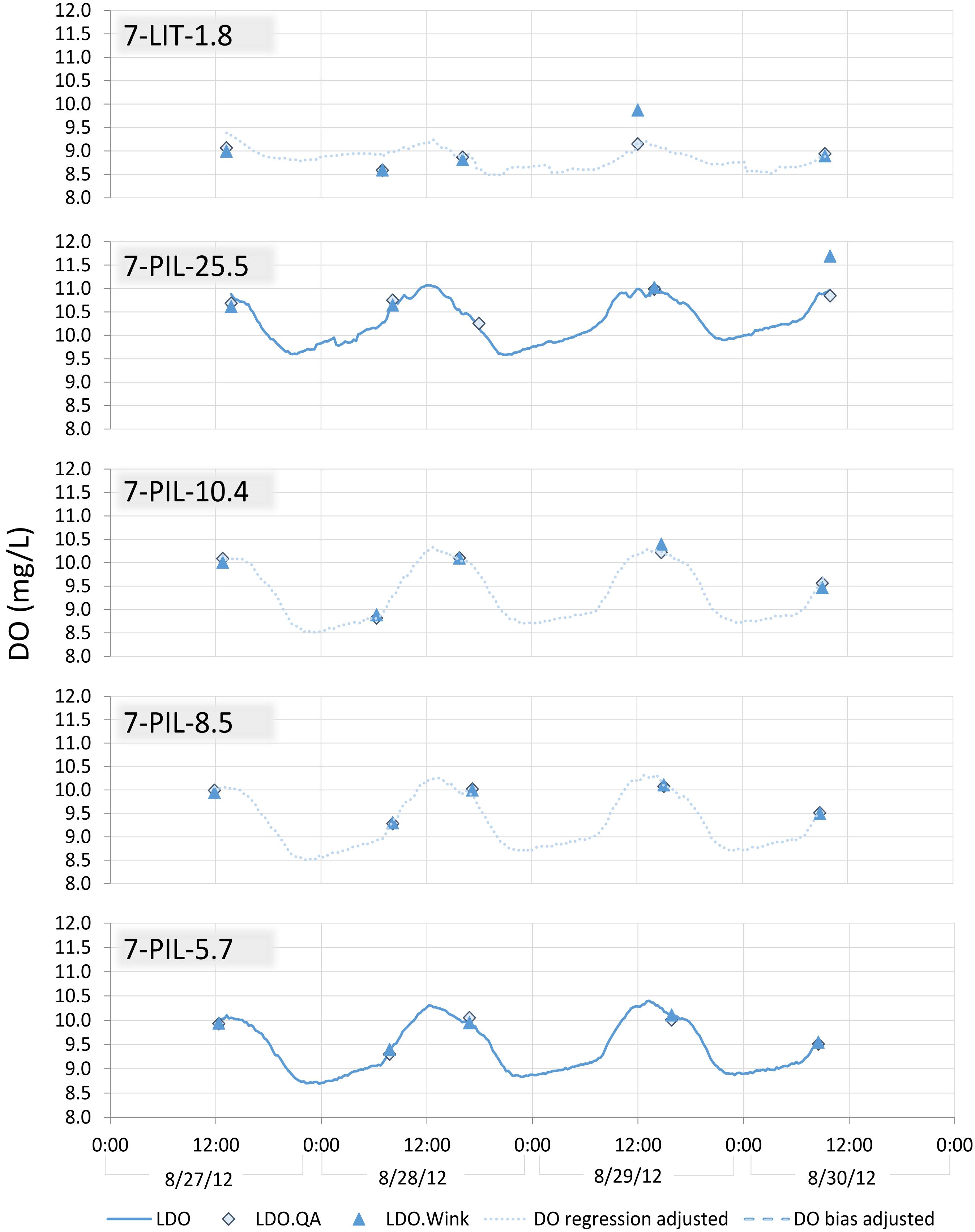

Figure D-7. Diel dissolved oxygen results for late August 2012 deployment.

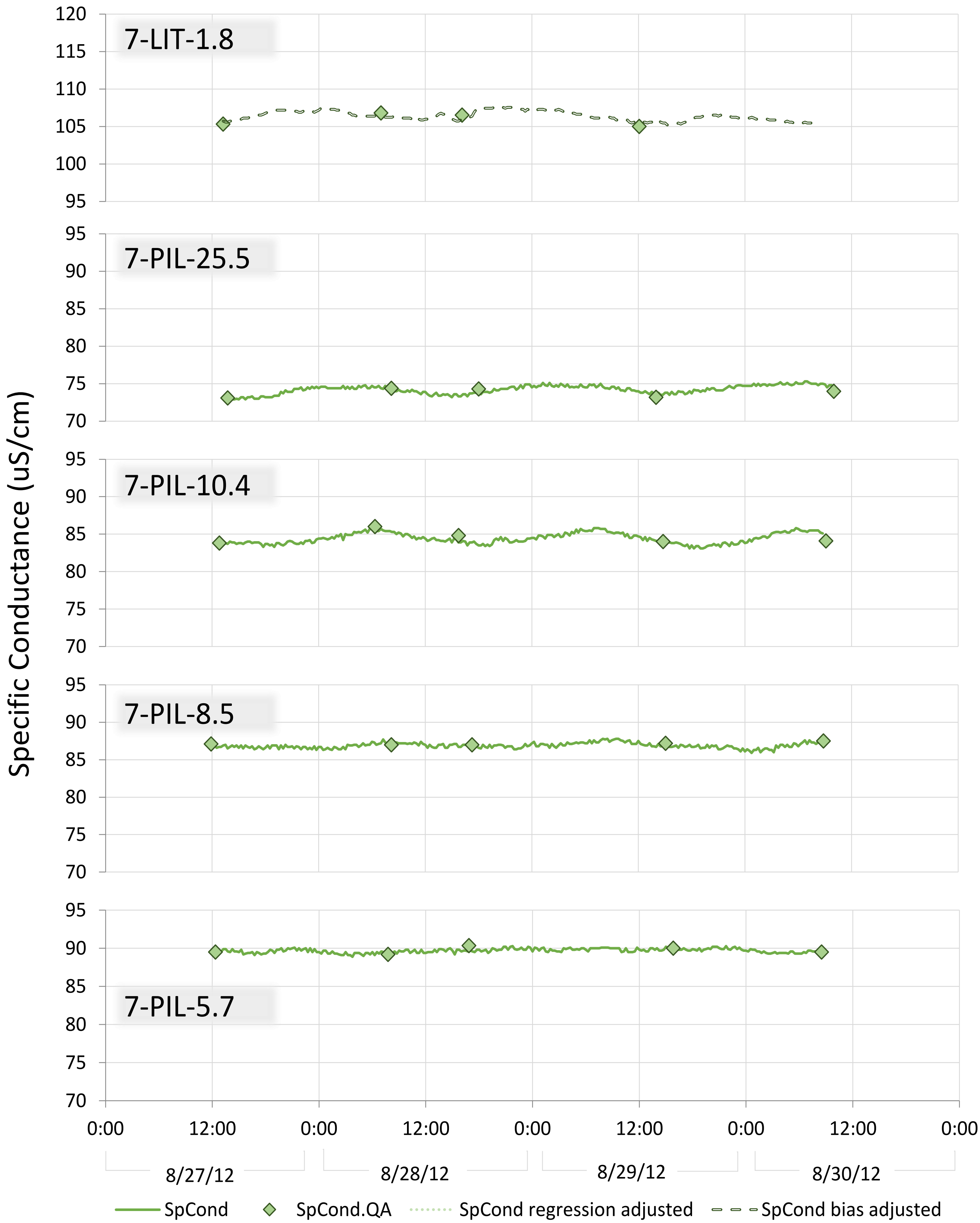

Figure D-8. Diel specific conductance results for late August 2012 deployment.

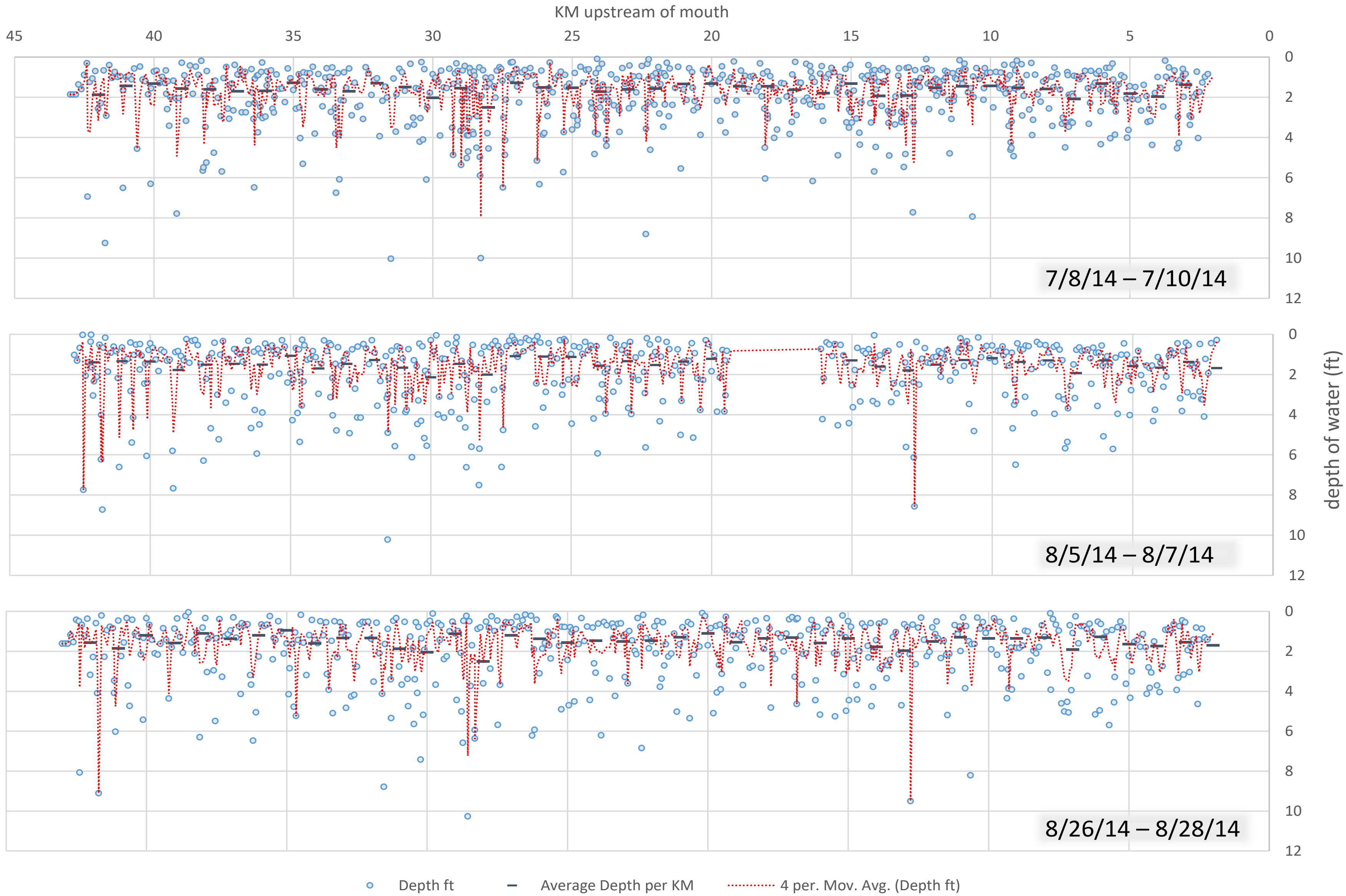

Figure D-9. Longitudinal depth profiles for the Pilchuck River based on 2014 float surveys.

Appendix E. Data Quality Results

This appendix describes the quality of data that were collected specifically for the Pilchuck River Temperature and Dissolved Oxygen TMDL in the summers of 2012, 2014, and 2016.

All data used for the TMDL analysis were assessed for quality. Typically this was done by comparing some sort of quality metric such as a replicate precision statistic or an instrument calibration end check to a target Measurement Quality Objective (MQO). All data were found to be of appropriate quality for their use in the TMDL analysis, unless otherwise noted.

In summary:

- For synoptic survey deployments, with a few exceptions the Hydrolab sondes met all data quality criteria for end of the day checks against National Institute of Standards and Technology (NIST) thermometer NIST-certified conductivity and pH standards, and Winkler samples.
- All thermistors readings fell within specifications (±0.2 °C) when compared to a NIST-certified thermometer in room temperature and ice bath, post-deployment.
- Partial continuous temperature records were obtained at a few locations due to either:
  - The instrument was found out of water due to rapidly changing water levels. Associated data were rejected based on paired air temperature records.
  - The instrument was lost (due to large flow events or theft).
- Several data quality issues were identified with Ecology's 2012 air temperature data:
  - Field notes for 2012 state that several thermistors were deployed without a shade device. It is unclear from field notes whether this occurred at all sites or just those specifically mentioned. In particular, the HoboPro V2 has a larger, dark color body (compared to Tidbits small translucent body) and must be properly shaded to avoid bias due to direct solar radiation.
  - Onset Tidbit V1s were used at several locations. While these thermistors passed the NIST post-check, they were ~10+ years old at the time of the study and their reliability, particularly above 20 °C, is uncertain.
  - The project manager rejected data where no shade device was used. The project manager also compared Ecology's air temperature data to the AgWeatherNet Snohomish and predicted DayMet data. Ecology data where air temp exceeded these sites by greater than 5 degrees C was rejected.
- Field replicate samples for all parameters met their respective measurement quality objectives for precision.
- Field blanks for all parameters fell below the detection limit.
- Laboratory quality control samples fell within established acceptance limits, with a few minor exceptions.

Discrete Data Quality

Table E-1 contains results for field replicates collected during the 2012 study. Field replicate samples for all parameters met their respective measurement quality objectives for precision.

All field blanks were below detection limits.

Laboratory quality control samples fell within established acceptance limits, with a few exceptions:

- Duplicates (Table E-2) – Out of 125 duplicate pairs: 1 Chlorophyll (water), 1 Chlorophyll (periphyton tissue), 1 Ash Free Dry Weight (periphyton tissue), 2 Total Phosphorus, 2 TSS, and 3 TNVSS failed to meet the MQO (20%RSD). Of these, 2 Total Phosphorus, 2 TSS, and 3 TNVSS were less than 5 times the reporting limit. Associated results were qualified as estimates.
- Method blanks (Table E-3) – Out of 134 blanks: 1 Total Phosphorus, and 1 AFDW had some level of contamination. The level of contamination was relatively low (<10% of lowest batch sample result).
- Lab Control Samples (Table E-4) – All 101 lab control samples were within acceptance limits. Alkalinity sample recoveries showed evidence of some method bias with median recoveries at ~90% of the spike amount.
- Matrix Spikes (Table E-5) – All 68 matrix spike recovery results were within acceptance limits.

Table E-6 contains the results of replicate flow measurements collected during the study. Table E-7 contains a summary of replicate precision for the flow replicate pairs. The median of 4% RSD for all replicate pairs met the project MQO (median of <10%RSD).

Table E-1. Field replicate results.

TNVSS results not included because the replicate results were mostly below the reporting limit.

Parameter	Mean % RSD	Precision standard	Meets MQO criteria?	Number of replicates taken	Number of samples less replicates	Percent of samples replicated
Alkalinity, Total	0.7	10% RSD	Yes	10	103	10
Ammonia	3	10% RSD	Yes	11	111	10
Biochemical Oxygen Demand, 5-day	0	25% RSD	Yes	1	7	14
Chloride	1.2	5% RSD	Yes	8	80	10
Chlorophyll *a*	7.1	20% RSD	Yes	8	80	10
Dissolved Organic Carbon	3.1	10% RSD	Yes	8	80	10
Nitrate-Nitrite as N	3.3	10% RSD	Yes	11	111	10
Ortho-Phosphate	2.5	10% RSD	Yes	11	111	10
Total Organic Carbon	2.6	10% RSD	Yes	8	80	10
Total Persulfate Nitrogen	10.9	10% RSD	Yes	11	111	10
Total Phosphorus	9.8	10% RSD	Yes	11	111	10
Total Suspended Solids	2.9	15% RSD	Yes	8	80	10
Turbidity	9.2	15% RSD	Yes	8	80	10
Chlorophyll a (periphyton)	8	50% RSD	Yes	6	50	12
Ash-Free Dry Weight (periphyton)	9.3	50% RSD	Yes	6	50	12

Table E-2. Laboratory duplicate results.

Parameter	Count	Mean RSD	Median RSD	Min RSD	Max RSD	Target	# of Fails	% Failure
Alkalinity, Total	10	0.5%	0.3%	0.0%	2.1%	20	0	0%
Ammonia	11	1.4%	0.0%	0.0%	7.7%	20	0	0%
Biochemical Oxygen Demand, 5-day	2	0.0%	0.0%	0.0%	0.0%	30	0	0%
Chloride	6	0.7%	0.6%	0.0%	1.7%	20	0	0%
Chlorophyll *a*	10	9.3%	5.4%	0.0%	44.4%	20	1	10%
Nitrate-Nitrite as N	11	2.1%	1.4%	0.0%	7.0%	20	0	0%
Ortho-Phosphate	11	3.0%	2.5%	0.0%	10.2%	20	0	0%
Total Non-Volatile Suspended Solids	11	9.7%	0.0%	0.0%	40.0%	20	3	27%
Total Organic Carbon	1	2.0%	2.0%	2.0%	2.0%	20	0	0%
Total Persulfate Nitrogen	12	2.7%	2.9%	0.0%	6.7%	20	0	0%
Total Phosphorus	11	14.3%	6.8%	0.0%	66.7%	20	2	18%
Total Suspended Solids	11	9.6%	0.0%	0.0%	40.0%	20	2	18%
Turbidity	7	1.1%	0.0%	0.0%	8.0%	20	0	0%
Chlorophyll *a* (periphyton)	6	11.6%	13.1%	0.3%	24.0%	20	1	17%
Ash-Free Dry Weight (periphyton)	5	7.8%	0.0%	0.0%	28.6%	20	1	20%

Table E-3. Laboratory Blank Results.

Parameter	Count	Number of Contaminated Blanks	Percent Contaminated Blanks	Potential Magnitude of Contamination
Alkalinity, Total	10	0	0%	
Ammonia	12	0	0%	
Biochemical Oxygen Demand, 5-day	2	0	0%	
Chloride	6	0	0%	
Chlorophyll *a*	6	0	0%	
Dissolved Organic Carbon	7	0	0%	
Nitrate-Nitrite as N	11	0	0%	
Ortho-Phosphate	11	0	0%	
Total Non-Volatile Suspended Solids	12	0	0%	
Total Organic Carbon	5	0	0%	
Total Persulfate Nitrogen	12	0	0%	
Total Phosphorus	11	1	9%	2 - 9%
Total Suspended Solids	12	0	0%	
Turbidity	7	0	0%	
Ash-Free Dry Weight	6	1	17%	1%

Table E-4. Laboratory Control Sample Results (Batch Spikes).

Parameter	Count	MEL QC Lower Limit	MEL QC Upper Limit	Min	Max	Median Recovery
Alkalinity, Total	10	80	120	84	107	90
Ammonia	11	80	120	99	112	102
Biochemical Oxygen Demand, 5-day	2	70	130	105	114	109.5
Chloride	6	90	110	101	104	102
Dissolved Organic Carbon	7	80	120	96	100	99
Nitrate-Nitrite as N	11	80	120	89	112	104
Ortho-Phosphate	11	80	120	89	108	96
Total Non-Volatile Suspended Solids	2	85	115	49	71	60
Total Organic Carbon	5	80	120	98	99	99
Total Persulfate Nitrogen	12	80	120	97	109	103
Total Phosphorus	11	80	120	91	105	98
Total Suspended Solids	6	80	120	84	113	97.5
Turbidity	7	95	105	96	98	97

Table E-5. Matrix spike results.

Parameter	Count	MEL QC Lower Limit	MEL QC Upper Limit	Min	Max	Median Recovery
Ammonia	11	75	125	88	103	95
Chloride	12	75	125	97	109	100
Nitrate-Nitrite as N	11	75	125	84	107	100
Ortho-Phosphate	11	75	125	90	105	99
Total Organic Carbon	1	75	125	100	100	100
Total Persulfate Nitrogen	11	75	125	93	108	99
Total Phosphorus	11	75	125	93	115	98

Table E-6. Flow replicate results.

Study Location Name	Date	Time	Average Depth (ft)	Avg. Velocity (ft/sec)	Wetted Width (ft)	Flow (cfs)
PIL14.9	8/27/14	12:23	1	0.98	52.5	54
PIL14.9	8/27/14	12:45	1	0.94	52.8	51
PIL25.5	8/5/14	8:30	0.7	0.95	69.4	49
PIL25.5	8/5/14	8:50	0.8	0.82	69.5	45
PIL5.7	8/6/14	14:29	1.3	0.83	61.2	65
PIL5.7	8/6/14	15:07	1.3	0.83	60.6	65
PIL3.6	8/7/14	11:00	0.9	1.4	56.2	67
PIL3.6	8/7/14	11:28	0.9	1.5	55.9	74
PIL25.5	7/8/14	8:30	1	1.1	67.7	73
PIL25.5	7/8/14	9:00	1	1.1	67.8	76
PIL14.9	7/9/14	9:30	1	1.2	65.5	79
PIL14.9	7/9/14	11:15	1	1.5	57.9	91
PIL5.7	7/10/14	12:00	1	1.5	58.9	92
PIL5.7	7/10/14	14:15	1.4	1.1	60.9	99

Table E-7. Precision results for flow replicate pairs. Median RSD% for all replicate pairs is 4%.

Study Location Name	Date	Replicate Type	Average Flow (cfs)	Replicate Precision RSD%
PIL14.9	8/27/14	same team	52.5	4%
PIL25.5	8/5/14	different teams	47	6%
PIL5.7	8/6/14	same team	65	0%
PIL3.6	8/7/14	same team	70.5	7%
PIL25.5	7/8/14	different teams	74.5	4%
PIL14.9	7/9/14	same team	85	1%
PIL5.7	7/10/14	same team	95.5	2%

Continuous Data Quality

All Hobo Water Temp Pro V2 thermistors readings fell within instrument specifications (±0.2 °C) when compared to a NIST-certified thermometer in both a room temperature and ice bath, post-deployment. All deployed thermistors and sondes met field QC check MQOs.

Table E-8 contains the MQOs for post-deployment sonde checks.

Table E-8. Measurement quality objectives for post-deployment checks.

Parameter	Units	Accept (Excellent)	Qualify (Good or Fair)	Reject (Poor)
Temperature	° C	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8
Specific Conductance*	uS/cm	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%
Dissolved Oxygen**	% saturation	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%
pH	std. units	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8

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

For synoptic survey deployments, the Hydrolab sondes met all data quality criteria for end of the day checks against NIST-certified conductivity and pH standards, and DO% saturation checks, with a few exceptions (Tables E-9 to E-20).

Table E-9. Specific conductance continuous data quality results for 2012 Synoptic #2 (8/27/12 - 8/30/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	1%	+1%	Regression	-1.2 to +0.1	Accept
8.5	Accept	5%	-5%	Regression	+3.6 to +3.7	Accept
5.7	Accept	0%	0%	n/a	n/a	Accept
LIT1.8	Qualify	9%	-9%	Regression	+7.1 to +7.7	Qualify
CON0.0	Qualify	26%	-25%	Bias	+14.7 to+15.3	Qualify

Table E-10. Specific conductance continuous data quality results for 2012 Synoptic #1 (7/30/12 - 8/2/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	1%	0%	n/a	n/a	Accept
10.4	Accept	1%	0%	n/a	n/a	Accept
8.5	Accept	0%	0%	n/a	n/a	Accept
5.7	Accept	0%	0%	n/a	n/a	Accept
LIT1.8	Reject	32%	32%	n/a	n/a	Reject

Table E-11. Specific conductance continuous data quality results for 2016 Synoptic (8/16/16 - 8/20/16).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	3%	4%	n/a	n/a	Accept
21.5	Accept	5%	4%	n/a	n/a	Accept
18.7	Accept	2%	2%	n/a	n/a	Accept
15	Accept	3%	2%	n/a	n/a	Accept
11.6	Accept	6%	6%	n/a	n/a	Accept
8.5	Accept	2%	2%	n/a	n/a	Accept
5.7	Accept	3%	3%	n/a	n/a	Accept
3.6	Accept	4%	4%	n/a	n/a	Accept
2.0	Accept	2%	2%	n/a	n/a	Accept

Table E-12. pH continuous data quality results for 2012 Synoptic #2 (8/27/12 - 8/30/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.05	+0.01	n/a	n/a	Accept
8.5	Reject	n/a	n/a	n/a	n/a	Reject
5.7	Accept	0.23	+0.18	Bias	-0.18	Accept
LIT1.8	Accept	0.15	+0.10	n/a	n/a	Accept
CON0.0	Accept	0.04	+0.04	n/a	n/a	Accept

Table E-13. pH continuous data quality results for 2012 Synoptic #1 (7/30/12 - 8/2/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.19	+0.12	Bias	-0.12	Accept
10.4	Accept	0.20	-0.13	Regression	+0.12 to +0.15	Accept
8.5	Accept	0.38	-0.22	Bias	+0.23	Accept
5.7	Accept	0.21	-0.01	n/a	n/a	Accept
LIT1.8	Accept	0.13	+0.03	n/a	n/a	Accept

Table E-14. pH continuous data quality results for 2016 Synoptic (8/16/16 - 8/20/16).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.03	-0.04	n/a	n/a	Accept
21.5	Accept	0.32	-0.27	Bias	+0.29	Accept
18.7	Accept	0.28	+0.34	n/a	n/a	Accept
15	Accept	0.09	-0.04	n/a	n/a	Accept
11.6	Accept	0.30	0.14	n/a	n/a	Accept
8.5	Accept	0.30	0.30	n/a	n/a	Accept
5.7	Accept	0.20	0.08	n/a	n/a	Accept
3.6	Accept	n/a	n/a	n/a	n/a	Accept
2.0	Accept	0.14	-0.14	n/a	n/a	Accept

Table E-15. Dissolved oxygen continuous data quality results for 2012 Synoptic #2 (8/27/12 - 8/30/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.09	+0.09	n/a	n/a	Accept
8.5	Accept	0.25	-0.16	n/a	n/a	Accept
5.7	Accept	0.07	0.00	n/a	n/a	Accept
LIT1.8	Accept	0.22	+0.14	n/a	n/a	Accept
CON0.0	Accept	1.05	-0.92	n/a	n/a	Reject

Table E-16. Dissolved oxygen continuous data quality results for 2012 Synoptic #1 (7/30/12 - 8/2/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.35	+0.12	n/a	n/a	Accept
10.4	Accept	0.21	+0.16	n/a	n/a	Accept
8.5	Accept	0.15	+0.13	Regression	-0.01 to -0.23	Accept
5.7	Accept	0.04	0.00	n/a	n/a	Accept
LIT1.8	Accept	0.78	-0.67	Regression	+0.55 to +0.88	Qualify

Table E-17. Dissolved oxygen continuous data quality results for 2016 Synoptic (8/16/16 - 8/20/16).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	Accept	0.08	-0.04	n/a	n/a	Accept
21.5	Accept	0.42	-0.07	n/a	n/a	Accept
18.7	Accept	0.07	-0.02	n/a	n/a	Accept
15	Accept	0.28	0.31	n/a	n/a	Accept
11.6	Accept	0.15	0.03	n/a	n/a	Accept
8.5	Accept	0.81	0.81	n/a	n/a	Reject
5.7	Accept	0.07	-0.02	n/a	n/a	Accept
3.6	Accept	0.02	0.02	n/a	n/a	Accept
2.0	Accept	0.27	0.27	n/a	n/a	Accept

Table E-19. Temperature continuous data quality results for 2012 Synoptic #2 (8/27/12 - 8/30/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	n/a	0.01	-0.02	n/a	n/a	Accept
8.5	n/a	0.03	+0.01	n/a	n/a	Accept
5.7	n/a	0.01	0.00	n/a	n/a	Accept
LIT1.8	n/a	0.05	+0.02	n/a	n/a	Accept
CON0.0	n/a	0.68	-0.33	n/a	n/a	Qualify

Table E-13. Temperature continuous data quality results for 2012 Synoptic #1 (7/30/12 - 8/2/12).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	n/a	0.04	+0.01	n/a	n/a	Accept
10.4	n/a	0.10	+0.01	n/a	n/a	Accept
8.5	n/a	0.04	+0.02	n/a	n/a	Accept
5.7	n/a	0.03	+0.01	n/a	n/a	Accept
LIT1.8	n/a	0.07	-0.04	n/a	n/a	Accept

Table E-20. Temperature continuous data quality results for 2016 Synoptic (8/16/16 - 8/20/16).

River Mile	Post-Check Rating	Field Check RMSE	Field Check Bias	Adjustment Type	Adjustment Amount	Final Rating
25.5	n/a	0.06	0.05	n/a	n/a	Accept
21.5	n/a	0.09	0.00	n/a	n/a	Accept
18.7	n/a	0.03	0.00	n/a	n/a	Accept
15	n/a	0.16	-0.08	n/a	n/a	Accept
11.6	n/a	0.03	-0.02	n/a	n/a	Accept
8.5	n/a	0.06	0.05	n/a	n/a	Accept
5.7	n/a	0.06	0.06	n/a	n/a	Accept
3.6	n/a	0.08	0.08	n/a	n/a	Accept
2.0	n/a	0.13	-0.13	n/a	n/a	Accept

USGS Data Quality

USGS follows standardized protocols for stage and discharge measurement outlined in USGS Water- Supply Paper 2175 - MEASUREMENT AND COMPUTATION OF STREAMFLOW (Rantz et al., 1983). The methods include standard and well documented quality control procedures. For stage and discharge data used in this TMDL, the following accuracy ratings (Table E-21) apply:

- WY2003 No estimated daily discharges. All Records good.
- WY2004 No estimated daily discharges. Records good, except for April 27 to July 8, which is fair.
- WY2012 Records good, except estimated daily discharges and flows above 4,000 ft^3/s, which are poor.
- Water Year 2014 to 2016: No estimated daily discharges. Records good except flows above 4,000 ft^3/s, which are fair.

Table E-21. USGS flow data quality rating criteria.

USGS Rating	Description
Excellent	The data is within 2% (percent) of the actual flow
Good	The data is within 5% (percent) of the actual flow
Fair	The data is within 8% (percent) of the actual flow
Poor	The data are >8% (percent) of the actual flow

References

Rantz, S. E. and others, 1983. Measurement and computation of streamflow: Vol. 1 Measurement of stage and discharge & Vol. 2 Computation of discharge. US Geological Survey Water-Supply Paper, 2175.

Appendix F. Model Documentation

Introduction

Washington State Department of Ecology developed a dynamic one-dimensional QUAL2Kw (Version 6.0) model of the Pilchuck River to simulate biological productivity and diel pH swings; with the overall purpose of identifying loading capacity and assigning allocations for the Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load study.

Ecology developed and calibrated the model using data collected in the summer of 2012. Details of the data collection, study area, and project goals and objectives are available in the QAPPs (Swanson et al., 2012; Mathieu, 2014; Mathieu, 2016) and the main body of this report.

This appendix documents the development, calibration, and model quality analysis of the 2012 Pilchuck River QUAL2KW model. Note that the original QAPP planned to create and calibrate an HSPF watershed model to couple to the QUAL2Kw model. The necessary project funding to retain a consultant to complete the watershed model was not available at the time of model development. Given that the data and preliminary modeling suggested that the temperature and DO impairments were driven by instream biological processes during dry, baseflow conditions, the project team decided that the considerable resources necessary to develop a complex, runoff-focused watershed model such as HSPF was no longer warranted.

QUAL2Kw Modeling Framework

The QUAL2Kw 6.0 modeling framework (Pelletier and Chapra, 2008) was used to develop the loading capacity for nutrients and to make predictions about water quality under various scenarios. Additional information on QUAL2Kw model framework and complete documentation[8] is available.

The QUAL2Kw 6.0 modeling framework has the following characteristics:

- One dimensional. The channel is well-mixed vertically and laterally. Also includes up to two optional transient storage zones connected to each main channel reach (surface and hyporheic transient storage zones).
- Non-steady, non-uniform flow using kinematic wave flow routing. Continuous simulation with time-varying boundary conditions for periods of up to one year.
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying or repeating diel time scale.
- Dynamic water-quality kinetics. All water quality state variables are simulated on a continuously varying or repeating diel time scale for biogeochemical processes.
- Heat and mass inputs. Point and nonpoint loads and abstractions are simulated.
- Phytoplankton and bottom algae in the water column, as well as sediment diagenesis, and heterotrophic metabolism in the hyporheic zone are simulated.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of N and P.

[8] http://www.ecy.wa.gov/programs/eap/models.html

The previous versions of Ecology's QUAL2Kw modeling framework assume flows are constant, and other boundary conditions are represented by a repeating diel pattern. Ecology recently updated QUAL2Kw to include use of the kinematic wave (KW) method of flow routing (Chapra, 1997) for simulation of continuously changing channel velocity and depth in response to changing flows. In addition, the updated QUAL2Kw framework allows input of continuous changes in other boundary conditions (e.g., tributary loading and meteorology). Incorporation of KW transport and continuous boundary forcing now allows QUAL2Kw to be used to simulate continuous changes in water quality for up to a year.

The updated QUAL2Kw framework was selected because the dominant primary producers in the Pilchuck River are bottom algae and it was considered necessary to simulate continuous changes in nutrients, biomass, and pH over an entire growing season, including representation of diel variations. QUAL2Kw (with KW transport) is capable of dynamic simulation of river pH and includes kinetics that are representative of bottom algae as the dominant primary producers.

Within QUAL2Kw, hydrodynamics for each reach are simulated based on channel characteristics, user supplied flow parameters, and the one-dimensional KW method. The KW equation is used to drive advective transport through free-flowing segments and to calculate flows, volumes, depths, and velocities resulting from variable upstream inflow.

Ecology also used depth (from the 2014 float surveys), width (digitized from aerial photography), and velocity (2016 dye study) to develop the channel geometry for the QUAL2Kw model. Ecology used depth and width data from a range of flow conditions to generate power curves for the QUAL2Kw channel geometry.

Ecology used additional tools to develop the shade inputs for the QUAL2Kw model:

- The Oregon Department of Environmental Quality (ODEQ) and Ecology's TTools extension for ArcGIS (Ecology, 2015) was used to sample and process GIS data for input to the QUAL2Kw model.
    - Ecology has recently updated TTools with more modern python code and some additional improved features. This new version was used for the White River.
- Ecology's Shade.xlsm model (version 40b04a06; Pelletier, 2015)) was used to estimate effective shade along the mainstem of the Pilchuck River.
    - Effective shade was calculated at 50-meter intervals along the streams and then averaged within each model segment for input to the QUAL2Kw model.
    - The Shade model was adapted from a program also originally developed by the ODEQ as part of the HeatSource model. The Shade model uses (1) mathematical simulations to quantify potential daily solar load and generate percent effective shade values, and (2) an effective shade algorithm, modified from Boyd (1996) using the methods of Chen et al. (1998a and 1998b).
    - Ecology recently updated the Shade model to simulate shade over a 365 day period (previously only 1 day simulation).

Ecology also used a tool called the River Metabolism Analyzer (RMA) (Pelletier, 2013) to estimate reaeration, primary productivity, ecosystem respiration, and sediment oxygen demand.

Modeling Assumptions

In order to simulate the complex physical, chemical, and biological processes of the Pilchuck River, both the modeling framework and modeling staff need to make some assumptions based on practical and computational limitations, as well as knowledge and data gaps. The assumptions applicable to the Pilchuck River TMDL model include:

General

- The model framework assumes the channel is generally well mixed vertically and laterally and can be represented in a one-dimensional model.
- During periods when the river is not light limited (midday, sunny weather, low flow), the model is configured to assume that periphyton growth is primarily limited by a single nutrient at any given time, either phosphorus or nitrogen, depending on whichever nutrient is currently in the shortest supply relative to the cellular needs of the periphyton.
- The model framework assumes that periphyton growth rates, in relation to nutrients, are controlled by intracellular concentrations, not external concentrations in the water column; Internal concentrations can differ from external because periphyton are capable of variable stoichiometry, or storing nutrients in excess of needs during periods of increased supply.
- The model is configured based on the assumption that hyporheic flow occurs in all the model reaches, with increased hyporheic flow in the middle section of the river. Project staff based this assumption on a thorough qualitative assessment of the river during floats conducted in 2014 and 2016.
- The TMDL model scenarios assume that changes in periphyton and hyporheic biofilm productivity will be accurately represented by the model under conditions which are different than the calibrated model conditions (e.g. at lower flows or reduced nutrient loading).

Inputs

- The model assumes there are reaches gaining significant flow from groundwater inputs. This assumption is based on the results of flow balances, piezometer temperatures/water levels, and observations/measurements of seeps.
- The model groundwater inputs assume the averages of water quality samples collected from gaining piezometers and seeps are representative of water quality in groundwater discharging to the river throughout the study area.
- Modeling staff assumed that the continuous time series of nutrient concentrations for boundary conditions and sources, developed through interpolation between data points or regression with another time series record, are reasonably representative of nutrient loading during periods with no observed data.

Model Setup

QUAL2Kw General Settings

Ecology set-up the QUAL2Kw model as a continuous model simulating hydrodynamics, water quality, and periphyton growth for the period of 6/7/12 to 10/9/12 (124 days) (Table F-1).

Table F-1. QUAL2Kw setup options for the 2012 Pilchuck River Model.

Simulation Option or Input	Value
Month	6
Day	7
Year	2012
Local standard time zone relative to UTC	-8 hours
Daylight savings time	No
Calculation step	1.40625 minutes
Number of days for the simulation period	124 days
Simulation mode	Continuous
Solution method (integration)	Euler
Solution method (pH)	Newton-Raphson
Simulate hyporheic transient storage zone (HTS)	Level 2
Simulate surface transient storage zone (STS)	No
Option for conduction to deep sediments in heat budget	Segmented
State variables for simulation	All
Simulate sediment diagenesis	No
Simulate alkalinity change due to nutrient change	Yes

Model Segmentation

The model divides the Pilchuck River into 40 segments of uniform length over the course of 25 river miles (~42 km) (Table F-2). The model is segmented into 1 kilometer reaches, with the exception of the most upstream reach, which is 1.2 kilometers long.

Table F-2. Reach labels, segment lengths, elevations, and slopes for the QUAL2Kw model.

Reach Label	Reach Number	Reach Length (km)	Downstream location (km)	Channel Slope	Upstream Elevation (m)	Downstream Elevation (m)
Headwater (boundary)	0		42.2			133.5
PIL25.5 - Menzel Lake Rd	1	1.20	41	0.0040	133.4	128.7
	2	1.00	40	0.0047	128.7	124.0
	3	1.00	39	0.0035	124.0	120.5
	4	1.00	38	0.0037	120.5	116.8
	5	1.00	37	0.0040	116.8	112.8
	6	1.00	36	0.0031	112.8	109.7
PIL21.5 - Robe Menzel Rd	7	1.00	35	0.0062	109.7	103.5
	8	1.00	34	0.0044	103.5	99.1
	9	1.00	33	0.0039	99.1	95.2
	10	1.00	32	0.0036	95.2	91.6
	11	1.00	31	0.0046	91.6	87.0
PIL18.7 - Ray Gray Rd	12	1.00	30	0.0036	87.0	83.4
	13	1.00	29	0.0020	83.4	81.4
	14	1.00	28	0.0006	81.4	80.8
	15	1.00	27	0.0056	80.8	75.2
	16	1.00	26	0.0025	75.2	72.7
	17	1.00	25	0.0032	72.7	69.5
PIL15.1 - 64th	18	1.00	24	0.0027	69.5	66.8
	19	1.00	23	0.0011	66.8	65.7
	20	1.00	22	0.0020	65.7	63.7
	21	1.00	21	0.0054	63.7	58.3
	22	1.00	20	0.0028	58.3	55.5
PIL 11.6 - 28th Pl NE	23	1.00	19	0.0026	55.5	52.9
	24	1.00	18	0.0028	52.9	50.1
	25	1.00	17	0.0032	50.1	46.9
PIL 10.4 - Russell Rd	26	1.00	16	0.0031	46.9	43.8
	27	1.00	15	0.0031	43.8	40.7
	28	1.00	14	0.0033	40.7	37.4
PIL 8.5 - OK Mill Rd	29	1.00	13	0.0029	37.4	34.5
	30	1.00	12	0.0018	34.5	32.7
	31	1.00	11	0.0050	32.7	27.7
	32	1.00	10	0.0020	27.7	25.7
PIL 5.7 - Dubuque Rd	33	1.00	9	0.0043	25.7	21.4
	34	1.00	8	0.0024	21.4	19.0
	35	1.00	7	0.0026	19.0	16.4
	36	1.00	6	0.0024	16.4	14.0
PIL 3.6 - Three Lakes Rd	37	1.00	5	0.0023	14.0	11.7
	38	1.00	4	0.0020	11.7	9.7
PIL 2.0 - 6th St	39	1.00	3	0.0020	9.7	7.7
2nd St (Boundary)	40	1.00	2	0.0021	7.7	5.6

Ecology developed power rating curves to define the geometry in the QUAL2Kw model (Table F-3). Three data sources were used to develop these rating curves:

- Segment-averaged depth values collected during the 2014 longitudinal depth surveys. Given that depths were collected in the thalweg of the stream (deeper than average depth) a factor of 0.9 (based on flow measurement transects) was applied to the thalweg depth values to estimate the average cross-section depth.
- Digitized wetted widths using National Agriculture Imagery Program (NAIP) aerial photography from the years 2009, 2011, 2013, and 2015. The aerial image dates were used to relate the widths to river flows, the images were collected at range of flows from ~40 to 100 cfs.
- Velocity curves were first estimated using the depth and width values, then adjusted based on the results of the time of travel study conducted in August 2016.

Channel geometry for each model segment was calculated using power functions relating width and velocity to flow by the equation:

$$X = aQ^b$$

Where:

X = width (m) or velocity (m/s)
a = width/velocity coefficient
b = width/velocity exponent

The average depth for each model segment was then calculated based on the predicted flow, width, and velocity.

Table F-3. Channel geometry power rating curves details for the QUAL2Kw model.

Reach #	Downstream location (km)	Downstream location (~river mile)	Velocity Rating Coefficient "a"	Velocity Rating Exponent "b"	Width Rating Coefficient "a"	Width Rating Exponent "b"
0	42.2	26.2	0.19	0.68	16.1	0.27
1	41	25.5	0.19	0.68	16.1	0.27
2	40	24.9	0.23	0.63	15.7	0.29
3	39	24.2	0.20	0.32	14.3	0.40
4	38	23.6	0.26	0.38	15.3	0.16
5	37	23.0	0.24	0.37	14.4	0.27
6	36	22.4	0.25	0.26	15.2	0.27
7	35	21.7	0.32	0.17	16.2	0.36
8	34	21.1	0.19	0.74	14.2	0.21
9	33	20.5	0.24	0.16	15.0	0.46
10	32	19.9	0.28	0.64	12.6	0.31
11	31	19.3	0.19	0.67	12.6	0.28
12	30	18.6	0.17	0.60	12.3	0.35
13	29	18.0	0.27	0.28	17.0	0.23
14	28	17.4	0.15	0.39	14.2	0.45
15	27	16.8	0.39	0.34	11.3	0.44
16	26	16.2	0.31	0.24	13.9	0.40
17	25	15.5	0.25	0.53	14.7	0.28
18	24	14.9	0.28	0.17	11.6	0.53
19	23	14.3	0.25	0.56	12.9	0.23
20	22	13.7	0.21	0.57	13.7	0.35
21	21	13.0	0.22	0.79	15.0	0.16
22	20	12.4	0.29	0.33	14.8	0.33
23	19	11.8	0.19	0.83	15.7	0.12
24	18	11.2	0.24	0.58	15.2	0.35
25	17	10.6	0.32	0.26	14.3	0.30
26	16	9.9	0.21	0.58	16.6	0.14
27	15	9.3	0.26	0.62	14.4	0.33
28	14	8.7	0.26	0.35	12.6	0.40
29	13	8.1	0.15	0.76	16.6	0.19
30	12	7.5	0.20	0.78	16.5	0.19
31	11	6.8	0.31	0.31	14.0	0.45
32	10	6.2	0.25	0.50	17.0	0.31
33	9	5.6	0.28	0.41	13.5	0.34
34	8	5.0	0.27	0.48	15.7	0.14
35	7	4.3	0.18	0.57	14.3	0.26
36	6	3.7	0.21	0.75	17.1	0.19
37	5	3.1	0.25	0.56	12.6	0.21
38	4	2.5	0.23	0.65	13.1	0.10
39	3	1.9	0.17	0.80	16.0	0.15
40	2	1.2	0.22	0.64	11.5	0.27

Flow and Water Quality Inputs

Ecology used the time series and discrete data collected at RM 25.5, at Menzel Lake Rd, to derive the headwater boundary condition.

Significant inputs (Table F-4) within the model were represented in the continuous sources worksheet and included:

- Gaining groundwater input in 36 model segments (Reach 1-26, 28-33, 35, 37-40).
- Tributary (surface water) inputs in 17 segments (Reach 1, 8, 9, 12, 14, 17, 18, 23, 25, 29, 30, 31, 33, 35, 38, 39, and 40).
- Municipal wastewater treatment facility for the city of Granite Falls (Reach 11).

Ecology developed continuous flow inputs using the continuous USGS gage, results of the seepage surveys, and USGS StreamStats (Figure F-1). StreamStats was used to obtain estimates of peak 2 year storm flows for each tributary basin. A rating curve was the developed between the USGS gage on the Pilchuck River and each tributary using observed values and the StreamStats estimates.

Continuous dissolved oxygen (DO) inputs (Figure F-2) were constructed by 1) calculating the potential DO at saturation using temperature, specific conductance, and barometric pressure; and 2) using the observed daily variation in saturation from the synoptic surveys to estimate DO concentrations.

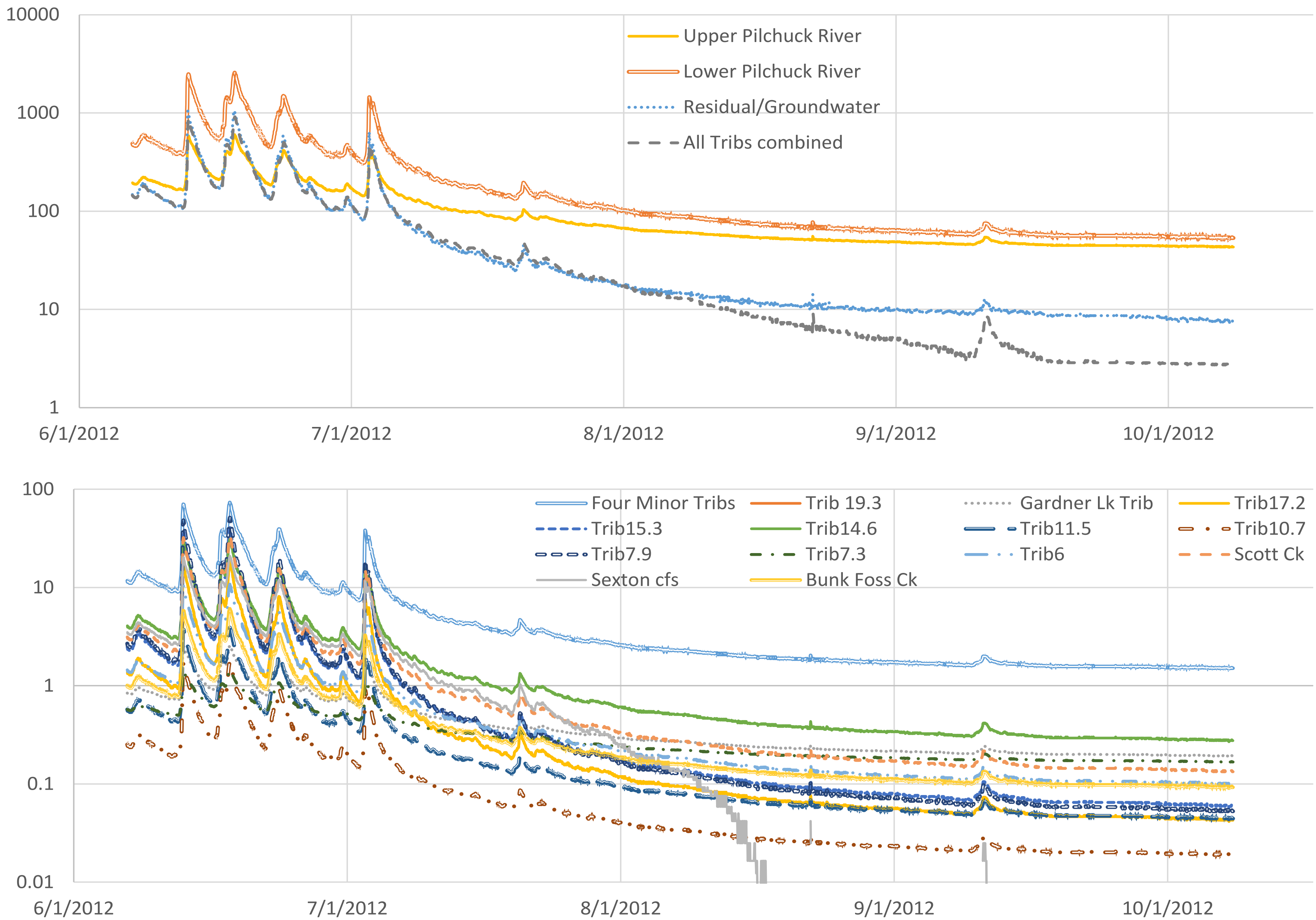

Figure F-1. Flow residuals and inputs for the 2012 model.

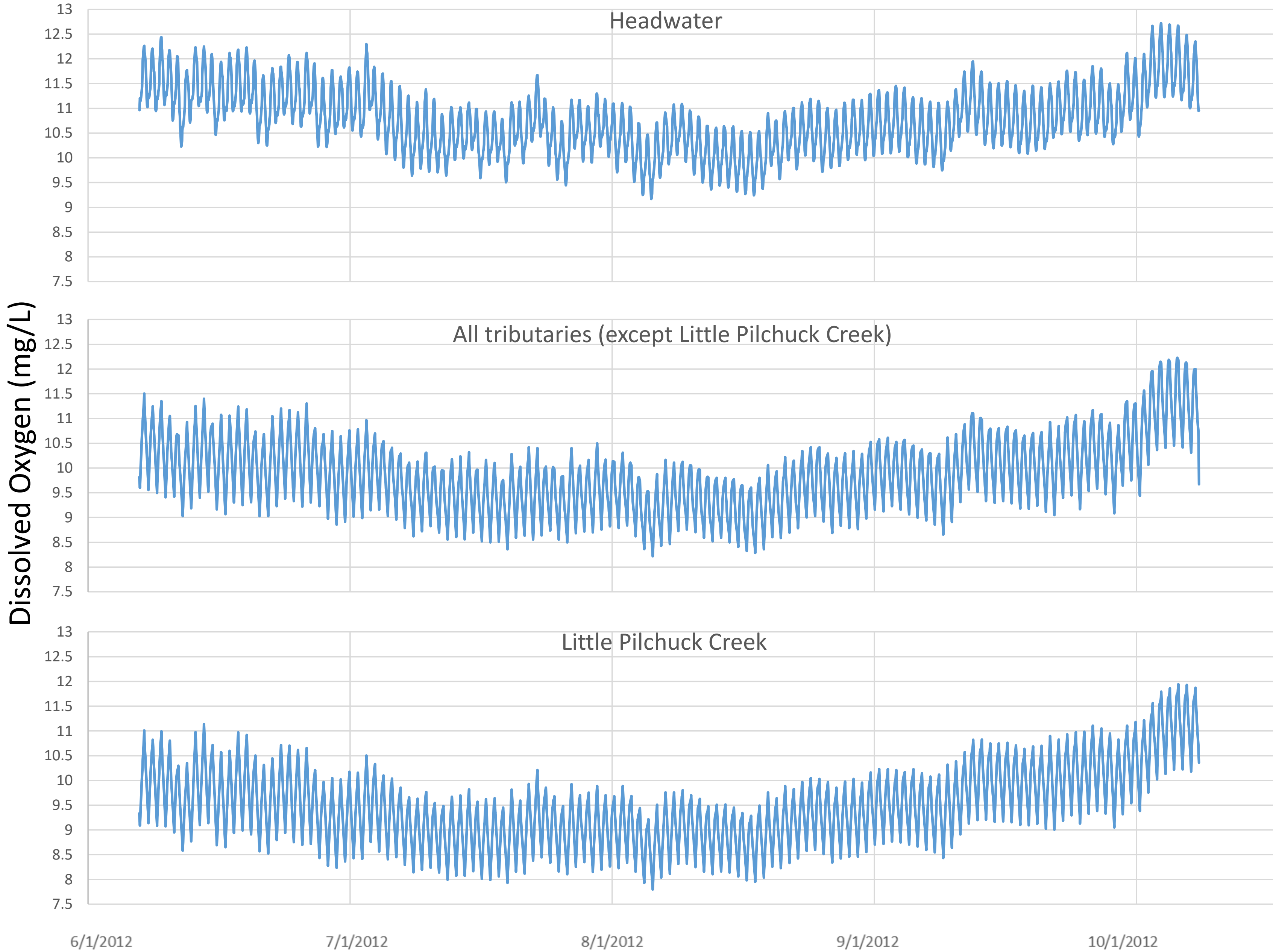

Figure F-2. Dissolved oxygen inputs/ boundary conditions for the 2012 model.

Table F-4. Inflows in the 2012 Pilchuck River QUAL2Kw model.

Reach Number	Inflow Source#1	Inflow Source#2	Inflow Source#3	Inflow Source#4
1	Groundwater			
2	Groundwater			
3	Groundwater			
4	Groundwater			
5	Groundwater			
6	Groundwater			
7	Groundwater			
8	Groundwater	Four Minor Tribs		
9	Groundwater	Trib 19.3		
10	Groundwater			
11	Groundwater		Granite Falls WWTP	
12	Groundwater	Garner Lk Trib		
13	Groundwater			
14	Groundwater	Trib 17.2		
15	Groundwater			
16	Groundwater			
17	Groundwater	Trib 15.3		
18	Groundwater	Trib 14.6		
19	Groundwater			
20	Groundwater			
21	Groundwater			
22	Groundwater			
23	Groundwater	Trib 11.5	Large seep	
24	Groundwater			
25	Groundwater	Trib 10.7		
26	Groundwater			
27				
28	Groundwater			
29	Groundwater	Dubuque Creek	Little Pilchuck Creek	
30	Groundwater	Trib 7.9		
31	Groundwater	Trib 7.3		
32	Groundwater			
33	Groundwater	Trib 6	Large seep	
34				
35	Groundwater	Scott Creek		
36				
37	Groundwater			
38	Groundwater	Sexton Creek		
39	Groundwater	Bunk Foss Creek		
40	Groundwater			

Meteorology Inputs

Ecology used meteorology time series data from various external sources, as described in the main report.

Shade model inputs

Shade input data was derived using the ArcGIS extension "Ttools" and Ecology's Shade.xlsm model. Near-stream vegetation cover, along with stream depth, air temperature and groundwater, represent the most important factors that influences stream temperature (Adams and Sullivan, 1989). To obtain a detailed description of existing riparian conditions in the Pilchuck River basin, a combination of GIS analysis, interpretation of aerial photography, and hemispherical photography was used.

A GIS coverage of riparian vegetation in the study area (Figure F-3) was created from:

- Field notes and measured tree heights collected during riparian surveys Ecology conducted as part of the 2012 study.
- Analysis of the color digital Snohomish County orthophotos from 2012.
- Analysis of LiDAR (first return minus bare earth) data collected by Snohomish County.

Polygons representing different vegetation types were mapped within a 300-foot buffer on either side of the river at a 1:2000 scale using GIS. Riparian vegetation was classified into vegetation categories (Table F-5). Each vegetation category was assigned three characteristic attributes: maximum height, average canopy density, and streambank overhang.

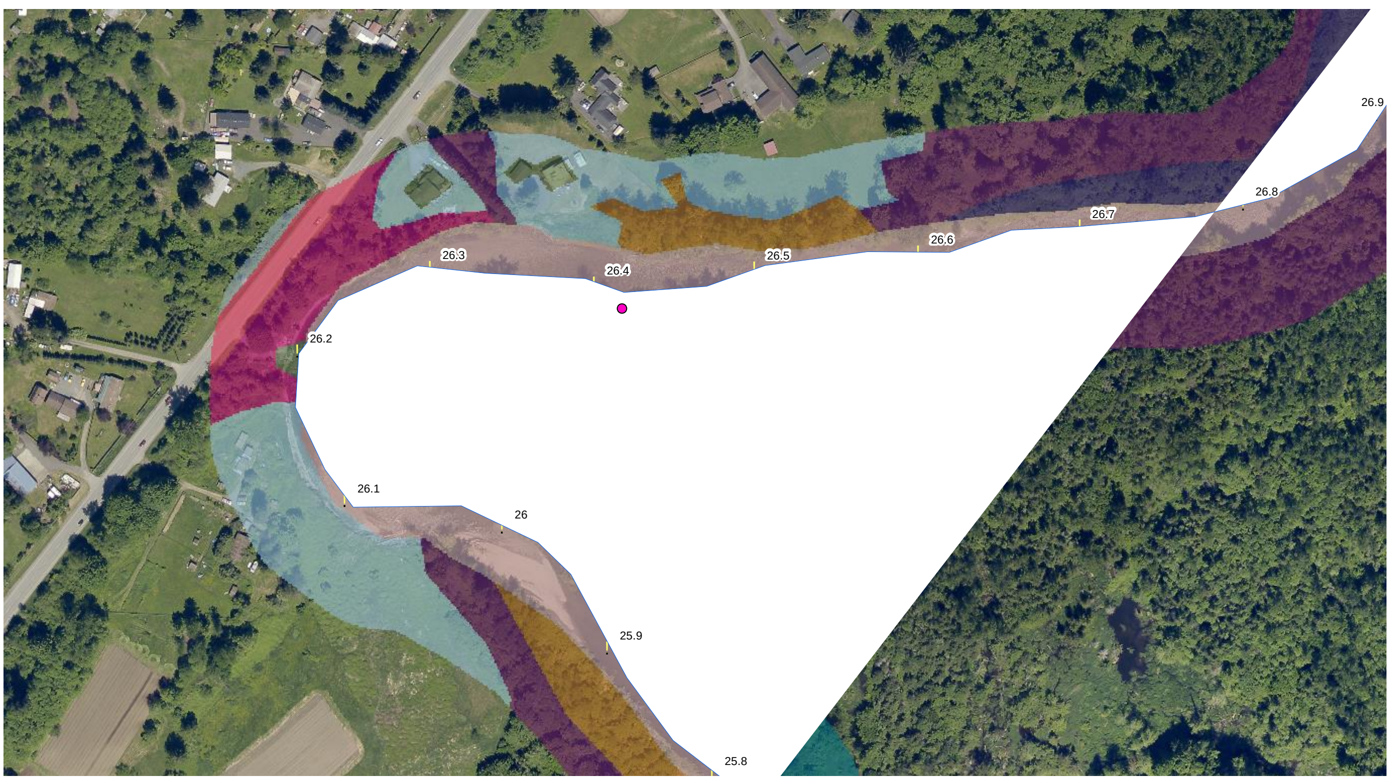

Figure F-3. Example of digitized riparian vegetation polygons.

After the vegetation polygons were delineated, a longitudinal profile of vegetation information along the Pilchuck River was created by sampling these polygons along the right and left banks of the stream at 50-meter intervals using GIS, using the TTools extension for ArcView. Stream aspect, elevation, and topographic shade angles to the west, south, and east were also calculated by TTools at each 50-meter interval using a digital elevation model (DEM).

The following settings were used when running TTools:

- Sampling was conducted at 50-m intervals along the mainstem of the Pilchuck River.
- LiDAR was used to determine the stream gradient using a 25-cell sample size, which is the maximum accuracy provided by TTools (cell sample size dictated by the input raster, therefore 6ft-by-6ft cells).
- 10-m DEM (Digital Elevation Model) was used for topographic shade angles because it was available for an extent beyond the immediate channel region, sampled to 10 km away in 7 directions as the maximum accuracy provided by TTools.
- Vegetation sampling occurred at 6-m intervals into the riparian buffer (nine samples total within the 180-foot buffer width) perpendicular to the stream aspect. Sampling occurred for both left and right banks.

In addition to vegetation information, TTools was also used to sample each 50-m interval for channel wetted width, NSDZ width, stream aspect, stream elevation, and topographic shade angles in all directions. All of the TTools extracted/calculated information was exported to a data table for later use in modeling effective shade.

The output from TTools was then used as an input into Ecology's Shade model (Ecology, 2008) to estimate effective shade along the Pilchuck River. Effective shade is defined as the fraction of incoming solar shortwave radiation above the vegetation and topography that is blocked from reaching the surface of the stream. Effective shade from 50m intervals was then averaged within each model reach for input into the QUAL2Kw model.

These settings were specified within the Shade model:

- Channel incision depth was estimated as the average incision measured from field sites.
- The Bras Method for the Solar Radiation model.
- The Chen Method of shade calculation: recommended for QUAL2Kw models.

The initial riparian vegetation coding, Ttools analysis, and shade modeling was conducted by Tetra Tech (Kennedy and Nicholas, 2013). Ecology reviewed the analysis, made some minor modifications, re-ran TTools, and re-ran the shade model.

Most notably, Ecology adjusted the 'tall' riparian height classifications from 144 feet (44 m) to 100 feet (30.5 m) and then recalculated effective shade. Initially, Tetra Tech assigned the 'tall' riparian vegetation categories a height classification of 144 feet (44 m). Ecology compared this to 36 field measurements of this height class and found a significant bias. The field measured values ranged from 40 to 140 feet with a median of 100 feet (Figure F-4).

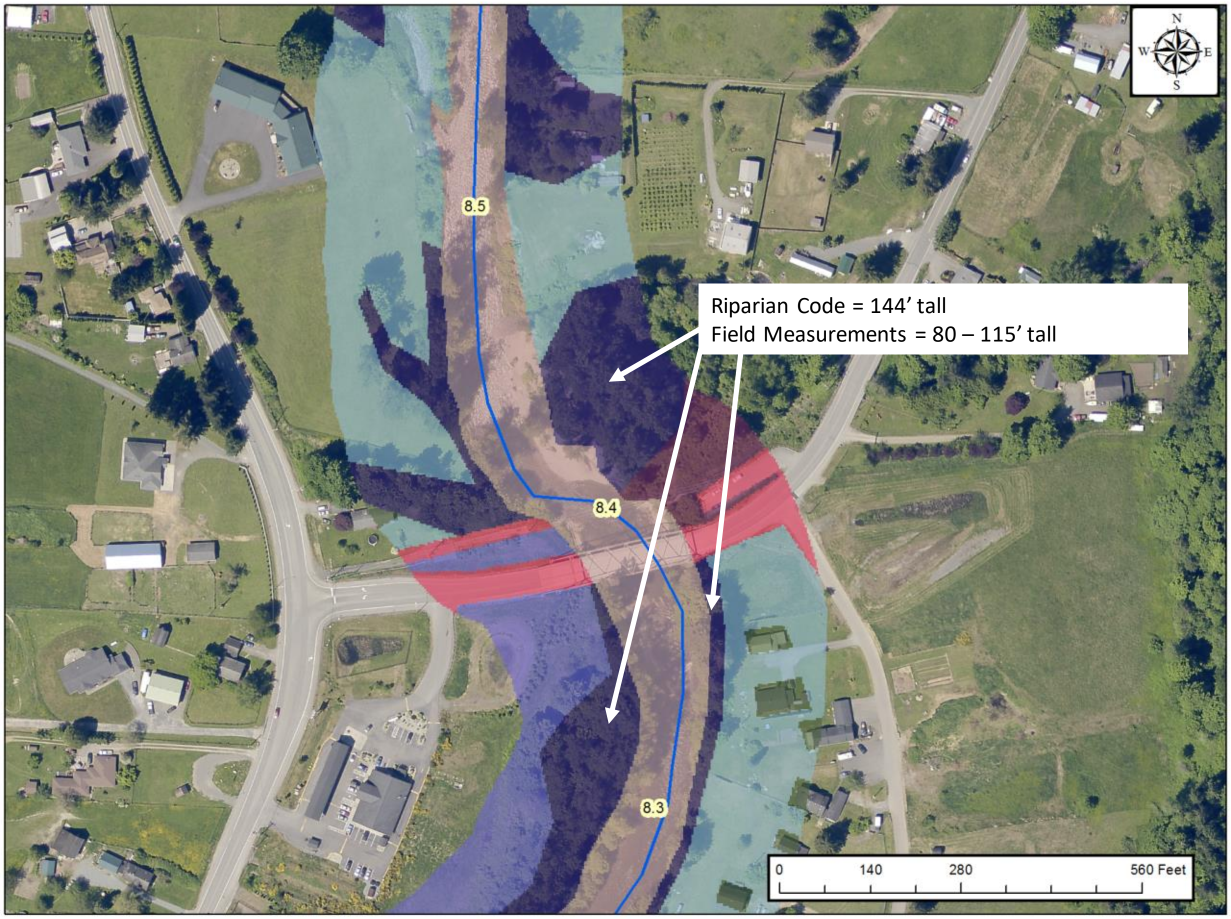

Figure F-4. Site level comparison of preliminary (uncorrected) tree heights against field measurements for Pilchuck River at OK Mill Rd.

Table F-514. Vegetation codes, heights, densities, and overhang values.

Description	Height (m)	Density (%)	Overhang (m)
Conifer-Small-Dense	4.2	75%	0.4
Conifer-Small-Sparse	4.2	25%	0.4
Conifer-Medium-Dense	21.3	75%	2.1
Conifer-Medium-Sparse	21.3	25%	2.1
Conifer-Tall-Dense	30.5	75%	3.1
Conifer-Tall-Sparse	30.5	25%	3.1
Deciduous-Small-Dense	4.2	75%	0.4
Deciduous-Small-Sparse	4.2	25%	0.4
Deciduous-Medium-Dense	21.3	75%	2.1
Deciduous-Medium-Sparse	21.3	25%	2.1
Deciduous-Tall-Dense	30.5	75%	3.1
Deciduous-Tall-Sparse	30.5	25%	3.1
MixeE-Small-Dense	4.2	75%	0.4
MixeE-Small-Sparse	4.2	25%	0.4
MixeE-Medium-Dense	21.3	75%	2.1
MixeE-Medium-Sparse	21.3	25%	2.1
MixeE-Tall-Dense	30.5	75%	3.1
MixeE-Tall-Sparse	30.5	25%	3.1
Shrub-Dense	2.0	75%	0.2
Shrub-Sparse	2.0	25%	0.2
Grass (non-residential)	0.5	100%	0.1
Grass (residential lawn)	0.5	100%	0.1
Water	0.0	100%	0.0
Pasture-Agriculture	0.0	100%	0.0
Road	0.0	100%	0.0
House	6.1	100%	0.0
Sand/Barren	0.0	100%	0.0
Clear-Cut Forest	0.0	100%	0.0
Gravel-pit/Industrial	0.0	100%	0.0
Powerline	0.0	100%	0.0
Open-Recreational	0.0	100%	0.0
Parking Lot	0.0	100%	0.0

Hyporheic and Light Extinction Settings

In general, Ecology used default rates, constants, kinetics and options for the initial model setup and systematically adjusted these variables during model calibration. In a few cases, Ecology made alterations prior to calibration including:

- The hyporheic transient storage zone was turned on to simulate potential effects of the hyporheic zone. The quality of the alluvial substrates and numerous field observations suggested that hyporheic flow was likely present throughout the study reach. Table F-6 contains parameters used for the hyporheic zone.

- The background and ISS light extinction rates (Table F-7) were altered based on light extinction surveys from other Ecology studies (Snouwaert and Stuart, 2015; Mathieu, 2020)

Table F-6. Thermal and hyporheic properties for the hyporheic transient storage (HTS) zone for the QUAL2Kw model.

Reach Number	Sediment thermal conductivity (W/m/ degC)	Sediment thermal diffusivity (cm^2 /sec)	Sediment/ hyporheic zone thickness (cm)	Hyporheic Flow fraction (unitless)*	Hyporheic sediment porosity (fraction of volume)	Deep sediment temperature below sediment/HTS (deg C)
1 – 6	1.57	0.0064	20	0.1	0.4	13.5
6 – 33	1.57	0.0064	60	0.15	0.4	13.5
34 - 40	1.57	0.0064	20	0.1	0.4	13.5

* Parameter for diffusive exchange

Table F-7. Non-default light extinction rates for the QUAL2Kw model.

Parameter	Value	Unit
Background light extinction	1	*/m*
ISS light extinction	0.065	*1/m-(mgD/L)*

Model Calibration

Error Statistics

Ecology used the following error statistics to help guide calibration and evaluate (see “Model evaluation - sensitivity and error analysis” section) the fitness of the model.

Root-Mean-Square Error Statistic (RMSE

The RMSE (E_{rms}) is defined as:

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

where,
O = observation
P = model prediction at same location and time as the observation
n = number of observed-predicted pairs

Root-Mean-Square Coefficient of Variation

$$RMSE\ CV = \frac{RMSE}{Mean\ of\ observed\ values}$$

Mean Error Statistic

The mean error (E) or overall bias between model predictions and observations is defined as:

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

A mean error of zero is ideal. A non-zero value is an indication that the model might be biased toward either over- or under-prediction, and typically represented by either a plus or negative sign (e.g., +0.5 or -0.5).

Relative Percent Difference

The relative percent difference (%RPD) is defined as:

$$RPD = \left[\frac{|P_i - O_i| * 2}{O_i + P_i}\right] * 100$$

Hydraulics Calibration

To calibrate the velocity rating coefficients in the QUAL2Kw model, Ecology compared predicted time of travel data in QUAL2Kw with observed time of travel data from the 2016 dye study. The average absolute difference of predicted vs observed time of travel in the model was 2.5 hours (6% of total time of travel), with a range of 45 minutes to 4 hours (Figure F-5). Within the model, the August 2016 dye release (70-74 cfs) was simulated on 8/18/12 (73 cfs flow range; this represents a typical baseflow value as described in the main report). The velocity coefficients of the channel geometry were scaled in order to match the observed travel time.

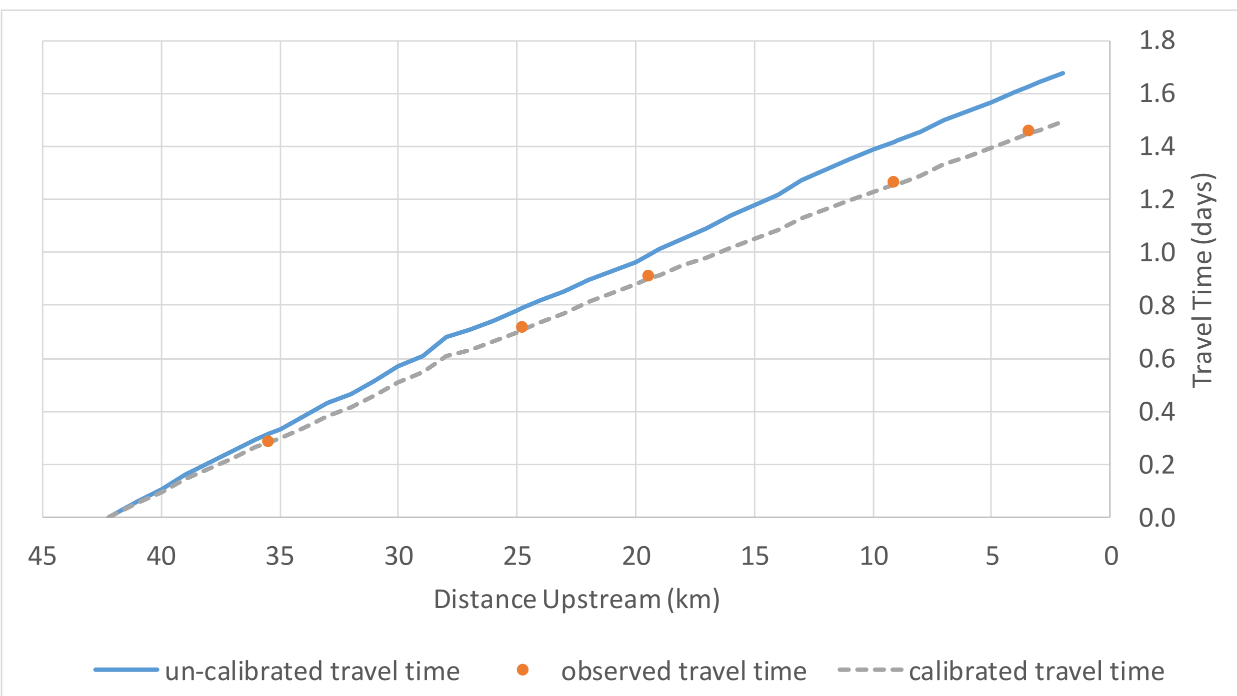

Figure F-5. Predicted and observed time of travel results, including model adjustment.

Flow Calibration

Ecology calibrated flow in the model by developing and making minor adjustments to input flows in the model (Figures F-6 and F-7). Regressions based on low flow surveys and high flow estimates were used to develop time series inputs for tributaries.

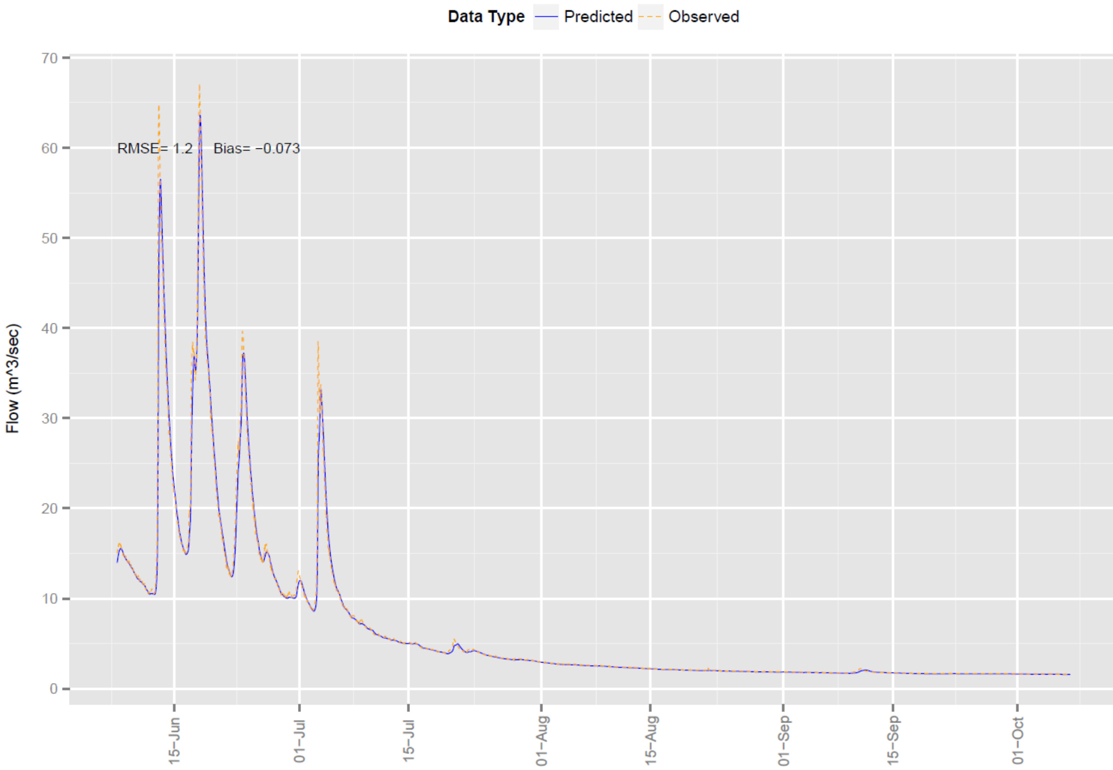

Figure F-6. River flow calibration for entire modeling period at USGS gage at RM 3.6.

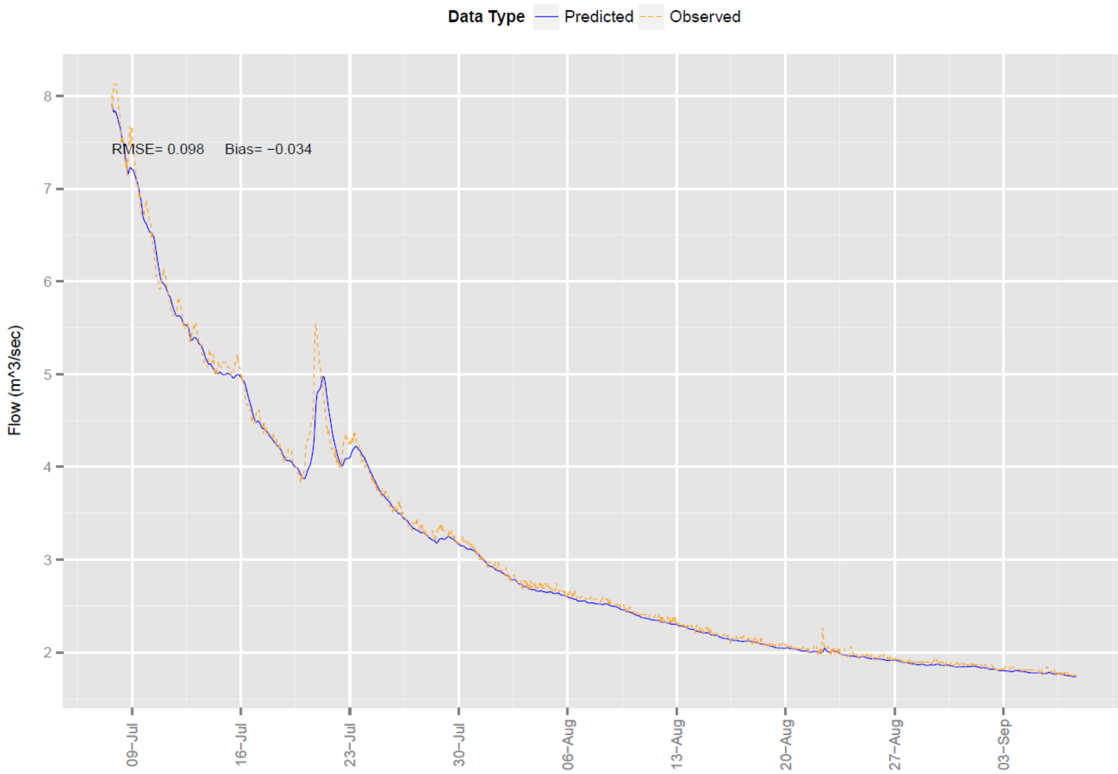

Figure F-7. River flow calibration for most critical period (7/8/12 to 9/8/12) at USGS gage at RM 3.6.

Temperature Calibration

After Ecology completed calibration of the hydraulics and channel geometry, the initial goodness of fit for temperature was calculated using the root mean squared error (RMSE), as a measure of unbiased overall error, and the average difference between predicted and observed values, as a measure of the bias (hereafter referred to as just bias). Error statistics were calculated on an hourly basis throughout the 124 day modeling period and represent a comprehensive goodness of fit for the entire diel cycle and multiple temperature regimes within the model period, rather than an evaluation of daily max/min/mean during critical conditions. In some reaches this represented the entire modeling window, while others had some data gaps.

The initial temperature fitness was reasonable; however, some parameters were adjusted and evaluations made to improve the temperature fitness and better represent system processes observed in the field. These measures included:

- Adjusting groundwater temperatures:
  - Ecology used a groundwater temperature of 13.5 °C based on the stable lowest thermistor temperature in the piezometer at Dubuque Rd. This also agreed with temperature measurements from seeps, which had a median temperature of 13.8 °C.
- Switching to Satterlund longwave radiation:
  - Switched from Brunt (default) to Satterlund model for longwave emissivity.
- Adjusting hyporheic flow parameters:
  - Increased hyporheic zone thickness from 10 to 20-60 cm and flow fraction from 0.05 to 0.1 - 0.15 based on qualitative observations of hyporheic flow throughout study area.
- Using observed solar radiation values in place of an atmospheric attenuation model

Ecology also evaluated fitness visually to assess calibration using longitudinal, diel, and dynamic temperature plots (Figures F-8 through F-10).

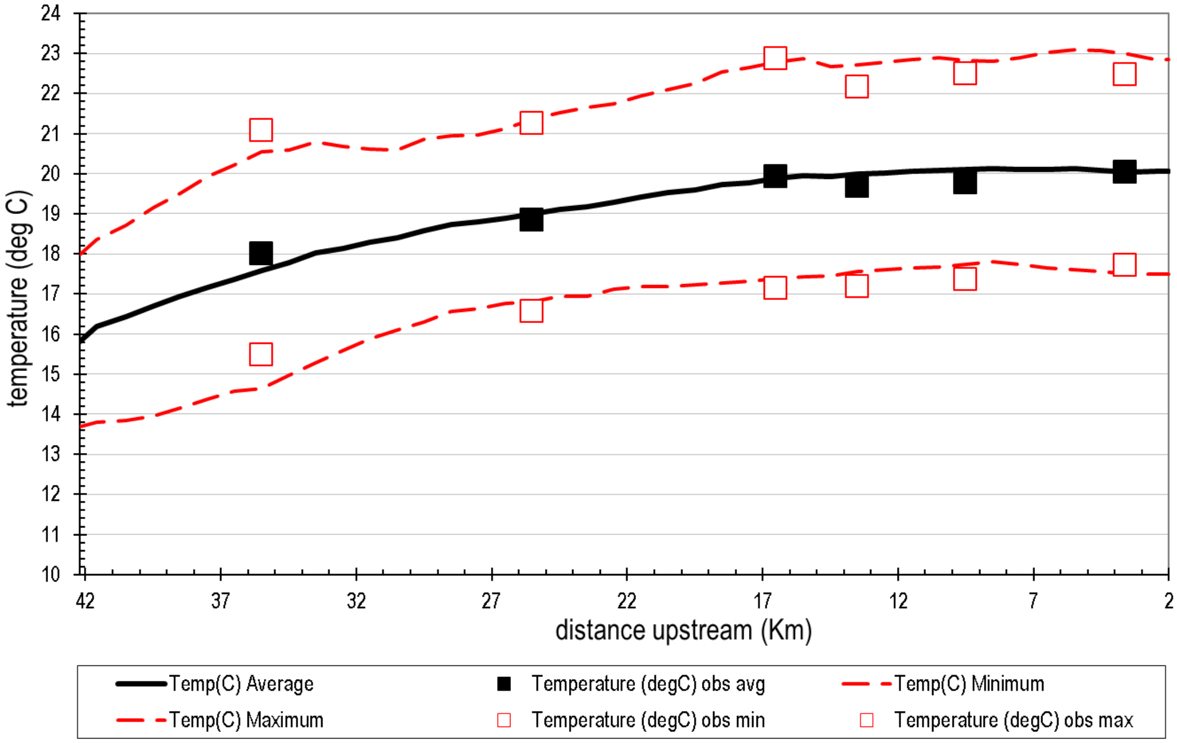

Figure F-81. Longitudinal temperature profile for 8/17/12 in the calibrated 2012 QUAL2Kw model.

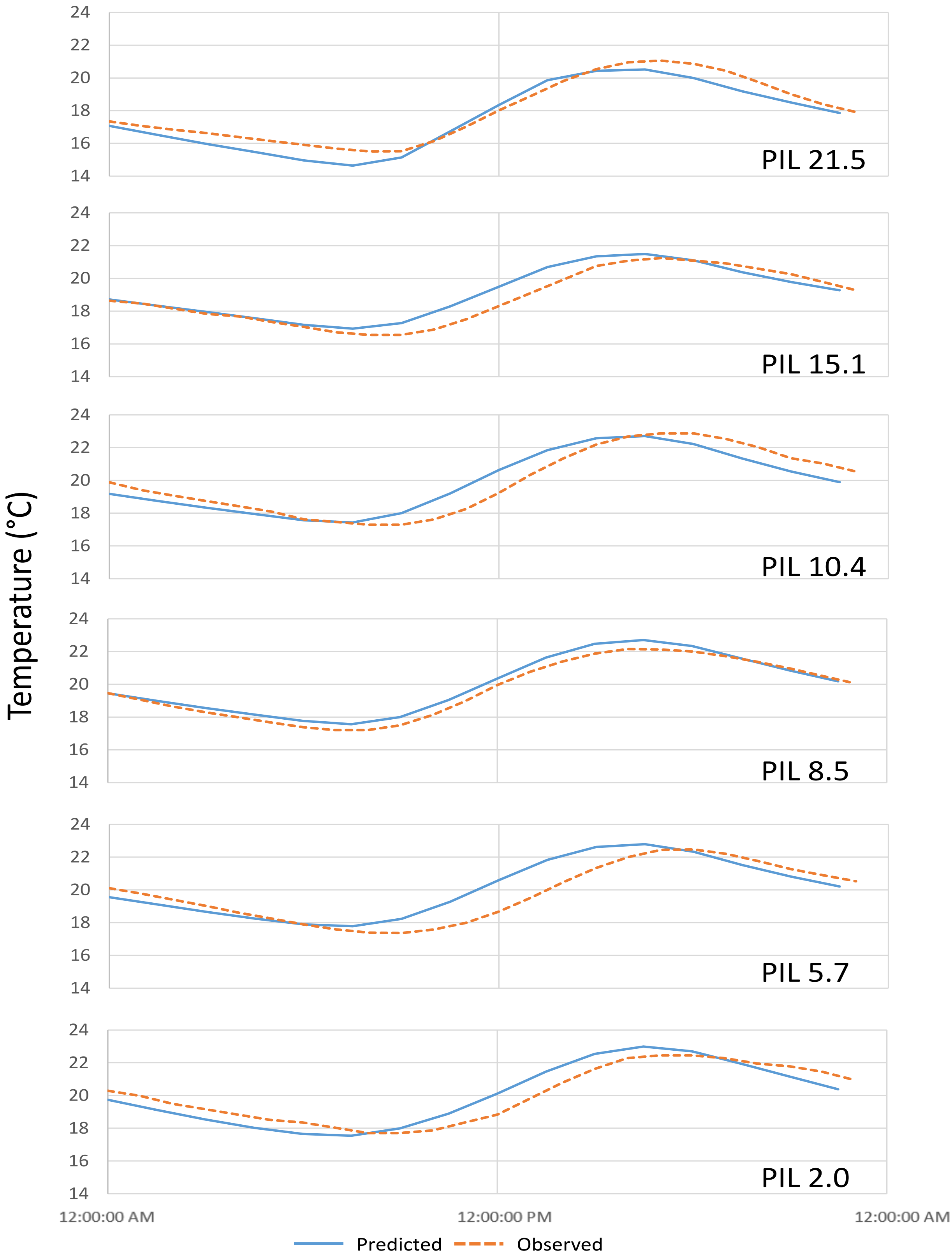

Figure F-9. Predicted vs Observed Diel temperature for 8/17/12.

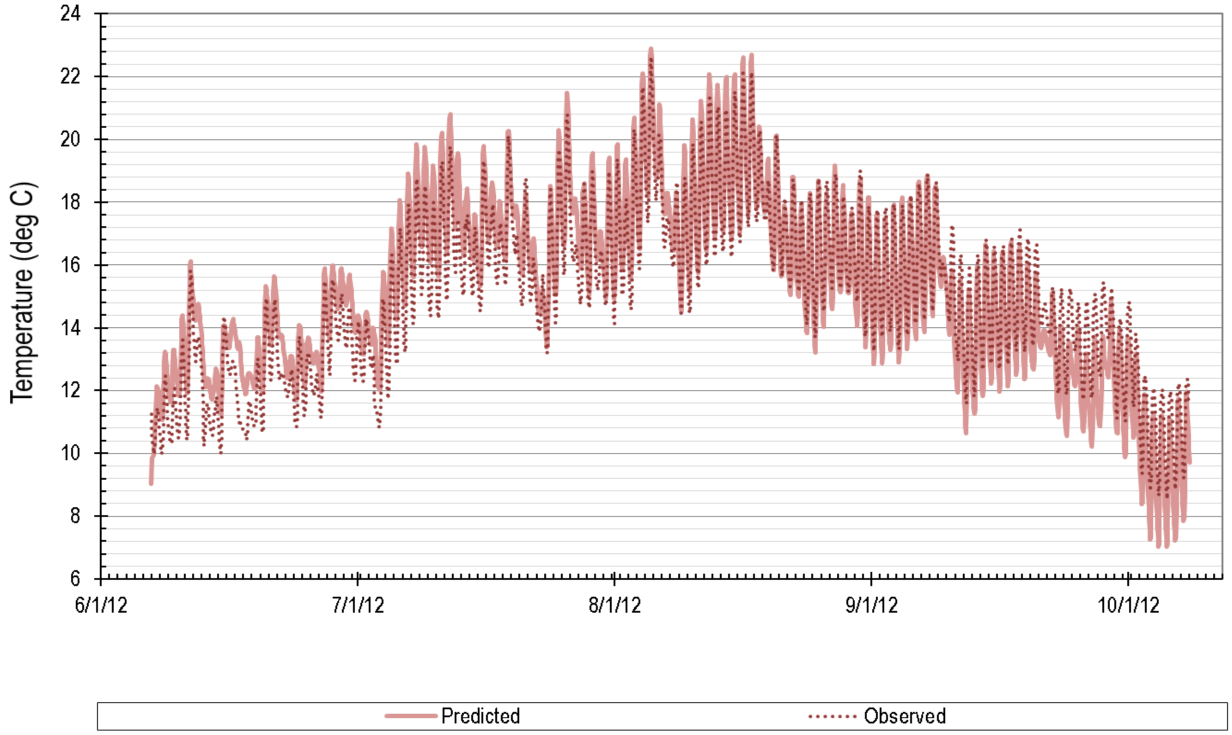

Figure F-10. Dynamic temperature goodness of fit for the calibrated model at Reach 29 (observed data from RM 8.5).

Overall the model describes the temperature regime of the Pilchuck River fairly well, including diel fluctuations and periods of erratic temperature change (i.e. storm events).

Estimating Productivity, Respiration, Reaeration, and SOD using RMA

Ecology's River Metabolism Analyzer (RMA) (Pelletier, 2013) tool was used to provide estimates of gross primary productivity (GPP), ecosystem respiration (ER), and reaeration. This provides alternate estimates of these processes to compare to the outputs from the QUAL2Kw model.

RMA estimates of reaeration averaged 12.8 $gO_2/m^2/day$ and ranged from 9.5 to 24.1 $gO_2/m^2/day$, depending on the method used (Delta, nighttime regression, or inverse modeling), survey date, and location (Table F-e F-8). Ultimately, the average of the Delta and nighttime regressions were compared to model-predicted reaeration during calibration.

Hobson et al. (2014) suggests that the sediment oxygen demand (SOD) can be estimated by subtracting the GPP from ER, assuming that in net heterotrophic systems (ER is greater than GPP) the additional respiration comes from the sediment or hyporheic zone. RMA estimates of SOD ranged from 0.9 to 2.6 gO_2/m^2, with an average of 1.7 gO_2/m^2 (Table F-9159). All estimates of GPP and ER indicated the Pilchuck River was net heterotrophic, with the ratio of GPP:ER consistently between 0.6 and 0.8.

Table F-8. Reaeration estimates (in gO^2/m^2) for the Pilchuck River based on 2012 diel data.

RM	Date	Delta Method-DO reaeration (centroid)	Nighttime Regression-DO reaeration	Inverse Modeling-DO reaeration	Avg DO Reaeration (no inverse modeling)
5.7	7/31/2012	16.6	13.22	14.88	14.9
8.5	7/31/2012	18.4	10.02	24.05	14.2
5.7	8/28/2012	14.4	9.82	19.34	12.1
8.5	8/28/2012	14.8	9.5	10.66	12.2
10.4	8/28/2012	12.7	8.25	14.05	10.5
	Average =	15.4	10.2	16.6	**12.8**
	Median =	14.8	9.8	14.9	**12.2**

Table F-915. Gross primary productivity, ecosystem respiration, and sediment oxygen demand estimates (in gO^2/m^2) for the Pilchuck River based on 2012 diel data.

RM	Date	Delta Method Avg GPP (cent)	Delta Method Avg Resp (cent)	Delta Method GPP: ER	Inverse Modeling Avg GPP	Inverse Modeling Avg Resp	Inverse Modeling GPP:ER	Estimated SOD
5.7	7/31/2012	2.7	4.5	0.60	2.09	3.63	0.58	1.7
8.5	7/31/2012	4.3	5.3	0.81	4.89	6.37	0.77	1.2
5.7	8/28/2012	3.4	5.6	0.61	4.00	7.01	0.57	2.6
8.5	8/28/2012	2.6	3.6	0.72	1.76	2.61	0.67	0.9
10.4	8/28/2012	4.9	6.3	0.78	4.88	7.21	0.68	1.9
	Average =	3.6	5.1	0.7	3.5	5.4	0.7	**1.7**
	Median =	3.4	5.3	0.7	4.0	6.4	0.7	**1.7**

Based on the RMA analysis, the value of 1.7 gO_2/m^2 was used as target for calibrating hyporheic productivity parameters and oxygen demand.

Calibration of pH, nutrient, bottom algae, and other water quality parameters

By calibrating for light extinction first (depth, ISS, and chlorophyll a), a more accurate calibration of nutrient limitation is likely. Therefore, Ecology began calibration of water quality parameters by calibrating inorganic suspended solids (ISS) and chlorophyll *a* (CHL*a*) in the water column.

In a free floating, shallow system such as the Pilchuck River, these parameters typically do not have much direct influence on productivity; however, they can have a significant effect on light extinction in the water column.

For both ISS and CHL*a*, the model suggested a source that was unaccounted for. At moderate to low settling rates, these parameters decreased downstream and failed to match observed data in the lower river. A significant load of ISS was added to the diffuse inputs to the model in order to match observed downstream data (Figure F-11). For CHL*a*, a large increase was observed in the data between river mile 21.5 and 15, so a concentrated input was added within this reach (Figure F-12). The results of these modifications matched observed data well and allowed for more accurate depiction of light extinction. The effect of these loads on other important parameters was negligible (see sensitivity analysis).

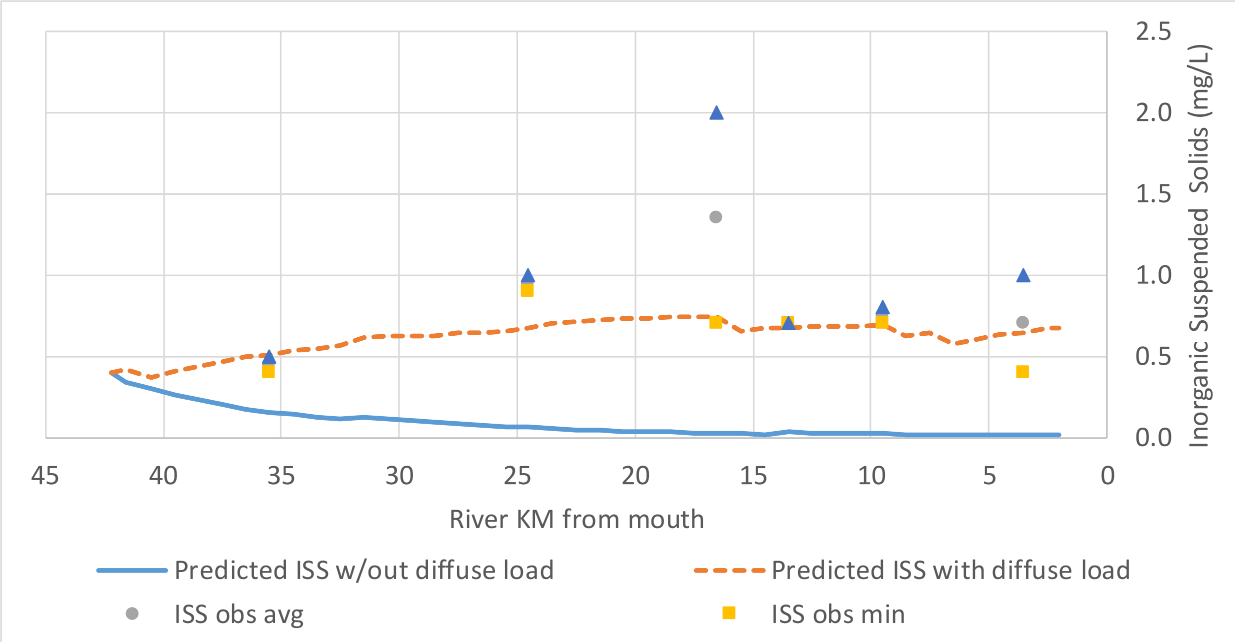

Figure F-11. Model predicted inorganic suspended solids with and without diffuse load.

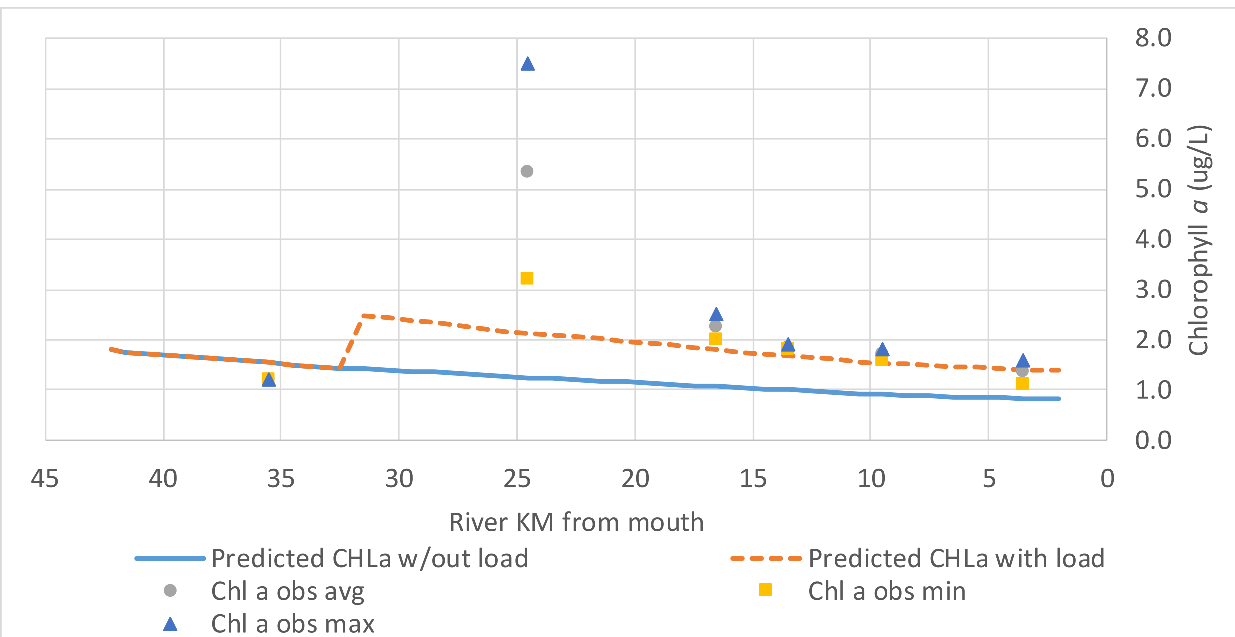

Figure F-12. Model predicted Chlorophyll a with and without concentrated load.

After calibrating to observed solids and chlorophyll data, Ecology began calibrating the model for pH, DO, nutrients, and bottom algae. Ecology used compiled rate sets from 29 calibrated QUAL2Kw models developed throughout the Western U.S. (Tables F-10 and F-11) to guide parameterization. These models were all developed for TMDLs by, or for, state agencies including:

- Washington State Department of Ecology (Carroll et al., 2006; Mohamedali and Lee 2008; Sargeant et al., 2006; Snouwaert and Stuart, 2015).
- Oregon Department of Environmental Quality (DEQ) (Turner et al., 2006).
- Utah DEQ (Neilson et al., 2014).
- Montana DEQ (Flynn and Suplee, 2011)
- California Regional Water Quality Board (Butkus, 2011; Tetra Tech, 2009).

Table F-10. Statistics for select parameters from calibrated QUAL2Kw models in the Western U.S.

Parameter	n	Min	25th Percentile	Median	75th Percentile	Max
Stoichiometry:						
Carbon	20	28.5	40	40	40	70
Nitrogen	20	2.8	7.2	7.2	7.2	10
Phosphorus	20	0.4	1	1	1	1
Dry weight	20	100	100	100	100	107
Chlorophyll	20	0.3	0.5	1	1	3
Inorganic suspended solids:						
Settling velocity	28	0.000001	0.2	0.59344	1.01974	2
Slow CBOD:						
Hydrolysis rate	26	0	0.1	0.365	1.10032	3.9988
Oxidation rate	11	0	0.065	0.2	0.549855	3.57425
Fast CBOD:						
Oxidation rate	20	0	0.35	2.7121	4	6
Organic N:						
Hydrolysis	29	0.001	0.1	0.25	0.6	3.8998
Settling velocity	20	0	0.09271	0.16743	0.2225	1.8312
Ammonium:						
Nitrification	29	0.01	0.93	2.5	4	10
Nitrate:						
Denitrification	29	0	0.44	1	1.01	1.94
Sed denitrification transfer	29	0	0	0.1	0.6	0.99
Organic P:						
Hydrolysis	29	0.001	0.11	0.25	1.5	4.21255
Settling velocity	21	0	0.08	0.11	0.5	1.84958
Inorganic P:						
Settling velocity	21	0	0.08802	1.26	1.80012	2
Sed P oxygen attenuation	22	0	0.202685	1.01094	1.40852	2
Detritus (POM):						
Dissolution rate	29	0.001	0.5	1.58	3	5
Settling velocity	27	0	0.108375	0.42	0.860875	1.95865

Table F-11. Statistics for select bottom algae parameters from calibrated QUAL2Kw models in the Western U.S.

Parameter	n	Min	25th Percentile	Median	75th Percentile	Max
Max Growth rate	26	8.6	12.1	25.6	49.7	161.1
Basal respiration rate	26	0.0068	0.1	0.2	0.4651	1.2
Photo-respiration rate parameter	9	0.01	0.01	0.01	0.01	0.39
Excretion rate	25	0	0.07	0.2037	0.3439	0.4816
Death rate	26	0.001	0.0775	0.2582	0.5	4.46
External N half sat constant	26	15	185.5	300	342.5	493.2
External P half sat constant	26	10	52.9	67.5	100	178
Inorganic C half sat constant	25	0	1.30E-05	3.10E-05	9.00E-05	1.30E-04
Light constant	26	1.69	50	56	70.3	100
Ammonia preference	26	1.2	15.25	22.75	25	80.96
Subsistence quota for N	25	0.7	1	7.2	24.1	72
Subsistence quota for P	25	0.1	0.1285	1	4.66	10
Maximum uptake rate for N	25	28	360	500	750	1405
Maximum uptake rate for P	25	4	50	100	145	232
Internal N half sat ratio	25	0.9	1.2	2.04	3.68	9
Internal P half sat ratio	25	0.13	1.3	1.4	3.42	5

Ecology inserted the 25th and 75th percentile values into the Pilchuck River QUAL2Kw model as ranges for calibration. Ecology performed manual calibration by iteratively adjusting one rate and comparing improvements in fit mathematically and visually. Calibration started with bottom algae biomass and primary productivity.

Calibration to this point suggested an additional sink for DO, which was supported by the estimates of sediment oxygen demand (SOD) derived from the RMA results. Calibration then focused on sediment oxygen demand from heterotrophic biofilm in the hyporheic zone.

In order to generate the necessary amount of SOD (see RMA analysis) and match observed organic carbon levels in the river, a source of cBOD (20 mg/L) was added to the diffuse/groundwater inflow to the model. Organic carbon and cBOD were not measured in groundwater 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 particular organic matter from storm events during the winter/spring, or settling organic matter during the model period (QUAL2Kw does not account for this). The effect of SOD and carbon loading is discussed further in the sensitivity analysis.

Tables F-12 through F-15 contain the calibrated rate parameters used in the 2012 model.

Table F-1216. Calibrated (non-default) parameters in the 'Rates' worksheet for the QUAL2Kw model.

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	1	m/d	v_i
Oxygen:			
Reaeration model	User model		
User reaeration model parameter A	3		
User reaeration model parameter B	0.5		
User reaeration model parameter C	-1.5		
O2 for carbon oxidation	3.08	gO2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO2/gN	r_{on}
Slow CBOD:			
Hydrolysis rate	1	/d	k_{hc}
Oxidation rate	.08	/d	k_{dcs}
Fast CBOD:			
Oxidation rate	0.08	/d	k_{dc}

Table F-13. Calibrated (non-default) nutrient related parameters in the 'Rates' worksheet for the QUAL2Kw model.

Parameter	Value	Units	Symbol
Organic N:			
Hydrolysis	0.1	/d	k_{hn}
Settling velocity	0.5	m/d	v_{on}
Ammonia:			
Nitrification	2	/d	k_{na}
Nitrate:			
Denitrification	2	/d	k_{dn}
Sediment denitrification transfer coefficient	0.02	m/d	v_{di}
Organic P:			
Hydrolysis	0.1	/d	k_{hp}
Settling velocity	0.5	m/d	v_{op}
Inorganic P:			
Settling velocity	0.5	m/d	v_{ip}
Sediment P oxygen attenuation half sat constant	1.57	mgO_2/L	k_{spi}

Table F-14. Calibrated bottom algae parameters in the 'Rates' worksheet for the QUAL2Kw model.

Parameter	Value	Units	Symbol
Growth model	Zero-order		
Max Growth rate	17	$gD/m^2/d$ or /d	C_{gb}
Temp correction	1.025		q_{gb}
First-order model carrying capacity	100	gD/m^2	$a_{b,max}$
Basal respiration rate	0.5	/d	k_{r1b}
Photo-respiration rate parameter	0.389	unitless	k_{r2b}
Temp correction	1.04		q_{rb}
Excretion rate	0.1	/d	k_{eb}
Temp correction	1.07		q_{db}
Death rate	0.25	/d	k_{db}
Temp correction	1		q_{db}
Scour function	Flow		
Coefficient of scour function	0.1	/d/cms or /d/mps	*cdet*
Exponent of scour function	0.1		*ddet*
Minimal biomass after scour event	1.2	gD/m^2	*X0*
Catastrophic scour rate during flood event	20	/d	*Kcat*
Critical flow or vel for catastrophic scour	36	cms or m/s	*Qcrit*
External nitrogen half sat constant	180	ugN/L	k_{sNb}
External phosphorus half sat constant	25	ugP/L	k_{sPb}
Inorganic carbon half sat constant	1.30E-04	moles/L	k_{sCb}
Bottom algae use HCO3- as substrate	Yes		
Light model	Smith		
Light constant	75	langleys/d	K_{Lb}
Ammonia preference	5	ugN/L	k_{hnxb}
Nutrient limitation model for N and P	Minimum		
Subsistence quota for nitrogen	3.6	mgN/gD	q_{0N}
Subsistence quota for phosphorus	0.5	mgP/gD	q_{0P}
Maximum uptake rate for nitrogen	108	mgN/gD/d	r_{mN}
Maximum uptake rate for phosphorus	15	mgP/gD/d	r_{mP}
Internal nitrogen half sat ratio	1.1		$K_{qN,ratio}$
Internal phosphorus half sat ratio	1.1		$K_{qP,ratio}$
Nitrogen uptake water column fraction	1		$N_{UpWCfrac}$
Phosphorus uptake water column fraction	1		$P_{UpWCfrac}$

Table F-15. Calibrated hyporheic metabolism parameters in the ‘Rates’ worksheet for the QUAL2Kw model.

Parameter	Value	Units	Symbol
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		q_{dt}
Settling velocity	1	m/d	v_{dt}
pH:			
Partial pressure of carbon dioxide	391	ppm	p_{CO2}
Hyporheic metabolism			
Model for biofilm oxidation of fast CBOD	Zero-order		*level 1*
Max biofilm growth rate	1.9	gO2/m^2/d or /d	"
Temp correction	1.07		"
Fast CBOD half-saturation	1.5	mgO2/L	"
Oxygen inhib model	Half saturation		"
Oxygen inhib parameter	0.60	mgO2/L	"
Respiration rate	0.5	/d	*level 2*
Temp correction	1.07		"
Death rate	0.05	/d	"
Temp correction	1.07		"
External nitrogen half sat constant	15	ugN/L	"
External phosphorus half sat constant	2	ugP/L	"
Ammonia preference	5	ugN/L	"
First-order model carrying capacity	100	gD/m^2	"
Photosynthetic quotient and respiratory quotient for phytoplankton and bottom algae			
Photosynthetic quotient for NO3 vs NH4 use	1.30	dimensionless	*PQ*
Respiratory quotient	1.00	dimensionless	*RQ*

Figures F-13 and F-14 contain results for nitrogen and phosphorus from the calibrated model and field surveys. The model predicts large instream increases in both phosphorus and nitrogen downstream of the Granite Falls WWTP based on the measured nutrient loads. Although there was no nutrient data immediately downstream of the WWTP in 2012, downstream nutrient data collected in 2016 confirmed the magnitude and pattern of these predictions.

Figures F-15 and F-16 contain results for dissolved oxygen (DO) and pH from the calibrated model and associated field survey. Figures F-17 and F-18 illustrate diel results for DO and pH from the calibrated model at Reach 33 (Pilchuck River at Dubuque Rd). Longitudinal profiles and diel fluctuations are shown for 8/28/12, the synoptic survey with greater productivity. Unfortunately, in 2012 useable diel water quality data was only obtained from three downstream locations that span a relatively short area of the overall model domain. However diel water quality results from the 2016 data collection show relatively good agreement in respect to the general diel ranges and pattern of the 2012 model predictions (Table F-16).

The comparison suggests the model may be slightly over-predicting diel DO range in the upstream half of the model and slightly under-predicting in the lower half. The 2016 results also confirmed that the most critical reach for low DO is in the lower river where good quality data was collected in 2012.

Table F-16. Comparison of diel DO ranges for time series data collected in 2012 and 2016 to predicted 2012 conditions in the model.

River Reach	2012 average diel range	2012 predicted diel range	2016 average diel range
RM 25.5	1.68	1.73	1.64
RM 25 - 21		2.14	1.89
RM 20 - 16		1.92	1.76
RM 15 - 11		1.82	1.98
RM 10 - 6	1.77	1.69	1.89
RM 5 - 0		1.74	1.96

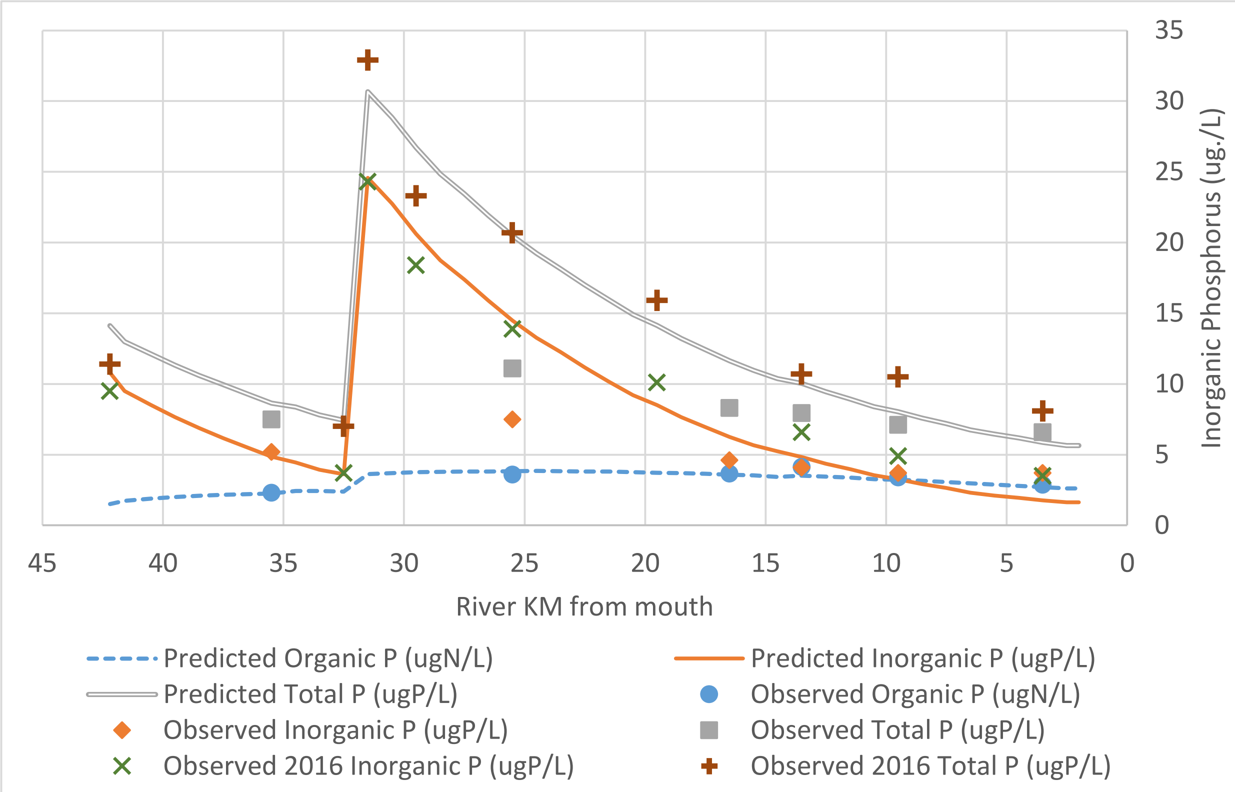

Figure F-13. Longitudinal phosphorus predictions for 8/28/12 compared to observed data.

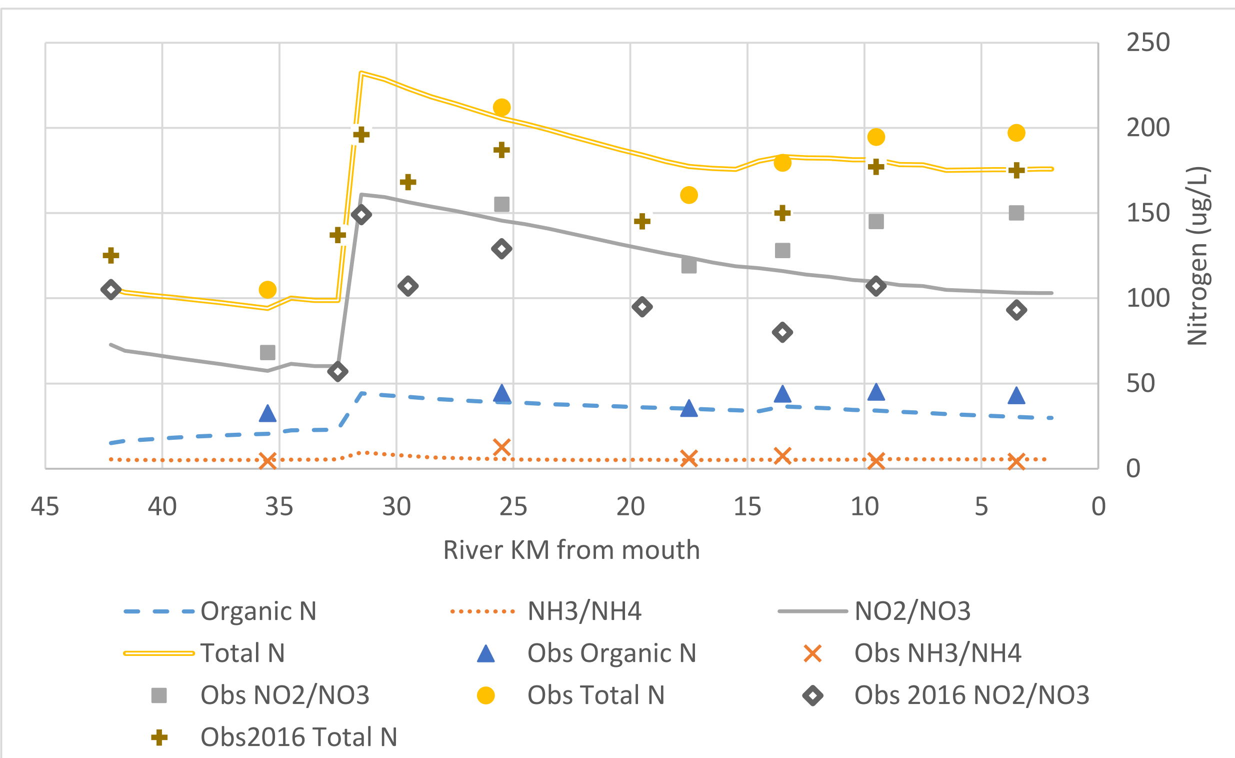

Figure F-14. Longitudinal nitrogen predictions for 8/28/12 compared to observed data.

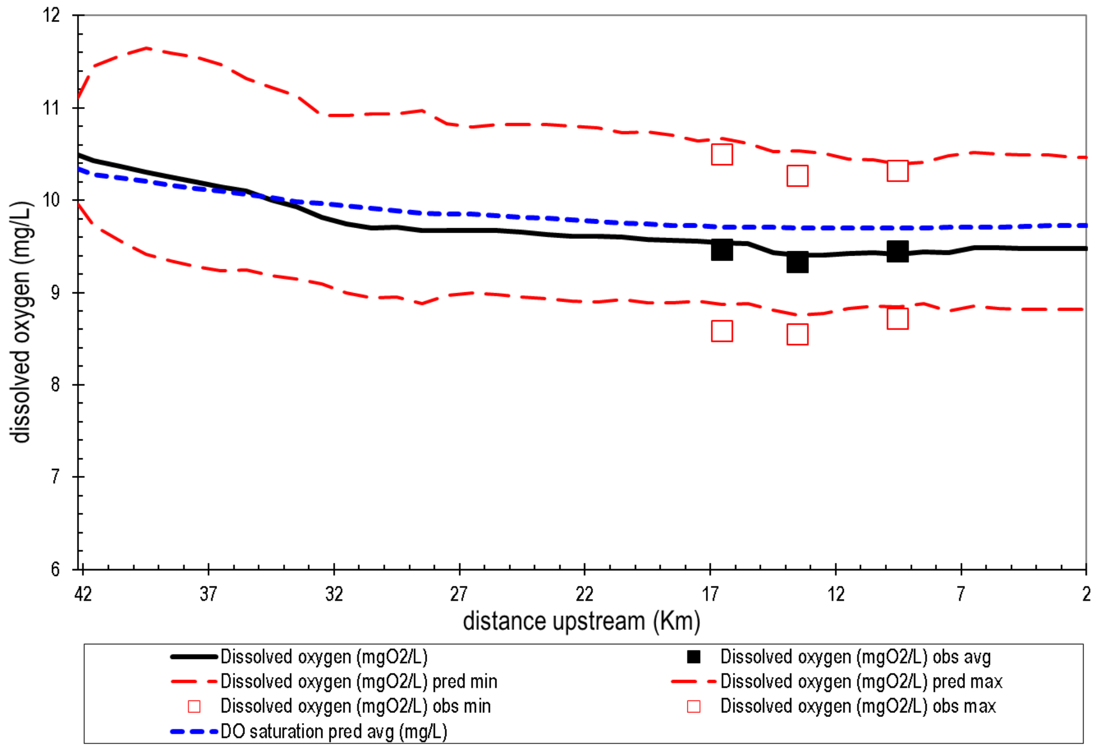

Figure F-15. Longitudinal DO predictions for 8/28/12 compared to observed data.

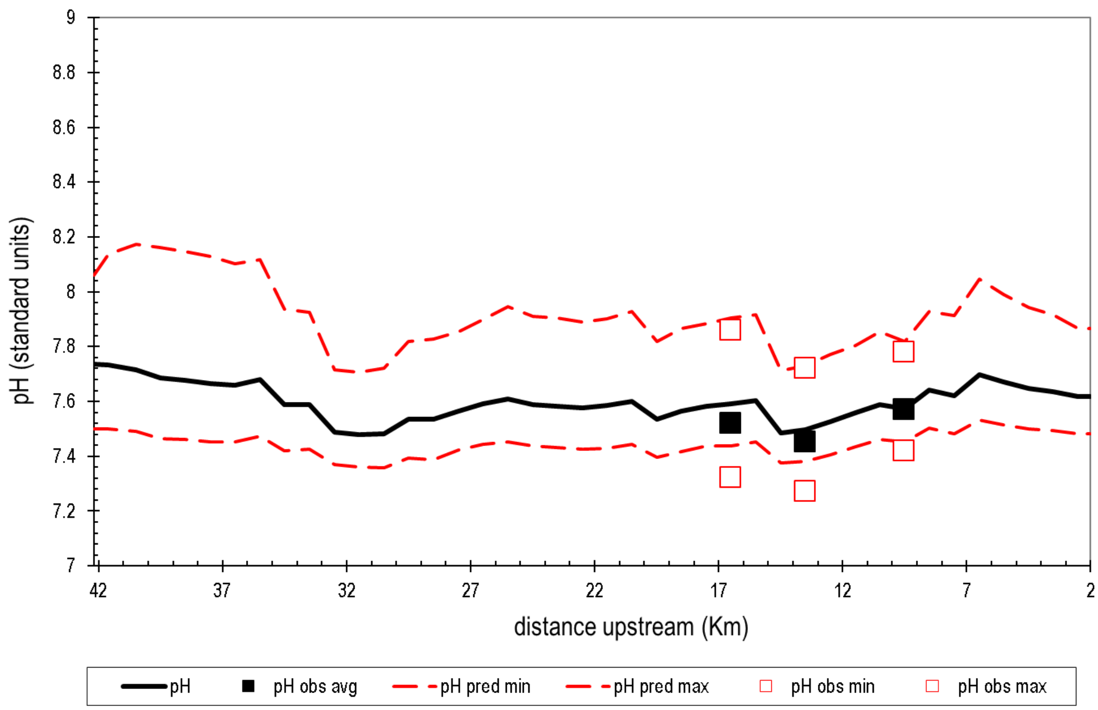

Figure F-16. Longitudinal pH predictions for 8/28/12 compared to observed data.

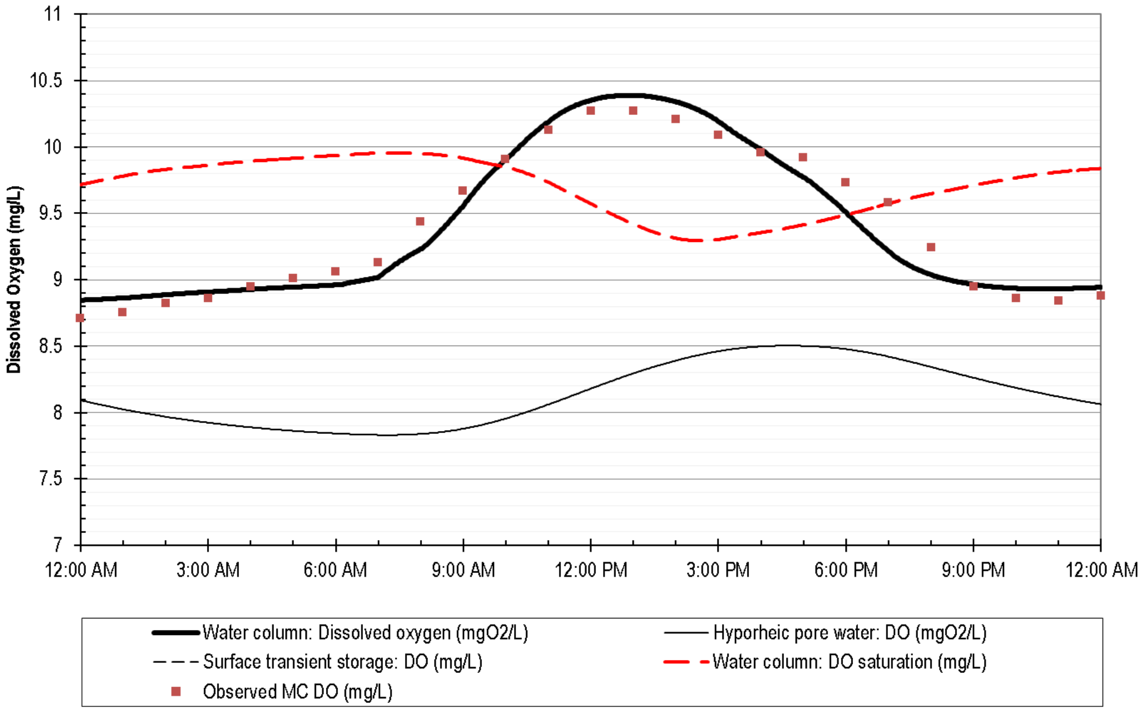

Figure F-17. Diel DO predictions for Reach 33 on 8/28/12 compared to observed data.

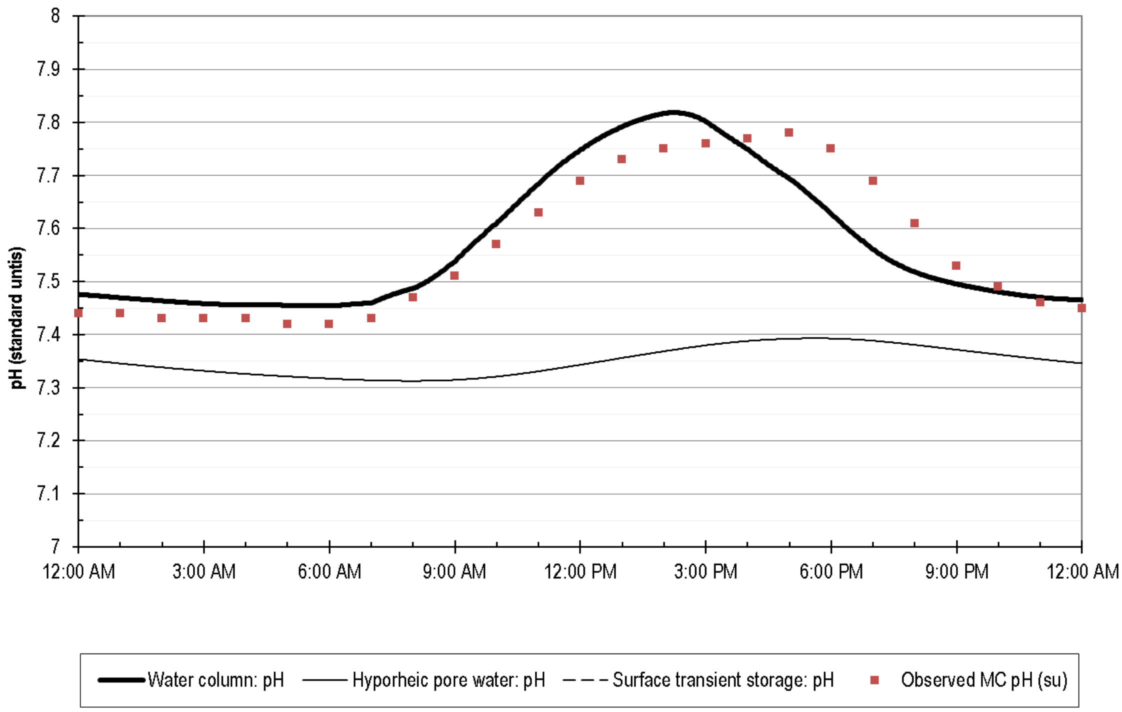

Figure F-18. Diel pH predictions for Reach 33 on 8/28/12 compared to observed data.

Model Evaluation - Sensitivity and Error Analysis

Ecology evaluated the quality of the model through both quantitative and qualitative methods, including:

- Quantitative
  - Assessing goodness of fit to observed data using RMSE.
  - Assessing the bias of the model compared to the observed data.
  - Sensitivity analysis on key rate parameters and inputs.
- Qualitative
  - Visual comparison of observed vs predicted spatial and temporal patterns in the data.
  - Model review and consultation from two senior water quality modelers from Ecology's Environmental Assessment Program.

Error Analysis

The Pilchuck River QUAL2Kw model goodness of fit to observed data is summarized in Tables F-17 and F-19. The Root Mean Squared Error (RMSE) statistic expresses the magnitude of typical model error for a variable in the same units as that variable. The Root Mean Squared Error Coefficient of Variation (RMSE CV) expresses the proportion of typical model error to the typical value of the variable. The overall bias statistic expresses the tendency of the model to over- or under-predict the value of a given variable. Bias% expresses this tendency as a proportion of the typical value of the variable. The average observed values from this study for most variables are given for reference.

For most variables, RMSE and bias are calculated by comparing modeled daily average values to observed daily average or grab sample values. For variables that display a marked diel swing, such as temperature, DO, and pH, the RMSE and bias are calculated for daily maximums and minimums as well. RMSE CV and Bias%, which express error as a proportion of typical variable values, are given for those variables that express a quantity or concentration of something. These statistics are not appropriate for temperature or pH.

The QUAL2Kw model provides a good simulation of DO in the Pilchuck River. In particular, daily minimum DO had a minimal amount of error (RMSE = 0.23 mg/L) and bias (overall bias = +0.11 mg/L). The model also provides a good simulation of SRP concentrations, with low error (RMSE = 1.7 ug/L) and bias (+0.4 ug/L).

Table F-1717. Summary statistics for goodness-of-fit of the QUAL2Kw model to observed continuous data.

Statistic	Temp-Min (degC)	Temp Max	Temp Mean	SpCond Mean (uS/cm)	DO Min (mg/L)	DO Max	DO Mean	pH Min	pH Max	pH Mean
RMSE	0.89	0.81	0.82	5.02	0.23	0.49	0.31	0.06	0.07	0.08
Bias	-0.35	-0.22	-0.30	-3.81	0.10	0.19	0.03	0.02	-0.04	-0.05
Mean	13.14	16.74	14.82	82.53	8.71	10.14	9.39	7.39	7.78	7.58
RMSCV	0.07	0.05	0.06	0.06	0.03	0.05	0.03	0.01	0.01	0.01
Bias %	-3%	-1%	-2%	-5%	1%	2%	0%	0%	-1%	-1%

Table F-18. Summary statistics for goodness-of-fit of the QUAL2Kw model to observed discrete data.

Statistic	Total Nitrogen (ug/L)	Ammonia (ug/L)	Nitrate-Nitrite as N (ug /L)	Soluble Reactive Phosphorus (ugP/L)	Total Phosphorus (ugP/L)
RMSE	34.10	1.61	34.18	1.73	2.49
Bias	3.45	0.31	6.99	0.38	0.90
Mean	160.36	5.33	105.19	4.01	8.01
RMSCV	0.21	0.30	0.32	0.43	0.31
Bias %	2%	6%	7%	10%	11%

Table F-19. Summary statistics for goodness-of-fit of the QUAL2Kw model to observed discrete data.

Statistic	Bottom Algae (gD/m^2	Inorganic Suspended Solids (mgD/L)	Total Suspended Solids (mgD/L)	Alkalinity (mg/L)	Dissolved Organic Carbon (mgD/L)
RMSE	0.85	0.69	0.80	2.90	0.20
Bias	0.30	-0.32	0.37	2.52	-0.13
Mean	2.41	1.25	2.25	34.86	0.89
RMSCV	0.35	0.55	0.35	0.08	0.23
Bias %	12%	-25%	16%	7%	-15%

Effective Shade Error Analysis

Ecology also performed an error analysis for the shade by comparing Shade model outputs to estimates from two different methods for calculating effective shade from hemispherical photos using: (1) HemiView software (2) Gap Light Analyzer (GLA) software (Tables F-20 and F-21). Comparisons were made for effective shade on August 14 during critical period for temperature. GLA effective shade showed slightly better agreement with the shade model, which may be in part related to the fact that HemiView does not include diffuse radiation for daily calculations or the differences in the solar model and parameterization used for each. GLA documentation has recommended solar model parameters for varying conditions based on regionally relevant data collected in Victoria, British Columbia (Fraser et al., 1999).

Table F-20. Comparison of Shade model effective shade to GLA and HemiView software outputs.

Site	Shade.xls	HemiView	GLA	HemiView – Shade.xls	GLA – Shade.xls
PIL25	53.7%	62.2%	54.1%	8.5%	0.3%
PIL21.5	26.4%	19.9%	25.7%	-6.5%	-0.7%
PIL15	34.1%	56.8%	51.9%	22.7%	17.7%
PIL10	19.4%	15.9%	12.7%	-3.5%	-6.6%
PIL8.5	34.1%	53.4%	51.7%	19.3%	17.6%
PIL5.7	33.3%	54.4%	41.8%	21.1%	8.5%
PIL2	33.5%	24.7%	33.9%	-8.9%	0.4%

Table F-21.

Statistic	HemiView – Shade.xls	GLA – Shade.xls
Bias =	7.54%	5.31%
RMSE =	15%	10%

Temperature Error Analysis (combine with above)

The average temperature RMSE for all evaluated reaches, for the entire 124 day model period, was 0.91°C and the average bias was -0.42°C (Table F-22 and Table F-24). Results of other modeling efforts suggest this would generally be considered an acceptable level of model skill for this type of application (Sanderson and Pickett, 2014). The average RMSE for all evaluated reaches, for 7/8/12 to 9/8/12 (period of warmest temperatures), was 0.64°C and the average bias was -0.11°C (Tables F-23 and F-24; Figure F-19). The significant improvement in model fitness for this period was likely related to the fact that the majority of the input data was collected in the months of July and August and the fact that the model was calibrated to critical low-flow, warmer temperature conditions.

Table F-22. Error statistics for temperature in the QUAL2Kw model from 6/8/12 to 10/8/12.

Model Reach	~River Mile	Hourly Temperature Mean RMSE	Hourly Temperature Mean Error	7-DADMax Temperature Mean RMSE	7-DADMax Temperature Mean Error
7	21.5	0.73	-0.11	0.54	0.00
18	15.1	0.93	-0.56	0.76	-0.57
26	10.4	1.00	-0.77	1.11	-0.97
29	8.5	0.94	0.18	0.65	0.19
23	5.7	0.89	-0.53	0.60	-0.35
39	2.0	0.96	-0.73	0.79	-0.48

Table F-23. Error statistics for temperature in the QUAL2Kw model from 7/8/12 to 9/8/12.

Model Reach	~River Mile	Hourly Temperature Mean RMSE	Hourly Temperature Mean Error	7-DADMax Temperature Mean RMSE	7-DADMax Temperature Mean Error
7	21.5	0.72	-0.10	0.46	0.16
18	15.1	0.66	-0.10	0.4	-0.17
26	10.4	0.65	-0.36	0.67	-0.55
29	8.5	0.74	0.35	0.54	0.38
23	5.7	0.56	-0.06	0.28	0.03
39	2.0	0.57	-0.31	0.39	0.04

Table F-24. Summarized Error statistics for temperature in the QUAL2Kw model for the whole domain.

Model Period	Hourly Temperature Mean RMSE	Hourly Temperature Mean Error	7-DADMax Temperature Mean RMSE	7-DADMax Temperature Mean Error
6/8/12 to 10/8/12	0.91	-0.42	0.74	-0.36
7/8/12 to 9/8/12	0.65	-0.10	0.46	-0.02

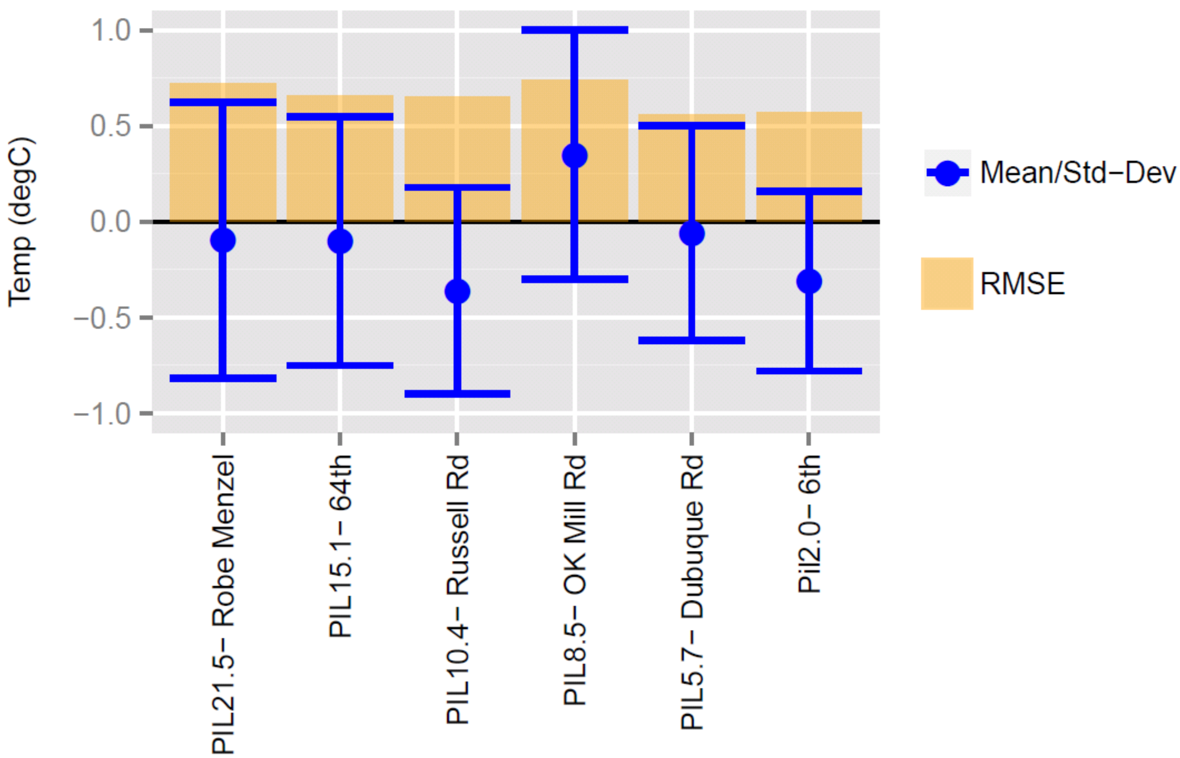

Figure F-19. Error statistics for temperature in the QUAL2Kw model from 7/8/12 to 9/8/12.

Sensitivity Analysis

In order to analyze the sensitivity of individual parameter estimates for the calibrated QUAL2Kw model, Ecology perturbed one parameter at a time. First the parameter was set to the 25th percentile of the auto-calibration range (low) and then set to the 75th percentile (high) (see Table F-7 in *Model calibration*). If the calibrated model parameter value was set at the high or low end of the perturbed range, then the model parameter was only altered for the opposite end of the range.

Sensitivity was evaluated by recalculating the RMSE between simulated and observed values, or goodness of fit, (as described in *Error Analysis*) after each parameter was perturbed.

Ecology evaluated the sensitivity in goodness of fit for six key model metrics: daily min DO, daily max DO, inorganic phosphorus, nitrate-nitrite, bottom algae biomass, and daily max pH based on the low and high variations (Figures F-20 to F-24). The baseline RMSE represents the calibrated model fitness, while the low and high end RMSE values show how each parameter change would affect model fitness.

Additional information

- For the QUAL2Kw bottom algae parameters:
  - The scour function sensitivity was tested by turning the function off. The scour function is based on terms for periphyton detachment and catastrophic loss of biomass determined in the model developed by Uehlinger et al. (1996).
  - Bottom Algae "use HCO3- as substrate" option sensitivity was tested by changing from 'Yes' (calibrated) to 'No'

    - Ecology used the half-saturation light extinction model in the calibrated model. Only the light model constant was adjusted. Other extinction models were not tested for sensitivity.

- For QUAL2Kw hyporheic biofilm parameters:
    - The Fast CBOD oxidation model sensitivity was tested by changing from zero-order (calibrated) to first-order.
    - Hyporheic flow sensitivity was tested by changing the calibrated values for zone depth from 20-60 cm to 100cm and flow fraction from 10-15% to 25%.

Results of the sensitivity analysis showed

- For bottom algae parameters,
    - DO, bottom algae biomass, and max pH goodness of fit were all significantly negatively impacted by a higher maximum growth rate. They were also negatively impacted by lower respiration rates (Figure F-20). These results illustrate why the calibrated model used a lower maximum growth rate and higher respiration rates. This agrees with evidence that the Pilchuck River is likely a relatively low primary productivity stream, which is evident from:
        - The relatively low algal biomass levels,
        - Relatively low nutrient levels,
        - Predominance of diatoms over green algae, and
        - Estimate of respiration being greater than gross primary productivity.
    - SRP concentration in the river was, predictably, most sensitive to max growth rate and the kinetic phosphorus rates. Kinetic phosphorus rates are affected by the following model parameters: external half saturation constant, subsistence quota, max uptake rate, and internal half sat ratio.
    - NO2-NO3 concentration in the river was, predictably, most sensitive to max growth rate and the kinetic nitrogen rates. Kinetic nitrogen rates are affected by the following model parameters: internal half sat ratio, subsistence quota, and max uptake rate.
    - The Pilchuck River calibrated growth rate (17 gD/m^2/d) was similar to the median growth rate of the 27 QUAL2Kw models (25 gD/m^2/d) with zero-order growth rates (interquartile range of 12 to 50 gD/m^2/d; see Table E-7 in *Model calibration*).
- **For hyporheic biofilm parameters**
    - DO model fitness was most negatively impacted by a higher max growth rate, the removal of hyporheic flow, and switching from the zero-order to the first-order fast CBOD oxidation model (Figure F-22). A first-order model assumes growth is limited by surface area space, where a zero-order assumes organisms can grow on top of each other.
    - These results suggest that limiting primary productivity growth and including heterotrophic growth in the hyporheic zone are important to the model calibration
    - The RMA analysis and initial model concluded that a significant source of oxygen demand was likely coming from the sediment or hyporheic zone. Oxygen demand from the hyporheic zone made the most sense given the significant amount of hyporheic activity observed in the field and the coarse substrates.

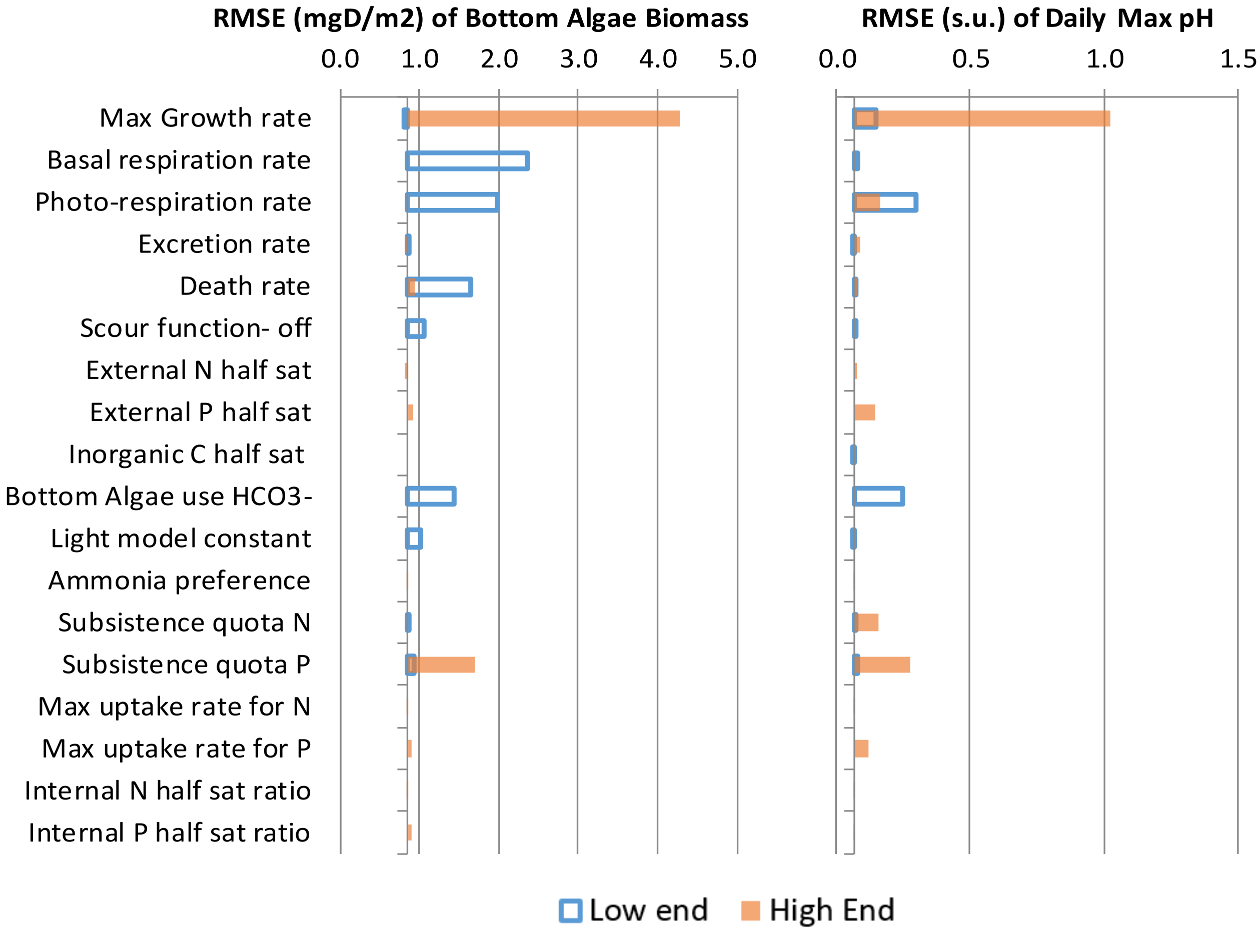

Figure F-20. Sensitivity (RMSE) of bottom algae biomass and daily max pH goodness of fit to variations in bottom algae parameters.

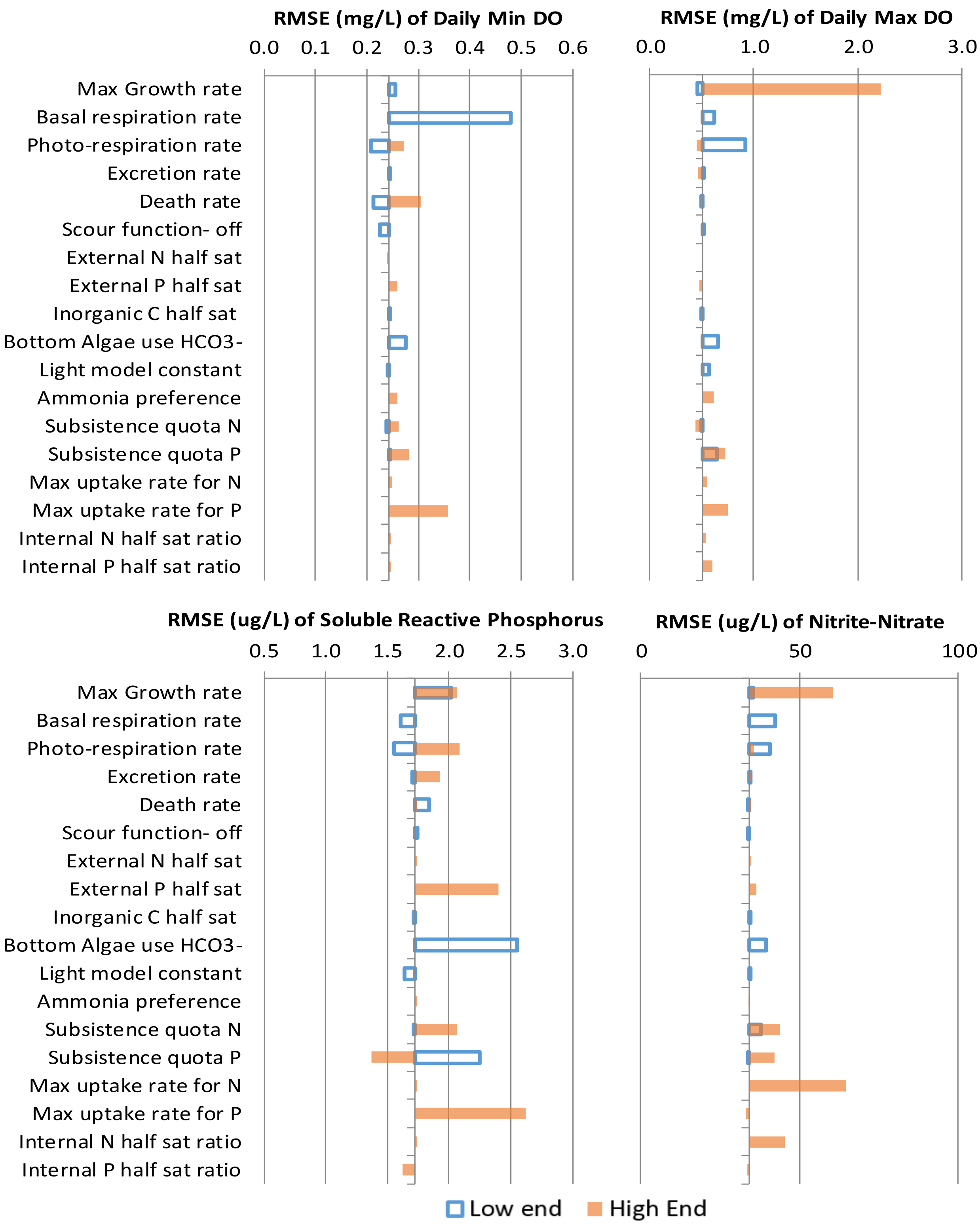

Figure F-212. Sensitivity (RMSE) of dissolved oxygen, soluble reactive phosphorus, and nitrite-nitrate goodness of fit to variations in bottom algae parameters.

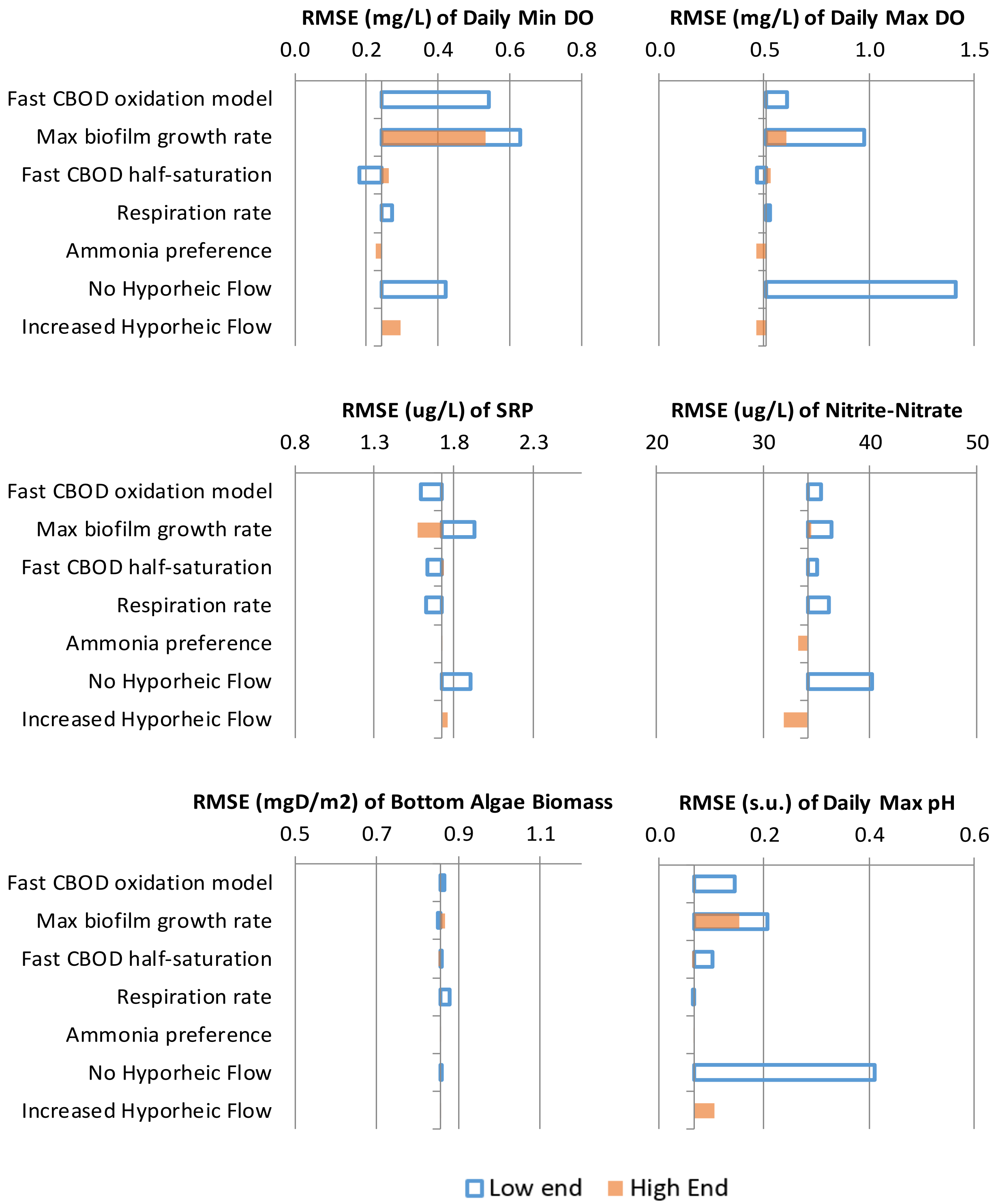

Figure F-223. Sensitivity (RMSE) of dissolved oxygen, soluble reactive phosphorus, nitrite-nitrate, bottom algae biomass, and daily max pH goodness of fit to variations in hyporheic parameters and inputs.

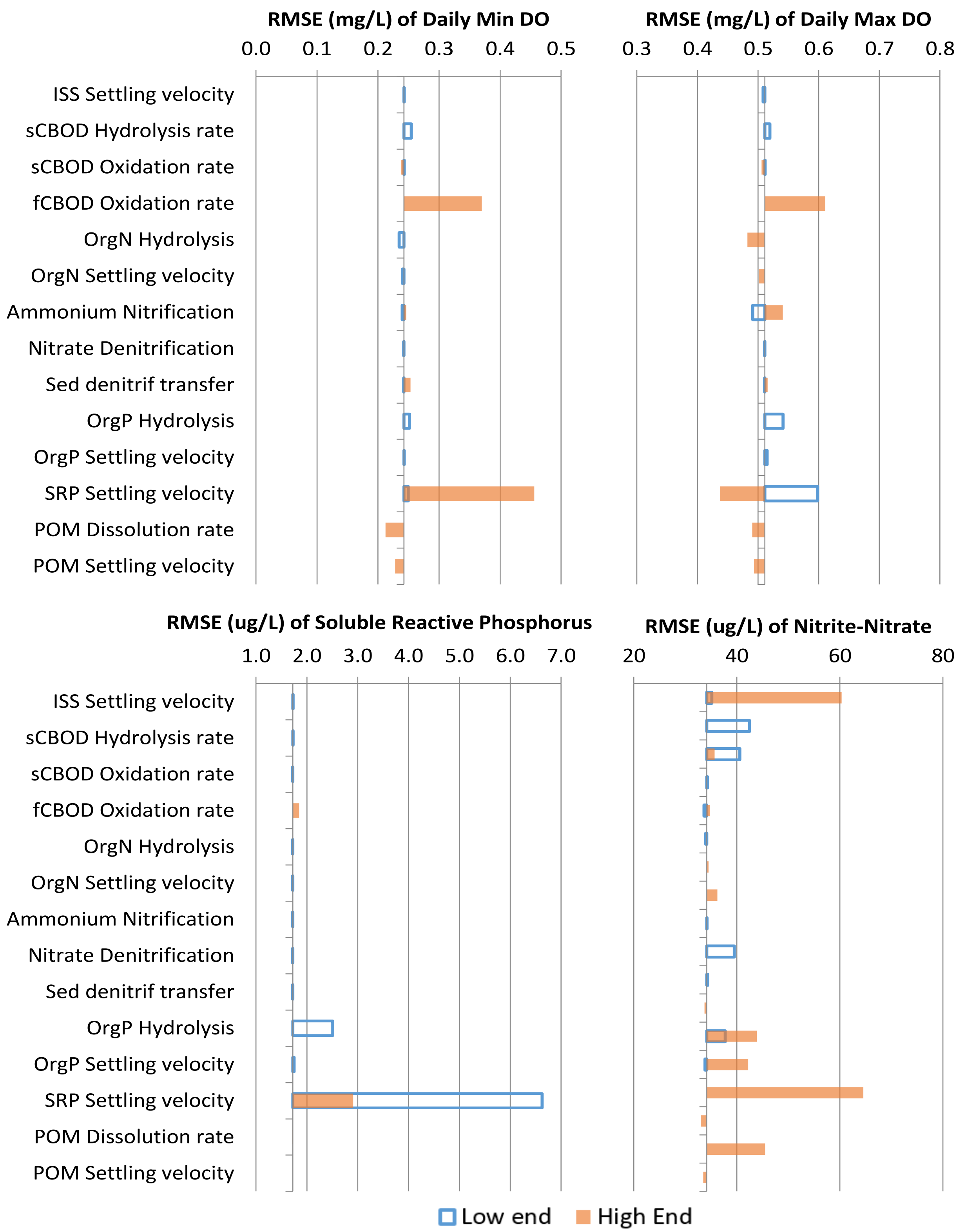

Figure F-23. Sensitivity of dissolved oxygen, soluble reactive phosphorus, and nitrite-nitrate goodness of fit to variations in nutrient and settling parameters.

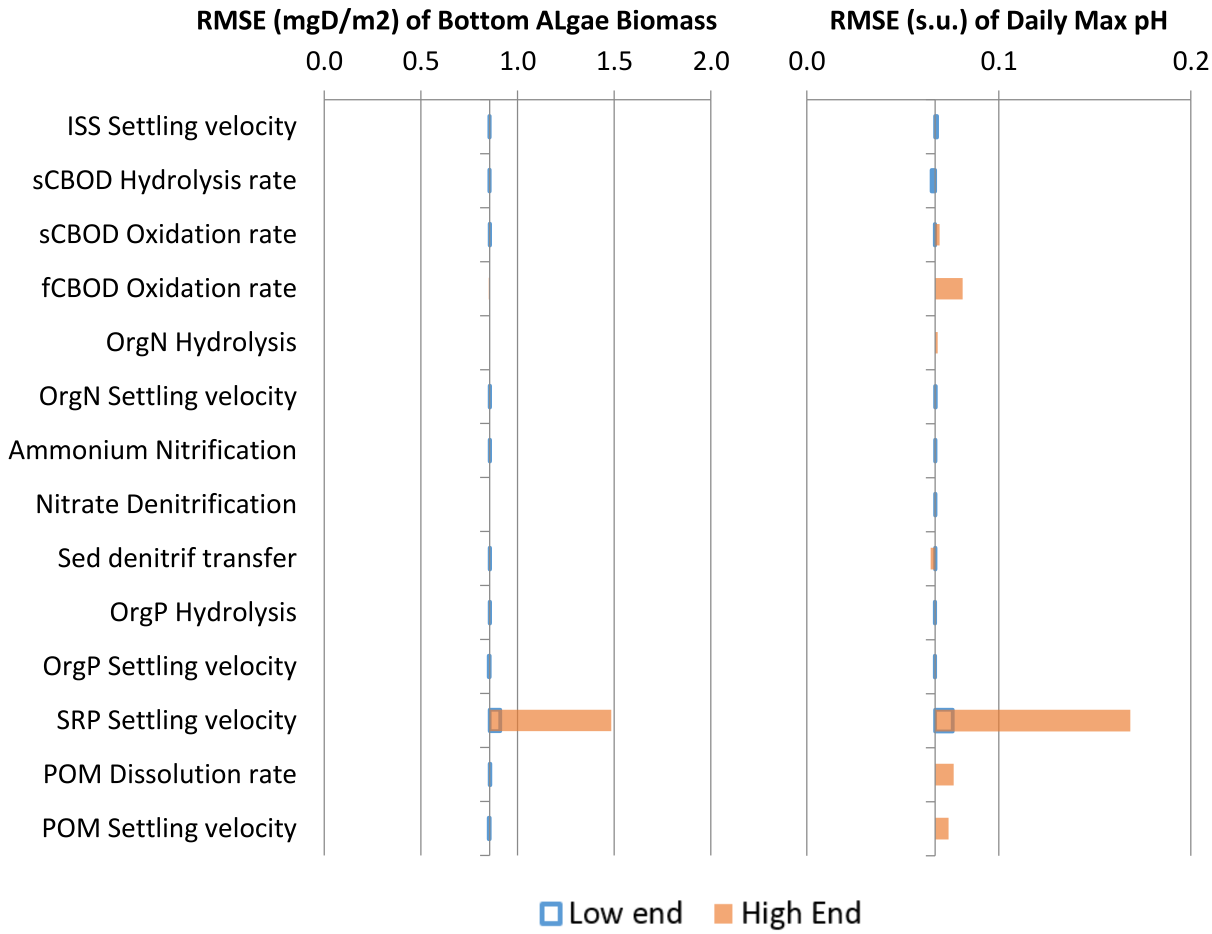

Figure F-24. Sensitivity of bottom algae biomass and max pH goodness of fit to variations in nutrient and settling parameters.

Model Sensitivity to Nutrient Limitation

Ecology also tested the sensitivity of bottom algae growth limitation and growth saturation to concentrations of inorganic phosphorus and nitrogen in the river. This was accomplished by setting one nutrient artificially very high (well above saturation) and the other nutrient at zero (limiting nutrient) at the upstream boundary. The concentration of the limiting nutrient was then gradually increased both downstream and over time to create a large gradient of nutrient concentrations and bottom algae growth in the river.

Model outputs for growth limitation factor and nutrient concentration were then plotted for July and August at noon (Figures F-25 and F-26), to represent peak primary productivity. The model growth limitation factor is scalar that is applied to maximum growth rate parameter. Growth saturation occurred at a limitation factor of ~0.9 for SRP and 0.85 for DIN. Thus 90 percent growth saturation was estimated at a limitation factor of 0.81 for SRP and 0.77 for DIN (90% of 0.9 and 0.85 respectively) and an inorganic phosphorus concentration of ~9.7 ug/L and dissolved inorganic nitrogen of ~59 ug/L. These values are within the literature range for diatom growth saturation in rivers and streams for phosphorus of 3 ug/L (Bothwell, 1985) and 23 ug/L (Rier and Stevenson, 2006). For nitrogen, only one known estimate is available from the literature, 86 ug/L (Rier and Stevenson, 2006).

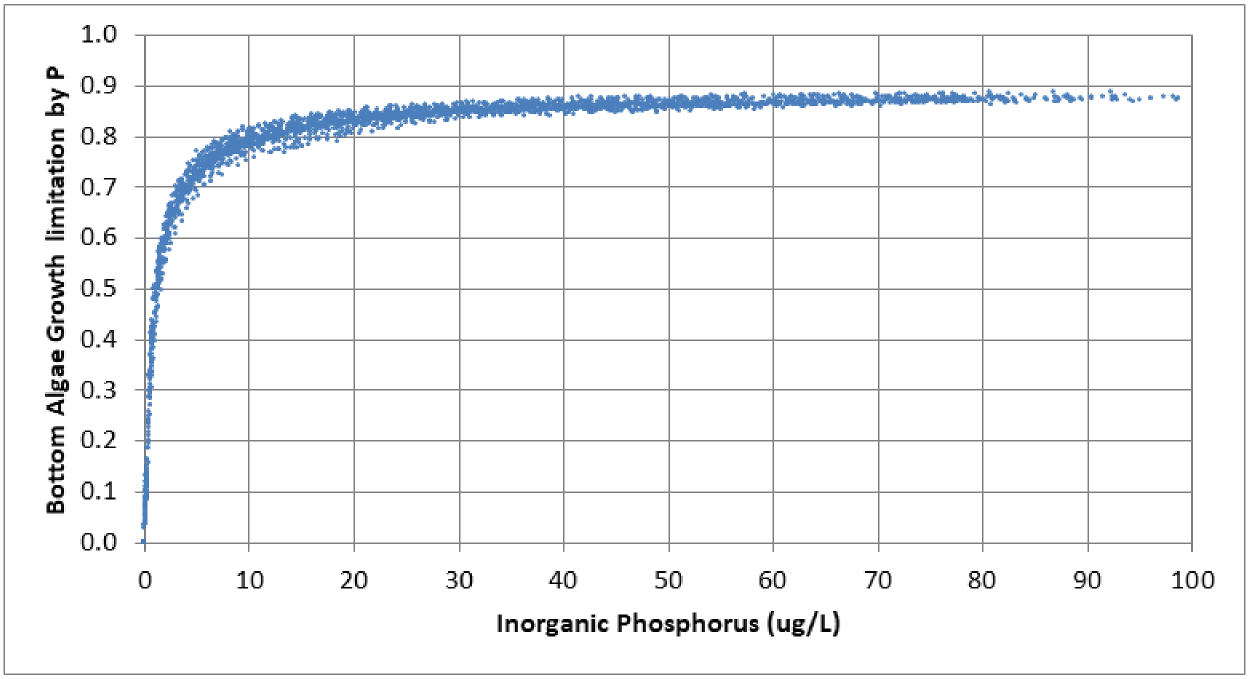

Figure F-25. Growth limitation and saturation sensitivity tests for inorganic phosphorus.

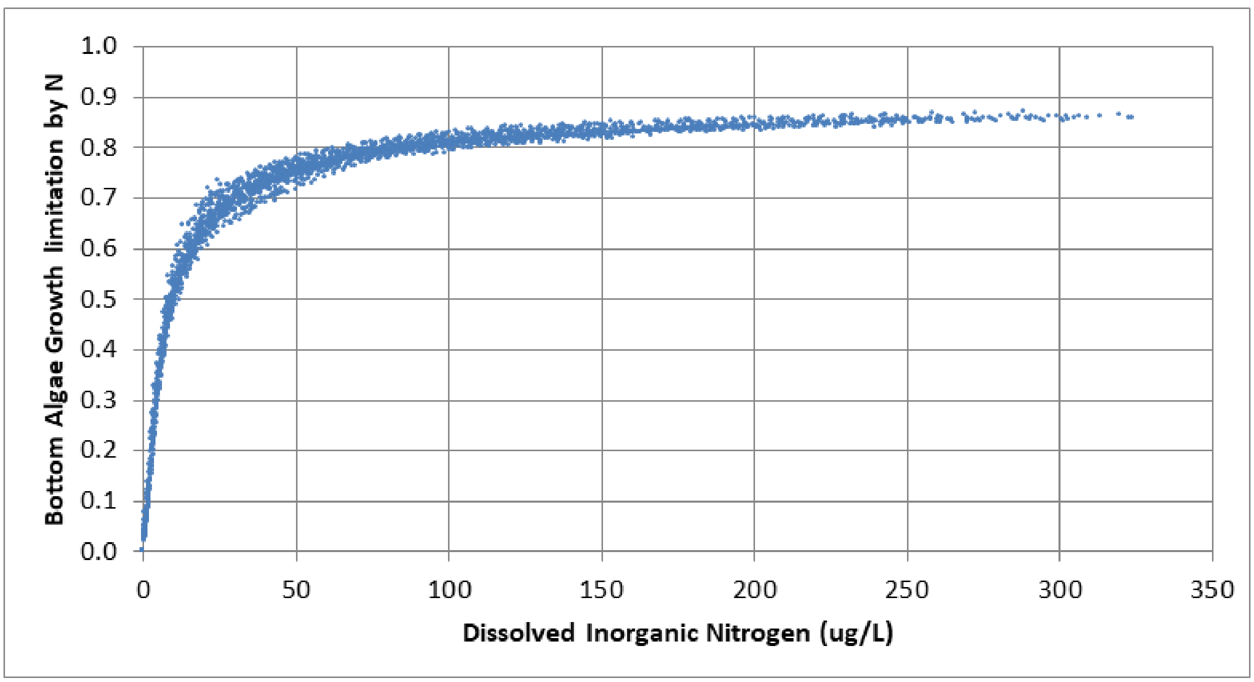

Figure F-26. Growth limitation factor and saturation sensitivity tests for dissolved inorganic nitrogen.

Uncertainty Analysis

Finally, Ecology evaluated the uncertainty associated with using the model to evaluate management scenarios by comparing the temperature and DO outputs from the existing (calibrated 2012) and system potential models. Assuming that the system potential coefficient of variation (CV) is similar to that of the existing conditions, the RMSE attributed to the difference between the existing and system potential scenarios (RMSEdiff) can be calculated using the existing model RMSE and the coefficient of determination for the simple linear regression (R^2) between the two scenarios (Figure F-27). The RMSE between scenarios was estimated to be 0.16°C for temperature and 0.08 mg/L for DO (Table F-25). This provides an estimate of uncertainty between the two models.

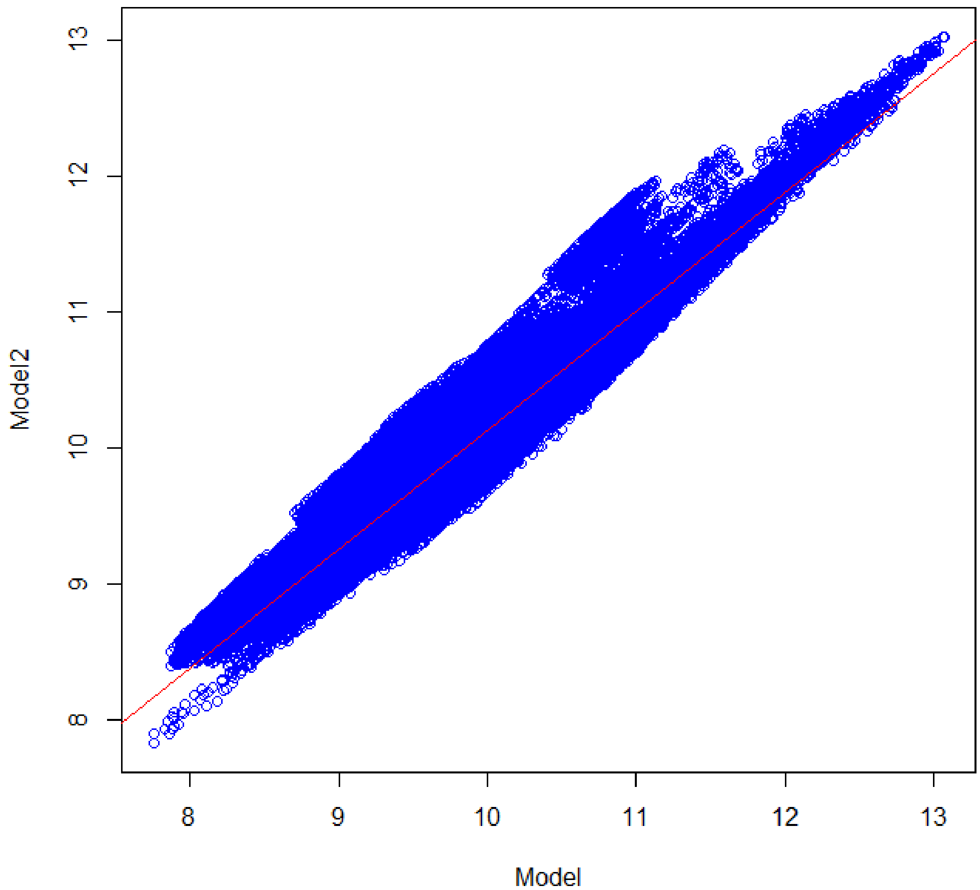

Figure F-274. Simple linear regression between existing (model) and system potential (model2) scenarios.

Table F-25. Variance and RMSE between modeling scenarios.

Parameter	RMSE	Coefficient of Determination for linear regression (R^2)	Variance between scenarios	RMSEdiff (between scenarios)
Temp	0.65 °C	0.97	0.02535	0.16 °C
DO	0.23 mg/L	0.94	0.006577	0.08 mg/L

References

Collins, B.D., Montgomery, D.R. and Sheikh, A.J., 2003. Reconstructing the historical riverine landscape of the Puget Lowland. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, WA, pp.79-128.

Frazer, G.W., Canham, C.D. and Lertzman, K.P., 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York, 36.

Hobson, A.J., Neilson, B.T., von Stackelberg, N., Shupryt, M., Ostermiller, J., Pelletier, G. and Chapra, S.C., 2014. Development of a Minimalistic Data Collection Strategy for QUAL2Kw. Journal of Water Resources Planning and Management, 141(8), p.04014096.

Pelletier, 2013. RMA.xls - River metabolism analyzer for continuous monitoring data. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models.html.

Appendix G. Natural Conditions Model

Introduction

In order to represent the natural condition of the Pilchuck River, Ecology developed a modified version of the QUAL2Kw model that removes or alters inputs or conditions in the model that are clearly impacted by human influence.

Accurately representing river conditions, pre human influence, is challenging given the lack of information about these conditions. Ecology relied on several sources of information to develop the model including:

- Historic federal land survey records created between the years of 1866 to 1892 compiled by the Bureau of Land Management's (BLM) General Land Office (GLO). The GLO records consist of two primary sources of information:
  - Cadastral survey plats (maps) - These maps define the sub-divisions of federal land and include land and water features encountered on surveys (Figure G-1).
  - Cadastral survey field notes – The notes associated with developing survey plats include descriptions of vegetation, waterbodies, and topography.
- Three academic assessments of historical conditions documented in publications titled:
  - *Reconstructing the historical riverine landscape of the Puget Lowland: Restoration of Puget Sound Rivers* (Collins et al. 2003).
  - *The legacy of Pleistocene glaciation and the organization of lowland alluvial process domains in the Puget Sound region* (Collins and Montgomery, 2011).
  - *Climate and the origin of old-growth Douglas-fir forests in the Puget Lowland* (Brubaker, 1991).
- Site potential vegetation (species and mature height) indexes based on local soils obtained from the United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) soil surveys. Soil survey information is available from multiple sources including:
  - The Web Soil Survey: https://websoilsurvey.nrcs.usda.gov/app/
  - gSSURGO GIS data (USDA/NRCS, 2014).
  - Snohomish County Soil Survey manuscripts from 1947 (Anderson et al., 1947) and 1983 (Debose and Klungland, 1983).
- Estimates obtained from academic literature, historic reference condition data, and 2012 study data collected in relatively un-impacted areas.
- In situations where no reasonable information could be found to estimate natural conditions, either:
  - An approach was used based on precedent from an approved TMDL study, or
  - No change was made to the existing model and the justification was documented.

Figure G-1. Example of historic survey map at the mouth of the Pilchuck River from GLO records.

Modeling Considerations Checklist

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. Table G-1 contains the summarized information included in the checklist. The following sections include the details of these elements.

Table G-1. Modeling natural conditions consideration checklist and summary.

Element	How applied	Sources/References
Boundary conditions	Reduce highest temperature to 16. Scale remaining values (above 10 deg C) by same percentage. Recalculated DO based on decreased temperatures.	Precedent set by other TMDLs. Assumes that the river upstream can obtain 16 deg C with improvements in shade throughout the upper watershed.
Channel morphology changes	Increased hyporheic flow by reach specific percentage in natural conditions model.	Anthropogenic impact (bank hardening) identified on 16% of total banks (SCSWM, 2004).
Flow reductions or increases	Included restored baseflow from estimated groundwater and surface water use.	See Appendix J.
Hydrologic modifications	10 ft diversion dam upstream of study area with relatively small surface water withdrawal. Flow restored based on water treatment plant design capacity.	City of Snohomish Water Treatment Plant and Water Supply Study (Murray, Smith, and Associates, Inc., 2009).
Invasive species	Native disturbance zone species (alder, cottonwood, willow) replace spotted knotweed and other invasive vegetation. No invasive aquatic plants identified during field surveys.	BLM, 2016; Collins et al., 2003
Microclimate	Reduced hourly air temperatures by 5%. Increased dew point by 3%, except for times when that would exceed 100% relative humidity	Bartholow, 2000; Brosofske et al., 1997; Chen et al., 1993.
Natural nutrient concentrations *(required only for DO and pH natural conditions determinations)*	Mainstem, tributary, and groundwater inputs for phosphorus not reduced, because already less than EPA ecoregion 25th percentile.	EPA, 2000; Carroll and Anderson, 2009
Nonpoint sources	See natural nutrient concentrations for DO. See System Potential Shade for temperature.	See associated references.
Point source effluent	Removed Granite Falls WWTP discharge.	
System potential shade	Composite system potential tree height based on site soil index percentages within riparian zone.	BLM, 2016; Anderson et al., 1947; Debose and Klungland, 1983; Collins et al., 2003

Element	How applied	Sources/References
Any biological measures or indices that indicate the water body has high quality biological integrity (or a narrative of how the water body is achieving its use through temporal use, refugia, etc.)	B-IBI scores on the mainstem Pilchuck range from 20 – 32, with an average of 27 based on 5 macroinvertebrate samples in the study area. These range from poor to fair and generally indicate impairment. Documented fall chinook, fall chum, winter steelhead spawning. Documented presence or rearing for summer chinook, coho, summer steelhead, sockeye, pink, and bull trout.	Puget Sound Stream Benthos Database. http://pugetsoundstreambenthos.org/Default.aspx WDFW SalmonScape web application. http://apps.wdfw.wa.gov/salmonscape/map.html
Discuss how errors and uncertainty in modeling are addressed		
Sensitivity analysis performed and documented in report. Uncertainty in field results quantified and documented. The root mean squared error between the system potential model and existing conditions model was calculated using the RMSE of existing model fitness and correlation between scenarios. This quantifies uncertainty between scenarios (assuming that variance under system potential conditions is the same as existing), which was 0.16 deg C for temperature and 0.08 mg/L for DO.		
Describe the model or other predictive method chosen and why it is the most appropriate method		
QUAL2Kw version 6 was used to perform a dynamic 124 day system potential simulation for the entire critical season of June through September. This method is appropriate because it can estimate system potential temperature and DO at different times throughout the critical season, and not just the most critical point. For example, shade is more effective during critical Chinook spawning window (September) compared to critical temperatures (Late July/ Early August). Also the dynamic model is better simulation of natural biological productivity accumulation and patterns (periphyton in the case of the Pilchuck) over the growing season including variation in light, temperature, nutrient, and scouring limitation.		

Definitions

Boundary conditions – Considers upstream inputs to the water body or segment being evaluated for natural conditions. Also must ensure downstream uses and criteria are not adversely affected.

Channel morphology changes – Considers channel straightening, dredging, levees, aggregation, and incision

Flow reductions or increases - Considers groundwater and surface water changes such as withdrawals and inputs

Hydrologic modifications – Considers hydrologic controls such as dams and weirs

Invasive species – Considers whether other organisms are affecting the biology or chemistry of the water. For example plants influencing DO/pH levels or carp influencing turbidity and sediment oxygen demand

Microclimate – Considers changes in temperature and relative humidity due to increased riparian vegetation to the system potential shade level.

Point source effluent – Removes all effect of permitted discharges.

Natural nutrient concentrations – Considers whether there are natural nutrient sources contributing to the water chemistry and biology or if there is legacy nutrient contamination. This is required only for DO and pH natural conditions determinations.

Nonpoint sources – Factors in land use changes, vegetation removal, and diffuse pollution from human activities.

System potential shade – Ensures full water body shading possible under a natural condition is applied.

Boundary Conditions

Flow

The headwater flows were reduced from 2012 values (7-day low flow of 56.5 cfs) to values that represent ~7Q10 flow conditions (41.8). Ecology plotted the 7-day flows from the four lowest 7-day flow years from the 7Q10 analysis for USGS station 12155300, for the period of 1992-2016 (Figure G-2). Of these years, 2003 has a 26 year recurrence interval, or the lowest 7-day flow on record, so it was not used to simulate critical conditions. Ecology also ruled out 2015, a 7Q13 year, because it had the lowest June/July on record.

Of the remaining years, 2004 and 2009 displayed a more typical flow pattern for this time of year and were tied as 7Q9 years (44.7 cfs). Ultimately, 2009 was selected because it had lower flows in early June. Next, two modifications were made to the 2009 flow record:

- Daily flows were reduced by 3 cfs to achieve a 7Q10 value of 41.7 cfs.
- The mid-August storm (flow increase) was delayed by one week, to avoid impacting the most critical days for DO (8/5/12) and 7-DADMax temperature (8/11/12 – 8/17/12).

Finally, an additional source of baseflow was added back as diffuse inputs in each model reach and for the Little Pilchuck and Dubuque Creek tributaries (see flow reductions section).

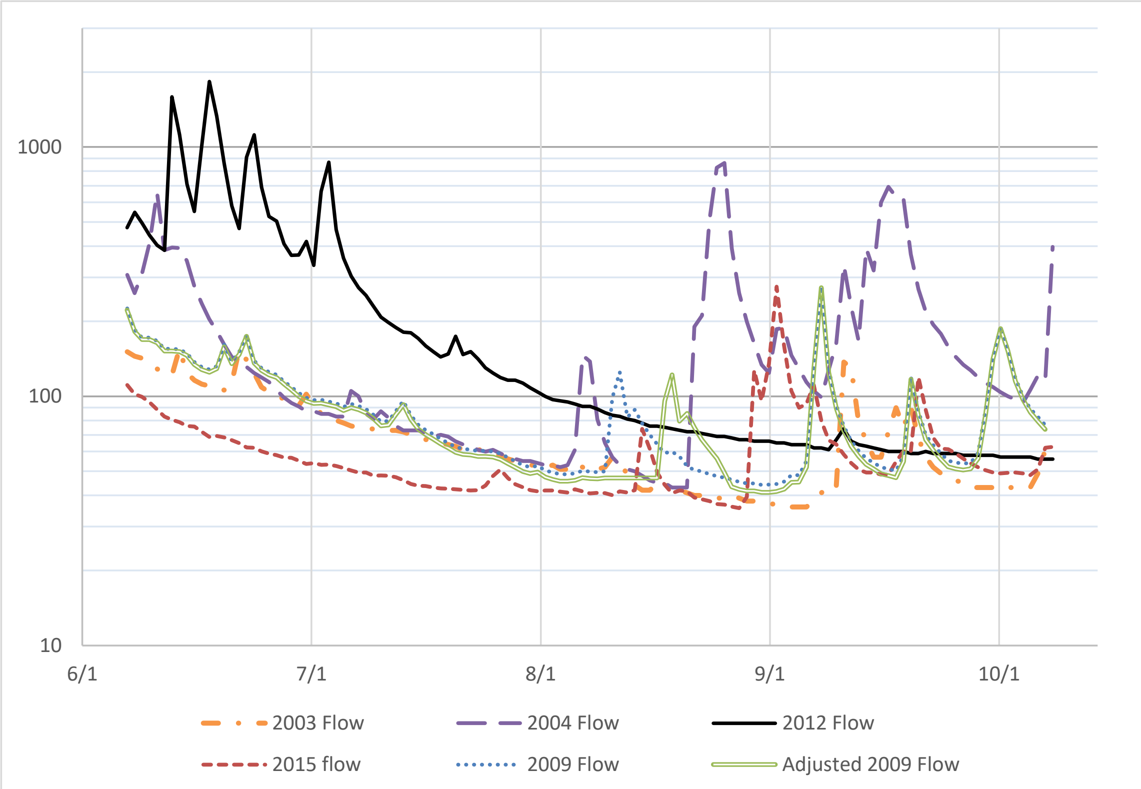

Figure G-2. Comparison of 7Q low flow years for USGS station 12098500.

Temperature

Boundary temperatures for the mainstem Pilchuck River were reduced to meet the water quality criterion of a 7-DADMax temperature of 16°C (Figure G-3). Hourly temperatures were reduced by a factor of 0.91, with the exception of those below 10°C, which were not reduced (Figure G-4). These low temperatures typically represent the influence of air temperatures and/or groundwater only.

The same approach was taken for the tributary inputs to the Pilchuck River, with 7-DADMax temperatures reduced to meet 16°C. Hourly tributary temperatures were reduced by a factor of 0.81, with exception of those below 10°C.

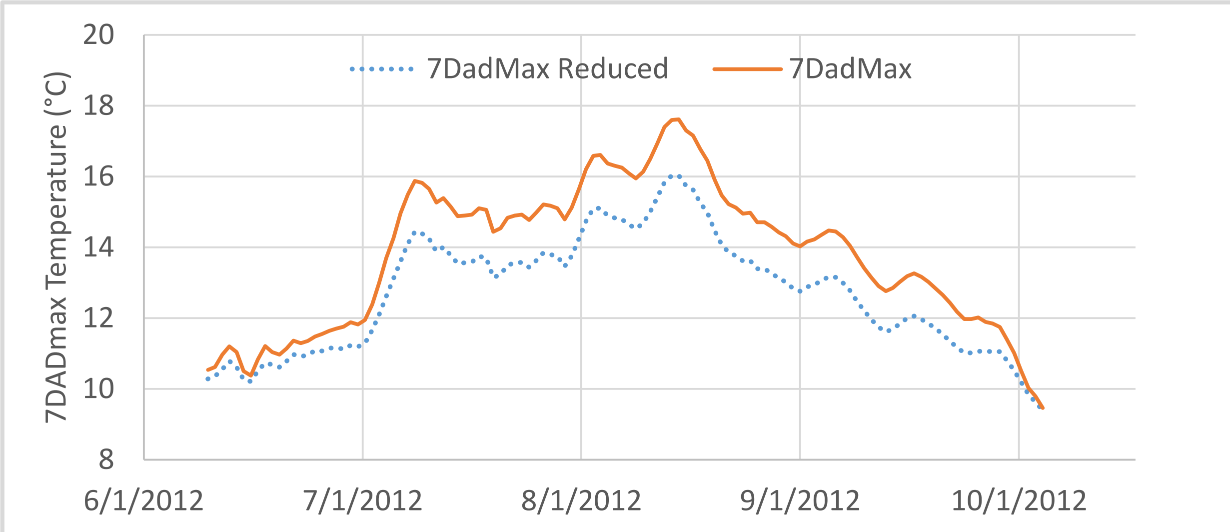

Figure G-3. 7-DADMax temperatures at the Pilchuck model boundary for 2012 and reduced for the natural conditions model.

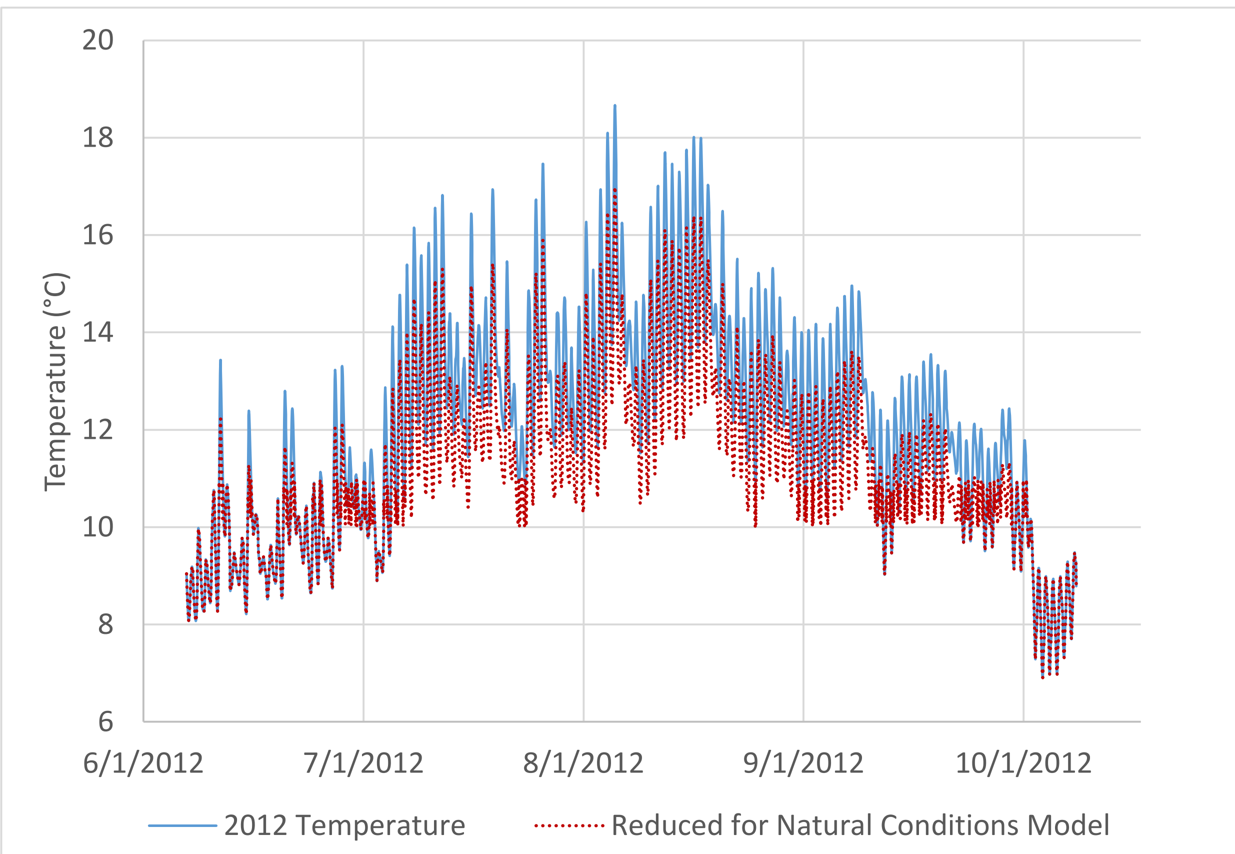

Figure G-4. Continuous temperatures at the Pilchuck model boundary for 2012 and reduced for the natural conditions model.

Dissolved Oxygen

Boundary DO concentrations for the mainstem Pilchuck River and its tributaries were recalculated using the reduced temperatures described above (Figure G-5). The DO percent saturation was not altered, because the range of these values was relatively small and near saturation (95-105% saturation).

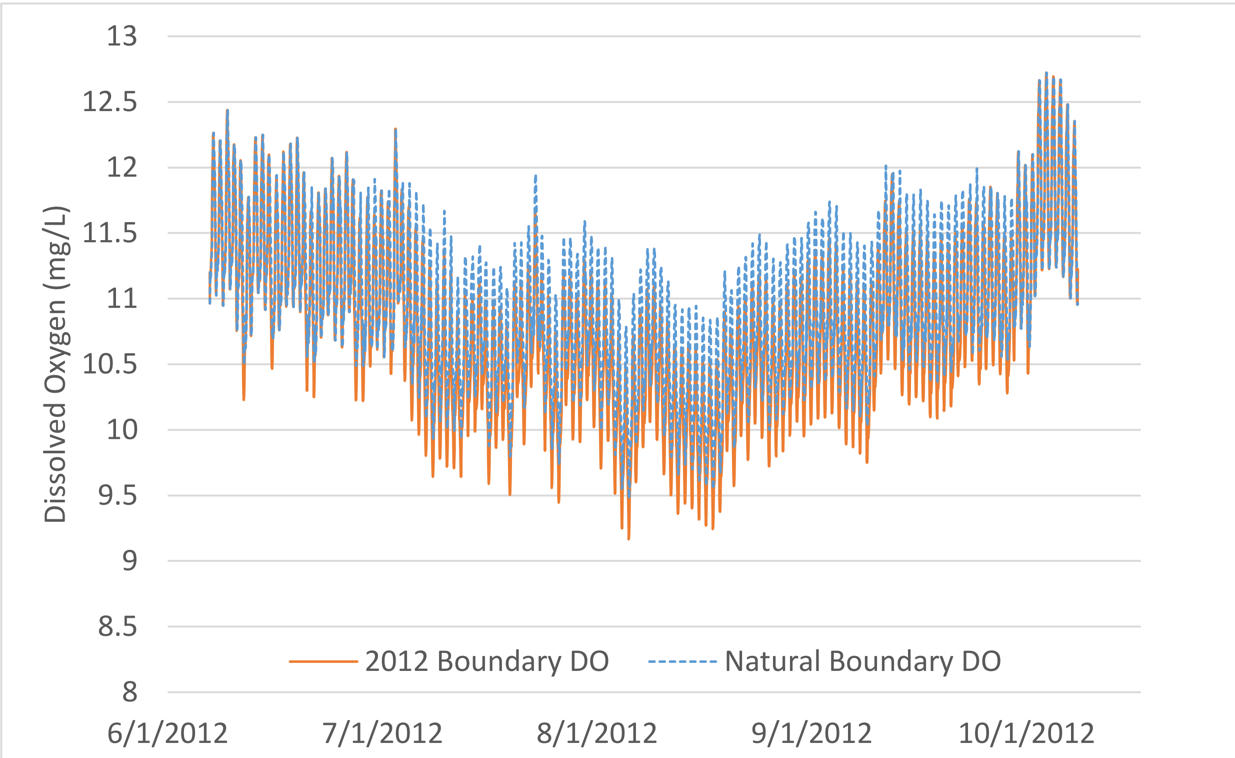

Figure G-5. Boundary conditions dissolved oxygen concentrations for the 2012 and natural conditions models.

Other Water Quality Parameters

EPA (2000) analyzed regional ambient water quality data based on Level II ecoregion, Level III sub-ecoregion, and season. Table G-2 contains 25th percentile (of median values for individual streams) summer chlorophyll *a* or turbidity values for the Western Forested Mountains eco-region and Puget Lowlands sub-ecoregion.

Table G-2. Seasonal summer 25th percentile Chlorophyll *a* and Turbidity concentrations for the Puget Lowland Sub-ecoregion (EPA, 2000)

Sub-ecoregion	Chlorophyll *a* (mg/L)	Turbidity (NTU)
Puget Lowlands	0.6	1.5

Observed boundary condition turbidity values were below the EPA 25th percentile on the Pilchuck River (0.5 to 0.7 NTU) during the summer of 2012. Chlorophyll *a* was a bit elevated compared to EPA 25th percentile (0.8 – 3.2 mg/L); however, the natural conditions model was not sensitive to decreased concentration at the boundary. With Chlorophyll *a* set at 0.5 mg/L, DO in the downstream reaches changed by less than 0.01 mg/L.

Observed dissolved and total organic carbon in the Pilchuck River were typically very low (<1 mg/L). Thurman (1985) suggests that pristine streams range from 1 to 3 mg/L DOC. Forest/riparian soils in the floodplain terrace can represent a significant source of DOC to rivers through the hyporheic zone (Clinton et al., 2002; Mei et al., 2012). Natural contributions of carbon and organic matter depend on the origin of the source (autochonous vs alloctonous) and complex ecosystem, atmospheric, and watershed-level processes.

Autochotonous carbon input, or carbon generated from primary producers within the stream, is typically greater in streams with a more open canopy and lower gradient. Alloctonous carbon input, or carbon from terrestrial inputs such as soil leaching or leaf litter, is typically greater in headwater streams. Removing human influence from upper Pilchuck River might result in less autochonous carbon (due to increased riparian canopy and decreased periphyton biomass), but could also result in greater alloctonous carbon input (due to less export of carbon from the watershed due to forestry).Ultimately, no changes were made to the other water quality parameters in the system potential model due to observed low levels and/or lack of model

Channel Morphology Changes

Numerous human influenced changes have occurred that could impact the channel morphology of the Pilchuck River including bank hardening, levees, diking and draining of floodplain and wetlands, removal of riparian vegetation, and gravel mining in the river channel.

Channel Slope and Sinuosity

The Pilchuck River valley, within the study area, is a “post-glacial” valley where, since deglaciation, sedimentary fill is currently being eroded and deposited in the glacial Snohomish River valley as fill (Collins and Montgomery, 2011). In this sense, the channel morphology has been out of equilibrium since deglaciation and is likely changing in response to natural geomorphology processes originating from before human influence.

Collins and Montgomery (2011) provide an estimate of historic channel slope and sinuosity for the Pilchuck River, in “pre- or early settlement conditions.” This was accomplished by 1) removing obvious human artifacts (buildings/roads) and extensive areas of artificial fill from Digital Elevation Models (DEM) based on LiDAR data and 2) digitizing the historic channel from GLO or USGS maps, prior to artificial straightening.

The estimate of historic sinuosity in the Pilchuck River (1.26) was slightly lower, but very similar to the sinuosity measured from the current Pilchuck model geometry (1.32). Historic channel slope (0.00341 m/m) was also very similar to that of the current conditions model (0.00318). This suggests that natural fluvial geomorphology processes may control channel slope and sinuosity at the scale of the entire Pilchuck River TMDL study area.

Channel Widening

Anthropogenic impacts to the geometry (disturbance zone width, channel width/depth) of the active river channel are more complicated to estimate.

Removal of riparian vegetation can increase disturbance zone and channel width; however, Pilchuck widths are also heavily influenced by sediment transport processes that occur during peak flow events on an approximately annual basis.

Other TMDL studies in the Puget Sound region of Washington State have included or explored a reduced channel or disturbance zone width scenario in the natural conditions model (Roberts et al., 2012; Mohamedali and Lee, 2008; Roberts, 2003). Although Roberts (2003) notes that:

> *No evidence of channel widening was identified in the present study, and Mastin (1998) found no evidence of increased flood frequency or changes in channel geometry over the period 1965 to 1990.*

Channel widths were measured during the late 19th century federal land surveys, whenever the river was encountered along a survey route. Ecology reviewed the field notes and plat maps and found 25 of these measurements for the Pilchuck River within the study area, with a median channel width of 34 m (112 ft) and maximum width of 70 m (231 ft).

Disturbance zone widths were sampled every 50 meters (n = 805) from digitized aerial photography for 2012 and used in the shade model. These disturbance zone widths had a median of 35m and a 90th percentile of 67 m. This comparison, although limited by the amount and uncertainty of the historical data, does not suggest a major anthropogenic impact to channel widths on a watershed scale.

Given that, on a larger scale, the Pilchuck River's sinuosity, slope, and channel widths have likely not been significantly impacted by human development, physical processes that affect DO and pH are likely not greatly impacted either. In the model this is primarily represented by reaeration, which was not adjusted for natural conditions.

Bank and Floodplain Modifications

Snohomish County (2012) performed a detailed habitat assessment of the middle Pilchuck River from RM 8.6 to 26.4. The report found that over 16% of the total bank length was modified, with 5.6 miles of armoring/bank hardening. The remaining 84% of the bank length was classified as natural. This does not include modifications beyond the bank condition, but within the floodplain, such as setback dikes and revetments. In 2017 (Cardno, 2018) Snohomish County performed a detailed habitat assessment of the lower Pilchuck River from RM 0 to 8.6. Table G-3 contains a summary of the observed modifications from these surveys.

Table G-3. Observed bank modifications from Snohomish County habitat assessments of the lower and middle Pilchuck River.

~River Mile Lower	~River Mile Upper	ECY Model Reaches	Snohomish County Reach	Total Bank Length (ft)	Modified Bank Length (ft)	Natural Bank Length (ft)	% Modified
0.0	1.6	40	L1	16,984	10,630	6,357	63
1.6	2.7	39	L2	11,362	3,018	8,344	27
2.7	3.8	37,38	L3	11,857	5,573	6,284	47
3.8	4.2	36	L4	3,808	1,197	2,608	31
4.2	5.8	34,35	L5	17,289	5,838	11,450	34
5.8	6.5	33	L6	6,872	1,499	5,369	22
6.5	7.1	31,32	L7	7,308	2,247	5,061	31
7.1	8.6	29,30	L8	14,842	4,963	9,879	33
8.6	11.2	25 - 28	M1	28,133	7,023	21,110	25
11.2	14.2	20 - 24	M2	31,756	4,085	27,671	12.9
14.2	17.9	14 - 19	M3	38,689	4,770	33,919	12.3
17.9	19.6	11 - 13	M4	18,289	3,429	14,861	18.7
19.6	20.7	10	M5	11,122	519	10,602	4.7
20.7	21.9	8,9	M6	13,005	3,683	9,322	28.3
21.9	24.1	4 - 7	M7	23,246	2,064	21,182	8.9
24.1	25.4	1 - 3	M8	13,261	3,766	9,495	28.4

Both bank and floodplain modifications, particularly armoring using rip-rap, can:

- Limit natural channel migration, reducing the river's ability to form hydrologic connections to side channels and the floodplain (Opperman, 2012; Blanton and Marcus, 2013; Reid and Church, 2015), which ultimately decreases the potential surface area for hyporheic exchange.
- Reduce large woody debris recruitment (Larsen et al., 2006; Florsheim and Mount, 2008) by inhibiting natural bank erosion. Natural bank erosion can provide the primary source of large wood, even in low-gradient streams (Martin et al., 2016). Large wood addition can increase hyporheic exchange through localized upwelling (Sawyer and Cardenas, 2012) or by creating anastomosing river pattern with numerous floodplain channels (Collins et al., 2002).
- Increase fine sediment deposition (Stein et al., 2013). Fine sediment can restrict hyporheic flow by clogging the interstitial spaces between coarse sediments (Rehg et al., 2005).
- Reduce the quality of edge habitat for fish (Collins et al., 2002; Quigley and Harper, 2004). While the quality of habitat is not directly related to hyporheic flow, it is an important component in creating cold-water refuge in areas of hyporheic connectivity restoration.

Given these human modifications, the natural conditions model includes an increase in the hyporheic flow fraction to represent some level of impact due to channel modifications.

The natural conditions model assumed that the fraction of hyporheic flow has decreased directly in relation to the percentage of bank length modification in a given model reach, using the following equation:

$$HFF_{natural} = \frac{HFF_{existing}}{F_{Natural\ Banks}}$$

Where, HFF = Hyporheic Flow Fraction and F=Fraction of Natural Banks

For example in reach 33 of the model (Snohomish County Reach L6) 22% of the bank length has been modified (78% natural banks). In the 2012 model, the calibrated hyporheic flow fraction was 0.15 (or 15% of the main channel flow) for reach 33. In the natural conditions model the hyporheic flow fraction was increased by dividing the existing hyporheic by 0.78 for an estimated natural hyporheic flow fraction of 0.1923.

Increasing the hyporheic flow fraction in the natural conditions model has some impacts to other aspects of the model including a decrease in max temperature, decrease in SRP, and increase in sediment oxygen demand.

Flow Reductions

An additional source of baseflow was added back into the natural conditions model to the upstream boundary, tributary, and diffuse inputs, based on estimates of water use in the watershed. Appendix H provides a detailed description of the estimates of baseflow loss in the Pilchuck River TMDL study area.

Hydrologic Modifications

The City of Snohomish has historically operated a diversion dam for municipal water supply just upstream of the study area at ~RM26. The diversion dam is 10 feet tall with a fish ladder and does not create a reservoir, but operates similar to a weir with a flow diversion.

The diverted flows from the dam were restored in the natural conditions model (see flow reductions section), but no changes were made to the upstream temperature, DO, or water chemistry, due to the fact that there is no reservoir and estimating these potential impact is complex. It is possible that the diversion dam provides aeration (increases oxygen) to some extent; however, this was not considered in the model as the dam may replace some natural aeration, given the steeper gradient in this portion of the Pilchuck River.

It is important to note that the city of Snohomish has decided to discontinue use of the Pilchuck River water supply and the diversion dam is scheduled to be removed in the future. For this reason the future TMDL model scenario used to set allocations includes fully restored flows to the river at the diversion dam withdrawal.

Invasive Species

Large quantities of spotted knapweed were observed during data collection along recently disturbed areas of the Pilchuck River channel and its banks. In the natural conditions model, trees of system potential height are included throughout the riparian zone.

No invasive aquatic plants or algae were observed during the study that might impact natural aquatic plant and algae species.

Microclimate

Increases in vegetation height, density, and riparian zone width are expected to result in localized decreases in air temperature. To evaluate the effect of this potential change in microclimate on water temperature, all hourly air temperatures along the Pilchuck River mainstem were reduced by 5%, resulting in a decrease of less than 0.5°C at low temperatures (less than 10°C) and a decrease of up to 1.75°C at maximum air temperatures (35°C).

Bartholow (2000) presents a summary of literature on air temperature differences between forested riparian areas and clearcuts and found an average air temperature decrease of 2.0°C. These studies were conducted in small, headwater streams and the effects were not studied above the water surface. Because much of the Pilchuck River and its disturbance zone is wide compared to the area of riparian overhang it was deemed appropriate to set the increase below the literature range of improvement.

Dew point temperatures were increased by 3%. This increase, combined with the air temperature decrease, resulted in an average relative humidity increase of 5.1%. Several studies found that relative humidity increased by 6% to 11% between forested and clear-cut areas (Brosofske et al., 1997; Chen et al., 1993). Again, these studies were conducted in small, headwater streams and the effects were not studied above the water surface. For this reason it was deemed appropriate to set the increase below the literature range. Microclimate effects would be expected to improve with increasingly wide riparian buffers adjacent to the Pilchuck River.

Natural Nutrient Conditions

EPA (2000) analyzed regional ambient water quality data and made recommendations for nutrient criteria based on Level II ecoregion, Level III sub-ecoregion, and season. Table G-4 contains 25th percentile (of median values for individual streams) summer nutrient values for the Western Forested Mountains eco-region and Puget Lowlands sub-ecoregion.

Table G-4. Seasonal summer 25th percentile nutrient concentrations (ug/L) for the Puget Lowland Sub-ecoregion (EPA, 2000)

Sub-ecoregion	Nitrite-Nitrate	Total Nitrogen	Total Phosphorus
Puget Lowlands	140	170	17

Given that the Pilchuck River has been identified as primarily phosphorus limited, phosphorus is the most important nutrient input in the natural conditions model. In general, phosphorus levels in the Pilchuck River, tributary, and groundwater samples were below the Puget Lowlands 25th percentile value. In addition there was no evidence for large scale anthropogenic phosphorus inputs from diffuse, nonpoint sources, based on a mass balance analysis from the calibrated model and study sampling results.

The 2012 phosphorus concentrations for the headwater boundary at Menzel Lake Road were not reduced in the natural conditions model, due to the low (4.8 to 11.1 ug/L SRP, mean = 8.4 ug/L) measured values and the lack of potential anthropogenic nutrient sources upstream.

Phosphorus concentrations for surface water inputs (tributaries) were also not reduced in the natural conditions model. Based on the limited nutrient data available, these values were also low for phosphorus (5.2 to 10.9 ug/L SRP, mean = 7.4 ug/L)).

Phosphorus concentrations for groundwater inputs were not reduced in the natural conditions model. The median of samples (11.1 ug/L SRP; 11.6 TP) was used for all reaches in the 2012 model (not varied by reach). The median is derived from the 2016 samples collected from piezometers, springs, and seeps in the study area. Figure G-7 depicts the cumulative frequency distribution (CFD) for orthophosphate in groundwater samples within the study area.

The Wenatchee River TMDL (Carroll and Anderson, 2009) used the inflection point, or change in slope, from the CFD of sample values collected in the watershed as the natural nutrient levels:

> *Natural phosphorus concentrations are expected to vary spatially and temporally, depending on such things as local geology and seasonal conditions that affect biological processes. Ecology estimated a natural conditions inorganic-P concentration range for tributaries and groundwater based on the distributions of observed values measured in the watershed's tributaries and groundwater during the critical period (March-May and July-October).*

For groundwater, the Wenatchee TMDL estimated the maximum natural P concentration as 14 ug/L following this method (Figure G-6).

The Wenatchee inflection point analysis was conducted on the Pilchuck groundwater data as a point of reference (Figure G-7). The result was an estimated maximum natural P concentration of 15.3 ug/L, which supports the approach of using the same concentration for existing and natural conditions in the model (11.1 ug/L, see above).

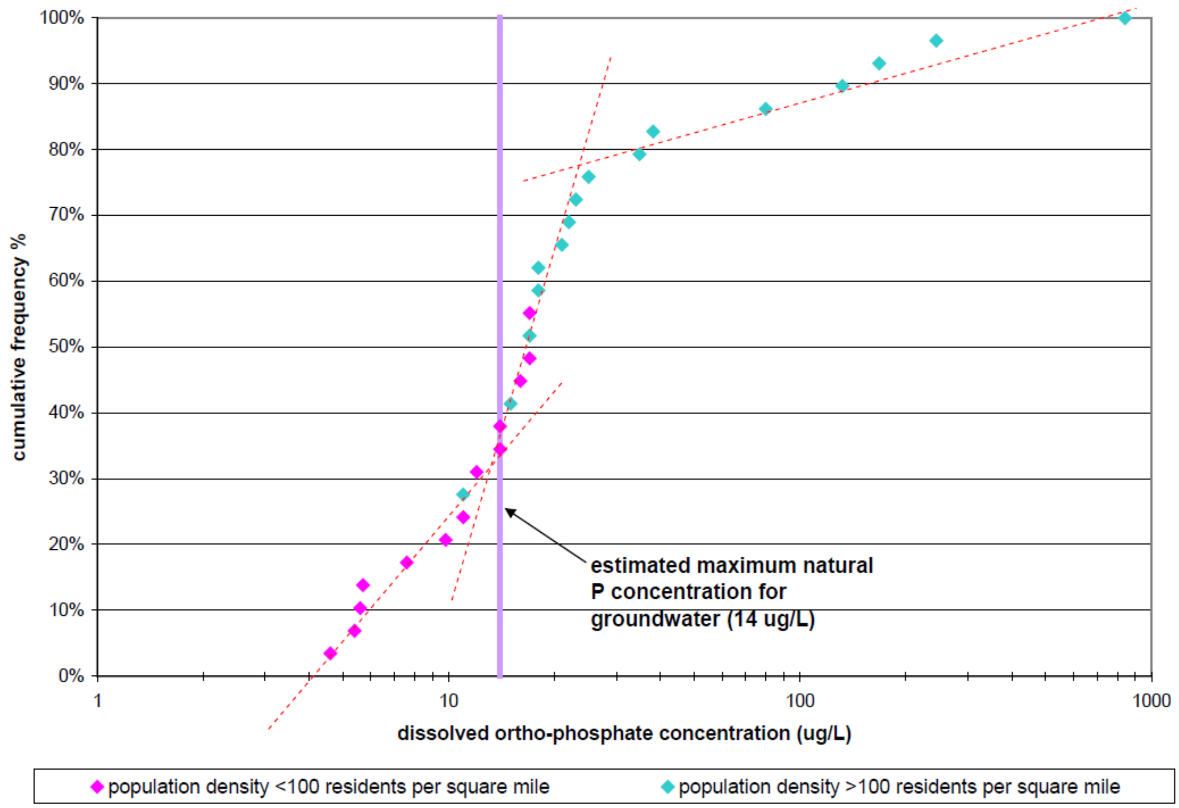

Figure G-6. Estimated natural groundwater concentrations from the Wenatchee River DO and pH TMDL. From: Carroll and Anderson (2009).

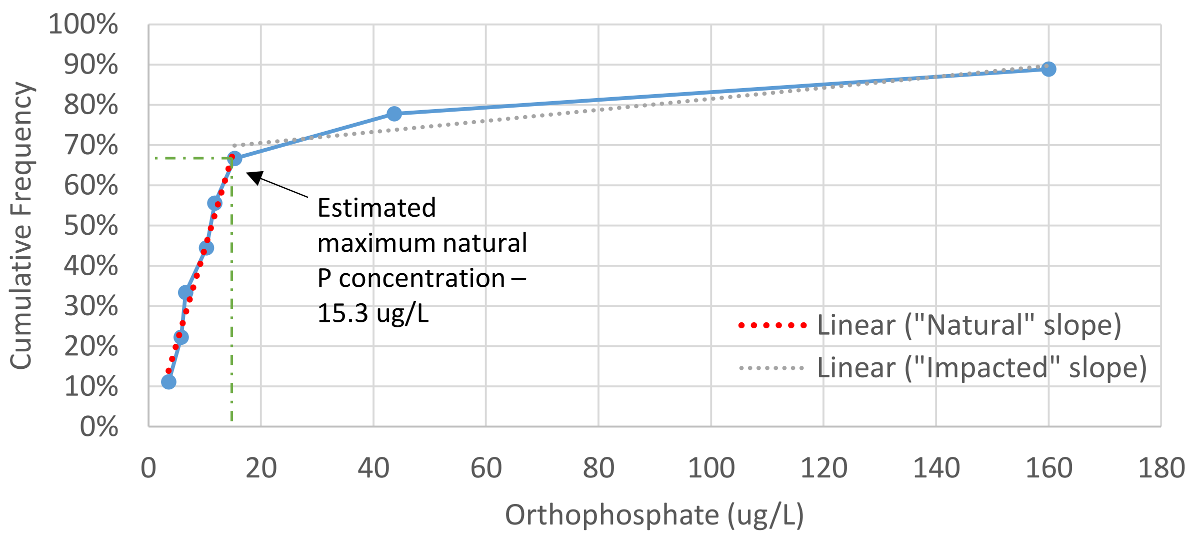

Figure G-7. Cumulative frequency distribution of orthophosphate in groundwater samples for the Pilchuck River TMDL.

Nitrogen inputs, although not identified as the limiting nutrient in the Pilchuck River, could still potentially impact algal growth as some stretches of the river could be co-limited by both nitrogen and phosphorus. In addition nitrogen inputs to the Snohomish River estuary and the Salish Sea can cause anthropogenic eutrophication impacts. Nitrogen is typically more mobile in both surface and groundwater, compared to phosphorus.

Nitrate was reduced in the natural conditions model to the EPA 25th percentile for the Puget Lowlands of 140 ug/L.

System Potential Shade

Ecology estimated historic system potential tree height by:

- Analyzing soil types within the riparian zone.
- Determining the dominant site index species and associated height using the Snohomish County soil survey (Debose and Klungland, 1983) and gSSURGO database (USDA/NRCS, 2014).
- Determining a composite/average system potential vegetation height based on the soil survey site index values and percentage of the overall riparian buffer zone (Table G-6). One composite system potential vegetation (SPV) height was used for the entire Pilchuck River, given that there was not a clear delineation of dominant soil types/species based on river reach.

To corroborate general species occurrence and heights, Ecology used:

- Descriptions of historic riparian tree species and measurements of diameters taken directly from GLO survey maps and field notes of the area circa 1860-1880.
    - Diameter at breast height (DBH) measurements from the GLO field notes were converted from DBH to tree height using species specific height/DBH models developed for coastal areas of the Pacific Northwest (Hanus et al., 1999; Keyser, 2015).
- Historical analysis of GLO surveys in the Snohomish and Pilchuck River valleys from Collins (2003) of historic freshwater riparian and forested floodplain tree species frequency and basal area estimates. Table G-5 summarizes the results applicable to the study area.
- Academic interpretations of pollen and fossil records for Puget lowland forests taken from lake and bog sediments (Brubaker, 1991; Cwynar, 1987; Leopold et al., 1982).

Table G-5. Summary of historic tree frequency and basal area estimates for the Snohomish River valley from Collins (2003).

Species	Freshwater Riparian Frequency (n=15)	Freshwater Riparian Basal Area (n=15)	Forested Floodplain Frequency (n=124)	Forested Floodplain Basal Area (n=124)
Red Alder	13%	3%	18%	11%
Willow spp.	40%	3%	5%	1%
Vine Maple	13%	1%	12%	1%
Black Cottonwood	13%	10%	4%	9%
Other Deciduous	0%	0%	7%	1%
Pacific Crabapple	0%	0%	7%	<1%
Big-leaf Maple	7%	35%	10%	10%
Western Redcedar	7%	20%	11%	44%
Sitka Spruce	7%	28%	19%	22%
Western Hemlock	0%	0%	5%	1%
Pacific yew	0%	0%	2%	<1%

Ecology reviewed 19th century field survey notes of bearing trees documented within ~500 feet of the Pilchuck River. The 52 trees found consisted of: 25% alder, 15% hemlock, 13% cedar, 12% big-leaf maple, 12% vine maple, and 23% other species combined (spruce, willow, barberry, cottonwood, fir, and hazel).

Another source of reference for evaluating historical riparian information was academic interpretation of pollen and fossil data collected from lakes and bogs in the Puget Lowlands (Figure G-8). These records indicate that over the last ~5,000 years, Western redcedar have been most common in the forests of the central and north Puget lowlands. Alder, Western hemlock, and Douglas-fir were also commonly identified. These records do not provide fine-scale spatial information, because they are primarily derived from pollen which can travel several kilometers. Thus they are more representative of overall forest composition in the vicinity of these lakes, but not information specific to riparian, floodplain, or upland.

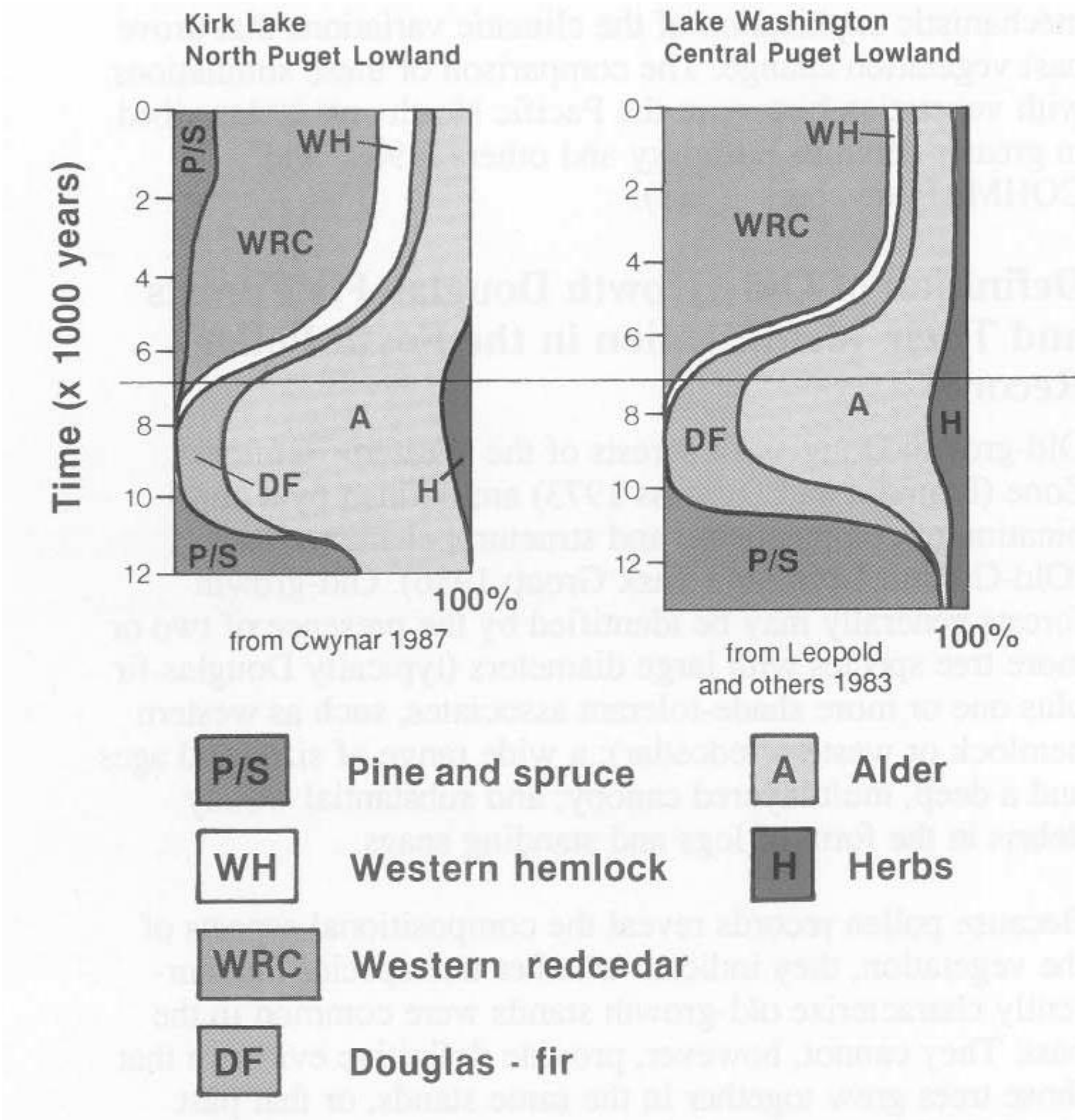

Figure G-8. Forest species composition based on pollen and fossil records for Puget lowland forests taken from lake and bog sediments From: Brubaker (1991).

Notes:

"Leopold and other" incorrectly cited as 1983, actually published in 1982.

Horizontal line indicates timing of ash layer from Mt. Mazama eruption.

Table G-6. Composite system potential vegetation height based on the soil survey site index values and percentage of the overall riparian buffer zone.

Mapunit Name	% of Total Riparian Area	Dominant Species	Site Index	Site Index Year Basis	Site Index Used	Contribution to SPV Height
Sultan silt loam	30.5%	Red alder	87	50	87	26.53
Pilchuck loamy sand	27.5%	Doug Fir	152 (115)	100 (50)	152	41.73
Tokul-Winston gravelly loams	6.1%	Doug Fir/W. Hemlock	173/166 (131/117)	100 (50)	169.5	10.26
Puyallup fine sandy loam	5.7%	Doug Fir/ Red Alder	173/na (115/85)	100 (50)	129	7.41
Menzel silt loam	5.1%	Doug Fir	179	100	179	9.13
Norma loam	4.9%	Red alder	106	50	106	5.19
Puget silty clay loam	3.4%	Red alder	95	50	95	3.25
Ragnar fine sandy loam	2.9%	Doug Fir/W. Hemlock	165/159 (125/112)	100 (50)	162	4.70
Tokul-Ogarty-Rock outcrop complex	2.4%	Doug Fir/W. Hemlock	173/166 (131/117)	100 (50)	169.5	4.02
Sumas silt loam	2.3%	Red alder	80	50	80	1.88
Winston gravelly loam	2.2%	Doug Fir/W. Hemlock	167/164 (127/104)	100 (50)	165.5	3.67
Tokul gravelly medial loam	1.7%	Doug Fir/W. Hemlock	173/166 (131/117)	100 (50)	169.5	2.96
Riverwash	1.4%	n/a	n/a		0	0.00
Pits	1.2%	n/a	n/a		0	0.00
Pastik silt loam	0.8%	Doug Fir	180 (135)	100 (50)	180	1.48
Cathcart loam	0.5%	Doug Fir	175 (130)	100 (50)	175	0.85
Everett gravelly sandy loam	0.5%	Doug Fir	141 (111)	100 (50)	141	0.65
Nargar-Lynnwood complex	0.3%	Doug Fir	185/158 (138/121)	100 (50)	171.5	0.59
Sultan variant silt loam	0.2%	Red alder	85	50	85	0.18
Skykomish gravelly loam	0.1%	Western Hemlock	152 (106)	100 (50)	152	0.21
Terric Medisaprists, nearly level	0.1%	n/a	n/a		0	0.00
Kitsap silt loam	0.1%	Doug Fir	166 (123)	100 (50)	166	0.08
Sulsavar gravelly loam	0.0%	Doug Fir	183 (141)	100 (50)	183	0.06
					Composite SPV height ft =	124.8
					Composite SPV height m =	38.1

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Appendix H. Baseflow Loss and Water Use

Introduction

In order to represent the natural condition of the Pilchuck River, estimates of water withdrawals/use were determined for the Pilchuck River watershed. Water use estimates were based on 5 use categories and developed using the methods summarized in later sections:

- Irrigation for Pasture/Turf
- Domestic Outdoor Use
- Domestic Indoor Use
- Livestock Watering
- Sand and Gravel Operations

Imported water was also estimated and counted as a gain for the Pilchuck baseflow. In the Pilchuck natural conditions model, the baseflow was increased by the net consumptive water use (consumptive water use estimate – imported water estimate), over existing conditions baseflow.

In summary, the total baseflow loss was estimated at **12.4** cubic feet/second (cfs) on average for the dry season (May through September) and **14.5** cfs during the critical month of August.

General Assumptions

An important assumption for this analysis was that all water use directly impacted the Pilchuck or one of its tributaries (the ratio of water use to Pilchuck flow loss was 1:1). A review of well logs and surficial hydrogeology of the Pilchuck watershed found that the majority of wells down in the river valley are set at fairly shallow depths that are likely directly hydraulically connected to the river.

Upland wells are set at deeper depths, but generally align in elevation with the same aquifer layer that intersects the adjacent or slightly downstream river valley. The timing and location of impacts is unknown, but is assumed to occur within the subbasin of origin during the same month the water was withdrawn.

These simplified assumptions are considered conservative, in that they result in larger estimates of baseflow loss than what would be obtained if not all consumptive water use resulted in Pilchuck flow loss or if the baseflow impacts of summer irrigation use were delayed by more than a month due to time of travel.

The location of baseflow impacts is divided into 8 subbasins for this analysis (Figure H-1). Baseflow impacts within the Little Pilchuck and Dubuque subbasins are implemented at the mouths of these tributaries in the water quality model. Impacts within the remaining 6 subbasins are dispersed equally throughout the model segments that overlap each corresponding subbasin.

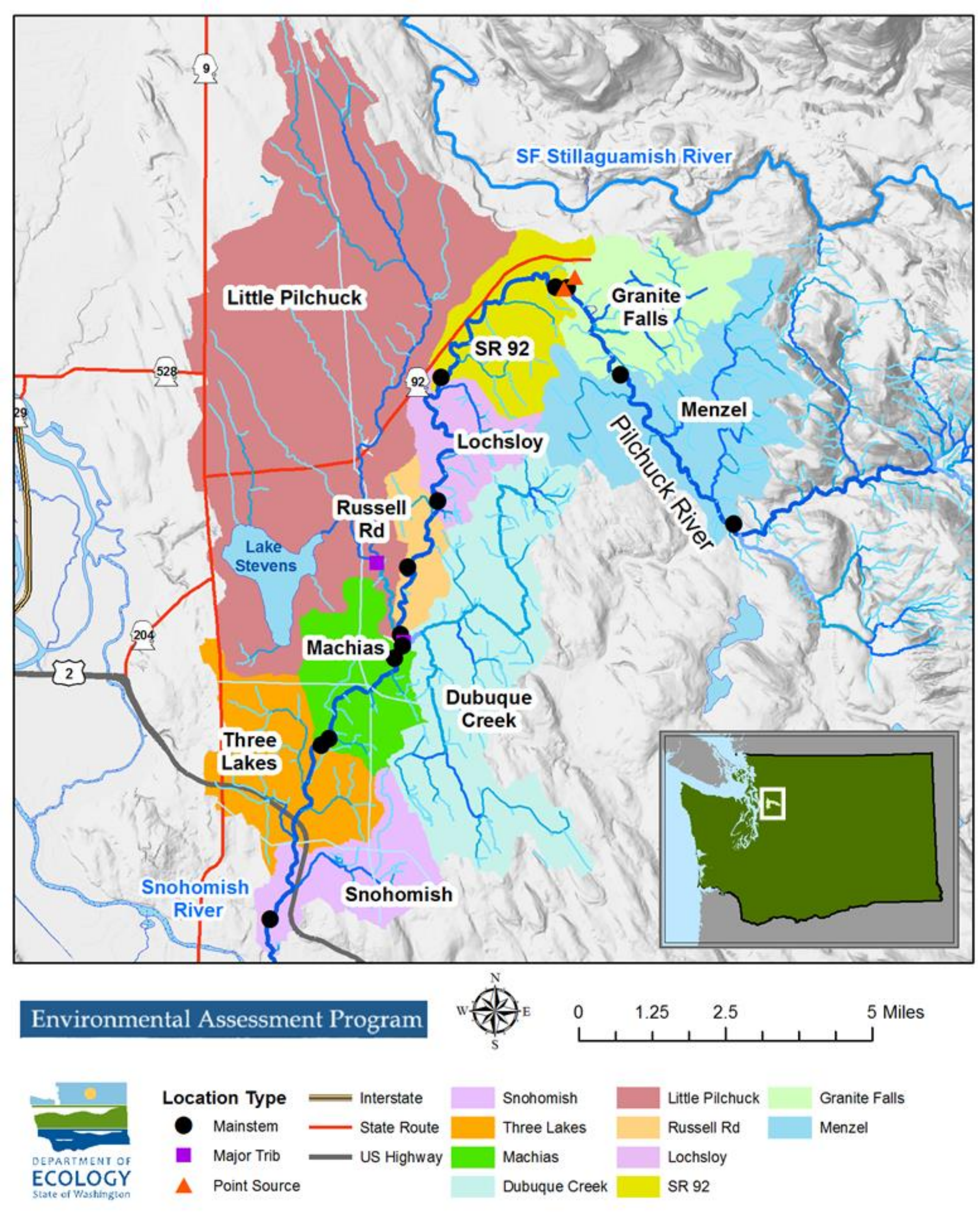

Figure H-1. Map of Pilchuck River TMDL subbasins used for water use analysis.

Several other factors that could result in additional baseflow loss were not included in this analysis, including loss of recharge from impervious surface areas, loss of wetlands, and using groundwater to create or supplement man-made ponds for fish propagation, wildlife use, or aesthetic value.

Baseflow loss due to impervious surfaces can be significant. The Pilchuck watershed is fairly rural in nature, with an average total impervious area (TIA) of 7% and subbasins with as low as 2% TIA; however, the more developed subbasins have TIA of up to 13%. An analysis of effective impervious area (EIA), or the area of impervious that is connected hydrologically to the stream network, was not performed as part of this study; however based on a 39% ratio of EIA:TIA from other studies, the EIA in the Pilchuck subbasins would range from less than 1 to ~5%.

Based on these relatively low impervious area numbers, it is not anticipated that baseflow loss due to impervious surface would be large. The lack of impervious baseflow loss in the estimate is balanced, to some degree, by the multiple conservative assumptions used throughout the analysis.

Self-Supplied vs Imported Water Use

A balance of total water users was created for each subbasin using GIS and water resources databases including active wells, Snohomish County PUD water meters, group A and B water systems, and city water service coverage (add references to Ecology and DOH databases as well as personal communication with PUD).

The methodology used involved the following:

$$Residual = Total\ Water\ Using\ Parcels - Active\ Wells - PUD\ water\ meters - Group\ A\ users - Group\ B\ users$$

$$Self\ supplied\ water\ users = Active\ Wells + Group\ A\ \&\ B\ users\ (wells\ only) + \left(\frac{Residual}{2}\right)$$

$$Imported\ water\ users = Snohomish\ PUD\ \#1\ meters + Group\ A\ \&\ B\ users\ (nonwells\ only) + Parcels\ within\ city\ of\ Snohomish\ or\ Granite\ Falls + \left(\frac{Residual}{2}\right)$$

Agricultural Irrigation

Estimates of irrigation water use for the Pilchuck River watershed were completed in accordance with state and agency guidance on agricultural water use. The following method was used to estimate the amount of irrigation water use in the watershed:

1. **Calculated an updated Crop Irrigation Requirement (CIR) based on recent meteorological data**.
    a. Compiled and averaged monthly total rain and monthly cumulative evapotranspiration (ET) data from 2008-2017 for Snohomish, WA. Obtained data from AgWeatherNet (WSU, 2018) monitoring program (Table H-1).
    b. Estimated the average monthly effective rain based on total rain and effective to total ratios for Monroe, WA from the WA irrigation guide (USDA-NRCS, 1997) estimates in Appendix A and B.
    c. Estimated the CIR by subtracting the effective rain from the evapotranspiration totals.
    d. A CIR of **14.67** inches of water was estimated.

e. For comparison, Table H-1 also includes estimates of CIR from the WA irrigation guide (USDA-NRCS, 1997) developed in 1985 (Appendix A) and 1992 (Appendix B).

2. **Calculated Total Irrigation Requirement (TIR) and consumptive use (CU) in inches of water**
   a. Used updated CIR divided by an assumed irrigation efficiency of 0.75 to obtain TIR.
   b. Used the TIR and a CU coefficient of 0.85 to calculate the CU in inches per month.
   c. The coefficient of 0.85 is based on an irrigation efficiency of 0.75 combined with an "evaporation" loss of 0.1 (see irrigation assumptions for detail).
   d. TIR and CU were estimated at **19.56** and **16.63** inches of water, respectively (Table H-4)

3. **Estimated the acreage of irrigated pasture/turf land for each subbasin in the Pilchuck TMDL study area.**
   a. Used the National Land Cover Dataset (NLCD) for 2011 to calculate acreage.
   b. A total of **2,881** acres of "Pasture/Hay" cover type was estimated for the study area.

4. **Calculated the CU in acre-feet per year and cfs based on the irrigated acreage and CIR**
   a. The CU was estimated at **3,705** acre-feet for the entire irrigation season and an average of **13.2** cubic feet per second (cfs), with a peak of **20.2** cfs in July (Table H-4).

Table H-1. Average monthly total and effective rain, ratio, and crop irrigation requirement for pasture/turf for Monroe area from Appendix A of the Washington irrigation guide (developed in 1985).

Parameter	May	June	July	Aug	Sept	Total
Total Rain (in)	2.82	2.46	1.28	2.00	2.83	11.39
Effective Rain (in)	1.99	1.85	0.96	1.43	1.88	8.11
Rain ratio	0.71	0.75	0.75	0.72	0.66	0.71
Crop Irrigation Requirement	0.57	2.67	4.46	2.86	1.13	**11.69**

Table H-2. Average monthly total and effective rain, ratio, consumptive use, and crop irrigation requirement pasture/turf for Monroe area from Appendix B of the Washington irrigation guide (developed in 1992).

Parameter	May	June	July	Aug	Sept	Total
Total Rain (in)	2.93	2.4	1.38	1.78	2.92	11.41
Effective Rain (in)	2.05	1.8	1.03	1.28	1.93	8.09
Rain ratio	0.70	0.75	0.75	0.72	0.66	0.71
Consumptive Use	3.94	4.54	5.39	4.31	3.00	21.18
Crop Irrigation Requirement	1.89	2.74	4.36	3.04	1.07	**13.10**

Table H-3. Average monthly total and effective rain, evapotranspiration, and crop irrigation requirement pasture/turf for Snohomish, WA for the period of 2008-2017.

Parameter	May	June	July	Aug	Sept	Total
Total Rain (in)	2.02	1.5	0.56	1.02	2.12	7.22
Estimated Effective Rain (in)*	1.42	1.13	0.42	0.73	1.40	5.10
Estimated Evapotranspiration (ET)**	3.82	4.29	4.91	4.13	2.63	19.77
Estimated Crop Irrigation Requirement ***	2.40	3.16	4.49	3.40	1.22	**14.67**

*Total rain multiplied by average rain ratio from 1985 and 1992.
**Average monthly cumulative Evapotranspiration (ET) from AgWeatherNet for 2008-17.
***Estimated ET minus the 2008-17 effective precipitation estimate.

Table H-4. Monthly estimates of irrigation requirements and consumptive water use for the Pilchuck River watershed.

Month	Pasture/ Turf Acreage	Crop Irrigation Requirement (in)	Total irrigation Requirement (in)	Consumptive Use (in)	Consumptive Use (acre ft)	Average Consumptive Use (cfs)
May	2881.2	2.40	3.20	2.72	606	10.8
June	2881.2	3.16	4.21	3.58	798	14.2
July	2881.2	4.49	5.99	5.09	1,134	20.2
Aug	2881.2	3.40	4.53	3.85	859	15.3
Sept	2881.2	1.22	1.63	1.38	308	5.5
May - Sept	2881.2	**14.67**	**19.56**	**16.63**	**3,705**	13.2

Additional Assumptions Used to Develop Irrigation Estimates

- An irrigation efficiency of 0.75 was selected based on the median of methods in Ecology Water Resources Guidance 1210 (Ecology, 2005), excluding micro-irrigation which is unlikely to be used for pasture irrigation.
- “Evaporation” loss refers to the total applied water that is consumed while transporting the water to the root zone. This includes several different mechanisms of consumptive loss including spray evaporative loss, canopy loss, and wind drift. An evaporative loss coefficient of 0.1 was selected based on the median of methods in Ecology Water Resources Guidance 1210 (Ecology, 2005), excluding micro-irrigation.
- The NLCD land cover type of “Grassland” was assumed to be completely unirrigated. It is likely that some portion of this land cover is under irrigation; however it is also likely that some portion of the NLCD “Pasture/Hay” cover type, which was assumed to be irrigated, is actually unirrigated. Although it is uncertain to what extent, it was assumed that these two factors cancel each other out.

The NLCD cover type of “Cultivated” was lumped in with “Pasture/Hay” and assumed to have the same irrigation requirements. While some cultivated crops have a smaller irrigation requirement, this was treated as a conservative assumption. There were only 70.1 acres of “Cultivated” cover type in the study area, which represents just 2.4% of the total irrigated acreage.

Domestic Outdoor Water Use

For domestic outdoor water, the following method was used to develop estimates of total and consumptive water use:

1. **Residential Irrigated Lawn Size-** The Lochsloy subbasin (Figure H-1) was selected as a test basin to investigate residential irrigation practices in the watershed.
    a. Aerial photography from July 2013 and residential tax parcel layer were used to digitize lawn areas that appeared to be irrigated for all residences in the subbasin.
    b. This process found that 113 out of 470 parcels (24%) appeared to have fully irrigated lawns. Of the 113 irrigated residences the average irrigated lawn size was **0.34** acres (average lot size was 2.17 acres).
    c. For the remaining subbasins were assumed to have the same lawn size and percent of homes with irrigated lawns. The combination of 0.34 acres and 24% of residences irrigated equates to an average irrigated lawn size of **0.08** acres per household. This is somewhat lower than the **0.13** acres used in the Draft Big Lake Mitigation Plan (Ecology, 2018).
2. **Irrigation requirement-** The recent (2008-2017 analysis) water duty number of **14.67** inches of Crop Irrigation Requirement (CIR) was used (see agricultural irrigation section).
3. **Annual consumptive use per household-** This process resulted in an estimated outdoor consumptive use of **0.11** acre-feet/year per household, which is lower than the Draft Big Lake Mitigation Plan outdoor consumptive use estimate of **0.136** acre-feet/year per household.
4. **Self-supplied consumptive households-** The estimated number of self-supplied households, at total of **3,328** for the study area, was multiplied by the per-household consumptive use to estimate the total consumptive use for the watershed and each individual subbasin.
5. **Monthly outdoor domestic use-** The AFY estimate was distributed over the 5 month irrigation season, based on the monthly CIR needs from the agricultural irrigation analysis.

Some slightly green lawns were not counted as irrigated even though they may have been partially irrigated; however relatively few of the lawns counted as irrigated were dark green enough to be using the full CIR of 14+ inches. It was assumed this generally had a canceling effect.

Table H-5 contains the outdoor consumptive use results, with an irrigation season average of 1.21 cfs.

Table H-5. Estimates of monthly domestic outdoor consumptive water use in cubic feet per second for the Pilchuck Watershed.

Subbasin	May	June	July	Aug	Sept	Irrigation Season Average
Menzel	0.06	0.09	0.12	0.09	0.03	0.08
Granite Falls	0.07	0.09	0.13	0.10	0.04	0.08
Lochsloy	0.03	0.04	0.05	0.04	0.01	0.03
Machias	0.09	0.12	0.16	0.12	0.05	0.11
Little Pilchuck	0.55	0.75	1.03	0.78	0.29	0.68
Dubuque	0.15	0.20	0.27	0.21	0.08	0.18
Three Lakes	0.01	0.02	0.02	0.02	0.01	0.01
Snohomish	0.03	0.04	0.05	0.04	0.01	0.03
Totals	0.98	1.33	1.84	1.39	0.52	1.21

Domestic Indoor Water Use

For domestic indoor water use, the following method was used to develop estimates of total and consumptive water use:

1. **Annual consumptive use per household**- Assumptions from a domestic water use study in Skagit County (Golder Associates, 2013; Golder Associates, 2014) were used, based on metering of 18 self-supplied, exempt domestic wells. The estimate is **0.015** acre-feet/year of consumptive use per household.
2. **Self-supplied consumptive households-** The estimated number of self-supplied households, at total of **3,328** for the study area, was multiplied by the per-household consumptive use to estimate the total consumptive use for the watershed and each individual subbasin.

Table H-6 contains the indoor consumptive use estimates, with an annual average of 0.07 cfs.

Table H-6. Estimates of monthly domestic indoor consumptive water use for the Pilchuck Watershed.

Subbasin	Self-Supplied Households	Indoor Consumptive Use (cfs)
Menzel	219	0.0044
Granite Falls	231	0.0047
Lochsloy	95	0.0019
Machias	293	0.0059
Little Pilchuck	1,861	0.0377
Dubuque	497	0.0101
Three Lakes	41	0.0008
Snohomish	91.00	0.0018
Totals	3,328	**0.07**

Livestock Watering

Determined estimates of livestock water use for the Pilchuck River rural watershed (outside of the cities of Snohomish, Lake Stevens, and Granite Falls) using the following method:

1. Determined the size of the Pilchuck River rural watershed (74.8 square miles).
2. Estimated the size of the “livestock friendly” area of Snohomish County (1,007 square miles).
3. Calculated the percent of Snohomish “livestock friendly” area in the Pilchuck rural watershed (7.4%).
4. Obtained the 2012 USDA NASS livestock census data for Snohomish County.
5. Multiplied the Snohomish County livestock census data by 7.4% to obtain estimate of rural Pilchuck livestock numbers (Table H-7).
6. Used USGS water-use coefficients (in gals/day) multiplied by Pilchuck livestock estimates to obtain the estimated livestock water use for the TMDL study area.

The total livestock water use for the Pilchuck rural watershed was estimated as 48,245 gallons/day, or **0.07** cubic feet/second.

The “livestock friendly” area of Snohomish County was determined by removing waterbodies, major public lands, and urban cities (e.g., Everett, Lynnwood) from the total Snohomish County area.

The 2012 USDA National Agricultural Statistics Service (NASS) livestock census data was obtained from https://quickstats.nass.usda.gov/ on April 6, 2018.

USGS water-use coefficients were obtained from USGS Scientific Investigations Report 2009-5041 *Methods for Estimating Water Withdrawals for Livestock in the United States, 2005*.

The one exception was for rabbits which was obtained from: http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#8.

Estimates were not available for some of the minor animal categories, in each case the water use from a similar animal was applied (for example goat/sheep water use was applied to alpacas/llamas).

Table H-7. Snohomish County livestock census data and estimates of Pilchuck livestock and water use.

Data Item	Snohomish County Census	CV (%)	Estimated Rural Pilchuck Population	Water Use Coefficient Median (gals/ head/ day)	Estimated Water Use (gals/day)
Alpacas	849	20.9	63	2*	126
Bison	51	70.8	4	12*	45
Cattle (excl. Cows)	9,350	12	695	12	8334
Cattle, Cows, Beef	3,357	5.4	249	12	2992
Cattle, Cows, Milk	11,181	3.5	831	35	29068
Chickens, Broilers	916	36.7	68	0.06	4
Chickens, Layers	759,220	15	56395	0.06	3384
Chickens, Roosters	86	52.1	6	0.06	0
Ducks	464	43.7	34	0.1*	3
Equine, Horses & Ponies	3,826	12.2	284	12	3410
Equine, Mules & Burros & Donkeys	196	31.2	15	12	175
Geese	54	48.4	4	0.1*	0
Goats, Angora	153	70.4	11	2	23
Goats, Meat & Other	530	29.8	39	2	79
Goats, Milk	755	45.9	56	2	112
Guineas	12	67.1	1	0.06*	0
Hogs, Breeding	104	12.6	8	3.5	27
Hogs, Market	359	4.8	27	3.5	93
Llamas	124	39.3	9	2*	18
Peafowl, Hens & Cocks	92	46	7	0.06*	0
Pigeons & Squab	210	69.8	16	0.06*	1
Poultry, Other	73	73.8	5	0.06*	0
Rabbits, Live	1,650	24.1	123	0.16	19
Sheep, Ewes, Breeding, Ge 1 Year	770	19.7	57	2	114
Sheep (incl. Lambs)	1,431	20.2	106	2	213
Turkeys	188	28.8	14	0.1	1

*Estimated from a similar animal.

Sand and Gravel Mining Water Use

Estimates of sand and gravel operational water use were determined for the Pilchuck River watershed using the following method:

1. Assume that consumptive water use only occurs at sand and gravel operations that either:
    a. Discharge process water based on their permit application.
    b. Produce ready-mix concrete.
2. Identified the one facility in the Pilchuck watershed that met one of these criteria, Concrete Northwest- Getchell Pit (Permit# WAG503166).
3. Assumed that consumptive use for this facility was equal to the amount in its water right certificate.

The total sand and gravel operational water use for the Pilchuck watershed was estimated as **0.056** cubic feet/second.

Return Flow from Imported Water

Return flow from use of imported water was counted as a net gain to Pilchuck River baseflow (Table H--H-8). The following method was used to develop estimates of total and consumptive water use:

1. **Domestic indoor return flow**
    a. The estimate of **0.015** acre-feet/year of consumptive use per household (Golder Associates, 2013; Golder Associates, 2014) was multiplied by a return flow coefficient of 0.90 for a return flow of **0.0135** per household.
    b. Estimated the number of total households with on-site septic systems using imported water at total of **6,767** for the study area. This was multiplied by the outdoor per-household return flow of **0.0135** per household for a total of **91.4** acre-ft per year of return flow.
2. **Domestic outdoor return flow**
    a. The estimated outdoor consumptive use of **0.11** acre-feet/year per household (see domestic outdoor use section) was multiplied by a return flow coefficient of 0.25 for a return flow of **0.0275** per household.
    b. Estimated the number of total households using imported water at total of **15,518** for the study area. This was multiplied by the outdoor per-household return flow of **0.0275** per household for a total of **427** acre-ft per year of return flow.
    c. The AFY estimate was distributed over the 5 month irrigation season, based on the monthly CIR needs from the agricultural irrigation analysis.

Table H-8. Estimates of imported return flow to the Pilchuck River by subbasin.

Subbasin	"Imported" households	Aug "Imported" return flow (cfs)	Imported households on septic	Indoor "imported" flow per month (cfs)
Menzel	470	0.03	470	0.08
Granite Falls	1,532	0.11	758	0.14
Lochsloy	176	0.01	176	0.03
Machias	1,173	0.09	1,173	0.21
Little Pilchuck	7,400	0.55	1,400	0.25
Dubuque	940	0.07	940	0.17
Three Lakes	2,572	0.19	1,501	0.27
Snohomish	1,257	0.09	351	0.06
Totals	15,518	1.14	6,767	1.21

Total Estimated Baseflow Loss

Table H- H-9 contains monthly (May to Sept) estimates of water use/baseflow loss for each of the Pilchuck River subbasins. Table H--H-10 contains monthly (May to Sept) estimates of water use/baseflow loss for each estimated use category.

Table H-9. Monthly estimates of water use/baseflow loss for each of the Pilchuck River subbasins

Subbasin	May	June	July	Aug	Sept	Average
Menzel	-1.20	-1.61	-2.32	-1.74	-0.58	-1.49
Granite Falls	-1.96	-2.62	-3.77	-2.83	-0.93	-2.42
Lochsloy	-0.75	-1.00	-1.42	-1.07	-0.37	-0.92
Machias	-0.62	-0.87	-1.31	-0.95	-0.22	-0.80
Little Pilchuck	-4.22	-5.62	-8.01	-6.03	-2.09	-5.19
Dubuque	-0.01	-0.06	-0.14	-0.07	0.07	-0.04
Three Lakes	-0.49	-0.73	-1.14	-0.80	-0.12	-0.66
Snohomish	-0.72	-0.97	-1.40	-1.04	-0.34	-0.89
Totals	-10.0	-13.5	-19.5	-14.5	-4.6	-12.4

Table H-10. Monthly (May to Sept) estimates of water use/baseflow loss for each estimated use category.

Water Use	May	June	July	August	Sept
Sand and Gravel	-0.06	-0.06	-0.06	-0.06	-0.06
Stock Watering	-0.07	-0.07	-0.07	-0.07	-0.07
Indoor Domestic Use	1.14	1.14	1.14	1.14	1.14
Outdoor Domestic Use	-0.17	-0.27	-0.33	-0.25	-0.11
Pasture/Turf Irrigation	-10.80	-14.22	-20.20	-15.30	-5.49
Totals	-10.0	-13.5	-19.5	-14.5	-4.6

References

Ecology, 2005. Determining Irrigation Efficiency and Consumptive Use. Water Resources Program Guidance: GUID-1210. Washington State Department of Ecology. Effective Date: 10/11/2005.

Ecology, 2018. Big Lake Mitigation Plan (Draft). Washington State Department of Ecology. https://ecology.wa.gov/Water-Shorelines/Water-supply/Protecting-stream-flows/Instream-flow-implementation/Skagit-River-basin-projects/Developing-solutions.

Golder Associates, 2013. Skagit County Exempt Well Metering Program: Technical Memorandum, October 10, 2013.

Golder Associates, 2014. Skagit County Exempt Well Metering Program – 2012-2013, March 27, 2014.

USDA National Resource Conservation Service (NRCS), 1997. Washington Irrigation Guide. Last accessed 5/10/2018.

Washington State University (WSU), 2018. AgWeatherNet meteorological and evapotranspiration data for the Snohomish station. https://weather.wsu.edu/. Last accessed 5/10/2018.

Appendix I. NPDES Facility Analysis

During the study period for this TMDL, Ecology used the Facility Interaction layer in ArcView GIS to identify permitted facilities in the Pilchuck River watershed. Each category of permitted discharger is discussed below. For general permits, Ecology's Northwest Regional Office (NWRO) staff contacted the Compliance Technical Assistance Unit Supervisor and/or the appropriate NWRO inspector. We contacted the appropriate Ecology Headquarters (HQ) permit manager of wasteload allocation (WLA) decisions and/or approaches for addressing that category of dischargers. Jeff Killelea was the industrial stormwater permit manager when this analysis was done. Cynthia Walker was the NWRO sand & gravel permit manager. Dairies are also discussed briefly below as well since that information showed up in the Facility Interaction layer. The Granite Falls wastewater treatment plant (WWTP) is discussed thoroughly as part of our field work and modeling and is not discussed in Appendix I.

Dairies

GIS analysis did not reveal any permitted dairies in the Pilchuck Study Area and none have been observed in our field work.

Industrial Individual Permit

No permitted industrial individual facilities were identified in the Pilchuck Study Area.

Construction Stormwater General Permit

As of June 2020, 62 Construction Stormwater General Permits were identified in the Pilchuck Study area.

Industrial Stormwater General Permit

NWRO stormwater inspectors were consulted during the period 2009-17 for specific questions about the discharge characteristics of facilities covered by the Industrial Stormwater General Permit in the Pilchuck Study area. Industrial stormwater permittees must meet standards at all discharge points off-site (e.g. end of pipe, sheet flow discharge, etc.). The need for industrial permittees to measure temperature has gone to the PCHB as part of a previous appeal of the permit and they ruled that temperature monitoring was not needed as part of the permit (PCHB ruling is in the TMDL administrative record). The analysis below is designed to confirm that no special circumstances exist at the facilities currently located in the Pilchuck River watershed.

Table I-1 provides a summary of the industrial facilities in the Pilchuck watershed. In the WLA column below, "Future" was used for facilities with certificates of conditional non-exposure, or are currently not permitted; these properties have an increased likelihood of needing a permit in the future due to their current zoning. "Yes" indicates that some type of WLA, aggregated or otherwise, is needed for the current discharge. "No" indicates very little or no possibility for stormwater discharges to cause or contribute to temperature or dissolved oxygen (DO) violations.

Jeff Killelea requested in a voicemail that industrial facilities with the potential to cause temperature violations (need a WLA) and which discharge into a municipal MS4 have a WLA assigned to them and not be rolled into a municipal stormwater WLA.

Table I-118. General industrial stormwater facilities as identified in the Facility Interaction GIS layer.

Facility name	Permit number	Contact/comment	WLA?
UPF Washington LLC	WAR000752	Greg Stegman/request inspection or input	Yes
Central Steel	WAR012091	Tracy Walters/request inspection or input	Yes
Snohomish Valley Roofing	WAR308103	No Ecology contact in PARIS	Future
Barmon Door & Plywood Inc*	CNE126488	Ken Waldo	Future
Northwest Auto Recyclers	WAR303981	Evan Dobrowski	Yes
4 Facilities			

*Included in analysis although June 2020 GIS analysis does not show an active permit.

UPF Washington LLC, formerly NEPA Pallet & Container Co Inc, WAR000752

PARIS indicates that it discharges to land several parcels to the south, which may be incorrect; this might need to be fixed in PARIS (see outfall location at green dot in Figure I-1). The facility is located in the lower portion of the Pilchuck watershed. It has about 10 acres of roof, open air storage, parking, and roadway area. All of the parking and storage area appears to be paved. Considerable amounts of pallets are stacked onsite and exposed to weather. The facility is ACTIVE and permitted.

Figure I-1. UFP Washington LLC.

Central Steel, WAR012091

PARIS indicates an outfall about 2,000’ northwest of the facility; however, it seems more likely that the facility discharges to the local MS4. A review of 2011 orthophotography shows a building on site but 2012 Bing imagery does not show the building present (Figure I-2). The SW corner of the lot appeared to have a water treatment facility of some type covering 0.1 acres. ArcMap analysis shows there are 2 acres of imperious surface due to roof, roadway, and parking lot areas. Analysis in GIS in June 2020 showed the facility to be active.

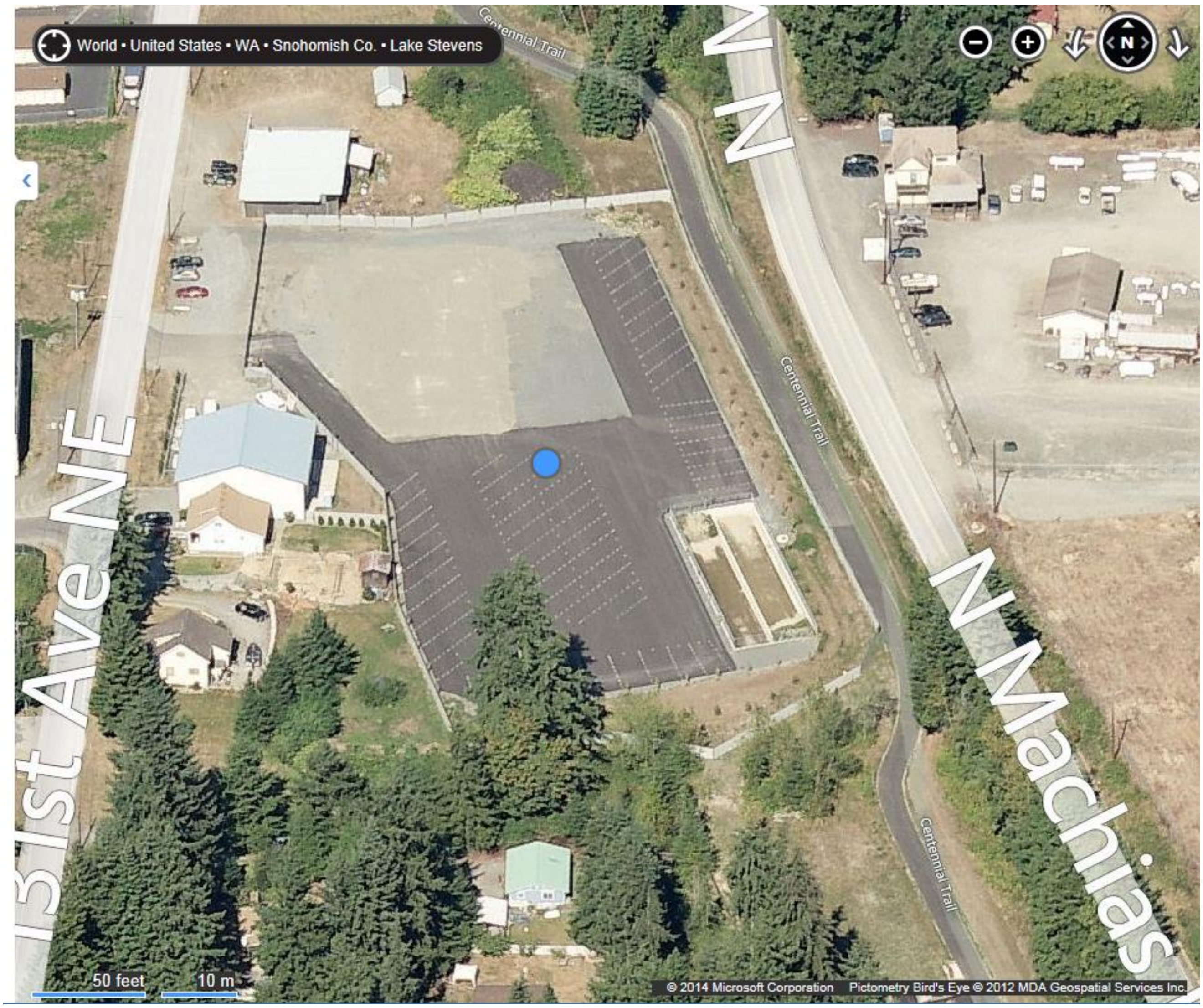

Figure I-2. Central Steel. Orthophotography of the facility from 2012.

Snohomish Valley Roofing, WAR308103.

PARIS confirmed that there is a company by this name and says it is located at 2705 Old Waterford Rd in Lake Stevens. However, that address was not found using Google or Bing Maps. PARIS' latitude/longitude coordinates show it to be located at the corner of 28th and Hartford in Lake Stevens (Figure I-3). June 2020 analysis in PARIS showed the facility to be active. The total roof, parking lot, and outside uncovered storage area is approximately 1.3 acres. The facility is located within the city of Lake Stevens UGA. Given the distance from the nearest waterbodies it is anticipated that this facility discharges either to ground or to the city of Lake Stevens MS4.

Figure I-3. Snohomish Valley Roofing.

Barmon Door & Plywood Inc. CNE126488

In our initial analysis, PARIS indicates that this facility is located at 21508 Hartford Drive in Lake Stevens. The GIS location in PARIS was incorrect according to Bing Maps, which shows it at the NW corner of the intersection of Hartford Drive and 131st Ave NE. Our early analysis showed that Ecology issued a certificate of Conditional No Exposure and it did not have an active industrial stormwater permit. The facility and its parking lot cover approximately 0.9 acres. The facility and its parking area can be seen in Figure I-4. Because this facility is in an industrial area, it seems likely that a different industry may occupy this site in the future. This facility is included in this analysis, although June 2020 GIS analysis does not show an active permit. Therefore, this land area will likely be included in the future aggregated WLA.

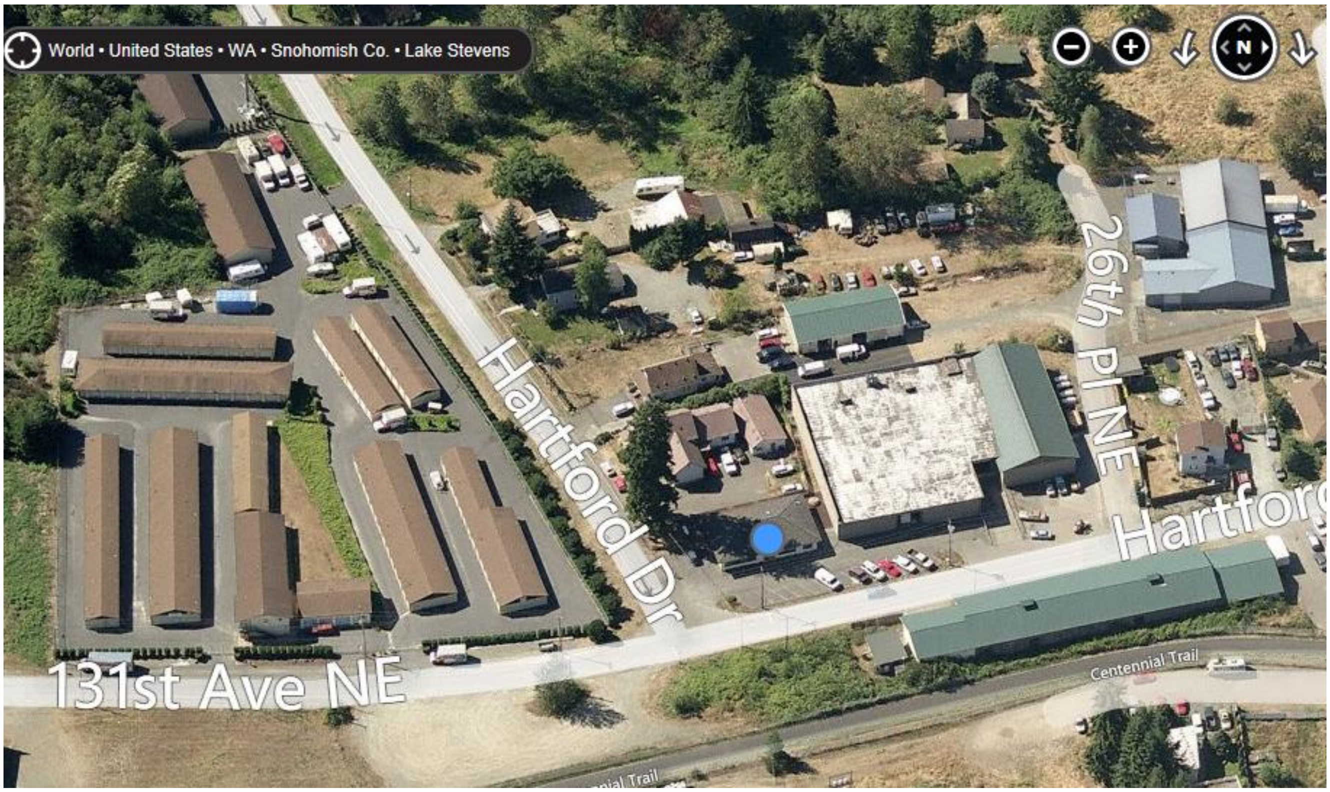

Figure I-4. Barmon Door and Plywood.

Municipal Stormwater General Permit

TMDL staff worked with several NWRO Municipal Separate Storm Sewer System (MS4) General Permit Planners over the course of the study. Foroozan Labib is the general permit writer and our contact for WSDOT MS4 permit issues.

Table I-2. Municipal stormwater permittees.

<table>
<tr><th>Facility name</th><th>Permit number</th><th>Comment</th></tr>
<tr><td>LAKE STEVENS</td><td>WAR0021130</td><td rowspan="5">*Marysville’s stormwater currently drains away from Pilchuck River watershed.</td></tr>
<tr><td>GRANITE FALLS</td><td>WAR045517</td></tr>
<tr><td>SNOHOMISH</td><td>WAR045543</td></tr>
<tr><td>MARYSVILLE</td><td>See note*</td></tr>
<tr><td>SNOHOMISH COUNTY</td><td>WAR044502</td></tr>
<tr><td>WSDOT</td><td>WAR043000</td><td>Work with Foroozan Labib.</td></tr>
<tr><td>6 Facilities total</td><td></td><td></td></tr>
</table>

*Marysville as a very small part of its UGA in the Pilchuck River according to watershed boundaries and UGA boundaries in 2012 analysis.

Sand and Gravel General Permit

Regional TMDL staff worked with Sand and Gravel Permit Inspector Cynthia Walker to evaluate the potential for discharges of warm water during summer months early in the study phase of this TMDL. Regional staff continued to work with sand and gravel permit inspectors to evaluate new facilities in June 2020.

Table I-3. Sand and Gravel general permits identified by Facility Interaction layer.

Facility name	Permit number	Comment
PILCHUCK SAND & GRAVEL INC.	WAG503379	AGGREGATE WLA
RIVERSIDE SAND & GRAVEL	WAG 503086	AGGREGATE WLA
GRANITE FALLS QUARRY L MATHESON	WAG503085	Did not see any active quarrying.
LAKE INDUSTRIES MENZEL LAKE GRAVEL	WAG503312	AGGREGATE WLA
JAXICO REAL ESTATE INVESTMENT GROUP LLC	WAG994258 (was WAG503362)	AGGREGATE WLA
THOMCO AGGREGATE LLC	WAG503027	AGGREGATE WLA
PREMIER PACIFIC PROPERTIES, (PREVIOUSLY ISLAND CONSTRUCTION SITE & UTILITIES)	WAG503327	AGGREGATE WLA
CONCRETE NORWEST GETCHELL PIT	WAG503166	AGGREGATE WLA
GREAT WESTERN TRANSPORT, INC.	WAG503046	AGGREGATE WLA
GIRARD RESOURCES & RECYCLING	No Permit # in GIS	NO EXISTING FACILITY, NO WLA
GREEN DOT CONCRETE	WAG994446	AGGREGATE WLA
UNNAMED FACILITY IN GIS	WAG503092	NO FACILITY W/THIS PERMIT # FOUND IN PARIS
12 Facilities total		

Pilchuck Sand & Gravel, WAG503379.

Location of this facility in PARIS is incorrect. It is located just south of the UPC Pallet facility and is about 1,000' east of the Pilchuck River separated by Hwy 2. It appears to have an infiltration pond in the as shown in Figure I-5. The cover page for the general permit indicates no surface water discharge, which was corroborated by the NWRO sand and gravel (S&G) inspector.

Figure I-5. Pilchuck Sand & Gravel.

Large green dot shows location of facility as per PARIS. Actual location shown by red arrow. Facility is about 100' from Unnamed stream 0126 (Washington Stream Catalog, shown by blue line) and 1,000' from the Pilchuck River to the west.

Riverside Sand & Gravel, WAG503086.

Although compliance actions have been taken related to a surface water discharge, this facility infiltrates its stormwater under normal operations. Its permit coverage page indicates that there is a surface water discharge but that discharge is to the mined pit pond and not the Pilchuck River. The NWRO inspector notified the facility that is should use form 3c and report “no discharge” if the pit lake does not discharge to the Pilchuck River. There are no discharges to surface water although beneficial cool groundwater discharges may have been observed in this area.

Figure I-6. Riverside Sand & Gravel.

Riverside S&G is located just below the large pond in the bottom of the picture above.
Great Western Transport, Inc. is located just north and is discussed later in this summary of sand and gravel facilities.

Granite Falls Quarry L Matheson, WAG503362.

The 2010 application and current cover page for the general permit indicates no surface water discharges expected from this facility, which is inactive. Address provided did not allow viewing in Bing Maps. PARIS location shows a forested area. GIS analysis located a parcel owned by Louis Matheson just SW of the Menzel Lake Rd and Scotty Rd intersection (Figure I-7). This is just NW of the location shown in PARIS. Recent BING Map analysis shows no mining activity on this site.

Figure I-7. Parcel owned by a L. Matheson from 2013 Parcel layer.

Lake Industries Menzel Lake Gravel, WAG503312.

PARIS indicates that there is an active outfall #G002 that conveys stormwater/mine dewatering water and discharges it to ground. The location of the outfall in PARIS seems unlikely unless it is piped over local streams and pumped uphill. There is a large infiltration pond and any summer discharge would go to one of two locations.

One is a stream identified as perennial in the NHD Flowline data layer that travels about 1,400’ to Swartz Lake (NE of facility) where it flows about 2 miles through Millard Lake, various wetlands, forestry, and rural residential land uses to the mainstem Pilchuck. Another flow path would take water to a small stream that also travels a similar distance to the mainstem Pilchuck.

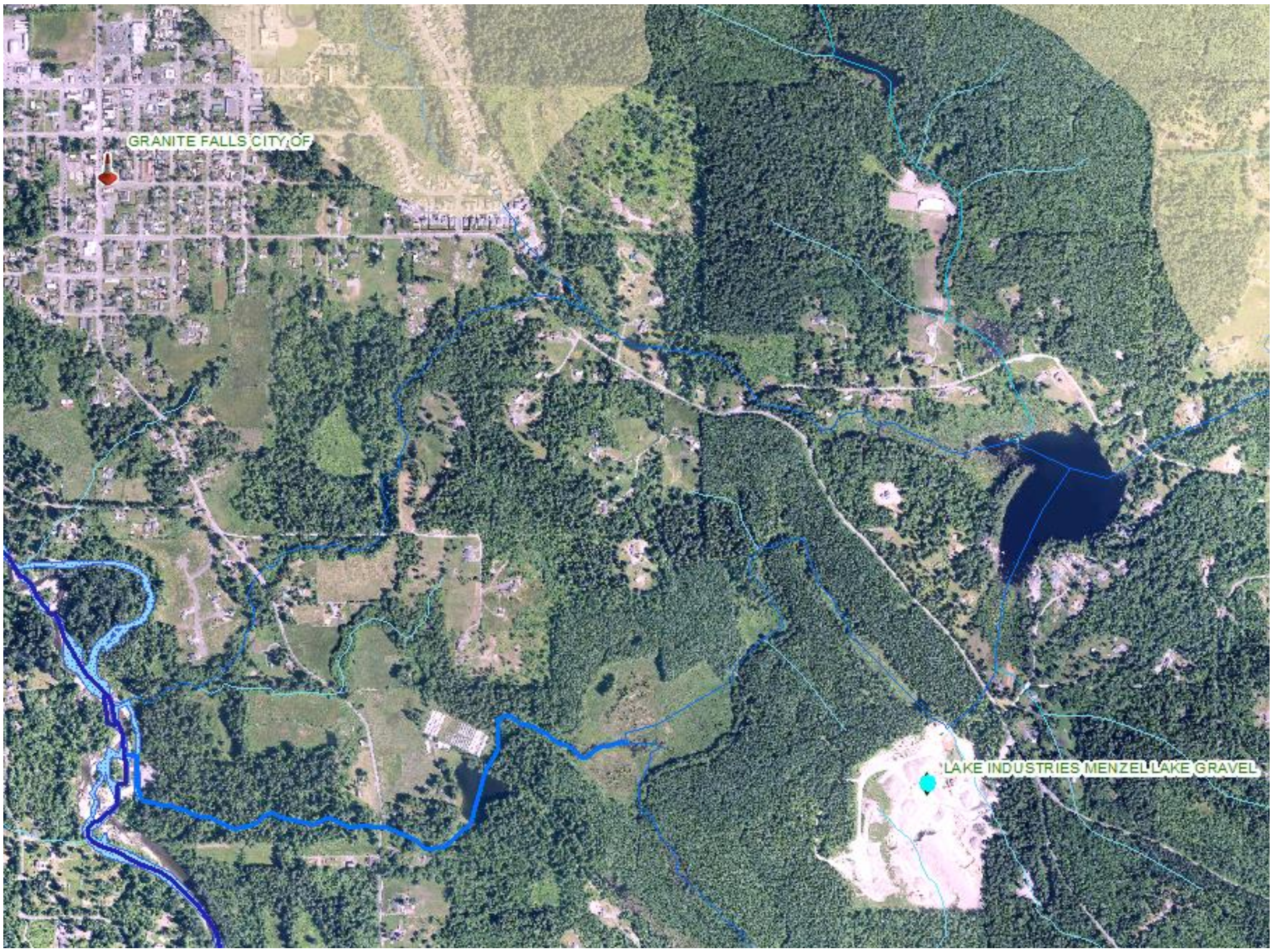

Figure I-8. Lake Industries Menzel Lake Gravel.

Jaxico Real Estate Investment Group LLC (formerly Obrien Sand & Gravel), WAG994258

The general permit cover page indicates that this facility does not discharge to surface water. There are intermittent streams surrounding the facility, which is located upslope of the streams. The NWRO inspector confirms that there is no surface water discharge.

Figure I-95. Jaxico Real Estate Investment Group LLC (formerly Obrien Sand & Gravel), WAG503362)

Thomco Aggregate LLC, WAG503027.

The current permit cover page indicates that Thomco does have a surface water discharge to an unnamed roadside ditch. Figure I-10 shows the facility, which is about 300' from Little Pilchuck Creek (upper green dot). Lower green dot shows the stormwater infiltration pond. NWRO inspector does not believe there is a possibility of a surface water discharge during summer months. Given the porous soils and the presence of a pond there does not appear to be a potential for discharges of stormwater during critical periods.

Figure I-10. Thomco Aggregate LLC, WAG503027

Premier Pacific Properties (also known as Island Construction Site & Utilities), WAG503327.

This facility is located about 160’ from Boyd Lake Creek, located SW of Granite Falls. The permit coverage page indicates that no stormwater is discharged to surface waters.

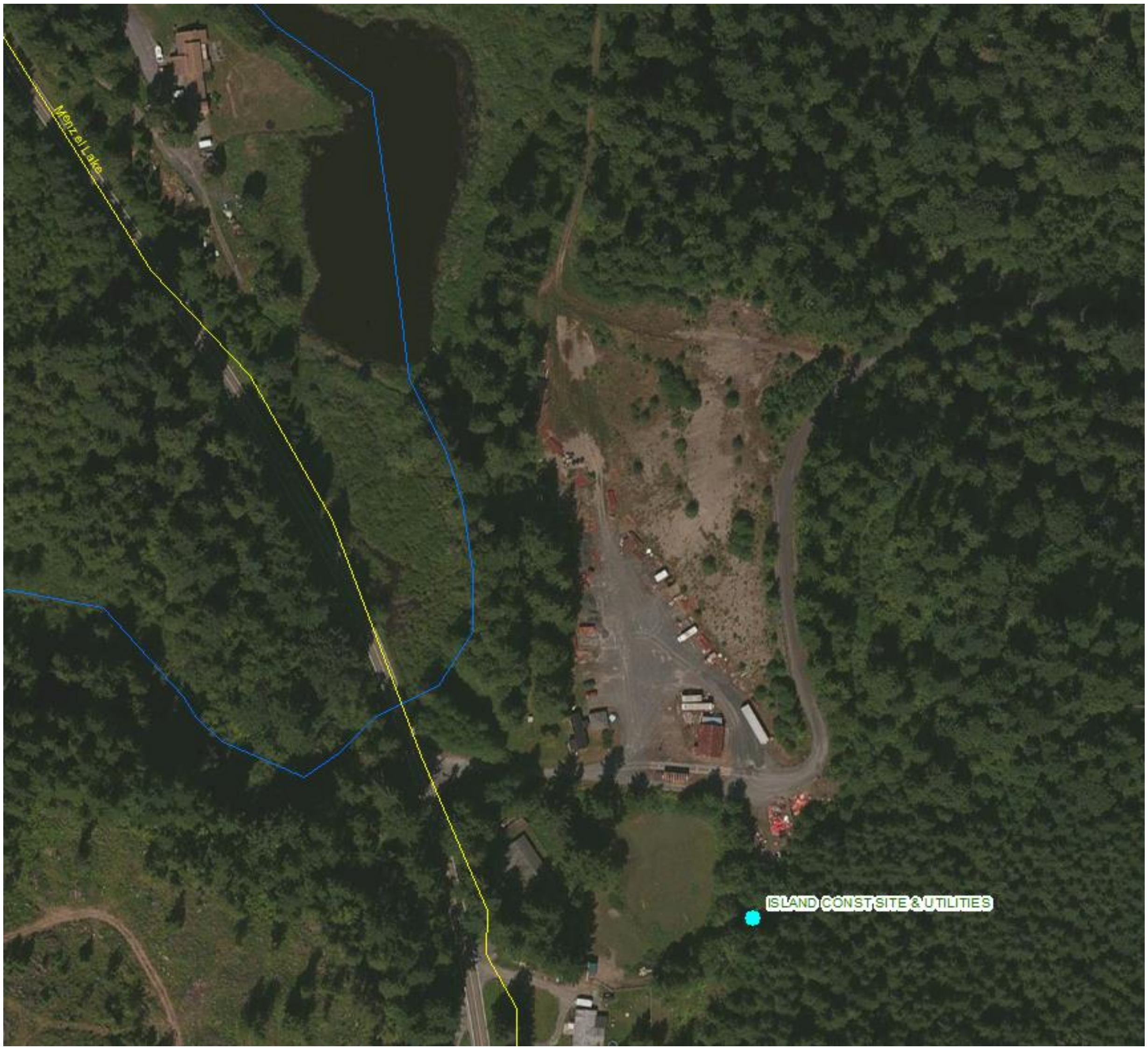

Figure I-11. Premier Pacific Properties (also known as Island Construction Site & Utilities).

Great Western Transport, Inc. (formerly Marysville Construction and Paving), WAG503046.

This facility applied for and received a permit modification removing the surface water discharge from their permit in 2013.

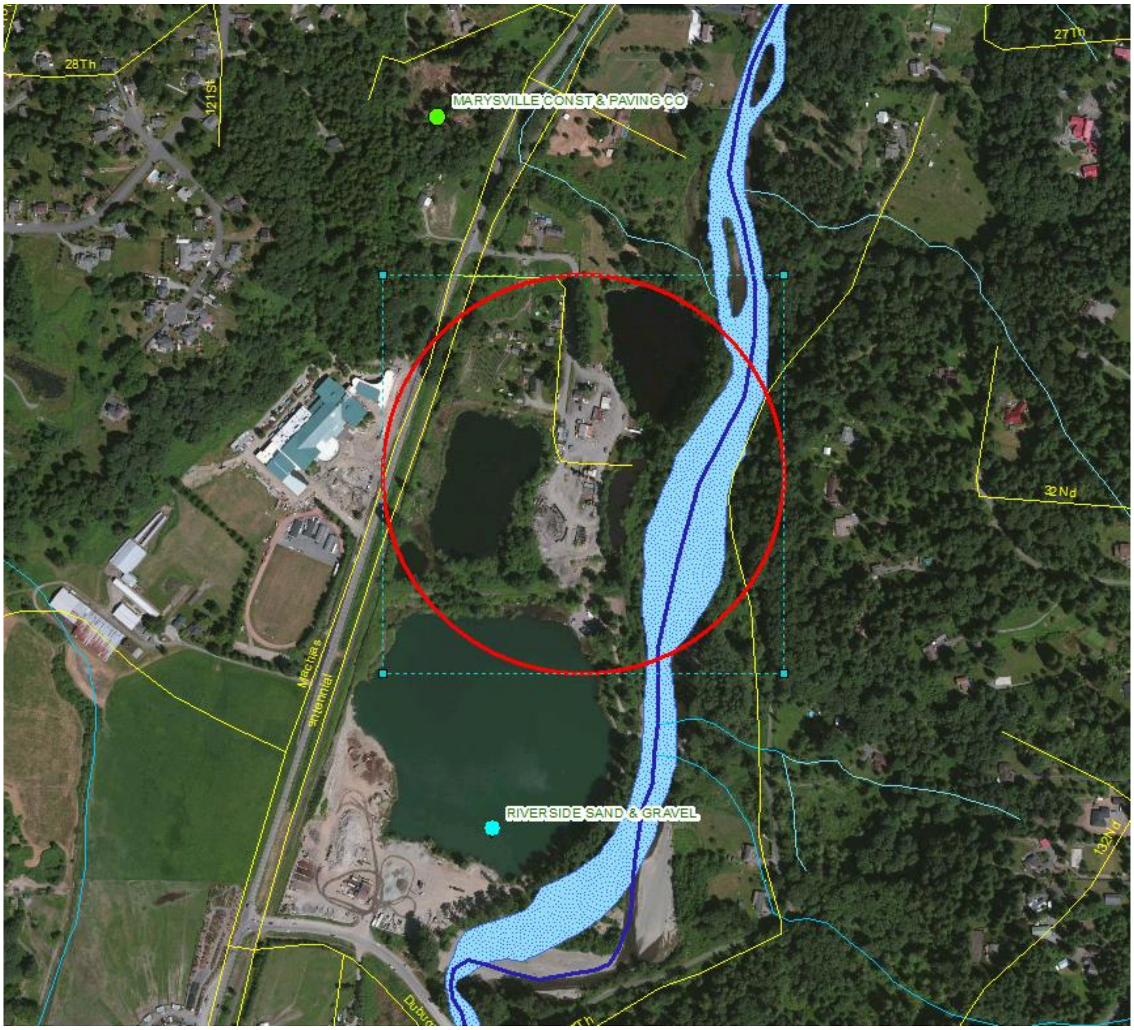

Figure I-12. Great Western Transport, Inc. (formerly Marysville Construction and Paving). Green dot shows GIS location of facility in PARIS. Actual location is within the red circle above.

Green Dot Concrete, WAG994446.

This facility is located about 800 feet east of the Pilchuck River off of 92^{nd} Street SE. PARIS indicates there are two outfalls: (1) open ditch at bridge/property line and (2) overflow point near fence and storage tanks. The facility was issued a warning letter on March 3, 2020 for failing to submit a discharge monitoring report for the last quarter of 2019. Information about summer discharge for this facility is currently unavailable. The inspector report indicates process wastewater is going to ground.

Figure I-13. Green Dot Concrete.

Green dot shows GIS location in PARIS**.**

Concrete Norwest Getchell Pit, WAG503166

The cover page for the Concrete Norwest Getchell Pit indicates that there is no discharge to surface water.

Figure I-14: Concrete Norwest, Getchell Pit. Yellow dot shows GIS location in PARIS.

Girard Resources & Recycling, unpermitted facility

PARIS indicates that there was a sand and gravel facility located outside of the city of Snohomish in the lower part of the Pilchuck watershed in 2010. It was operating without a permit and was issued a field ticket. The facility does not exist now and does not have a permit. It showed up in the Facility Interaction GIS layer because we did have some interaction with this site in the past.

Permit number WAG503092

Although this facility was identified in the Facility Interaction GIS layer, there is no record of this facility existing in PARIS.

Appendix J. Streamflow Augmentation Analysis

Summer temperatures in the mainstem of the Pilchuck River (MPR) and Little Pilchuck Creek (LPC) exceed the State of Washington Water Quality Standards. Practices that augment summer baseflows are needed to reduce summer temperatures and achieve TMDL targets. Table J-1 shows baseflow increases needed to achieve TMDL targets for both the MPR and LPC.

Table J-1. Baseflow increases, in flow (cfs) and volume (acre-feet), needed to meet water quality standards in the mainstem of the Pilchuck River and Little Pilchuck Creek.

Waterbody	Flow (cfs)	Volume (acre-feet)
Mainstem Pilchuck River	5.1	313.6
Little Pilchuck Creek	4.5	276.7

This appendix focuses on just two of the many practices capable of increasing baseflow. The first is stormwater capture and infiltration. The second is the use of beavers and beaver dam analogs (BDAs). Both of these practices increase groundwater, which provides a steady supply of cool baseflow during warm summer months. Achieving TMDL targets will likely rely on the combined benefits of a variety of practices.

This appendix provides example calculations for: (1) groundwater velocity and travel time; and (2) estimating the drainage area needed to capture a given amount of stormwater based on percent imperviousness. The results of these calculations are specific to the examples given in this appendix.

Estimating Groundwater Velocity and Travel Time

Capturing and infiltrating stormwater during months with high average rainfall (October through May) will increase groundwater volume and has the potential to increase baseflows during the dry summer months. Groundwater velocity and travel time estimates for a given site can help stakeholders decide where to construct a stormwater infiltration facility.

An equation for the average linear velocity at which groundwater moves through soil can be derived from Darcy’s law. The equation consists of velocity (v), soil conductivity (K), soil porosity (n), and slope. Slope is the change in elevation, or head, divided by the distance to the stream ($\Delta H/ \Delta L$) (Figure J-1). The equation looks like this: $v = -K/n *(\Delta H/ \Delta L))$

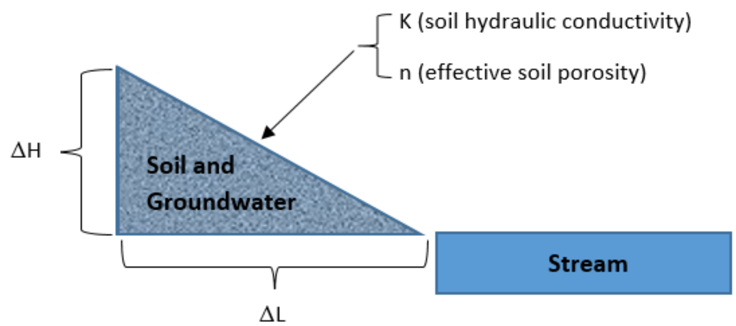

Figure J-1. Components of the average velocity equation derived from Darcy's Law.

Once the average linear velocity is determined, an estimate of travel time can be made. Table J-2 displays a spreadsheet that can be used to calculate groundwater velocity and travel time. The spreadsheet contains soil characteristic information that came from the United States Department of Agriculture's Soil Survey Geographic (SSURGO) database. It allows a user to enter site information and determine if a particular site is suitable for a stormwater infiltration facility. The orange row in Table J-2 highlights an example in which the travel time is 166 days based on site-specific soil and slope conditions. This means that rainfall captured and infiltrated in February would arrive at the stream in July, rainfall captured in March would arrive in August, etc.

This document recognizes that variations in rainfall amounts and intensities will play a role in the amount of rainfall captured, infiltrated, and delivered to the stream. This document also recognizes that actual groundwater travel times may differ from theoretical values due to site specific factors.

Table J-2. Example spreadsheet displaying travel time and linear velocity calculations based on soil type, saturated hydraulic conductivity, porosity, slope, and distance to stream.

Soil data were taken from the U.S. Department of Agriculture's Soil Survey Geographic (SSURGO) database.

Soil Name	Saturated hydraulic conductivity		Estimated Porosity	Infiltration Elevation	Stream Elevation	Distance to Stream	Hydraulic Gradient	Linear Velocity	Travel Time
	in/hr	*ft/day*	*Pct*	*ft*	*ft*	*ft*	*ft/ft*	*ft/day*	*days*
Alderwood	3.97	7.94	0.33	10	0	200	0.05	1.2	166
Bellingham	0.38	0.77	0.55	10	0	200	0.05	0.1	2,874
Cathcart	1.28	2.55	0.4	10	0	200	0.05	0.3	627
Elwell	1.28	2.55	45	10	0	200	0.05	0.0	70,556
Everett	52.94	105.87	0.37	10	0	200	0.05	14.3	14

Estimating Drainage Area and Stormwater Volume

Stormwater infiltration facilities collect and infiltrate stormwater from drainage areas with impervious surfaces such as roads, parking lots, sidewalks, and roofs. A drainage area with more impervious surface area, or a higher intensity of development, generates more stormwater than a drainage area with less impervious surface area.

Figure J-2 displays land use intensity within Pilchuck watershed. An analysis of the USDA's National Agricultural Statistics Service (NASS) 2019 land cover dataset suggests that the Pilchuck watershed has approximately 472 acres of high intensity developed land, 4,161 acres of medium intensity developed land, and 12,665 acres of low intensity developed land. Knowledge of impervious percentage within a drainage area can provide an estimate of how much stormwater can be captured and potentially added to streams via subsurface flow. Table J-3 shows how many acres would be needed to generate 1 cfs of streamflow at various levels of imperviousness (e.g. 10%, 20%, etc.). Rainfall data from the Granite Falls area was used in this calculation.

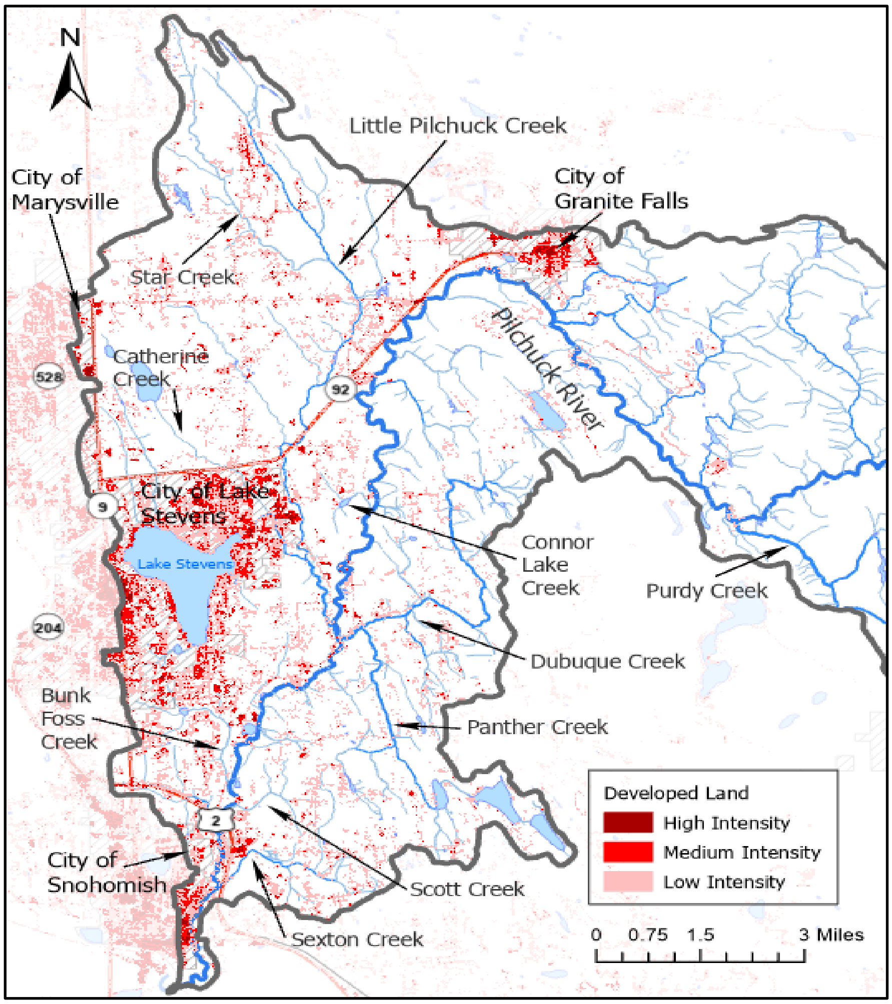

Figure J-2. Impervious surfaces, represented by developed land intensity, in the lower and middle portions of the Pilchuck watershed. Data from USDA National Agricultural Statistics Service 2019 landcover dataset.

Table J-3. Acres needed to generate 1 cfs in the Pilchuck watershed. Based on average October to May monthly rainfall values in Granite Falls.

Imperviousness	Acres needed to generate 1 CFS
10%	1150
20%	575
30%	383
40%	288
50%	230
60%	192
70%	164
80%	144
90%	128
100%	115

Using GIS to site infiltration facilities

GIS can speed up the process of identifying potential infiltration facility locations. For example, Figure J-3 shows the saturated hydraulic conductivity of soils in a portion of the Pilchuck River watershed. When combined with soil porosity and slope data, a map can be developed that highlights locations with high potential suitability for an infiltration facility.

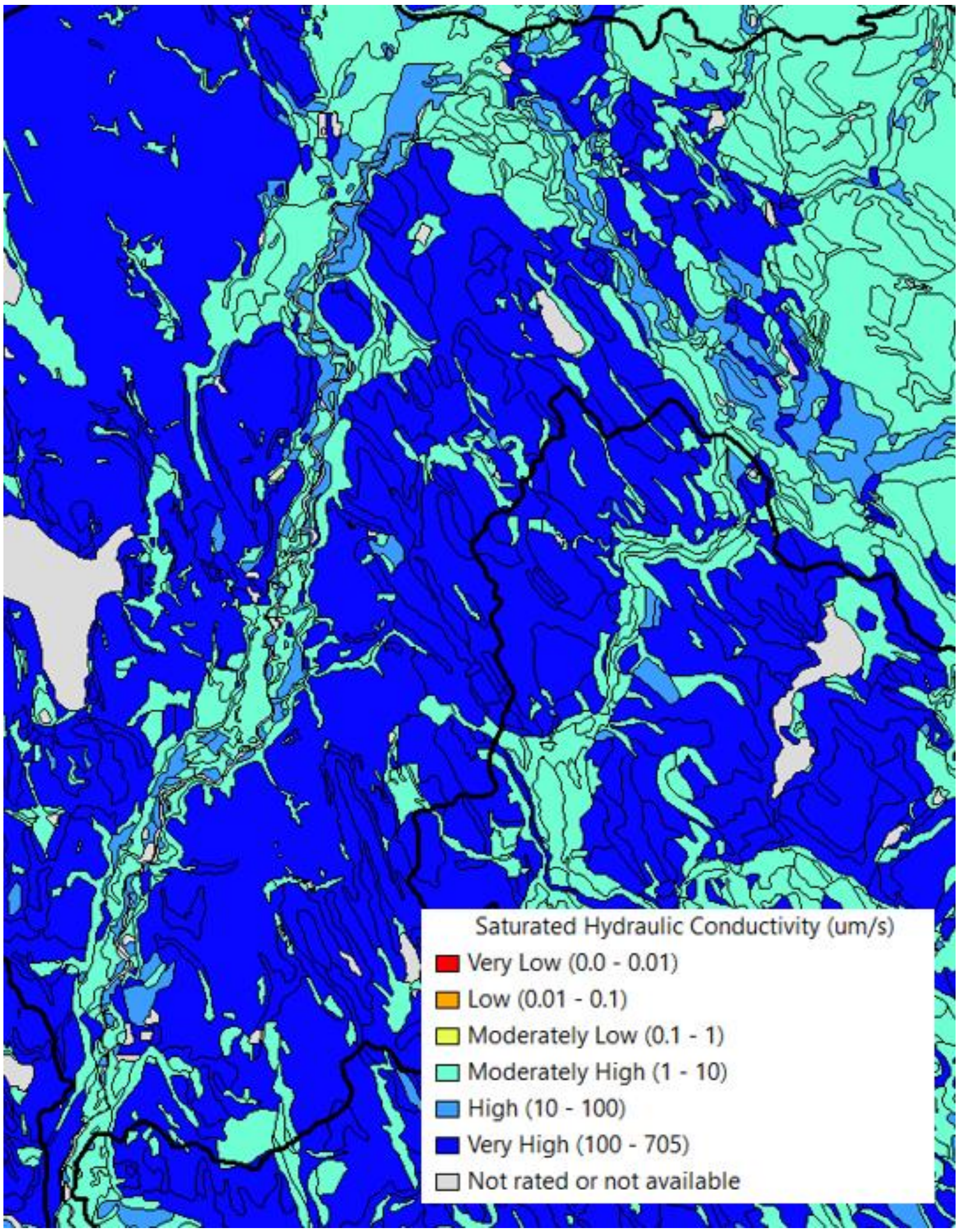

Figure J-3. Saturated hydraulic conductivity of surface soils across a portion of the Pilchuck River watershed. From United States Department of Agriculture's Web Soil Survey.

Feasibility of stormwater infiltration facilities

A GIS analysis of soils in the middle and lower portions of Pilchuck watershed suggests that surface soils have high saturated hydraulic conductivity (Figure J-3) but shallow depths to restrictive or impermeable layers (Figure J-4). Across much of the watershed the depth to restrictive layer is only 20 to 40 inches (Figure J-4). Both hydraulic saturated conductivity and depth to restrictive layer play a role in determining the size of infiltration facility that is feasible in a given area.

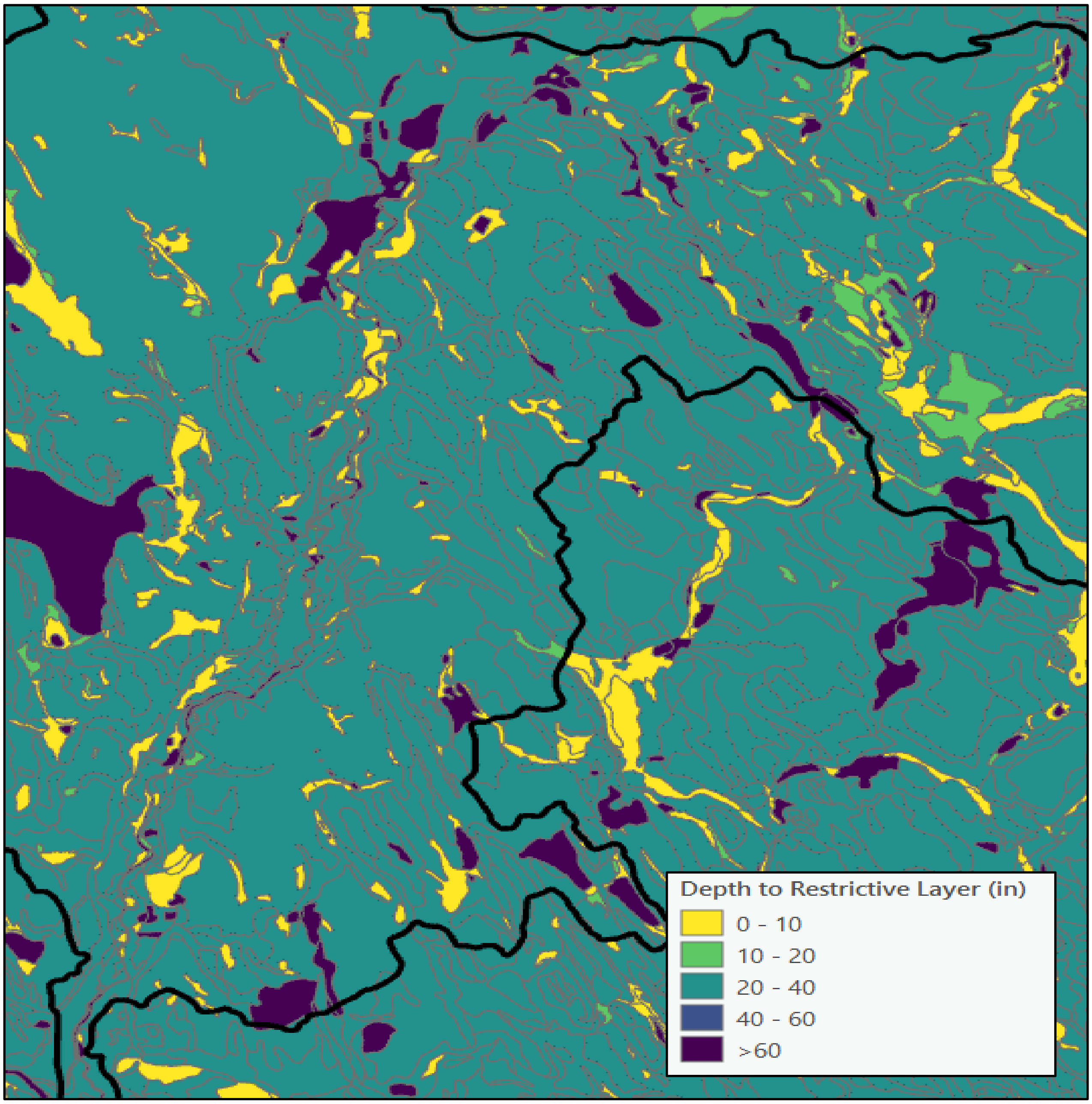

Figure J-4. Depth to restrictive layer (seasonal high water table, bedrock, or other impervious layer) in inches across a portion of the Pilchuck watershed. From United States Department of Agriculture's Web Soil Survey.

Table J-4 outlines Ecology's 2019 Stormwater Management Manual for Western Washington[9] feasibility criteria based on soil depth to a restrictive layer (seasonal high water table, bedrock, or other impervious layer) and facility size. The manual places facilities into two categories: facilities that treat less than 5,000 square feet of pollution-generating impervious surface (PGIS) and less than 10,000 square feet of impervious surface, and facilities that treat 5,000 square feet or more of PGIS and 10,000 square feet or more of impervious surface. In this document we refer to these as small facilities and large facilities, respectively. From Table J-4, all infiltration facilities are infeasible in soils with less than 12 inches to a restrictive layer. Small facilities are feasible in soils with a depth to restrictive layer between 12 and 36 inches but large facilities are not. Infiltration facilities of all sizes are feasible in soils with greater than 36 inches to a restrictive layer. Based on these "assumptions", in cases where depths are 12 to 36 inches, a large volume of stormwater can still be treated using a greater number of small facilities.

Table J-4. Feasibility of infiltration facilities at various soil depths to a restrictive layer.

Soil Depth to Restrictive Layer (inches)	Feasibility
Less than 12	Infeasible
12 to 36	[1]Small facilities - feasible [2]Large facilities - infeasible
Greater than 36	[1]Small facilities - feasible [2]Large facilities - feasible

[1]Small facilities treat < 5,000 square feet (PGIS) and < 10,000 square feet of impervious surface.
[2]Large facilities treat ≥ 5,000 square feet (PGIS) and ≥ 10,000 square feet of impervious surface.

Beaver Dams and Beaver Dam Analogs

Beaver dams and beaver dam analogs (BDAs) pond and infiltrate water, significantly increasing surface water and groundwater volumes and increasing summer baseflows. 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 groundwater storage per 100 m of stream reach in the first year following relocation. A recent study in Northern California (Yokel et al. 2018) found "that for every 30 cm of height that the BDAs are raised, groundwater levels rise 15 cm or more, as far as 0.9 kilometer up valley.

There were also less dramatic increases observed as much as 350 m down valley. A conservative estimate suggests that the lower BDA in Sugar Creek increased water storage capacity by about 37,000 m^3 (about 30 acre-feet). It is likely that the area of groundwater influenced by the BDAs

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

extends beyond the limits of our groundwater monitoring network.” 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).

BDAs are human-built channel-spanning structures that are designed to mimic or reinforce natural beaver dams (Pollock et al. 2018). In regard to water storage, BDAs behave like beaver dams and can cause similar positive effects on surface water storage and groundwater recharge (Pollock et al. 2018).

Table J-5 shows the number of stream miles needing beavers/BDAs and percent of stream miles needing beaver/BDAs to reach TMDL baseflow targets. The calculations behind these values are based on findings from Dittbrenner 2019. The upper Pilchuck subbasin did not receive a TMDL target but contributes water to the MPR and is included in the table as “MPR + Upper”. Beavers and BDAs would be needed on just 10% of MPR + upper watershed stream miles to reach the MPR TMDL goal. In the LPC, beavers and BDAs would need to be applied to 79% of stream miles. It is unrealistic to expect that beavers and BDAs be the only practice used to restore summer baseflows, especially in the LPC. It is much more likely that beavers and BDAs can restore a portion of the summer baseflow TMDL target. For example, if beavers and BDAs were implemented on just 8 miles of stream in the MPR or LPC, 1 cfs could potentially be added to baseflows.

Table J-5. Number of stream miles needing beavers/BDAs and percent of stream miles needing beaver/BDAs to reach TMDL targets.

Subbasin	Stream miles needing beavers/BDAs to reach targets	Percent of stream miles needing beavers/BDAs to reach targets
Little Pilchuck Creek (LPC)	35.8	79%
Lower/Middle Pilchuck (MPR)	40.6	26%
MPR+ Upper Pilchuck (excludes LPC)	Upper not included in TMDL analysis	10%

Below are the calculations used to derive the stream mile values in Table J-5. Included in the calculations is a variable called beaver dam units (BDUs), which is this document’s translation of the “100m reaches” found in the Dittbrenner 2019 study.

Mainstem of the Pilchuck River

- 581 m^3 of groundwater storage per BDU = 20,518 ft^3 of groundwater storage per BDU
- 20,518 ft^3 per BDU / 2,628,000 seconds per month = 0.0078 cfs per BDU in a month
- 1 cfs / 0.0078 cfs per BDU = 128.08 BDUs
- 128.08 BDUs / 16.09 BDUs per mile = 7.96 stream miles of BDU implementation to achieve 1 cfs
- 7.96 miles * 5.1 cfs needed in the mainstem of the Pilchuck River = **40.6 miles**

Little Pilchuck Creek

- 581 m^3 per BDU = 20,518 ft^3 per BDU
- 20,518 ft^3 per BDU / 2,628,000 seconds per month = 0.0078 cfs/month per 100m reach
- 1 cfs / 0.0078 cfs per BDU = 128.08 BDUs
- 128.08 BDUs / 16.09 BDUs per mile = 7.96 stream miles of BDU implementation to achieve 1 cfs
- 7.96 miles * 4.5 cfs needed in Little Pilchuck Creek = **35.8 miles**

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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

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Woo, M.K., and J.M. Waddington. 1990. Effects of Beaver Dams on Subarctic Wetland Hydrology. Arctic 43(3), pp.223-230.

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Appendix K. Reach Metrics

During the drafting of the implementation plan, Ecology discovered the river miles used in our technical work do not completely line up with the river miles used by Snohomish County. Ecology decided to reconcile this discrepancy by also referencing the reach polygons that Snohomish County used in their Lower Pilchuck and Middle Pilchuck Assessments {(Cardno, 2018) and (SCSWM, 2012c) respectively}.

Middle Pilchuck Reaches

To characterize the implementation actions in the "Where do we have opportunities for Improvement section" and reasons stated above, the Middle Pilchuck River study area was divided into the following eight reaches (Table K-1) based on reach designations already established by Snohomish County (SCSWM, 2012c). Figure K-1 shows an overall visual depiction of these reaches. Figures K-1A through K-1E are zoomed in on these reaches to show more detail.

Table K-1. Designated Middle Pilchuck Reaches

Reach	River Mile	
	Start	End
1	8.60	11.38
2	11.38	14.45
3	14.45	18.32
4	18.32	20.12
5	20.12	21.29
6	21.29	22.52
7	22.52	24.79
8	24.79	26.44

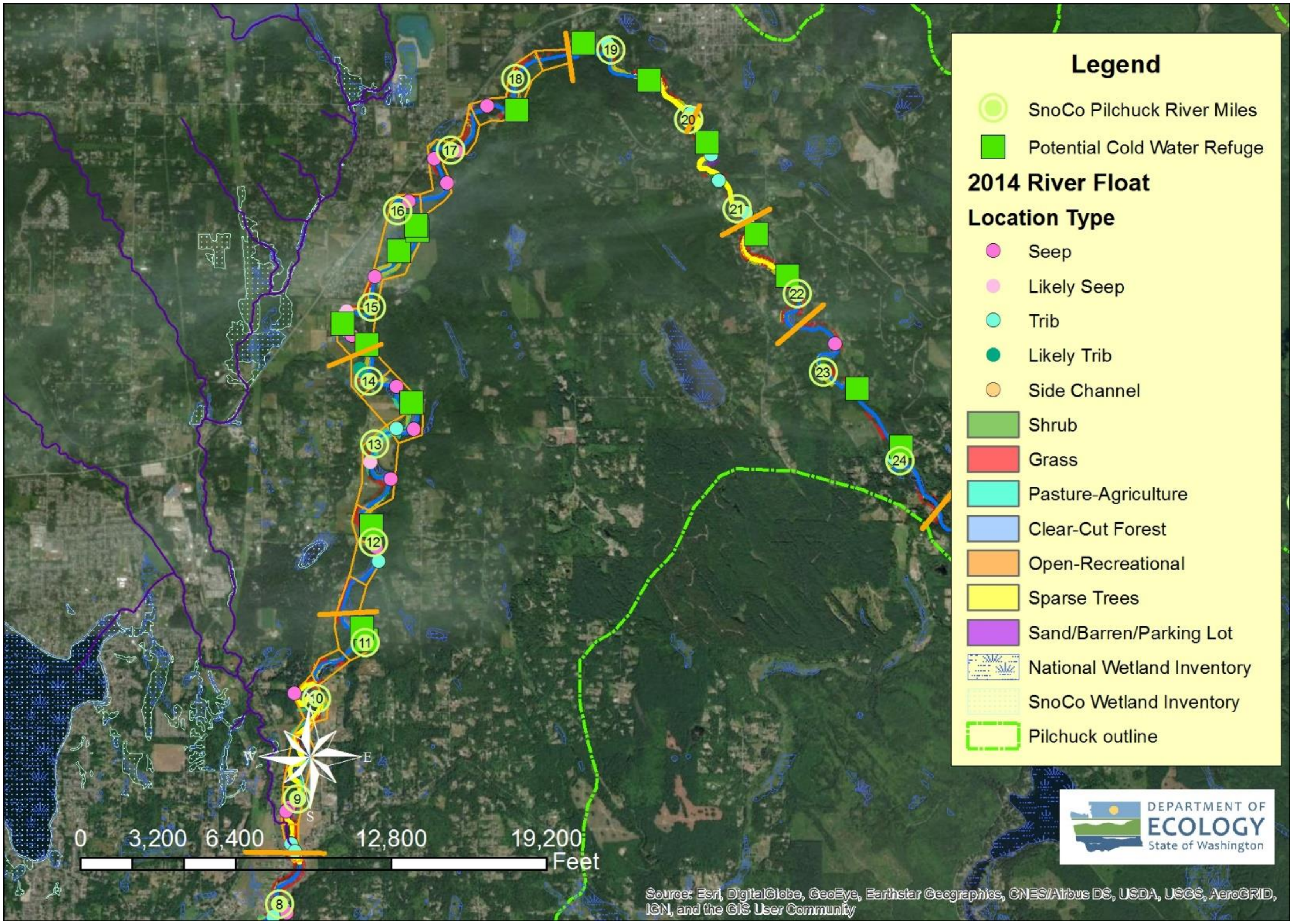
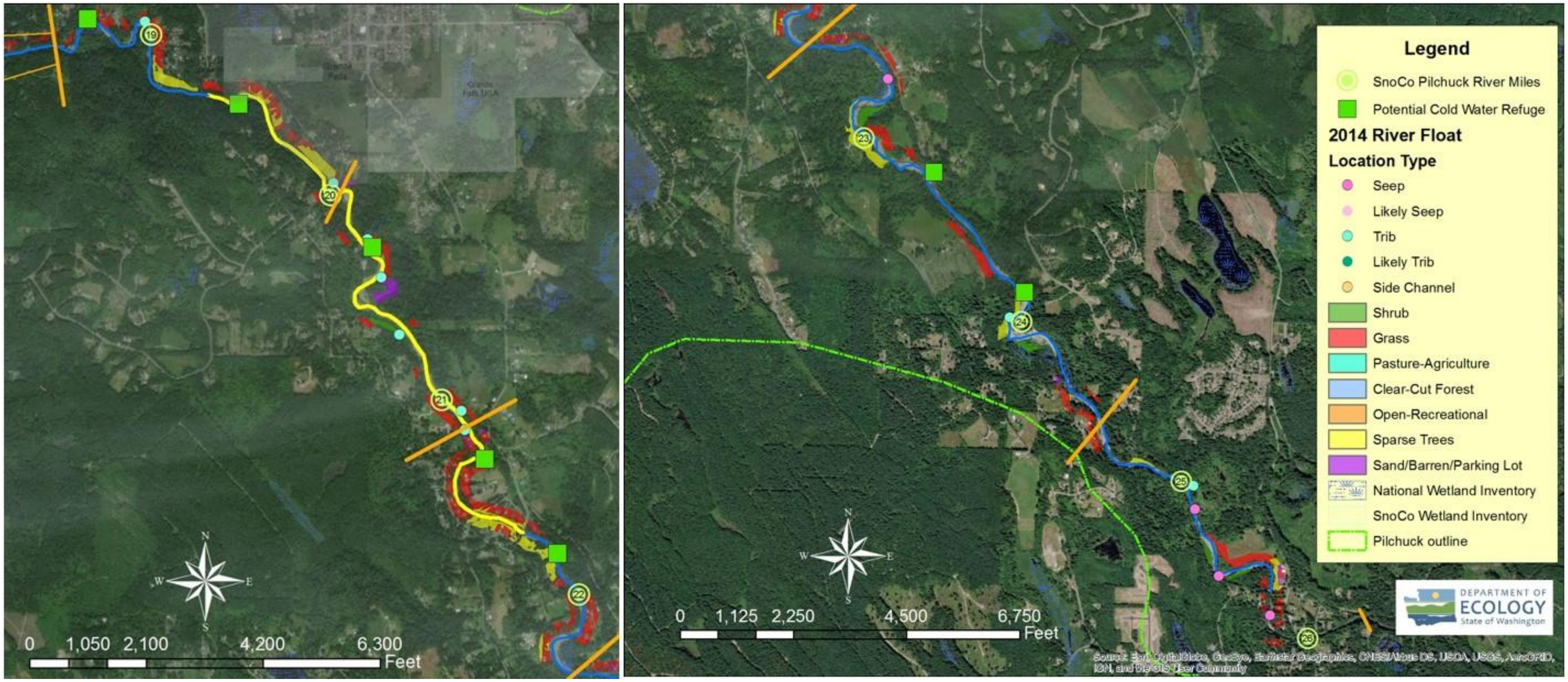


Figure K-1. Middle Pilchuck Map reach designations and implementation nee



Figures K-1A and K-1B: Figure K-1A on the left shows Reaches 4, 5 and 6. The yellow line represents an area of significant groundwater gain. Figure K-1B on the right shows Reaches 7 and 8.

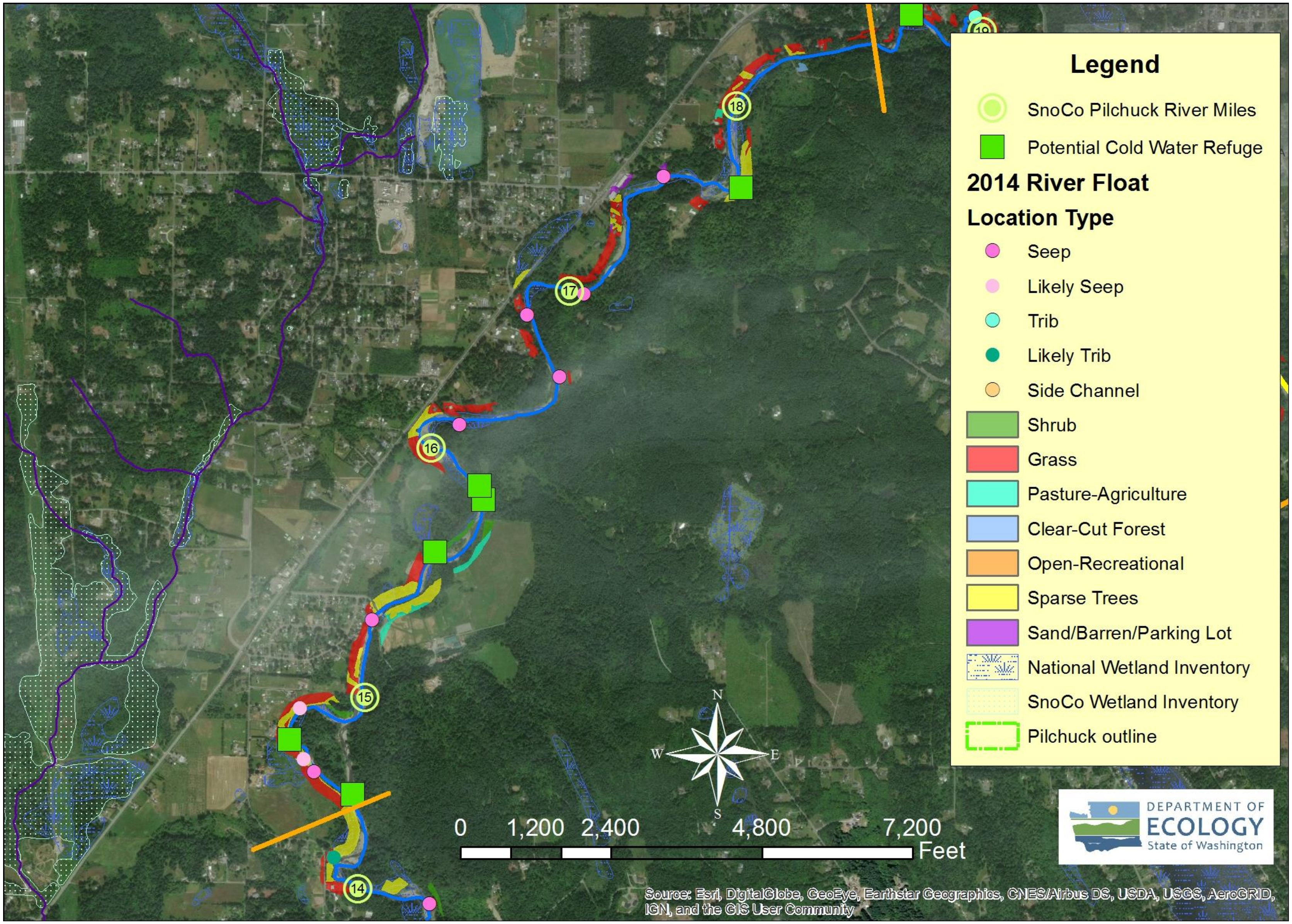
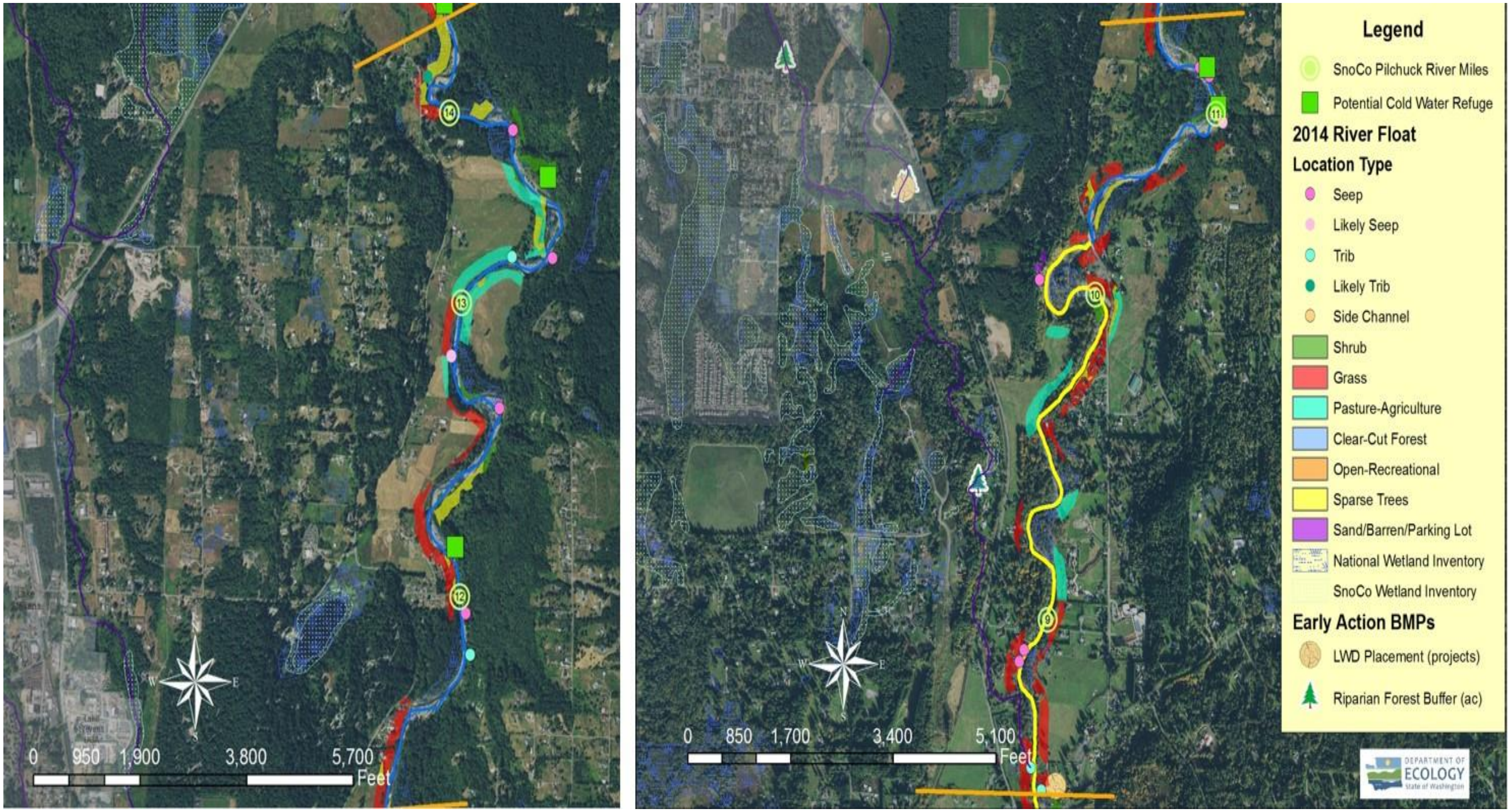


Figure K-1C: Reach 3



Figures K-1D and K-1E: Figure K-1D on the left shows Reach 2. Figure K-1E on the right shows Reach 1. The yellow line represents an area of significant groundwater gain.

Lower Pilchuck Reaches

To characterize the implementation actions in the "Where do we have opportunities for Improvement section" and reasons stated above, the Lower Pilchuck River study area was divided into the following eight reaches (Table K-2) based on reach designations already established by Snohomish County (Cardno, 2018). Figure K-2 shows an overall visual depiction of these reaches. Figures K-2A through K2-D are zoomed in on these reaches to show more detail.

Table K-2. Designated Lower Pilchuck River Reaches

Reach	River Mile	
	Start	End
1	0	1.80
2	1.80	2.90
3	2.90	4.01
4	4.01	4.56
5	4.56	5.83
6	5.83	6.49
7	6.49	7.23
8	7.23	8.60

References

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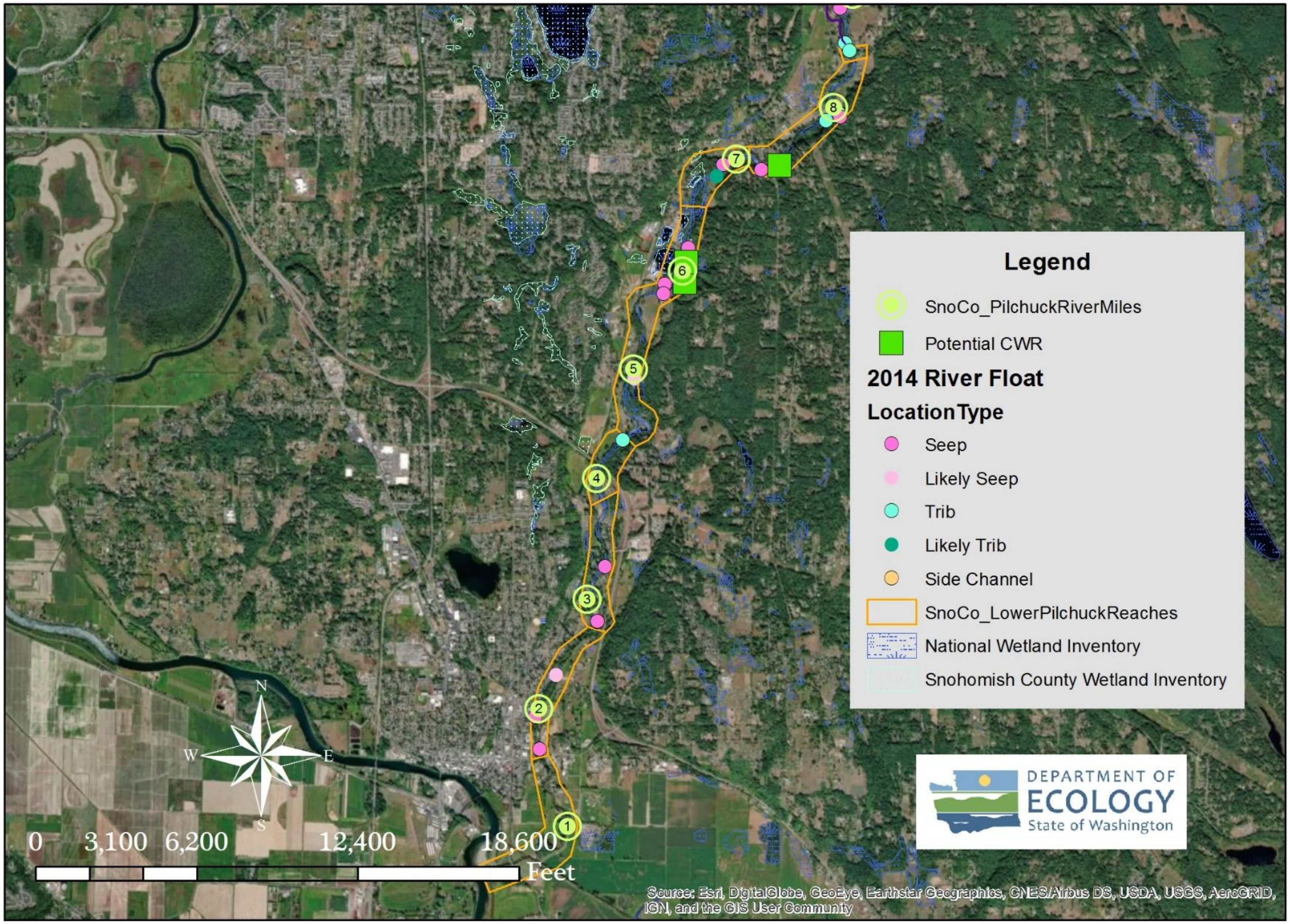


Figure K-2. Lower Pilchuck Reach Designation Map

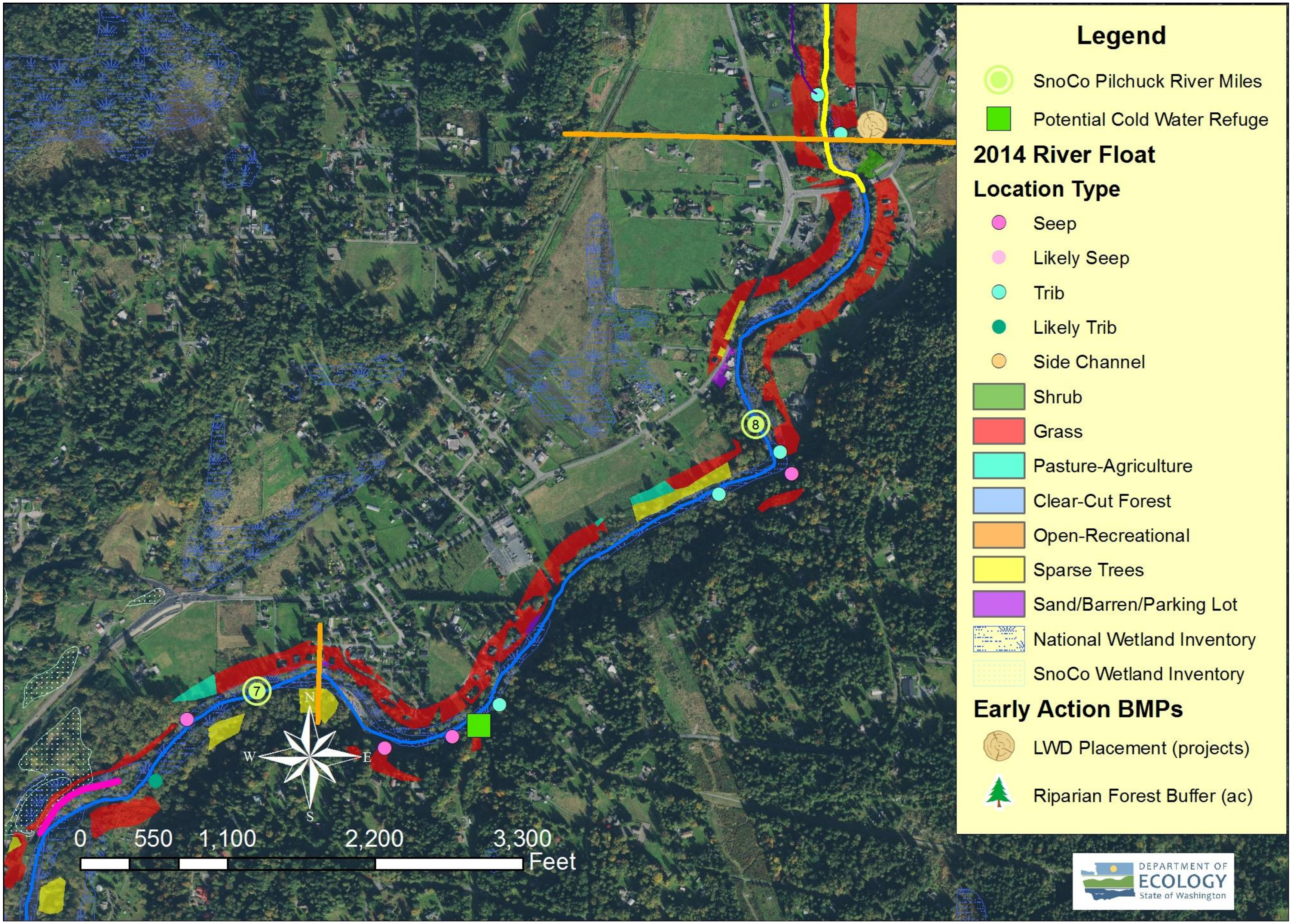


Figure K-2A: Reach 8. The yellow line represents an area of significant groundwater gain.

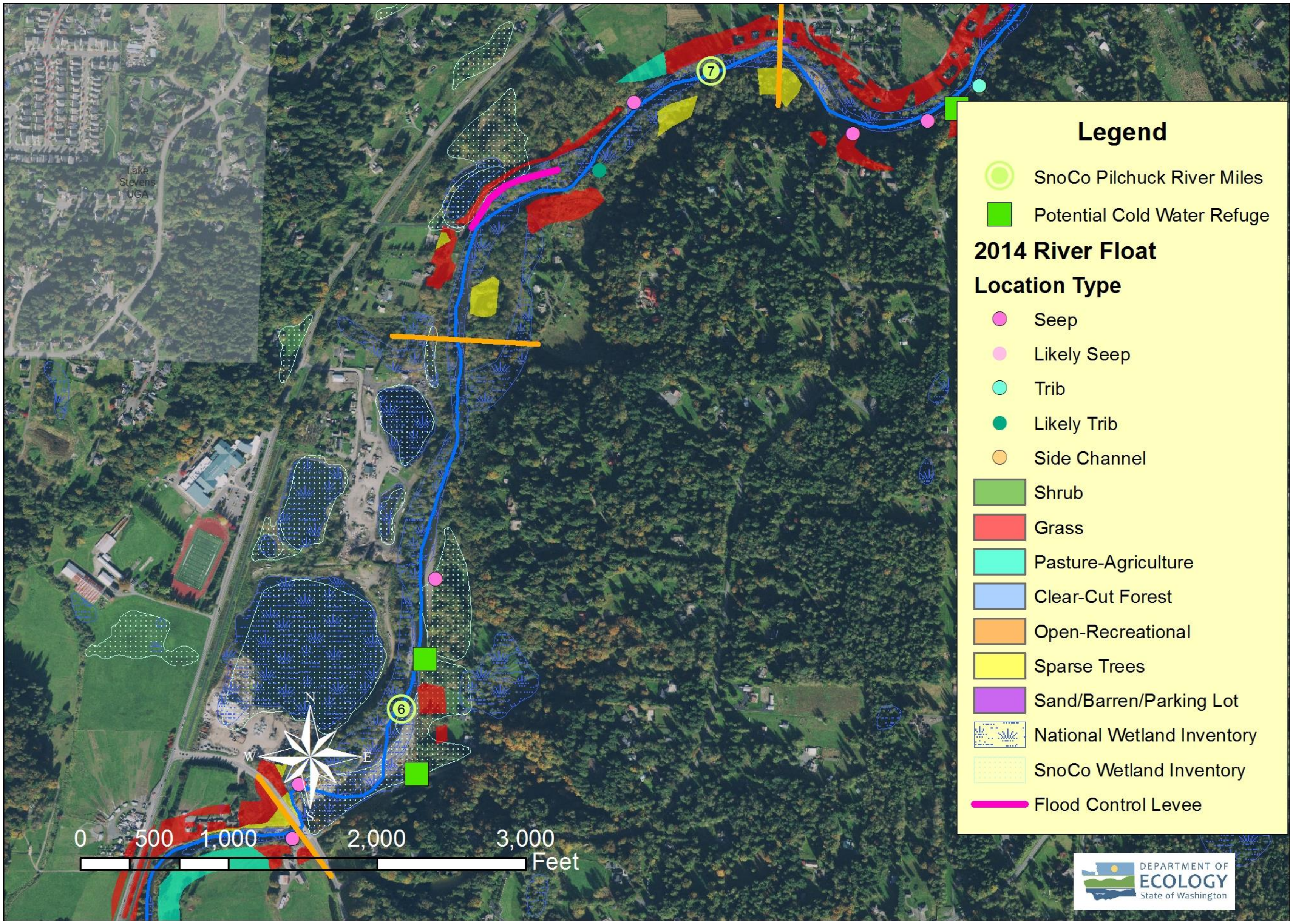
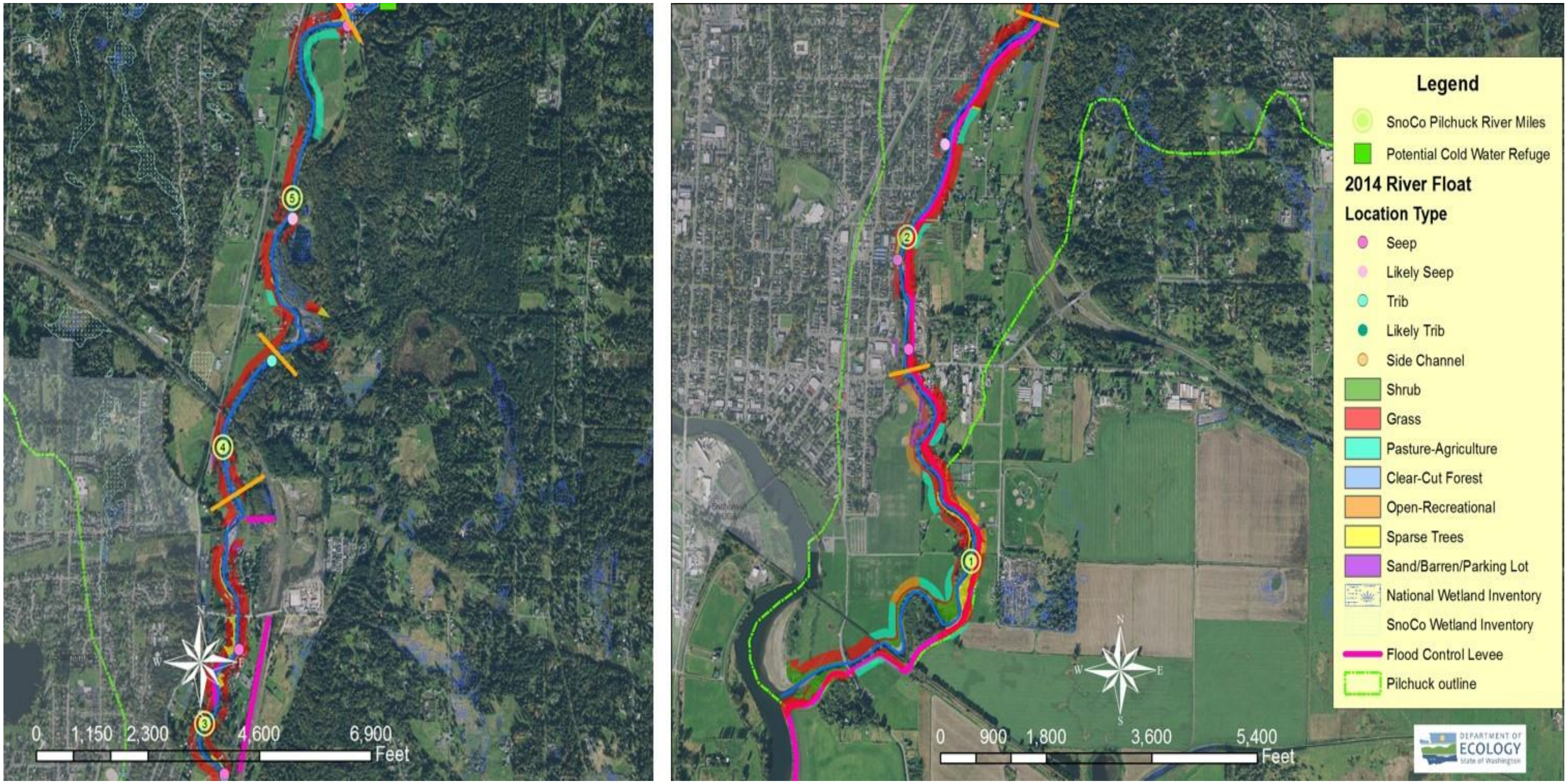


Figure K-2B 1: Reaches 6 and 7



Figures K-2C and K-2D: Figure K-2C on the left shows Reaches 3, 4 and 5. Figure K-2D on the right shows Reaches 1 and 2.