Quality Assurance Project Plan

Snoqualmie River Temperature Total Maximum Daily Load Study

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303(d) Listings Addressed in this Study

Listing ID	Category	Waterbody Name	Parameter	Waterbody ID	Old Waterbody ID
7415	5	Snoqualmie River	Temperature	QW73YS	WA-07-1060
6571	5	Snoqualmie River	Temperature	QW73YS	WA-07-1100
6570	5	Snoqualmie River	Temperature	QW73YS	WA-07-1100

Study Tracker Code: 06-017

Approvals

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Glossary of Acronyms

BMP	Best Management Practices
cfs	cubic feet per second
DNR	Washington State Department of Natural Resources
EIM	Environmental Information Management (system)
EPA	US Environmental Protection Agency
FMU	Freshwater Monitoring Unit
NIST	National Institute of Standards and Technology
NPS	Nonpoint Source
NPSU	Nonpoint Source Studies Unit
NPDES	National Pollutant Discharge Elimination System
PST	Pacific Standard Time
QA Project Plan	Quality Assurance Project Plan
RM	river mile from mouth
TI	Temperature Instrument
TIR	Thermal Infra-red
TMDL	Total Maximum Daily Load
USGS	US Geological Survey
WAC	Washington Administrative Code
WRIA	Watershed Resource Inventory Area
WWTP	Wastewater Treatment Plant

Abstract

The Snoqualmie River basin has been selected for a temperature Total Maximum Daily Load study as it is listed on the 303(d) list of impaired waterbodies for high stream temperatures. This Quality Assurance Project Plan describes the technical investigation used to evaluate stream temperature in the Snoqualmie River from its confluence with the Skykomish River to the Mt. Baker-Snoqualmie National Forest. Continuous temperature, streamflow, channel characteristics, and riparian assessment data collection is planned for the summer of 2006. Data collection will build on previous efforts conducted by a variety of governmental and private organizations. Water temperature will be characterized and load and wasteload allocations established to reduce heat sources in the system to achieve water quality standards.

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. Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Washington State Water Quality Standards (Washington Administrative Code 173-201A) consist of designated uses for protection (such as cold water biota and drinking water supply) and criteria (usually numeric criteria, to achieve those uses).

Every two years, states are required to prepare a list of waterbodies--lakes, rivers, streams, or marine waters--that do not meet water quality standards. This list is called the Federal Clean Water Act Section "303(d) list." The state of Washington has created a broader process of sharing water quality information with its citizens called the *Water Quality Assessment*. To develop the Water Quality Assessment, Ecology compiles its own water quality data along with data submitted by local, state, and federal governments, tribes, industries, and citizen monitoring groups. In the assessment, 303(d) listings are put in Category 5, Impaired Waters. All data used for a Category 5 listing must be collected using appropriate scientific methods. You can learn more about the assessment process at www.ecy.wa.gov/programs/wq/links/impaired_wtrs.html.

TMDL Process Overview

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the waterbodies on the 303 (d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then the local community works with Ecology to develop a strategy to control the pollution, put the strategy into action, and follow up with a monitoring plan to assess the effectiveness of the water quality improvement activities.

Elements Required in a TMDL

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and then allocates that load among the various sources.

If the pollutant comes from a discrete source (referred to as a point source), such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse sources (referred to as a nonpoint source) 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 loads from growth pressures is sometimes included . The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

Washington State Water Quality Assessment

The Water Quality Assessment allows citizens to learn about the condition of Washington's waters across the state and in their own neighborhoods. This assessment divides each river/stream/creek into segments, based on the Township/Section/Range coordinate system. If monitoring within a stream segment indicates it is polluted, that segment is put into one of five categories:

- Category 1 – Meets tested standards for clean water.
- Category 2 – Waters of concern.
- Category 3 – No data available.
- Category 4 – Polluted waters that do not require a TMDL since the problems are being solved in one of three ways:
  - 4a – Has a TMDL approved and its being implemented.
  - 4b – Has a pollution control plan in place that should solve the problem.
  - 4c – Impaired by a non-pollutant such as low water flow, dams, culverts.
- Category 5 – Polluted waters that require a TMDL – or the 303d list.

This study focuses on the known Category 5 temperature listings in the Snoqualmie River, which are discussed in more detail later in this plan.

Total Maximum Daily Load Analyses: Loading Capacity

Identification of the contaminant loading capacity for a waterbody is an important step in developing a TMDL. The US Environmental Protection Agency (EPA) defines the loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or wasteload allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

Why is Ecology Conducting a TMDL Study in this Watershed?

Overview

Washington State Department of Ecology (Ecology) is conducting a TMDL study in this watershed because there are three reaches on the Snoqualmie River exceeding water temperature standards. Also. there is a high interest in water quality issues in this basin demonstrated by the level of cooperative sampling and water management currently occurring. Ecology hopes to build on previous efforts and work cooperatively with all contributing entities to generate a better understanding of stream temperatures in this watershed.

As part of this TMDL, Ecology will conduct field work during the summer of 2006 to characterize water temperatures. The study will also establish load and wasteload allocations to reduce heat sources in the system to meet water quality standards for surface water temperature. The TMDL will use effective shade as a surrogate measure of heat flux to fulfill the requirements of the federal Clean Water Act Section 303(d) for a temperature TMDL. Effective shade is defined as the fraction of incoming solar shortwave radiation that is blocked by vegetation and topography from reaching the surface of the stream

This Quality Assurance (QA) Project Plan will describe the study design for the Snoqualmie River temperature TMDL. Topics discussed include the watershed study area, project objectives, historical data, influential thermal processes, field data collection plan, and computerized modeling.

Project Objectives

The proposed project has the following objectives:

- Characterize June-September stream temperatures in the Snoqualmie River basin by compiling existing data and collecting additional data in cooperation with other organizations.
- 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.
- Investigate the Raging River because it has important Chinook spawning habitat while also exhibiting high stream temperatures.
- Evaluate the ability of various watershed Best Management Practices (BMPs) to reduce water temperature to meet water quality standards.
- Establish a TMDL for temperature in the Snoqualmie River basin.

- For ease of implementation, load allocations may be reported in terms of surrogates for solar radiation, such as: shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, and channel width-to-depth ratio.
- Address all impaired waterbodies within the Snoqualmie River watershed and mitigate reaches with detrimentally high instream temperatures.

Study Area

The study area for this TMDL consists of the Snoqualmie River system from its confluence with the Skykomish River to the headwater at the National Forest boundary (Figure 1).

Although the study area includes the entire watershed, the most intensive study will be on the Main Stem Snoqualmie River and the Middle Fork Snoqualmie River from the National Forest boundary to its mouth.

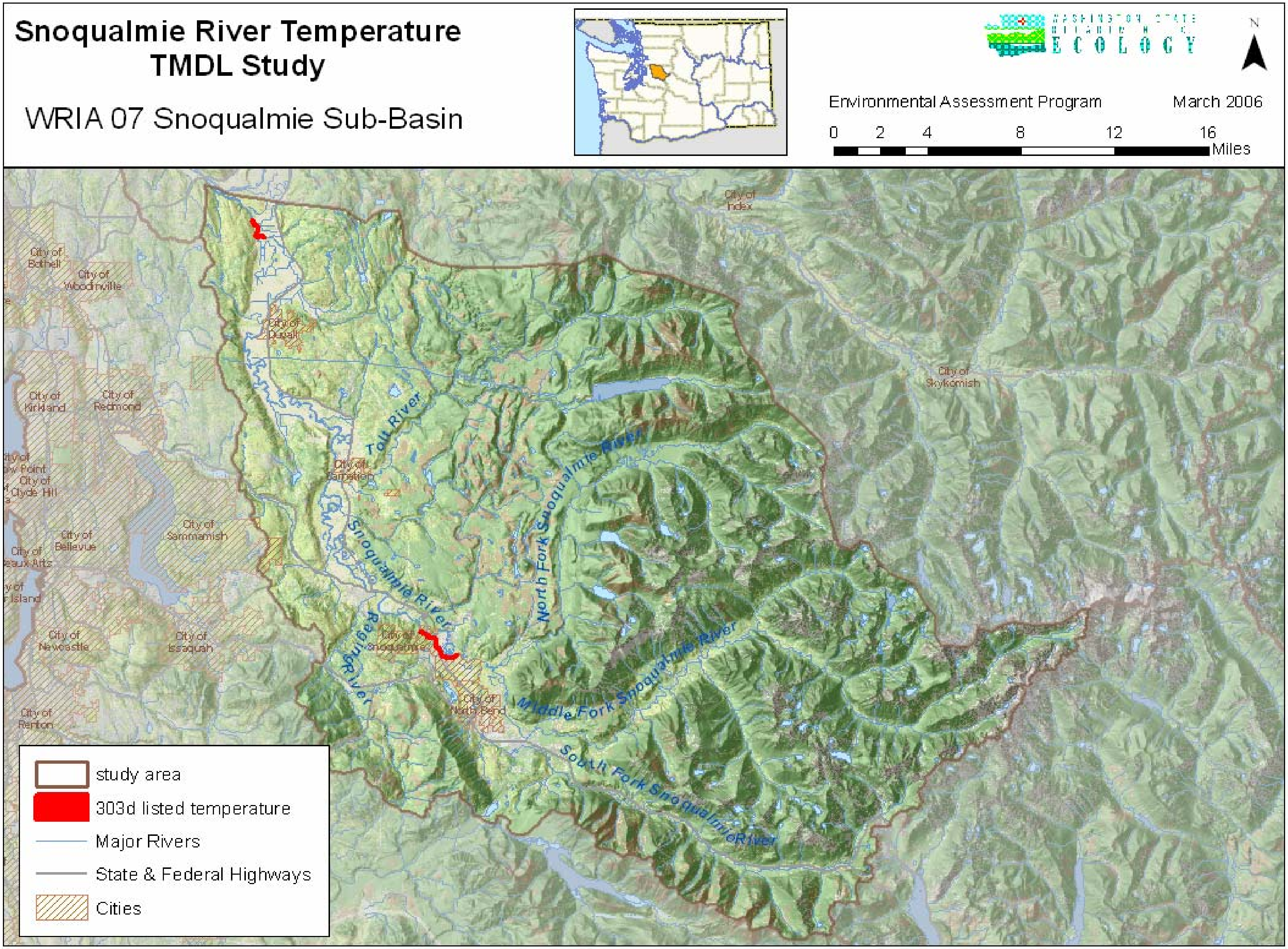


Figure 1. Study area for the Snoqualmie River temperature Total Maximum Daily Load study.

Pollutants Addressed by this TMDL

This TMDL addresses temperature only. Therefore, heat is the pollutant of concern.

Impaired Beneficial Uses and Waterbodies on Ecology's 303(d) List of Impaired Waters

This TMDL addresses the Category 5 listed segments of the Snoqualmie River shown in Table 1.

Table 1. Study area 303(d) listings (2004 list) addressed in this report.

Waterbody Name	Listing ID	Township	Range	Section
Snoqualmie River	7415	24N	08E	30
	6571	24N	08E	32
	6570	27N	06E	26

We will be looking at this watershed more thoroughly and may find other segments of the Snoqualmie River and its tributaries that exceed state criteria for temperature.

The Snoqualmie River and tributaries have other water quality issues that will not be addressed in this TMDL. In particular, the following additional 303(d) listings (for parameters other than temperature) occur in the study area but are not addressed in this QA Project Plan:

Table 2. Additional 303(d) listings not addressed by this report.

Waterbody	Parameter	Listing ID
South Fork Snoqualmie River	pH	7428

Why Are We Doing this TMDL Now?

Ecology has been concerned with the protection of the Snoqualmie River system for over a decade. Due to concern about the degradation of water quality from the expansion of wastewater treatment plants to accommodate future growth, Ecology prepared the Snoqualmie River TMDL for dissolved oxygen and fecal coliform bacteria in 1994 (Joy, 1994). Recommendations for controlling phosphorus levels were also made at that time.

During the WRIA 6 & 7 Water Quality Scoping process conducted by Ecology in late 2004, Snoqualmie temperature impairments were ranked among the highest priority TMDL projects. The WRIA 7 Salmon Recovery Forum has determined that the watershed is an important spawning and rearing area for the threatened fall chinook salmon population and has focused considerable resources to prioritize chinook populations in the Snohomish watershed. 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, which is within their usual and accustomed hunting and fishing areas.

King County and local governments are also very engaged in protecting both salmon resources and the agricultural resources in the Snoqualmie Valley. The Snoqualmie Forum was created to provide local input and guidance to the process of protecting and enhancing the watershed and recently King Conservation District assessments to local land owners was doubled to improve district services in the area and provide additional funding to aid in the salmon recovery effort.

King County has also been at the forefront of working with local landowners to protect water and agricultural resources through the conservation tax programs, purchase of development rights, and technical assistance/funding to farmers to try and protect local waters. The county also is a major force behind the Puget Fresh program to help support local agriculture.

Because of the importance of this watershed to the multiple salmon species and the active involvement of local government and citizens in the watershed, the Snoqualmie River temperature problems were given a high priority for action by Ecology.

How Will the Results of this Study be Used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve clean water. This is done by assessing the situation and then recommending practices to reduce pollution. Limits are established for facilities that have National Pollution Discharge Elimination System (NPDES) permits. When the study identifies sources or source areas of pollution, Ecology and local partners use these results to decide where to focus water quality improvement activities. Where additional data is needed, the study suggests areas for follow-up sampling to further pinpoint sources for cleanup.

Water Quality Standards and Beneficial Uses - Temperature

Water Quality Standards

Under Chapter 173-201A-030 WAC, numeric freshwater water quality criteria for Class AA, Class A, and Lake Class are described in the following designations:

- *Class AA*: Freshwater temperature shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increases will be allowed, which will raise the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed $t=23/(T+5)$, where T represents the background waterbody temperature and t is the maximum permissible temperature increase measured at the edge of the mixing zone. Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C when the temperatures are less than the standard.
- *Class A*: Water temperature shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increases will be allowed, which will raise the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed $t=28/(T+7)$. Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.

- *Lake Class*: The water quality standards do not include numeric temperature targets, but lakes must maintain no measurable change from natural conditions.

Waterbodies not specifically classified under WAC 173-201A-130 or 173-201A-140 are accounted for in WAC 173-201A-120 General Classifications. The non-specified waterbodies within national parks, national forests, or wilderness are classified as AA or Lake. Non-specified tributaries of classified streams must be of equal or better classification. Non-specified streams flowing into Lake Class are Class AA unless otherwise specified.

The Snoqualmie River and its tributaries are designated Class A waters from the mouth to the west border of Twin Falls State Park at river mile (RM) 9.1 on the South Fork (Table 3). The entire Middle Fork and North Fork Snoqualmie Rivers are Class AA waters. The South Fork Tolt River system is also Class AA, with a special condition on the South Fork Tolt (a Seattle water supply) above RM 6.9 prohibiting any waste discharge (WAC, chapter 173-201A-130). The Tolt River provides 30 percent of the drinking water for the 1.3 million people in the Seattle area (Onwumere and Batts, 2004).

Table 3. Water quality classifications and river mile (RM) of named waterbodies within the Snoqualmie River basin. Left bank (LB) and right bank (RB) are relative when facing downstream.

Stream Name	Snoqualmie RM confluence	Water Quality Classification
Ricci Creek	0.4 (LB)	A
Pearson Eddy Creek	3.6 (LB)	A
Peoples Creek	4.3 (RB)	A
Duvall Creek	5.7 (RB)	A
Cherry Creek	6.7 (RB)	A
Tuck Creek	10.3 (LB)	A
Coe Creek	10.3 (RB)	A
Adair Creek	13.3 (LB)	A
Ames Creek	17.0 (LB)	A
Weiss Creek	19.9 (RB)	A
Harris Creek	21.3 (RB)	A
East Horse Shoe Lake	22.8 (RB)	A
Tolt River	24.9 (RB)	AA
Langlois Creek	26.4 (RB)	A
Griffin Creek	27.2 (RB)	A
Patterson Creek	31.2 (LB)	A
Raging River	36.2 (LB)	A
Rutherford Slough	35.3 (RB)	A
Skunk Creek	38.6 (RB)	A
Tokul Creek	39.7 (RB)	A
South Fork Snoqualmie River	44.2 (LB)	A and AA (9.1)
North Fork Snoqualmie River	45.0 (RB)	AA
Middle Fork Snoqualmie River	45.0	AA

Recent Changes to the Washington State Water Quality Standards

In July 2003, Ecology made significant revisions to the state's surface water quality standards (Chapter 173-201A WAC). These changes included eliminating the classification system the state had used for decades to designate uses to be protected by water quality criteria (e.g., temperature, dissolved oxygen, turbidity, bacteria). Ecology also revised the numeric temperature criteria that were to be assigned to waters to protect specific types of aquatic life uses (e.g., native char, trout and salmon spawning and rearing, and warm water fish habitat).

The revised water quality standards regulation was submitted to EPA for federal approval. EPA was not satisfied that Ecology's 2003 standards met the requirements of the federal Clean Water Act (CWA) and the federal Endangered Species Act (ESA). Their main concerns were over the temperature criteria applied to waters that support endangered and threatened fish species (e.g., bull trout, chinook salmon, steelhead). As a consequence, EPA has formally disapproved portions of the revised standards.

EPA has developed maps showing the fisheries uses that must be established in order to gain their approval. The specific locations and time frames for the application of supplemental temperature criteria to protect spawning and incubation periods can be found on EPA's website @ yosemite.epa.gov/R10/WATER.NSF/Water+Quality+Standards/WA+WQS+EPA+Disapproval. EPA is specifying that lower temperatures are needed during the fish spawning periods (generally 13^{o}C for salmonids from September through May 15, June 15, or July 1; February 15 through June 15; or year round (12^{o}C) for char). Ecology has agreed to initiate state rule revision proceedings that will consider the changes EPA has proposed. The state rule revision is expected to increase the number of stream segments requiring more stringent temperature and dissolved oxygen criteria.

The state expects to conclude its rule revision in October 2006, and have approved state standards in early 2007. Until that time, TMDLs will need to be based on the 1997 version of the state water quality standards, rather than the 2003 version that has been disapproved by EPA. After the new standards have been approved, however, the state will need to ensure that TMDLs and permits will meet the new state standards.

TMDLs will be designed during this uncertain transition period with formal allocations that meet the existing (1997) approved standards. TMDLs must also, however, include alternative allocations that meet the expected 2007 standards for the waterbody, or include the technical components necessary to readily calculate those allocations. This process will prevent Ecology from needing to completely repeat the TMDL process once the new standards have been approved by EPA.

Proposed revisions to the existing standards can be found online at Ecology's water quality standards website www.ecy.wa.gov/programs/wq/swqs. It is important to examine the proposed changes for the specific waterbodies undergoing TMDL development in order to see what water quality criteria are likely to be in early 2007. Table 4 provides a general structure for understanding the expected changes to temperature and dissolved oxygen standards:

Table 4. Proposed Water Quality Standards for 2007.

1997 Standards Classification	Water Quality Parameter	1997 Criteria[3]	2003 Use-based Revision	2003/2007 Criteria[3]
Class AA [1]	Temperature	16°C 1-Dmax[5]	Native Char	12°C 7-DADMax[4, 6]
			"Core" Salmon/Trout	16°C 7-DADMax[4, 6]
	Diss. Oxygen	9.5 mg/l 1-DMin[7]	*Either of above*	9.5 mg/l 1-DMin[7]
Class A[2]	Temperature	18°C 1-Dmax[5]	Native Char	12°C 7-DADMax[4, 6]
			"Non-core" Salmon/Trout	17.5°C 7-DADMax[4, 6]
	Diss. Oxygen	8.0 mg/l 1-DMin[7]	Native Char	9.5 mg/l 1-DMin[7]
			"Non-core" Salmon/Trout	8.0 mg/l 1-DMin[7]
Class B	Temperature	21°C 1-Dmax[5]	"Rearing only" Salmon/Trout	17.5°C 7-DADMax[6]
	Diss. Oxygen	6.5 mg/l 1-DMin[7]		6.5 mg/l 1-DMin[7]

Footnotes:

1. Class AA waters were subcategorized into *native char* and *salmon/trout core rearing* designated use types during the 2003 revision to the water quality standards regulation.
2. Class A waters were subcategorized into *native char* and *salmon/trout non-core rearing* designated use types during the 2003 revision to the water quality standards regulation.
3. Special criteria have been established in the existing water quality standards for specific waterbodies that differ from the general criteria assignments shown in the above table.
4. The 2007 corrected water quality standards rule will contain supplemental spawning and incubation temperature criteria (13°C for salmon and trout and 9°C for native char) that will be applied to specific portions of many of these waters.
5. 1-DMax means the highest annual daily maximum temperature occurring in the waterbody.
6. 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
7. 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the waterbody.

Beneficial Uses

The water quality standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for water quality parameters. The criteria are intended to define the level of protection necessary to support all beneficial uses. The beneficial uses of the waters in the Snoqualmie River basin are:

- *Recreation:* The recreational opportunities on the Snoqualmie watershed include fishing, swimming, and boating in both the Class A and AA designated waters.

- *Municipal and Agricultural Water Supply and Stock Watering:* Water is withdrawn from the Snoqualmie River and aquifers for agricultural use. Drinking water is withdrawn from aquifers and the Tolt River reservoir.

- *Wildlife Habitat:* Riparian areas are used by a variety of resident and migratory aquatic and terrestrial wildlife.

Watershed Description

Study Area

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 (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. 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 towns of Fall City and Preston are located in the lower basin. Historical economies were based on agricultural and logging. They now have become the focal points for residential, commercial, and industrial projects which require increased wastewater services. Additional wastewater and NPS impacts from land-use changes threaten to degrade water quality in the basin. (Joy, 1994).

The Raging River drains an estimated 32.8 mi^2 (85.1 km^2) and enters the Snoqualmie River at RM 36.2 from the left bank. The Raging River mainstem is approximately 15 RM long with a vertical relief of 3,500 feet. Significant numbers of fall Chinook spawn the lower 9.3 miles of the Raging River. Land uses on the Raging River include roads, forest management, housing, and city development (Haring, 2002).

The upper basin (the area above the three forks confluence at North Bend) 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. 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 percent of the water gauged at the USGS station at Carnation during the summer low flow season (Joy et al., 1991).

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 Federal Energy Regulatory Commission (FERC) license in 2004.

The power plants divert 65 percent 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 5).

Table 5. Puget Sound Energy streamflow criteria for water passing over Snoqualmie Falls at given dates and times.

Time Period	Daytime	Nighttime
May 16 - May 31	200 cfs	200 cfs
June 1 - June 30	450 cfs	450 cfs
July 1 - July 31	200/100 cfs	200/25 cfs
August 1 - August 31	200/100 cfs	200/25 cfs
September 1 - May 15	100 cfs	25 cfs

PSE currently works with Ecology, Washington Department of Fish and Wildlife (WDFW), and Tribes developing a flow regime designed to protect fish during critical low-flow periods from August 1 to October 31 (FERC, 2004).

Geology

The easternmost extent of the Puget Lobe, part of the Cordilleran ice sheet, successively advanced and retreated between 10,000 and 1,600,000 years before present times. As a result, most of the Snoqualmie River basin is covered by unconsolidated deposits from both glacial and nonglacial origins. These glacial deposits can be as much as 1,200 feet thick. Consolidated layers referred to as bedrock primarily exist beneath the unconsolidated glacial deposits. Bedrock is exposed to the surface covering approximately 13 percent, most of this occurring in the east and southwest regions of the watershed. Most of the bedrock consist of andesite; however, sandstone, siltstone, and conglomerate predominate the southwest region (Turney et al., 1995).

Hydrogeology

A region where groundwater discharges to surface water, thus augmenting streamflow, is known as a gaining reach. The opposite occurrence, known as a losing reach, happens when 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 (Harring, 2002). A seepage study conducted in September 1991 shows Snoqualmie watershed streams generally gaining 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 contributed by 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).

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 influences stream-flow conditions with most snowmelt occurring in May and June. Low flows typically occur during August when very little precipitation falls and most of the snowmelt runoff has already taken place for the season. Streamflows begin to increase in September, carry through January, and then gradually decrease reaching the lowest flow in August (Harring, 2002).

Sources of Thermal Pollution

A number of environmental variables can affect water temperature (Brown, 1969) including:

- Solar Radiation.
- Air Temperature.
- Stream Width, Depth, and Velocity.
- Tributary and Groundwater Influence.

We expect that all of these factors will play a role in water temperatures in the Snoqualmie River system.

Potential Sources of Point Source Thermal Pollution

The Snoqualmie River receives treated waste water from two municipal facilities located in Snoqualmie and Duvall. The South Fork Snoqualmie River receives treated wasted water from the North Bend water treatment facility. The municipal waste water treatment plants (WWTP) will be monitored for temperature and discharge in cooperation with facility managers. These WWTPs are considered point source inputs for this proposed TMDL. An additional WWTP is planned for Carnation to be complete in the next two-to-four years. Tokul Creek fish hatchery will be monitored as well for stream flow and temperature both above and below the facility. All facilities have a National Pollutant Discharge Elimination System (NPDES) permit.

The Tolt River reservoir is also a potential point source of thermal influence. USGS continuous flow stations exist above and below the reservoir recording stream flow and temperature. These data will address the thermal regime near the reservoir.

Potential Sources of Nonpoint Thermal Pollution

Past land use practices can have both short (10 yr) and longer term effects on thermal pollution levels in river systems. Examples include historic logging practices, conversion of land for residential, commercial, and agricultural purposes, and water withdrawals to name a few. In other TMDLs conducting in Washington State, these sources can be categorized into three major sources: 1) loss of shade, 2) changes in channel morphology, and 3) hydrologic changes.

- 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 stream-flow 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.

Historical Data Review

The following section gives a brief summary of exiting Snoqualmie River watershed. Existing information helps guide our field sampling decisions and acts as a platform to start this proposed study. Data collected over the 2006 summer will be looked at in concert with historical information.

The Snoqualmie River and tributaries experience a range of maximum stream temperatures from approximately 17°C to 24°C. Snoqualmie River temperature drops approximately 2°C from the three forks to Snoqualmie Falls and then gradually rises 2°C from the falls to its confluence with the Skykomish River. During the summer of 2005, the highest stream temperature was recorded on the Raging River at the Snoqualmie River confluence (23.6°C).

United States Geological Survey (USGS)

The USGS has collected data in the Snoqualmie River basin since the 1950s providing much information. Currently, the USGS operates 15 continual streamflow stations in the basin. Four of the 15 stations include a measurement of temperature, all located in the Tolt River watershed. Ecology will place thermistors at relevant USGS flow stations. Figure 2 comes from the USGS water resources internet website, depicting daily average streamflow during 2004 for the Snoqualmie River near Carnation. USGS generates many other reports and figures available at the website. water.usgs.gov/cgi-bin/dailyMainW?state=wa&map_type=real.

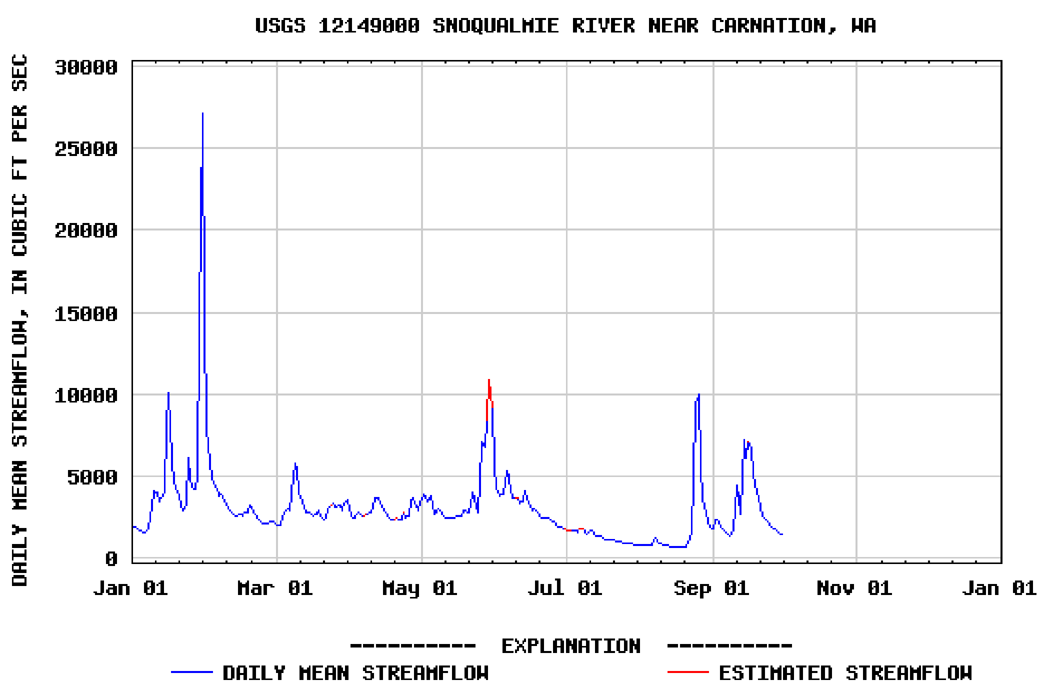


Figure 2. Daily average streamflow during 2004 from USGS gage 12149000 on the Snoqualmie River, near Carnation.

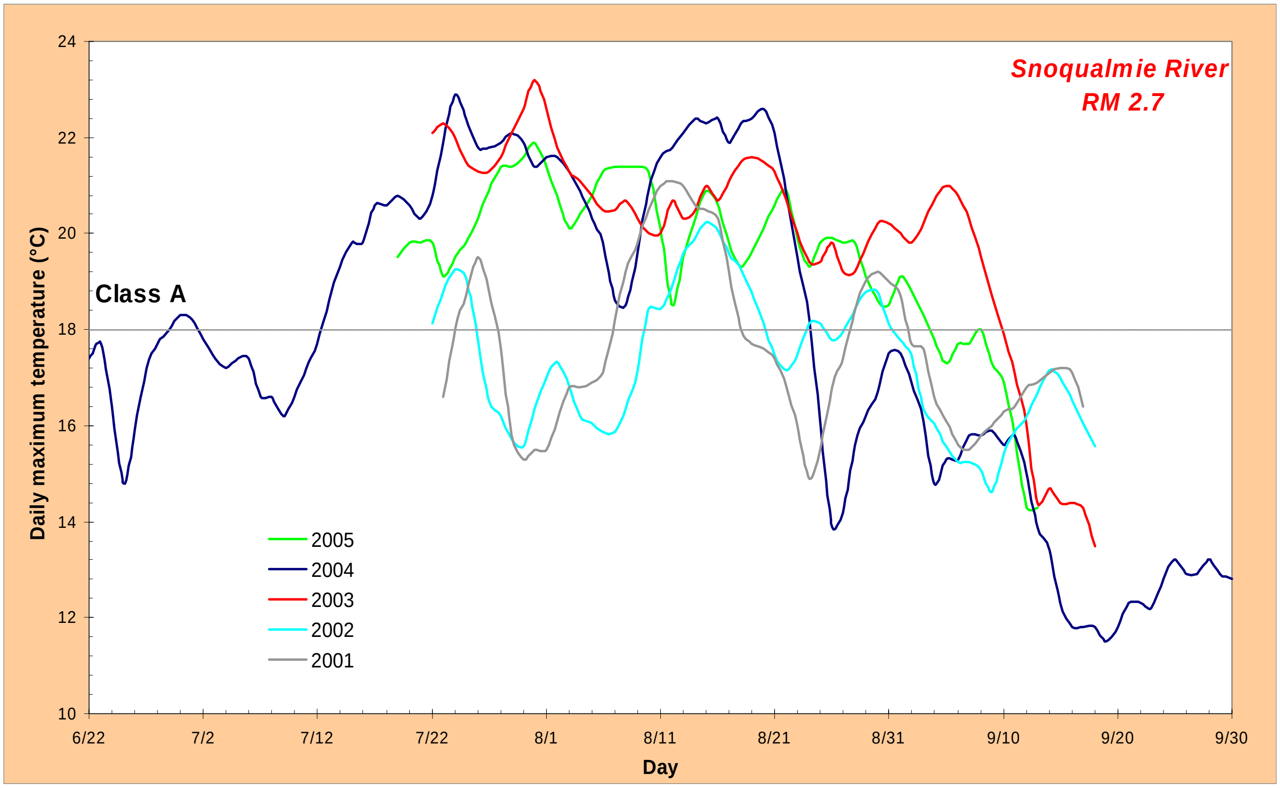
The document, Geohydrology and Groundwater Quality of East King County, Washington (Turney et al., 1995), provides a thorough description of hydrogeological characteristics within the Snoqualmie River basin. It also provides valuable estimates of groundwater contribution to various reaches of the Snoqualmie River.

Washington State Department of Ecology (Ecology)

In 1994, Ecology published a Snoqualmie River TMDL study for biochemical oxygen demand (BOD), ammonia, and fecal coliform for the critical low-flow months of August through October (Joy, 1994). A related Snoqualmie River low-flow water quality assessment study includes dye studies (time of travel) and measurement of channel cross sections and velocity profiles at 22 sites (Joy et al., 1991).

An evaluation of the effectiveness of the existing Snoqualmie River TMDL is underway, including monitoring of fecal coliform bacteria, ammonia, BOD, and temperature (Onwumere and Batts, 2004). Data collected from all studies will be utilized, and collaborative field work is planned between effectiveness monitoring efforts and this currently proposed temperature TMDL.

Ecology has two long-term water quality monitoring stations in the Snoqualmie River, one near Monroe, and the other near the town of Snoqualmie upstream of Snoqualmie Falls. Station 07D050 (near Monroe) is at river mile (RM) 2.7 and began in 1992. Station 07D130 upstream of Snoqualmie Falls is at RM 42.3 and began in 1959. Daily maximum temperatures at these sites are shown in figure 3. Two manual stage height flow stations also exist at RM 2.7 (station 07D050, installed October 1997) and RM 45.3 (station 07D150, installed October 2000) on the Middle Fork Snoqualmie River. Figure 4 shows the longitudinal temperature profile from RM 45.3 to RM 2.7. Figure 5 shows a map of maximum stream temperatures recorded by 14 continuous temperature data loggers during 2005.



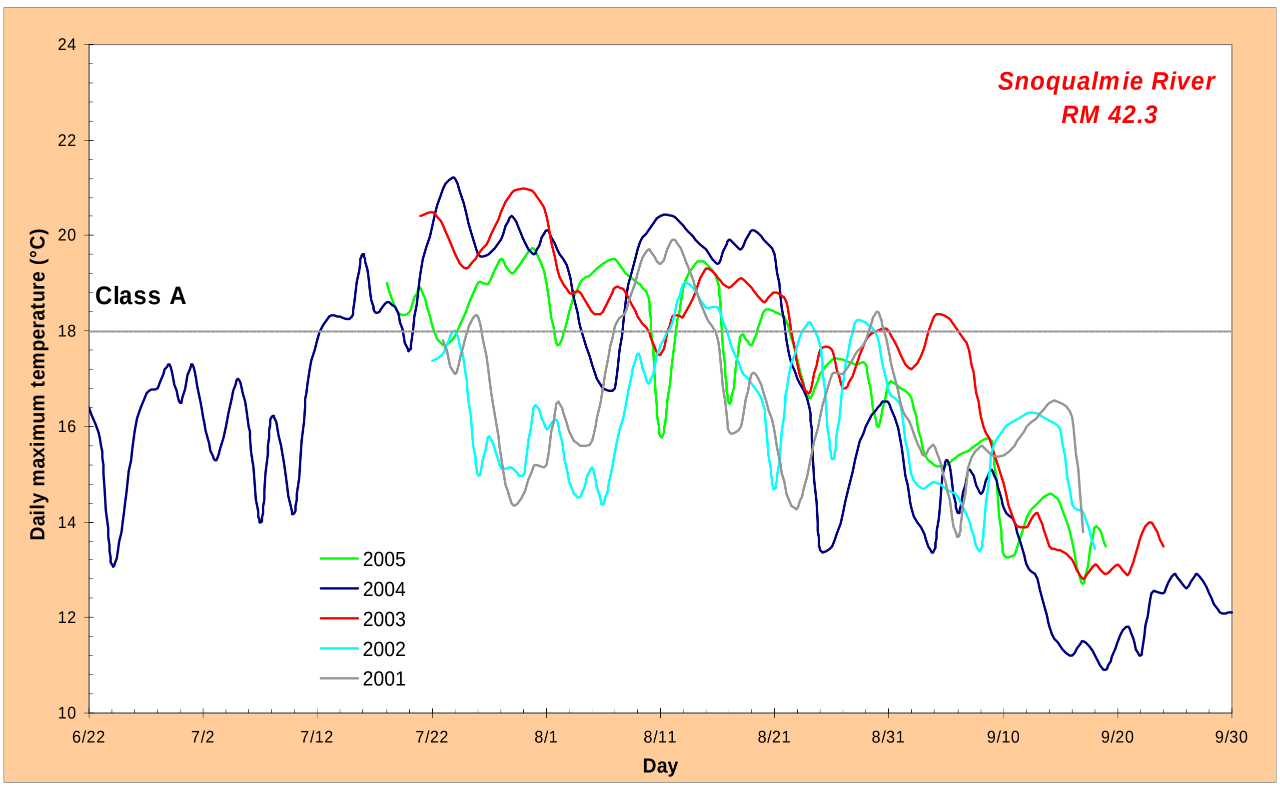


Figure 3. Snoqualmie River temperatures at RM 2.7 (07D050) and RM 42.3 (07D130) Ecology stations.

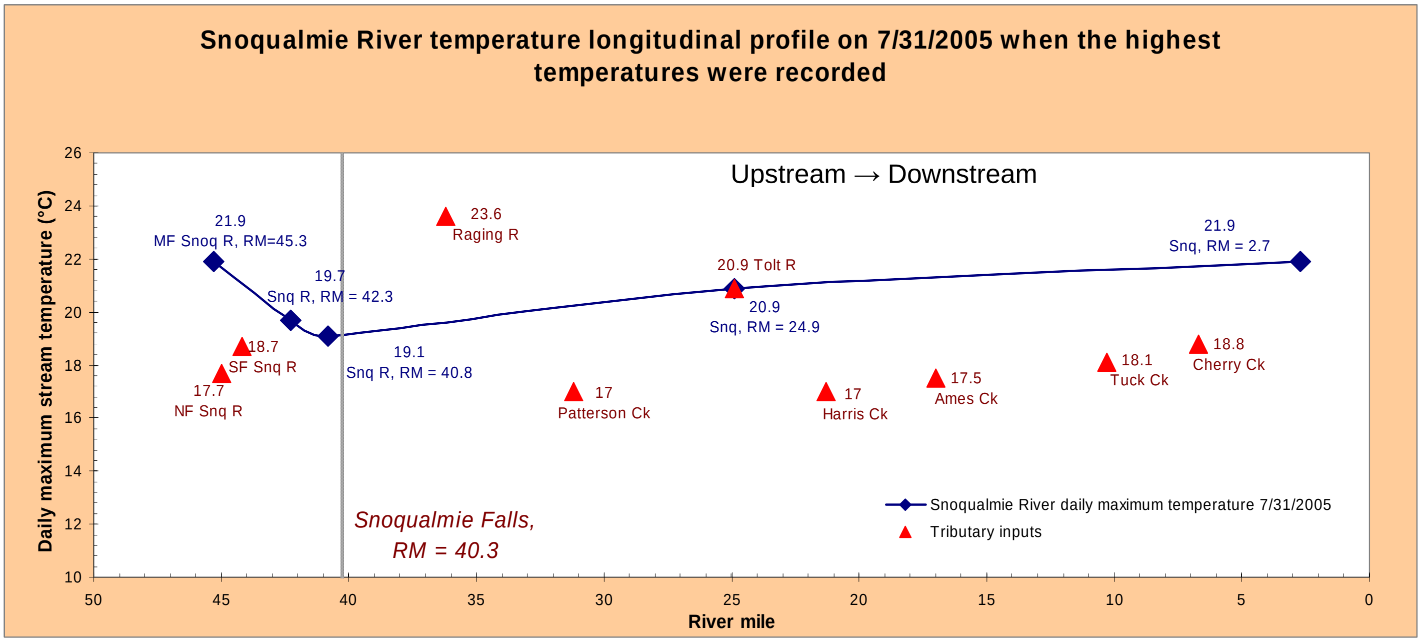


Figure 4. Longitudinal thermal profile for the Snoqualmie River including tributary temperatures.

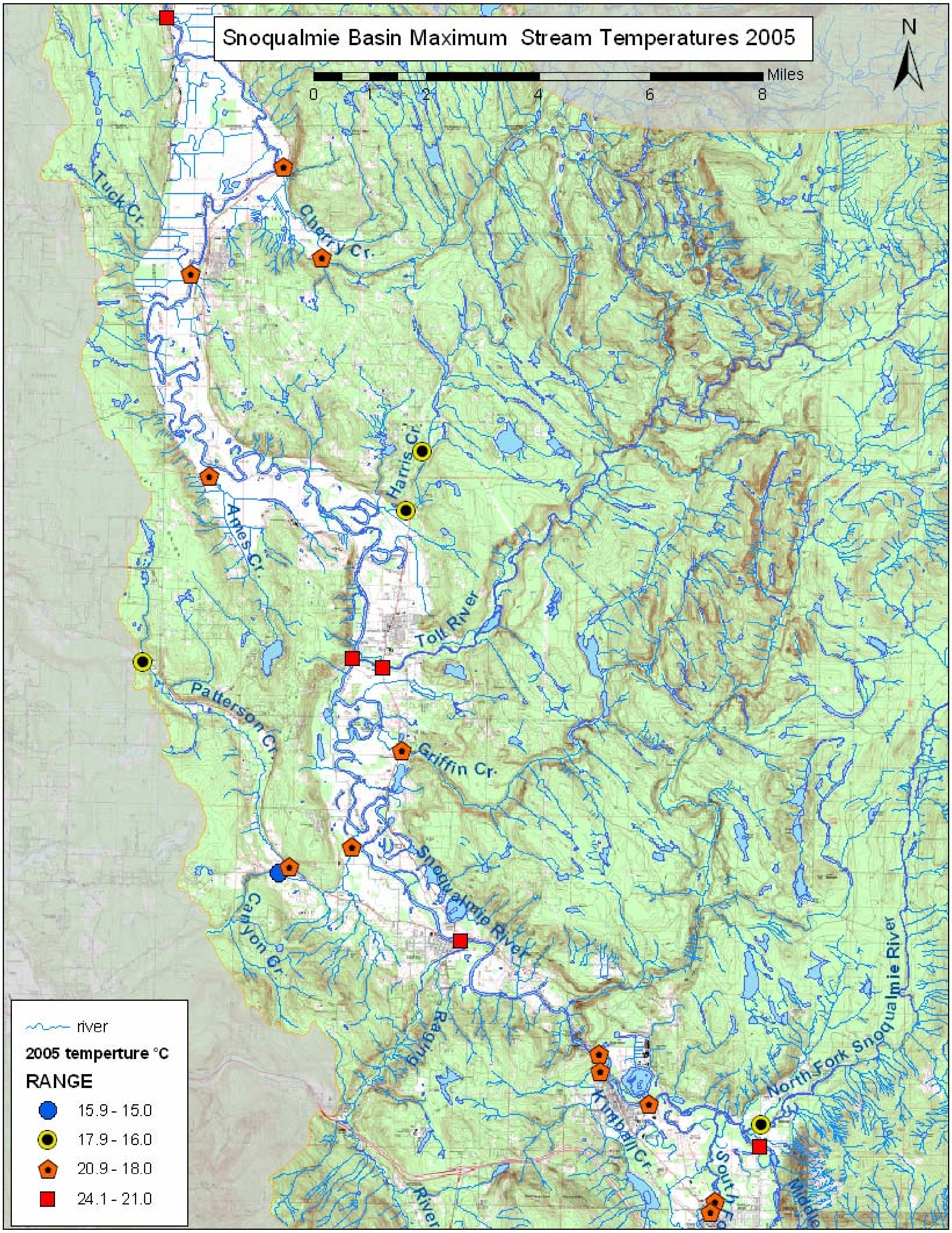


Figure 5. Maximum stream temperatures for the Snoqualmie River watershed during 2005.

Washington State Department of Natural Resources (DNR)

DNR has completed two watershed analysis reports in the Snoqualmie River basin including the watersheds of Tolt River and Tokul/Griffin subbasins. Watershed analysis is a physical and biological assessment of a watershed designed to address the cumulative effects of forest practices on cultural and public resources (DNR, 2006). Completed watershed analysis reports may be accessed at the DNR website: www.dnr.wa.gov/forestpractices/watershedanalysis/.

King County

King County operates ten continual flow stations coupled with stream temperature data loggers. Six of the ten flow stations record air temperature as well. These flow stations collect baseline data and serve to assist with riparian restoration effectiveness monitoring. King County flow stations are distributed in the lower elevation tributaries of the Snoqualmie River including Adair Creek, Patterson Creek, Griffin Creek, Harris Creek, and Cherry Creek.

King County has authored many documents related to planning and watershed analysis. A newly designated Middle Fork Snoqualmie Park Natural Area protects and revitalizes 644 acres located along the river starting near Sallal (RM 49.5) and ending upstream of the Granite Creek confluence (RM 56.5).

University of Washington

The University of Washington has conducted groundwater and surface water studies in the Snoqualmie River basin. A report published in 1968 provides pertinent historical data in the upper basin of the North Fork Snoqualmie River from the USGS gage station (RM 9.2) and upstream (Nece, 1968).

Habitat Limiting Factors Analysis

In 1998, the Washington State Conservation Commission was tasked in House Bill 2496 with assessing the habitat-based factors limiting the success of salmonids in Washington State. Habitat Limiting Factors reports are available for most WRIAs in Washington State. The conservation commission worked with a watershed Technical Advisory Group (TAG) to author the report for the Snoqualmie River watershed (Haring, 2002). The TAG included members from tribes, local county groups, fisheries agencies, conservation districts, timber management groups, and others.

Fish habitat includes the biological, chemical, and physical components of the environment such as water quality, water quantity, stream morphology, riparian zones, upland terrestrial conditions, and ecosystem interactions lending to habitat. These components intertwine closely. For example, low stream flows can alter water quality by increasing temperatures and decreasing the amount of available dissolved oxygen, and concentrating toxic materials.

Additional Data

The Snoqualmie River basin is studied by a variety of organizations such as: Washington State Department of Fish and Wildlife (WDFW), Snoqualmie Ranger District (USFS), USGS, Tulalip and Snoqualmie Nations, King County, and others.

A brief list of studies not previously mentioned include the following:

- Snoqualmie Watershed Aquatic Habitat Conditions report 1999-2001.
- Pentec Environmental. 2002. Bull Trout Monitoring in the Snohomish River during Historical Periods of Hydraulic Dredging. Draft Report. Prepared for the US Army Corps of Engineers.
- Pentec Environmental and NW GIS. 1999. Snohomish River basin Conditions and Issues Report.
- Revised Final Report. Prepared for the Snohomish River basin Work Group.

As this TMDL continues, Ecology expects that additional data sources may become known. These data sources will be considered as appropriate.

Project Goal and Study Objectives

Project Goal

The goal of the overall TMDL project is to address temperature problems in the Snoqualmie River watershed so that water quality is improved and beneficial uses restored. More specifically, the goal is for the Snoqualmie River and its tributaries to meet state temperature water quality criterion.

Study Objectives

Objectives of the proposed study are 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.
- 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, load allocations may be reported where applicable 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 stream banks.
- Address all impaired waterbodies with in the Snoqualmie River watershed and mitigate reaches with detrimentally high instream temperatures.

Study Design

Representativeness and Completeness

Representativeness of the data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries and point sources, and seasonal variation of instream flow and temperatures in the watershed. Stream temperature measurements will be made in the well-mixed portion of the streamflow where there is no thermal stratification and no direct influence from standing water in pools or the stream margins. Five types of field studies will be conducted to measure physical processes in the river system: 1) temperature monitoring network, 2) groundwater/surface water interactions, 3) stream gauge and flow, 4) stream velocity, and 5) riparian habitat and channel geometry.

Study Design Overview

The Snoqualmie River Temperature TMDL will be developed for heat, which is considered a pollutant under Section 502(6) of the Clean Water Act. Heat energy processes that control energy transfer to and from a given volume of water include:

- Shortwave solar radiation.
- Longwave radiation exchange between the stream and both the adjacent vegetation and the sky.
- Evaporative exchange between the stream and the air.
- Convective exchange between the stream and the air.
- Conduction transfer between the stream and the streambed.
- Groundwater exchange with the stream (Adams and Sullivan, 1989).

If the heat energy entering the water from these sources is greater than the heat energy leaving the water, then stream water temperature will rise. Water temperature change, which is an expression of heat energy exchange per unit volume (Equation 1), is most strongly influenced by solar radiation input (Adams and Sullivan, 1989).

Equation 1. Relationship between Temperature and Heat Energy for Surface Waters.

$$\Delta Temperature = \frac{\Delta\ Heat\ Energy}{Volume}$$

Increased solar radiation levels at the stream surface due to anthropogenic causes result from the following conditions:

- Channel widening (increased width-to-depth ratios) that increases the relative stream surface area exposed to energy processes.

- Riparian vegetation disturbance that reduces stream surface shading through reductions in riparian vegetation height and density. (Shade is commonly measured as percent effective shade.)
- Reduced summer baseflows resulting from instream withdrawals, wells in hydraulic continuity with the stream, or altered streamflow patterns due to land-use practices that increase runoff instead of storage.

The sources of increased stream temperatures will be examined as part of the Snoqualmie River temperature TMDL to produce a loading capacity and load and wasteload allocations for the heat sources. Loading capacity and allocations will be established via field surveys and development of a predictive computer temperature model. Field data collection and assessment will be governed by the data set requirements of the computer temperature model (Table 4).

Table 4: Model Data Requirements and Collection Source.

		MODEL		Collection By				
	PARAMETER	**Effective Shade**	**Qual2K**	**TIR**	**King Co.**	**USFS**	**WDFW**	**Ecology**
Flow	discharge - tributary		x		x			x
	discharge (upstream & downstream)		x		x			x
	flow regression constants		x		x			x
	flow velocity		x		x			x
	groundwater inflow rate/discharge		x					x
	travel time		x					x
General	calendar day/date	x	x	All Data Collected Primarly from USGS or GIS Maps				
	duration of simulation	x	x					
	elevation - downstrean	x	x					
	elevation - upstream	x	x					
	elevation/altitude	x	x					
	latitude	x	x					
	longitude	x	x					
	time zone	x						
Physical	channel azimuth/stream aspect	x						
	cross-sectional area	x	x		x			x
	Manning's n value	x	x		x			x
	percent bedrock	x	x					x
	reach length	x	x					x
	stream bank slope	x						x
	stream bed slope	x	x	Collect from USGS or GIS Maps				
	width - bankfull	x			x			x
	width - stream	x	x		x			x
Temperature	temperature - ground		x					x
	temperature - groundwater		x					x
	temperature - water downstream		x	?	x	x	x	x
	temperatures - water upstream		x	?	x	x	x	x
	temperature - air		x	?	x	x	x	x
	thermal gradient		x					
Vegetation	% forest cover on each side	x						x
	canopy-shading coefficient/veg density	x						x
	diameter of shade-tree crowns	x						x
	distance to shading vegetation	x						x
	topographic shade angle	x						x
	vegetation height	x			x			x
	vegetation shade angle	x						x
	vegetation width	x						x
Weather	relative humidity		x	Weather Staion/RH meters				
	% possible sun/cloud cover		x	Weather Station				
	solar radiation		x	Weather Station				
	temperature - air		x	Field check/Weather Station				
	wind speed/velocity		x	Weather Station				

Study Approach

The Snoqualmie River temperature TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. Edinger et al. (1974), Thomann and Mueller (1987), and Chapra (1997) have summarized the fundamental approach to the analysis of heat budgets and temperature in natural waters that will be used in this TMDL.

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 6.

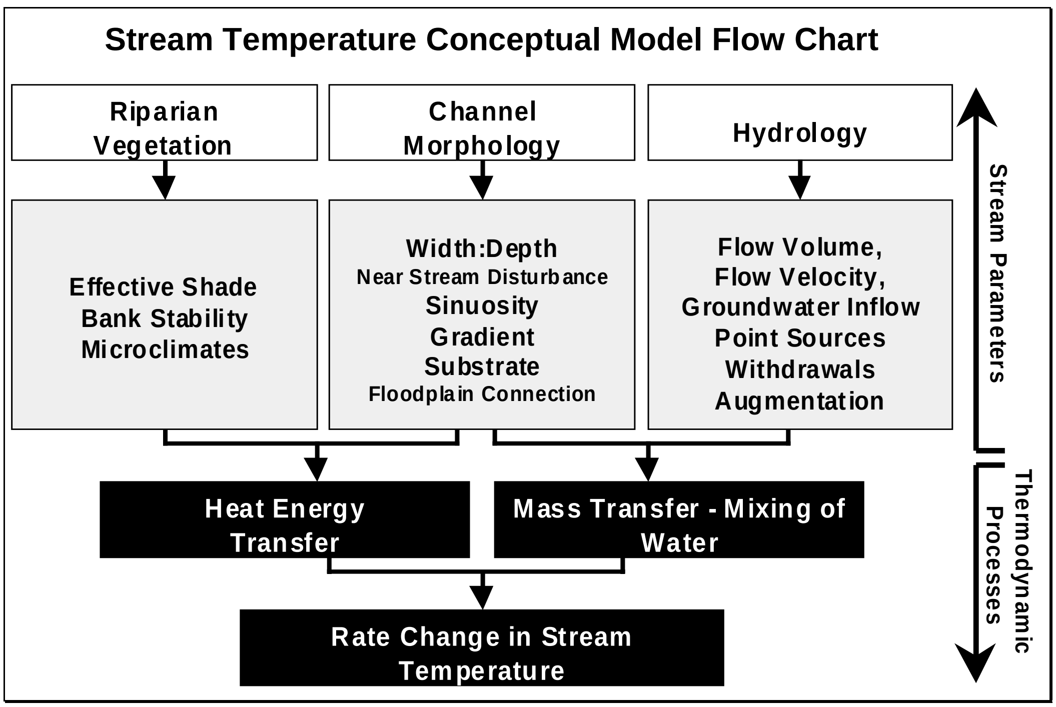


Figure 6. Conceptual model of factors that affect stream temperature.

The heat exchange processes occur between the waterbody and the surrounding environment and control stream temperature. The main components of the heat balance are presented schematically in Figure 7 and discussed below.

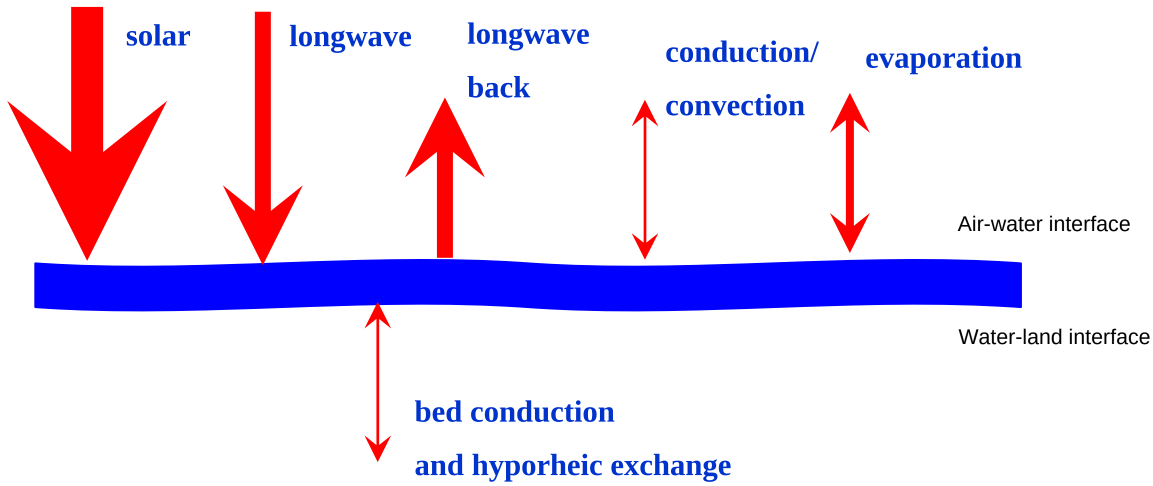


Figure 7. Surface heat exchange processes that affect water temperature (net heat flux = solar + longwave atmosphere + longwave back + conduction/convection + evaporation + bed). Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

- *Shortwave solar radiation* is the difference between the energy that comes directly from the sun and that reflected by the water body. Short wave 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 short-wave radiation received at a particular location. Vegetation and topographic shading can reduce short wave radiation. 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* is the amount of longwave radiation determined by a series of atmospheric components such as water vapor, carbon dioxide, ozone, and air temperature. This heat budget component is most significant during warm cloudy conditions and at night. The long-wave radiation from the atmosphere ranges in wavelength range from about 4 μm to 120 μm. Longwave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. The daily average heat flux from long-wave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974).

- *Longwave radiation from the water* is the radiation emitted by the waterbody to the atmosphere. This is an important component among the processes that define energy loss. Its mathematical description is based on the Stefan-Boltzmann fourth power radiation law for a blackbody as a function of the water emissivity and temperature. Water sends heat energy back to the atmosphere in the form of long-wave radiation in the wavelength range of about 4 μm 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 long-wave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

- *Conduction/convection flux at the air-water interface (also known as sensible heat)* is driven by the temperature difference between water and air and by the wind speed. It is related to evaporation flux through the Bowen ratio.

- *Evaporation flux at the air-water interface* is influenced mostly by the wind speed and the vapor pressure gradient between the water surface and the air. When the 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, the reversal of evaporation takes place, and this term then becomes a gain component in the heat balance.

- *Bed conduction flux and hyporheic exchange* component of the heat budget 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 and usually affects the temperature diel profile.

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 transport of flow volume downstream, instream mixing, and the introduction or removal of water from a stream.

Shade is an important parameter that controls the stream heating derived from solar radiation, one of the largest heat transfer mechanisms in a stream system. There is a natural maximum level of shade that a given stream is capable of attaining, which is a function of species composition, soils, climate, and stream morphology. Reductions in shade have the potential to cause significant increases in heat delivery to a stream system. Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al., 1998; Ice, 2001; OWEB, 1999; and Teti, 2001).

To estimate the relative effect of riparian vegetation on stream temperatures, a modeling system comprised of a shade model and a receiving water quality model will be used. This modeling package (Figure 8) is routinely used by Ecology in stream temperature and water quality TMDL studies.

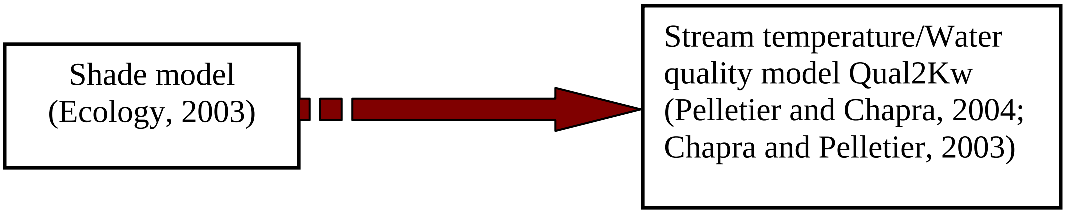


Figure 8. The shade – stream temperature modeling system.

The shade model is an implementation of the shade estimation method proposed by Chen et al. (1998). The shade model uses the relationships among sun position, stream location, date, stream orientation, and local topography with the riparian vegetation characteristics to compute a time-series of the effective shade levels. 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. A detailed description of the *Shade.xls* model can be found in the paper *Stream Temperature Simulation of Forested Riparian Areas*: I. Watershed-Scale Model Development (Chen et. al., 1998). Estimates of hourly effective shade levels at various stream locations can be simulated using the shade model. The shade model output becomes an input variable to the Qual2Kw model.

QUAL2Kw (Pelletier and Chapra, 2004; Chapra and Pelletier, 2003) is a version of QUAL 2E water quality model implemented within the Microsoft Windows environment. The model uses the mathematical formulations of the heat exchange processes combined with the representations of stream hydraulics and mass transfer processes to simulate diurnal variations of stream water temperature. The model will be calibrated and confirmed based on the field data collected during the summer of 2006. Furthermore, the model will be used beyond its calibration and confirmation periods to predict possible thermal behaviors of the Snoqualmie system under different flow and near stream vegetation cover conditions. Load allocations will be established for system conditions represented by the 7-day average with 10- year return period low flow and site potential mature riparian vegetation.

Study Design Details

Field data collection for development of the temperature TMDL consists of five components:

- Water and air temperature monitoring.
- Streamflow measurements.
- Channel geometry and riparian vegetation surveys.
- Time-of-travel study.
- Thermal Infrared Radiation (TIR) over flight.

Water and Air Temperature Monitoring

Continuously recording temperature instruments (TIs) will be deployed at approximately 30 additional key locations along the Mainstem Snoqualmie River, the Middle Fork Snoqualmie River and at the mouths of perennial tributaries. TIs placement will occur where stream gage stations are present, and lack thermistors. TIs will also be placed at national forest boundaries in the three forks of the Snoqualmie River. This TMDL will not focus on national forest areas overseen by the US Forest Service (USFS). 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 has collaborated with the USFS on these plans in the past, this TMDL assumes that USFS practices used today are generally considered protective of designated uses; therefore, this TMDL will not measure stream temperatures and model effective shade requirements within the Mt. Baker-Snoqualmie National Forest.

Each TI will measure temperature at 30 minute intervals. Monitoring locations will typically consist of an air TI (measuring air temperature near the edge of the stream) and an instream TI. Instream TIs are deployed in the thalweg of a stream such that they are suspended off the stream bottom and in a well-mixed portion of the stream, typically in riffles or swift glides. The intent is to avoid measurement bias from vertical and horizontal temperature stratification.

Air TIs will be co-located with all instream TIs to provide a quality check for the instream data and a comparison with weather station air temperature data. Figure 8 is an example of a possible monitoring network of all TIs. Tables 5 and 6 list Ecology's 43 proposed sampling sites totaling 43. Table 5 displays the Ecology Nonpoint Source Studies Unit (NPSU) sites designed specifically for this proposed TMDL. Table 6 displays the Ecology Freshwater Monitoring Unit (FMU) site list. Final placement will depend on site access considerations such as having landowner permission and/or using public right of way access at road crossings.

Existing weather stations in the Snoqualmie River watershed will also provide data useful for this study. Ecology will install one temporary weather station near the river capable of recording air temperature, dew point, windspeed/direction, precipitation, and solar radiation.
Three to four additional dew point/relative humidity data loggers will be installed throughout the watershed based on proximity to existing weather stations and stream temperature monitoring stations.

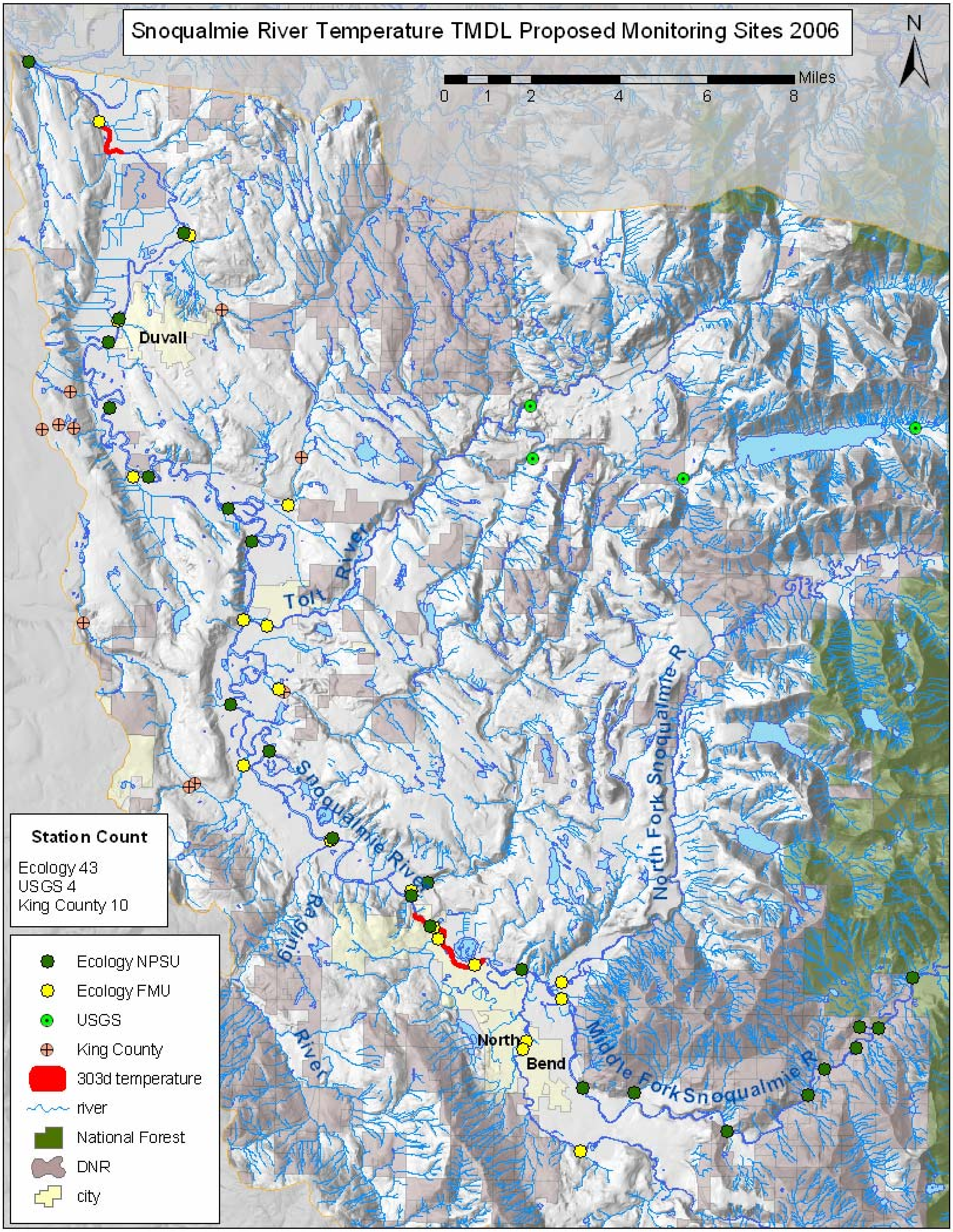


Figure 8. Proposed sampling locations for the Snoqualmie River Temperature TMDL study.

Table 5. Proposed stream temperature monitoring sites for the Snoqualmie River temperature TMDL study to be performed by Ecology's Nonpoint Source Studies Unit (NPSU).

River mile (RM) originates from the stream mouth/confluence and latitude/longitude are North American Datum 27 (NAD27).

Site ID	Site Description	RM	Latitude (dd)	Longitude (dd)
07-GIF-00.1	Gifford Lakes stream at confluence w M.F. Snoqualmie	0.1	47.50811	-121.61353
07-GRA-00.1	Granite Creek at confluence with M.F. Snoqualmie R	0.1	47.49457	-121.63928
07-MFS-47.8	Middle Fork Snoqualmie R at Mt Si Rd	47.8	47.48722	-121.75715
07-MFS-52.7	M.F. Snoqualmie R DNR access	52.7	47.4734	-121.68595
07-MFS-55.6	Middle Fork Snoqualmie R at USGS gaging station	55.6	47.4858	-121.64776
07-MFS-57.5	M.F. Snoqualmie R on DNR land	57.5	47.50162	-121.62434
07-MFS-60.6	Middle Fork Snoqualmie R at Forest Service boundary	60.6	47.52514	-121.59691
07-SNO-00.4	Snoqualmie R/Skykomish R confluence above Ricci Ck	0.4	47.82332	-122.03721
07-SNO-06.9	Snoqualmie R above Cherry Ck	6.9	47.76807	-121.96017
07-SNO-10.2	Duvall WWTP	10.2	47.73881	-121.99006
07-SNO-10.9	Snoqualmie R at Duvall	10.9	47.73082	-121.99551
07-SNO-14.6	Snoqualmie R at Novelty	14.6	47.70937	-121.99415
07-SNO-17.5	Snoqualmie R at 100th St abv Ames Ck	17.5	47.68662	-121.97421
07-SNO-21.5	Snoqualmie R above Harris Ck	21.5	47.67662	-121.93495
07-SNO	Snoqualmie R near Chinook Bend	to be determined including additional sites		
07-SNO-23.1	Snoqualmie R at Carnation Farm Rd, USGS gage station	23.1	47.66603	-121.92369
07-SNO-26.7	Snoqualmie R above Griffin Ck	26.7	47.61199	-121.93208
07-SNO-33.0	Snoqualmie R at boat launch Neal Rd	33	47.59638	-121.91277
07-SNO-36.3	Snoqualmie R at Fall City	36.3	47.56837	-121.88181
07-SNO-39.7	Snoqualmie R above Tokul Ck, near USGS station	39.7	47.54966	-121.84244
07-SNO-40.6	Snoqualmie R below Snoqualmie WWTP	40.6	47.54006	-121.83276
07-SNO-44.1	Snoqualmie R below three forks	44.1	47.52625	-121.78788
07-RAG	Raging River upstream	to be determined		
07-TOK-00.5	Tokul Ck above Hatchery	0.5	47.5541	-121.83424
07-UNN-00.2	Unnamed Creek to MFS at Mt Si Rd near Sallal	0.2	47.4857	-121.73223
07-UN1-00.1	Unnamed tributary of MFS downstream of Gifford L	0.1	47.50879	-121.62223

Table 6. Ecology's Freshwater Monitoring Unit (FMU) stream sampling locations. River mile (RM) originates from the stream mouth/confluence and latitude/longitude are North American Datum 27 (NAD27).

FMU ID	Site ID	Site Description	RM	Latitude (dd)	Longitude (dd)
07V070	07-AME-00.1	Ames Ck at 100th St	0.1	47.688889	-121.992222
07S070	07-CHE-00.2	Cherry Ck at hwy 202	0.2	47.766944	-121.960556
07W070	07-GRI-00.7	Griffin Ck at hwy 203	0.7	47.617500	-121.914444
07U070	07-HAR-00.7	Harris Ck at hwy 203	0.7	47.685833	-121.910000
07Y060	07-KIM-00.1	Kimball Ck at hwy 202	0.1	47.537222	-121.836944
07D150	07-MFS-45.3	Middle Fork Snoqualmie R at 428th, ECY gage station	45.3	47.516389	-121.768222
07N070	07-NFS-00.3	North Fork Snoqualmie R at 428th Ave SE	0.3	47.521944	-121.768056
07P070	07-PAT-00.4	Patterson Ck near Fall City R Rd SE	0.4	47.591667	-121.925556
07Q070	07-RAG-00.1	Raging River at confluence	0.1	47.568611	-121.893611
07M065	07-SFS-01.6	S.F. Snoq. R below N. Bend WWTP at Valley Trail	1.6	47.503889	-121.786389
07M075	07-SFS-01.8	S.F. Snoqualmie R at Bendigo Blvd S (hwy 202)	1.8	47.499167	-121.792222
07M120	07-SFS-05.5	S.F. Snoqualmie R at 468th SE	5.5	47.466167	-121.757667
07D050	07-SNO-02.7	Snoqualmie R nr Monroe FMU, ECY gage station	2.7	47.803972	-122.001667
07D100	07-SNO-24.9	Snoqualmie R above Carnation nr Tolt R confluence	24.9	47.640111	-121.926528
07D125	07-SNO-40.8	Snoqualmie R above Snoqualmie WWTP at hwy 202	40.8	47.543333	-121.841111
07D130	07-SNO-42.3	Snoqualmie River in Snoqualmie	42.3	47.527083	-121.810917
07X070	07-TOK-00.1	Tokul Ck at confluence below Hatchery	0.1	47.552222	-121.848889
07G070	07-TOL-00.5	Tolt R nr Carnation, hwy 203	0.5	47.638000	-121.914972
07T050	07-TUC-00.1	Tuck Ck at mouth	0.1	47.741389	-121.995000

In addition, Ecology plans to cooperate with other organizations collecting data in the watershed by data sharing and coordinating proposed sampling sites.

Streamflow Measurements

Streamflow measurements will be conducted at each sampling location at least once a month totaling five to seven measurement per site throughout the study. Among the five to seven measurements will be three seepage events (synoptic flow surveys). The intent of the synoptic flow survey is to quantify surface water and groundwater inputs using a mass balance approach. During each synoptic survey, flow will be measured at all of the approximately 40 monitoring sites over the course of one to three days (depending on staffing levels). Stations with continuous flow monitoring or clearly established and current rating curves with tapedown points or gauges will not require new transects and flow measurements.

Ecology hopes to conduct synoptic surveys during the weeks of July 24, August 14, and September 11, weather permitting. Ideally, each survey will employ five or more teams of two to perform the flow measurements.

Channel Geometry and Riparian Surveys

Thermal reach surveys will follow Timber-Fish-Wildlife (TFW) stream temperature survey methods (Schuett-Hames et al., 1999). The surveys will be conducted during summer conditions at selected temperature sites established by Ecology. Depending on stream access, field measurements will either be taken at six to ten locations over a 300-meter thermal reach or at set intervals along the length of an entire stream. Measurements will consist of bankfull width and depth, wetted width and depth, effective shade, and channel type. Riparian management zone (RMZ) characteristics, such as active channel width, cover, size, density, and bank erosion, will also be recorded during the surveys. Riparian assessment includes 150 feet on both sides of the stream. Vegetation heights will be measured in the field using a laser range/height finder.

Image analysis of digital hemispherical pictures and field measurements taken using a Solar Pathfinder at the center of the stream will be used to estimate the total solar radiation contribution at the stream surface at each temperature monitoring station during the critical period. This data will provide validation for the site factor assumptions and effective shade predictions generated from the model.

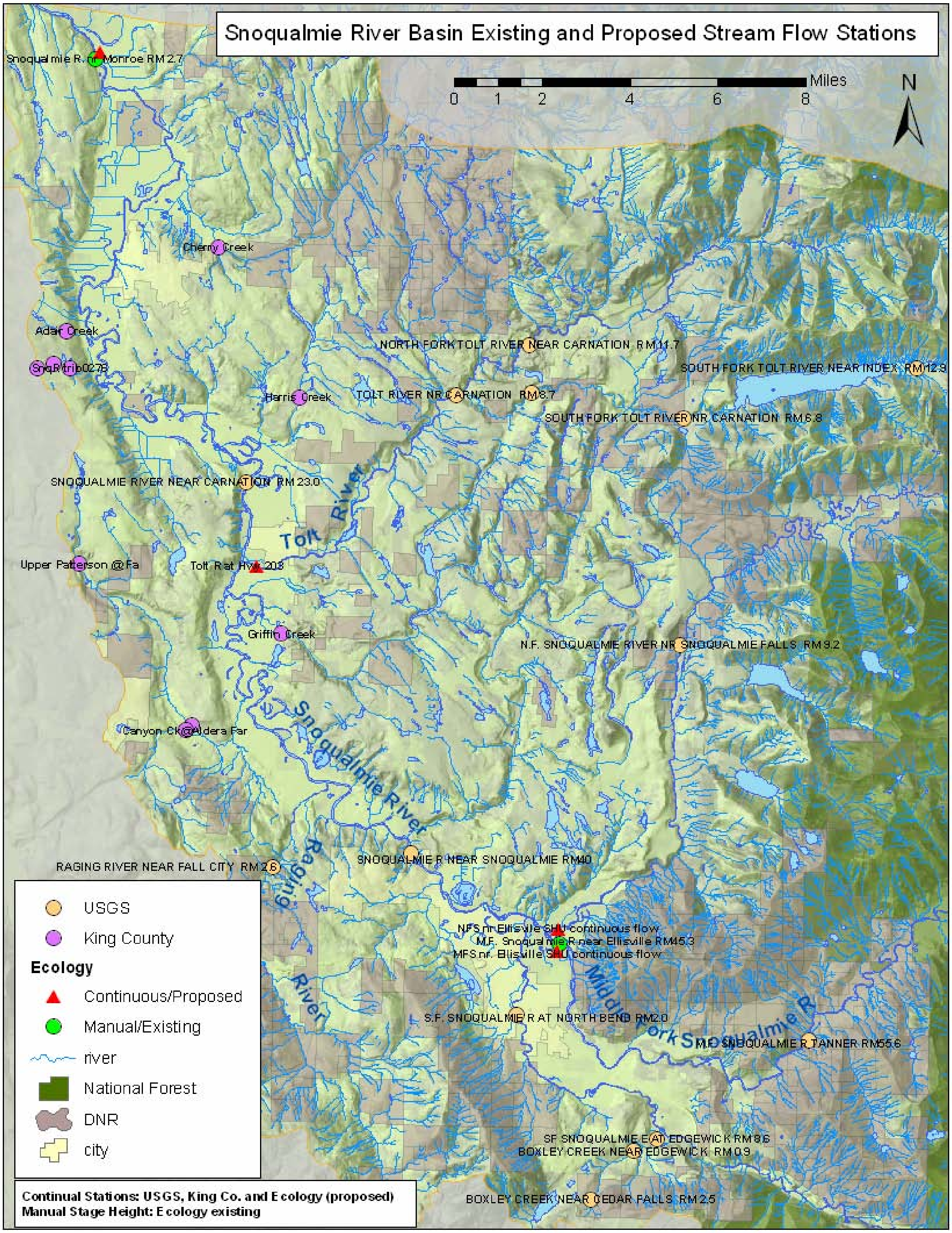


Figure 9. Flow stations in the Snoqualmie River basin including active and proposed stations.

Time of Travel Study

Time of travel studies (dye studies) indicate the time it takes a local body of water to travel downstream. Rhodamine dye is injected 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, much like the waves that the PSE power generation plant emits.

Two separate time of travel events are scheduled during two of the three synoptic flow events. The time of travel studies will build upon the previous study conducted by Ecology in the early 1990s.

Weather Stations

Existing weather stations in the Snoqualmie River watershed will provide data useful for this study. In addition, one temporary weather station will be installed near the river capable of recording air temperature, dew point, windspeed/direction, precipitation, and solar radiation. Three to four additional dew point/relative humidity data loggers will be installed throughout the watershed based on proximity to existing weather stations and stream temperature monitoring stations.

Channel Geometry and Riparian Surveys

Thermal reach surveys will follow Timber-Fish-Wildlife (TFW) stream temperature survey methods (Schuett-Hames et al., 1999a). The surveys will be conducted during summer conditions at selected temperature sites established by Ecology. Depending on stream access, field measurements will either be taken at six to ten locations over a 300-meter thermal reach or at set intervals along the length of an entire stream. Measurements will consist of bankfull width and depth, wetted width and depth, effective shade, and channel type. Riparian management zone (RMZ) characteristics, such as active channel width, cover, size, density, and bank erosion, will also be recorded during the surveys. Riparian assessment includes 150 feet on both sides of the stream. Vegetation heights will be measured in the field using a laser range/height finder.

Image analysis of digital hemispherical pictures and field measurements taken using a Solar Pathfinder at the center of the stream will be used to estimate the total solar radiation contribution at the stream surface at each temperature monitoring station during the critical period. This data will provide validation for the site factor assumptions and effective shade predictions generated from the model.

Thermal Infrared Radiation (TIR) Overflight

Pending funding, a TIR survey will fly over the Mainstem and Middle Fork Snoqualmie River during one of the three synoptic stream flow surveys. A helicopter-mounted TIR sensor and color video camera will be used to take TIR and visible color images of selected segments of the streams and rivers in the watershed to provide a spatially continuous image of surface temperature.

Measurement Procedures

Field

Field sampling and measurement protocols will follow those described in the Continuous Temperature Monitoring Protocols for the Environmental Monitoring and Trends Section (Ward, 2003). Temperature thermographs will be installed in the water and air in areas which are representative of the surrounding environment and are shaded from direct sunlight. To safeguard against data loss, data from the loggers will be downloaded monthly or midway through the sampling season. The stream surveys will collect data according to the TFW Stream Temperature Survey Manual for bankfull width and depth, wetted width and depth, canopy closure, and channel type (Schuett-Hames et al., 1999a). Riparian management zone (RMZ) characteristics, such as width, cover, size, density, and windthrow, will also be recorded during the surveys.

Quality Considerations

Quality Goals

The overall quality goals for this study are as follows:

- Data are sufficiently representative and complete to meet study objectives.
- Data precision, bias, and sensitivity are appropriate for meeting study objectives.

Quality Design

The quality goals will be met through a variety of measures as described below.

Quality Objectives

Accuracy of the thermograph data loggers will be maintained by a two-point comparison between the thermograph and a Certified Reference Thermometer. The Certified Reference Thermometer, manufactured by HB Instrument Co. (part number 61099-035, serial number 2L2087), is certified to meet ISO9000 standards and calibrated against National Institute of Standards and Technology traceable equipment.

Precision, Bias, and Sensitivity

The most important detail for using continuously recording data loggers is to ensure that they are all synchronized to the same time. There is an official U.S. time that is a public service cooperatively provided by the two time agencies of the United States: a Department of Commerce agency, the National Institute of Standards and Technology (NIST) and its military counterpart, the U.S. Naval Observatory (USNO). The official time can be found at: www.time.gov/timezone.cgi?Pacific/d/-8/java. All date and time stamps will be recorded in Pacific Daylight Savings Time (PDT).

Table 7 summarizes the accuracy and reporting limits of the equipment that will be utilized for this study. Certain instruments are used exclusively for water temperature and others for air as noted in the table. A WTW 340i multi-meter will be used to measure water conductivity and temperature.

Table 7: Summary of measurement quality objectives and manufacturer measurement limits of field equipment.

Measurement/Instrument Type	Accuracy (% Deviation from True Value)	Required Reporting Limits
Stream Velocity Marsh McBirney Flo-Mate model 2000	±2% of reading; 0.1 ft/s 5%-8% measurement error	0.05 ft/s
Continuous Temperature Hobo Water Temp Pro	±0.2°C at 0 to 50°C (± 0.36°F at 32° to 122°F)	0.2°C for water temperature
Continuous Temperature StowAway Tidbits -5°C to +37°C model	±0.4°F (±0.2°C) at +70°F	0.2°C for water temperature
Continuous Temperature StowAway Tidbits -20°C to +50°C model	±0.8°F (±0.4°C) at +70°F	0.4°C for air temperature
Hobo Pro Relative Humidity	±3% RH	n/a
Hobo Wind speed/direction smart sensor	±0.5 m/s (±1.1 mph) for <17 m/s (<38 mph) ±3% for 17 to 30 m/s (38 to 67 mph) ±4% for 30 to 44 m/s (67 to 99 mph)	n/a
Hobo Barometric Pressure smart sensor	±1.5 mbar (0.044 in Hg) over full pressure range at +25°C (+77°F)	n/a
Hobo Rain Gage smart sensor	±1.0% at up to 20 mm or 1" per hour	n/a
Hobo Silicon Pyranometer smart sensor	±10 W/m2 or ±5%, whichever is greater in sunlight. Additional temperature induced error ±0.38 W/m^2 /°C from 25°C (0.21 W/m^2/°F from 77°F)	n/a

Comparability

If the mean difference between the NIST-certified thermometer and the thermal data loggers differs by more than the manufacturer's specifications during the pre-study calibration, the thermal data logger will not be used during field work.

Representative data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries, and seasonal variation of instream flow and temperatures in the basin. Extra thermistors will be taken in the field during site visits and surveys to minimize data loss due to damaged or lost equipment.

Quality Control Procedures

The Onset StowAway Tidbits© and Hobo Water Temp Pro© instruments will be calibrated pre- and post-study in accordance with Ecology temperature monitoring protocols (Ward, 2003) to document instrument bias and performance at representative temperatures. A NIST certified reference thermometer will be used for the calibration. At the completion of the monitoring, the raw data will be adjusted, based on the pre- and post-study calibration results, if the temperature for the instrument differs from the NIST certified thermometer by more than the manufacturer stated accuracy of the instrument (i.e. by more than ±0.2°C or ±0.4°C). The mean difference of the pre- and post-study calibration values from the NIST thermometer reading will be used for calculating the adjusted temperature.

Variation for field sampling of instream temperatures will be addressed with a field check of the data loggers with a reference temperature measurement at all thermograph sites upon deployment, download events, and at TidBit removals at the end of the study period. Variation for field sampling of instream temperatures and potential thermal stratification will be addressed with a field check of stream temperature at all monitoring sites upon deployment, during regular site visits, and during instrument retrieval at the end of the study period. Air temperature data and instream temperature data for each site will be compared to determine if the instream TI was exposed to the air due to stream stage falling below the installed depth of the stream TI.

Stream velocity instruments such as the Marsh McBirney Flo-Mate model 2000 is factory calibrated once every two to three years. The instrument is also manually zeroed to still water several times throughout the sampling season.

Data Verification and Validation

Field notebooks will be checked for missing or improbable measurements before leaving each site. Field-generated data will be entered into EXCEL® spreadsheets (Microsoft, 2001) as soon as practical after returning from the field. The EXCEL® Workbook file will be labeled *Draft* until data verification and validity are completed. Data entry will be checked by the field assistant against the field notebook data for errors and omissions. Missing or unusual data will be brought to the attention of the project manager for consultation. Valid data will be moved to a separate file labeled *Final*.

After data validity and data entry tasks are completed, all field and flow data will be entered into a file labeled "FINAL," and then into the EIM system. EIM data will be independently reviewed by another EA Program field assistant for errors at an initial 10% frequency. If significant entry errors are discovered, a more intensive review will be undertaken. At the end of the field collection phase of the study, the data will be complied in a data summary. Quarterly progress reports will be available every three months throughout the five-month data collection period of the project.

Data Analysis and Use

Data analysis will include evaluation of data distribution characteristics and, if necessary, appropriate distribution of transformed data. Streamflow data will be frequently reviewed during the field data survey season to check longitudinal water balances.

Project Organization

The roles and responsibilities of Ecology staff are as follows:

- *Nicoleta Cristea, Environmental Assessment Program, Nonpoint Studies Unit, Technical Project Manager*: Responsible for overall project management of the study, including study design. Responsible for development of TMDLs for temperature, including model development and writing the technical report.
- *James Kardouni, Environmental Assessment Program, Nonpoint Studies Unit, Field Investigator:* Responsible for assisting with development of the temperature study, QA Project Plan, temperature field data collection and data entry to EIM, and writing sections of the technical report related to temperature data collection and data quality review.
- *Ralph Svrjcek, Overall TMDL Project Lead, Water Quality Program, Northwest Regional Office*: Acts as point of contact between Ecology technical study staff and interested parties. Coordinates information exchange, technical advisory group formation, and organizes meetings. Supports, reviews, and comments on QA Project Plan and technical report. Responsible for implementation, planning, and preparation of TMDL document for submittal to EPA.
- *Dave Garland,* Unit Supervisor, *Water Quality Program, Northwest Regional Office*: Responsible for approval of TMDL submittal to EPA.
- *Will Kendra, Section Manager, Environmental Assessment Program, Watershed Ecology Section*: Responsible for approval of project QA Project Plan and final TMDL report.
- *Darrel Anderson, Unit Supervisor, Environmental Assessment Program, Nonpoint Source Studies Unit:* Reviews and approves the project QA Project Plan, staffing plan, final TMDL report, and technical study budget.
- *Karol Erickson***,** *Unit Supervisor, Environmental Assessment Program, Water Quality Studies Unit*: Reviews and approves the project QA Project Plan, staffing plan, final TMDL report, and technical study budget.
- *Chuck Springer, Environmental Assessment Program, Stream Hydrology Unit*: Responsible for the deployment and maintenance of continuous flow loggers and staff gauges. Responsible for producing records of hourly flow data at select sites for the study period.
- *Bill Kammin***,** *Ecology Quality Assurance Officer, Environmental Assessment Program:* Reviews QA Project Plan and all Ecology quality assurance programs. Provides technical assistance on QA/QC issues during the implementation and assessment of the project.

Project Schedule

Environmental Information System (EIM) Data Set	
EIM Data Engineer	James Kardouni
EIM User Study ID	NCRI0001
EIM Study Name	Snoqualmie River Temperature TMDL
EIM Completion Due	June 1, 2008
Quarterly Reports	
Report Author Lead	Nicoleta Cristea
Schedule:	
1st Quarter Report	November 30, 2006
Final Report	
Report Author Lead	Nicoleta Cristea
Schedule:	
Report Supervisor Draft Due	September 2007
Report Client/Peer Draft Due	October 2007
Report External Draft Due	November 2007
Report Final Due (original)	February 2008

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