STILLAGUAMISH TEMPERATURE TMDL ADAPTIVE ASSESSMENT AND IMPLEMENTATION PROJECT –

LONGITUDINAL WATER TEMPERATURE PROFILES FOR SELECTED RIVER REACHES IN THE STILLAGUAMISH RIVER BASIN, WASHINGTON

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Project Background

This report, “Longitudinal Water Temperature Profiles for Selected River Reaches in the Stillaguamish River Basin”, is a stand-alone document as well as one of a series that together detail the key tasks and associated findings and conclusions of the Stillaguamish Temperature TMDL Adaptive Assessment and Implementation Project ("Stillaguamish TMDL Project").

The purpose of the Stillaguamish TMDL Project is to improve water quality standards 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. The need for the project was identified in the 2004 Stillaguamish River Water Quality Improvement Plan.

The Stillaguamish TMDL Project incorporates several methodologies in its approach, which are documented in separate reports, as follows:

- Watershed Process Characterization
- Base Flow Analysis
- Temperature Regime Studies
  - FLIR Temperature Imagery Analysis
  - USGS Thermal Profiling Report
  - 2008-2012 Temperature Data Report
- Groundwater Seepage Study
- Assessment Synthesis and Project Identification Report
- Riparian Implementation Project Report
- Feasibility Analysis for Two Temperature Improvement Projects

The project was funded through a Centennial Clean Water grant agreement between the Washington State Department of Ecology and Snohomish County. It was initiated by Snohomish County Public Works Surface Water Management in 2010 and completed in 2015.

The final summary report and associated maps can serve as a tool for policy and regulation development, species conservation, water quality and watershed management planning efforts in the Stillaguamish Basin.
Executive Summary

Downstream longitudinal profiles of near-streambed temperature were collected for eight river reaches in the Stillaguamish River basin, Washington, during August, 2011, to provide information about areas of groundwater flow into rivers. Locations included parts of Pilchuck Creek, Jim Creek, North Fork Stillaguamish River, and South Fork Stillaguamish River. Temperature profiling along the streambed in a downstream direction measures temperature that is influenced by many factors. During the summer, groundwater flow (termed discharge) can be a source of cold water to streams that controls stream warming and can create cold-water thermal refugia for native stream fauna including salmon and trout. To assess areas of groundwater discharge to streams, temperature was measured using a probe with an internal data logger towed behind a raft moving downstream at ambient stream velocity. Depth was also recorded (same data logger) as a possible co-variate with temperature. The temperature and depth data were referenced to position, concurrently surveyed with a Global Positioning System. Data are retained in spreadsheet files consisting of date, time, near-streambed water temperature, water depth, latitude and longitude. Data are summarized in this report in maps and longitudinal profile graphs.

Temperature variability was strong in lower Pilchuck Creek and changed within individual habitat units (downstream cooling from riffles to deep pools) and over stream reaches (100-1000 meters) due to river reach-scale cooling and strong heating. Deeper pools, in particular appeared to be thermally stratified, though deep pools were rare. In Jim Creek, temperature variability was notable among locations – strong heating was coincident with poor riparian shading and one location with baseflow loss (see Seepage Study companion report). Elsewhere in Jim Creek, stream cooling appeared in proximity to Vos Creek, the Jim Creek “slot” canyon, and lower Jim Creek. In the North Fork Stillaguamish River, thermal profiling detected locations with cooling from significant cold-water inflow. This was mostly true for the upper river reaches where total river discharge was less than down-river where greater flow accumulation occurred. Higher discharge likely reduced the possibility that cold-water influence would be detected at the center of the river channel (thalweg). At the same time, longitudinal profiling in the North Fork Stillaguamish and South Fork Stillaguamish occurred during relatively higher flow and cooler air temperature overall, which may have reduced the likelihood that groundwater cooling effects would be observed due to greater mixing and lower diurnal heating on those sample days.

For both rivers, aerial infrared imagery collected in 2001 from low flying aircraft documented many more small cold-water flow anomalies (see Companion Report) than were detected with thermal profiling. That methodology is more suitable for larger river temperature investigations. The field-based longitudinal profiling implemented as part of this task appeared to be very well suited to smaller rivers and streams (navigable with small watercraft) that also may be obscured from aerial imaging techniques due to tree canopy cover. Based on this project task and others, actions that promote deep pool formation, that improve shading, that sustain or improve tributary flow, that connect flow access to cold-water habitats (namely, side channels) are supported by information summarized here and included in the Assessment Synthesis and Project Identification Report (ASPIR) for selected rivers and streams.
Introduction

Longitudinal profiles of near-streambed temperatures surveyed at ambient river velocity have been demonstrated to provide information about potential areas of ground-water discharge that cool rivers, as well as salmonid habitat and thermal refugia (Cox et al. 2005; Vaccaro and Maloy 2006). Longitudinal profiles of stream temperature can also reveal the magnitude and extent of cooling influence from tributary streams (provided they are cooler than a mainstem river). Stream water temperature typically increases in temperature throughout the day often as a direct result of solar energy input to the stream surface and other heating processes (convection and conduction), except where cooler water inflow occurs. Because groundwater is typically about 10 °C, ideally longitudinal temperature profiling is accomplished at absolute summer baseflow and during hot weather so as to maximize the possibility of detecting cold-water inflow in otherwise warmer ambient water. Longitudinal thermal profiles have previously been surveyed in several rivers in Washington State including the Yakima River and its tributaries (Vaccaro et al. 2008) and the Nooksack River (Cox et al. 2005) documenting cold-water inflow to these systems.

This report presents 8 thermal profiles within the Stillaguamish River basin including portions of the North Fork Stillaguamish River, South Fork Stillaguamish River, Jim Creek, and Pilchuck Creek (Figure 1). These rivers and streams have segments with known temperature impairments, but at the same time are important for salmonid fish use in the Stillaguamish watershed and represent a range in channel sizes (and still navigable). These data supplement previous investigations of longitudinal river temperature within the Stillaguamish River and its tributaries using forward looking infrared (FLIR) technology (Watershed Sciences 2002).

These thermal profiling data may be used to determine locations of groundwater discharge, identify river segments with strong daily heating, and improve understanding of the relationship between the groundwater and surface water systems of the Stillaguamish River basin. Inputs of cold water to rivers, whether from groundwater or tributaries, are influenced by surface-groundwater processes that result from local climatic and geologic influence operating outside of stream boundaries or upslope from groundwater discharge locations (seeps and springs). Therefore these data, along with watershed characterization (climate and geology), FLIR imagery, in situ field sampling and continuously recording temperature loggers will be used together as tools to develop a better understanding of groundwater/surface-water interactions within the Stillaguamish River basin and develop recommendations for temperature protection or improvement.
Figure 1. Map of Stillaguamish River watershed and selected thermal profile reaches (from Gendaszek 2011).
**Methods**

Thermal longitudinal profiling of portions of the North Fork, South Fork, Jim Creek, and Pilchuck Creek was conducted during eight surveys between August 15, 2011, and August 26, 2011, using methodology developed by the U.S. Geological Survey (Vaccaro and Maloy 2006) (Figure 1). This method was used to document stream bottom temperatures and approximate water depths in a longitudinal profile. Longitudinal profiling was conducted in the month of August because the survey should ideally be conducted at absolute summer low flow and during hot weather to maximize the possibility of detecting cold-water inflow locations. This methodology has been summarized by Gendaszek (2011), is described in part here, and is available in its entirety at:


Continuous water temperature and global positioning system (GPS) data were collected at 3-second intervals while drifting downstream at the same velocity as the stream (Figure 2). Profiling at ambient stream velocity tracks a parcel of water as it moves downstream during the day. The data logger (which measures both temperature and depth) moves with the ambient flow. It was generally expected that the data logger would record increasing temperatures over the course of the day, except where there are cooling effects from a cool tributary, groundwater inflow, or river reach–scale groundwater discharge.

Sampled locations included Pilchuck Creek between river miles (RMs) 0.0 and 3.7, the North Fork Stillaguamish River between RMs 0.0 and 34.2, the South Fork Stillaguamish River between RMs 0 and 15.7, and Jim Creek between RMs 0.0 and 7.0 (Table 1). A one-half mile gap exists between the beginning of the North Fork Stillaguamish datasets collected on August 18 and August 22 (Table 1) because of inadequate equilibration of the temperature probe to ambient stream temperature during the initial one-half mile of the August 22 survey.

Continuous temperature was measured using a Solinst Levelogger® LT temperature probe, verified by a NIST-certified thermistor. The temperature probe was towed behind a watercraft following the stream’s thalweg, and was dragged along the streambed in protective flow-through casing. GPS data was measured using a Garmin GPSMAP® 60Cx unit. The location of each temperature measurement was determined by relating the GPS data to the temperature data. If a GPS position was not recorded at the same time as a temperature measurement, the position of the temperature measurement was determined by linear interpolation of the two GPS positions that bracketed the temperature measurement. Additionally, during the thermal profile, individual temperature measurements were taken in the field of observed surface water inflow (seeps, springs, and tributaries) using a NIST-calibrated YSI 550A temperature probe.
In many instances the probe needed to be raised momentarily to avoid obstacles and in all instances the exact line of the stream thalweg could not be followed. As a result, the depth of the water column is considered to be approximate and relative, with better accuracy expected with greater thalweg depth. Therefore, overall, the water depth profile probably best reflects the location, spacing, and relative depths of the deepest pools. Additionally, the Solinst temperature probe was not depth calibrated.

Figure 2. View of thermal profiling in Jim Creek, 8/25/2011, using small watercraft. The data logger tethered to the kayak is on the stream bottom in thalweg. Photo credit Frank Leonetti.

Results from this thermal profiling are depicted in graph and map form in the Results section. Locations of tributaries are highlighted.

Table 1. Stillaguamish River Basin Thermal Profiling Study Overview.

<table>
<thead>
<tr>
<th>Location</th>
<th>River Miles</th>
<th>Date</th>
<th>Applicable State Water Temperature Criteria</th>
<th>Average Maximum Air Temperature (°C)</th>
<th>Stream Temperature Range (°C)</th>
<th>Estimated Discharge (cubic feet per second)</th>
</tr>
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<td>0-3.7</td>
<td>8/15/2011</td>
<td>17.5</td>
<td>21.3</td>
<td>16.2-19.3</td>
<td>9.9</td>
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<td>22.7</td>
<td>12.8-16.3</td>
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<td>17.6-30.0</td>
<td>8/17/2011</td>
<td>12, 16</td>
<td>21.7</td>
<td>11.0-16.5</td>
<td>378</td>
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<td>Estimated Discharge (cubic feet per second)</td>
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<td>25.3</td>
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<td>26.0</td>
<td>16.9-19.8</td>
<td>474</td>
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</tbody>
</table>

Sources: Flow information was accessed online from USGS (2013) or Washington Department of Ecology (Ecology 2013). Air temperature data are for 15 Stillaguamish watershed locations and are from Snohomish County (unpublished data).

**Results**

Data tables for Stillaguamish basin thermal profiling described in this report are available from the USGS data series 654 report (Gendaszek 2011) archived at the following link.


**Pilchuck Creek**

The lower 3.7 miles of Pilchuck Creek were surveyed on August 15, 2011. Near-minimum stream flow occurred in Pilchuck Creek that day, as shown in Figure 3. Daily stream temperature recorded near Interstate-5 shows increasing stream temperature throughout the time of thermal profiling (Figure 4), indicating river water flowing downstream gradually increased in temperature throughout the day due to heating and consistent mixing. The time of the actual longitudinal profiling is shown within the sample box (Figure 4).

In Pilchuck Creek, the longitudinal profile of water temperature was highly variable (Figure 5) and exceeded the Washington State water quality criteria of 17.5°C for this location. However, instead of a gradually increasing temperature profile (as in Figure 4) from RM 3.7 to the mouth, there were many locations of punctuated cooling near the streambed or longer stretches of decreasing temperature at the stream reach scale. In addition, other locations had slower rates of temperature increase, suggesting a moderate amount of cooling was present that mitigated warming. In other locations, water temperature rapidly increased.
Figure 3. Pilchuck Creek summer stream flow estimated from continuous stream gauging at Interstate 5 by Ecology. The arrow identifies the day of the thermal profile, August 15, 2011.

Figure 4. Pilchuck Creek water temperature during August 15, 2011, near Interstate 5 by Ecology.
In the first half of the surveyed segment, seven pools were identified with a depth greater than 1.5 meters (150 centimeters [cm]). Two of these pools were deeper than 2 meters (200 cm) (Figure 5). Within each deep pool, there was a subtle or strong local cooling effect in the downstream direction (as depicted in Figure 6) that appeared to terminate at the downstream extent of each pool, suggesting that groundwater inflow was reducing overall water temperature at these pools. Hence, the bottom and tailout locations of deep pools may provide some thermal refuge for salmonid fishes when temperature exceeds criteria. Conversely, locations with rapid warming (about 0.1 degrees/minute) appear to mostly be located where water depth is shallow, where the stream course has a “north-south” alignment, and where shading may be deficient. Of course, neither pattern is without exception.

Other variability in temperature change is also notable. For example, one long area of pronounced cooling was identified just upstream from the end of the surveyed segment and spans many individual habitat units. This cooling occurs at the river reach scale and can only be explained by the presence of increasing groundwater seepage in the downstream direction, as no surface inflow is present that could be contributing to the cooling. The temperature difference in this cooler stretch is more than 1°C, and it is probably a significant thermal refuge for fish near the mouth of Pilchuck Creek.

Figure 5. Measured lower Pilchuck Creek water temperature and depth during August 15, 2011. The water temperature criterion for lower Pilchuck Creek is 17.5°C. Survey direction is left to right.
Figure 6. Sequential downstream water temperature profile and point-point sequential difference (each 30 seconds) highlighting locations of strong warming and cooling.

The longitudinal thermal profile is shown in map view in Figure 7 and includes additional temperature observations.
Figure 7. Lower Pilchuck Creek thermal profile, August 15, 2011, and other in situ point observations. Apparent heating and cooling locations are noted.
Jim Creek

A thermal profile of temperature in Jim Creek was conducted between RM 0 and 7.0 (Figure 1). Stream flow on this date was near the lowest baseflow of the summer (Figure 8). Water temperature in Jim Creek on this day, as measured at the Whites Road gauge, was near the warmest of the year (Figure 9).

Figure 8. Jim Creek average daily flow based on stream gauging at Whites Road by Ecology. The arrow identifies the day of the thermal profile, August 25, 2011.

Figure 9. Jim Creek summer 2011 average daily temperature at Whites Road (data from Ecology).
At one fixed location, Whites Road, temperature was recorded at 15-minute intervals. On August 25, 2011, temperature rose from approximately 15.5°C to 19.5°C at a nearly continuous rate throughout the day (Figure 10) before peaking at approximately 5 pm. However, thermal profiling revealed strong variations in temperature, including distinct locations of cooling, stasis, or heating.

![Temperature Profile](image)

**Figure 10.** Jim Creek temperature recorded at Whites Road during thermal profiling, August 25, 2011. The thermal profiling period is shown in the boxed area. The water temperature criterion is 16°C in Jim Creek.

Figure 11 shows the thermal profile by time of day (starting at RM 7 and ending at RM 0). Some cooling appeared to coincide with tributary junctions, but cooling was also identified where no tributaries are present. Each observed tributary discharged water cooler than the mainstem Jim Creek (Figure 11).

Several locations of moderate cooling were observed, along with one location of strong cooling (Figure 12). The location with strong cooling was downstream of the Bear Creek confluence, through the Jim Creek slot canyon, where the greatest pool depth was observed. Cooling was observed downstream of this deep pool, at a location where the stream profile was steep and the floodplain was completely confined. The downstream cooling extended over 1,700 lineal feet. At this location surface and groundwater may be forced through the slot canyon where bedrock is confining and a strong hydraulic gradient forces groundwater discharge into the deep pool.

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Figure 11. Jim Creek thermal profile, water depth estimate, and temperature measured at inflow from tributaries, August 25, 2011. Survey direction is left to right.

Figure 12. Sequential downstream temperature difference (each 30 seconds) in Jim Creek highlights locations of strong warming and cooling.
In addition to the cooling observed, strong warming was observed in three locations, including in the middle of the profile. Upstream from the Bear Creek confluence, temperature increased slowly and even cooled slightly in places. This moderate temperature increase was presumably due to cooler tributary inflow, relatively confined floodplain walls, and riparian shading. The exception to this moderate temperature increase was strong warming where the channel appeared to widen due to streambank erosion and where riparian shading was degraded (first warming location in Figure 12).

Downstream from the Bear Creek confluence and the Jim Creek slot canyon, stream temperature increased at a high rate over a distance of approximately 2 miles (second warming location in Figure 12). The increase in water temperature is moderated at the Vos Creek confluence, where the tributary inflow is cold. This appears to be the only temperature control for a distance of 2,600 lineal feet, before rapid heating occurs again. It is assumed that Vos Creek flow is abundant and cold because the creek originates from a large, deep, permeable glacial outwash plain (Figure 13) that contributes a large amount of surface water recharge to the Vos Creek groundwater system.

Downstream of the zone of heating, there is another cooling stretch extending over a long river reach into the lower Jim Creek canyon, where Jim Creek changes direction from a southwesterly flow to a northwesterly direction (Figure 13). In the lower canyon, stream temperature both warms and cools with no obvious cause or influence. Cooling toward the mouth of Jim Creek may be due to groundwater inflow from the same recessional outwash plain as Vos Creek.
Figure 13. Jim Creek thermal profile, August 25, 2011, and other in situ point observations of temperature from tributaries. Locations of apparent heating and cooling are identified. Ecology-designated Assessment Units (AUs) are also shown.
North Fork Stillaguamish River

The North Fork Stillaguamish River was sampled over 4 non-consecutive days from RM 34 to the mouth in the following reach order: Upper North Fork, French-Segelsen, Middle North Fork, and Lower North Fork. However, unlike at Pilchuck and Jim Creeks where the sampling occurred near lowest flows, this was not the case in the North Fork Stillaguamish (Figure 14) as flow continued to decrease after thermal profiling was conducted.

![North Fork Stillaguamish average daily flow at Oso gauge from Ecology stream gauging. The green arrows bracket the sampling days.](image)

**Upper North Fork**

Flow in the Upper North Fork is lowest among North Fork reaches, as much of this reach is upstream of many large tributaries, including Squire Creek, French Creek, Boulder River, and Deer Creek. Low water volume relative to other North Fork locations presumably makes this reach more susceptible to warming. This is evident in the thermal profile (Figure 15). Warming is present and mostly continuous in the floodplain upstream from Squire Creek, which can also be seen in the map view of the thermal profile (Figure 16).

Two cold-water inflow locations were observed during the thermal profiling: 1) a cold side channel (11.6°C) outlet returning flow back to the river, and 2) Squire Creek (12.9°C), a major tributary contributing flow approximately equal to the North Fork Stillaguamish River. Water temperature in the Upper North Fork begins to decline 1,800 lineal feet upstream from the surface confluence with Squire Creek, suggesting the temperature reduction upstream from Squire Creek is due to groundwater seepage from the Squire Creek drainage, which is at a higher elevation than the mainstem North Fork.
Because the North Fork Stillaguamish River continues to decline in temperature for an additional 2,500 lineal feet downstream from Squire Creek, this indicates there is continuing and extensive groundwater seepage from the Squire Creek drainage area to the left bank of the North Fork. This area is highlighted in Figure 15 as the green boxed area. It is not known whether there is also seepage and some temperature influence from the right bank of the North Fork floodplain.

Figure 15. Upper North Fork Stillaguamish thermal profile and water depth.
Figure 16. Upper North Fork Stillaguamish River thermal profile. Locations of apparent heating and cooling are identified.
North Fork – French-Segelsen

The thermal profile for the French-Segelsen reach showed warming at a steady rate throughout the day, except for a few discrete locations. Cold-water inflow measured at Fortson Ponds and Boulder River (Figure 17 and Figure 18) decreased river temperature downstream of these confluences. Other, more subtle changes in stream cooling and heating were also apparent. For example at French Creek and Blue Slough (green circle in Figure 17), temperature did not increase for approximately 3,500 lineal feet downstream.

![Figure 17. Upper North Fork Stillaguamish thermal profile and water depth at French-Segelsen stream reach, including two locations of cold-water inflow measured in situ during the thermal profile. The green circle shows the French Creek and Blue Slough confluences.](image-url)
Figure 18. French-Segelsen reach thermal profile. Locations of cooling identified by the thermal profiling are also identified.
Middle North Fork and Lower North Fork Thermal Profiles

The Middle North Fork thermal profile is shown in Figure 19. Conditions were not ideal at the time of sampling because air temperature was low, and flow was not at absolute summer baseflow (Figure 14). The total heating that occurred during the course of the thermal profile was less than 3°C. However, some variability in the thermal profile is interpretable. For instance, heating was observed coincident with the Deer Creek confluence (Figure 19).

Downstream from the Deer Creek confluence, a location with relatively little heating was observed (Figure 19), the extent of which was approximately 1 mile. During the thermal profiling, cold tributary inflow (11.8°C) from the left bank was measured at Hell Creek (Figure 19), and groundwater seepage was observed on the right bank over this mile of river. In the next mile downstream, river temperature increases rapidly in a river reach that is wide, shallow, and devoid of deep pools.

![Graph showing water temperature and depth over time.](image)

**Figure 19.** Middle North Fork Stillaguamish River thermal profile and water depth.

The Lower North Fork thermal profile is shown in Figure 20. Sampling conditions were poor as flow was higher than ideal and air temperature was low that day. Water temperature increased by less than 2°C during the day. Therefore, these results are not discussed further.
South Fork Stillaguamish River

The South Fork was flowing at a relatively high level on the sampling days (Figure 21) and air temperature was relatively cool, making sampling conditions less than ideal for this reach.

Figure 21. South Fork Stillaguamish River 2011 daily mean flow (cfs) during summer. Thermal profiling sample dates are shown with green arrows.
The thermal profile along the length of the river was fairly homogeneous (Figures 22 and 23) and indicated continuous heating through each day. Smaller cold-water flow inputs were generally not influential on the South Fork temperature profile in a spatially discrete way. One exception to this was identified immediately downstream of an unnamed tributary on August 26, 2011 (Figure 23).

At the same time, many of these small discrete flow inputs probably had real temperature influence near the margin of the channel within a relatively small area, and may act to create temperature complexity along the channel edge. This is also where smaller summer-rearing juvenile salmonids are likely to be found. It is possible that if sampling had occurred at a lower flow level, more variability in temperature would have been measured that would reflect these smaller discrete cold-water sources. Because of the suboptimal sampling conditions, no recommendations are made for the South Fork Stillaguamish based on these thermal profiling results.

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**Figure 22.** South Fork Stillaguamish River thermal profile from RM 15.7 to 8.2.
Figure 23. South Fork Stillaguamish River thermal profile from RM 8.2 to 0.0. Cold-water inflow measured during the thermal profile is shown for an unnamed stream, as is slight temperature variability in thermal profile at this location (green circle).

Conclusions

Thermal profiling appeared to be most effective in Pilchuck Creek and Jim Creek, where summer low flow was substantially lower than in the wider rivers. The likelihood of detecting cold-water influence at the channel thalweg is greater in channels with narrower wetted width compared to larger rivers, particularly if cold water is originating at the channel margin. At the same time, narrower channels are less amenable to aerial infrared imaging due to tree canopy cover that may obscure the channel. In wider rivers, where more of the channel is open to the sky, aerial infrared imaging is more useful for surface water temperature assessment than field-based thermal profiling. Aerial infrared imagery allows for visualization and temperature estimation at river channel margins where small-volume cold-water inputs may be present and functionally meaningful, but may not be detected at the channel thalweg. Some of these locations are side channels, which often discharge cold water back to the main river channel. Many historical and/or existing side channels could be evaluated for re-connection or enhancement of accessible habitat where temperature conditions are likely to be favorable compared to the mainstem. Habitat conditions at each location of cold-water inflow could also be evaluated to
determine whether structures such as engineered log jams could be improved at locations with better thermal characteristics, which in larger rivers, will be most frequently located at channel margins.

There are factors at four spatial scales potentially affecting stream temperature measured using thermal profiling. The smallest scale is the individual habitat unit (a pool or riffle). In particular, deep pools formed by woody debris and or lateral streambank scour may create hydraulic gradients favorable for groundwater inflow in locations where groundwater seepage is present. Here, thermal profiling may detect discrete cooling at the bottom of individual pools. The functional significance of pools on temperature was apparent in Pilchuck Creek, but less so elsewhere. Interestingly, Pilchuck Creek and Jim Creek contained pools as deep as many pools in the larger rivers, yet had very low summer discharge by comparison. Pool formation due to scour generally occurs during high flow and often at locations of flow resistance (streambanks, bedrock/clay/till outcrops, and woody debris). This potentially allows for greater stratification of cold-water inflow and creation of temperature refuges when flow (and mixing presumably) is lower in the summer.

The second scale is the stream reach scale (i.e., 100-1,000 meters) where groundwater inflow is strong enough to produce significant changes in total stream discharge (resulting in “gaining” stream reach), which promotes overall stream cooling among all habitat units in the stream reach. This influence on temperature is detectable with thermal profiling, particularly in smaller rivers, as was the case in lower Pilchuck Creek and in Jim Creek. Upper North Fork habitat conditions are presumably more favorable for fish during summer within the area of Squire Creek temperature influence, extending 4300 lineal feet. Protecting natural water delivery, recharge, groundwater connectivity, instream flows, and shading in Squire Creek is critical, particularly since Squire Creek contributes approximately 18% of flow to the North Fork Stillaguamish River. In the larger rivers, observations of reach-scale groundwater inflow consisted of return flow from side channels, groundwater discharge at seeps, thermal profile temperature, and hyporheic seepage that sustained native grasses (Carex sp.) on low elevation gravel bars (Figure 24). These occurrences were useful indicators of groundwater-surface water interactions in the field, but are not always detectable or easily quantified by thermal profiling.

Figure 24. Example of native grasses flourishing at mid-summer on gravel bar with groundwater seepage. Photo credit Frank Leonetti.
The third scale affecting stream temperatures is the individual tributary scale. Tributaries draining upland areas and with summer baseflow supported by high recharge, shallow surface and groundwater storage, and hydraulic connections to deeper glacial aquifers can contribute cold water to the mainstem. These tributaries have relatively cool temperatures (because of their close connection to groundwater) and less variable summer flow. This suggests these tributaries have a proportionately greater contribution to mainstem flow during summer. The influence of these tributaries will be relatively greater in smaller drainage basins (such as Vos Creek in the Jim Creek basin) relative to the mainstem rivers, and are detectable with thermal profiling, especially in smaller rivers.

A fourth factor affecting stream temperature is riparian shading. Stream warming in the absence of cold-water inflow (i.e., groundwater and tributaries) can only be limited by stream shading. As channel width increases, the full benefits from maximum shading decrease (often in the downstream direction). Thermal profiling can help detect locations where rapid heating occurs and locations where no heating occurs. Rapid heating was observed in many locations with poor riparian conditions, as well as at locations with shallow depth.

Rapid heating could also result at a flow “losing” reach, where stream flow volume decreases as surface water recharges groundwater. Rapid heating was observed upstream of Squire Creek in the sampled part of the Upper North Fork. Because stream shading is largely intact in this area, it’s possible this reach is a “losing” reach. This could be tested by implementing a seepage study in this reach along with quantifying hydraulic gradients using piezometers to determine if there are flow losses in the reach. Locations without riparian shade and without groundwater inflow or cooler tributary contributions should be planted, particularly where the observed rate of warming in the longitudinal profile is highest (and diagnostic of poor shading).

Consideration of these factors suggests there are different kinds of management actions that could deliver temperature improvements or create more suitable habitat conditions where temperature is favorable, and that different management actions may have short-term and long-term benefits. Site-specific recommendations are included in the Assessment Synthesis and Project Identification Report (ASPIR).
References


