

FINAL PROJECT REPORT

FOR

G1000349

Stillaguamish Temperature TMDL Adaptive Assessment and Implementation Project

Snohomish County Public Works, Surface Water Management

Total Cost of Project:	\$296,481
Grant or Loan Amount:	\$222,361

Project Start Date: 1/1/2010
End Date: 5/1/2015

<u>Janell Majewski</u>	<u>8/10/2015</u>	&/or	<u>Ralph Svrjcek</u>	<u>8/10/15</u>
(AUTHORIZED SIGNATORY)	DATE		(PROJECT MANAGER)	DATE

Stillaguamish Temperature TMDL Adaptive Assessment and Implementation Snohomish County Public Works, Surface Water Management G1000349

1/1/2010 – 5/1/2015

Final Total Project Cost: \$296,481

Final Ecology Grant Contribution: \$222,361

Project Description

The purpose of the Stillaguamish TMDL Project is to improve water quality conditions for temperature and salmon habitat in the Stillaguamish basin by identifying sources of cold groundwater in the streams and rivers which would most benefit from protection.

Several methodologies were followed, which led to task completion. These are documented in separate reports (appended here), as follows:

- Watershed Characterization
- Base Flow Analysis
- Temperature Regime Studies
 - FLIR (Forward Looking Infrared Imagery) Temperature Imagery Analysis
 - River Thermal Profiling
 - 2008-2012 Continuous Temperature Monitoring
- Groundwater Seepage Study
- Assessment Synthesis and Project Identification Report
- Riparian Implementation

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*Beginning thermal profile of NF Stillaguamish River in
front of Whitehorse Mountain, river mile 34.*

August 16, 2011

Project Accomplishments

Watershed Characterization

Watershed Characterization maps locations of water flow importance and relative degradation among 107 Assessment Units following department of Ecology's detailed methods (Stanley et al. 2011).

Results were used to describe how stream temperature may be influenced by the relative importance of water flow processes - *Delivery, Storage, (Recharge & Discharge – Groundwater)* – and *Degradation*.

58 Assessment Units (AUs) draining tributaries were used to test whether water temperature (standardized 7-day average daily maximum C) in 2008-2012 was related to water flow process results.

Cooler water temperature among AUs was significantly correlated with relative water *Recharge* importance and the *Groundwater* component of the water flow importance model.

Water temperature was not correlated with AU drainage area (2-10 mi²), percent riparian buffer forest cover, any other water flow importance process, overall importance or overall degradation.

For 38 floodplain and tributary AUs with cold-water inflow mapped from infrared imagery, we found significantly higher count and thermal effect (temp x size) for AUs with greater *Groundwater* flow importance. For tributaries only, the thermal effect (but not count) was significant.

These results suggest that the combined influence of *Recharge* and *Discharge* as components of the *Groundwater* process have relatively more weight influencing water temperature.

To our knowledge, this is the first evaluation of water flow responses based on hypothesis testing of the processes that Watershed Characterization in Puget Sound represents, and therefore validates it (at least partially) as a coarse screening tool for planning-level decision-support.

Baseflow (1911-2013)

Forty gages in the Stillaguamish watershed (1911-2013) are described for the period of record, drainage area, climate phase and computed average 7-day and 30-day averaged daily flow. A USGS Baseflow Index model (PART) was implemented for 34 gages for each year of useable data.

Variable low flow pattern between cool- and warm-climate phases was persistent for decades. A sharp decline in flow in 1985 defined a break in flow response for this report, but lagged the 1976-1977 North Pacific Ocean phase change as published elsewhere.

The annual low flow in the NF Stillaguamish River was 55% higher in 1947-1984, compared to 1985-present, but flow has been significantly increasing in the NF Stillaguamish River since 1985. The nearby Skykomish and Sauk Rivers confirm the same low flow patterns between 1928-2013. Jim Creek, Pilchuck Creek, SF Stillaguamish River, and Squire Creek show similar patterns of flow response between climate phases, but have varying severity of responses (and limited datasets).

Squire Creek, the snow-dominated, headwater mountain stream appears to be more flow sensitive to climate phase changes compared to Pilchuck Creek and Jim Creek. Higher elevation, headwater streams with relatively protected land conservation status may actually be more vulnerable to temperature increases based on flow sensitivity to climate change than some developed lowland locations. But, this warrants additional investigation.

Temperature Regime Analysis

129 cold-water inputs were identified in the Stillaguamish River, NF and SF Stillaguamish rivers, and in Pilchuck Creek from Thermal Infrared (TIR) imagery. 96 of these were considered cold-water “refuges.”

Cold-water refuges were classified by source (tributaries, floodplain, side channels, seep/springs, hyporheic) and estimated size of influence on the receiving river (*temperature difference x size*).

Half of all cold-water inputs were located in the NF Stillaguamish River where spacing (per mile) was most frequent due to cold-water discharge from side channels, floodplain locations and seeps/springs, in addition to tributaries. Cold-water inputs into the SF Stillaguamish River were dominated by tributary sources.

Restoration of cold-water refuges in the North Fork will be supported by river and floodplain restoration, whereas restoration of cold-water refuges in the South Fork will be more based on AU restoration and habitat enhancement at tributary confluence locations.

Field-based thermal profiling using a continuously recording thermistor found numerous locations of tributary and groundwater inflow that mitigated downstream heating in Jim Creek and Pilchuck Creek.

Patches of colder water were often in (or downstream from) deeper pools in locations with groundwater inflow (seepage), suggesting restoration of pool scour in flow gaining reaches should provide temperature benefits as well as habitat improvement in Pilchuck and Jim creeks.

Between 2008-2012, 242 datasets of continuously recorded temperature were collected in summer in mainstems, side channels, and tributaries where temperature standards are 12, 16, or 17.5 Celsius.

The 7-day average daily maximum temperature, on average, was warmest in 2009 and 2010 and coolest in 2008 and 2011. Tributaries and side channels were coldest, exceeding temperature standards by 30% among all years. Mainstem locations were warmest, exceeding temperature standards by 70% among all years.

- 17.5 C standard - tributaries were coolest and exceeded the standard only 2% of the time (1.4 days/year). Side channels were notably warm compared to elsewhere, but still may be temperature refuges in discrete locations.
- 16 C standard, side channels were coolest, then tributaries, compared to mainstem sites, and the difference between side channel temperature and mainstem locations was greatest relative to other comparisons. Side channels exceeded the temperature standard 9% of the time.
- 12 C standard, water temperature was coldest in side channels, then tributaries and mainstems, but exceeded standards 74% of the time. Protecting tributaries and restoring side channels is recommended.

Climate changes may have a relatively greater impact on flow and temperature in headwaters (12 C), as increasing AU sensitivity to heating corresponded with increasing exceedance (%), making protection more challenging.

Restoration of side channels and riparian vegetation along mainstem locations for sites with a 12 C and 16 C standard will offer temperature benefits in the floodplain where resilience to effects from climate change are likely to be greatest relative to tributaries, except in Puget Lowland tributaries.

Seepage Study

A seepage study to determine reach-scale flow gain or flow loss was implemented on September 1, 2011 in lower Pilchuck Creek and in Jim Creek on September 4, 2012 near the time of annual low flow.

In Pilchuck Creek, groundwater seepage contributed 60% of the flow accumulation in the lower 7 miles. The majority of groundwater inflow, 77%, occurred from RM 0-3.1.

In this reach, upstream from I-5, flow contribution from tributaries, floodplain areas, or other groundwater discharge locations predominantly arose from the east, coincident with permeable upland glacial deposits or alluvium in the floodplain, as also highlighted by the Watershed Characterization.

In locations with flow gaining reaches, such as lower Pilchuck Creek, large wood jams that scour deep pools will improve groundwater seepage flow to this key habitat type.

In Jim Creek, the contribution of groundwater as seepage flow was estimated for 3 cross-section pairs. Whereas the first cross-section pair far upstream was estimated to have groundwater inflow, the other 2 locations appeared to be losing reaches, where net surface flow decreased downstream due to loss of surface flow downstream of Vos Creek.

Vos Creek contributed 16.5% of the total Jim Creek flow during the seepage study. And, Vos Creek was very cold, originating from the Arlington Heights outwash aquifer. As above, promoting AU area restoration of water flow processes (*Recharge, Surface Storage*) could support seasonal storage and summer base flow.

Project Identification and Implementation

This project identifies 90 potential projects, of which, 40 are side channel and wood placement project types. Restoring isolated side channel habitats and river processes that support side channel formation along with tributary protection and restoration in floodplain locations is recommended.

Strategically, restoration of cold-water refuges in the North Fork Stillaguamish River will be supported by side channel connections and river process restoration, whereas restoration of cold-water refuges in the South Fork will be based more on Assessment Unit restoration and habitat enhancement at tributary confluence locations.

Due to past low flow variability and expected future climate change, restoration of side channels and riparian vegetation within floodplain locations for sites with a 12 C standard will offer temperature benefits where sensitivity to effects of climate change are likely to be less.

In locations with flow gaining reaches, such as lower Pilchuck Creek, large wood jams that scour deep pools should improve groundwater seepage flow to this key habitat type (as well as providing structural habitat improvement).

In a flow-losing reach, protecting and restoring tributary shading and flow (such as at Vos Creek in Jim Creek), as well as habitat quantity and quality at the cold tributary confluence is important. Large wood restoration can improve habitat suitability (pools and cover) at locations where temperature characteristics are most likely to be favorable during summer.

AU area protection and restoration of water flow processes that target *Recharge, Discharge and Groundwater* model parameters from Watershed Characterization will promote seasonal water flow that improves temperature and/or creates more favorable (temperature/size) habitat patches.

This project identifies 50 potential riparian planting locations that are spatially discrete and functionally linked to the water flow processes and temperature results, and do reflect shading deficits identified in Department of Ecology's Temperature TMDL Plan. Many locations with shading deficits also need planting, in tributaries and not along larger rivers. Tributary locations can be shaded faster with smaller trees and narrower buffers, are not typically subject to erosion from channel migration.

Smaller tributaries contribute colder water to mainstem locations creating thermal refuges, and our results suggest many locations are relatively insensitive to warmer air temperature and watershed position relative to mainstem river locations.

Finally, the projects suggested here are not exhaustive of all possible strategies, ideas, data, and public or private stakeholder interests that could address this habitat and water quality problem.

Recommendations are additive to those proposed in the TMDL implementation plan. Also, project concepts require additional feasibility, review and consideration of costs, benefits, and risks.

Water Quality Improvements

Two locations were planted as part of this project, in the lower South Fork Stillaguamish River and in Trib 80 (Pilchuck Creek). A total of 8.8 acres riparian buffer was planted in 2013 and 2014, along 2700 lineal feet of channel.

Finally, we estimated pollutant load reduction values for these BMPs using the EPA's STEPL 4.1 model for implementation of 3.5 acres and 5.3 acres of the "streambank stabilization and fencing" model BMP on Trib80 in Pilchuck Creek and South Fork Stillaguamish River, respectively.

The Next Steps for Continued Success

Results from this grant, including recommended projects will be communicated to watershed stakeholder groups that implement water quality improvement projects. Detailed, area-specific descriptions and presentation of supporting data from component studies that support project identification will continue to be developed for outreach and communication.

Detailed feasibility analysis, including landowner outreach needs to be conducted for construction implementation, particularly for more complicated projects involving side channel restoration and wood placement. For some projects, conceptual designs will be needed in order to seek grant funding for final design and implementation.

Projects that improve shading, as recommended in the TMDL Implementation Plan, should continue to be implemented, particularly on smaller streams draining to the North Fork, South Fork, and mainstem Stillaguamish Rivers.

Annual temperature monitoring should continue at multiple locations in mainstem rivers and tributaries to evaluate long-term trends and determine how or whether locations are relatively sensitive to effects of climate variability or are resilient to these changes.

STILLAGUAMISH TEMPERATURE TMDL ADAPTIVE ASSESSMENT AND IMPLEMENTATION PROJECT

Assessment Synthesis and Project Identification Report

August 2015

Acknowledgements

The Stillaguamish Temperature TMDL project was funded by Washington State Department of Ecology under the Centennial Clean Water Program, project number G1000349. This report represents fulfillment of Task 6. At the Department of Ecology (DOE), in particular, we thank Ralph Svrjcek (grant project manager) and Alissa Ferrell (project fiscal manager). This report was completed with significant assistance from Cardno, Inc. This report and project completion was improved by Janell Majewski, Snohomish County SWM Supervisor. Other acknowledgements of project support from 2010-2015 are included in each individual Appendix report.

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Appendix C. Stillaguamish Watershed Characterization.

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Appendix E. Longitudinal Water Temperature Profiles for Selected River Reaches in the Stillaguamish River Basin, Washington.

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Appendix G. Stillaguamish Watershed Baseflow Analysis; 1911–2013.

Appendix H. Summer Temperature Monitoring Among Channel and Habitat Types in the Stillaguamish Watershed, 2008-2012.

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PROJECT PURPOSE AND APPROACH

Ecology has established Total Maximum Daily Loads (TMDLs) for temperature in Washington waterways where ambient conditions exceed established temperature limits, including the Stillaguamish River watershed. Cold-water fish species such as salmon do poorly when exposed to high stream temperatures during both adult migration and as juvenile fish rearing in the stream. The goal of the TMDL for temperature is to protect these fish and their habitats.

Throughout major portions of the Stillaguamish River basin, instream temperatures routinely exceed established water quality criteria and pose a continuing problem for protection and recovery of cool-water-dependent fish and wildlife. Thus, the purpose of the Stillaguamish Temperature TMDL Adaptive Assessment and Implementation Project is to identify means of improving temperature conditions in the river basin (Figure 1). Specifically, the project aims to identify sources of cold groundwater input to the basin's streams that would most benefit from protection, and to restore those tributary, riparian, and off-channel areas that could be most effective in reducing temperatures throughout the channel network.

The need for the Stillaguamish TMDL Project was identified in the 2006 Stillaguamish River Water Quality Improvement Plan (Lawrence 2006). The project was funded through a Centennial Clean Water grant agreement between the Washington State Department of Ecology (Ecology) and Snohomish County (County). It was initiated by Snohomish County Public Works' Surface Water Management Division in 2010 and completed in 2015. An overview of all project findings is summarized in **Appendix A**.

This Assessment Synthesis and Project Identification Report summarizes the County's Watershed Characterization effort and integrates that with temperature data collection. Based on the data collected under the Stillaguamish TMDL Project, the County has assembled a preliminary list of actions to guide the development and implementation, over time, of specific protection and restoration activities to improve temperature conditions across the watershed, listed in **Appendix B**.

Since 2010, Snohomish County Surface Water Management conducted several studies to characterize the Stillaguamish watershed and to gather key data on what influences water temperatures across the watershed. The County also conducted an expanded analysis of thermal infrared imaging data collected in 2001 (Watershed Sciences 2002). Each of these studies is documented in detail in separate appended reports, as follows:

- **Appendix C.** Stillaguamish Watershed Characterization.
- **Appendix D.** Temperature Anomalies in the Stillaguamish River Mapped from 2001 Thermal Infrared Imagery.
- **Appendix E.** Longitudinal Water Temperature Profiles for Selected River Reaches in the Stillaguamish River Basin, Washington.
- **Appendix F.** Pilchuck Creek and Jim Creek Seepage Study.
- **Appendix G.** Stillaguamish Watershed Baseflow Analysis; 1911–2013.

- **Appendix H.** Summer Temperature Monitoring Among Channel and Habitat Types in the Stillaguamish Watershed, 2008-2012.
- **Appendix I.** Riparian Project Implementation Summary.

In general, areas important for protection generally are guided by the results of Watershed Characterization, whereas proposed restoration actions generally derive from river-scale or habitat-scale temperature and flow information contributed from the other studies. This final summary report, individual studies and associated maps are intended to guide policy development, water quality and watershed management planning, and individual project identification and implementation efforts based on strategies proposed here throughout the Stillaguamish watershed. Specific recommendations regarding study components and their utility, value, and applicability to this project or transferability to other areas are included in the separate study reports (Appendices).



Figure 1. Overview of Stillaguamish River watershed.

WATERSHED CHARACTERIZATION

Watershed Characterization is a decision-support tool that provided the framework for the present study of temperature conditions and management alternatives in the Stillaguamish River watershed. It was designed to help local and regional governments decide how best to protect and restore aquatic resources, providing a systematic, science-based structure to prioritize specific geographic areas on the landscape as focus areas for subsequent protection and restoration. Ecology has been creating and refining this approach over the last decade across western Washington; its guidance document is the Puget Sound Characterization—Volume 1: The Water Resource Assessments (Stanley et al. 2011).

Watershed Characterization is based on the fundamental principle that water flow *processes*—that is, the *delivery, movement, and loss of water* within the watersheds of the Puget Sound basin—are the critical determinants of aquatic ecosystem health. Watershed Characterization hypothesizes that not every location is equally important to the support of these processes, and so not every area of a watershed requires the same degree of function in order for the system as a whole to support its beneficial or otherwise desired uses. Similarly, not every location is in an equivalent condition: some areas have been heavily degraded by past human activity, leading to forest loss, roads, other impervious area, wetland fill, and well withdrawals, for example. Other areas have barely been affected by past human activity.

Thus, remedial management actions do not need to be uniform across a watershed. The greatest attention should presumably be paid where the effectiveness of watershed processes are most important and validated by data. The type of actions taken in these priority areas should depend on whether conditions are already degraded or simply need to be protected from future harm. This results in a conceptual “management matrix” (Figure 2), where four major strategies for management actions can be applied to specific assessment units and locations within a watershed; *Protection, Restoration, Conservation, Development*. The degree of precision and confidence in management prescriptions would be limited only by the quality and resolution of the data that underlie the designations and the certainty about their actual relationship to water flow, water quality, channel, and biological responses.

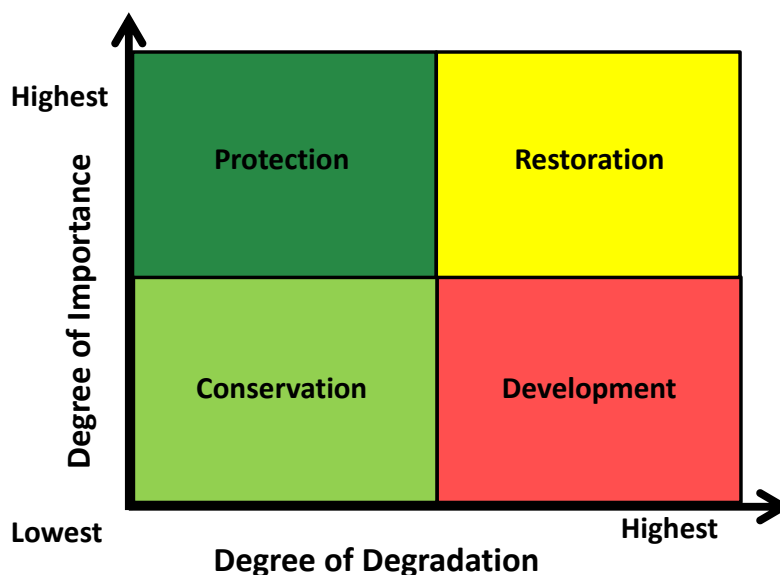


Figure 2. Watershed management matrix (from Stanley et al. 2011).

The management matrix categorizes watershed areas based on their degree of importance to water flow in the watershed (the vertical axis of Figure 2) and the degree of degradation they have experienced (the horizontal axis). So, for instance, areas that are categorized as *Restoration* are those that are judged most important to water resource functions and have also experienced the greatest degradation. Conversely, locations with relatively high water flow importance but low degradation from human activity are recommended for a lower level of management attention—*Protection* (i.e., from future impacts).

Watershed areas that the management matrix recommends as *Conservation* or *Development*¹ are those that have relatively lower levels of overall water flow process importance. If these areas have experienced high degradation, they may not be suitable for full restoration or protection and are likely to be the parts of a landscape best suited for development. This designation assumes that development would have less additional impact to water flow processes (than elsewhere) due to the lower overall importance. However, the actual sensitivity of water flow processes to new development in these areas isn’t known, relative to higher importance areas. These are important assumptions and limitations with respect to management strategy designation in Watershed Characterization. If these low importance areas have experienced relatively little degradation, they may be most appropriately maintained in their current state of conservation.

Because it has been applied across the entire Puget Sound region, Watershed Characterization relies on relatively coarse data and so distinguishes only relatively coarse sub-watershed areas. Its basic “assessment units” (AUs) cover 1 to 10 square miles, and therefore it can provide overarching guidance but must be supported by more site-specific information that directs

¹ *Development* is defined broadly as part of the Watershed Characterization process and does not refer to any specific type or intensity of land use.

recommendations of activities and actions. The Stillaguamish TMDL Project has integrated these multiple spatial scales to incorporate not only the guidance provided for AUs as a unit but also more localized reach- and site-scale data collected as part of the project, in order to identify conditions and recommend projects to improve temperature conditions across the Stillaguamish River watershed.

Using Watershed Characterization to Implement the Temperature TMDL

The value of the Watershed Characterization approach here is in helping to identify those areas that should be targeted first for implementing actions that can best support achieving the TMDL temperature criteria. Stream segments for which the Watershed Characterization predicts relatively high water flow importance and low water flow degradation are anticipated to be most likely to support suitable temperatures for fish species such as salmon at the present time. These areas warrant the greatest degree of protection from future degradation, because their overall temperature condition should already be acceptable and they are key to maintaining those beneficial conditions. In contrast, locations with high importance but *high* degradation are likely less able now (or potentially in the future) to support suitable water temperatures for fish without more active efforts at restoration. These assumptions were tested as part of our evaluation of temperature conditions in comparison to Watershed Characterization results, with the hope that Watershed Characterization results can help validate direction to efforts to implement the TMDL.

Watershed Characterization in the Stillaguamish Watershed

The 1,770-square-kilometer Stillaguamish River basin contains about 1,400 kilometers of stream channel that provides habitat for anadromous salmon in Snohomish and Skagit Counties, Washington (Pelletier and Bilhimer 2004). Ecology has listed several sections of the watershed under Section 303(d) of the Clean Water Act as exceeding water quality standards for temperature.

Ecology has divided the Stillaguamish watershed into 107 sub-watershed AUs that form the spatial framework for Watershed Characterization used for this project. The AUs are shown in Figure 3, along with the major subbasin drainages in the watershed.

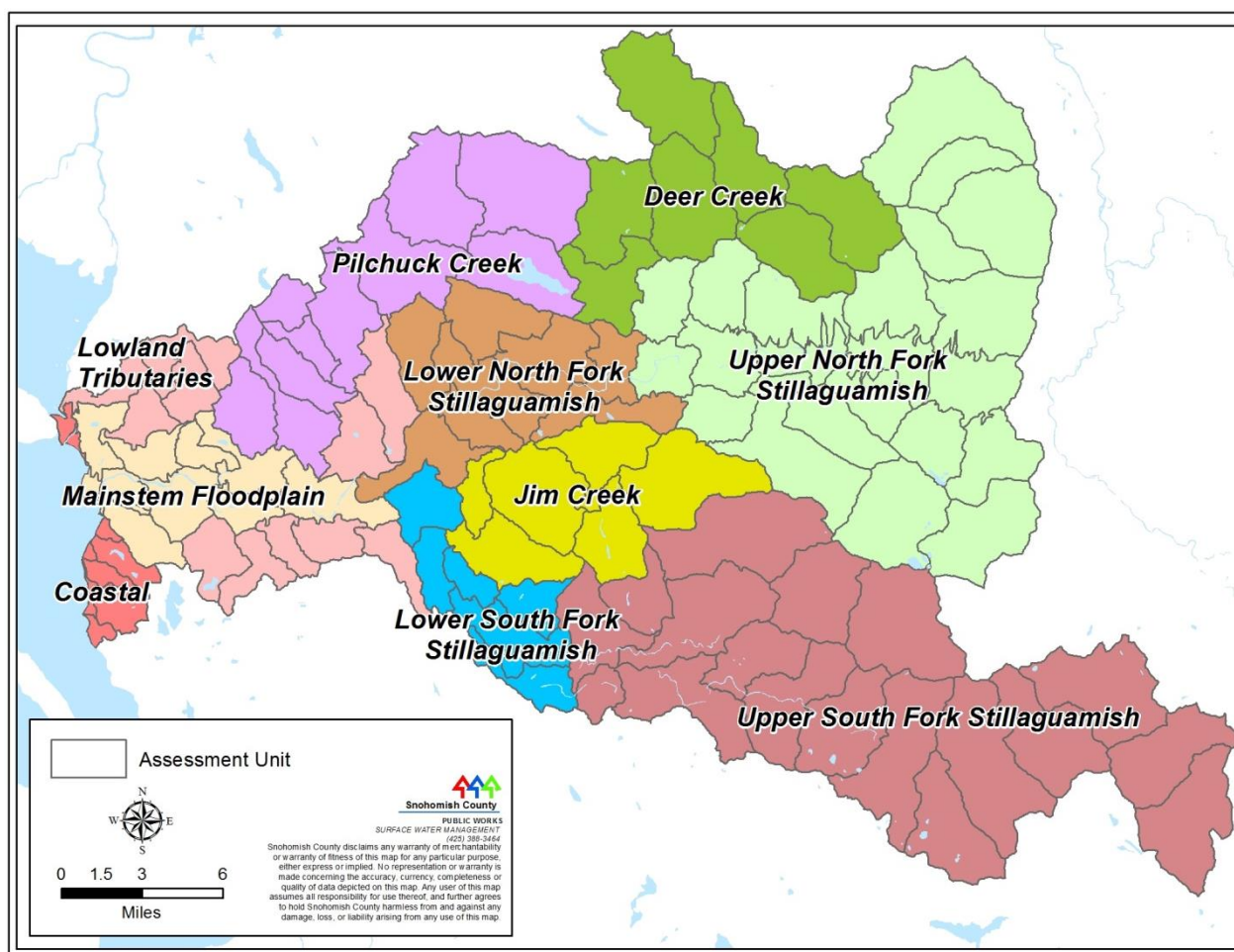


Figure 3. Natural drainage areas and 107 AUs designated by Ecology in the Stillaguamish watershed.

Stillaguamish Watershed Management Categories

Based on the areas of water flow importance and degradation, the County has determined the management categories for each AU in the watershed (the complete report, including methodology is provided in Appendix C). Figure 4 shows the spatial distribution of areas expected to be best suited for *Restoration*, *Protection*, *Conservation*, or *Development*, as characterized by the management matrix approach (see Figure 2).

These management categories are based on separate, but additive, evaluation of water flow importance for each water flow process component – *Delivery*, *Surface Storage*, *Recharge*, and *Discharge* and a combined *Groundwater* component. Even AUs with lower overall importance may have one or more model components that have moderate-high to high importance, so sub-categories of water flow processes may be important to consider in terms of the relative effects of those model components on actual flow, temperature, or other channel or biological response, as highlighted below.

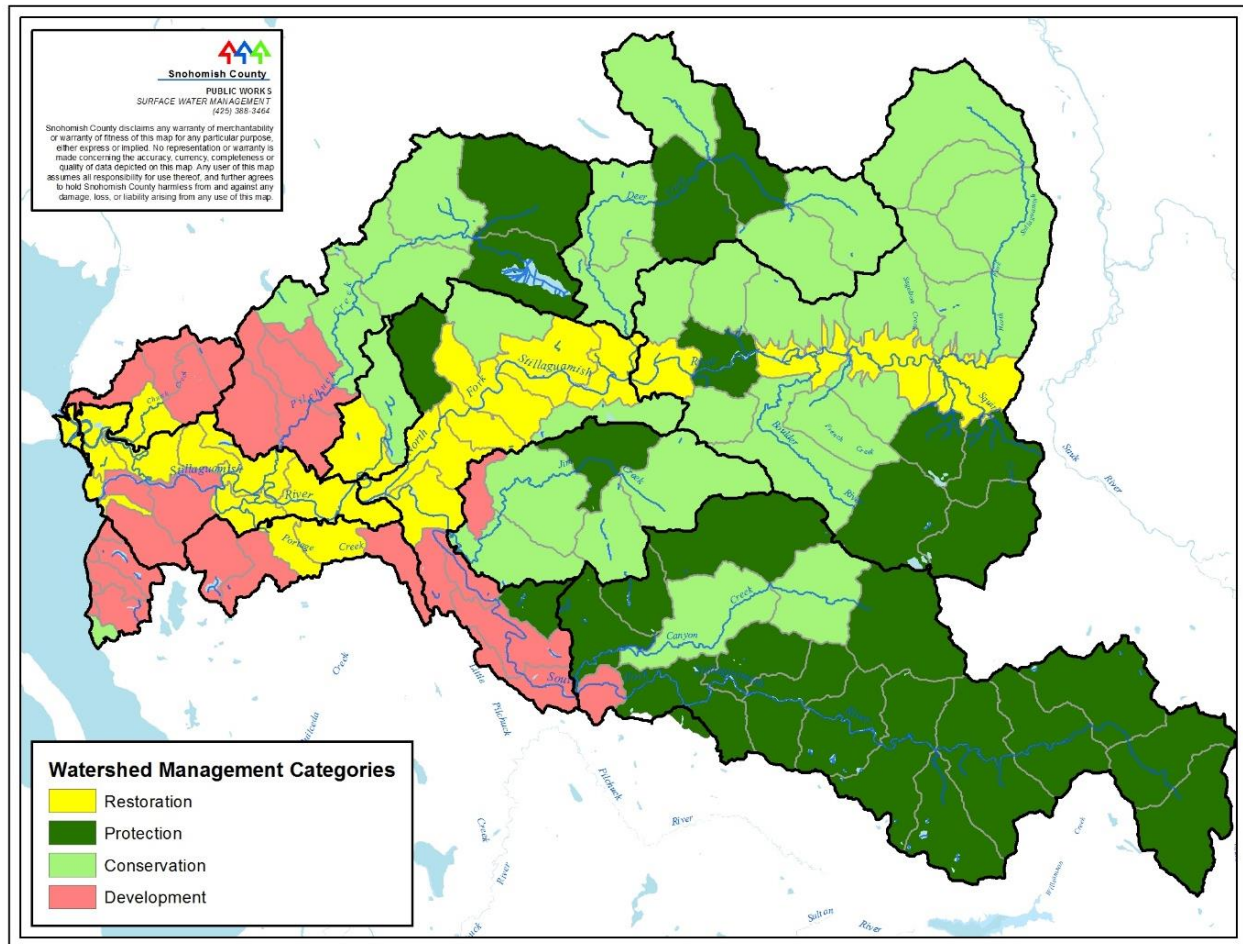


Figure 4. Map showing management matrix category for each AU. The black boundaries represent the major drainage areas in the watershed and the gray boundaries show individual AUs.

IMPROVING TEMPERATURE CONDITIONS IN THE WATERSHED

Studies Conducted

From 2010 to 2012, the County conducted a variety of studies to assess temperature conditions in the watershed (Figure 5):

- Thermal infrared imagery mapping: FLIR (forward-looking infrared) imagery commissioned by Ecology in September 2001 was used to identify and map areas with colder or warmer surface water compared with upstream median river surface temperatures (termed *anomalies*) (Appendix D). A total of 129 cold-water anomalies and 97 warm-water anomalies were identified. These were categorized by the inferred source of the anomaly (tributary, seep, side channel, floodplain, and hyporheic), the size of effect, and relative temperature difference relative to the surrounding conditions.

- Thermal profiling: Water temperatures along the streambed of the channel thalweg were measured along eight river reaches in Pilchuck Creek, Jim Creek, North Fork Stillaguamish, and South Fork Stillaguamish during low-flow conditions in August 2011 (Appendix E), when temperatures were presumably at or near their maximum. Temperatures and depths were measured using a probe towed behind a raft moving downstream at ambient stream velocity.
- Seepage study: Along Jim and Pilchuck Creeks, detailed measurements of flow were made in September 2011 and 2012 to identify where groundwater either discharges into a stream (a “gaining reach”) or is recharged by the stream water (a “losing reach”) (Appendix F). By measuring flow nearly simultaneously at multiple points along the stream, seepage studies can provide an estimate of interactions between groundwater and surface flow. Any relative change in flow between measurement points not accounted for by all other surface water inflows or outflows can be assumed to reflect water exchanged between the stream and groundwater storage (Sinclair and Pitz 1999). Groundwater inflow normally is colder than surface water, so water temperature may also be an indicator of seepage exchange. Flow gaining and flow losing reaches were identified in this study.
- Baseflow analysis: Baseflow is the portion of total flow that is generated from groundwater discharge, and it is the critical component of flow during the summer when stream temperatures are highest. The baseflow analysis summarized the metrics that characterize low flow using data from historical and current stream gaging (Appendix G).
- Temperature probe deployment: Direct and continuous measurements of temperature were collected from 2008 to 2012 across the watershed. Results were evaluated based on temperature criteria, channel type, and Watershed Characterization results (Appendix H).

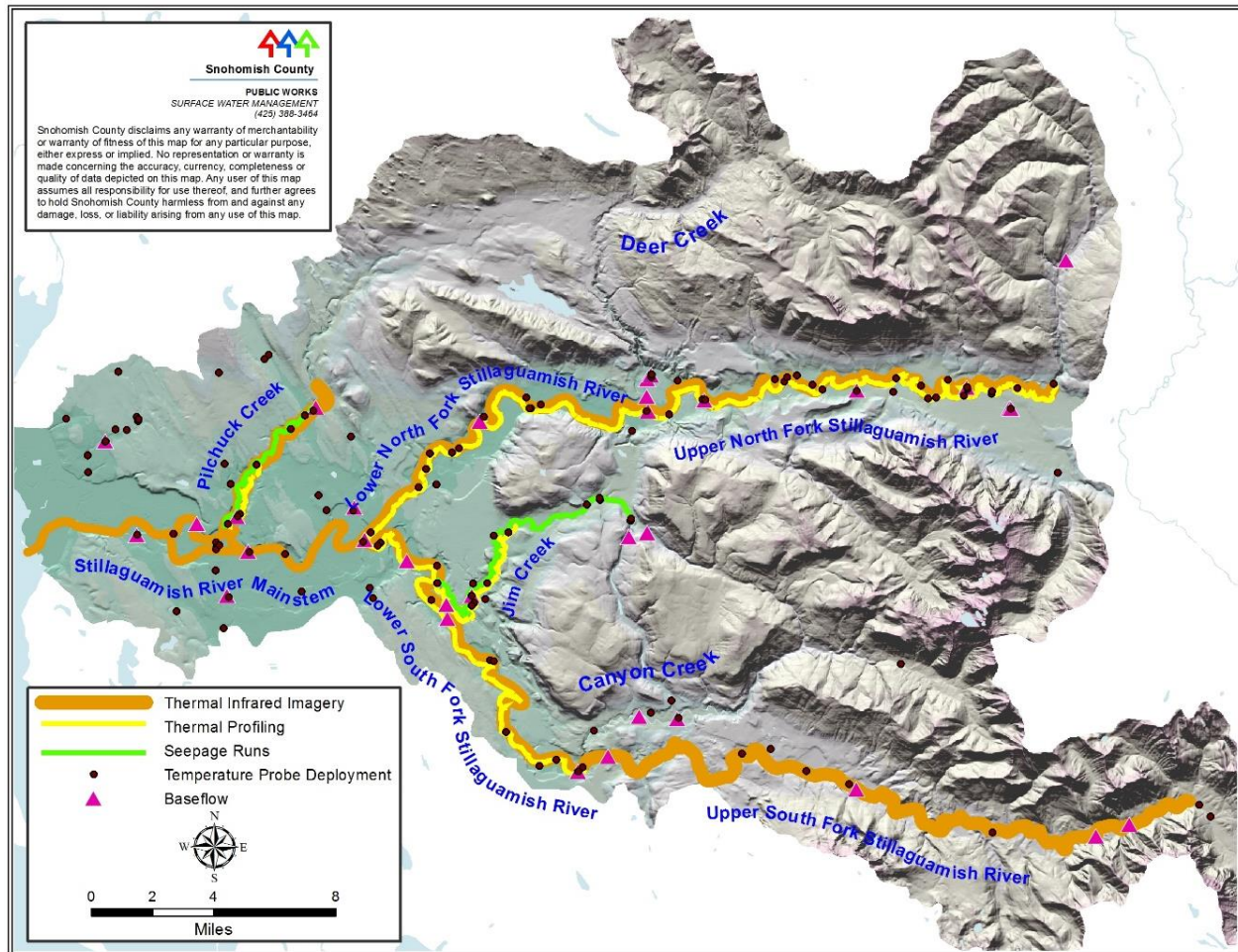


Figure 5. Locations of data collection to assess temperature conditions in the Stillaguamish River basin.

Temperature Criteria in the Stillaguamish Watershed

Ecology has set three temperature criteria for fish use in the Stillaguamish River basin, depending on location (12°C, 16°C, and 17.5°C) (Water Quality Program 2012). Figure 6 shows where measured temperatures have met or exceed these fish-use criteria across the watershed, based on the temperature threshold for each specific location. This map also shows the spatial relationships between the measured temperature data and the Watershed Characterization management matrix categories for each AU.

For the most part, the AUs recommended for restoration do show widespread locations with temperature exceedance. This is particularly apparent along the North Fork, mainstem Stillaguamish, and lower South Fork. Other, more scattered areas of temperature exceedance are present along the Upper South Fork, Jim Creek, and Pilchuck Creek, primarily in areas identified as *Development* (i.e., high degradation but low water-flow importance). Only a few measurement sites are located in *Protection* AUs, and most of these also show water temperature exceedances, which can be attributed, in part to their lower temperature standard (12°C).

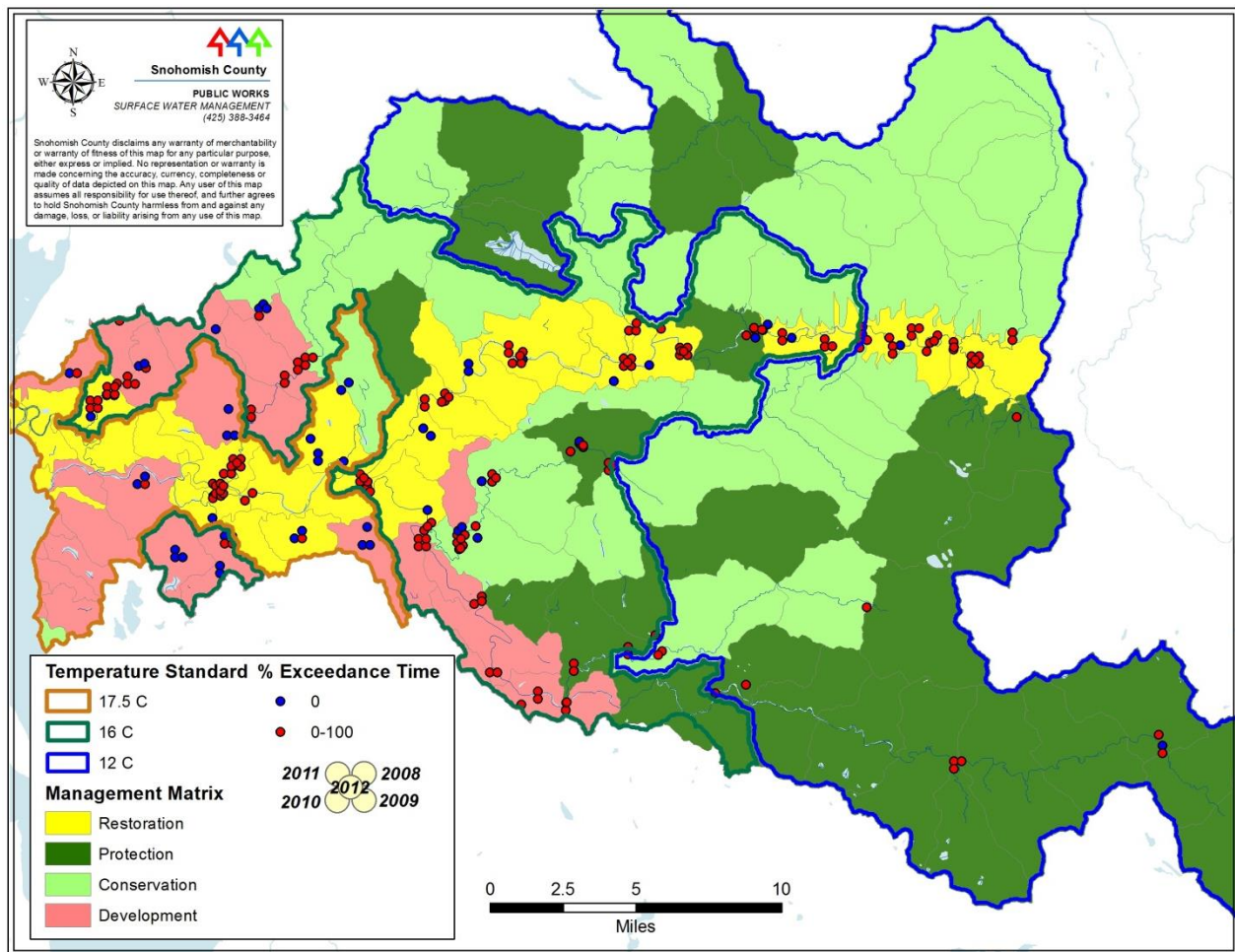


Figure 6. Measured water temperatures overlaid on fish-use temperature criteria and Watershed Characterization management matrix results. Measurements are based on the 7-day average daily maximum temperature, which was measured each summer from 2008 to 2012. Some locations meet or exceed temperature criteria depending on the year sampled.

At the same time, for 58 tributary locations among 39 AUs, we found cooler water temperatures were significantly correlated with relative water *Recharge* importance and the *Groundwater* component of the water flow importance model (Appendix H). Water temperature was not correlated with AU drainage area (2-10 mi²), percent riparian buffer forest cover (within 150 feet), any other water flow component process, overall importance or overall degradation. This does not mean water temperature does not respond to these conditions, only that a response was not detected among the AUs tested.

For 38 floodplain and tributary AUs containing cold-water anomalies mapped from infrared imagery (Appendix D), we found significantly higher count and thermal effect of anomalies for AUs with greater *Groundwater* flow importance. For tributaries only, the thermal effect (but not count) was significant. These results suggest that the combined influence of *Recharge* and *Discharge* as components of the *Groundwater* flow process have relatively more influence on summer maximum water temperature than other components of the Watershed Characterization.

With this in mind, we mapped the AUs that contained a different management matrix category recommendation for the *Groundwater* flow process. In particular, we zoom into AUs (crosshatched in Figure 7) that have a recommendation for *Groundwater* other than *Development*. For two AUs (Vos Creek and Engebretsen near Granite Falls), the *Groundwater* management category is *Restoration* rather than *Development*. Attention to discrete water flow processes with relatively more importance than represented in the overall management matrix allows more specific management strategies to be developed for AUs that otherwise are ranked similarly.

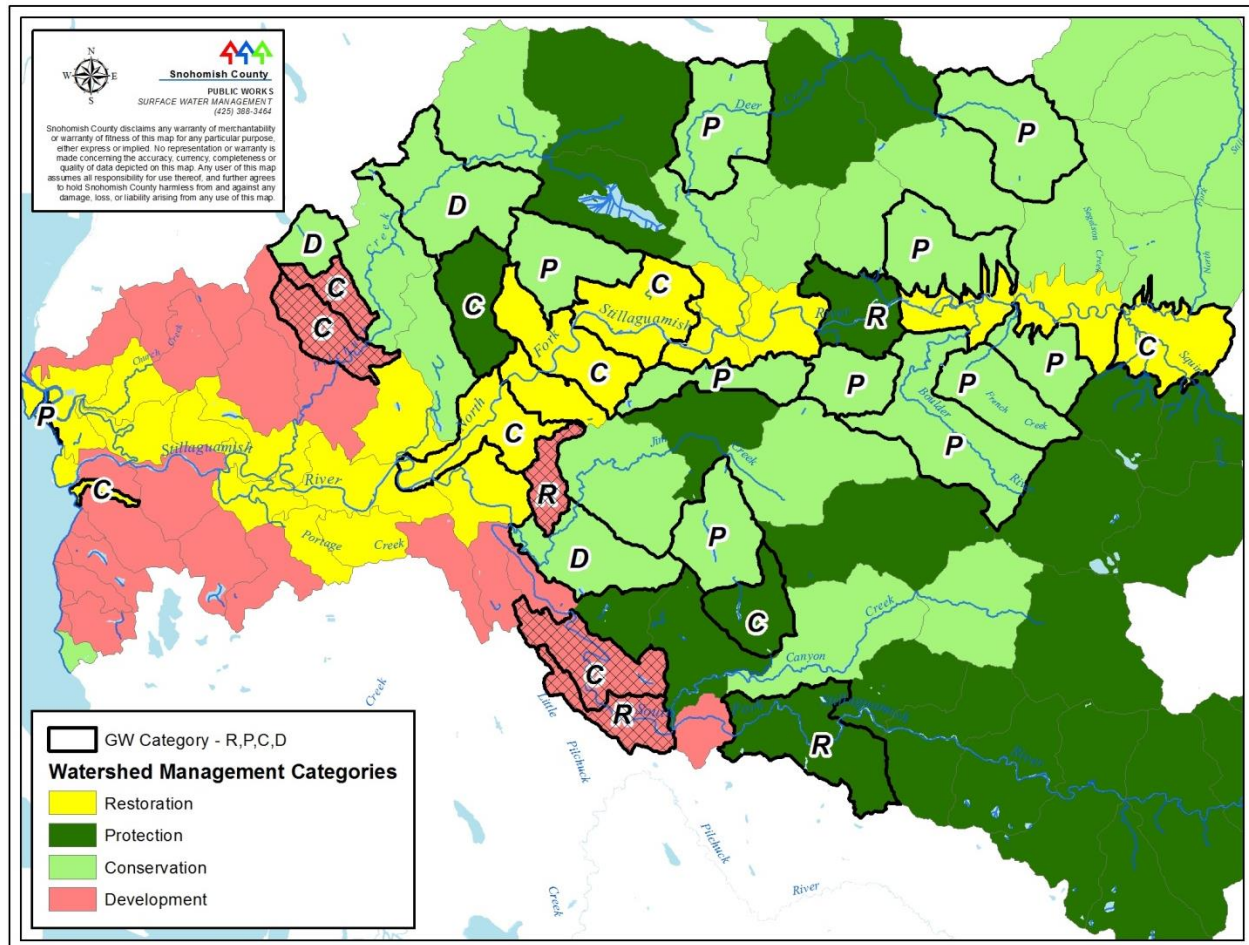


Figure 7. Zoomed view of AUs with management matrix category recommendations (labeled) for the *Groundwater* flow process that differ from the overall management matrix results (Figure 4), particularly for AUs in the *Development* category (cross-hatched).

General Concepts

General management concepts to address temperature impairments for three spatial scales are included in Table 1. This table includes goals supported by the temperature results at the AU scale, as well as the point locations of summer critical temperature monitoring described in other reports (Appendices). The three general spatial scales as follows:

1. The subbasin (AUs), where flow and temperature are influenced by protection and restoration of water flow process components, notably *Recharge*, *Discharge* and *Groundwater*.
2. The whole-river or stream-reach scale, where heating is broadly limited by the presence and absence of shading and surface-groundwater interactions (flow gain or loss)
3. The habitat-unit scale where the frequency, source, magnitude and habitat quality of thermal refuges may be manipulated structurally in the short-term to increase temperature benefits and made more resilient to long-term climate change as part of protection and restoration of the first two strategies.

Other supporting data from mapping cold-water anomalies and conducting reach-scale flow and temperature evaluation are incorporated into the medium spatial scale.

Table 1. Multi-scale water temperature management concepts.

Spatial Scale	Large- AUs (1-10km²)	Medium – River/ stream reach Scale (100-1000m)	Small- in channel Habitat Units (10-100m²)
Goals	Protecting & restoring water flow processes – <i>Delivery/ Surface Storage/ Recharge/Discharge</i>	Improving shading/ future LWD recruitment/ complex channel patterns and flow routing in floodplains	Enhancing habitat & hydraulic complexity and connections for thermal refuge at point locations of cold discharge
Supporting Info./data	Watershed Characterization/ Hydrogeology/ Flow measurement (seepage runs and baseflow analysis)	Shade Deficits/ Bank armoring/ Channel morphology/ Floodplain connectivity/ Seepage runs/ FLIR imagery-mapping/ Longitudinal thermal profiling	Site-based summer temperature/ pool formation & stratification /side channel connectivity/ tributary junctions/ thermal profiling/ TIR imagery
Action/ Activity	Promote AU-scale solutions for targeted water flow process protection and restoration – focus on <i>Recharge/Discharge</i>	Riparian planting/ floodplain acquisition and restoration/ remove armoring to restore flow routing and channel forming processes	Construct Log jams/ connect side channels/ enhance tributary confluences
Response time,	Long-term (>20 years)	Medium term (5-20 years)	Short-term (1-10 years)

Protection

Identifying and protecting the sources of flow that produce larger and cooler temperature flow to rivers is important, particularly where there is a greater temperature difference between the source and adjacent ambient river water. Tributaries and springs may be more stable and predictable by site and relative flow contribution over long time periods (>100 years) compared to side channels or floodplain discharge locations that are re-worked by erosion, channel migration and re-deposition. At the same time, cold side channels act as important habitat units themselves, and may be relatively more important as thermal refuges in unconstrained floodplains where the difference between mainstem river temperature and side channels is greater (Appendix H). These may be thermal refuges in reaches which are otherwise thermally unsuitable.

For protection of cold-water sources, it can be assumed that larger cold-water refuges, created both by large temperature differences and higher flow volume, will be most persistent seasonally and annually, and may be influential over many habitat units. Water temperature in AUs with higher relative *Recharge* and *Groundwater* flow importance based on the Watershed Characterization was generally cooler than in locations with lower *Groundwater* flow importance. Although degradation to this water flow process was not correlated with increasing water temperature, limiting degradation to recharge and focusing on locations for protection that yield higher flow per unit area will protect individual locations with refuge and enhancement potential. Larger thermal anomalies from larger tributary flow may also create fish habitat suitability as a result of stream confluence effects including sediment deposition, reduced channel slope, and higher woody debris loading (Kiffney et al. 2006; Rice et al. 2006). The Boulder River confluence with the North Fork Stillaguamish River is a good example of such confluence effects.

For tributaries located in the 17.5 °C areas, actions that sustain summer low flow, protect or improve shading, and protect or improve connectivity to locations of cold-water discharge will be beneficial for habitat and temperature suitability in these streams and at their confluences with the mainstem Stillaguamish River. These locations may mitigate some of the future habitat risk of temperature increases due to effects from climate change. Counter-intuitively, protecting existing conditions may be more challenging in higher elevations and headwater locations (that are un-developed) due to their flow sensitivity to changes between climate phases (Appendix G). Higher elevation streams and rivers currently fed by snow-pack are predicted to become more rain-dominated and therefore will have lower summer flow volume, in addition to predicted higher air temperature (Battin et al. 2007). Lower elevation, Puget Lowland locations were less sensitive to the modeled climate change scenarios and are locations where riparian buffer width regulations have been implemented, and increased over time, as part of “growth management.” Protecting tributaries and smaller cold-water refuges at lower elevations may be more feasible than similar actions at higher elevations. This would be true for protection of colder side channel habitat and floodplain discharge locations as well, especially in lowland areas where temperature anomalies are cold and relatively rare along the warmer mainstem river.

Restoration

At the risk of over-simplification, restoration at the habitat-unit scale can be described as leading to “more,” “bigger,” or “better” temperature response or “favorableness” as previously described by Torgersen et al. (2012). The blue shaded locations in Figure 8 depict how the concepts for restoration create more favorable temperature conditions, though some unfavorable (impaired) locations may not be restored.

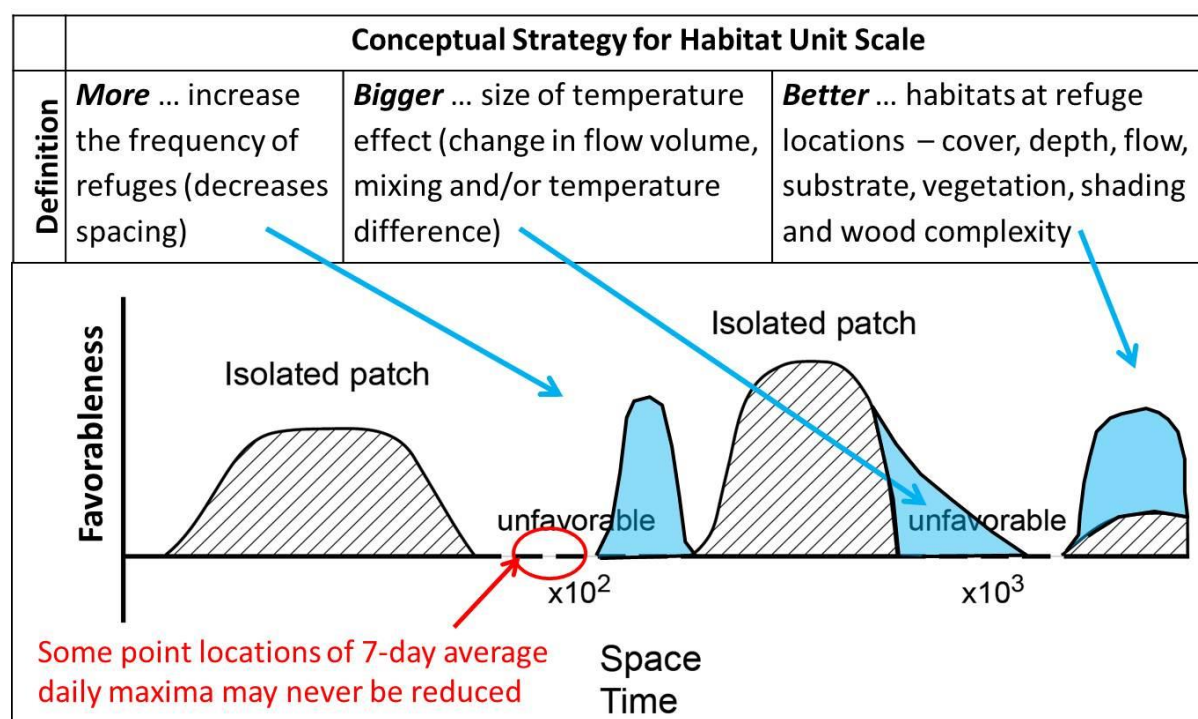


Figure 8. Depiction of improving water temperature “favorableness” as blue shaded locations as a result of actions leading to “more,” “bigger,” and “better” temperature conditions within a river continuum. Based on the graphic in Figure 2.4.2.2 in Torgersen et al. 2012.

More specifically, these conceptual strategies are applied in Table 2 to the channel and habitat types that were evaluated using continuous temperature monitoring (Appendix H) and which overlap the cold-water anomalies by source, as described in the Thermal Infrared Mapping report (Appendix D).

Table 2. Application of concepts in Table 1 and Figure 8 to habitat types found in Stillaguamish rivers.

Habitat Type	MoreRefuges	Bigger....Temperature Effect	Better.....Habitat
Tributary	Generally can't form new tributaries to increase frequency. Historical flow routing of tributaries may have been reduced due to road, railroad, ditch, or other linear conveyance / modification altering discharge(s). Kurylyk et al. (2014) describe groundwater pumping that could generate a focused discharge location (much like a tributary outlet).	Shading at tributary AU- and river-reach scales; smaller streams will show bigger effect in shorter time from shading effectiveness; Flow increase due to AU-scale restoration is uncertain but may be possible where water withdrawals can be mitigated.	Instream and confluence restoration based on stream size, channel classification and habitat condition, prioritized by cooler temperature and size effect, where summer low flow is high relative to drainage area.
Side Channel/ Floodplain	Short-term, connect remnant habitat if isolated and prioritize if fed by tributary, hillslope, or floodplain/springbrook discharge; Long-term, side channel formation and floodplain complexity from restoration helps mitigate effects of changing climate (Beechie et al. 2012).	Increasing length, width, flow and shading increases existing capacity for rearing due to a temperature and area effect.	Depends on habitat impairment of existing or potential side channels – restoration of cover, wood, edge habitat quality, pools, and riparian functions increase potential density of use by fish, thereby increasing capacity.
Mainstem	Short-term by increasing scour in flow gaining reaches to reduce spacing between cold-water inflow sources. Long-term, through floodplain reconnection, channel migration and backwater formation, channel aggradation, increased local scour, increased floodplain recharge, hyporheic discharge and shading to . reduce longitudinal gaps in suitability for salmon rearing and migration.	Cool inflow to mainstem either from upstream locations or reduce/delay mixing of cool water with flow shadowing effect (Kurylyk et al. 2014). Long-term, through floodplain reconnection, channel migration and backwater formation to increase area of better conditions.	Habitat improvement at existing mainstem locations of cold-water inflow from discrete locations or in flow-gaining reaches to improve cover, depth, velocity, structural complexity to support greater fish capacity.

Results from this study suggest side channel restoration, particularly in the lower North and South Forks Stillaguamish River should be effective for creating temperature benefits either by reconnecting historical side-channel locations and or restoring channel migration processes that help form side channels. Beechie et al. (2012) indicate it makes sense to focus resources on locations and actions where water temperature may be naturally resilient to climate changes. Side channels with the greatest water temperature difference by flow volume compared to the mainstem river are sites that potentially will be resilient to predicted climate change of increasing air temperature and lower river flow, particularly in flow gaining reaches of floodplains.

Side channels in the lower Stillaguamish River did not exhibit a large water temperature difference, on average, compared to the mainstem river at the locations sampled as part of this study. The average 7DADMax temperature among side channels was actually higher than the mainstem. At the same time, Cold-water refuges in lower Stillaguamish River mainstem locations did not usually derive from tributary inflow as classified using thermal infrared imagery (Appendix D). Nevertheless, the lower mainstem Stillaguamish River is in a wider, permeable floodplain with (presumed) hydraulic connectivity among floodplain channels that receive discharge from shallow groundwater storage in adjacent alluvial terraces.

A cold groundwater discharge has been observed in the excavated North Meander side channel restoration project (Leonetti et al. 2009). Other conceptual projects, such as excavation of a South Meander side channel would also create temperature benefits due to its close proximity to Portage Creek, a cold-water discharge to the mainstem Stillaguamish River. Moreover, side channels, as a habitat type have been significantly reduced in size or lost over time due to other land uses (Pess et al. 1999). Therefore restoration of side channel area for rearing capacity in the lower mainstem Stillaguamish makes sense even without the added benefit of temperature refuge. The benefits of this approach have also been described for the Willamette River, Oregon (Seedang et al. 2008). For cold-water fishes, thermal refuges will be found more frequently where connectivity to off-channel and side channel habitats are present. Thermal refuges may also be found in the floodplain sections of tributaries draining to the mainstem river. Temperatures may be restored at these locations by planting riparian vegetation for shading over smaller streams with longer flow pathways, and side-channel/ponded habitats that aren't subject to mainstem channel migration that erodes newly planted trees.

As mentioned, tributaries draining locations with a 17.5 °C temperature standard often did not exceed that standard and were on average as cool as many other tributaries in the watershed. Tributaries draining areas with a 12°C water temperature standard exceeded that standard most often, even though overall temperature was coldest among tributaries. However, many locations are well forested and already managed under various resource management plans. Therefore, apart from locations with real riparian restoration need, our results (Appendix H) suggest restoration should focus on tributaries draining locations with 16°C water temperature standard where water temperature is elevated and summer flow volume is large enough to influence (habitat-unit scale) the lower North Fork and South Fork Stillaguamish rivers. Moreover, these

streams may be vulnerable to heating in floodplains with developed uses where shading is absent and vegetation is in need of planting. The effectiveness of these measures depends in part on stream width (larger streams can't be effectively shaded).

In the long term, an increasing amount and connectedness of cooler floodplain habitats will be created where more natural river channel migration can feasibly be restored so a diversity of channels, habitat types, and floodplain vegetation types form. These changes would be expected to provide cold-water refuge areas in summer for salmonids, as well as greater floodplain rearing capacity in winter and spring during typically higher river flow when juvenile anadromous salmon migrate to Puget Sound. Improving mainstem river temperatures by restoring shading in buffers along the lower Stillaguamish, North Fork Stillaguamish, South Fork Stillaguamish, Deer Creek, and Pilchuck Creek, in particular, will take a long time but is needed. At the same time, some existing plantings along the larger rivers have already been eroded from their banks. As suggested above, in the long run, restoring more functional river corridors will be the best approach to improving the availability of suitable water temperature.

RECOMMENDATIONS FOR IMPLEMENTATION

Potential actions for restoration and protection to improve temperature conditions in the Stillaguamish watershed are listed by AU in Appendix B (Table B-1) and project locations are shown in Figure 9 and Figure 10. The projects are derived from our synthesis of studies and support the following objectives:

1. Enhance stream confluence habitat complexity at locations with cold-water refuges to improve habitat conditions at locations where good thermal conditions are likely to occur and persist, notably at tributary junctions or side channel inlets/outlets.
2. Connect or enhance floodplain habitats, such as abandoned or blocked side channels, with good or potential cold-water sources.
3. Restore river meander processes that can lead to creation of multiple channel and habitat types within the floodplain to sustain temperature refuges, particularly in river reaches where flow gain occurs.
4. Restore deep pools to promote groundwater inflow to channel by targeting locations where seepage occurs with poor existing pool habitat, and where the depth of streambed gravel to bedrock is 1 meter or more.
5. Enhance recharge to support summer baseflow and control stream temperature by preserving flow volume (therefore increasing resistance to heating).

These objectives are not prioritized, nor are potential projects. These actions are aimed at improving conditions at either a habitat unit scale (10 to 100 square meters) or a river or stream reach scale (100 to 1,000 linear meters of channel extent). These projects do not necessarily address the protection or restoration of AU-scale conditions, including degradation, based on

Watershed Characterization — instead, they primarily focus on smaller scale treatments that attempt to improve temperature conditions in specific sites or river reaches based on our conclusions about AU flow processes in combination with the supporting studies (Appendices).

The projects suggested here are not exhaustive of all possible strategies, ideas, data, and stakeholder interests that could address this habitat and water quality problem, and project sponsors may not be interested in all project types or locations. Recommendations are additive to those already proposed in the TMDL implementation plan to address shade deficits, thus these actions also are not prioritized relative to existing TMDL implementation recommendations. It should be noted that these project concepts require additional review and consideration of costs, benefits, and risks.

Potential projects have varying response times in which improvements in water temperature can be expected. Some will create a benefit within a few years (“short term”), whereas others can only be expected to show temperature improvement after a period of many years to a few decades (“medium term”). At the river reach scale, actions such as riparian planting, floodplain wetland restoration, and removal of armoring to restore flow can reduce the rate of heating along treated reaches and recharge floodplains. These actions tend to have a longer response time, which can be many decades depending on the channel width and the rate of vegetation regrowth (particularly trees, which provide the most extensive shade coverage). However, these benefits are typically sustainable and effective over longer periods as well.

At the habitat unit scale, habitat and hydraulic complexity and connectivity can be improved as well. Actions such as construction of logjams, connection of side channels, and enhancement of tributary confluences can create bigger and more numerous habitat refuge locations for fish, as well as creating local thermal refugia. Table B-1 suggests such actions as improving side channel connectivity at locations such as the Fortson Ponds, which provides significant cold water to the North Fork. Results from habitat unit scale actions may be seen in a relatively short time compared with river reach-scale actions (1 to 10 years), but may be less sustainable as woody debris decays, side channels aggrade, or channels migrate away from constructed project sites.

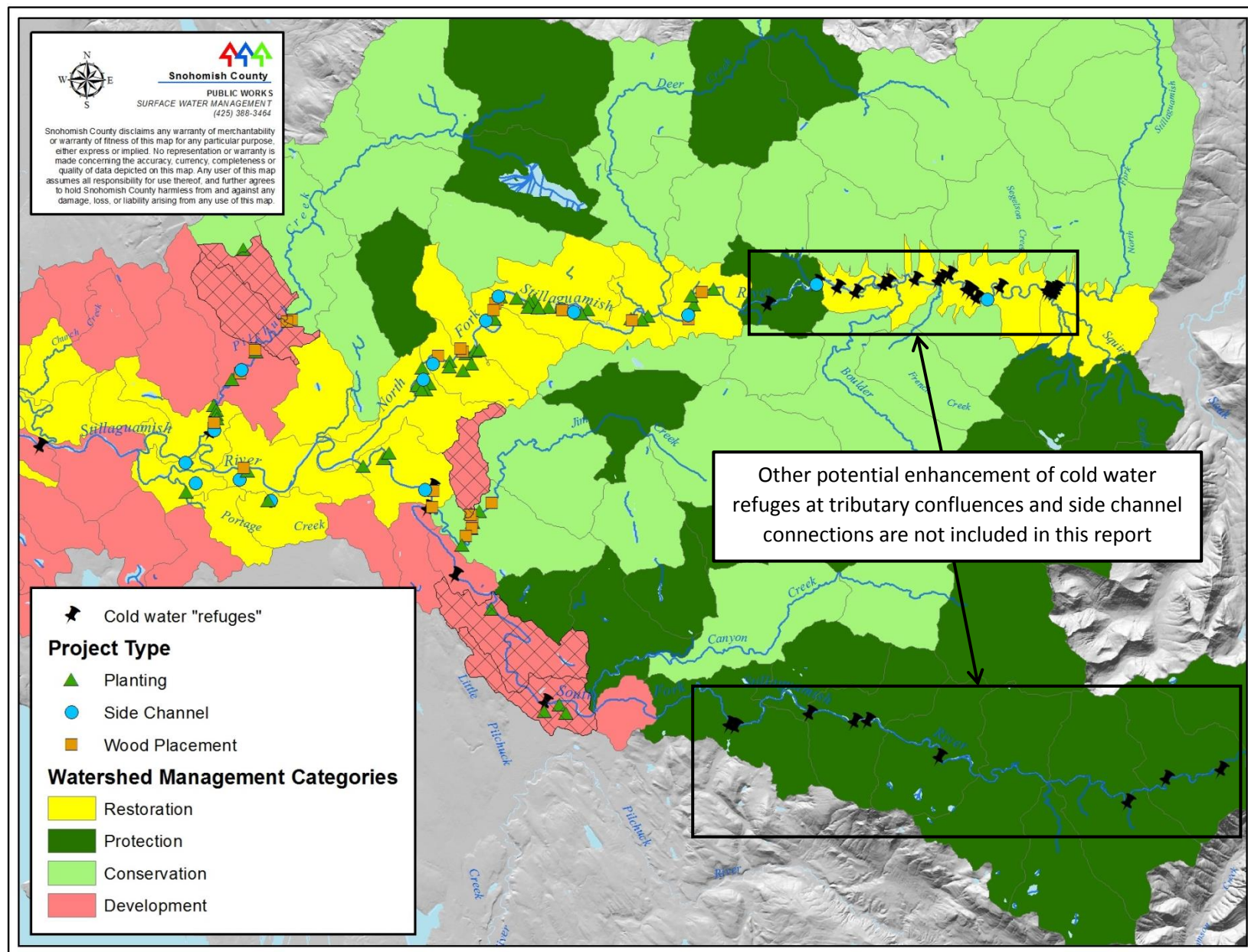


Figure 9. Potential project locations among management matrix areas. Cross-hatched *Development* AUs have *Groundwater*-specific management categories of *Restoration* or *Conservation* as in Figure 7. Larger cold-water refuges (35 of 96) are from Appendix D.

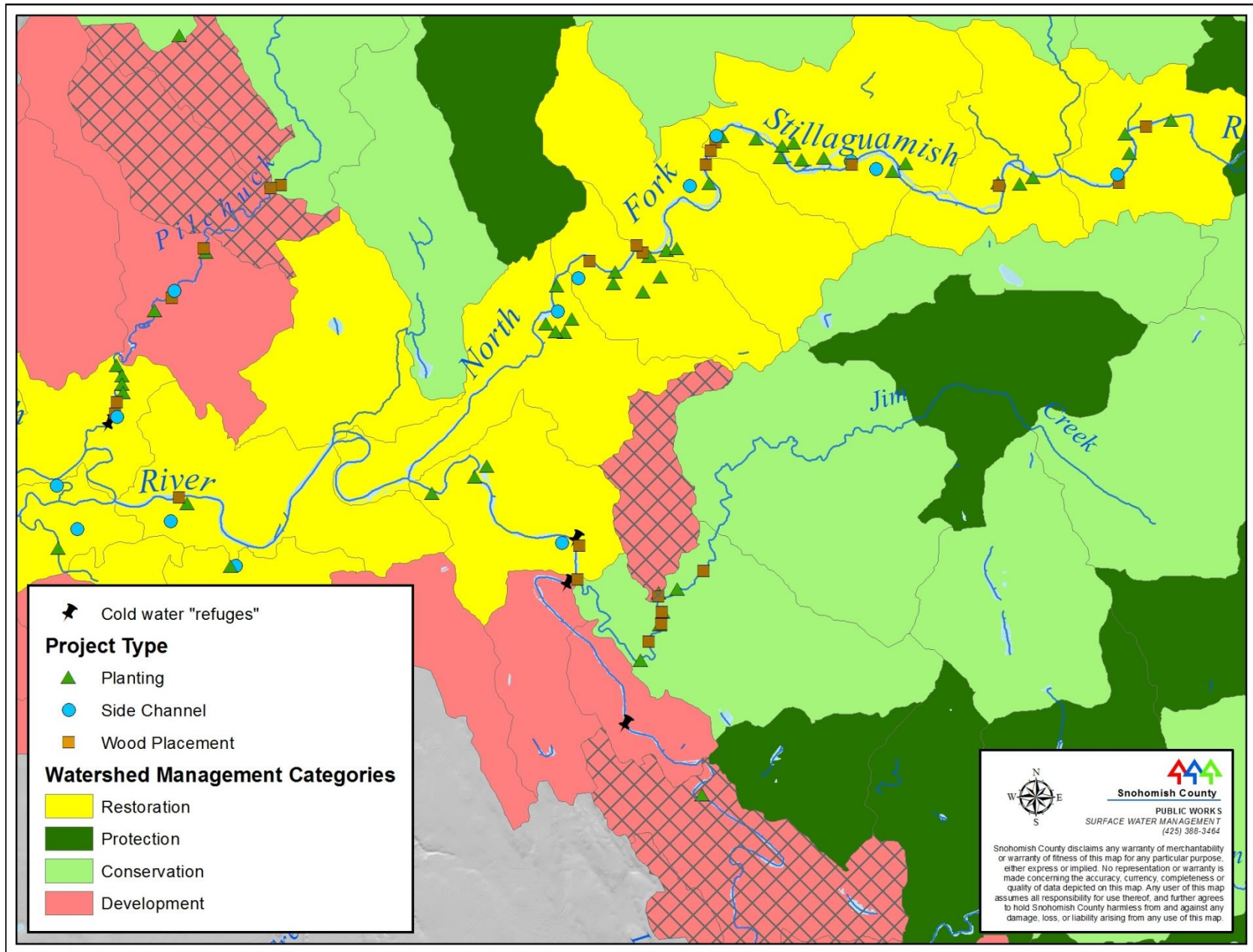


Figure 10. Zoomed version of Figure 9 that includes 84 out of 90 projects in Figure 9.

Conditions and Management in *Restoration* Assessment Units

Characterization of the *Restoration* Assessment Units

The *Restoration* AUs are so designated because they reflect the intersection of two conditions: high intrinsic importance of the area for sustaining water flow and temperature processes (such as an abundance of wetlands, unconstrained floodplains, or permeable soils) and a high degree of existing degradation of those features. Thus, they are most severely compromised, but their underlying attributes make them most potentially valuable for supporting a healthy aquatic ecosystem. Restoration of these beneficial attributes in these key areas is therefore the highest priority for management action across the Stillaguamish watershed.

Generally, *Restoration*-designated AUs are located along the mainstem of the North Fork Stillaguamish River up to its headwaters, and in the lower reaches of the North Fork and South Fork, Pilchuck Creek, Portage Creek, and the lower mainstem Stillaguamish River to its confluence with Puget Sound. Available data, primarily from the component studies of this project that cover these reaches, support this designation—in particular, they show pervasively high temperatures in the North and South Forks, mainstem, and lowermost Pilchuck Creek, together with multiple groundwater seeps and gaining reaches that reflect the intrinsic importance of the underlying water flow processes.

Application and Management Recommendations

Given this context, the following AUs within natural drainage areas are identified as being most appropriate for focused restoration efforts. Potential projects are shown in Figure 9 and Figure 10 and are listed in Appendix Table B-1:

Mainstem Stillaguamish

The entire mainstem river, from the confluence of the North and South Forks down to Puget Sound is highlighted by the Watershed Characterization for *Restoration*. To identify individual locations, a primary data source available along this reach was the FLIR temperature survey, which identified specific locations of cold-water anomalies (and “refuges”) compared with the median stream temperature. In particular, ten cold-water anomalies were identified in the mainstem from its mouth to the North and South Forks confluence.

Cold-water anomalies in the mainstem are thought to be relatively important, despite their small number, because the FLIR study found that they were more than 2°C colder than the median river temperature, which suggests that they may be functioning as thermal refugia (Torgersen et al. 2012). It also suggests that these anomalies are associated with groundwater inflow, particularly from side channels. Restoration of side channels would likely promote the most rapid recovery of closely spaced cold temperature anomalies, as well as increasing a habitat type that has been significantly lost in the lower mainstem. Locations such as South Slough, Blue Stilly Park, and South Meander, in particular, are recommended for side channel restoration feasibility. Other potential side channel restoration projects may be identified in the future or side channel conditions and functions may be created as a result of implementing other restoration actions, such as a “dike setback.”

Similar thermal refuges may also be found in the floodplain sections of tributaries draining to the mainstem river. Colder water may be restored at these locations by planting riparian vegetation for shading over smaller streams with longer flow pathways, and side-channel/ponded habitats. Specifically, continued planting is recommended along Portage Creek downstream from Fish Creek and in South Slough.

Pilchuck Creek

The lowermost reach of Pilchuck Creek is part of an identified *Restoration* AU. Data collected from the FLIR study, seepage studies, and longitudinal thermal profiling study indicate that there are some localized areas here and upstream where restoration actions would be beneficial. For the purposes of this study locations in Snohomish County are highlighted. These locations would benefit from riparian planting and wood placement, as outlined in Table B-1, with a particular emphasis on the lowermost areas where the importance of restoring water flow processes is anticipated to be greatest.

The three tributaries contributing the most surface flow to Pilchuck Creek are Tributary 80, an unnamed Stanwood-Bryant Road tributary, and Tributary 50065–50067 near the Stillaguamish Tribal Nursery. These tributaries accounted for 12% of Pilchuck Creek flow at the time of the 2011 seepage study, and each contribute colder water than the mainstem of Pilchuck Creek. Although the entire AUs containing these tributaries do not themselves have restoration designation, the benefits of the summer flow and cooler water at these locations could be further enhanced by improving shading in these stream buffers and increasing the habitat complexity at these tributary confluence locations by placing large woody debris where feasible. In Tributary 80, in particular, riparian planting has been implemented by Snohomish County and the Snohomish Conservation District on public and private land, respectively, to improve shading.

South Fork Stillaguamish

The lower South Fork Stillaguamish River includes one *Restoration* AU just upstream of its confluence with the North Fork, a designation that is supported by the high temperatures found in the FLIR study and temperature probes placed along this part of the channel network. The tributaries to the South Fork generally contribute colder water than the mainstem, notably from discharge along Jordan Road downstream from Jim Creek. This discharge originates from the Arlington Heights area. Individual locations for potential restoration are shown in Figure 9, Figure 10 and in Table B-1.

Apart from the lower South Fork Stillaguamish River, one other AU is recommended for *Restoration* based on the results from the *Groundwater* process component (Figure 7). This AU, located near Granite Falls and Engebretsen Rd. discharges tributary flow from several tributaries draining the historical, now isolated floodplain. Due to the exceedance of the temperature criteria for this area, restoration is recommended in the reach downstream of the Canyon Creek confluence to the downstream terminus of Engebretsen Rd. (Table B-1).

North Fork Stillaguamish

Nearly all of the AUs along the valley of the North Fork are identified for restoration by Watershed Characterization, reflecting the degree to which this key area for supporting water flow processes has been impacted by past human activity (e.g.; Pess et al. 1999; SSRP 2005). The majority of are located in the lower North Fork, where restoration has been limited.

The upper North Fork contains many sources of cold-water inflow from tributaries, according to both the thermal profiling and FLIR studies. Existing and historical side channels in this area may benefit from reconnection or enhancement given the relatively large temperature difference between side channels and mainstem. For instance, at Fortson Ponds, where there is cold-water inflow to the Upper North Fork, improvements to side channel connectivity and increased area are recommended and are in the progress of implementation

In general, studies indicate that the lower North Fork AUs are more degraded and will require more restoration than the upper North Fork both in terms of AU characteristics and in-channel conditions (Leonetti et al. 2015). The frequency of discrete cold-water inputs declines downstream and losses of side channel habitats are greater (Pess et al. 1999). Consistent with this, a majority of potential side channel and wood placement locations identified here are located along the lower North Fork Stillaguamish River, but not at all tributary confluence locations.

Downstream from Cicero there are locations of cold-water inflow and general reach cooling indicating greater groundwater discharge. Wood jams that increase flow divergence to side channels or create channel migration toward cold water discharge along streambanks will help improve temperature and habitat characteristics for fish at discrete locations. Potential project locations are highlighted in Figure 9, Figure 10 and Table B-1, though projects are not identified for all locations of thermal refuge (identified in Appendix D). Finally, the sediment that blocked much of the North Fork Stillaguamish River after the devastating landslide in 2014 continues to erode and be transported downstream. It's not yet known how much sediment is filling existing side channels (and reducing habitat area for temperature refuge) and therefore whether side channel restoration would be premature to implement.

There are several stretches of warming in the lower North Fork that could be partially mitigated by improving shading, as shading is degraded along much of the lower North Fork Stillaguamish River. For instance, downstream from the Deer Creek confluence a 1-mile-long area benefits from cold tributary inflow from Hell Creek and groundwater seepage. This is followed by a rapidly warming area, suggesting the river reach here would benefit from restoration actions to improve shading. This location and others in the lower North Fork Stillaguamish were identified as having high shade deficit.

Jim Creek

Jim Creek has no AUs in the overall *Restoration* category and so is not predicted to be a promising candidate for active, widespread restoration efforts. A few reach-specific areas are potential restoration sites, however, as suggested by several of the supporting studies

(Appendices). The primary area of focus for Jim Creek restoration projects is near the confluence with Vos Creek and the areas immediately upstream and downstream of the confluence. Vos Creek contributes cooling inflow to Jim Creek based on the continuous temperature monitoring, thermal profiling and seepage study results. Approximately 16 percent of Jim Creek's baseflow comes from Vos Creek, which drains a large, deep, permeable glacial outwash AU (with relatively higher *Recharge* score in the Watershed Characterization). It also has a relatively short flow path length to the confluence with Jim Creek, so heating is limited. Vos Creek appears to moderate 2600 lineal feet of temperature in otherwise 2 miles of increasing water temperature in the lower three miles of Jim Creek. The Vos Creek AU was identified as a *Restoration* AU for the *Groundwater* flow process, even though it is designated as *Development* based on the overall water flow importance and degradation. The flow and temperature inflow substantiates the AU *Groundwater* flow characterization for Vos Creek.

The reach downstream of the Vos Creek confluence is a losing reach, suggesting that it receives no further groundwater input and would benefit from restorative actions such as stream shading and increasing wood loading (as would Vos Creek itself). Another potential restoration site suggested by supporting studies, particularly the thermal infrared imagery, is at the mouth of Jim Creek, near the confluence with the South Fork Stillaguamish River. Wood placement for habitat complexity and cover would benefit juvenile and adult salmon in both Jim Creek and those migrating by in the South Fork Stillaguamish River. Because the channel width of Jim Creek is relatively narrow, planting riparian vegetation should be effective at improving stream shading sooner than for larger rivers, and the two miles of Jim Creek mentioned above should be targeted.

Conditions and Management in *Protection* Assessment Units

Characterization of *Protection* Assessment Units

The *Protection* AUs are so designated because they encompass areas with high intrinsic importance for water flow processes (such as an abundance of wetlands, unconstrained floodplains, or permeable soils) that have not been highly degraded by human activity. They are predicted to be performing their hydrologic functions at a high level, and so the only necessary actions from a management perspective are those that can ensure that they will continue to do so, or to address localized areas of human impact that are not sufficiently pervasive to affect AU conditions as a whole. Thus, protection of the beneficial attributes in these key areas should be a high priority for management across the Stillaguamish watershed, because the greatest ongoing benefits can be achieved with the least cost.

Overall, *Protection*-designated AUs are located primarily in the upper headwaters of the South Fork Stillaguamish River, with additional scattered locations in the headwaters of Pilchuck Creek, Deer Creek, Canyon Creek, Jim Creek, the North Fork, and the Boulder River. Many of these areas are beyond the upstream limits of the various component studies that have been conducted; those data-collection efforts that have extended into these reaches provide mixed support for this designation. For example, AUs with higher *Groundwater* importance were observed to contain relatively higher count and temperature effect of cold-water thermal

anomalies mapped from thermal infrared imagery. Side channels in locations with a 12°C temperature standard were among the coldest habitats observed in summer. Other locations exceeded water temperature standards and more than elsewhere the percent exceedance rate appeared to correspond to temperature sensitivity hypothesized by Watershed Characterization.

Application and Management Recommendations

Given this context, the following AUs are identified as being most appropriate for protection efforts:

Mainstem

Although no mainstem AUs were identified as primarily requiring protection, the FLIR data indicate that smaller tributaries such as Church Creek, Armstrong Creek, Harvey Creek, Fish Creek, Portage Creek, Glade Bekken Creek, and Jackson Gulch Creek provide cold-water inflow to the mainstem and often these tributary temperatures are as cold as other tributaries in headwater locations; protection of the existing shading along these streams is important.

South Fork

Several South Fork AUs were designated as *Protection* AUs, especially in the upper South Fork, which has large areas of relatively cool water as indicated by the FLIR data. Thirty-seven cold-water anomalies were identified, of which 23 were from tributaries. Although the anomalies were relatively widely spaced, they were large compared with other streams in the watershed and are an important source of cold water for the watershed as a whole. In particular, the FLIR data indicates the presence of large cold-water refuges in the Robe Canyon in the upper South Fork, upstream of the Canyon Creek confluence. Protection of the water flow processes in these AUs, as well as minimizing degradation by protecting riparian shading is important for these AUs but also for the benefit of the South Fork Stillaguamish farther downstream.

North Fork

A small region of the North Fork drainage area is recommended for protection by Watershed Characterization, based on its limited disturbance and high importance for the overall health of the watershed. The cool water temperatures reported by thermal profiling and FLIR data studies support this. Additionally, considering the *Groundwater* flow importance results; this area would also have nine additional *Protection* AUs, rather than the *Conservation* management matrix category. This suggests the relatively greater weight of *Recharge* and *Discharge* importance for protection as part of the *Groundwater* component.

Squire Creek is important to the upper North Fork, as it contributes approximately 18 percent of the flow to the North Fork and provides a significant source of cold water. Squire Creek inflow results in extensive upstream (~1,800 feet) and downstream (~2,500 feet) cooling for the North Fork due to groundwater seepage. Thus, protecting the natural processes of water delivery, recharge, and groundwater connectivity, as well as maintaining instream flows and shading in Squire Creek, is critical to the maintenance of these high-quality conditions.

Pilchuck Creek

Two Pilchuck Creek AUs were designated as *Protection* units in the Watershed Characterization, due to their high importance for water flow processes and relatively low level of degradation. These areas have experienced minimal (permanent) disturbance and require little more than passive protection to maintain their function, partly due to the absence of significant residential development pressure.

Some additional, smaller areas meriting protection (and restoration) are identified from the thermal infrared imaging and seepage studies. The FLIR study identified 13 cold-water anomaly locations in lower Pilchuck Creek, which would benefit from protection. These cold-temperature anomalies were relatively small and slightly warmer than other anomalies in the watershed, but they were relatively densely spaced in the lower 7.2 miles. Cold-water anomalies appeared at locations discharging tributary flow or near floodplain deposits that may discharge shallow groundwater even where no channelized inflow is apparent. Six of the 13 anomalies were colder than median stream temperature by 2°C, suggesting they may function as localized thermal refugia.

Over the lowermost 0.5 miles of Pilchuck Creek, temperature declined significantly (FLIR study) and two cold-water anomalies were identified. This decline in temperature occurred downstream from the warmest stream segment in lower Pilchuck Creek, and is caused by diffuse groundwater inflow rather than by discrete cold-water inflow locations. This was confirmed by the longitudinal thermal profile and seepage study studies, which also noted a long area of cooling that spans many individual habitat units in this segment of the river and is attributed to groundwater inflow. The temperature difference over the survey distance is more than 1°C, probably forming a broad thermal refuge near the mouth of Pilchuck Creek. The conditions giving rise to these unusually cool temperatures should be protected and further enhanced if at all possible at the river reach scale. Protecting and improving stream shading from riparian vegetation is crucial and should be effective here, because Pilchuck Creek channel widths are sufficiently narrow (18–24 meters) for plantings to provide shade.

Jim Creek

One AU in the Jim Creek drainage area falls within the *Protection* management category. This area contains a relatively high percentage of permeable surfaces for recharge and relatively high extent of sloping wetlands for discharge. The characteristics contribute to relatively cool inflow from Knudsen Creek and other smaller tributaries along Jim Creek Road. Other areas of Jim Creek that experience cooling inflow from tributaries, especially Vos Creek, are particularly important areas for protection. Another prominent area of cooling is downstream of the Bear Creek confluence, through the Jim Creek canyon, where the greatest pool depth was observed during thermal profiling. The cooling extended over 1,700 feet; this is another strong candidate area for protection given its existing contribution of cold water to the channel network.

Conservation and Development Assessment Units

From the perspective offered by Watershed Characterization, those AUs designated as either *Conservation* or *Development* share a fundamental attribute in common—they are not likely to

have as great an importance for supporting watershed-scale processes. Thus, neither their protection (the *Conservation* category) nor their active restoration (the *Development* category) is anticipated to have the same degree of benefit as in the areas discussed above, unless action is focused on discrete water flow processes or degradation.

Measured water temperatures from *Development* AUs do not uniformly exceed their temperature criterion, in part because some are fed by cold water (presumably from deep aquifers), and in part because most of these AUs are in areas with the most liberal temperature standard (17.5°C). Any improvement in water temperatures in these AUs will likely be most successful through implementation of streamside planting or critical area protections for buffers to enhance shading. In most locations, these streams are relatively small, and so shading from riparian vegetation can be effective in limiting stream heating, if not in providing all riparian buffer functions and values. Several such projects have been identified in these areas (riparian buffer protection and planting); they have been included in the project table in Appendix B but at a lower level of priority, reflecting their likely lower significance to the temperature regime of the Stillaguamish watershed as a whole.

SUMMARY AND NEXT STEPS

Based on the integrated efforts of the County under the Stillaguamish TMDL Project, an ambitious but still only partially complete list of project actions has been compiled (Table B-1) to improve temperature conditions throughout the watershed. These recommended project actions are all at the site or reach scale. The most common recommended action is for enhanced riparian planting, which by providing shade offers one of the most direct treatments for high water temperatures.

Actions targeting the protection or restoration of features that support water flow processes at the AU scale would also help improve temperature conditions and the characteristics of several AUs warranting protection have been highlighted. AU-scale management actions have not been integrated into this table nor developed for each AU in the watershed. However, AU-scale actions comprise such activities as wetland enhancement, protection or replanting of upland forests, stormwater management, limits to development and floodplain management that will require different approaches to implementation other than at discrete project sites. Actions at the AU scale may have potentially greater cost, but also benefits that may be more sustainable in the long study for temperature and flow. Examples of actions to implement at the AU-scale based on protecting or treating water flow importance processes and degradation that affect temperature would be useful. However, cause and effect linkages of AU-scale characteristics on temperature response is still less-well understood than direct effects from shading or measurement of actual temperature contrasts (i.e., anomalies, refuges, confluences, stratification) that support identification of actions.

The next step in implementing the recommendations of the Stillaguamish TMDL Project should be the engagement of a diversity of stakeholders, particularly those with first-hand understanding of the river and a direct stake in the location and progress of prospective projects. This includes

both technical experts and streamside landowners, two groups who will be essential for identifying those actions with the greatest positive impact on temperature conditions and fish use in the watershed and for assessing their feasibility and supporting their implementation. The Centennial Clean Water grant agreement requires that this report be used to identify the locations of riparian plantings and numerous potential projects are proposed here.

Table B-1 is not intended to be a complete project list. As new data become available, additional projects will surely need to be considered. For instance, updated information about riparian conditions at relatively high resolution is expected to be generated from regional efforts based on newer vegetation classification and mapping approaches supported by the Puget Sound Partnership. Existing data on river and stream habitat conditions and locations of structural habitat impairment were not explicitly considered as part of project identification. However, additional projects could be considered not only based on temperature and flow considerations but also locations where habitat deficiencies exist. Conversely locations needing habitat improvement could be prioritized based on locations where temperature is more favorable for fish. It is presumed that new data will become available describing the supply, delivery and downstream accumulation of sediment in the North Fork Stillaguamish River from the 2014 SR530 landslide which could influence side channel restoration feasibility due to sedimentation.

Future data acquisition should also improve the detail of local and regional hydrogeology in areas being considered for management actions under this effort, which would help refine the priority and locations of specific treatments being proposed. As part of this project, seepage studies were only conducted in two locations, Pilchuck Creek and Jim Creek, but were very valuable in identifying reach scale contributions (or losses) to baseflow that both corroborated Watershed Characterization results at the AU-scale and helped explain the variable combination of reach-scale and site-scale temperature fluctuations and flow observations. Seepage studies at baseflow could be implemented more widely to support project development, particularly if observations of flow gain (or losses), temperature response, and fish use are correlated.

Because thermal infrared imaging from aircraft is usually infeasible over smaller streams due to tree cover, the thermal profiling accomplished in Pilchuck Creek, Jim Creek, and the upper North Fork Stillaguamish River likewise was invaluable in discriminating site scale (10-100 meters) and reach scale (100-1000 meters) changes in temperature characteristics that corroborated seepage study data (such as locations of groundwater inflow) and filled in longitudinal gaps in temperature variability between locations with continuously recording temperature probes.

Acquisition of additional temperature data throughout currently unsampled areas of the Stillaguamish watershed could aid in identifying other locations that are presently sustaining cold water temperatures and would warrant protection. Results from the Watershed Characterization and baseflow analysis can help target locations for more detailed investigation based on landscape scale attributes to find targets for protection, or that have impairments to either local riparian conditions or more broad-scale water flow processes requiring restoration. Thus, detailed characterization of those landscape features (e.g., wetlands, floodplains,

infiltrative soils) that support key water flow processes—and their impairment across this watershed—should continue, particularly given climate change scenarios. These additional data are unlikely to change the designation of AU categories based on Watershed Characterization, but will support ongoing refinements in the restoration and protection efforts designed to improve temperature conditions in the Stillaguamish River watershed.

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Appendix A. Overview of Grant Results

Watershed Characterization

The Watershed Characterization maps locations of water flow importance and relative degradation among 107 Assessment Units following department of Ecology's detailed methods (Stanley et al. 2011).

Results were used to describe how stream temperature may be influenced by the relative importance of water flow processes - *Delivery*, *Storage*, (*Recharge & Discharge – Groundwater*) – and *Degradation*.

58 Assessment Units (AUs) draining tributaries were used to test whether water temperature (the standardized 7-day average daily maximum C) in 2008-2012 was related to water flow process results.

Cooler water temperature among AUs was significantly correlated with relative water *Recharge* importance and the *Groundwater* component of the water flow importance model, though the relationship was weak.

Water temperature was not correlated with AU drainage area (2-10 mi²), percent riparian buffer forest cover, any other water flow importance process, overall importance or overall degradation.

For 38 floodplain and tributary AUs with cold-water inflow mapped from infrared imagery, we found significantly higher count and thermal effect (cold temperature x size) for AUs with greater *Groundwater* flow importance. For tributaries only, the thermal effect (but not count) was significant.

These results suggest that the combined influence of *Recharge* and *Discharge* as components of the *Groundwater* process have relatively more weight influencing water temperature than other model components of Watershed Characterization.

To our knowledge, this is the first evaluation of water flow responses based on hypothesis testing of the processes that Watershed Characterization in Puget Sound represents, and therefore validates it (at least partially) as a coarse screening tool for planning-level decision-support.

Baseflow (1911-2013)

Forty gages in the Stillaguamish watershed (1911-2013) are described for the period of record, drainage area, climate phase and computed average 7-day and 30-day averaged daily flow. A USGS Baseflow Index model (PART) was implemented for 34 gages for each year of useable data.

Variable low flow pattern between cool- and warm-climate phases (described by University of Washington) was persistent for decades. However, a sharp decline in flow in 1985 defined a break in flow response for this report, but which lagged the 1976-1977 North Pacific Ocean phase change.

The annual low flow in the NF Stillaguamish River was 55% higher in 1947-1984, compared to 1985-present, but flow has been significantly increasing in the NF Stillaguamish River since 1985. The nearby Skykomish and Sauk Rivers confirm the same low flow patterns between 1928-2013. Jim Creek, Pilchuck Creek, SF Stillaguamish River, and Squire Creek show similar patterns of flow response between climate phases, but have varying severity of responses (and limited datasets).

Squire Creek, the snow-dominated, headwater mountain stream appears to be more flow sensitive to climate phase changes compared to Pilchuck Creek and Jim Creek. Higher elevation, headwater streams

with relatively protected land conservation status may actually be more vulnerable to temperature increases based on flow sensitivity to climate change than some developed lowland locations. But, this warrants additional investigation.

Temperature Regime Analysis

129 cold-water inputs were identified in the Stillaguamish River, NF and SF Stillaguamish rivers, and in Pilchuck Creek from Thermal Infrared (TIR) imagery. 96 of these were considered cold-water “refuges.”

Cold-water refuges were classified by source (tributaries, floodplain, side channels, seep/springs, hyporheic) and estimated size of influence on the receiving river (*temperature difference x size*).

Half of all cold-water inputs were located in the NF Stillaguamish River where spacing (per mile) was most frequent due to cold-water discharge from side channels, floodplain locations and seeps/springs, in addition to tributaries. The SF Stillaguamish River was dominated by tributary sources.

Restoration of cold-water refuges in the North Fork will be supported by river and floodplain restoration, whereas restoration of cold-water refuges in the South Fork will be more based on AU restoration and habitat enhancement at tributary confluence locations.

Field-based thermal profiling using a continuously recording thermistor found numerous locations of tributary and groundwater inflow that mitigated downstream heating in Jim Creek and Pilchuck Creek, but also detected locations of rapid downstream heating.

Patches of colder water were often in (or downstream from) deeper pools in locations with groundwater inflow (seepage), suggesting restoration of pool scour in flow gaining reaches could provide temperature benefits as well as habitat improvement in Pilchuck and Jim creeks.

Between 2008-2012, 242 datasets of continuously recorded temperature were collected in summer in mainstems, side channels, and tributaries where temperature standards are 12, 16, or 17.5 Celsius.

The 7-day average daily maximum temperature, on average, was warmest in 2009 and 2010 and coolest in 2008 and 2011. Tributaries and side channels were coldest, exceeding temperature standards by 30% among all years. Mainstem locations were warmest, exceeding temperature standards by 70% among all years during the summer critical period (July 1-September 30).

- 17.5 C standard - tributaries were coolest and exceeded the standard only 2% of the time (1.4 days/year). Side channels were notably warm compared to elsewhere, but still may be temperature refuges in discrete locations.
- 16 C standard, side channels were coolest, then tributaries, compared to mainstem sites, and the difference between side channel temperature and mainstem locations was greatest relative to other comparisons. Side channels exceeded the temperature standard 9% of the time.
- 12 C standard, water temperature was coldest in side channels, then tributaries and mainstems, but exceeded standards 74% of the time. Protecting tributaries and restoring side channels is recommended.

Climate changes may have a relatively greater impact on flow and temperature in headwaters (12 C), as increasing AU sensitivity to heating corresponded with increasing exceedance (%), making protection more challenging.

Restoration of side channels and riparian vegetation along mainstem locations for sites with a 12 C and 16 C standard will offer temperature benefits in the floodplain where resilience to effects from climate change are likely to be greatest relative to tributaries, except in Puget Lowland tributaries.

Seepage Study

A seepage study to determine reach-scale flow gain or flow loss was implemented on September 1, 2011 in lower Pilchuck Creek and in Jim Creek on September 4, 2012 near the time of annual low flow.

In Pilchuck Creek, groundwater seepage contributed 60% of the flow accumulation in the lower 7 miles. The majority of groundwater inflow, 77%, occurred from RM 0-3.1.

In this reach, upstream from I-5, flow contribution from tributaries, floodplain areas, or other groundwater discharge locations predominantly arose from the east, coincident with permeable upland glacial deposits or alluvium in the floodplain, as also highlighted by the Watershed Characterization.

In locations with flow gaining reaches, such as lower Pilchuck Creek, large wood jams that scour deep pools may capture groundwater seepage flow to this key habitat type.

In Jim Creek, the contribution of groundwater as seepage flow was estimated for 3 cross-section pairs. Whereas the first cross-section pair far upstream was estimated to have groundwater inflow, the other 2 locations appeared to be losing reaches, where net surface flow decreased downstream due to loss of surface flow downstream of Vos Creek (RM 3.5).

Vos Creek contributed 16.5% of the total Jim Creek flow during the seepage study. And, Vos Creek was very cold, originating from the Arlington Heights outwash aquifer. As above, promoting AU area protection and restoration of water flow processes (*Recharge, Surface Storage*) could support groundwater storage and summer base flow.

Project Identification and Implementation

This project identifies 90 potential projects, of which, 40 are side channel and wood placement projects. Restoring isolated side channel habitats and river processes that support side channel formation along with tributary protection and restoration in floodplain locations is recommended.

Strategically, restoration of cold-water refuges in the North Fork Stillaguamish River will be supported by side channel connections and river process restoration, whereas restoration of cold-water refuges in the South Fork will be based more on Assessment Unit restoration and habitat enhancement at tributary confluence locations.

Due to past low flow variability and expected future climate change, restoration of side channels and riparian vegetation within floodplain locations for sites with a 12 C standard will offer temperature benefits where sensitivity to effects of climate change in restored floodplains are likely to be less than in tributary drainages having a 12 C standard.

In locations with flow gaining reaches, such as lower Pilchuck Creek, large wood jams that scour deep pools could capture groundwater seepage flow to this key habitat type (as well as providing structural habitat improvement).

In a flow-losing reach, protecting and restoring tributary shading and flow (such as at Vos Creek in Jim Creek), as well as habitat quantity and quality at the cold tributary confluence is important. Large wood restoration can improve habitat complexity at locations where temperature characteristics are most likely to be favorable during summer.

AU area protection and restoration of water flow processes that target *Recharge, Discharge and Groundwater* model parameters from Watershed Characterization will promote seasonal water flow that improves temperature and/or creates more favorable habitat patches.

This project identifies 50 potential riparian planting locations that are spatially discrete and functionally linked to the water flow processes and temperature results, and do reflect shading deficits identified in Department of Ecology's Temperature TMDL Plan. Many other locations with shading deficits also need planting.

Many locations identified are located in tributaries and not along larger rivers. Tributary locations can be shaded faster with smaller trees and narrower buffers, are not typically subject to lateral erosion from channel migration, which can limit the success of planted buffers along larger rivers.

Smaller tributaries contribute colder water to mainstem locations creating thermal refuges, and our results suggest many locations are relatively insensitive to warmer air temperature and watershed position relative to mainstem river locations.

Two locations were planted as part of this project, in the lower South Fork Stillaguamish River and in Trib 80 (Pilchuck Creek). A total of 8.8 acres riparian buffer was planted in 2013 and 2014, along 2700 lineal feet of channel. We estimated pollutant load reduction values for these BMPs using the EPA's STEPL 4.1 model for implementation of 3.5 acres and 5.3 acres of the "streambank stabilization and fencing" model BMP on Trib80 in Pilchuck Creek and South Fork Stillaguamish River, respectively.

Finally, the projects suggested here are not exhaustive of all possible strategies, ideas, data, and public or private stakeholder interests that could address this habitat and water quality problem. Recommendations are additive to those proposed in the TMDL implementation plan. Also, project concepts require additional feasibility, review and consideration of costs, benefits, and risks.

Appendix B. Table B-1: Potential Projects for Temperature Improvement in the Stillaguamish Watershed

Table B-1. Potential Projects for Temperature Improvement in the Stillaguamish Watershed as of May 1, 2015.

Drainage Area	Project Type - Description	Management Matrix Group	AU	X Coordinate*	Y Coordinate*	Spatial Scale of Project	Response Time
Jim Creek	Planting along Vos Creek up to County parcel at 208th St NE	<i>Development</i>	50899	1343217	433281	Reach	Medium-term
Jim Creek	Planting along Jim Creek downstream of Whites Road to fill gaps between Conservation District and Fisheries Enhancement projects	<i>Conservation</i>	50900	1343505	431844	Reach	Medium-term
Jim Creek	Planting (interplanting) along right bank of Jim Creek on state land on former “Indian Ridge” corrections parcel	<i>Conservation</i>	50900	1343300	430903	Reach	Medium-term
Jim Creek	Wood placement in plane-bed reach from Washington Department of Natural Resources (WDNR)–owned side downstream from cool outflow from slot canyon	<i>Conservation</i>	50900	1346479	434898	Habitat Unit	Short-term
Jim Creek	Planting along single-family parcels along right bank from end of 208th St NE down to Vos Creek	<i>Conservation</i>	50900	1344597	433528	Reach	Medium-term
Jim Creek	Wood placement downstream of Whites Road to improve habitat quantity and quality of thermal influence from Vos Creek	<i>Conservation</i>	50900	1343421	431847	Habitat Unit	Short-term
Jim Creek	Wood placement on WDNR parcel where there is low LWD abundance and channel complexity to create greater connectivity between Jim Creek and Siberia Creek	<i>Conservation</i>	50900	1343357	430975	Habitat Unit	Short-term
Jim Creek	Wood placement in plane-bed channel for increased habitat complexity in warming stream reach	<i>Conservation</i>	50900	1342457	429691	Habitat Unit	Short-term
Jim Creek	Planting along left and right banks between Nicks Road and downstream Jim Creek canyon	<i>Conservation</i>	50900	1341865	428288	Reach	Medium-term
Jim Creek	Wood placement in Jim Creek at the cold-water outflow from Vos Creek	<i>Conservation</i>	50900	1343954	432988	Habitat Unit	Short-term
Jim Creek	Wood placement near mouth of Jim Creek	<i>Conservation</i>	50900	1337208	434255	Habitat Unit	Short-term
Mainstem Stillaguamish River	Side channel reconnection of South Slough to southern part of floodplain connected to Quilceda trough and cooler inflow from Portage Creek	<i>Restoration</i>	50902	1311993	435276	Habitat Unit	Short-term
Mainstem Stillaguamish River	Planting along South Slough	<i>Restoration</i>	50902	1311617	435234	Reach	Medium-term
Mainstem Stillaguamish River	Side channel reconnection to 1930s alignment to improve cold-water discharge to mainstem	<i>Restoration</i>	50933	1307190	438553	Habitat Unit	Short-term
Mainstem Stillaguamish River	Planting along left bank with big trees; may be able to plant some higher elevation bars	<i>Restoration</i>	50933	1308451	439859	Reach	Medium-term
Mainstem Stillaguamish River	Wood placement to split flows and scour left channel; cold-water seepage is on left side of channel	<i>Restoration</i>	50933	1307801	440298	Habitat Unit	Short-term
Pilchuck Creek	Planting to restore left bank shading—the left bank is currently dense shrub/scrub or non-native buffer	<i>Restoration</i>	50939	1303240	450048	Reach	Medium-term
Pilchuck Creek	Planting along left bank, which needs shading	<i>Restoration</i>	50939	1303618	449288	Reach	Medium-term
Pilchuck Creek	Planting along left bank, which needs shading	<i>Restoration</i>	50939	1303646	448649	Reach	Medium-term
Pilchuck Creek	Planting along left bank, which is severely eroding into agricultural field	<i>Restoration</i>	50939	1303716	448017	Reach	Medium-term
Pilchuck Creek	Wood placement to restore/increase left bank meander planform to create/restore greater contact with left bank floodplain discharge	<i>Restoration</i>	50939	1303102	446504	Habitat Unit	Short-term
Pilchuck Creek	Side channel connectivity to cold discharge area at downstream end of floodplain with documented cold inflow	<i>Restoration</i>	50939	1303226	446253	Habitat Unit	Short-term
Pilchuck Creek	Wood placement downstream of cold inflow at historical meander; may	<i>Restoration</i>	50939	1303236	447339	Habitat Unit	Short-term

Table B-1. Potential Projects for Temperature Improvement in the Stillaguamish Watershed as of May 1, 2015.

Drainage Area	Project Type - Description	Management Matrix Group	AU	X Coordinate*	Y Coordinate*	Spatial Scale of Project	Response Time
	address connectivity of shallow riffles						
Mainstem Stillaguamish River	Side channel excavation off of Cook Slough in mainstem Stillaguamish to improve groundwater discharge from floodplain and connectivity to cold water of Portage Creek	<i>Restoration</i>	50940	1300305	437978	Habitat Unit	Short-term
Mainstem Stillaguamish River	Side channel additional excavation in North Meander side channel—North Meander has known cold-water seepage at depth	<i>Restoration</i>	50940	1298768	441198	Habitat Unit	Short-term
NF Stillaguamish R	Planting along left bank near Oso	<i>Restoration</i>	50918	1370796	463932	Reach	Medium-term
NF Stillaguamish R	Planting along Hell Creek near Entsminger Road, near Oso Loop, which needs a small buffer width and south shading	<i>Restoration</i>	50918	1369840	463408	Reach	Medium-term
NF Stillaguamish R	Planting of thin buffer	<i>Restoration</i>	50918	1368239	463529	Reach	Medium-term
NF Stillaguamish R	Wood placement for scour and cover in right bank backwater side channel at downstream end of Oso dike draining abandoned North Fork oxbows	<i>Restoration</i>	50918	1368285	463267	Habitat Unit	Short-term
NF Stillaguamish R	Planting along left bank low floodplain terrace with limited shading downstream from confluence with Grant Creek	<i>Restoration</i>	50919	1350417	466743	Reach	Medium-term
NF Stillaguamish R	Planting expanded along narrow buffer of left bank	<i>Restoration</i>	50919	1347871	466935	Reach	Medium-term
NF Stillaguamish R	Planting and interplanting along Lower Grant Creek on private property upstream of Hillis Road	<i>Restoration</i>	50919	1353141	466434	Reach	Medium-term
NF Stillaguamish R	Planting along Lower Grant Creek on private property downstream from Hillis Road	<i>Restoration</i>	50919	1352323	466207	Reach	Medium-term
NF Stillaguamish R	Planting along left bank continuously downstream of Cicero Bridge	<i>Restoration</i>	50919	1352176	465365	Reach	Medium-term
NF Stillaguamish R	Side channel new inlet to historical side channel to contact cold-water discharge from Cicero Ponds	<i>Restoration</i>	50919	1357351	465104	Habitat Unit	Short-term
NF Stillaguamish R	Planting along Cicero Ponds to shade outflow from oxbow	<i>Restoration</i>	50919	1355364	465343	Reach	Medium-term
NF Stillaguamish R	Planting along a small unnamed baseflow tributary that needs a small buffer on the south side for up to 2,500 linear feet	<i>Restoration</i>	50919	1361405	464927	Reach	Medium-term
NF Stillaguamish R	Planting the original left bank 150-foot planting has eroded by more than half	<i>Restoration</i>	50919	1360432	464349	Reach	Medium-term
NF Stillaguamish R	Planting to improve shading on a small, unnamed tributary to Grant Creek that contributes low flow discharge to the North Fork	<i>Restoration</i>	50919	1353714	465205	Reach	Medium-term
NF Stillaguamish R	Wood placement near Cicero to engage right bank forest and left bank side channel containing cold inflow from wall base channel—overall there are poor habitat conditions in this reach	<i>Restoration</i>	50919	1357419	464856	Habitat Unit	Short-term
NF Stillaguamish R	Wood placement to shift away from left bank and toward right bank, and removing relict bank armor on right bank to facilitate side channel overflow at location of cooler discharge from right bank	<i>Restoration</i>	50919	1347369	466489	Habitat Unit	Short-term
NF Stillaguamish R	Wood placement to shift away from left bank toward cooler discharge from right bank	<i>Restoration</i>	50919	1347008	465872	Habitat Unit	Short-term
NF Stillaguamish R	Side channel reconnection by removing relict bank armor	<i>Restoration</i>	50919	1347430	466983	Habitat Unit	Short-term
NF Stillaguamish R	Side channel excavation in meander lobe adjacent to wall-base near Cicero – would likely require acquisition	<i>Restoration</i>	50919	1359215	464543	Habitat Unit	Short-term
NF Stillaguamish R	Planting potential on left bank of private property opposite Rubicon Foundation	<i>Restoration</i>	50927	1342508	458083	Reach	Medium-term

Table B-1. Potential Projects for Temperature Improvement in the Stillaguamish Watershed as of May 1, 2015.

Drainage Area	Project Type - Description	Management Matrix Group	AU	X Coordinate*	Y Coordinate*	Spatial Scale of Project	Response Time
NF Stillaguamish R	Planting potential on Whitehorse Trail along left bank of river upstream from previous planting (in AU 50928)	<i>Restoration</i>	50927	1343796	458534	Reach	Medium-term
NF Stillaguamish R	Planting on right bank along Smoke Farm	<i>Restoration</i>	50927	1346949	463476	Reach	Medium-term
NF Stillaguamish R	Side channel restoration at Smoke’s Farm side channel through meander lobe, which requires removal of right bank armor	<i>Restoration</i>	50927	1345477	463289	Habitat Unit	Short-term
NF Stillaguamish R	Planting to improve buffer on unnamed tributary	<i>Restoration</i>	50927	1344537	458678	Reach	Medium-term
NF Stillaguamish R	Wood placement to shift thalweg right to Pentland Creek and create complex habitat at Pentland Creek outflow	<i>Restoration</i>	50927	1341986	458375	Habitat Unit	Short-term
NF Stillaguamish R	Wood placement to shift flow away from left bank, increase bar area, and move planform/thalweg toward Smoke Farm side channel	<i>Restoration</i>	50927	1346686	464862	Habitat Unit	Short-term
NF Stillaguamish R	Wood placement at Pentland Creek mouth to create more favorable habitat in cold-water refuge	<i>Restoration</i>	50927	1341565	458890	Habitat Unit	Short-term
NF Stillaguamish R	Planting along Whitehorse Trail on left bank of river	<i>Restoration</i>	50928	1339994	456919	Reach	Medium-term
NF Stillaguamish R	Planting to improve tributary shading	<i>Restoration</i>	50928	1343320	456558	Reach	Medium-term
NF Stillaguamish R	Planting to improve tributary shading	<i>Restoration</i>	50928	1342051	455477	Reach	Medium-term
NF Stillaguamish R	Planting to improve tributary shading	<i>Restoration</i>	50928	1339884	456091	Reach	Medium-term
NF Stillaguamish R	Wood placement in lower river to increase meander length and shift planform to right bank and toward cooler temperature along right bank tributary outlets	<i>Restoration</i>	50928	1338091	457734	Habitat Unit	Short-term
NF Stillaguamish R	Side channel restoration at historically filled left bank side channel	<i>Restoration</i>	50928	1337228	456484	Habitat Unit	Short-term
NF Stillaguamish R	Side channel creation near Cloverdale	<i>Restoration</i>	50930	1335723	454054	Habitat Unit	Short-term
NF Stillaguamish R	Planting at Trafton Trailhead (Cloverdale) set back from erosion alignment on left bank of river	<i>Restoration</i>	50930	1334880	453122	Reach	Medium-term
NF Stillaguamish R	Planting along left bank opposite Rock Creek; this was started as a Stillaguamish Big Trees grant project	<i>Restoration</i>	50930	1335665	455900	Reach	Medium-term
NF Stillaguamish R	Planting upper floodplain for forested wetland development, surface storage, and recharge functions	<i>Restoration</i>	50930	1336802	453459	Reach	Medium-term
NF Stillaguamish R	Planting upland buffer on private unnamed tributary adjacent to county park	<i>Restoration</i>	50930	1336255	452470	Reach	Medium-term
NF Stillaguamish R	Planting unnamed tributary buffer in right-of-way along Whitehorse Trail	<i>Restoration</i>	50930	1335581	452516	Reach	Medium-term
NF Stillaguamish R	Side channel improved connectivity and size to improve cold inflow from a small upland tributary	<i>Restoration</i>	51881	1423616	466562	Habitat Unit	Short-term
NF Stillaguamish R	Planting buffer to treat eroding right bank downstream of SR530 at Oso	<i>Restoration</i>	51883	1377910	465686	Reach	Medium-term
NF Stillaguamish R	Wood placement at Fry Creek mouth to create scour at a cold inflow location	<i>Restoration</i>	51883	1377104	463509	Habitat Unit	Short-term
NF Stillaguamish R	Side channel connection to existing overflow channel and tributary	<i>Restoration</i>	51883	1376999	464145	Habitat Unit	Short-term
NF Stillaguamish R	Planting (and interplanting) left bank low terrace buffer to potentially 100 feet width	<i>Restoration</i>	51883	1380994	468137	Reach	Medium-term
NF Stillaguamish R	Wood placement to migrate river to the right bank to improve right bank edge complexity, increase sinuosity and scour, and connections with 3 cold tributaries on right bank	<i>Restoration</i>	51883	1380710	468130	Habitat Unit	Short-term

Table B-1. Potential Projects for Temperature Improvement in the Stillaguamish Watershed as of May 1, 2015.

Drainage Area	Project Type - Description	Management Matrix Group	AU	X Coordinate*	Y Coordinate*	Spatial Scale of Project	Response Time
NF Stillaguamish R	Planting and bank treatments to improve edge habitat and improve right bank edge complexity downstream from Brooks Creek, which contributes cold-water inflow	<i>Restoration</i>	51883	1377607	467116	<i>Reach</i>	<i>Medium-term</i>
NF Stillaguamish R	Side channel expanded to increase flow in left bank side channel at C-post bridge to create greater habitat area for cold water influence. Wait until channel adjustment from SR530 slide is stabilized to re-evaluate.	<i>Protection</i>	51884	1396965	468860	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Wood placement downstream of new Department of Transportation right-of-way—cold inflow occurs from the right bank at this location	<i>Conservation</i>	50926	1315311	463333	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Wood placement at Tributary 80 confluence with Pilchuck Creek or near right bank side channel	<i>Conservation</i>	50926	1314563	463128	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Planting expanded at Centennial Trail North Trailhead park; this location has potential for more beaver colonization and surface water storage and discharge	<i>Conservation</i>	50934	1307837	474360	<i>Reach</i>	<i>Medium-term</i>
Pilchuck Creek	Planting along left bank at degraded location	<i>Development</i>	50937	1309795	458380	<i>Reach</i>	<i>Medium-term</i>
Pilchuck Creek	Wood placement in reach with low wood to promote vertical sediment storage, bar aggradation, and hyporheic recharge/discharge	<i>Development</i>	50937	1309628	458677	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Wood placement downstream from cold inflow	<i>Development</i>	50937	1307282	455003	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Side channel expanded connection along right bank upstream from Stanwood-Bryant Rd to provide better shading over more flow volume	<i>Development</i>	50937	1307467	455570	<i>Habitat Unit</i>	<i>Short-term</i>
Pilchuck Creek	Planting along left bank in private property downstream from Stanwood-Bryant Road to provide shading	<i>Development</i>	50937	1306048	454077	<i>Reach</i>	<i>Medium-term</i>
Portage Creek	Planting to improve buffer functions along up to 9,900 linear feet of lower Portage Creek (4 landowners)	<i>Restoration</i>	50940	1298916	436589	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Planting along the left bank, downstream of SR530 Bridge near Arlington	<i>Restoration</i>	2011	1326465	440628	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Planting along left bank at City of Arlington and Arlington School District forested island and low floodplain terrace	<i>Restoration</i>	2011	1329653	441822	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Wood placement on right bank of the South Fork near Jordan Road and Jim Creek confluences. This location receives groundwater discharge for approximately 1,000 linear feet from AUs 2011 and 50899	<i>Restoration</i>	2011	1337337	436729	<i>Habitat Unit</i>	<i>Short-term</i>
SF Stillaguamish R	Planting along right bank opposite City of Arlington’s Country Charm Park	<i>Restoration</i>	2011	1330544	442625	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Side channel flow split improves habitat and reduces risk to Jordan Road	<i>Restoration</i>	2011	1336049	436975	<i>Habitat Unit</i>	<i>Short-term</i>
SF Stillaguamish R	Planting to improve shading over ponds and channel; this will improve temperature outflow to the South Fork	<i>Development</i>	50893	1354699	402465	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Planting to improve shading over ponds and channel; this will improve temperature outflow to South Fork	<i>Development</i>	50893	1357077	403477	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Planting to improve shading over ponds and channel; this will improve temperature outflow to South Fork	<i>Development</i>	50893	1358066	402119	<i>Reach</i>	<i>Medium-term</i>
SF Stillaguamish R	Planting along right bank	<i>Development</i>	50894	1346418	418384	<i>Reach</i>	<i>Medium-term</i>

* NAD 1983 State Plane Washington North FIPS 4601 Feet