Snoqualmie River Basin Temperature Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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Cover photo: Middle Fork Snoqualmie River (RM 51.2) near Roaring River Bed and Breakfast, North Bend, Washington

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Snoqualmie River Basin Temperature Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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Abstract

The Snoqualmie River basin has high water temperatures that do not protect fish and other native species that depend on cool, clean water. This report, the *Snoqualmie River Basin Total Maximum Daily Load* (TMDL) *Water Quality Improvement Report and Implementation Plan*, documents this problem and outlines the solutions needed to improve river temperatures. The Snoqualmie River has three Category 5 (303(d)) listings in the Washington State Water Quality Assessment and 38 additional impaired areas that should be in Category 5.

Ecology conducted fieldwork to examine temperature patterns in the Snoqualmie River watershed. Most locations measured during 2005 and 2006 were several degrees warmer than state standards.

Ecology used the stream temperature model QUAL2Kw (Pelletier and Chapra, 2008) to investigate how meteorology, shade, and headwater temperatures influence water temperature in the impaired reaches. The model predicted reductions in water temperature from improved mature riparian vegetation and microclimate. Model simulations performed at critical (1 in 10 year) low-flow and meteorological conditions show an average reduction of 2.8ºC compared to current conditions. This reduction lowers maximum daily temperatures from near lethal levels (22ºC for salmonids) to about 20ºC. Model simulations for a hot week in a typical year showed an average cooling of 2.0ºC, from 19.2ºC to 17.0ºC which is much closer to the numeric criteria of 16 and 17.5ºC.

Ecology developed load allocations for effective shade to describe the need for increased stream shading in the Snoqualmie Watershed. Wasteload allocations were developed for wastewater treatment plants, stormwater discharges, and fish hatcheries. In addition to improved riparian vegetation, Ecology also recommends improving channel complexity, increasing, and protecting groundwater connectivity.

Gradual improvements in water temperatures are expected as the amount of riparian restoration increases and as trees and other vegetation mature. Best management practices needed to provide shading should be completely implemented no later than ten years after completion of this TMDL.

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Executive Summary

Introduction

Water temperatures in the Snoqualmie River watershed are too high to support the needs of fish and their supporting ecosystem. The goal of the *Snoqualmie River Basin Temperature Total Maximum Daily Load (TMDL) Water Quality Improvement Report and Implementation Plan* (the Plan) is to describe the extent of the problem and actions needed to cool river waters.

Snoqualmie River water temperatures were first determined to exceed (not meet) Washington State standards based on data collected by Puget Sound Energy (formerly Puget Power) in 1991 and data collected in 2001 by the Washington State Department of Ecology (Ecology). During the Water Resource Inventory Area (WRIA) 6 and 7 Water Quality Scoping process conducted in late 2004, Ecology consulted with other watershed advisors and ranked Snoqualmie temperature impairments as the highest priority TMDL project in the basin.

The Snoqualmie River watershed is an important spawning and rearing area for several salmonid species including the threatened fall Chinook salmon, steelhead, and bull trout populations. Chinook are known to spawn heavily in the mainstem just below the confluences of the Raging and Tolt rivers. Both the Tulalip and Snoqualmie tribes are working to improve salmon resources in the Snoqualmie watershed. King County, local governments, conservation districts, and nonprofit organizations are also working with local landowners to protect both salmon resources and the agricultural resources in the Snoqualmie Valley.

This water quality improvement report contains the TMDL, recommendations for cleaning up the water body, and an implementation plan that outlines roles and responsibilities for the cleanup process.

What is a total maximum daily load (TMDL)?

The federal Clean Water Act requires that a TMDL be developed for each of the water bodies on the 303(d) list. The Clean Water Act 303(d) list details water bodies that do not meet Washington State water quality standards. The TMDL study identifies pollution problems in the watershed, and then specifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology, with the assistance of tribes, local governments, agencies, and the community, develops a plan that describes actions to control the pollution and a monitoring plan to assess the effectiveness of the water quality improvement activities. The water quality improvement report (WQIR) consists of the TMDL study and implementation strategy or plan. This TMDL report is comprised of two major sections: the water quality improvement report (WQIR), which consists of the TMDL study and analyses, and an implementation plan.

Watershed description

The Snoqualmie River basin is in Water Resource Inventory Area (WRIA) 7, in northwest Washington State. The study area for this TMDL (Figure ES-1) consists of the Snoqualmie River system from its confluence with the Skykomish River (where it becomes the Snohomish River) to the many headwater areas originating within the Snoqualmie National Forest and other high elevation areas within the watershed boundary. Although the study area map includes the entire watershed, the most intensive study was on the mainstem Snoqualmie River and the Middle Fork Snoqualmie River from the national forest boundary to its mouth.

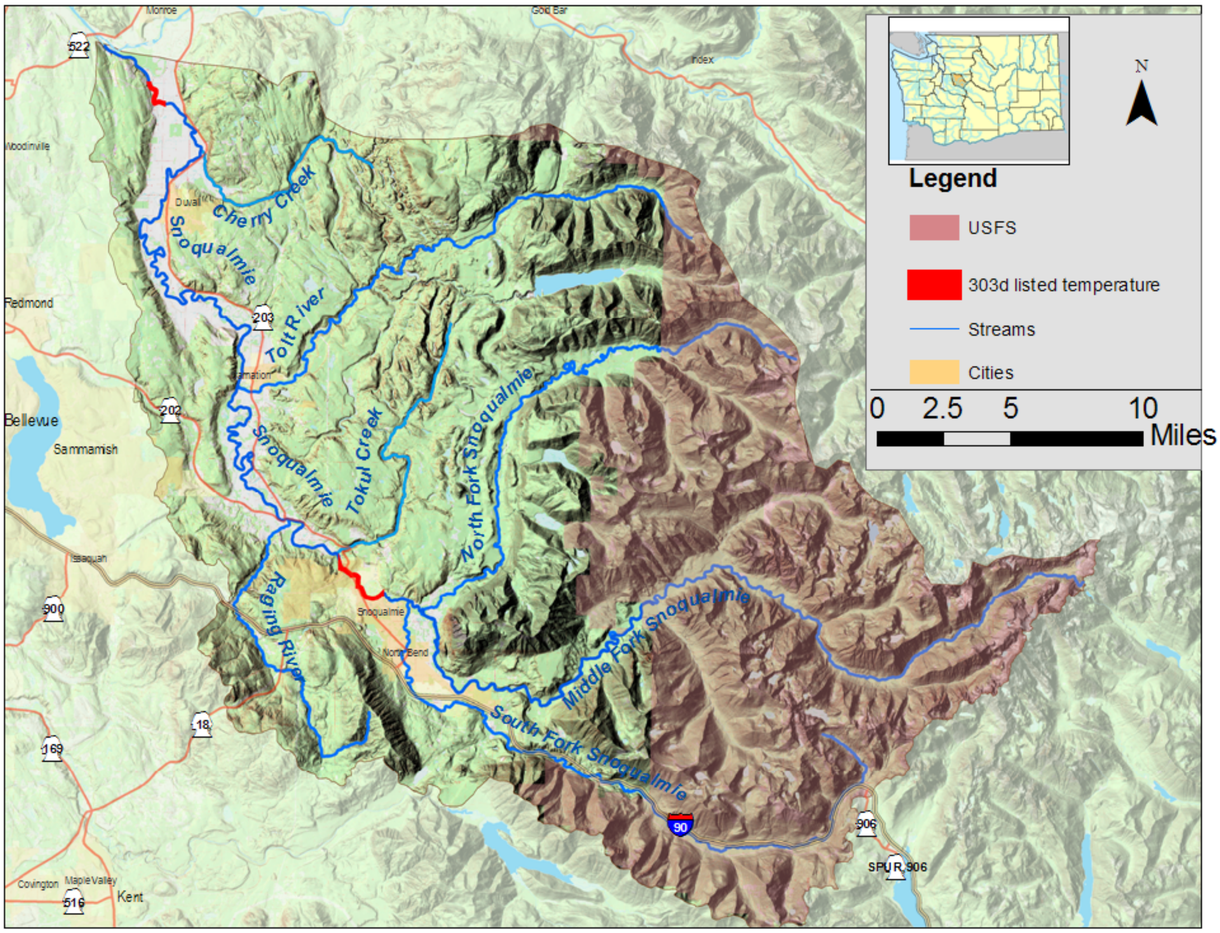

Figure ES-1. Snoqualmie River Temperature TMDL study area.

Load allocation targets are set for all waters in the basin except for those areas overseen by the U.S. Forest Service (USFS). The USFS has agreed to manage all waters on National Forest System (NFS) lands to meet or exceed water quality standards, laws and regulations, and that activities on NFS lands will be provided with a level of protection consistent with those applied on private and state forests in Washington. Typically, these areas are governed by different regulations and stream protections that call for the development of water quality restoration plans, to be developed by the USFS. Although Ecology collaborated with the USFS on these plans in the past, this TMDL assumes USFS practices are protective of designated uses; therefore, this TMDL will not model effective shade requirements within the NFS lands and assumes waters leaving those lands will meet state standards as riparian vegetation matures and buffers continue to be protected under USFS management.

The goal of the *Snoqualmie River Basin Temperature TMDL* study is to characterize the water temperature in the basin and to establish load and wasteload allocations for the heat sources to meet water quality standards for surface water temperature.

What needs to be done in this watershed?

To protect or reduce water temperatures in the Snoqualmie River watershed, action is needed to control the discharges from wastewater treatment plants (WWTPs), improve riparian shading, control water withdrawals, and improve instream habitat. A summary of this study's key findings follows.

Stream temperatures from 2006 exceeded Washington State standards (16°C or 17.5°C) in much of the Snoqualmie River watershed. The highest temperatures were recorded at the mouth of the Raging River, where the 7-day average of the daily maximum temperatures (7-DADMax) was 25.1°C. The coolest locations in the watershed are the tributaries to the Middle Fork, which tend to be small groundwater- or wetlandfed streams that often dry up toward the end of the summer. These tributaries typically had 7-DADMax temperatures less than 16°C, with one as low as 11.4°C. Water temperatures in the basin do not meet numeric water quality standards during the hottest period of the year and thus drive the need for maximum protection from direct solar radiation (Figure ES-2).

The load allocation for all streams in the Snoqualmie River watershed study area located downstream of the USFS boundary is the effective shade that would occur from system-potential mature riparian vegetation. *System-potential mature riparian vegetation* is defined as that vegetation which would have grown and reproduced naturally on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes. System-potential effective shade was determined using data from the King and Snohomish County Soil Surveys, the LiDAR survey from the Puget Sound consortium, and from field measurements taken in 2006. System-potential vegetation was determined to be represented by 100-year-old vegetation with an average tree height of 45 meters (about 150 feet), canopy density of 85%, and overhang of 7.3 meters.

Exceptions to the load allocation are three small tributaries (Granite Creek, Gifford Lakes stream drainage, and unnamed tributary D) to the Middle Fork Snoqualmie that met the numeric standard in 2006. Current shade levels are sufficient for those tributaries.

Some documentation indicates that the area of the Snoqualmie River between river mile (RM) 2 and 12, which contained historical wetlands may only be able to produce vegetation classified as 50-year old. Fifty-year-old vegetation is assumed to be mixed conifer and deciduous species of height 36.6 meters (120 feet), canopy density 85%, and overhang of 7.3 meters. For tributaries with bankfull channel width less than 15 meters (50 feet), 50-year-old vegetation provides the required shading because the assumed overhanging vegetation will cover the stream.

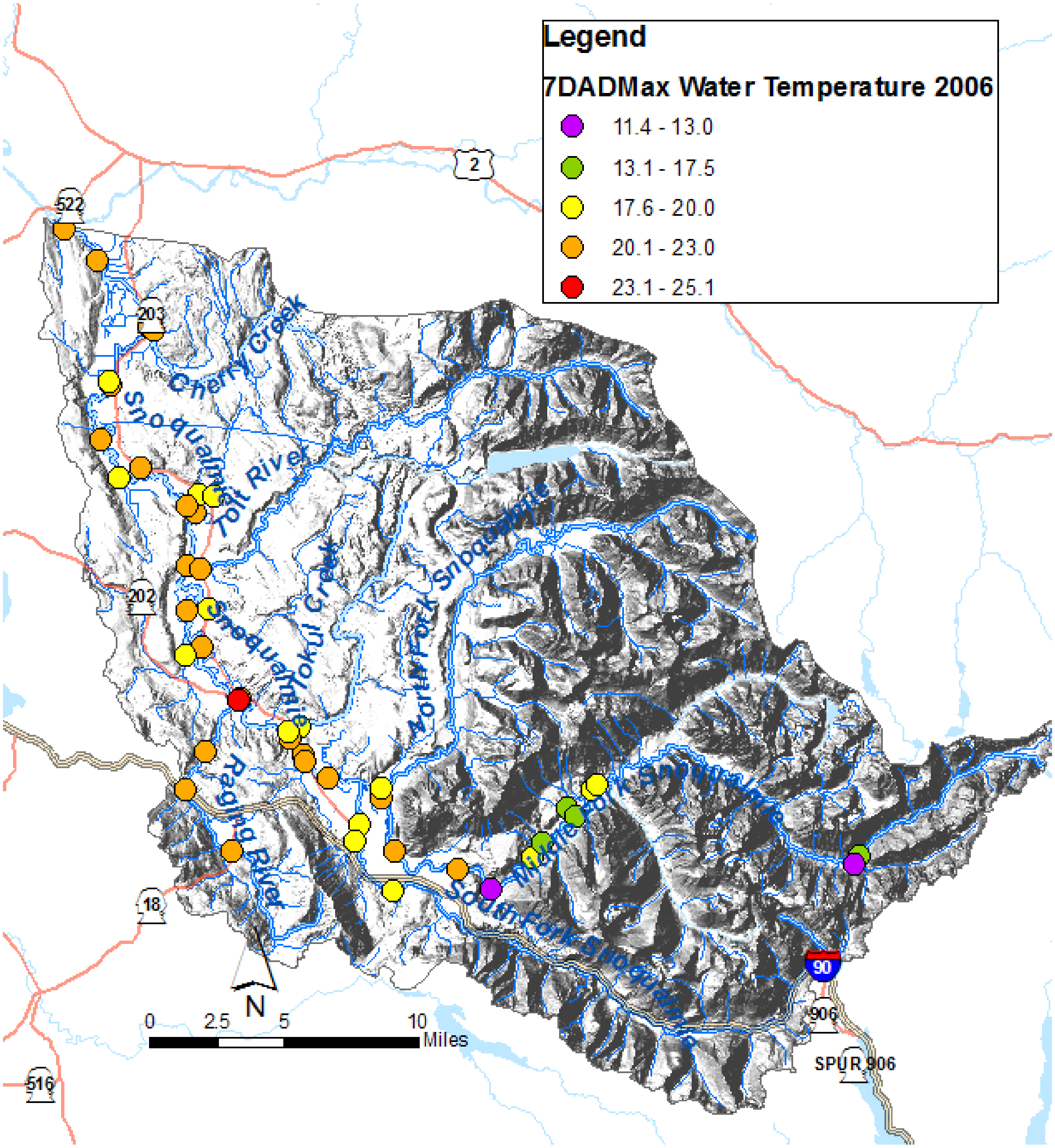

Figure ES-2. The highest 7-day average of the daily maximum water temperatures in the Snoqualmie River and its tributaries during 2006.

The wasteload allocations (WLAs) for National Pollutant Discharge Elimination System (NPDES)-permitted discharges for wastewater treatment plants and fish hatcheries in the Snoqualmie River watershed are shown in Table 1.

Table 1. Temperature wasteload allocations for NPDES permitted dischargers

Waterbody name	Time period restrictions	Permittee name and ID	Permit type	Wasteload allocation
South Fork Snoqualmie River	June - August	North Bend (WA-002935-1)	WWTP discharge	23.5°C or [1]flow curve
	September			22.0°C or [1]flow curve
Snoqualmie River	June - September	Snoqualmie WWTP (WA-002240-3)	WWTP discharge	24.7
Tokul Creek	June 16 - Sept 14	Tokul Creek Hatchery	General Fin Fish	16.3
	Sept 15 - June 15			13.3
Snoqualmie River	June - September	Carnation WWTP (WA-003218-2)	WWTP discharge	33
Snoqualmie River	June - September	Duvall (WA-002951-3)	WWTP discharge	29.7
Boxley Creek	June - September	Boxley Creek Hatchery WAG 133017	General Fin Fish	16.3

[1]Flow curve is explained in *North Bend* section below.
Wasteload allocation = Maximum allowable effluent temperature (°C).

Data collected in 2006 indicate that stormwater discharges are not a significant source of thermal pollution during the June-September period of concern. However, WLAs are necessary for permitted stormwater discharges if they are a source of pollutant loading when receiving water temperatures are impaired. Although thermal loadings from permitted stormwater are of minimal size, all NPDES-permitted discharges must be provided WLAs. Ecology developed a cumulative WLA for all permitted stormwater discharges described as follows:

> When a water body's temperature is warmer than state criteria due to natural conditions (or within 0.3^{o}C), the cumulative discharge from all permitted sources may not cause the 7DADMax receiving water temperature under those conditions to increase more than 0.2^{o}C (0.36^{o}F)[1]. That allowable 0.2^{o}C increase is quantified using the following equation, which provides a numeric loading value to assess compliance with the WLA.

$$\text{WLA}_{\text{critical period}} = \frac{\sum_{N=1}^{7}(\Delta T * Q_N * C_F)}{7}$$

[1] The remaining 0.1^{o}C of the incremental warming allowance is reserved for unpermitted stormwater and other human sources and a margin of safety. Cummulative allowable loadings can be measured at the TMDL monitoring locations representative of the impaired segments identified earlier in this TMDL

Where:

$WLA_{critical\ period}$ = the waste load allocation in Kilocalories/day
ΔT= allowable cumulative temperature increase for point sources=0.2°C
Q_N= daily receiving water flow, in cfs,
N = day 1 through 7 of the 7DAD averaging period
C_F=2,446,665 (kcal·second)/°C·ft^3·day (a conversion factor to transform the units to Kilocalories/day)

Further discussion of the permits covered in Table 1, stormwater permits, and other general permit categories are covered in the *Wasteload Allocation* section of this TMDL. Additional findings of this report are as follows.

- Under the current riparian status during critical low-flow (7Q10) and 90th percentile meteorological conditions, Snoqualmie River maximum water temperature is expected to average 22.8°C and in some locations to exceed the 22°C lethal threshold to salmonids. With all management scenarios in place, temperatures are expected to remain significantly below the lethal threshold, averaging 20 °C during critical conditions.

- Maximum water temperature (7-DADMax) during the hottest week of a year with typical flow and meteorological conditions is predicted to average 19.2°C under the current riparian status, and to be near 17.0°C with all management scenarios in place. Portions of the lower river (km 75/RM 46 to mouth) would be able to meet numeric water quality standards during most years.

- The larger tributaries, especially the North Fork, the South Fork, and the Tolt Rivers generally have a cooling effect on temperature in the mainstem of the Snoqualmie River.

- The Raging River delivers exceptionally warm water to the mainstem, but flow quantity is not large enough to influence mainstem temperatures. The warm water could, however, be a barrier to salmonid migration into the Raging River. Additional study for the Raging River could be beneficial.

- Increasing shade to the area of the Middle Fork just above the North Fork confluence reduces water temperature in this currently warm section to temperatures similar to reaches immediately upstream.

- The load allocations are expected to re-establish mature riparian vegetation. Establishing mature riparian vegetation benefits temperatures directly through reduced solar radiation and indirectly though an increase in channel complexity. A natural fully-functioning channel would be expected to have more sinuosity and braiding, more woody debris, reduced bank erosion, and better interaction with subsurface water and flood plain. Large mature buffers will also reduce local air temperatures and provide microclimate benefits.

- Effective shade from mature vegetation is also beneficial to dissolved oxygen (DO) levels and pH. Cooler water temperatures hold more oxygen and riparian shade reduces the growth of aquatic plants that affect DO and pH.

- Levee setback is an option for areas needing channel restoration that currently have levees. This is currently being applied near the mouth of the Tolt River with an anticipated benefit to both stream habitat and flood protection. The levee setback project will reconnect existing wetlands to the river system while maintaining, or potentially improving, flood protection to the north of the Tolt River.

- NPDES permit-mandated stormwater controls requiring the use of low impact development techniques to infiltrate stormwater will help prevent stormwater from affecting surface water temperatures. Data collected during the study show that stormwater does not have a significant impact on the temperature of small tributaries. As stormwater systems expand with increased development, it is important to evaluate stormwater discharge volumes. If stormwater discharge volumes increase, they can later be evaluated for appropriateness of temperature data collection and the analysis of impacts on local surface waters.

- It is important that NPDES permittees follow permit requirements. Municipal wastewater permittees (cities of Duvall, Snoqualmie, North Bend, and King County) must meet the wasteload allocations as described in future permits. Municipal stormwater permittees (cities of Duvall and Sammamish, King County, Snohomish County, Washington State Department of Transportation (WSDOT), and any future permittees) should infiltrate as much stormwater as is feasible. Sand and gravel and construction stormwater permittees should show particular attention to controlling sediment discharges. Delivery of sediment can cause changes to the stream that subsequently allow greater heating. Two examples are filling of spaces between gravels to reduce exchange of cooler subsurface waters, and by stream channel widening.

- Riparian restoration is essential. Approximately 900 acres of the Snoqualmie mainstem need to be planted with trees. Over 90% of that need occurs below Snoqualmie Falls in the floodplain. Additional planting needs exist along much of the tributary streams. Each side of the mainstem river needs a 150-foot-wide buffer planted with trees that will reach a mature height of 150 feet. Tributary streams need buffers tall and wide enough to provide complete shade at a minimum. Larger buffers that provide microclimate effects are desirable where feasible. Tributaries with high salmonid use should be prioritized for restoration.

- Ecology anticipates that if state and local coordination proceed as expected for increasing effective shade, required plantings to begin the reconditioning of riparian conditions will be achieved by 2021. Because of the time needed for trees to grow to a mature size and provide maximum shade and microclimate benefits, fully reaching TMDL goals will not be achieved until all trees reach their mature height. However, the majority of the shade that will be provided should be in place by 2071, when trees are 50 years old.

Why this matters

Reducing high water temperatures in the Snoqualmie watershed is necessary to recover threatened cold water fish species that spawn, rear, or live there. These fish species are highly valued by the many state residents that depend upon them for cultural, recreational, or economic reasons. Over the past century, the lands of the Snoqualmie watershed have seen many changes as they were developed to provide lumber, agricultural land and homesteads, water storage and power production, and locations to dispose of treated domestic wastewaters and stormwater. The Snoqualmie Watershed has four urban centers that are expected to grow in size and impact the watershed. Although logging activity has diminished greatly, agricultural activities will thrive and recreational opportunities can be expected to grow. All of these activities could affect stream temperatures in the future.

This water quality improvement plan studies this changed environment, reports on the state of water temperatures now, what we can expect in the future, and what we need to do to improve this degraded watershed.

What is a Total Maximum Daily Load (TMDL)

Federal Clean Water Act requirements

The Clean Water Act (established a process to identify and clean up polluted waters. The act requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

The Water Quality Assessment and the 303(d) List

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

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The list of waters that do not meet standards [the 303(d) list] is the Category 5 part of the larger assessment.

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

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

Category 2 – Waters of concern.

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

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

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

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

Further information is available at Ecology's Water Quality Assessment website.

The Clean Water Act requires that a TMDL be developed for each of the water bodies on the 303(d) list. A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

TMDL process overview

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

After the public comment period, Ecology addresses the comments as appropriate. Then Ecology submits the WQIR/IP to the U.S. Environmental Protection Agency (EPA) for approval.

Who should participate in this TMDL?

Because thermal pollution comes from diffuse sources, all upstream watershed areas have the potential to affect downstream water temperatures. Therefore, all areas contributing excessive levels of solar radiation, or other factors contributing to high water temperature, must use the appropriate best management practices to reduce impacts to water quality. The area subject to the TMDL is shown in Figure 1.

Streamside landowners are the most important participants in reducing water temperatures in the Snoqualmie River watershed and meeting the nonpoint pollutant load targets. Governmental and private organizations that provide technical assistance and other support to these landowners are critical partners that need to work with these landowners to improve riparian shading of local waters. Regulatory agencies responsible for managing forestry practices and public lands are also essential participants. Specific agencies, organizations, and their role in reducing water temperatures are discussed in more detail in the *implementation plan* at the end of this document.

All point source dischargers in the watershed must comply with the wasteload allocations established in this TMDL. The Duvall, Carnation, Snoqualmie, and North Bend WWTPs, and the Tokul Creek and Boxley Creek Fish Hatcheries have been identified as point sources. Ecology will ensure compliance with the wasteload allocations through their individual NPDES permits. Municipal stormwater permits are held by King and Snohomish counties, the city of Duvall, and the Department of Transportation. It is important that best management practice (BMP) and monitoring requirements documented in those permits be followed. These permits will be discussed in more detail in the *implementation plan* at the end of this document.

Elements the Clean Water Act requires in a TMDL

Loading capacity, allocations, seasonal variation, margin of safety, reserve capacity, and surrogate measures

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

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

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

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

To provide more meaningful and measurable pollutant-loading targets, this TMDL may also incorporate *surrogate measures* other than daily loads. EPA regulations [40 CFR 130.2(i)] allow other appropriate measures in a TMDL. See the *Glossary* section of this document for more information.

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Why Ecology Conducted a TMDL Study in this Watershed

Overview

The Snoqualmie River basin has high water temperatures that do not protect fish and other native species that depend on cool, clean water. Snoqualmie River water temperatures were first determined to exceed Washington State standards based on data collected by Puget Sound Energy (formerly Puget Power) in 1991 and data collected in 2001 by Ecology. This resulted in the river's inclusion on the 303(d) list. In response to those listings, Ecology is required to prepare a water quality improvement plan for these impaired waters.

During the WRIA 6 and 7 Water Quality Scoping process conducted in late 2004, Ecology consulted with other watershed advisors and ranked Snoqualmie temperature impairments as the highest priority TMDL project in the basin. The study of Snoqualmie River watershed water temperatures was ranked highest priority because of the importance of this watershed to the survival of threatened and depleted salmon stocks in the Puget Sound area.

The goal of this water quality improvement plan is to characterize the water temperature in the basin, establish load and wasteload allocations for the heat sources, and detail the corrective actions needed to meet water quality standards for river water temperature. Our study of the extent and causes of high water temperatures began in 2006, and those study results are detailed in the first half of this document.

Study area

The Snoqualmie River basin is in Water Resource Inventory Area (WRIA) 7, in northwest Washington State. The study area for this TMDL (Figure 1) consists of the Snoqualmie River system from its confluence with the Skykomish River to the headwater at the Snoqualmie National Forest boundary. Although the study area map includes the entire watershed, the most intensive study is on the mainstem Snoqualmie River and the Middle Fork Snoqualmie River from the national forest boundary to its mouth. Load allocation targets are set for all waters in the basin except for those located in national forest areas overseen by the U.S. Forest Service (USFS).

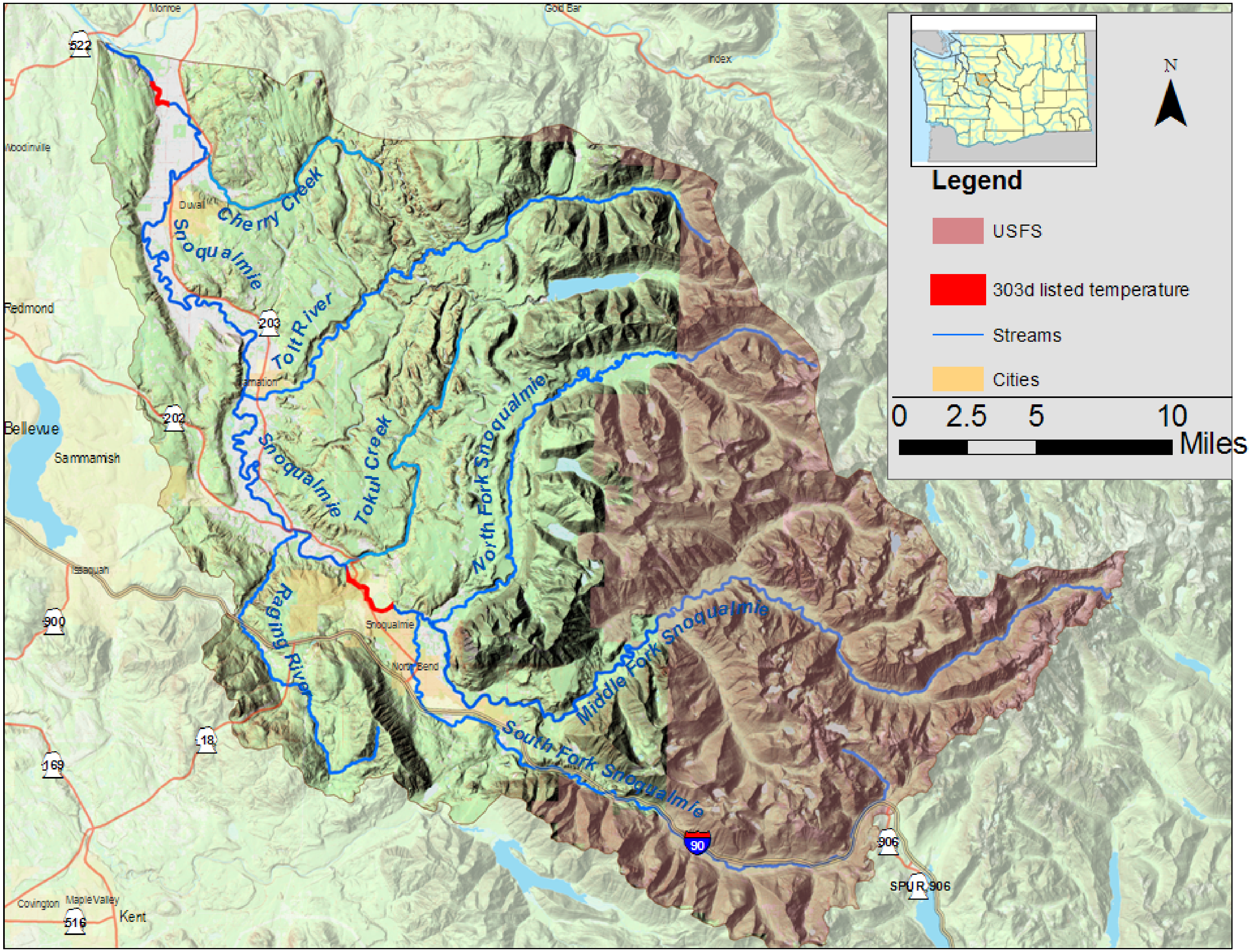

Figure 1. Snoqualmie River Temperature TMDL study area.

Impairments addressed by this TMDL

This TMDL addresses temperature impairments in the Snoqualmie River basin. The main beneficial uses to be protected by this TMDL are aquatic life uses, including core summer salmonid habitat, salmonid spawning, rearing, and migration. In addition, these water bodies are also to be protected for primary contact recreation and for domestic, industrial, and agricultural water supply.

Washington State established water quality standards to protect these beneficial uses. Table 2 shows listings for temperatures that violate these standards within the Snoqualmie River watershed. Although only three locations are included in Table 2, Ecology and other groups in recent years have collected data that showed exceedances throughout the watershed (Kardouni and Cristea, 2006). One example is the continuous temperature monitoring data collected by Ecology in 2003, 2004, and 2005 that were not assessed in time for the 2008 Water Quality Assessment. Because the locations where temperature exceeds the water quality standard are spread throughout the watershed, this TMDL was developed to address water temperature in perennial streams in the entire watershed. A listing of locations exceeding the temperature standard in 2005 and 2006 are detailed in Table 11 later in this document.

Table 2. Study area water bodies on the 2008 303(d) list for temperature.

Water body	Parameter	Category	Listing ID	Township	Range	Section
Snoqualmie River	Temperature	5	7415	24N	08E	30
Snoqualmie River	Temperature	5	6571	24N	08E	32
Snoqualmie River	Temperature	5	6570	27N	06E	26

This watershed has other water quality issues that will not be addressed in this TMDL. In particular, Table 3 below shows additional 303(d) listings that occur in the study area but are not specifically addressed in this report. However, cooler water temperatures inhibit growth of aquatic plants, which often leads to improvements in pH. Listings for dissolved oxygen and fecal coliform were addressed in previous TMDL documents (Joy, 1994; Sargeant and Svrjcek, 2008).

Table 3. Additional 303(d) listings not addressed by this report.

Water body	Parameter	Category	Listing ID	Township	Range	Section
South Fork Snoqualmie River	pH	5	7428	23N	09E	30
Deep Creek	pH	5	51227	25N	08E	13
Cherry Creek	pH	5	50742	26N	07E	01

Water Quality Standards and Designated Uses

Designated beneficial uses

Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC; Ecology, 2006), include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state.

The designated aquatic life uses for the Snoqualmie River and tributaries include (WAC 173-201A-200):

- *Char spawning and rearing.* The key identifying characteristics of this use are spawning or early juvenile rearing by native char (bull trout and Dolly Varden), or use by other aquatic species similarly dependent on such cold water. Other common characteristic aquatic life uses for waters in this category include summer foraging and migration of native char; and spawning, rearing, and migration by other salmonid species.
- *Core summer salmonid habitat*. This use protects summer season (June 15 through September 15) salmonid spawning or emergence, adult holding, summer rearing habitat by one or more salmonids, or foraging by adult and sub-adult native char. Other protected uses include spawning outside of the summer season, rearing, and migration by salmonids.
- *Salmonid spawning, rearing, and migration.* This use protects salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 – June 14). Other uses include rearing and migration by salmonids.

Other non-aquatic life uses include water supply (domestic, industrial, and agricultural), stock watering, fish and shellfish harvesting, wildlife habitat, recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment), and commerce and navigation. Numeric criteria for specific water quality parameters are intended to protect these designated uses.

Ecology revised the Washington State water quality standards in July 2003 and in 2006. EPA approved these changes in February 2008. Table 4 contains a list of tributary streams and associated water quality classifications from the Snoqualmie River Quality Assurance Project Plan (Kardouni and Cristea, 2006) and adds the new classifications that were approved in 2008.

Table 5 shows the water quality classifications for the mainstem Snoqualmie River. In addition, there are locations in the upper reaches of the Tolt, North Fork, and Middle Fork Snoqualmie River that are designated as char habitat. Often these designations begin near the USFS border. For specific locations see Appendix H (Table 602 for Snoqualmie River basin) which shows the legal descriptions of designations for all waters in WRIA 7.

Table 4. Water quality classifications and river mile (RM) of tributary water bodies within the Snoqualmie River basin. *Left bank (LB) and right bank (RB) are relative when facing downstream*.

Water body	Snoqualmie RM confluence	Old Water Quality classification	2008 Water Quality classification	Numeric criterion (degrees C)	Supplemental Spawning/ Egg Incubation criterion
Pearson Eddy Creek	3.6 (LB)	A	Spawning/ rearing	17.5	
Peoples Creek	4.3 (RB)	A	Spawning/ rearing	17.5	
Duvall Creek	5.7 (RB)	A	Spawning/ rearing	17.5	
Cherry Creek	6.7 (RB)	A	Core Summer Habitat	16	13°C Feb 15–June 15
Tuck Creek	10.3 (LB)	A	Spawning/ rearing	17.5	
Coe Creek	10.3 (RB)	A	Spawning/ rearing	17.5	
Adair Creek	13.3 (LB)	A	Spawning/ rearing	17.5	
Ames Creek	17.0 (LB)	A	Spawning/ rearing	17.5	
Weiss Creek	19.9 (RB)	A	Spawning/ rearing	17.5	
Harris Creek	21.3 (RB)	A	Core Summer Habitat	16	
East Horse Shoe Lake	22.8 (RB)	A	Core Summer Habitat	16	
Tolt River[1]	24.9 (RB)	AA	Core Summer Habitat	16	13°C Sept 15–June 15
Langlois Creek	26.4 (RB)	A	Core Summer Habitat	16	
Griffin Creek	27.2 (RB)	A	Core Summer Habitat	16	13°C Feb 15–June 15
Patterson Creek	31.2 (LB)	A	Core Summer Habitat	16	13°C Feb 15–June 15
Rutherford Slough	35.3 (RB)	A	Core Summer Habitat	16	
Raging River	36.2 (LB)	A	Core Summer Habitat	16	13°C Sept 15–June 15
Skunk Creek	38.6 (RB)	A	Core Summer Habitat	16	
Tokul Creek	39.7 (RB)	A	Core Summer Habitat	16	13°C Sept 15–June 15
Kimbal Creek	41.1 (LB)	A	Core Summer Habitat	16	
South Fork Snoqualmie River	44.2 (LB)	A and AA (9.1)	Core Summer Habitat	16	
North Fork Snoqualmie River[1]	45.0 (RB)	AA	Core Summer Habitat	16	
Middle Fork Snoqualmie River[1]	45.0	AA	Core Summer Habitat	16	

[1] Char Spawning and Rearing criterion apply for the upper reaches of these watersheds as shown in Figure 2.

Each beneficial use designation described above has associated water quality criteria. The relevant temperature criteria that apply to the Snoqualmie River and its tributaries are detailed in Tables 4 and 5. Figure 2 shows the water quality standards for the Snoqualmie River basin in map form.

Table 5. Water quality classifications for the mainstem Snoqualmie River.

Downstream point	Upstream point	2008 Water Quality classification	Numeric criterion (degrees C)	Supplemental Spawning/ Egg Incubation criterion
Confluence with Skykomish River RM 0	The confluence with Harris Creek RM 21.3	Spawning/ rearing	17.5	
Confluence with Harris Creek RM 21.3	Confluence with Patterson Creek RM 31.2	Core Summer Habitat	16	13°C Sept 15–May 15 RM 22.7 to RM 31.2
Confluence with Patterson Creek RM 31.2	Just upstream of confluence with Tokul Creek RM 40.2	Core Summer Habitat	16	13°C Sept 15–June 15 RM 31.2 to RM 40.2
RM 40.2	Junction with Middle and North Fork RM 45.0	Core Summer Habitat	16	

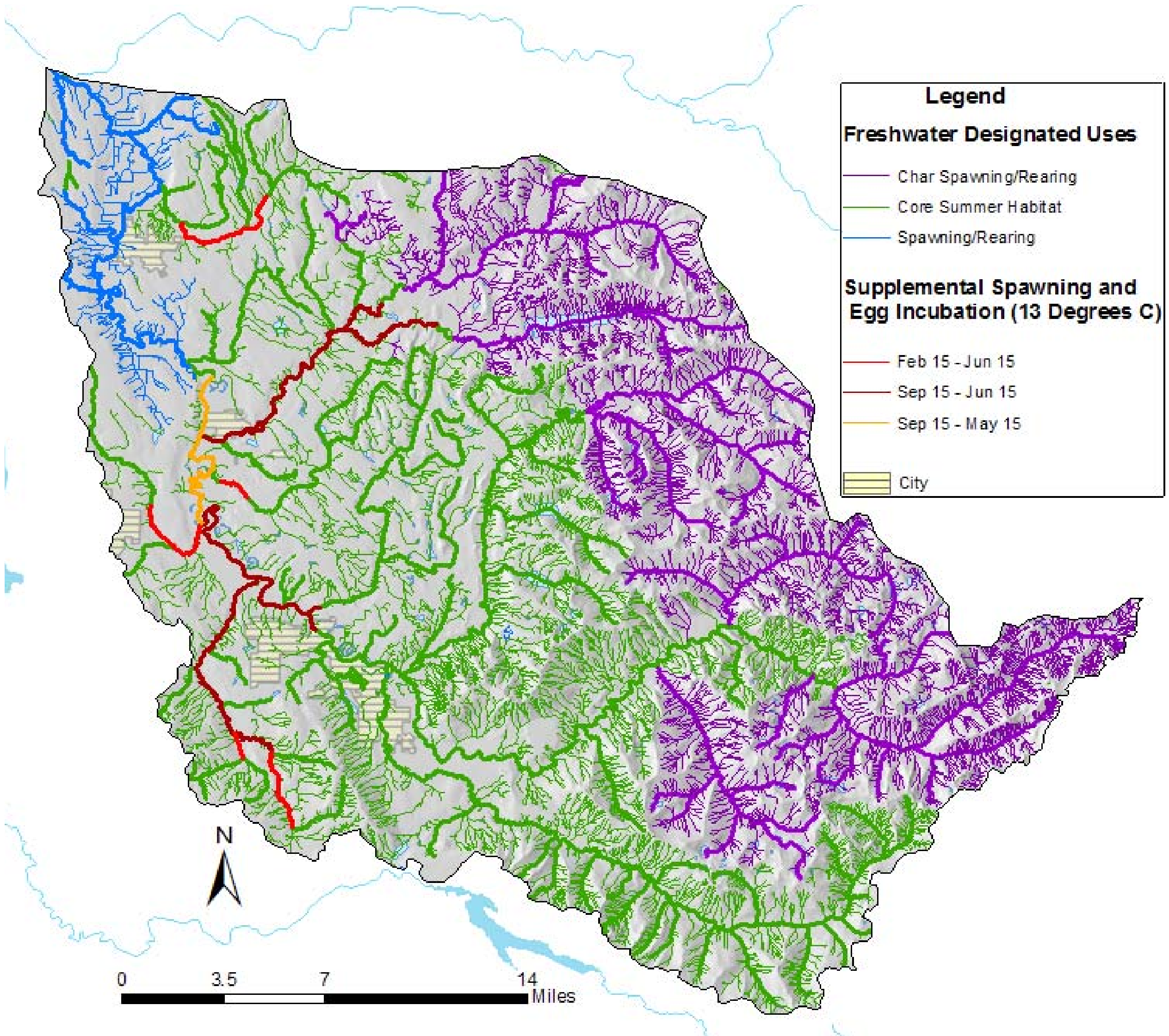

Figure 2. Water quality standards for temperature in the Snoqualmie River basin beneficial uses and supplemental spawning criteria.

Temperature criteria

Fresh waters

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

In the Washington State water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) (WAC 173-201A-200; 2003 edition). The three pertinent categories are:

1. To protect the designated aquatic life uses of "Char Spawning and Rearing" the highest 7-DADMax temperature must not exceed 12°C (53.6°F) more than once every ten years on average.

2. To protect the designated aquatic life uses of "Core Summer Salmonid Habitat" the highest 7-DADMax temperature must not exceed 16°C (60.8°F) more than once every ten years on average.

3. To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only" the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, the state provides a small allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition. Whether or not the water body is naturally high in temperature is determined using a model. The model roughly approximates natural conditions, and is appropriate for determining the implementation of the temperature criteria. This model results in what is called the "system thermal potential" or "system potential" of the water body.

In addition to the maximum criteria noted above, compliance must also be assessed against criteria that limit the incremental amount of warming, by human actions, of otherwise cool waters. When water is cooler than the criteria noted above, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

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

B. Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not at any time exceed 2.8°C (5.04°F).

Special consideration is also required to protect spawning and incubation of salmonid species. Where it has been determined that the temperature criteria established for a water body would likely not result in protective spawning and incubation temperatures, the following criteria apply:

A. Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char.

B. Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Washington State treats lakes differently for protecting temperature conditions. For all lakes, and for reservoirs with a mean annual retention time of greater than 15 days, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C (0.54°F) above the modeled system thermal potential.

While the criteria generally applies throughout a water body, it is not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that measurements should be taken from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously cold areas such as at discrete points where cold groundwaters flow into the water body.

Global climate change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005). Summer streamflows depend on the snowpack stored during the wet season. Studies of the region's hydrology indicate a declining tendency in snow water storage coupled with earlier spring snowmelt and earlier peak spring streamflows (Hamlet et al., 2005). Factors affecting these changes include climate influences at both annual and decadal scales, and air temperature increases. Increases in air temperatures result in more precipitation falling as rain rather than snow and earlier melting of the winter snowpack.

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases.

Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperature improvements obtained by growing mature riparian vegetation corridors along streambanks, reducing channel widths, and enhancing summer baseflows may all help offset the changes expected from global climate change – keeping conditions from getting worse. It will take considerable time, however, to reverse those human actions that contribute to excess stream warming. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our stream resources.

These efforts may not result in streams meeting the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

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

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Overview of Stream Heating Processes

Introduction

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature within a particular segment of a stream are induced by the balance of heat exchange between the water and the surrounding environment during transport through the segment. If there is more heat energy entering the water in a stream segment than there is leaving, then the temperature will increase. If there is less heat energy entering the water in a stream segment than leaving, the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer) and stream temperature change are outlined in Figure 3.

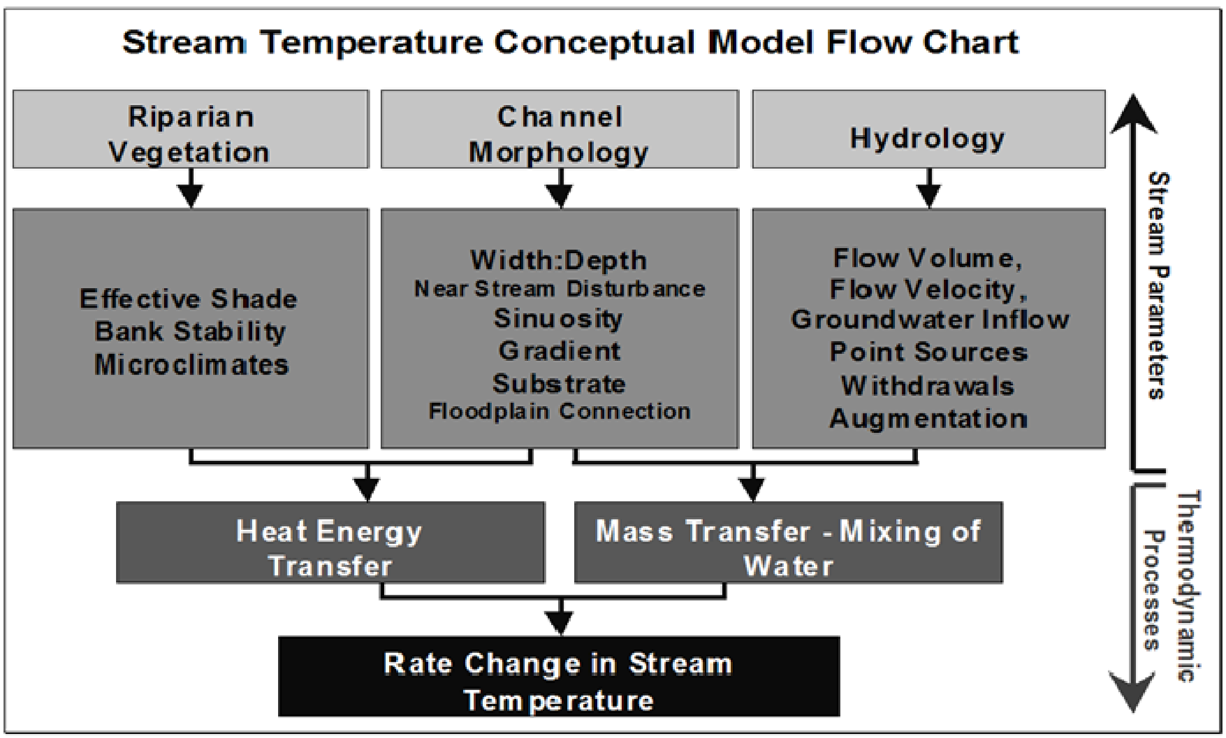

Figure 3. Conceptual model of factors that affect stream temperature.

Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- ***Stream depth.*** Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- ***Air temperature.*** Daily average stream temperatures and daily average air temperatures are both highly influenced by incoming solar radiation (Johnson, 2004). When the sun is not shining, the water temperature in a volume of water tends toward the dew-point temperature (Edinger et al., 1974).
- ***Solar radiation and riparian vegetation.*** The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- ***Groundwater.*** Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream as well as the difference in temperatures between the groundwater and the stream.

Heat budgets and temperature prediction

The heat exchange processes occur between the water body and the surrounding environment and control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure 4 shows the major heat energy processes or fluxes across the water surface or streambed.

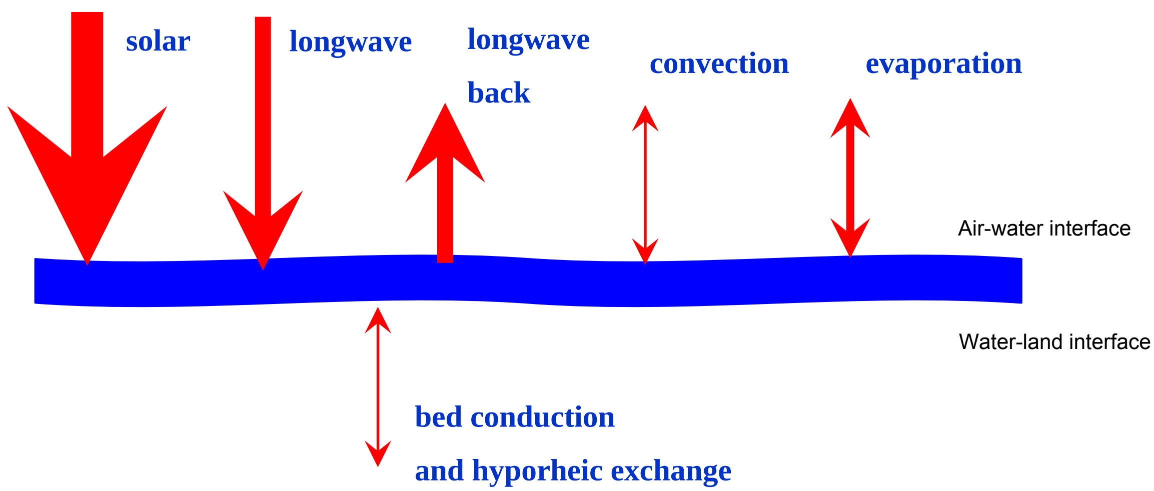

Figure 4. Surface heat exchange process that affect water temperature (net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed).

Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- ***Shortwave solar radiation. T****his is the difference between the energy that comes directly from the sun and that reflected by the water body. Shortwave solar radiation is the most significant input in the heat balance during the day when the sky is clear. However, the surrounding physical features such as vegetation and topography can significantly reduce the amount of shortwave radiation received at a particular location. Vegetation and topography that is completely opaque will reduce shortwave radiation by 100%. Solar exposure was identified as the most influential factor in stream heating processes (Sinokrot and Stefan, 1993; Johnson and Jones; 2000; Danehy et al., 2005).
- ***Longwave atmospheric radiation.*** Longwave radiation from the atmosphere ranges in wavelength from about 4 to 120 μm. Longwave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974). NOAA's Integrated Surface Irradiance Study (ISIS) station in Seattle measures longwave radiation.
- ***Longwave back radiation from the water to the atmosphere.*** Water sends heat energy back to the atmosphere in the form of longwave radiation in the wavelength range from about 4 to 120 μm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

The remaining heat exchange processes generally have less magnitude and are as follows:

- ***Convection flux at the air-water interface*** is driven by the temperature difference between water and air and by wind speed. It is related to evaporation flux through the Bowen ratio. Heat is transferred in the direction of decreasing temperature.
- ***Evaporation flux at the air-water interface*** is influenced mostly by wind speed and the vapor pressure gradient between water surface and air. When air is saturated, evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation takes place and this term then becomes a gain component in the heat balance.
- ***Bed conduction flux and hyporheic exchange*** is the component of the heat budget, which represents the heat exchange through conduction between the bed and the water body and the influence of hyporheic exchange. The magnitude of bed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher; this usually affects the temperature diel profile, rather than affecting the magnitude of the maximum daily water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the daylight hours. Heat is typically transferred from the water into the streambed during the day then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

Hyporheic exchange recently received increased attention as a possible important mechanism for stream cooling (Johnson and Jones, 2000, Poole and Berman, 2000, Johnson, 2004). The hyporheic zone is defined as the region located beneath and adjacent to a stream bed, where there is mixing of shallow groundwater and surface water. This mixing can have significant implications for stream temperature.

Selker (2008) layed fiber-optic temperature sensing cable along the thalweg of the Blue River in Oregon. As expected, the varying influence of hyporheic exchange between the bedrock and alluvial reaches of the stream was pronounced. Daytime water-bottom temperatures rose as the water flowed downstream over the bedrock, which represents an area of little or no hyporheic exchange, and fell in the alluvial reach, where surface-water interaction with the sediment is more pronounced; at night the reverse was true. Notably, the downstream end of the alluvial reach maintained the same temperature to within 0.1ºC throughout the period of observation.

The complete heat budget for a stream also accounts for the mass transfer processes, which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a segment of a stream. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries and groundwater inflows and outflows. Mass transfer relates to transporting flow volume downstream, instream mixing, and introducing or removing water from a stream. For instance, flow from a tributary changes temperature in the mainstem river if the temperature is different in the two water bodies.

Thermal role of riparian vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation is well documented (e.g., Holtby, 1988; Lynch et al., 1984, 1985; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; Levno and Rothacher, 1967; Hewlett and Fortson, 1983). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in greater daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of diurnal fluctuations in solar heat flux.

The warming of water temperatures as a stream flows downstream can be a natural process. However, the rates of heating can be dramatically reduced when high levels of shade exist and heat flux from solar radiation is minimized. Riparian vegetation restoration was identified as one of the most important management steps that may improve stream temperatures (Johnson and Jones, 2000; Blann et al., 2002). The overriding justification for increases in shade from riparian vegetation is to minimize the contribution of solar heat flux in stream heating. There is a natural maximum level of shade that a given stream is capable of attaining, and the importance of shade decreases as the width of a stream increases.

Riparian vegetation may act as an efficient insulating barrier, where the vegetation influences heat exchange rates with the atmosphere and the surrounding environment. Riparian vegetation may also change microclimatic conditions by decreasing air temperature, ground temperatures, and wind speeds and by increasing the relative humidity. It also plays an important role in bank stability and channel morphology. As the river enlarges and widens, riparian vegetation influences on stream temperatures lessen (Poole and Berman, 2000).

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. The balance of all heat exchange and mass transfer processes in the stream determines whether the temperature is increased, maintained, or decreased, as the water flows downstream.

Effective shade

Shade is an important parameter that controls the stream heating from solar radiation. Solar radiation can be one of the largest heat transfer mechanisms in a stream system. Human activities can degrade near-stream vegetation and channel morphology. This, in turn, affects shade. Reductions in shade can cause significant increases in heat delivery to a stream system. Stream shade is an important factor in describing the heat budget for the present analysis. Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al. 1998a and 1998b; Ice, 2001; OWEB, 1999; Teti, 2001 Teti and Pike, 2005).

Shade is the amount of solar energy that is obscured or reflected by vegetation or topography above a stream. Effective shade is defined as the fraction or percentage of the total possible solar radiation heat energy that is prevented from reaching the surface of the water:

$$\text{effective shade} = (J_1 - J_2)/J_1$$

where J_1 is the potential solar heat flux above the influence of riparian vegetation and topography and J_2 is the solar heat flux at the stream surface.

Canopy cover is the percent of sky covered by vegetation and topography at a given point. Shade is influenced by cover but changes throughout each day, as the position of sun changes spatially and temporally with respect to the canopy cover (Kelley and Krueger, 2005).

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summer, allowing longer day length and higher solar altitude. (See Figure 5.) Geographic position fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation or direction of streamflow. Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can produce shade. (See Table 6.) The solar position has a vertical component and a horizontal component that are both functions of time/date and the earth's rotation.

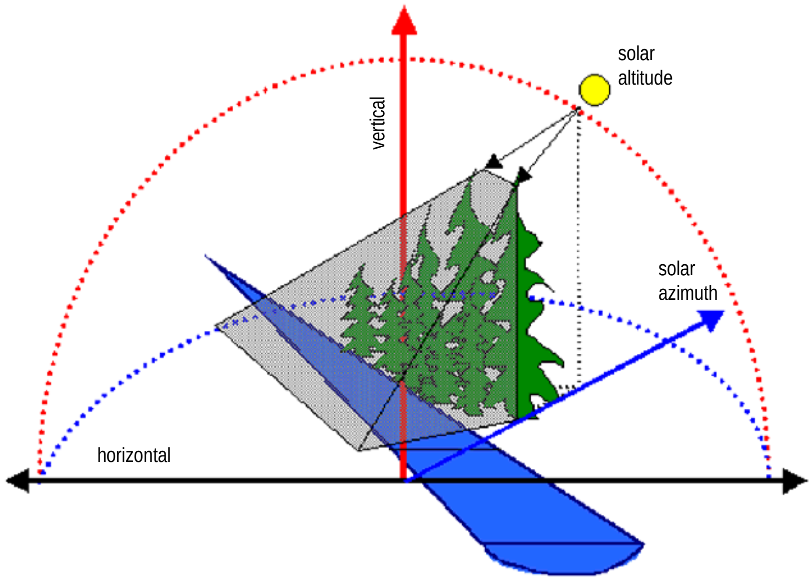

Figure 5. Parameters that affect shade and geometric relationships.

Solar altitude is a measure of the vertical angle of the sun's position relative to the horizon. Solar azimuth is a measure of the horizontal angle of the sun's position relative to north (Boyd and Kasper, 2003).

Table 6. Factors that influence stream shade

Italics indicate influence by human activities.

Description	Parameter
Season/time	Date/time
Stream characteristics	Aspect, *channel width*
Geographic position	Latitude, longitude
Vegetative characteristics	*Riparian vegetation height, width, and density*
Solar position	Solar altitude, solar azimuth

While the interaction of these shade variables may seem complex, the mathematics that describe them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, including hemispherical photography and solar pathfinder.

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table 5 (Ecology, 2003; Chen, 1996; Chen et al. 1998a and 1998b; Boyd, 1996; Boyd and Park, 1998).

Microclimate - surrounding thermal environment

A secondary consequence of near-stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures. Relative humidity increases result from the evapotranspiration that is occurring by riparian plant communities. Wind speed is reduced by the physical blockage produced by riparian vegetation.

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet (45 meters) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams (channel width less than 4 meters) in the foothills of the western slope of the Cascade Range in western Washington with predominantly Douglas-fir and western hemlock.

Bartholow (2000) provided a thorough summary of literature of documented changes to the environment of streams and watersheds associated with extensive forest clearing. Changes in conditions listed below, summarized by Bartholow (2000), are representative of hot summer days and indicate the mean daily effect unless otherwise indicated.

- ***Air temperature***. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (*Cervus canadensis*) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7°C for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima.

  Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988). In an evaluation of buffer strip width, Brosofske et al. (1997) found that air temperatures immediately adjacent to the ground increased 4.5°C during the day and about 0.5°C at night (estimate). Fowler and Anderson (1987) measured a 0.9°C air temperature increase in clearcut areas, but temperatures were also 3°C higher in the adjacent forest. Chen et al. (1993) found similar (2.1°C) increases.

  All measurements reported here were made over land instead of water, but in aggregate support about a 2°C increase in ambient mean daily air temperature resulting from extensive clearcutting.

- ***Relative humidity***. Brosofske et al. (1997) examined changes in relative humidity within 17 to 72 m buffer strips. The focus of their study was to document changes along the gradient from forested to clearcut areas, so they did not explicitly report pre- to post-harvest changes at the stream. However, relative humidity at the stream appeared to be reduced by an estimated 7% during the day and 6% at night. Relative humidity at stream sites increased exponentially with buffer width. Similarly, a study by Chen et al. (1993) showed a decrease of about 11% in mean daily relative humidity on clear days at the edges of clearcuts.

- ***Wind speed***. Brosofske et al. (1997) reported almost no change in wind speed at stream locations within buffer strips adjacent to clearcuts. Speeds quickly approached upland conditions toward the edges of the buffers, with an indication that wind actually increased substantially at distances of about 15 meters from the edge of the strip, and then declined farther upslope to pre-harvest conditions. Chen et al. (1993) documented increases in both peak and steady winds in clearcut areas; increments ranged from 0.7 to 1.2 m/s (estimated).

Thermal role of channel morphology

Changes in channel morphology, primarily widening, affects stream temperatures. As a stream widens, the surface area exposed to heat flux increases, resulting in increased energy exchange between a stream and its environment (Chapra, 1997). Further, wide channels are likely to have decreased levels of shade due to the increased distance created between vegetation and the wetted channel and the decreased fraction of the stream width that could potentially be covered by shadows from riparian vegetation. Conversely, narrow channels are more likely to experience higher levels of shade.

Channel widening is often related to degraded riparian conditions that allow increased streambank erosion and sedimentation of the streambed, both of which correlate strongly with riparian vegetation type and condition (Rosgen, 1996). Channel morphology is not solely dependent on riparian conditions. Sedimentation can deposit material in the channel, fill pools and aggrade the streambed, reducing channel depth and increasing channel width. Channel straightening can increase flow velocities and lead to deeply incised streambanks and washout of gravel and cobble substrate.

Channel modification usually occurs during high-flow events. Land uses that affect the magnitude and timing of high-flow events may negatively impact channel width and depth. Riparian vegetation conditions will affect the resilience of the streambanks/flood plain during periods of sediment introduction and high flow. Disturbance processes may have differing results depending on the ability of riparian vegetation to shape and protect channels Riparian vegetation affects channel morphology by:

- ***Building streambanks***. Riparian vegetation traps suspended sediments, encouraging deposition of sediment in the flood plain, instead of in the streambed, and reducing incoming sources of sediment.
- ***Maintaining stable streambanks***. High rooting strength, high streambank, and flood plain roughness prevents streambank erosion.
- ***Reducing flow velocity*** (erosive kinetic energy). Riparian vegetation supplies large woody debris to the active channel, increases the pool-to-riffle ratio, and adds channel complexity that reduces shear stress exposure to streambank soil particles.

Pollutant sources

Many human activities impact the natural environment. The pollutant targeted in this TMDL is heat from human-caused increases in solar radiation loading to the stream, and heat from warm water discharges of human origin.

Heat loading from point sources includes discharges from domestic wastewater, combined sewer, and separate storm sewer systems operating under National Pollutant Discharge Elimination System (NPDES) permits. Other potential permitted discharges include those operating under general permits for stormwater. Waste load allocations are developed for point sources that discharge to temperature impaired water bodies or discharge into water bodies that drain to temperature impaired water bodies.

Nonpoint sources are those traditionally more diffuse in origin that cannot be identified with a discrete discharge location. Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. Although humans do not control climate and geographic location, our land use activities affect riparian condition, channel morphology and hydrology.

Streamflows influence water temperatures by varying the volume over which heat is dissipated. As the volume of water decreases, the temperature, equivalent to the concentration of heat, increases. Natural contributors to low streamflows include seasonally varying meteorology and hydrogeology. Potential anthropogenic contributors include water withdrawals and altered hydrogeology due to land surface processes that increase the heat load of stormwater runoff and decrease groundwater recharge.

Specifically, the elevated summertime stream temperatures attributed to anthropogenic sources in TMDLs conducted in Washington State, including the Snoqualmie watershed, can be categorized into three major sources: (1) loss of shade, (2) changes in channel morphology, and (3) hydrologic changes, as described below.

- Riparian vegetation disturbance and loss of shade due to:
  - Removal of trees and shrubs for pasture, crops, timber harvest, roads, or buildings.
  - Heavy grazing by livestock.
  - Alteration of the local hydrograph to such an extent that riparian vegetation cannot complete its life history requirements.

- Channel morphology impacts resulting from:
  - Removal of large, woody debris by commercial harvest, agriculture, and flood control.
  - Increased sediment loading from agriculture, timber harvest, and roads.
  - Channel constraint/diking for agriculture, flood control, and roads.
  - Bank instability/erosion and sedimentation from removal of root structure and increased land-use practices in the watershed.
  - Altered sediment/energy regimes that result in channel incision or aggradation.

- Hydrologic changes influenced by:
  - Extraction and return of water.
  - Discharge management with reservoirs maintaining artificially-high flows.
  - Altered streamflow patterns from urban and timber harvest areas resulting in increased spring runoff and decreased summer-base flows.
  - Altered sediment/energy regimes that result in channel incision or aggradation.
  - Historic draining of wetlands for agricultural and other development purposes.

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Watershed Description

Geography

The Snoqualmie River system drains 700 mi^2 [1,813 square kilometers (km^2)] in King and Snohomish Counties before meeting the Skykomish River to create the Snohomish River (See Figure 1). Within 15 miles of the Seattle-Bellevue metropolitan area, the Snoqualmie River system is highly valued for its recreational, aquatic habitat, and domestic water supply uses.

Population centers and mixed agricultural uses such as dairies, berry fields, pastures, and row crop fields are numerous in the lower valley, which is located below Snoqualmie Falls. Wildlife reserves, golf courses, and other recreational facilities are also present along the river. The slopes and upland sub-drainage areas of the lower valley have supported forestry and water supply uses, but much has been converted to residential developments. The cities of Duvall and Carnation and the unincorporated town of Fall City are located next to the mainstem Snoqualmie, and the city of Sammamish is located in the upper Patterson Creek in the lower basin. Historical economies were based on agriculture and logging. They now have become the focal points for residential, commercial, and industrial projects that require increased wastewater services. Additional wastewater and nonpoint source impacts from land use changes threaten to degrade water quality in the basin (Joy, 1994).

The upper basin (the area above Snoqualmie Falls) is mostly forest land managed either privately or by the U.S. Forest Service. Residential and commercial land uses are concentrated in two areas: along the Interstate 90 corridor around the city of North Bend, and in the city of Snoqualmie (Onwumere and Batts, 2004). Snoqualmie Falls, where a sudden drop of 268 feet (81.7 m) occurs, is a predominant feature of the river at river mile (RM) 40.4 within the city of Snoqualmie.

The Tolt River, which drains 101 mi^2 (262 km^2), is the largest tributary to the lower river (Joy, 1994). The Tolt River can constitute 20% of the water gaged at the U.S. Geological Survey (USGS) station at Carnation during the summer low-flow season (Joy et al., 1991). Like the Tolt River, the Raging River drains a large portion of the lower basin, an estimated 32.8 mi^2 (85.1 km^2), and enters the Snoqualmie River at RM 36.2 at Fall City. Both watershed play an important role in supporting the Snoqualmie's fall Chinook population (Haring, 2002).

Climate

The Snoqualmie River basin has a temperate marine climate with warm, dry summers and cool, mild, wet winters. Precipitation is distributed unevenly primarily due to the topographic relief of the Cascade Range. Higher elevations receive more precipitation than lower elevations. Mountain snowpack and snowmelt runoff strongly influence streamflow conditions, with most snowmelt occurring in May and June. The lowest flows typically occur during early September, when very little precipitation falls and most of the snowmelt runoff has already taken place for the season. Streamflows begin to increase in late September, rise through January, and then stay relatively high through the end of the snowmelt period. Flows sharply decrease during July, August, and early September.

Vegetation

The Snoqualmie River watershed is mostly forested with several flood-plain areas. Upper watershed areas were and still are predominantly mixed conifer forests. Before the flood plains were settled and altered by farming, homesteading, and forestry activities, they had diverse vegetation based on relatively small elevation changes and their susceptibility to flooding.

Not all of the Snoqualmie flood plain was historically forested with large trees. General Land Office field notes from the 1870s indicate that the extensive marsh area from RM 2 to RM 12 was primarily an almost impassable thick growth of shrubs and small trees, with a scattering of a few scrubby spruce and cedar (Collins and Sheikh, 2002). Most streamside trees were hardwoods: alder, willow, vine maple, maple, cottonwood, and crabapple. Of these, only maple, cottonwood, and alder were typically of a large enough size to create stable in-channel wood. Conifers accounted for 7% or less of streamside trees, yet accounted for 43% of streamside basal area, indicating that conifers were the largest trees and would have provided nearly half of the dead wood biomass to rivers from streamside forests.

The development of land for farming and the practice of logging greatly changed vegetation patterns and led to a decrease in riparian vegetation. Lack of riparian vegetation results in decreased riverbank stability, excessive erosion, and reduction of shading, which lead to higher water temperatures. Lack of mature trees in the riparian zone also limits large woody debris (LWD) recruitment to the river, thus reducing the structural and hydraulic complexity of instream habitat.

Haring (2002) assessed the limiting factors for salmonid habitat within the Snoqualmie River basin (WRIA 7) for the Washington State Conservation Commission (WCC). Table 7 shows data from one of the numerous studies cited that document riparian condition as a limiting factor in this basin. At least 60% of the mainstem Snoqualmie River had little or no riparian cover as of the late 1990s (Pentec Environmental and NW GIS, 1999). About 33% of the surveyed area had a riparian forest with a 20' or greater width.

Another assessment of riparian condition in the summer of 2000 reconfirmed the paucity of mature riparian forests along the banks of the mainstem Snoqualmie; mature trees were now found along only 1.8% of the river's left bank (looking downstream) and 9% of the right bank (Solomon and Boles 2002).

The Snoqualmie River is too wide for the currently existing riparian vegetation to have a significant shading effect. Aerial photograph interpretation indicated that mature riparian forests can shade more than 50% of the Snoqualmie River, which could help create or maintain local temperature refuge areas along the banks of the river, as well as provide cover habitat along the bank (Pentec Environmental and NW GIS, 1999).

Throughout much of the Snoqualmie Valley, riparian vegetation between ordinary high water and bankfull height is a monoculture of the invasive species reed canary grass, which is subject to sloughing, precludes natural forest regrowth, and does not provide riparian function (Anderson, as reported in Haring, 2002); there is opportunity for improved riparian function in this area which is not typically used for active agriculture or grazing.

Table 7. Riparian conditions on the mainstem Snoqualmie River (right and left banks combined) for 102 miles surveyed. *(From Pentec Environmental and NW GIS 1999.)*

Riparian condition	Total miles	% of total
1. Grass or brush	46.57	45
2. Single line of trees	15.78	15
3. 20-200 foot forested	8.50	8
4. 200-400 foot forested	9.02	9
5. >400 foot forested	16.88	16
6. Residences or farms, little forest	3.02	3
7. Residences or farms, significant forest	0.28	0
8. Roads or railroads	0.24	0
9. Industrial	0.52	1
10. Unforested wetland	1.83	2

Fisheries

Table 8 shows timing of salmon runs in the Snoqualmie River system. The Snoqualmie River watershed contains some of the healthiest aquatic habitat remaining in King County and supports wild populations of chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*); steelhead trout (*Oncorhynchus mykiss*), rainbow (*Oncorhynchus mykiss*), brook (*Salvelinus fontinalis*), and cutthroat trout (*Oncorhynchus clarki*); and native char, e.g., Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). Three of these species, Chinook, bull trout, and steelhead trout, are listed as threatened under the Endangered Species Act (http://wdfw.wa.gov/conservation/endangered/esa/federally_listed_esa_fish.pdf).

Table 8. Snohomish River salmon stock run timing and juvenile freshwater residence. *(Pentec and NW GIS, 1999; Haring, 2002)*

Species (Run)	Time of Adult return	Spawning season	Time in freshwater	Estuarine residence time
Summer Chinook	June-July	Late Sept-Nov	90-180 days	April-July
Fall Chinook	Aug-Sept	Fall	90-180 days	April-July
Coho	Aug-Nov	Oct-Dec	1 year	March-May
Chum	Sept-March	Sept-March	0-30 days	April-June
Pink	Aug-Sept	Sept-Oct	0-7 days	April-June
Winter Steelhead	Nov-April	Jan-June	2-3 years	March-May
Summer Steelhead	May-Oct	Jan-June	2 years	March-May
Sea-run Cutthroat	Dec-June	Dec-June	1-4 years	Jan-Oct
Bull Trout/Dolly Varden	April-Aug	Sept-Oct	2-3 years	March-May

Salmonid spawning in the mainstem Snoqualmie River occurs in the gravel riffles below the confluence with the Tolt River (RM 24), at the confluence with the Raging River (RM 35), and in a section of channel below Tokul Creek (RM 38). These mainstem spawning areas are the same areas supplied with coarse sediment from the Tolt and Raging rivers and Tokul Creek. Chinook and steelhead spawning are concentrated in these areas and in the lower Raging and Tolt Rivers (Solomon and Boles, 2002).

Pink and chum salmon spawn in the lower Tolt River as well. Pink salmon have historically spawned in the Raging River; some still do. Most coho spawning and some steelhead spawning occurs in the tributary rivers and streams. Maps that show the distribution of each species within WRIA 7 are available from King County Water and Land Resource Division (WLRD). Anadromous fish do not travel above Snoqualmie Falls. However, resident populations of cutthroat, rainbow, and brook trout can be found above the Falls. Native char were found historically as well (Pentec Environmental and NW GIS, 1999). More detailed information on specific spawning locations within the watershed and information on Steelhead can be found in Solomon and Boles (2002) and the Limiting Factors report (Haring, 2002). Pess et al. (2002) found that index reaches bordered by lands designated as forest supported far more fish than areas under other types of land use.

Further information on Salmonid usage in this basin and behavior of salmonids in warm water can be found by consulting Lindsay et al. (1985), Lestelle et al. (2005), and Hicks (2002).

Hydrology

Hydrogeology

A region where groundwater discharges to surface water, thus augmenting streamflow, is known as a *gaining reach*. In contrast, a *losing reach*, is where surface water discharges to groundwater (Turney et al., 1995). Based on a limited investigation, groundwater contributes up to 30% of the total surface water flow (Haring, 2002).

A seepage study conducted in September 1991 shows that Snoqualmie watershed streams generally gain water as they flow downstream. The Snoqualmie River itself seems to gain groundwater along its entire length except for the reach from Carnation to Monroe where it is a losing reach. Based on the seepage study, the Raging River and Tolt River also lose surface water to groundwater. However, during wetter weather patterns, groundwater will discharge into surface water because regional water table levels rise. Furthermore, during significant rain events, interflow occurs where water enters the shallow water table and seeps directly into adjacent streams relatively quickly (Turney et al., 1995).

The South Fork Snoqualmie River in a reach from Edgewick Road to North Bend received 25 – 31% of surface water flow from groundwater inputs (Turney et al., 1995). An additional groundwater study conducted from 1957 to 1964 suggests the South Fork Snoqualmie River received an average of 50 cubic feet per second (cfs) of groundwater from contributing Chester Morse Lake and Masonry Pool (Hidaka and Garrett, 1967). From the three Snoqualmie River forks downstream to the Snoqualmie Falls, approximately 20% of streamflow is gained from groundwater upwelling. From Fall City to Carnation, the Snoqualmie River gains approximately 11 – 13% of its surface water flow from groundwater upwelling (Turney et al., 1995).

Ecology's well log database shows that 72 of the 3286 wells in the study area, or 2%, have been drilled in the last two years, between April 2008 and March 2010. The bulk of new wells are in the lower basin, below the confluence with Tokul Creek. Increase in pumping of water that is in hydraulic continuity with surface water can affect water temperatures. Many of the new wells were located in the smaller tributary watersheds of Patterson, Cherry, Harris, and Tuck Creeks. If the number of wells drilled in these lower watershed tributaries were to increase, it could impact temperatures in those salmon-bearing streams.

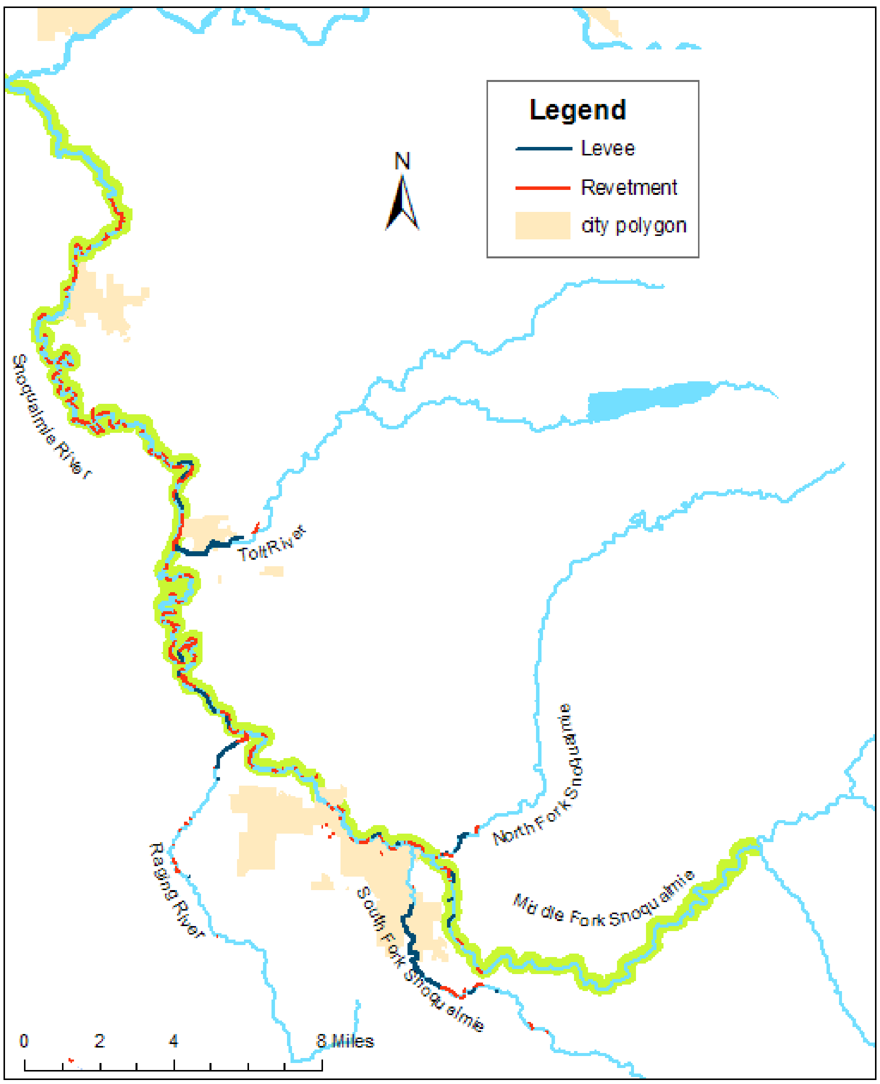

Figure 6. Levees and revetments in the Snoqualmie River basin (source: King County 2002).

In the summer of 2000, King County (2002) conducted a survey of revetments and levees in the Snoqualmie River basin (Figure 6). Bank hardening was observed on 35.5% of river miles on the toe of the left bank (LB), 9.5% of river miles on the upper LB, 30.4% of river miles on the toe of the right bank (RB), and 29.4% of river miles on the upper RB of the mainstem Snoqualmie River. Bank hardening can disconnect the main channel of the river from its side channels and inhibit natural channel migration. This limits the creation of summer rearing habitat and winter refuge habitat for salmonids and restricts fish access to off-channel habitat. Bank hardening also accelerates the natural process of bank erosion on adjacent or opposite unprotected banks; excessive erosion can degrade habitat conditions by contributing excessive fine sediment to the river, aggrading the channel bed, or filling pools. Scours, slumps, and other erosional features were observed at many locations directly downstream or on the opposite bank from revetments (Solomon and Boles, 2002).

Channel widening occurred in the early 1900s in many Puget Sound drainages as a result of logging of the riparian forest. Riparian logging can reduce the root strength and allow bank erosion to widen the channels. Resulting increased sediment supplies can also cause or exacerbate channel widening. Since the 1930s, mainstem channels have been narrowed due to revetments and agricultural development, and they may have recovered from some of the earlier logging (Pess et al., 1999).
Because of the extensive network of revetments and levees, which artificially restrict the channel, channel width reduction as a result of revegetation and channel restoration is not an expected result for the Middle Fork and mainstem Snoqualmie River. In the neighboring Stillaguamish watershed, Pelletier and Bilhimer (2004) used a relationship between drainage area and current and historical channel width reported in Pess et al. (1999). The Stillaguamish and Snoqualmie watersheds are very similar in land use, geology, and basin orientation. Pess found that for watershed drainage areas less than about 380 km^2, channel narrowing could be expected, but for drainage areas greater than 380 km^2, narrowing would not be expected and may even be narrower than the historical condition due to restrictions from revetments and other in-channel structures.

Similarly, the drainage area for the Snoqualmie Middle Fork headwater site (07MFS60.4) at the USFS boundary is 400 km^2, which suggests that further channel width reduction from the current condition is not likely and should not be modeled with QUAL2Kw. Ecology reviewed historical General Land Office maps (1989) and aerial photos (1936) and could not detect any obvious changes in channel width in the Middle Fork. Effects on channel widths from past logging practices were also not immediately obvious.

Although the mainstem and Middle Fork have large drainage areas, tributaries with smaller drainage areas and less revetments could very well experience channel narrowing as riparian restoration takes place.

A restored fully-functioning channel would be expected to have more wood, sinuosity, and braiding that potentially could contribute additional shade and decrease water temperatures. Historical channels contained more wetlands, oxbows, and side channels with shading from shrubs, vine maple, alder, and dogwood. Natural channels also typically have more interaction with the flood plain and subsurface groundwater, providing additional potential cooling and localized cool-water refugia. However, these attributes are more qualitative and are difficult to measure and model as a specific temperature reduction. For that reason, Ecology has not modeled the effect of improved shading from in-water large woody debris (LWD), creation of braided reaches, or reconnection with wetlands and oxbows.

The geologic formation that creates Snoqualmie Falls creates a natural backwater effect, slowing Snoqualmie River velocities upstream of the falls. As a result, only fine sediment is transported as far as the falls (King County DNR, 1996, as cited in the WRIA 7 Limiting Factors Report). Under its current Federal Energy Regulatory Commission (FERC) (FERC, 2004) license, the Snoqualmie Falls Dam located 150 feet upstream of the falls, has a crest elevation 397.0 feet mean sea level (msl). A 2009 amendment calls for installation of a new rubber dam that would allow the dam to be lowered by 2 feet. The flexibility in height helps reduce the pool area and assists in flood control.

Instream flow rule and dam regulation for the Snoqualmie River

Instream flows and water withdrawals are managed through regulatory avenues separate from TMDLs. However, stream temperature is related to the amount of instream flow, and increases in flow generally result in decreases in maximum temperatures. The complete heat budget for a stream segment accounts for the amount of flow and the temperature of water flowing into and out of the stream.

The instream flow rule for the Snohomish River basin, Chapter 173-507 WAC, can be found at www.ecy.wa.gov/pubs/wac173507.pdf.

Puget Sound Energy (PSE) operates two power generating plants near Snoqualmie Falls. Two outfalls discharge below the falls: one in the plunge pool, and the other approximately 1,550 feet downstream of the falls. The power plant received updates to its FERC license in 2004. The power plants divert 65% of the annual flow of the Snoqualmie River for power production (FERC, 2004). Ecology's water quality certification requires that the project be operated to ensure that the following flows (as measured at the diversion weir) or natural flow, whichever is less, pass over Snoqualmie Falls (Table 9).

Table 9. Puget Sound Energy minimum streamflow criteria (cfs) for water passing over Snoqualmie Falls at given dates and times.

Time period	Daytime	Nighttime[1]
May 16 - 31	200	200
June 1 - 30	450	450
July 1 - 31	200/100[2]	200/25[2]
August 1 - 31	200/100[2]	200/25[2]
September 1 - May 15	100	25

[1] Nighttime hours are defined as one hour after sunset to one hour before sunrise. [2] Weekends and holidays flat 200 day/night, weekdays 100 day/25 night. cfs: cubic feet per second.

Surface water withdrawals

Withdrawal of water from a stream is an important consideration for the instream flow and heat budget. Actual water withdrawals at any given time from streams in the Snoqualmie River watershed are not known, but Ecology maintains a database indicating the amount of water that may be legally withdrawn (Water Rights Application Tracking; WRAT). In addition, a portion of users, usually those with larger withdrawals, are required to measure their water use. This information is stored in Ecology's Water Rights Metering database. The mainstem Snoqualmie and Middle Fork modeling required a water budget. Since tributary mouths were measured for flow, it was important to know how much additional flow was directly withdrawn from the mainstem or Middle Fork.

The Metering Database for 2006 showed that only three organizations have permits allowing water withdrawals in excess of 1 cfs: city of Seattle, Sallal Water Association in North Bend, and Fall City water district. The city of Seattle is the largest permittee but gets its water from the Tolt Reservoir. They also manage Rattlesnake Lake, which drains to the South Fork. Since both the South Fork tributary and the Tolt are monitored for flow downstream of any withdrawal, these are already accounted for in the mainstem Snoqualmie water budget. The Sallal Water Association near North Bend and the Fall City Water District are allowed, as reported in the database, 3.57 and 1.11 cfs respectively. However, both of these districts are relying primarily on well water and withdrew quantities far less than those permitted in 2006.

The WRAT database has records for all permittees including those not required to meter. The WRAT can be used as an indicator of the amounts of water that may be legally withdrawn. Possible undocumented or illegal withdrawals are not considered in this analysis.

Table 10 shows a summary of active certified surface water rights by named stream. The water quantity potentially withdrawn from surface waters for consumptive use in the Snoqualmie River is 15.5 cfs and in the Middle Fork is 0.04 cfs. Because we are monitoring tributary mouths for flows, these are the only withdrawals that could impact our model results.

Mainstem and Middle Fork direct withdrawals, as reported in both the WRAT and Metering Databases, were too small to measurably affect the Snoqualmie River water budget in 2006. Therefore, the QUAL2Kw model water budget does not include these withdrawals.

Table 10. Summary of consumptive water rights in the Snoqualmie River watershed (WRTS database, 6/27/2011).

Consumptive surface withdrawals	Total of all water right flows	
	(cfs)	(cms)
MIDDLE FORK SNOQ	0.03	0.0011
SNOQUALMIE RIVER	3.43	0.4389

TMDL Study

Project goals

The goal of this water quality improvement plan is to address temperature problems in the Snoqualmie River watershed so that water quality is improved and beneficial uses are restored. More specifically, the goal is for the Snoqualmie River and its tributaries to meet the Washington State water quality criterion for temperature. This section describes Ecology's field study and the data collected during that study. The following section, *TMDL Determination*, will use that data, along with the background information provided in the *Watershed Description* section of this Plan, to model temperature processes in the Snoqualmie Watershed, determine the loading capacity for temperature, and set load allocations, wasteload allocations, and a margin of safety.

Field study objectives

Objectives of the study were as follows:

- Characterize June-September stream temperatures in the Snoqualmie River basin by compiling existing data and collecting additional data in cooperation with other organizations.
- Characterize vegetation, flow, channel characteristics, and related variables to support modeling.
- Develop a predictive computer temperature model for the Middle Fork Snoqualmie River from the USFS boundary and continuing with the mainstem Snoqualmie River to its confluence with the Skykomish River, focusing on the instream temperature regime at critical conditions.
- Evaluate the ability of various watershed BMPs to reduce water temperature to meet water quality standards.
- Establish a TMDL for temperature in the Snoqualmie River basin.
- For ease of implementation, report load allocations in terms of surrogates for solar radiation such as: shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, channel width-to-depth ratio, or miles of active eroding streambanks.
- Address all water bodies within the Snoqualmie River watershed and mitigate reaches with detrimentally high instream temperatures.

Field data study methods

Study data collection activities

The study was conducted under a Quality Assurance (QA) Project Plan (QA Project Plan) that was reviewed by Ecology, EPA Region 10, and local stakeholders. The project plan was approved after incorporating reviewer's comments in July 2006 (Kardouni and Cristea, 2006). A brief description of the 2006 data collection and analysis activities is presented here. Interim data were provided in quarterly reports.

Water quality and streamflow data were collected from monitoring sites distributed throughout the study area (Figure 7). The study design included a combination of continuous results, grab samples, synoptic surveys, float surveys, and aerial monitoring.

Originally the QA Project Plan called for three synoptic flow surveys occurring in July, August, and September and two dye studies. However, due to competing needs for personnel and equipment, Snoqualmie mainstem flows were not measured during the August synoptic flow and dye survey. A hydrolab equipment malfunction resulted in no data for one of the five reaches in the August dye study.

All other planned data collection occurred as documented in the QA Project Plan. Data collected under earlier studies by Ecology, including Onwumere and Batts (2004), Hallock (2006), and Joy el al. (1991), were also used, as was data collected by King County.

Study quality assurance evaluation

All environmental studies conducted by Ecology must have an approved QA Project Plan that documents study objectives and procedures for achieving those objectives (Lombard and Kirchmer, 2004). In addition to describing the sampling design and protocols, the Project Plan establishes data quality objectives. Continuous temperature data collection follows the QA methods described in Ecology's temperature standard operating procedure (SOP) document (Bilhimer and Stohr, 2007).

As described in Bilhimer and Stohr (2007), thermistors were tested both prior to and after use in the field. NIST-certified thermometer readings were compared against those recorded by thermistors in both an ice bath and a room temperature bath. Thermistors that did not measure within $\pm$ 0.2°C of the NIST reading during the pre-field season testing were not used in the project for measuring water temperature. During the post season check, all thermistors met the data quality objective and measured temperatures within 0.2°C of the NIST readings. QA results showed that the average absolute difference between thermistor-measured and NIST-measured temperature was 0.12°C. Data used in this study met or exceeded the data quality objectives established for this project. The quality of project data is adequate to support the TMDL analysis.

Anomalous data that should not be used is the air temperature data gathered at site 07SNO36.3, Snoqualmie River near the mouth of the Raging River. Instead, air temperature data gathered 250 feet away at site 07RAG00.1 should be used. It is suspected that the solar shading device for this thermistor was not operating correctly and was influenced by direct solar radiation.

Data collection results and discussion

Continuous water temperature data

A network of continuous temperature dataloggers was installed in the Snoqualmie River watershed to monitor stream temperatures during June through September 2006. The locations of these stream temperature sensors are shown in Figure 7.

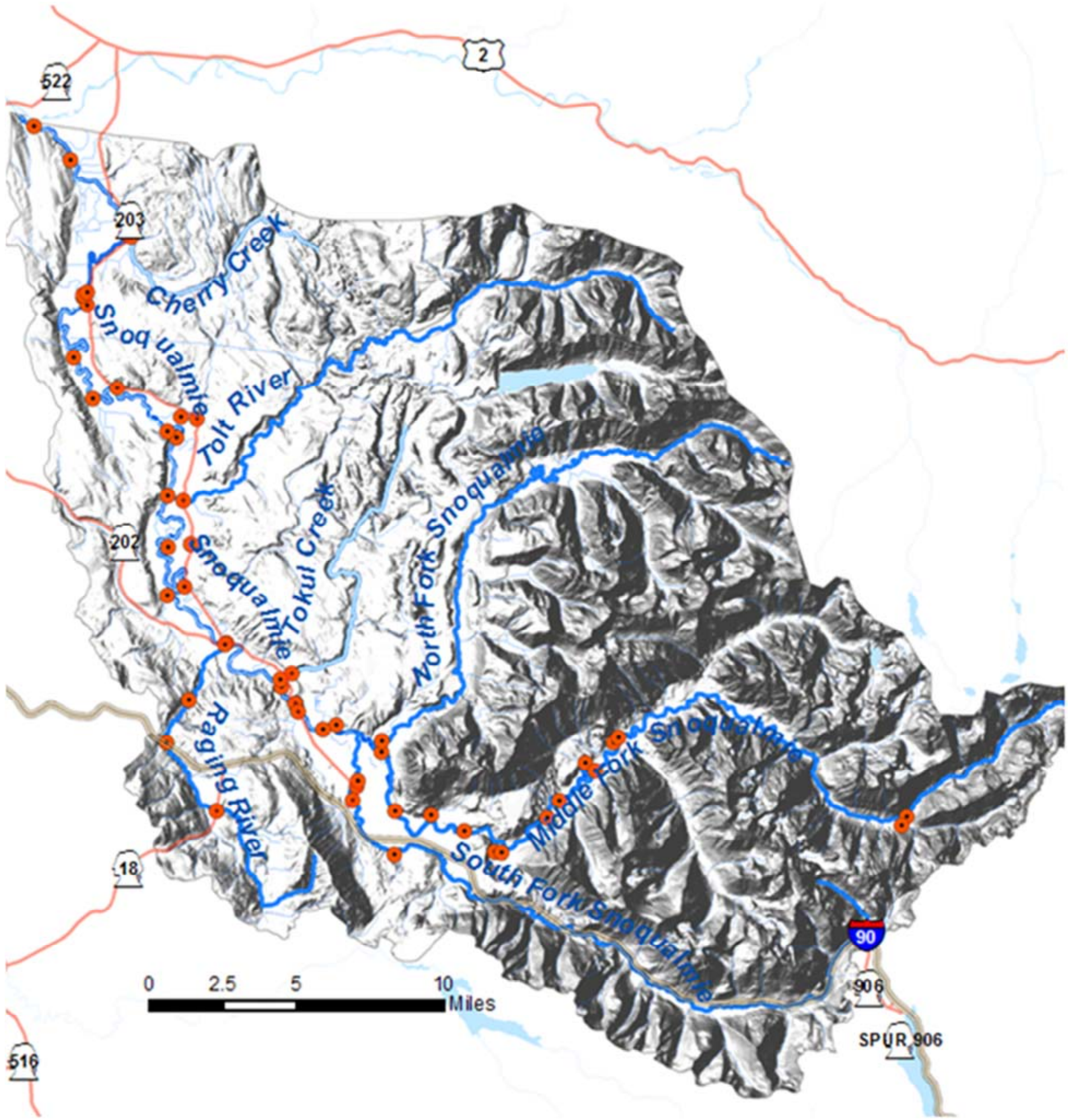

Figure 7. Stream temperature sensor locations in the Snoqualmie River watershed during the monitoring period in 2006.

Many of these same locations were also sampled by Ecology's Ambient Monitoring Program in 2005 (Hallock, 2006). Data from 2005 and 2006 show that water temperatures in excess of the current water quality criteria are common throughout the watershed (Table 11). Three locations, Cherry Creek and the two upper Raging River stations, were not recording during the 2006 7-day maximum period. An estimate of the temperature that would have occurred for July 22 -28 was made for each of these stations based on data from a nearby station or based on temperature differences between 2005 and 2006.

Table 11. Summary of 7-day average (7-DADMax) of the daily maximum water temperatures in the Snoqualmie basin during 2005 and 2006.

Site ID	Description	Greatest 7-DADMax 2006	Date occurred 2006	Greatest 7-DADMax 2005	Date Occurred 2005	Criteria July/Aug
07RAG00.1*	Raging R at mouth in Fall City (07Q050)	25.1	7/24/06	23.1	8/06/05	16
07DWP00.0	Duvall WWTP Manhole outfall[4]	23.88	8/19/06			permit
07SNO00.8*	Snoq R above Skykomish R confluence	22.8	7/26/06			17.5
07NWP00.0	North Bend WWTP on site at outfall[4]	22.68	7/24/06			permit
07RAG02.6*	Raging R at USGS gage Natural Areas	22.67	7/24/06			16
07SNO02.7	Snoq R near Monroe (07D050)	22.6	7/25/06	21.3	7/30/05	17.5
07SNO14.8*	Snoq R at 124th Novelty	22.6	7/25/06			17.5
07RAG04.7 *	Raging R btwn Upper Preston and I-90[1,2]	22.56 (20.94)	8/7/06			16
07SNO10.4*	Snoq R above Coe and Tuck Ck, Duvall	22.4	7/25/06			17.5
07SNO06.8*	Snoq R above Cherry Ck	22.3	7/25/06			17.5
07SNO18.7*	Snoq R above Ames Ck at Stillwater	22.3	7/25/06			17.5
07TOL00.5*	Tolt R near Carnation (07G070)	22.0	7/24/06	20.9[3]	8/06/05	16
07MFS45.3*	MF Snoq R 428th near Ellisville (07D150)	22.0	7/24/06	20.7	7/28/05	16
07SNO29.0*	Snoq R above Griffin Ck on 8th	21.9	7/25/06			16
07MFS47.8*	Middle Fork Snoqualmie at Mt Si Rd	21.8	7/24/06			16
07SNO33.0*	Snoq R at Neal Rd boat launch	21.6	7/25/06			16
07SNO22.0*	Snoq R below Chinook Bend	21.6	7/25/06			16
07SNO22.8*	Snoq R at Carnation USGS gage station	21.4	7/25/06			16
07CHE00.2*	Cherry Cr Hwy 203 (07S070)[2]	21.4 (18.6)	8/8/06	20.1[3]	7/30/05	16
07SNO24.9*	Snoq R above Tolt and Carnation (07D100)	21.2	7/25/06	20.9[3]	8/07/05	16
07SNO42.3	Snoq R at Snoqualmie (07D130)	20.8	7/24/06	19.3	7/29/05	16
07SNO36.3*	Snoq R above Raging R	20.8	7/25/06			16
07SNO40.8	Snoq R Hwy 202 (07D125)	20.7	7/25/06	18.9[3]	7/30/05	16
07SNO39.8*	Snoq River at PSE outfall, USGS gage	20.4	7/25/06			16
07RAG07.9 *	Raging R at Hwy 18 (King Co data) [1,2]	20.3 (19.1)	8/7/06			16

Site ID	Description	Greatest 7-DADMax 2006	Date occurred 2006	Greatest 7-DADMax 2005	Date Occurred 2005	Criteria July/Aug
07KIM00.1*	Kimball Cr Hwy 202 (07Y060)	20.3	7/25/06	18.0	8/07/05	16
07MFS51.2*	MF Snoq R above Roaring River BnB	20.3	7/24/06		+++	16
07TUC00.1*	Tuck Cr at Mouth (07T050)	19.8	7/26/06	18.6[3]	7/30/05	17.5
07MFS55.6*	MF Snoq at USGS gage	19.7	7/24/06			16
07GRI00.7*	Griffin Cr Hwy 203 (07W070)	19.5	7/24/06			16
07AME00.1*	Ames Ck at NE 100th St (07V070)	19.1	7/24/06	17.3	7/20/05	17.5
07NFS00.3*	NF Snoq R near Ellisville (07N070)	19.0	7/24/06	17.3	7/29/05	16
07SFS01.6*	SF Snoq at Valley Trail R (07M065)	19.0	7/24/06	18.3	7/28/05	16
07SFS01.8*	SF Snoq at Bendigo Blvd S (07M075)	18.8	7/24/06	18.0	7/28/05	16
07MFS60.4*	MF Snoq at USFS boundary	19.0	7/24/06			16
07HAR01.1*	Harris Ck at Sno Trail below FMU site	18.8	7/24/06			16
07PAT00.4*	Patterson Cr near Fall City (07P070)	18.8	7/24/06	18.4	7/28/05	16
07SFS05.5 *	SF Snoqualmie at 468th SE (07M120)	18.54	7/24/06			16
07TOK00.1*	Tokul Cr SE Fish Hatchery (07X060)	18.2	7/24/06			16
07UNA00.2*	Unnamed tributary A (MFS) before USFS	18.2	7/25/06			16
07TOK00.6*	Tokul Cr above hatchery, off of Hwy 202	18.06	7/24/06			16
07HAR01.6 *	Harris Cr Hwy 203 (07U070)	17.68	7/24/06	16.7	7/28/05	16
07UNB00.4*	Unnamed tributary B (MFS) at culvert	16.9	7/24/06			16
07GRA00.1	Granite Cr 0.2 miles up from MFS conf	15.3	7/24/06			16
07MFS75.0	MF Snoq R above Goldmyer Hot Spr	14.6	7/24/06			12
07GIF00.1	Gifford Lakes stream drainage	13.7	7/24/06			16
07BUR00.5	Burntboot Ck below Goldmyer Hot Spr	12.2	7/24/06			12
07UND00.4	Unnamed tributary D (MFS) off MFS Rd	11.4	7/24/06			16

1. King County site.
2. Installed after the season high 7-day period in 2006. These stations have an estimated 7-DADMax for 7/25/06 and record the actual daily high for that station in parentheses.
3. Installed after the season high 7-day period in 2005.
4. Effluent (non-stream) measurement.

*. Indicates impaired water overlooked for listing in the 2008 Water Quality Assessment

Figure 8 shows a map of the highest 7-day average maximum (7-DADMax) water temperatures in 2006. The majority of these were recorded on July 24 and July 25, 2006. Complete temperature records can be found in Appendix D, Figures D-1 through D-11. These figures show continuous 7-DADMax water temperatures during May-October 2006 at each of the sampling locations.

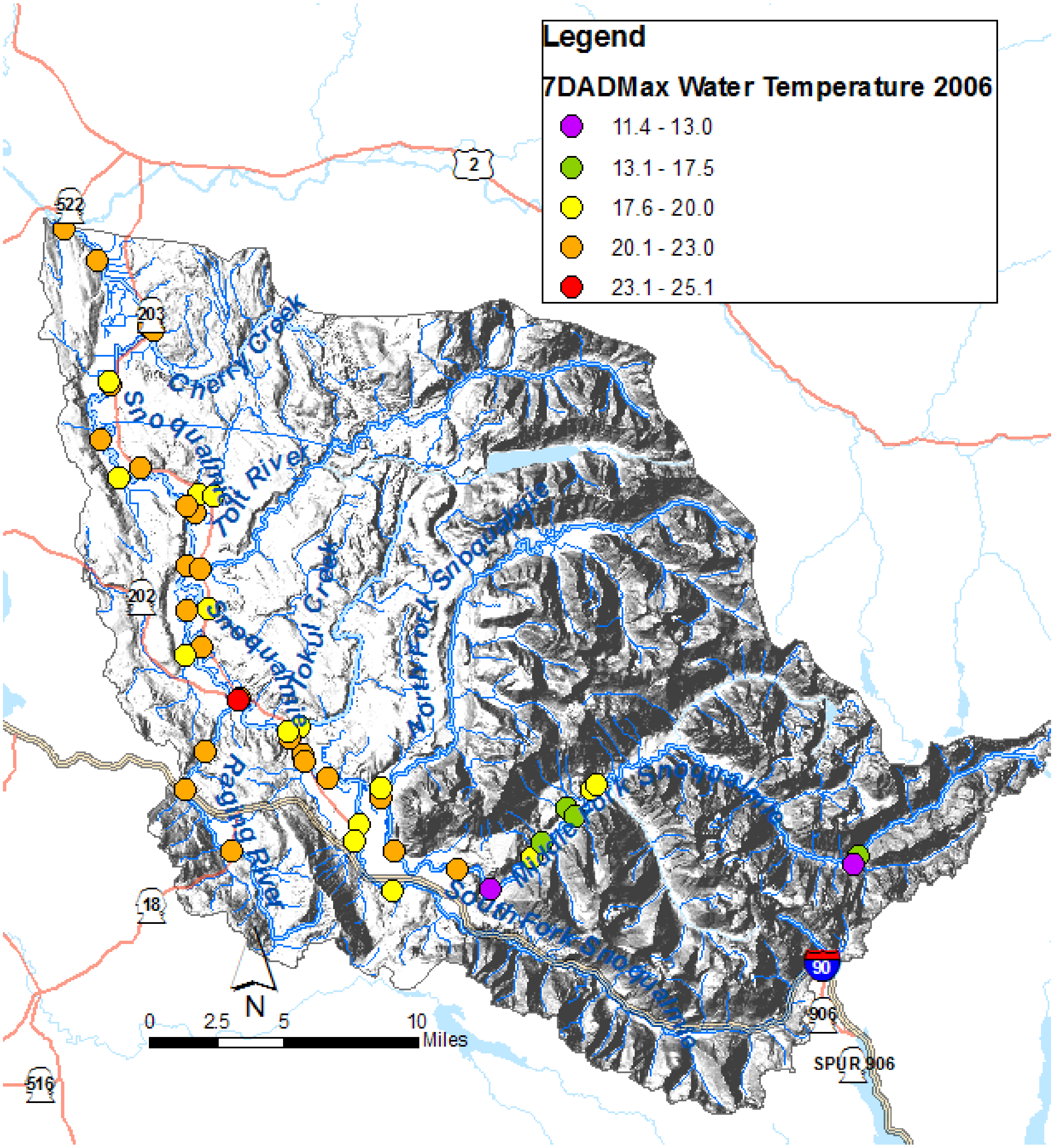

Figure 8. The highest 7-day average of the daily maximum (7-DADMax) water temperatures (°C) in the Snoqualmie River and its tributaries during 2006.

Stream temperature data from 2006 show that water temperatures in excess of the 16°C or 17.5°C 7-DADMax are common in the Snoqualmie River watershed (Table 11 and Figure 8). The highest temperatures were recorded at the mouth of the Raging River where the 7-DADMax was 25.1°C. Temperatures above 23°C can be lethal to salmonids (Ecology, 2006). The 30-minute interval water temperature data records show that in July and August, the median time for

the daily maximum temperature is 17:06 (5:06 pm) and the median time for the daily minimum water temperature is 8:15 am.
Figure 9 shows that daily maximum water temperatures in the Middle Fork Snoqualmie River steadily increase moving downstream from the USFS boundary to the confluence of the North and South Forks. The North (RM 45.0) and South (RM 44.2) Forks deliver cooler water to the mainstem and reduce the temperature by several degrees. The water then goes over Snoqualmie Falls (RM 40.5) and begins slowly heating until reaching the confluence with the Skykomish River.

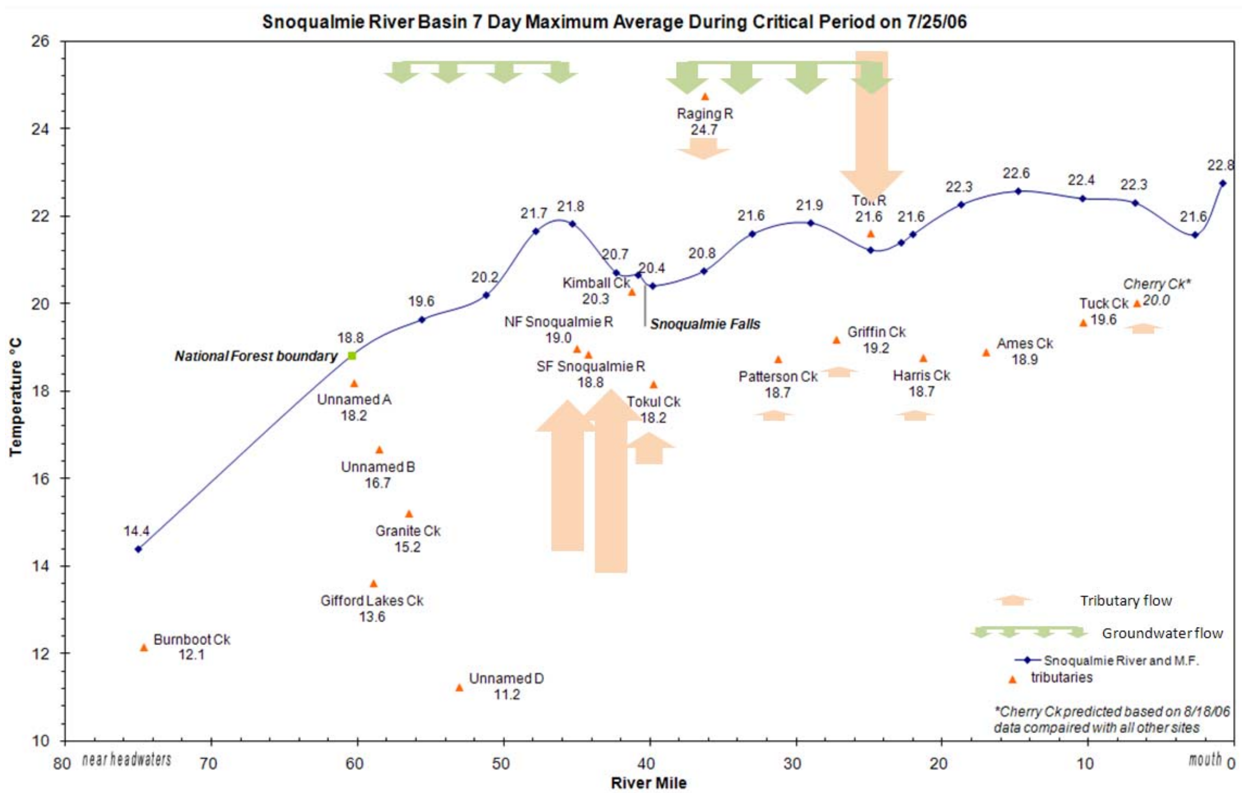

Figure 9. Snoqualmie River longitudinal profile 7-DADMax during the 2006 critical period, July 22 to 28, 2006.

The Tolt River at RM 24.9 is large enough to influence the temperature of the mainstem. It often delivers water at a similar temperature as the mainstem, but in some cases delivers cooler water, which reduces mainstem temperature.

The Raging River at RM 36.2 is the hottest tributary in the system, reaching a peak 7-DADMax of 25.1°C in 2006. However, during the summer, streamflow from the Raging River is low, often ranging from 10 to 15 cfs, and is not large enough to greatly influence mainstem temperatures.

The coolest locations in the watershed are the tributaries to the Middle Fork, which tend to be small groundwater- or wetland-fed streams that often dry up toward the end of the summer. These tributaries typically had 7-DADMax temperatures less than 16°C, with one as low as

11.4°C. However, tributaries located further downstream did not meet the numeric criteria for daily maximum temperatures, though they were cooler than the mainstem Snoqualmie River.

Figure 10 shows that Middle Fork Snoqualmie river temperatures in excess of the water quality standard are common from the end of June to the beginning of September. Graphs for all sample locations are available in Appendix D. Tributaries in the lower watershed, such as Harris Creek and Patterson Creek, exceeded (did not meet) the water quality standard for a shorter time period of time, e.g., the month of July instead of the entire summer. These lower river tributaries may be areas where shade and channel improvements have the potential to cool waters to the numeric standard.

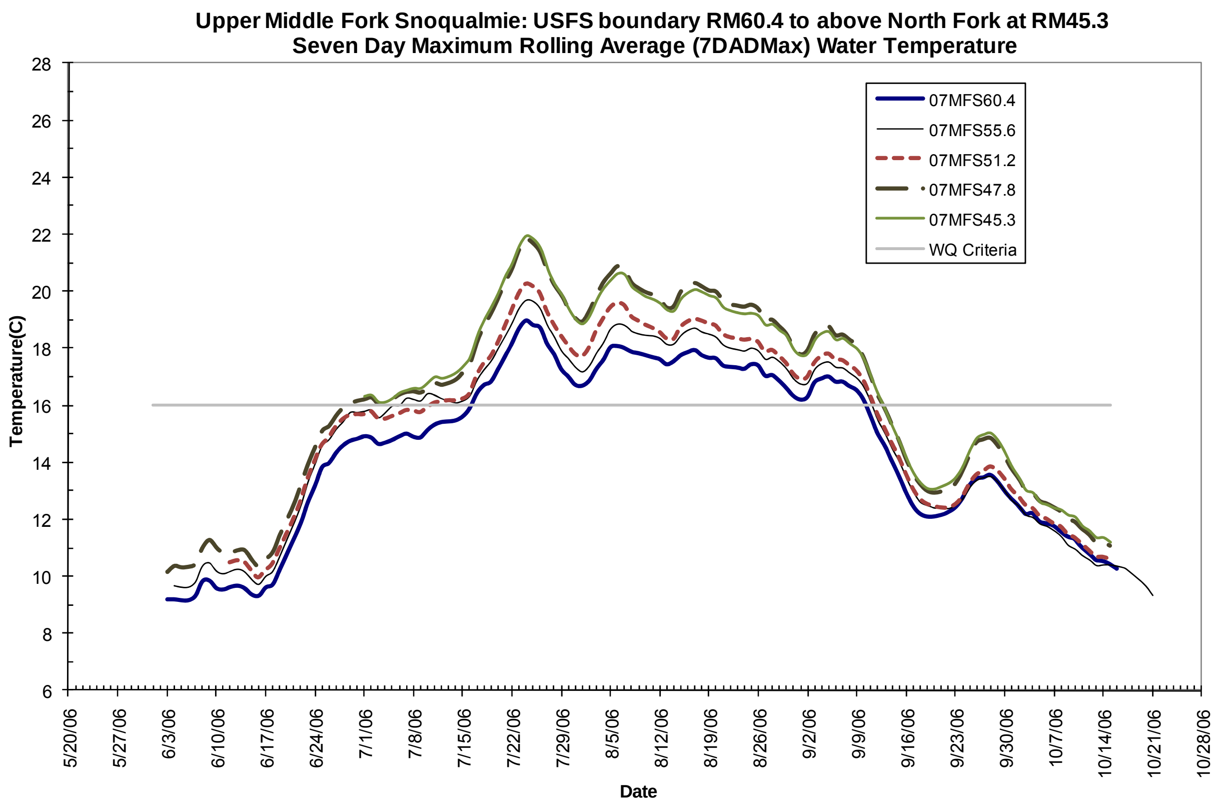

Figure 10. 7-Day average of daily maximum water temperatures in the Middle Fork Snoqualmie River from June to October 2006.

The highest daily maximum stream temperatures occurred July 24 and July 25, 2006 during a period of relatively high air temperatures (Figure 11). Stream temperature patterns often mimic air temperature patterns. Both air and water temperatures respond to the major factor affecting them, the incoming solar radiation.

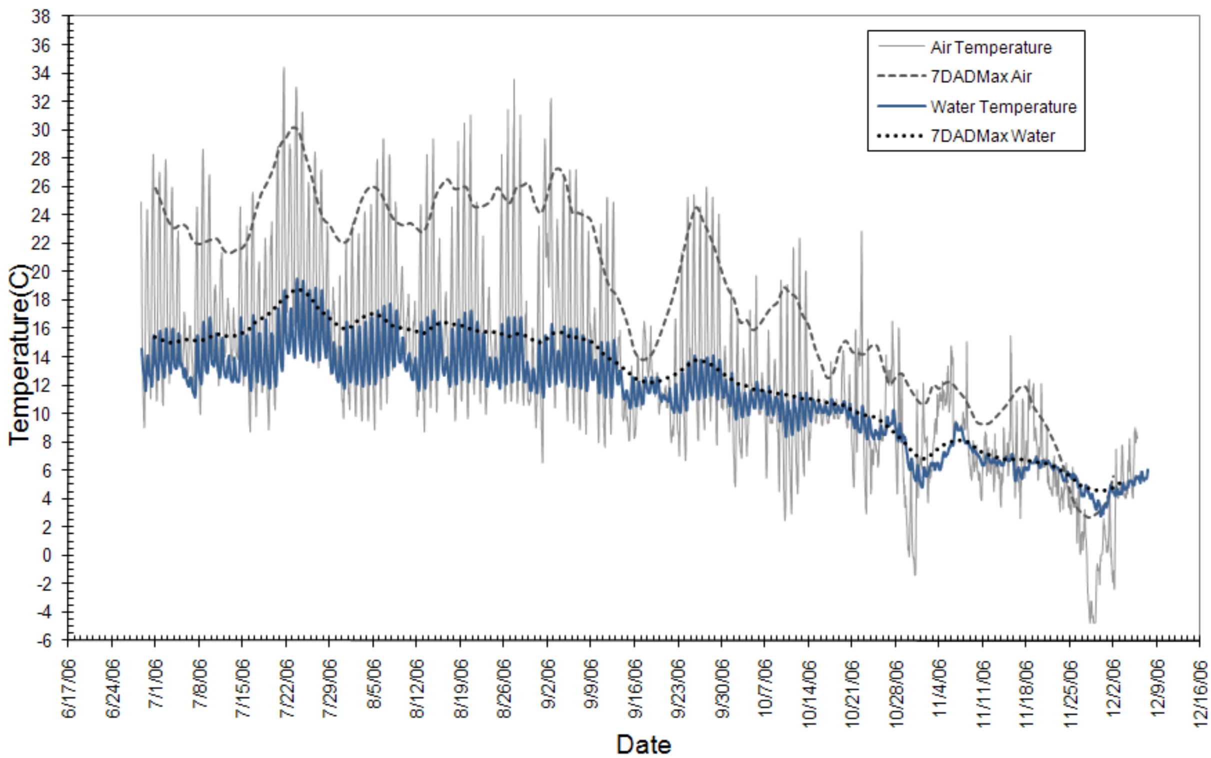

Figure 11. Air and water temperature recorded at South Fork Snoqualmie station 07SFS01.8 (USGS gage at Bendigo Blvd.) during June to December, 2006.

Thermal infrared (TIR) aerial water temperature survey

A thermal infrared survey was conducted August 13, 2006 (Watershed Sciences, 2007) to characterize surface water temperatures from the Middle Fork Snoqualmie River near the USFS boundary downstream to the confluence with the Skykomish River. Thermal infrared images and visible band images were recorded from a helicopter flying at 1000 feet above the ground. The survey was flown in six segments beginning upstream near the USFS boundary at the Taylor River. The first four segments were flown from 2:15 to 3:11 pm, and the two remaining downstream segments were flown from 5:13 to 5:42 pm (Figure 12). Six instream temperature sensors were deployed to calibrate the conversion of radiance from the images to temperature.

Figure 13 presents example thermal infrared and visible band images. These images do not account for water temperatures beneath vegetation or any stratification (layering) of the water column. The average error was 0.1°C at the six instream sensor locations.

Figure 14 shows the longitudinal profile of centerline water temperatures together with instream temperatures recorded by Watershed Sciences. The longitudinal profile shows that stream temperatures in the Middle Fork steadily increase from the USFS boundary and peak just upstream of the confluence of the North and South Forks of the Snoqualmie River. Downstream of the confluence, the radiant water temperatures in the Snoqualmie River decreased rapidly from ~18.6°C at mile 43.2 to ~16.6°C at mile 42.2. The decrease appeared primarily due to the cooling influence of the North Fork and South Fork Snoqualmie Rivers. The cooling continued downstream reaching a local minimum of 16.1°C at mile 40.4 near the town of Snoqualmie. After passing over Snoqualmie Falls, the water begins to warm back up until the confluence with the Tolt River at RM 24.9

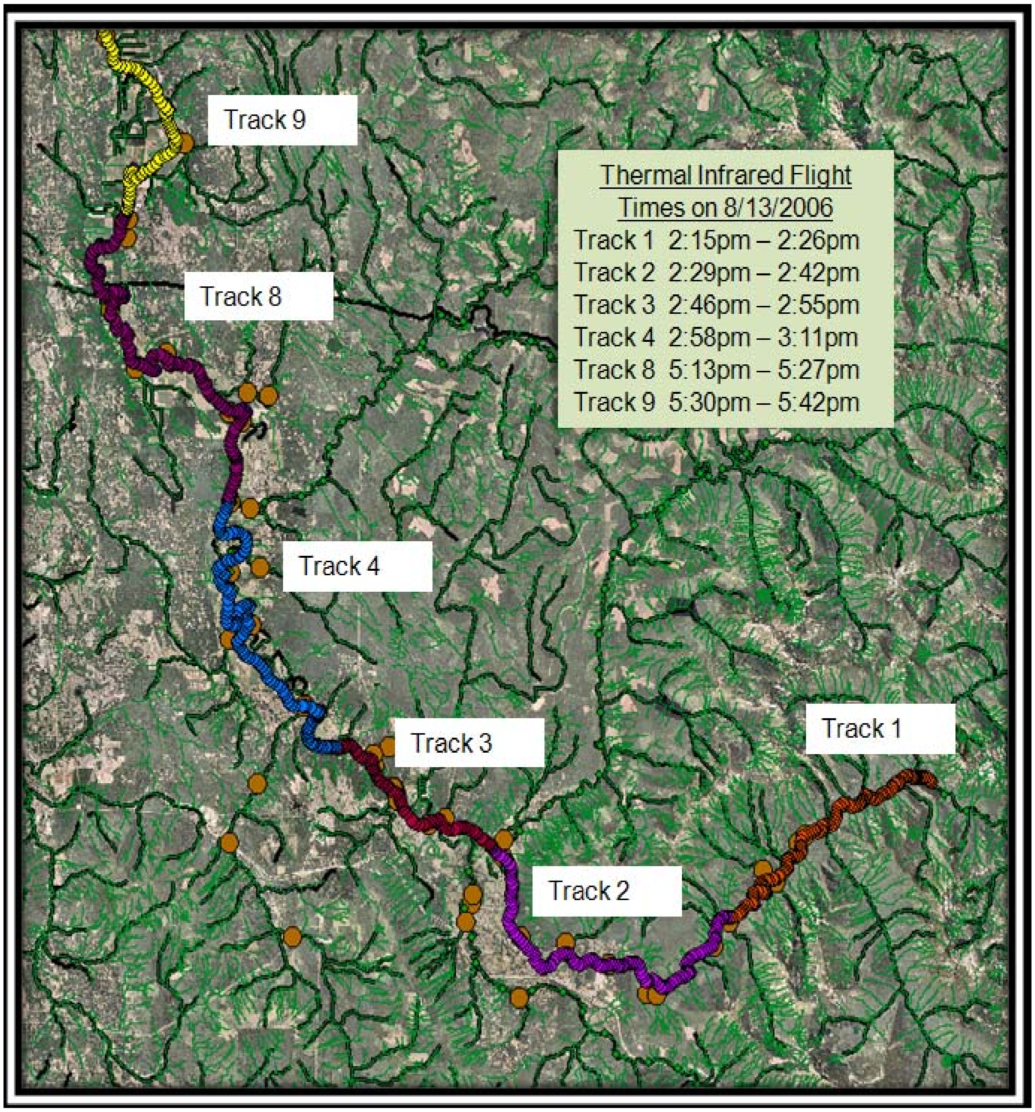

Figure 12. Thermal infrared flight times on August 13, 2006.

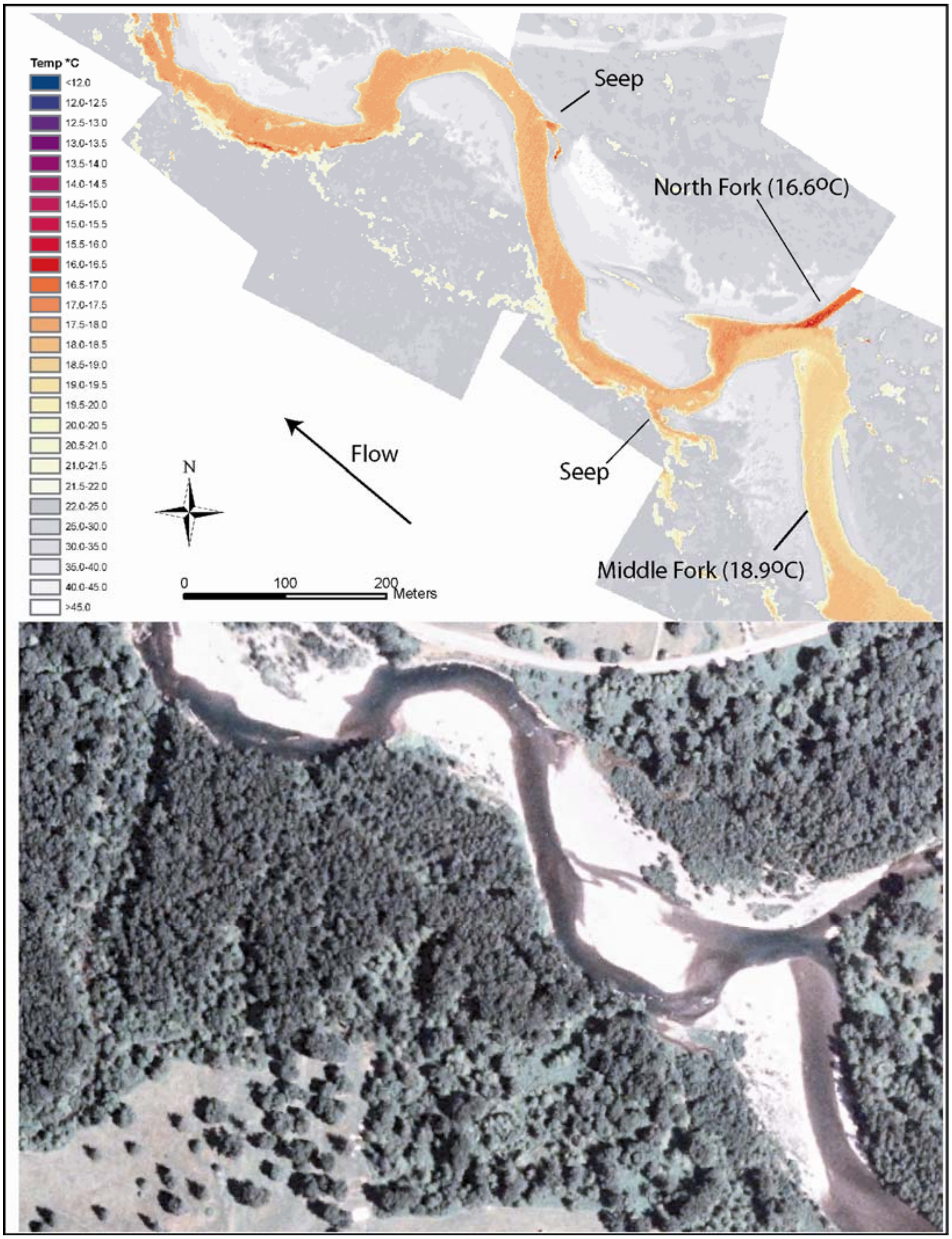

Figure 13. Sample image; thermal infrared (top) and true color (bottom) showing the confluence of the North Fork and Middle Fork Snoqualmie River (Watershed Sciences, 2007).

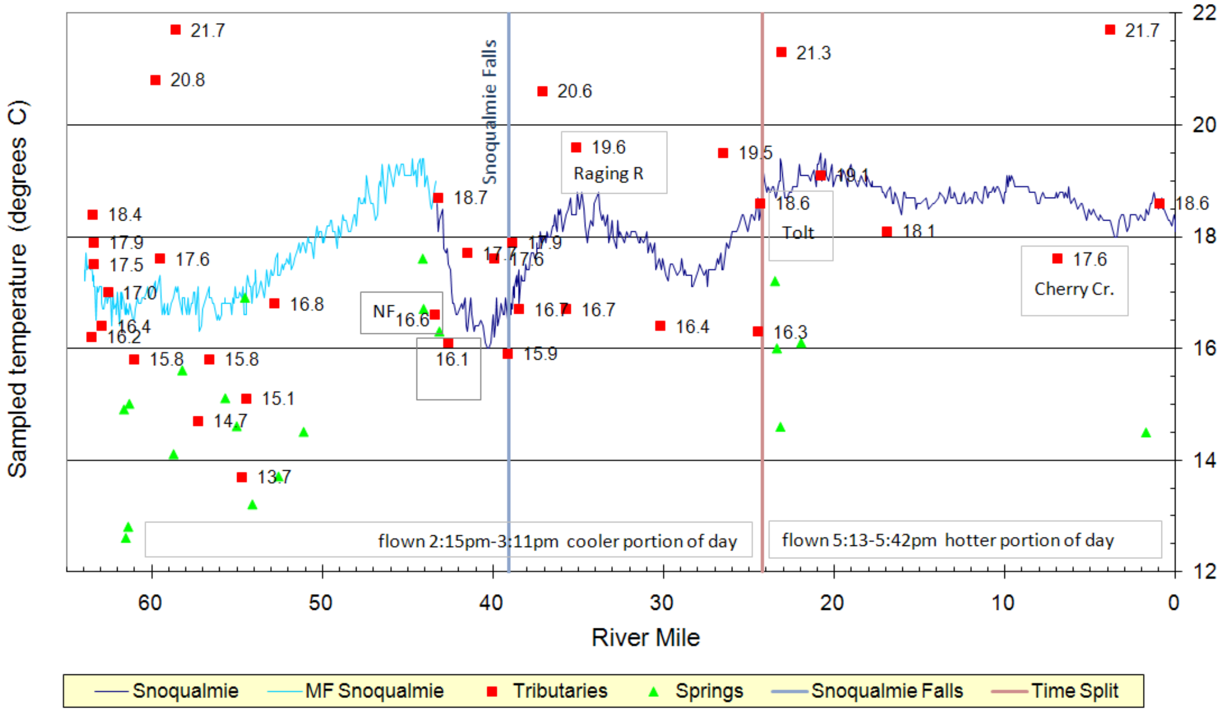

Figure 14. Water temperature from thermal Infrared imaging for 60 miles of the Middle Fork and mainstem Snoqualmie River, August 13, 2006.

The flight took place during two time periods because of a technical issue on the aircraft. Waters upstream of the Tolt River were flown during a cooler portion of the day, and waters downstream of the Tolt River were flown at a time that is typically near the daily maximum. August 13 was a warm and clear day, but overall several degrees cooler than the peak water temperatures in late July.

An area of interest is the warm section upstream of the confluence with the North Fork. Watershed Sciences (2007) reported that at about Middle Fork river mile 10.6 (RM 55.6 from the Snoqualmie mouth) radiant water temperature exhibited a steady downstream warming trend reaching ~19.2°C at mile 3.3 (RM 48.3). Inspection of the topographic base maps shows that the change in longitudinal heating rate corresponds to change in stream aspect (east/west) and distinct change in valley form. At mile 10.6 (RM 55.6), the Middle Fork transitions, in a downstream direction, from a relatively confined forested canyon to the more open valley at the town of North Bend. Additionally, fewer springs were detected in the lower portion of the Middle Fork than were found in the upstream reaches.

Stream temperature remained relatively constant (~19.3°C) over the lower three miles of the Middle Fork. The entire text of the Watershed Sciences (2007) report can be found at www.ecy.wa.gov/apps/watersheds/temperature/tir/Snoqualmie/reports/snoqualmie%20TIR%20Remote%20Sensing%20Final.pdf

Hydrology overview

Characterization of hydrology and the physics of how water moves through the system is one of the most important components of a water quality model. Table 12 shows data sets available to evaluate flow balance and hydraulic geometry for the Snoqualmie River. Hydraulic geometry is the relationship between streamflow and the wetted width, wetted depth, and water velocity of that stream. High quality data are available to calculate hydraulic geometry for two flow conditions, approximately 1000 cfs and approximately 600 cfs. The 1991 USGS flow and dye survey at a flow condition of 798 cfs is useful for verifying velocity and flow for the 7Q2, typical low-flow condition discussed later.

The terms *seepage run* and *synoptic flow survey* are both used throughout this report to refer to the practice of measuring flow at numerous places in a basin during a short time period for the purpose of establishing a flow balance.

Table 12. Flow and hydraulic geometry data for Snoqualmie River.

Date	Flow data	Travel-time dye study	Wetted width and/or wetted depth	Snoqualmie at Carnation Approximate flow condition (cfs)
July 24, 2006	Synoptic flow survey including SHU[1] mainstem measurements, 3 USGS and 1 SHU continuous gage	none	Orthophoto flight July 23- 24, 2006 and SHU mainstem sites	1070
August 14-18, 2006	Synoptic flow survey of tributaries and wadeable mainstem sites, 3 USGS and 1 SHU continuous gages	30 of 50 miles Aug 14-18	None Note: Thermal infrared flight on August 13	665
September 11-13, 2006	3 USGS and 1 SHU continuous gage, (seven SHU mainstem measurements on 14th)	50 of 50 miles Sept 11-14	Float survey Sept 14-19 every 2 miles, SHU mainstem sites	533
August 7-17, 1989	22 flow measurements	none	22 cross-section measurements	945
September 19-22, 1989	USGS continuous gages	South Fork to mouth		608
September 1991	USGS seepage run	Forks to Monroe		798

[1] SHU = Ecology’s Stream Hydrology Unit.

Streamflow data

Continuous streamflow measurements were recorded at three USGS gages and one Ecology gage (Springer, 2009) along the Middle Fork and mainstem Snoqualmie River (Figure 15). Additional USGS gages are located in the tributaries (Figure 16).

On July 25-27, 2006, a complete synoptic flow balance was performed with measurements taken at 35 sites on July 26, five sites on July 25, and one site on July 27 (Appendix Tables B1 and B2). These flow measurements were taken close enough to the time of the season high temperature on July 25 to be used as the flow balance for the July 7-DADMax QUAL2Kw model.

During the week of August 16, a travel-time study, a synoptic flow survey, and the thermal infrared flight were all scheduled to happen at the same time. Travel time and water velocity were evaluated using a dye study that sampled the entire river with six benchmarks. An extensive flow survey for the Middle Fork and tributaries was done at the same time. Thirty-three flow measurements were taken including all tributary mouths and two measurements on the Middle Fork Snoqualmie (Appendix B Table B3). Anticipated resources from Ecology's Stream Hydrology Unit (SHU) to measure ten mainstem sites during the dye study did not materialize because of scheduling conflicts. Flow values generated from the four continuous mainstem gages were substituted. The thermal infrared flight took place as scheduled.

From September 11-14, a second dye study was performed. The Stream Hydrology Unit made seven mainstem streamflow measurements on September 14, but rain beginning at 0300 hours likely influenced the results. Tributary measurements for September were spread throughout the month instead of occurring on the same day. A stream float survey collecting channel widths, depths, and vegetation information occurred from August 29 to October 3 with many of the measurements occurring at a similar flow level to that during September 11-13.

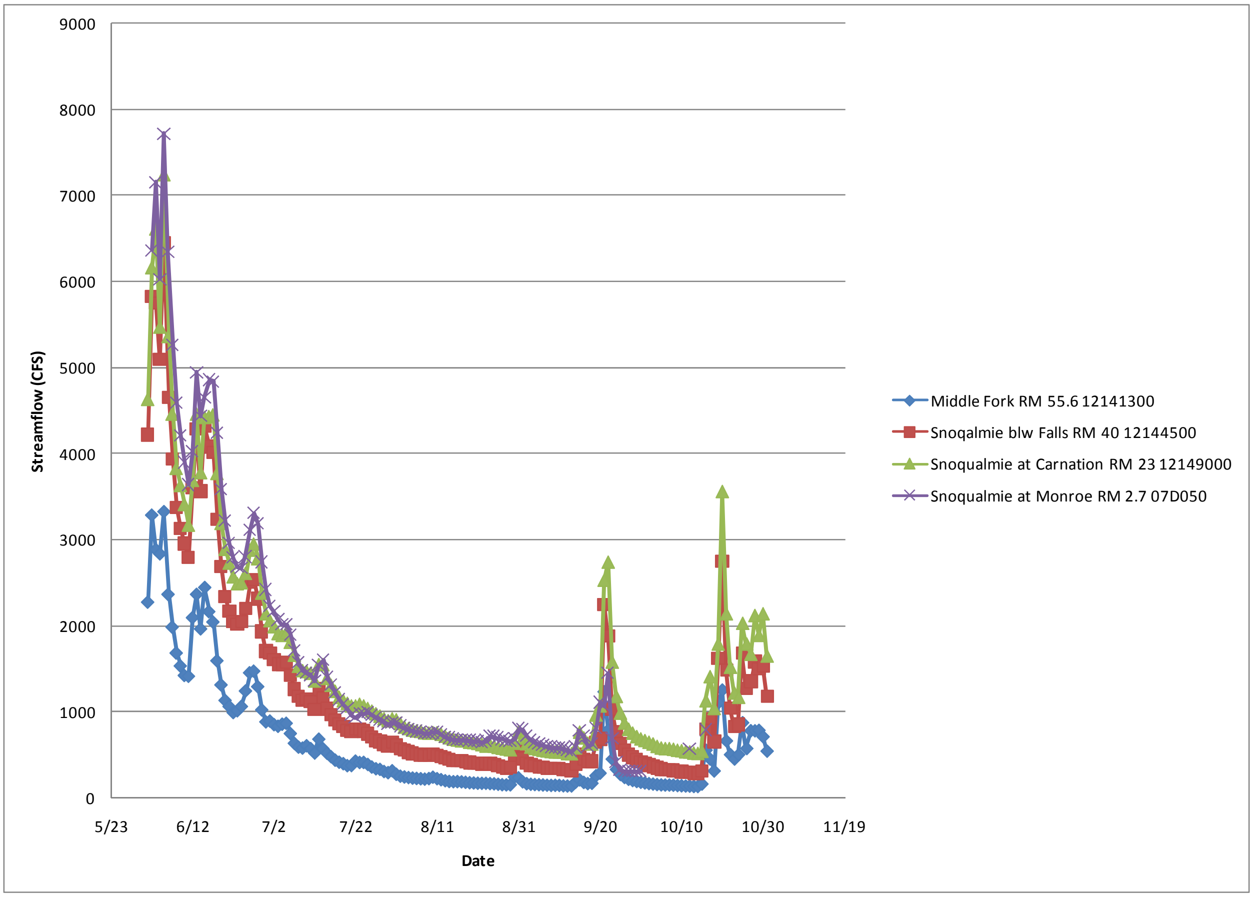

Figure 15. Daily streamflows in the mainstem and Middle fork Snoqualmie River as measured by three USGS and one Ecology gage during June 1 to October 31, 2006.

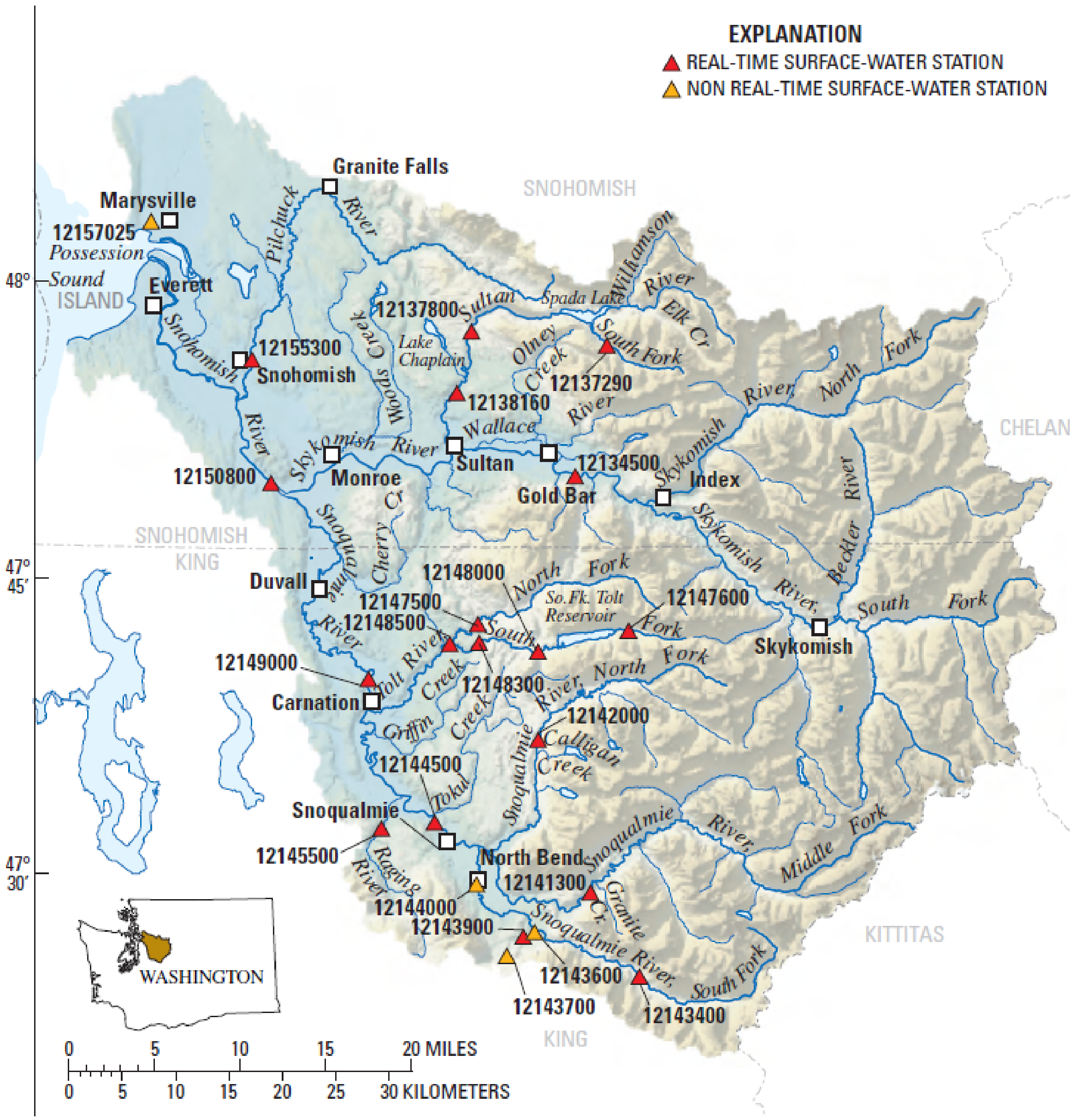

Figure 16. Location of streamflow gages in the Snohomish River basin, including the Snoqualmie River basin (source: USGS).

Low-flow stream statistics

Table 13 shows low-flow statistics for the period of record at four USGS gages in the Snoqualmie River basin. These low-flow statistics are often used as a basis for critical conditions when limiting pollutants from point sources.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is often calculated for the months of July and August as these typically represent the months with the highest water temperatures in our state. The July/August 7Q10 is used to establish nonpoint load allocations (e.g. shade) and can be used to establish point source wasteload allocations for most months. However, since the lowest annual flows generally occur in September, and since the fall is critical for salmonid spawning (often having a lower numeric temperature criteria), an annual 7Q10 is used as the critical low-flow condition for calculation of point source effluent limits for September discharges.

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

Table 13. Low-flow (7Q10 and 7Q2) statistics for selected USGS stream gages in the Snoqualmie River basin (cfs).

USGS gage number	Dates	July/August rank based		Annual USGS		Location
		7Q10	7Q2	7Q10	7Q2	
12149000	1929-2008	496	730	442	588	Carnation WWTP
12144500	1898-2008	368	520	386	480	Snoqualmie WWTP
12141300	1961-2008	152	229	148	195	Upper Middle Fork
12144000	1907-2008	95	126	78	99	South Fork gage at North Bend

WWTP – Wastewater Treatment Plant.

Table 14 shows low-flow statistics for the July through August period in more recent years (1961-2008) rather than the period of record. These values will be used as the critical condition to establish nonpoint load allocations in this temperature TMDL. All calculations in Table 14 use the same 47-year period, so they can be used together to represent a critical condition flow balance in the QUAL2Kw model. Because the four commonly used methods to calculate flow statistics produce similar results, the simplest to understand rank-based flows are used in the final flow balance.

Table 14. Low-flow, July/August, 7Q10 and 7Q2 statistics for 1961-2008.

Type	Number	Dates	Rank Based		Log Normal 3		Log Pearson type III		Weibull 3	
			7Q10	7Q2	7Q10	7Q2	7Q10	7Q2	7Q10	7Q2
USGS	12149000	1961-2008	535	766	517	760	524	745	517	728
	12144500		368	501	371	510	365	519	362	507
	12141300		152	229	148	227	147	225	145	217
	12144000		101	136	103	136	103	136	100	132

Travel-time dye study

Time-of-travel studies (dye studies) measure the time it takes a local body of water to travel downstream. Rhodamine dye is released into the stream and tracked using a dye sensor that is mounted to a data logging instrument. The data logging instruments are placed consecutively downstream, recording the dye slug as it passes. Time of travel is different than wave velocity because it describes the velocity of the entire water column and not a physical wave passing through the water.

Time-of-travel data were collected August 14-18 (Table 15) to coincide with the thermal infrared flight, and Sept 11-14 (Table 16) to coincide with the scheduled synoptic flow survey. These time-of-travel studies build upon a previous study which measured travel time in the South Fork and from mainstem RM 39.5 to RM 2.7 during 1989 (Table 17). Figure 17 shows reach velocities for all three studies. Reach lengths in the 1989 study were not identical to those in the 2006 study.

In August, a Hydrolab malfunction contributed to lost data for the reach between RM 29.0 and RM 22.8. An estimate of travel time for that reach was calculated using September data and the ratio:

$$\frac{Travel\ Time\ August\ reach\ 29.0to22.8}{TravelTime\ August\ reach\ 36.3to29.0} = \frac{TravelTime\ September\ reach\ 29.0to22.8}{TravelTime\ September\ reach\ 36.3to29.0}$$

In September, travel-time data were collected for the entire 60 miles of river. A rain storm that began at 3 am on September 14 likely affected the travel time to station 07MFS45.3.

Table 15. Travel-time dye study results for August 14-18, 2006.

Site	Distance			Leading Edge			Peak Concentration			Stream-flow USGS or *Ecology* (cfs)	Cumulative travel time (days)
	River mile upstream from mouth (mi)	Sub reach length (mi)	From point of injection (mi)	Travel-time (hour)	Average velocity (mi/hour)	Average velocity (ft/sec)	Travel-time (hour)	Average velocity (mi/hour)	Average velocity (ft/sec)		
Dye Injection 8/17/06 1340											
07MFS60.4	60.4	--	0.0	--	--	--	--	--	--	*132.02*	0.000
07MFS51.2	51.2	9.2	9.2	15:05	0.61	0.89	18:20	0.50	0.74	**185.00**	0.764
07MFS45.3	45.3	5.9	15.1	24:50	0.61	0.89	27:20	0.55	0.81	*183.12*	1.139
Dye Injection 8/16/06 1650											
07MFS45.3	45.3	--	0.0	--	--	--	--	--	--	--	--
07SNO40.8	40.8	4.5	4.5	9:55	0.45	0.67	12:55	0.35	0.51	**428.00**	1.677
07SNO36.3	36.3	4.5	9.0	17:10	0.52	0.77	21:25	0.42	0.62	--	2.031
Dye Injection 8/15/06 0940											
07SNO36.3	36.3		0.0	--	--	--	--	--	--	--	--
07SNO29.0	29.0	7.3	7.3	11:05	0.66	0.97	13:05	0.56	0.82	--	2.576
07SNO22.8	22.8	6.2	13.5	no data: the Hydrolab malfunctioned after deployment						**674.00**	2.031
Dye Injection 8/15/06 1141											
07SNO22.8	22.8	--	0.0	--	--	--	--	--	--	**674.00**	--
07SNO10.4	10.4	12.4	12.4	15:04	0.82	1.21	17:34	0.71	1.04	--	2.763
Dye Injection 8/14/06 1636											
07SNO10.4	10.4	--	0.0	--	--	--	--	--	--	--	--
07SNO02.7	2.7	7.7	7.7	16:24	0.47	0.69	19:24	0.40	0.58	--	3.572

This time-of-travel study was conducted 8/14/06 to 8/18/06.
Travel time for the reach ending at 07SNO22.8 was estimated from September 2006 data.
Gage flow shown on line 07MFS51.2 was actually taken at the USGS gage at RM 55.6.

Table 16. Travel-time dye study results for September 11-14, 2006.

Site	Distance			Leading Edge			Peak Concentration			Stream-flow USGS (cfs)	Cumulative travel time (days)
	River mile upstream from mouth (mi)	Sub reach length (mi)	From point of injection (mi)	Travel-time (hour)	Average velocity (mi/hour)	Average velocity (ft/sec)	Travel-time (hour)	Average velocity (mi/hour)	Average velocity (ft/sec)		
Dye Injection 9/13/06 0045											
07MFS60.4	60.4	--	0.0	--	--	--	--	--	--	--	0.00
07MFS51.2	51.2	9.2	9.2	18:30	0.50	0.73	22:45	0.40	0.59	137.00	0.95
07MFS45.3	45.3	5.9	15.1	34:17	0.44	0.65	38:17	0.39	0.58	--	1.60
Dye Injection 9/12/06 1913											
07MFS45.3	45.3	--	0.0	--	--	--	--	--	--	--	--
07SNO40.8	40.8	4.5	4.5	12:17	0.37	0.54	16:02	0.28	0.41	317.00	2.26
07SNO36.3	36.3	4.5	9.0	21:32	0.42	0.61	28:02	0.32	0.47	--	2.76
Dye Injection 9/12/06 0920											
07SNO36.3	36.3	--	0.0	--	--	--	--	--	--	--	--
07SNO29.0	29.0	7.3	7.3	12:40	0.58	0.85	15:55	0.46	0.67		3.43
07SNO22.8	22.8	6.2	13.5	30:40	0.44	0.65	34:40	0.39	0.57	517.00	4.21
Dye Injection 9/11/06 1814											
07SNO22.8	22.8	--	0.0	--	--	--	--	--	--	517.00	--
07SNO10.4	10.4	12.4	12.4	17:01	0.73	1.07	20:01	0.62	0.91	--	5.04
Dye Injection 9/11/06 1850											
07SNO10.4	10.4	--	0.0	--	--	--	--	--	--	--	--
07SNO02.7	2.7	7.7	7.7	19:25	0.40	0.58	24:10	0.32	0.47	--	6.05

This time-of-travel study was conducted 9/11/06 to 9/14/06.
Rain interrupted this study beginning on 9/14/06 at approximately 0300 hrs. This rain seems significant enough to slightly influence the last two or three hours of this study specifically at 07MFS45.3.
Gage flow shown on line 07MFS51.2 was actually taken at the USGS gage at RM 55.6.

Table 17. Travel-time data for September 1989 (Joy et al., 1991).

Water body	River mile	Action	Peak concentration travel rate (mi/hr)	Peak concentration travel rate (ft/s)	Flow (cfs)	Date	USGS flow station	Reach travel time (hours)	Cumulative travel time (days)
S. Fork Snoqualmie R.	46.1	dumped 9/22/89			25	9/22/1989	SF Snoq R at Garcia		
	44.4	monitored	0.53	0.78					
Mainstem Snoqualmie R.	42.3	monitored	0.58	0.85					
	42.6	based on temp							
	40.7		0.25	0.37					
	39.5	dumped 9/22/89			407	9/22/1989	Snoq R below Falls		2.115
	36.2	monitored	0.53	0.78				6.2	2.37
	36.3	dumped 9/20/89			431	9/20/1989	Snoq R below Falls		
	25.1	monitored	0.43	0.63	608	9/20/1989	Snoq R at Carnation	26.1	3.46
	24.6	dumped 9/29/89			588	9/29/1989	Snoq R at Carnation		
	10.6	monitored	0.72	1.06				19.3	4.27
	10.6	dumped 9/19/89			629	9/19/1989	Snoq R at Carnation		
	9.7	monitored	0.57	0.84					
	7.3	monitored	0.60	0.88				6.5	4.54
	2.7	estimate	0.33	0.48				13.1	5.08

Reach travel times from page 24 in Joy et al., 1991.
Cumulative travel time uses estimate of travel time to Snoqualmie site 39.5 based on 2006 data.

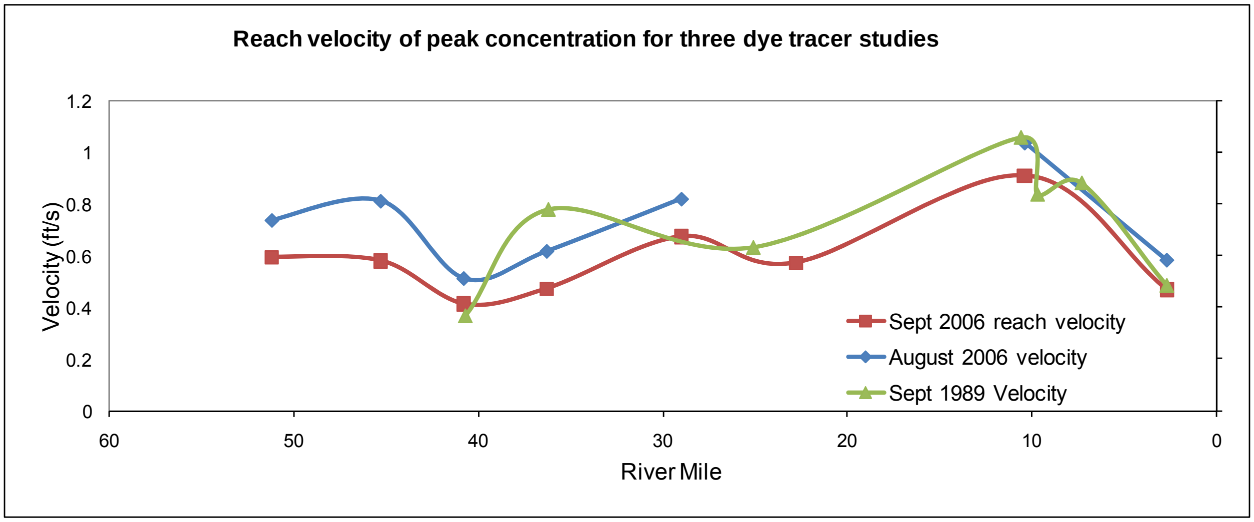

Figure 17. Travel-time reach velocity results for three dye tracer studies.

Water balance and diffuse groundwater inputs

The flow survey (seepage run) performed on July 26, 2006 assisted in determining the influence of groundwater in the basin and quantifying a water balance during a time of typically high water temperatures. Groundwater inputs to a stream generally affect water temperature by cooling the stream. The survey consisted of measuring instantaneous flow along the length of the mainstem and Middle Fork Snoqualmie River. Streamflow measurements were also taken at the mouth of both major (> 5 cfs) and minor tributaries (> 0.5 cfs) on July 25.

These flow data (Appendix B), along with continuous flow gage data and instantaneous measurements taken throughout the summer, determined reaches that gain and lose groundwater. These findings were consistent with earlier groundwater studies reported in Turney et al. (1995) and Haring (2002) that the system tends to gain groundwater along its length except for the lower reach, below Carnation. Quantities of permitted water withdrawals from the mainstem were determined to be insignificant in the water balance (see *Water Withdrawals* section).

Three sets of flow data from July through August 2006 were used to calculate average diffuse gains and losses between major gage locations. September flow values were not used in the calculations because (1) of rain falling during September 14 when many of the mainstem flows were measured and (2) tributary mouths were not measured in September as part of a seepage event.

Table 18 shows the diffuse inflow and outflow of groundwater used in all 2006 modeling scenarios. First, the total flow gain or loss between each gage was calculated, and then the measured tributary mouth flows were subtracted from this total. The remaining difference was assigned to diffuse inflow or diffuse outflow. Since there was little difference in the diffuse values calculated from each of the three sets of data, these were averaged and used in all 2006 model runs. USGS found similar gains and losses between these gages during a September 1991 seepage run (Turney et al., 1995).

Table 18. Groundwater gain and loss estimates for the Snoqualmie River.

Middle Fork or mainstem gage	Average of 3 periods in July-August 2006			Calculated diffuse groundwater gain/loss	
	Total flow gain between gages (cfs)	Gain due to tributaries (cfs)	Gain due to diffuse input – calc. by subtraction (cfs)	2006 (cms)	July 2005 (cms)
USGS 12141300 RM 55.6 (km 8.6)					
Ecology 07D150 RM 45.3 not continuous (km 24.85)	52.8	7.4	45.4	1.29	1.75
USGS 12144500 RM 39.8 (km 33.5)	303.5	292.1	11.4	0.32	0.44
USGS 12149000 RM 23 (km 59.45)	274.6	191.4	83.2	2.36	1.30
Ecology 07D050 RM 2.7 (km 91.86)	-22.7	13.4	-36.1	-1.02	-1.02

Note: Streamflow data was collected in units of cfs, but converted to cms for use in modeling.

Diffuse gains and losses calculated for 2005 were somewhat different for 2006. Joy (1991) found that quantity of groundwater inputs can change depending on whether the previous year was wet or dry. Therefore, the flow diffuse values for 2005 were calculated using the data from USGS gages and gage flow measurements of major tributaries. Minor tributary flows in 2005 were assumed to be the same as in 2006.

Float survey: channel cross-sections and riparian vegetation

Riparian vegetation and channel cross-section data were collected during a stream survey that covered approximately 60 miles of the river during 2006. The survey was conducted by boat from the US Forest Service boundary at the Middle Fork downstream to the confluence with the Skykomish River.

Prior to the survey, color images of the watershed were printed on waterproof paper so that vegetation heights and densities measured during the survey could be recorded directly on the photos (Figure 18).

During the survey, detailed channel cross-section and riparian shade information was collected at 30 transects (approximately every two miles). Data collected at each transect consisted of bankfull width and depth, wetted width and depth, effective shade (using a Solar Pathfinder), near-stream disturbance zone (active channel width), vegetation height, vegetation density, general vegetation type, distance that vegetation covers the stream channel, and bank incision. Additionally hemispherical photography was used to measure effective shade and canopy density at all water temperature stations. Many of these data are used as field checks to compare against data gathered from orthophotos and to help construct the hydraulic geometry portion of the water quality model. The solar pathfinder and hemispherical photography effective shade measurements are used as field checks to compare against effective shade values generated by the Shade Model. These data are reported in Appendix E.

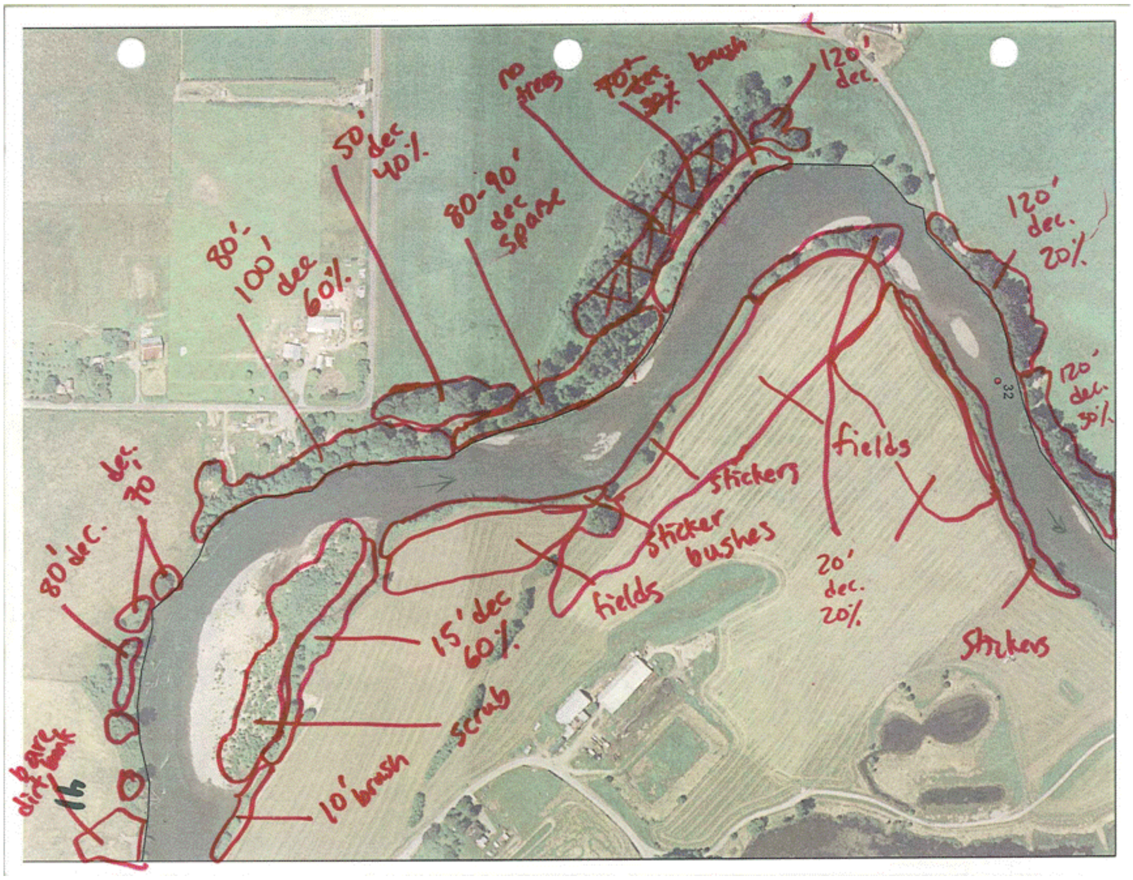

Figure 18. Example float survey notes for the Snoqualmie River, 2006.

Hydraulic geometry

Manning's equation was used to describe the relationship between flow and wetted width, depth, and velocity for the Snoqualmie River. As flow levels are changed in the QUAL2Kw model, this relationship allows appropriate adjustments to be made in the other parameters.

Application of the Manning equation is thoroughly discussed in Chapra (1997). A Manning's n spreadsheet calculator is available at www.ecy.wa.gov/programs/eap/models.html

Manning's n was calculated using inputs of:

- Wetted width
- Channel slope
- Wetted depth
- Flow

Reach-specific water velocity and travel time are generated from the above parameters in the QUAL2Kw model. Travel times measured from the dye studies are then used for confirmation that velocities are correct.

Data that are continuous along the river should result in hydraulic geometry relationships that are closest to reality. The best continuous data were the wetted width from the orthophoto flight during late July 2006 at the time when water temperatures were highest. High quality flow data are available for four continuous gages and for all tributary mouths at this same time. Stream channel slope was calculated from 6-foot pixel LiDAR data (King County), Figure 19.

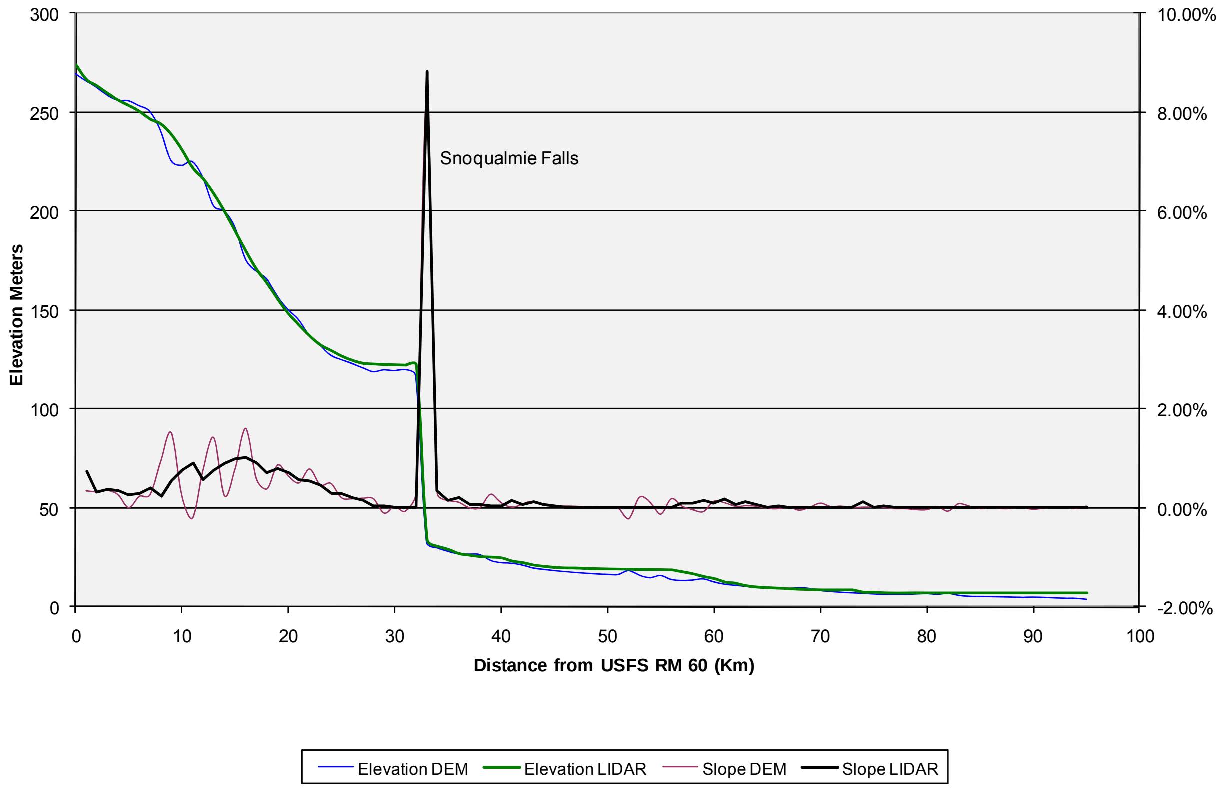

Figure 19. Stream channel elevation and slope for the Snoqualmie River from USFS boundary to confluence with Skykomish River.

The only remaining value needed for the Manning's n calculation was wetted depth. Since wetted width (ww) and wetted depth (wd) change continuously along the river and since ww x wd = area, we decided to use the cross-sectional area and the accurate ww to calculate a continuous depth record.

Cross-section data were collected every two miles along the river during the float survey. Additional cross-section data are available from the July and September measurements by Stream Hydrology Unit staff, and from a 1989 study that took place during a similar flow condition. From these wetted width and cross-sectional area measurements, depth can be calculated generally for two flow conditions: near 600 cfs and near 1000 cfs.

Figure 20 shows cross-section data from the 2006 stream and flow surveys and from the 1989 cross-section survey (Joy et al., 1991). These data are plotted by river kilometer. Lines and symbols show specific measurements. Cross-sections are expected to stay fairly constant over areas with similar flow conditions and are expected to change near confluences with major tributaries.

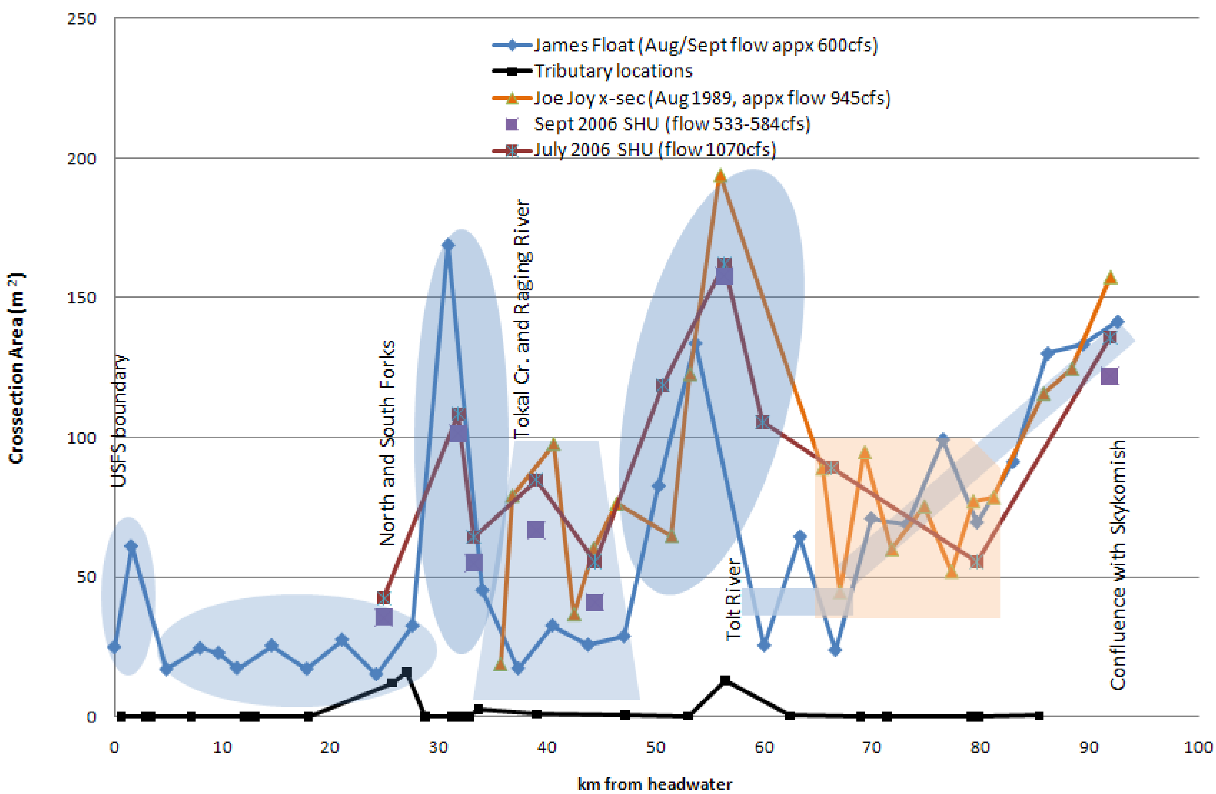

Figure 20. Wetted cross-section area (river Km) along the Middle Fork and mainstem Snoqualmie River.

Since cross-section measurements may or may not be taken at a typical location and may or may not be taken at the same place from one study to the next, they should be averaged over areas with similar flow. The shadowing in Figure 20 shows groupings of similar cross-sectional areas. The cross-sectional areas stayed fairly consistent, with large changes occurring at confluences with major tributaries such as the North and South Forks and the Tolt River. Locations just before and after entry of major tributaries, or areas with changes in stream slope, often create pooling which results in a short section of stream with larger cross-sectional areas.

Table 19 shows final cross-section area measurements that were used to recalculate depth at that flow condition from the continuous wetted width.

Table 19. Snoqualmie River wetted cross-section area for two flow conditions.

Approximate river mile (RM) label	Specific start and end points (km) where the cross-section value applies	Cross-section area (m^2) (flow condition appx 600 cfs) used for Aug/Sept 7Q2/7Q10 depth calculation[1]	Cross-section area (m^2) (flow condition appx 1000 cfs) used for July 2005-6 depth calculation[2]
RM 60-58	0 - 1.55	45.14	48.83
RM 58-42	1.55 - 29.15	24.84	26.88
RM 42-38 near falls and NF, SF	29.15 - 35.6	85.98	93.01
RM 38-30	35.6 - 48.6	47.53	51.41
RM 30-26 Tolt River	48.6 - 56.775	121.36	131.29
RM 26-22	56.77 - 61.6	53.60	57.98
RM 20	61.6 - 64.875	53.60	57.98
RM 18	64.875 - 68.15	53.60	57.98
RM 16	68.15 - 71.45	63.83	69.05
RM 14	71.45 - 74.775	68.97	74.61
RM 12	74.775-78.005	74.20	80.26
RM 10	78.0 - 81.23	79.04	85.51
RM 8	81.23 - 84.50	84.25	91.14
RM 6	84.50 - 87.73	110.43	119.46
RM 4	87.73 - 90.95	119.78	129.58
RM 2	90.95 - end	140.57	152.06
Average over all reaches		76.67	82.94

[1]Sources: Ecology float survey during August and September 2006 and SHU measurements in mid-September 2006. See Appendices for actual dates.
[2]Sources: Ecology SHU measurements in July 2006 and measurements from similar flow condition in August 1989 (Joy et al., 1991).

Water velocity and hydraulic routing was confirmed with results from the travel-time dye studies. Velocity for the river is available through the dye studies, and could have been used to back calculate water depth. But because the 2006 dye studies divide the river into just six large reaches, using these to calculate depth would result in a much more generalized river. The dye study field-measured, travel-time results provide an excellent check against predicted model travel time. Manning's n was recalculated for each specific flow condition from the width, depth, flow, and slope for input to the QUAL2Kw model. See the information on hydraulics in the *QUAL2Kw Temperature Model Calibration* section for graphical comparisons.

Meteorology/climate data

Ecology monitored air temperature at 39 locations in the watershed in 2006 (Figure 21). Six of these stations also collected relative humidity (RH) and dewpoint data. A more complete weather station (07WEA10.0) was installed approximately 700 feet from the river near the police station in Duvall. In addition to air temperature and relative humidity, this station gathered wind speed, solar radiation, precipitation, barometric pressure, wind speed, and wind direction.

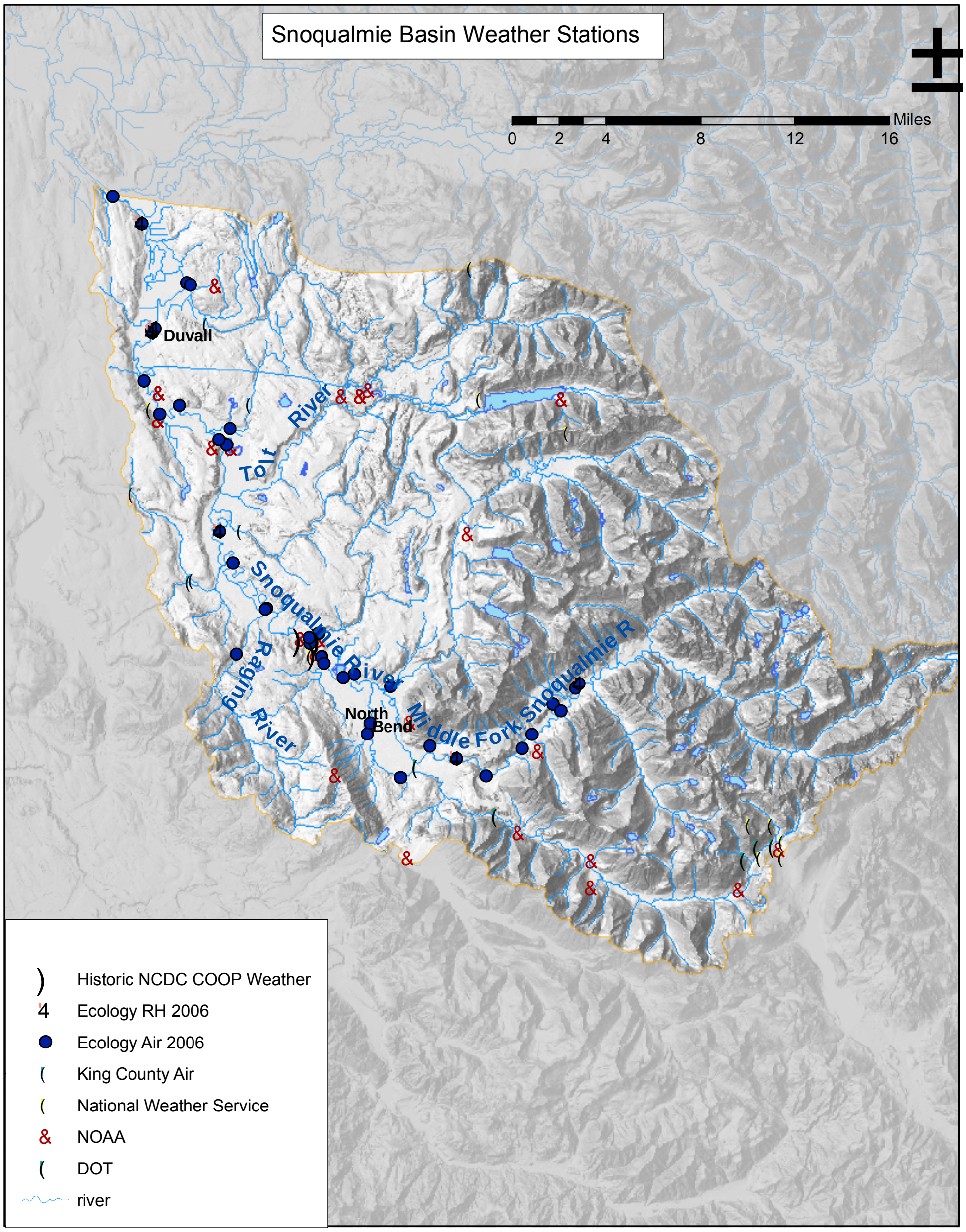

Figure 21. Snoqualmie basin weather stations and Ecology's year 2006 air temperature and relative humidity monitoring locations.

Air temperature 2006

Hourly air temperature data from the hottest week in 2006, July 22 -28, show minimum temperatures near 15°C and peaks ranging from 22.9 to 33.9°C. Daily minimum air temperatures occurred at a median time of 06:15 (am) and daily maximums at 16:20 (4:20 pm). Air temperature does not show a strong upstream to downstream pattern (Figure 22). There is no measureable trend in minimum or mean temperature along the length of the river. Daily maximums show more variation but not a trend. Some of the cooler daily maximums are from monitors located near narrow tributary mouths with more riparian shade.

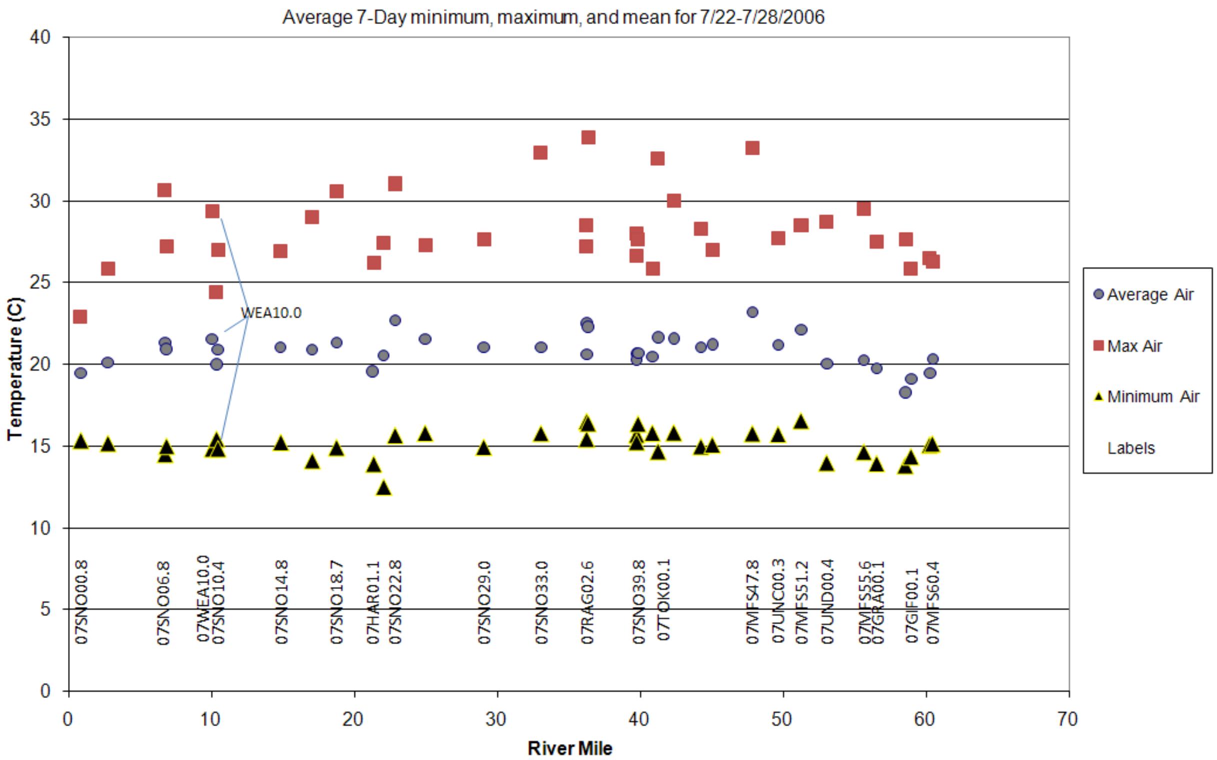

Figure 22. Snoqualmie River air temperature monitoring data by river mile with comparison to values measured at the weather station 07WEA10.0.

Two options were available for air temperature model input: a composite air temperature record of all sites or the simpler approach of calculating data from the weather station. The average 7-day maximum and 7-day minimum air temperature across all 37 monitoring stations was 28.2°C and 15.1°C, respectively. Hourly air temperature for model input calculated using only the WEA10.0 weather station resulted in a value of 28.9°C for the maximum at hour 16:00 and a value of 15.0°C for the minimum at hour 06:00.

Since there was no distinct trend and since temperatures calculated from the composite stations and from the weather station were very close, air temperatures and wind measured at the weather station in Duvall were used for model input for the entire river. It was noted that air temperature in the reach nearest the confluence with the Skykomish River (RM 0.8) is potentially cooler, but since it is the end model reach, it would not have a large influence on modeled water temperatures.

Relative humidity, 2006

Diurnal relative humidity values for the week of July 22- 28, 2006 are shown in Figure 23, and the trend of the 7-day maximum, minimum, and mean by river mile are shown in Figure 24. There is a weak trend with river mile for relative humidity. The air is drier further upstream and away from Puget Sound. Also the weather station at Duvall, which is located about 700 feet from the river, has similar maximum daily humidity values, but lower daily minimums than do the near-stream stations. This is a common pattern with most off-stream weather stations.

The station at 07SNO39.8 was used for the model runs because it is in the middle of the basin and has median type relative humidity values. Although a tighter fit to the data may be possible if relative humidity were entered into the model as a function of elevation or distance from the mouth, we decided to go with the simpler model of just using data from SNO39.8 to represent the river. This enabled us to more easily look at different years, e.g., 2005, when less extensive relative humidity data were collected.

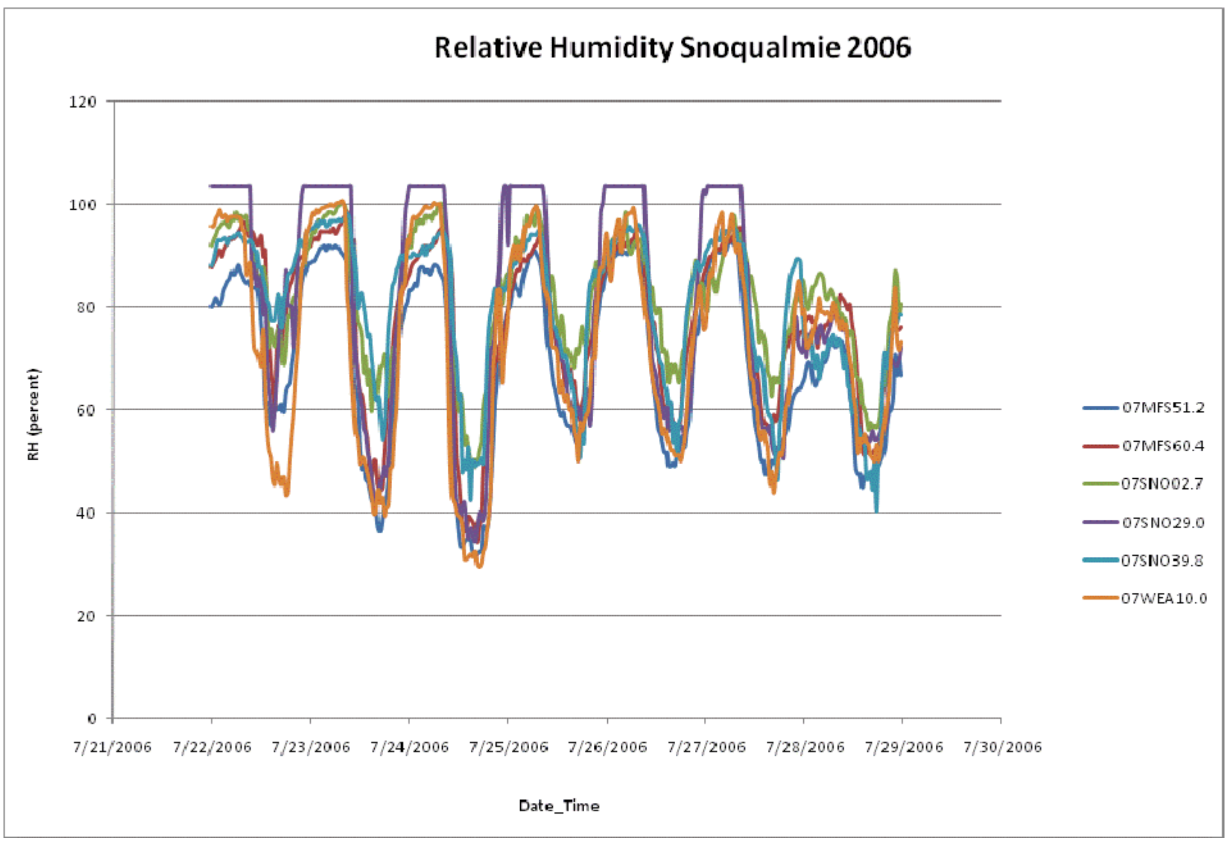

Figure 23. Diurnal relative humidity measured at six Snoqualmie River locations during July 22 to 28, 2006.

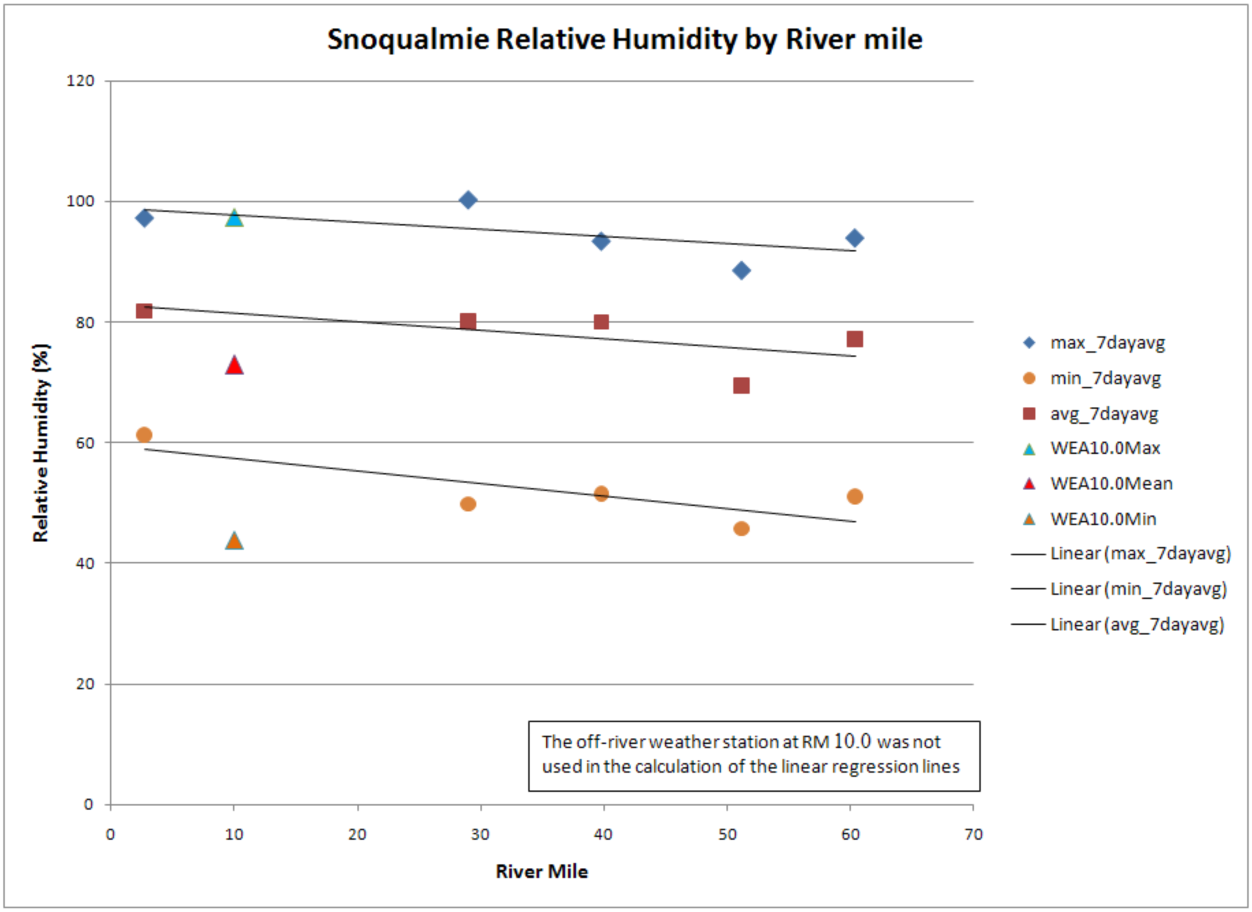

Figure 24. Relative humidity trend by Snoqualmie river mile.

Air temperature, 1949-2009

This TMDL project requires evaluation of the watershed at critical (90th percentile air temperature) conditions and typical (50th percentile air temperature) conditions. Long-term climate data were consulted to determine (1) if our data have been gathered in a warm or cool year and (2) which weather data should be used during model evaluation of the critical and typical conditions.

The National Weather Service (NWS) Coop site at Snoqualmie Falls, station 457773, provides a long-term (1899-2008) record of climate data. Because of changes in methods and periods of missing data, the period 1949-2008 was used to determine the typical (50% percentile) and the more extreme (90% percentile) years for climate conditions. The annual highest 7-day average of daily maximum air temperature was used to determine the median and the 90th percentile conditions. Fifty-nine years of data were used for this statistical analysis (Table 20).

A complete record of hourly data for the years 2001-2009 was also available for the Fire Training Academy RAWS station in North Bend. Other weather station data are available through King County, DOT, NOAA Coop, and USGS. These had shorter periods of record, measured daily mean values, or were located further from the mainstem so were not used to calculate long-term statistics.

Table 20. Air temperature statistics for Snoqualmie, Washington.

Condition	Snoqualmie Falls (NWS Coop Station # 457773) (1949-2008)		North Bend Fire Training Academy RAWS temperature (2001-2009)	
	(ºF)	(ºC)	(ºF)	(ºC)
Extreme weather condition (exceeded 10% of time)	89.0	31.7	89.3	31.8
Typical weather condition (exceeded 50% of time)	84.3	29.1	84.0	28.9
7-day average of daily maximum (2006)	89.0	31.7	88.0	31.1
7-day average of daily maximum (2005)	83.1	28.4	84.0	28.9

The 90th percentile temperature for the Snoqualmie Falls weather station was 31.7ºC, which was the identical condition for the week of July 21-27, 2006. Since peak water temperatures occurred one day after peak air temperatures, the water temperature model will use the actual hourly air and dewpoint temperatures measured in the watershed for July 22-28, 2006. These were used for both the July 2006 model run and for the 90% critical condition.

The hottest week of 2005 (July 25-31) was a 45th percentile condition based on the weather stations in Table 20 and confirmed by an additional station in Monroe. The 2005 year was determined to be sufficient to look at a typical median year; however, 2005 may be slightly cooler than the true median. Figure 25 shows the air temperature pattern during the last 20 years measured at Snoqualmie Falls, Washington.

Cloud cover and solar radiation

Cloud cover and solar radiation data from the long-term weather station on the University of Washington roof and from the Ecology Duvall station were virtually identical. A cloud cover of 10% was used for these weeks (July 21-27, 2006 and July 25-31, 2005) which were both very clear.

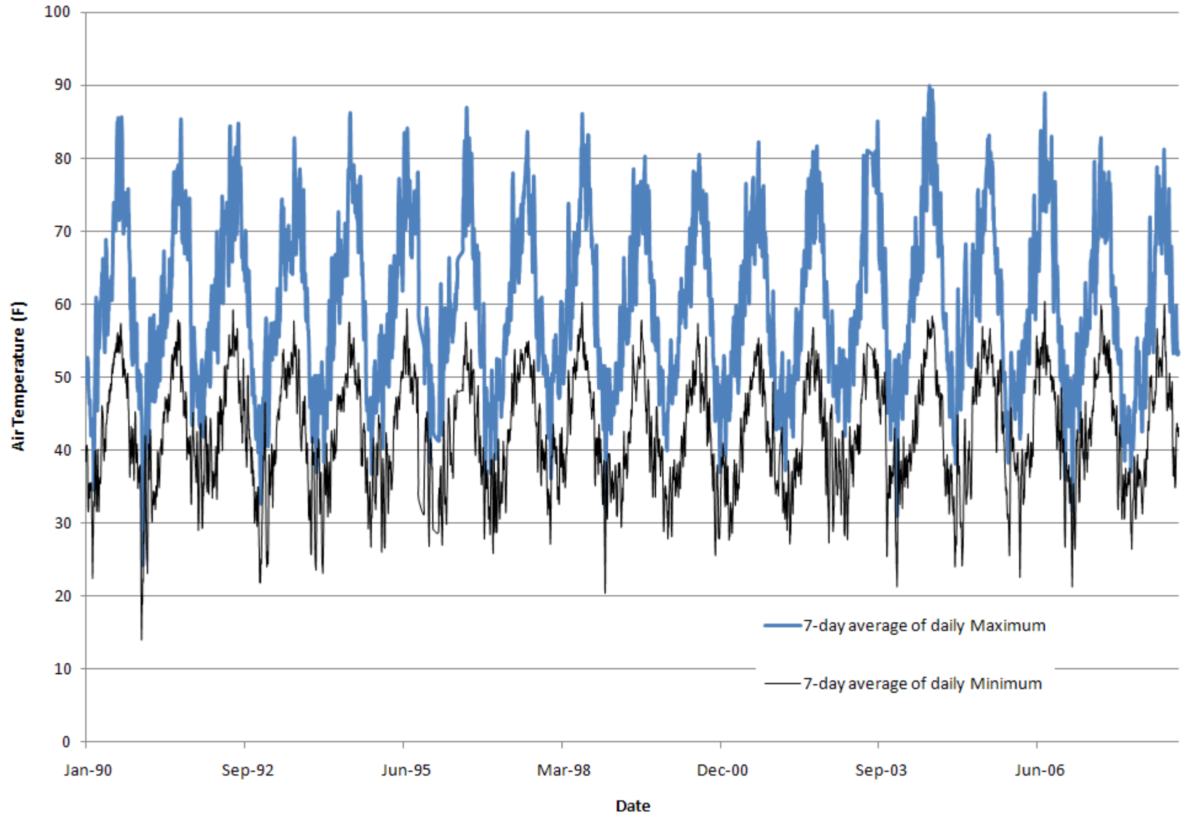

Figure 25. Maximum and minimum air temperature at Snoqualmie Falls, 1990 to 2008.

Data shown are from the National Weather Service Coop site at Snoqualmie Falls, station 457773.

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TMDL Analyses

Analytical framework

Data collected for this TMDL study were used to simulate water temperature with a computer model that is both spatially continuous and which spans full days (steady flow, dynamic heat, budget and water temperature). The Geographic Information System (GIS) and modeling analyses use three specialized software tools. All three tools are available from www.ecy.wa.gov/programs/eap/models.html

1. TTools is an ArcGIS extension used to measure stream channel widths; topographic shade angles to the west; south and east; stream aspect; and riparian vegetation characteristics. TTools was originally developed by the Oregon Department of Environmental Quality (ODEQ, 2001) for use with older ArcView software. Using a grant from EPA, Ecology upgraded TTools to make it compatible with the newer ArcGIS software.

2. The Shade spreadsheet model (Ecology, 2003) estimates effective shade for the river surface based on the geometry of each reach and the attenuated shade through the riparian vegetation canopy. The model was modified from Boyd (1996) using the methods of Chen et al. (1998a and 1998b). Shade calculations are date-specific because the solar azimuth angle varies with time of year and the angle affects the shade calculations. Data required by the shade model include stream orientation, topographic shade angles, time of year, sun position, latitude, channel width, and riparian vegetation characteristics (height, type, density). Model output includes percent shade by stream reaches and by hour of the day for a specific day of the year.

3. The QUAL2Kw model (Pelletier and Chapra, 2008; Pelletier et al., 2006; Chapra and Pelletier, 2003) was used to calculate the components of the heat budget and to simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw was applied by assuming that flow remains constant for a given condition such as a 7-day or 1-day period, but key variables are allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures were specified or simulated as diurnally varying functions. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget that are shown in Figure 4 and described in Chapra (1997).

All input data for the Shade and QUAL2Kw models are longitudinally referenced. The river was divided into 100-m units using TTools. Model input data were determined from available GIS coverages using the TTools extension for ArcGIS, or from data collected by Ecology or other data sources. Spatial data were collected and applied in the Shade model for each 100-m unit. These data were then averaged appropriately for final heat load modeling in QUAL2Kw using a 1000-m simulation unit.

Pollutants and surrogate measures

Heat loads to the stream are calculated in this TMDL in units of calories per square centimeter per day or watts per square meter (W/m^2). However, heat loads are of limited value in guiding management activities needed to solve identified water quality problems.

The Snoqualmie River Temperature TMDL will incorporate measures other than "daily pollutant loads" to fulfill the requirements of Section 303(d). This TMDL allocates other appropriate measures, or "surrogate measures," as provided under EPA regulations [40 CFR 130.2(i)]. The *Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program* (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

> When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional *pollutant*, the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.

Water temperature increases as a result of increased heat flux loads. A loading capacity for radiant heat energy (e.g., incoming solar radiation) can be used to define a reduction target that forms the basis for identifying a surrogate for heat loading from solar radiation. This technical assessment for the Snoqualmie River Temperature TMDL uses effective shade as a surrogate measure of heat flux from solar radiation to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. The definition of effective shade allows direct translation of the solar radiation loading capacity.

Because factors that affect water temperature are interrelated, the surrogate measure (effective shade) relies on restoring/protecting riparian vegetation to increase stream surface shade levels, reducing streambank erosion, stabilizing channels, reducing the near-stream disturbance zone width, and reducing the surface area of the stream exposed to radiant processes. Effective shade screens the water's surface from direct rays of the sun. Other factors influencing heat flux and water temperature were also considered, including microclimate, channel geometry, groundwater recharge, and instream flow.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat-exchange and mass-transfer processes in the stream.

Daily pollutant loads for point sources will be calculated using a mixing zone equation and expressed as a temperature measurement made just prior to effluent discharge into the receiving water. The mixing zone equation considers both the volume of water discharged and the receiving water characteristics. Loading to the water body will tracked using effluent flows and temperatures.

Seasonal variation

Clean Water Act Section 303(d)(1) requires that TMDLs "be established at the level necessary to implement the applicable water quality standards with seasonal variations". The current regulation also states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(2)]. Finally, Section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The Snoqualmie River basin experiences seasonal variation with cooler temperatures occurring in the winter and warmer temperatures in the summer. The highest temperatures typically occur from mid-July through mid-August. This time frame is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The critical period for evaluation of solar flux and effective shade will be assumed to be August 1, because it is the mid-point of the period when water temperatures are typically at their seasonal peak.

Critical streamflows for the TMDL were evaluated as the lowest 7-day average flows with a 2-year recurrence interval (7Q2) and 10-year recurrence interval (7Q10) for July and August. The 7Q2 streamflow was assumed to represent conditions that would occur during a typical climatic year, and the 7Q10 streamflow was assumed to represent a reasonable worst-case climatic year.

Since the load allocations resulting from the summer model runs resulted in requiring the maximum riparian protection to the stream, a fall scenario was not performed. Fall temperature criteria for salmon begin September 15. If a model evaluation were performed, it would need to be done with September climate conditions, an annual 7Q10 flow (because the lowest annual flows typically occur in September), and an estimate of the shade produced by the vegetation on September 15. Additional modeling would not change the resulting load allocation. If the resulting water temperature were below the standard, the shade load allocation would still need to be met to comply with the summer condition. If the resulting water temperature were greater than the standard, the load allocation would still be the maximum shade.

For point sources, seasonal variation is taken into account, as described later in the *Wasteload Allocation* section.

Riparian vegetation and effective shade

Mapping the near-stream vegetation cover at current conditions

Near-stream vegetation cover, along with channel morphology and stream hydrology, represents the most important factors that influence stream temperature. To obtain a detailed description of the existing riparian conditions in the mainstem and Middle Fork Snoqualmie River, a combination of field-collected riparian vegetation data, GIS analysis, and aerial photography interpretation was used.

GIS coverages of riparian vegetation in the study area (Figure 26) were created from field information collected during the 2006 temperature study and analysis of the color digital orthophotos flown during the summer of 2006 by the National Agricultural Imagery Program (NAIP). During the time of mapping, the NAIP orthophotos had a resolution of 36", but are being improved to 18". NAIP flight dates for the Snoqualmie images were:

- 7/24/06 for the mouth of the Snoqualmie upstream to USGS RM 38 (between Raging River and Tokul Creek).
- 7/23/06 for the Snoqualmie USGS RM 38 upstream to the Middle Fork Snoqualmie RM 48.5 (just upstream of Mt. Si Road).
- 7/21/06 for the Middle Fork Snoqualmie RM 48.5 upstream to RM 58 (downstream of Gifford Lakes Creek).
- 8/5/06 for the Snoqualmie RM 58 to RM 61 (USFS boundary).

The near-stream disturbance zones (NSDZ) or channel bank edges and the wetted width were digitized from the digital rectified orthophotos. The NSDZ is the active stream channel area without riparian vegetation that includes features such as gravel bars.

Polygons 150 feet wide were created at 1:2000 scale in GIS to describe riparian vegetation conditions along both sides of the river. Using the NAIP digital photos and Ecology's field observations, a vegetation type code (Table 21) that combines information about the average height, canopy density, and type (conifer, deciduous, shrub) was assigned to each polygon. Current vegetation height was also verified with LiDAR data provided by King County and the Puget Sound LiDAR Consortium. Some analysis later required vegetation information out to 180 feet from the channel bank. For these analyses, vegetation growing between 150 to 180 feet from the stream was assumed to be the same as that growing at 150 feet.

Figure 26. Example of the NAIP color digital orthophotos and vegetation polygons for the mainstem Snoqualmie River below the confluence with the Raging River.

Inset shows TTools vegetation sampling points.

Table 21. Riparian vegetation classification scheme for the Snoqualmie River basin.

Code	Description	Height	Density	Overhang[1]
		(m)	(%)	(m)
111	css- conifer, small, sparse	9	25%	1
112	csd- conifer, small, dense	9	75%	1
113	csm- conifer, small, medium	9	50%	1
131	cms- conifer, medium, sparse	20	25%	1.5
132	cmd- conifer, medium, dense	20	75%	1.5
133	cmm- conifer, medium, medium	20	50%	1.5
121	cls- conifer, large, sparse	30.5	25%	3
122	cld- conifer, large, dense	30.5	75%	3
123	clm- conifer, large, medium	30.5	50%	3
211	dss- deciduous, small, sparse	9	25%	2.7
212	dsd- deciduous, small, dense	9	75%	2.7
213	dsm- deciduous, small, medium	9	50%	2.7
231	dms- deciduous, medium, sparse	22	25%	6.6
232	dmd- deciduous, medium, dense	22	75%	6.6
233	dmm- deciduous, medium, medium	22	50%	6.6
221	dls- deciduous, large, sparse	32	25%	9.6
222	dld- deciduous, large, dense	32	75%	9.6
223	dlm- deciduous, large, medium	32	50%	9.6
311	mss- mixed, small, sparse	9	25%	1.8
312	msd- mixed, small, dense	9	75%	1.8
313	msm- mixed, small, medium	9	50%	1.8
331	mms- mixed, medium, sparse	22	25%	4.4
332	mmd- mixed, medium, dense	22	75%	4.4
333	mmm- mixed, medium, medium	22	50%	4.4
321	mls- mixed, large, sparse	32	25%	6.4
322	mld- mixed, large, dense	32	75%	6.4
323	mlm- mixed, large, medium	32	50%	6.4
400	r- riparian scrub/ shrub	2	75%	0.2
401	s- scrub/ shrub upland	2	25%	0.2
500	g- grass/ rush/ sedge riparian	0.5	75%	0.10
600	b- barren	0	100%	0
700	w- water	0	100%	0
800	d- developed	6.1	100%	0.6
850	c- pastures, cultivated, lawn	0	100%	0
870	o- orchard	3	75%	1
1000	wb- water flows under bridge	50	100%	0
605	nsdz within channel banks	0	100%	0
880	t- tidal marsh grass	0.8	75%	0.1
1001	wr- water flows under road, overpass, rr	15.2	100%	0.0
2000	wc- water flows under road, via culvert	10.0	100%	0.0
3000	hh- house / houses	6.1	50%	0.0
601	be- barren/ embankment	0.0	100%	0.0

[1]Overhang measures how far branches extend into the channel for a tree trunk growing at the channel edge. Similar to ½ crown.

Shade calculations for current conditions

Effective shade produced by current riparian vegetation was estimated using Ecology's Shade model (Ecology, 2003). Ecology's Shade model quantifies the solar radiation above and below the vegetation canopy and topographic features such as hills. It calculates effective shade as the reduction in solar radiation at the water surface.

The Middle Fork and mainstem Snoqualmie River was divided into 100-meter units using TTools to sample and process GIS data for input to both the Shade model and QUAL2Kw. Using the GIS vegetation coverages described above, the vegetation size and density in the riparian zone on the right and left bank was sampled from the coverages along the stream at 100-meter intervals. At each 100-meter location (inset Figure 26), vegetation type was sampled at nine 6.0-meter (20-ft) intervals from the streambank perpendicular to the stream aspect.

In addition to vegetation information, wetted width, channel width, stream aspect, stream elevation, and topographic shade angles to the west, south, and east were also gathered at each of the 100-meter locations. Manual changes to the wetted width were made in areas where in-channel islands made the width artificially high. Topographic shade angles were calculated using elevations from the 10-meter digital elevation model (DEM) layer, while stream channel centerline slopes were calculated from the 6-foot pixel LiDAR elevation data provided by the Puget Sound LiDAR Consortium. This allowed calculation of effective shade based on the geometry of the channel, vegetation, and solar position.

Effective shade values produced by the model compare extremely well with effective shade values collected in the field during the float survey.

Figure 27 shows model and field-collected effective shade values from the USFS boundary to the confluence with the Skykomish River. Solar pathfinder measurements were taken at transects located every 2 miles along the course of the river (Appendix E, Table E-2 canopy closure data from 2006 float survey). Solar pathfinder measurements matched up well with the model input values, producing a root mean square error of only 8%.

Hemiview pictures were taken at each water temperature monitoring location (Table E-5). Since water temperature monitoring locations are selected to be in a more shaded location to avoid direct solar radiation from hitting the thermistor, these values usually match up less well with model produced values. Hemiview shade values are usually a bit higher than model-generated shade values along the entire reach. In this case, Hemiview values matched very well with the model with a root mean square error of 11%.

Most effective shade values along the mainstem Snoqualmie River are less than 30%. An exception is the 75% shade value for the location at the base of Snoqualmie Falls. The falls provides topographic shading at that location.

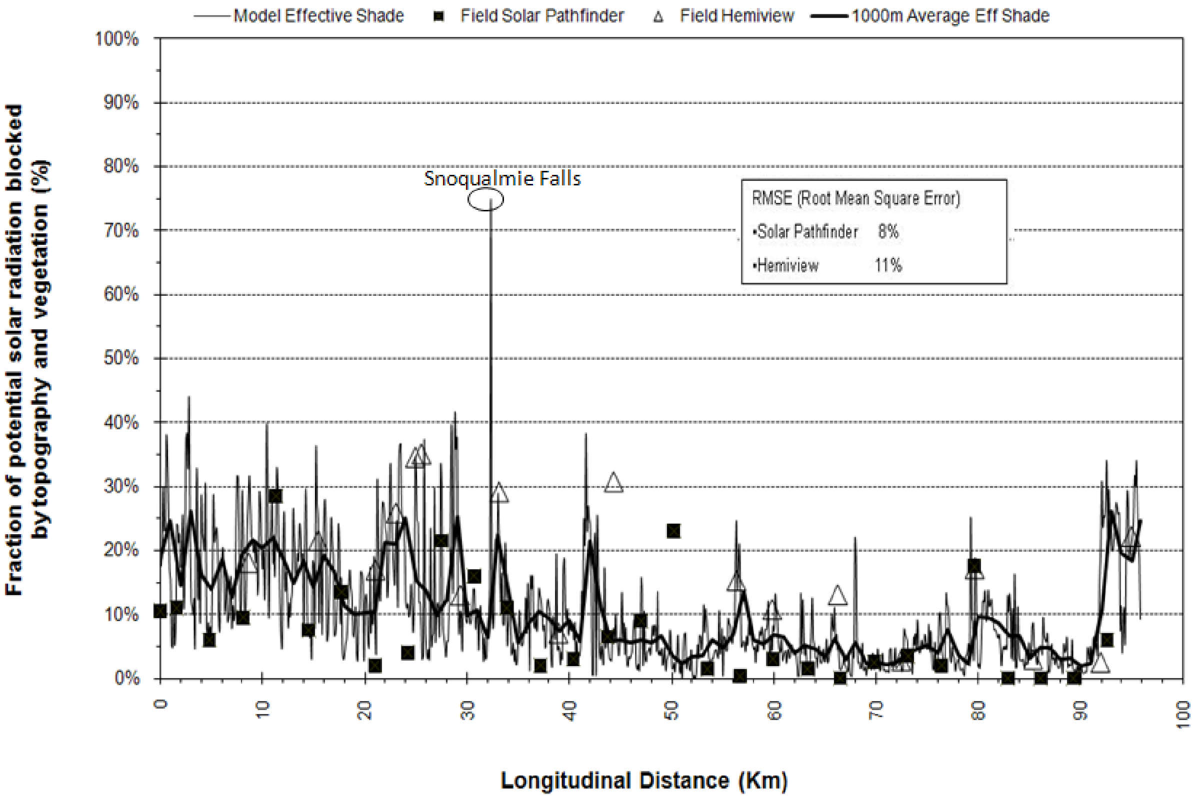

Figure 27. Field measured, Hemiview and Solar Pathfinder, and model generated effective shade values for the Snoqualmie River from the USFS boundary to the confluence with the Skykomish River.

Potential near-stream vegetation cover and effective shade

System-potential mature riparian vegetation that would naturally occur in the Snoqualmie River watershed was estimated using the GIS coverages and information described below.

- Washington State Department of Natural Resources (WDNR) soils polygon coverage (http://fortress.wa.gov/dnr/app1/dataweb/metadata/soils.htm) provides digitized soil delineations and soil attributes. Site index data – a designation of the quality of a forest site based on the height of the dominant and co-dominant tallest trees in a stand – is one of the polygon attributes in the WDNR soils coverage. For lands west of the Cascade mountain crest, the site index value is a height at age 50 years.
- The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) publishes soil surveys by county. Digital soil-survey data and a related Access database file that provide information on vegetation characteristics for each soil are provided in the Soil Survey Geographic (SSURGO) database for King and Snohomish Counties. For western Washington, estimated height at 100 years can be found in the publication text, and estimated height at 50 years can be found in the digital database.

- LiDAR data for King County gives heights of vegetation currently growing in the watershed.
- Historical documents.

The soils survey for King County (USDA, 1973) reports the most common trees growing on riparian soils in the Snoqualmie River basin are as follows:

> "Although the native stands of trees were primarily conifers, at least half the woodland is now deciduous. Douglas-fir is the dominant conifer; western hemlock and western red cedar grow in smaller but significant numbers. The dominant deciduous tree is red alder, and there are small stands of big leaf maple. Black cottonwoods grow near streams. Red alder commonly invades logged-off areas and becomes dominant unless intensive management is applied or unless soil conditions are unfavorable for its establishment."

Four scenarios of vegetation were considered for the Snoqualmie River mainstem and Middle Fork corridor. Figure 28 shows the percent effective shade produced by each of these scenarios. Topographic shading was held constant. Ultimately, option 3 was used in the load allocation section to represent the maximum riparian condition. Supporting data and analysis for these values are discussed below.

1. **Current vegetation.** Estimates for current vegetation were based on spatial data for height and canopy density.
2. **Maximum effective shade from 50-year-old riparian vegetation**. The height and density of trees for 50-year riparian vegetation was estimated based on the King County soil survey (USDA, 1973; USDA, 1992), the Snohomish County Soil Survey (USDA, 1983) and the WDNR soil polygon coverage. The 50-year riparian vegetation was assumed to be mixed conifer and deciduous species of height 120 feet (36.6 meters), canopy density 85%, and overhang (1/2 crown) of 7.3 meters, which was 20% of the tree height.
3. **Maximum effective shade from mature (100-year) riparian vegetation**. The height and density of trees for potential maximum riparian vegetation was estimated based on the description of the historically mixed deciduous and coniferous species in the flood plain and was assumed to be represented by an average tree height of 45 meters (about 150 feet), density of 85%, and overhang of 7.3 meters. The estimated characteristics were selected to represent a mid-range for mature vegetation from the values presented in the King and Snohomish County soil surveys. A separate soil analysis for the lower 20 miles of the river showed that 45 meters was also an appropriate maximum height for that portion of the river (Table 22).
4. **Maximum effective shade from mature (100-year) riparian vegetation with an assumption that vegetation growing from RM 2 to RM 12 will only reach 50-year potential height.** Historical records including General Land Office (GLO) maps from the late 1890s show that this region had numerous wetlands and more deciduous vegetation. This scenario is shown in Figure 28 as a dashed black line from kilometer 77 to 93.

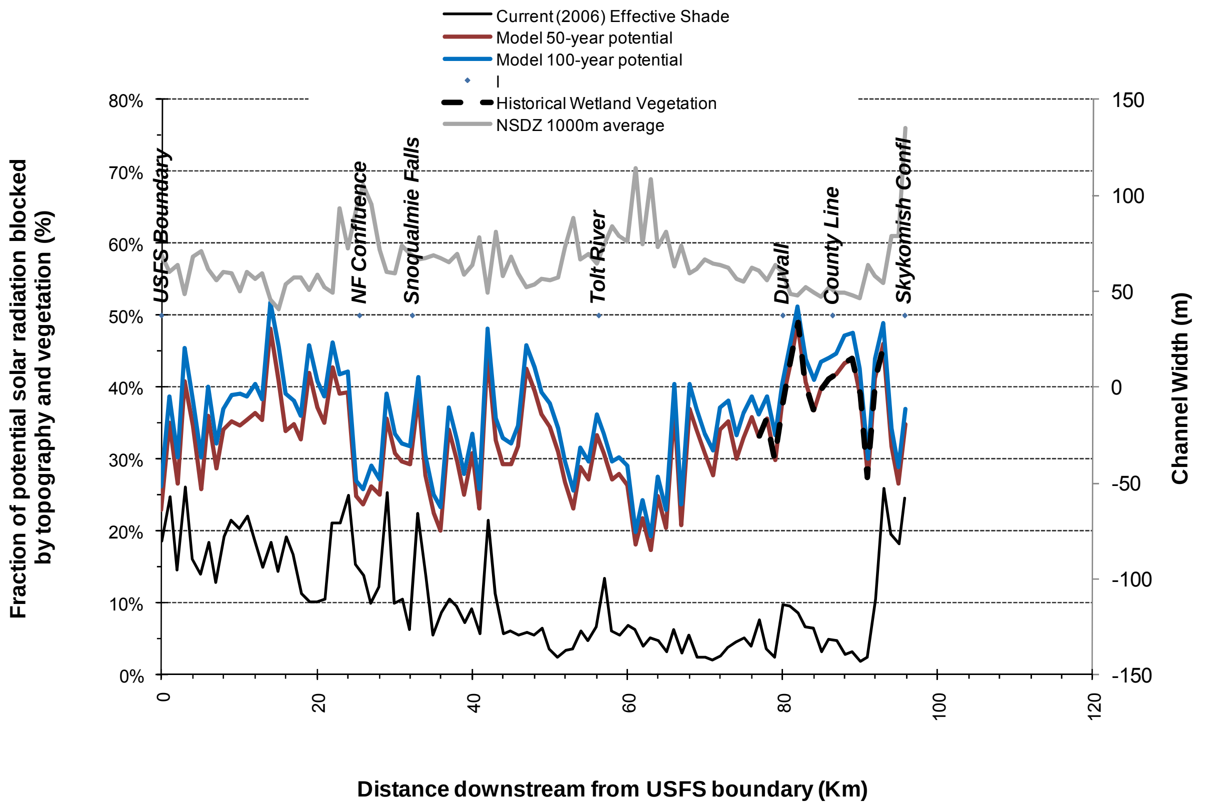

Figure 28. Effective shade from topography, current riparian vegetation, and potential mature vegetation in the Snoqualmie River basin.

Figure 28 shows that although the effective shade generated by the 100-year trees is greater, much of the potential shade is provided by the 50-year trees. Locations along the river where the active stream channel is wider (NSDZ) have a lesser amount of shade provided by mature vegetation. Although the quantity of shade provided by these scenarios is similar, since our Washington State criterion is the natural condition, the largest of these (scenario 3) was chosen to be used in the load allocation.

Some older texts discuss the presence of wetlands between river miles 2 and 12, but soils information indicates that larger trees grow in those locations if they are not limited by wet soils. Due to activities such as building of levees, much of that land is now drier for large portions of the year. In reality, implementation activities under both scenario 3 and 4 will be the same, and we will not need to decide until 50 years has passed, whether those trees will grow taller.

The remaining text in this section shows supportive data for the vegetation sizes and composition chosen for scenarios 2, 3, and 4.

Figure 29 shows the mean vegetation height that can be obtained after 50 years on soils in the Snoqualmie River basin. Since upland values look like they may be different from near-stream values, a GIS analysis looked at soils within 300 feet of the Middle Fork and mainstem Snoqualmie River channel. This analysis showed that near-stream conifers on those soils would average 122 feet (37.2 m) and have a maximum height of 135 feet in 50 years. Red alders would average 94.5 feet (28.8 m) in 50 years. Therefore, a mid-range value of 120 feet was used for the 50-year shade analysis.

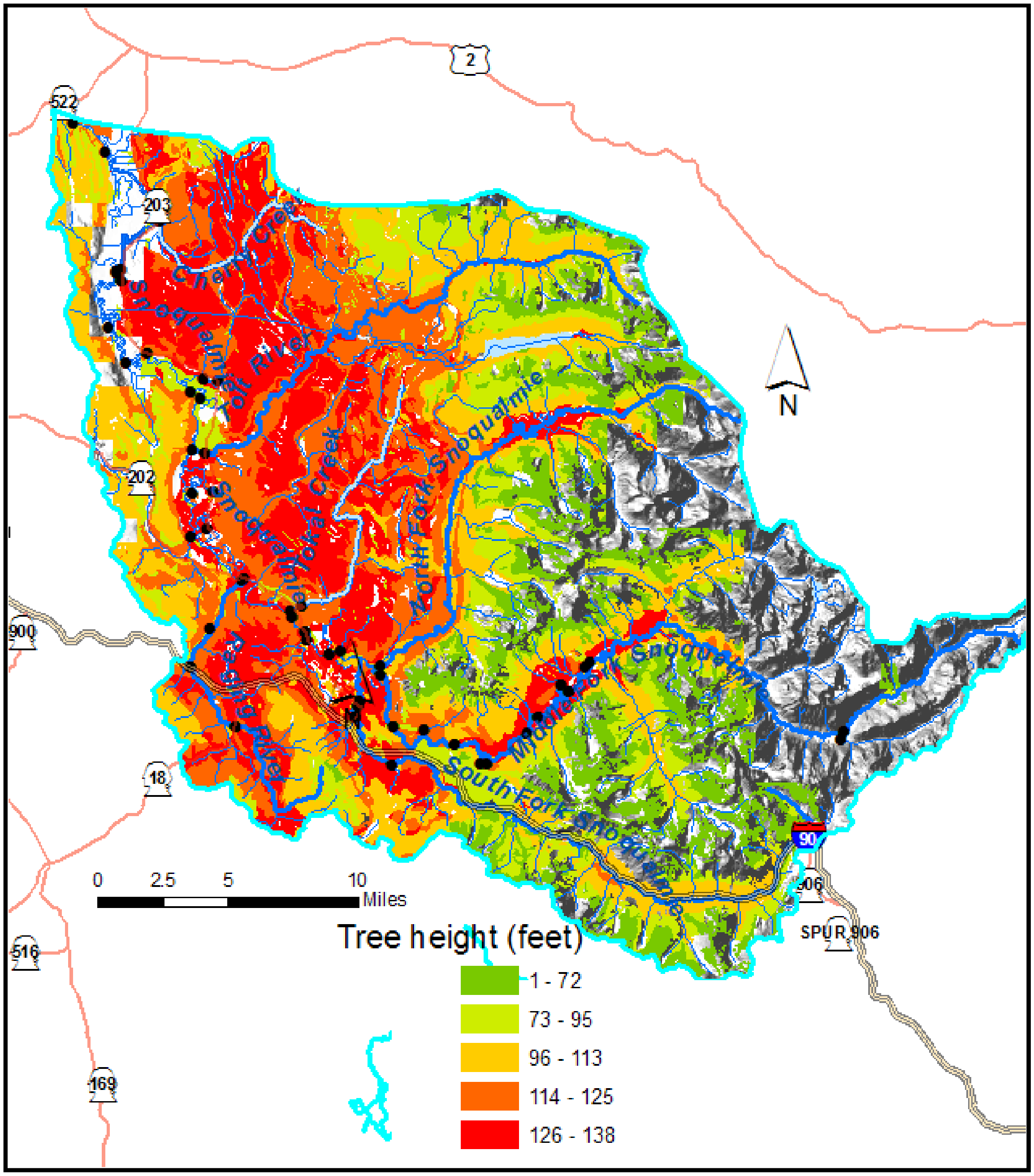

Figure 29. Soil site index 50-year height for first major tree species (DNR soils).

The WDNR coverage does not contain information for the lower section of the river from approximately RM 20 to the county line. Since some texts have discussed that wetlands were more prevalent in the lower watershed, a more detailed analysis using the county SSURGO data was done in this area. (Table 22)

Table 22. Soils from King County SSURGO for lower Snoqualmie River, RM 20 to county line.

Map Unit Symbol (Musym)	Soil name	Acres	% of area	100-year soil index	Wood-land group*	100-year height	Limiting factor
AgC	Alderwood gravelly sandy loam, 6 to 15 percent slopes	3.21	0.71	150	3d1	125-154	root depth
AgD	Alderwood gravelly sandy loam, 15 to 30 percent slopes	12.93	2.84	150	3d1	125-154	root depth
AkF	Alderwood and Kitsap soils, very steep	0.00	0.00	150	2d1	155-184	root depth
Br	Briscot silt loam	259.57	57.00	150	3w1	125-154	wet
Ma	Mixed alluvial land	2.67	0.59	184	2o1	155-184	no limit
Nk	Nooksack silt loam	38.29	8.41	184	2o1	155-184	no limit
Pc	Pilchuck loamy fine sand	41.89	9.20	150	2s1	155-184	sand
Pu	Puget silty clay loam	26.63	5.85	150	3w2	125-154	wet
Re	Renton silt loam	17.37	3.81	150	3w1	125-154	wet
So	Snohomish silt loam	4.82	1.06	150	3w2	125-154	wet
Su	Sultan silt loam	48.00	10.54	150	3w1	125-154	wet

* This woodland group code is for King County soils map units only.

The King and Snohomish County soil surveys estimate 100-year site index values of 120 feet (36.6 m) for red alder and 145-174 feet (44-53 meters) for Douglas fir (USDA, 1973; 1983). The lower river analysis from RM 20 to the county line shows a 100-year potential range of 125-184 feet (38-56 meters). A mid-range value of 150 feet (45 meters) was chosen as a reasonable system-potential height for the Snoqualmie. The neighboring Stillaguamish basin temperature TMDL used the same system-potential riparian values of 45 meters height and 85% density based on work by Pess et al. (1999) (Pelletier and Bilhimer, 2004).

Current vegetation heights from LiDAR and field data confirmed that 150 feet is a reasonable system-potential height for this watershed. Figure 30 shows the height of vegetation currently growing within 300 feet of the stream channel. Although there is much land with little shading vegetation, there are significant areas with trees in the 31-100 feet height category and lands with trees in the 101-150 feet category.

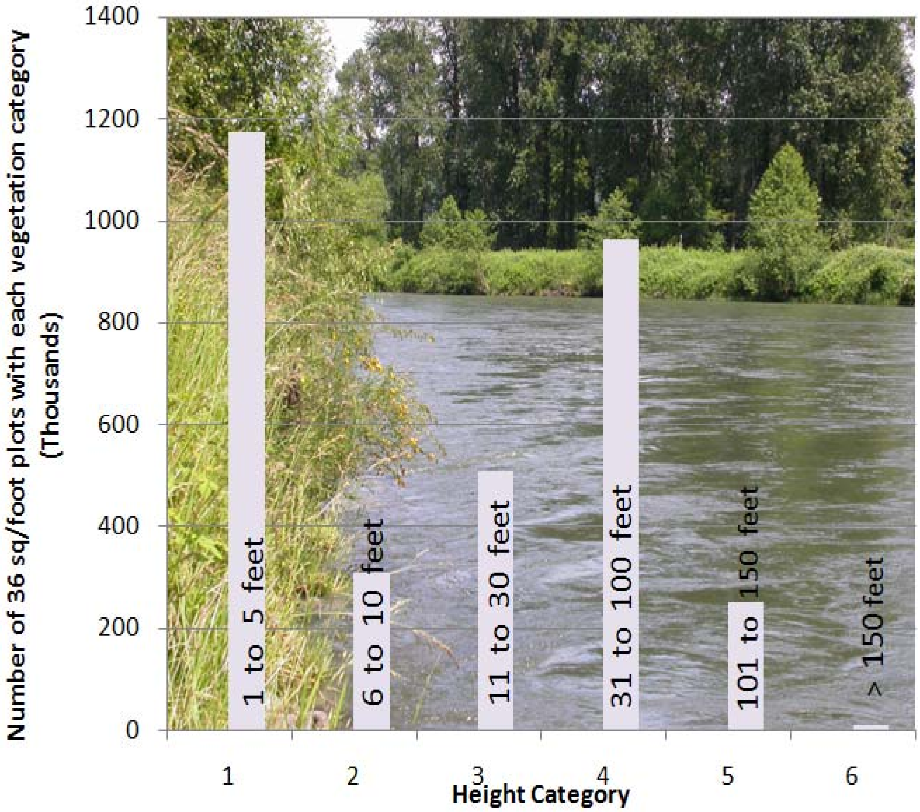

Figure 30. Height of vegetation currently growing within 300 feet of the stream channel.

Source: LiDAR survey data, year 2000.
Photo near station 07SNO22.8, Snoqualmie R. at Farm Road near Carnation.

Some temperature studies have included a scenario that calculates expected shade from vegetation growing on the bank of a narrower width channel. In many cases, channel width reduction is expected to occur as riparian restoration and associated channel recovery take place. In the case of the Snoqualmie mainstem and Middle Fork, a reduction in channel width is not expected as riparian growth takes place. The presence of levees and other bank hardening has artificially restrained the channel. Smaller tributaries that have fewer artificial restrictions are more likely to see channel recovery as riparian restoration takes place. See the *Hydrogeology* section under Watershed Description in this report.

Calibration and confirmation of the QUAL2Kw model

Calibration and confirmation time periods were selected using annual peaks in the 7-day average of daily maximum temperatures and times of intensive instream data collection in 2005 and 2006. Figure 31 shows the 2006 and 2005 streamflow and water temperature patterns for July through September and the calibration and confirmation periods selected.

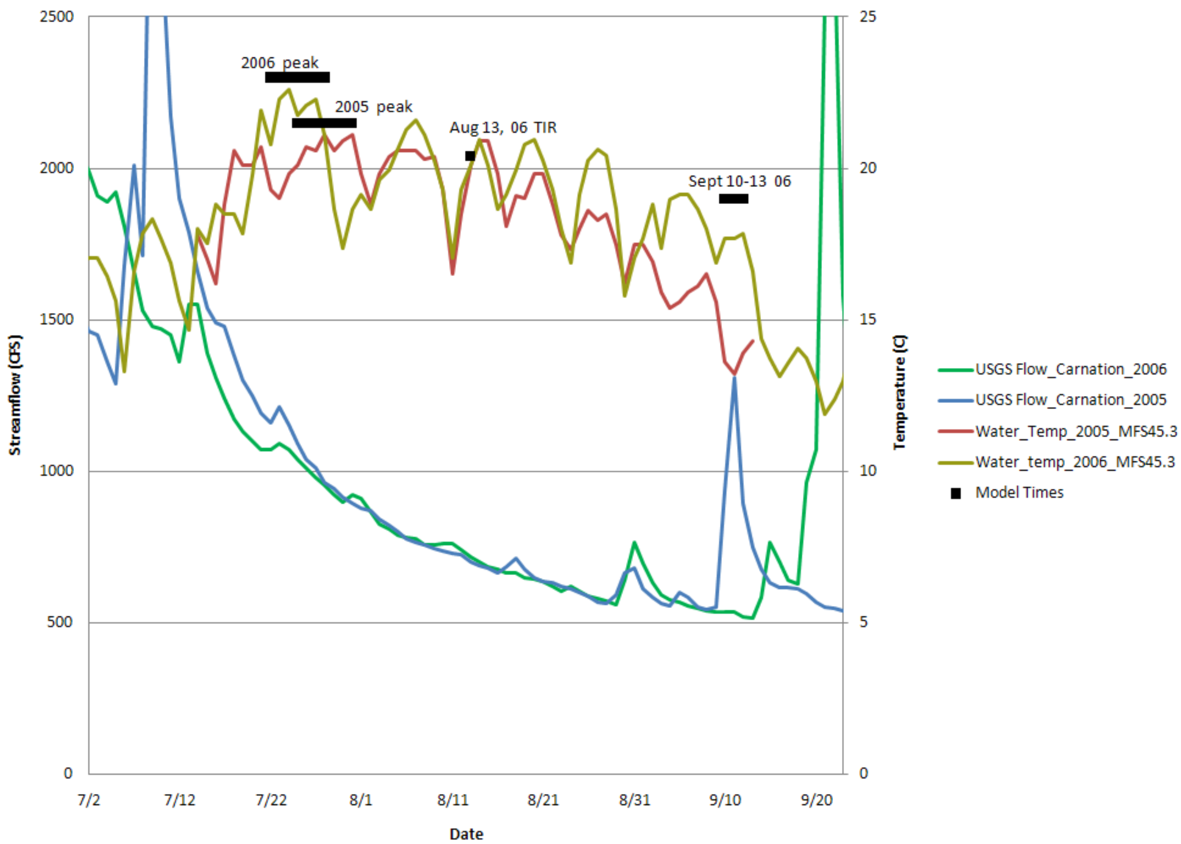

Figure 31. Streamflow at the USGS Carnation long-term gauging site and water temperature (7-day average of daily maximum) at station MFS45.3 (07D150) for 2005 and 2006, including the dates selected for calibration and confirmation of the QUAL2Kw model.

Three time periods were used for calibration of the QUAL2Kw model. The week of July 22-28 2006 was used with just one-half of the available instream temperature data points. This week was the hottest week in 2006. August 13, the time of the thermal infrared flight (TIR), was used as a second calibration period. September 10-13, the time of a travel-time dye study, flow survey, and cross-section survey, was used as the third calibration period.

Confirmation was performed by holding all parameters constant and just updating to measured values of flow, point source (tributary) temperature, and weather for the confirmation period.

Two confirmation model runs were performed.

- The first confirmation was done by using the remaining one-half data points to the July 22-28, 2006 period. This method is described in the National Research Council (2007) as "*The calibration step can be linked with a "validation" step where a portion of the observations are used to calibrate the model, and then the calibrated model is run and results compared with the other portion of the data to "validate" the model.*"
- The second confirmation was done for July 25-31, 2005, which was the hottest week in 2005.

The QUAL2Kw model covers the Middle Fork and mainstem Snoqualmie River with the from the USFS boundary to an end point at the confluence with the Skykomish River. When discussing model results, the term headwaters refers to water entering the Middle Fork at the USFS boundary. The detailed model network with reach and point source locations can be found in Appendix C.

QUAL2Kw Temperature Model Calibration Input Parameters

Hydraulics

Manning's equation was used to describe hydraulic and transport properties within the Middle Fork and mainstem Snoqualmie River. Manning's n values could be developed for most of the watershed using continuous wetted width from high-quality orthophotos, cross-sectional area from current and past field surveys, stream slope from LiDAR, and streamflow from a combination of instantaneous measurements and continuous gages.

Travel-time dye studies were available to confirm model travel-time estimates generated through the use of the Manning's equation and geometry measurements. Figures 32 and 33 show that model-generated travel time is comparable to field-collected travel-time data.

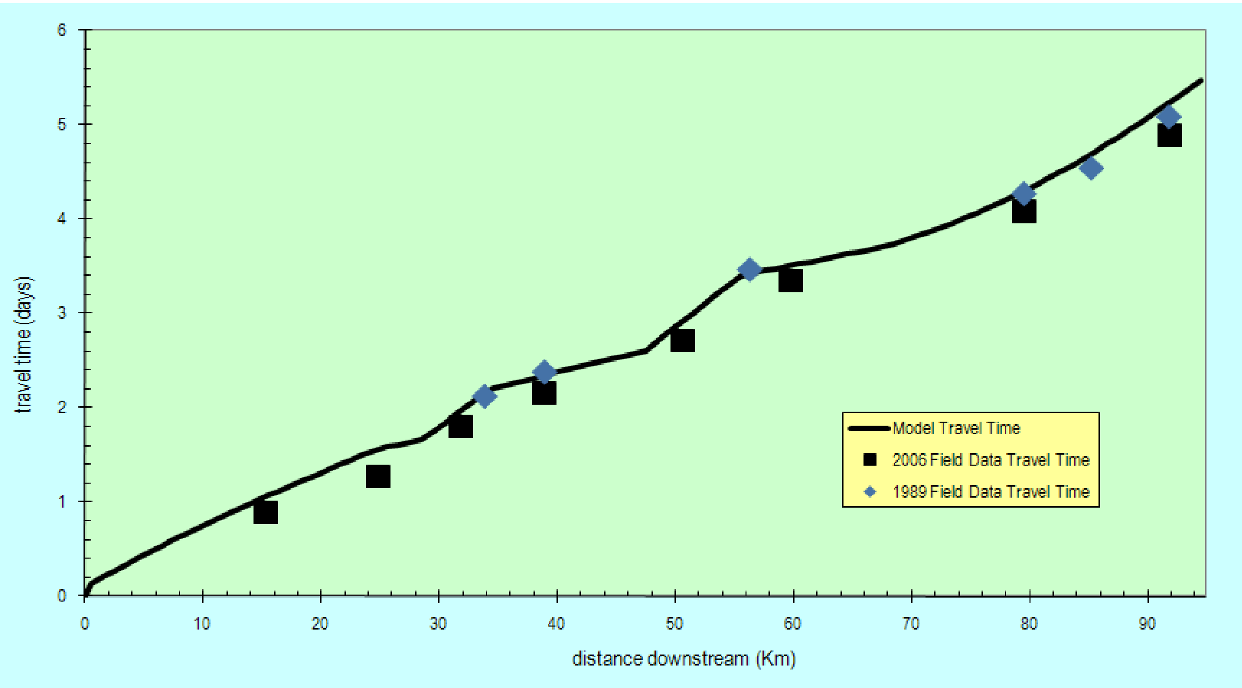

Figure 32. Model travel time vs. field-dye-study travel time for August 13, 2006.

Field data points are Aug 14-18 2006 (flow 665 cfs) and Sept. 1991 (flow 608 cfs) (Joy et al., 1991).

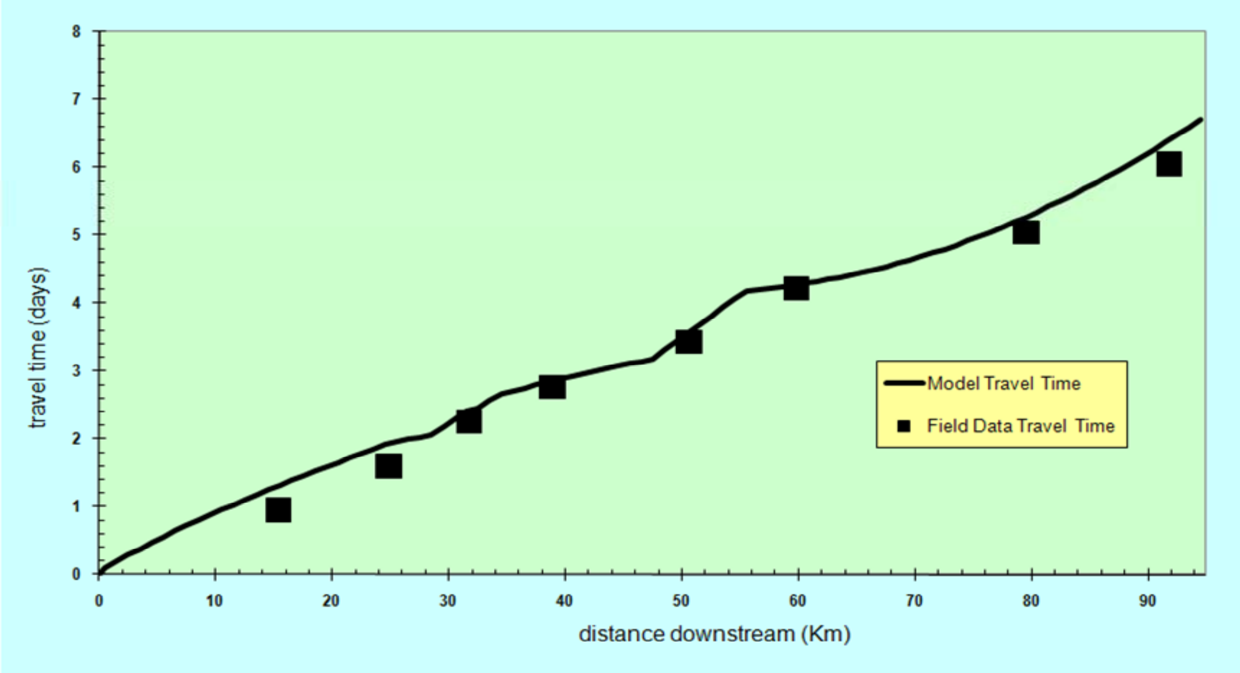

Figure 33. Model travel time vs. field-dye-study travel time for September 11, 2006.

Tributary inputs and other point sources

Tributaries are represented as point sources that enter the Middle Fork or mainstem Snoqualmie River. Tributary inflows were measured during synoptic surveys that took place at the same time as the July and August modeling. For September, major tributary flow is calculated from gages, and minor tributary flow was assumed to be equal to those measured in August. Tributary mouth temperatures were monitored continuously in 2006. Because WWTP effluent rates are small compared to river discharge, they were not modeled explicitly. See *Wasteload Allocations* for how WWTPs are handled.

Diffuse sources

For flow regimes other than the synoptic surveys, the diffuse inflows (from groundwater, seeps, or intermittent streams) were calculated by difference from discharges measured at the USGS mainstem gages, minus tributary flow. Diffuse inflow temperatures were assigned a value of 14°C for locations in the Middle Fork Snoqualmie upstream from the confluence with the North Fork. Diffuse inputs to the mainstem Snoqualmie River downstream of the confluence with the North Fork (approximately RM 45) were assigned a value of 14.5°C. Modeling began with a value of 14ºC for all locations and was calibrated to the final values.

Headwater

Station 07MFS60.4 had a water thermistor deployed continuously during all 2006 calibration time periods. Headwater flow was measured three times during the summer. Actual flow was used for the July and August runs. Flow for the September run was estimated from the USGS gage at RM 55.6 by assuming that the headwater-flow to gage-flow ratio was the same as in August.

Reach thermal properties

QUAL2Kw guidance was used to select default values for sediment thermal properties. Large rivers, such as the Snoqualmie, are generally influenced less by hyporheic exchange and sediment properties than are smaller, shallow rivers with lower flow. Therefore, default values for all sediment thermal properties were chosen. Sediment thermal conductivity was set to 1.6 W/m-°C, sediment thermal diffusivity was set to 0.0064 cm^2/s, and sediment thickness was set to 10 cm.

Hyporheic exchange flow, which is the proportion of surface discharge exchanged with the hyporheic zone within a simulation reach, was set to 5%. Hyporheic sediment porosity was set to 40% as a value typical of cobble, sand, silt systems.

Meteorology

As described earlier, for the calibration period, the Ecology weather station WEA10.0 at Duvall was used for the air temperature model input values. Relative humidity values measured at the near-stream station 07SNO39.8 were used to model relative humidity for the model network.

Wind speed values collected at the Duvall weather station were averaged for each calibration period. Cloud cover was set to 10% for July, August, and September.

Calibration methods

The goodness of fit for both calibration and confirmation periods was summarized using the root mean square error (RMSE), as a measure of the deviation of model-predicted stream temperature from the measured values. The RMSE represents an estimation of the overall model performance and was calculated as:

$$RMSE = \sqrt{\frac{\Sigma(T_{measured} - T_{predicted})^2}{n}}$$

The parameters varied to improve the RMSE of the calibration runs include the temperature of diffuse inputs and the grouping of cross-section data to use in the depth calculation. Diffuse inputs include gains from groundwater and from any small unmonitored tributaries. Modeling began with a typical temperature of 14ºC. Final calibrated values were 14ºC and 14.5ºC depending on location in the watershed. Cross-section groupings were tested to see which produced channel widths, depths, and travel times that were closest to those measured in the field.

QUAL2Kw Temperature Model Confirmation Input Parameters

Hydraulics

No changes were made to channel geometry characteristics. The correct measured flow for the confirmation period was used to recalculate Manning's n for that flow condition.

Tributary inputs (QUAL2Kw refers to these as point sources)

Measured 2005 streamflow was available for the North Fork, South Fork, Tolt, and Raging Rivers and for the USGS gages on the mainstem Snoqualmie. For tributaries with no measured 2005 flow, values for the July 22-28, 2006 synoptic survey were used. Use of the 2006 tributary measurements were determined to be a valid substitute since the flow conditions for these time periods were very similar. The average daily 7-day flow at Carnation 1214900 was 979.7 cfs during July 25-31, 2005 and 1030 cfs in July 22-28, 2006.

Water temperatures for 2005 were available for most large tributaries. The actual recorded 7-day averages were used where available. Thermistors were installed a few days after the 2005 peak for some tributaries. For these tributaries with partial data records, temperature for the peak period was estimated. For very small unmonitored tributaries, the same temperature as measured in 2006 was used since these contribute little heat load.

Diffuse sources

No changes to groundwater or seep temperature were used in the confirmation runs. Diffuse inflows were calculated by difference from discharges measured at the USGS mainstem gages minus tributary flow.

Headwater

Headwater flow for 2005 was estimated based on the measured flow for July 25-31, 2005 at the USGS gage at RM 55.6 minus the expected diffuse flow gain between that gage and the headwater. Hourly headwater temperature was reduced by 1.21°C from the 2006 record. The average hourly temperature difference between the 2006 and 2005 critical weeks measured at station MFS45.3 was 1.21°C. Station MFS45.3 was the closest site to the headwater that was monitored in both 2005 and 2006.

Meteorology

Air temperature, dewpoint temperature, and wind speed were updated to 2005 conditions for the 2005 confirmation period. All other meteorological parameters, e.g., cloud cover, were held constant. Although near-stream air temperature was not monitored in 2006, air temperature at the Snoqualmie Falls (NWS) site was available for both 2005 and 2006.

Air temperature recorded at Snoqualmie Falls during the confirmation time, July 25-31 2005, was similar to that recorded during August 6-8, 2006. Therefore the meteorological data for August 6-8, 2006 was used to represent conditions for 2005. This allowed us to use the same weather stations, 07WEA10 and 07SNO39.8, for all modeling runs. Meteorological data for August 6-8, 2006 was also used to represent the 50th-percentile weather condition.

Shade

Shade and vegetation were held constant.

QUAL2Kw model calibration and confirmation results

Table 23 shows the RMSE for both the calibrated and confirmed temperature model runs. RMSE values near 0.5ºC are reported for both the daily maximum temperature and the combined daily minimum and maximum values, indicating that the model describes the temperature regime of the Snoqualmie River well.

Table 23. Summary of RMSE of differences between the predicted and observed daily maximum and minimum temperatures in the Middle Fork and mainstem Snoqualmie River.

Statistic	RMSE (deg C) Model Calibration		RMSE (deg C) Model Confirmation	
Total (max+min)	0.59	July 22-28, 2006 (using ½ data points)	0.41	July 22-28, 2006 (with other 1/2 data points)
Maximum	0.50		0.28	
Total (max+min)	0.63	August 13, 2006 (one day-TIR)	- -	- -
Maximum	0.69		- -	- -
Total (max+min)	0.45	September 10-12	- -	- -
Maximum	0.38		- -	- -
Total (max+min)		--	0.45	July 25-31, 2005
Maximum			0.52	

TIR: Thermal infrared flight.

The July 22-28, 2006 run shown in Figure 34 is a 7-day climate and 7-day water temperature run which is the preferred model scenario. However, if there are large changes in streamflow or weather during the desired 7-day model period, a shorter timeframe becomes necessary.

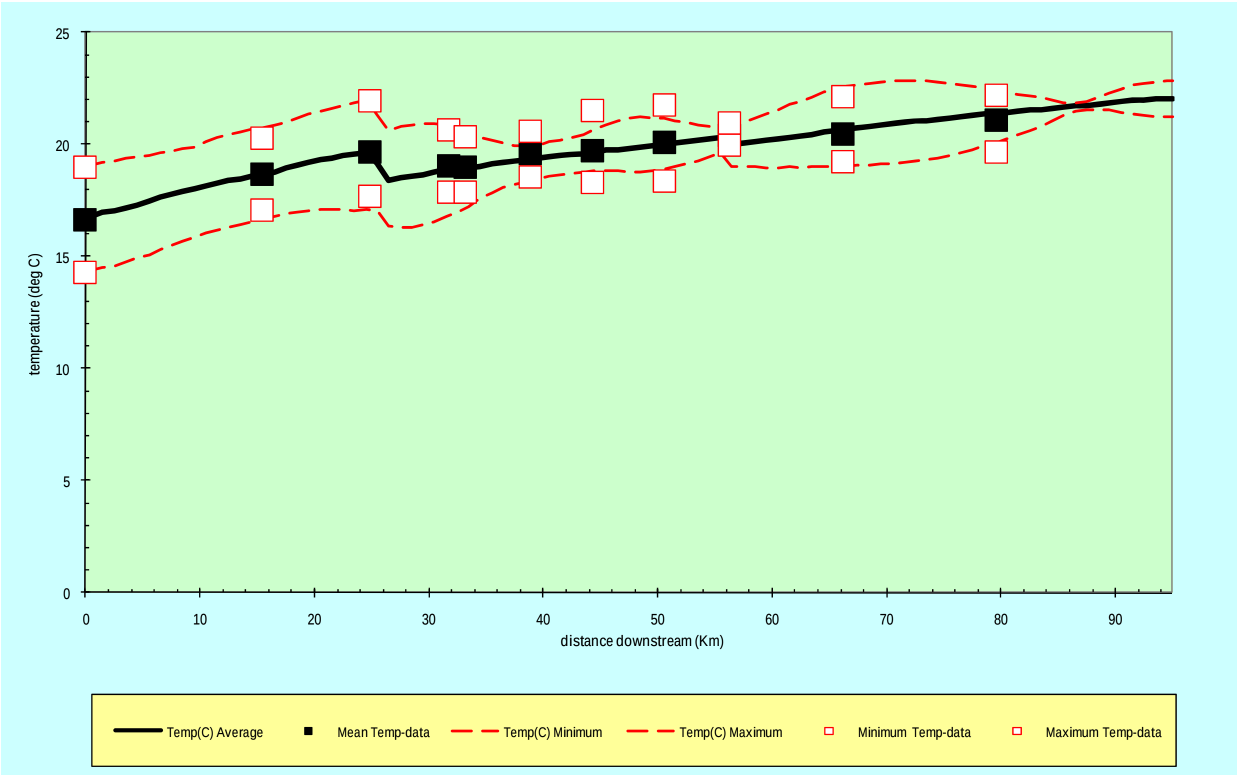

Figure 34. QUAL2Kw for critical 7-day period, July 22 to 28, 2006, with data points used for calibration (appx. half).

The August 13 run (Figure 35) uses climate data from the period August 10-16, 2006 to get a best estimate of water temperature for the day of the thermal infrared flight. The modeled temperatures match the thermistor measurements well. The discrepancies with the thermal infrared flight data can be explained by travel times in large rivers such as the Snoqualmie causing day-to-day variations over the 7-day data input period. In addition the flight took place at two times, one in early afternoon (2 pm) until an equipment malfunction, and the second in the early evening (5 pm) closer to the time of the daily maximum water temperature. In all cases, the thermal infrared flight data fall near the daily maximum and above the daily mean temperature, consistent with expected time-of-day patterns.

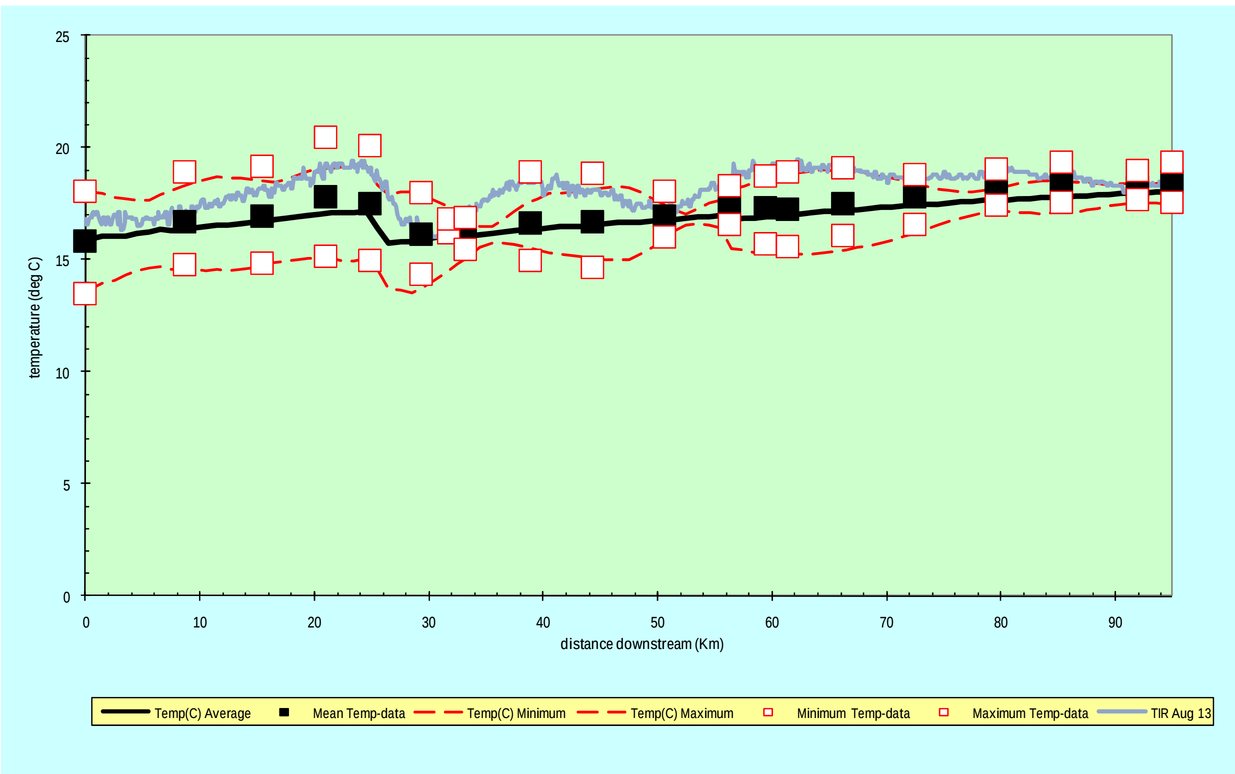

Figure 35. QUAL2Kw for August 13, 2006 (date of the thermal infrared flight) used for calibration.

The September model run (Figure 36) is a 3-day climate and 3-day water temperature run. A 7-day run works better for prediction, but it is also important to have a fairly constant weather condition over the days being modeled. The September period was chosen because a travel-time dye study and additional mainstem streamflow data were collected during that time. A 7-day run would have been performed, but September 9 was exceptionally cool as compared to September 10, 11, and 12, and a large rain storm occurred late on September 13 and 14.

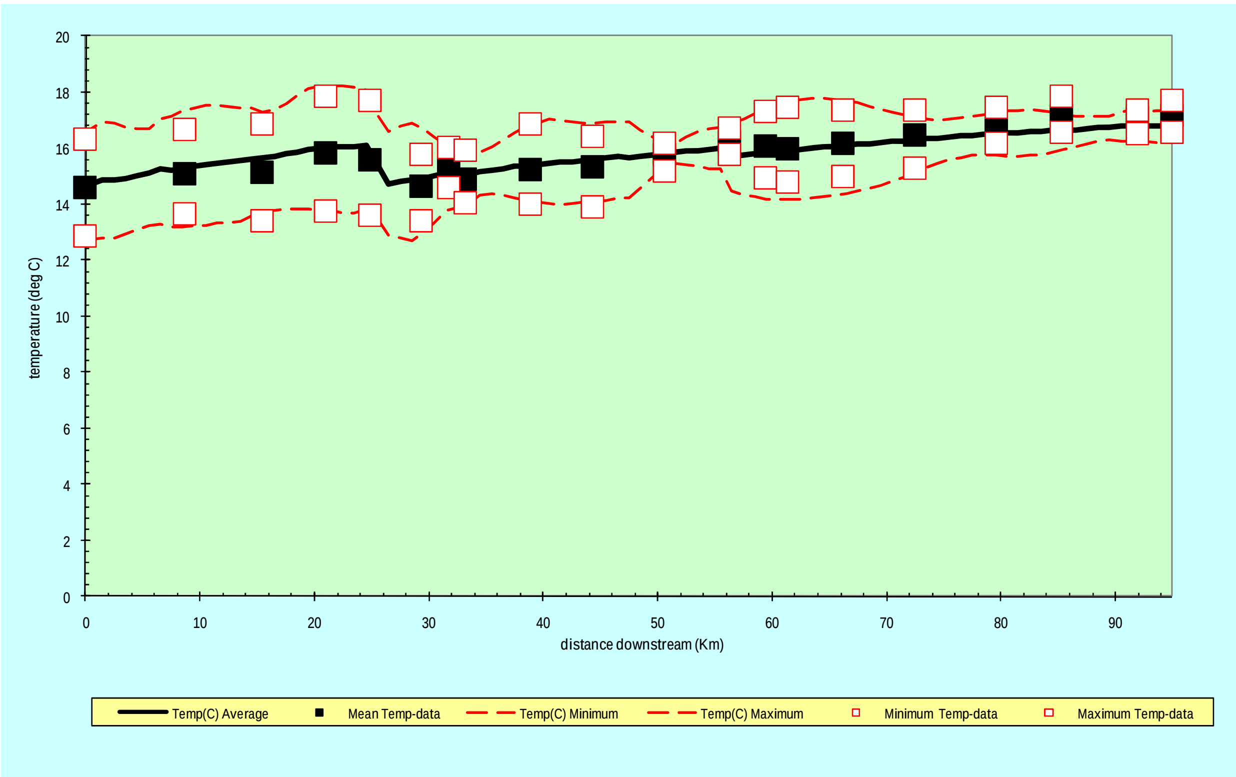

Figure 36. QUAL2Kw for September 10 to 12, 2006 used for calibration.

Figures 37 and 38 show the model-predicted and field-measured maximum, mean, and minimum water temperature profiles for the confirmation periods for the mainstem and Middle Fork Snoqualmie River.

The July 22-28, 2006 run shown in Figure 37 is the identical model run as shown in Figure 34, but with the confirmation data displayed. This second half of the data were not used during the calibration analysis and are used here to confirm the model fitness.

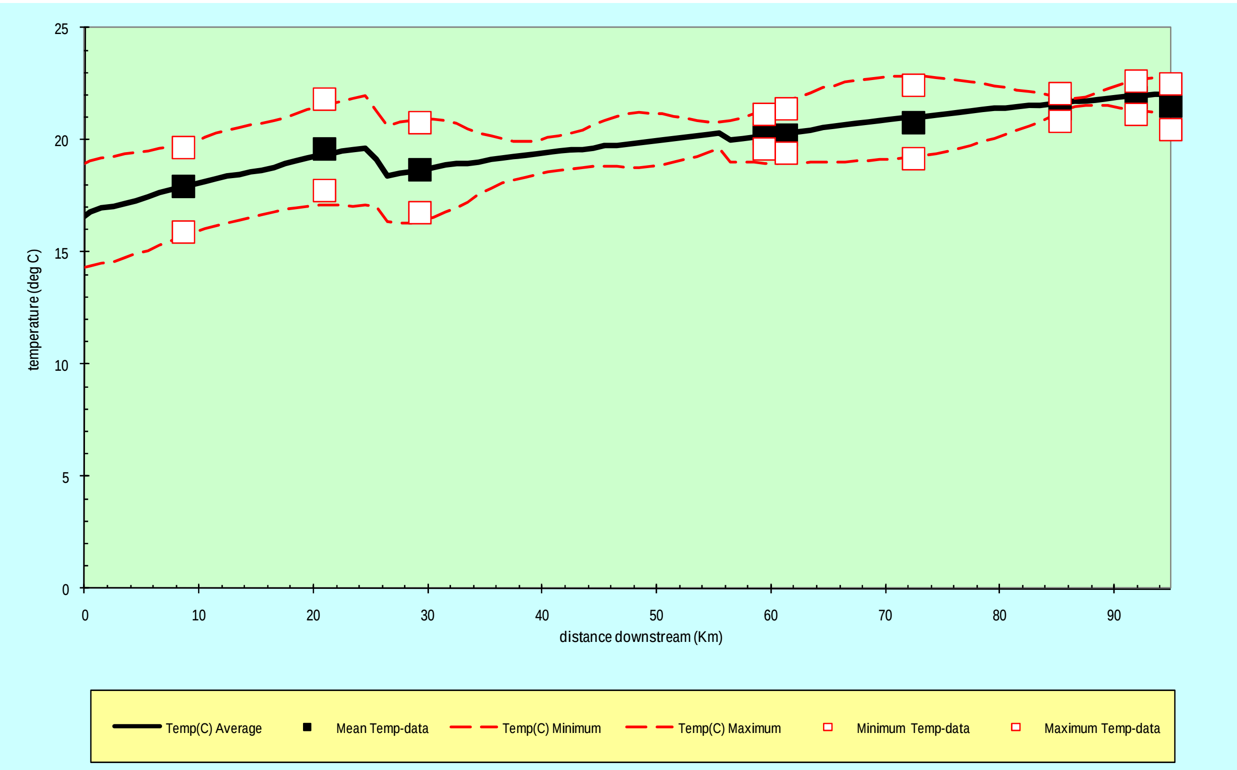

Figure 37. QUAL2Kw for critical 7-day period July 22 to 28, 2006 with data points used for confirmation (other half).

The July 2005 run (Figure 38) was a 7-day climate and 7-day water temperature run during a time of constant flow and temperature. This model looked at July 25- 31, 2005, which was also the hottest week for that year. After completing the modeling exercise, when graphing the field measured data for comparison, we realized that only three of the mainstem data monitors were installed in time to monitor the 7-day high temperature. The 2005 data were collected under a previous study and included tributary mouth temperatures.

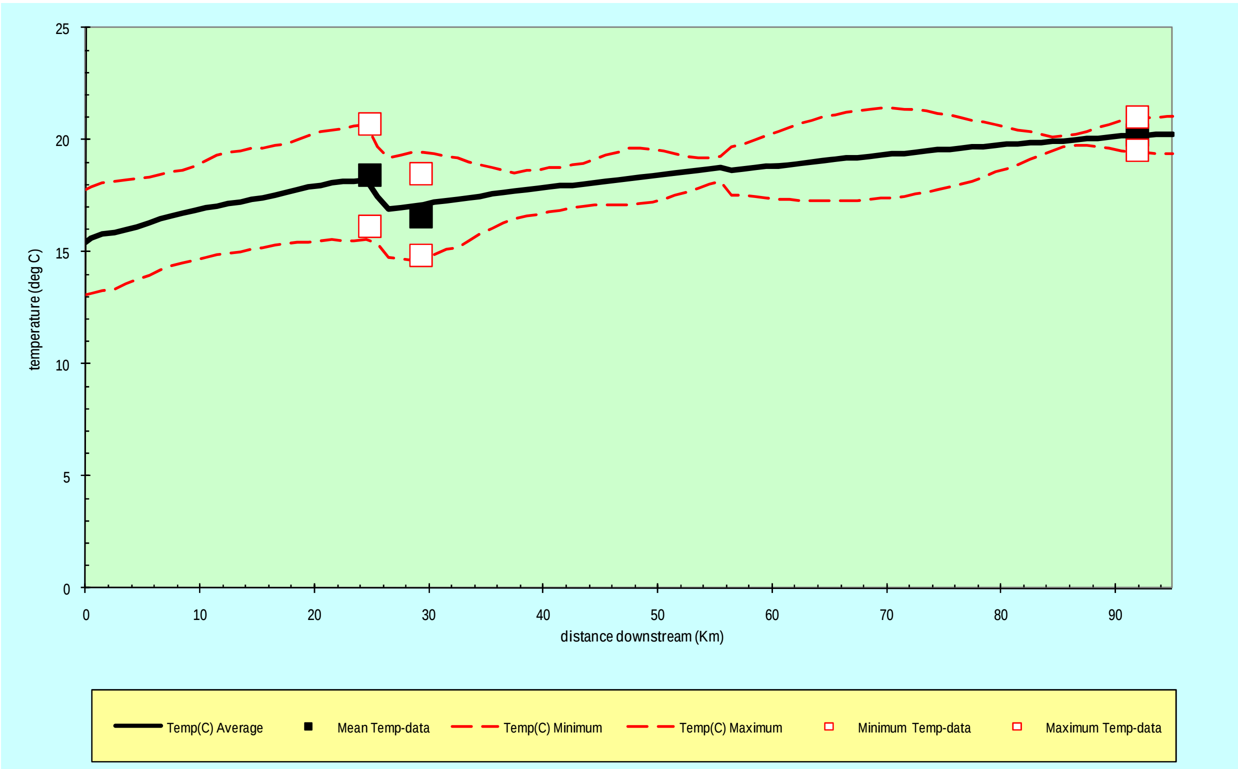

Figure 38. QUAL2Kw for July 2005 confirmation.

Calibration and confirmation graphs show model-predicted and field-measured water temperatures are similar. There is no evidence of systematic over- or under-predicting of temperature. There also is no evidence that there is a trend in error over the length of the river. The average RMSE for calibration runs was 0.52ºC for the maximum temperatures and 0.56ºC for the combined minimum and maximum temperatures. The average RMSE for confirmation runs was 0.45ºC for the maximum temperatures and 0.46ºC for the combined minimum and maximum temperatures. RMSE less than 1.0ºC are considered sufficient for temperature TMDL modeling. RMSE near 0.5ºC are considered excellent results.

Therefore, the model produces results of a quality adequate to predict water temperature for establishing load and wasteload allocations for this TMDL.

TMDL Determination

Loading capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water can receive without violating water quality standards" (40 CFR § 130.2(f)).

This TMDL uses the modeled system-potential temperature as an approximation of the natural temperature *during critical high air temperatures and low-flow conditions.* TMDL load allocations are supposed to be set for the critical condition in order to be protective of the stream during the rest of the year. The modeled system-potential condition uses best estimates of potential mature riparian vegetation and riparian microclimate. The TMDL design condition is the system-potential condition with "minimized human disturbance". The human modifications that affect the system include the Snoqualmie Falls dam located at RM 40, the modified channel morphology, and the riparian areas affected by the presence of dikes and levees in the lower Snoqualmie watershed.

The calibrated QUAL2Kw model was used to determine the loading capacity in the mainstem and Middle Fork Snoqualmie River. Loading capacity was determined based on prediction of water temperatures under low-flow (July-August 7Q10) and extreme climate (90^{th} percentile) conditions combined with a range of effective shade conditions. The QUAL2Kw model was also used to look at the typical low-flow (July-August 7Q2) and climate (50^{th} percentile) condition that would occur every other year.

The 7Q2 flow water balance was constructed using the long-term values shown in Table 24. These values are discussed further in the *Low Flow Statistics* section. A comparison between 7Q2 flows from gaged major tributaries with measured flow on August 16, 2006 showed virtually identical values. For example, the South Fork 7Q2 flow was 136 cfs, and the measured August 2006 seepage run flow was 141 cfs. Therefore measured August 2006 tributary flow was used for the 7Q2 condition. Diffuse gains and losses were then recalculated by subtracting tributary flows from mainstem and Middle Fork 7Q2 flows. A USGS travel-time dye study in 1991 (Table 24) at flows comparable to the 7Q2 condition could be used to confirm travel times calculated by the model.

The historical July/August 7Q10 low-flow condition was very similar to the flow quantities measured in September 2006 (Table 24). However, it was also found that for gaged major tributaries and mainstem sites that the 7Q10 flow values could be closely approximated by multiplying the 7Q2 flows by a factor of 0.7. For simplicity and ease of understanding, the 7Q10 condition was approximated by multiplying 7Q2 mainstem, tributary, and diffuse flows by a factor of 0.7. Values for the actual 7Q10, the modeled 7Q10, and for September 2006 are reported in Table 24 for comparison. Since flows were similar, the channel geometry relationships developed for September 2006 are valid for the 7Q10 model run.

Table 24. Loading capacity low flow data (all values in cfs.).

USGS gage number	Description	Dates	Rank based July/August		7Q10 in model = 7Q2 x .7	7Q2 in model	1991 USGS seepage and travel time similar to 7Q2.	Sept 11-13 2006 Ecology measured flow
			7Q10	7Q2				
12149000	Carnation	1961-2008	535	766	536	766	798	522
12144500	Snoqualmie	1961-2008	368	501	350	501	534	318
12141300	Middle Fork	1961-2008	152	229	160	229	--	138
12144000	SF at North Bend	1961-2008	101	136	98.7	141	132	101

Air temperatures associated with the critical flow conditions were assumed to be represented by the July 22-26, 2006 week corresponding to the historic 90th percentile air temperature condition at the Snoqualmie Falls and North Bend Fire (RAWS) meteorological stations.

Air temperatures for the 50th percentile condition were represented by conditions measured during July 25-31, 2005. As discussed in the *Meteorology/Climate Data* section and the *Model Confirmation Parameter* section, this week was a 45th percentile condition, but for the purposes of this study was determined to be sufficient to represent a typical median year.

Model scenarios for the TMDL determination

A series of scenarios that are expected to reduce the Snoqualmie River water temperature was evaluated as follows:

- **Maximum potential shade**. This scenario would be provided by 180-ft wide buffers of system-potential mature (100-year) riparian vegetation along the Middle Fork and Snoqualmie mainstem.
- **Maximum potential shade minus areas with levees.** This scenario used a GIS coverage of levees and revetments (rip-rap) from King County and assumed that the riparian areas with levees do not have vegetation. Seven locations were designated as levee areas on the mainstem or Middle Fork of the Snoqualmie River. Locations designated as revetments could contain vegetation in the adjacent riparian area and were therefore modeled as containing mature riparian vegetation. Note: Currently most of these levee areas contain vegetation, but some proposed regulations may require the vegetation be removed.
- **Reduced headwater and tributary temperatures.** A scenario was evaluated with the assumption that the inflowing headwaters and tributaries did not exceed the water quality numeric criteria of 16°C or 17.5°C. The tributaries to the Middle Fork that currently deliver water cooler than the numeric criteria were held to current conditions. Headwater temperatures as measured at the USFS boundary currently exceed 16°C for just part of the 24-hour period. Hours that are currently cooler than 16°C were held to temperatures measured in July 2006, for the critical condition, and July 2005 for the median condition. The remaining hours were set to 16°C.
- **Microclimate improvements.** Increases in vegetation height, density, and riparian zone width are expected to result in localized decreases in air temperature. To evaluate the effect

of this potential change in microclimate on water temperature, all hourly air temperatures along the Middle Fork and Snoqualmie mainstem were reduced by 2ºC based on the summary of literature presented by Bartholow (2000). Because much of the Snoqualmie River is wide compared to the area of riparian overhang, this may or may not be a valid expected improvement. A second scenario, for the 7Q2 condition only, was performed by reducing the maximum daily temperature by 2ºC, keeping the daily minimum the same, and scaling the reduction for the remaining hours.

Some TMDL reports have included a scenario evaluating expected temperature changes due to channel width reduction brought about as a result of near-stream revegetation and restoration. Channel width reduction is not expected to occur in the Middle Fork or Snoqualmie mainstem because of extensive bank hardening (i.e., riprap) and fewer levees. Channel width reduction could occur in smaller tributaries. See further discussion in the *Hydrogeology* section.

Additional model scenarios were performed at the request of the Snoqualmie Temperature TMDL Advisory Group. These were:

- **Narrower buffer of trees.** Riparian shade was recalculated using a 79-foot wide buffer of system-potential vegetation instead of the original 180 feet. A maximum density of 81% was used for the 79-foot buffer, instead of the 85% used for the wider buffer. There is assumed to be no microclimate effect with the narrower buffer. Evaluation of a 75-foot buffer was requested, but model configuration made it much simpler to instead evaluate a 79-foot buffer.

- **Further reduction of tributary temperatures to 1°C below criteria.** This scenario further reduced the temperature of inflowing headwaters (as measured at the Middle Fork USFS boundary) and tributaries. Instead of the reduction to the water quality numeric criteria of 16°C or 17.5°C above, the streams in this scenario did not exceed 15°C or 16.5°C.

Results of the model runs for critical conditions are presented in Table 25 and Figure 39. Results of the model runs for typical conditions are presented in Table 26 and figure 40. To best approximate the natural condition, the scenario used as the final loading capacity is that with 100-year mature vegetation, 180-foot buffers, tributaries at the numeric water quality criteria and with microclimate effects.

Table 25. Summary of predicted 7-DADMax water temperatures at critical flow (7Q10) and meteorological (90th percentile) conditions during July and August in the Snoqualmie River (all values in °C).

Scenario	Average maximum			
	All reaches	USFS boundary to Snoqualmie Falls	Falls to Tolt	Tolt to Skykomish
Current condition	22.8	21.8	22.3	24.0
Mature riparian veg – no vegetation on levees	21.0	20.4	20.8	21.8
Mature riparian veg – levees have trees	20.9	20.3	20.6	21.6
Tributaries at WQS (unless currently cooler)	20.4	19.6	20.2	21.3
Microclimate (minus 2°C hourly air temperature)	20.0	19.3	19.8	20.6
Mature riparian veg 79-foot buffer	21.3	20.6	20.9	22.0
Microclimate (minus 2°C hourly air) and tributaries at WQS – 1°C (unless currently cooler)	19.6	18.9	19.4	20.3

WQS - water quality standard

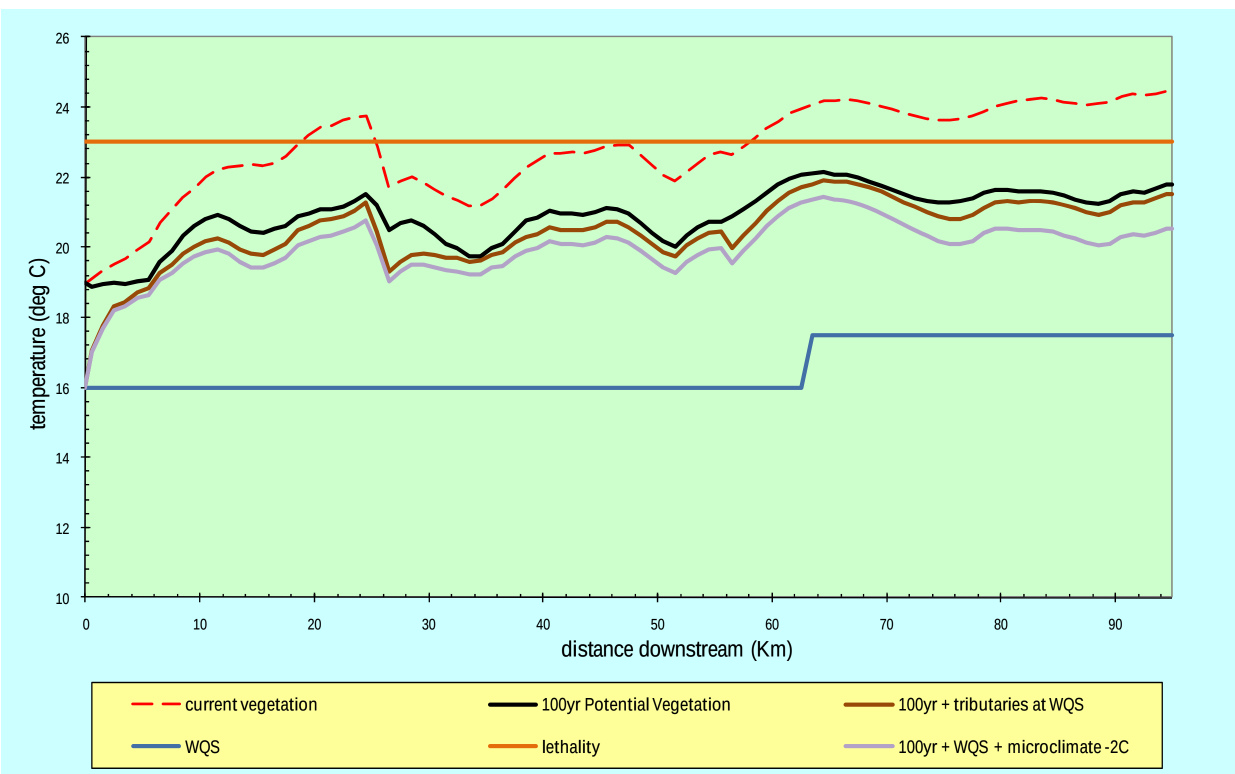

Figure 39. Predicted 7-DADMax water temperatures for critical flow (7Q10) and meteorological (90 percentile) conditions for various scenarios during July and August in the Middle Fork and mainstem Snoqualmie River.

Table 26. Summary of predicted 7-DADMax water temperatures at typical low- flow (7Q2) and meteorological (50th percentile) conditions during July and August in the Snoqualmie River (all values in °C).

Scenario 7Q2	Average maximum			
	All reaches	USFS boundary to Snoqualmie Falls	Falls to Tolt	Tolt to Skykomish
Current condition	19.2	18.8	18.7	20.0
Mature riparian veg – no vegetation on levees	18.0	17.8	17.6	18.5
Mature riparian veg – levees have trees	17.9	17.8	17.5	18.3
Tributaries are at WQS[1]	17.7	17.4	17.5	18.2
Microclimate (minus 2°C hourly air temperature)	17.0	16.9	16.8	17.3
Microclimate (minus 2°C daily max, no change daily min)	17.3	17.1	17.1	17.7

[1]Upper tributaries, including North Fork and South Fork, are below a mean of 16°C at 50 percentile conditions. (WQS – water quality standards)

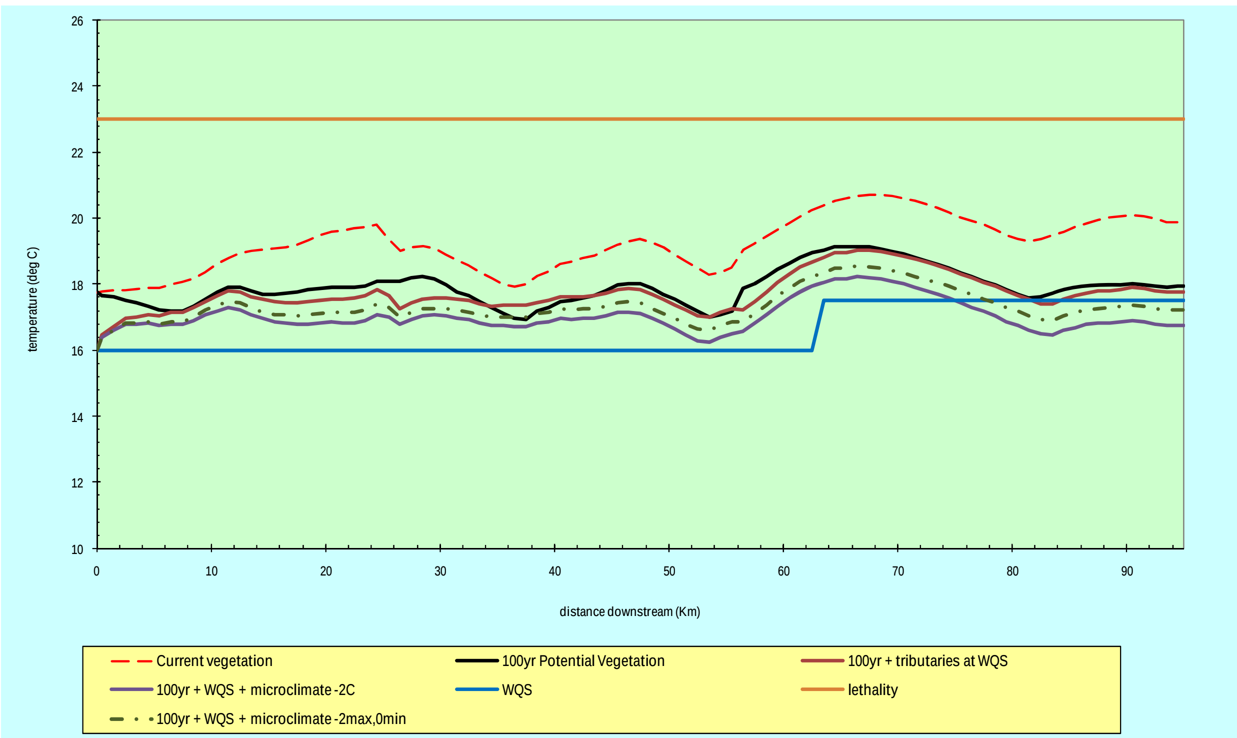

Figure 40. Predicted 7-DADMax water temperatures for typical low-flow (7Q2) and meteorological (50 percentile) conditions for various scenarios during July and August in the Middle Fork and mainstem Snoqualmie River.

Summary of QUAL2Kw model simulation findings

1. A buffer of mature riparian vegetation along the banks of the Middle Fork and mainstem Snoqualmie River is expected to decrease the average daily maximum temperature. For the critical low-flow scenario, the daily maximum temperature across the stream length could be decreased by about 1.9ºC (3.4ºF) compared to current conditions.
2. If restoration activities in the tributaries and headwater result in waters that meet the numeric temperature standards, a further reduction of 0.5ºC is expected.
3. The changes in microclimate associated with mature riparian vegetation could further lower the daily average maximum water temperature by about 0.4ºC.
4. Under the current riparian status, the Snoqualmie River maximum water temperature is expected to average 22.8^{o}C and in some locations to exceed the 23^{o}C lethal threshold to salmonids during critical low-flow (7Q10) and 90th percentile climate conditions. With all management scenarios in place (Table 25), temperatures are expected to remain significantly below the lethal threshold, averaging 20 ^{o}C during critical conditions. These temperatures are still above the numeric water quality criteria but result from natural conditions.
5. Maximum water temperatures during typical low-flow and climate conditions are predicted to average 19.2°C under the current riparian status and to be near 17.0^{o}C with all management scenarios in place (Table 26). Portions of the lower Snoqualmie River (km 75 to mouth) would be able to meet numeric water quality standards during most years.
6. The larger tributaries, especially the North Fork, South Fork, and Tolt River, generally have a cooling effect on temperatures in the mainstem Snoqualmie River.
7. The Raging River delivers exceptionally warm water to the mainstem, but flow quantity is not large enough to influence mainstem temperatures. However, the warm water could be a barrier to salmonids migrating into the Raging River.
8. Increasing shading to the area of the Middle Fork above Snoqualmie Falls reduces water temperature in this currently warm section to temperatures similar to reaches immediately upstream.
9. With all management scenarios in place, the overall decrease in the average maximum stream temperature for the simulated critical condition was 2.8ºC. While some areas would still reach temperatures above the maximum values established in the numeric water quality criteria, the cooling will be significant for the designated beneficial uses of these water bodies.
10. If a 79-foot buffer of trees were established along the mainstem and Middle Fork instead of the 150-180-foot system-potential condition, there would be a 5% reduction in effective shade and a 0.4°C increase in temperature. Effect of microclimate was not included in this scenario.
11. Reduction of tributary and headwater temperatures, to a maximum of 1°C less than the water quality standard of 15°C or 16.5°C (depending on location), results in a 0.4°C decrease (improvement) in mainstem Snoqualmie River temperature.

Other conclusions and recommendations

1. Because of the extensive network of revetments and levees that is already keeping the channel narrow, further narrowing of the channel as a result of revegetation and channel restoration is not expected in the Middle Fork and mainstem Snoqualmie River.

2. Although the mainstem and Middle Fork have large drainage areas, tributaries with smaller drainage areas and less revetments could experience channel narrowing as riparian restoration takes place.

3. Establishing mature riparian vegetation benefits water temperatures directly through reduced solar radiation and indirectly though an increase in channel complexity. These changes in channel complexity generally include increases in recruitment of large woody debris to help sediment trapping and pool forming and increases in water exchange with subsurface groundwater in the gravels and flood plain. A natural fully functioning channel would be expected to have more sinuosity and braiding that potentially could contribute additional shade. Historical channels contained more wetlands, oxbows, side channels with shading from shrubs, vine maple, alder, and dogwood. These attributes all provide potential cooling, but are more qualitative and are difficult to measure and model as a specific temperature reduction.

4. Riparian restoration of tributaries that are high value for salmonid use should be a priority. It is often easier and faster to establish vegetation to shade narrower tributary streams.

5. Levee setback is an option for areas needing channel restoration that currently have levees. This is currently being applied near the mouth of the Tolt River with an anticipated benefit to both stream habitat and flood protection. The levee setback project will reconnect existing wetlands to the river system while maintaining, or potentially improving, flood protection to the north of the Tolt River.

6. Hyporheic exchange flows and groundwater discharges are important in maintaining the current temperature regime and reducing maximum daily instream temperatures. Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the hydraulic conductivity of streambed sediments. Activities that reduce the hydraulic conductivity of streambed sediments could increase stream temperatures. Management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.

7. Riparian vegetation buffers should be restored and managed in accordance with the setting of the system potential of the watershed in order to maximize temperature improvements..

8. Effective shade from mature vegetation is also beneficial to dissolved oxygen levels and pH. Cooler water temperatures hold more oxygen, and riparian shade reduces the growth of aquatic plants that affect dissolved oxygen and pH. Some tributaries in the Snoqualmie River basin are also impaired by high pH, possibly resulting from aquatic plant growth; improved shade could have a secondary benefit to pH.

Load allocations

The Snoqualmie Temperature TMDL covers the entire watershed shown in Figure 42 except U.S. Forest System lands. The load allocations in this TMDL set limits on the allowable heat coming from all areas except WWTPs. The TMDL quantifies this heat energy in terms of Watts/m^2 and as effective shade. These effective shade load allocations control delivery of direct solar radiation, which is by far the largest contributor of heat to the river. Load allocations for the Snoqualmie River Middle fork and mainstem are detailed in Appendix F in 1,000-meter increments. The effective shade deficit by 1,000-m increment is shown graphically in Figure 41.

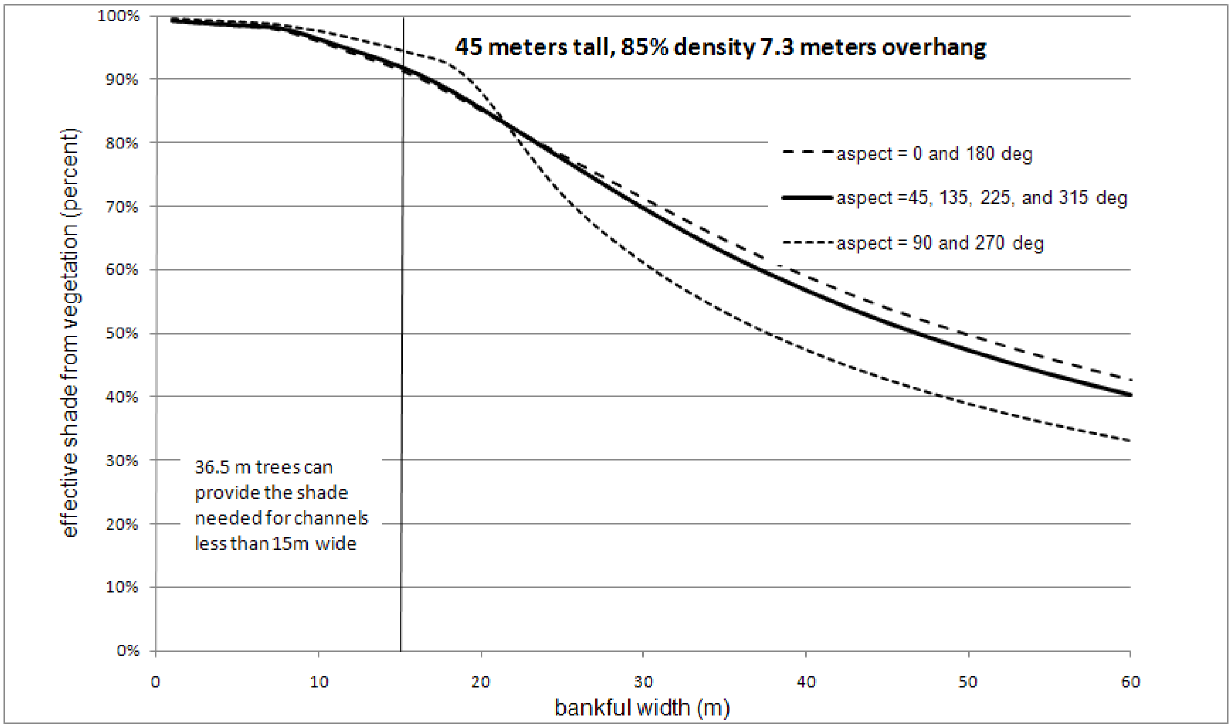

Figure 41. Load allocations for effective shade for various bankfull width and aspect of streams in the Snoqualmie River watershed assuming a riparian vegetation height of 45.5 meters, a canopy density of 85%, and 7.3 meter overhanging vegetation.

For the Snoqualmie River tributaries, which were not modeled individually using the QUAL2Kw model, the load allocations for effective shade are represented in Figure 41 and Appendix G. These allocations are based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum 100-year riparian vegetation condition. Effective shade corresponding to system-potential vegetation (100-year) was estimated assuming riparian vegetation at mature stages with an average height of 45 meters (150 ft) and 85% canopy cover.

Figure 42 shows that the amount of shade decreases as the width of the channel increases. For streams with a channel width less than 15 meters (50 ft), 50-year vegetation of 36.5 meters, 85% canopy cover, and 7.3 meters overhanging vegetation provide the required shading because the assumed overhanging vegetation will cover the stream. Topographic shade in Figure 42 was assumed equal to zero.

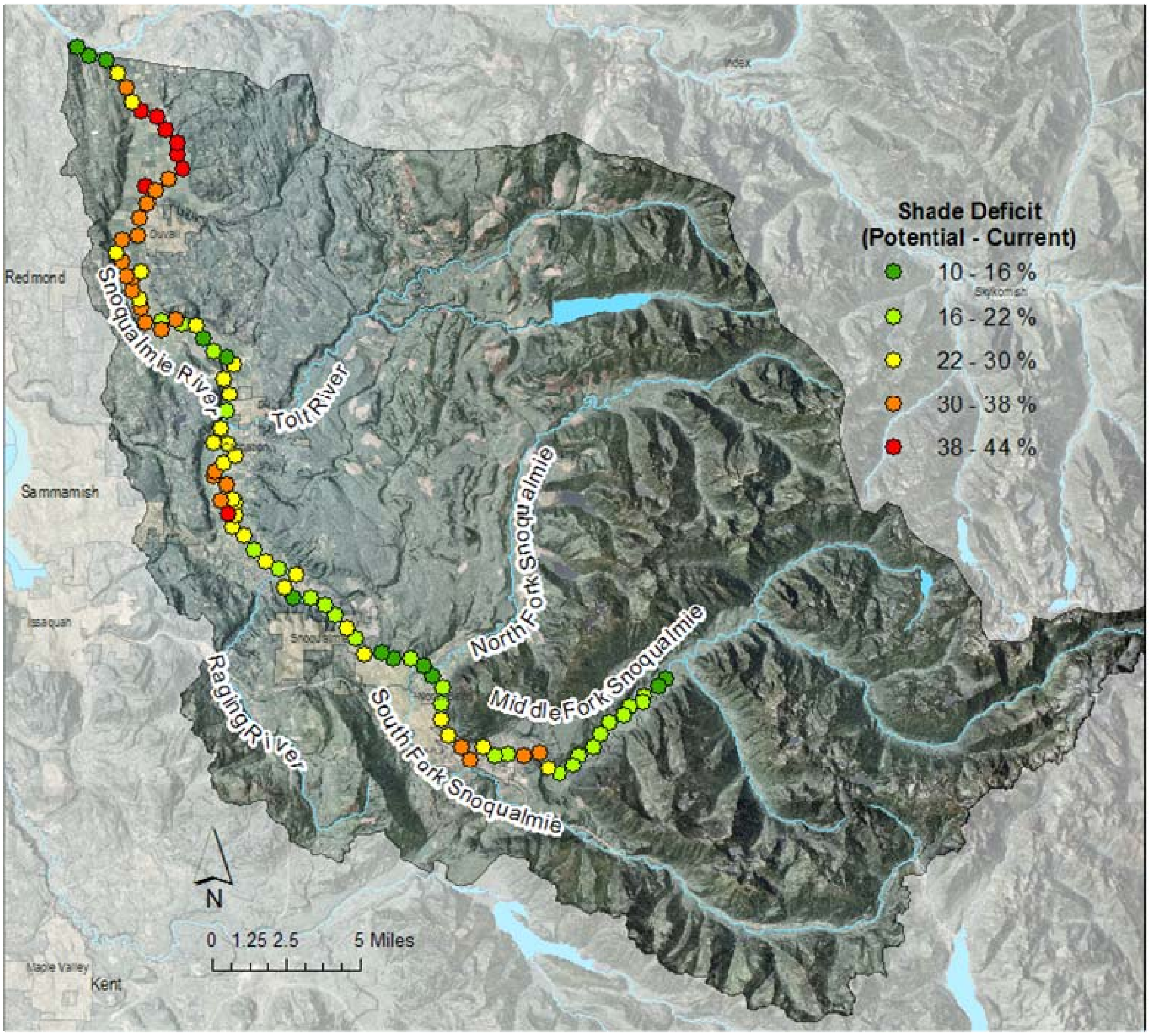

Figure 42. Effective shade deficit by 1,000-meter increment.

The deficit is the difference between the mature riparian shade condition and the current riparian shade condition.

The load allocations represent shade levels produced by mature riparian vegetation. Re-establishing mature riparian vegetation benefits temperatures directly through reduced solar radiation and indirectly though an increase in channel complexity. A natural fully functioning channel would be expected to have more sinuosity and braiding, more woody debris, reduced bank erosion, and better interaction with subsurface water and flood plain.

These allocations will result in water temperatures that are equivalent to the temperatures that would occur under natural conditions. At that point in time, either the stream will have cooled to meet or be cooler than the numeric criterion, or the stream will have cooled to its natural temperature, which may be warmer than the numeric criterion. In either case, the standard will be met, based on the natural conditions provision of the water quality standards, WAC 173-201A-070(2), which states: "*Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria*."

Establishing mature riparian vegetation is expected to have a secondary benefit of improving microclimate conditions. Management actions that control other influences on stream temperature such as sediment loading, groundwater inflows, and hyporheic exchange are also recommended.

An exception to this load allocation are the three small tributaries (Granite Creek, Gifford Lakes stream drainage, and unnamed tributary D) to the Middle Fork Snoqualmie that were measured as meeting the numeric standard in 2006. Current shade levels are sufficient for those tributaries and should be maintained.

Although an effective shade value is the load allocation, a buffer width needs to be selected to run the shade model. Other configurations may be appropriate on a local scale for achieving the target shade values. For this study, a buffer width of 180 foot was used. 180 feet is the distance for which landowners enrolled in a Conservation Reserve Enhancement Program (CREP) can receive payment. Another often-used buffer width for analysis is one site-potential tree height. One site-potential height is 45 meters (150 feet). The justification is that because of geometry, one tree height is the maximum that can cast shade. Wider buffers, those greater than 150 feet, are necessary to provide microclimate and other water quality benefits. Areas presently occupied by roads and urban development were assumed to be vegetated in the system-potential shade model.

Wasteload allocations

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

> *Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T"*

represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge).

At times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times.

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

The load allocations for the nonpoint sources are considered to be sufficient to attain the water quality standards by resulting in water temperatures that are equivalent to natural conditions. Therefore, the standards allow an increase over natural conditions for the point sources for establishing the wasteload allocations. However, point sources must still be regulated to meet the incremental warming restrictions established in the standards to protect cool water periods.

Maximum effluent discharge temperature was calculated for six NPDES permit holders in the Snoqualmie River basin. Effluent temperatures that would increase the river temperature by 0.3°C were calculated using a mass balance equation and provisions in Washington State water quality standard (WQS) which allow mixing zones of up to 25% by volume of the streamflow. Table 27 shows the final wasteload allocations for these dischargers. The remaining text and tables in this section step through the process and data used to calculate these wasteload allocations. There are no measureable cumulative temperature effects from these six point discharges because they are located too far apart.

Table 27. Temperature wasteload allocations for NPDES-permitted dischargers.

Permittee Name and ID	Water-body Name	Time period restrictions	Permit type	Wasteload allocation
North Bend (WA-002935-1)	South Fork Snoqualmie River	June-August	WWTP discharge	23.5°C or [1]flow curve
		September	WWTP discharge	22.0°C or [1]flow curve
Snoqualmie WWTP (WA-002240-3)	Snoqualmie River	June - September	WWTP discharge	24.7°C
Tokul Creek Hatchery	Tokul Creek	June 16 – Sept 14	General Fin Fish	16.3°C
		Sept 15 – June 15		
Carnation WWTP (WA-003218-2)	Snoqualmie River	June - September	WWTP discharge	33°C
Duvall (WA-002951-3)	Snoqualmie River	June - September	WWTP discharge	29.7°C
Boxley Creek Hatchery WAG 133017	Boxley Creek	June - September	General Fin Fish	16.3°C

[1]Flow curve is explained in *city of North Bend* section below.

Ecology policy (Ecology, 2007) is to use the following mass balance equation(s) to calculate effluent discharge (T_{NPDES}) in recognition that the system-potential upstream temperature is greater than the numeric standard of 17.5ºC, 16.0ºC, or 13.0ºC depending on classification. The calculated T_{NPDES} ensures that the discharge will not raise the temperature of the river by more than 0.3ºC at the edge of the mixing zone under all but the most extreme, 1 in 10 year, conditions. Effluent limits derived using these equations will also meet the incremental warming criteria.

Salmonid spawning, rearing and migration:

$$T_{NPDES} = [17.5^{\circ}C - 0.3^{\circ}C] + [\text{chronic dilution factor}] \times 0.3^{\circ}C$$

Core summer salmonid habitat:

$$T_{NPDES} = [16^{\circ}C - 0.3] + [\text{chronic dilution factor}] \times 0.3^{\circ}C$$

Supplemental Spawning/Egg Incubation:

$$T_{NPDES} = [13^{\circ}C - 0.3] + [\text{chronic dilution factor}] \times 0.3^{\circ}C$$

Where: chronic dilution factor = $(Q_{eff} + 0.25 \times Q_{7Q10}) / Q_{eff}$
T_{NPDES} = effluent temperature (°C)
Q_{eff} = effluent flow (cfs)
Q_{7Q10} = 7Q10 river flow (cfs)
0.25 = 25% by volume mixing zone allowance (unitless)

For all permittees, a chronic dilution factor and effluent temperature limits were first calculated using summer-season, facility-design condition effluent flow volumes and annual 7Q10 low-flow river volumes. The annual 7Q10 flow typically occurs in September. This method accounts for seasonal variation and produces a conservative effluent temperature that is protective of aquatic life any time of year when ambient stream temperatures rise above the numeric standard (Table 28). This method also produces a dilution factor that often is already documented in the current permit and is being used to manage other pollutants that the facility discharges.

Three WWTP facilities, Snoqualmie, Carnation, and Duvall can meet the design condition discharge temperatures with negligible chance of causing a 0.3°C temperature exceedance to the receiving water. These dischargers can adopt the wasteload allocation into their permits with the knowledge that they will be in compliance until such a date when their design capacity is increased. Further calculations were not done for these facilities, although monitoring data are shown in the subsections below.

For the North Bend WWTP and the Tokul Creek Fish Hatchery, further seasonal analyses were performed. In Washington State, the months likely to exceed the water temperature criteria are June-September, with most occurrences in July and August. June and September generally are cooler but often have a lower aquatic life temperature criterion to be protective of spawning salmonids. Because streamflow is higher during July and August when stream temperature is also at its highest, a wasteload allocation generated with the flows that correspond to that period is protective of the aquatic life standard and is appropriate.

Therefore, a second chronic dilution factor using a July/August 7Q10 flow can be calculated. This second dilution factor will generate a higher effluent temperature that will not cause a 0.3°C temperature increase to the river and is applicable to the summer months of June, July, and August. The annual 7Q10 low flow will still need to be used for the month of September. Additionally, since the North Bend WWTP is currently operating well below its design capacity, an estimate of the current effluent flow can be used.

If a permittee is currently discharging less than 85% of its full design flow during the critical period, effluent TMDL limits may be based on an alternate effluent flow. The language specifying critical design conditions for mixing zones dealing with aquatic life criteria is as follows:

> *The facility effluent flow condition to be used in calculation of chronic critical conditions is defined as the dry weather design flow if the facility is operating between 85 and 100% of design during the critical period. If the facility is operating at less than 85% of design flow during the critical period, the critical plant effluent flow is defined as the highest monthly average plant effluent flow for the past three years during the critical flow or when the critical condition is likely to occur. (Bailey, 2010a).*

Table 29 shows allowable effluent temperature by season for the North Bend WWTP and the Tokul Creek Hatchery. The July/August 7Q10 flow was used for the low-flow estimate for generation of a June-August wasteload allocation temperature. Per mixing zone guidance, current effluent flow for both facilities was the *highest monthly average plant effluent flow for the past three years during June-September.* For North Bend, calculation of a dilution factor with this alternate flow information will generate a higher effluent temperature that will not cause a 0.3°C temperature increase to the river and is applicable to the summer months of June, July, and August. September wasteload allocation numbers are also calculated using current effluent flow but with the annual 7Q10 flow which occurs in September. For Tokul Creek, the alternate dilution factor is not large enough to change the original effluent discharge temperature.

Table 28. Wasteload allocations for effluent temperature for design condition discharge.

This table generates conservative effluent temperatures that are protective of temperature on a year-round basis.

NPDES facility (permit #)	River Flow		Effluent Flow (cfs)			Chronic dilution factors (cfs)			T_{NPDES} (ºC)		
	Nearest USGS gage	7Q10 Annual (cfs)	Current[3]	Design	Water Quality Criteria (time of year)	Chronic dilution factor in current permit	Using annual 7Q10 (25% rule) and current effluent flow	Chronic dilution factor at approved design capacity	Using factor in current permit	At current flow	At design flow
North Bend WWTP (WA-002935-1)	12144000	78	1.01 (0.65 mgd[5])	3.7 (2.4 mgd)	16	18.7	20.3	6.25	21.3	21.8	17.6
Snoqualmie WWTP (WA-002240-3)	12144500	386	1.92 (1.24 mgd)	3.3 (2.15 mgd)	16	73.7	51.3	30.0	33	31.1	24.7
Tokul Hatchery (General Fin Fish)	12145000 (old data from 1907-1945)	12.8 est.	3.56 (2.3 mgd)	Not Available (*assume = current*)	16 (June 16-Sept 14)	1.0	1.9	1.9	16	16.3	16.3
					13 (Sept 15-June 15)				13	13.3	13.3
Carnation WWTP (WA-003218-2)	12149000	442	0.74 (0.48 mgd)	0.74 (0.48 mgd)	16 (May 16-Sept 14)	150.0	150.3	150.3	33	33.0	33
					13 (Sept 15-May 15)				33	33	33
Duvall WWTP (WA-002951-3)	12149000 (Carnation)	442	2.01 (1.3 mgd)	2.7 (1.75 mgd)	17.5	71.2 (64.2 wet season)	55.9	41.8	33.0	33.0	29.7
Boxley Creek Hatchery (General Fin Fish)	12143900 (Boxley Creek)	21[6]	10.8 (7 mgd)	Not Available (assume = current)	16	1.0	1.5	1.5	16	16.3	16.3

[1] T_{NPDES} = [Water Quality Criterion, ºC - 0.3ºC] + [chronic dilution factor] x 0.3ºC
[2] Reported in Table 13 of this report and as reported on 7/29/2008 at http://wa.water.usgs.gov/data/
[3] Current effluent flow can be reported in the permit as a design condition or as a typical operating condition from Discharge Monitoring Reports (DMRs) or other monitoring data. See main text for conditions used for each facility.
[4] cfs = cubic feet per second.
[5] mgd = Million gallons per day.
[6] mean monthly discharge 1981-2010 for September = 21 cfs. The 7Q10 flow will be lower, but because the dilution factor is near 1.0, it will not change the effluent limit from 16.3.

Table 29. Alternate wasteload allocations for effluent temperature using seasonal limits for selected NPDES permit holders.

NPDES facility	NPDES permit number	Nearest USGS gage	Sept Annual 7Q10 reported by USGS[2] (cfs)	July/Aug 7Q10 from Table 24 (used in Sept/06 and July/Aug 7Q10 model)	Current effluent flow[1], (cfs) (mgd)	Criteria at point of discharge °C (time of year)	Chronic dilution (cfs)		T_{NPDES} wasteload allocation (°C)	T_{NPDES} wasteload allocation (°C)
							For September	Using July/Aug 7Q10 Applies June-Aug	September	June-Aug
North Bend WWTP current flow	WA-002935-1	12144000	78	101	1.01 (0.65 mgd)	16	20.3	26.0	21.8	23.5
North Bend WWTP design flow	WA-002935-1	12144000	78	101	3.7 (2.4 mgd)	16	6.25	7.8	17.6	18.0
Tokul Hatchery	General Fin Fish	12145000 (old 1907-1945)	12.8 est.	14.8	3.56 (2.3 mgd)	16 (June 16-Sept 14)	1.9	2.0	16.3	16.3
						13 (Sept 15-June 15)			13.3	13.3

[1] Current effluent flow can be reported in the permit as a design condition or as a typical operating condition from Discharge Monitoring Reports (DMRs) or other monitoring data. See individual facility sections below for details on the source for current effluent flow reported in this table.
[2] Reported in Table 13 of this report and as reported on 7/29/2008 at http://wa.water.usgs.gov/data/

The following pages describe the size and characteristics of each of the NPDES facilities receiving wasteload allocations. Unique operating conditions and challenges in meeting wasteload allocations are also discussed. Additional detailed information on these facilities can be found on Ecology's web site.

- Operating Permits and Fact Sheets for dischargers with individual NPDES permits can be found at www.ecy.wa.gov/programs/wq/permits/northwest_permits.html.
- Fish Hatchery, Sand and Gravel, and Stormwater discharges are most often covered under General Permits available at www.ecy.wa.gov/programs/wq/permits/genpermits.html.
- Availability of on-line facility discharge data through Ecology's Water Quality Permit database is discussed at www.ecy.wa.gov/programs/wq/permits/paris/index.html.

City of Snoqualmie

The city of Snoqualmie WWTP and reclaimed water facility NPDES permit was reissued on June 18, 2008 and expires on June 18, 2013 (Ecology, 2008). During three months of the year, the Snoqualmie WWTP produces reclaimed water that is largely discharged to the Snoqualmie Ridge planned community for irrigation. Page 55 of the NPDES permit fact sheet reports that effluent discharges to the Snoqualmie River during May-Sept 2003-2007 ranged from 0.223 to 1.017 mgd, with an average of 0.639 mgd. Recent discharges during 2008-10 show June through September maximum discharge rates ranged from 0.1 to 2.7 mgd and averaged 0.5 mgd.

Ecology has approved engineering reports for a two-phase expansion of the Snoqualmie WWTP. Phase 1 design capacity is currently 1.24 mgd and Phase 2 design capacity is 2.15 mgd. The maximum amount of effluent that can be treated to reuse standards and used for irrigation is approximately 1 mgd. The highest monthly average WWTP flow for the last three years during the summer months is 1.12 mgd in June 2010 (Figure 43). Therefore the current Phase 1 design capacity of 1.24 mgd is a reasonable estimate of current operations. However, to be protective of the river in the event of a failure of the reclaimed water facility, wasteload allocations were set using the maximum design flow of 2.15 mgd. Due to the high dilution rates in the receiving water, the allowable effluent temperature of 24.7°C can be met by the WWTP at design capacity conditions. Discharge Monitoring Report (DMR) data in Figure 44 show that WWTP effluent temperatures have remained below 23°C.

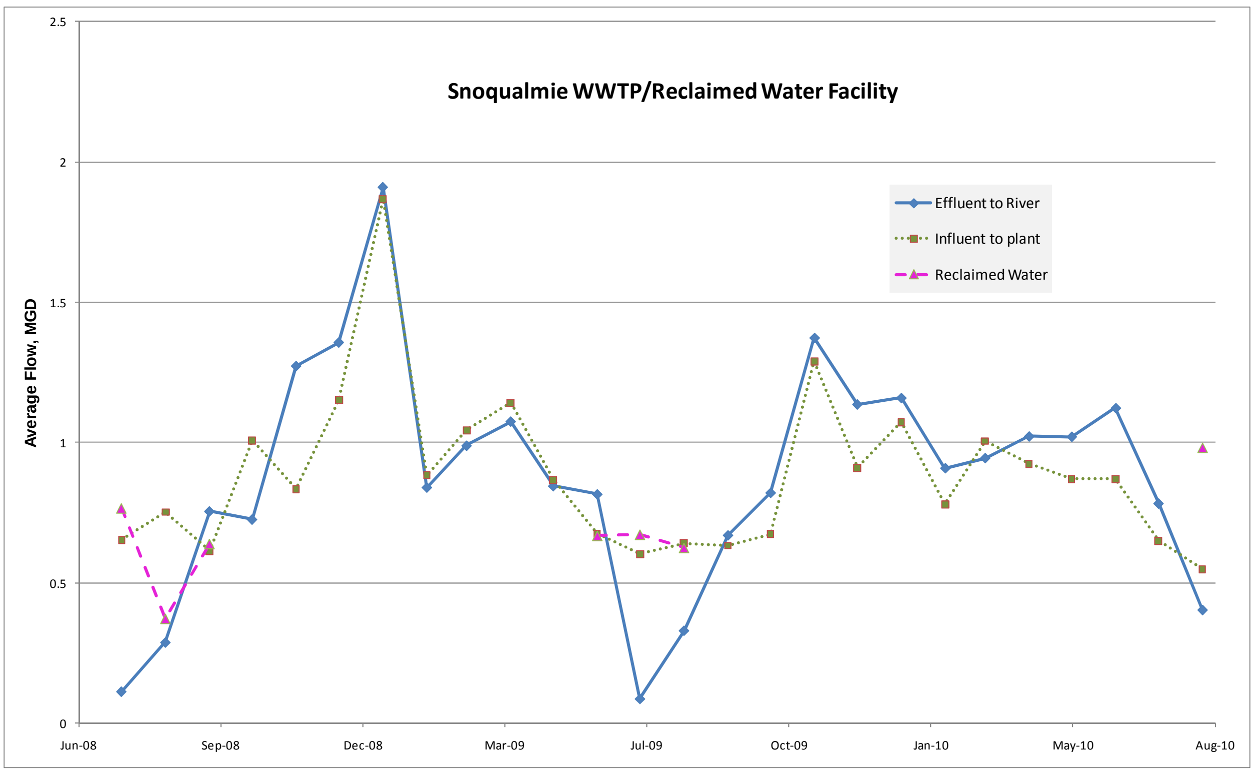

Figure 43. Snoqualmie WWTP average effluent flow, July 2008 to August 2010.

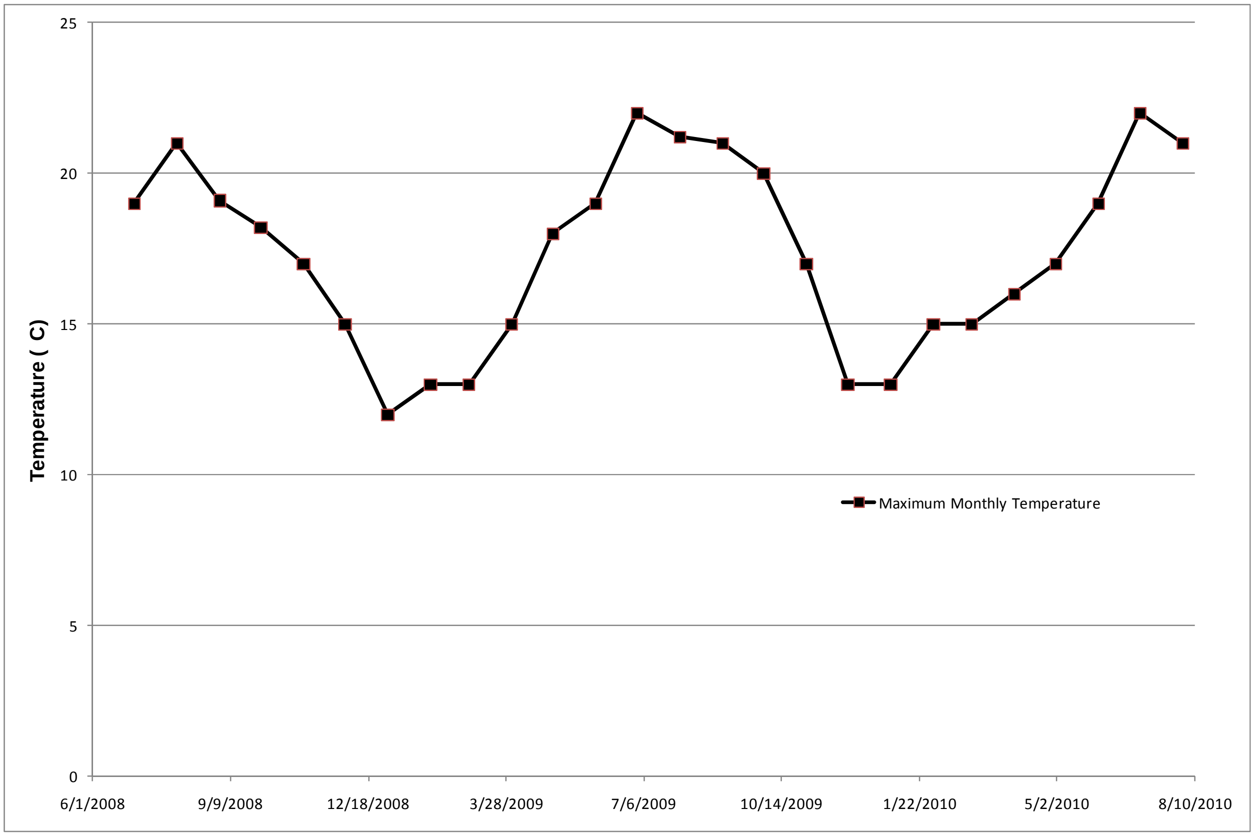

Figure 44. Snoqualmie WWTP maximum effluent temperature, July 2008 to August 2010.

City of Duvall

The city of Duvall NPDES discharge permit was reissued in June 2006 (WA-002951-3). This permit allows monthly average flows of 1.313 mgd based on the present configuration of three membrane bioreactors and 1.75 mgd when a fourth membrane bioreactor is installed. Flow data reported under the current permit for 2008-2010 show summer monthly average flows range from 0.4 to 0.6 mgd (averaging 0.43 mgd), while wet-weather flows range from 0.4 to 0.8 mgd (averaging 0.6 mgd) (Figure 45). Thus, current dry-weather flows tend to be lower than winter flows, and design conditions are likely sized to meet wet-weather needs. The maximum summer flow during the last three years was 0.85 mgd.

Current condition dilution was calculated using the lower 1.3 mgd value, and maximum design condition dilution was calculated using the 1.75 mgd value. Maximum design condition flows the result in an allowable effluent temperature of 29.7°C. Maximum daily effluent temperatures for Duvall WWTP during summer typically do not exceed 24°C. DMR data gathered by the facility and continuous temperature data gathered by Ecology in 2006 (Figure 46) support this. Thus, under the currently approved design conditions, temperature is not limited because there is no reasonable chance of exceeding the allowable effluent temperature.

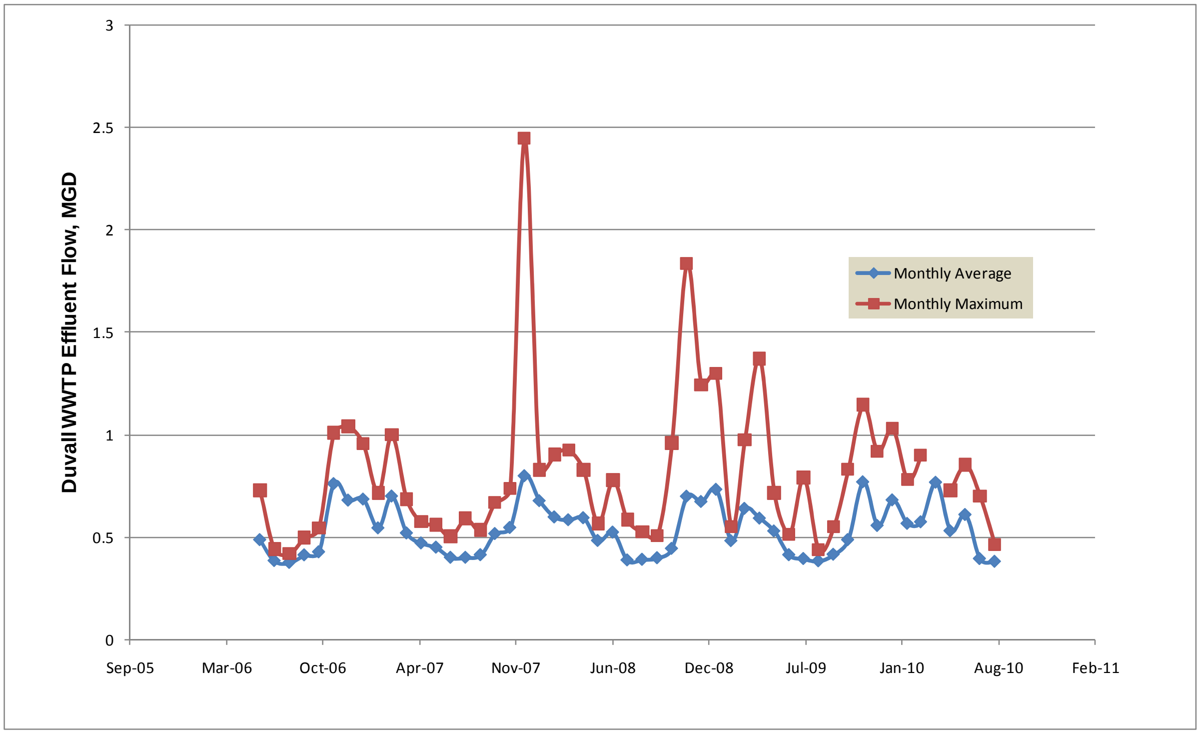

Figure 45. Duvall WWTP effluent flow July 2006 to August 2010.

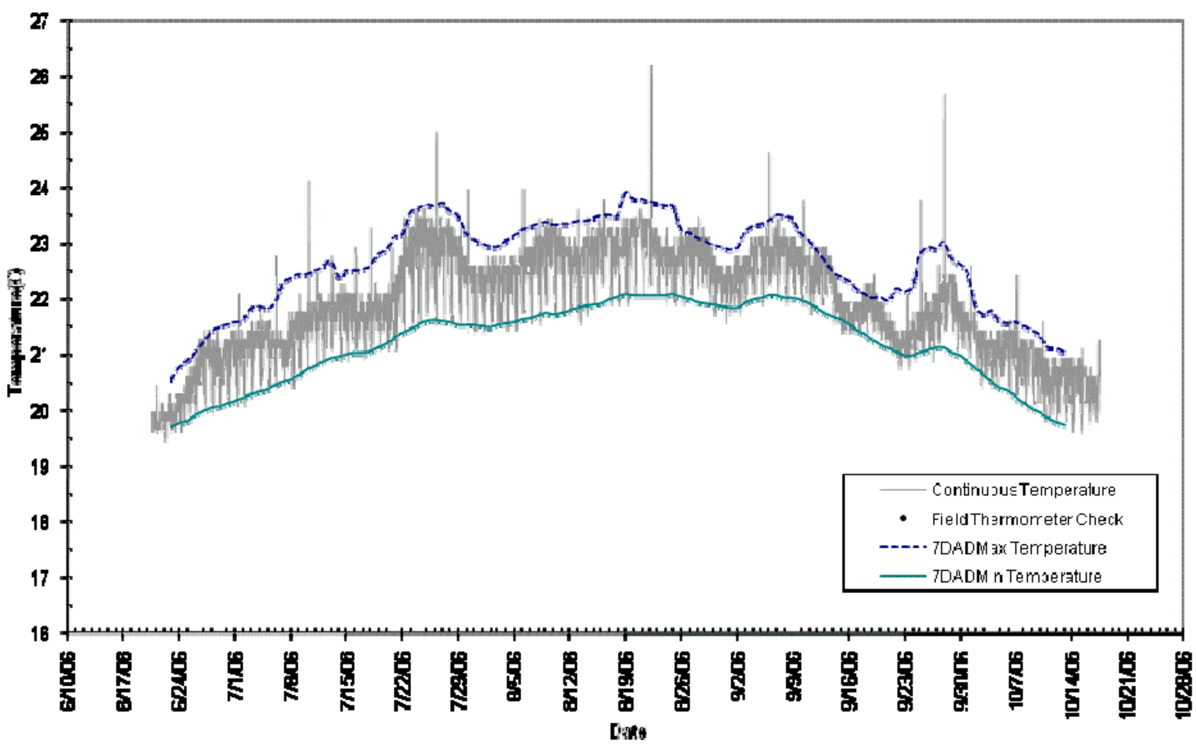

Figure 46. Duvall WWTP effluent temperature (07DWP00.0), June to October, 2006.

City of Carnation

The Carnation WWTP is a new facility that began discharging in June 2008 (WA-003218-2). Ecology issued the NPDES discharge permit on April 15, 2008; it expires April 15, 2013. The facility will primarily discharge to a wetland system and will use a river discharge on a limited basis. Design criteria for the facility show a monthly maximum effluent flow of 0.48 mgd. Carnation is currently discharging to the Snoqualmie River at a low rate in order to collect data for the new WWTP (Figure 47). The river discharge is located in an area that has a supplemental fall spawning criteria of 13°C. Continuous temperature monitoring is a permit requirement from July through October at this plant. Maximum effluent temperatures ranged from 18.3°C in October 2009 to 26.0°C in August 2009 (Figure 48). Due to the high dilution rates in the receiving water, the allowable effluent temperature of 33.0°C can be met by the plant at design capacity conditions.

The wetland discharge is expected to seep into the river below the bend, which does not have a supplemental spawning criterion and the water quality criterion remains at 16°C year-round. Ecology expects that this discharge will not degrade groundwater quality when applied as supplemental water to the wetlands (Fact Sheet for State Reclaimed Water Permit ST-7450, page 9) and may in fact increase local cool groundwater resources. No discharge to the Snoqualmie River is expected from the wetland during summer months, so there is no reasonable potential to exceed the temperature standards in the river. No wasteload allocation is needed for the discharge to wetlands under the current design conditions.

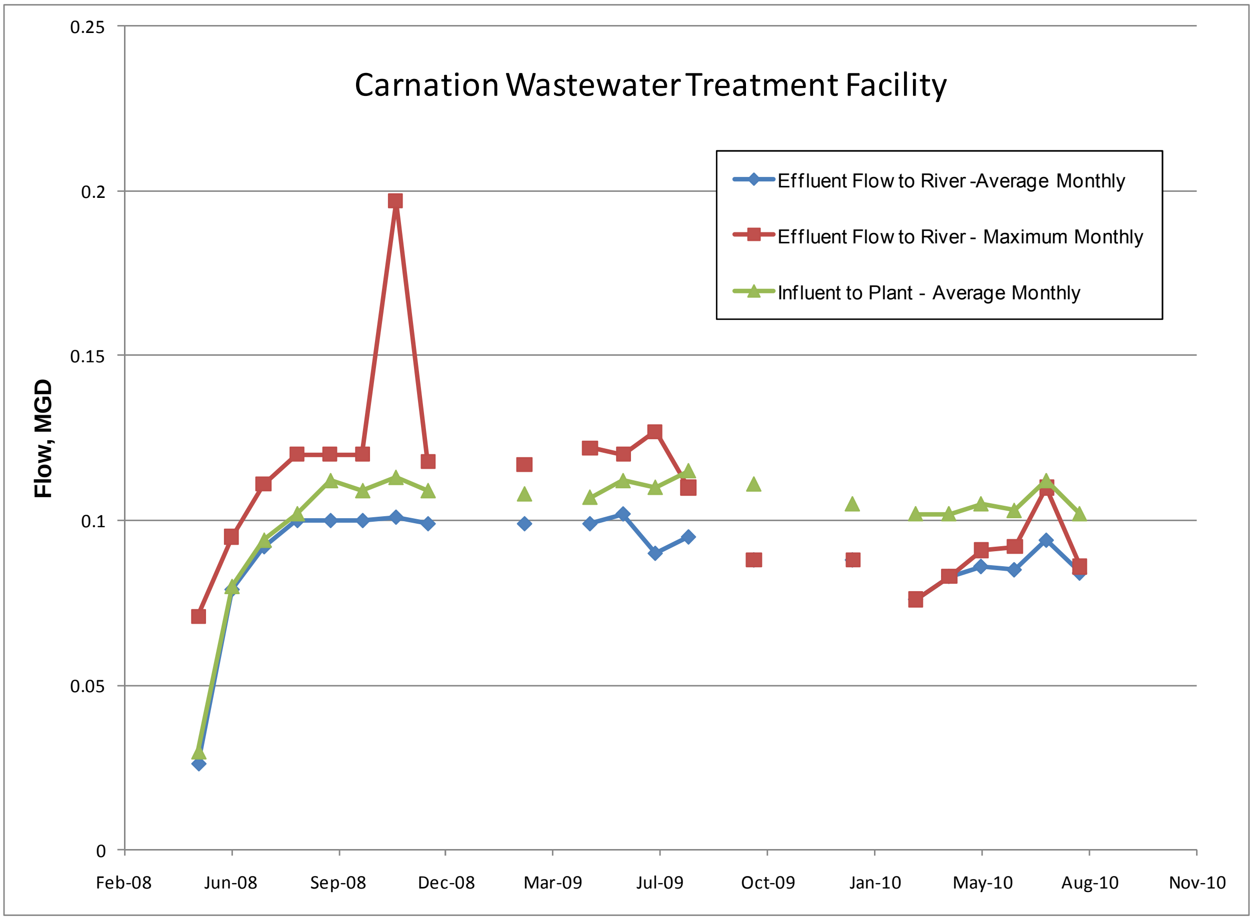

Figure 47. Carnation WWTP effluent flow, June 2008 to August 2010.

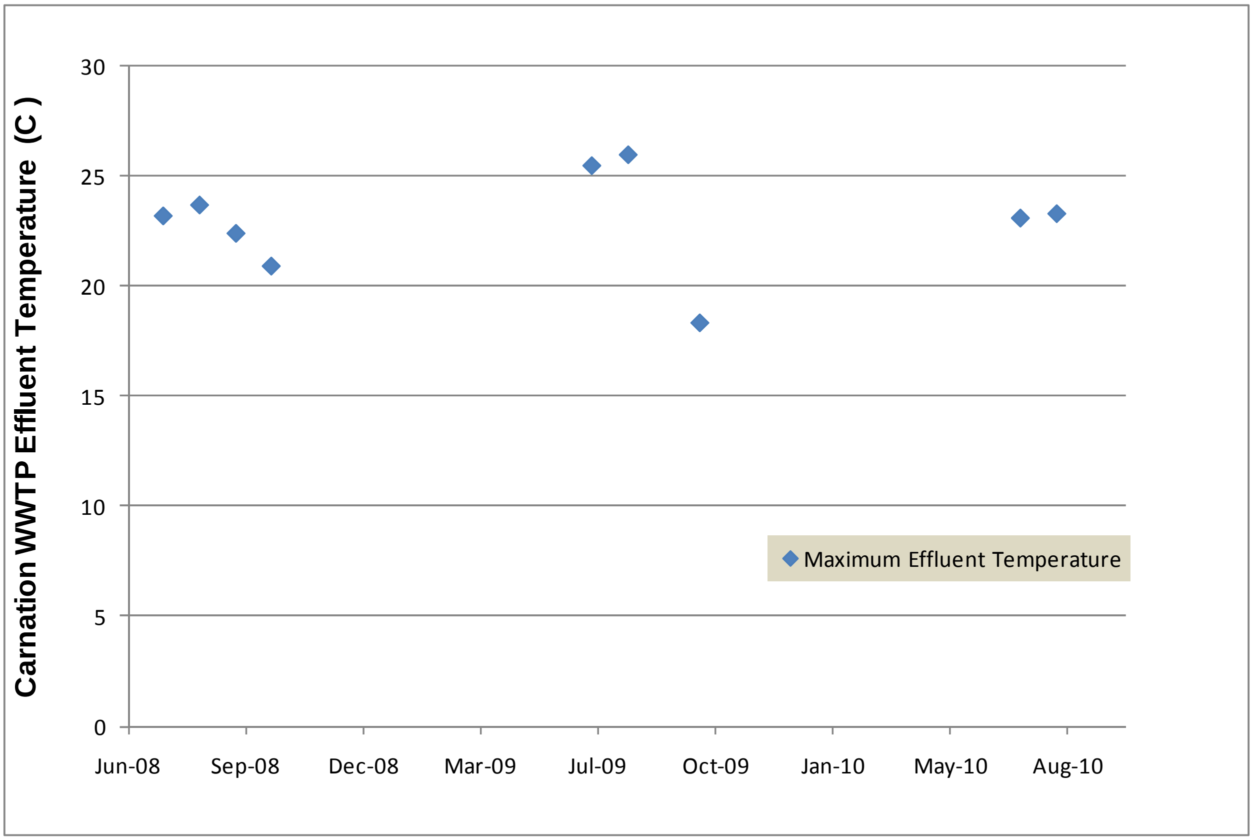

Figure 48. Carnation WWTP effluent temperature, June 2008 to August 2010.

City of North Bend

The North Bend WWTP discharges to the South Fork Snoqualmie River. The South Fork is a tributary to the mainstem Snoqualmie River, and the WWTP discharge is located approximately 1.7 miles upstream of the confluence. Ecology issued the current NPDES permit for the North Bend WWTP on April 7, 2006; it expires April 7, 2011. Effluent flows have increased significantly since the issuance of that permit. Comparison of flow data used to establish the permit (2001-2004) to more recent flow data (2006-2010) show that daily maximum flow has increased from 0.61 to 1.25 mgd, and maximum monthly average flow has increased from 0.47 to 0.81 mgd.

Although effluent flows have increased, the North Bend WWTP is currently operating well below its effluent flow design capacity of 2.4 mgd (Figure 49). Because summer and early fall is the critical season for water temperature, the wasteload allocation is based on flows occurring in June-September.

Maximum daily effluent flows for June through September 2008-2010 ranged from 0.40 to 0.78 mgd and averaged 0.48 mgd. The effluent flow used to calculate the dilution factor and numeric wasteload allocation temperature is the highest average monthly flow occurring in the months of June-September in the last three years. This effluent flow value is 0.653 mgd in June 2010.

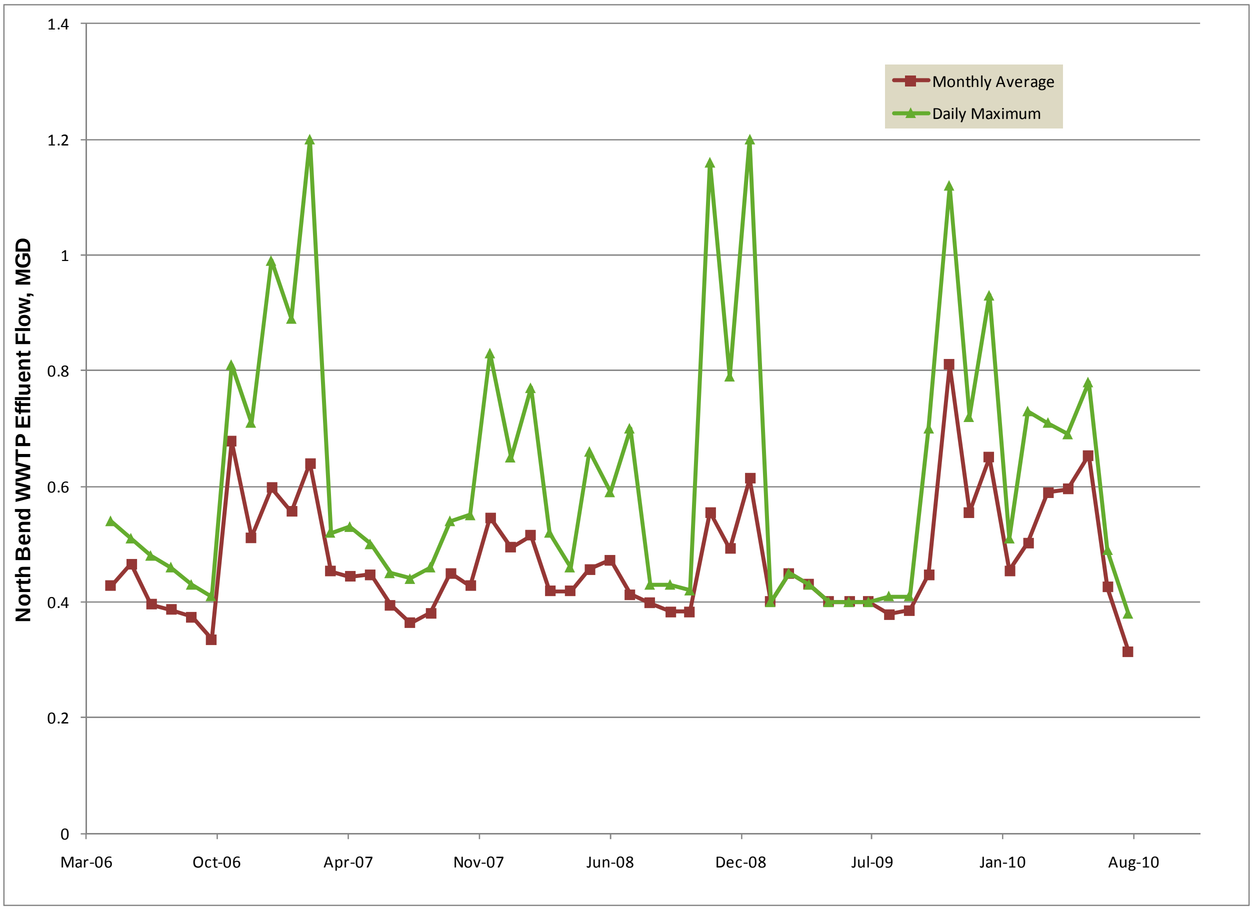

Figure 49. North Bend WWTP effluent flows.

The South Fork Snoqualmie River temperatures for 2005 and 2006 are shown in Figure 50. The water quality criterion (16°C) is met for the majority of the year, with measurements over the criterion during July and August, and less than three days of exceedances during September.

Two options for structuring a wasteload allocation for the North Bend WWTP are described below. Option 1 (Figure 50) gives two numeric temperature limits, one that applies during September and the other that applies during the months of June, July, and August. Option 2 is a flow-based limit, which requires actual effluent flow and actual river flow to calculate an allowable discharge temperature (Table 30 and Figure 51).

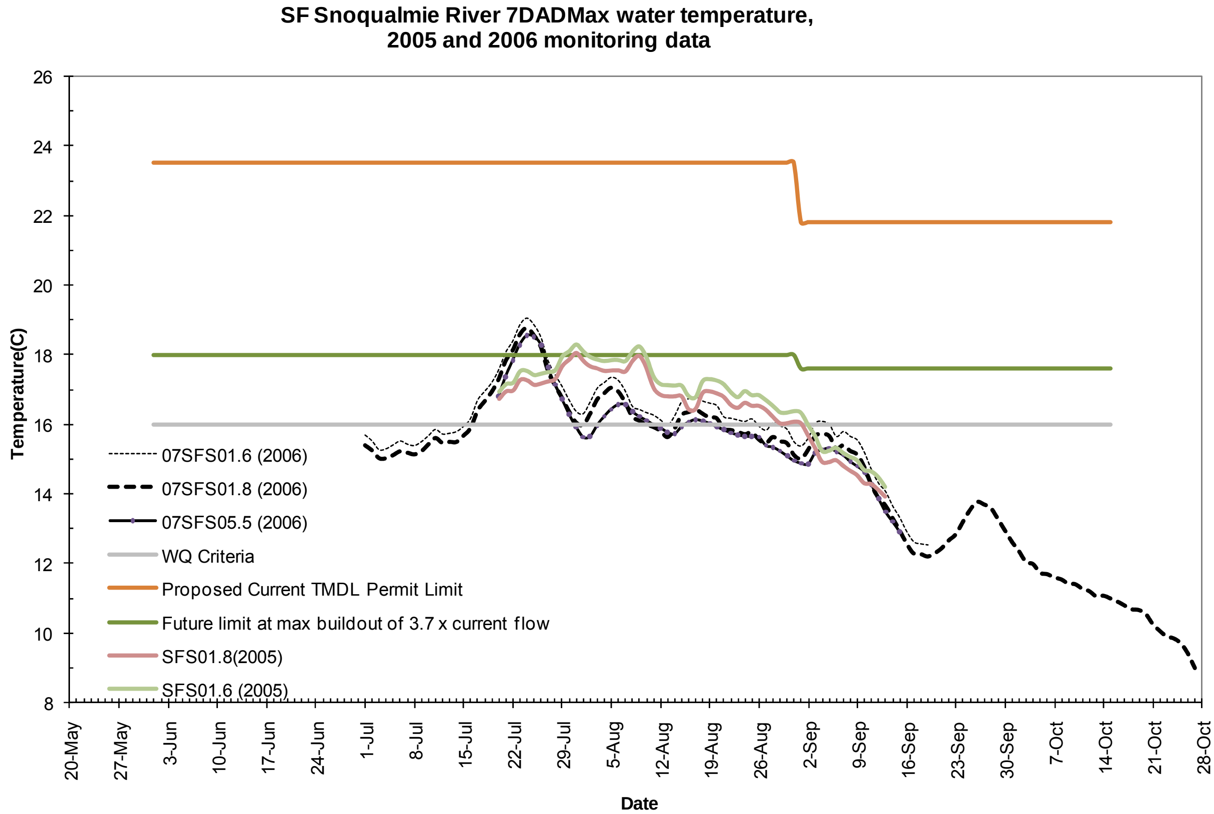

Figure 50. South Fork Snoqualmie water temperature (7DADMax), measured in 2005 and 2006 with proposed numeric effluent limits (option 1).

Table 30. North Bend WWTP effluent temperature wasteload allocations, °C.

WWTP Effluent Discharge		South Fork Snoqualmie River Flow at North Bend WWTP Outfall (cfs)			
MGD	cfs	60	80	100	120
0.3	0.46	25.7	28.9	32.2	35.4
0.5	0.77	21.8	23.8	25.7	27.6
1.0	1.55	18.9	19.9	20.8	21.8
1.5	2.32	17.9	18.6	19.2	19.9
2.0	3.09	17.5	17.9	18.4	18.9
2.5	3.87	17.2	17.6	17.9	18.3
3.0	4.64	17.0	17.3	17.6	17.9

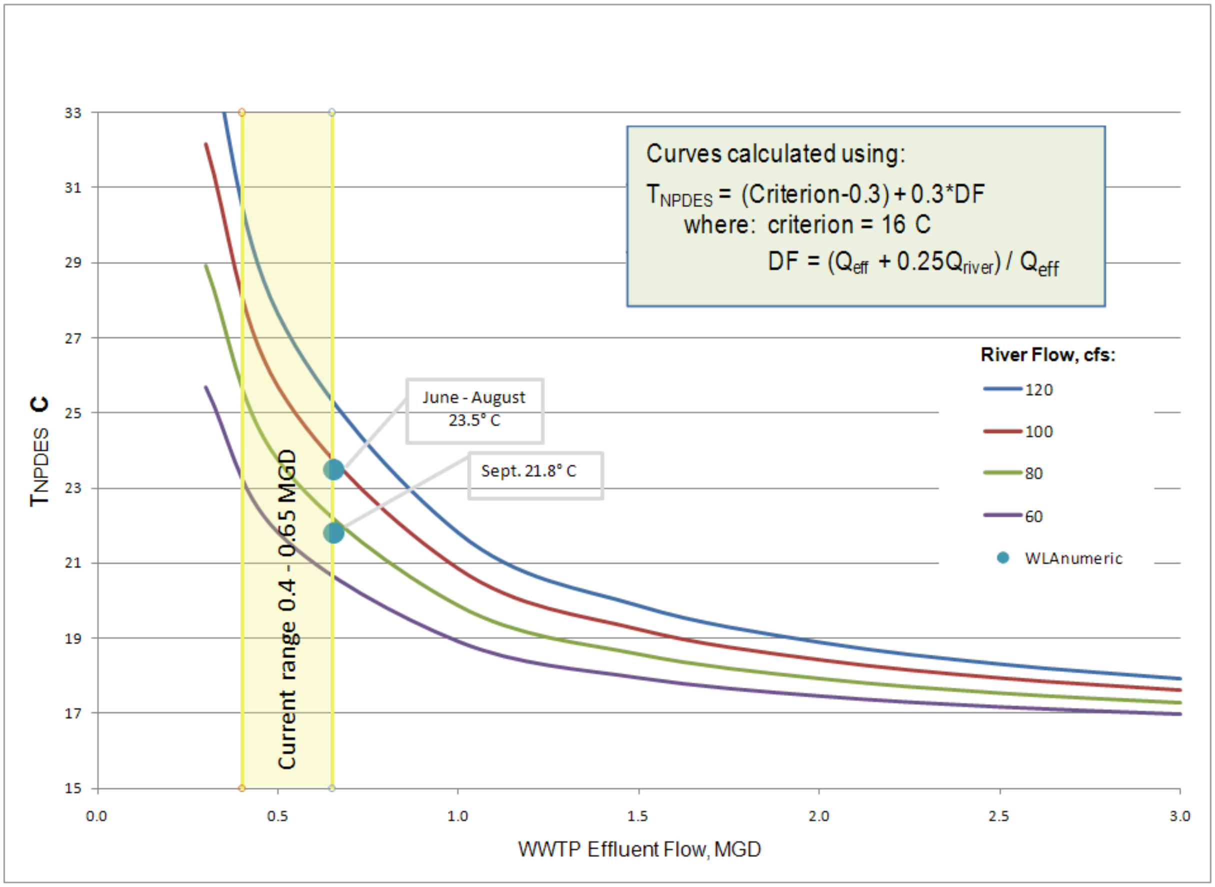

Figure 51. North Bend WWTP temperature wasteload allocations as a function of effluent and South Fork Snoqualmie River and flow (option 2).

DF = dilution factor; WLA= wasteload allocation.

These allocations ensure that permit limits do not result in greater than a 0.3°C increase in river temperature at the chronic mixing zone. These allocations are intended to apply only during times when the receiving water temperature is expected to exceed numeric temperature criteria, that is, June through September according to historic river data. It is expected that these limits will be incorporated directly into subsequent NPDES permits.

The North Bend WWTP is currently operating within allowable limits under both wasteload allocation methods. As discussed above, the river flow during July and August is 101 cfs, and WWTP effluent flow currently ranges from 0.4 – 0.65 mgd. Imposing this information onto Figure 51 shows the allowable discharge temperature would range from a high of 28°C to a low of 23.5°C depending on flow. DMRs from 2006 to 2010 show that the maximum reported effluent temperature during critical conditions was 22°C (Figure 52).

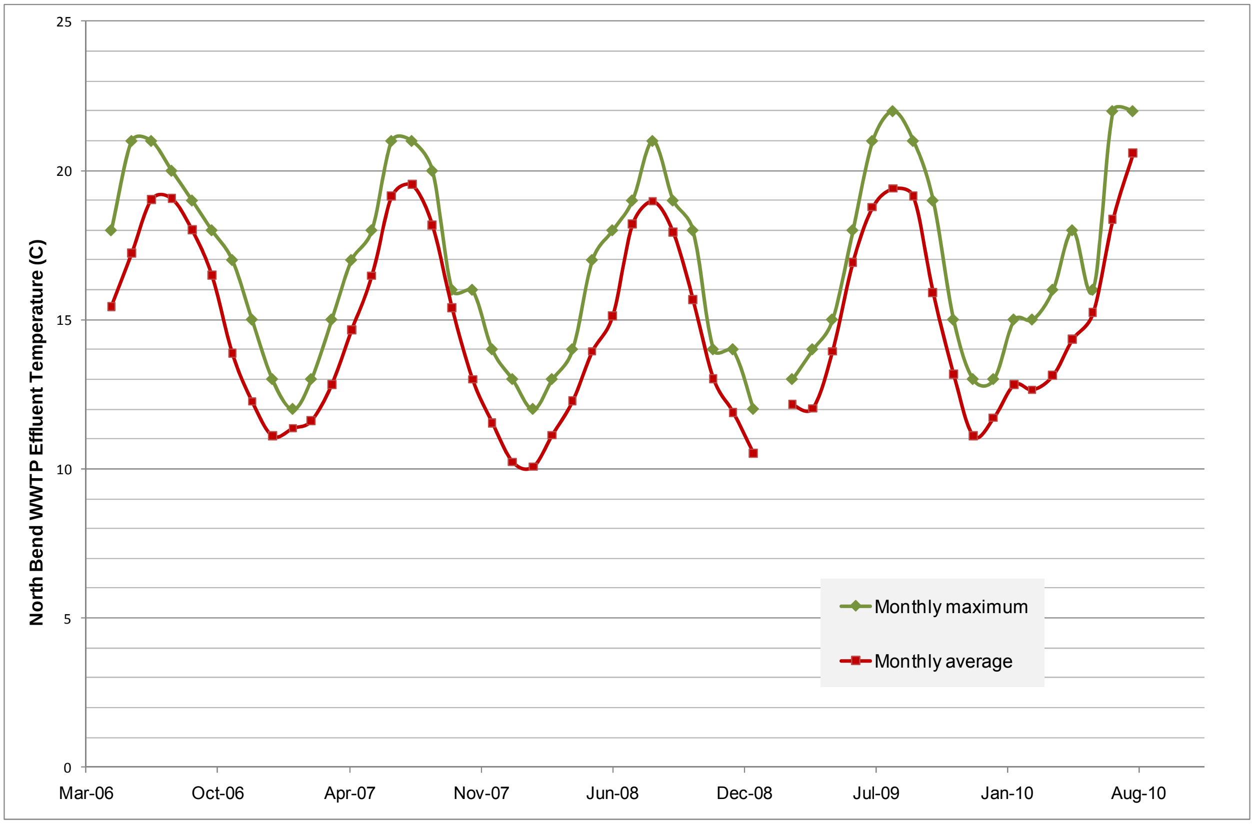

Figure 52. North Bend WWTP effluent temperature.

For planning purposes, if the river flow and effluent temperatures remain approximately the same as they are now, the WWTP will need to consider alternatives as they approach flows of approximately 0.81 mgd during the critical summer months. If effluent temperatures increased to 23°C, however, alternatives would need to be considered sooner at flows of approximately 0.70 mgd. Alternatives can consist of either reduction of effluent temperature or reduction of effluent flow rates during periods of high temperature.

Fish Hatcheries

Tokul Creek Fish Hatchery

The Tokul Creek Fish Hatchery is covered by the Upland Fish Hatchery General Permit (number WAG13-3004). The permit was issued June 28, 2010; it expires August 1, 2015. The Tokul Creek Hatchery is one of the smaller hatcheries operated by the Washington Department of Fish and Wildlife. The hatchery raises and releases approximately 190,000 winter run steelhead trout per year (Kaje, 2009).

Source water is diverted from Tokul Creek just upstream of the hatchery and supplemented with spring water from the hillside. The spring water is a constant 47° F (8.3C°). It is used in the incubation room and as augmentation water in the raceways. Hatchery effluent is then discharged to Tokul Creek through a ditch that joins the creek about 200 feet below the hatchery buildings. The distance from the raceway discharge to Tokul Creek is about 400 feet.

Boxley Creek Fish Hatchery

Boxley Creek Fish Hatchery is covered by the Upland fish Hatchery General Permit (number WAG13-3017). This facility was formerly known as Sea Springs Co Christmas Creek Hatchery and is located on Boxley Creek, a tributary to the South Fork Snoqualmie River. The current permit was issued August 1, 2010; it expires August 1, 2015.

Boxley Creek Hatchery is a privately owned hatchery raising steelhead fingerlings and Donaldson trout for commercial sale. There will be no release of fish from this site. Source water is diverted from Boxley Creek and is supplemented with well water. The hatchery was not in operation during the 2006 field season, but in recent years has recorded discharge volumes of 7MGD (as reported in Discharge Monitoring Reports) to Boxley Creek when in operations. The hatchery is undergoing renovation during the spring of 2011.

The federal Clean Water Act requires developing of a wasteload allocation for the Tokul Creek Fish Hatchery because it falls within the TMDL study area. Because there is not a water temperature monitoring requirement for fish hatcheries, the first step was to see if there was a reasonable chance that the hatchery was causing a temperature impact to Tokul Creek, and the second step was to calculate a numeric wasteload allocation for effluent temperature.

The general permit says the following about water temperature as a pollutant from fish hatcheries.

> *The pollutants of potential concern in the first version of this permit were temperature and dissolved oxygen. The concern was raised in a 1988 study by Ecology on the "Quality and Fate of Fish Hatchery Effluents During the Summer Low Flow Season." The facilities monitored these parameters during their first year of permit coverage. The results of this monitoring showed that these facilities do not have a reasonable potential to exceed these parameters. Based upon this information, Ecology determined that it would not require further monitoring of temperature and dissolved oxygen in subsequent permits.*

Tokul Creek water temperature monitoring data from 2006 support the above statement that there is not a likely temperature impact to the stream from the hatchery. Temperature measurements show that Tokul Creek is a relatively cool tributary that remained close to or under the numeric criteria for the majority of the summer (Figure 53 and Appendix C). The June numeric criteria of 13 and 16 °C were slightly exceeded for 7 days by an average of 0.4°C. In July, the numeric criterion of 16°C was exceeded for 13 days by an average of 1.0°C.

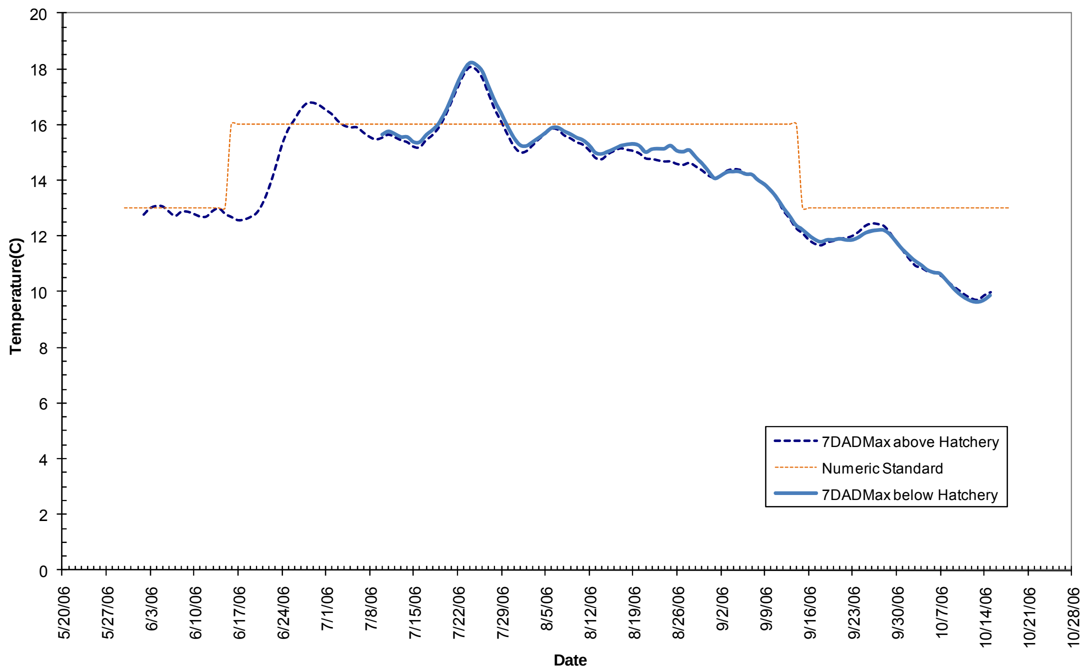

Figure 53. Tokul Creek water temperature above (07TOK00.6) and below (07TOK00.1) the Tokul Creek Fish Hatchery.

Comparison of above-hatchery with below-hatchery water temperature shows that for July 10 through September 30, when both thermistors were recording, there was an average temperature increase of 0.1°C. Washington State standards say that when the creek temperature is above the numeric criteria, that a point source cannot cause more than a 0.3°C increase. For the days that the creek exceeded the numeric criteria, the increase in temperature over the ½ mile reach where the hatchery discharge enters averaged 0.2°C and ranged from a minimum of. 0.1°C to a maximum of 0.3°C. The increase in temperature must be greater than 0.3°C to be considered a measureable increase in Washington State standards.

All previous temperature TMDLs have used a “dilution factor = 1” for fish hatcheries. Calculation of a dilution factor, using the same method as for other point source dischargers, results in values of 1.9 for September and 2.0 for June-August. Both of these dilution factors produce an allowable discharge temperature of 16.3°C or 13.3°C depending on the numeric standard in place. The effluent flow used in these calculations was 2.3 mgd in June 2010, which was the highest average monthly summer flow reported for the last three years. Effluent flow for July through October 2010 ranged from 1.7 – 2.0 mgd (Lori Levander, personal communication).

In general, a hatchery relies on having cold water for its fish. As hatchery improvements are made, adding shading to concrete ponds and other methods to keep water from heating during hatchery operations should be considered.

Other Non-Stormwater General Permits

Other permitted facilities in the basin are not a concern for water temperature because they do not discharge during the critical months of June – September. Fiorito Brothers Homestead Valley near North Bend is the only facility operating under the Sand and Gravel General permit that identifies a surface water discharge. This facility has not discharged since 2007 and is not likely to discharge during the summer months.

The fact sheet for the recently approved Sand and Gravel general permit says that of the 137 facilities evaluated during the permit renewal only nine (7%) may have some potential to cause a rise in the temperature of the receiving water (Bailey, 2010b). Ecology inspectors will make individual assessments on these facilities; however, the industry does not have a large potential to impact the temperature of surface waters. Ecology removed the temperature study from the proposed permit as a requirement for dischargers to surface waters. Ecology may require a study for new dischargers to surface waters if Ecology determines there is a potential for violation of water quality standards.

Stormwater Wasteload Allocations

Wasteload allocations (WLAs) are necessary for permitted stormwater discharges if they are a source of pollutant loading to the stream when receiving water temperatures are impaired. The Snoqualmie River watershed has permitted stormwater sources discharging into the mainstem or tributaries of the Snoqualmie River. The largest sources of permitted stormwater are discharged from the municipal storm sewer systems operated by King County, Snohomish County, WSDOT, and the cities of Duvall and Sammamish. Ecology does not consider permitted stormwater discharges to be a significant source of thermal pollution during the critical period. Although thermal loadings from permitted stormwater are of minimal size, all NPDES-permitted discharges must be provided wasteload allocations.

Ecology's stormwater permits do not authorize discharges that would violate Washington State surface water quality standards, groundwater quality standards, sediment management standards or the human health-based criteria in the national Toxics Rule, as indicated in their permits.

Ecology's use-based temperature criteria (WAC 173-201A (Table 200(1)(c))) are expressed in 7DADMax values. In order to be both consistent with these temperature criteria and practical (a receiving water may be affected by multiple stormwater outfalls with wide spatial distribution and controlled discharge rates), this TMDL expresses cumulative stormwater WLAs as a 7-day average daily (7DAD) loading value as measured at the TMDL monitoring points established in the TMDL study. Although the WLAs incorporate seven daily values, they are expressed as a daily value and are consistent with the state's 7DADMax criteria.

The following criteria express the cummulative temperature WLA for all stormwater permittees:

- When a water body's temperature is warmer than state criteria due to natural conditions (or within 0.3^{o}C), the cumulative discharge from all permitted sources may not cause the 7DADMax receiving water temperature under those conditions to increase more than 0.2^{o}C

(0.36°F)[2]. That allowable 0.2°C increase is quantified using the following equation, which provides a numeric daily loading value to assess compliance with the aggregate WLA.

$$WLA_{critical\ period} = \frac{\sum_{N=1}^{7}(\Delta T * Q_N * C_F)}{7}$$

Where:

$WLA_{critical\ period}$ = the waste load allocation in Kilocalories/day
ΔT= allowable cumulative temperature increase for point sources=0.2°C
Q_N= daily receiving water flow, in cfs,
N = day 1 through 7 of the 7DAD averaging period
C_F=2,446,665 (kcal·second)/°C·ft^3·day (a conversion factor to transform the units to Kilocalories/day)

- Appropriate best management practices required through stormwater permits for controlling pollutant loadings to surface waters are applied to the discharge to protect designated aquatic life uses.

Natural conditions for the Snoqualmie River are not defined in this TMDL. However, "system potential" temperature has been determined by the model used in this TMDL and can be used to offer an estimation of natural condition temperatures for mainstem river areas during critical periods. All tributaries monitored as part of Ecology's field studies are considered to have system potential temperatures equal to that waterbody's assigned temperature criteria or within 0.3°C of that temperature.

At this time, Ecology anticipates that there will be no additional TMDL-required conditions in municipal stormwater permits and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees. Stormwater discharges may be considered for mixing zones as specified in WAC 173-201A-400, which should be applied in conjunction with the WLA in the previous paragraphs.

Background

Thermal loading from municipal stormwater discharges has the potential to increase the temperature of small receiving waters at certain times of the year. Runoff from late spring or early fall rainfall onto heated pavement may be quite warm initially, but that runoff cools rapidly during long rain events and is not expected to cause a 0.3°C increase of the 7-day average temperature. The Snoqualmie River watershed has both permitted and nonpermitted municipal stormwater sources.

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[2] The remaining 0.1°C of the incremental warming allowance is reserved for unpermitted stormwater and other human sources and a margin of safety. Cumulative allowable loadings can be measured at the TMDL monitoring locations representative of the impaired segments identified earlier in this TMDL

Municipal Stormwater Permit holders in the Snoqualmie River watershed include King County and Snohomish County (Phase I permittees), and the Cities of Duvall and Sammamish (Phase II permittees). Phase I permits were issued in January 2007 and modified in June 2009. Phase II permits were issued in January 2007 and revised in March 2008. Mapping of stormwater outfalls is taking place and is due to be completed in 2011.

The Washington State Department of Transportation (WSDOT) has a stormwater permit that regulates stormwater discharges from state highways and related facilities contributing to discharges from separate storm sewers owned or operated by WDSOT within the Phase I and II designated boundaries. WSDOT's permit also covers stormwater dischargest to any wterbody in Washington State for which there is an EPA approved TMDL with load allocations and associated implementation documents specifying actions for WSDOT stormwater discharges (applicable TMDLs listed in Appendix 3 of the current WSDOT permit). WSDOT's permit was issued in February 2009 and modified in May 2010[3].

Phase I and II municipal stormwaer permits will be re-issued in mid 2010. WSDOT's permit is expected to be re-issued in March 2014.

Ecology's next round of Phase I /Phase II municipal stormwater permits will be reissued in mid 2012. These permits are anticipated to include new requirements intended to minimize stormwater discharges from development and redeveloped areas to meet pre-developed, forested conditions. This will include a requirement to implement low impact development (LID) practices to the maximum extent feasible. This new requirement is intended to minimize the generation of new stormwater and should retain onsite a large percentage of the stormwater generated by the smaller storms that occur from June through September. Much of the existing storm sewer systems in outlying areas transport stormwater in grass-lined ditches that already infiltrate some stormwater. Where underground pipes are conveying stormwater, a cooling effect due to thermal exchange within those pipes is expected to moderate discharge temperature.

Discussion of Ecology's evaluation of thermal loading from stormwater in the Snoqualmie Watershed follows.

Current condition

Data gathered in 2006 show that stormwater has little if any warming effect on the temperature of streams in the Snoqualmie River basin. Information from the small tributary streams of Kimball, Harris, Griffin, Cherry, Tuck and Patterson Creeks and the larger South Fork Snoqualmie was explored to see if stream temperature increases after a storm.

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[3] For detailed information on municipal stormwater permits, see the following websites: www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIpermit/phipermit.html , www.duvallwa.gov/departments/publicworks/2007_npdes_swmp.pdf, and www.ecy.wa.gov/programs/wq/stormwater/municipal/wsdot/finalPermitdocs2009/wsdotPermitcorrections050109red.pdf

Table 31 shows that there were only three periods of rain measured during the summer months when the 07WEA10.0 weather station was in operation. The small storm event on August 29 and 30, where 0.2 inches of rain fell each day, was not large enough to have a stormwater effect on stream temperature.

Table 31. Rainfall and air temperature data from 07WEA10.0 station in Duvall.

Date	Maximum daily air temperature (°C)	Rainfall (inches)	Total storm (inches)
8/29/06	17.07	0.21	
8/30/06	17.73	0.23	0.44
9/13/06	16.66	0.03	
9/14/06	14.90	0.90	
9/15/06	15.83	0.14	1.07
9/18/06	18.38	0.61	
9/19/06	15.28	0.32	
9/20/06	12.40	0.27	
9/21/06	14.59	0.23	1.43

A second period of rain occurred September 13 through 15, and a third period from September 18 through 21. The two days between the September rain events were warm. Figure 54 shows water temperature for seven streams, air temperature, and rainfall for the nine-day period September 13 through 21. Regression analysis of the daily maximum stream temperature shows that four of the six small tributary streams decrease in temperature, while two, Harris and Griffin, slightly increase. Of these six streams, just Kimball Creek drains an area with large amounts of pavement nearby. The remaining small streams primarily drain farm land. Patterson Creek has a development with pavement several miles upstream of the thermistor.

Temperature decreased in most of the tributaries during the first portion of the nine-day period. Stations generally had an increase in temperature after the beginning of the rain storm on September 18, but this also could be due to warmer conditions on that day. Regardless, the water quality criterion is a 7-day average, and there was not a water temperature increase over 7 days. Temperature data gathered in the South Fork, which could be influenced by impervious surface from the city of North Bend, also followed this same pattern of overall reduction in temperature with a slight increase after the September 18 rain storm. All of the water temperatures measured during the nine-day period were below 16°C.

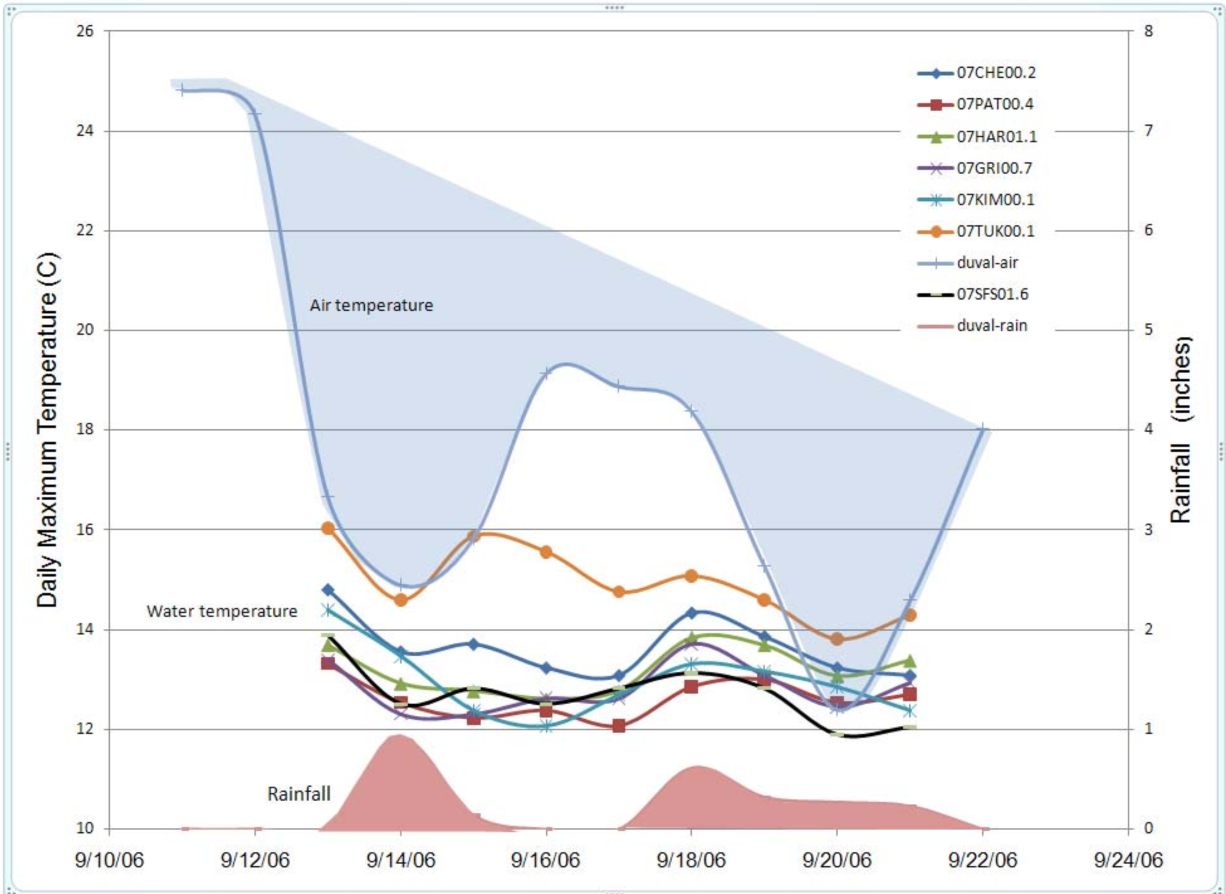

Figure 54. Tributary stream temperature during periods of rainfall, September 13-21, 2006.

Future condition

As growth occurs in the Snoqualmie River watershed and additional data on thermal pollution from stormwater is collected around Puget Sound, the larger stormwater discharges should be evaluated for contribution of heat to tributary streams in the watershed. Smaller discharges, those with flows less than 1% of the receiving water flow, are considered to have negligible individual impact on stream temperature. Additionally, direct stormwater discharges to the mainstem and Middle Fork Snoqualmie River are not large enough in comparison to the receiving water to raise water temperatures.

The highest water temperatures in western Washington typically occur in July and August. These temperatures are caused by a combination of weather conditions and lower summertime streamflows. Table 32 shows that average precipitation is extremely low during the hottest months of July and August, and thus generation of stormwater flow in large enough quantity to impact stream temperature is also extremely low.

Table 32. Air temperature and rainfall monthly averages for Snoqualmie Falls reported by the Western Regional Climate Center, October 1, 1898-April 30, 2010.

Red text highlights: period to focus on for potential stormwater impact to stream temperature.

	Jan	Feb	Mar	Apr	May	**Jun**	**Jul**	**Aug**	**Sep**	Oct	Nov	Dec	Annual
Maximum Temperature (F)	44.3	48.3	53.2	59.3	65.7	**70.6**	**76.7**	**76.1**	**69.7**	59.8	50.6	45.2	60.0
Minimum Temperature (F)	32.7	33.9	35.3	38.4	43.2	**48.0**	**50.9**	**50.8**	**46.6**	41.8	37.2	34.0	41.1
Total Precipitation (in.)	8.25	5.86	5.89	4.43	3.49	**2.84**	**1.31**	**1.49**	**2.97**	5.46	8.49	8.61	59.08
Total Snowfall (in.)	4.6	2.6	1.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.1	12.7
Snow Depth (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0

Percent of possible observations for period of record.
Max. Temp.: 99.1% Min. Temp.: 99.1% Precipitation: 99.3% Snowfall: 97.6% Snow Depth: 95.7%
Check station Metadata or Metadata graphics for more detail about data completeness.

Stormwater is also not a likely heat source during November to May. These months are typically much cooler and also typically have higher streamflow. Storms producing rainfall do not occur on the hottest days. Therefore it is expected that storm-generated flow will occur during periods that are cool enough to not impact stream temperature.

In the Snoqualmie River basin, June and September are the most likely months for stormwater to have an impact on water temperatures that could potentially exceed water quality criteria. In most watersheds, June streamflows are large enough to make it difficult for stormwater quantities to affect temperature. However, some smaller tributary streams have supplemental temperature criterion of 13°C in place through June 15. There is a potential for June stormwater to be warmer than this lower numeric criterion, but it is unlikely that prolonged rainfall will occur during these times to cause the applicable 7-day average criteria to be exceeded.

September streamflows are typically some of the lowest of the year and rainfall is also typically low (Table 2), but early fall rain storms could cause increased temperatures. Whether stormwater runoff is affecting stream temperature by 0.3°C would be determined using streamflow and stormwater flow volumes and the temperature difference between them. The standards also allow for a 1 in 10 year exception (e.g., they need to be met in 9 of 10 years). Any future wasteload allocations for stormwater sources of thermal-pollution allocation would likely only apply to discharges occurring during the critical summer (June – September) period.

Margin of safety

The margin of safety accounts for uncertainty about pollutant loading and water body response. In this TMDL, the margin of safety is addressed by using critical conditions in the modeling analysis. The margin of safety in this TMDL is implicit because of the following:

- The 90^{th} percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the Snoqualmie Falls Coop weather station #457773 (1949-2008) represents a reasonable worst-case condition for prediction of water temperatures in the Snoqualmie River watershed. Typical conditions were represented by the 45^{th} percentile of the highest 7-day averages of daily maximum air temperatures for each year of record.

- The lowest 7-day average flows during July-August with recurrence intervals of 10 years (7Q10) were used to evaluate reasonable worst-case water temperature conditions. Typical conditions were evaluated using the lowest 7-day average flows during July-August with recurrence intervals of 2 years (7Q2).

- The lowest 7-day average annual flows, which typically occur during September, with recurrence intervals of 10 years (7Q10) were used to evaluate reasonable worst-case conditions for discharge of point source effluent. Model uncertainty for prediction of water temperature was assessed by estimating the root mean square error (RMSE) of model predictions compared with observed temperatures. The average RMSE for model calibration and confirmation of maximum temperatures was 0.5ºC.

- Model bias evaluation shows no evidence of systematic over- or under-predicting of temperature. There also is no evidence that there is a trend in error over the length of the river.

- The load allocations are set to the effective shade provided by full mature riparian vegetation, which are the maximum values achievable in the Snoqualmie River basin.

Reasonable assurance

The goal of the Snoqualmie Temperature Water Quality Improvement Plan is for temperature-impaired waters to meet Washington State water quality standards. The Snoqualmie TMDL requires reductions of heat sources from both point and nonpoint sources. Ecology's water quality improvement plans must show "reasonable assurance" that these sources will be reduced to their allocated amount. The following rationale helps provide reasonable assurance that the implementation of BMPs to address nonpoint source TMDL goals will be met by the year 2022.

Ecology will control point source thermal loadings from NPDES-permitted wastewater treatment plants (WWTPs) as part of engineering plan review and approval as well as basic permit administration activities. Reclaimed water facilities are already in place at the Snoqualmie and Carnation WWTPs, and most of the effluent from those facilities is discharged to land during summer months.

There is also considerable interest and local involvement in riparian and instream restoration actions that will help reduce stream temperatures in the Snoqualmie River watershed. Ecology believes that the following activities already support this TMDL and add to the assurance that Snoqualmie River water temperatures, from nonpoint sources, will meet conditions provided by Washington State water quality standards. This assumes that the following activities are continued and maintained.

- Tulalip Tribes: technical assistance, research and problem identification, and special project support for riparian and instream improvement projects.
- Snoqualmie Tribe: technical assistance and special project support for riparian and instream improvement projects and watershed monitoring activities.
- Ecology: technical assistance, project development and coordination, Centennial Grant funding, State Revolving Fund Loan program, wetlands protection, regulation of NPDES permitted discharges.
- Stillaguamish/Snohomish Fisheries Enhancement Task Force: riparian planting and maintenance, instream restoration.
- Stewardship Partners: outreach, riparian planting project development, implementation, and maintenance.
- Partnership for a Rural King County: community outreach and interagency coordinator.
- King Conservation District: technical and financial assistance, project coordination.
- Snohomish Conservation District: technical and financial assistance, project coordination.
- Wild Fish Conservancy: landowner outreach, project development, and implementation for riparian plantings and instream rehabilitation.
- Seattle Public Utilities: instream restoration work on the Tolt River system.

- Snohomish Forum: technical assistance and funding for riparian restoration and instream improvements.
- Snoqualmie Forum: funding assistance to tribes, local governments, nonprofit organizations, and private landowners.
- King County Department of Natural Resources and Parks: regulatory authority, funding assistance, and direct support through fisheries protection, agricultural support, and invasive species removal services.
- King County Department of Development and Environmental Services: critical areas ordinance enforcement, Livestock Ordinance enforcement, wetlands protection.
- Mountains to Sound Greenway: education, special projects to improve riparian habitat.

The *Snoqualmie River Basin Fecal Coliform Bacteria, Dissolved Oxygen, Ammonia-Nitrogen, and pH TMDL: Water Quality Effective Monitoring Report* (Sargeant and Svrjcek, 2008) has already begun to educate the public about temperature problems in the watershed.

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

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

The goal of this plan is to achieve improved water quality through voluntary control actions. Ecology will consider and issue notices of noncompliance, in accordance with the Regulatory Reform Act, in situations where the cause or contribution to the cause of noncompliance with load allocations can be established.

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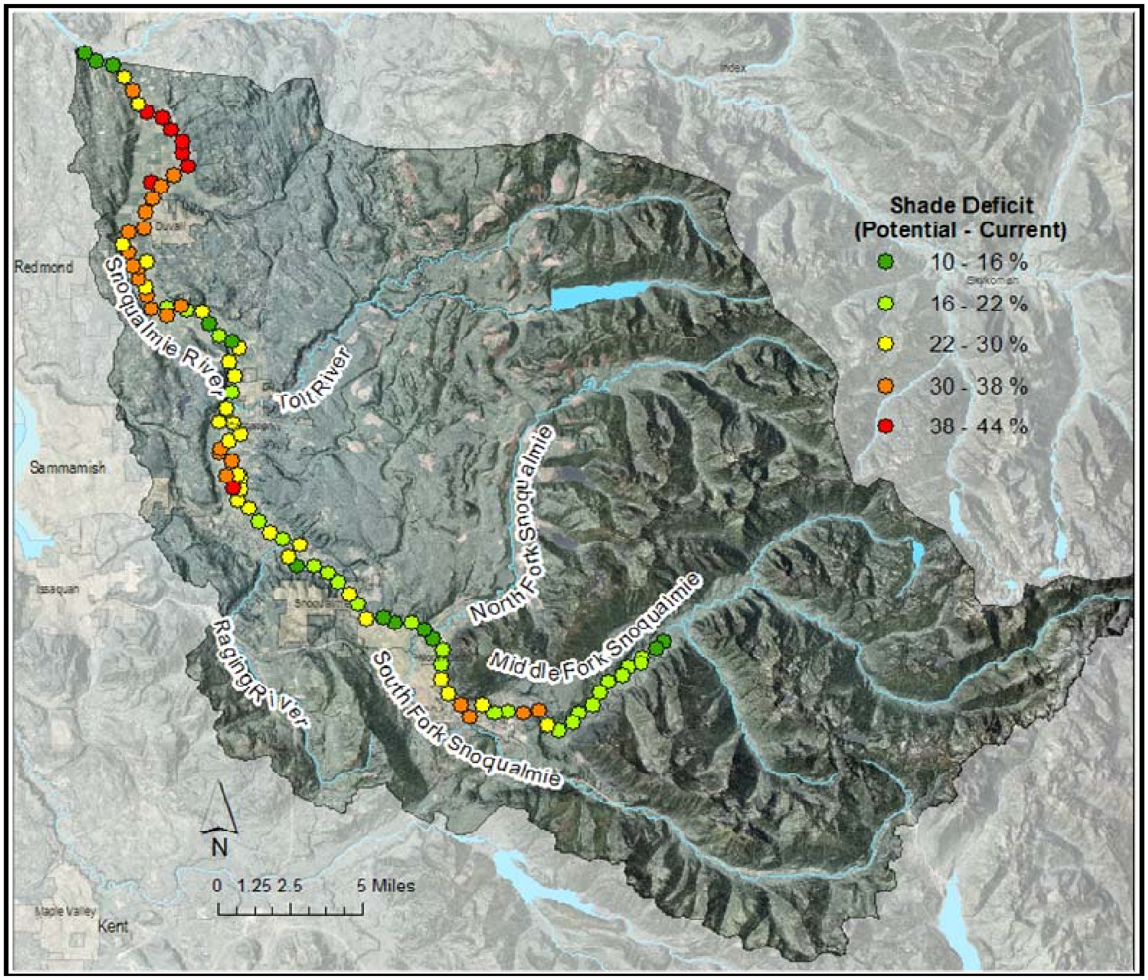

Figure 55. Additional shade is needed along the Snoqualmie River mainstem. *There are multiple reasons why the Snoqualmie River is not receiving maximum shade. In some cases trees are present but need to grow taller. Sometimes the buffer size is smaller than 150 feet. In most cases below Snoqualmie Falls, there are no trees along the river at all. Because the Snoqualmie is a wide river, even the largest trees can only provide shade 50% of the time.*

Implementation Plan

In the first part of this report, Ecology described the Snoqualmie Temperature TMDL study, its findings, and its conclusions. In the past, we published this type of information along with an *implementation strategy* and submitted it to the U.S. Environmental Protection Agency (EPA) for approval. Then, following EPA's approval, we worked with interested and responsible parties to develop a water quality implementation plan. However, our new approach is to save time and resources by combining these two processes. This portion of the report constitutes the Snoqualmie River TMDL Water Quality *Implementation Plan*.

This TMDL applies to the entire Snoqualmie River watershed shown in Figure 55, with the exception of U.S. Forest Service lands. Our study documented that water temperatures throughout the Snoqualmie watershed far exceed state standards during summer. As shown in Figure 55, the shade deficits for the mainstem river are very high. Approximately 900 acres of the Snoqualmie mainstem need to be planted with trees. Over 90 % of that need occurs below Snoqualmie Falls in the floodplain. Additional plantings are needed along tributary streams.

There are actions we can take to cool Snoqualmie waters. Local governments and other organizations worked together to compile those actions in this *implementation plan.* There is no single solution to improving water quality in the Snoqualmie watershed. Everyone will need to pitch in to solve the problem. If you want to know how you can help, the best place to start is right in your own backyard. To help even more, read about what your local government is already doing and how you can help them work for you. If you have a small farm, or a special interest in fish or wildlife, read about the activities sponsored by the organizations discussed below to get more involved.

The goal of this implementation plan is to support the local community and the local aquatic resources in the Snoqualmie watershed. The single most important thing that needs to be done is to improve the shading of waterways. Cooling water temperatures should be gradually realized from 2020 through 2071 and beyond as existing and newly planted vegetation grows larger and creates more shade. The quickest gains will occur in tributary streams where the time needed to provide complete shade can be as short as five-ten years in some locations.

What other plans to improve water quality are in place now?

Over the past decade, several salmon recovery and water quality plans have discussed actions to improve Snoqualmie water temperatures: *Snohomish River Basin Chinook Salmon Near-Term Action Agenda* (SBSRF, 2001), *Snohomish Basin 3-year Plan* (2009 update, SBSRF, 2009), the *Snohomish River Basin Salmon Conservation Plan* (SBSRF, 2005), *Snoqualmie 2015* (SWF, 2006), *Snoqualmie River TMDL Effectiveness Monitoring Report* (Sargeant and Svrjcek, 2008), and the *Snoqualmie Watershed Water Quality Synthesis Report* (Kaje, 2009). This Plan builds on those efforts to provide additional detail to target water quality improvement work.

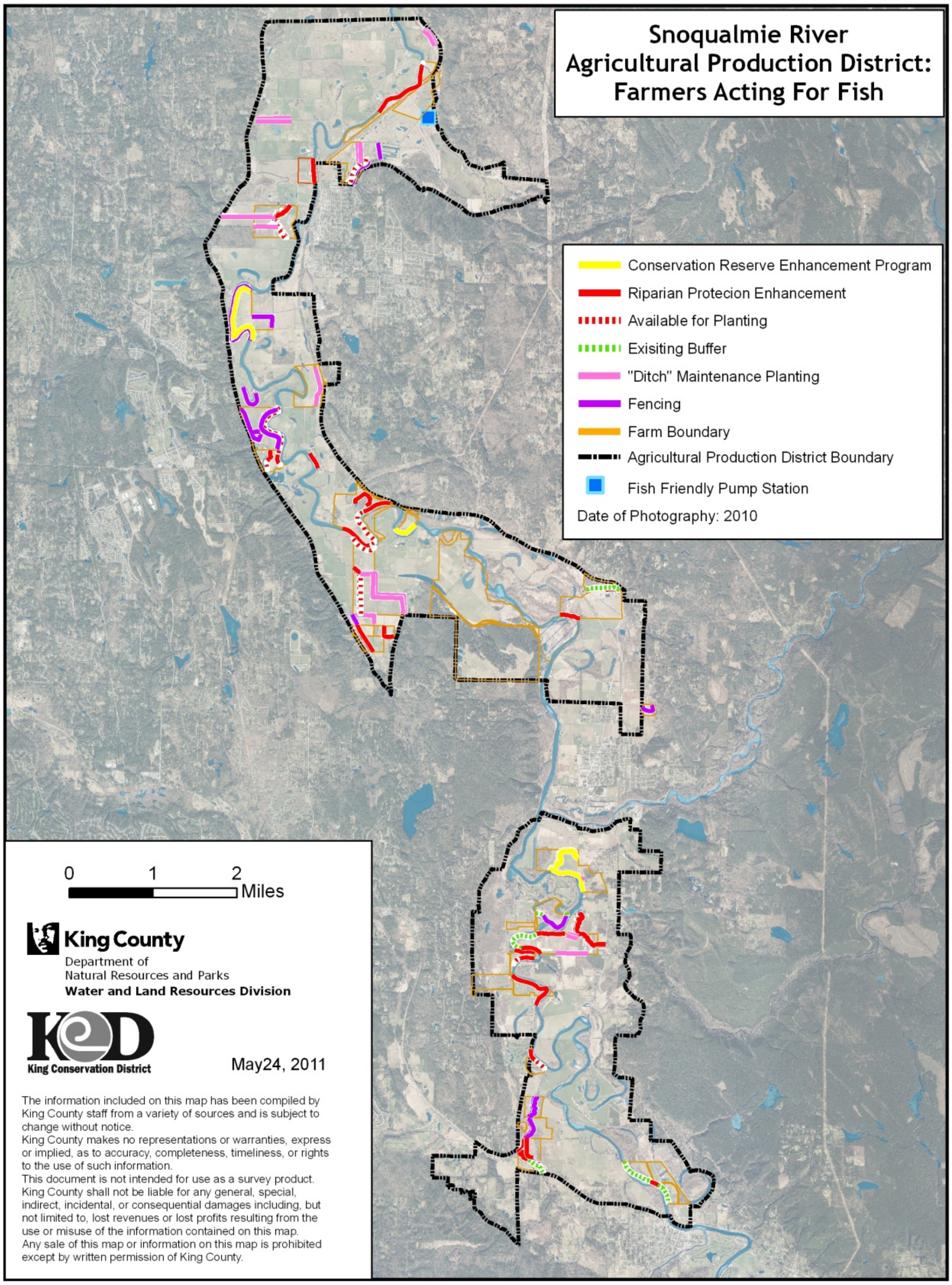

Figure 56. Snoqualmie Farmers Acting for Fish. *Twenty-five farms in the Snoqualmie Valley are already working to improve riparian conditions. Over 13 miles of mainstem and tributaries have been planted and 5 miles are available to be improved.*

Many actions identified in salmon recovery plans will also help to improve water temperature. Similarly, actions that reduce summer water temperatures will also benefit salmon populations. Projects in the Snohomish Basin three-year workplan for 2010 that can help improve water temperatures in the Snoqualmie watershed are incorporated in the text of this implementation plan and the Activity Tracking Table in Appendix I.

The agricultural community has been working with a variety of government and private organizations to improve water quality in recent years. Twenty-five farms are working with King County, the King Conservation District, and Stewardship Partners to provide over 13 miles of the riparian vegetation needed to improve Snoqualmie water temperatures (Figure 56).

How are fish affected?

Because state standards for temperature are designed to sustain healthy fish populations, it is helpful to know how high temperatures affect fish and where fish are likely found during the summer.

Ecology reviewed the effect of high temperatures on spawning and rearing salmonids and found that reduced fish survival can occur in many ways (Hicks, 2002). In the weeks immediately preceding spawning, temperatures above 14-16°C can reduce the health of the eggs and sperm in adult fish. Various studies showed reduced survival of eggs when prespawn chinook and steelhead experience holding temperatures above state standards. Migration can be impaired when average temperatures exceed 15°C and maximum temperatures exceed 18-20°C.

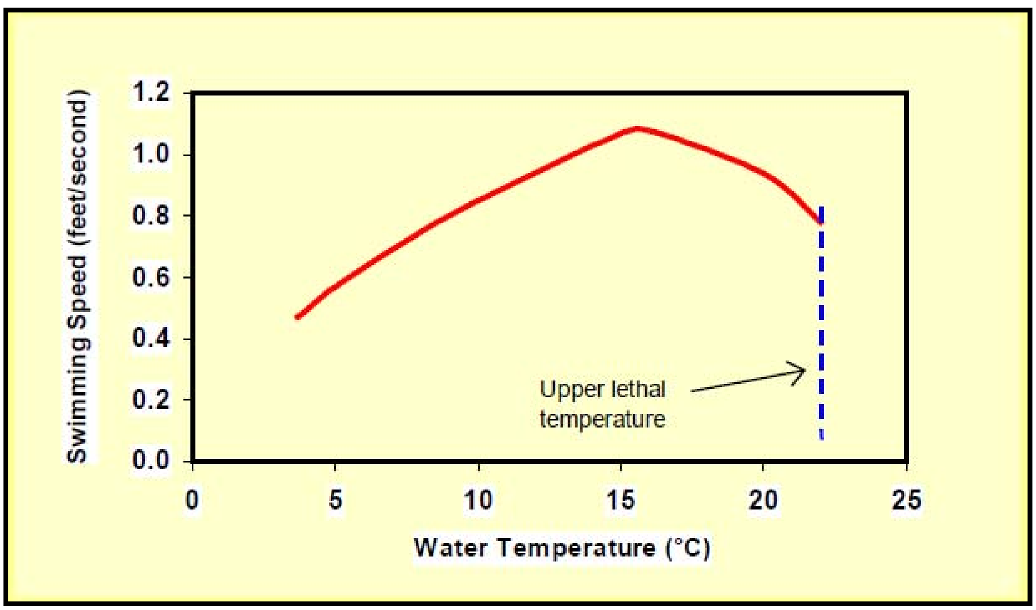

Figure 57. Warm water makes juvenile salmon vulnerable to predation. *The swimming speed of juvenile salmon decreases when water temperatures exceed 15°C. Warmer water also accelerates the metabolism of predator fish, increasing their ability to prey upon juvenile salmon (adapted from Brett, 1958).*

Temperatures above 21-22^{o}C have blocked migration completely. Single day peak temperature of 24-25^{o}C is capable of killing salmonids that have not been well acclimated. Warm water diseases increase the risk of losses to both migrating adults and rearing juveniles when temperatures rise above 17-18^{o}C. Special consideration is also required to protect spawning and incubation of salmonid species. Constant temperature in the range of 8-10^{o}C and a daily maximum temperature below 13-15^{o}C are necessary to ensure fertilized eggs have high survival success and the embryos develop properly (Hicks, 2002). Warmer water also accelerates the metabolism of predator fish, increasing their ability to prey upon juvenile salmonids (Figure 57, Brett, 1958).

What fish are present during the summer critical period?

In the Snoqualmie watershed, summer and fall chinook adults, summer steelhead adults, 0-year stream type chinook juveniles, coho juveniles, and steelhead juveniles can be expected to hold or rear in the watershed during the warmest periods of the year. The following discussion of how salmon utilize fresh waters during summer months comes largely from a literature review prepared by Lestelle et al. 2005 and provides good information to help us understand the general usage pattern of chinook and other salmonids in Pacific Northwest streams.

During the summer rearing period chinook juveniles tend to migrate from backwater pools to low velocity areas within main channels and migrate to pools during the night. Steelhead fingerlings are likely to follow stream use patterns similar to chinook. Coho juveniles rear in lower-energy environments generally found in tributary streams. Rearing is not limited to natural, pristine rivers and tributaries; for example, thousands of coho have been observed rearing in agricultural drainage waterways during the summer in the Snoqualmie floodplain.

When high temperatures and low dissolved oxygen (DO) levels are occurring in natal rearing areas, these patterns can be expected to change. In one study on the Columbia river, 0-year stream type chinook were observed to use non-natal streams for rearing in the John Day River system, presumably to escape high temperatures in favor of cooler water (Lindsay et al., 1985). Studies have shown juvenile chinook presence from 0.25 to 10 miles upstream in non-natal tributaries (from Lestelle et al., 2005). Thus, where high temperatures or other poor water quality conditions are observed in the Snoqualmie system, it seems logical that fry might also relocate to areas of the watershed that provide a better combination of basic rearing needs.

Summer and fall chinook adults, and summer steelhead trout adults may also be present in the Snoqualmie Watershed during the warm summer months.

What fish are present during the spawning season?

Salmonid spawning in the mainstem Snoqualmie River occurs in the gravel riffles below the confluence with the Tolt River (RM 24), at the confluence with the Raging River (RM 35), and in a section of channel below Tokul Creek (RM 38). These mainstem spawning areas are the same areas supplied with coarse sediment from the Tolt and Raging rivers and Tokul Creek. Chinook and steelhead spawning are concentrated in these areas and in the lower Raging and Tolt Rivers (Solomon and Boles, 2002).

Pink and chum salmon spawn in the lower Tolt River as well. Pink salmon have historically spawned in the Raging River and some still do. Most coho spawning and some steelhead spawning occurs in the tributary rivers and streams. Anadromous fish do not travel above Snoqualmie Falls. However, resident populations of cutthroat, rainbow, and brook trout can be found above the falls. Native char were found historically as well (Pentec Environmental and NW GIS, 1999). More detailed information on specific spawning locations within the watershed and information on steelhead can be found in Solomon and Boles (2002) and the Limiting Factors report (Haring, 2002).

How can we improve Snoqualmie water temperatures?

Both the TMDL study and other accepted scientific research on stream temperatures tell us that a substantial increase in shading over Snoqualmie watercourses will result in cooler water temperatures. The scientific literature also confirms that a number of factors, including air temperature; shading; elevation; surface hydrology; channel shape and complexity; and connectivity to ground water combine to influence stream temperature (Poole and Berman, 2000). This implementation plan relies upon a number of core methods of improving stream temperatures (Table 33).

Table 33. Key strategies for improving stream temperatures.

Strategy	Description
Restore riparian shading and the supply of large wood	Planting native vegetation where buffers are lacking is a priority. Trees provide a direct temperature benefit by creating shade. In some locations they provide indirect benefits related to air cooling, supplying woody debris, and eventual narrowing and deepening of the stream channel. Big trees in riparian areas eventually fall down and improve stream processes that help keep water cooler.
Control erosion and sedimentation.	Streams that are wide and shallow due to upstream erosion and sedimentation are susceptible to warming and should be investigated to determine the causes of erosion and sources of sediment. Eroding streambanks and poorly managed upland areas should be addressed through appropriate riparian restoration and improved land management.
Reduce surface water use during late-summer, lowflow conditions.	Even though instream flows and water withdrawals are managed under a state regulatory program, this common-sense advice can lead to more water in local watercourses. More water usually means cooler water.
Maintain/increase cool groundwater inputs during summer months.	Protecting/enhancing wetlands and infiltrating stormwater can help maintain or improve groundwater levels. Where groundwater from wetlands and other sources is available near a stream, the strategic installation of large wood structures can connect it to a stream or river. Scour pools created by large wood structures create cooler, deeper pools that can tap into groundwater. Another strategy is to restore or augment hyphorheic exchange where warm water temporarily seeps into the stream bed only to emerge downstream after being cooled during its subsurface travel.
Limit thermal loading point sources.	The wastewater treatment plants and fish hatcheries operating in the Snoqualmie Watershed are considered "point sources" of pollution. Ecology regulates these facilities to ensure their thermal discharges are controlled.

The Snoqualmie Watershed is home to farming, rural residential living, forestry activities, and four urban centers. Activities that cool local waters benefit both people and fish. The ways in which we can work together to improve watershed conditions are discussed in more detail in the following paragraphs, for each of these areas.

Actions for residential properties

Residential properties throughout the watershed provide opportunities to improve water temperatures in local streams. Following are the most common ways to help improve water temperatures in the Snoqualmie Watershed.

- *Establish or maintain good riparian vegetation:* For homeowners living next to water, it is important to plant native trees and shrubs that provide as complete shade as possible to the neighboring water body. If a property is being developed for the first time, county or city government will have set the minimum buffer size that should remain around the stream. For established properties where trees were removed in the past, it is important to replant next to a stream. Plant enough trees to maximize shade over the water.

  Tree height and density work together to prevent solar radiation from reaching the water. As noted in the technical portion of this TMDL, large buffers will significantly lower air temperatures around a stream and provide an added dimension of cooling. Each property owner must determine what is optimal for their situation. This TMDL recommends that the local conservation district or one of the nonprofit groups discussed later in this document be contacted to develop a planting plan and perhaps assist in the funding and planting of native plant species.

- *Infiltrate stormwater on your property:* Nearly all residential properties have the ability to infiltrate water that lands on them. The water you store in the ground will charge local groundwater supplies that support our long-term drinking water needs, as well as supply water to local springs and streams during the dry summer months. Infiltrating stormwater can help remove pollutants and help minimize flood frequencies.

  Individual land owners should examine stormwater pathways on their properties and assess the feasibility of infiltrating stormwater onsite to maintain local groundwater levels and reduce the potential for creating contaminated stormwater. Property owners can use an abundance of Low Impact Development (LID) tools, including harvesting and infiltrating rain water with rain barrels, installing bio-swales, replacing lawn grass with native species or a rain garden, augmenting lawn soils to improve water absorption, and replacing paved areas with gravel or permeable concrete. Riparian buffers also infiltrate and slow down stormwater. Information on these different LID options is available through Snohomish Conservation District, King Conservation District, Stewardship Partners, Puget Sound Partnership, and most local governments.

Figure 58. Riparian Restoration in the Snoqualmie Watershed. *Many landowners along the Snoqualmie River and its tributaries are working to make the river safe for people and fish. This newly planted riparian area along the mainstem Snohomish is getting good care by Stewardship Partners who are working with landowners to establish healthy riparian areas*

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

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

  In King County, the number of livestock and the manner in which they are regulated is detailed in the King County Livestock Ordinance (King County Code 21A.30) to make sure that polluted rainwater runoff does not reach local waters. King County requires livestock to be fenced a minimum of 25 feet away from water bodies. In Snohomish County, Water Pollution Ordinance (Snohomish County Code 7.53) requires best management practices (BMPs) described in appropriate stormwater prevention plans. In both cases, the need to plant trees in riparian areas is not specifically discussed in the ordinances, so landowners must be sure to include this in the design of animal grazing areas.

Small farms should receive periodic technical assistance visits from the King or Snohomish Conservation District to ensure BMPs are being followed. Technical assistance visits to new landowners are especially important when livestock properties change ownership.

Actions for agricultural lands

Agriculture is essential to our community and economy. Farmers and landowners in the Snoqualmie Agricultural Production District are among the most important partners for making the Snoqualmie watershed healthy for people and fish. Rural watersheds offer the best hope for improving badly damaged fish habitat. It is understandable that many farmers are conflicted by the need to shade local waters versus the need to maximize available sunlight and growing area on their land. Similarly, local regulators are conflicted because the activities that assist farmers (draining of groundwater by use of ditches and drain tiles, removal of trees that provide shade to streams) can result in a loss or degradation of fish habitat.

Like most human activities, farming activities can have negative impacts on the environment. The removal of riparian trees increases water temperatures. In many locations, drain tiles have been installed and watercourses are managed to collect and remove groundwater more quickly than would normally happen. Although this TMDL did not study changes in groundwater movement due to agricultural activities, it is assumed that ditching activities change the amount, timing, and location of beneficial subsurface groundwater releases to surface waters.

Figure 59. Shade keeps reed canary grass in check. *Farmers in the Snoqualmie River Watershed battle reed canary grass in their drainage systems as shown in the picture to the left. However, shade provided by relatively low growing trees (e.g., willows, dogwood) can reduce or eliminate reed canary grass growth. Trees can thus help farmers reduce maintenance costs, while also helping to keep local waters cool for fish.*

Fortunately, the actions detailed in this TMDL can also benefit farmers while they help mitigate some of the negative impacts. Trees planted to shade agricultural watercourses will help keep water cool after it leaves the ground and becomes fish habitat. That same shade reduces the cost of future maintenance to farmers by controlling reed canary grass growth. Vegetation also stabilizes stream banks and reduces the loss of land to erosion during high-flow events. Trees and shrubs also provide habitat for birds and other insectivores that help to keep pests in check. Reducing the frequency of maintenance also lowers Ecology's concerns regarding the increased potential for turbidity violations due to regular, repeated maintenance activities. Listed are the most common opportunities for farmers to improve water temperatures in the Snoqualmie Watershed.

- *Establish or maintain good riparian vegetation*: It is important to plant trees that provide as complete shade as possible to the neighboring water body. Although this TMDL calls for tall trees and large buffers, Ecology recognizes that this is impractical for some tributary watersheds where agricultural activities are performed. In addition, planting large, tall native species that would typically be established in farming areas poses a significant challenge for the relatively small farms found in the Snoqualmie watershed. Benefits that come from dedicating part of an agricultural property to riparian plantings include control of reed canary grass and associated reduced maintenance costs and increased positive pollinators. Trees can also act as natural "flood fences" that can trap flood-borne debris and reduce the cost of debris removal following a flood event.

  This TMDL recommends farmers plant the largest reasonable buffer possible. The mainstem Snoqualmie needs large trees with wide buffers. Only large trees can make a difference shading and providing microclimate effects to the mainstem, which is typically 150 feet wide. Large trees along the mainstem Snoqualmie can benefit the farming community by helping to stabilize the river's present location and prevent excessive erosion of banks and loss of farmland. Although the Snoqualmie River mainstem has a relatively slow channel migration rate, the effect of a significant change in river location would be great for individual farms. The USDA Conservation Reserve Enhancement Program (CREP) provides payments to farmers to assist in the financial impact of losing arable land when improving riparian vegetation.

  Within tributary watersheds, farmers manage watercourses that are much smaller than the mainstem river, typically less than 10 feet wide. That makes the job of shading them much easier. Because mature trees along tributaries can make a difference quickly, plantings in these areas are a very high priority. Farmers should provide complete, high-density shade for all tributary watercourses. Additional research is needed to determine the best way to get complete shade on smaller water bodies. This TMDL recommends additional research during the implementation phase to examine the best tree combinations for maximizing shading while minimizing buffer widths and crop impact in agricultural production areas. At this time, our implementation goals for riparian plantings are as follows:

  - **Tributary mainstems**. Whether natural or modified, most tributary mainstems should have the largest possible riparian buffer, no less than 35' on each side of the stream. Tree height should be large enough to provide full stream shade with good density.

- o **Tributary sidestreams**. All watercourses that actively flow during the summer dry season must have complete shade. Buffer widths and tree species should be determined in consultation with the Washington Department of Fish and Wildlife in conjunction with the Snohomish Conservation District, King Conservation District, or other qualified governmental or nonprofit entity.

- *Infiltrate stormwater on your property:* Landowners should strive to manage all the rainwater that falls on their property. Nearly all rural residential properties have the ability to infiltrate all the water that lands on them. Water stored in the ground will charge local groundwater supplies that support our long-term drinking water needs, as well as supply water to local springs and streams during the dry summer months.

- *Added protections are needed where livestock are present*: As discussed earlier under *Actions for Residential Properties*, livestock owners need to establish and protect riparian vegetation (see previous detailed recommendations). Landowners leasing land to cattle ranchers should ensure that fencing erected, or provided, is preventing damage to riparian areas. All professional livestock-rearing operations should obtain a farm plan and fully implement all water quality elements of that plan. In order to protect water from excessive solar radiation, all farm plans should contain planting plans that will result in complete shade for tributary water bodies.

- *Restore wetlands where feasible:* Wetlands store water and slowly charge groundwater supplies during dry weather periods. In marginal agricultural lands where crop yields are poor, farmers are encouraged to work with private entities or government agencies with programs to provide positive community benefits by wetland restoration.

Actions for forestry areas

Figure 60. Tracking Forest Practice Rule Compliance. *State forestry experts evaluate planned and ongoing forest practices to help ensure adequate riparian buffers and prevent sediment delivery to state water. (photo courtesy of WDNR)*

Historic forestry practices may have made many rivers more susceptible to warming by making them shallower, and wider, and by reducing channel complexity. Reductions in forest cover and in-channel woody debris can lead to increases in the number and intensity of high flow events. This in turn increases bank and bed erosion, which widens stream channels.

Sediment input from the resulting erosion and from unstable logging roads can make the problem worse by depositing sediments such that the channels become more shallow. Poorly designed and maintained roads placed along streams increase the frequency of landslides and further sediment influx and channel scouring events.

It is unclear whether or not the active channels of the mainstem Snoqualmie or the upper forks have widened as a result of logging of riparian forests. Ecology reviewed Government Land Office (GLO) maps of the Middle Fork and could not detect significant changes in channel morphology, so any effects that may have occurred are not readily observable.

In the Snoqualmie mainstem floodplain, it is similarly unclear how sediment deposition may be affecting river morphology and water temperatures. Because post-glacial deposition by the river naturally built up the river and its meander belt, the banks sit as much as six feet above the valley floor (Solomon and Boles, 2002). The many levees, revetments, and bank hardening activities along the Snoqualmie ensured that large portions of the river are contained within its present boundaries and reduce the ability of sediments to be deposited during many higher flow events.

Ecology evaluated orthophotography of the 150 foot buffer surrounding each side of the Middle Fork Snoqualmie above the city of Snoqualmie from RM 55 to RM 75 to identify opportunities for riparian plantings. Although riparian tree heights above RM 60 (NFS lands) could not be determined, no bare or treeless areas were observed within the 150 foot buffer. Below National Forest System (NFS) lands, where Ecology field studies documented riparian vegetation types, we observed very little non-treed riparian area along the mainstem. An orthophoto analysis of the North and South Fork mainstem riparian areas indicated similarly good protections. Mature tree heights, verified using LIDAR data, have not been achieved along much of the area between RM 60 and RM 55 of the mainstem. About 40% of riparian vegetation along the mainstem Snoqualmie and Middle Fork above Snoqualmie Falls was designated as being either small or medium sized trees. Thus, trees are largely in place and should be expected to provide more shade in the coming decades.

Forest management regulations

The proper management of federal, state, and private forest lands is critical to controlling high water temperatures in the Snoqualmie Watershed. However, this plan places most emphasis on correcting riparian vegetation problems where no other existing federal or state plans are in place. Several forestry management plans are in place now and are under active management by state and federal governments. These management strategies are discussed below. Although these other plans are in place, land managers within the basin should refer to this implementation plan in the ongoing management of forestlands and in any revision of existing regulations and agreements.

The state's forest practices regulations will be relied upon to bring waters into compliance with the load allocations established in this TMDL on private and state forest lands. This strategy, referred to as the Clean Water Act Assurances, was established as a formal agreement to the 1999 Forests and Fish Report (http://www.dnr.wa.gov/Publications/fp_rules_forestsandfish.pdf).

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

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

Consistent with the directives of the 1999 Forests and Fish agreement, Ecology conducted a formal ten-year review of the forest practices and adaptive management programs in 2009[4]. Ecology noted numerous areas where improvements were needed, but also recognized the programs provide a substantial framework for bringing the forest practices rules and activities into full compliance with the water quality standards. Therefore, Ecology conditionally extended the Clean Water Act assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific milestones for program accomplishments and improvement. These milestones were designed to provide Ecology and the public with confidence that forest practices will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

The Snoqualmie Temperature TMDL Study did not analyze the effect of clearcutting and other forest management practices on basin hydrology and resulting surface water temperature effects. However, the adaptive management process for the Forest Practices Rules includes research being conducted by the Cooperative Monitoring, Evaluation, and Research Committee (CMER)[5]. Among their work is research on the effect of forest management strategies on stream temperature, sedimentation, and hydrology.

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

- **Private forests and state trust land*s:*** Private forest landowners must follow the Forest Practices Rules (FPRs, Chapter 76.09 RCW). The FPRs are regulations adopted by the Forest Practices Board that establish minimum guidelines for timber harvesting and riparian forest management. Riparian management zones are established along all perennial streams where silvicultural activities are restricted to protect shade and large woody debris at levels that meet the water quality standards and protect the stream's ecological functions[6]. The

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[4] See http://www.ecy.wa.gov/programs/wq/nonpoint/ForestPractices/CWAassurances-FinalRevPaper071509-W97.pdf

[5] More information on CMER activities is available from the Washington Department of Natural Resources at http://www.dnr.wa.gov/BusinessPermits/Topics/FPAdaptiveManagementProgram/Pages/fp_am_program.aspx

[6] Detailed descriptions of different riparian scenarios for private forest lands are available in the Forest Practice Rules (Timber Harvesting section, 222-30); stream type descriptions are also in the forest practice rules (Definitions section, 222-16) available online at http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_rules.aspx

widths of Riparian Management Zones (RMZ) are based on the soil site class (its ability to grow trees), and varies from 90-200 feet. Management within the RMZ is strictly controlled by a complex set of forestry prescriptions established in the state forest practices rules. Although the rules will allow management (thinning) to within 50 feet of the water, along most fish-bearing streams a 101 to 118 foot wide no-entry buffer is established. Along major rivers such as the Snoqualmie, these buffers would be established outside the channel migration zone, which typically has the effect of making the buffers substantially wider.

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

State Trust Lands are subject to the *State Lands Habitat Conservation Plan* (HCP). The State Lands HCP is a multi-species agreement that ensures management activities on State Trust lands will not result in degradation of habitats that are important for federally listed species. This agreement establishes alternative harvesting prescriptions for State Trust lands that are believed to provide equal or greater protection than those required for private forestry operations. Buffer widths along watercourses depend on the stream type[7]. Fish bearing streams have a site index buffer applied. The width of a site index buffer depends on the productivity of the soil, and is equal to the height the site dominant tree species is expected to get in 100 years. Currently, under the HCP, some silvicultural activities are allowed within the riparian management zones if the stand does not meet the desired future condition. Where riparian zones will be entered, a core zone of 25 feet on each side of the stream is considered a no touch area, and is not subject to any management practices. Within the remaining buffer area, thinning can occur, as well as creation of downed woody debris and snags. These activities are to be designed based on site specific conditions so as to have a positive influence on the stream itself, as well as on the riparian ecosystem and the species, which rely on it.

- **National Forest System lands:** The U.S. Forest Service (USFS) is the designated management agency for meeting federal Clean Water Act requirements on National Forest System (NFS) lands. Under a Memorandum of Agreement between the USDA Forest Service (Region 6) and Ecology (USDA and WDOE, 2000), the Forest Service has agreed to manage all waters on NFS lands so as to meet or exceed water quality standards, laws and regulations, and that activities on NFS lands will be provided with a level of protection consistent with those applied on private and state forests in Washington. The Forest Service is presently not in compliance with the road maintenance requirements of the MOA.

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[7] For a description of what occurs on State Lands, refer to the State Lands HCP, found at http://www.dnr.wa.gov/ResearchScience/Topics/TrustLandsHCP/Pages/lm_hcp_trust_lands_report.aspx

The Snoqualmie Ranger District of the Mt. Baker-Snoqualmie National Forest (MBS) manages lands under its jurisdiction within the Snoqualmie River subbasin according to direction in pertinent management documents. The *MBS Land and Resource Management Plan* was signed in 1990 (MBS, 1990) and amended in 1994 by the Record of Decision for Amendments to the Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl (USDA FS and USDI BLM, 1994), also known as the *Northwest Forest Plan* (NWFP). These two documents establish goals and objectives, standards and guidelines, and a system of management areas and land allocations for NFS lands managed by the MBS.

The purpose of the *Northwest Forest Plan* is to move National Forest management, in the range of the Northern Spotted Owl, into a more ecosystem and science-based approach. The objectives of the NWFP are as follows:

- Meet requirements of existing laws and regulations.
- Maintain a healthy forest ecosystem, including riparian areas and waters, with habitat that will support populations of native species (particularly those associated with late-successional and old-growth forests).
- Maintain a sustainable supply of timber and other forest products that will help maintain the stability of local and regional economies on a predictable long-term basis.

Restoration of stream temperatures and sediment regimes on National Forest System lands in the Snoqualmie Watershed rests heavily on implementation of the NWFP standards and guidelines, and specifically, on the *Aquatic Conservation Strategy (ACS)*. The ACS is intended to maintain and restore ecosystem health, preventing further degradation and restoring habitat over broad landscapes instead of small watersheds or individual projects (USDA FS and USDI BLM, 1994). Implemented as envisioned, this would protect aquatic and riparian-dependent species and resources, and restore degraded habitats.

Recommendations for federal, state, and county forest managers

Although NFS lands are not covered by this TMDL, and state and private forest lands are managed under other authorities, this TMDL has the following general recommendations for forest managers to promote the improvement of Snoqualmie Watershed water temperatures:

- ***Establish or maintain good riparian vegetation:*** Where significant portions of riparian buffers are found to be poorly vegetated (such as with grasses, shrubs, or invasive species), riparian restoration and replanting with appropriate native species is needed. Due to the prevalence of wetlands of a number of areas, the restoration of forested wetlands should be evaluated where applicable.

- ***Provide treatment for logging road systems:*** Proper attention to the state of logging roads and their drainage facilities is needed to prevent sediment delivery to the watershed. Older roads, sediment control structures, and stormwater conveyance systems should be evaluated for maintenance, removal, or decommissioning.

- *Evaluate large scale land use changes from forestry activities:* Large scale land use changes from forestry activities affect watershed hydrology. Changes in interflow, groundwater storage, and surface runoff can occur from the construction of roads and clearing of land associated with forestry activities. It is expected that existing forestry management rules and plans will consider this impact on water quality as they are revised. About half of the watershed above Snoqualmie Falls is managed by the U.S. Forest Service. Approximately 20 % of this upper watershed area is comprised of state owned forest lands.

- *Continue to monitor and improve compliance with established management plans:* The WDNR Forest Practices Compliance Monitoring Report for 2008/2009 (WDNR 2011) reported that road-related compliance was 79 % and riparian/wetland activities were 78 % compliant. Stream typing, which determines the size of a riparian management zone, was largely accurate but 8% of fish-bearing streams should have received larger riparian management zone (RMZ) buffer widths, indicating a need for more field verification of small fish bearing and perennially-flowing nonfish-bearing streams. The report listed several actions that could improve water typing: 1) assure that procedures are followed by requiring that Forest Practices Applications be submitted with a Water Classification Worksheet or description of how the water type was determined, and 2) increase the rate of field reviews by the various agencies for proposed water type modifications.

- *Continue Forestry Improvement and Protection Programs:* King County's Forestry Program provides education, technical assistance, and economic incentives aimed at retaining the forest resources of King County. The County provides free assistance to forest property owners to help them meet their individual goals for growing a healthy forest, enhancing timber quality, improving wildlife habitat, and protecting water resources. The Forestry Program recently received federal funding to support the *Stewardship in Action* project in the Raging River and Patterson Creek watersheds. Forestry program elements that promote healthy basin hydrology and riparian enhancement or protection are expected to contribute to the long-term goal of improving water temperatures in the Snoqualmie Watershed.

Actions for municipalities

Municipalities have a major role in improving Snoqualmie water temperatures. Their roles as a regulator, purveyor of stormwater and wastewater services, manager of public properties, and general educator of the public contribute to the protection and restoration of water quality. The following are key activities municipalities can take to protect the Snoqualmie and its resources:

- *Establish or maintain good riparian vegetation on public and private properties:* Municipalities are encouraged to request Ecology's GIS data for mainstem riparian vegetation types and use this information in conjunction with other efforts to identify properties needing more trees in riparian areas within their jurisdiction. Outreach programs to work with local residents are encouraged where needed. Public properties needing better riparian vegetation should be identified and scheduled for planting at the earliest date and no later than five years from the date this TMDL is approved.

- *Infiltrate stormwater to the maximum extent practicable:* Roofs, roads, and parking lots increase the potential for adverse impacts from impervious surfaces. Impervious surfaces prevent the natural processing of stormwater and recharging of groundwater. Infiltrating stormwater helps maintain or restore natural hydrologic processes that support stream flows during summer. The proper infiltration of stormwater also helps prevent surface water pollution problems. Since much of the Snoqualmie watershed is forested, farmed, or has rural densities, hydrologic alterations are less dramatic than the more urbanized portion of Puget Sound. However, the increase in impervious surfaces that accompany growing populations in North Bend, Snoqualmie, Fall City, Sammamish, Carnation, and Duvall can still threaten natural hydrologic processes.

This plan recommends that state and local governments work together to advance the use of Low Impact Development (LID) practices in new development, redevelopment and retrofit projects. Low impact development is a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions (PSAT, 2005). Ideally, site planning and stormwater management are integrated at the initial design phases of a project to maintain a more hydrologically functional landscape. Municipalities not covered under Ecology's Phase II Municipal Stormwater Permit are encouraged to adopt the elements of those permits that will improve or protect local water quality.

- *Operate wastewater treatment plants to consistently meet permit conditions:* All of the wastewater treatment plants located in the Snoqualmie watershed have good compliance records and should keep up the good work.

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

  TMDLs should be considered during State Environmental Policy Act (SEPA) and other local land use planning reviews (www.ecy.wa.gov/biblio/0806008.html). If the land use action under review is known to potentially impact temperature as addressed by this TMDL, then the project may have a significant adverse environmental impact. SEPA lead agencies and reviewers are required to look at potentially significant environmental impacts and alternatives and to document that the necessary environmental analyses have been made. Land use planners and project managers should consider findings and actions in this TMDL to help prevent new land uses from violating water quality standards. This TMDL should be considered in the issuance of land use permits by local authorities.

Figure 61. Rain Gardens are Attractive and Effective Stormwater Facilities. *This rain garden is one of several low impact development (LID) techniques in use at a public park to control surface water pollution and hydraulic scouring of a local stream. Infiltrating stormwater helps maintain groundwater supplies that are essential to maintaining adequate summer streamflows.*

The Washington State legislature recently passed ESHB 1886, which establishes an alternate process for addressing Growth Management Act requirements to address critical areas in agricultural areas. King and Snohomish Counties should incorporate the findings of this TMDL into the selection process for priority watersheds when implementing ESHB 1886. Workgroups formed under ESHB 1886 should also incorporate the findings of this TMDL when developing watershed workplans.

Other actions to protect and reduce water temperatures

Several other actions to protect and reduce water temperatures should also be addressed during the implementation of this TMDL. For example, the use of LID stormwater management practices and wetlands protection and enhancement were mentioned as important ways to ensure a good supply of cool groundwaters, but other actions to protect natural hydrology have not been discussed. Similarly, sediment control in forest management areas has been covered but the importance and overall control of sediments from all sources has not. Discussion of these and other important implementation actions follow.

Water withdrawals

Growing populations need clean drinking water. Outside of urban areas, groundwater is a key source of water for new development. Ecology set minimum instream flows and allowable groundwater withdrawal rates to protect those instream flows. The instream flow rule for the Snohomish River basin, Chapter 173-507 WAC, can be found at www.ecy.wa.gov/pubs/wac173507.pdf.

This TMDL did not determine that regulated water withdrawals were a significant contributor to temperature problems in the mainstem Snoqualmie River. However, on a localized basis, illegal water withdrawals have the potential to affect water temperatures and should be reported to Ecology at 425-649-7000. All surface water diversions must be authorized through a water rights permit. Ecology's Water Resources Program in Bellevue will work with local landowners that need water for crop irrigation and can be contacted at the telephone number in this paragraph.

Reducing water demand will ultimately conserve and perhaps increase groundwater supplies, and should also be promoted as part of this *implementation plan*.

Protecting, restoring, and augmenting cool groundwater inflow

Land use and water withdrawal are the key human actions that can be controlled to help protect and restore groundwater inputs to the Snoqualmie River watershed. County and city planning departments should protect springs and side channels that improve habitat, refuge, and cooler water to salmon species. Projects that take a landscape approach to understanding groundwater processes on a watershed or subwatershed basis are highly encouraged and should consult Ecology's FLIR study (http://www.ecy.wa.gov/apps/watersheds/temperature) as applicable.

The strategic placement of large woody debris (LWD) to improve the amount of cool water inputs and localized fish refuges is also highly encouraged as a means of implementing this TMDL. The placement of large woody debris in stream channels creates channel complexity and forms scour pools, improving fish habitat as well as enhancing groundwater inflow to the stream (Booth, 1997; Drury, 1999). Projects to install LWD must be well researched and should include the likelihood of creating new or increased groundwater inputs as a prioritization criterion. Public safety should also be weighed as a factor during LWD project design.

The processes of instream hyporheic exchange (Grant et al., 2006) and cool groundwater seepage can reduce localized water temperatures, creating fish refuges during critical periods. With proper study and site selection it may be possible to employ this technique to reduce river temperatures by increasing stream complexity, reconnecting floodplains, and other actions. This plan recommends additional research to examine how this natural process could be restored or augmented in the Snoqualmie Watershed to reduce localized stream temperatures.

Control sediment inputs

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

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

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

The most common sources of sediment and altered stream processes typically include 1) landslides; 2) erosion resulting from poor forestry management practices; 3) construction site runoff; 4) alteration of natural stream channels and riparian areas; and 5) hydraulic scouring following urban and rural development. Actions to control sediment releases from forest roads, control hydraulic scouring through stormwater infiltration, and control damage to riparian areas are discussed previously. This implementation plan supports the following additional actions aimed at reducing sediment buildup and improving natural processes that contribute to improved water temperatures.

- *Erosion control during construction activities:* Good erosion control during land clearing and grading activities is essential. Ecology's general construction permits combined with local clearing and grading ordinances should control this potential source of sediment.

- *Improve stream morphology and natural processes:* Properly located large woody debris placement can also help to control erosion.

Relationship of this TMDL to land use decisions

Ecology's water cleanup process does not in itself bring any additional authority to control local land uses that improve and protect local water quality. However, federal, tribal, state, and local governments and non-governmental organizations should incorporate the recommendations of this TMDL in the revision or development of their critical areas ordinances, shoreline management plans, and other land use regulations during the public process to allow for effective outreach and involvement by the public. The public should be provided information explaining how those authorities will optimize stream shading to restore and protect critical habitat.

Climate change

Although this implementation plan recognizes the potential effect of climate change on stream flows in the future, it is beyond the scope of this document to examine any current effects or to predict future challenges. As more information on the potential effects of climate change in the Pacific Northwest become available, it should be considered during the adaptive management of this *implementation plan*. More information on climate change can be found at www.ecy.wa.gov/climatechange/.

Where do we have opportunities for improvement?

Many reaches of the mainstem Snoqualmie and its feeder streams need riparian planting and restoration. Shade is needed along major river segments and all major tributaries. As part of this implementation plan, Ecology reviewed our 2006 field data and modeling results, information from the *Snoqualmie Watershed Water Quality Synthesis Report* (Kaje, 2009), FLIR study results, and orthophotography from 2006 and 2009 as applicable. The following analysis divides the Snoqualmie Watershed into three areas (Figure 62) as it discusses current data on riparian vegetation and temperature levels in; the lower mainstem Snoqualmie below Carnation, the middle mainstem from Carnation to Snoqualmie Falls, and the upper mainstem above Snoqualmie Falls. Except where noted, temperatures in the section below refer to the 7-Day Average Daily Maximum (7DADMax).

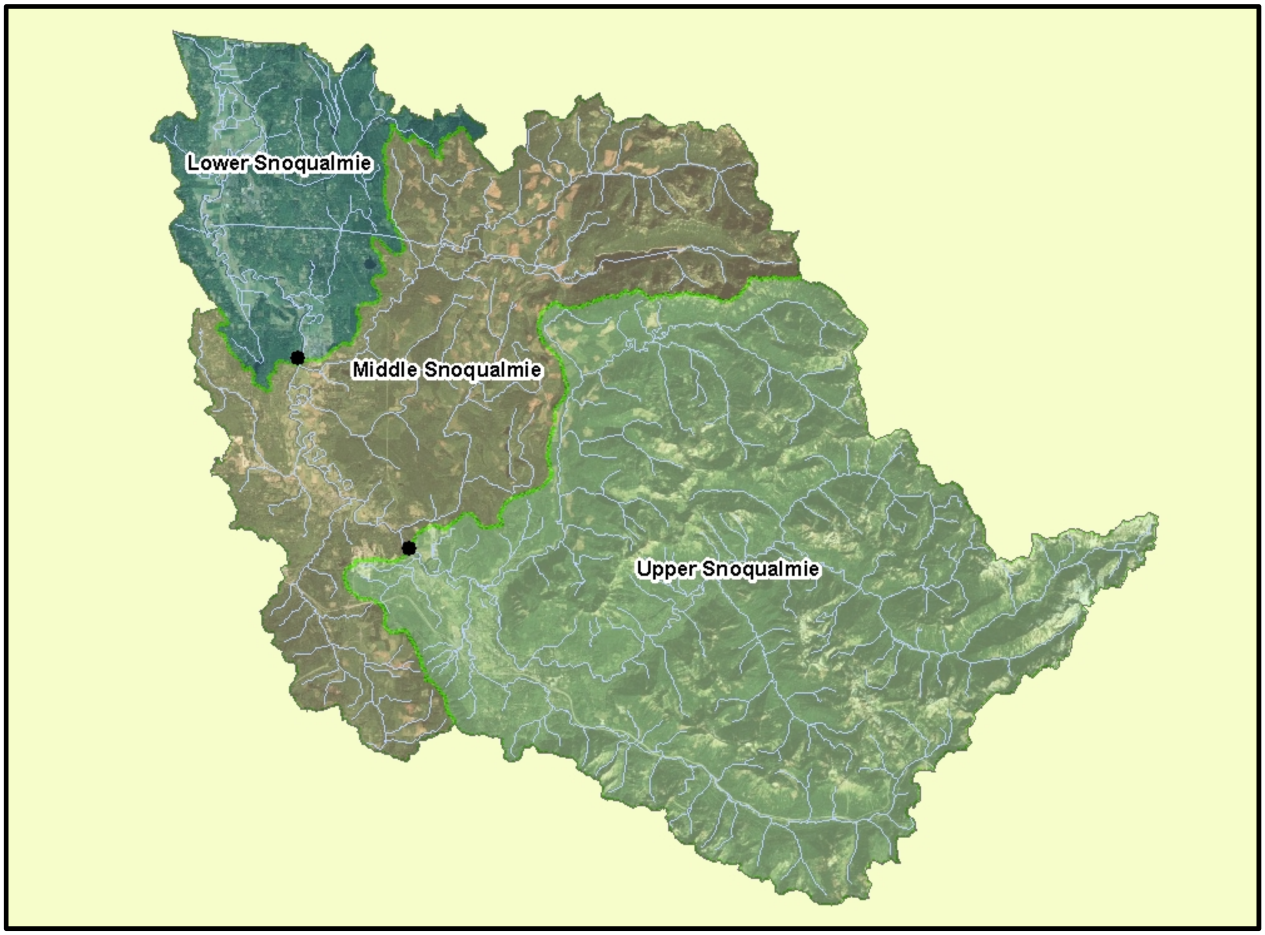

Figure 62. TMDL Implementation Analysis Areas. *The implementation plan groups the following discussion of temperature impairment into three areas as shown above. The Upper Snoqualmie contains all subbasins above Snoqualmie Falls. The Middle Basin contains all subbasins above the Snoqualmie at Carnation. Subbasins below Carnation are in the Lower Snoqualmie area*.

Upper Snoqualmie mainstem and subbasins

The Upper Snoqualmie is comprised of flows from the Middle Fork, North Fork, South Fork, Kimball/Coal Creeks, and drainage adjacent to the mainstem between the confluence of the South Fork and Snoqualmie Falls.

Middle Fork/mainstem: During July and August (summer) of 2006, water temperatures in the Middle Fork at RM 75 were just above state standards, ranging from 12-13°C and peaking at about 14.5 °C during the warmest part of summer 2006. River mile 75 represents the highest points of the watershed, which extend only about 9 miles farther. Just below that point, Burnboot Creek (which is below Goldmyer Hot Springs), enters at temperatures ranging from 10-11°C. Burnboot temperatures suggest that Goldmyer Hot Springs are not a major heat input. Burnboot may be representative of other large south-to-north-flowing tributaries located within USFS boundaries.

Table 34. Upper Snoqualmie mainstem riparian areas most in need of improvement.

Land Use	Acres	% of Total Riparian Area
Total riparian area	734	100
Areas with planting possibilities		
Barren acres	3	<1
Pasture/grass/sedge/rush	26	3
Scrub/shrub	30	4
Areas that need time to grow		
Medium sized trees	247	34
Small sized trees	49	7

The summertime temperature standard for the Middle Fork changes to 16°C as water travels halfway down the 15 mile distance to USFS boundary. By the time water reaches the end of NFS lands at RM 60, summer water temperatures increase and exceed state standards, typically ranging from 15 to 18°C. Much of the channel migration zone along this corridor is wide exhibiting braided reaches and large gravel bars that provide the opportunity for solar radiation to reach and heat the river.

Solar heating appears especially high from RM 72 to RM 74 where considerable channel migration occurs. Orthophoto observations of riparian vegetation levels along the mainstem Middle Fork in NFS lands show good riparian cover although tree ages appear to vary. No obvious areas needing additional riparian planting were observed along the Middle Fork within NFS lands.

For the first five miles below the USFS boundary (down to about RM 55), the Middle Fork travels though state DNR managed lands. Orthophoto observations of riparian vegetation levels along the mainstem Middle Fork on DNR managed lands show good wooded riparian cover although tree ages also tend to vary.

Watershed Sciences (2007) reported that at about RM 55.6 (where water leaves the DNR managed streamside area) radiant water temperature began a steady increase reaching ~19.2°C at

RM 48.3. The increase corresponds to change in stream aspect (East/West) and distinct change in valley form from a relatively confined forested canyon to the more open valley. The channel migration zone increases in many areas reaching twice the typical river width in some stretches. Stream temperature remained relatively constant (~19.3°C) over the lower three miles of the Middle Fork just prior to meeting the North Fork at about RM 45.

About 8% of the 150 foot buffer along the Upper Mainstem and Middle Fork Snoqualmie had nontree vegetation (Table 34) in 2006. About 40% had trees considered only medium or small in height. Many of those small to medium trees were located on the south side of the mainstem. We can expect these trees to increase in size and provide more shade over the next few decades.

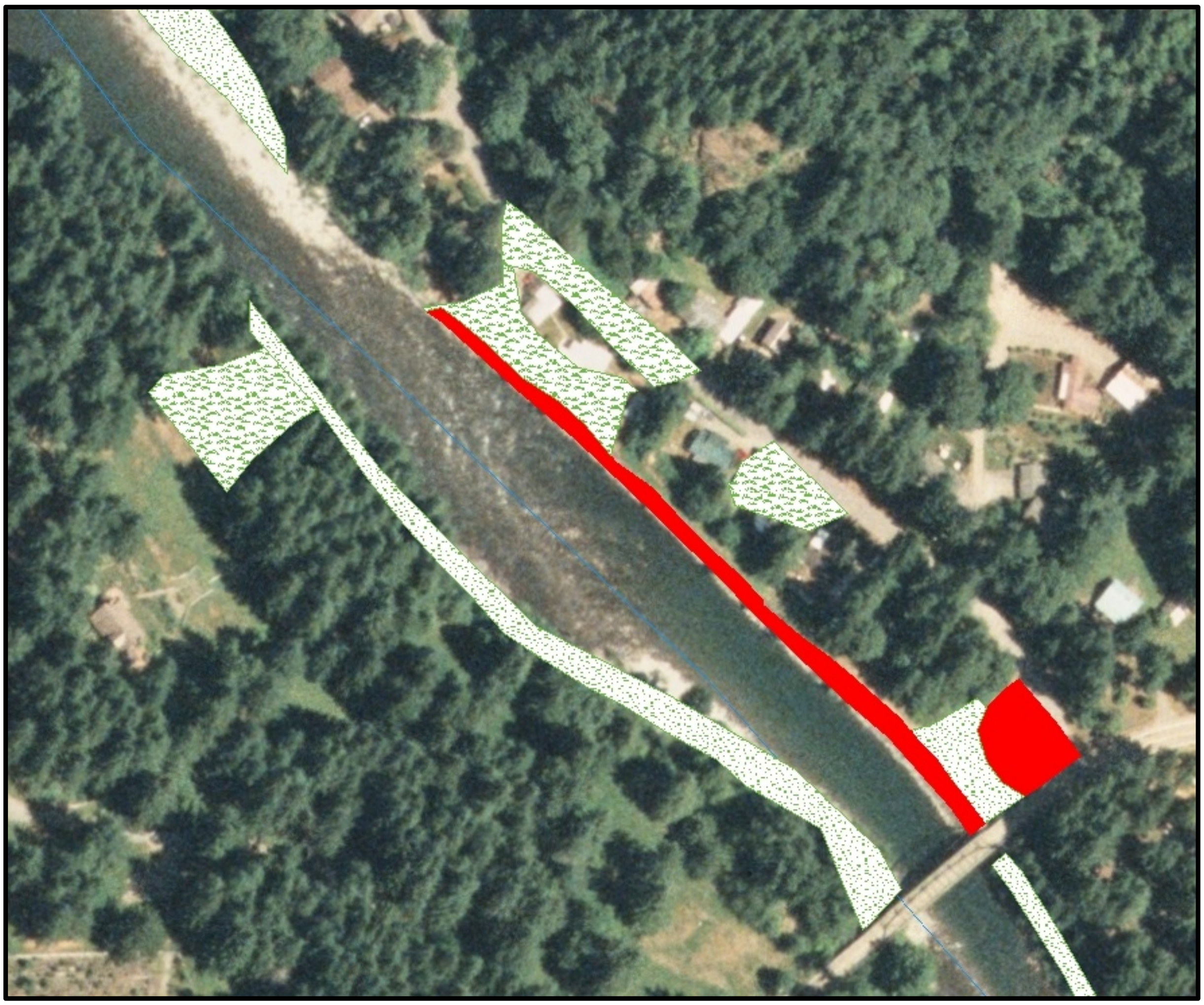

Figure 63. Riparian areas in the Upper Snoqualmie Watershed without trees. *Ecology's field study characterized vegetation in the 150 foot areas on both sides of the mainstem Snoqualmie from the River Mile 60 to the confluence with the Skykomish River. Areas in red above are barren of vegetation and the green/white areas show where grass or shrubs were observed. Planting trees in these areas can help reduce water temperatures in the Snoqualmie River.*

About 40 properties identified along the Middle Fork using orthophotograph should be investigated for improving riparian vegetation levels. One very small area that may need additional riparian plantings in DNR managed lands was observed near RM 58. Most properties are located below RM 49. Rural residential housing begins around RM 53.5 although riparian tree cover is not affected greatly. Most houses in the upper watershed are set back about 100' and sporadic opportunities for riparian plantings begin around RM 52. The amount of riparian vegetation along the Middle Fork decreases noticeably with development activities at RM 49 (Trucktown).

King County Noxious Weed Program has been working with Mountains to Sound Greenway Trust in the Middle Fork since 2006 to remove knotweed in riparian areas and replant with native species. This work has continued over the past five years and their current focus is the lower Middle Fork from RM 0 to RM 4.5. Areas with the potential for improved riparian vegetation are located within the jurisdictions of King County and North Bend. King County, the city of North Bend, and other organizations should work with landowners using efforts such as the Noxious Weed Program to engage local landowners and improve riparian vegetation the Middle Fork.

All six tributary streams monitored by Ecology were cooler than the mainstem Middle Fork and met state standards for all or nearly all of the summer dry period. The two north-to-south flowing streams located on a south-facing slope were generally two or more degrees higher than the south-to-north flowing streams draining to the Middle Fork. Tributary temperatures ranged from about 10-14 ^{o}C.

Upper Mainstem: Water entering the Upper Mainstem decreases in temperature significantly compared to Middle Fork temperatures after mixing with cooler waters from the North and South Forks. During the mid-August dry period in 2006, about 45 % of the Upper Mainstem flows measured at the USGS Snoqualmie station came from the Middle Fork, 33% from the South Fork, and 16% from the North Fork. The significant cooling effect of the North Fork is illustrated by FLIR results shown earlier and repeated in Figure 64.

From the three Snoqualmie River forks downstream to Snoqualmie Falls approximately 20% of streamflow is contributed by groundwater upwelling (Turney et al., 1995). Although some cool water is introduced by Brockway Creek, groundwater inputs between the South Fork confluence and Snoqualmie Falls may be the significant factor in cooling water temperatures in this area. As shown earlier in Figure 14, FLIR results indicated 14 cool water seeps. Fewer springs were detected in the lower portion of the Middle Fork than were found in the upstream reaches, but water depth also increases making the detection of subsurface seeps by FLIR less likely.

The significant groundwater contribution occurring in the Upper Mainstem suggests that infiltration of stormwater may be a valuable implementation action for the city of Snoqualmie in order to maintain, or further improve, water temperatures leaving the Upper Snoqualmie watershed. Twenty three parcels were identified to have the potential for improved riparian vegetation within 150' of the mainstem. Most of these properties are managed by the either the city of Snoqualmie, King County, or Puget Sound Energy. King County has identified 35 acres of riparian planting needs within the Three Forks Natural Area and the city of Snoqualmie has identified planting needs at Sandy Cove Park. Plantings in these and other areas of the Upper Mainstem should be pursued by the public landowners and service organizations.

North Fork: The mainstem North Fork is about 24 miles long. The upper 22 miles is mountainous with a 10-mile long low gradient valley. After descending through steeper forest it travels about 2 miles through a gently sloping mountain valley to meet the Middle Fork. Outside critical periods lasting 1-2 weeks, the North Fork near the Middle Fork confluence met the state temperature standard of 16°C for much of the summer of 2006. Forest harvesting is widespread throughout most of the North Fork with about a third of the mainstem streamside area managed by DNR.

Like the Middle Fork, the channel migration zones for portions of the upper North Fork are wide allowing for considerable solar input even when mature riparian vegetation exists. Mainstem vegetation levels appear good with 150' or better buffers in most areas and some slightly smaller buffers in a few locations. Tree heights appear to vary suggesting that shading on portions of the North Fork will likely improve over time as trees mature. Simple orthophotography analysis did not allow for an evaluation of vegetation types. Rural residential land use starts at about RM 2.5 where shade levels decrease.

Some of the forest buffers between North Fork RM 4 and RM5 appeared to have fewer large trees but the outer buffer appeared revegetated and future improvements in shade in this area seem likely. Otherwise, no obvious areas needing additional riparian plantings were identified along the mainstem North Fork in forestry management areas. Along the lower 2.5 miles of the North Fork, about 35 properties appear to need additional riparian plantings. Many of the planting opportunities have limited buffer sizes as the setback distance from the river for many homes is small. This *implementation plan* supports WADNR and USFS efforts to decommission roads to reduce erosion potential and improve watershed hydrology. Planning is currently underway to decommission 11 miles of road in the North Fork basin.

South Fork: The South Fork Snoqualmie extends about 30 miles from the confluence with the Upper Mainstem to the upper headwaters near Snoqualmie Pass. It contributed about a third of the flows measured at the USGS site at Snoqualmie in mid-August 2006. Water temperatures fluctuated around 16°C during most of the summer with a peak reaching about 19°C during the late July critical period. The upper watershed above RM 18 is managed largely by the USFS. WADNR has significant land holdings on the northern side of the South Fork between RM 11 and RM 17. The watershed along Interstate 90 is part of the Mountains to Sound Greenway and includes Twin Falls Park. Like the North and Middle Forks, channel migration zones widen in a number of areas but riparian vegetation outside that area is good. Rural residential development starts at about RM 9.

Obvious opportunities for improving shade begin with the residential development starting at RM 9. Fifty-five parcels appeared to need more riparian shading. As with other areas in the Upper Watershed, most of these areas are residential properties with limited buffer possibilities. WADOT has a small right-of-way planting opportunity at about RM 4.5. Trail alignment and all related riparian planting opportunities should be systematically evaluated along the John Wayne/Snoqualmie Valley trail, which runs along the right bank in many locations. Besides the numerous residential planting locations, significant planting appears possible on the right bank above RM 3 in what appear to be natural vegetation easements.

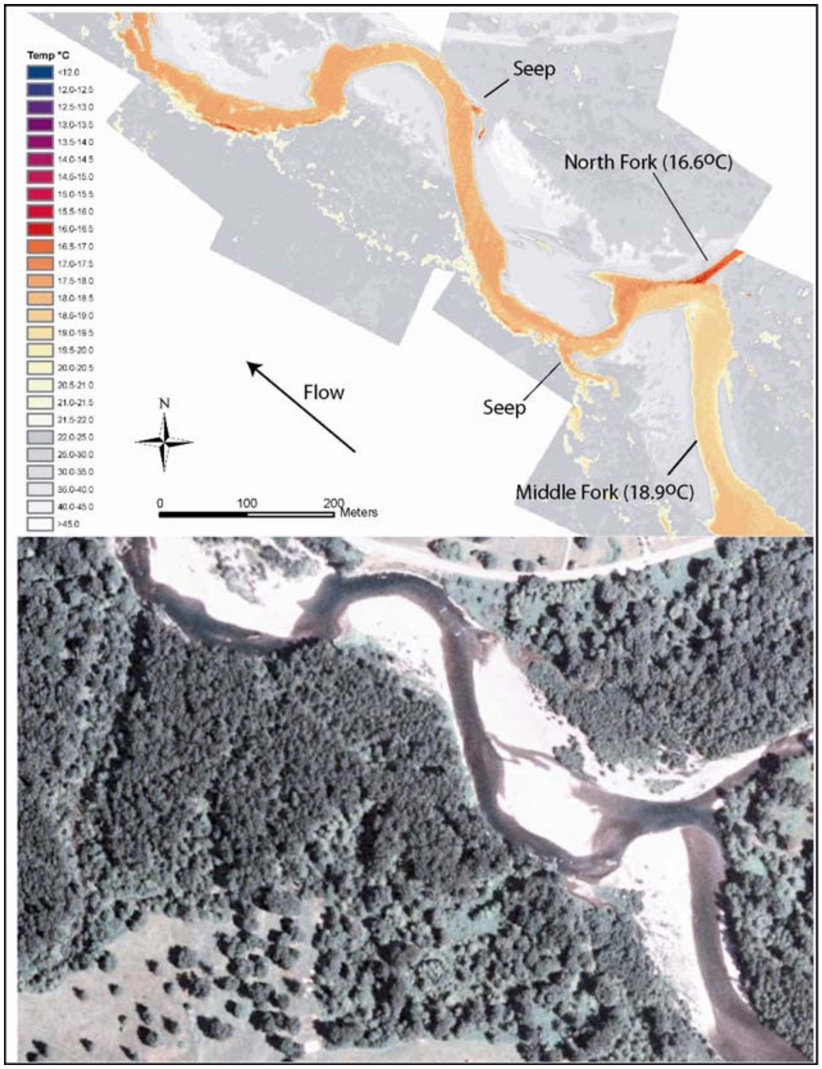

Figure 64. Sample image; thermal infrared (top) and true color (bottom) showing the confluence of the North Fork and Middle Fork Snoqualmie River (Watershed Sciences, 2007).

King County Noxious Weed Program is now working to remove knotweed and reestablish native vegetation on the South Fork from RM 6 to 17. The city of North Bend has been working with The Mountain to Sound Greenway Trust to improve riparian shading on Ribary Creek. Because of the numerous small planting opportunities along the South Fork, and the importance of maximizing the cooling effect that this river stretch provides throughout the summer, granting agencies should give strong consideration to well organized projects that can address the riparian shading needs on numerous small parcels, or as otherwise documented from other riparian analyses. This *implementation plan* supports WADNR and USFS efforts to decommission roads to reduce erosion potential and improve watershed hydrology. Planning is currently underway to decommission 30 miles of road in the South Fork basin and convert another 30 miles to trails.

Kimball/Coal Creek: Flows from the Kimball/Coal Creek subbasin contribute a very small proportion of the mainstem flow but are still important as one of the many sources of cool water needed to control high mainstem water temperatures. During the warm summer months Kimball Creek consistently exceeds the state temperature standard of 16°C, with 7 DADMax temperatures ranging from 16 to 20.5°C during the summer of 2006.

Coal Creek, the major tributary of the Kimball Creek system, drains both developed and forested headwaters into Kimball Creek about 1.25 miles from the Snoqualmie River. Coal Creek was not evaluated during this TMDL, but spot measurements of Coal Creek by the King County Road Maintenance Service (KCRMS) indicate it is generally 1-2°C cooler than Kimball Creek during the critical period. Portions of the Coal Creek subbasin are densely forested, but it also contains a significant fraction of the Snoqualmie Ridge development area. Intact shade-producing vegetated stream buffers should be protected, as the cool water that results is essential for improving temperature conditions in Kimball Creek.

Kimball Creek primarily drains a large floodplain area and another forested upland. Some solar heating occurs in the floodplain drainage adjacent to Meadowbrook Road, Mt. Si High School, and 384th Ave SE. Much of the Kimball Creek riparian zone is classified as wetlands. A habitat study performed by the Snoqualmie Tribe in 2010 revealed that impoundments created by beaver may be contributing to solar heating (Baerwalde, personal communication).

In the flat, floodplain portions of the Kimball Creek subbasin, opportunities for improving riparian shading are limited by the presence of extensive riparian wetlands and the low-gradient, ponded nature of the stream. Although Ecology identified 50 parcels as lacking wooded riparian areas, the ability to plant shade-producing vegetation should be assessed on a site-by-site basis during the implementation phase of this TMDL. The Snoqualmie Tribe's study did find that many stretches of the Creek between 384th Ave SE and SE 76th Street are limited in terms of shading by extensive Himalayan blackberry infestations. For those areas that can clearly be planted for shade and are currently or likely to be used for livestock grazing, exclusion fencing should also be considered as part of riparian restoration efforts.

Middle Snoqualmie mainstem and subbasins

The Middle Snoqualmie Mainstem subarea receives flow from the Upper Snoqualmie Mainstem, Tokul Creek, Raging River, Patterson Creek, Griffin Creek, the Tolt River, as well as drainage adjacent to the Middle Snoqualmie mainstem. The mainstem river gradient is low as it meanders through a flat and exposed floodplain where it experiences extensive exposure to solar radiation.

Middle Snoqualmie mainstem: During the warmest part of the summer nearly all the water entering the Middle Snoqualmie mainstem is above state standards (Appendix Figure D5). The highest 7DADMax temperatures between Snoqualmie Falls and Carnation consistently exceeded standards ranging from about 20.5°C to 21.9°C. Ecology's model predicts a high 7DADMax of 22.8 °C. During most of the summer, water leaving Snoqualmie Falls was ~ 17°C, rising to~ 19°C just before meeting the Tolt River. The 2006 critical period lasted two weeks in late July--temperatures rose 3.5°C in one week to 20.5°C then fell back to 17°C over the course of a week.

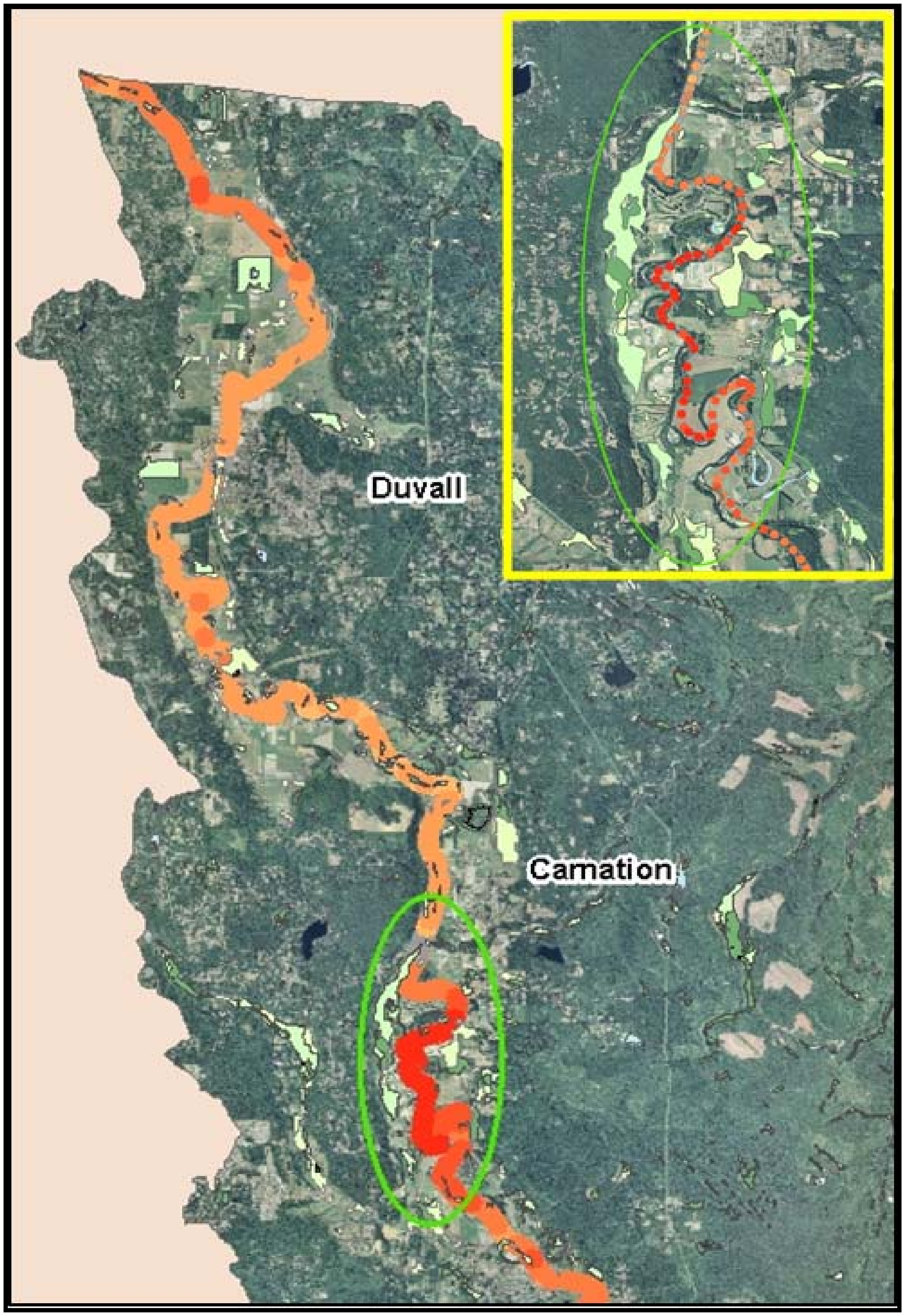

Figure 65. Do wetlands cool the Snoqualmie River? *Wetland areas within the circled area appear to be contributing cool groundwater to the river between the Raging and Tolt Rivers. Forward Looking Infra Red (FLIR) data shows cooler (redder) water adjacent to the largest remaining wetland complex (green shaded areas) in the lower Snoqualmie floodplain. The small red circles in the inset picture show selected temperature measurements from the study. See inset for more detail.*

Table 35. Middle Snoqualmie mainstem riparian areas most in need of improvement.

Land Use	Acres	% of Total Riparian Area
Total riparian area	562	100
Areas with planting possibilities		
Barren acres	5	1
Pasture/grass/sedge/rush	167	30
Scrub/shrub	85	15
Areas that need time to grow		
Medium sized trees	102	18
Small sized trees	23	4

Significant inputs of groundwater increased river flow an average of 18% between Snoqualmie Falls and Carnation. Similar findings were made by Turney et al. 1995, where groundwater upwelling accounted for approximately 11 – 13% of surface water flow gain. These groundwater inputs are believed to be responsible for a cooling effect that occurs between the Raging River and the Tolt River (Figure 65).

Ecology's field study showed 0.7°C cooling (7DADMax) occurred during the critical period between RM 31 (near Patterson Creek) and RM 25 (above the Tolt). FLIR data shows instantaneously measured temperature dropped nearly 2°C between RM 35 and RM 28. The area of cooling occurred adjacent to the largest forested/scrub-shrub wetland complex in the Snoqualmie floodplain.

Our field work revealed that the river depth in this area was noticeably deeper than most other locations suggesting a possible mechanism for creating hydraulic connectivity with groundwater. It should be noted that our field work only measured depth every two miles on average so additional work is necessary to confirm if water depth was a likely contributing factor. Finally, river sinuosity appeared higher in this stretch of the Snoqualmie, which could enhance groundwater exchange.

The TMDL study determined that there are many opportunities for improving riparian vegetation along the Middle Snoqualmie mainstem (Table 35). Of the 562 acres of riparian zone within 150' of the river, almost half of it has no trees planted. About 167 acres (30%) of that area is either pasture, grass, sedges, or rush vegetation. Eighty-five acres (15%) are scrub or shrub vegetation. Over three quarters of the properties located along the mainstem appeared to have riparian enhancement opportunities based on a combination of orthophoto and field study observations (111 properties needing additional trees). Combined, over 250 acres of riparian area has barren, pasture, or scrub/shrub vegetation that needs improvement.

Riparian plantings, like the ones along Weiss Creek (WFC), or those established at the many Salmon-Safe Farms in the Middle Mainstem area, should receive maintenance weeding and follow-up plantings as needed. Stewardship Partners has been very successful in its outreach to local farmers and should continue their work with the Snoqualmie's floodplain community.

King County is currently evaluating a project called the Snoqualmie-Fall City Reach Reconnection to explore opportunities for restoration, including levee removal and setback projects. In addition to the large groundwater input observed in the river between the Raging

River and the Tolt River, one groundwater seep was observed along the left bank property in the project area. Innovative opportunities to maximize groundwater inputs to the mainstem during the summer months should be evaluated as part of this project. The Snoqualmie Tribe has been removing invasive species and replanting riparian areas at Fall City Park. This TMDL recommends this work continue until a 150 foot buffer is well established at Fall City Park.

Tokul Creek: Tokul Creek temperatures were similar to the mainstem Snoqualmie at the beginning of the summer of 2006. As the summer progressed, including the critical period in late July, Tokul temperatures were 2°C or more lower than the mainstem. Although Tokul Creek Hatchery is present, the facility augments its raceway with spring water (a constant 8.3°C), which keeps its discharge temperatures low.

During the warm summer months Tokul Creek temperatures are about 2°C cooler than the mainstem. As shown in Figure 66, a cool water refuge area about 50 feet in length (upper right hand portion within the red circle) is created where Tokul Creek flows into the mainstem Snoqualmie. The existing mainstem channel morphology may be helping to reduce dilution and increase the size of the refuge area.

The entire Tokul basin remains relatively undeveloped based on a review of 2006 orthophotography. The basin is almost entirely managed as commercial forest under private ownership, with the vast majority of potential development rights purchased by King County. Water quality is expected to be dominated by upper watershed land use, which is a forest production area. Trees within the 150 foot buffer along portions of upper Tokul Creek appeared to have been logged in the past. Newer regulations should protect these areas and improvement of Tokul Creek water temperatures appears possible. One small area about 0.6 miles upstream appears to need improvements in riparian vegetation. Otherwise, the primary implementation activities recommended for Tokul Creek are proper operation of the fish hatchery and protection of existing buffers in the forest production area.

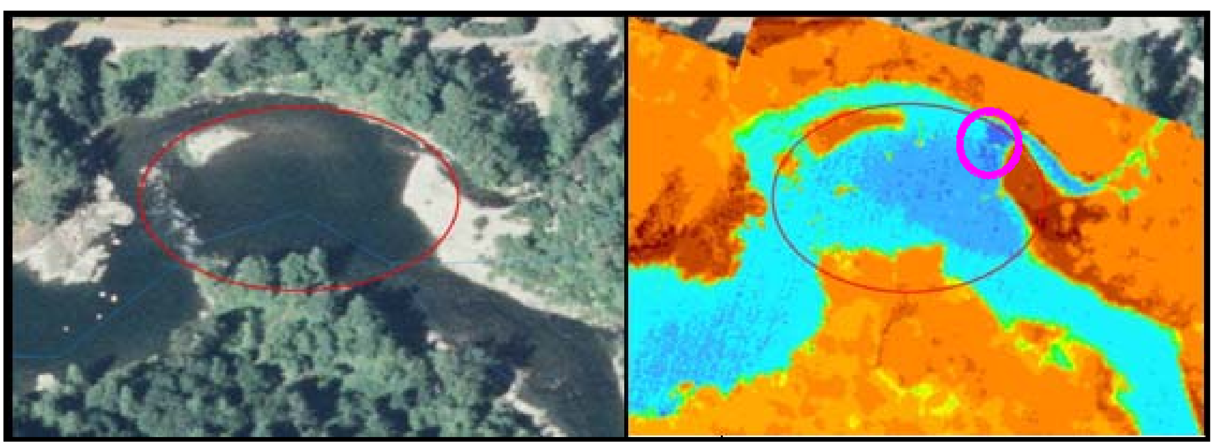

Figure 66. Tokul Creek cool water refuge area. *During the warm summer months Tokul Creek temperatures are about 2°C cooler than the mainstem. The dark blue areas show the location of the cooler areas (note: FLIR color scheme used throughout this document was changed for this image to improve the visibility of cooler water).*

Raging River: Water leaving the Raging River is consistently warm during the summer ranging from 19 to 25°C. From 2.5 to 4.7 miles upstream, temperatures are lower, but still high, ranging from 17 to 22.5°C during that same July-August period. Water leaving the forest production area was only measured during August 2006 and was about 2°C cooler than at RM 4.7.

Flows from the Raging River drop considerably during the summer so these high temperatures do not have a large effect on the mainstem. Like the Tolt, the lower portion of the Raging River is a "losing reach", meaning that a significant amount of the river flow is discharged into groundwater instead of remaining part of the surface flow (Turney et al., 1995). In the Turney study, about 21% of the flow was observed to discharge to groundwater in the last two miles of the river. The lower half mile of the Raging River is confined by levees but has a wide area where gravel transported from upstream accumulates. This exposed area creates an opportunity for considerable solar warming. Flows in the winter can get very high resulting in significant movement of gravel and changes in this lower river area.

Over three quarters of the Raging River watershed is public land, the vast majority managed by WDNR. Much of the remainder is private forest holdings. These areas appear to have been managed using clearcut harvesting techniques and no significant bare areas were noted adjacent to the mainstem Raging or its major tributaries. In 2009, with the support of Mountains to Sound Greenway Trust and Cascade Land Conservancy, King County partnered with the WDNR to purchase the development rights from over 4,000 acres of forestland in the Raging River basin. As part of the purchase, the state acquired roughly 7,000 acres of privately-owned forest land that remains in active forestry. King County also recently completed a project to acquire 6 acres of upper watershed land. The project improved stream habitat and morphology and added 1,300 feet of restored riparian edge habitat.

Farther downstream, rural residential land uses, and opportunities for improving riparian vegetation, start at about RM 6. Most of the potential planting sites are small and encroach quickly on housing footprints. About 70 properties needing more trees to create a 150' buffer were observed.

Mountains to Sound Greenway Trust (MSGT) received funding in 2010 to begin outreach and riparian restoration on properties with knotweed infestations—additional planting needs and barriers to plantings on the Raging River should be evaluated when this project is completed. The MSGT should continue to collaborate with the King County Noxious Weed Program and ensure that all knotweed removals are followed by plantings of riparian trees to maximize shade on adjacent water bodies.

King County is currently scoping a project to acquire an additional 12 acres (1,100 feet of riparian corridor) in the lower Raging River as part of its salmon recovery goals in the Snoqualmie 2015 plan. Riparian vegetation within this new parcel, as well as the existing 60 acre parcel under county management, should be evaluated and planted as needed with trees expected to reach typical tree heights under natural conditions.

Patterson Creek: Flows from Patterson Creek exceeded state temperature standards for about the first half of the summer of 2006 reaching a high 7DADMax of ~19^{o}C. The creek cooled to 15-16^{o}C during most of August. Patterson has relatively abundant forested/shrub-scrub/emergent wetlands along its upper mainstem, which may be important in augmenting summer baseflow levels. The lower floodplain is comprised largely of agricultural properties (equestrian properties, one dairy, small cattle ranches) and a golf course.

Numerous opportunities for improving riparian vegetation levels were observed along the mainstem Patterson Creek as it flows roughly parallel to State Hwy 202. Ecology evaluated the levels of wooded vegetation within 50 of the stream center line using LIDAR (Figure 67). Seven mile-long segments had less than 10% riparian vegetation over 10 feet high. Orthophoto analysis of Patterson Creek performed on the first four miles of its mainstem clearly indicated that nearly all of the 24 properties evaluated had inadequate riparian vegetation.

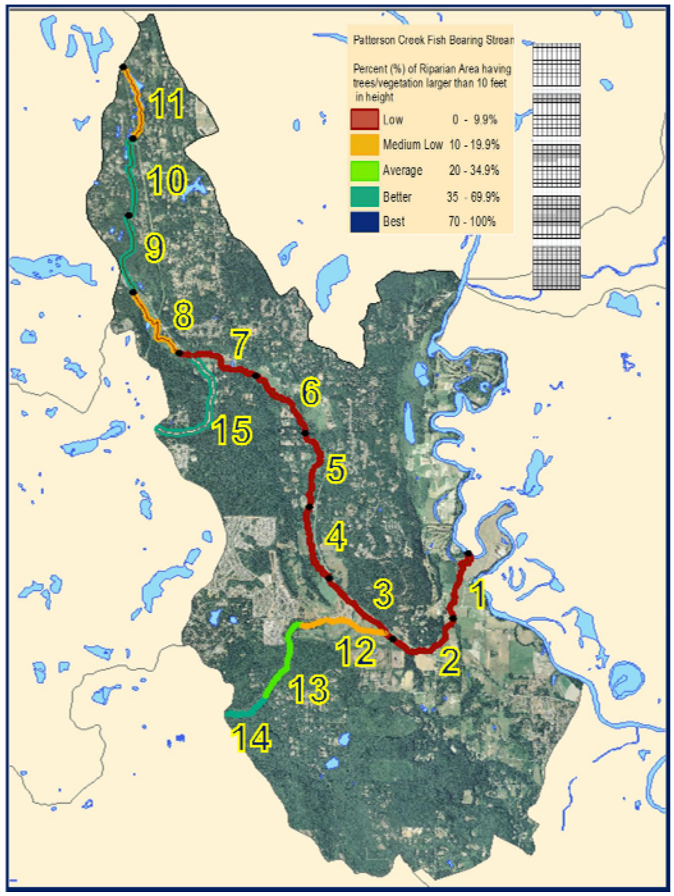

Figure 67. Patterson Creek Riparian Report Card. *Ecology evaluated riparian vegetation within 50 feet of stream center at 1-mile intervals. The first seven miles of Patterson Creek had very low levels of riparian vegetation larger than 10 feet tall. Improving the number of trees along the streamside will increase shade and keep Patterson Creek cool.*

In recent years, riparian plantings have taken place along some locations of the Patterson mainstem and lower Canyon Creek (shown as area 12 in Figure 67, see also Figure 56). A quick windshield survey of lower Patterson also revealed the presence of relatively new exclusion fencing and buffers of 30 feet or less. Buffers this narrow are not adequate for shade, and also not adequate to prevent livestock impacts from reaching a stream. Most areas needed more trees to be planted in order to provide complete shade to the creek. Extensive areas along Hwy 202 were devoid of trees.

Although this lack of vegetation is certainly increasing stream temperatures, it also shows there is a great potential for lower stream temperatures in Patterson Creek. The large parcel sizes and types of current uses suggest Patterson Creek is a good watershed for continued outreach, education, and investments in riparian improvements. King County's Forestry Program is working together with the Partnership for Rural King County on an innovative program called Stewardship in Action.

Griffin Creek: Flows from Griffin Creek were slightly higher than nearby Patterson Creek exceeding state temperature standards for about most of the summer of 2006. During the critical period in late July Griffin reached a high 7DADMax of ~19.5°C. The creek did not cool to a consistent 16°C or less until late August. The Griffin Creek watershed is about 10 miles in length. The upper eight miles is managed as a forest production area, most of it private land holdings. The majority of developments rights in the forested portion of the basin have been purchased via King County's Transfer of Development Rights Program. The lower two miles of the watershed is comprised of agricultural, forestry, residential, and public open space uses. Most farming occurs adjacent to the last 0.5 miles of the creek, below Ecology's monitoring station at Hwy 203.

Large sections of the upper watershed are categorized as forested or schrub/scrub wetlands. For example, the largest continuous wetland section is about 2.5 miles in length. Much of the vegetation in these areas is too small to provide stream shading therefore there are many areas in the upper watershed where stream heating may be occurring.

King County has planted and maintained 3.5 acres of riparian restoration plantings along lower Griffin Creek at an existing farm and purchased 9.7 acres that included some riparian area. The benefits of this and other work done over the last decade will eventually help lower Griffin water temperatures. Approximately 20 acres of farmland adjacent to Griffin Creek in the floodplain are now part of the Farmland Preservation Program. About a quarter mile upstream of that farm, King County has established the Griffin Creek Natural Area, which is over 20 acres in size and covers 2,100 feet of the right bank of Griffin Creek. Unless it is determined that the upland wetland areas need assistance in establishing mature wooded vegetation, most of Griffin Creek has relatively few opportunities for improving riparian vegetation. The lower mile of Griffin should be evaluated to see what if any riparian areas need more trees to provide complete shade.

Tolt River: The Tolt River is the largest tributary to the lower Snoqualmie watershed and thus has the greatest potential to influence localized mainstem temperatures. Flows from the Tolt entering the Snoqualmie consistently exceeded state standards. Most of the summer in 2006, lower Tolt 7DADMax temperatures were 18 °C or higher, variously peaking to 19, 20, and 22°C.

The Tolt is comprised of three major basins: South Fork Tolt, North Fork Tolt, and the Lower Tolt. The South Fork contains a major water reservoir surrounded by a well forested watershed. The remainder of the North and South Fork watersheds is extensively managed for timber production. Stream channel morphology in the 16-mile-long South Fork appeared stable with relatively narrow channel migration zones. Although tree heights along the South Fork were not examined, buffer widths were generally good. Large trees along the South Fork should be able to provide high quality, dense shade. Outflow from the South Fork Tolt dam is actively managed by Seattle Public Utilities to provide a downstream temperature regime that is more similar to natural. Seattle Public Utilities uses the unregulated North Fork as a surrogate for natural temperatures.

Channel migration zones in similarly sized North Fork Tolt are much wider than the South Fork. The lower six miles of the North Fork Tolt had obvious channel migration zones (CMZs) ranging from 75 to 200 feet. The generally wide CMZs continued in the Lower Tolt, which is about nine miles in length. It seems likely that these wide CMZs are contributing to high water temperatures leaving the Tolt watershed.

Over 50 land parcels identified in the Tolt River Basin through 2006 orthophoto analysis needed additional trees to create 150' buffers or support smaller buffers where building structures prevent larger riparian plantings. Most opportunities are less than 0.1 acre in size. Because of the significant flows, existing land uses, and the importance of the Tolt as a fishery resource, additional work to examine the factors controlling Tolt water temperatures is warranted. The Tolt may be a good candidate for the following activities, which should be considered by salmon recovery efforts. One is to evaluate existing vegetation types and heights in mainstem riparian areas to estimate the likelihood of improved temperatures due to increased shade through a no-action policy that assumes existing trees will grow undisturbed to mature heights. Second is the value of installing large wood structures to create stable pools for cool water refuge areas.

In recent years, King County purchased 37 acres of riparian habitat along the Tolt River and completed a levee setback project with the city of Seattle at the confluence with the Snoqualmie to improve water quality, flood conveyance, and salmon habitat. The project will help restore natural processes in lower half mile of the Tolt River. Seattle City Light has identified approximately three acres of riparian area needing rehabilitation and this work is in progress.

Lower Snoqualmie Mainstem and Subbasins

The Lower Snoqualmie Mainstem subarea receives flow from the Middle Snoqualmie Mainstem, Ames Creek, Harris Creek, Cherry Creek, Tuck Creek, as well as many smaller tributaries and drainages adjacent to the Lower Snoqualmie mainstem. The mainstem river gradient is low as it meanders through a flat and exposed floodplain where it experiences extensive exposure to solar radiation.

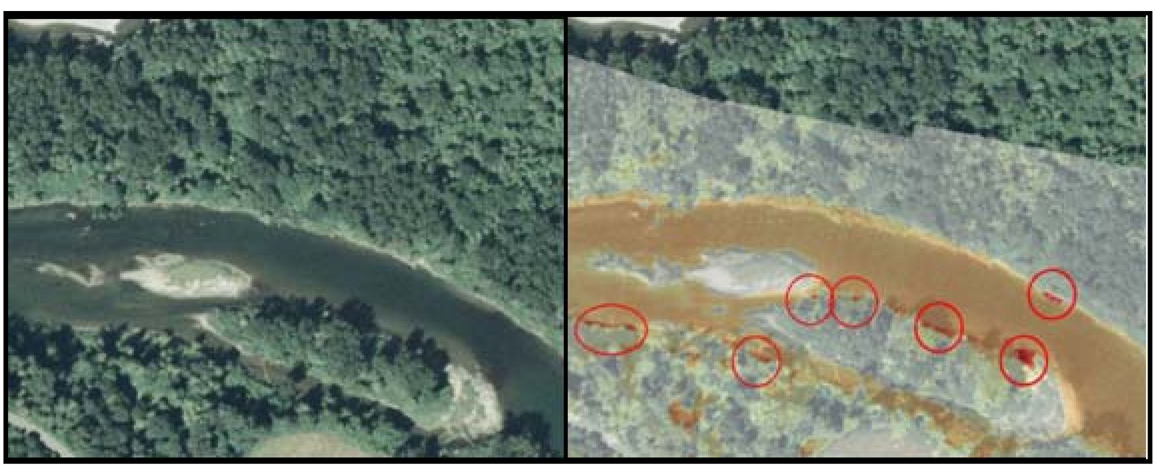

Figure 68. Cool water seeps observed between RM 0 and RM 1.5. *Numerous cool water seeps were observed in the FLIR imagery between RM 0 and RM 1.5 as shown on the right by the red circles. Each of the circles shown is 140 feet wide.*

Lower Snoqualmie mainstem: Water entering and leaving the Lower Snoqualmie mainstem during the summer of 2006 (July-August), consistently exceeded state standards (Figure D10, Appendix), even as the state temperature standard increases to 17.5°C at Harris Creek.

Table 36. Lower Snoqualmie mainstem riparian areas most in need of improvement.

Land Use	Acres	% of Total Riparian Area
Total riparian area	872	100
Areas with planting possibilities		
Barren acres	2	<1
Pasture/grass/sedge/rush	359	41
Scrub/shrub	194	22
Areas that need time to grow		
Medium sized trees	110	13
Small sized trees	48	5

The highest 7DADMax temperatures in this area between the Tolt River and the Snoqualmie's confluence with the Skykomish River Falls ranged from about 21.5°C to 22.8°C. Ecology's model predicts a high 7DADMax of 24°C under current 7Q10 conditions (at the 7Q10 flow and 90th percentile meteorological conditions). During most of the summer, water leaving the Carnation area was over 18 °C, peaking at times to 19, 20, and 21.5°C. The 2006 critical period lasted two weeks in late July--temperatures rose 3.5°C in one week to 21.5°C then fell back to ~18.5°C over the course of a week before starting another increase to 20°C.

Unlike the Middle Snoqualmie, the Lower Snoqualmie is a losing reach, meaning that between Carnation and Monroe river flow actually dropped about eight percent, even considering the input of tributary streams (Ecology had similar findings to those of Turney et al. 1995). Even so, close observation of the FLIR imagery revealed 38 areas that appeared to be small cool water seeps from RM 1.5 to RM 25. A nearly continuous band of cool water seeps were observed on the left bank from RM 0 to RM 1.5 (Figure 68).

As shown in Table 36, nearly 63% of the 150 foot riparian buffers along the lower Snoqualmie mainstem do not have vegetation with the potential to provide shade to the river. That means that well over 500 acres of the lower mainstem appears to need riparian improvements. Nearly all of the properties adjacent to the mainstem had opportunities for plantings (146 parcels). Eighteen percent of the riparian buffer had small or medium-sized trees and over time these areas should provide better quality shade.

Stewardship Partners has worked with seven farms along the Lower Mainstem Snoqualmie to improve riparian vegetation. Ecology encourages Stewardship Partners, and other organizations to maintain existing planting and increase them where possible to 150 feet width. The Stilly/Snohomish Fisheries Enhancement Task Force has worked in partnership with the city of Duvall to plant public properties located along the mainstem Snoqualmie. The city should continue to work with the Task Force, or other entity as needed, until all public property along the mainstem or its tributaries within city limits have established wooded riparian buffers. The area of the planned off-channel habitat and riparian plantings at the McElhoe-Pearson Levee setback also contained a cool water seep as detected by FLIR. This project should be completed and water temperatures monitored to evaluate if cool water refugia has been created.

Harris Creek: The first major tributary draining to the Lower Mainstem Snoqualmie is Harris Creek. As measured 1.6 miles upstream from its confluence with the Snoqualmie (Hwy 203), Harris Creek 7DADMax water temperatures ranged from 14 to 17.5°C during July and August 2006 (Figure D8, Appendix). Other than the critical period in July 2006, this portion of Harris was 16°C or cooler during the remainder of the summer. This is several degrees lower than the mainstem in the area. However, there is very little shading provided in the creek's last mile and temperatures increase significantly before reaching the Snoqualmie. In late July 2006, water at Ecology's monitoring site 0.5 miles below the Hwy 203 station measured nearly 2°C warmer (Kaje, 2009). No cool water plume was observed in the FLIR imagery where Harris met the Snoqualmie mainstem.

Harris has a north and south fork that meet about 4.5 miles upstream. Each of the forks travels through a number of wetland complexes. The south fork is relatively undeveloped and the north fork has scattered rural residential development. Going downstream from the forks the stream passes through more wetlands adjacent to rural residential land uses before entering a mile of heavily wooded watershed. After Harris crosses Hwy 203 the creek enters the floodplain, which again has numerous wetlands.

Ecology evaluated the levels of wooded vegetation able to properly shade Harris Creek using LIDAR (Figure 69) confirming that riparian vegetation over 10 feet high was consistently low in the agricultural area. Orthophoto analysis of Harris Creek performed on the first 1.5 miles of its

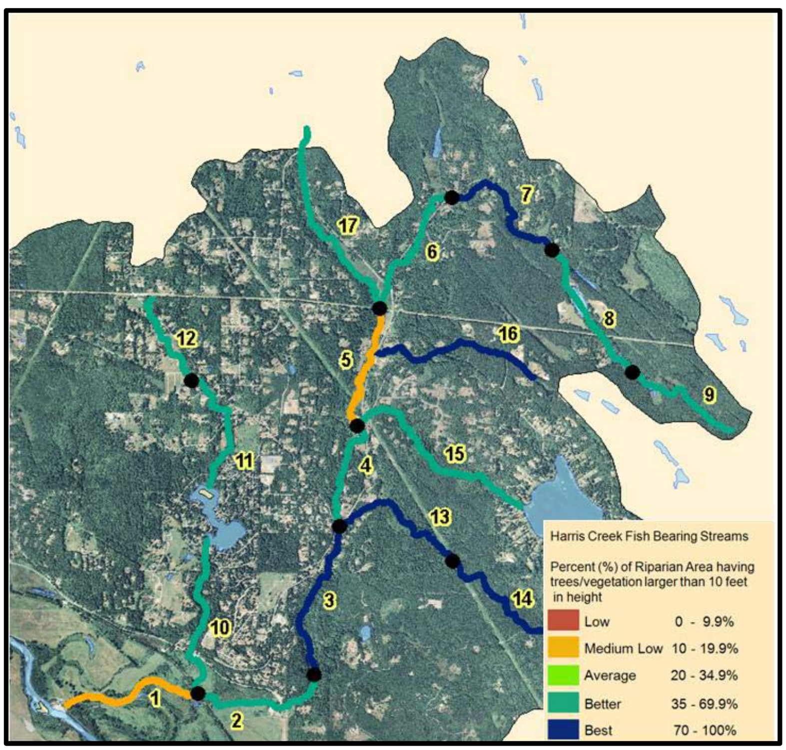

Figure 69. Harris Creek Riparian Report Card. *Ecology evaluated riparian vegetation along Harris Creek within 50 feet of stream center at 1-mile intervals. Mile segments 1 and 5 had low levels of riparian vegetation larger than 10 feet tall. These two areas are the highest priority for restoration activities along Harris Creek.*

mainstem indicated that all floodplain parcels had little wooded riparian vegetation and need closer evaluation based on 2006 imagery. This *implementation plan* supports Stewardship Partners proposed project to improve riparian areas on five acres of Harris Creek farmland.

Over 21 upper watershed parcels were identified as having potential opportunities for riparian enhancement to improve shade levels. Many of these opportunities occur in riparian wetlands. These areas should be evaluated by staff with knowledge on restoring forested wetlands.

Ames Lake Creek: Unlike several neighboring streams, the state temperature criterion for Ames Lake Creek is higher at 17.5^{o}C during the summer months. Ames exceeded this value near its confluence with the Snoqualmie mainstem on several occasions, once for up to a week. During most of August, Ames was able to meet the higher standard of 16^{o}C 7DADMax. 7DADMax temperatures during July and August 2006 ranged from about 14.5^{o}C to 19^{o}C. Daily temperature fluctuations appeared higher than some other water bodies reaching as high as 5^{o}C.

The mainstem of Ames Lake Creek flows from Ames Lake, which is about 3.5 miles from the confluence with the Snoqualmie mainstem. Water travels from Ames Lake through about 1.5 miles of well wooded forest until reaching the floodplain, which has been developed for agricultural production. Ames travels two miles through the floodplain before reaching the Snoqualmie mainstem. Along that two miles are two major tributaries: Ames/Sikes Lake Creek and another unnamed tributary with good flow that runs along NE 80th St into a wooded headwater area. A 75-foot-long cool water plume was observed in the FLIR imagery where Ames Creek met the Snoqualmie mainstem (Figure 70).

Ecology evaluated the levels of trees able to properly shade Ames Creek using LIDAR (Figure 71) confirming that riparian vegetation over ten feet high was consistently low in the agricultural area. Orthophoto analysis of Ames Creek performed on the first two miles of its mainstem clearly indicated that nearly all of the 16 parcels evaluated had inadequate wooded riparian vegetation based on 2006 imagery. No upper watershed areas on the mainstem were identified as needing riparian enhancement.

Figure 70. Cool water seeps observed at the mouth of Ames Creek. *A 75 foot plume of cooler water is shown where Ames Creek meets the Snoqualmie mainstem (pink circle inside the larger red circle to the left). Within the red circle to the right, several small seeps were observed suggesting positive influences on local water temperatures due to groundwater seepage.*

Previous tours of the watershed in recent years revealed that a number of riparian projects have been performed. The agricultural community in the Ames watershed has been active in working to improve water quality and projects to continue outreach and improvement in the Ames watershed should be a priority for grant authorities. Stewardship Partners, King County, the Snoqualmie Forum, and the King Conservation District have been active building partnerships with Ames Creek watershed landowners. Continued effort by these groups to make further gains in improving riparian vegetation levels on agricultural and small farm properties along Ames Creek and its tributaries is highly recommended by this TMDL.

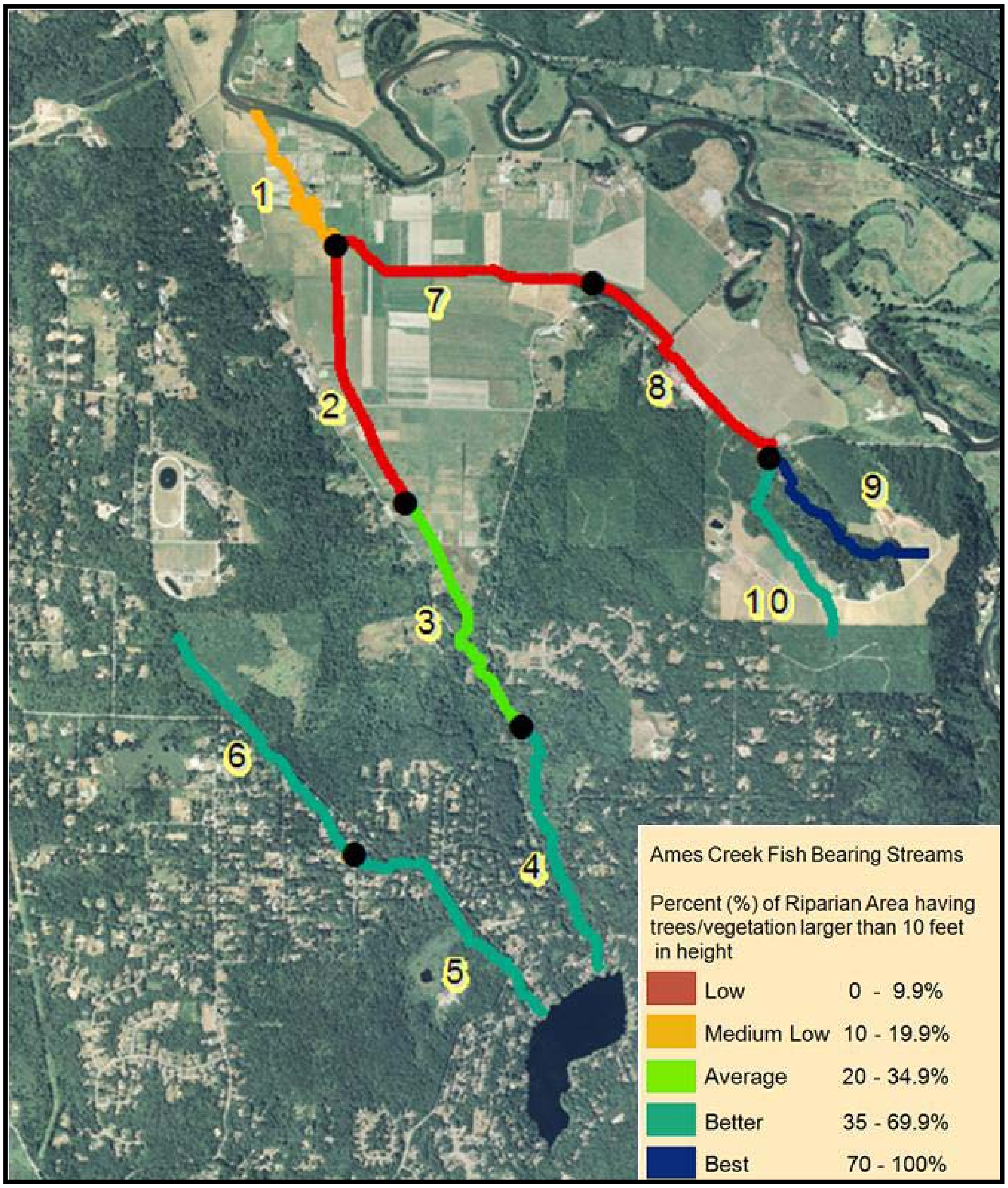

Figure 71. Ames Creek Riparian Report Card. *Ecology evaluated riparian vegetation within 50 feet of stream center at 1-mile intervals. Mile segments 2, 7, and 8 shown above indicate where Ames Creek has very little riparian vegetation larger than 10 feet tall. Upper watershed riparian vegetation was much better.*

Tuck Creek: The state temperature criterion for Tuck Creek is 17.5°C during the summer months. Tuck exceeded this value near its confluence with the Snoqualmie mainstem on several occasions, once for up to a week. During early July and late August Tuck was just below the17.5°C criterion. 7DADMax temperatures during July and August 2006 ranged from about 16.5°C to 19.5°C.

The Tuck Creek watershed is about 3.5 miles long. The upper two miles of the watershed originate in wooded rural residential areas that appear to provide good shade to the creek. Tuck Creek breaks into two forks in the upper watershed: one contains open wetlands and the other a small lake. After the forks join, Tuck Creek flows downstream through a heavily wooded area to the agricultural floodplain. Tuck meanders through the floodplain for about 1.5 miles. As measured in 2006, Tuck Creek was usually about 2°C cooler than the Snoqualmie mainstem where it discharges. As shown in Figure 72, this cool water creates a potential refuge area over 100 feet long for fish rearing in the mainstem Snoqualmie.

King County has worked with Tuck Creek landowners over many years. Together they have made some good progress in providing shade to Tuck Creek and its agricultural watercourse over the past decade. Although progress has been made in shading portions of Tuck Creek, areas where tree establishment failed due to severe weather, and other areas where no trees currently exist, need new riparian plantings.

Because Tuck Creek's "Middle Ditch" watercourse has an established buffer utilizing small trees recommended for agricultural areas by some organizations, the shade density provided by this buffer should be evaluated at full leaf out during the July critical period when solar radiation levels are highest. It may also be valuable to measure local soil temperatures to see to what extent the buffer is helping to moderate temperature diffusion via the ground.

Figure 72. Cool water plume from Tuck Creek. *FLIR imagery shows a cool water plume (red color within the red oval) about 30 feet wide and 120 feet long on the left bank of the Snoqualmie River during the summer of 2006.*

Cherry Creek: The significant salmonid use in Cherry Creek is reflected in its lower state temperature criterion of 16 ^{o}C during the summer months. Water temperatures were not measured in Cherry Creek during July 2006, only August. During August, Cherry Creek consistently exceeded this value at the crossing with Hwy 203 reaching a high 7DADMax of 18^{o}C. Ecology estimated that peak July temperature to be over 21^{o}C based on historical data. However, Cherry Creek is still cooler than the mainstem Snoqualmie.

Cherry Creek originates well into the Cascade Mountains and has many feeder streams. Its mainstem winds nearly eight miles through well forested areas to the Cherry Creek floodplain, which is about two miles long. About half of the watershed above the floodplain appears to be dedicated to timber production and half of that land is managed by WDNR. Orthophoto analysis shows some clearcutting activity and good buffers along the stream. Some upstream areas appear to have wide CMZs and are exposed to sunlight. The entire floodplain is cleared for agricultural use, with much of the hydrology controlled by a pump station. Portions of the floodplain drainage originate in the city of Duvall. About 290 acres of the floodplain is enrolled in the Farmland Preservation Program and much of the land is managed by WDFW.

Cherry Creek needs improved riparian vegetation in the floodplain. Twenty-seven parcels along the mainstem were observed to need better riparian buffers, nearly all of them being located in the floodplain. The Wild Fish Conservancy (WFC) has developed plans and received funding to improve in-stream fish habitat, water quality, and agricultural field drainage in the floodplain. This TMDL encourages the local drainage district to support this effort, which will improve stream temperatures when riparian vegetation is planted. WFC is also working to improve riparian conditions on a North Fork Cherry Creek floodplain property where 0.6 miles (4 acres) of Cherry Creek is now being restored.

WDFW and the Stilly/Snohomish Fisheries Enhancement Taskforce are working with a local landowner to improve the riparian area near Cherry Creek's confluence with the Snoqualmie mainstem. The Taskforce is also working with a floodplain landowner to improve fish habitat and riparian conditions on a small tributary. There is one dairy operating in the floodplain which

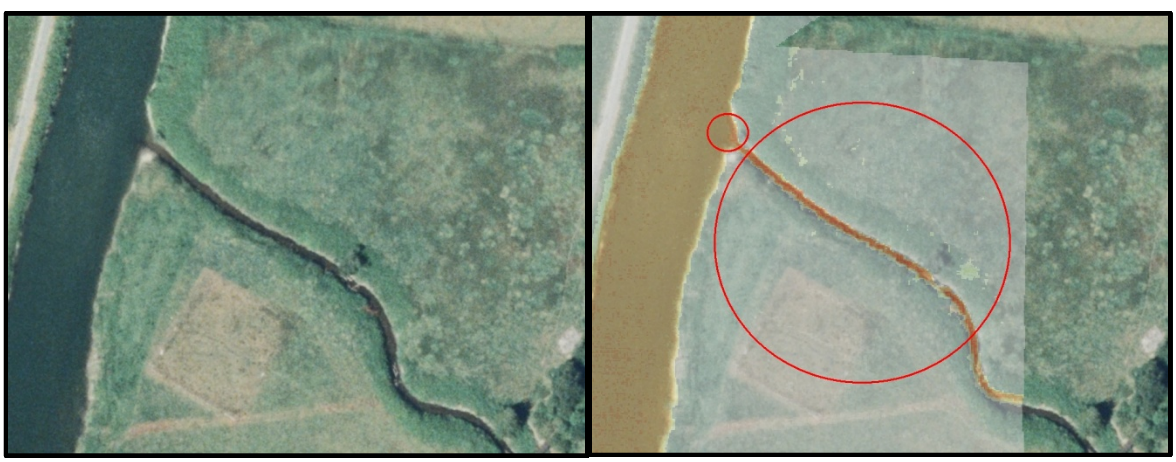

Figure 73. Cool water refuge at the mouth of Cherry Creek. *FLIR imagery shows small a cool water plume about 50 feet long where Cherry meets the Snoqualmie mainstem (red area inside the small red circle). Just upstream of the plume is a much larger refuge area approximately 500 feet long (reddish area inside the large red circle).*

has a small tributary on its property that needs riparian plantings. This TMDL supports these riparian improvement projects and future efforts to provide complete shade to Cherry Creek and its tributaries. The city of Duvall should evaluate its stormwater system in the Cherry Creek drainage and pursue management practices that infiltrate stormwater in new development, redevelopment, and retrofit projects. Infiltrated stormwater reduces surface water pollution and can enhance groundwater supplies and summer baseflows in local streams.

WDFW may wish to investigate upper areas of the watershed to determine if there are riparian areas that would benefit from additional plantings to remedy the loss of riparian trees due to past logging practices (approximately RM 4.5 to RM 5.5, mainstem Cherry Creek).

Who needs to participate in implementation?

Many organizations have a role in accomplishing the activities identified in this *implementation plan* (Table 37). The general roles of many of these TMDL partners are described below.

Table 37. Key Organizations implementing the Snoqualmie Temperature TMDL.

Federal, Tribal, State Agencies	Local Agencies and Special Purpose Districts	Nonprofit Environmental Groups, Businesses, Citizens
U.S.EPA	King County	Stewardship Partners
Tulalip Tribes	Snohomish County	Agricultural Community and Small Farm Owners
Snoqualmie Tribe	King Conservation District	Nonagricultural Landowners
WA Detent of Ecology	Snohomish Conservation District	Ducks Unlimited
WA Department of Natural Resources	City of North Bend	Wild Fish Conservancy
WA Department of Fish and Wildlife	City of Snoqualmie	Stilly Snohomish Fisheries Enhancement Task Force
US Forest Service	City of Carnation	Mountains to Sound
WA Department of Agriculture	City of Duvall	Partnership for a Rural King County
US Department of Agriculture	City of Sammamish	Cascade Land Conservancy
US Natural Resources Conservation Service	Seattle Public Utilities	

Environmental Protection Agency

The 1997 Memorandum of Agreement between the Environmental Protection Agency, Region 10 and Ecology requires that EPA and Ecology jointly evaluate the implementation of TMDLs in Washington.

These evaluations will address whether interim targets are being met, whether implementation measures such as BMPs have been put into effect, and whether NPDES permits are consistent with TMDL wasteload allocations. EPA provides technical assistance and funding to states and tribes to implement the Clean Water Act (CWA). For example, EPA's CWA Section 319 grants are combined with Ecology's grant and loan funds are made available to stakeholders through Ecology's annual Water Quality Grant and Loan Process. On occasion, the EPA also has other grant monies available (CWA 104(b)(3)) to address storm water pollution problems.

US Forest Service

The U.S. Department of Agriculture Forest Service (USFS) is a Federal agency that manages public lands in national forests and grasslands. The Forest Service is also the largest forestry research organization in the world, and provides technical and financial assistance to state and private forestry agencies. The mission of the USDA Forest Service is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. The Mt. Baker-Snoqualmie National Forest (MBS) carries out this mission largely through the implementation of standards and guidelines in the 1990 *Land and Resource Management Plan* and amendments, including the 1994 *Northwest Forest Plan* (NWFP). National Forest System (NFS) lands managed by the MBS under these plans are not addressed by this TMDL. Because properly managed headwater areas are critical to protecting downstream water temperatures, the USFS has agreed to participate in the development and implementation of this plan.

The MBS is currently replacing two culverts in the Middle Fork Snoqualmie to restore fish passage, and decommissioning 15 miles of roads in the North Fork Snoqualmie. The MBS has also been partnering with the Mountains to Sound Greenway Trust to treat roads on NFS lands in the South Fork Snoqualmie. About 48 miles are planned to be treated and closed or decommissioned, with about 16 miles completed, and another 5 miles planned for treatment in 2011. The city of Seattle is also planning on decommissioning about two miles of ridgetop road accessed from within the Cedar River Watershed.

Tulalip Tribes

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

The Tulalip Tribes shares a common interest in and responsibility for the protection and enhancement of the environment. The Tribe focuses its resources in the Snoqualmie Watershed on activities related to salmon recovery including pollution source identification and control, and salmon recovery plan implementation.

Snoqualmie Tribe

The Snoqualmie Tribe is a federally recognized tribe with approximately 650 members. Tribal Environmental and Natural Resources Department staff engage in significant environmental issues across the Snoqualmie watershed, including active participation in the Snoqualmie Forum and monitoring activities above and below Snoqualmie Falls. The Snoqualmie Tribe promotes environmental awareness to its members as well as the community at large and continues to restore riparian habitat at the Fall City Park through knotweed removal and revegetation with native plants.

Washington State Department of Ecology

Ecology performs three activities that help to control thermal pollution inputs to the Snoqualmie watershed:

- Issues National Pollutant Discharge Elimination System (NPDES) permits for wastewater treatment plants and other point source discharges. These permits will implement the wasteload allocations (WLAs) set for each of the four plants located in the Snoqualmie Watershed.

- Administers the total maximum daily load (TMDL) program, which prepares studies, reports, and provides technical assistance to organizations implementing water improvement activities.

- Provides competitive grant funding to correct point and nonpoint pollution problems through the State Revolving Fund and Centennial/319 Grant Programs, respectively.

Washington State Department of Fish and Wildlife

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

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

Washington State Department of Natural Resources

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

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

An important DNR program aimed at controlling sediment discharges from large private and State Trust forest lands is the Road Maintenance and Abandonment Program (RMAP). Under RMAP, all large industrial landowners, including DNR State Lands, were required to have submitted an inventory and rehabilitation plan for all roads within their ownership by December 31, 2005. These landowners have fifteen (15) years from that date to fix all identified issues. The issues specifically targeted by this program include road-related fish blockages and road segments on unstable slopes. To help address similar problems in smaller forest parcels, small forest landowners can take advantage of the Family Forest Fish Passage Program, which is a cost share program designed for forestland owners that do not meet the requirements for RMAP to fix fish blockages related to forest roads.

Puget Sound Partnership

PugetSoundPartnership
our sound, our community, our chance

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

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

King Conservation District

The King Conservation District (KCD) is a nonregulatory agency that supports TMDL goals by providing education and technical assistance to rural landowners and the agricultural community on how to manage land and animals in an environmentally sustainable manner. The KCD also provides grant funding to implement farm best management practices (BMPs) and other projects that can improve water quality. Landowners within the KCD boundaries also receive free information and technical assistance for water quality protection, farm management plans, soil and slope stability information, volunteer opportunities, stream restoration/enhancement assistance, and many other natural resource topics on an as-requested basis.

Snohomish Conservation District

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

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

Natural Resources Conservation Service

The Natural Resources Conservation District (NRCS) works in partnership with the King and Snohomish Conservation Districts to provide technical guidance and funding for a number of programs that affect water quality. The NRCS works primarily with the agricultural community acting as the technical resource aid for farm plan preparation. In partnership with other parts of the U.S. Department of Agriculture, the NRCS also oversees the construction and operation of dikes, pump stations, and other devices associated with the engineering of floodplain areas in agricultural areas. The NRCS also administers several important financial assistance programs including the Environmental Quality Incentives Program (EQIP), Wild Life Incentive Program (WHIP), and the Wetland Reserve Program (WRP).

King County

King County services to the public play an important role in reducing and controlling thermal pollution inputs into the Snoqualmie watershed.

Programs assisting rural and agricultural areas

King County has several programs to help rural landowners and to support a strong and viable agricultural community. By doing so, landowners get technical assistance and will have the economic ability to both sustain their activities and do so in an environmentally acceptable manner. County efforts are discussed below:

- *Forestry Program:* King County's Forestry Program focuses on the retention of forest land for its environmental, social, and economic benefits. Healthy forests help maintain natural watershed hydrology (proper river and stream flows) and introduce less sediment into local waters. The county mails a Farm and Forest newsletters to about 10,000 residents in the Rural Drainage Program area every year. Currently the Forestry program has expanded its outreach work through an EPA grant that supports the Stewardship in Action project administered by the Partnership for a Rural King County.

- *Snoqualmie Basin Steward:* King County's Snoqualmie Basin Steward works directly with landowners to protect water quality and aquatic resources in many ways. Many of the salmon recovery projects underway now in the Snoqualmie Watershed were developed by King County Basin Stewards.

- *Livestock Program:* The King County Council passed the King County Livestock Management Ordinance (LMO) in December 1993. The LMO requires the preparation and implementation of Farm Plans on those farms of a specified animal density. The ordinance requires setbacks of 50’ or greater between Class 1 and 2 streams, natural ponds, and wetlands for pastures with additional requirements for heavy confinement areas. Enforcement of the LMO is a complaint-driven system, meaning that County staff do not investigate compliance with the ordinance unless a complaint is received from an outside entity.

- *Farmland Preservation Program:* This program buys development rights in existing King County farmlands. Covenants restrict land use to agriculture or open space, and limit housing density, to help preserve agricultural lands that would otherwise be susceptible to urban sprawl. Although this is not a water quality program, it can help protect the environment by providing farmers with a new source of funding that could be used to improve riparian areas, install fencing, or implement other best management practices. The program limits the nontillable agricultural land to no more than 5%.

- *Current Use Taxation Programs:* King County’s current use taxation programs provide tax incentives to encourage private landowners to voluntarily conserve and protect land resources and open space. In return, the county assesses land at a value consistent with its “current use” rather than the “highest and best use.” The reduction in assessed land value is greater than 50% and as much as 90% for the portion of the land participating in the program.

  King County’s current use taxation programs are administered by two entities depending on the type of land use. The King County Assessor’s Office administers the current use taxation program for forestlands (property with more than 20 acres of forest devoted to timber production) and commercial farm and agricultural lands (livestock production or agricultural commodities for commercial purposes). Following the initial valuation of a property by the Assessor’s Office, the Department of Natural Resources administers the Public Benefits Rating System (open spaces as defined in K.C.C. 20.36) and Timberland Program (properties containing between 5 and 20 acres of forestland devoted to timber production).

Drainage Assistance Program and Stormwater Services Section

King County’s Agricultural Drainage Assistance Program (ADAP) has helped farmers with maintenance of watercourses on their property for over a decade. As part of ADAP, the county assists farmers with project development, engineering services, defishing, and provides other general assistance. This program is now transitioning to administration by the county’s Stormwater Services Section. King County is currently working with regulators and the agricultural community to streamline ADAP procedures into the future. ADAP has a great potential to improve water temperatures in the tributary streams to the mainstem Snoqualmie River that currently provide little or no shading to agricultural watercourses.

Major Lake and Stream Monitoring Program

The King County Major Lake and Stream Monitoring Program is designed to protect the significant investment in water quality improvement and protection made by the people of King County. Currently, water quality is characterized at 27 waterway locations across the county on a monthly basis. The county has recently decided to add new long-term stations to the Snoqualmie watershed, which had been in need of additional monitoring for many years. This TMDL encourages King County to add continuous temperature monitoring to some or all of new monitoring locations.

Rivers and Floodplain Management Section

King County plays an important role in reducing flood risks and protecting public safety along the County's major rivers. Funded by a combination of Flood Control District fees and various grants, the River and Floodplain Management Section (RFMS) performs many duties associated with its core mission. Their projects to stabilize river banks and perform levee setbacks affect river temperatures by adding or removing shade to adjacent waters and in some cases by creating instream structures that improve pool formation and groundwater exchange. The RMFS maintains a system of continuous levees along the South Fork through North Bend, many discontinuous levees and revetments along the lower North and South Forks and mainstem Snoqualmie below the falls. None of the Snoqualmie river flood protection facilities satisfy federal certification criteria for protection against 100-year floods.

Flood Control project priorities are regularly reevaluated by the RFMS. There are currently 16 proposed projects for the Snoqualmie River watershed in the 2006 King County Flood Control Management Plan. Several projects appear to have some potential for improving pool formation, groundwater exchange, and greatly improved riparian vegetation. These projects in particular, and other current and future projects planned for the Snoqualmie Watershed, should evaluate designs which will contribute to lower water temperatures and the creation of fish refugia during periods of high water temperatures. King County has documented two goals related to these needs in Chapter 6 of the Flood Control Management Plan (IMP-5, IMP-9): 1) active coordination with salmon habitat plan implementation and continued discussions with the U.S. Army Corps of Engineers.

Wastewater Treatment Division

The Carnation Wastewater Treatment Plant (WWTP) is one of five municipal wastewater facilities operated by King County's Wastewater Treatment Division in the Seattle metropolitan area. As discussed in the TMDL study and analyses sections of this report, the Carnation WWTP is high quality reclaimed water that is being used to enhance a wetland in Chinook Bend. Ecology regulates this and all NPDES facilities to ensure compliance with state water quality standards. King County will be required to meet the wasteload allocation for temperature established in this TMDL as described in their NPDES permit.

Ecology's primary means for protecting water quality in wetlands themselves is by maintaining and protecting the hydrologic conditions, hydrophytic vegetation, and substrate characteristics in the wetland. The Carnation WWTP discharge to the Chinook Bend wetlands is designed to enhance those characteristics. The Chinook Bend wetland enhancement project may be contributing to the goals of this TMDL by increasing local groundwater resources. Increased groundwater supplies can increase the number of cool water seeps or volume of cool groundwater released to the river during warm summer months. FLIR imagery did detect one cool water seep from Chinook Bend in 2006 so the presence of suitable geology and hydrologic processes that could lead to improved subsurface discharges seems likely.

Department of Development and Environmental Services

King County's Department of Development and Environmental Services (DDES) develops and administer county regulations for commercial and residential development as well as public projects. The DDES enforces the King County Code as it relates to protection of water quality and the Livestock Management Ordinance and implements the Critical Areas Ordinance (CAO) and other development regulations.

Under requirements of the Growth Management Act (GMA), King County protects sensitive areas through its Critical Areas Regulations (CAO). These regulations became effective in 2004 and include protections for riparian buffers and wildlife habitat along streams and areas of groundwater recharge, such as wetlands, that can influence stream flow and temperature. Under the GMA, the county is required to update its CAO every seven years. When reviewing the CAO pertaining to aquatic habitat, the county must consider this TMDL, and subsequently the pronounced impacts of lack of shade on water temperature, and the water quality standards, as best available science. This TMDL meets and exceeds the criteria for best available science for water temperature impairments of the Snoqualmie River Watershed provided under WAC 365-195-905.

The Washington State legislature recently passed ESHB 1886, which establishes an alternate process for addressing Growth Management Act requirements to address critical areas in agricultural areas. King County should incorporate the findings in this TMDL into the selection process for priority watersheds when implementing ESHB 1886. Workgroups formed under ESHB 1886 should also incorporate the findings of this TMDL when developing watershed workplans.

Snohomish County

Snohomish County WASHINGTON

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

Working together for people, streams & fish.

Snohomish County Public Works--Surface Water Management:

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

- Education is conducted through targeted programs as well as through the activities of Watershed Stewards.
- A Water Pollution Control Ordinance (Chapter 7.53 Snohomish County Code). The ordinance prohibits the discharge of pollutants to County Streams.
- Co-leadership and support for the Snoqualmie Forum and its goals of increasing salmonid populations and improving water quality throughout the basin.
- Riparian restoration work through discretionary and grant funding.
- Continuous temperature monitoring is conducted in accordance with Ecology protocols in receiving waters across unincorporated Snohomish County.

The Washington State legislature recently passed ESHB 1886, which establishes an alternate and voluntary process for addressing Growth Management Act requirements to address critical areas in agricultural areas. Snohomish County should incorporate the findings in this TMDL into the selection process for priority watersheds if this alternate process is implemented. Workgroups formed under ESHB 1886 should incorporate the findings of this TMDL when developing watershed workplans.

Snohomish County Planning and Development Services:

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

Along with other parts of Snohomish County Government, the PDS is promoting Low Impact Development (LID) principles and has adopted an LID ordinance to help facilitate the use of this innovative stormwater management technique (Ordinance 30.63C). The county helps sponsor the Sustainable Development Task Force, which is a public/private partnership dedicated to the adoption of strategies that protect the environment by promoting the wise use of building materials, energy efficiency, and the reduction or elimination of stormwater. The PDS is also working with the agricultural community to develop and implement the Sustainable Lands Strategy (SLS), which seeks to reconcile the land-base needs of agriculture and habitat restoration activities in Snohomish County and find net gains for both of these county needs. Development of the SLS *implementation plan* (Phase 2) is planned for Fall 2011.

Under requirements of the Growth Management Act (GMA), Snohomish County protects sensitive areas through its Critical Areas Regulations (CAR). These regulations became effective in 2007 and include protections for riparian buffers and wildlife habitat along streams and areas of groundwater recharge, such as wetlands, that can influence stream flow and temperature. Under the GMA, the county is required to update its CAR every seven years. When reviewing the CAR pertaining to aquatic habitat, the county must consider this TMDL, and subsequently the pronounced impacts of lack of shade on water temperature, and the water quality standards, as best available science.

Snohomish and Snoqualmie Salmon recovery forums

During 1994 to 2004, state agencies, local governments, tribes, and others increased their efforts to restore chinook salmon populations through the Snohomish River basin salmon recovery process. To coordinate this work, the Snohomish Salmon Recovery and Snoqualmie Watershed Forums were created.

The primary tasks for these groups were to guide the initial planning and early implementation actions to help restore chinook populations. Early implementation focused on the acquisition and restoration of estuarine habitat. Ecology expects that future activities will place greater emphasis on water quality in tributary streams where water quality is a greater factor in salmon health and survival.

Snohomish Salmon Recovery Forum

The Snohomish Forum is a 39-member voluntary group of citizens, businesses, tribal representatives, farmers and elected officials who guide conservation efforts in the Snohomish River basin. The Forum's mission is to protect, restore, and enhance the productivity and diversity of all wild salmon stocks in the Snohomish River basin by putting the Snohomish River Basin Salmon Recovery Plan into action. The state of Washington distributes most of its salmon recovery funds for the Snoqualmie Watershed through a prioritization processes performed largely by the Snohomish Forum.

Snoqualmie Watershed Forum

The Snoqualmie Forum is comprised of representatives from the cities of Carnation, Duvall, North Bend, and Snoqualmie; King County; the Snoqualmie Tribe; the King Conservation District; a non-governmental organization member; and three citizens. The Forum plays a key role in the coordination of habitat protection and restoration throughout the watershed; assists local governments in the development of environmental policies and regulations; represents local governments in regional forums; facilitates coordination between project sponsors; and a variety of other activities. The Snoqualmie Forum works to protect and restore the health of the Snoqualmie watershed in harmony with the cultural and community needs of valley residents. The Snoqualmie Forum makes recommendations to the Snohomish Forum and oversees the distribution of approximately $575,000 annually to support habitat protection and restoration projects, stewardship projects and programs, and studies. Financial support for Forum-sponsored projects is provided by King County, King Conservation District, and the participating entities.

City of North Bend

The city of North Bend operates a wastewater treatment plant and stormwater management system and participates actively in the Snoqualmie Forum. The North Bend WWTP National Pollutant Discharge Elimination System (NPDES) permit is discussed earlier in this report under the TMDL Determination Section. North Bend will be required to meet the wasteload allocation for temperature established in this TMDL, which will be expressed as needed in their NPDES permit.

The city of North Bend has a history of working cooperatively with neighboring jurisdictions and environmental protection organizations to improve watershed health. Examples include the joint purchase of the 460-acre Meadowbrook Farm with King County and the city of Snoqualmie to purchase the 460-acre Meadowbrook Farm and partnership with the Mountains to Sound Greenway Trust to remove invasive plant species and provide animal exclusion fencing along Ribary Creek.

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

The city should review development codes to make sure that Low Impact Development approaches can be incorporated into development designs.

City of Snoqualmie

The city of Snoqualmie operates a wastewater treatment plant and stormwater management system and participates actively in the Snoqualmie Forum. Most of the discharge from the WWTP during summer months is used to irrigate the Snoqualmie Ridge golf course, athletic fields at Snoqualmie Community Park, and landscaping at nearby businesses. The Snoqualmie WWTP National Pollutant Discharge Elimination System (NPDES) permit is discussed earlier in this report under TMDL Determination Section. The Snoqualmie WWTP will be required to meet the wasteload allocation for temperature established in this TMDL, which will be expressed as needed in their NPDES permit.

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

The city should review development codes to make sure that Low Impact Development approaches can be incorporated into development designs.

City of Carnation

The city of Carnation, which operates a stormwater management system, participates actively in the Snoqualmie Forum. Domestic wastewater generated within the city is treated partially by the new Carnation WWTP and partially by existing onsite septic systems.

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

The city should review development codes to make sure that Low Impact Development approaches can be incorporated into development designs.

City of Duvall

The city of Duvall operates a wastewater treatment plant and a stormwater management system and participates actively in the Snoqualmie Forum. The city has promoted riparian planting projects along the mainstem Snoqualmie River in recent years. Duvall will be required to meet the wasteload allocation for temperature established in this TMDL, which will be expressed as needed in their NPDES permit.

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

City of Seattle, Seattle City Light, and Seattle Public Utilities

The Tolt River is one of the major tributaries to the Snoqualmie River, with the South Fork Tolt River regulated by a dam operated by Seattle City Light (SCL) and Seattle Public Utilities (SPU). The dam provides hydropower for the 15 MW South Fork Tolt Hydroelectric Project, and has a reservoir that supplies about 30% of the drinking water for 1.3 million residents in the Seattle metropolitan area. The city owns 70% of the watershed above the dam, with the remainder managed as part of the Mt. Baker-Snoqualmie National Forest. Management of the city owned portion of the watershed is guided by the South Fork Tolt Watershed Management Plan completed in 2008. SPU actively manages outflow from the dam to provide a temperatures regime that is more similar to natural in the South Fork Tolt using the unregulated North Fork as a surrogate for natural temperatures.

Seattle City Light staff members participate actively in the work of the Snohomish Basin Salmon Recovery Forum in implementing *the Snohomish River Basin Salmon Conservation Plan,* a restoration program to protect and enhance river habitat for chinook and other salmon species. The city of Seattle is committed to protecting fish in this basin by providing guaranteed instream flows, providing specially designed structures to keep fish out of the powerhouse tailrace, replacing culverts with fish-friendly bridges on Tolt tributaries, and contributing to habitat restoration projects in several nearby streams. The city in partnership with King County completed the Lower Tolt Floodplain Restoration Project in 2010, which reconnected 50 acres of floodplain that was previously disconnected from the river by a dike.

Stewardship Partners

Stewardship Partners is a nonprofit conservation organization that promotes incentive-based programs to encourage private landowners to participate in voluntary conservation practices while promoting sustainable land management. Since 2002, Stewardship Partners has restored nine miles of riparian habitat and created bank protection for eroding farmland in the Snoqualmie Watershed. They continue to lead the Snoqualmie Salmon-Safe Program, which uses a market-based approach to encouraging farms to follow best management practices to protect water quality and habitat. Stewardship Partners is currently completing riparian restoration activities under an Ecology Centennial Grant and is on Ecology's draft 2012 funding list to receive more support for their work in the Snoqualmie Watershed.

Stilly/Snohomish Fisheries Enhancement Taskforce

The Stilly-Snohomish Fisheries Enhancement Task Force (Task Force) is a 501(c)(3) not-for-profit corporation registered as a charitable organization with Washington State. The Task Force's mission is to ensure the future of salmon in the Stillaguamish, Snohomish, and Island County watersheds. Funding for Task Force activities comes from the Washington Department of Fish and Wildlife, National Fish and Wildlife Foundation, Salmon Recovery Funding Board, grants, donations, and fee-for-service contracts. More information about projects and volunteer opportunities with the Task Force are at the website: www.stillysnofish.org/index.html.

Working with landowners of all types, the Task Force conducts volunteer events and stream restoration projects that improve water quality and fish habitat. Past projects include tree planting along the mainstem Snoqualmie in the city of Duvall; at the Oxbow Farm; along Griffin Creek; within the Stillwater Wildlife Refuge, and at the Members Club at Alderra along Canyon Creek, a tributary of Patterson Creek. The Task Force offers educational programs, including the Restoration Education for Young Stewards (REYS), to elementary through high school classrooms.

Wild Fish Conservancy

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

Mountains to Sound Greenway Trust

The Mountains to Sound Greenway Trust is a nonprofit organization created to protect the Mountains to Sound Greenway. The Greenway stretches along100 miles of Interstate 90 from the waterfront in Seattle to the edge of desert grasslands in Central Washington. Much of the Greenway is located in the headwaters of the Snoqualmie watershed. The Greenway includes historic towns and over 700,000 acres of foothills, working farms and forests, spectacular alpine scenery, wildlife habitat, campgrounds, trails, lakes, and rivers. The Mountains to Sound Greenway Trust has dedicated resources to removing invasive species, re-planting riparian areas, and providing animal exclusion fencing in the Snoqualmie Watershed. Past projects include Ribary and Gardner Creeks, which are located in the Meadowbrook Farm adjacent to the South Fork Snoqualmie River. They are currently doing similar work in the Raging River Watershed.

Partnership for a Rural King County

Partnership for Rural King County (PRKC) is a grassroots consortium of neighborhood residents, community associations, non-profits, outdoor user groups, and educational agencies dedicated to preservation of rural communities and surrounding lands in eastern King County. PRKC works within the Snoqualmie Valley and surrounding area in eastern King County to ensure the long-term sustainability of working forestland, farmland, outdoor recreation, and biodiversity of our special region. Since September 2009, PRKC has been providing technical and financial assistance to landowners in the Patterson Creek and Raging River watersheds as part of the Stewardship in Action project.

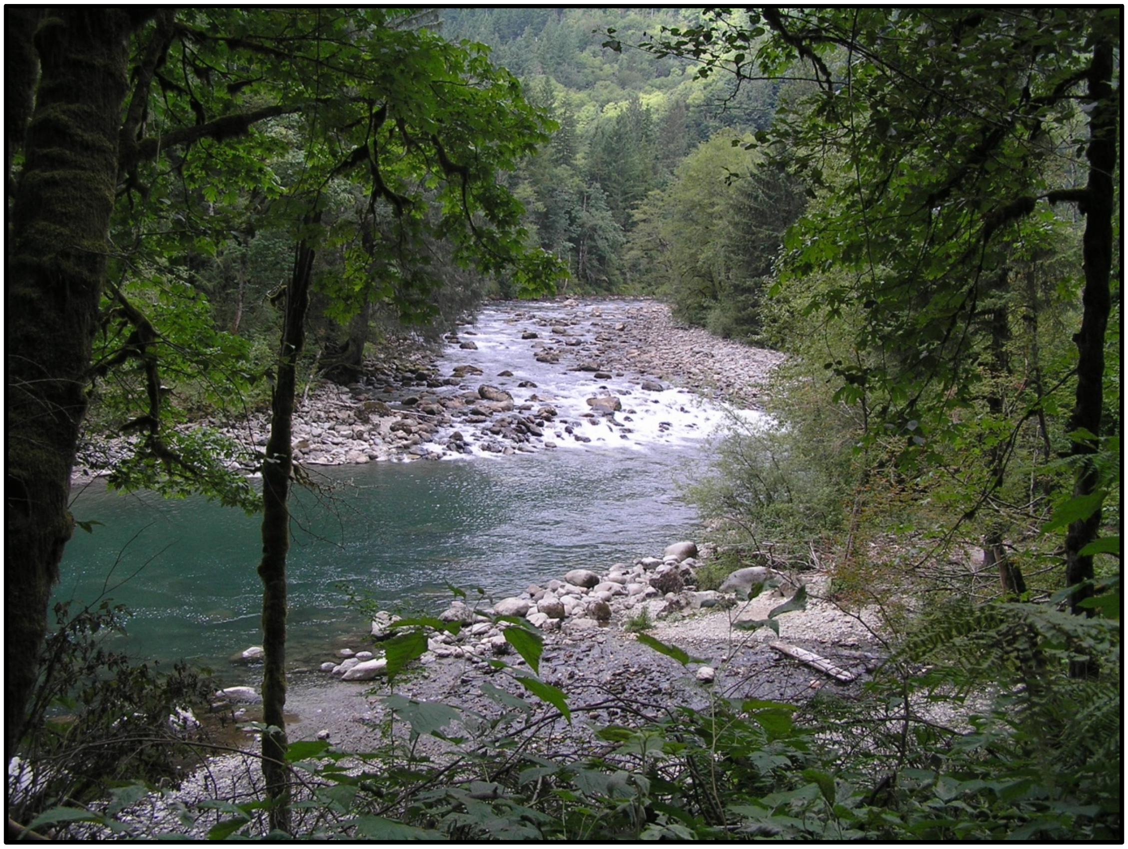

Figure 74. Middle Fork Snoqualmie River. *About 40% of the riparian area along the Middle Fork Snoqualmie has small to medium sized trees. High river flows, long-past logging practices, and land clearing activities all are likely to have played a role in removing large mature trees needed to shade the Snoqualmie. Over time, we can expect the existing trees to mature and reduce water temperatures in the Middle Fork Snoqualmie.*

Measuring Progress toward Goals

The progress of this *implementation plan* will be measured by 1) assessing the pollution control activities underway or completed and 2) direct measurement of water quality. Ecology anticipates that if state and local coordination proceed as expected for increasing effective shade, required plantings to begin the reconditioning of riparian conditions will be achieved by 2021. Because of the time needed for trees to grow to a mature size and provide maximum shade and microclimate benefits, fully reaching TMDL goals will not be achieved until all trees reach their mature height. However, the majority of the shade that will be provided should be in place by 2071, when trees are 50 years old.

Performance measures and targets

Ecology chose several methods to measure the progress of the Snoqualmie Temperature TMDL. Implementation activity tracking will evaluate riparian conditions across the watershed with a special focus on the mainstem Snoqualmie and three geographically separated subbasins: Patterson Creek, Harris Creek, and Ames Creek. Because the goal of the plan is to improve all riparian habitats along the mainstem and tributary streams by 2021, a 50% reduction in the level of poor riparian conditions by 2016 is set as the interim target for each of these areas (Table 38). Ecology expects water temperatures to decrease gradually over time as existing and newly planted trees in these areas by 2016 based upon riparian improvements that have taken place since temperature data was collected for this study.

Table 38. Interim targets for Snoqualmie Watershed riparian improvement.

Mainstem Area	Area needing trees to be planted (acres)	
	2006 Level	2016 Interim 50% Reduction Target
Upper Mainstem	59	30
Middle Mainstem	257	128
Lower Mainstem	555	268
Tributary Watershed	**Stream miles with less than 10% of riparian vegetation > 10' tall**	
	2006 Level	**2016 Interim Reduction Target**
Patterson Creek	7	3
Harris Creek	0	Plant 50% of the lower 1 mile riparian area
Ames Creek	3	1

In order to track the progress in implementing this TMDL, all entities performing riparian restoration, or other activities, should provide site-specific information on their planting projects to Ecology, or another designated watershed lead organization. In addition to documenting progress in meeting shading needs, this information will allow all entities to determine where additional restoration programs need to target their work. Other methods of tracking progress, such as the Habitat Work Schedule, may be the most logical core repository for information on riparian restoration progress. Ecology's NPDES permits will track compliance with TMDL WLAs at wastewater treatment plants.

Effectiveness monitoring

Effectiveness monitoring determines if the interim targets and water quality standards have been met after the corrective actions described in this plan are functioning. Effectiveness monitoring of TMDLs is usually conducted by Ecology's Environmental Assessment (EA) Program. The EA Program evaluates many factors as part of their assessment including monitoring done by other entities, the location and amount of implementation activities, and related changes in the watershed.

The primary implementation activity needed to improve temperatures in the Snoqualmie Watershed is riparian restoration. Because it takes many years for restored areas to provide measureable amounts of shade, we expect the earliest improvements to be measured in tributary streams, which are smaller in size and more responsive to improved riparian conditions. For that reason, implementation tracking will focus heavily on tributary watersheds.

The locations and amount of riparian improvements must be documented and evaluated in relation to periodic temperature monitoring within all watersheds, especially those with interim targets shown in Table 38. At a minimum, long term monitoring should be performed at the locations shown in Figure 75. Continuous monitoring from mid-June through September is needed at a minimum frequency of five years. Monitoring of additional tributaries and upstream areas in high flow water bodies or watersheds undergoing significant restoration processes is recommended where resources are available.

Ecology will evaluate water temperatures at its two mainstem Snoqualmie sites starting in 2015. King County is establishing 11new monitoring sites in the Snoqualmie Watershed as part of its Major Lake and River Monitoring Program. King County is encouraged to periodically evaluate continuous temperature levels at these sites. The Snoqualmie Tribe is also increasing its monitoring activities and should coordinate with Ecology and King County when adding water temperature monitoring to its program.

Adaptive management

Natural systems are complex and dynamic. The way the Snoqualmie Watershed will respond to human management activities is often unknown and can only be described as probabilities or possibilities. For example, this TMDL relies on computer model to predict our success in improving Snoqualmie water temperatures. Even though our QUAL2Kw model is very good, it is still only able to approximate what will happen in the environment. We also saw in this study

Figure 75. Long-term Monitoring Locations. *A total of eight tributary and five mainstem locations should be evaluated every five years as part of a long-term monitoring process. Red dots indicate mainstem monitoring locations and yellow dots show tributary locations*.

that groundwater can play an important role in providing both large and small scale water temperature improvements. The future effects of improving/modifying agricultural drainage on water temperatures are not fully understood. It is also difficult for us to completely predict climate change and its effect on Snoqualmie water temperatures.

Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. In the case of TMDLs, Ecology uses adaptive management to assess whether the actions identified to solve temperature problems in the Snoqualmie watershed are the correct ones and whether they are working. As we work together to implement these actions, the system will respond, and it will also change. Adaptive management allows us to fine-tune our actions to make them more effective, and to try new strategies if we have evidence that a new approach could help us to achieve compliance.

Ecology will use adaptive management as it evaluates progress in meeting the implementation targets in Table 38, when performing Effectiveness Monitoring, and any occasion where we can improve the quality and efficiency of TMDL implementation (e.g., outreach programs, design and placement of instream wood structures, design of incentive programs, and riparian planting and maintenance strategies). It is ultimately Ecology's responsibility to assure that implementation is being actively pursued and water standards are achieved.

Funding Opportunities

This *implementation plan* encourages all affected landowners to take actions to reduce water temperatures during the summer dry season. Although projects should be designed to meet site-specific conditions and landowner expectations, they should generally be judged or prioritized by their ability to address the following critical elements for success. Grant programs should incorporate the following criteria when prioritizing funding for watershed and fisheries improvement projects:

- *Promote high design standards:* Riparian restoration projects should strive to establish 150-foot wide buffers on each side of the mainstem Snoqualmie, North, South, and Middle Forks, and the Tolt River and its major tributaries so that microclimate gains can be reached. Projects on tributary mainstems and their major feeder streams within agricultural areas should strive for at least 35' buffers with the largest trees possible. All watercourses with flowing waters should provide complete shade at the maximum density feasible.

  Planting sites should be properly prepared based on local soil, topography, and location within the channel migration zone. The need for annual plant maintenance for a period of 5 years following plantings should be evaluated and always be included where the previous dominant vegetation was composed of blackberries, reed canary grass, Japanese knotweed, and other invasive or noxious weeds. Restoration specialists should regularly review the success of techniques to ensure that planting, watering, weed management, and outreach techniques are the most effective ones available.

- *Focus work where it is needed:* Although project managers should take advantage of all good opportunities for improving riparian vegetation, systematic approaches to developing successful projects are needed. Subbasin-scale projects should start with a clear understanding of where planting needs exist and focus outreach efforts on those properties—GIS-based tools are available to facilitate this. All organizations completing riparian restoration projects should share information on the location, type, and amount of restoration performed through the Snohomish Forum, the Snoqualmie Forum, and their related activities.

- *Monitoring project effectiveness is critical to long-term success:* Monitoring the effectiveness of projects helps ensure that the time and effort of public, private, and citizen resources are put to the best use. Most project managers have some level of effectiveness they are required to meet as part of their riparian planning projects. Forestry management, city and county mitigation plantings, and even voluntary riparian plantings are examples of different projects subject to different rules. Federal (EPA Clean Water Act 319 fund program), state (Joint Legislative Audit and Review Committee), and local authorities are demanding additional data regarding accountability. All project managers should consider including an effectiveness monitoring component that is representative of the work they are doing.

  Monitoring of project effectiveness can be done in many ways and should help improve the quality of restoration projects over time. All relevant aspects of a project should be considered for effectiveness assessment. Initially, the efficiency of outreach efforts (changes in stakeholder behavior, number and percentage of watershed residents participating, etc.) can be evaluated. After plants are in the ground, it is important to establish good baseline numbers and plan for additional monitoring at approximately 5 year intervals up to 15 years. Plant type and survival rates should be calculated for representative projects. Water temperatures should be measured, along with reductions in bacteria or nutrients where appropriate.

All monitoring efforts should be coordinated to reduce duplication of effort.

The evolving condition of riparian areas throughout the watershed should also be evaluated periodically. Factors that should be analyzed through GIS analysis and associated field verification include trends in riparian vegetation composition and stream width.

- *Use innovation to overcome obstacles:* Where there are impediments to progress in meeting TMDL goals, this *implementation plan* encourages innovation to solve difficult problems. For example, if economic issues stand in the way of increasing buffer sizes after all available tools have been used, then new policies and strategies should be investigated to resolve this problem such as secondary crop harvests (fiddleheads, mushrooms), the use of carbon credits, additional private or public support, or changes in current regulations.

  If research is needed to investigate new watershed tools, this *implementation plan* supports targeted pilot projects to test new techniques and hypotheses to improve progress toward reaching water quality goals on a long term, sustainable basis.

  This *implementation plan* recognizes that the state-of-the-art for restoration projects can be site-specific and is constantly evolving and improving. All restoration projects should strive to follow the latest standards for their development, execution, and maintenance.

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

Funding is available from a number of the agencies mentioned in this document. The most popular funds used in our area are discussed below. There are many other funding sources, especially for projects that benefit both water quality and salmon. A good source of information on funding sources is the Catalog of Federal Funding Sources for Watershed Protection website. This site provides a searchable database of financial assistance sources (grants, loans, cost-sharing) available to fund a variety of watershed protection projects. To learn more about the federal catalog, use the following link: http://cfpub.epa.gov/fedfund/

An important aspect of gaining funding is to have a clear need identified. It is recommended that you contact the grant specialist for the grant you are considering in order to obtain up-to-date information on current grant priorities, deadlines, and procedures. The following is a partial list of funding opportunities that are popular in western Washington.

Environmental Protection Agency

National Estuary Program

EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national importance. In the Puget Sound and surrounding watersheds, this includes protection of fish, shellfish, wildlife, and recreational activities and requires the control of point and nonpoint sources of pollution. EPA Region 10 is currently administering NEP funds through grants to "Lead Organizations" in Washington State shown in Table 39. Each Lead Organization is responsible for administering funds for individual projects in one of five areas. Most funding is expected to be awarded on a competitive basis beginning in the summer/fall of 2011 and continuing for approximately five years under current policies. Interested parties should contact Morgan Schneidler at the Puget Sound Partnership, or the Partnership website, for specific information on how to apply for these funds.

Table 39. National Estuary Program Lead Organizations. *The following organizations will be receiving funds from EPA to assist in the restoration of Puget Sound watershed*.

Environmental Focus Area	Lead (co-Lead) Organization(s)	Estimated 2011 Funding
Outreach, Education, and Stewardship	Puget Sound Partnership	$2M
Watershed Protection and Restoration	Ecology (WA Dept. of Commerce)	$3.1M
Toxics and Nutrients	Ecology	$3.1M
Marine and Nearshore Protection and Restoration	WA Dept. of Fish and Wildlife (WA Dept. of Natural Resources)	$3.1M
Pathogens	WA Dept. of Health (Ecology)	$3.1M
Tribal implementation of the Action Agenda*	Northwest Indian Fisheries Commission	$3.0M
Puget Sound Action Agenda Implementation Management*	Puget Sound Partnership	$3.0

* These funds may not be available to nontribal entities or outside agencies and nonprofits.

Environmental Education Grants Program

Education institutions, environmental and educational public agencies, and not-for-profit organizations are eligible for this funding, which supports environmental education projects. These grants require non-federal matching funds for at least 25 % of the total cost of the project. If project requests are $5,000 or less through a Regional Office or $100,000 or less through EPA Headquarters, chances of being funded increase. For more information contact Diane Berger @ (202) 260-8619, berger.diane@epa.gov, or on the Internet @ www.epa.gov/enviroed.

Ecology Funding Opportunities

Centennial/SRF/319 Fund

These three funding sources are managed by Ecology through one combined application program. Centennial and 319 funds are grants and the State Revolving Fund (SRF) is a low interest loan program and each is available to public entities. Grants require a 25% match and may be used to provide education/outreach, technical assistance, on-the-ground restoration for specific water quality projects, or as seed money to establish various kinds of water quality related programs or program components.

At the time of this report, grant funds are available for riparian fencing, riparian re-vegetation, off-stream stock watering, and selected property improvements that provide a clear benefit to local water quality. It is recommended that you contact your Ecology Water Cleanup Specialist directly to discuss and develop grant proposals.

Low-interest loans are available to public entities for all the above uses, and have also been used as "pass-through" to provide low-interest loans to homeowners for septic system repair or agricultural best management practices (loan money can be used for a wider range of improvements on private property), for instance. Ecology's grant and loan cycle typically kicks off in September of each year with public meetings held throughout the state. See Ecology's webpage for more information on Ecology financial assistance opportunities as well as other funding sources (http://www.ecy.wa.gov/programs/wq/funding/funding.html).

Coastal Protection Fund

Since July 1998, water quality penalties issued under Chapter 90.48 RCW have been deposited into a sub-account of the Coastal Protection Fund. A portion of this fund is made available to regional Ecology offices to support on-the-ground environmental restoration and enhancement projects. Local governments, tribes, and state agencies must propose projects through Ecology staff. Projects seeking to reduce bacterial pollution are encouraged. Contact an Ecology Water Cleanup specialist to investigate fund availability and to determine if your project is a good candidate.

Salmon Recovery Funding Board (SRFB)

The Salmon Recovery Funding Board (SRFB) provides grants to local governments, tribes, nonprofit organizations, and state agencies for salmon habitat restoration, land acquisition, and habitat assessments. Projects and programs must produce sustainable and measurable benefits for fish and fish habitat. Most projects designed to improve salmon habitat also provide water quality benefits. Salmon recovery projects funded by the SRFB are coordinated through the Snoqualmie Forum.

ECO Net

ECO Net (Education, Communication, and Outreach Network) is a Sound-wide network of professionals working to help save Puget Sound. It draws on the combined experience, skills and community-level knowledge of local organizations and individuals while linking to and benefiting from regional resources and a comprehensive vision for restoring Puget Sound. There are twelve local ECO Networks across the twelve counties of Puget Sound. Each Local ECO Net has a designated coordinator and meetings are held at least quarterly. You can find the local ECO Net Coordinator and other information about ECO Net at the Puget Sound Partnership website http://www.psp.wa.gov/econet.php.

Aquatic Lands Enhancement (ALEA) Program

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

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

All projects must be consistent with the local shoreline master program and must be located on lands adjoining a water body that meets the definition of "navigable." Projects intended primarily to protect or restore salmonid habitat must be consistent with the appropriate lead entity strategy or regional salmon recovery plan. Recipients must provide at least 50% match. For more information, view the Office of the Interagency Committee website at http://wdfw.wa.gov/grants/alea/.

USDA Programs

Conservation Reserve Enhancement Program (CREP)

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

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

- Annual payments can equal 100% of the weighted average soil rental rate (incentive is 110% in areas designated by Growth Management Act).

- Annual soil rental rates in King County for 2011 vary greatly (from about $100/acre[8] to $232/acre) depending on the quality of soil and type of crops typically raised on them. Several soil types present in the Snoqualmie Agricultural Production District include Seattle Muck, Snohomish Silt Loam, and Woodinville Silt Loam. Rental rates for these valuable soils are currently $232/acre.

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

Conservation Reserve Program (CRP)

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

Environmental Quality Incentives Program (EQIP)

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

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

- 75% cost sharing but allows 90% if producer is a limited resource or beginning farmer or rancher.

- Program funding divided 60% for livestock-related practices, 40% for crop land.

- Contracts are 1 to 10 years.

- NO annual payment limitation; sum not to exceed $450,000 per individual/entity.

King Conservation District Funds

Funding of on-the-ground watershed improvement projects by the King

[8] CREP buffers can range from 15 feet to 180 feet wide. A small agricultural watercourse with a 15 foot wide buffer on each side generates an acre of CREP income every 1,450 feet. For a larger 150 foot buffer like those needed on the Snoqualmie mainstem, an acre of CREP income is generated every 290 feet of streamside buffer created (one side only).

Conservation District (King CD) is critical to the success of the Snoqualmie Temperature TMDL. The King CD provides over $4M annually across King County to support of on-the-ground conservation projects and environmental education programs. King CD funds are provided through several programs in the Snoqualmie Watershed. Detailed information can be found at the Snoqualmie/Skykomish Salmon Conservation and Restoration Website at http://www.govlink.org/watersheds/7/funding/default.aspx#application .

Landowner Incentive Program

The Landowner Incentive Program (LIP) has been developed by the King CD to address soil and water resource concerns in King County by funding on-the-ground conservation projects. The King CD LIP is intended to promote stewardship by enabling landowners to implement best management practices (BMPs) on their land. A landowner will be required to have either an approved farm plan, forest stewardship plan, or be currently receiving technical assistance from the King CD in order to apply. Typical LIP grants focus on forest health management, aquatic buffer plantings, waste storage facilities and other activities involving the implementation of best management practices.

The King CD LIP is an incentive based program that can fund 50-90% of the project cost with the remainder to be provided by the applicant. The list of funded practices includes both agricultural related BMPs and non-agricultural BMPs. There is no lifetime maximum on the number of BMPs a landowner can fund through the King CD LIP. However, the landowner must complete and receive reimbursement for a funded practice before another application to fund additional practices or BMPs will be considered.

WRIA Forum Grants (Regular Grant Round)

King CD typically provides over $400,000 annually to the Snoqualmie Forum in its Regular Grant Round to support substantial natural resource improvement projects in the Snoqualmie Watershed. Funding is awarded for salmon habitat enhancement projects and other programs including knotweed control and invasive species removal, watershed education programs, riparian corridor enhancements, fish passage barrier removal and fish habitat improvement. These funds are strategically leveraged with state salmon recovery funds and other grant sources to fund watershed restoration priorities identified by the Snoqualmie Forum. Draft applications are typically due by March.

Opportunity Fund

The King CD also assists watershed restoration activities in partnership with the Snoqualmie Forum by supporting the Opportunity Fund. The Opportunity Fund provided smaller grants (up to $30,000) to both private and public landowners for projects such as livestock exclusion fencing, riparian restoration, culvert replacement, and educational activities. Pre-applications are typically due in May.

Local Government Grants

The King CD's local government program enables jurisdictions to implement a wide variety of natural resource improvement projects such as riparian corridor enhancements, community education programs, invasive weed removal and more. Each jurisdiction works in partnership with King CD to determine how grant funds allocated to them will be utilized for conservation.

SCD grant opportunities

The Snohomish Conservation District (SCD) assists landowners directly through their cost share program. The sign-up period runs from October through February. Recipients need to pay the up-front cost of installing approved best management practices (BMPs) and typical reimbursement rates are 50 to 75 % of project cost. SCD can provide engineering services and help you determine the cost of your project as well. Projects with the greatest likelihood of improving water quality get the highest priority for funding. Since there are multiple sources of funding used to help landowners with their projects, the best thing to do is to contact the SCD at 425-335-5634, ext 4, or visit www.snohomishcd.org to get in touch with a small farm planner. Typical BMPs that can help implement this TMDL are the installation of exclusion fencing combined with riparian plantings.

Summary of Public Involvement Methods

An advisory committee assisted in the preparation of this water quality implementation report and implementation plan. Advisory committee meetings were held on February 10, March 3, and March 24 of 2011. The following local government agency staff, Tribal natural resources agency staff, and local organizations (Table 40) participated in the meetings or via phone or email.

Table 40. Advisors to the preparation of the Snoqualmie Temperature TMDL Improvement Report/ Implementation Plan.

Federal, Tribal, State Agencies	Local Agencies and Special Purpose Districts	Nonprofit Environmental Groups, Businesses, Citizens
U.S.EPA	King County	Stewardship Partners
Tulalip Tribes	Snohomish County	Wild Fish Conservancy
Snoqualmie Tribe	King Conservation District	Stilly Snohomish Fisheries Enhancement Task Force
WA Department of Natural Resources	Snohomish Conservation District	
WA Department of Fish and Wildlife	City of North Bend	
US Forest Service	City of Snoqualmie	
US Farm Service	City of Carnation	
	City of Duvall	
	City of Sammamish	
	Seattle Public Utilities	

Ecology's public comment period ran from May 18th through June 17th. A display ad (Appendix K) was placed in the Snoqualmie Valley Record and a new webpage was constructed to provide information on the Snoqualmie TMDL. A focus sheet was created (Appendix K), distributed at several public meetings, and made available on our webpage along with the draft TMDL.

Ecology sent email notifications to the listserve for the Snoqualmie Watershed Forum. Copies of the Draft Snoqualmie Temperature TMDL were delivered to the reference desks of the North Bend, Snoqualmie, Fall City, Carnation, and Duvall public libraries.

A public meeting was held on May 26th at the Carnation Public Library.

TMDL Conclusions

The Snoqualmie River mainstem and most of its major tributaries are too warm during summer months and do not meet state water quality standards for temperature. Ecology's Temperature TMDL Study concludes that mature native riparian vegetation will provide shade that measurably improves water temperatures in the mainstem river during this period. The study indicates even after mature riparian vegetation is established along the river's mainstem, state water quality standards cannot be consistently met during summer months.

Getting Snoqualmie River waters cooler will benefit both fish and people. Cooler water during the summer benefits recreational and commercial fisheries as well as local cultural values. Getting to cooler water requires the cooperation of landowners, technical and financial assistance of government and other organizations, as well as enforcement of current regulations.

The Snoqualmie Temperature TMDL had the following key findings:

- Even after mature riparian vegetation is established along the river's mainstem, state water quality standards cannot be consistently met during summer months.

- Establishing 150-foot-wide buffers with 150-foot-tall trees along the mainstem river significantly reduces solar radiation, lowers localized air temperatures (microclimate), and reduces water temperatures. During the warmest conditions (those occurring once every 10 years), modeling predicts these buffers will reduce water temperatures near the mouth of the Snoqualmie by 2.8^{o}C (5^{o}F). During a typical warm weather week (warmest week during a typical year), they reduce water temperatures by 2.2^{o}C (4^{o}F).

- Tributary streams provide cooler water to the mainstem river but most also consistently exceed state standards. These streams provide local cool water refugia where they meet the mainstem river.

- Each of the four municipal wastewater treatment plants discharging to the Snoqualmie River meets state temperature standards. The North Bend WWTP must begin planning now to ensure it will be able to meet its WLA in the future as the plant increases its discharge rate.

- Because of the extensive network of revetments and levees that is already keeps the channel narrow, further narrowing of the channel as a result of revegetation and channel restoration is not expected in the Middle Fork and mainstem Snoqualmie River. Tributary streams with smaller drainage areas and fewer revetments could experience channel narrowing as riparian restoration takes place.

- Historical channels contained more wetlands, oxbows, side channels with shading from shrubs, vine maple, alder, and dogwood. These attributes all provide potential cooling, but are more qualitative and are difficult to measure and model as a specific temperature reduction.

- Over time, mature riparian vegetation needed to reduce solar radiation can also indirectly reduce stream temperatures by increasing channel complexity. Channel complexity generally increases recruitment of large woody debris, helps trap fine sediments, increases cool water pool formation, and increases exchanges between surface water and cooler groundwater. A natural fully functioning channel would be expected to have more sinuosity and braiding that potentially could itself reduce stream temperatures.

- Hyporheic exchange flows and groundwater discharges are important to maintain the current temperature regime and reduce maximum daily instream temperatures. Two major areas of groundwater input to the mainstem were documented: adjacent to the city of Snoqualmie and between Patterson Creek and the Tolt River. Activities that reduce the hydraulic conductivity of streambed sediments (such as upland channel erosion and sedimentation from fine sediments) could increase stream temperatures.

- Riparian restoration is essential. Each side of the mainstem river needs a 150-foot-wide buffer planted with trees that will reach a mature height of 150 feet. Tributary streams need buffers tall and wide enough to provide complete shade at a minimum. Larger buffers that provide microclimate effects are desirable where feasible. Tributaries with high salmonid use should be prioritized for restoration.

- Levee setback is an option for areas needing channel restoration that currently have levees. This is currently being applied near the mouth of the Tolt River with an anticipated benefit to both stream habitat and flood protection. The levee setback project will reconnect existing wetlands to the river system while maintaining, or potentially improving, flood protection to the north of the Tolt River.

- Current rules and regulations should be enforced and updated as necessary: Forest Practices Regulations/HCPs for state and private forests; Northwest Forest Plan for National Forest Lands; Critical Areas Ordinances overseeing land use within county and city jurisdictions; water withdrawal regulations.

- Grant funding authorities should prioritize funding projects with the best documented record of success. Salmon recovery funding sources should include the improvement of water temperature as a criterion for scoring projects.

- If the schedule in this TMDL is followed, Ecology expects the Snoqualmie mainstem will meet TMDL temperature implementation goals by 2021. After that time, trees will need time to mature.

- Other innovative strategies should be evaluated and implemented as feasible to lower water temperatures. Examples include: wetland restoration/enhancement that increases cool groundwater inputs during summer months; strategic placement of large wood structures that create localized cool water refugia; water conservation and strategic use of reclaimed water; improvement of stream processes that create cooler surface water; infiltration of municipal and private stormwater to maintain/augment groundwater supplies that provide cool water inputs during summer.

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Appendices

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Appendix A. Glossary, acronyms, and abbreviations

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Glossary

Aspect: Streamflow direction in decimal degrees from north.

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

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

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

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

Critical period: For this study, mid-July through mid-August.

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

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

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100.
http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

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

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

Exceeded criteria: Did not meet criteria.

Hydraulic gradient: The difference in hydraulic head between two measuring points, divided by the distance between the two points.

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

Hyporheic: The area under and along the river channel where surface water and groundwater meet

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

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

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

Mixing zone: That portion of a water body adjacent to an effluent outfall where mixing results in the dilution of the effluent with the receiving water. Water quality criteria may be exceeded in a mixing zone as conditioned and provided for in WAC 173-201A-400.

Morphology: Shape (e.g., channel morphology).

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

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

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

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

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

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Seepage run: The practice of measuring streamflow at numerous places in a basin during a short time period for the purpose of establishing a flow balance. (interchangeable with *synoptic flow survey).*

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

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

Surrogate measures: To provide more meaningful and measurable pollutant loading targets, EPA regulations [40 CFR 130.2(i)] allow other appropriate measures, or surrogate measures in a TMDL. The Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:
When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.

Synoptic flow survey: The practice of measuring streamflow at numerous places in a basin during a short time period for the purpose of establishing a flow balance (interchangeable with *seepage run).*

System potential: The design condition used for TMDL analysis.

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

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

Thermistor: An electronic device that uses semiconductors to measure temperature. Also called a temperature data logger.

Total maximum daily load (TMDL): A distribution of a substance in a water body designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

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

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

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

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

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

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

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

Acronyms and Abbreviations

BMP	Best management practices
BnB	Bed and breakfast
DMR	Discharge Monitoring Report
DOT	Washington State Department of Transportation
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency

FERC	Federal Energy Regulatory Commission
FMU	Freshwater Monitoring Unit (formerly the Stream Hydrology Unit)
GIS	Geographic Information System software
LiDAR	Light Detection And Ranging
MF	Middle Fork
MFS	Middle Fork Snoqualmie
NAIP	National Agricultural Imagery Program
NF	North Fork
NCDC	National Climate Data Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPDES	(See Glossary above)
NSDZ	(See Glossary above)
NWS	National Weather Service
PSE	Puget Sound Energy
RAWS	Remote automated weather station
RM	River mile
RMSE	Root mean squared error
SF	South Fork
SHU	Stream Hydrology Unit (currently Freshwater Monitoring Unit)
SSURGO	Soil Survey Geographic
TIR	thermal infrared radiometry
TMDL	(See Glossary above)
T_{NPDES}	Temperature of effluent regulated under the National Pollutant Discharge Elimination System
USFS	United States Forest Service
USGS	United States Geological Survey
WDNR	Washington State Department of Natural Resources
WRIA	Water Resources Inventory Area
WWTP	Wastewater treatment plant

Units of measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
km	kilometer
m	meter
mgd	million gallons per day

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Appendix B. Flow data from Ecology's field surveys

Appendix B contains these tables:

Abbreviations in Appendix B tables:

A	Area
Nq	Number of samples
Ns	Total number of samples
Q	Flow
S	Slope
V	Velocity
WP	Wetted perimeter

The following are initials of staff who worked on this project:

AD
BB
BE
CH
DB
DG
DN
JK
JW
NC
RS
RS
SL

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Table B-1. Snoqualmie River mainstem streamflow from Stream Hydrology Unit, July 25-27, 2006.

Site ID	Name	RM	Date	Time	Width (ft)	Average Velocity (ft/sec)	Average Depth (ft)	Q (cfs)	Adj. Q*	Δ_Q	$\%\Delta_Q$
07D150	Middle Fork Snoq R. near Ellisville	45.3	7/25/06	920	178	0.82	2.57	382	382		
--	Snoqualmie R. at Snoqualmie	--	7/25/06	1020	187	0.61	6.24	727	727	345	90.3%
07SNO39.8	Snoqualmie R. below Tokul Creek	39.8	7/25/06	1400	185	1.38	3.74	815	819	92	12.7%
07SNO36.3	Snoqualmie R. above Raging River	36.3	7/25/06	1450	187	0.84	4.88	795	799	-20	-2.5%
07SNO33.0	Snoqualmie R. at Neal Rd. Launch	33.0	7/25/06	1550	167	1.35	3.58	800	809	10	1.2%
07SNO29.0	Snoqualmie R. above Griffin Creek	29.0	7/27/06	1030	188	0.55	6.79	730	778	-31	-3.8%
07SNO24.9	Snoqualmie R. above Tolt River	24.9	7/26/06	715	218	0.45	8.00	762	783	5	0.7%
07SNO22.8	Snoqualmie R. at Farm Rd.	22.8	7/26/06	1105	227	0.86	5.00	965	994	211	26.9%
07SNO18.7	Snoqualmie R. at Stillwater	18.7	7/26/06	1330	186	1.02	5.16	961	998	5	0.5%
07SNO10.4	Snoqualmie R. above Duvall	10.4	7/26/06	1840	134	1.50	4.46	942	989	-9	-0.9%
07D050	Snoqualmie R. near Monroe	2.7	7/25/06	1730	162	0.65	9.02	1010	1021	32	3.2%

* Adjusted discharge (Q) is time weighted to account for net loss in discharge of 66 cfs that occurred during this time period.

Table B-2. July 26, 2006 tributary and headwater measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07RAG00.1	11.69	29	26	24.18	32.73	34.80	0.48	0.69	SL, KB	930	7/26/06
07GIF00.1	2.02	22	15	6.68	11.73	12.40	0.30	0.54	SL, KB	1244	7/26/06
07MFS59.1	328.40	27	24	159.79	133.74	138.50	2.06	1.15	SL, KB	1135	7/26/06
07COE00.3®	0.15	9	4	0.42	2.20	2.20	0.36	0.19	CH, JW	1435	7/26/06
07COE00.3	0.08	9	1	0.25	2.27	2.30	0.31	0.11	CH, JW	1410	7/26/06
07WAL00.5	0.98	16	8	0.99	4.68	4.80	1.00	0.21	CH, JW	1300	7/26/06
07TUC00.1	0.11	21	2	1.15	7.76	7.50	0.09	0.15	CH, JW	1342	7/26/06
07CHE00.2	5.24	23	21	4.14	7.85	7.70	1.27	0.54	CH, JW	1006	7/26/06
07TOL00.5	148.02	25	21	106.56	98.86	98.70	1.39	1.08	CH, JW	1200	7/26/06
07GIF00.1®	1.78	20	12	6.26	10.34	12.30	0.28	0.51	SL, KB	1306	7/26/06
07NFS00.3	142.94	23	22	204.97	127.87	127.41	0.70	1.61	RS, DN	1010	7/26/06
07SFS01.6	195.42	28	26	103.55	85.88	94.00	1.89	1.10	RS, DN	1130	7/26/06
07UNE00.3	0.73	23	19	1.33	4.33	5.50	0.55	0.24	RS, DN	1445	7/26/06
07UND00.4	1.36	21	19	2.16	7.93	8.20	0.63	0.26	RS, DN	1340	7/26/06
07UND00.4®	1.49	21	20	2.16	7.92	8.20	0.69	0.26	RS, DN	1400	7/26/06
07UNB00.4	2.80	24	17	4.22	12.65	13.00	0.66	0.32	BB, F		7/26/06
07UNA00.2	3.44	30	17	5.63	8.41	8.60	0.61	0.65	BB, F	1340	7/26/06
07UNA00.2®	3.18	30	18	5.51	8.50	8.60	0.58	0.64	BB, F	1410	7/26/06
07BRO00.2	1.02	15	10	1.15	4.51	4.40	0.89	0.26	SL, JK	1700	7/26/06
07UNC00.3	0.61	15	11	1.52	4.79	6.20	0.40	0.25	SL, JK	1800	7/26/06
07WEI00.3	0.42	16	11	4.96	7.88	8.90	0.08	0.56		1300	7/26/06
07PAT00.4	7.21	30	29	15.82	14.90	14.50	0.46	1.09	BB, F	950	7/26/06
07SFS01.1	178.91	25	20	153.74	93.35	93.00	1.16	1.65	BB, F	1135	7/26/06
07AME00.1	3.09	21	19	5.41	10.07	9.98	0.57	0.54		1342	7/26/06
07AME00.1®	3.52	20	19	5.41	10.09	10.00	0.65	0.54		1430	7/26/06
07HAR01.1	5.06	19	15	32.61	19.52	22.20	0.16	1.47		1200	7/26/06
07TOL00.5(D)	154.12	25	24	111.69	94.94	100.30	1.38	1.11		1038	7/26/06
07GRI00.7	4.09	28	27	6.30	17.00	17.60	0.65	0.36		943	7/26/06
07TOK00.1	33.76	27	25	25.15	35.69	36.80	1.34	0.68	JK	1540	7/26/06
07KIM00.1	1.15	15	8	6.18	14.50	16.60	0.19	0.37	JK	1620	7/26/06

R=replicate
D=duplicate

Table B-3. August 16, 2006 tributary and headwater measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07WAL00.5	0.95	16	13	1.11	4.07	4.70	0.85	0.24	JK, JW	1130	8/16/06
07CHE00.2	2.79	22	20	13.74	18.83	19.80	0.20	0.69	JK, JW	915	8/16/06
07TOL00.5	119.34	20	19	104.36	95.34	100.50	1.14	1.04	JK, JW	1300	8/16/06
07TUC00.1	0.22	19	16	1.83	7.36	7.60	0.12	0.24	JK, JW	1015	8/16/06
07TUC00.1®	0.20	19	15	1.87	7.29	7.60	0.11	0.25	JK, JW	1040	8/16/06
07MFS45.3	183.12	20	17	288.92	125.26	210.00	0.63	1.38	JK, SL	1230	8/18/06
07RAG00.1	9.81	27	25	20.61	32.47	33.50	0.48	0.62	DG, NC	1316	8/16/06
07BRO00.2®	1.33	19	15	3.04	7.64	7.70	0.44	0.39	DG, NC	1132	8/16/06
07BRO00.2	1.02	16	11	3.01	7.56	7.80	0.34	0.39	DG, NC	1100	8/16/06
07UNC00.3	0.33	17	12	1.48	4.98	5.20	0.22	0.28	DG, NC	1220	8/16/06
07KIM00.1	0.75	16	11	4.30	16.10	17.10	0.17	0.25	DG, NC	1008	8/16/06
07TOK00.1	21.17	26	21	19.28	34.75	35.50	1.10	0.54	DG, NC	905	8/16/06
07RAG00.1(D)	12.07	30	28	18.52	32.94	34.90	0.65	0.53	SL, KB	855	8/16/06
07GRA00.1	4.88	23	18	10.28	13.78	14.10	0.47	0.73	SL, KB	1011	8/16/06
07GRA00.1®	4.86	25	23	10.15	13.01	14.10	0.48	0.72	SL, KB	1040	8/16/06
07MFS59.1	132.02	21	20	149.37	96.35	102.00	0.88	1.46	SL, KB	1150	8/16/06
07GIF00.1	1.76	20	18	5.94	11.88	12.40	0.30	0.48	SL, KB	1339	8/16/06
07TOL00.5®	113.92	26	24	102.38	99.29	99.60	1.11	1.03	CH, S	1016	8/16/06
07GRI00.7	2.46	22	17	6.40	15.87	15.70	0.38	0.41	CH, S	941	8/16/06
07WEI00.3	0.50	19	16	2.80	8.84	9.30	0.18	0.30	CH, S	1200	8/16/06
07HAR01.1	3.29	19	13	24.60	15.17	13.80	0.13	1.78	CH, S	1130	8/16/06
07AME00.1	3.40	22	21	6.18	10.35	10.00	0.55	0.62	CH, S	1245	8/16/06
07AME00.1®	3.50	23	21	6.24	10.47	10.10	0.56	0.62	CH, S	1310	8/16/06
07PAT00.4	7.26	31	28	16.85	15.18	15.00	0.43	1.12	BB, AD	916	8/16/06
07SFS01.6	142.73	31	29	79.56	57.88	60.00	1.79	1.33	BB, AD	1026	8/16/06
07UNA00.2	2.37	28	14	4.35	7.93	8.20	0.54	0.53	BB, AD	1207	8/16/06
07UNB00.4	2.40	23	16	3.89	9.71	11.30	0.62	0.34	BB, AD	1330	8/16/06
07UNB00.4®	2.44	23	17	3.90	11.03	11.30	0.63	0.34	BB, AD	1351	8/16/06
07UND00.4	0.83	21	15	1.03	4.49	4.50	0.80	0.23	RS, DN	1315	8/16/06
07UNE00.3	0.62	24	23	1.68	5.05	5.40	0.37	0.31	RS, DN	1330	8/16/06
07NFS00.3	67.89	23	20	184.56	127.50	126.91	0.37	1.45	RS, DN	930	8/16/06
07NFS00.3®	70.01	23	20	184.28	127.52	126.91	0.38	1.45	RS, DN	950	8/16/06
07SFS01.6®	139.45	23	22	83.06	87.61	89.50	1.68	0.93	RS, DN	1045	8/16/06

Table B-4. May 30-31, 2006 tributary and headwater measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07GRA00.1	47.93	21	19	24.05	23.23	25.90	1.99	0.93	JK, SL	1700	5/31/06
07UNA00.2	21.87	26	25	21.53	20.93	21.50	1.02	1.00	JK, SL	1415	5/31/06
07UNB00.4	21.31	20	19	10.99	19.26	20.50	1.94	0.54	JK, SL	1500	5/31/06
07TOK00.6	29.42	21	17	28.26	25.10	25.80	1.04	1.10	JK, SL	1640	5/30/06

Table B-5. July 11-12, 2006 tributary measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07AME00.1	3.93	22	19	5.91	10.21	10.31	0.67	0.57	JK, SL	1530	7/11/06
07CHE00.2	9.13	27	26	17.04	18.78	20.30	0.54	0.84	JK, SL	1400	7/11/06
07GRA00.1	14.82	22	20	14.07	16.32	18.01	1.05	0.78	JK, SL	1620	7/13/06
07GRI00.7	5.14	26	25	7.94	14.49	16.10	0.65	0.49	JK, SL	1000	7/11/06
07HAR01.1	6.94	25	24	28.82	21.19	22.20	0.24	1.30	JK, SL	1200	7/11/06
07HAR01.6	3.72	26	24	7.79	15.10	16.70	0.48	0.47	JK, SL	1100	7/12/06
07KIM00.1	3.14	23	21	6.88	14.05	16.20	0.46	0.42	JK, SL	1615	7/12/06
07PAT00.4	9.76	25	24	12.45	14.29	14.50	0.78	0.86	JK, SL	1700	7/11/06
07RAG00.1	19.82	26	25	24.46	32.94	35.10	0.81	0.70	JK, SL	1730	7/11/06
07BRO00.2	1.07	15	9	1.54	5.53	5.20	0.69	0.30	JK, SL	1720	7/12/06
07TOK00.1	42.85	19	18	27.08	33.07	36.50	1.58	0.74	JK, SL	1500	7/12/06
07TOK00.6	44.72	24	22	25.19	25.62	27.30	1.78	0.92	JK, SL	1600	7/12/06
07TOL00.5	203.73	25	24	119.74	96.38	101.80	1.70	1.18	JK, SL	1100	7/11/06
07TUC00.1	0.40	15	13	2.18	7.28	7.70	0.18	0.28	JK, SL	1430	7/11/06
07UNA00.2	9.32	19	18	11.67	18.40	20.10	0.80	0.58	JK, SL	1830	7/13/06
07UNB00.4	7.45	28	23	6.16	18.64	20.00	1.21	0.31	JK, SL	1700	7/13/06
07UNC00.3	1.71	19	17	1.64	6.38	7.10	1.05	0.23	JK, SL	1830	7/12/06

Table B-6. August 8-11, 2006 tributary measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07AME00.1	3.39	22	19	6.25	9.35	10.07	0.54	0.62	JK, SL	1130	8/8/06
07CHE00.2	4.66	23	22	11.26	18.40	20.10	0.41	0.56	JK, SL	900	8/8/06
07GRA00.1	5.11	22	19	9.89	13.46	13.61	0.52	0.73	JK, SL	1310	8/11/06
07GRI00.7	2.80	21	20	6.81	13.68	15.65	0.41	0.44	JK, SL	1600	8/8/06
07HAR01.1	6.26	20	19	38.80	22.56	23.70	0.16	1.64	JK, SL	1530	8/8/06
07KIM00.1	1.39	17	15	7.06	12.66	15.90	0.20	0.44	JK, SL	1200	8/10/06
07PAT00.4	8.84	21	20	14.94	12.84	16.70	0.59	0.89	JK, SL	1720	8/9/06
07TOK00.1	31.18	24	23	25.77	35.07	37.40	1.21	0.69	JK, SL	1030	8/9/06
07TOK00.6	29.75	19	18	25.90	24.39	25.55	1.15	1.01	JK, SL	1130	8/9/06
07TOL00.5	125.57	23	22	100.72	94.77	97.90	1.25	1.03	JK, SL	1330	8/8/06
07TUC00.1	0.37	15	14	2.00	7.24	7.40	0.19	0.27	JK, SL	1000	8/8/06
07UNA00.2	4.35	19	18	11.00	19.05	19.90	0.40	0.55	JK, SL	1800	8/9/06
07UNB00.4	3.10	21	15	4.22	13.28	14.80	0.73	0.29	JK, SL	1700	8/9/06

Table B-7. Snoqualmie River mainstem streamflow from Stream Hydrology Unit September 14, 2006.

Site ID	Name	RM	Date	Time	Width (ft)	Avg. Vel (ft/sec)	Avg. Depth (ft)	Q (cfs)	Adj. Q*	ΔQ	% ΔQ	Area (ft)	Area (m)	km
07D150	Middle Fork Snoqualmie R. near Ellisville	45.3	9/14/06	710	161	0.38	2.39	152	152			384.79	35.75	24.85
Just above falls at RM 40.8	Snoqualmie R. at Snoqualmie		9/14/06	825	180	0.29	6.06	348	345	193	126.9%	1090.8	101.34	31.75
07SNO39.8	Snoqualmie R. below Tokul Creek	39.8	9/14/06	1000	185	0.71	3.20	404	392	47	13.7%	592	55.00	33.15
07SNO36.3	Snoqualmie R. above Raging River	36.3	9/14/06	1130	180	0.57	4.00	417	401	9	2.3%	720	66.89	38.88
07SNO33.0	Snoqualmie R. at Neal Rd. Launch	33.0	9/14/06	1240	162	0.96	2.72	435	415	13	3.3%	440.64	40.94	44.30
07SNO29.0	Snoqualmie R. above Griffin Creek	29.0	9/14/06	710				378	378	-37	-8.8%	0		50.60
07SNO24.9	Snoqualmie R. above Tolt River	24.9	9/14/06	1425	212	0.28	8.01	402	372	-6	-1.6%	1698.12	157.76	56.30
07SNO22.8	Snoqualmie R. at Farm Rd.	22.8	9/14/06	710				483	483	111	29.9%	0		59.80
07SNO18.7	Snoqualmie R. at Stillwater	18.7	9/14/06	710				485	485	2	0.4%	0		66.2
07SNO10.4	Snoqualmie R. above Duvall	10.4	9/14/06	710				481	481	-4	-0.8%	0		79.56
07D050	Snoqualmie R. near Monroe	2.7	9/14/06	1550	159	0.41	8.25	621	574	93	19.4%	1311.75	121.87	91.86

Table B-8. September 19-22, 2006 tributary and headwater measurements.

Site ID	Q	Ns	Nq	A	WP	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07AME00.1	5.79	25	23	8.72	10.21	10.10	0.66	0.86	JK, SL	1300	9/19/06
07CHE00.2	12.45	21	19	24.60	20.29	22.10	0.51	1.11	JK, SL	1045	
07GIF00.1	1.30	19	14	6.27	11.77	11.90	0.21	0.53	JK, SL	1230	9/27/06
07GRA00.1	11.66	22	19	13.61	15.28	16.20	0.86	0.84	JK, SL	1100	9/22/06
07GRI00.7	6.54	21	20	10.16	12.90	15.80	0.64	0.64	JK, SL	1600	9/19/06
07HAR01.1	5.10	18	13	43.43	22.16	23.80	0.12	1.82	JK, SL	930	
07KIM00.1	4.75	25	20	6.25	13.21	14.60	0.76	0.43	JK, SL	1500	9/18/06
07PAT00.4	7.50	23	22	24.17	14.11	16.10	0.31	1.50	JK, SL	1100	9/20/06
07RAG00.1	67.65	29	24	27.21	34.83	37.60	2.49	0.72	JK, SL	1030	
07MFS45.3	547.86	25	24	213.33	130.78	146.30	2.57	1.46	JK, SL	1700	9/18/06
07MFS59.1	194.54	18	17	211.91	81.49	91.40	0.92	2.32	JK, SL	1200	9/27/06
07NFS00.3	284.09	24	23	216.08	117.59	121.90	1.31	1.77	JK, SL	1600	9/18/06
07SFS01.6	241.09	23	20	174.52	77.67	78.90	1.38	2.21	JK, SL	1500	9/22/06
07TOK00.1	35.21	27	24	24.11	34.28	35.60	1.46	0.68	JK, SL	1445	9/20/06
07TOL00.5	433.01	21	20	191.64	99.05	103.40	2.26	1.85	JK, SL	1530	9/19/06
07TUC00.1	1.29	26	25	3.18	7.91	7.95	0.41	0.40	JK, SL	1300	9/19/06
07UNA00.2	7.51	21	18	15.32	20.59	21.50	0.49	0.71	JK, SL	1730	9/21/06
07UNB00.4	23.64	23	21	14.47	21.97	23.00	1.63	0.63	JK, SL	1800	9/21/06
07UND00.4	0.43	11	7	2.20	3.50	4.60	0.20	0.48	JK, SL	1300	9/22/06

Table B-9. October 17-24, 2006 tributary measurements.

Site ID	Q	Ns	Nq	A	WP	S^0.5/n (M)	Wet Width	Avg V	Avg Depth	Crew	Time	Date
07AME00.1	11.30	21	20	11.32	10.75	0.65	10.00	1.00	1.13	BE, JK	1230	10/24/06
07CHE00.2	31.88	21	20	29.28	20.93	0.58	23.45	1.09	1.25	JK, SL	915	10/17/06
07GRA00.1	75.88	20	19	26.01	18.98	1.59	19.70	2.92	1.32	BE, JK	1620	10/19/06
07GRI00.7	3.73	23	17	12.23	12.98	0.21	14.10	0.30	0.87	JK, SL	1610	10/17/06
07HAR01.1	8.47	22	21	35.53	18.21	0.10	20.80	0.24	1.71	JK, SL	1200	10/17/06
07HAR01.6	4.11	21	20	9.39	15.53	0.41	17.50	0.44	0.54	JK, SL	1340	10/17/06
07KIM00.1	6.60	21	20	13.75	17.58	0.38	18.30	0.48	0.75	BE, JK	1150	10/19/06
07PAT00.4	11.18	22	21	29.42	15.70	0.17	16.90	0.38	1.74	JK	1100	10/18/06
07RAG00.1	25.18	26	23	23.14	34.87	0.96	37.40	1.09	0.62	JK	955	10/18/06
07SFS01.6	183.41	23	22	138.22	74.36	0.59	76.90	1.33	1.80	BE, JK	1240	10/19/06
07TOK00.1	37.00	23	21	30.01	35.30	0.92	38.50	1.23	0.78	BE, JK	1000	10/19/06
07TOL00.5	32.96	20	16	27.52	25.43	0.76	26.00	1.20	1.06	BE, JK	1100	10/19/06
07TUC00.1	2.10	22	21	3.80	7.81	0.60	8.00	0.55	0.47	JK, SL	1030	10/17/06
07UNB00.4	51.76	24	23	19.73	19.85	1.77	20.01	2.62	0.99	BE, JK	1530	10/19/06

Appendix C. Snoqualmie River QUAL2Kw Model Setup

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Table C-1. Snoqualmie River QUAL2Kw Model Setup.

River mile (USGS) from confluence with Skykomish River to USFS boundary	Kilometer (km) from USFS boundary and start of QUAL2Kw model	Mainstem station	Tributary station	Official Station Name	USGS gage number	SHU gage number	USGS gage comment
60.4	0.00	07MFS60.4		Middle Fork (MF) Snoqualmie River at national forest boundary			
60.2	0.60		07UNA00.2	Unnamed tributary A (MFS) before national forest			
59.1	2.50	07MFS59.1		Middle Fork Snoq R off MF Snoqualmie Rd above Gifford			
58.9	2.85		07GIF00.1	Gifford Lakes Creek stream drainage			
58.5	3.30		07UNB00.4	Unnamed tributary B (MFS) at culvert downstream			
56.5	7.05		07GRA00.1	Granite Creek, 0.2 miles upstream of MFS conf			
55.6	8.60	07MFS55.6		Middle Fork Snoq R at USGS gaging station	12141300		
53.0	12.05		07UND00.4	Unnamed tributary to MF Snoq R off MF Snoqualmie Rd			
52.8	12.95		07UNE00.4	Unnamed tributary to MF Snoq R off MF Snoqualmie Rd			
51.2	15.37	07MFS51.2		Middle Fork Snoq R above Roaring River BnB			
49.6	17.90		07UNC00.3	Unnamed tributary (MF Snoq) off of Mt Si Rd, below Mt Si			
47.8	20.95	07MFS47.8		Middle Fork Snoq at Mt Si Rd			
45.3	24.85	07MFS45.3		Middle Fork Snoq R at 428th Ave SE near Ellisville (07D150)		07D150	
45.0	25.60		07NFS00.3	North Fork Snoq R at 428th Ave SE near Ellisville (07N070)	12142000		USGS gage at RM 9.2 is far upstream
44.2	26.90		07SFS01.6	South Fork Snoq at Valley Trail R (07M065) and North Bend WWTP	12144000		USGS gage at RM 2.0
42.6	28.65		07BRO00.2	Brockway Ck at Reining Rd			
42.3	29.28	07SNO42.3		Snoq R at Snoqualmie (07D130)			
41.2	31.15		07KIM00.1	Kimball Creek Hwy 202 (07Y060)			
40.8	31.73		07SWP00.0	Snoqualmie WWTP at manhole			
40.8	31.75	07SNO40.8		Snoq R Hwy 202 (07D125)			
40.7	32.10			Diversions to Powerhouse 1 and 2			
40.6	32.17			PSE Weir for Flows (Bob Barnes)			
40.5	32.30			Snoqualmie Falls			
40.4	32.40			Powerhouse 1 return			
40.1	32.77			Powerhouse 2 return			
39.8	33.15	07SNO39.8		Snoq R at PSE outfall, USGS station	12144500		
39.7	33.60		07TOK00.1	Tokul Creek SE Fish Hatchery (07X060)			
39.6	33.80	07SNO39.8alt		SHU flow 7/25/06 below Tokul and 07SNO39.8			

River mile (USGS) from confluence with Skykomish River to USFS boundary	Kilometer (km) from USFS boundary and start of QUAL2Kw model	Mainstem station	Tributary station	Official Station Name	USGS gage number	SHU gage number	USGS gage comment
36.3	38.88	07SNO36.3		Snoq R above Raging R			
36.2	38.92		07RAG00.1	Raging R at mouth in Fall City (07Q050)	12145500	07Q070	USGS gage at RM 2.6
33.0	44.30	07SNO33.0		Snoq R at Neal Rd boat launch			
31.2	47.15		07PAT00.4	Patterson Creek near Fall City (07P070)			
29.0	50.60	07SNO29.0		Snoq R above Griffin Ck on 8th			
27.2	52.95		07GRI00.7	Griffin Creek Hwy 203 (07W070)			
24.9	56.30	07SNO24.9		Snoq R above Tolt R and Carnation (07D100)			
24.9	56.35		07TOL00.5	Tolt R near Carnation (07G070)	12148500	07G070	USGS gage at RM 6.7
23.0	59.40			Snoq R at Farm Rd and Carnation WWTP River Discharge			
22.8	59.80	07SNO22.8		Snoq R at Carnation USGS gage station	12149000		
22.0	61.30	07SNO22.0		Snoq R blw Chinook Bend and Carnation WWTP Wetlands Discharge			
21.3	62.27		07HAR01.1	Harris Ck at Sno Trail below FMU site			
18.7	66.20	07SNO18.7		Snoq R above Ames Ck at Stillwater			
17.0	68.85		07AME00.1	Ames Ck at NE 100th St (07V070)			
14.8	72.40	07SNO14.8		Snoq R at 124th Novelty			
10.6	79.10		07DWP00.0	Duvall WWTP outfall 07DWP00.0			
10.4	79.56	07SNO10.4		Snoq R above Coe and Tuck Ck, Duvall			
10.3	79.70		07TUC00.1	Tuck Creek at Mouth (07T050)			
10.2	79.90			Ecology Weather Station near Duvall			
6.8	85.27	07SNO06.8		Snoq R above Cherry Ck			
6.7	85.34		07CHE00.2*	Cherry Creek Hwy 203 (07S070)			
2.7	91.86	07SNO02.7		Snoq R near Monroe (07D050)		07D050	
0.8	94.88	07SNO00.8		Snoq R above Skykomish R confluence			
0							

Stream gage numbers with box outline have continuous data. Blue shading denotes potential WWTP input. MFS – Middle Fork Snoqualmie River.

Appendix D. Snoqualmie River Basin Continuous Temperature Data, 2006

Figures D-1 through D-11 show continuous 7-day average of daily maximum (7-DADMax) water temperatures during May-October 2006 at each of the sampling locations in the Snoqualmie River basin study. Table D-1 shows the sampling location details.

Table D-1. Ecology sample site location details for the Snoqualmie basin, 2006

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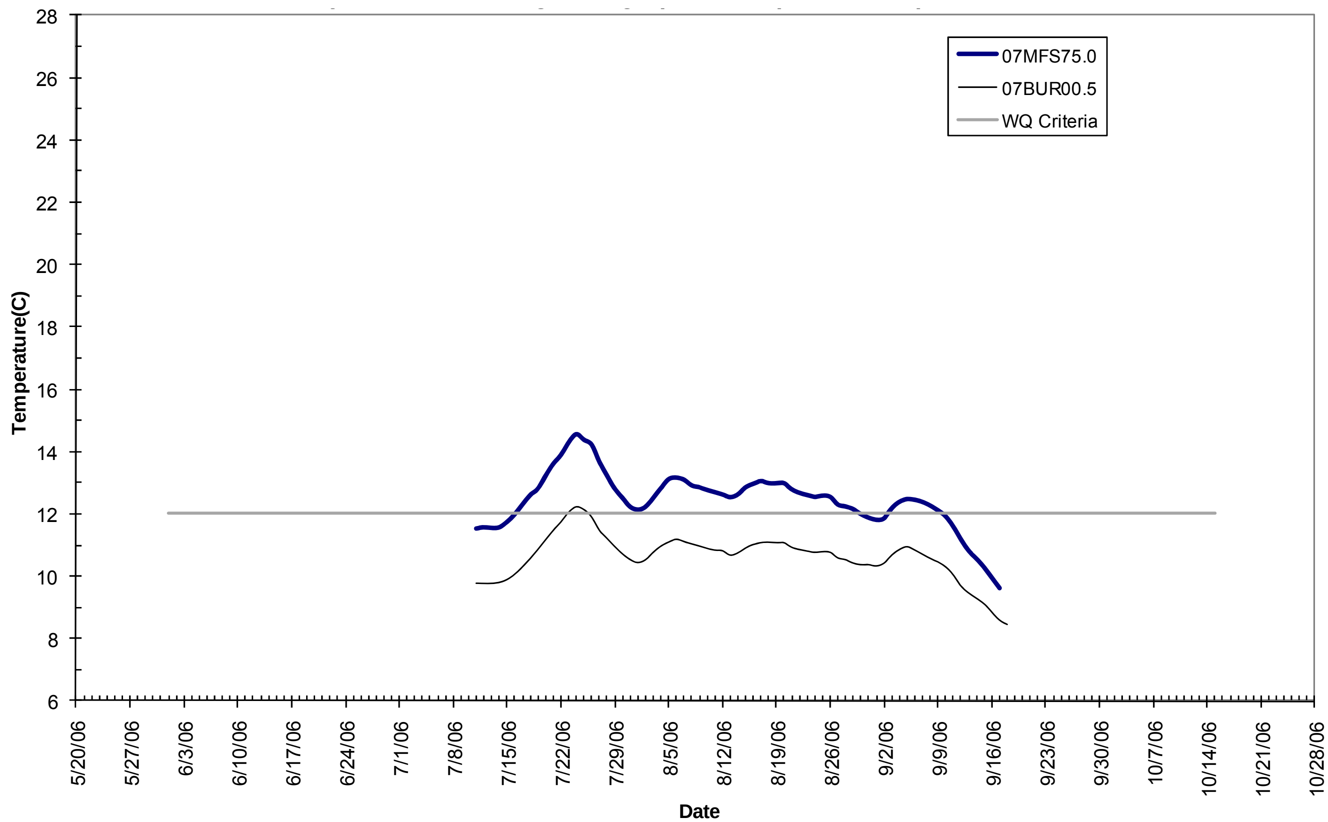

Figure D-1. 7DADMax water temperatures for Upper Middle Fork Snoqualmie near Goldmyer Hot Springs.

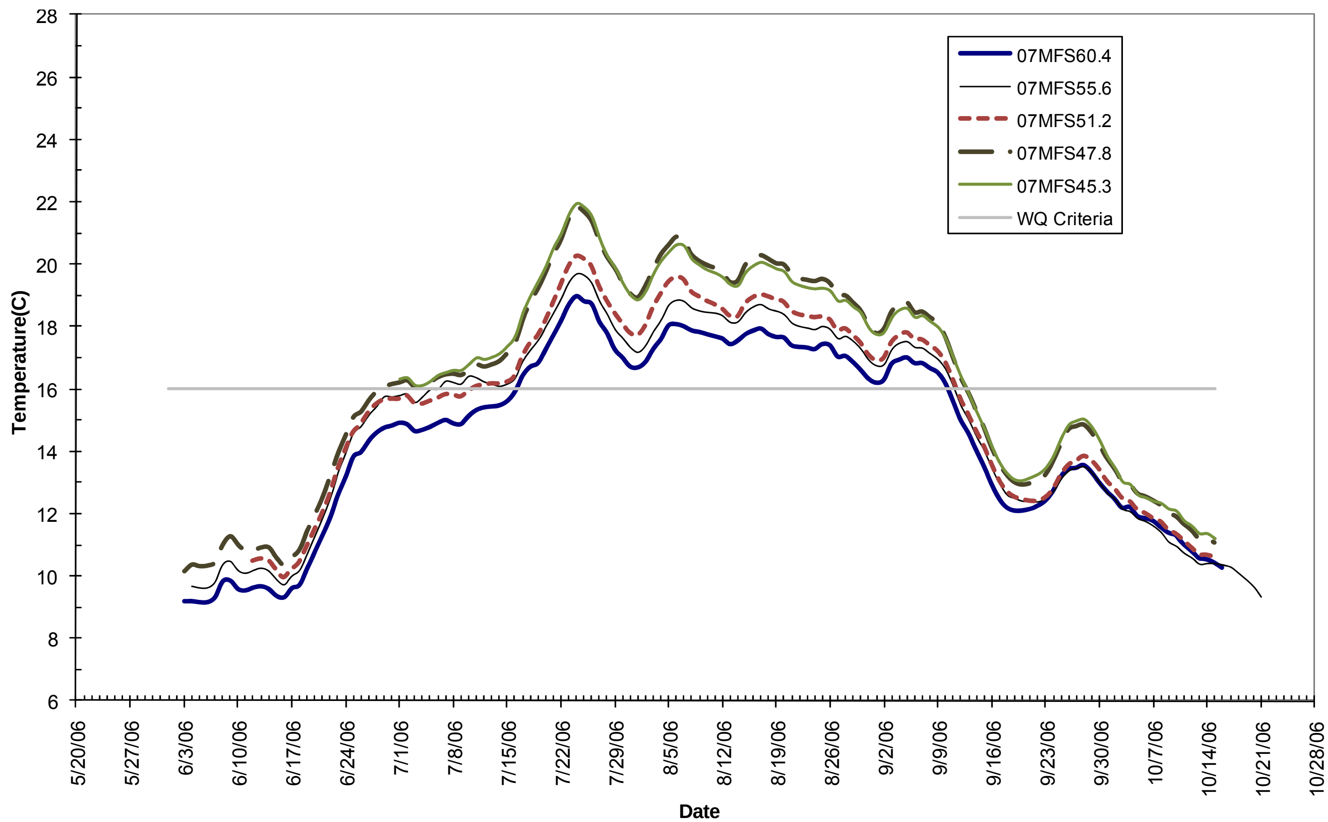

Figure D-2. 7DADMax water temperatures for Upper Middle Fork Snoqualmie: USFS boundary RM 60.4 to above North Fork at RM 45.3.

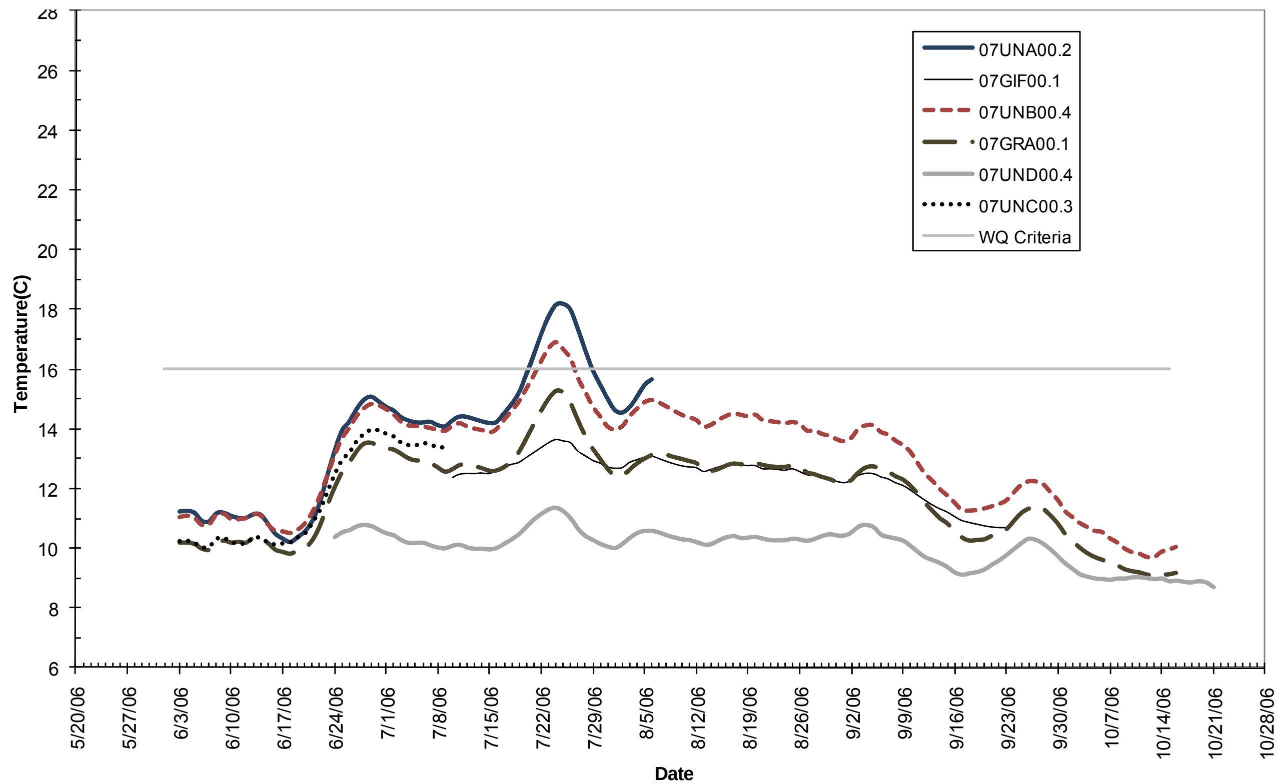

Figure D-3. 7DADMax water temperatures for Upper Middle Fork Snoqualmie tributaries from RM 60.4 to RM 45.3.

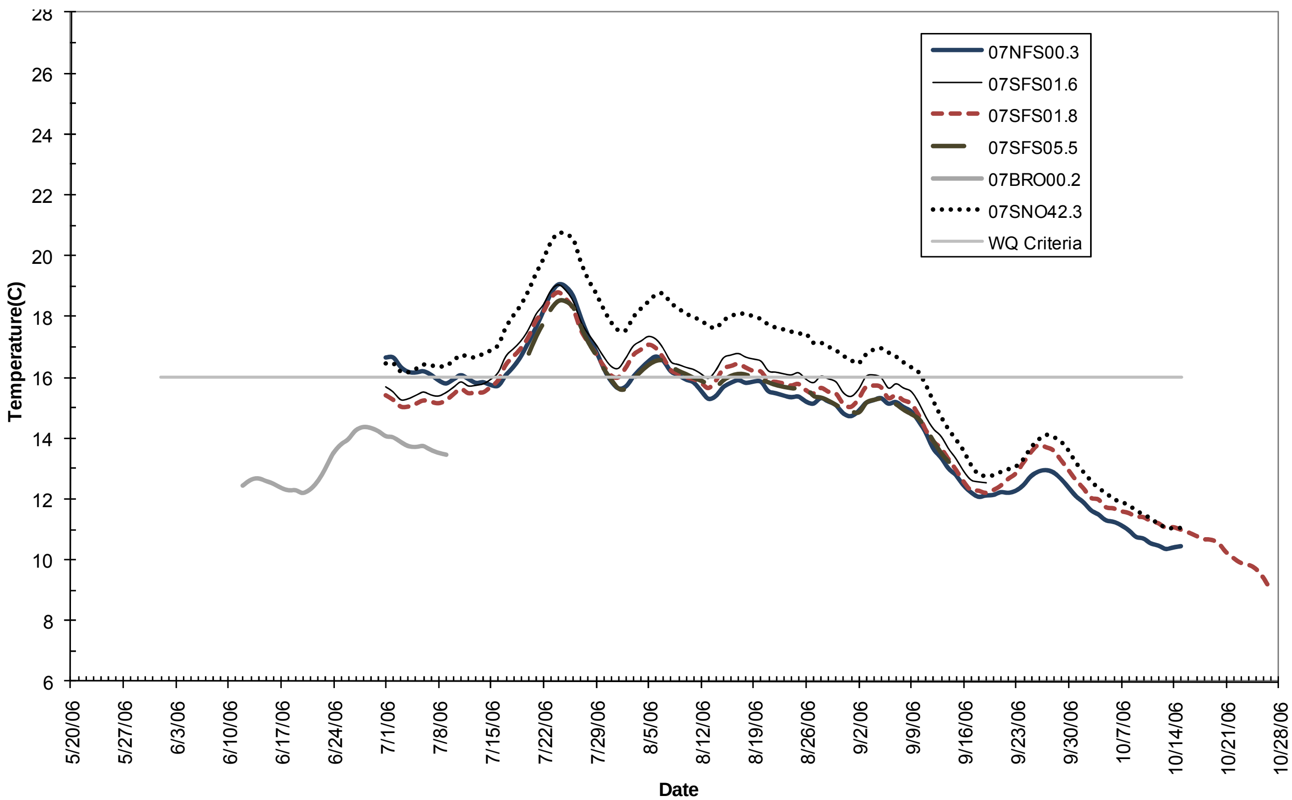

Figure D-4. 7DADMax water temperatures for Snoqualmie River and tributaries from North Fork to RM 42.3.

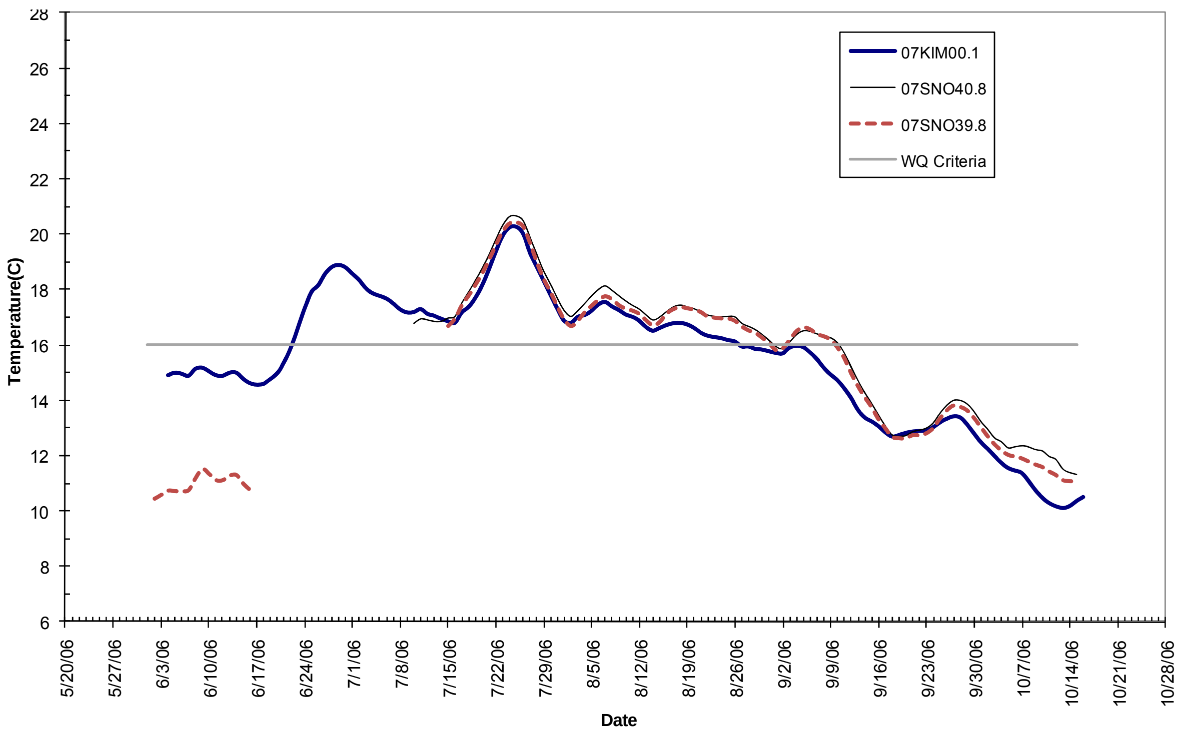

Figure D-5. 7DADMax water temperatures for Snoqualmie River and tributaries from RM 42.2 to RM 39.8 just below Snoqualmie Falls.

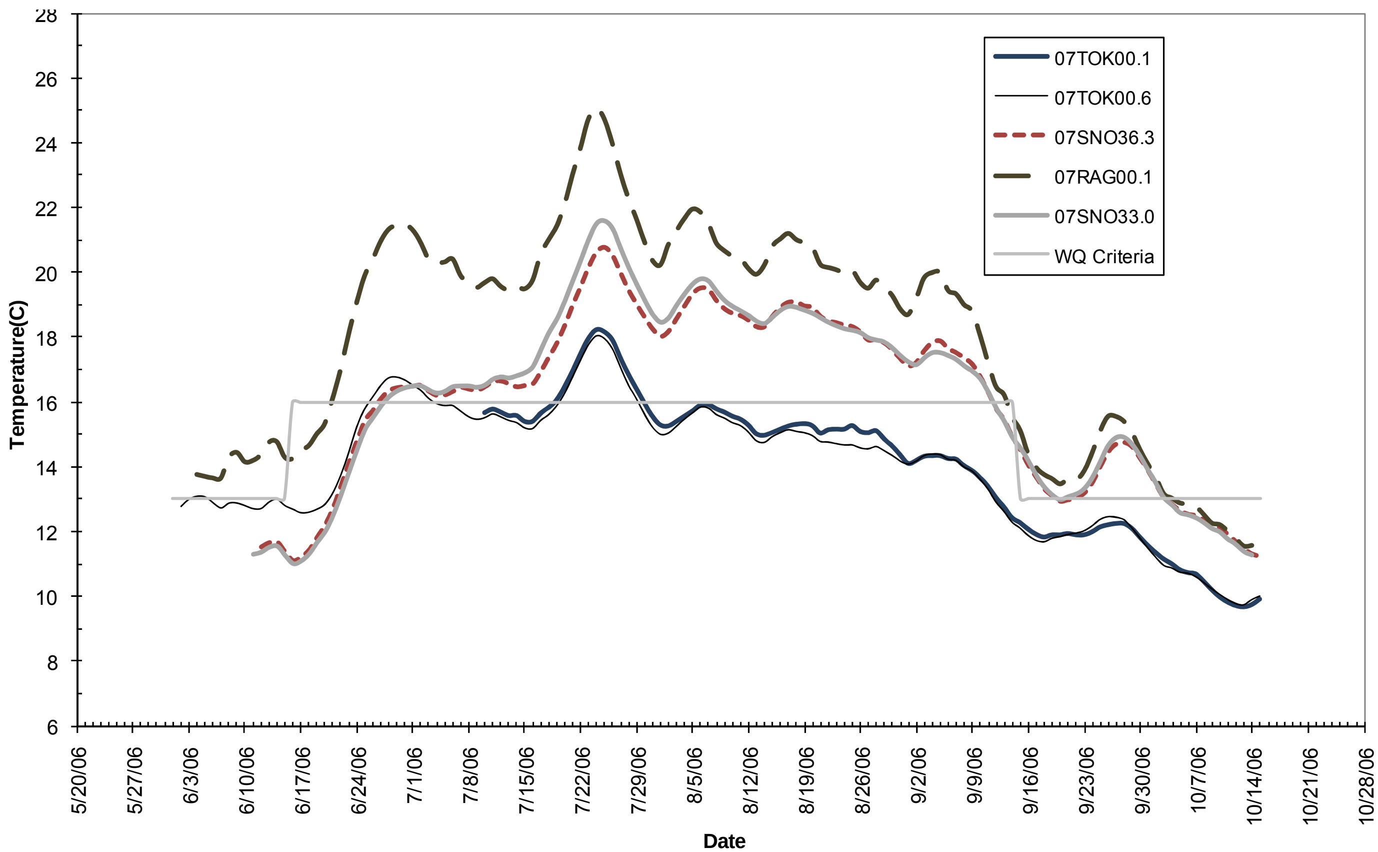

Figure D-6. 7DADMax water temperatures for Snoqualmie River and tributaries from RM 39.7 (Tokul Creek) to RM 31.2 (above Patterson Creek).

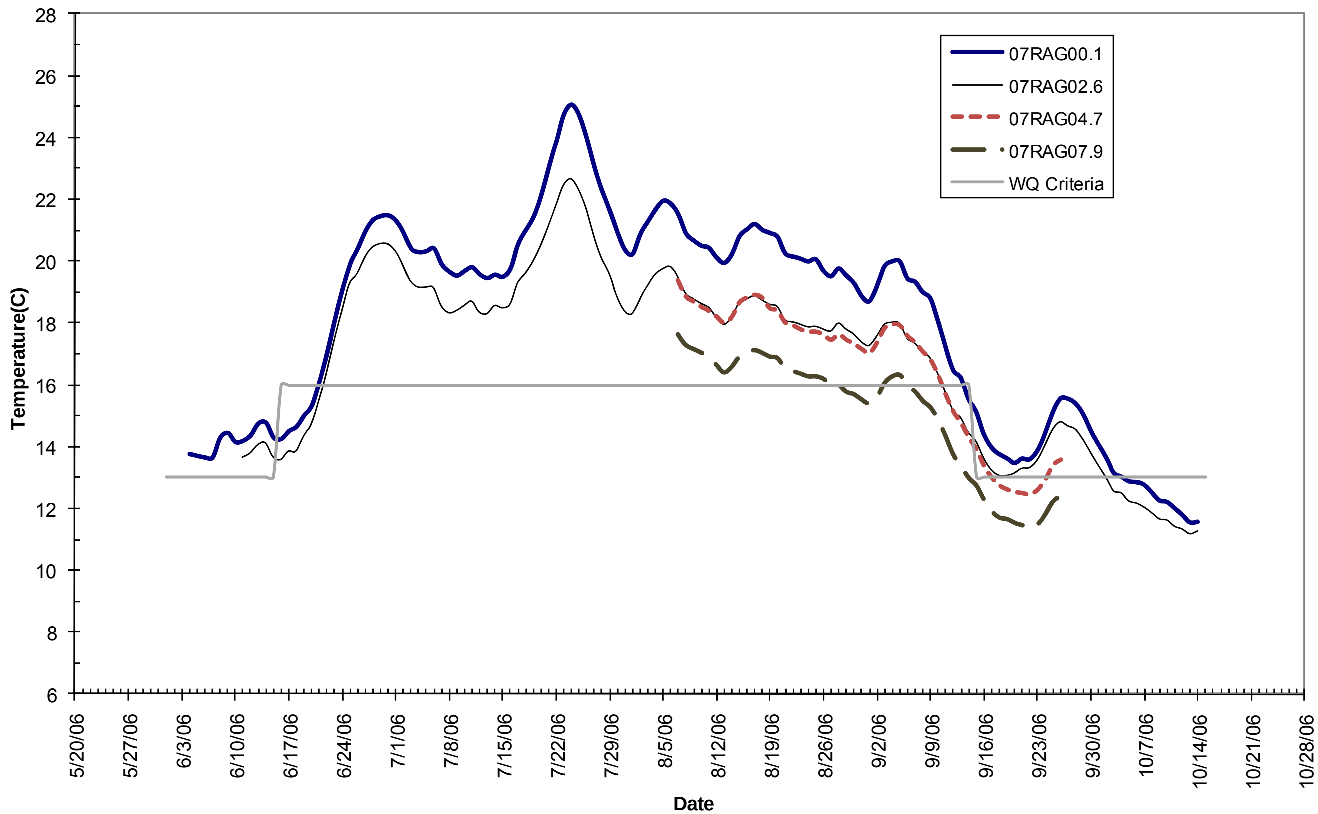

Figure D-7. 7DADMax water temperatures for Raging River: four sites.

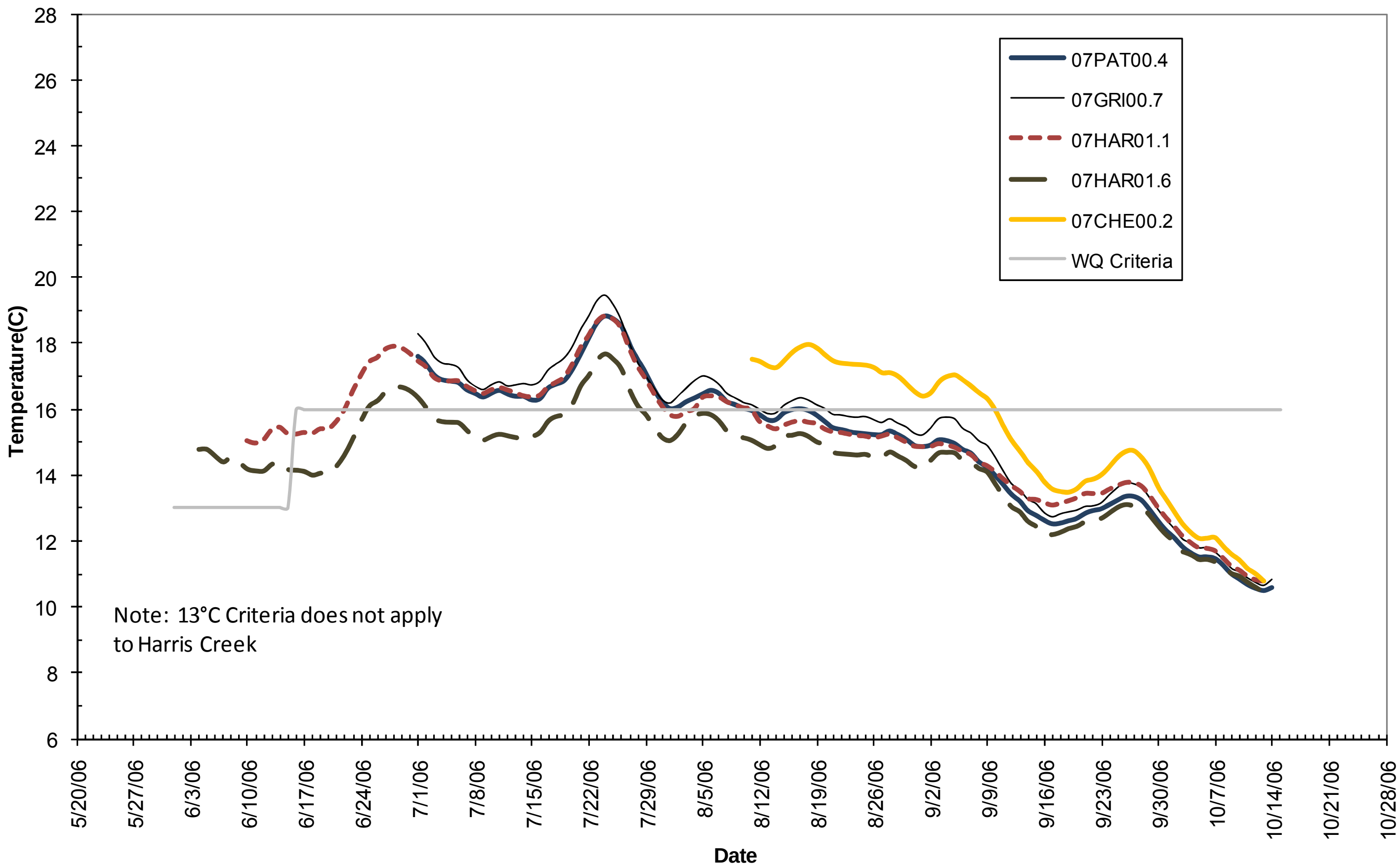

Figure D-8. 7DADMax water temperatures for Snoqualmie River tributaries from RM 31.2 (Patterson Creek) to RM 21.3 (Harris Creek) plus Cherry Creek.

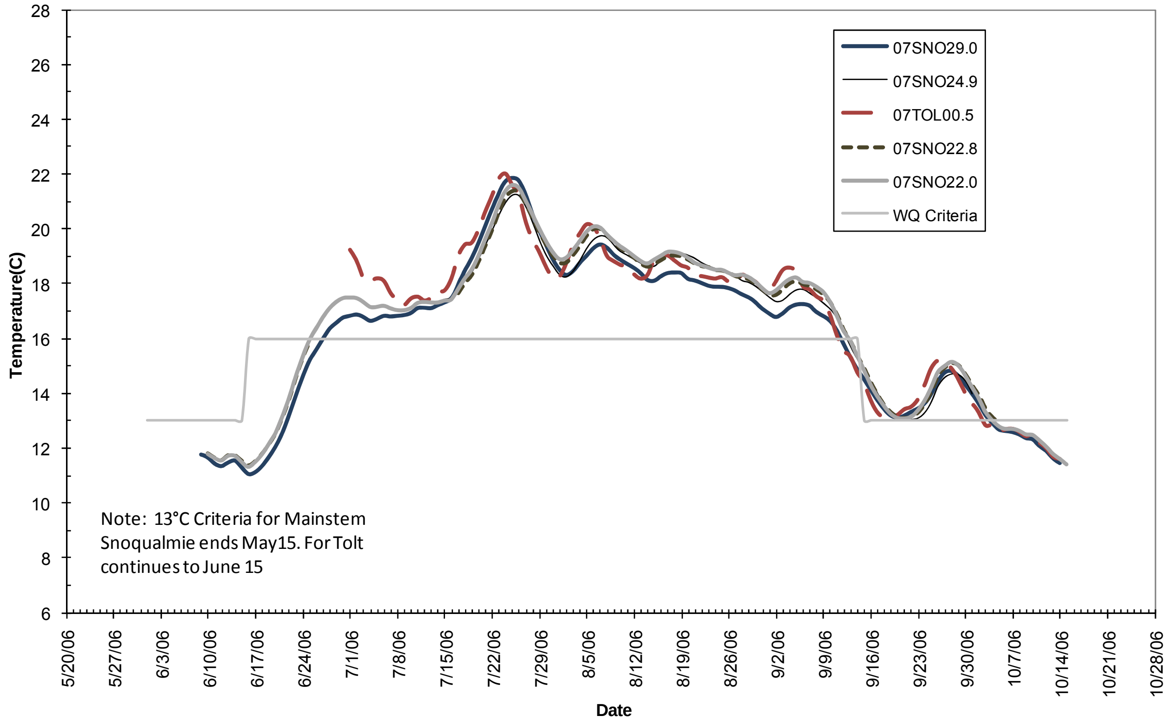

Figure D-9. 7DADMax water temperatures for Snoqualmie River from RM 29.0 to RM 22.0 plus Tolt River at mouth.

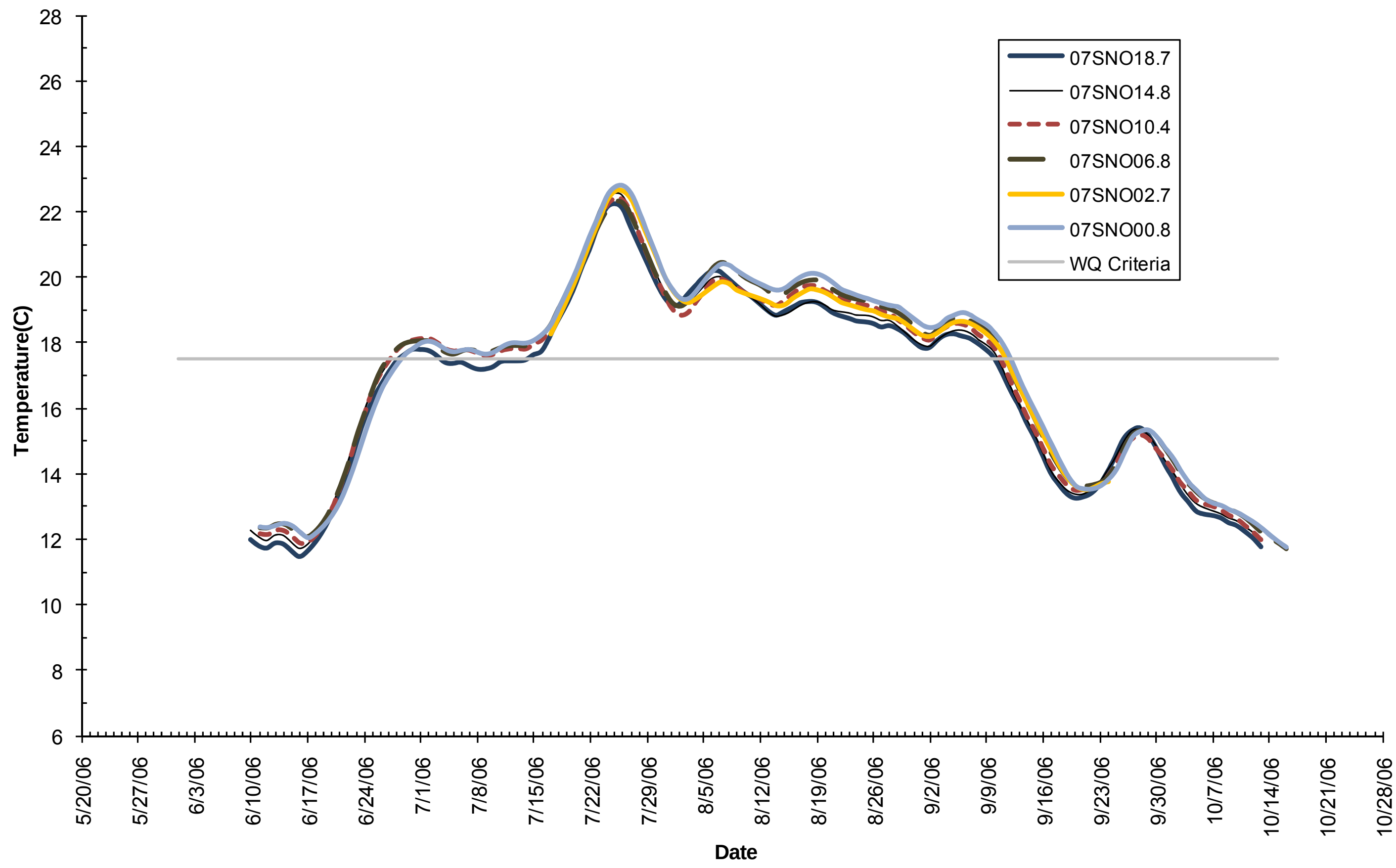

Figure D-10. 7DADMax water temperatures for Snoqualmie River mainstem from RM 18.7 to Skykomish confluence.

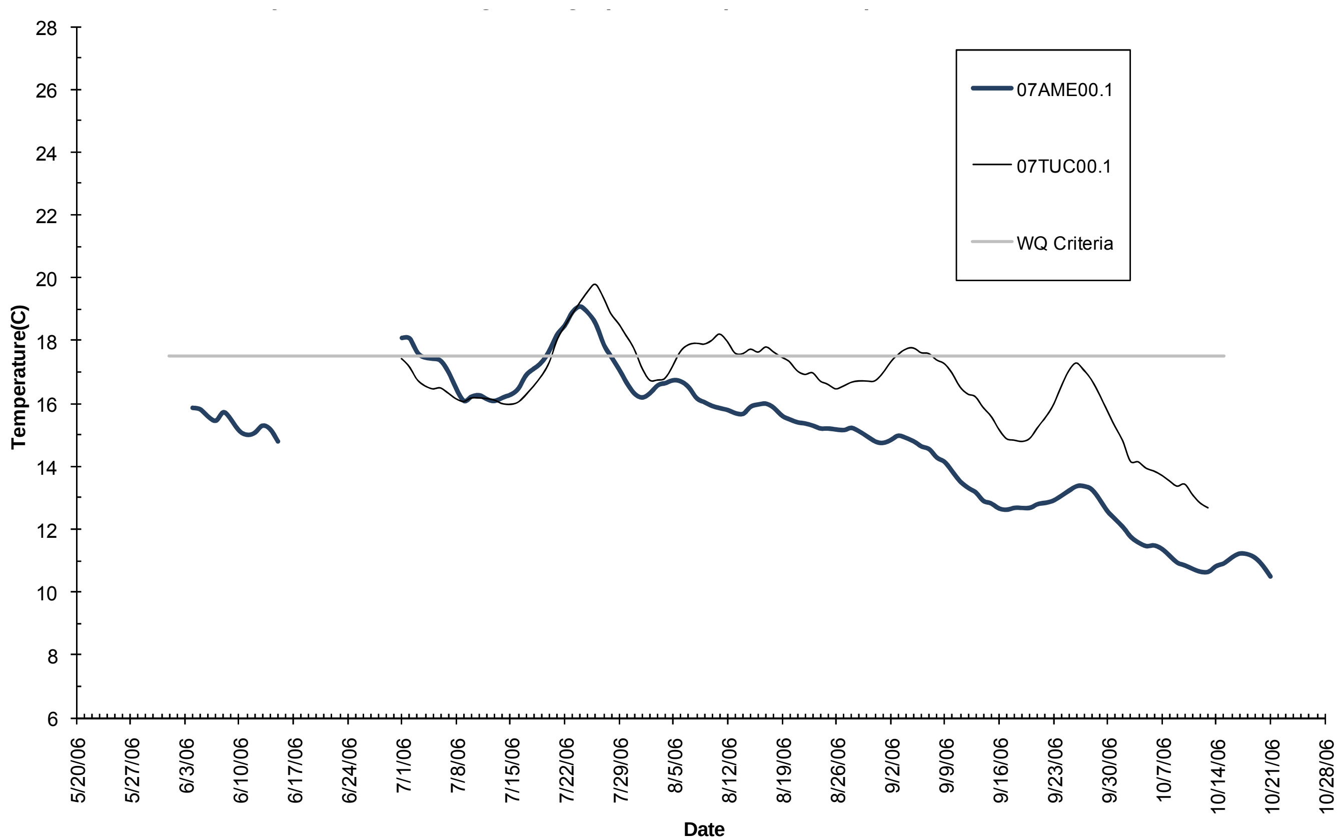

Figure D-11. 7DADMax water temperatures for Snoqualmie River tributaries RM from 18.7 to Skykomish confluence.

Table D-1. Ecology sample site location details for the Snoqualmie basin, 2006

Station ID	Stream name	Site description	Temperature data	Latitude	Longitude	Elevation (meters)	Magnetic declination
				NAD 83			
07AME00.1	Ames Creek	Ames Creek at NE 100th St (07V070)	stream, air	47.68633	-121.98317	12.1	17.5167
07BRO00.2	Brockway Creek	Brockway Creek at Reining Rd	limited stream and air	47.52944	-121.80222	128.2	17.4333
07BUR00.5	Burntboot Creek	Burntboot Creek below Goldmyer Hot Springs	stream	47.48386	-121.39202	533.5	
07CHE00.2	Cherry Creek	Cherry Creek at Hwy 203 (07S070)	stream, air	47.76694	-121.96056	11.9	17.5500
07DWP00.0	Duvall WWTP	Manhole out fall at Duvall Wastewater Treatment Plant	water (effluent)	47.73190	-121.99212		
07GIF00.1	Gifford Lakes Creek	Gifford Lakes stream drainage	stream, air	47.50850	-121.61434	259.4	17.3833
07GRA00.1	Granite Creek	Granite Creek 0.2 miles upstream of MFS conf	stream, air	47.49472	-121.63972	253.5	17.3833
07GRI00.7	Griffin Creek	Griffin Creek Hwy at 203 (07W070)	stream	47.61750	-121.91444	27.5	17.5000
07HAR01.1	Harris Creek	Harris Creek at Sno Trail below FMU site	stream, air	47.67889	-121.91889	14.2	17.5167
07HAR01.6		Harris Creek at Hwy 203 (07U070)	stream, (air malfunction)	47.67803	-121.90735	18.3	17.5167
07KIM00.1	Kimball Creek	Kimball Creek Hwy 202 (07Y060)	stream, air	47.53538	-121.83016	122.6	17.4500
07MFS45.3	Middle Fork Snoqualmie River	MF Snoq R at 428th Ave SE near Ellisville (07D150)	stream, air from near site	47.51643	-121.76994	125.4	17.4167
07MFS47.8		Middle Fork Snoq R at Mt Si Rd	stream, air	47.48762	-121.75879	145.8	17.4000
07MFS51.2		Middle Fork Snoq R above Roaring River BnB	stream, air, dew point	47.47818	-121.70849	186.4	17.4000
07MFS55.6		Middle Fork Snoq R at USGS gaging station	stream, air	47.48511	-121.64875	234.1	17.3833
07MFS60.4		Middle Fork Snoq R at national forest boundary	stream, air, dew point	47.52396	-121.59921	269.3	17.3833
07MFS75.0		Middle Fork Snoq R above Goldmyer Hot Springs	stream	47.48828	-121.38836	534.7	
07NFS00.3	N F Snoqualmie River	NF Snoq R at 428th Ave SE near Ellisville (07N070)	stream, air	47.52178	-121.76925	125.5	17.4333
07NWP00.0	North Bend WWTP	North Bend WWTP on site at outfall	water (effluent)	47.49927	-121.78705		
07PAT00.4	Patterson Creek	Patterson Creek near Fall City (07P070)	stream	47.59167	-121.92556	20.8	17.4833
07RAG00.1	Raging River	Raging R at mouth in Fall City (07Q050)	stream, air	47.56739	-121.88370	24.3	17.4667
07RAG02.6		Raging R at USGS gage station Natural Areas	stream, air	47.54017	-121.90956	76.3	17.4667
07RAG04.7		Raging R between Upper Preston Rd and I-90 (King Co.)	stream	47.51914	-121.92531		
07RAG07.9		Raging R at Hwy 18 (King Co. data)	stream	47.48611	-121.88802		
07SFS01.6	South Fork Snoqualmie River	South Fork Snoq R at Valley Trail R (07M065)	stream, air from near site	47.50201	-121.78627	128.4	17.4167
07SFS01.8		South Fork Snoq R at Bendigo Blvd S (07M075)	stream, air	47.49247	-121.78969		
07SFS05.5		South Fork Snoq R at 468th SE (07M120)	stream, air	47.46600	-121.75889		
07SNO00.8	Snoqualmie River	Snoqualmie R above Skykomish R confluence	stream, air	47.82003	-122.03015	4.1	17.5833
07SNO02.7		Snoqualmie R near Monroe (07D050)	stream, air, dew point	47.80397	-122.00167	4.8	17.5833
07SNO06.8		Snoqualmie R above Cherry Creek	stream, air	47.76800	-121.96101	6.4	17.5500
07SNO10.4	Snoqualmie River	Snoqualmie R above Coe and Tuck Creek, Duvall	stream, air	47.73686	-121.99189	7.2	17.5333
07SNO14.8		Snoqualmie R at 124th Novelty	stream, air	47.70697	-121.99795	7.5	17.5333

Station ID	Stream name	Site description	Temperature data	Latitude	Longitude	Elevation (meters)	Magnetic declination
				NAD 83			
07SNO18.7		Snoqualmie R above Ames Creek at Stillwater	stream, air	47.69197	-121.96507	9.6	17.5167
07SNO22.0		Snoqualmie R below Chinook Bend	stream, air	47.67182	-121.92784	11.4	17.5000
07SNO22.8		Snoqualmie R at Carnation USGS gage station	stream, air	47.66892	-121.92219	13.4	17.5000
07SNO24.9		Snoqualmie R above Tolt R and Carnation (07D100)	stream, air	47.63994	-121.92787	13.9	17.5000
07SNO29.0		Snoqualmie R above Griffin Creek on 8th	stream, air, dew point	47.61520	-121.92720	16.4	17.4833
07SNO33.0		Snoqualmie R at Neal Rd boat launch	stream, air	47.59606	-121.91443	18.9	17.4833
07SNO36.3		Snoqualmie R above Raging R	stream, air	47.56853	-121.88299	23.3	17.4667
07SNO39.8		Snoqualmie R at PSE outfall, USGS station	stream, air, dew point	47.54743	-121.84277	33.4	17.4500
07SNO40.8		Snoqualmie R at Hwy 202 (07D125)	stream, air	47.53943	-121.83213	118.1	17.4333
07SNO42.3		Snoqualmie R at Snoqualmie (07D130)	stream, air	47.52701	-121.81207	118.3	17.4333
07SWP00.0	Snoqualmie WWTP	Snoqualmie WWTP at manhole near Snoq R (lost logger)	hourly water data	47.53949	-121.83210		
07TOK00.1	Tokul Creek	Tokul Creek SE Fish Hatchery (07X060)	stream, air	47.55109	-121.84382	36.1	17.4500
07TOK00.6		Tokul Creek above hatchery, off of Hwy 202	stream, air	47.55405	-121.83532	53.3	17.4500
07TOL00.5	Tolt River	Tolt R near Carnation (07G070)	stream, air from near site	47.63777	-121.91619	20.7	17.5000
07TUC00.1	Tuck Creek	Tuck Creek at Mouth (07T050)	stream, air	47.73804	-121.99245	8.7	17.5500
07UNA00.2	Unnamed A	Unnamed tributary (MFS) before national forest	stream, air	47.52269	-121.60146	269.6	17.3833
07UNB00.4	Unnamed B	Unnamed tributary (MFS) at culvert downstream	stream, air	47.51254	-121.62167	274.4	17.3833
07UNC00.3	Unnamed C	Unnamed tributary (MFS) off of Mt Si Rd	limited stream, all air	47.48587	-121.73290	178.1	17.4167
07UND00.4	Unnamed D	Unnamed tributary to MFS off MFS Rd	stream, air	47.46792	-121.68136	240.8	17.4000
07UNE00.3	Unnamed E	Unnamed tributary to MFS off MFS Rd	streamflow only	47.46818	-121.68626		
07WEA10.0	Duvall Weather Station	Near Duvall Police station in McCormick Park	air, dew point, others	47.73923	-121.98876	12.1	

MFS – Middle Fork Snoqualmie

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Appendix E. Snoqualmie River stream survey and cross-section measurements

Appendix E contains these tables and figures:

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Table E-1. Channel widths and depths from 2006 float survey: August 29-October 3, 2006.

This table contains wetted width, wetted depth, bankfull width, bankfull depth, near-stream disturbance zone width, channel incision measurements, and coding for the Entrenchment Ratio as described in Rosgen (1996). Fifteen to 20 depth measurements were made at each cross-section.

Measurements are in meters.

Entrenchment Ratio Code	Flood Prone Width and Bankfull Width relationship	Description
1	FPW < 1.4 x BFW	Entrenched
2	FPW = 1.4 to 2.2 x BFW	Moderately Entrenched
3	FPW > 2.2 x BFW	Slightly Entrenched

River Miles 60 to 46

transect #	date	Wetted Width			Bankfull Width			NSDZ	WD	BFD	BFD	Entr code	Incision	
		RB	LB	WW	RB	LB	BFW		Avg	Avg	Max		RB	LB
RM 60	08/29/06	0.00	86.37	86.37	-1.23	87.39	88.62	88.6	0.29	1.63	1.68	2	2.1	0.8
RM 58		39.90	0.00	39.90	41.60	-41.33	82.93	111.9	1.53	0.59	1.22	3	8.5	0.9
RM 56		41.89	0.00	41.89	43.92	-10.85	54.77	64.1	0.40	1.28	1.68	2	0.9	1.2
RM 54	08/31/06	69.37	0.00	69.37	72.51	-26.93	99.44	114.3	0.35	1.17	1.68	3	0.5	0.6
RM 53		25.67	0.00	25.67	29.02	-14.40	43.42	48.8	0.89	1.08	1.83	2	9.1	1.8
RM 52	09/27/06	48.39	0.00	48.39	51.82	-11.34	63.16	63.1	0.36	1.83	1.83	3	7.6	0.3
RM 50		0.00	58.21	58.21	-8.83	64.00	72.83	65.5	0.44	1.14	1.43	1	6.1	12.2
RM 48	10/03/06	0.00	45.67	45.67	-4.49	55.06	59.54	64.3	0.37	1.36	1.77	2	4.6	0.6
RM 46	09/08/06	27.79	0.00	27.79	31.46	-15.10	46.56	64.0	0.99	1.00	1.68	2	2.1	2.0
Average				**49.25**			**67.92**	**76.1**	**0.62**	**1.23**	**1.83**	**2**	**4.6**	**2.3**

River Miles 44 to 28

transect #	date	Wetted Width RB	Wetted Width LB	Wetted Width WW	Bankfull Width RB	Bankfull Width LB	Bankfull Width BFW	NSDZ	WD Avg	BFD Avg	BFD Max	Entr code	Incision RB	Incision LB
RM 44 main	09/08/06	33.81	0.00	33.81	35.29	-17.61	52.90	56.4	0.45	1.27	1.98	3	0.3	0.6
RM 44 side		101.80	81.69	20.12	139.60	79.25	60.35	61.0	0.08	0.61	1.83	3	1.2	0.3
RM 42	08/30/06	50.40	0.00	50.40	50.40	-17.01	67.41	71.3	0.64	1.37	1.83	3	2.4	1.8
RM 40		78.07	0.00	78.07	81.31	-3.33	84.63	91.1	2.17	1.97	2.13	3	1.2	1.8
RM 38	09/06/06	67.89	0.00	67.89	70.00	-6.37	76.37	93.6	0.67	1.25	1.40	3	1.4	1.0
RM 36		55.27	0.00	55.27	62.39	-12.08	74.46	76.2	0.31	0.90	1.22	1	4.6	1.8
RM 34		65.83	0.00	65.83	66.96	-6.85	73.82	78.6	0.49	1.77	1.98	3	3.0	1.2
RM 32		39.91	0.00	39.91	43.93	-15.96	59.90	64.9	0.64	1.51	2.06	3	1.5	3.0
RM 30	09/07/06	0.00	29.98	29.98	-26.55	32.33	58.88	59.4	0.96	1.55	3.05	3	1.5	2.4
RM 28		0.00	47.79	47.79	-3.83	51.05	54.88	53.3	1.73	2.65	3.05	3	1.2	1.8
Average				**48.91**			**66.36**	**70.6**	**0.81**	**1.48**	**3.05**	**3**	**1.8**	**1.6**

River Miles 26 to 10

transect #	date	Wetted Width RB	Wetted Width LB	Wetted Width WW	Bankfull Width RB	Bankfull Width LB	Bankfull Width BFW	NSDZ	WD Avg	BFD Avg	BFD Max	Entr code	Incision RB	Incision LB
RM 26	09/07/06	47.69	0.00	47.69	50.14	-7.39	57.53	61.0	2.81	2.46	3.05	3	0.9	1.5
RM 22	09/28/06	51.73	0.00	51.73	88.30	-4.57	92.87	93.0	0.49	1.10	1.98	3	0.6	1.2
RM 20	10/05/06	60.46	0.00	60.46	65.75	-33.84	99.58	110.6	1.07	0.74	1.22	3	2.6	1.5
RM 18		57.00	-25.36	82.36	58.52	-30.69	89.21	94.5	0.29	1.74	1.89	3	1.5	1.5
RM 16		41.95	0.00	41.95	45.42	-10.89	56.31	60.0	1.69	1.82	2.44	3	2.1	1.2
RM 14	09/26/06	33.96	0.00	33.96	51.15	-3.05	54.20	58.8	2.03	1.43	2.29	3	1.8	2.4
RM 12		51.10	12.90	38.20	56.40	0.00	56.40	62.8	2.60	1.03	1.52	3	2.4	1.5
RM 10		60.66	5.18	55.47	63.70	0.00	63.70	68.9	1.25	1.86	2.13	1	3.7	4.6
Average				**51.48**			**71.22**	**76.2**	**1.53**	**1.52**	**3.05**	**3**	**2.0**	**1.9**

River Miles 8 to 2

transect #	date	Wetted Width			Bankfull Width			NSDZ	WD	BFD	BFD	Entr code	Incision	
		RB	LB	WW	RB	LB	BFW		Avg	Avg	Max		RB	LB
RM 8	09/28/06	58.00	0.00	58.00	60.96	-3.05	64.01	70.7	1.57	1.93	2.13	3	2.7	2.7
RM 6		53.24	0.00	53.24	56.39	-3.05	59.44	61.0	2.44	1.91	2.13	3	3.0	3.0
RM 4		0.00	46.95	46.95	-1.83	49.38	51.21	60.7	2.84	2.52	2.74	3	4.6	3.0
RM 2		63.54	0.00	63.54	67.06	-6.10	73.15	73.8	2.23	2.65	3.05	3	0.9	2.1
Average				**55.43**			**61.95**	**66.5**	**2.27**	**2.25**	**3.05**	**3**	**2.8**	**2.7**

RB – right bank
LB – left bank
WW – wetted width
BFW – bankfull width
WD – wetted depth
BFD – bankfull depth
Entr – entrenchment
NSDZ – near stream disturbance zone

Table E-2. Canopy closure (Solar Pathfinder) data from 2006 float survey.

X-Section Name	Open Canopy % July	Open Canopy % August	Closed Canopy (% Shade) July/August Average
RM 60	90	89	10.5
RM 58	92	86	11.0
RM 56	94	94	6.0
RM 54	94	87	9.5
RM 53	73	70	28.5
RM 52	94	91	7.5
RM 50	95	78	13.5
RM 48	99	97	2.0
RM 46	95	97	4.0
RM 44	81	76	21.5
RM 42	87	81	16.0
RM 40	88	90	11.0
RM 38	99	97	2.0
RM 36	98	96	3.0
RM 34	93	94	6.5
RM 32	91	91	9.0
RM 30	90	64	23.0
RM 28	98	99	1.5
RM 26	100	99.5	0.3
RM 22	98	96	3.0
RM 20	98	99	1.5
RM 18	100	100	0.0
RM 16	100	95	2.5
RM 14	97	96	3.5
RM 12	98	98	2.0
RM 10	88	77	17.5
RM 8	100	100	0.0
RM 6	100	100	0.0
RM 4	100	100	0.0
RM 2	93	95	6.0

Table E-3. Substrate composition data from 2006 float survey.

X-Section Name	Estimate of substrate composition (%)				
	silt/ sand	gravel	coble	boulder	bedrock
RM 60	1	4	65	30	0
RM 58	19	40	40	1	0
RM 56	3	7	80	10	0
RM 54	1	4	65	30	0
RM 53	2	8	10	80	0
RM 52	1	9	30	60	0
RM 50	1	3	8	88	0
RM 48	2	2	9	87	0
RM 46	5	10	35	50	0
RM 44	4	12	60	24	0
RM 38	15	10	40	35	0
RM 36	1	9	90	0	0
RM 34	5	35	35	25	0
RM 32	10	40	50	0	0
RM 30	29	40	30	1	0
RM 28	99	0	0	1	0
RM 26	70	28	1	1	0
RM 22	1	55	43	1	0
RM 20	97	3	0	0	0
RM 18	39	60	0	1	0
RM 16	99	0	0	1	0
RM 14	95	0	2	3	0
RM 12	100	0	0	0	0
RM 10	100	0	0	0	0
RM 8	100	0	0	0	0
RM 6	100	0	0	0	0
RM 4	100	0	0	0	0
RM 2	100	0	0	0	0

Table E-4. Data from Snoqualmie River cross-section surveys: August 7-17, 1989 (Joy et al., 1991; Table 8).

Map No.*	RM	Description	Average Velocity ft/sec	Average Depth ft	Max. Depth ft	Area ft²	Width ft	Elevation ft	Disch. cfs
1	2.87	Near High Bridge	0.54	7.5	14.6	1684	226	17	903
2	5.30	Near County Line	0.69	9.0	14.6	1339	149	18.5	930
3	6.64	Near Cherry Creek	0.78	8.3	12.9	1250	150	19.5	978
4	9.40	Below Duvall	1.20	6.3	10.0	851	134	21	1018
5	10.50	Duvall WWTP area	1.23	5.0	8.8	832	166	22	1022
6	11.70	Above Duvall	1.85	3.7	5.3	562	151	23	1038
7	13.55	Below N.E. 124th Bridge	1.18	5.0	12.1	804	162	24	945
8	15.40	Above bridge shallow	1.53	3.1	5.1	650	208	25	995
9	16.70	Below Ames Deep	0.88	7.9	16.6	1021	129	27	904
10	18.05	Near Ames shallow	1.92	1.8	4.4	483	266	30	928
11	19.40	Below Carnation Farms	1.00	5.8	10.6	951	165	33	948
12	25.30	Above Tolt River	0.24	9.9	15.6	2094	211	58	508
13	27.10	Below Griffin Creek	0.53	9.3	19.0	1320	142	58.3	696
14	28.30	Above Griffin Creek	0.98	2.6	4.1	701	268	58.6	687
15	31.75	Neal Rd. - channeled	0.84	5.7	11.1	815	144	60	685
16	32.80	Above Neal Rd. boat l.	1.06	3.6	4.7	646	180	62	681
17	34.10	Riffle above Patterson	1.65	2.8	4.1	401	141	65	664
18	35.35	Below Fall City	0.68	7.3	14.2	1057	144	75	719
19	37.80	Above Fall City - pool	0.75	6.6	11.8	843	129	85	634
20	38.30	Below Snoq. Fall riffle	2.95	1.2	3.4	205	168	87	604
21	**40.71	Above Falls near Hwy 202	0.25	7.8	11.0	1512	195	390	378
22	**42.10	Above Falls at Meadowbrook	0.37	5.1	8.9	1009	197	398	378

Table E-5. HemiView effective shade data from 2006 float survey.

Mainstem Stations	Effective Shade	Tributary Stations	Effective Shade
Station_Picture_Name	(TotAb-TotBe) /TotAb	Station_Picture_Name	(TotAb-TotBe) /TotAb
07_SNO_00.8_C.hvs	0.222	07_AME_00.1_C..hvs	0.301
07_SNO_02.7_C.hvs	0.025	07_BRO_00.2_C.hvs	0.815
07_SNO_06.8_C.hvs	0.030	07_CHE_00.2_C.hvs	0.331
07_SNO_10.4_C.hvs	0.172	07_GIF_00.1_C.hvs	0.893
07_SNO_14.8_C.hvs	0.028	07_GRA_00.1_C.hvs	0.875
07_SNO_18.7_C.hvs	0.131	07_GRI_00.7_C.hvs	0.752
07_SNO_22.8_C.hvs	0.108	07_HAR_01.1_C.hvs	0.695
07_SNO_24.9_C.hvs	0.153	07_HAR_01.6_C.hvs	0.643
07_SNO_33.0_C.hvs	0.308	07_KIM_00.1_C.hvs	0.403
07_SNO_36.3_C.hvs	0.071	07_NFS_00.3_C.hvs	0.351
07_SNO_39.8_C.hvs	0.292	07_PAT_00.4_C.hvs	0.259
07_SNO_42.3_C.hvs	0.130	07_RAG_00.1_C.hvs	0.508
07_MFS_45.3_C.hvs	0.346	07_RAG_02.6_C.hvs	0.831
07_MFS_47.8_C.hvs	0.170	07_SFS_01.6_C.hvs	0.259
07_MFS_51.2_C.hvs	0.216	07_TOK_00.6_C.hvs	0.767
07_MFS_55.6_C.hvs	0.181	07_TOL_00.5_C.hvs	0.396
07_MFS_60.4_C.hvs	0.604	07_TUC_00.1_C.hvs	0.818
		07_UNA_00.2_C.hvs	0.851
		07_UNB_00.4_C.hvs	0.806
		07_UNC_00.3_C.hvs	0.781

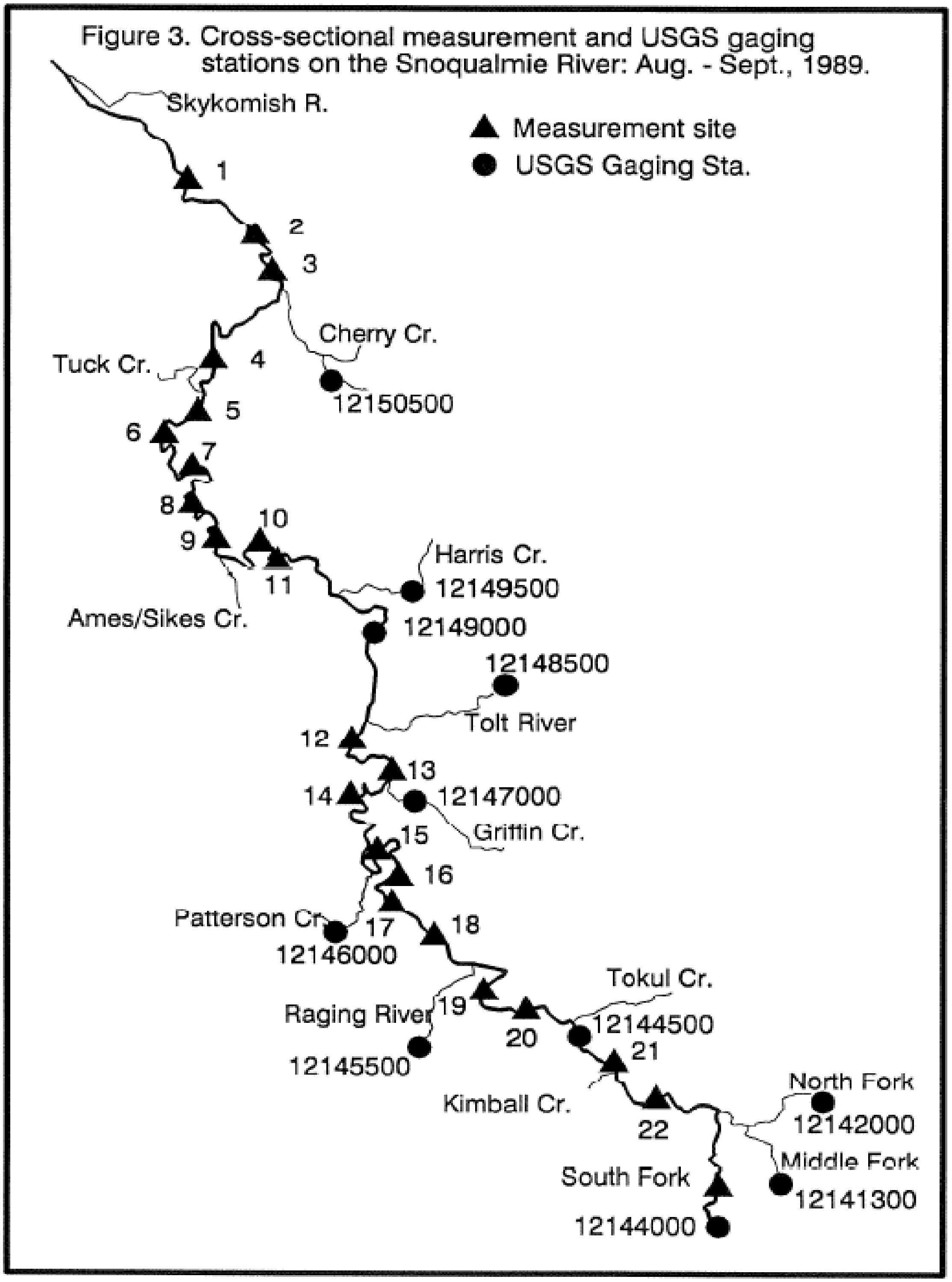

Figure E-1. Data from Snoqualmie River cross-section surveys: August 7-17, 1989 (Joy et al., 1991; Figure 3)

Appendix F. Load allocations for effective shade for the Middle Fork and Mainstem Snoqualmie River

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Table F-1. Load allocations for the effective shade in the Snoqualmie River for the condition of mature riparian vegetation. (on August 1) (percent).

Distance from USFS boundary to upstream segment boundary (meters)	Distance from USFS boundary to downstream segment boundary (meters)	Current shade condition (%)	System-potential shade (%) (roll_ave from Q)	Increase in shade needed	Landmark	Load allocation for shortwave solar (watts/m2) (roll from C value)
0	1000	24.7%	38.7%	14.0%	USFS (RM 60.4)	200.8
1000	2000	14.5%	30.2%	15.7%		222.0
2000	3000	26.1%	45.5%	19.4%		185.6
3000	4000	16.2%	38.1%	21.9%		204.4
4000	5000	14.0%	30.3%	16.3%		221.8
5000	6000	18.5%	40.0%	21.6%		199.8
6000	7000	12.8%	32.2%	19.4%		218.8
7000	8000	19.1%	37.1%	18.0%		204.9
8000	9000	21.5%	39.0%	17.5%		199.5
9000	10000	20.3%	39.0%	18.7%		196.7
10000	11000	22.0%	38.8%	16.7%		200.3
11000	12000	18.8%	40.4%	21.5%		200.6
12000	13000	15.0%	38.4%	23.4%		200.6
13000	14000	18.4%	51.7%	33.4%		167.2
14000	15000	14.4%	45.7%	31.3%		189.0
15000	16000	19.1%	39.2%	20.0%		202.8
16000	17000	16.7%	38.1%	21.4%		205.6
17000	18000	11.2%	36.0%	24.8%		209.7
18000	19000	10.1%	45.8%	35.7%		186.8
19000	20000	10.2%	40.8%	30.6%		198.2
20000	21000	10.5%	38.6%	28.2%		202.8
21000	22000	21.1%	46.3%	25.2%		184.9
22000	23000	21.1%	41.7%	20.6%		191.2
23000	24000	25.0%	42.2%	17.2%		190.6
24000	25000	15.4%	26.9%	11.6%		230.2
25000	26000	13.8%	25.9%	12.1%	NF Confluence	232.6
26000	27000	9.9%	29.1%	19.2%		227.9
27000	28000	12.2%	27.1%	14.9%		233.4
28000	29000	25.3%	39.2%	13.8%		202.1
29000	30000	9.9%	33.6%	23.7%		218.1
30000	31000	10.6%	32.1%	21.5%		218.6
31000	32000	6.4%	31.8%	25.4%		220.2
32000	33000	22.5%	41.3%	18.9%	Snoqualmie Falls	188.7
33000	34000	13.6%	30.7%	17.1%		222.3
34000	35000	5.5%	25.1%	19.6%		237.4
35000	36000	8.6%	23.2%	14.6%		242.0
36000	37000	10.5%	37.1%	26.6%		207.7
37000	38000	9.5%	32.5%	22.9%		218.7
38000	39000	7.3%	28.0%	20.7%		232.2

Distance from USFS boundary to upstream segment boundary (meters)	Distance from USFS boundary to downstream segment boundary (meters)	Current shade condition (%)	System-potential shade (%) (roll_ave from Q)	Increase in shade needed	Landmark	Load allocation for shortwave solar (watts/m2) (roll from C value)
39000	40000	9.1%	33.5%	24.4%		215.2
40000	41000	5.7%	25.7%	20.0%		234.6
41000	42000	21.5%	48.2%	26.7%		179.9
42000	43000	11.2%	35.7%	24.5%		211.1
43000	44000	5.8%	33.0%	27.2%		215.3
44000	45000	6.1%	32.1%	26.1%		217.8
45000	46000	5.5%	34.7%	29.2%		212.2
46000	47000	6.0%	45.8%	39.8%		188.9
47000	48000	5.5%	42.7%	37.2%		195.3
48000	49000	6.5%	39.4%	32.8%		201.3
49000	50000	3.6%	37.8%	34.2%		206.3
50000	51000	2.4%	34.3%	31.9%		215.0
51000	52000	3.4%	29.6%	26.1%		227.3
52000	53000	3.5%	25.5%	22.0%		236.2
53000	54000	6.0%	31.7%	25.7%		221.4
54000	55000	4.7%	29.7%	24.9%		226.8
55000	56000	6.8%	36.3%	29.5%		208.7
56000	57000	13.5%	33.4%	20.0%	Tolt River	214.2
57000	58000	6.1%	29.6%	23.6%		223.8
58000	59000	5.5%	30.2%	24.7%		222.4
59000	60000	6.9%	29.0%	22.1%		225.8
60000	61000	6.4%	19.9%	13.6%		248.3
61000	62000	3.9%	24.3%	20.4%		237.4
62000	63000	5.2%	19.2%	14.0%		249.7
63000	64000	4.7%	27.6%	22.9%		229.6
64000	65000	3.3%	22.9%	19.7%		241.8
65000	66000	6.2%	40.5%	34.3%		196.9
66000	67000	3.0%	23.7%	20.7%		239.8
67000	68000	5.6%	40.5%	34.9%		198.3
68000	69000	2.4%	36.9%	34.5%		209.8
69000	70000	2.5%	33.6%	31.1%		214.6
70000	71000	2.1%	31.2%	29.1%		220.7
71000	72000	2.6%	37.2%	34.6%		207.8
72000	73000	3.8%	38.2%	34.4%		203.9
73000	74000	4.6%	33.4%	28.7%		215.3
74000	75000	5.2%	36.4%	31.2%		208.3
75000	76000	4.1%	38.7%	34.6%		203.6
76000	77000	7.6%	36.1%	28.6%		207.4
77000	78000	3.6%	38.7%	35.1%	River Mile 12	203.7
78000	79000	2.4%	33.3%	30.9%		217.2
79000	80000	9.7%	40.5%	30.7%		199.8

Distance from USFS boundary to upstream segment boundary (meters)	Distance from USFS boundary to downstream segment boundary (meters)	Current shade condition (%)	System-potential shade (%) (roll_ave from Q)	Increase in shade needed	Landmark	Load allocation for shortwave solar (watts/m2) (roll from C value)
80000	81000	9.5%	46.1%	36.6%	Duvall	185.1
81000	82000	8.6%	51.3%	42.7%		174.0
82000	83000	6.7%	43.8%	37.2%		189.8
83000	84000	6.6%	41.0%	34.5%		197.2
84000	85000	3.2%	43.6%	40.3%		193.1
85000	86000	4.9%	44.2%	39.3%		190.8
86000	87000	4.8%	44.7%	39.9%	County Line	189.3
87000	88000	2.9%	47.1%	44.3%		183.0
88000	89000	3.2%	47.6%	44.5%		182.0
89000	90000	1.9%	42.5%	40.6%		197.5
90000	91000	2.4%	30.1%	27.6%		224.9
91000	92000	10.6%	44.0%	33.4%		190.5
92000	93000	26.0%	49.0%	23.0%		175.6
93000	94000	19.5%	34.3%	14.8%	River Mile 2	214.6
94000	95000	18.3%	28.8%	10.5%		228.0
95000	95800	24.6%	37.0%	12.4%		205.7

Load allocations are defined as the site potential maximum achievable effective shade (fraction of the incoming solar radiation blocked by vegetation and topography)

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Appendix G. Load allocations for effective shade for the Snoqualmie River tributaries based on bankfull width and stream aspect

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Table G-1. Load allocations for effective shade based on 100-year potential vegetation: height = 45 meters, density = 85%, overhang = 7.3 meters.

Bankfull width (meter)	Effective shade from vegetation (percent) at the stream center at various stream aspects (degrees from N)			Daily average global solar shortwave radiation (W/m2) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225 and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
1	99.1%	99.2%	99.6%	3	2	1
2	99.0%	99.0%	99.5%	3	3	2
3	98.8%	98.8%	99.3%	4	3	2
4	98.6%	98.7%	99.2%	4	4	2
5	98.4%	98.5%	99.1%	5	4	3
6	98.2%	98.4%	98.9%	5	5	3
7	98.0%	98.3%	98.8%	6	5	4
8	97.6%	97.8%	98.5%	7	7	5
9	96.8%	97.2%	98.0%	10	9	6
10	96.0%	96.3%	97.6%	12	11	7
12	94.2%	94.7%	96.5%	17	16	10
14	92.5%	93.0%	95.3%	23	21	14
16	90.4%	90.9%	93.9%	29	27	18
18	87.9%	88.4%	92.4%	36	35	23
20	85.1%	85.4%	88.1%	45	44	36
25	78.0%	77.5%	71.9%	66	68	84
30	71.2%	69.7%	61.1%	86	91	117
35	64.7%	62.7%	53.4%	106	112	140
40	59.0%	56.8%	47.5%	123	130	158
45	53.9%	51.7%	42.8%	138	145	172
50	49.7%	47.4%	39.0%	151	158	183
55	45.9%	43.6%	35.8%	162	169	193
60	42.6%	40.4%	33.1%	172	179	201

Note: For streams with a channel width less than 15 meters (50 feet), 50-year vegetation of 36.5 meters, 85% canopy cover, and 7.3 meters overhanging vegetation provide the required shading because the assumed overhanging vegetation will cover the stream.

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Appendix H. Table 602 for the Snoqualmie River Basin

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Table H-1. Table 602 for the Snoqualmie River basin.

TABLE 602	Aquatic Life Uses						Recreation Uses			Water Supply Uses				Misc. Uses				
Use Designations for Fresh Waters by Water Resource Inventory Area (WRIA)	Char Spawning /Rearing	Core Summer Habitat	Spawning/Rearing	Rearing/Migration Only	Redband Trout	Warm Water Species	Ex Primary Cont	Primary Cont	Secondary Cont	Domestic Water	Industrial Water	Agricultural Water	Stock Water	Wildlife Habitat	Harvesting	Commerce/Navigation	Boating	Aesthetics
WRIA 7 Snohomish																		
Cherry Creek and tributaries from mouth to headwaters		✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Cripple Creek and all tributaries	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Kelly Creek and tributaries	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓

TABLE 602	Aquatic Life Uses						Recreation Uses			Water Supply Uses				Misc. Uses				
Use Designations for Fresh Waters by Water Resource Inventory Area (WRIA)	Char Spawning /Rearing	Core Summer Habitat	Spawning/Rearing	Rearing/Migration Only	Redband Trout	Warm Water Species	Ex Primary Cont	Primary Cont	Secondary Cont	Domestic Water	Industrial Water	Agricultural Water	Stock Water	Wildlife Habitat	Harvesting	Commerce/Navigation	Boating	Aesthetics
Miller River, East Fork, and West Fork Miller River: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
North Fork Creek and unnamed creek at latitude 47.7409 longitude -121.8231 (Sect. 18 T26N R8E): All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Pilchuck River from mouth to Boulder Creek		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Pilchuck River and Boulder Creek: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Pratt River and all tributaries	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Skykomish River and tributaries from mouth to May Creek (above Gold Bar at river mile 41.2).		✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Skykomish River and May Creek (above Gold Bar at river mile 41.2): All waters (including tributaries) above junction (Except where designated Char).		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Skykomish River, North Fork, beginning below Salmon Creek at latitude 47.8790 longitude –121.4594) to headwaters (including tributaries).	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Skykomish River, South Fork, and Beckler River: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snohomish River from mouth and east of longitude 122°13'40"W upstream to latitude 47°56'30"N (southern tip of Ebey Island at river mile 8.1).[1]			✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Snohomish River from latitude 47°56'30"N (southern tip of Ebey Island at river mile 8.1) to below Pilchuck Creek at latitude 47.9045 longitude -122.0917.			✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Snohomish River from below Pilchuck Creek (latitude 47. 9045 longitude -122.0917) to confluence with Skykomish and Snoqualmie River (river mile 20.5).		✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓

TABLE 602	Aquatic Life Uses						Recreation Uses			Water Supply Uses				Misc. Uses				
Use Designations for Fresh Waters by Water Resource Inventory Area (WRIA)	Char Spawning /Rearing	Core Summer Habitat	Spawning/Rearing	Rearing/Migration Only	Redband Trout	Warm Water Species	Ex Primary Cont	Primary Cont	Secondary Cont	Domestic Water	Industrial Water	Agricultural Water	Stock Water	Wildlife Habitat	Harvesting	Commerce/Navigation	Boating	Aesthetics
Snoqualmie River from mouth to junction with Harris Creek (latitude 47.7686 longitude -121.9605; Sect.5 T25N R6E)			✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River and tributaries from and including Harris Creek (latitude 47.7686 longitude -121.9605; Sect.5 T25N R6E) to west boundary of Twin Falls State Park on south fork (river mile 9.1).		✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River, South Fork, from west boundary of Twin Falls State Park (river mile 9.1) to headwaters (including tributaries).		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River, North Fork, from mouth to Sunday Creek		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River, North Fork, and Sunday Creek: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River, Middle Fork, from mouth to Dingford Creek (Except where designated char).		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River, Middle Fork, and Dingford Creek: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Snoqualmie River's Middle Fork's unnamed tributaries at latitude 47.5389 longitude -121.5629 (Sect. 29 T24N R10E).	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Sultan River and tributaries from mouth to Chaplain Creek (river mile 5.9).		✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Sultan River and tributaries from Chaplain Creek (river mile 5.9) to headwaters.[2]		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Taylor River and all tributaries	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolt River, North Fork, and unnamed creek at latitude 47.7183 longitude -121.7775: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolt River, South Fork, and tributaries from mouth to west boundary of Sec. 31-T26N-R9E (river mile 6.9).		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓

TABLE 602	Aquatic Life Uses						Recreation Uses			Water Supply Uses				Misc. Uses				
Use Designations for Fresh Waters by Water Resource Inventory Area (WRIA)	Char Spawning /Rearing	Core Summer Habitat	Spawning/Rearing	Rearing/Migration Only	Redband Trout	Warm Water Species	Ex Primary Cont	Primary Cont	Secondary Cont	Domestic Water	Industrial Water	Agricultural Water	Stock Water	Wildlife Habitat	Harvesting	Commerce/Navigation	Boating	Aesthetics
Tolt River, South Fork, and tributaries from west boundary of Sec. 31-T26N-R9E (river mile 6.9) to headwaters, except for the waters specifically listed in this table: South Fork Tolt River and South Fork Tolt River's unnamed tributaries.[3]		✓					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolt River, South Fork, and unnamed creek at latitude 47.6925 longitude -121.7392: All waters (including tributaries) above the junction.	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Tolt River's South Fork's unnamed tributaries at latitude 47.6889 longitude -121.7856 (Sect.33 T26N R8E).	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Trout Creek and all tributaries	✓						✓			✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes for WRIA 7:

1. Fecal coliform organism levels shall both not exceed a geometric mean value of 200 colonies/100 mL and not have more than 10 percent of the samples obtained for calculating the mean value exceeding 400 colonies/100 mL.

2. No waste discharge will be permitted above city of Everett Diversion Dam (river mile 9.4).

3. No waste discharge will be permitted for the South Fork Tolt River and tributaries from west boundary of Sec. 31-T26N-R9E (river mile 6.9) to headwaters.

Appendix I. Implementation tracking table

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Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
Federal, State, and Tribal Governments							
U.S.E.P.A	Administer Clean Water Act (CWA) 319 Program						
	Provide CWA 104(b)(3) funding opportunities						
	Administer National Estuary Program/ Great Waters Funds as allocated by Congress						
U.S. Forest Service	Decommision 60 miles or more of roads within its service area.						
	Encourage and monitor efforts to protect forested wetlands. Emphasize compliance with forestry regulations, particularly in riparian areas.						
U.S. Geological Survey	Participate in long-term continuous monitoring of water temperatures at selected USGS gauging stations. Coordinate with Ecology and King County monitoring efforts.						
Department of Ecology	Provide State Revolving Fund, Centennial, Lead Organization funding opportunities						
	Provide technical assistance for stormwater program and TMDL activities						
	Develop shade curves for streams less than 10' in width						
	Perform long-term and effectiveness monitoring as needed						
Puget Sound Partnership	Administer salmon-recovery funding in consideration of TMDL goals						
	Develop Low Impact Development Tools						
	Provide technical assistance through ECO Net and Recovery Specialists						
Department of Natural Resources	Decommission 11 miles or more of roads within its service area.						
	Encourage and monitor efforts to protect forested wetlands. Address deficiencies in forest practices related to environmental protections as identified in the Forest Practices Compliance Monitoring Report 2008/2009 report and subsequent reports.						
Tulalip Tribes	Coordinate the long-term stewardship of restored project sites (in partnership with Snohomish County, King County, and other basin partners).						
	Continue QUALCO Energy Corporation activities and consider investments in riparian plantings as resources allow.						
	Provide leadership, expertise, and resources as available for understanding the relationship between water quality needs and fishery needs.						
Snoqualmie Tribe	Continue current invasive species removal and riparian restoration at Fall City Park and other sites as resources allow.						
	Perform water quality and other environmental monitoring to support problem identification, corrective actions, and trend analysis.						

Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
Special Purpose Districts							
King Conservation District	Continue to provide grant opportunities for projects benefiting fish and water quality.						
	Perform outreach, technical assistance, cost sharing to small farms						
	Circulate 1,000 newsletters annually to small farms across District service area in the Snoqualmie Watershed with at least one TMDL-related message every other issue.						
	Promote riparian planting projects on small farms and other properties with a goal of planting 1 mile per year						
	Include riparian planting needs in all farm plans along state surface waters.						
	Provide beaver management services to small farms						
Snohomish Conservation District	Perform outreach, technical assistance, cost sharing to small farms						
	Circulate 200 newsletters annually to small farms across District service area in the Snoqualmie Watershed with at least one TMDL-related message every other issue.						
	Include riparian planting needs in all farm plans along state surface waters.						
	Promote riparian planting projects on small farms and other properties with a goal of planting 0.25 mile per year						
	Complete design and move to implementation of Peoples Creek Levee setback/riparian restoration project.						
School Districts	Educate K-12 students on temperature pollution problems and solutions. Engage students in planting projects.						
	Implement Low Impact Development strategies as part of the LEED new development standards or in retrofit/upgrade projects.						
	Plant riparian vegetation on school properties as needed.						
Drainage District #7	Participate in floodplain restoration activities including but not limited to Waterwheel Creek/Lateral A projects.						
	Encourage landowners to participate in riparian planting projects						
Citizens, Local Businesses, Local Organizations							
Mountains to Sound Greenway Trust	Continue work to identify and eradicate riparian knotweed infestations. Follow-up all projects with riparian plantings using trees that provide the maximum possible shade to the affected waterbody.						
	Continue to work with the WADNR and USFS on road decommissioning issues.						
Stewardship Partners	Work with local landowners to plant 1 mile of riparian habitat annually.						
	Pilot the “Corporate-sponsored Buffer Enhancement Program”						

Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
	Work with local governments to develop implement Low Impact Development retrofit strategies that will augment local groundwater inputs to Snoqualmie waters.						
	Pursue riparian plantings at the Keller Dairy along both mainstem and Patterson Creek riparian areas.						
	Complete design and move to implementation of Peoples Creek Levee setback/riparian restoration project.						
	Complete the Cherry Valley Dairy Stream Enhancement project (1 acre riparian)						
	Complete riparian restoration on Harris Creek farmlands (5.3 acres)						
Stilly-Snohomish Fisheries Task Force	Work with local landowners to plant 1 mile of riparian habitat annually.						
	Include information on thermal pollution in K-12 education program						
	Complete riparian restoration at the Stillwater Floodplain Restoration site and perform maintenance as needed.						
	Continue the REYS educational program within the Snoqualmie watershed integrating information on the importance of shading and water temperatures to fish and farmers.						
Wild Fish Conservancy	Perform riparian restoration and LWD at the Stillwater Floodplain restoration site						
	Complete and maintain 4 acres of riparian restoration on the North Fork of Cherry Creek						
	Complete restoration of the lower Cherry Creek Floodplain restoration project						
	Pursue improved correct water typing in the Snoqualmie watershed in order to ensure proper shading of flowing waters.						
Partnership for a Rural King County	Develop Stewardship in action (SIA) volunteer program to perform citizen outreach and coordination of stewardship activities in areas with known temperature and other water quality impairments. Complete work in the Patterson and Raging River watersheds then consider other areas where current programs or activities are inadequate.						
Local Businesses, (as needed)	Plant riparian areas and provide complete shade to streams to the extent feasible.						
	Implement Low Impact Development strategies in new development, redevelopment or retrofit projects. Reduce existing or new stormwater volumes						
Citizens	Plant riparian areas and provide complete shade to streams to the extent feasible.						
	Reduce stormwater volumes from private property as appropriate (soil augmentation, rain gardens, absorption swales						
	Educate neighbors and participate in local planting events.						

Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
County Government							
Snohomish County	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and consider high water temperature as a fisheries impairment as part of salmon recovery responsibilities. Prioritize riparian planting priorities in conjunction with chinook salmon recovery work.						
	Continue to provide Basin Steward support to the lower Snoqualmie watershed.						
	Provide web-based water quality information (monitoring data, volunteer and education opportunities, etc…).						
	Meet twice per year with Snohomish Conservation District to review farm plans and coordinate activities in the Snoqualmie River watershed.						
	Enforce Critical Areas and Water Quality Ordinances						
	Promote LID/stormwater infiltration in private development/redevelopment, retrofit projects.						
	Protect groundwater resources via planning and permiting processes						
	Coordinate the long-term stewardship of restored project sites (in partnership with King County, Tulalip Tribes, and other basin partners).						
King County	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Provide meaningful incentives and support to encourage riparian planting on agricultural lands along the mainstem Snoqualmie and all applicable tributaries. Encourage use of other riparian incentive programs, such as CREP, where appropriate.						
	Evaluate and consider high water temperature as a fisheries impairment as part of salmon recovery responsibilities. Prioritize riparian planting priorities in conjunction with chinook salmon recovery work.						
	Continue to work with US Army Corps of Engineers to secure a variance to national levee vegetation management standards to allow vegetation of all sizes on levees where ever deemed safe and appropriate by County engineers.						
	Continue to protect critical riparian areas through acquisition, regulations, incentives, and development right purchases.						
	Continue to pursue levee removal and setback projects that provide benefits to public safety and also enhance hyporheic exchange in the floodplain and provide opportunities for riparian restoration.						
	Utilize existing incentive programs (like PBRS) to target opportunities for habitat protection in riparian areas.						

Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
	Continue to provide Basin Steward support to the lower Snoqualmie watershed.						
	Provide web-based water quality information (monitoring data, volunteer and education opportunities, etc…).						
	Enforce Critical Areas, Livestock, and Water Quality Ordinances						
	Promote LID/stormwater infiltration in private development/redevelopment, retrofit projects.						
	Continue knotweed removal efforts throughout the watershed combined with replanting with trees to maximize shade on adjacent waterbodies.						
	Evaluate all opportunities for improving surface water temperatures as part of the Snoqualmie at Fall City Reach Project (improved groundwater to surface water inputs, off-stream cool water refugia)						
	Complete riparian plantings at McElhoe-Pearson Levee setback project and characterize water temperatures periodically.						
	Coordinate the long-term stewardship of restored project sites (in partnership with Snohomish County, Tulalip Tribes, and other basin partners)						
	Operate the Carnation WWTP according to NPDES permit conditions.						
	Perform continuous monitoring of temperature periodically at Snoqualmie monitoring sites. Coordinate with Ecology and USGS as needed.						
	Evaluate levee stabilization and levee setback designs that will contribute to lower water temperatures through the creation of fish refugia during periods of high water temperatures.						
City Government							
City of North Bend	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and prioritize riparian planting priorities in conjunction with salmon recovery work and public land enhancement projects						
	Enforce critical areas ordinances						
	Public Education and Outreach on the importance of protecting and restoring riparian vegetation						
	Promote LID/stormwater infiltration in private development/redevelopment projects						
	Operate the North Bend WWTP according to NPDES permit conditions.						
City of Snoqualmie	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and prioritize riparian planting priorities in conjunction with salmon recovery work and public land enhancement projects						

Entity	Action	Year					
		2011	2012	2013	2014	2015	2016
	Enforcement of critical areas ordinances						
	Public Education and Outreach on the importance of protecting and restoring riparian vegetation						
	Promote LID/stormwater infiltration in private development/redevelopment projects						
	Operate the Snoqualmie WWTP according to NPDES permit conditions.						
City of Carnation	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and prioritize riparian planting priorities in conjunction with salmon recovery work and public land enhancement projects						
	Enforcement of critical areas ordinances						
	Public Education and Outreach on the importance of protecting and restoring riparian vegetation						
	Promote LID/stormwater infiltration in private development/redevelopment projects						
City of Duvall	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and prioritize riparian planting priorities in conjunction with salmon recovery work and public land enhancement projects						
	Enforcement of critical areas ordinances						
	Complete riparian restoration at Coe-Clemmns Creek.						
	Public Education and Outreach on the importance of protecting and restoring riparian vegetation						
	Duvall WWTP according to NPDES permit conditions.						
City of Sammamish	Promote LID practices in new development, redevelopment, and stormwater retrofit work						
	Evaluate and prioritize riparian planting priorities in conjunction with salmon recovery work and public land enhancement projects						
	Enforcement of critical areas ordinances						
	Public Education and Outreach on the importance of protecting and restoring riparian vegetation						

Appendix J. Response to public comments

The following summarized comments were received during the public comment period for the Snoqualmie River Temperature TMDL Water Quality Improvement Report and Implementation Plan. Comments regarding factual inaccuracies, improved wording, or those that clarify policy positions by other government agencies have been directly incorporated into the text of this report. All other comments are summarized below. Some comments have been combined in order to avoid redundant responses to similar or related comments.

1. Comment: The city of Duvall predicts that stormwater discharges from our ponds and outfalls may exceed state standards, but not a WLA based upon existing receiving water conditions. The city requests that the stormwater WLA be revised as follows:

> "Discharges permitted under Ecology's stormwater permit programs must meet the following temperature criteria and comply with other state water quality standards as indicated in their permits. The following criteria express the temperature WLA for all stormwater permittees.
>
> - When a water body's temperature is warmer than state criteria due to natural conditions, the cumulative stormwater discharges from all permitted sources may not cause the water body's existing 7DADMax receiving water temperature to increase more than 0.3°C (0.54°F)."

Response: *Ecology has modified the stormwater WLA to reflect several changes to the proposed WLAs for permitted stormwater discharges. See the revised text under Stormwater Wasteload Allocations. At times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times. The cummulative impact of stormwater discharges is limited to 0.2°C with the remaining 0.1°C assigned to nonpoint stormwater impacts and a margin of safety.*

2. Comment: In the first bullet, and for the remainder of the section on WLAs, Ecology should clarify whether municipal stormwater permittees are allowed mixing zones for discharges from their drainage systems.

Response: *Due to the large number of municipal stormwater discharge points, Ecology determined that it is impractical to address stormwater discharge points on an individual basis in NPDES permits. Ecology's assumption is that most, if not all, stormwater pollution will be controlled over time as permit holders implement the wide range of pollution prevention and treatment strategies specified in their permits. Should an individual outfall, or series of outfalls, be suspected of causing a localized exceedance of state water quality standards, the outfall(s), can be evaluated for application of a mixing zone as specified in WAC 173-201A-400. When Ecology determines there is sufficient evidence to trigger a mixing zone evaluation, permittees will be required to document compliance with criteria in WAC 173-201A-400(1) through (9).*

Where those criteria cannot be met, permittees can still be granted an exemption to those criteria as specified in the following (see WAC 173-201A-400(10)):

(i) All appropriate best management practices established for storm water pollutant control have been applied to the discharge.

(ii) The proposed mixing zone shall not have a reasonable potential to result in a loss of sensitive or important habitat, substantially interfere with the existing or characteristic uses of the water body, result in damage to the ecosystem, or adversely affect public health as determined by the department.

(iii) The proposed mixing zone shall not create a barrier to the migration or translocation of indigenous organisms to a degree that has the potential to cause damage to the ecosystem.

3. Comment: The report makes recommendations based not on averages over the whole year, but concentrates reporting in the driest part of the year with the least amount of river flow. There are some years, 2003 and 2004, which testing extented to February, but in other cases the reports are limited to two week observations in August. In addition there are no considerations given to the average flow over the last 20 years, which should be taken into account, because some years are obviously drier than other years. In addition the previous year total accumulated snowpack has a distinct impact on the river flow in August. There is also a tendency to base future recommendations on the unproven fact of global warming. The question here is: can you scientifically base recommendations for the next 20 years on a limited sampling of the past 20 years with an assumption of global warming? Here is where the following statute should apply:

> "It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria."

Response: *Ecology's study shows that under both present conditions and improved conditions, the mainstem river will not achieve compliance with the assigned criteria established in state regulation. Because the Snoqualmie River cannot meet the numeric standard during the warmest times of the year, the maximum amount of restoration is necessary. Thus, under those periods of extreme thermal stress, following the implementation of the corrective actions identified by the TMDL, the modeled values represent the best possible approximation of natural conditions.*

Some readers may have been confused by our use of the 7Q10 flows. Our guidance requires us to set load allocations so that the standards are not exceeded more often than one time in every ten years. The 7Q10 flow is the lowest flow expected to occur for seven continuous days, which is one time every ten years. Federal law requires that we evaluate water quality during the critical condition—one of the critical conditions is very low flows. For temperature, this critical condition occurs during the summer. Ecology used 47 years of stream flow data (1961-2008) to determine the flow condition to use in this analysis (see the section on low-flow statistics).

Ecology did not analyze the effect of global warming, or base future recommendations on the assumption of global warming. The global warming section is included for information only. The purpose of mentioning global warming is to state that if warming does occur, stream temperatures are expected to rise further. Needed on-the-ground actions have been made regardless of any global warming effects. Climate change text in the "Other Actions to Protect and Reduce Water Temperatures" section specifically states that it is beyond the scope of this document to examine any current effects or to predict future challenges due to climate change

4. Comment: The report's findings on ammonia concentrations and bacteria counts are based upon assumptions for which there is no scientific basis provided.

Response: *The Snoqualmie Temperature TMDL did not discuss ammonia concentrations and did not discuss bacteria counts.*

5. Comment: Evapotranspiration of adding 900 acres of trees will have an impact. What effect does that have on the temperature of the remaining water? If the tributaries dry up there would be no benefit of shading the non existing water flow!

Response: *The ability of trees and other vegetation to affect stream flows is not incorporated into Ecology's model, or other commonly used water temperature models. The amount of riparian vegetation called for in this TMDL is a small fraction of the total treed vegetation found historically in the watershed, which has been greatly reduced by agriculture and other types of development. Ecology did not find any mention in historical records that the Snoqualmie River experienced periods of dryness during summer months when many more trees were present. In response to the comment above, Ecology performed a short review of scientific literature and considered several other factors to help shed more light on the question.*

Much of a tree's biomass is found in the water conducting elements (xylem) of a tree, which are essentially dead cells. Water is drawn up through the xylem to support new tree growth around the tree's perimeter and the leaves. When considering differences in water usage, the actual leaf area is a likely significant factor, along with the availability of water, environmental conditions (air temperatures, solar radiation, and humidity), the sophistication of the plant's photosynthetic processes and water conducting elements, and the height of the plant (ability to lift water and support growth). Many different tree and shrub species beyond cottonwoods are native to the Snoqualmie Watershed and any thorough analysis of water usage should consider all those tree species.

The most recent research we found that discussed water use by trees compared evapotranspiration rates of three different trees to several crop species. Kabenge (2011) compared transpiration of common reed, cottonwood, and peach-leaf willow to that of clipped grass and alfalfa and found the trees to have lower water use. After assigning reference values of 1.00 to the grass crops, the seasonal mean reference transpiration coefficients were 0.67, 0.59, and 0.73 for common reed, cottonwood and peach-leaf willow, respectively, in the case of clipped grass and 0.57, 0.51, and 0.62, for common reed, cottonwood, and peach-leaf willow, respectively, when compared to alfalfa. Water uptake by plants was higher during spring flood flows and lower during the summer. Cottonwood tree heights considered in this work appear to *be about 40 feet high. Similarly, research reported by Allen et al. 1998 shows small fruit trees to use less water than grasses and cultivated vegetable crops to use more water.*

Given these relative water usage values, combined with the relatively low number of trees needed to shade Snoqualmie waters as compared to historical tree numbers, Ecology does not believe there is a reasonable potential for needed shade trees to create a significant stress on instream flow levels in the Snoqualmie River watershed.

Many factors need to be considered when evaluating the effect of vegetation on stream temperatures. The comment regarding tree uptake of water did not consider the reduction of evaporation from both water surfaces and unshaded ground when shade is provided. Reductions in evaporation were considered in Ecology's model along with the overall cooling effect provided by shading. Mature riparian vegetation can also have other beneficial effects beyond reducing stream temperatures. In work conducted in Oregon, an Independent Multidiciplinary Science Team (IMST) report evaluated riparian vegetation influences on streamflow and surface/subsurface water interactions. Among their findings, they determined that during floods, riparian areas temporarily store excess water, which delays and attenuates the flood peak in downstream areas (IMST 2004). In the Snoqualmie River watershed, mature riparian buffers should also act as a flood fence to improve the capture of woody debris that might otherwise be deposited on farmed lands during high water events.

6. Comment: <u>There is no recommendation for sediment management. Deeper, cooler waters should be recommended to help fish survive and sediment management should be the first doable recommendation.</u>

Response: *Ecology recommends both preventative and corrective sediment management actions. Preventive management through erosion control is needed as part of forestry management, construction site runoff, and post-construction stormwater runoff management. Once sediments have been deposited in the river (corrective action), natural processes are the preferred alternative for controlling sediment levels. The strategic placement of large wood to form scour pools and improve groundwater inputs is also discussed.*

Dredging of gravels and instream sediments is not encouraged by this TMDL. Gravel movement is essential to creating natural fish habitat and can in some cases lower stream temperatures. For example, high gravel levels, such as those found at instream bars and at the confluence of the Tolt River may be creating subsurface pathways for stream waters, which is a water cooling process. Thermal infrared images often show cooler water upwelling at the downstream end of those gravel bars. This cooled water would provide both a warm weather refuge area and high quality Chinook salmon spawning habitat. Unlike dredging to create cool water pools, the strategic placement of LWD can perform that function on an ongoing basis, presumably at a lower long-term cost with the added benefit of providing other types of fish habitat.

7. Comment: <u>The TMDL plan creates solutions and recommendations contrary to the study findings. The report finds that when water flows faster, less solar energy will be absorbed. However there are recommendations to create more woody debris, which in turn slow down the water. Instead there should be a plan to remove large gravel bars which would create faster and cooler water.</u>

Response: *Removal of wood and gravel has not been shown to speed up streamflow or cool stream temperatures. The Snoqualmie Temperature TMDL states that if a stream reach has no shade that water spending less time in that reach will heat up less. However if the stream reach is shaded then the heat input will be greatly reduced. Please see the response regarding gravel bars and use of woody debris in the previous comment response. Removal of large gravel bars would only be a temporary solution, as they would redevelop in the same locations due to geomorphic conditions.*

8. Comment: Other recommendations are made, contrary to the report findings, that shallow water heats up and should be avoided. The creation of more wetlands are recommended, which by definition are shallow waters heating up groundwater and evaporating great quantities of water and emitting large quantities of air pollutants as methane. It is true that wetland functions do lower fecal bacterial concentrations and nitrogen levels, but it also generates ammonium NH4 and nitrates. The report fails to discuss the impacts of wetlands on water quality, that wetlands increase the water temperature and are polluting the water and the air, specifically adding Ammonium and Nitrates to groundwater or release such to rivers. The air pollution is especially important in urban settings where higher methane concentration contribute heavily to air pollution.

Response: *While water can warm in wetland environments, wetlands provide a net benefit of infiltrating water for cooler streamflow downstream. This TMDL is not intended to provide detail on pollution issues that do not relate to water temperature management such as pollution from various nitrogenous compounds or fecal coliform bacteria. Ecology does not consider nutrient loadings from wetlands to be a source of pollution; rather, they are part of the natural nutrient cycle. Wetlands do not always discharge directly to other surface waters. Instead, they recharge groundwater, which is the primary source of cool water for the Snoqualmie River and its tributary streams throughout summer months.*

9. Comment: There is a scientific lack of understanding what trees do at the later part of their growing season, especially when high temperatures are forcing the trees to survive by evaporating large quantities of water through their leaves. Trees actually will shut down during certain periods of high temperatures and are taking a siesta by wilting leaves. In addition there is very little uptake of nitrogen in mature trees at that time of the year, because it would cause damage or death to plants. What we do know is the fact that trees in August are starting to withdraw energy from the leaves to store them in other parts of the tree. Actually the tree depends on bacterial action to break down the nitrates from Ammonium and it is unclear how this bacterial action is impacted under the dry August conditions.

Response: *This TMDL is not intended to provide detail on pollution issues that do not relate to water temperature management. To the extent that the evaporation of water from leaves might be decreasing with increased temperatures due to stomate closures, this process would reduce any possible pressure on groundwater supplies during the critical periods where thermal loading to surface waters are highest. The overall recommendations are simply to put back the vegetative species and densities that historically occurred to the maximum level that is compatible with the adjacent land use.*

10. Comment: The report seems to suggest that large tracts of land will have to be dedicated to the good of the public. The report fails to indicate any specific nexus between the alleged water pollution (temperature, bacterial count, and ammonia) and the actions of these property owners which may be required to mitigate for the good of the public, without compensation. It is fair to set scientifically defensible standards and ask mitigation from those who violate these standards, however it is a clear "taking" of property, when requiring to set aside 35 feet on each side of any drainage channel for the good of the public, in violation of the 5th Amendment of the United States Constitution and its due process clause in the 14th Amendment.

Response: *Ecology's water quality standards are based upon scientifically defensible standards and our field studies and modeling efforts show a clear link between the lack of riparian vegetation and thermal loadings and high water temperatures in the Snoqualmie River. The purpose of the Snoqualmie Temperature TMDL is to document current condition water temperatures and provide solutions for improving temperatures where they exceed state standards. The TMDL does not create a "taking" of private property and does not constitute a legal requirement for private property owners. However, it does state the actions that must be taken in order to lower water temperatures.*

11. Comment: Is planting trees to grow 150'tall in a 150 foot buffer on a farm or private property a regulatory requirement or is it voluntary?

Response: *A TMDL is a document created to inform the public about current water quality problems and to provide solutions for improving those problems. Ecology initially intends to use approaches that cultivate cooperation of riparian property owners such as technical assistance, grant funding, and our ability to refer property owners to programs such as CREP, which provides rental payments for acreage placed in forested buffers along streams. If TMDL implementation progress falls behind schedule or effect however, Ecology will assess its options at that time. This TMDL constitutes "best available science" regarding the problems and solutions related to high water temperatures in the watershed. It should be consulted by both government agencies and citizens during the development or revision of regulations that affect the protection and improvement of water quality in the Snoqualmie Watershed.*

12. Comment: Is there compensation for loss of land use or revenue when riparian trees are planted?

Response: *The Snoqualmie Temperature TMDL contains a section on Funding Opportunities. Most funds now available help landowners plant and maintain riparian vegetation. One program called the "Conservation Reserve Enhancement Program (CREP) provides annual payments to landowners. King County has two programs that provide compensation to landowners including the Farmland Preservation Program and the Current Use Taxation Program—each of these programs is discussed in more detail in the report. This TMDL recommends continued dialogue between riparian landowners, government agencies, and other groups to discuss gaps or evolving needs regarding loss of revenue related to riparian plantings to reduce stream temperatures.*

13. Comment: Many areas already have trees. Will landowners get credit for continuing to let them grow with landowner's "right" to manage and use them (e.g., dangerous trees, firewood, cleanup, etc…)?

Response: *This TMDL encourages landowners to maintain riparian areas to provide good shade to streams. Management of riparian areas is primarily a local government responsibility regulated through critical areas ordinances or regulations.*

14. Comment: What types of trees are needed? Cottonwoods use a lot of water, alder's life span is 40-50 years, and hemlock are shallow rooted.

Response: *Ecology recommends choosing trees based on their ability to maximize shade to the adjacent water bodies. Over time, trees with a mature height of 150' are needed along the mainstem river. A combination of successional and climax vegetation species can make sense on many sites and might include a mix of various tall-growing conifers, alders, maples, and cottonwoods. Smaller trees can be appropriate for tributary mainstems and their smaller feeder streams in agricultural areas. In all cases, Ecology recommends landowners consult their local conservation district or salmon-recovery task force to choose trees and get assistance in tree planting and maintenance.*

15. Comment: Dredging should get more consideration to improve stream depth and flow.

Response: *Please see comment and response number six above.*

16. Comment: No information is provided on the geological history of the Snoqualmie Valley and how it relates to present conditions (elevation, material flow, and soils).

Response: *Ecology has considered the geologic history of the Snoqualmie Valley in decisions on tree species/heights in its modeling efforts (see the section named "Vegetation" on pg 28 and the subsection "Potential near-stream vegetation cover and effective shade" beginning on pg 78). Ecology modeled watershed characteristics that are achievable. Ecology did not model "pre-European development" conditions since that would involve the elimination of most existing land uses and would serve no practical value to watershed residents working to find the appropriate balance between the needs of competing societal needs.*

17. Comment: The timeline for public comment is short. Most affected landowners may not be aware of this report and the public comment period.

Response: *Ecology regrets that our four-week public comment period may be inadequate in some cases. Should any significant inaccuracies be detected in our field studies or modeling efforts after the close of the public comment period, we will evaluate and correct those deficiencies as needed.*

18. Comment: How does the newly legislated "watershed" authority relate to this TMDL? How does the TMDL relate to the use of "eminent domain?"

Response: *Ecology assumes that this comment refers to the alternate process for addressing Growth Management Act requirements set forth in ESHB 1886. As stated on page 157 of this report, King and Snohomish counties should incorporate the findings of this TMDL into the selection process for priority watersheds when implementing ESHB 1886. Workgroups formed under ESHB 1886 should also incorporate the findings of this TMDL when developing watershed workplans. Ecology does not believe there is a relation between the TMDL and the use of eminent domain.*

19. Comment: The actions called for in the report will result in a loss of farmland. The Soverenty of any nation depends on its food supply. Today we import 50% of our food.

Response: *Our state temperature standards are designed to protect fish, which are also an important food supply to the nation as well as an important natural resource legacy. Ecology recognizes that some loss of productive farmland will occur as a result of planting large riparian areas adjacent to the mainstem river. Ecology believes that plantings that provide complete shade to tributary streams and connected agricultural watercourses can be performed with little to no impact to surrounding agriculture. Properly planted agricultural watercourses can actually reduce maintenance costs to farmers and if properly designed may even enhance farm productivity.*

20. Comment: No people more than the "resource community" (agriculture, forestry, mining in rural areas) have "given" to and for the endangered species act. No society survives without a balance of resources.

Response: *Although the actions prescribed in this TMDL will assist in the recovery of endangered species, its primary purpose is to protect water quality for all cold-water species in the Snoqualmie River watershed, which are also a public resource. Ecology encourages continued dialogue with natural resource management agencies and others trying to find the correct balance between fisheries needs and those of the agricultural and forestry communities.*

21. Comment: Ecology has stated that "Wasteload allocations (WLAs) are necessary for permitted stormwater facilities if they are found to be a source of pollutant loading to the stream during periods where receiving water temperatures in the vicinity of the discharge are impaired." To be consistent with regulations and guidelines used to establish TMDLs, the WSDOT feels it is Ecology's responsibility to characterize the sources of pollution and assign numeric WLAs only when there is credible, site specific, data or information indicating WSDOT facilities are a significant source or contributor of the pollutant of concern. In the absences of site specific stormwater outfall data, a numeric WLA assigned to WSDOT is presumptuous and without just cause. Additionally, based on the fourth sentence in the paragraph "…stormwater does not contribute to temperature impairment in the Snoqualmie Watershed," a WLA is not warranted for permitted stormwater dischargers because stormwater has not been "found to be a source of pollutant loading to the stream." However, in the event new data or other actionable information should later reveal that WSDOT is a significant source or contributor, it would be appropriate to assign WSDOT actions, or a numeric WLA if supported by site-specific, scientifically credible data, under the TMDL via the adaptive management process.

Response: *Due to the large number of municipal stormwater discharge points, Ecology determined that it is impractical to address stormwater discharge points on an individual (site-specific) basis in most TMDLs and the municipal NPDES general permits.*

Federal regulations require numerical descriptions of thermal pollution impairments in TMDLs (CFR 130.7 (c)). Ecology must also evaluate and apply water-quality-based limitations (or WLAs) where they are necessary to protect beneficial uses (CFR 122.44(d)). Unlike, TMDLs, which require numerical descriptions of thermal pollution, water-quality-based effluent limits for NPDES-regulated stormwater discharges (in this case WLAs) may be expressed in the form of BMPs rather than numerical effluent limits (33 U.S.C. Section 1342(p)(3)(B)(iii), 40 CFR 122.44(k)(2)&(3)). Ecology chose this option to express effluent limitations in stormwater permits for small MS4s. This means that WLAs are expressed as BMPs in Washington State stormwater permits.

Point-source stormwater discharges that do not have a WLA for thermal loadings (regardless of the magnitude of that loading) are interpreted as having a WLA of zero. From a technical standpoint, that would not allow any thermal loading from that point source during critical periods. However minimal that discharge might be, it could be considered a contributing factor to existing instream impairment. For that reason, Ecology believes a WLA must be assigned to all point sources discharging during critical periods.

Ecology's assumption is that most, if not all, stormwater pollution will be controlled over time as permit holders implement the wide range of pollution prevention and treatment strategies specified in their permits. At this time, Ecology anticipates no additional TMDL-related conditions are needed in stormwater permits in the Snoqualmie River Watershed. This TMDL does not contain additional actions for municipal stormwater permittees.

Based on the comment above and others regarding stormwater WLAs, Ecology has modified those WLAs and the associated text describing stormwater effects.

22. Comment: WSDOT suggests that the numeric WLA should be deleted. Any WLA assigned should be in the form of actions since site-specific data is not available to assign numeric WLAs.

Response: *Ecology is required by the U.S.E.P.A. to express WLAs in numeric form in a TMDL. However, water-quality-based effluent limits for NPDES-regulated stormwater discharges may be expressed in permits the form of BMPs rather than numerical effluent limits (33 U.S.C. Section 1342(p)(3)(B)(iii), 40 CFR 122.44(k)(2)&(3)). Ecology chose this option to express effluent limitations in stormwater permits for MS4s. This means that WLAs are expressed as BMPs in municipal stormwater permits. Ecology anticipates no new TMDL-required conditions will be added to municipal stormwater permits as a result of this TMDL and compliance with the basic permit provisions will constitute compliance with the TMDL.*

23. Comment: WSDOT has not performed a QA/QC check on the water quality or flow data presented in this report, nor have we re-computed the math behind derived values, and reserves the right to make corrections if errors are found at a later date.

Response: *Ecology prepares quality assurance project plans (QAPPs) for all of its TMDLs and documents its findings in the final TMDL submitted to EPA. Water Quality Policy 1-25 describes the TMDL dispute resolution policy, which should begin no later than 30 days from the time the final TMDL is made available to the public (http://www.ecy.wa.gov/programs/wq/tmdl/documents/1-25Pol-TMDLDispResolrev.pdf) Should WSDOT review the study procedures or findings in the future beyond the dispute resolution period set forth in Policy 1-25 and find errors that it believes need to be corrected, Ecology will review, comment, and make corrections to the TMDL (if needed) as resources allow.*

24. Comment: We are somewhat uncomfortable with the largely hands-off approach in the TMDL toward forested lands in the upper watershed. As the report rightly points out, the majority of the basin is forested, though in various stages of succession. Of course the forested condition is far better than any alternative when it comes to temperature, and our intent is not to deflect attention away from other parts of the watershed where riparian conditions are in many cases truly poor. But, we do not feel confident that all of the effects of a century and a half of forestry are properly acknowledged in the report, such as the temperature effects of accelerated rates of debris flows in tributary streams, and the relative lack of large wood in both tributaries and mainstem areas which are known to have profound effects on hydraulic conditions and channel form. The loss of forested wetlands is also a factor that has been largely overlooked in the report.

As you note in the report, both Federal and State forest management plans are assumed to provide protection for water quality, but clearly the standards are not being met. We ask that the Department engage meaningfully with forest managers to discuss opportunities for accelerating the healing process for Snoqualmie watershed forestlands, specifically to target temperature impairment.

Response: *The Snoqualmie Temperature TMDL, and other temperature TMDLs that include lands overseen by state forest practices regulations and federal authorities, rely upon those other regulatory mechanisms for the majority of the watershed restoration and protection needed in those areas. Ecology believes that our oversight responsibilities related to forestry regulation are generally reasonable and sufficient to protect water quality in areas where forestry activities occur. Ecology did not examine the effects of either historical forestry or agricultural practices because our goal was to focus on practical actions that can be taken given the accepted land use practices now in place.*

The commenter correctly notes that water quality standards are not being consistently met in waters leaving forestry management areas. As this TMDL has shown, some water bodies cannot be expected to meet state standards even after implementation of all reasonable corrective actions. Ecology is relying on established regulatory programs to provide Clean Water Act assurances. However, TMDL staffs are not precluded from working with state and federal agencies to gain information and watershed improvements in forestry areas. It was our intention to begin that dialogue and future avenues of communication by inviting key agencies to the TMDL advisory group. Ecology staffs are eager to participate in future discussions regarding opportunities for improving water temperatures in forestry management areas.

Ecology acknowledges that additional study of watershed processes, whether historical or achievable in the future, could provide valuable information to support water quality improvement efforts. We are however limited in the scope of work we can perform for every TMDL. For that reason, we strongly encourage and support future studies that consider these questions in relation to implementation activities. Ecology's Centennial Grant Program is an excellent source of funds for this type of work.

25. Comment: In several instances throughout the document, the USFS boundary is described as the "headwaters". This is an incorrect characterization, even if it is the study boundary. Middle Fork continues for more than 25 miles with countless tributaries upstream of this location. While forest practices have certainly improved in recent years, we strongly urge the Department to perform a rigorous evaluation of Clean Water Act Assurances and other mechanisms intended to ensure that forest practices protect water quality.

Response: *The Qual2kw modeling software used to assess stream temperature uses the name "headwaters" for the upstream end of the analysis area. This location is also the upstream end of our study area. You are correct that the watershed above this point within the National Forest is large and includes the actual headwaters to Snoqualmie River tributaries. We do need to use the term headwaters when documenting model input parameters for the beginning point of the model. We have modified text in the report in response to this comment to improve clarity regarding the use of the word headwaters.*

26. Comment: The report describes some of the mechanisms that relate forest harvest practices to stream temperature. An important, omitted mechanism is the effect of debris flows in steep tributary streams as a result of forest practices. Several studies have shown that tributary streams that have experienced recent debris flows (within a decade) have significantly higher maximum and average water temperatures, largely due to loss of riparian cover. For example, Cover et al. (2010) found that maximum temperatures were 4-5^{o}C higher in recent debris flow streams than in streams that had not experienced a recent debris flow. Also, see Johnson and Jones (2000) who found increases in maximum stream temperatures of up to 7^{o}C in a small stream in the Oregon Cascades in the years immediately following a debris flow. To the extent that debris flows are more frequent as a result of forestry, dozens or hundreds of streams in the basin may be contributing water to the Snoqualmie that is substantially warmer than its natural condition. Among other factors, the lack of large wood in tributary channels exacerbates the frequency and severity of debris flow events. Absent direct restoration of forested tributary streams, it will take many decades for large wood loading to approach natural levels even in well managed forest settings.

Response: *Due to the extensive resources needed to perform temperature TMDLs, our study focused primarily on the mainstem Snoqualmie River. Tributaries like those noted in the comment above received less in-depth analysis and for modeling purposes, they were evaluated as thermal inputs. Additional study of the watershed processes discussed in the comment should support this TMDL's goal of reducing water temperatures, especially on a localized basis.*

As noted in this report, Ecology conditionally extended the forest practices Clean Water Act assurances to stimulate needed improvements. Readers should review the results of our 2009

Forest Practices Act Assurances Review of Washington's Forest Practices Program for a more detailed discussion of our findings and expectations for progress in forestry management areas (http://www.ecy.wa.gov/programs/wq/nonpoint/ForestRules.html). The study of mass wasting events is among the list of key research milestones that must be accomplished to support the continuation of Clean Water Act assurances (see Table 1 in the 2009 review).

We encourage and support watershed stakeholders to track and participate in those efforts. Ecology supports future research and implementation of activities that will improve water temperatures by improving stream processes (increasing large wood content, improving hyporheic exchange, increasing/modifying groundwater volumes, input locations, and release timing).

27. Comment: The report appropriately highlights the role of hyporheic exchange and groundwater inputs as important factors to the river's thermal regime. The specific mechanisms that drive hyporheic exchange vary with channel type and local channel morphology. The discussion on the thermal role of channel morphology (p.24) focuses almost exclusively on the widening of channels due to disturbances. However, other factors, such as the loss of instream complexity (large wood jams, boulders, etc), also retards hyporheic exchange by reducing the vertical head gradient that is a major factor in alluvial streams. See Buffington and Tonina (2009) for a review of mechanisms and how they may inform strategies in the non-forested and forested portions of the basin. Similarly, p. 87 describes the use of default values for sediment thermal conductivity and other parameters, whereas the literature suggests that the hyporheic characteristics of the river may differ substantially by reach type.

Response: *We reviewed the discussion in Buffington and Tonina about hyporheic exchange varying with channel type. However, the modeled portion of the Snoqualmie Middle Fork and mainstem are primarily pool-riffle channel type, with potentially a few segments in the plane bed category. Channel slope is a primary variable used to categorize channel type and Figure 19 shows that the slope of the modeled reaches ranges from 0 to about 1.5% with the exception of Snoqualmie Falls. In a river system with less flow and thus a larger percentage of the water in contact with and in exchange with the hyporheic zone, using different rates would be appropriate. Modeling theory tells us to use a simpler model over a complex one if that will adequately evaluate the system. If this was a smaller stream, for example 10 cfs, Ecology would in fact likely vary the sediment properties by substrate type or size. Because this is a much larger system, with a smaller percentage of water moving though the hyporheic area, sufficient calibration was reached using a constant set of hyporheic properties.*

28. Comment: Regarding water rights (p.36), while it may be true that permitted surface water withdrawals are not substantial in the Snoqualmie mainstem or Middle Fork, the values shown in Table 10 are somehow very incorrect. Our analysis of the same database shows certificated rights for Irrigation alone in the mainstem Snoqualmie River as over 14 cfs, as compared to 3.43 cfs listed as "consumptive" uses in Table 10. Moreover, many other rights seem to be missing from the table, such as Tokul Creek which has approximately 15 cfs in consumptive rights in addition to 12 cfs for fish propagation.

Response: *The water rights retrieval was done several years ago and the database has been updated since that time. In addition, the name of the database has been updated from WRAT to WRTS. A new retrieved run on 6/27/2011 shows that you are correct, the total certificated rights in the Snoqualmie mainstem has been updated from 3.43 cfs to 15.5 cfs. The change in the Middle Fork is smaller, with a current value of 0.04cfs compared to 0.03 in the report. Because streamflow is measured at all tributary mouths, the water rights reported in Table 10 for the tributaries was for information only and does not affect the water budget. Instead of taking additional resources to verify rights in all of the tributaries, these will be deleted from Table 10.*

29. Comment: The report relies on "Reasonable Assurances" (p.128) that a variety of activities and programs conducted by various basin entities will continue in the future. What does Ecology propose to do if these efforts are reduced as a result of shrinking local budgets? The purpose of this section is unclear, and the descriptions of agency/entity activities are in many cases erroneous and incomplete. For example, the Snoqualmie Watershed Forum does far more than provide funding to other entities. The Forum plays a key role in the coordination of habitat protection and restoration throughout the watershed; assists local governments in the development of environmental policies and regulations; represents local governments in regional forums; facilitates coordination between project sponsors; and a variety of other activities.

Response: *The U.S.E.P.A requires Ecology include a discussion called Reasonable Assurances when a TMDL addresses nonpoint pollution sources. In the event of shrinking local budgets, significant changes in the implementation strategy, or any other observation that additional resources are needed to support riparian restoration and other water quality improvement activities, Ecology will advocate for additional funding as opportunities arise. Ecology did not intend the list of activities in the Reasonable Assurances section to provide complete descriptions of agency/entity activities—more detailed descriptions are provided in the Implementation Plan. Ecology has included some additional text regarding the Snoqualmie Forum activities in the Implementation Plan in response to this comment.*

30. Comment: The description of King County implementation activities and programs is inaccurate and incomplete (beginning p.174). For example, the report describes a Rural Drainage Program that "provides funding for a comprehensive approach to protecting water-related resources…" and then lists a variety of county programs as components of the program. There is no program by that name. The County does maintain a modest Neighborhood Drainage Assistance Program and the Agricultural Drainage Assistance Program which is mentioned in the report, but neither of these match the described program. The report refers to the PBRS and Timberland tax incentive programs which are administered by the Water and Land Resources Division, but fails to mention the much larger current-use taxation programs for agriculture and forestry that are administered by the County Assessor. While the Farmland Preservation Program prevents the conversion of farmland to other uses such as urban development, the program also may restrict the ability to perform restoration actions on enrolled properties. Similarly, while ADAP mitigation plantings may contribute to shading, it is also true that the draining of groundwater during spring and summer months to benefit agriculture may have a negative effect on river temperature by reducing groundwater input later in the summer months.

Response: *Several changes have been made to the report to improve the accuracy of the text regarding King County programs. Because the Agricultural Drainage Assistance Program (ADAP) is in transition, it was not possible to provide more detailed information at this time. Ecology concurs that the draining of groundwater to support agricultural businesses can result in a loss or degradation of fish habitat and noted this briefly under the section on Actions for Agricultural Lands. However, our temperature study only examined groundwater inputs as they relate to gaining and losing reaches in the mainstem. This TMDL supports additional work as part of TMDL implementation to explore how agricultural watercourse maintenance activities affect water temperatures (and associated parameters) and how they can be performed with as little impact as possible.*

31. Comment: The network of continuous temperature monitors should be substantially enhanced within the Snoqualmie watershed by the Department and the USGS. Currently, only the USGS gages on the Tolt River and certain small tributary gages maintained by King County include temperature monitoring. The Three Forks and Mainstem Snoqualmie should be prioritized for temperature instrumentation as soon as possible.

Response: *Ecology will attempt to perform temperature monitoring periodically (once every 3-5 years) at each of the five mainstem locations shown in Figure 75. Ecology encourages King County to include temperature monitoring at its new monitoring locations in the Snoqualmie Watershed.*

32. Comment: The analysis of potential stormwater related temperature impacts on receiving water is founded upon limited data from unverified sources, all within either the City of Duvall or King County. To this end, it is not clear that the waste load allocation assigned to Snohomish County is based upon known and credible data as required by Ecology's credible data policy 1-11. To this end, Snohomish County suggests Ecology re-evaluate the data used and assignment of a waste load allocation.

Response: *Ecology used only data that was consistent with the credible data act. All water quality and weather data analyzed was collected by Ecology according to our Quality Assurance Project Plan. The data from Duvall was weather data collected at Ecology's weather station. No other weather data from unverified sources was used. Federal regulations and guidance state that it is reasonable to express allocations for NPDES-regulated stormwater discharges from multiple point sources as a single categorical wasteload allocation (WLA) when data and information are insufficient to assign each source or outfall individual WLAs (see 40 C.F.R. § 130.2(i)). Stormwater WLAs in this TMDL are cumulative for all permitted stormwater sources*.

33. Comment: Ecology is encouraged to use a reference for the last sentence in the first paragraph which requires that NPDES permitted discharges be provided a wasteload allocation.

Response: *Please see response to comment 21 above*.

34. Comment: Ecology should highlight data gaps that are critical in understanding temperature regulation in the Snoqualmie. In particular, three topics/resource questions could be better covered in this document: Why are temperatures in the upper forested reaches elevated and increase rapidly moving downstream (see Figure 39) and are they providing a heat load burden on the lower watershed? How do forest maturity and wetland complexes influence groundwater hydrology and potentially boost stream and hyporheic flow downstream? How does hyporheic flow influence stream temperatures in the Snoqualmie?

Response: *Ecology received several comments recommending additional analysis of watershed processes that play a role in controlling water temperatures. We believe that our study has covered the major factors affecting mainstem Snoqualmie River temperatures but also acknowledge that there are other areas of study that could contribute to our understanding of temperature regulating processes outside of the key study area. Ecology has tried to identify these processes as they are discussed in the implementation plan to encourage them as part of the implementation of this TMDL. As noted in response to comment #26, we expect our periodic review of the Forest Practices Act implementation to help in this area.*

One reason for the increase in water temperature from the USFS boundary is the natural increase that is seen as elevation changes. Figure 19 shows a very large decrease in elevation from the USFS boundary to Snoqualmie Falls. Our observations of the Upper Middle Form Mainstem (see the "Where do we have opportunities for Improvement?" Section) suggest that the large amount of medium and small sized trees (41%) need more time to grow. The same situation may be occurring in other upper watershed forested areas.

35. Comment: Due to dikes along the Snohomish River, its bed is four feet higher than that of the Snoqualmie, which creates a small dam to Puget Sound. Cleaning out both the Snohomish and Snoqualmie would result in faster flow. The lack of fish is due to improper management of fisheries.

Response: *River dredging is not included as an implementation activity for this TMDL. Please see response to comment #6 above. Dikes along rivers tend to constrain the width of a water body and make the available water flow faster. Increased water velocities reduce the deposition of sediments and spawning gravels and make a waterway deeper than it would be otherwise.*

Ecology acknowledges that the health of a fishery has roots in harvest levels, ocean conditions, and other factors beyond habitat levels in spawning and rearing areas. Regardless of these other factors, water temperatures are higher, and therefore less healthy, than is needed for the cool water species that live in the Snoqualmie River watershed.

36. Comment: Ecology refers to "groundwater-fed streams that often dry up toward the end of the summer." Please explain the definition of groundwater fed stream as used in this context. True groundwater streams are unlikely to go dry. These streams may be streams originating in forested wetlands, which we know have been reduced in number, size, and quantity by forestry practices.

Response: *Groundwater fed springflows tend to diminish as groundwater tables drop during summer. Although it is possible for a groundwater fed stream to go dry, it is also possible that some of the streams going dry may have forested wetlands contributing to their flows. Ecology* *study did not look at stream source waters. We have made changes in the text in response to this comment to improve clarity on this issue.*

38. Comment: How did Ecology determine the “default” temperature of 14°C for diffuse sources? Some may be much cooler, depending on the source.

Response: *Typical temperatures in western Washington for diffuse input of near-surface groundwater generally range from 12°C to 15°C. These values have been collected over time and are a combination of recommendations by Ecology hydrogeologists, well water temperatures, thermistor measurements from piezometer tubes installed in the stream bed, and spring fed tributary temperatures. Our standard procedure is to select an initial temperature in this range and make adjustments to calibrate the model. Just two model parameters are adjusted during calibration, and diffuse temperature is one of these.*

Appendix K. Public Involvement Materials

The following display ad ran in the Snoqualmie Valley Record to announce the public comment period, which ran from May 18th through June 17th. The display ad provided a link to a newly constructed Snoqualmie TMDL webpage, which provided a link to the draft plan and information on the public comment period. The webpage was located at: http://www.ecy.wa.gov/programs/wq/tmdl/SnoqRvrTMDL.html.

Dept. of Ecology Public Meeting & Comment Period – Stream Temperature

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Snoqualmie River Watershed
Temperature Study and Action Plan

The State Department of Ecology would like your comments on a draft document that includes technical information and a plan to address high-temperature problems in the Snoqualmie River and its tributaries.

This report details our study of high water temperatures in the watershed, and the actions needed to lower water temperatures. Our effort is aimed to improve water quality and help prevent potentially lethal stresses to fish or other aquatic animals in these waters. Our goal is to lower temperature levels in these streams so they will not exceed State Water Quality Standards.

We want to know how well the proposed solutions seem to address these problems, and welcome you to share your thoughts with us and your neighbors.

A public meeting will be held May 26 at the Carnation Library, 4804 Tolt Avenue in Carnation, WA 98014.

Open house, presentations, and discussion begin at 6:30 p.m.

- For a *Report* copy after 5/19/11, call the reference desk at libraries in: Carnation, Duvall, Fall City, North Bend, and Snoqualmie; or 425-649-7165.
- To submit written comments (must be received by June 17), go to:

http://www.ecy.wa.gov/programs/wq/tmdl/SnoqRvrTMDL.html

or contact the Ecology Department office c/o Ralph Svrjcek 3190 160th Ave SE, Bellevue WA 98008-5452; or email: rsvr461@ecy.wa.gov

If you have special accommodation needs or require this publication in an alternate format please contact: DouGlas Palenshus at (425) 649-7041 (Voice) or (425) 1-800-833-6388 (TTY).

Ecology also sent an email notification about the opening of the public comment period to the Snoqualmie Watershed Forum News. The Snoqualmie Forum staff forwarded that information to their listserve.

Ecology prepared the focus sheet shown on the following pages, distributed it at several meetings, and made it available at our website.

Watershed Streams Too Warm

Snoqualmie streams need our help. Cool water is important to protect the most sensitive beneficial uses of Snoqualmie waters: salmon and trout spawning, rearing of young, and fish migration. Fortunately, many things we can do to lower temperature also have other benefits, such as reducing erosion, ensuring cleaner water for people and livestock, and supporting wildlife.

Summer water temperatures are too high causing fish to become physically stressed, more susceptible to predators, and more likely to get diseases. Also, warm water doesn't hold as much oxygen as colder water and causes fish to "breathe harder." Temperatures above 23°C (73°F) can be lethal for salmonids.

Federal and state laws require corrective actions to reduce these high water temperatures. More importantly, Washington citizens take seriously our responsibility to protect and restore our waterways now and for those in the future.

What causes high stream temperatures?

Factors that affect stream temperature can occur from both natural and human-causes in the watershed. These include:

- Solar radiation which varies by latitude, time of year, time of day, cloud cover, and how much shade is available to block sunlight which heats both water and air;
- Stream depth, width, flow rate, and overall water volume;
- Availability of cooler groundwater flowing into streams.

Streamside vegetation is the key!

Trees and shrubs create shade (and windbreaks too). Without them, the sun hits and warms the water, and cool forest air (microclimate) near streams disappears.

WHY IT MATTERS

Warm water holds less oxygen and can harm fish and other aquatic creatures. Parts of the Snoqualmie River and its tributaries serve as important migration corridors and spawning and rearing areas for salmon species that require cold waters for optimum health and survival. Additionally, warm water may be a factor in the presence of bacteria, viruses, and other human pathogenic organisms.

These water bodies are too warm, fail Washington's water quality standards, and cause thermal stress to fish during various life stages. Affected species include Puget Sound Chinook, Bull Trout, Steelhead Trout (each are "threatened" under the Endangered Species Act), coho, chum, pink, sockeye, and rainbow and cutthroat trout.

Ecology is seeking comment on the plans for improving these streams thru June 15, 2011 and will hold a public meeting May 26 at 6:30 p.m. at the Carnation Public Library.

For information contact:

Ralph Svrjcek

425-649-7165

rsvr461@ecy.wa.gov

Special accommodations

If you need this document in a format for the visually impaired, call the Water Quality Program at 425-649-7105.

Persons with hearing loss, call 711 for Washington Relay Service. Persons with a speech disability, call 877-833-6341.

The absence of trees is the ***major*** factor resulting in increased stream temperatures. Tree removal also allows invasive grasses to thrive in agricultural waterways reducing the effectiveness of drainage facilities and increasing the cost of maintenance activities.

Loss of cool groundwater During our dry summer months, the Snoqualmie River is fed by groundwater. Groundwater is cool when it starts its journey in our local streams and rivers but becomes warm as it is exposed to air and sunlight.


Without shade streams like this heat up

Wetland loss, early draining of groundwater through ditching, creation of impervious surfaces (roads, roofs and parking lots), and forest-clearing can all contribute to a net loss of groundwater during summer. Reduced summer groundwater discharges results in higher water temperatures. Wetland loss and excessive stormwater from impervious surfaces can hit a watershed with a "double-whammy." Groundwater levels get reduced and in some cases flood frequency is increased.

Loss of natural stream processes When streams are moved to build housing, install roads, or perform agricultural activities, they usually lose some of the valuable characteristics that keep waters cool. The many twists and turns in an undisturbed stream provide more opportunities for groundwater to enter and for cooler deepwater pools to develop. Where it is practical, adding back natural stream shapes and placements of large wood can benefit stream temperatures.

Erosion Poorly-managed forest lands, agricultural areas, or construction sites can result in bank deterioration, landslides, and discharge of eroded soils. In addition to the direct loss of usable property to erosion, resulting sediment can make streams shallower and wider, hinder groundwater exchange, allows more sun on the water reducing salmon spawning habitat and groundwater inputs, and increases maintenance needed in downstream agricultural waterways.

Water withdrawals There are other human caused factors that increase stream temperatures too. Less water means warmer water. Water withdrawals for various purposes, including irrigation, reduce the amount of cool water stored in the ground to feed the local creeks during the summer when flows are already critically low. Reduced water makes streams slower and shallower, allowing them to become warmer during the dry summer months.

Snoqualmie River and watershed needs more shade, . . . waiting won't help!

Nearly 900 acres of the Middle Fork and mainstem Snoqualmie need to be planted with trees to achieve a healthier riparian forest over time. Over 90% of that need occurs below Snoqualmie Falls. Under current conditions, temperatures in the lower river are predicted to reach near-lethal levels for salmonids during warm periods. Even if we could plant all of this area tomorrow, it would still be many decades until those trees will mature and provide their maximum benefit.

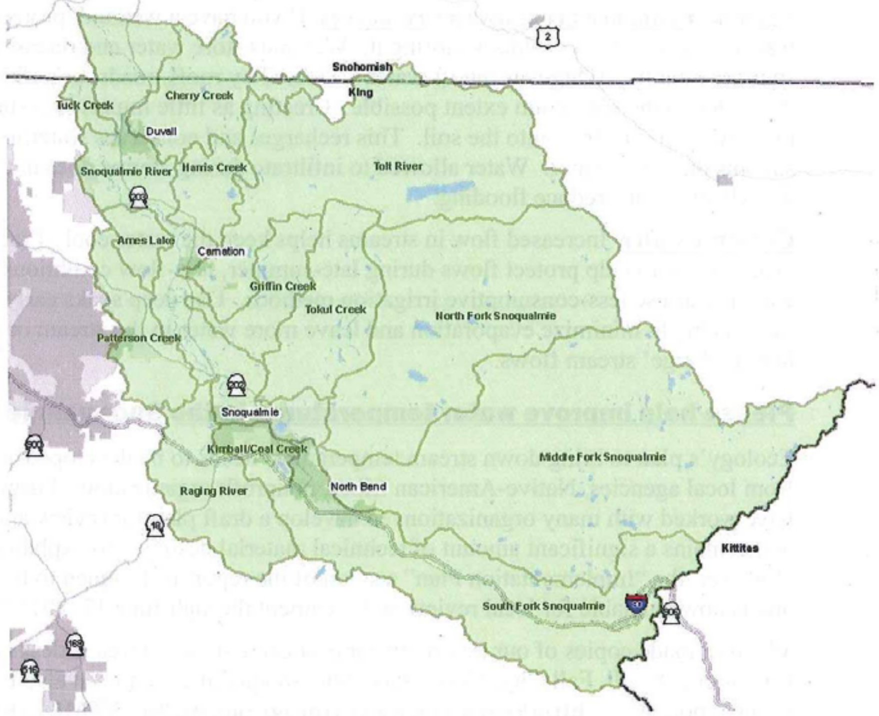
Focus on: Snoqualmie Watershed

Tributary streams throughout the watershed also need more shade. Because they are much narrower than the mainstem river, improved streamside vegetation along these waterways will reduce water temperatures more quickly. This in turn will provide benefits to the many cold-water fish in the Snoqualmie Watershed. The lack of shading in floodplain tributaries has also caused a proliferation of reed canary grass in agricultural waterways, which defeats the purpose of those drainage facilities.

The Snoqualmie River was once one of the most prolific salmon rivers in the state. Right now, chinook salmon and steelhead trout populations are in serious trouble. Improving water temperatures will help increase salmon resources.

Understanding and correcting problems

When a stream is too warm, Ecology collects data to confirm the problem and collaborates with others to understand ways to restore water quality. Ecology performed detailed monitoring of the watershed then developed several computer models to explain where problems exist and how much better the water can get. Streamside vegetation, sunlight, wind speed, and stream flow were all considered as they relate to stream temperatures.



Computer models predicted that improving riparian vegetation along the mainstem Snoqualmie River, combined with meeting the minimum standards for tributary streams, will reduce the "worst-case" water temperatures by 2.8°C (5°F). Under typical 'warmest-week' conditions, temperatures will fall by 2.2°C (4°F). What might not seem like a lot to us makes a big difference to fish health!

Focus on: Snoqualmie Watershed

Water Quality Program **May 2011**

What can we do to reduce stream temperatures in the Snoqualmie Watershed?

By acting now and taking at least one of the following actions, citizens, organizations, and local governments, can help reduce water temperatures and protect and restore water quality:

Protect and restore streamside vegetation Get involved in restoration projects to improve streamside (riparian) areas where trees have been removed. Trees shade the water, create cool microclimates, act as windbreaks, and increase stream bank stability. Restoration projects can help re-establish connections with the natural floodplain and cool groundwater resources. Woody debris, plant material, and insects that fall into water can also provide food and habitat for fish. Where feasible, to improve natural processes, streams that have been straightened and had large wood removed should be restored to a state closer to their natural shape.

Protect or enhance groundwater resources If you have a wetland, protect it. If you have land that was once a wetland, consider restoring it. Wetlands store water and release it slowly during the summer months. Wherever runoff water is created by roofs, roads, or parking lots, it should be infiltrated to the maximum extent possible. Creating as little impervious surface as needed also helps more water to infiltrate into the soil. This recharges and conserves water in the ground and supports streams during summer. Water allowed to infiltrate during storms does not run off to waterways so quickly and helps reduce flooding.

Conserve water Increased flow in streams helps keep the water cool. Practice wise use of water near streams to help protect flows during late-summer, low-flow conditions. Reduce lawn areas for watering or use less-consumptive irrigation methods. Use deep soaks early in the morning or late in the evening to minimize evaporation and leave more water in the stream or in groundwater resources that 'recharge' stream flows.

Please help improve water temperatures in the Snoqualmie Watershed

Ecology's plan to bring down stream temperatures needs to be developed and carried out with help from local agencies, Native-American tribes, nonprofit organizations, businesses, and residents. We have worked with many organizations to develop a draft plan for review and realize it is very large and contains a significant amount of technical material designed to explain our work to scientists. However, the "Implementation Plan" section of the report is designed to be readable by nonscientists and is now available for local review and comment through June 17, 2011.

We have made copies of our report available at each of the reference desks at public libraries in Carnation, Duvall, Fall City, North Bend, and Snoqualmie. You can also find an electronic version of the report at: http://www.ecy.wa.gov/programs/wq/tmdl/TMDLsbyWria/tmdl-wria07.html

The plan is now available for local review and comment through June 15, 2011
Send comments to: Ralph Svrjcek 3091 160th Ave. SE, Bellevue, WA 98008-5452
Email: rsvr461@ecy.wa.gov
Please consider coming to a public meeting to learn more:
Carnation Public Library -- May 26 at 6:30 p.m.