South Fork Nooksack River Temperature Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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Water Quality Improvement Report and Implementation Plan

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Abstract

Since 1996, the Washington State Department of Ecology (Ecology) has determined that portions of the South Fork Nooksack River and some of its tributaries had temperature levels greater than what Washington State allows in its fresh waters. High water temperatures are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. To address this issue Ecology, the Nooksack Indian Tribe, the Lummi Nation, and the U.S. Environmental Protection Agency (EPA) cooperated on development of a temperature total maximum daily load (TMDL) for the South Fork Nooksack River. A TMDL is required under the federal Clean Water Act for waters that do not meet state water quality standards.

The TMDL study area encompasses the South Fork Nooksack River watershed, which is in Whatcom and Skagit Counties of Washington and in Water Resource Inventory Area (WRIA) 01. The Nooksack River watershed, including the South Fork Nooksack River, Middle Fork Nooksack River, North Fork Nooksack River, and associated tributaries, provides migration spawning, incubation, rearing, and foraging habitats for all nine native Pacific Northwest salmonid species.

This water quality improvement report discusses the technical study and analysis, along with recommendations for restoring the water body. It includes an implementation plan that lays out roles, potential funding, and responsibilities for this process. The primary component of the implementation plan involves the protection and restoration of riparian shade along the South Fork Nooksack River and its tributaries. The report includes a wasteload allocation for temperature for one fish hatchery. An additional number of activities are recommended including forestry best management practices, flood plain reconnection, and instream restoration activities that will help provide cool water refugia.

This TMDL study also incorporates the results of an EPA pilot research project to consider how projected climate change impacts can be incorporated into the TMDL and implementation plans.

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  - Steve Hood
  - Karol Erickson
  - Stephanie E. Brock
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  - Hope Herron
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Steve Kline was a researcher with EPA's Office of Research and Development, and inspired portions of this project. He directed work addressing how climate change would affect water temperature in the SF Nooksack River. Those documents, published by EPA in October 2016, helped frame important steps in implementation, and highlight the urgency of addressing the temperature of the water in the South Fork Nooksack River (EPA/600/R-14/153 and EPA/600/R-14/233). Steve retired shortly after ORD published the reports. Unfortunately, Steve passed away before we could publish our Final South Fork Nooksack Temperature TMDL. We are sorry that he cannot join us in celebrating the completion of the project.

Executive Summary

Introduction

The 2012 water quality assessment by the Washington State Department of Ecology (Ecology) determined that portions of the South Fork Nooksack River (SFNR) and some of its tributaries had temperature levels greater than what Washington State allows in its fresh waters (some of these portions were determined to be impaired during prior assessments in 1996 and 1998). High water temperatures are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. To address this issue, Ecology, the Nooksack Indian Tribe, the Lummi Nation, and the U.S. Environmental Protection Agency (EPA) cooperated on development of a temperature total maximum daily load (TMDL) for the SFNR. This water quality improvement report contains the study, along with recommendations for restoring the water body, and an implementation plan that lays out roles and responsibilities and potential funding sources for this process.

The purpose of this water quality improvement report is to address temperature problems in the SFNR watershed so that water quality is improved and designated uses are restored and protected. More specifically, the goal is for the river and its tributaries to meet the Washington State water quality standards for temperature. The TMDL analysis uses the existing data and a calibrated model to describe temperature processes in the watershed, determine the loading capacity for temperature, and set load allocations, wasteload allocations, and a margin of safety.

Why did we develop a total maximum daily load (TMDL)?

The federal Clean Water Act (CWA) requires that a TMDL be developed for each of the water bodies on the 303(d) list. The 303(d) list is a list of water bodies, which the CWA requires states to prepare, that do not meet 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. This TMDL focuses on temperature. Potential fine sediments impairments were not addressed and may affect water temperature. Once the TMDL is developed Ecology, with the assistance of local governments, agencies, and the community prepares an implementation plan that describes actions to control the pollution, and a monitoring plan to assess the effectiveness of the water quality improvement activities.

Ecology gave a very high priority to the South Fork of the Nooksack River because of the spring Chinook salmon run that it supports. This run is one of the most stressed of the Chinook salmon in the Evolutionarily Significant Units (ESU) protected by the endangered species act in the designation of essential habitat. If we do nothing to improve the temperature, we expect climate change to warm the river to lethal temperatures through much of the length of the river, and expect the duration of lethal temperatures to be longer.

Watershed description

The TMDL study area encompasses the SFNR watershed, which is in Whatcom and Skagit Counties of Washington (Figure ES-1) and in Water Resource Inventory Area (WRIA) 01. The river flows to the mainstem Nooksack River, which flows through Nooksack Indian Tribe trust lands and through the Lummi Nation Reservation before discharging into Bellingham Bay.

The Nooksack River watershed, including the South Fork Nooksack River, Middle Fork Nooksack River, North Fork Nooksack River, and associated tributaries, provides spawning migration, incubation, rearing, and foraging habitats for all nine native Pacific Northwest salmon and trout species. These fish species are highly valued by the many state residents that depend on them for subsistence, cultural, recreational, or economic reasons. The Lummi Nation and Nooksack Indian Tribe rely on salmon in the Nooksack River watershed for ceremonial, subsistence, and commercial purposes. Local residents also rely on salmon. Many salmonid populations have diminished, however, to 8% of levels in late 19th century. (Lackey, R. 2000.).

Nooksack River early run (a.k.a. spring Chinook salmon) Chinook, bull trout, and steelhead populations comprise components of the Puget Sound Chinook and Puget Sound Steelhead ESUs, and the Coastal-Puget Sound Distinct Population Segment (DPS), all of which are listed as threatened under the federal Endangered Species Act (ESA). Improving water quality in the SFNR watershed is necessary to support the recovery of threatened cold water fish species that migrate, spawn, rear, or live there.

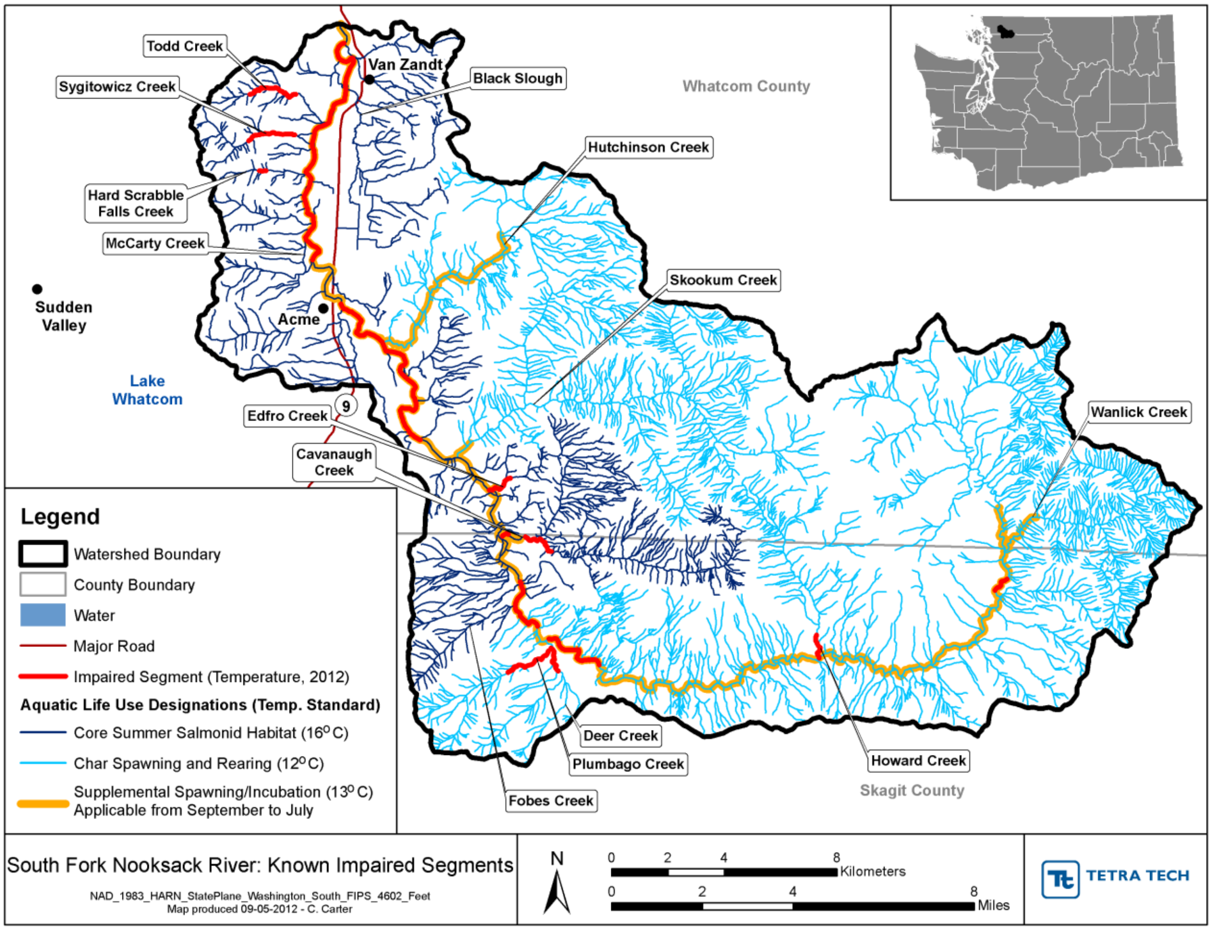


Figure ES-1. 303(d) listed segments in the South Fork Nooksack River watershed.

TMDL analysis

A TMDL analysis was developed to evaluate compliance with state water quality standards for temperature in the SFNR watershed and to support development of a Water Quality Improvement Report (WQIR) and Implementation Plan (IP). The analysis utilized steady state models (Shade and QUAL2Kw) to characterize stream temperatures and processes governing the thermal regime during critical summer conditions, system potential vegetation conditions (approximating the natural temperature conditions), and for a number of additional scenarios based on technical information provided by the Nooksack Indian Tribe. The models form the technical foundation for determining loading capacity to meet temperature water quality criteria and protect designated uses, and determine the allocation of those loads to point and nonpoint sources.

What needs to be done in this watershed?

The temperature TMDL for the SFNR represents the maximum amount of heat that a water body can receive and still meet the temperature standards, and an allocation of that amount to the contributing sources. The allocations take the form of a load allocation for nonpoint sources and a wasteload allocation for point sources.

Load allocations for the SFNR temperature TMDL establish limits on the allowable heat load from nonpoint sources. The TMDL quantifies heat loads in terms of Watts/m^2 and as effective shade. Effective shade allocations control delivery of direct solar radiation to the stream, both to the mainstem and its tributaries. This direct solar radiation is considered the largest source of heat. Load allocations (both effective shade and heat load) for the mainstem are provided in Appendix D. The effective shade deficit (the difference between existing and target effective shade) along the mainstem beginning at the confluence with Wanlick Creek by 1,000-m increments is shown graphically in Figure ES-2. Load allocations (both effective shade and heat load) for the tributaries are provided in Appendix D.

Shade deficits range from 4.0 to 32.0%, with an average of 13.4%. For the tributaries to the SFNR, which are not modeled individually, the load allocations for effective shade are represented based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum 100-year system potential vegetation (SPV) conditions. The 100-year system potential vegetation is used because there are published values for tree heights based on soil type at specific locations for 100 years of growth. When shade targets are met, Ecology will assess whether or not the increase in shade results in achievement of the water quality criteria or whether further action is needed. The shade targets and thermal loading for the mainstem are provided in Appendix C. The shade targets and thermal loading for the tributaries are provided in Appendix D of this document.

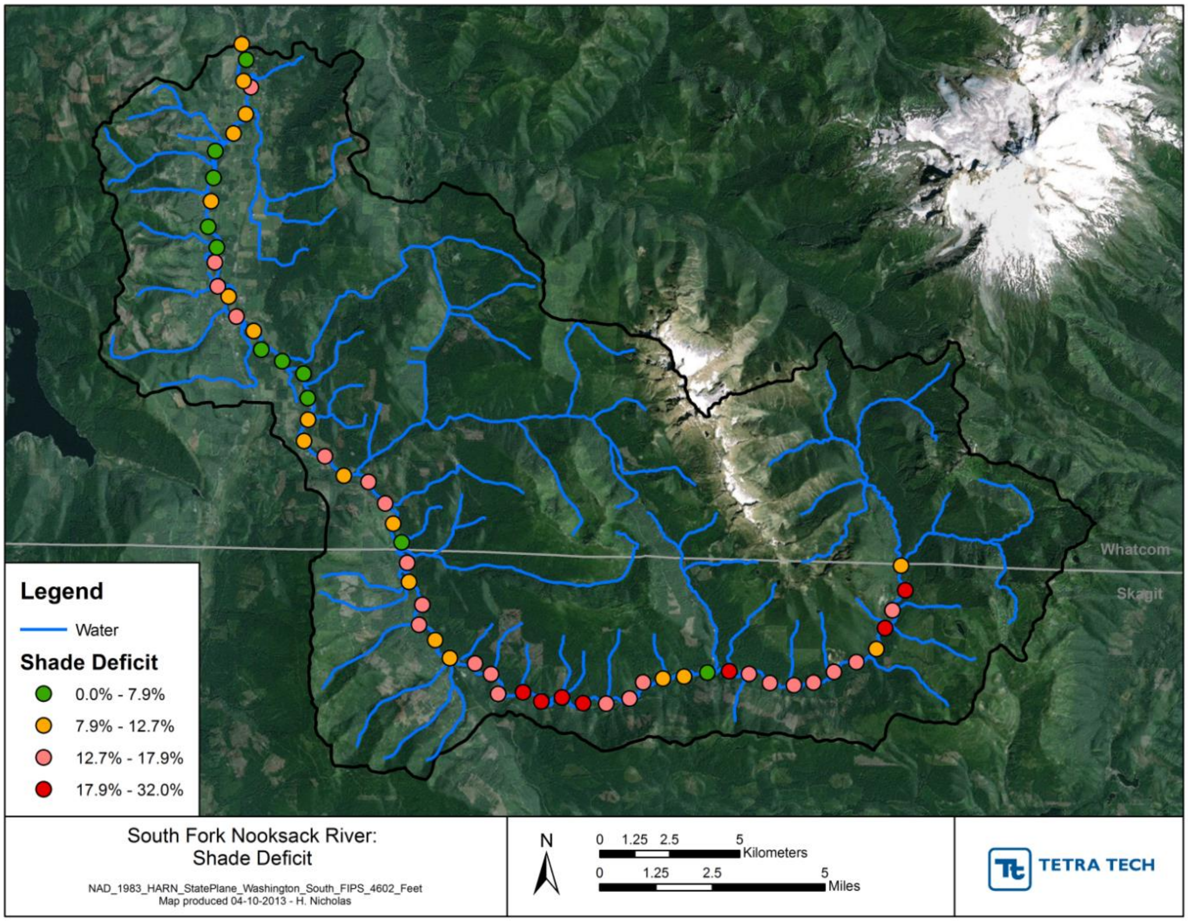


Figure ES-2. Effective shade deficit by 1,000-m increments.

The shade allocations for the SFNR watershed represent shade levels produced by 100-year riparian vegetation. The riparian vegetation will reduce direct solar radiation to the stream and riparian area, resulting in lower stream temperatures. An additional benefit of an improved microclimate is also expected. There might also be indirect benefits of a more stable channel because of the protection that a mature buffer would provide. In addition, riparian shading along tributaries of the SFNR is expected to reduce the temperature of tributaries entering the SFNR, contributing to additional cooling.

Although this temperature TMDL is heavily focused on the impact of stream shading, other management actions that can affect geomorphology, sediment loading, groundwater inflows, and hyporheic exchange, are also recommended to reduce stream temperatures.

Discharges to state waters are regulated through the National Pollutant Discharge Elimination System (NPDES). Facilities with an NPDES permit are considered point sources. The Washington State water quality standards (Washington Administrative Code [WAC] 173-201A) restrict the amount of warming that point sources can cause when river or stream temperatures are cooler than the numeric criteria. Wasteload allocations (“$\mathbf{T_{NPDES}}$”) for the one NPDES discharger in the SFNR watershed are shown in Table ES-1.

Table ES-1. Wasteload allocations for NPDES permitted dischargers.

NPDES facility; permit #	7Q10[a] (cfs)	Effluent Flow - Current[b]/Design (cfs)	Effluent Flow - Design (cfs)	Water Quality Criteria (°C)	Chronic Dilution Factor	Wasteload Allocations T_{NPDES} (°C)
Skookum Creek Fish Hatchery; WAG130017	91.1	10.2 (6.6 mgd)	Not Available (assume equals current)	16 (Jul 1 to Sept 1) 13 (Sept 1 to Jul 1)	3.2	16.7 (Jul 1 to Sept 1) 13 .7 (Sept 1 to Jul 1)

[a] Hatchery discharges upstream from U.S. Geological Survey at Saxon Road. Value used for wasteload allocation is assumed to be the 7Q10 from USGS 12209000 at Wickersham plus USGS 12209490 at Skookum.
[b] Based on the highest average monthly summer flow for 2010 and 2011, which occurred in September.

CWA 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 from the Code of Federal Regulations (CFR) 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)]. The SFNR watershed experiences seasonal variation with cooler temperatures occurring in the winter and warmer temperatures in the summer. Monitoring data show that 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. A check against temperatures when the more stringent temperature applies in fall through spring confirmed that meeting mid-summer temperature criteria is the critical condition. Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model.

Implementation summary

An implementation strategy and plan was developed to implement this TMDL for the SFNR. It describes the roles and authorities of cleanup partners, potential funding sources, monitoring, adaptive management, and timeframes for implementation, along with the programs or other means through which they will address these water quality issues. It prioritizes specific actions planned to improve water quality and achieve water quality standards.

A number of local, tribe, state, and federal organizations will coordinate and help to implement this TMDL. They include:

1. Whatcom County (regulatory authority): enforcement of Critical Areas code, and Shoreline Master Program
2. Skagit County: (regulatory authority): enforcement of Critical Areas code, and Shoreline Master Program
3. Nooksack Indian Tribe: technical assistance; research and problem identification; planning implementation and monitoring of salmon recovery actions, as well as watershed and water quality monitoring; projected climate change response and adaptive management.

4. Lummi Nation: technical assistance and special project support for riparian and in-stream improvement projects and watershed monitoring activities.
5. Ecology (regulatory authority): technical assistance, project development and coordination, Centennial and Section 319 Grant funding, State Revolving Fund Loan program, wetlands protection, regulation of NPDES permitted discharges.
6. Department of Natural Resources: Implementation of Forest Practice (WAC 222) Rules which have adopted goals of the forest and fish report pursuant to RCW 77.85 requiring protection of riparian zones, and land management.
7. EPA (regulatory authority): technical assistance, regulation of NPDES permitted discharges for facilities located in within Indian Country.
8. U.S. Forest Service (USFS): technical assistance, management of forest service lands

A wide range of implementation activities will be necessary to achieve compliance with water quality standards in the SFNR watershed. Table ES-2 lists ongoing and anticipated implementation activities. Each of these is discussed in more detail in the document.

Table ES-2. Implementation activities for the South Fork Nooksack River.

Implementation Activity	Agency
Forestry best management practices	USFS, Washington State Department of Natural Resources, Whatcom and Skagit counties
State Environmental Policy Act (SEPA) review and land use planning	SEPA lead agencies, local land use agencies
Protection and restoration of Critical Areas and shorelines	Whatcom and Skagit counties
WRIA 1 Salmonid Recovery Plan	NOAA, , WRIA 1 Salmon Recovery Board (Nooksack Indian Tribe, Lummi Nation, WDFW, Whatcom County, Cities of Bellingham, Lynden, Ferndale, Blaine, Everson, Nooksack and Sumas).
Climate Change Qualitative Assessment recommendations addressing barrier removal, floodplain reconnection, vertical connectivity, stream flow regimes, sediment reduction, riparian restoration, instream rehabilitation, and nutrient enrichment	Nooksack Indian Tribe, Lummi Nation, EPA, Ecology

The success of this TMDL project will be assessed using monitoring data from streams in the watershed.

Climate change considerations

This TMDL study incorporates the results of an EPA pilot research project to consider how projected climate change impacts can be incorporated into the TMDL and influence implementation plans, including salmon habitat restoration planning, and ESA recovery plans. The pilot project was conducted by EPA Region 10 and EPA's Office of Research and Development (ORD) and Office of Water (OW), the Nooksack Indian Tribe, and its partners, and consists of a Quantitative Assessment and a Qualitative Assessment, each of which are summarized in this TMDL.

In the Quantitative Assessment, the calibrated QUAL2Kw stream temperature model developed for the TMDL was used to estimate the impacts of potential future climate changes on the stream temperature with and without the restoration of riparian forest vegetation. A new set of boundary conditions were developed for QUAL2Kw by downsizing data from low, medium and high impact Global Climate Model scenarios for 2020, 2040 and 2080.

The QUAL2Kw model simulations suggest that, without restoration of riparian shade, maximum water temperatures during critical summer low-flow conditions could increase by almost 6°C by the 2080s. Restoration of full system potential riparian shading at 100 years can help buffer against temperature increases. However, even with system potential shade, the critical condition maximum 7-day average stream water temperatures are expected to increase by 1.1 to 3.6° C by the 2080s. In conjunction with this increase, the percent of stream miles in which critical condition water temperatures exceed levels identified as potentially lethal to salmon is predicted by the model simulations to increase dramatically - from about 18% at present to between 60% and 90% in the 2080s.

The Qualitative Assessment evaluates existing limiting physical factors that affect salmonid habitat and survival. Those factors include legacy impacts of land use and management, and impacts of climate change on salmonid species. There are other restoration actions and strategies beyond riparian shading that are expected to protect, improve and enhance salmon recovery in the SFNR under predicted climate change conditions. The restoration activities with the highest potential include:

- promote river longitudinal connectivity
- improve floodplain reconnection
- restore streamflow regimes
- reduce erosion and sediment delivery to the river
- restore watershed function and process
- restore riparian functions
- continue to implement instream restoration and rehabilitation
- develop and implement planning activities for the watershed
- monitoring of restoration actions and adaptive management

Why this matters

Water temperature influences what types of organisms can live in a water body. Cooler water can hold more dissolved oxygen that fish and other aquatic life need to breathe. Warmer water holds less dissolved oxygen. Threatened and endangered salmon need cold, clean water to survive. One way to cool water temperature is to shade the water body and tributaries by adding or retaining streamside vegetation. In addition, other watershed and instream practices can have a positive influence on streams and aquatic life. This study provides important information on historical and current activities impacting streams, as well as recommended strategies for restoration in the face of climate change.

Modeling of the effects of climate change indicate that stream temperatures will warm further between 3.4 to 5.9 °C by the 2080s without any change. Providing System Potential shade reduces that increase to 1.1 to 3.6 °C. At the most optimistic end of the range, 1.1°C is less than

3.4°C that is less warming and less harmful. At the least optimistic end of the range, 3.6°C is less than 5.9°C, so over the entire range of estimates more shade will be reduce thermal stress. Additional measures such as deeper channels, improved hyporheic flow, and improved groundwater connectivity could maintain current temperatures into the future, allowing fish additional time to adapt to warming conditions.

What is a Total Maximum Daily Load (TMDL)

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

Federal Clean Water Act requirements

The Clean Water Act (CWA) established a process to identify and clean up polluted waters. The CWA requires each state to 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 CWA 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 WQA. 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 they:

- 4a – Have a TMDL approved by EPA.
- 4b – Have a pollution control program in place.
- 4c – Are impaired by a non-pollutant such as low water flow, dams, or culverts.

Category 5 – Polluted waters on the 303(d) list.

Further information is available at Ecology’s Water Quality Assessment website (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d).

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

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community, 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 on the draft TMDL, Ecology addresses the comments as appropriate. Then, Ecology submits the WQIR/IP to the U.S. Environmental Protection Agency (EPA) for review and approval.

Who should participate in this TMDL process?

Nonpoint source pollutant load targets have been set in this TMDL. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have the potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices (BMPs) to reduce effects on water quality. The area subject to the TMDL, the South Fork Nooksack River (SFNR) watershed, is shown in Figure 1.

Similarly, all point source dischargers in the watershed must also comply with the TMDL.

Elements the Clean Water Act requires in a TMDL

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

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 source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (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 (non-regulated Municipal Separate Storm Sewer Systems (MS4s)), residential, forestry, or farm runoff, the cumulative share is called a *load allocation*.

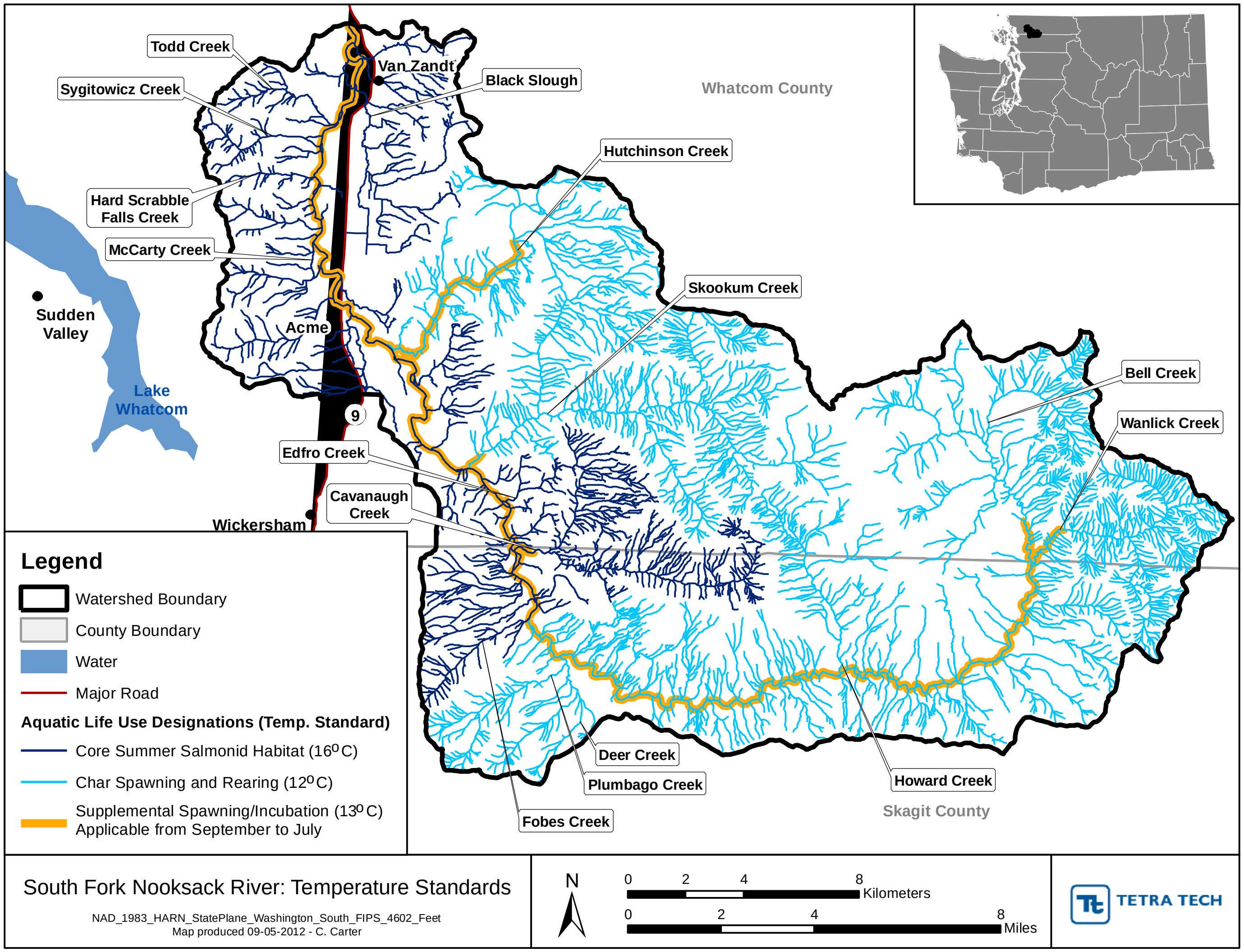


Figure 1. Study area and temperature standards for the South Fork Nooksack River watershed.

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.

Surrogate measures

EPA regulations [40 Code of Federal Regulations (CFR) 130.2(i)] allow TMDLs to be expressed in terms of mass per time, toxicity, or other appropriate measures (“surrogates”). In this TMDL, high temperature is the water quality parameter of concern, and heat is the pollutant of concern. Ecology has determined that heat from human-caused increases in solar radiation is the major source of temperature impairments in the SF Nooksack watershed. Heat loads can be measured in energy per area or the shading needed to block the energy from reaching the stream. In order to establish meaningful and measurable pollutant-loading targets, this TMDL contains allocations for heat loads expressed as units of “energy” (watts / m^2) as well as “effective shade” targets. Effective shade targets are useful in translating solar radiation loads into streamside vegetation objectives.

Why Ecology Conducted a TMDL Study in this Watershed

Background

The SFNR watershed is impaired by high water temperatures. High water temperatures are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. The EPA, Ecology, the Nooksack Indian Tribe, and the Lummi Nation are cooperating on developing a temperature TMDL for the SFNR.

The TMDL study area encompasses the SFNR watershed, which is in Whatcom and Skagit Counties of Washington (Figure 1). The river flows to the mainstem Nooksack River, which flows through Nooksack Indian Tribe trust lands and the Lummi Indian Reservation before discharging into Bellingham Bay.

The Nooksack River watershed, including the SFNR, Middle Fork Nooksack River, North Fork Nooksack River, and associated tributaries, provides migration spawning, incubation, rearing, and foraging habitats for nine native Pacific Northwest salmonid. These fish species are highly valued by the many state residents that depend on them for subsistence, cultural, recreational, or economic reasons. The Lummi Nation and Nooksack Indian Tribe rely on salmon in the Nooksack River watershed for ceremonial, subsistence, and commercial purposes. Local residents also rely on salmon. Yet, many salmonid populations have diminished to 8% of levels in late 19th century. (Lackey, R. 2000.).

Nooksack River early run (a.k.a. spring Chinook salmon) Chinook, bull trout, and steelhead populations comprise components of the Puget Sound Chinook Evolutionarily Significant Unit (ESU), Puget Sound Steelhead ESU, and Coastal-Puget Sound Distinct Population Segment (DPS), all of which are listed as threatened under the federal Endangered Species Act (ESA). Improving water quality in the SFNR watershed is necessary to support the recovery of threatened cold water fish species that migrate, spawn, rear, or live there.

This study predicts that more of the river will reach lethal temperatures in decades unless substantial actions are taken to reduce temperatures in the river. By the 2080's almost all of the river could have lethal temperatures if no action is taken. And, the duration of lethal conditions will be longer. However, salmon are very adaptable and have relatively short life spans. Significant shifts in population genetics can occur in four decades, ten generations (Suk, Ho et. al. 2012). Early implementation actions are our chance to preserve enough of the fish population so the fish have a chance to adapt.

Each study conducted by Ecology requires an approved Quality Assurance Project Plan (QAPP). The QAPP describes the objectives of the study and the procedures to be followed to achieve those objectives (Lombard and Kirchmer, 2004). A QAPP for this project was finalized in 2012 (Kennedy and Butcher, 2012). The study outputs are designed to support the development of corrective actions needed to meet applicable water quality standards for river water temperatures, which will be detailed in a TMDL WQIR and IP. Those will help guide Ecology and other stakeholders in our work to restore and protect aquatic life uses.

Impairments addressed by this TMDL

Washington State established water quality standards to protect designated uses. On the basis of existing data, 12 segments on the SFNR and 8 tributary segments are identified as being impaired for temperature on Washington's 2012 303(d) list (Table 1; Figure 2). These impairments are addressed in this TMDL. As is typical for a watershed-based TMDL, identification of impaired waters is limited by available data; and there are portions of the watershed for which no data are available. It is possible that additional segments of the river and tributaries may also be impaired. For that reason, wasteload allocations and load allocation are set to ensure all segments will achieve water quality standards.

Limited sampling data indicate that temperature impairments might also exist in Standard Creek, Jones Creek, and Tawes Creek. These three tributaries to the South Fork Nooksack are identified as *Waters of Concern* (i.e., Category 2) on the 2012 303(d) list. Figure 2 shows the distribution of 303(d) listed segments in the SFNR watershed.

Table 1. Study area water bodies on the 2012 303(d) list for temperature[1].

Water Body	Listing ID	Township – Range – Section
South Fork Nooksack River	7112	38N-5E-7
South Fork Nooksack River	7113	36N-5E-12
South Fork Nooksack River	35244	36N-7E-3
South Fork Nooksack River	35246	36N-6E-18
South Fork Nooksack River	36838	37N-5E-9
South Fork Nooksack River	36839	38N-5E-31
South Fork Nooksack River	36840	38N-5E-17
South Fork Nooksack River	39232	37N-5E-21
South Fork Nooksack River	42100	38N-5E-19
South Fork Nooksack River	42101	38N-5E-30
South Fork Nooksack River	42103	37N-5E-8
South Fork Nooksack River	42111	38N-5E-18
Edfro Creek	35238	37N-5E-26
Cavanaugh Creek	7064	37N-5E-35

[1] In the draft South Fork Nooksack River Temperature TMDL, listings 36846 and 42105 were included in Table 1. These listings have been rolled into 36840 and 42103 respectively.

Water Body	Listing ID	Township – Range – Section
Hard Scrabble Creek	37815	38N-4E-25
Howard Creek	7080	36N-6E-13
Plumbago Creek	42336	36N-5E-13
Roaring Creek	7119	36N-6E-18
Sygitowicz Creek	37814	38N-4E-24
Todd Creek	37813	38N-4E-13

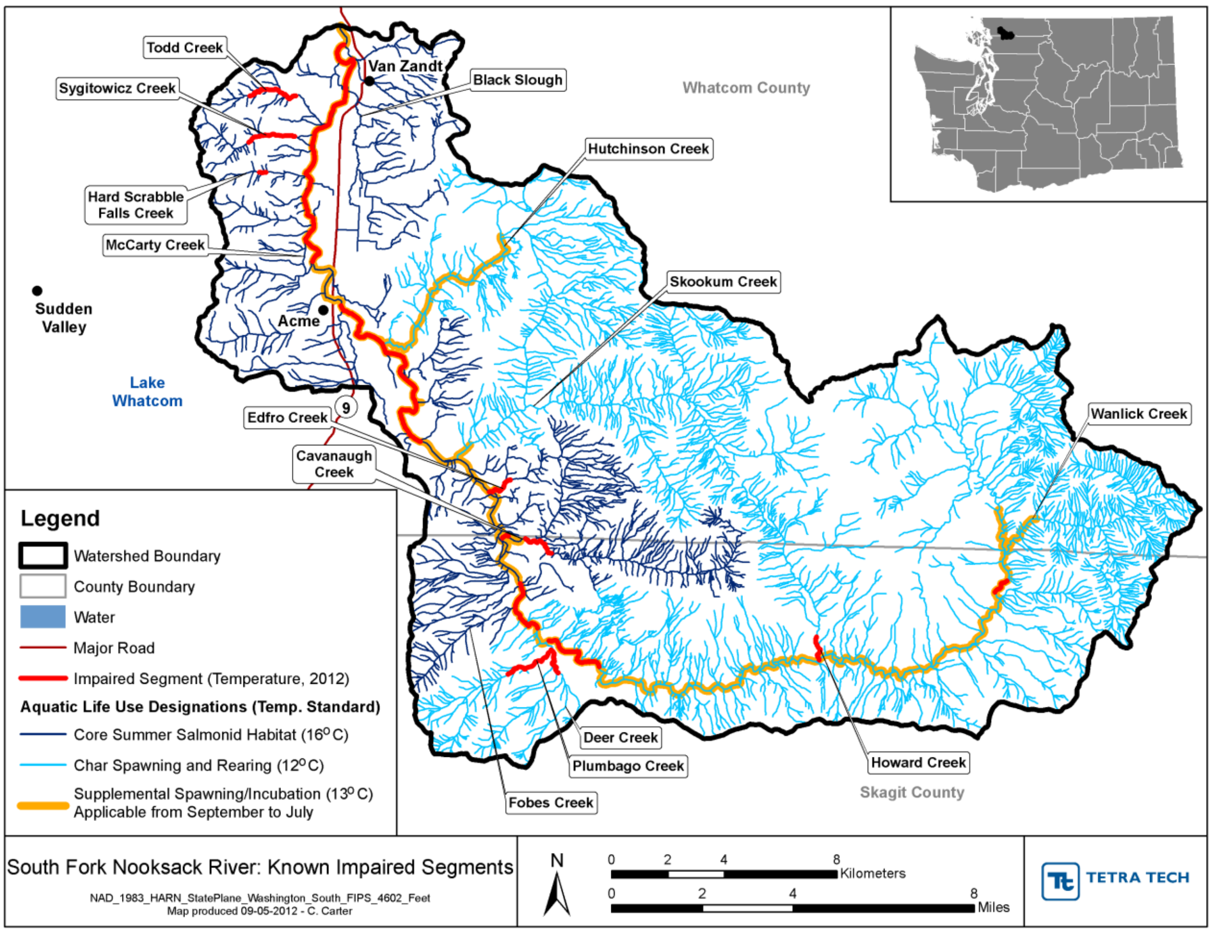


Figure 2. 303(d) listed segments in the South Fork Nooksack River watershed.

Water Quality Standards and Numeric Targets

The Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), are the basis for protecting and regulating the quality of surface waters in Washington State. The State's water quality standards include:

- Designated uses such as fishing, swimming, and aquatic life habitat.
- Numeric and narrative water quality criteria limits to protect the uses.
- Policies, such as antidegradation, to protect higher quality waters from being further degraded.

This section provides Washington State water quality information and those standards applicable to the SFNR watershed.

In July 2003, Ecology made significant revisions to the state's surface water quality standards (Chapter 173-201A WAC). These changes included restructuring the system that the state uses to designate uses for protection by water quality criteria (e.g., temperature, dissolved oxygen, turbidity, bacteria). Ecology also revised the numeric temperature criteria 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).

Ecology submitted the revised water quality standards regulation to address temperature to EPA for federal approval in July 2003. EPA approved the changed uses and criteria on February 11, 2008. The revisions to the existing standards are online at Ecology's water quality standards website: https://ecology.wa.gov/Water-Shorelines/Water-quality/Freshwater/Surface-water-quality-standards.

Segments of the SFNR and its tributaries are identified on the current Washington State 303(d) list as being impaired by excess temperature. Temperature affects the physiology and behavior of fish and other aquatic life. It also affects the physical and biological properties of the water body. For example, higher stream temperatures are generally associated with lower levels of dissolved oxygen in the water. Temperature is an influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

Temperatures in streams fluctuate over the day and year in response to changes in solar energy inputs, meteorological conditions, river flows, groundwater input, and other factors. Washington's water quality criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body. The 7-DADMax metric was determined by scientists involved in the development of EPA's Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (2003[2]) to include an adequate magnitude and duration (averaging period) to protect salmonids. The 7-DADMax temperatures represent conditions in the dominant aquatic habitat, therefore it is assumed that aquatic species have access to cold water refugia where they can reside in water that is cooler than the 7-

[2] Available at: https://www.epa.gov/nscep by searching on the publication number "910B03002".

DADMax temperatures. The 7-DADMax temperature criterion also assume that colder temperatures are available to protect fish at night.

In the water quality standards (WQS), aquatic life use categories are described using key species (e.g., salmonid or char versus warm-water species) and life-stage conditions (e.g., spawning versus rearing) [WAC 173-201A-200]. The temperature criteria established to protect these uses are described in Table 200 (1)(c) of the WQS and include numeric criteria of 12 °C for Char Spawning and Rearing; 16 °C for Core Summer Salmonid Habitat; both of which are applied throughout the entire year unless the supplemental criteria also applies. The 13 °C supplemental standard for spawning and incubation protection of salmonid species (WAC 173-201A-200 (1)(c)(B)(iv)) is effective seasonally from early fall to late spring (exact dates are specific to each stream) (Ecology, 2011). Temperatures are not to exceed the criteria at a probability frequency of more than once every 10 years on average (WAC 173-201A-200 (1)(c)(iii)).

Special consideration is also required to protect the spawning and incubation season of salmonid species. Where it has been determined that the lower temperatures are necessary to protect spawning and incubation, 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; and (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. Currently, Chapter 173-201A WAC specifies 13 °C in the South Fork and Hutchinson Creek from September 1 to July 1, (Ecology Publication 06-10-038).

While the criteria apply throughout a water body, there may be site-specific features, including 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 are taken from well-mixed portions of rivers and streams. For similar reasons, samples are not to be taken from anomalously cold areas such as at discrete points where cold groundwater flow into the water body.

For the area of the SFNR Watershed covered by this TMDL, the designated aquatic life uses to be protected are *core summer salmonid habitat*, *char spawning and rearing,* and *salmonid spawning and incubation.* The numeric water quality criteria established to protect those uses are summarized in Table 2.

Table 2. Washington State temperature criteria for protection of designated aquatic life uses in the South Fork Nooksack River watershed.

Use Classification	Criteria
Core summer salmonid habitat, spawning, rearing, and migration	$\leq$ 16 °C 7-DADMax[a,b]
Char spawning and rearing	$\leq$12 °C 7-DADMax[a,b]
Supplemental salmonid spawning and incubation	$\leq$ 13 °C 7-DADMax[a,b] (Sept 1–Jul 1)

[a] 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
[b] A human-caused variation within the above range of less than 0.3 °C for temperature is acceptable.

Washington State uses the criteria described previously to ensure full protection for its designated aquatic life uses. The standards recognize, however, that waters display thermal heterogeneity – some are naturally cooler, and some are naturally warmer than the numeric criteria. The water quality standards define a natural condition as the condition before any human-caused pollution. When the natural conditions of a water body are warmer than the previously-described numeric criteria, the state limits the allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3 °C (0.54 °F) increase above the warmer natural temperature condition.

This TMDL report estimates whether the water body is naturally warmer or naturally cooler than the criteria, using a computer model that simulates the physical and atmospheric processes affecting stream temperatures. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the standards state that the natural conditions constitute the water quality criteria (WAC 173-201A-260 (1)(a)). This provision of the water quality standards is implemented by using the modeled natural condition as the TMDL target. Ecology will consider a formal rule change to adopt site-specific criteria, as provided by WAC 173-201A-430. This will happen after significant implementation of the measures outlined in this TMDL has occurred; at which point the natural condition, determined by empirical and modeled data, could be used to set new water quality criteria through a public rule-making process. This process would involve updated analysis of natural conditions and legacy impacts, and all measures that facilitate bringing the river into water quality compliance.

Modeling natural conditions

Temperature modeling is generally a two-step process. First, the current river temperatures are measured through field monitoring. The stream's current physical characteristics (e.g., amount of shade provided by the canopy, river geometry, sources of flows, significant cold water flows, point source inputs) are also measured and documented. Using this information, a river model is developed that simulates current temperature conditions. The model is calibrated by comparing the simulated temperatures with in-stream measurements and adjusting model parameters to achieve a "best fit" based on model quality metrics.

Second, the calibrated model is used to evaluate different scenarios – including a "system thermal potential" or "system potential" scenario that represents the natural condition of the river system. Physical characteristics of the river are changed in the model to simulate the natural condition. Examples of these changes include removing point source discharges, changing the channel geometry to simulate a natural channel, and increasing the riparian shade to represent a natural forest. The model provides a plausible conservative estimate of natural conditions in rivers and streams, especially in the absence of adequate data from all potential non-disturbed reference conditions.

The water quality model provides only an estimate of the natural condition temperatures based on the 100-year site index conditions, therefore a degree of uncertainty is inherent in the model results. Ecology addresses uncertainty in model applications evaluating statistical measures for goodness-of-fit and incorporating an implicit margin of safety. Critical conditions that are used for the evaluation of natural conditions incorporate uncertainty in major environmental variables (e.g. stream flows and meteorological conditions).

For this TMDL project, Ecology also assessed the uncertainty of the natural condition estimates by assessing the water quality model's sensitivity to the changes in the numbered list below. The rational for these changes is discussed in the TMDL Analysis section on "Sensitivity analysis for natural conditions" and illustrated later in this report. Values for the changed parameters were provided by the Nooksack Indian Tribe based on their knowledge of the South Fork Nooksack River and watershed:

(1) Cooler headwater and tributary temperatures.

(2) Decreased channel width.

(3) Increased system potential vegetation (SPV) height and riparian buffer width consistent with climax vegetation conditions.

(4) Enhanced hyporheic exchange.

(5) The combined impact of the above four alterations.

To the extent that these (non-discharge) influences on temperature existed under natural conditions, or can be put in place now, these sensitivity analyses provide estimates of the variability associated with the natural condition estimates, impairment, land-use, permitting, or restoration decisions.

Watershed Description

The SFNR watershed is in Whatcom and Skagit counties, Washington, in WRIA 1 and Hydrologic Unit Code (HUC) 17110004 (Figure 1). The SFNR watershed covers approximately 186 square miles. It originates in the snow-dominated Twin Sisters range, Loomis Mountain, and Park Butte of the Cascade Mountains and discharges into the Nooksack River mainstem about 36 river miles (RM) upstream from where the Nooksack River mainstem discharges to Bellingham Bay.

The SFNR watershed is dominated by forest and shrubland with small amounts of alpine tundra, fellfields (places where wind and freeze/thaw cycles shape plant communities on scree slopes), and in the lower portion agriculture and development. The predominant land use in the watershed is commercial forestry, which is regulated by the Washington Department of Natural Resources. It includes portions of the towns of Van Zandt and Acme, and counties of Whatcom and Skagit. The Lummi Nation operates a salmon hatchery and established the Arlecho Creek Preserve in the watershed. The Nooksack Indian Tribe also owns land and other facilities in the watershed. The headwaters are lands managed by the U.S. Forest Service (USFS). A portion of the watershed is dominated by alpine tundra and bare rock of the Sisters Range where vestigial ice fields are present.

Geographic setting

Hydrology

The SFNR is fed by numerous tributaries as it flows down from the Cascade Mountains. Major tributaries are Wanlick Creek, Howard Creek, Cavanaugh Creek, Skookum Creek, Hutchinson Creek, and Black Slough. The river has an average annual discharge of 1,032 cubic feet per second (cfs), based on Ecology data at the S.F. Nooksack @ Potter Rd. gaging station 01F070 (WY 2004-2010). The station is on the left bank of the SFNR at the Potter Road Bridge crossing near the town of Van Zandt. Figure 3 shows average monthly flows and the range of flow for the Potter Road gage station.

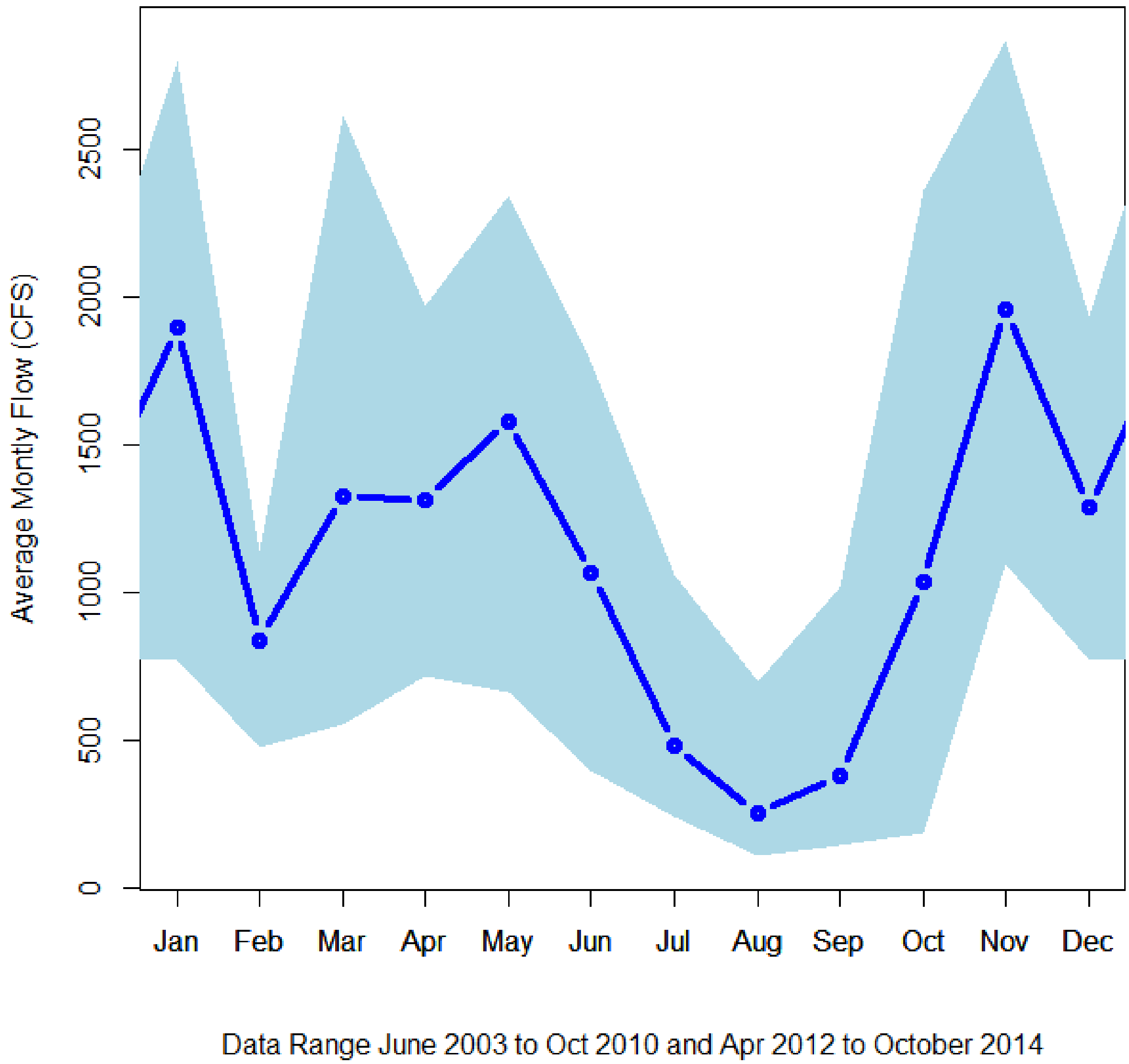


Figure 3. Mean monthly discharge also showing range of monthly averages measured.

The upstream portion of the SFNR is typically constrained by steep valley walls. The lower river flows through a broad, unconfined valley with an average gradient less than 0.1% (Soicher et al., 2006).

Geology

Surficial geology of Quaternary age occurs in the eastern portions of the watershed adjacent to the stream, and consists of mostly unconsolidated sediments of sand, silt, gravel, and clay deposits from Vashon glacial till and outwash (Washington Geological Survey, 2012). Also present are recessional and proglacial stratified sand (with gravel and cobbles and with minor silt and clay interbeds). Adjacent to the downstream reach of the SFNR, sorted combinations of silt, sand, and gravel dominate in streambeds and alluvial fans. The Lower SFNR is a wide alluvial valley flanked by Stewart Mountain to the west and the Van Zandt Dike to the east (Soicher et al., 2006). Upland areas include Jurassic age bedrock material consisting of muscovite, quartz, and phyllite, interbedded with greenschist, sandstone, and blueschist. There are also pockets of pre-Tertiary ultramafic rocks and Permian-Devonian metamorphic rocks.

Geology of the upper watershed (headwaters of the SFNR) is dominated by the Twin Sisters Range. The Twin Sisters range is made up of ultrabasic (ultramafic) rocks of the Jurassic-Triassic age. These mountains are composed of dunite and contain the largest olivine reserves in the United States (Washington Geological Survey, 2012). The Twin Sisters dunite is composed of virtually unaltered, coarse-grained enstatite bearing dunite with accessory amounts of chromite and chromium diopside (USGS, 2012). The dominant mineral is fosterite with minor amounts of chromite and trace amounts of lizardite (USGS, 2012).

Where the South Fork Nooksack channel flows around the Twin Sisters range, it follows the path of faults in the watershed. These fault contacts were previously scoured by glacial ice and filled with retreating glacial deposits. The fault zones generally erode more easily because the movement along the faults has fractured and weakened the bedrock. As the river has cut down through the fault zones around the southern flank of the Twin Sisters mountain range, it has created a steep and narrow channel choked with boulders collected from unstable hillsides (Brown and Maudlin, 2007).

Land use and land cover

The National Land Cover Dataset (NLCD; Fry et al., 2011) is developed under a national program overseen by the Multi-Resolution Land Characteristics Consortium, a group of federal agencies that cooperate to create a consistent land cover geographical information system (GIS) grid-based product for the entire United States. The data are based on interpretation of multi-seasonal Landsat satellite images (30-meter [m] grid cells) and were developed into three products: a land cover database with 21 categories, a database with estimates of percent impervious cover in each grid cell, and a database with estimates of forest canopy cover in each grid cell. The data sets are updated about every 5 years. Year 2006 land use/land cover is shown in Figure 4. The most prevalent land covers in the watershed are three forest types (deciduous, evergreen, and mixed) and Shrub/Scrub.

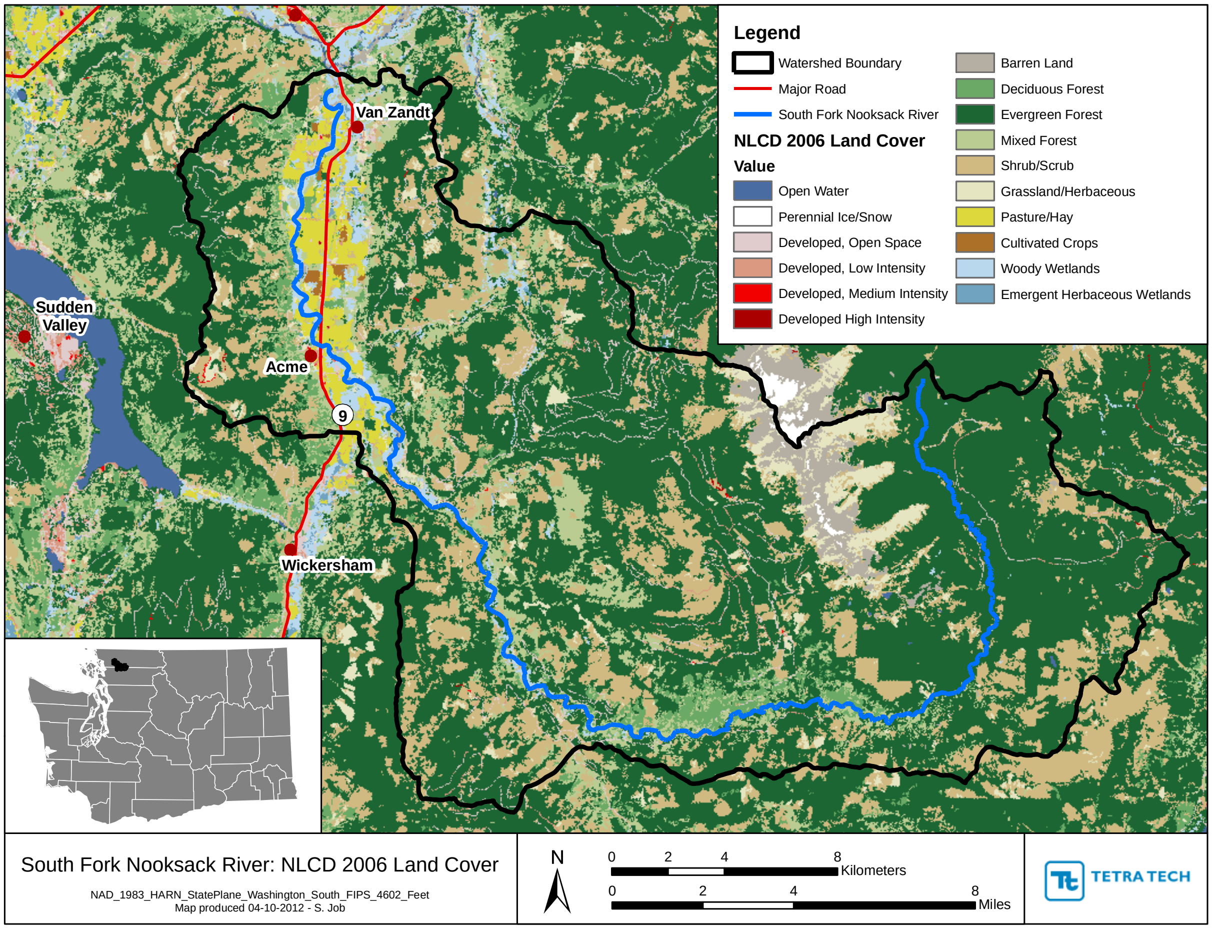


Figure 4. South Fork Nooksack River land cover (2006 NLCD).

The USFS/Department of Interior LANDFIRE data set, which provides a high level of detail about vegetation for wildfire management, is another useful resource for characterizing land cover (LANDFIRE, 2012). Like NLCD, LANDFIRE uses 30-m grid cells. LANDFIRE provides several data products including vegetation height, vegetation cover (percent canopy), vegetation type, and others. The first LANDFIRE data set (LF 1.0.0) represents conditions circa 2001; the most recent (LF 1.1.0, nicknamed *Refresh*) used data from a variety of sources to update the 2001 classification to conditions circa 2008. The Existing Vegetation Type (EVT) data set provides a high level of detail about plant communities, and some spatial information indicating areas of development and agricultural use. Numerous classification fields and classes are provided; for the purposes of this project, a preliminary classification of plant community types was developed for EVT data in the watershed (Figure 5).

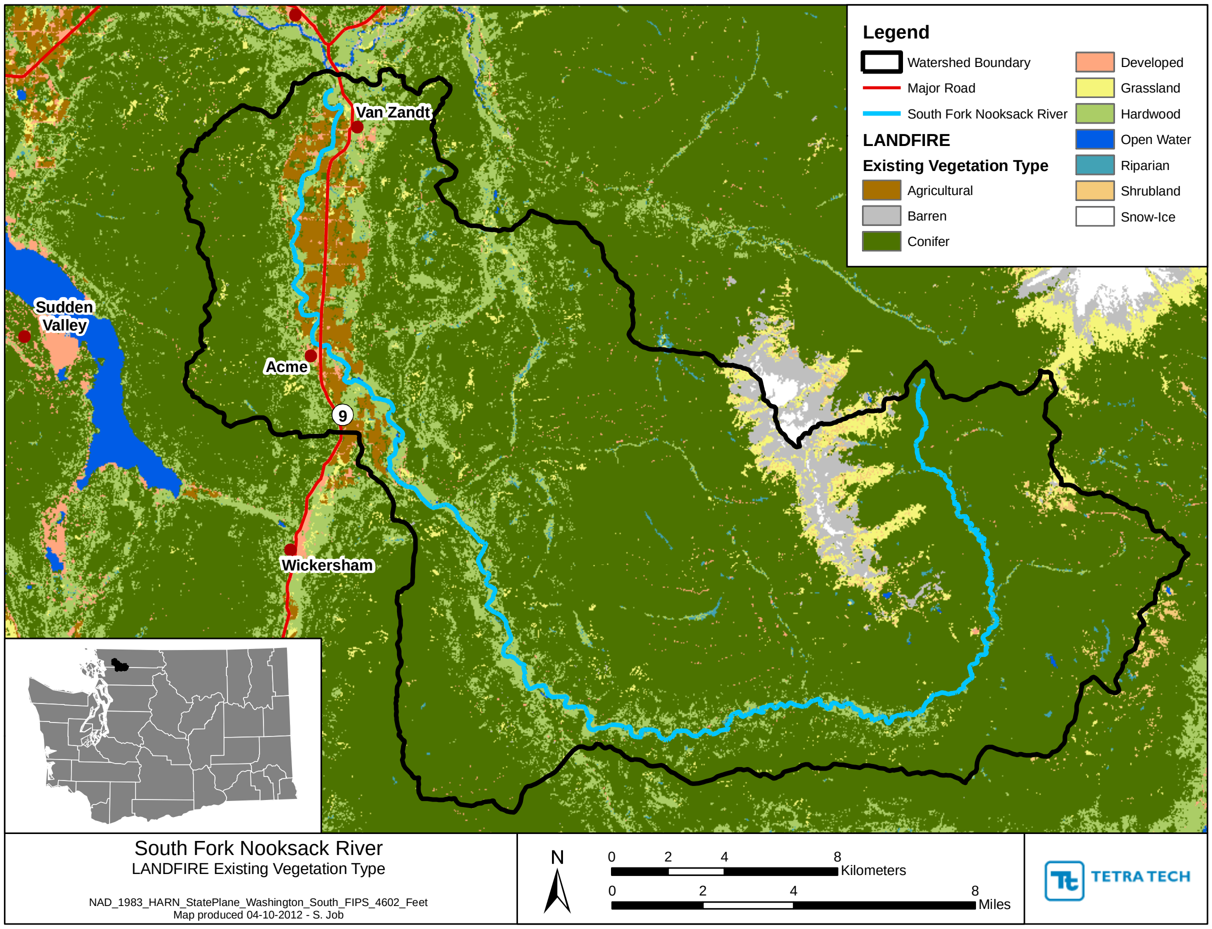


Figure 5. South Fork Nooksack River land cover (LANDFIRE). *LANDFIRE 2008 land use/land cover using preliminary vegetation groups.*

LANDFIRE and NLCD differ markedly in their interpretation of forest types and shrubland (Figure 6). Some of the difference may be related to the preliminary LANDFIRE groups, but it is more likely due to semantics. NLCD includes young trees less than 6 m in the Shrub/Scrub category, which would include recently harvested areas. LANDFIRE EVT on the other hand is focused on vegetation communities, and shrubland categories tend to be confined to true shrub species. The LANDFIRE Existing Vegetation Height (EVH) 2008 data supports this, though there is clearly disagreement in estimated tree height between NLCD 2006 and LANDFIRE EVH 2008—areas classified as shrubland by NLCD (less than 6 m) tend to overlay on areas with EVT tree height of more than 10 m.

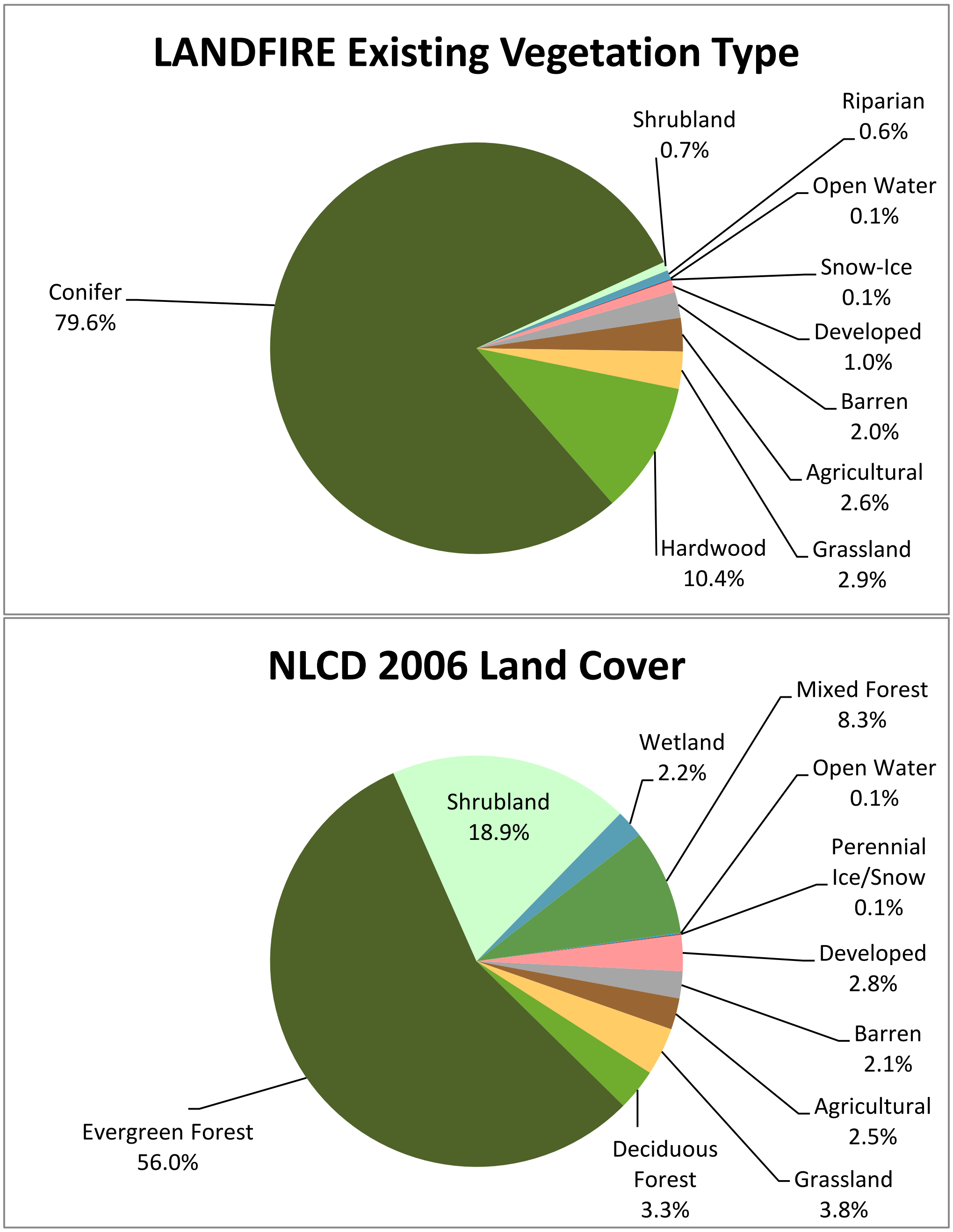


Figure 6. Comparison of LANDFIRE and NLCD land use/land cover estimates for the South Fork Nooksack watershed.

The National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (CCAP) produces land cover and land cover change data products for coastal areas of the United States. The SFNR watershed is in the regional land cover zone, where 30-m grid cell resolution is available. Data sets are provided for a range of years, with 2006 being the most recent.

The land cover classes are identical to NLCD, with the exception that wetlands classification is more robust in CCAP; the CCAP data set classifies both palustrine and estuarine wetlands separately and further classifies each of these as either forested, scrub/shrub, or emergent wetlands. In the watershed, CCAP 2006 is almost identical to NLCD 2006 outside wetland areas.

Figure 7 displays the CCAP land cover data set in which forested and scrub/shrub wetlands are combined into a woody wetlands category for a spatial comparison with the NLCD data set. A small amount of variation exists between the two data sets at a local scale, but the overall spatial distribution of land cover is essentially the same as NLCD 2006.

The CCAP land cover data set has been previously selected for use in studies of the Lower Nooksack River and it is recommended to rely on the same data set for this work. Therefore, CCAP is the selected land cover data set to accompany the use of aerial imagery in characterizing the land use and land cover of the watershed required for model development (e.g., for selecting areas of urban development and areas covered by wetlands that cannot be vegetated as one step in determining system potential shade).

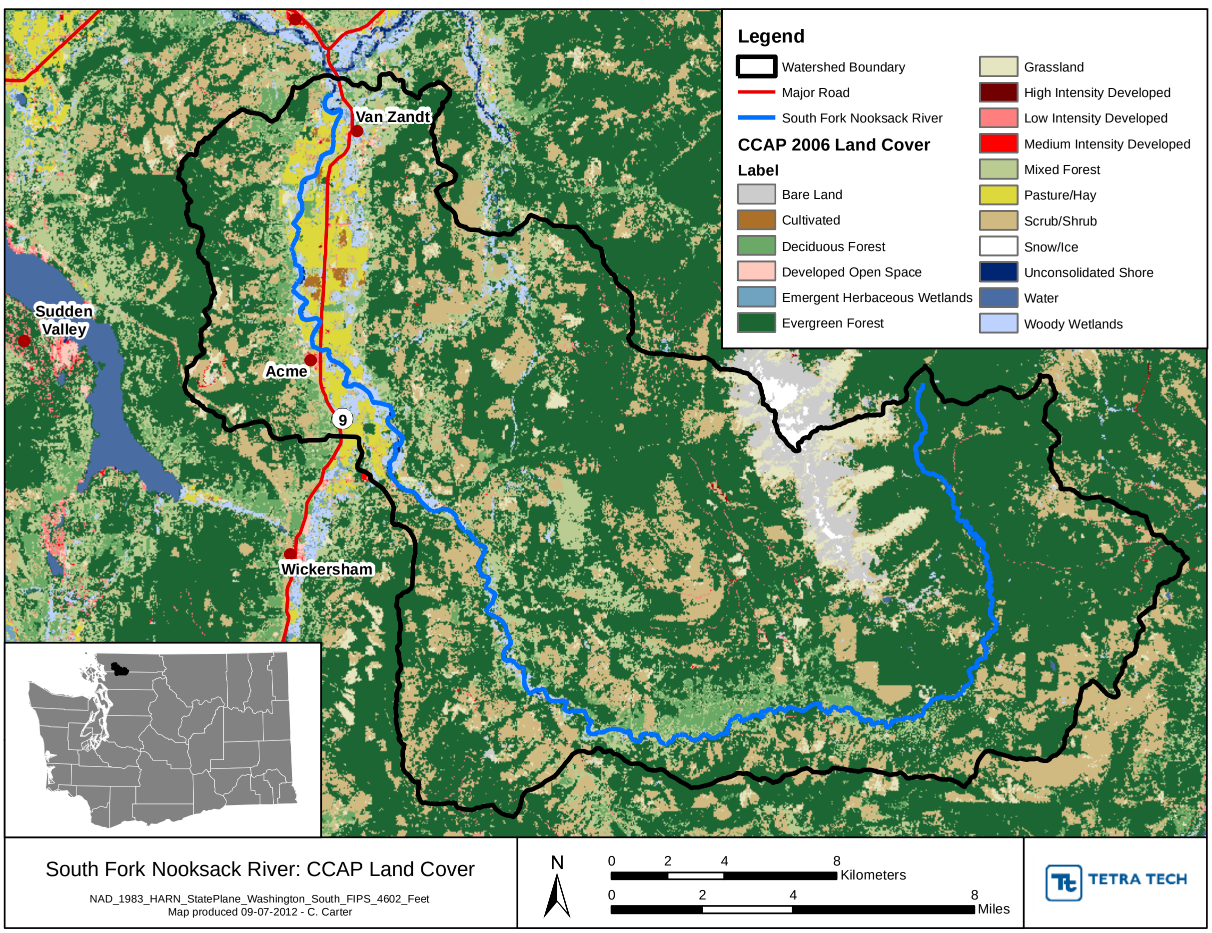


Figure 7. South Fork Nooksack River land cover (CCAP 2006).

Forest disturbance and maturity

GIS data files of active forest practices and fire history were obtained from the Washington Department of Natural Resources. The forest practices data set includes Forest Practices Application/Notification harvest unit boundaries and the number of acres associated with active Forest Practices Application/Notifications. The acres for all active Forest Practices Application/Notifications in the SFNR watershed are 3,387 acres over the 2003 to 2012 period. Figure 8 provides the spatial distribution of active timber harvesting throughout the watershed for this approximately 10-year period. This data set does not include forest practices that were active in the past and are currently inactive. These past forest practices have created legacy impacts that may continue to effect water temperatures today.

Five significant forest fires occurred in the watershed in the past 30 years (Figure 8). The largest fire occurred in 1979 when 130 acres of forest burned. Another major debris burn occurred in 2004 just outside the watershed boundary, affecting 100 acres. Aside from these five primary fire events, all other fire events occurring in the past 30 years individually burnt less than 3 acres.

In a study performed by Pollock et al. (2009), 42 subbasins in western Washington were selected for stream temperature monitoring. The study focus was to examine correlations between forest harvest patterns and summer stream temperatures to assess whether harvest patterns of riparian or upland forest can be used to predict variation in temperature regimes among streams. The team considered the condition of the *near upstream riparian forest*, the condition of the entire upstream *riparian forest network*, and the condition of the *total basin forest area*. The near upstream riparian forest was defined as a band 30 meters wide on each side of the stream and extending 0 to 600 meters upstream from each of the stream temperature data loggers. The riparian forest network was defined as a band 30 meters wide on each side of all channels that were upstream of the temperature loggers. The *total basin forest area* was defined as the entire area of the basin, upstream and downstream of the temperature loggers.

Results of Pollock et al. (2009) show that the percentage of the total basin forest area harvested (in the past 40 years) explains 39% of the variation in the average daily maximum temperature. The percentage of harvested riparian forest network upstream from temperature monitoring locations explains 33% of the variation in average daily maximum temperatures. No significant correlations were found between the percentages of near upstream riparian forest recently clear-cut and average daily maximum temperature.

The researchers observed a strong relationship between maximum daily stream temperatures and the total amount of harvest in the total forested area of the basin. They observed a strong but slightly weaker relationship between maximum daily stream temperatures and the total amount of harvest in the riparian forest network of a basin. They suggested that the likely causal mechanism was mass wasting altering channel morphology, with possible contributions related to bank erosion. On the basis of these findings, the researchers concluded that the probability of a stream exceeding the water quality standard increased with timber harvest activity. Furthermore, the impact of past forest harvest activities on stream temperature may not be entirely mitigated through reestablishing riparian buffers because of changes in channel morphology.

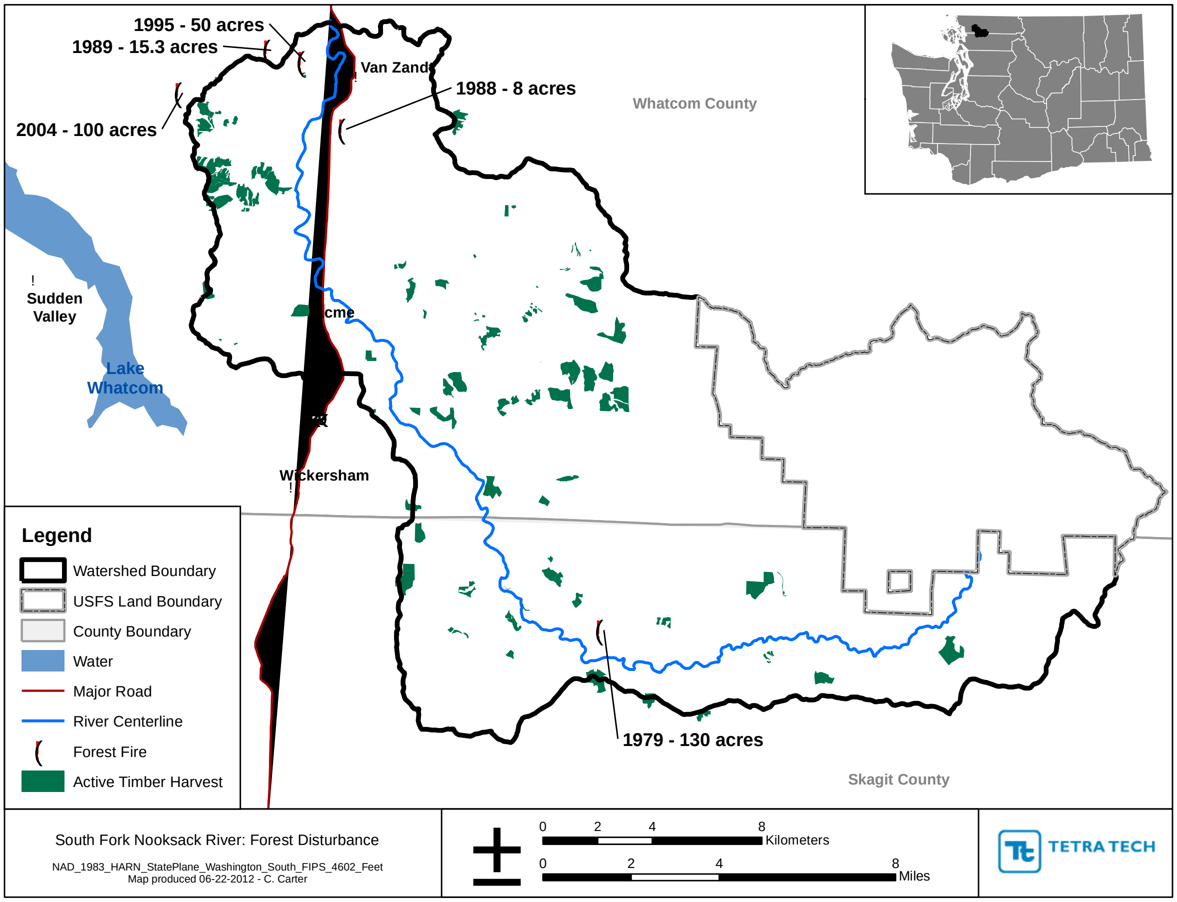


Figure 8. Forest disturbance from fires and timber harvest.

Their findings have important implications for the SFNR watershed. While most of the harvested areas shown in Figure 8 are not directly adjacent to known temperature-impaired reaches, there is a higher proportion of harvesting in the drainages in the vicinity of the impaired reaches. The potential for ongoing impacts from historic activity is significant, given the large proportion of the watershed zoned for commercial or private forest harvesting (Figure 9). In addition to potential impacts of active harvest, previously harvested areas recovering from canopy removal may affect stream temperature. A robust analysis of past harvest is beyond the scope of this TMDL because of the temporal nature of watershed recovery and lack of watershed data, but may be considered as part of the implementation plan.

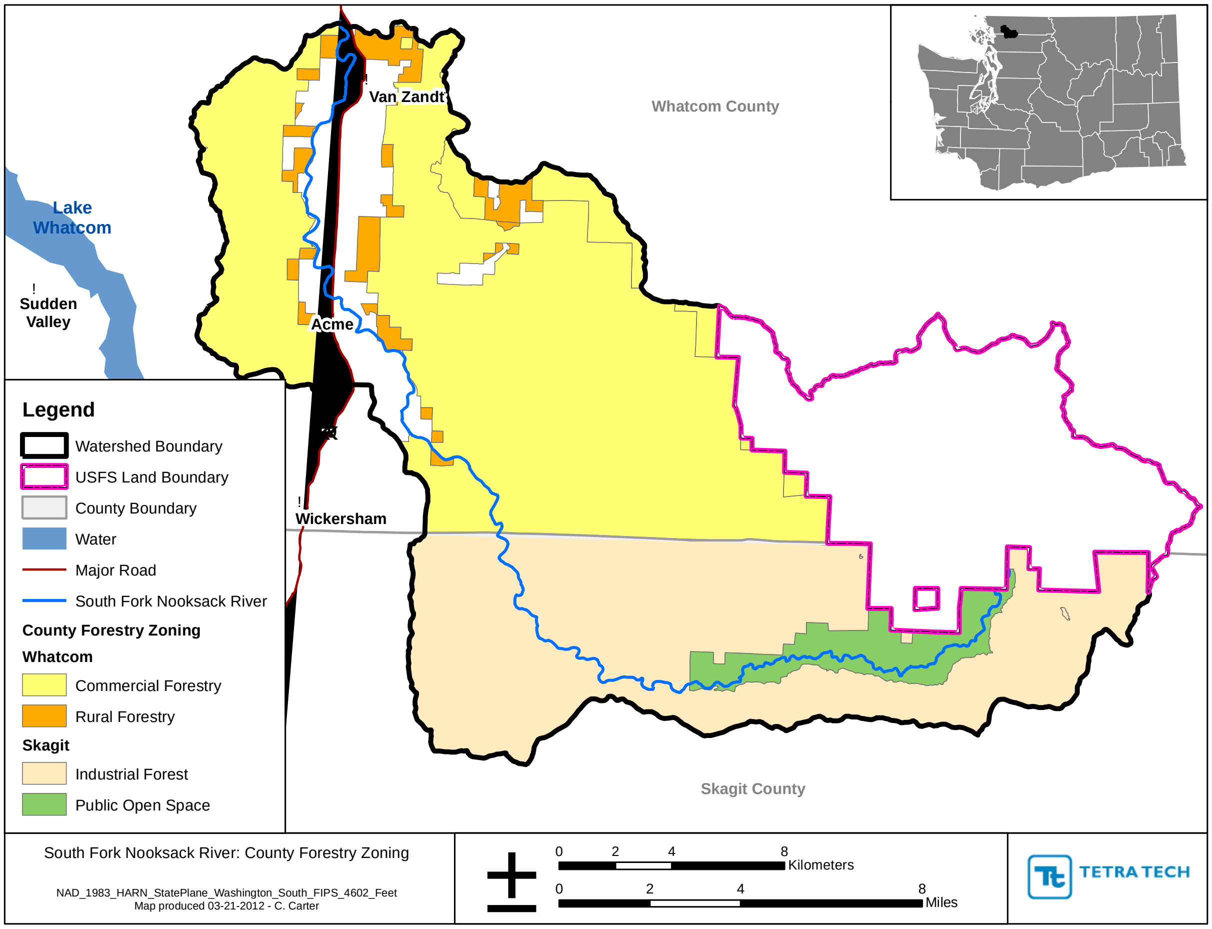


Figure 9. Forest zoning in the watershed.

Climate

The SFNR watershed is in a zone where Arctic weather from the north converges with Pacific weather systems from the south (USFS, 2006). In the summer, the Pacific systems dominate with mild, clear weather and low levels of precipitation. In the winter, Arctic systems move into the area bringing storms, high levels of precipitation, and occasionally very low temperatures (Smith, 2002).

Near the confluence of the South Fork Nooksack with the mainstem of the Nooksack River, annual average precipitation ranges from 50 to 60 inches. At higher elevations in the watershed, annual average precipitation ranges from 60 to 125 inches (USGS, 2000a). Monthly average precipitation is at its highest in November through January; however, extreme storm events resulting in more than 4 inches of precipitation per day have occurred outside these months. In high elevation areas where the headwaters of the South Fork Nooksack lie on the slopes of the Twin Sisters range, rain-on-snow events typically occur from late October through January and are characterized by rapid snowmelt accompanying intense rainfall triggering rapid runoff and flooding that can result in severe hill slope and channel erosion (Brown and Maudlin, 2007).

Mean annual air temperatures for the watershed range from 46 to 48 F at lower elevations and 40 to 45 F at higher elevations (USGS, 2000b).

Wildlife

Although many of the smaller tributaries of the SFNR have limited access for anadromous salmonids because of the steep terrain, the river channel and major tributaries contain accessible habitat. The smaller tributaries support numerous species of anadromous and resident salmon and trout. These include early (spring) Chinook, late (fall) Chinook, Coho, pink, chum and sockeye salmon, summer- and winter-run steelhead, bull trout, cutthroat trout, rainbow trout, and Dolly Varden trout. Winter steelhead, Coho, early and late-timed Chinook, pink, sockeye and chum salmon use these waters for spawning, rearing, migration, and holding. Steelhead, Coho, some Chinook, and sockeye juveniles also rear in these waters year-round (Brown and Maudlin, 2007).

All species of the SFNR salmonids require cold, clean water and a complex, connected habitat structure to survive. Chinook salmon (*Oncorhynchus tshawytscha*), bull trout (*Salvelinus confluentus*), and steelhead (*Oncorhynchus mykiss*) are federally listed as threatened under the Endangered Species Act.

The riparian corridors of the SFNR provide a potential for north-south wildlife habitat connectivity and serve as important wildlife corridors that provide access to higher elevations in the watershed. Portions of the SFNR watershed have the potential to serve as refugia and dispersal corridors for mammals, including gray wolves, wolverine, and moose that have been observed in large wilderness areas west of the Cascade Mountains crest. Agricultural fields along the SFNR provide foraging and wintering areas for a resident herd of Roosevelt elk (Whatcom County Planning and Development Services, 2005).

Coastal areas to the north and south of the Nooksack River watershed are major Pacific Flyway waterfowl wintering areas. The Skagit Estuary to the south supports the highest numbers of wintering waterfowl in Puget Sound. The Fraser Estuary to the north is the most important waterfowl wintering area in western Canada. Waterfowl and shorebirds often move between these two estuaries, passing through or stopping in the SFNR watershed and coastal waters downstream from the watershed. High numbers of waterfowl and shorebirds attract wintering raptors such as the bald eagle, gyrfalcon, and Merlin falcon (Whatcom County Planning and Development Services, 2005).

Potential sources of thermal impairment

Non-stormwater point source pollution

There is one active non-stormwater point source identified in the SFNR watershed (Table 3). The Lummi Nation operates the Skookum Creek Fish Hatchery, on Saxon Road at the mouth of Skookum Creek. The hatchery operates under a General Hatchery Permit issued by EPA and diverts water from Skookum Creek downstream from the gaging station location. This water isdischarged (along with groundwater pumped from six wells) to the SFNR upstream from the Saxon Road gaging station. There is no permit requirement to monitor temperature or dissolved oxygen in the discharged water. The average reported discharge for the hatchery in 2011 was about 5.6 million gallons per day (mgd), equivalent to 8.7 cfs.

Table 3. Active point sources in the South Fork Nooksack watershed.

Permit Number	Facility Name	Type	Parameters Monitored
WAG130017	Skookum Creek Fish Hatchery	EPA Fish Hatchery General Permit	Flow, Total Suspended Solids (TSS), Settleable Solids, and Chlorine

Agricultural irrigation

Surface water and groundwater withdrawals support agricultural irrigation in the watershed. About 775 acres are irrigated, according to information from Whatcom Farm Friends and their director Henry Bierlink. A consumptive use calculator was used to translate daily estimated irrigation (assuming an alfalfa crop and average irrigation efficiency) to an equivalent flow—2.8 cfs (Thomas Buroker, May 29, 2012, personal communication). The 7Q10 value for U.S. Geological Survey (USGS) gage 12209000 over the past 24 years is about 75.8 cfs according to USGS calculations, and 2.8 cfs represents less than 4% of the 7Q10 flow. The 2.8 cfs value is likely overestimated, because some irrigation use is from groundwater. To the extent that irrigation does reduce flows in the critical season it will cause increased temperatures.

Point source stormwater pollution

Two active point sources of stormwater pollution were identified in the SFNR watershed (Table 4). Concrete Norwest Saxon Pit is about 5 miles southeast of Acme and is on the watershed border, about a half mile west of SFNR; stormwater generated by the facility discharges to groundwater. A construction stormwater general permit was issued in early 2013 to replace a bridge on Potter Road. Other stormwater general permits for construction, industrial activity and Sand and Gravel may be issued in the future. Whatcom county and WSDOT also have Municipal Separate Storm Sewer Systems (MS4s) in the watershed that could come under regulation in the future.

Table 4. Active stormwater point sources in the South Fork Nooksack watershed.

Permit Number	Facility Name	Type	Parameters Monitored
WAG503013	Concrete Norwest Saxon Pit	Sand and Gravel General Permit	Oil and Grease
WAR126700	Potter Rd Nooksack Bridge 148 Replace	Construction Stormwater General Permit	Turbidity and pH

In storm events, rainwater can scour the surface of the pavement, rooftops, and other impervious surfaces. This stormwater runoff accumulates and transports pollutants and contaminants via stormwater drains to receiving waters and can degrade water quality. However, rainfall in the critical period is rare, and when rainfall occurs the temperature drops. Stormwater from point sources generally does not contribute to thermal impairments. Ecology issues National Pollutant Discharge Elimination System (NPDES) permits to larger entities that Operate MS4s responsible for collecting, treating, and discharging stormwater to local streams and rivers. There are no MS4s in the South Fork Nooksack River drainage covered by NPDES permits.

Nonpoint pollution sources

Nonpoint pollution sources are dispersed and not controlled or regulated through discharge permits. Potential nonpoint sources within the watershed that specifically can cause warmer temperatures include the following:

- Loss of vegetation in the riparian zone along the mainstem and tributaries caused by permanent clearing for roads, railroads, farm fields and temporarily by forest practices including harvest roads.

Temperature is also affected by human activities which change how water flows over the surface such as:

- Mass earth failures and debris flows from land development including forest roads and clearings.
- Human activities that have changed stream channel morphology and geometry.
- Reduction in baseflows, in-stream flows, groundwater flows and hyporheic exchange flows.
- Changes in timing and intensity of runoff.
- Altered channel conditions caused by land use and management.

Forest practices and agricultural activities contribute to the nonpoint sources listed above. Nonpoint source contributions are important to understand because they have an effect on stream water quality, and they are a major component of stormwater runoff. Temperature is directly affected by the removal of riparian zone vegetation, which increases solar radiation reaching the stream surface. This reduction of riparian zone vegetation reduces the available shade, which increases sunlight to the stream surface and subsequently increases water temperature. Also, there is some evidence that even-age forest harvest, away from tributaries, may also increase surface and subsurface flows to streams with elevated temperatures, but may increase temperatures if mass wasting has adverse effects on channel morphology.

Groundwater influences, in-stream flows, water withdrawals, and stream channel geometry also influence stream temperature. Where significant volumes of groundwater discharge to a stream or river, groundwater can warm a stream in winter and cool it in summer (Gendaszek, 2014).

Conversion of forest to developed and open agricultural land, and removal of forest cover through harvesting operations, can affect watershed hydrology and sediment loading. These land conversions contribute to upland sediment load. They can also reduce natural infiltration (leading to less cold baseflow) and contribute to loss of wetlands (potentially reducing thermal buffering capacity).

Land use and management in the watershed has likely caused an increase in upland sediment load. This, in turn, could contribute to loss of wetlands, filling of deep pools, and aggradation and widening of the channel. In turn, these impacts can result in reduced thermal buffering capacity and increased direct solar radiation. Filling of stream gravels with fine sediment can also reduce cooler hyporheic flows. Sediment loading has been identified as a limiting factor to the existence and recovery of native salmon stocks (Nooksack Indian Tribe, 2011).

The Washington State Department of Transportation (WSDOT) holds a MS4 permit. This permit addresses stormwater discharges from WSDOT MS4s in areas covered by the Phase I Municipal Stormwater Permit, the Eastern Washington Phase II Municipal Stormwater Permit, and the Western Washington Phase II Municipal Stormwater permit. It also covers discharges assigned a WLA or LA in TMDLs approved by EPA.

WSDOT has a *2011 Highway Runoff Manual* that provides tools for designing stormwater collection, conveyance, and treatment systems for transportation-related facilities. This manual has been approved by Ecology as functionally equivalent to the *Stormwater Management Manual for Western Washington* and is at
http://www.wsdot.wa.gov/Design/Hydraulics/HighwayRunoffManual.htm

Historical Data Review

The SFNR watershed is monitored regularly by the USGS, the Nooksack Indian Tribe, the Lummi Nation, and Ecology for many reasons, such as ESA-related fisheries enhancement projects support, existing TMDL implementation, water quality and quantity trend analysis, and flood control activities. Following is available and pertinent data on existing water temperatures and river flows from these agencies' sources. Data are presented to characterize historical and recent flow, water quality conditions, and general temporal and spatial resolution of available data. These data are assumed sufficient for this purpose and have not been subject to detailed secondary quality assurance and quality control (QA/QC) in addition to the QA/QC conducted by the data originators. The data have been checked for compliance with Ecology's Credible Data Policy (https://ecology.wa.gov/Asset-Collections/Doc-Assets/Water-quality/Assessment/wqp01-11-ch2-final090506).

Stream temperature data

Stream temperature monitoring data collected by the Nooksack Indian Tribe, USGS, and Ecology were analyzed for comparison with water quality criteria. Three periods were selected for analysis for each year on the basis of the effective dates for supplemental spawning and incubation of salmonid species (September 1 through July 1). The three periods are as follows:

- January 1 through July 1
- July 2 through August 31
- September 1 through December 31

Stream temperature monitoring data collected by each entity are presented and discussed in the following sections.

Nooksack Indian Tribe, Natural Resources Department

The Natural Resources Department of the Nooksack Indian Tribe has a program to monitor summer and year-round water temperatures in Chinook salmon habitats of the Nooksack River watershed. This ongoing work is funded through the Indian General Assistance Grant (IGAP) and EPA CWA sections 106 and 319 grant programs that constitute a component of the Nooksack Indian Tribe's Performance Partnership Grant with EPA (Coe and Cline, 2009). At all monitoring locations the Nooksack Indian Tribe recorded continuous data records of stream temperature, with the majority of data collected in June through October (every 30 minutes). In this section, continuous data have been summarized as highest 7-day average of daily maximum temperatures (7-DADMax) to be consistent with the water quality criteria. The 7-DADMax for any day was calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the 3 days prior and the 3 days after that date.

In 2007, nine locations were monitored for temperature along the SFNR, and six locations were monitored on tributaries to the South Fork (Figure 10, Figure 11, and Appendix B). Sites were selected to monitor water temperature throughout the range of Nooksack early run Chinook salmon habitats. In 2007 there was a general increase in stream temperature 7-DADMax from upstream to downstream monitoring locations. The boxplots in Figure 12 represent the distribution (25th, 50th, and 75th percentiles) of the 7-DADMax temperatures for each station. The whiskers represent the minimum and maximum 7-DADMax for each station.

Stations are displayed in the box and whisker plot from upstream to downstream locations and tributary stations appear at the location of their confluence with the South Fork (Figure 12). Temperatures recorded at the South Fork station locations show that these waters exceeded the applicable water quality criteria during the 2007 monitoring period, and that tributary temperatures were generally cooler than temperatures in the South Fork. Of the seven sites monitored in 2007 that are designated as char habitat, all exceeded the 12 °C criterion for at least a portion of the monitoring period; the total number of days temperatures exceeded the criterion ranged from 65 to 92. Of the eight sites designated as core summer salmonid habitat, only the site on McCarty Creek did not exceed the 13 or 16 °C criteria. For the remainder, the total number of monitored days temperatures exceeded the criteria ranged from 6 to 94 (Appendix B).

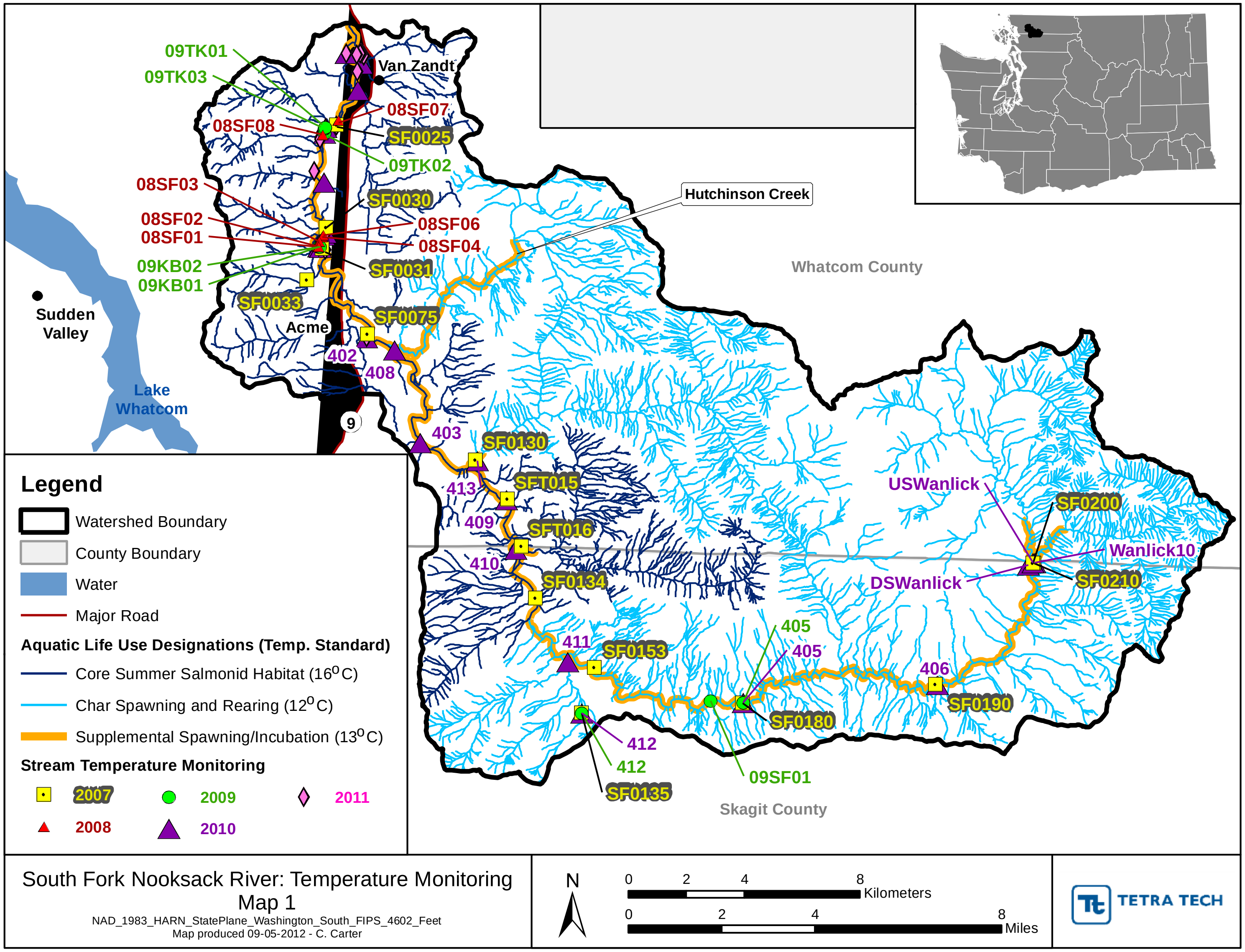


Figure 10. Nooksack Indian Tribe stream temperature monitoring station locations – Map 1.

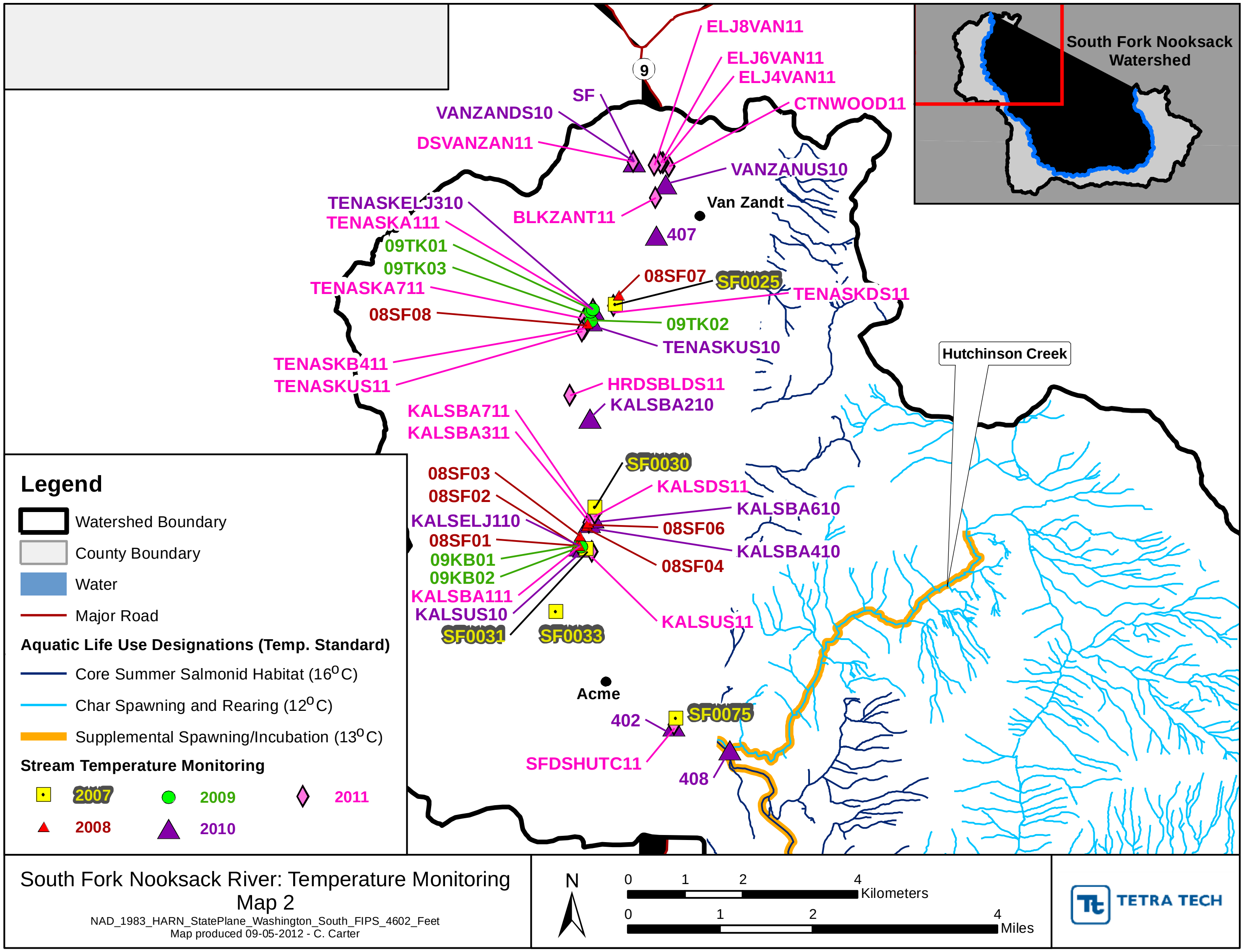


Figure 11. Nooksack Indian Tribe stream temperature monitoring station locations – Map 2.

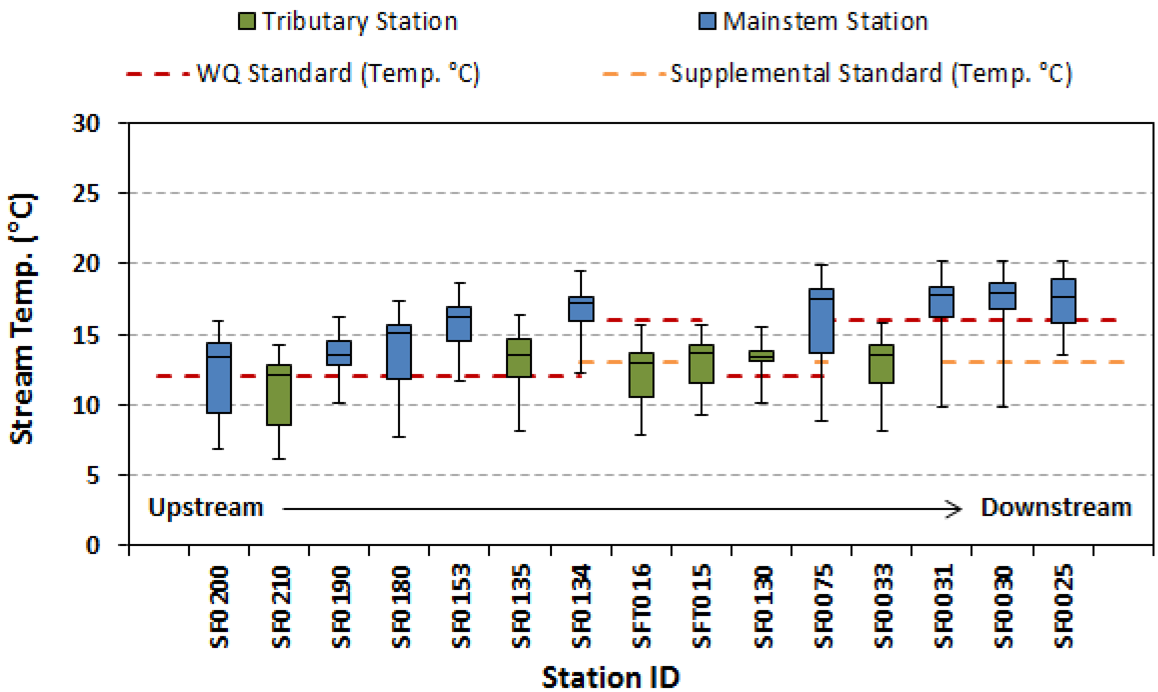


Figure 12. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2007 in the South Fork Nooksack.

In 2008, the Nooksack Indian Tribe's site selection shifted to implement its new *Water Resources Monitoring Program Strategy* (Coe and Doremus, 2007). This entails monitoring of temperature status and trends at fixed stations on a rotating panel basis, with at least one subbasin monitored each year. One of the goals of monitoring in the South Fork was to evaluate the effectiveness of log jams for creating thermal refuges. Five log jams were constructed in 2007 and two were constructed in 2008. Therefore, the seven locations monitored in 2008 for temperature along the SFNR (see Appendix B) were placed in the deepest sections of the log jam-associated pools. The temperature monitoring does not have as much spatial variation in 2008 (Figure 13) as in 2007. The 2008 stations are clustered in two reaches where the tribe had constructed log jam projects, and all are on the downstream portion of the South Fork where the 13 or 16 °C water quality criteria apply (depending on location and date).

All stations show exceedances of the applicable temperature criteria throughout the 2008 monitoring period; the total number of monitored days that temperatures exceeded the criteria ranged from 10 to 56 (Appendix B). Because some of these stations were selected to represent the enhanced condition (pools formed in areas of cool-water influence) rather than reach-average conditions, these data should not be used to assess attainment of standards.

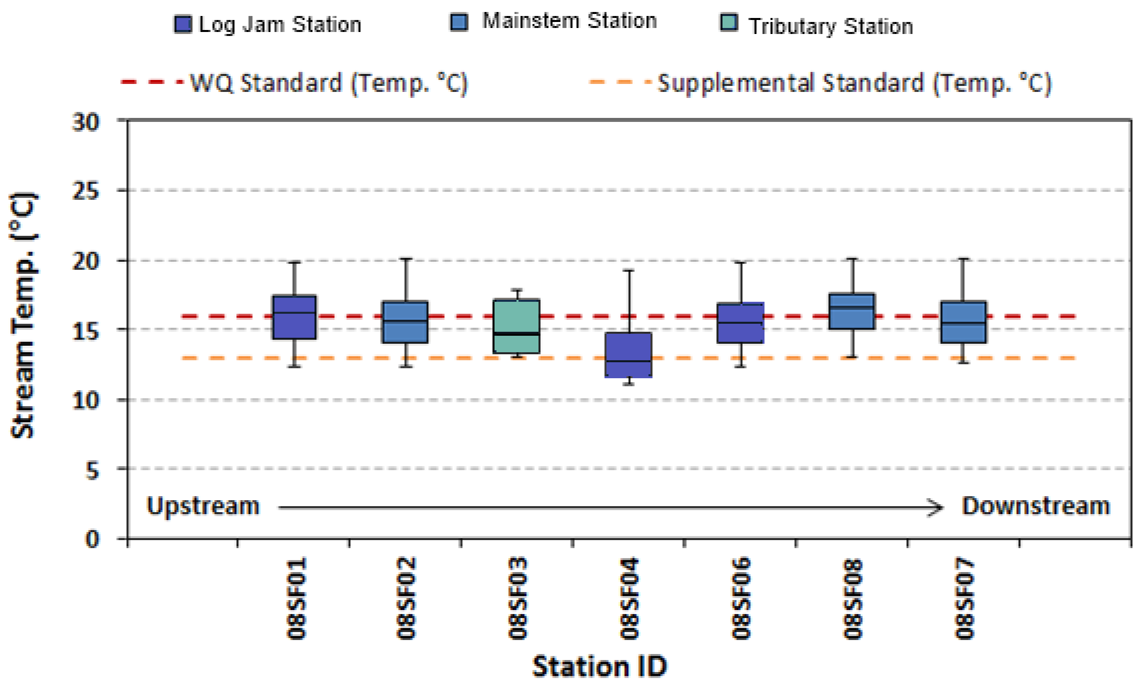


Figure 13. Box-and-whisker plots with the 25th, 50th, and 75th percentiles of the 7-DADMax stream temperature for 2008 in the South Fork Nooksack.

In 2009 seven locations were monitored for temperature along the SFNR, and one station was on the Deer Creek tributary at the same location as station SF0135 from the 2007 monitoring period (Appendix B and Figure 14). As in 2007, a general stream temperature increase occurred from upstream to downstream locations. However, station 09TK03, near the downstream portion of the South Fork, was found to have lower stream temperatures than the nearest upstream and downstream South Fork stations. Station 09TK03 is at a backwater slough and is isolated at the downstream end from the South Fork and is not representative of reach-average condition. The low temperatures recorded at this station are most likely due to the possible influence of cool hyporheic flow or lateral inflow of groundwater.

Of the three sites monitored in 2009 that are designated as char habitat, all exceeded the 12 °C criterion for at least a portion of the monitoring period; the total number of monitored days that temperatures exceeded the criterion ranged from 32 to 91. Of the four sites designated as core summer salmonid habitat (excluding site 09TK03), all exceeded the 13 °C or 16 °C (depending on location and date) criteria for at least a portion of the monitoring period. For these sites the total number of monitored days that temperatures exceeded the criteria ranged from 55 to 72.

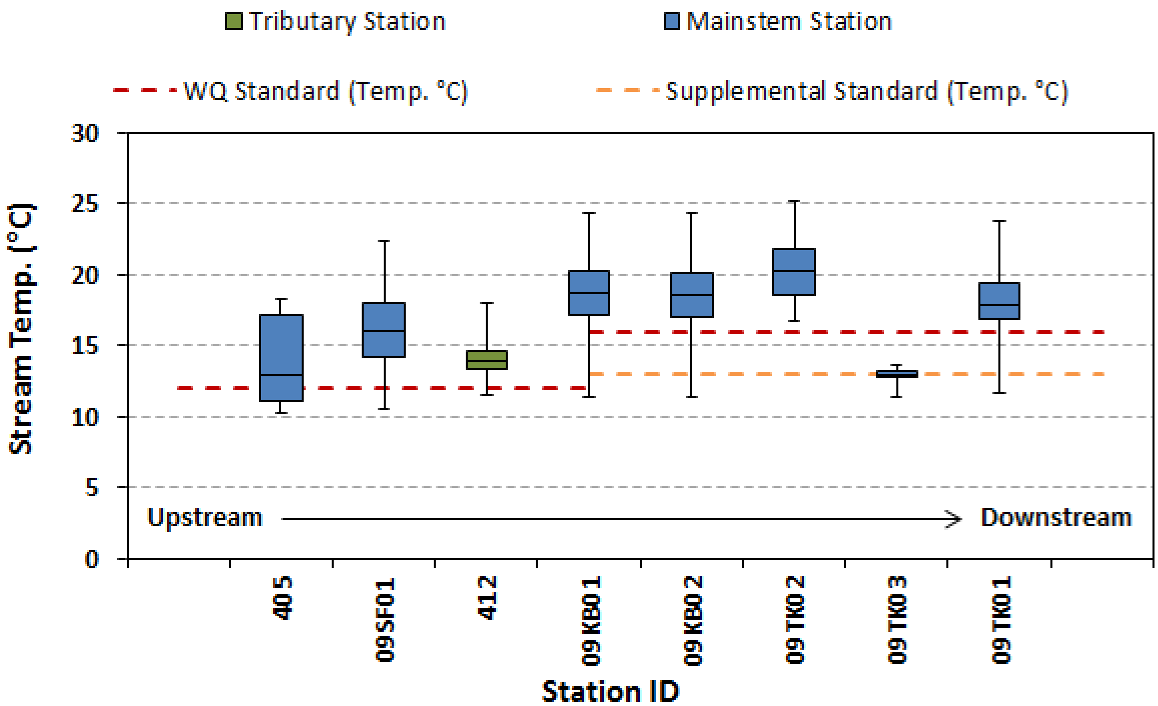


Figure 14. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2009 in the South Fork Nooksack.

In 2010, 22 locations on the South Fork Nooksack River and 8 locations on tributaries to the South Fork were monitored for stream temperature. Of the 9 sites designated as char habitat, all exceeded the 12 °C criterion for at least a portion of the monitoring period; the total number of monitored days temperatures exceeded the criterion ranged from 36 to 82. Of the 21 sites designated as core summer salmonid habitat, all exceeded the 13 or 16 °C (depending on location and date) criteria; the total number of monitored days temperatures exceeded the criteria ranged from 7 to 85 (Appendix B). The box and whisker plot for 2010 (Figure 15) demonstrates the upstream to downstream warming trend that is visible during previous years. In general, tributaries have lower stream temperatures than the South Fork. One exception is Cavanaugh Creek (site 410), where the highest and median 7-DADMax for the 2010 monitoring period appear to be higher than many of the South Fork monitoring locations.

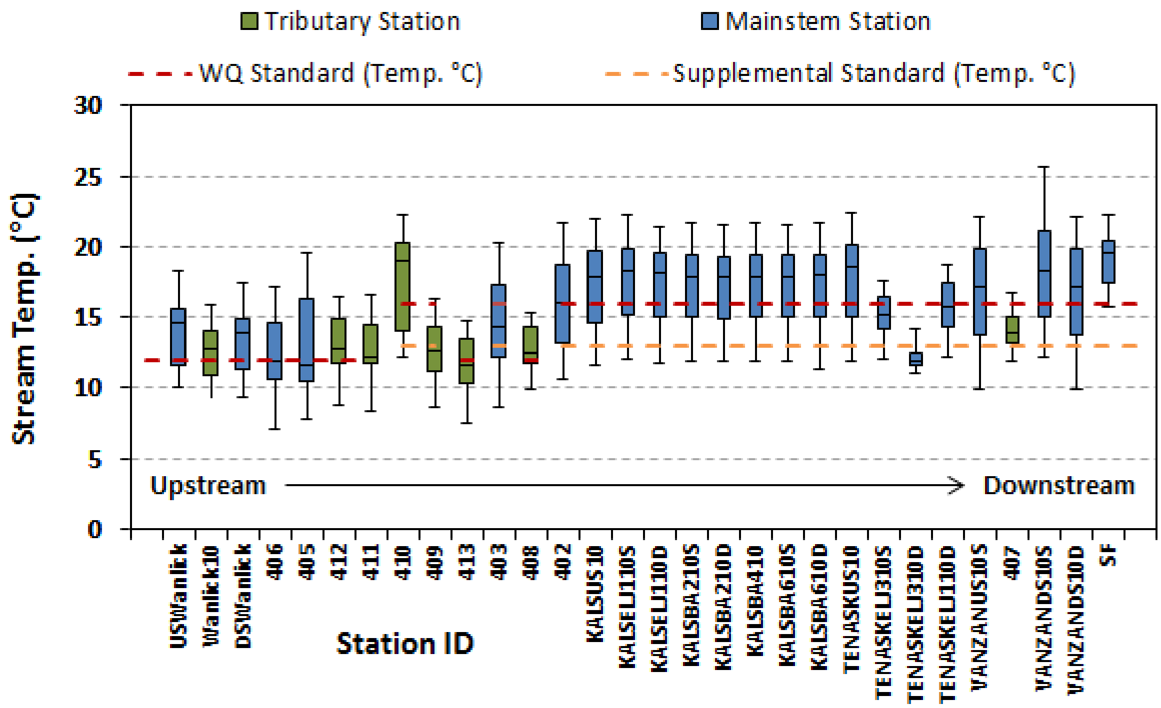


Figure 15. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2010 in the South Fork Nooksack.

In 2011, a total of 30 locations, most locations differing from those monitored in 2010, were monitored for stream temperature along the SFNR. Of these 30 sites, all are designated as core summer salmonid habitat and all exceeded the 13 or 16 °C (depending on location and date) criteria. The total number of days temperatures exceeded the criteria ranged from 26 to 65 (see Appendix B).

USGS stream temperature monitoring

Three USGS streamflow gage locations in the SFNR watershed have continuous monitoring data for stream temperature, even in non-summer months, between 2001 and 2011 (though specific years differ among these stations). Two stations are along the SFNR and the third is on Skookum Creek, a tributary to the South Fork (Figure 16). The South Fork stations are on waters designated for Core Summer Salmonid Habitat where the temperature criteria are 13 or 16 °C depending on the location and date.

The South Fork River gage at Saxon Bridge, WA (12210000) is downstream of the South Fork River gage near Wickersham, Washington (12209000). The confluence of Skookum Creek is between the two South Fork gage locations. The Skookum Creek station (12209490) is on water designated for Char spawning and rearing where the temperature criterion is 12 °C. The USGS suspended monitoring at the Wickersham gage at the end of September 2008, while the Saxon Bridge station began reporting temperature in July 2007. The Skookum Creek station began monitoring temperature in April 2008. As a result, there is a relatively short time in which temperature was monitored simultaneously at all three stations. Stream temperature for each gage location was summarized by 7-DADMax for the entire monitoring period for each year where data were available (summary table provided in Appendix B).

The Skookum Creek station (12209490) showed signs of exceedance of the water quality criteria for all monitored years, 2008 through 2011. Waters monitored by the South Fork gage at Saxon Bridge station (12210000) had periodic exceedances of the applicable temperature criteria from 2007 through 2011. Waters monitored at 12209000 (on the South Fork upstream from 12210000) exceeded the water quality criteria for all monitored years, 2001 through 2008 (Table 5).

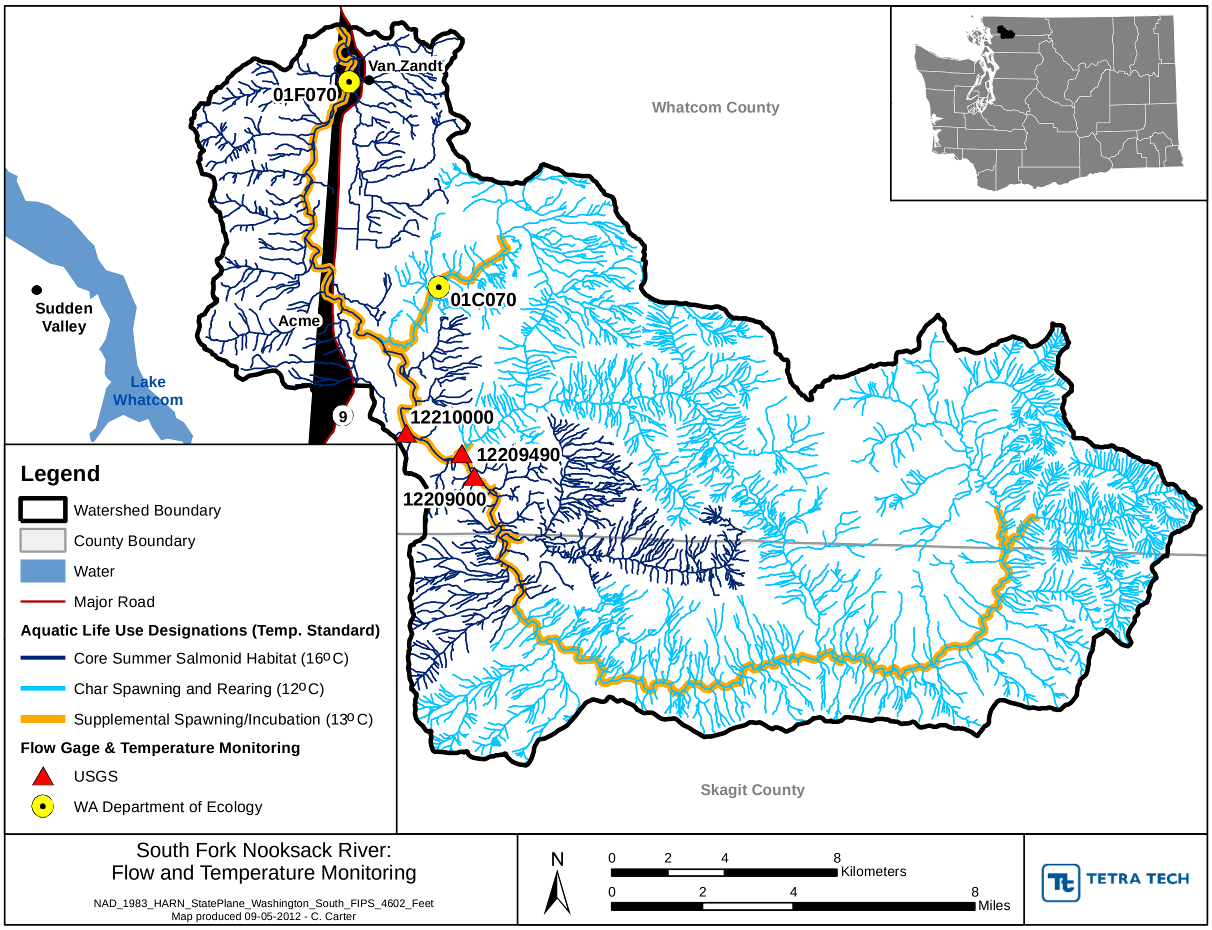


Figure 16. Monitoring locations for USGS and Ecology gages.

Table 5. USGS gage exceedances of water quality criteria (WQC), by location.

Station ID	Station Description	Year	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
12209000	SFNR near Wickersham, WA	2001	58	160	36%
		2002	66	359	18%
		2003	117	359	33%
		2004	80	353	23%
		2005	101	359	28%
		2006	93	303	31%
		2007	79	360	22%
		2008	21	268	8%
12209490	Skookum Creek above diversion near Wickersham, WA	2008	47	253	19%
		2009	93	359	26%
		2010	61	331	18%
		2011	52	327	16%
12210000	SFNR at Saxon Bridge, WA	2007	74	179	41%
		2008	35	343	10%
		2009	100	359	28%
		2010	81	359	23%
		2011	37	344	11%
		2012	0	33	0%

[a]Percent Exceedance = (# days exceeding WQC) / (total days monitored) x 100

Ecology stream temperature monitoring

Two Ecology gage station locations within the SFNR watershed were monitored continuously for stream temperatures, one from 2003 through 2010 and the other from 2003 through 2011. One station is along the SFNR at the Potter Road bridge (RM 1.8, Site 01F070, S. F. Nooksack @ Potter Rd. gage, funded by the Nooksack Indian Tribe) and the second station is on Hutchinson Creek (Site 01C070, Hutchinson Cr. near Acme gage). Station 01F070 (S.F. Nooksack @ Potter Rd. gage) is on waters designated for Core Summer Salmonid Habitat where the temperature criteria are 13 or 16 °C depending on the location and date. Station 01C070 (Hutchinson Creek gage) is on waters designated for Char Spawning and Rearing where the 12 °C criterion applies. Stream temperature for each gage location was summarized by 7-DADMax for the entire monitoring period of each year where data were available (see summary table in Appendix B).

The waters monitored from 2003 through 2011on Hutchinson Creek (Station 01C070) near the town of Acme, WA showed no sign of exceeding the water quality criteria for the years from 2007 to 2011; however, there were periodic exceedances of the applicable temperature criteria from 2003 to 2006 (Table 6). From 2003 through 2010, the monitoring of the South Fork (Station 01F070), farthest downstream, provides evidence of exceedance of the temperature water quality criteria for years 2003 through 2009. There was no sign of exceedance of the temperature criteria for waters monitored by this gage in 2010.

Table 6. Ecology gage exceedances of water quality criteria (WQC), by location.

Station ID	Station Description	Year	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
01C070	Hutchinson Creek near Acme	2003	35	196	18%
		2004	83	348	24%
		2005	52	359	14%
		2006	62	345	18%
		2007	0	359	0%
		2008	0	360	0%
		2009	0	359	0%
		2010	0	359	0%
		2011	0	267	0%
01F070	SFNR at Potter Road	2003	114	196	58%
		2004	99	354	28%
		2005	128	359	36%
		2006	113	359	31%
		2007	85	359	24%
		2008	31	360	9%
		2009	49	359	14%
		2010	0	268	0%

[a]Percent Exceedance = (# days exceeding WQC) / (total days monitored) x 100

Temperature data time series

Box and whiskers plots of annual water temperature 7-DADMax are shown in Figure 17 through Figure 20 for four monitoring stations along the lower half of the SFNR. The plots are not directly comparable to each other since monitored periods of record vary within a given year among the stations. However, the plots are useful for showing annual variation in the ranges of 7-DADMax values at each station.

Two of the stations were monitored by the Nooksack Indian Tribe (SF0031, Figure 17 and SF0025, Figure 18) during the summers of each year, generally from early June through early October. At both stations, 7-DADMax ranges are higher in 2007, 2009, and 2010, and lower in 2008 and 2011. Note that in the years with higher values, the majority of 7-DADMax values exceed the Core Summer Salmonid Habitat criterion of 16^{o} C. Monitoring at the USGS station 12210000 (Figure 19) occurred throughout the year[3], but there is still variation in both the interquartile ranges and the maximum/minimum values. There is a longer period of record at the Ecology Station 01F070 (Figure 20) which also monitored throughout the entire year[4]. 7-DADMax values appear to have been higher during the first four years of monitoring.

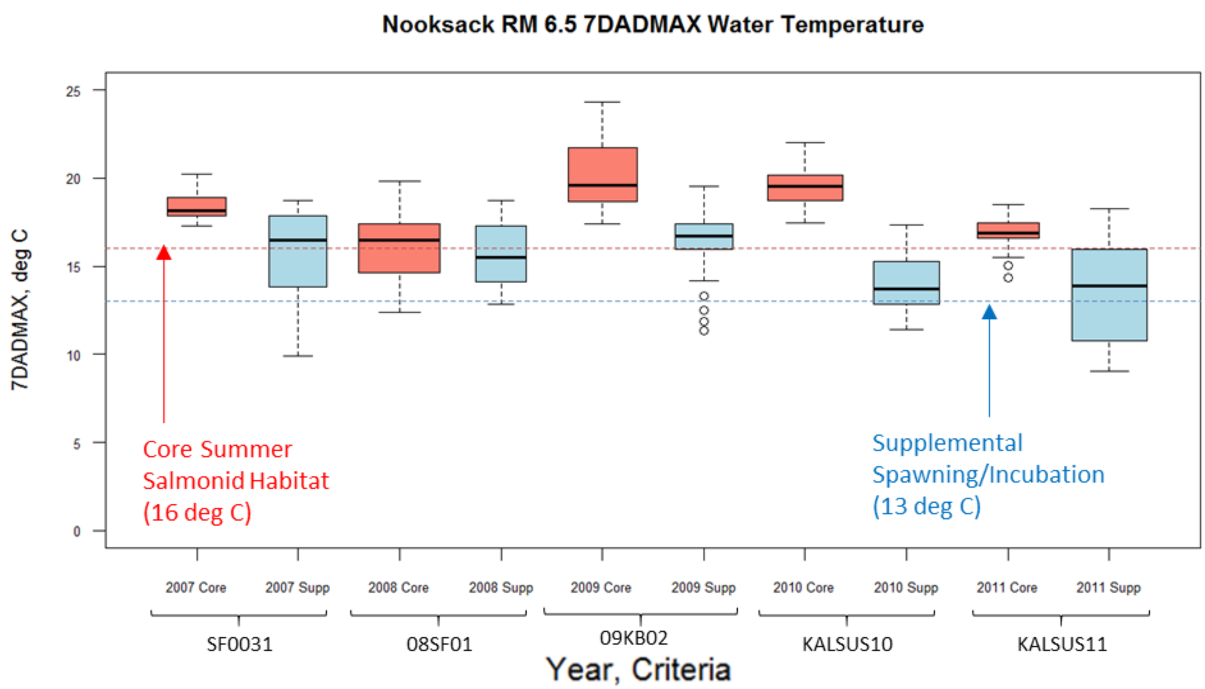


Figure 17. Seasonal box and whiskers plots of 7-DADMax at Nooksack Stations at River Mile 6.5, South Fork Nooksack River.

Red boxes were sampled July 2 – August 31, blue boxes were sampled September 1 – July 1. The width of each box is proportional to the number of samples. This location was generally sampled June to October.

[3] Monitoring at the USGS station began in July 2007, so 2007 is a partial year.
[4] Monitoring at the Ecology station began in June 2003 and ended September 2010, so 2003 and 2010 are partial years.

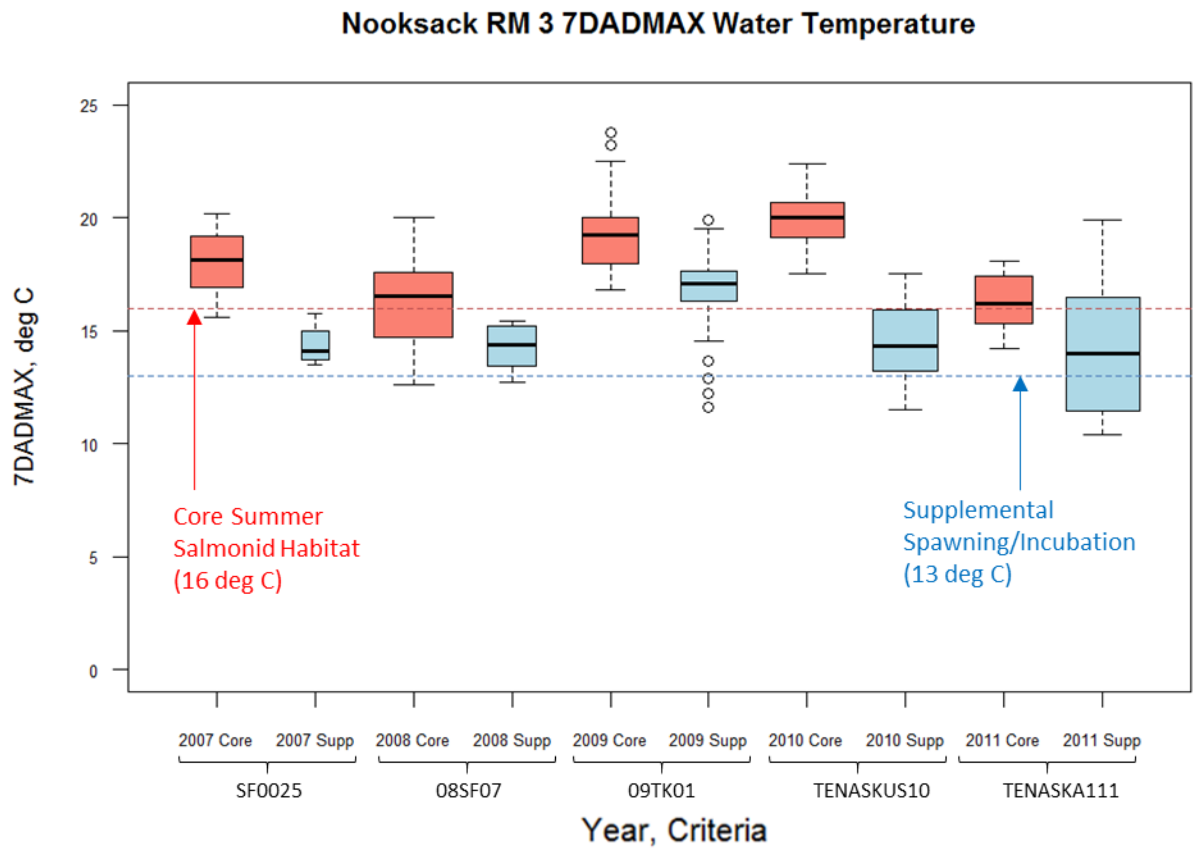


Figure 18. Seasonal box and whiskers plots of 7-DADMax at Nooksack Stations at River Mile 3, South Fork Nooksack River.

Red boxes were sampled July 2 – August 31, blue boxes were sampled September 1 – July 1. The width of each box is proportional to the number of samples. This location was generally sampled June to October.

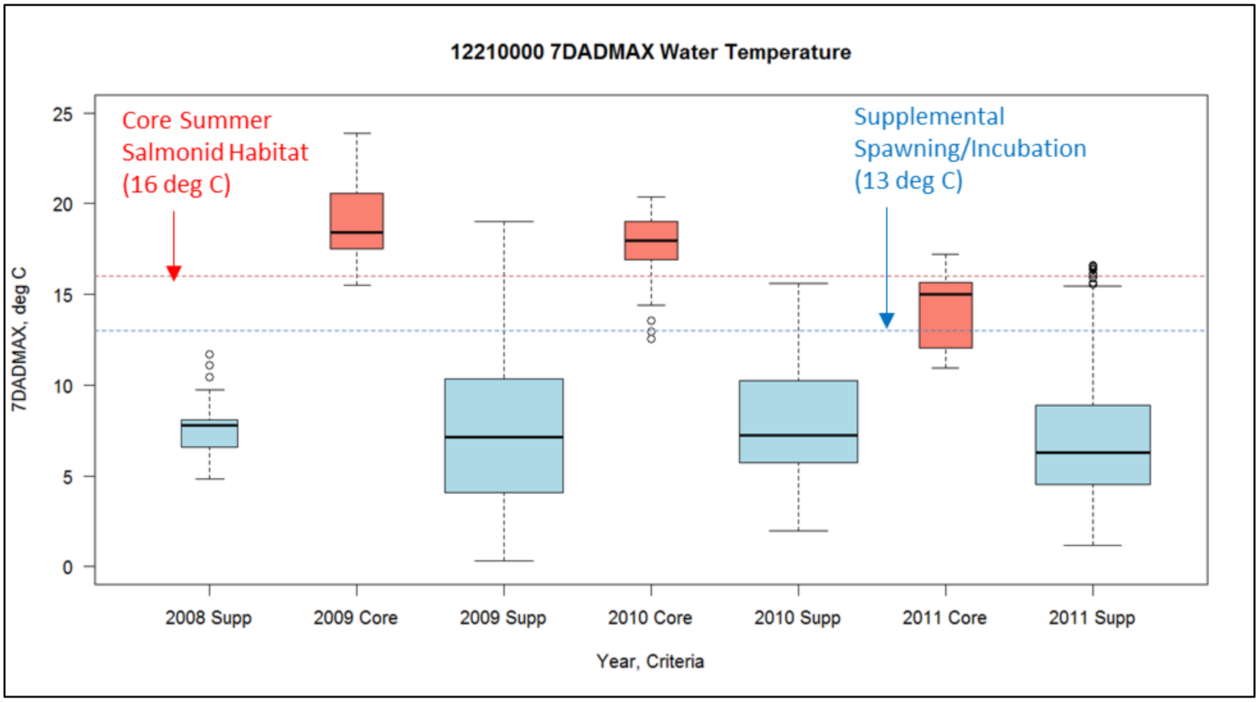


Figure 19. Seasonal box and whiskers plots of 7-DADMax at USGS Station 12210000 (2008-2011), South Fork Nooksack River.

Red boxes were sampled July 2 – August 31, blue boxes were sampled September 1 – July 1. The width of each box is proportional to the number of samples.

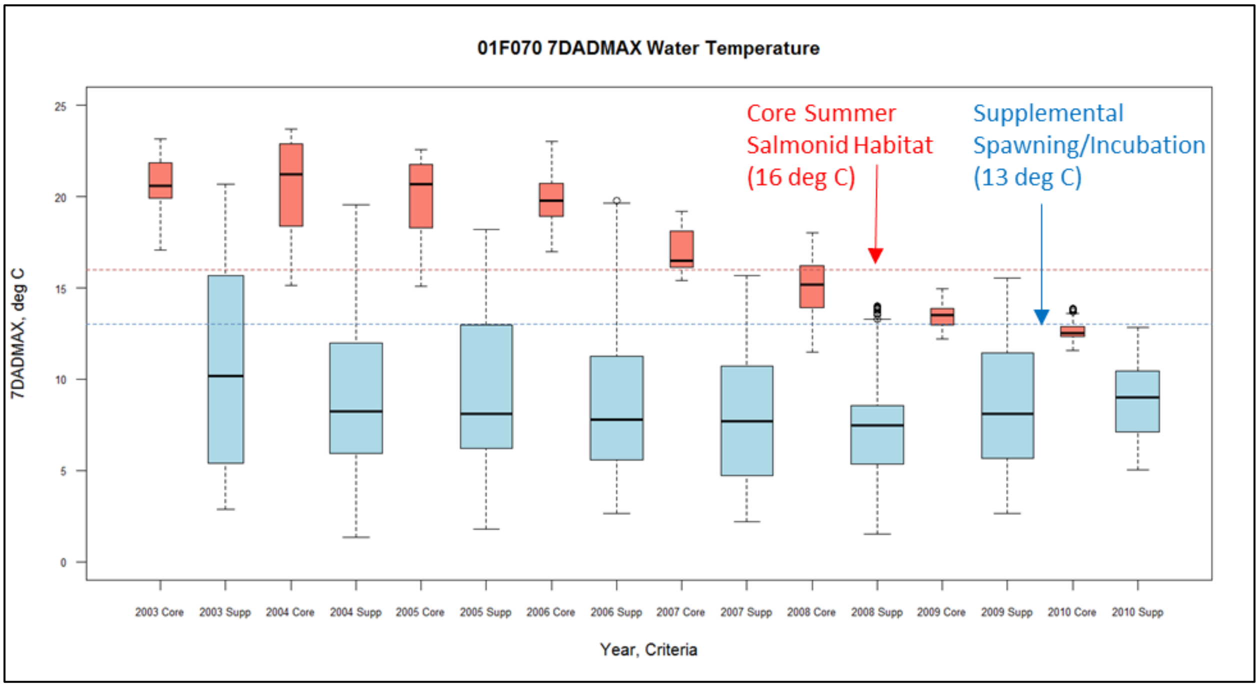


Figure 20. Seasonal box and whiskers plots of 7-DADMax at Ecology Station 01F070 (2003-2010), South Fork Nooksack River.

Red boxes were sampled July 2 – August 31, blue boxes were sampled September 1 – July 1. The width of each box is proportional to the number of samples.

Streamflow data

Recent daily or sub-daily streamflow monitoring data are available from the three USGS and the two Ecology monitoring stations, shown previously in Figure 16. As shown in Table 7, the periods of record for these stations vary. Monitoring ended at USGS station No. 12209000 at the end of September 2008, when this station was replaced a few miles downstream by USGS station No. 12210000, which began recording flow in October 2008. The Ecology station 01F070 is farther down the South Fork, 1.8 miles upstream of the SFNR confluence with the mainstem Nooksack River. Monitoring was suspended at the end of September 2010 but was reinstated in April 2012 with Nooksack Indian Tribe funding.

Two tributaries are also monitored: Skookum Creek by the USGS (12209490) and Hutchinson Creek by Ecology (01C070). Long-term flow data are available from USGS 12209000 beginning in 1934, though flow was monitored only seasonally from 1978 through 1995, generally from June through October.

Long-term annual average flow and annual 7-day average low flow at 12209000 appear relatively stable with no apparent trends (Figure 21). A comparison of average annual flow across all the gages can be seen in Figure 22. Flow statistics are generally consistent with contributing drainage areas, noting that different periods were used to generate the measures (Table 8). However, one discrepancy can be seen in the graph, where 12210000 and 01F070 change rank between water years 2009 and 2010. A comparison of the daily values revealed the same trend, with the change apparently occurring in fall 2009. Ecology reported extensive scour at the site after a major storm in January 2009, which could result in an inaccurate stage-discharge relation for the gaging station and a cumulative potential error of +/- 30% for water year 2009. No technical notes were available for water year 2010 when the change in rank occurred.

Table 7. Streamflow monitoring periods of record available for study.

Agency	Station ID	Station Name	Drainage Area (mi^2)	Beg. Date	End Date
USGS	12209000	SFNR near Wickersham, WA	103	5/1/1934	9/30/2008
USGS	12209490	Skookum Creek above diversion near Wickersham, WA	23	6/13/1998	Current
USGS	12210000	SFNR at Saxon Bridge, WA	129	10/1/2008	Current
Ecology	01C070	Hutchinson Creek near Acme	14	6/13/2003	Current
Ecology	01F070	SFNR at Potter Road	179	6/14/2003	9/30/2010

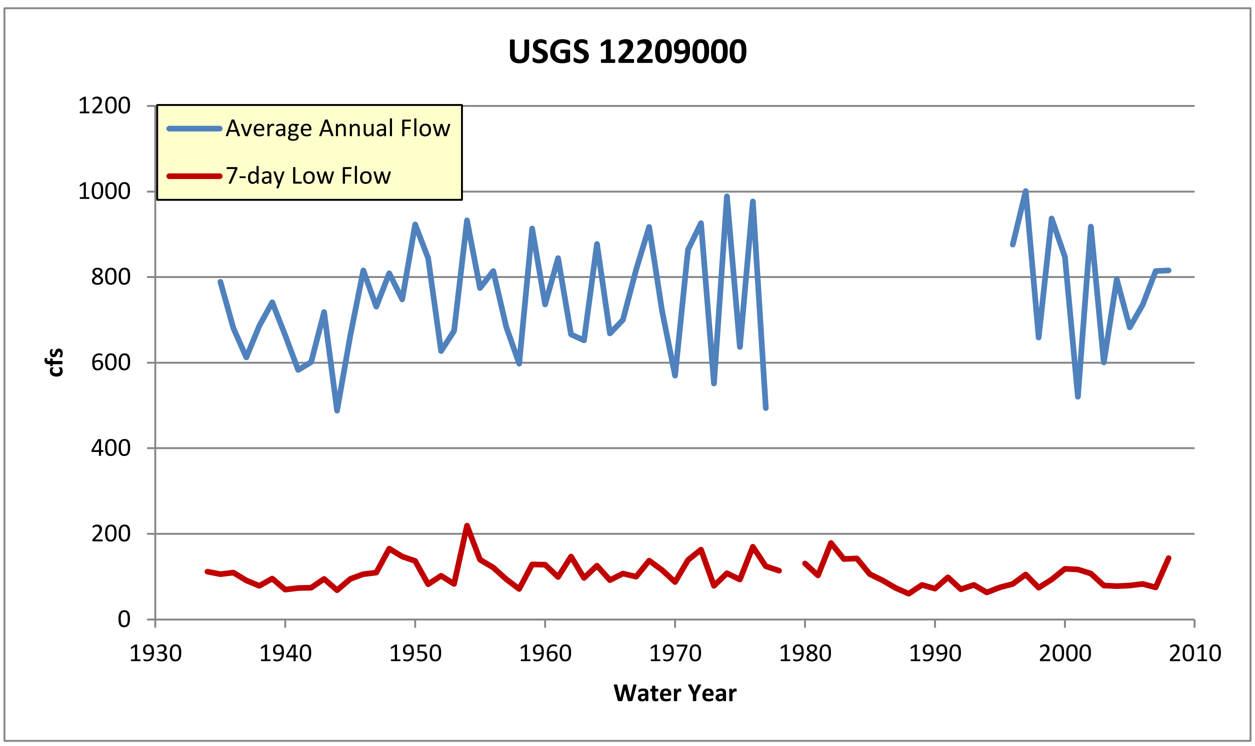


Figure 21. Average annual flow (complete water years only) and 7-day low flow at USGS 12209000.

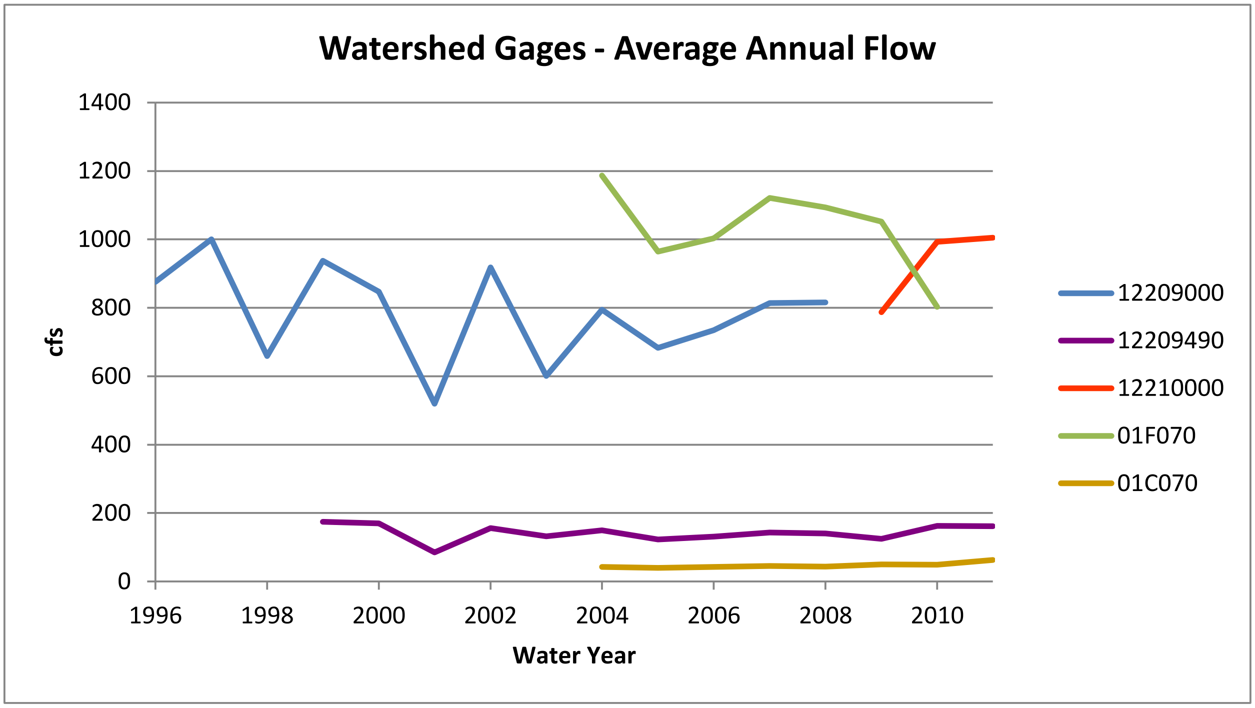


Figure 22. Average annual flow at all locations (complete water years only, beginning 1996)

Table 8. Flow statistics for monitoring stations.

Station ID	Period	Mean flow for Period (cfs)	Percentile Flow (cfs)		
			10th	50th	90th
12209000	WY 1996 - WY 2008	785	139	561	1,542
12209490	WY 1999 - WY 2011	143	32.0	99.0	274
12210000	WY 2009 - WY 2011	928	181	632	1,810
01C070	WY 2004 - WY 2011	47.1	6.9	33.9	96.8
01F070	WY 2004 - WY 2010	1,032	149	720	1,970

Kemblowski et al. (2001) summarize the state of knowledge of aquifer systems in the WRIA 1 region and discuss the results of two seepage runs on the SFNR that the USGS conducted in August and September 1998. The data indicate the river is typically a gaining system, though some short losing reaches were thought to be present. For instance, review of storm-related events suggest that the flows at Potter Road may be less than at Saxon during the rising limb of the hydrograph during the time that the floodplain between the two gages is being recharged. The report does not provide any analysis to distinguish between groundwater gains and inflows from tributaries. The seepage values reported represent the gross streamflow gains and losses measured along the SFNR between mainstem measurement transects (rather than the net stream flow gains from or losses to groundwater that are typically derived from seepage run data).

Meteorological data

The QUAL2Kw model used for TMDL analysis (described later) needs meteorological data to calculate surface heat flux for the temperature model (Ecology, 2003b). Four data types are required: air temperature, dew point temperature, wind speed, and percent cloud cover. Observed solar radiation can be specified, but it is optional because the model provides accepted methods for calculating extraterrestrial radiation, atmospheric attenuation, cloud attenuation, and cloud reflectivity. Inputs for meteorological data are specified for each model reach, allowing for spatial variation between reaches. Hourly or daily values can be entered for up to 365 days.

Potential data sources were screened and are shown in Figure 23 and presented in Table 9. A brief description of each is below.

- AgWeatherNet provides weather data from Washington State University's automated weather station network, with a focus on regions using irrigation.
- SNOTEL stations (for SNOwpack TELemetry) are operated by the Natural Resources Conservation Service and collect snowpack and related climatic data in the western United States.
- Ecology monitors weather data at a number of stations throughout the state.
- Cooperative Summary of the Day (SOD) stations, part of a network associated with the National Climatic Data Center (NCDC).
- NCDC Hourly Precipitation Data (HPD) is a collection of hourly precipitation amounts obtained from recording rain gauges at National Weather Service, Federal Aviation Administration, and cooperative observer stations.
- Surface Airways stations are major weather data collection stations generally at airports, and operated by the National Weather Service. In addition to precipitation, parameters such as wind, relative humidity, and dew point temperature are typically collected on an hourly basis.

The selection of final meteorological data depended on a number of factors including data quality, proximity to the watershed, period of record, and available parameters. Sources used for the modeling included AgWeatherNet, SNOTEL, Ecology, and NCDC SOD.

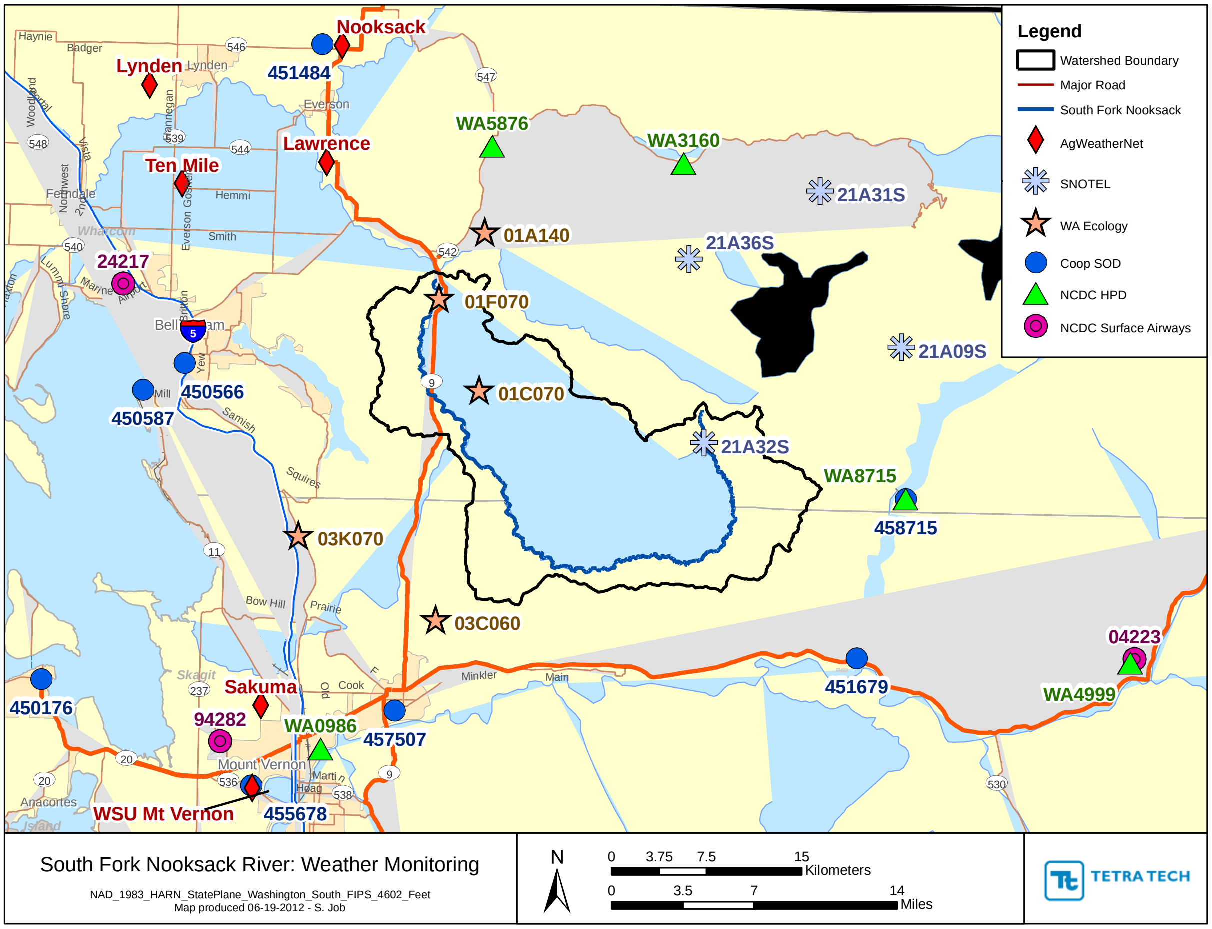


Figure 23. Meteorological monitoring stations near the watershed.

Table 9. Meteorological stations and monitored parameters.

Agency	Station	Approx. Period of Record.*	Frequency	Precipitation	Snow	Air Temp	Dew Point/RH	Solar Rad	Soil Temp	Wind	Cloud Cover
WSU	Lynden	2002 – Current	15 minute	X		X	X	X	X	X	
	Nooksack	2002 – Current		X		X	X	X	X	X	
	Ten Mile	2008 – Current		X		X	X	X	X	X	
	Lawrence	2008 – Current		X		X	X	X	X	X	
	Sakuma	2006 – Current		X		X	X	X	X	X	
	WSU Mt Vernon	1993 – Current		X		X	X	X	X	X	
SNOTEL	21A09S	2006 – Current	Hourly	X	X	X		X		X	
	21A31S	1995 – Current		X	X	X		X		X	
	21A32S	1995 – Current		X	X	X		X		X	
	21A36S	2002 – Current		X	X	X		X		X	
Ecology	01A140	2003 – 2010	15 minute			X					
	01C070	2003 – Current				X					
	01F070	2003 – 2010				X					
	03C060	2005 – Current				X					
	03K070	2005 – Current				X					
NCDC Coop SOD	450176	1905 – Current	Daily	X	X	X					
	450566	1998 – 2006		X	X	X					
	450587	1985 – Current		X	X	X					
	451484	1903 – Current		X	X	X					
	451679	1905 – Current		X	X	X					
	455678	1956 – 2005		X	X	X					
	457507	1896 – Current		X	X	X					
	458715	1965 – Current		X	X	X					
NCDC Hourly Precip. Data (HPD)	WA0986	1948 – TBD	Hourly	X							
	WA3160	1952 – TBD		X							
	WA4999	1948 – TBD		X							
	WA5876	1964 – TBD		X							
	WA8715	1964 – TBD		X							
NCDC Surface Airways	04223	2007 – Current	Hourly	X		X	X	X		X	X
	24217	1998 – Current		X		X	X	X		X	X
	94282	2003 – Current		X		X	X	X		X	X

* Some stations have varying periods of record for the listed parameters; the start date reflects the earliest date among the series, usually precipitation.

Other data

Existing vegetation and soils data

Riparian function assessment
The Nooksack Indian Tribe Natural Resources Department provided data on riparian condition units (RCUs) for the South Fork River and major tributaries throughout the SFNR watershed. Riparian data were discussed in a report produced by the Nooksack Indian Tribe (Coe, 2001). The following is a brief synopsis of the data provided:

> In May 2000, Nooksack Natural Resources and Lummi Natural Resources contracted with Duck Creek Associates to conduct a riparian function assessment for salmonid-bearing and contiguous streams in the Nooksack River watershed. Using 1:12,000 scale aerial photos obtained from the U.S. Forest Service (federal ownership; 1991 photo year) and Washington Department of Natural Resources (all other ownerships, 1995 photo year), riparian condition was classified in 100-ft-wide units beyond apparent channel migration zones along both right and left banks of relevant stream segments. Photo-classification was ground-truthed in numerous locations. Riparian function assessment was based on Watershed Analysis methods (WFPB, 1997) with some modification for non-forested lands. For each riparian condition unit, percentage canopy shading, vegetation type, vegetation size class, and vegetation density were classified (17,923 total acres).

Data produced through the riparian function assessment can be used to inform model development; however, riparian conditions from 1991 and 1995 might not reflect more current conditions being analyzed for the TMDL tools. Figure 24 displays percent canopy shading derived for assessment units for a subset of the watershed.

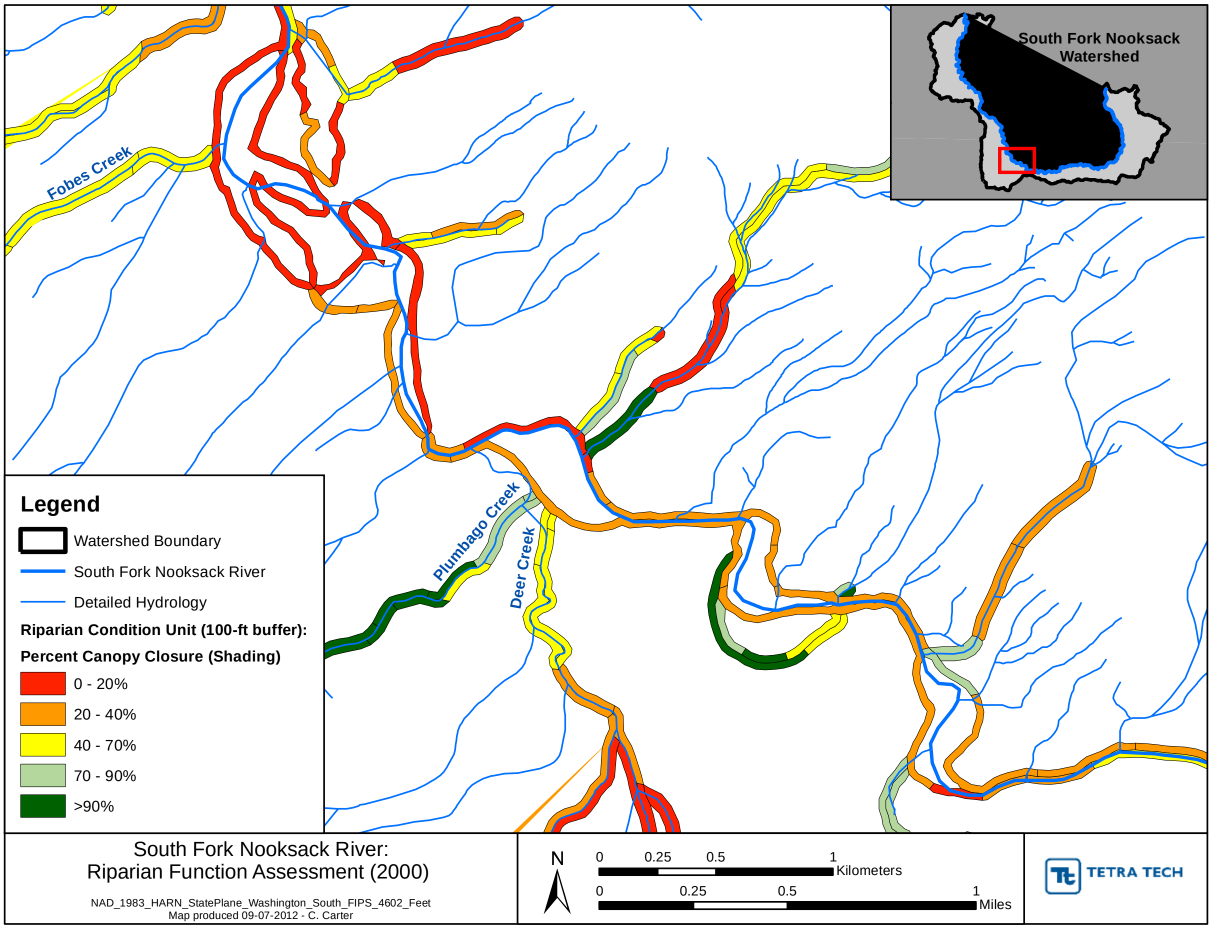


Figure 24. Subset of assessment units from riparian function assessment (based on 1991 and 1995 aerial imagery).

Digital ortho imagery

Flights were conducted by the USDA National Agricultural Imagery Program (NAIP) for both Whatcom and Skagit Counties. This aerial imagery was used to provide locations of channel bank, active channel, as well as differences in land use and land cover within the riparian corridor. Photography flights used for the modeling analysis occurred June 24 through August 18 in 2006, and on October 15th in 2009 for both Whatcom and Skagit Counties.

Coastal Change Analysis Program

The Coastal Change Analysis Program (CCAP) was created by the National Oceanic and Atmospheric Administration (NOAA) which defines land cover and land change along the U.S. coastlines using remote imagery and raster-based land cover maps. The CCAP data from 2006 was the most recent land use raster available for use to inform classifications of existing near-stream vegetation.

Soil data

Soil data can be used to identify where specific system potential vegetation (SPV) species are most likely to occur due to soil type. Washington Department of Natural Resources (WDNR) soil surveys for Skagit County (Klungland and McArthur, 1989) and Whatcom County (Goldin, 1992) provide data on major soil types across the entire watershed. Soil data is available in GIS format from the Soil Survey Geographic Database or SSURGO which was used to identify major soils within the riparian corridor (NRCS, 2012).

LiDAR data

Light Detection and Ranging (LiDAR) data can be used to identify existing vegetation types, heights, and densities. LiDAR data was commissioned and funded by the Nooksack Indian Tribe and Lummi Nation; vegetation height derived from these data is displayed in Figure 25. The LiDAR was flown by the Puget Sound LiDAR Consortium, with deliverable items including bare-earth elevation, top-of-vegetation elevation, as well as vegetation-height rasters. The LiDAR for the downstream half of the watershed was flown in 2005 on a 6ft x 6ft resolution, and the LiDAR for the upstream half of the watershed was flown in 2009 on a 3ft x 3ft resolution. The combination of both sets of LiDAR data were used to identify existing conditions and the combination of both types of soils data were used in the estimations related to SPV.

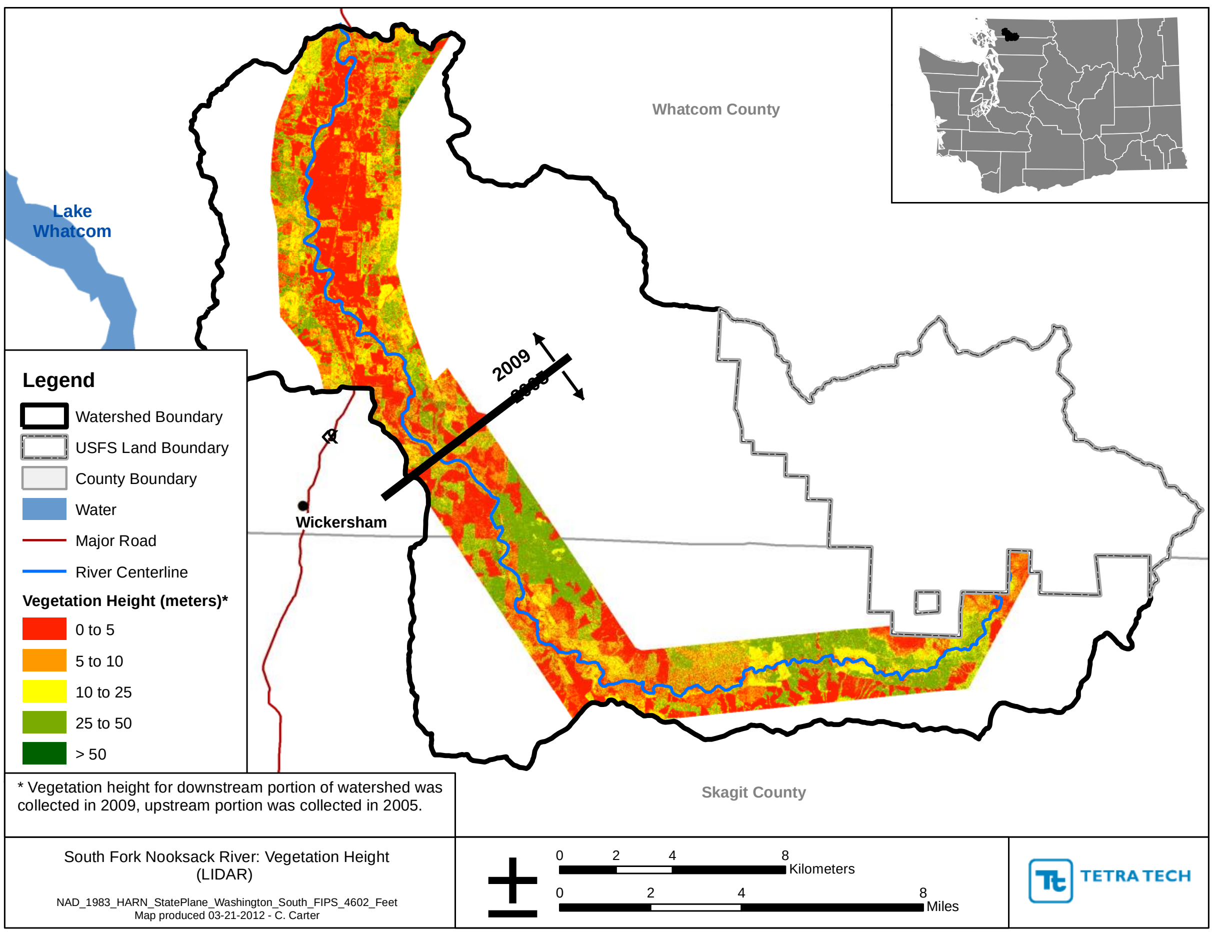


Figure 25. Existing vegetation height along the South Fork Nooksack River from LiDAR data collected in 2005 and 2009

FLIR

Forward looking infrared (FLIR) thermal imagery measures the temperature of the outermost portions of the objects captured in the image. On free-flowing streams, where water columns are generally well mixed, surface temperatures represent the temperature of the stream water column. The exception is in thermally stratified areas, which can occur in slow, deep channels or upstream of impoundments (ODEQ, 2001).

The FLIR data are collected from a sensor mounted on an aircraft and records digital data to an onboard computer. The FLIR detects emitted radiation at wavelengths from 8 to 12 microns (long-wave) and records the level of emitted radiation as a digital image across the range of the sensor. Each image pixel contains a measured value that is directly converted to a temperature (ODEQ, 2001).

A spatial tool called TTools can be used to sample FLIR temperature data to develop longitudinal temperature profiles (Kasper and Boyd, 2001). The data can also be used to identify subsurface hydrology, potential groundwater inflow areas, and spring locations throughout the extent of FLIR data collection by identifying cold water sections along the longitudinal profile that are not associated with cooler tributaries joining the main channel. Interpreted data can be used to inform model development.

Watershed Sciences, LLC, conducted the FLIR survey for the South Fork Nooksack in 2001 for the Nooksack Indian Tribe Natural Resources Department. The following information from the survey report details the location of surveying, the purpose for surveying at high and low altitudes, accuracy verification, and results discussion (Watershed Sciences, LLC, 2002):

> The aerial surveys covered the Nooksack River to the South Fork confluence and the South Fork (SF) Nooksack River to RM 38.5 [near the confluence of Bell Creek (Figure 1)] on August 20, 2001. In order to capture floodplain features, a high altitude flight was conducted on the Nooksack River and over the lower 13 miles of the South Fork. On the South Fork, [RMs] 0–11.2 were resurveyed at a lower altitude using multiple flight lines in order to produce higher resolution images of the floodplain area. The entire length of the SF Nooksack River to RM 38.5 was surveyed at the lower altitude.

Table 10 summarizes the time, extent, altitude, and approximate image footprint for each survey conducted in the basin. With the exception of the multiple flight lines on the South Fork, all surveys started at the river mouth and continued upstream.

Table 10. Time, altitude, and distance for the South Fork Nooksack River surveys on 8/20/01.

Stream	Time (PM)	Altitude AGL (ft)	Image Footprint Width (ft)	Pixel Size (ft)	Survey Extent
SF Nooksack River	2:24 - 2:37	5,000	1,763	≈2.9	Mouth to mile 13.7
SF Nooksack River Floodplain	2:44 - 4:37	1,500	528	≈0.9	Multiple flight lines; RM 0 to 11.2
SF Nooksack River	4:46 - 5:43	1,500	528	≈0.9	Mouth to mile 38.5

Higher altitude surveys are generally conducted on larger rivers to capture floodplain features of wide rivers. Low altitude surveys are ideal for smaller, narrower rivers where floodplain features can still be captured while producing higher resolution images.

Watershed Sciences, LLC (2002), verified the accuracy of radiant temperatures measured by the thermal infrared (TIR) sensor using in-stream temperature data loggers at 17 locations throughout the Nooksack River Basin. Its findings suggest that on the high-altitude survey (5,000 ft) of the SFNR, no significant difference was observed between the three in-stream sensors and the radiant temperatures. However, a larger range of differences was noted on the low altitude survey (1,500 ft) of the SFNR where differences between in-stream sensors and the radiant temperatures ranged from -1.3 °C to 1.3 °C, with an average difference of approximately 0.1 °C (Watershed Sciences, LLC, 2002). The survey report explains that the difference between radiant temperatures and temperatures measured by in-stream sensors could reflect inaccuracies that occur when not enough pixels are available to represent the stream to get a true radiant stream temperature sample. This often occurs at very narrow portions of the river where river width is relatively small in relation to pixel size of the survey.

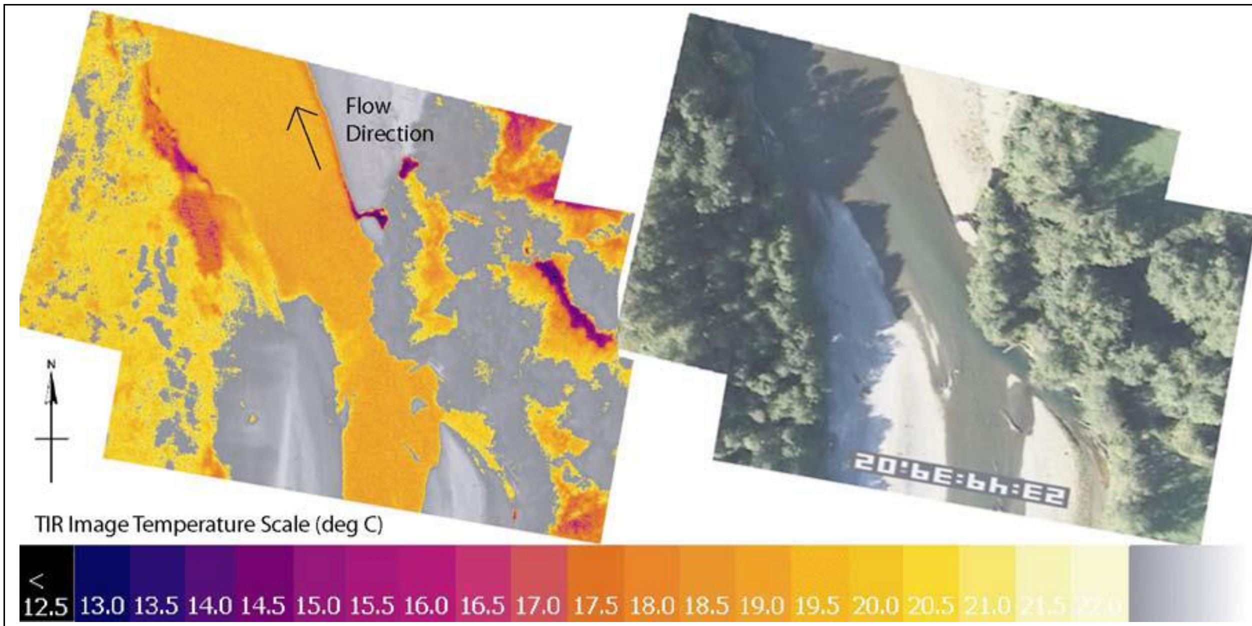
Watershed Sciences, LLC (2002), summarized FLIR survey results for the South Fork Nooksack as follows:

> The South Fork Nooksack River showed typical patterns of downstream warming with some reach scale variability. *Tributaries and other surface water inflows played a pronounced role in defining stream temperature patterns in the South Fork.* Several inflows detected during the analysis were not documented on the 7.5’ USGS topographic maps. In the lower 7.4 miles, the imagery indicates several cool inflows/seeps that have a fine scale influence on stream temperatures although larger-scale median water temperatures approached air temperatures through this reach. TIR and visible band image mosaics were created of the lower 11.2 miles of the South Fork and provide a good resource for examining features and hydrologic links within the floodplain. In some cases, further analysis and ground level reconnaissance are required to identify the possible mechanisms driving the observed spatial temperature patterns.

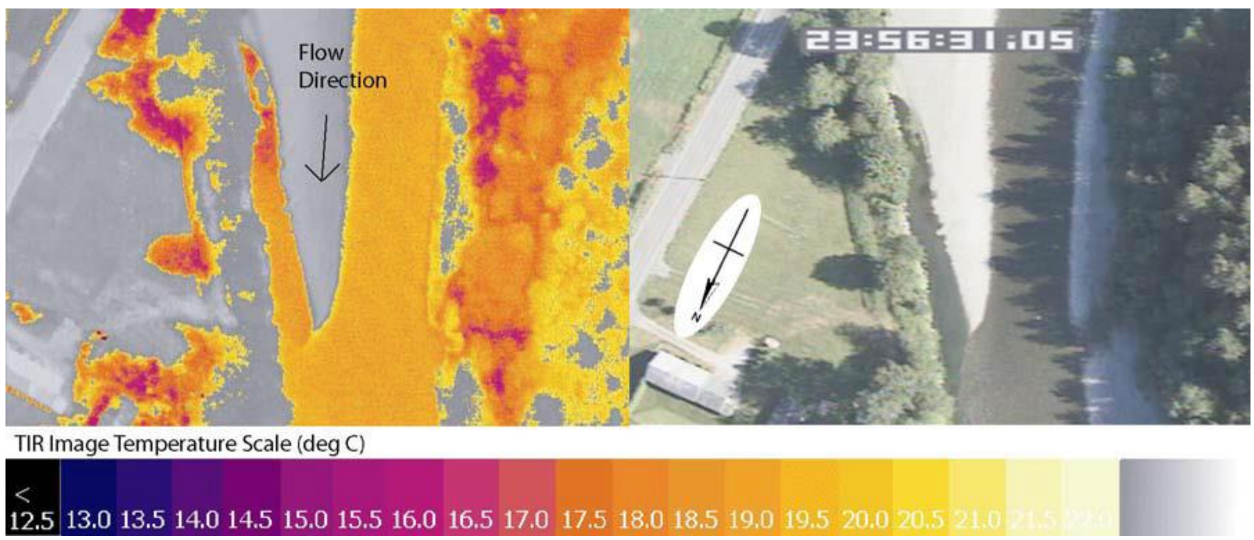
Figure 26 illustrates TIR (FLIR image results) and visible band color images showing features observed in the SFNR Basin. The stream temperatures presented with the images represent the median of 10 sample points taken longitudinally at the center of the apparent thalweg in the TIR image. The given tributary temperatures are the median of 10 sample points taken at the mouth of the tributary (Watershed Sciences, LLC, 2002). The survey report provides longitudinal profiles of median channel temperatures versus RM for the low-altitude survey (1,500 ft) of the SFNR (mouth to RM 38.5) and of the high-altitude survey (5,000 ft) of the lower 13.5 RM of the SFNR. The profiles include median temperatures and RM locations of all surface water inflows (e.g., tributaries, springs, ditches) that were visible from the imagery.

In areas where the low- and high-altitude surveys overlap along the SFNR (i.e., mouth to RM 13.5), median surface water temperatures from the two surveys are generally within about 2 °C of one another with median temperatures from the high-altitude survey often lower than those from the low-altitude survey.

Greatest differences between the two surveys are observed from RM zero to RM 8, after which (from RM 8 to 13.5) median temperatures from the two surveys are in closer agreement with one another and differences in median temperatures drop to within about 1 °C or less.



Frame: sfn0103-104: TIR/visible band images showing the SFNR (19.4 °C) at RM 2.0. The inflow of Black Slough (14.6 °C) is visible, except where obscured by vegetation, along the right bank near the center of the image.



Frame: sfn0310: TIR/visible band image pair showing the downstream end of a gravel bar on the SFNR (19.1 °C) at RM 7.1. Water temperatures are cooler in the side channel where surface water emerges from the gravel, evidence of hyporheic upwelling.

Figure 26. Subset of FLIR images captured for the South Fork Nooksack River.

Channel morphology

Channel cross sections of the SFNR and tributaries were surveyed at 22 locations, corresponding to the locations where data were collected in support of the USGS seepage study discussed in the *Streamflow Data* section. The following data were recorded for each cross section: flow (cfs), wetted channel width (ft), average velocity (ft/s), and average depth (ft). Data were collected for 17 of the cross sections on three dates: August and September 1998 and October 1999. For the remaining five sites, data were collected for only the two dates in 1998. Figure 27 displays the location of each cross section in the SFNR watershed. Table 11, Figure 28, and Figure 29 provide examples of typical data from the sites.

Additional channel morphology data were provided by the Lummi Nation Natural Resources Department. These data included channel positions for dates ranging from 1885 to 1998 for the lower portion of the SFNR (Collins and Sheikh, 2004a; 2004b) and from 1885 to 2005 for the upstream portion of the river (Brown and Maudlin, 2007). Data were generated from historic survey maps before 1990 and aerial photographs for the remaining years. Figure 30 displays channel positions for a small section of the river using data generated in support of Brown and Maudlin (2007).

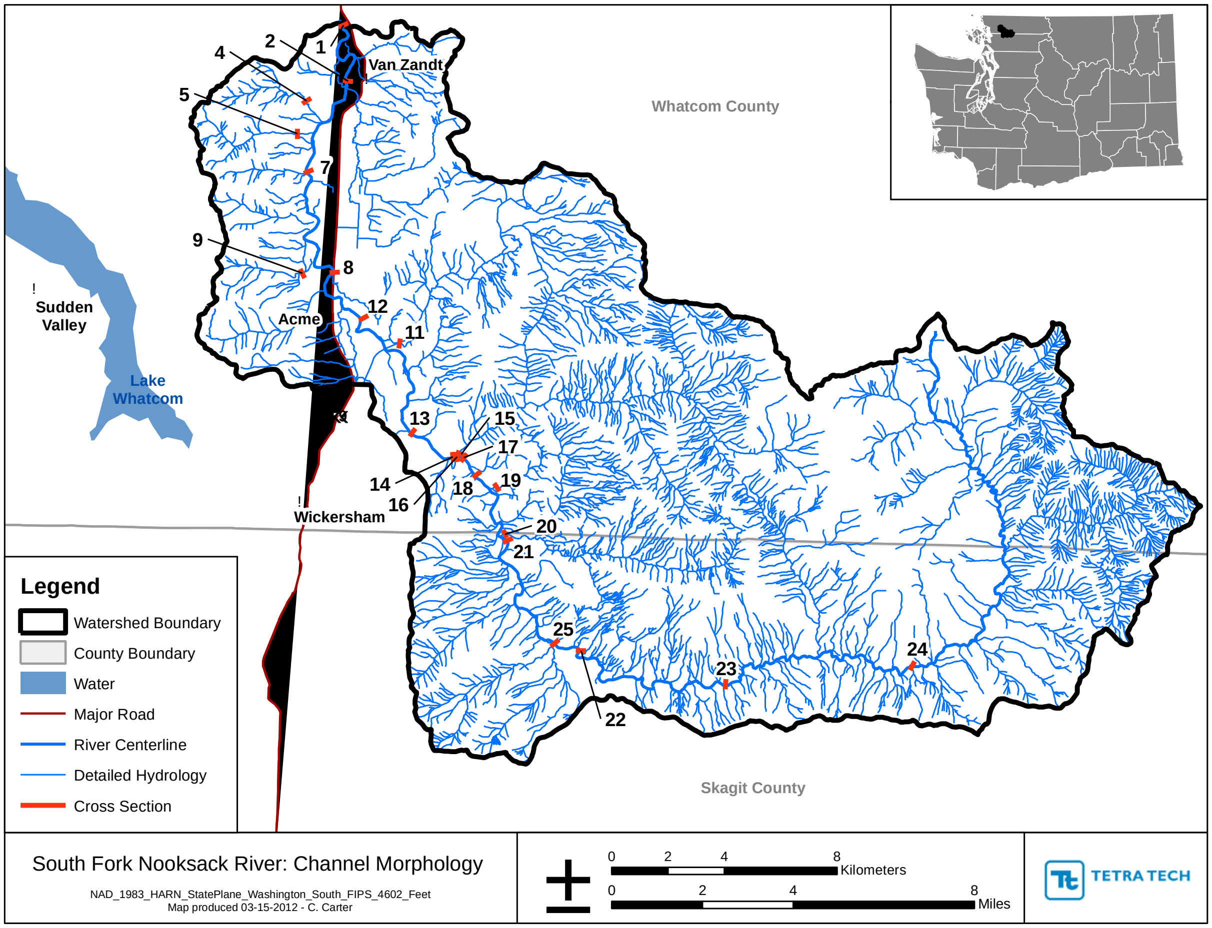


Figure 27. Cross-section locations along the South Fork Nooksack River and tributaries.

Table 11. Example of data available at cross-section sites.

Site	Site Description	Date	Flow (cfs)	Width (ft)	Average Velocity (f/s)	Average Depth (ft)
2	SF Nooksack River at Van Zandt	9/29/1998	109	80	1.4	0.966
		8/25/1998	126.92	79	1.64	1.047
22	SF Nooksack River at Larson Bridge	10/5/1999	100.74	86	0.67	1.748
		9/30/1998	63.6	45	1.28	1.126
		8/25/1998	77.6	46	1.43	1.191

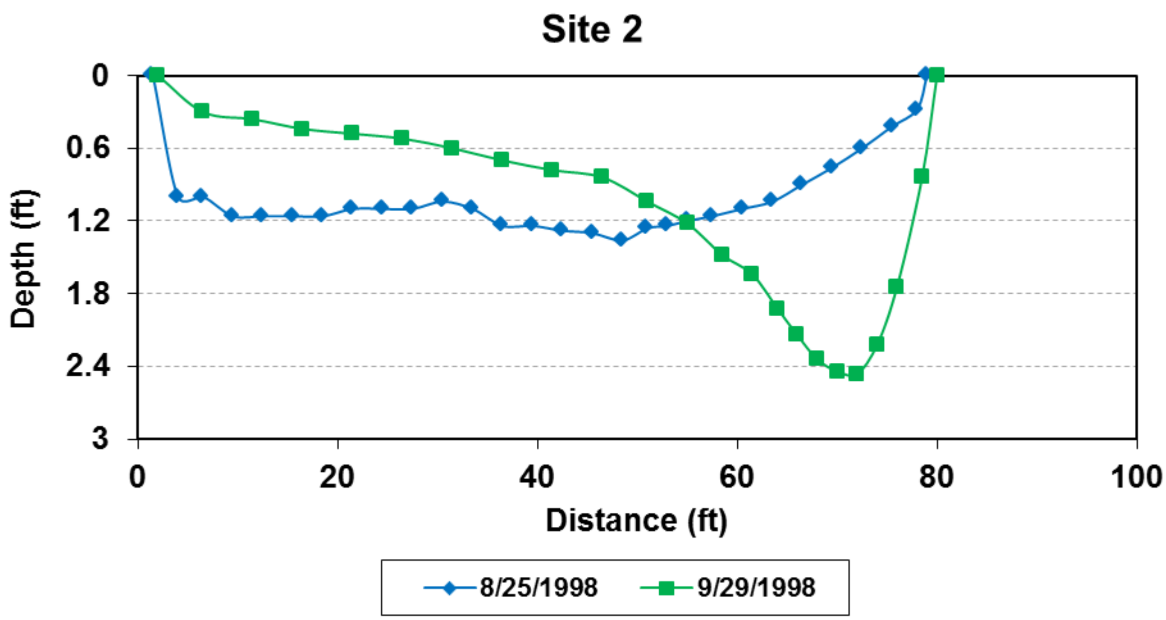


Figure 28. Cross-section survey measurements for Site 2.

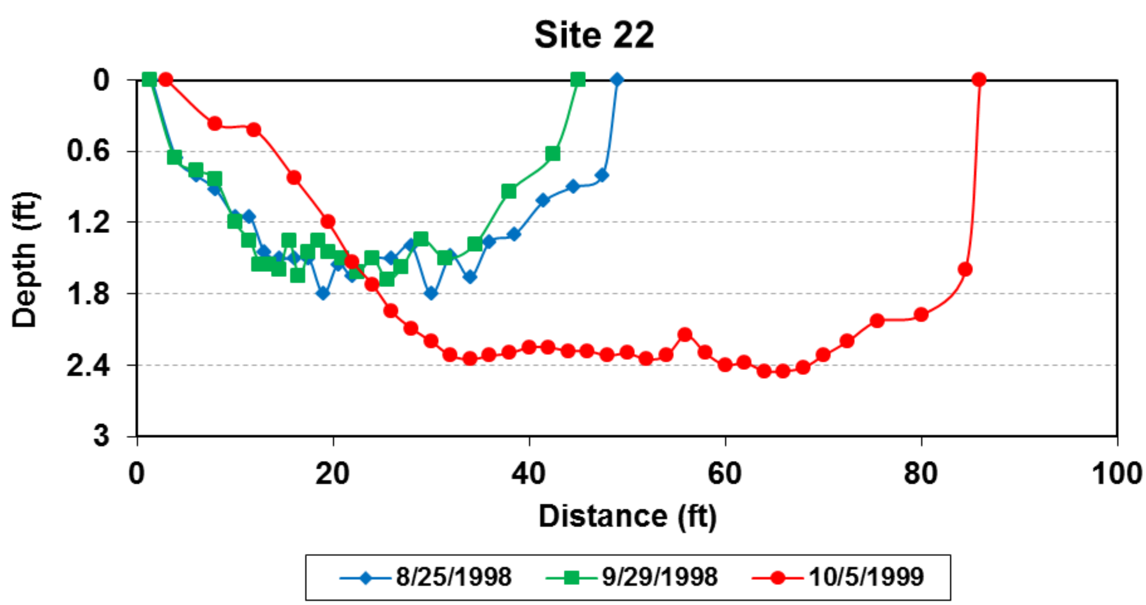


Figure 29. Cross-section survey measurements for Site 22.

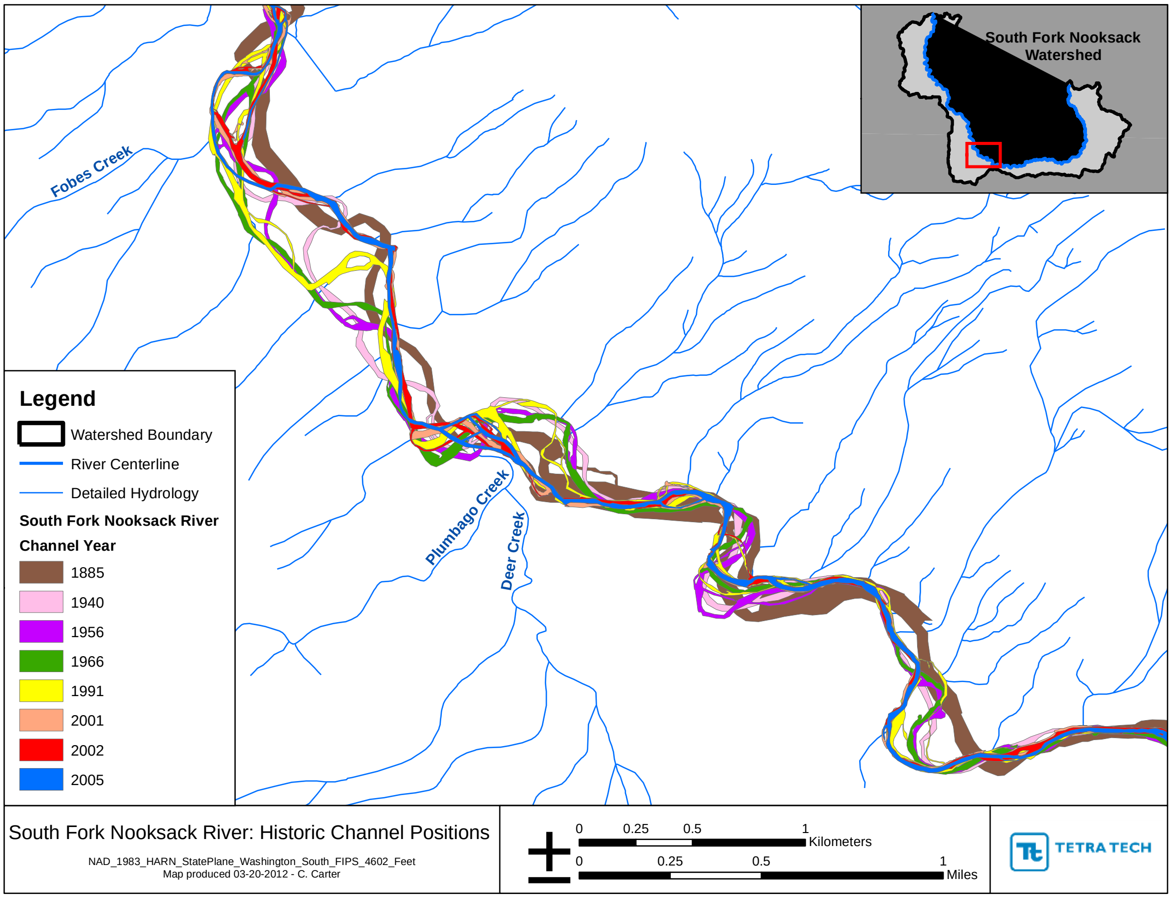


Figure 30. Historic channel positions of the South Fork Nooksack River.

Historic cover data sets

Several data sets are available representing historic conditions in the vicinity of the watershed from 1880 to 1938, using a combination of survey notes and land use maps, early topographic maps, and aerial photographs. A historical conditions data set was also created in support of the WRIA 1 Watershed Management Project (Winkelaar, 2004). Historic conditions data sets can be used to support modeling of natural conditions during TMDL development and to compare with SPV estimates as needed.

Other studies

Nooksack Indian Tribe and USGS Groundwater Study, 2005

Cox et al. (2005) discuss a set of field studies of groundwater/surface water interactions in the shallow glacial aquifer of the lower Nooksack River Basin, and the relationship to groundwater transport of bacteria and nitrate. The studies took place at various times between 2002 and 2005. In the South Fork basin, a longitudinal temperature profile was taken on August 28, 2003, between 9:00 a.m. and 4:00 p.m., on 14 miles of the river between Skookum Creek and the confluence with North Fork Nooksack River. The results suggest that five reaches of the river were influenced by the input of cooler groundwater. The locations appeared to be adjacent to geologic deposits possibly containing sufficient coarse-grained materials for aquifer formation. No further study in the SFNR watershed was conducted. The results are useful for identifying areas where groundwater discharge is occurring. As a supplement to the FLIR data, the descriptions of the types of geologic and alluvial formations could identify reaches in other locations where groundwater discharge might be occurring.

Ongoing Studies

Water Resource Inventory Area 1 Model

A hydrologic modeling effort (i.e., water budget for the lower basin) was completed by Christina Bandaragoda with Silver Tip Solutions, to update the WRIA 1 model previously developed by Utah State University (Tarboton et al., 2007a; Tarboton et al., 2007b). The SFNR falls within the southern portion of WRIA 1. The WRIA 1 Watershed Management Project is a planning effort required by the 1998 Washington State Watershed Management Act. According to the project website (http://wria1project.whatcomcounty.org/), the goal of the project is, "to have water of sufficient quantity and quality to meet the needs of current and future human generations, including the restoration of salmon, steelhead, and trout populations to healthy harvestable levels, and the improvement of habitats on which fish and shellfish rely." The updated model can be used to establish drainage-based estimates of precipitation, evapotranspiration, streamflow, and groundwater infiltration.

While the SFNR is included in the WRIA TOPNET model, flow is forced at the Wickersham gage. Difficulties with orographic precipitation estimation and glacier snowmelt resulted in problems replicating flows in high-elevation areas. As a result, a number of gages including the Wickersham gage, were used as upstream boundary conditions with forced flow using observed flow time series. The 2007 calibration report notes that flow was not well reproduced at Skookum Creek, the only calibration location in the SFNR watershed. Flow was overestimated by about 30% to 50% during the various calibration periods. Other statistics were not presented, but hydrographs show poor fit in most years with apparent seasonal bias including low-flow periods.

Therefore, though the model was indeed built for the South Fork Nooksack subwatersheds upstream of the Wickersham gage and model output is technically available, it is clear from the 2007 calibration report that quality of the simulation from those areas was not acceptable. In other words, no direct model output is available to characterize flow upstream of gaged locations in the watershed.

Nooksack Tribe and USGS Groundwater Study

A groundwater modeling study began in 2012 involving the USGS and the Nooksack Indian Tribe. The report was released in 2014 (Gendaszek, 2014). The goal of the study was to refine the characterization of groundwater/surface water interactions in the South Fork Nooksack valley through developing a hydrogeologic framework of data collection and analysis. The study area included the SFNR, its tributaries, and wetlands within its riparian corridor. In addition to domestic, agricultural, and commercial uses of groundwater within the SFNR basin, groundwater has the potential to provide ecological benefits by maintaining late-summer stream flows and buffering stream temperatures. Cold-water refugia, created and maintained in part by groundwater, have been identified by water resource managers as a key element to restore the health and viability of threatened salmonids in the SFNR.

The SFNR valley is underlain by unconsolidated glacial and alluvial sediments deposited over older sedimentary, metamorphic, and igneous bedrock. The primary aquifer that interacts with the SFNR was mapped within unconsolidated glacial outwash and alluvial sediment. The lower extent of this unit is bounded by bedrock and fine-grained, poorly-sorted unconsolidated glacio-marine and glacio-lacustrine sediments. In places, these deposits overlie and confine an aquifer within older glacial sediments. The extent and thickness of the hydrogeologic units were assembled from mapped geologic units and lithostratigraphic logs of field-inventoried wells.

Generalized groundwater-flow directions within the surficial aquifer were interpreted from groundwater levels measured in August 2012. Groundwater seepage gains and losses to the SFNR were calculated from synoptic streamflow measurements made in the SFNR and its tributaries in September 2012. Subsets of the field-inventoried wells were measured at a monthly interval to determine seasonal fluctuations in groundwater levels during the 2013 Water Year. Taken together, these data provide the foundation for a future groundwater-flow model of the SFNR that may be used to investigate the potential effects of future climate change, land use, and groundwater pumping within the study area.

Site-specific hydrologic data were measured to characterize the interaction between the SFNR, surficial aquifers, and riparian wetlands. The data included a time series of longitudinal temperature profiles measured with a fiber-optic distributed temperature sensor and continuous monitoring of stream stage and water levels measured in wells in adjacent wetlands and aquifers.

The Nooksack Indian Tribe contracted with University of Washington (glacier module) and Western Washington University (hydrology model) to model the hydrology of the Nooksack River, including the South Fork, using the Distributed Hydrology, Soils, Vegetation Model (DHSVM) along with currently down-scaled climate data and projections developed by the University of Washington Climate Impacts Group. This hydrologic modeling effort was completed in November 2015 (Murphy 2016), and will be used to update and refine previously-characterized hydrology of the river system, as well as facilitate TMDL implementation. In addition, Western Washington University was contracted to similarly model stream temperature (Truitt 2018) and sediment dynamics (Knapp 2018) in the Nooksack River system, including the South Fork, using the previously calibrated DHSVM. Combined, these three modeling efforts will provide additional information that can be used to facilitate TMDL implementation.

Goals and Objectives

Project goals

The goal of this water quality improvement plan is to address temperature problems in the SFNR watershed so that water quality is improved and designated uses are protected and restored. More specifically, the goal is for the river and its tributaries to meet the Washington State water quality standards for temperature. The following section, *TMDL Analysis*, uses the existing data described previously to support modeling of temperature processes in the watershed, determine the loading capacity for temperature, and set load allocations, wasteload allocations, and a margin of safety.

Study objectives

Objectives of the TMDL study are as follows:

- Characterize stream temperatures and processes governing the thermal regime. This includes characterizing riparian vegetation and shade, as well as the influence of tributaries and groundwater/surface water interactions on the heat budget.
- Develop a predictive temperature model. Using critical conditions in the model, determine the SFNR's capacity to assimilate heat, and evaluate the system potential temperature (approximate natural temperature conditions using the 100-year SPV as an estimate of natural conditions) for the river.
- Determine the loading capacity that meets temperature water quality criteria and protects designated uses.
- Allocate the allowable load to point and nonpoint sources.
- Provide an assessment of the potential impact of climate change on stream temperature in the SFNR.
- Develop an implementation plan for the TMDL.
- Support recovery efforts for salmon and to promote salmon habitat restoration effectiveness.

Analytical Approach

Study area

The study area for this TMDL is the SFNR and its tributaries, encompassing approximately 186 square miles (mi^2) (Figure 1). This watershed is in Washington State's Water Resources Inventory Area No. 1 (WRIA 1) and the U.S. Hydrologic Unit Code (HUC) No. 17110004.

Modeling framework

Addressing the principal study questions requires a modeling framework that can simulate flow and thermal loading. To predict thermal conditions and to assess relationships with riparian vegetation and topography, a combined Shade-QUAL2Kw modeling approach was selected. The approach consists of a GIS-based Shade model that provides shade inputs to a QUAL2Kw water quality model. The "TMDL Analysis" section provides a detailed description of the modeling framework.

Quality assurance

Ecology sources

Ecology temperature and flow data were collected under a Quality Assurance Monitoring Plan (QAMP). These are available at https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Water-quality-monitoring/River-stream-monitoring-methods

Sources outside of Ecology

Data from sources outside of Ecology were also used in the modeling approach. The Nooksack Tribe collected data according to a Quality Assurance Project Plan (QAPP) for the Nooksack River Watershed Water Temperature Monitoring Program (Nooksack Indian Tribe, 2009). These data are consistent with Ecology's Credible Data Policy, see this link for more information: https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11

In addition, data used to support model development from standard sources such as NCDC and USGS were collected under each organization's standard quality assurance procedures and is assumed appropriate for use in this TMDL.

Modeling QAPP

A modeling QAPP was developed for this project and was finalized in 2012 (Kennedy and Butcher, 2012). This document describes quality objectives for the modeling, data management procedures, and data quality components.

TMDL Analysis

A TMDL analysis was developed to evaluate compliance with state water quality standards for temperature in the SFNR watershed and to support development of a water quality improvement report (WQIR) and implementation plan (IP). The analysis used steady state models to characterize stream temperatures and processes governing the thermal regime in critical conditions, system potential conditions, and for a number of additional scenarios. The models form the technical foundation for determining loading capacity to meet temperature water quality criteria and protect designated uses, and allocation of those loads to point and nonpoint sources.

Modeling and analysis framework

Addressing the principal study questions requires a modeling framework that can simulate flow and thermal loading. To predict thermal conditions and to assess relationships with riparian vegetation and topography, a combined Shade-QUAL2Kw modeling approach was selected. The approach consists of a GIS-based Shade model that provides shade inputs to a QUAL2Kw water quality model. Table 12 summarizes the modeling components and their role in the technical approach, and each model component is described in more detail in the sections that follow.

Table 12. Shade-QUAL2Kw modeling components.

Model Component	Function
Shade Model	Calculates effective shade based on channel geometry, riparian vegetation and topography, and provides shade as input to QUAL2Kw stream model.
QUAL2Kw	Simulates in-stream temperature under low flow and high temperature steady state critical conditions.

Shade model

The Shade model was selected to evaluate solar radiation along the streams, modeling the mainstem explicitly, using watershed-specific GIS-based data derived with the TTools ArcView extension, developed by Oregon Department of Environmental Quality (ODEQ). TTools uses input coverages and grids to develop vegetation and topography data in transects along the stream channel, and samples longitudinal stream channel characteristics such as the near-stream disturbance zone (NSDZ) and elevation. TTools can sample spatial data within the riparian zone. Typically, these include LiDAR data, digital elevation models, riparian vegetation digitized from aerial imagery (digital orthophoto quadrangles and rectified aerial photos), and FLIR temperature data.

For this project, TTools was used to sample stream width, aspect, topographic shade angles, elevation, and riparian vegetation for incorporation into the Shade model. The riparian vegetation coverage contains four specific attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density.

Ecology's Shade model (Shade.xls—a Microsoft Excel spreadsheet available at https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs; Ecology, 2003a) was adapted from a program that ODEQ developed as part of its HeatSource model version 6. Shade calculates shade using one of two methods. The first is Chen's method, based on the FORTRAN program, HSPF SHADE. Y.D. Chen developed it for his 1996 Ph.D. dissertation at the University of Georgia (Chen, 1996), and it is further documented in the *Journal of Environmental Engineering* (Chen, 1998a, 1998b). The second method is ODEQ's original method from the HeatSource model version 6. Documentation of ODEQ's HeatSource model is at: https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Tools.aspx.

The Shade model quantifies the potential daily solar load and generates the percent effective shade. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because vegetative cover and topography intercept it. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics, such as height, width, overhang, and density. Most data inputs for the Shade model are readily available (e.g., aerial imagery and digital elevation models), and additional data (e.g., vegetation height) can be determined from other data sources discussed in the historic data review section. TTools output serves as input for the Shade model, which is then used to generate longitudinal effective shade profiles. Reach-averaged integrated hourly effective shade (i.e., the fraction of potential solar radiation blocked by topography and vegetation) in turn serves as input into the QUAL2Kw model (discussion follows).

Model calibration and assessment

Environmental simulation models are simplified mathematical representations of complex real-world systems. Models cannot fully depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigating how a system would likely respond to a perturbation from its current state. To provide a credible basis for predicting and evaluating mitigation options, the ability of the model to represent real-world conditions should be demonstrated through a process of model calibration and validation (CREM, 2009).

Objectives of model calibration and validation

Model calibration involves comparing how well model simulations match observed data as model parameters are adjusted within reasonable ranges. Model "validation" is a quality check where the results of the calibrated model are evaluated with a separate, independent set of environmental conditions. Model calibration and validation are designed to assess the adequacy of the model at providing necessary information to meet study objectives. The model must be able to provide credible representations of the movement of water and the generation and transport of thermal loads. The quality of those representations is assessed with the calibration and validation metrics.

Model setup and calibration/validation procedures

The QUAL2Kw and Shade model was developed for the mainstem of the SFNR beginning at its confluence with Wanlick Creek (just upstream of the first impaired segment) and extending downstream to the confluence with the mainstem Nooksack River. Tributaries are represented as point inflows into the SFNR in QUAL2Kw.

The Shade model was used to estimate effective shade along the mainstem segments. Effective shade was calculated at 100-meter intervals along the streams and then averaged over appropriate intervals for input to the QUAL2Kw model. Estimated system potential shade was also developed for use in analysis of loading capacity and allocations. The TTools extension for ArcView was used to sample and process GIS data for input to the shade and temperature models.

The QUAL2Kw model was used to calculate the components of the heat budget and simulate water temperatures under observed and critical conditions. Critical conditions are characterized by a period of low flows and high water and air temperatures. The model was calibrated to observed conditions for a critical day during 2007 using the available data and was validated using a critical day during 2010. These are the years with the greatest spatial and temporal coverage of temperature data. Sensitivity analyses were conducted to determine the model's sensitivity to key parameters.

Selection of the simulation period

The QUAL2Kw model was developed for a calibration (2007) and validation (2010) period primarily based on data availability. The objectives of the modeling focus on simulating high-temperature conditions in the mainstem, which occur in late summer when air temperature is high and flow is low. To select the simulation period for each year, data from mainstem stations were analyzed to determine a critical 7-DADMax temperature, the highest annual running 7-day average of daily maximum temperatures. In 2007, station SF0031 had the highest 7-DADMax occurring on August 3 (Figure 31). The highest instantaneous max contributing to this 7-DADMax was on August 2. For 2010, station VANZANDS10S was anomalously high compared to the other stations (Figure 32). As a result, the next highest station was chosen: TENASKUS10. The highest 7-DADMax for this station was August 15. The associated highest instantaneous max was on August 16. Therefore, August 2, 2007 and August 16, 2010, were selected as the simulation day for calibration and validation, respectively.

Air temperatures on the hottest weeks for each year of record and temperatures during the 2007 calibration year and 2010 validation year were compared. The maximum air temperatures on the selected calibration day at the low and high elevation weather stations were 31 ^{o}C and 25 ^{o}C, respectively. On the validation date at the low and high elevation weather stations, the maximum air temperatures were 35 ^{o}C and 28 ^{o}C, respectively. Compared to the 90th percentile maximum 7-day average maximum air temperatures based on the periods of record (30 ^{o}C for at low elevation and 29 ^{o}C at high elevation), 2007 and 2010 temperatures were higher at the low elevation and 1 to 4 degrees cooler at the high elevation station.

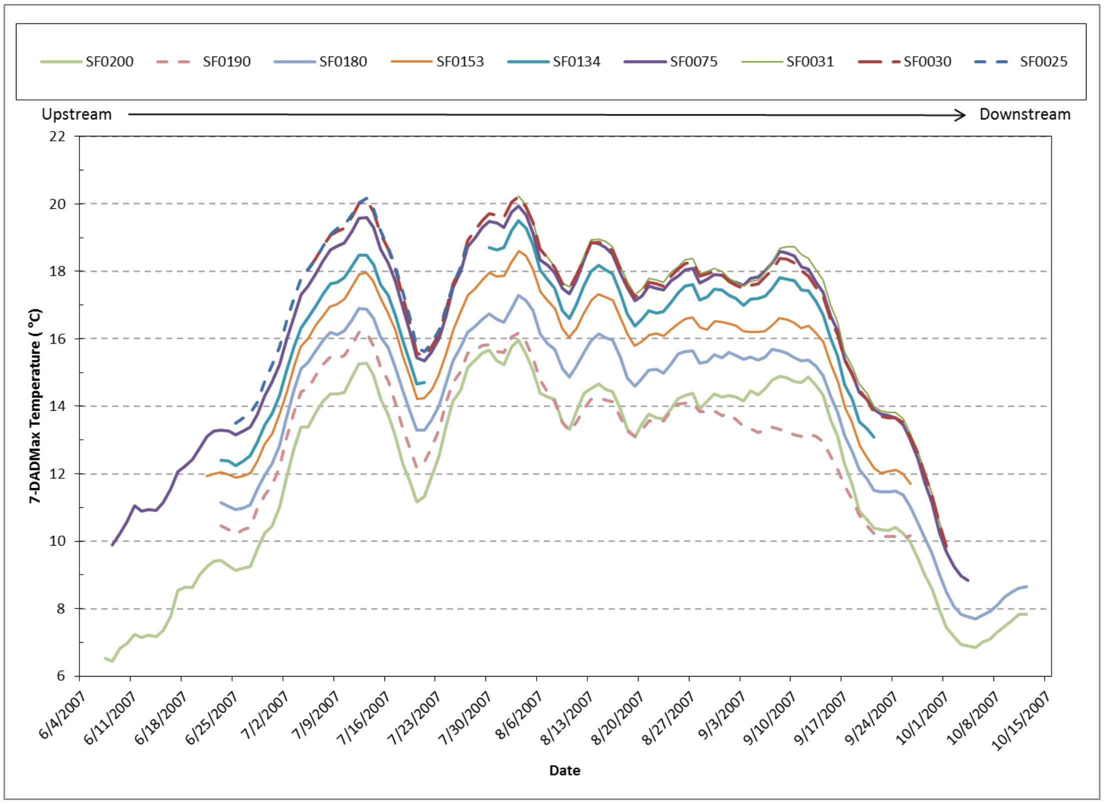


Figure 31. South Fork Nooksack River mainstem 7-DADMax temperature for 2007.

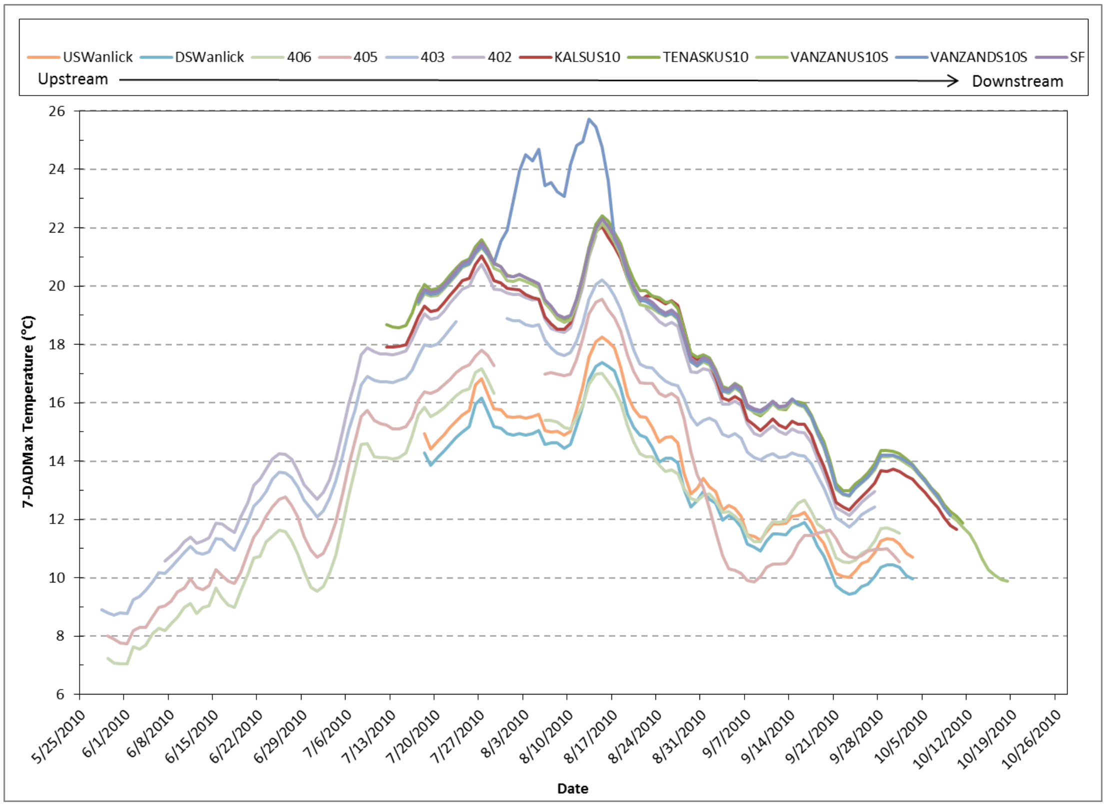


Figure 32. South Fork Nooksack River mainstem 7-DADMax temperature for 2010.

Model quality metrics

To conduct the model calibration and validation process, a visual comparison of temperature along with a set of statistical measures was used to compare model predictions and observations. Two primary statistical measures were used: root mean square error (RMSE), a commonly used measure of model variability, and relative percent difference (RPD) as a measure of bias. Means, maximums, minimums, and 90th percentiles were also determined from the data collected at each monitoring location.

The RMSE (E_{rms}) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O-P)^2}{n}} \quad \text{(Equation 1)}$$

Here, O is observed value, P is predicted value, and n is the number of samples.

An RMSE of zero is ideal. The RMSE is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error.

Bias is the systematic deviation between a measured (i.e., observed) and a computed (i.e., modeled) value and mathematically is calculated as RPD. This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

$$\text{RPD} = (P_i - O_i) / [(O_i + P_i) / 2] \quad \text{(Equation 2)}$$

where

P_i = ith prediction
O_i = ith observation

QUAL2Kw model

The QUAL2Kw model (Chapra and Pelletier, 2003; Ecology 2003b; version 6 beta) was used for detailed evaluation of temperature under critical flow and weather conditions. QUAL2Kw is a quasi-steady state model and is Ecology's preferred tool for TMDLs. The model simulates hourly temperature and heat budget with hourly variations in input parameters and boundary conditions. The model can also simulate other water quality dynamics (e.g., nutrients and dissolved oxygen), but it was used to simulate only temperature because temperature was the only parameter of interest for this TMDL.

QUAL2Kw can be applied to conduct focused analyses of critical conditions (e.g., late summer low flow, clear sky, high air temperature conditions) that affect temperature impairments from which TMDL targets can be determined directly. For this study, the QUAL2Kw model (beta version)[5] was used to evaluate thermal loading capacity and to develop allocations under critical conditions.

Model inputs include flow and temperature boundary conditions developed from available data. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, wind, headwater and tributary temperature, and groundwater flow temperature. These parameters are calculated (e.g., effective shade from Shade model), obtained from weather station information, or interpreted from other sources.

SHADE model development

The Shade model was developed consistent with the guidance in Mohamedali and Stohr (2011).

Riparian vegetation and effective shade

Riparian buffer width

Research has been conducted into how the width of a riparian buffer affects vegetation growth, micro-climate stability, and stream shading. The width of a riparian buffer is often determined on the basis of the local vegetation and climate, and the purpose for the buffer. For TMDL development, the impact of the riparian buffer width is tied to shade applied to the mainstem of the SFNR.

The USFS Forest Ecosystem Management Assessment Team report provides some guidance on the relationship of riparian forest width and ecological function (FEMAT, 1993). The relationship in Figure 33 suggests that the width of a riparian buffer affects stream shading dramatically until it approaches about 80% of the system potential tree height (FEMAT, 1993). Because the way in which riparian vegetation affects stream shading over the course of a day is directly related to the angle of the sun, it stands to reason that trees farther away from the stream

[5] A beta version of the model is capable of continuous simulation with dynamic boundary conditions for periods of up to one year, and also includes optional transient storage zones (surface and hyporheic transient storage zones). The beta version was used for this TMDL, but the continuous simulation capability was not employed.

will have less of an effect as the potential solar radiation decreases significantly as solar elevation decreases (Steinblums et al., 1984). In other words, shade provided by the trees farthest away will have an effect only when the sun is low in the sky, but that is also when solar radiation is the weakest.

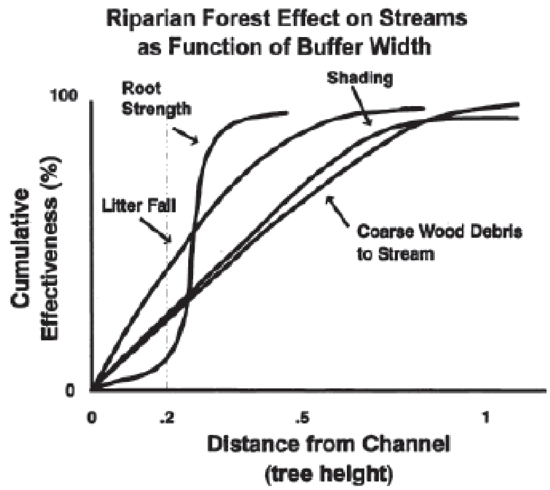


Figure 33. Generalized curves of riparian ecological functions (FEMAT, 1993).

The following research conclusions provide further insight into the relationship of riparian buffer width and shade for typical northwest conditions:

- Beschta et al. (1987) report that a 98-ft-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-ft (24-m) buffer would provide maximum shade to streams.
- Lynch et al. (1985) found that a 98-ft-wide (30-m) buffer maintains water temperatures within 2 °F (1°C) of their former average temperature.

The assigned riparian buffer width in Ecology TMDLs "is typically 150 feet on each side of the stream" but can vary (Mohamedali and Stohr, 2011). A review of other western Washington TMDLs from the Puget Sound region have reflected buffers of 96–112 ft in the Lower Skagit Watershed (Zalewsky and Bilhimer, 2004), 150–180 ft in the Snoqualmie Watershed (Stohr et al., 2011), 164 ft. in the Bear-Evans Watershed (Mohamedali and Lee, 2008), and 150 ft in the Stillaguamish, Whatcom/Squalicum/Padden, and Green River Watersheds (Pelletier and Bilhimer, 2004; Hood et al, 2011; Coffin and Lee, 2011).

Most of these TMDLs also completed sensitivity analyses to explore Shade model sensitivity to riparian buffer width. In the Bear-Evans Watershed, narrowing buffer widths [from 164 ft to 82 ft] made an average difference of less than 1% in system potential effective shade on the modeled streams (Mohamedali and Lee, 2008). Similarly, the Snoqualmie TMDL (Stohr et al., 2011) notes that modeled effective shade decreased by 5% when the buffer was decreased from 180 ft to 79 ft, and that in Green River Watershed, "narrowing buffer widths [from 150 ft to 80 ft] made an average difference of less than 2% in system potential modeled effective shade" (Coffin and Lee, 2011).

For this study, a buffer width of 150 ft was chosen. To examine the sensitivity of buffer width on the SFNR, the Shade model was run under two different scenarios, representing the SPV in a 150-ft buffer and a 75-ft buffer. The results of a sensitivity analysis revealed the difference in modeled effective shade along the entire mainstem was about +2.6% shade with the increase of buffer width from 75 to 150 ft. These results suggest that minor changes to width (e.g., +/- 30 ft) would not have a significant effect on the resulting shade values from a modeling perspective.

Mapping near-stream vegetation cover at current conditions

Stream temperature characteristics for a reach are controlled externally by solar forcing along with heat exchange with the atmosphere, but they are heavily affected by localized channel morphology, stream hydrology, and near-stream or riparian vegetation. The greatest impact riparian vegetation can have on stream temperature is through the direct shading of the active channel. To determine the near-stream vegetation and land use conditions for the mainstem of the SFNR, a combination of aerial photography and GIS-based analysis was employed.

The various data sources (described in the Historical Data section) used to define vegetation during the period of interest, 2007 for model calibration and 2010 for model validation, are listed below:

- LiDAR data from 2005 and 2009
- RCU riparian vegetation data from 2001 based on 1990s imagery
- CCAP land use and land cover from 2006
- Digital ortho imagery from 2006

The data sources and associated model years are summarized in Table 13.

Table 13. Data sources and applications for modeling for the South Fork Nooksack River.

Data Source	Date(s) Used For	Analysis Conducted
Digital Ortho Imagery for Whatcom County, Washington. Provided by the USDA National Agricultural Imagery Program (NAIP). Photography flights occurred June 24 through August 18 for Washington State in 2006.	2007	Aerial Imagery was used to digitize locations of the channel bank, the active channel, and distinct differences in land use/land cover along the 150-ft-wide riparian corridor.
Digital Ortho Imagery for Skagit County, Washington. Provided by the USDA NAIP. Photography flights occurred June 24 through August 18 for Washington State in 2006.		
Digital Ortho Imagery for Whatcom County, Washington. Provided by the USDA NAIP. Completed on 10/15/2009.	2010	
Digital Ortho Imagery for Skagit County, Washington. Provided by the USDA NAIP. Completed on 10/15/2009.		
Vegetation Height Map created using LiDAR completed in 2005 by the Puget Sound LiDAR Consortium. Note: only available for the upstream half of the analysis area. (6 ft x 6 ft resolution). Included bare-earth elevation, top-of-vegetation elevation, as well as the resulting vegetation-height data.	Both years	LiDAR was used to determine vegetation height (using natural breaks in the data set for relatively short, medium, and tall trees) and vegetation density (inspected visually). Note that because the data from neither 2005 nor 2009 covered the entire analysis area, they were combined into one raster and clipped to the riparian corridor. LiDAR was the primary resource to determine vegetation height, and used in tandem with ortho imagery in determination of density.
Vegetation Height Map created using LiDAR completed in 2009 by the Puget Sound LiDAR Consortium. Note: only available for the downstream half of the analysis area (3 ft x 3 ft resolution). Included bare-earth elevation, top-of-vegetation elevation, as well as the resulting vegetation-height data.		
Riparian Condition Units (RCU) as specified by the Riparian Function Assessment created by Duck Creek Associates, Inc., in 2001 using aerial photography from 1991 and 1995. Provided by the Nooksack Indian Tribe, Natural Resources Department.	Both years	RCU provided supplemental classifications of near-stream vegetation including type, size, and density of vegetation.
Coastal Change Analysis Program (CCAP) created by the National Oceanic and Atmospheric Administration (NOAA) which defines land cover and land change along the U.S. coastlines using remote imagery and raster-based land cover maps. CCAP 2006 land use raster was used.	Both years	CCAP was used to provide supplemental classifications of near-stream vegetation providing land use/land cover classes. CCAP identified areas with potential wetland soils.

Using the GIS-based data provided in Table 13, the ortho imagery was used from 2006 and 2009 to digitize the location of the channel center line, the wetted channel width, and the NSDZ where the active channel extent is non-vegetated (see example in Figure 34 using 2006 imagery). While this naturally flowing river does experience significant changes in meanders over time, it was assumed that 2006 and 2009 imagery would provide a reasonable representation of 2007 and 2010 stream characteristics. Note that the width of the NSDZ is highly important because it represents the low-lying/non-vegetated area, which, if large enough, might receive all shade provided by near-stream vegetation. Where perennial side channels meet the main channel, riparian areas were defined as open water. The NSDZ was digitized to avoid including forested islands which seemed non-transient and appeared to provide significant shade to the stream. Where braiding or forested islands did occur, the main channel was identified as the center line and any other water within the riparian buffer area was defined as open water.

The riparian corridor was defined for the river by adding a 150-ft riparian buffer outside the NSDZ on either side of the channel. This riparian area was digitized by creating new polygons for each new change in land use or land cover along the full extent of the river on either side. This visual assessment of changes in vegetation/development/agriculture was supported by the paired analysis with Coastal Change Analysis Program (CCAP) and Riparian Condition Unit (RCU) riparian function data. Vegetation type was determined from the aerial imagery supplemented by CCAP. Classifying vegetation height and density composition was done using visual inspection of aerial imagery and using LiDAR data (and RCU as needed). As shown in Table 14, each combination of land use or land cover was designated with a specific code that mirrors the coding used for the *Snoqualmie River Basin Temperature TMDL* report (Stohr et al., 2011).

Vegetation height under the current condition was determined using the relative differences in first and last return LiDAR height for the entire study area, and grouped on the basis of relatively short, medium, and tall vegetation heights (e.g., Figure 35). The three height classes were dictated by identifying three natural breaks in the overall tree heights.

Density percentages were assigned as midpoint values of what we deemed visually (using the NAIP ortho imagery) to be sparse (0%–25%), medium (25%–75%), or dense vegetation (75%–100%).

Overhang estimates of branches extending over the channel were assigned on the basis of the *Snoqualmie River Temperature TMDL* (Stohr et al., 2011), which used field measurements to predict average overhang according to vegetation type and height. While field measurements were not available for the SFNR watershed, the dominant coniferous species of Douglas fir represented in the Snoqualmie River TMDL (Stohr et al., 2011) was considered a reasonable representation to estimate tree overhang. The Skagit TMDL (Zalewsky and Bilhimer, 2004) adopted the same overhang value: a 3-m overhang for large coniferous 100-year system potential trees. Both of these watersheds are in northwest Washington and are relatively recent TMDLs.

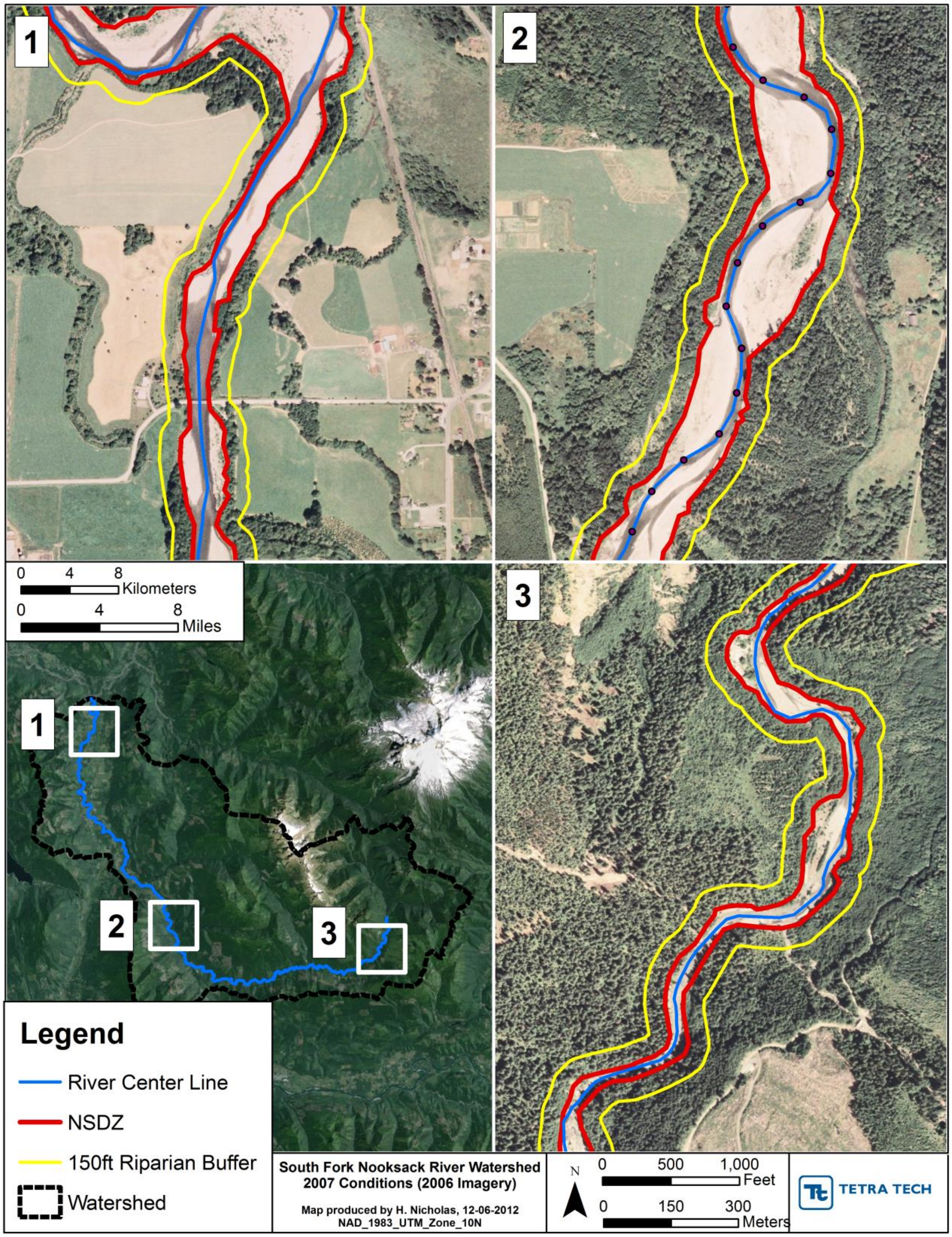


Figure 34. Examples of digitized river center line, near-stream disturbance zone (NSDZ) and 150-ft riparian buffer (which starts at the NSDZ) created using ortho imagery from 2006.

Inset 1 shows an agricultural area downstream, Inset 2 shows a sinuous reach in the middle of the mainstem, and Inset 3 shows the thick-forested, upper watershed. Note that the digitized wetted width is not shown for simplicity. This digitization was also completed for the 2010 conditions using 2009 ortho imagery.

Table 14. Riparian vegetation classification scheme for the current land use/land cover in the South Fork Nooksack River watershed.

Code	Riparian Feature Description	Height (m)	Density (%)	Overhang[a] (m)
111	cts - conifer, tall, sparse	46.5	25%	3.0
112	ctd - conifer, tall, dense	46.5	75%	3.0
113	ctm - conifer, tall, medium	46.5	50%	3.0
131	cms - conifer, medium, sparse	16.5	25%	1.5
132	cmd - conifer, medium, dense	16.5	75%	1.5
133	cmm - conifer, medium, medium	16.5	50%	1.5
121	css - conifer, short, sparse	4.5	25%	1.0
122	csd - conifer, short, dense	4.5	75%	1.0
123	csm - conifer, short, medium	4.5	50%	1.0
211	dts - deciduous, tall, sparse	46.5	25%	9.6
212	dtd - deciduous, tall, dense	46.5	75%	9.6
213	dtm - deciduous, tall, medium	46.5	50%	9.6
231	dms - deciduous, medium, sparse	16.5	25%	6.6
232	dmd - deciduous, medium, dense	16.5	75%	6.6
233	dmm - deciduous, medium, medium	16.5	50%	6.6
221	dss - deciduous, short, sparse	4.5	25%	2.7
222	dsd - deciduous, short, dense	4.5	75%	2.7
223	dsm - deciduous, short, medium	4.5	50%	2.7
311	mts - mixed, tall, sparse	46.5	25%	6.4
312	mtd - mixed, tall, dense	46.5	75%	6.4
313	mtm - mixed, tall, medium	46.5	50%	6.4
331	mms - mixed, medium, sparse	16.5	25%	4.4
332	mmd - mixed, medium, dense	16.5	75%	4.4
333	mmm - mixed, medium, medium	16.5	50%	4.4
321	mss - mixed, short, sparse	4.5	25%	1.8
322	msd - mixed, short, dense	4.5	75%	1.8
323	msm - mixed, short, medium	4.5	50%	1.8
411	ss- shrub, sparse	3.0	25%	0.2
412	sd - shrub, dense	3.0	75%	0.2
511	g - grass/rush/sedge riparian	0.5	75%	0.1
611	br - barren rock	0.0	100%	0.0
1000	w - water	0.0	100%	0.0
711	dr - developed residential	6.1	100%	0.6
512	c - pastures, cultivated field, lawn	0.0	100%	0.0
612	bc - barren clearcut	0.0	100%	0.0
613	brd - barren road	0.0	100%	0.0
911	rb - river bottom - floodplain	0.0	100%	0.0

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

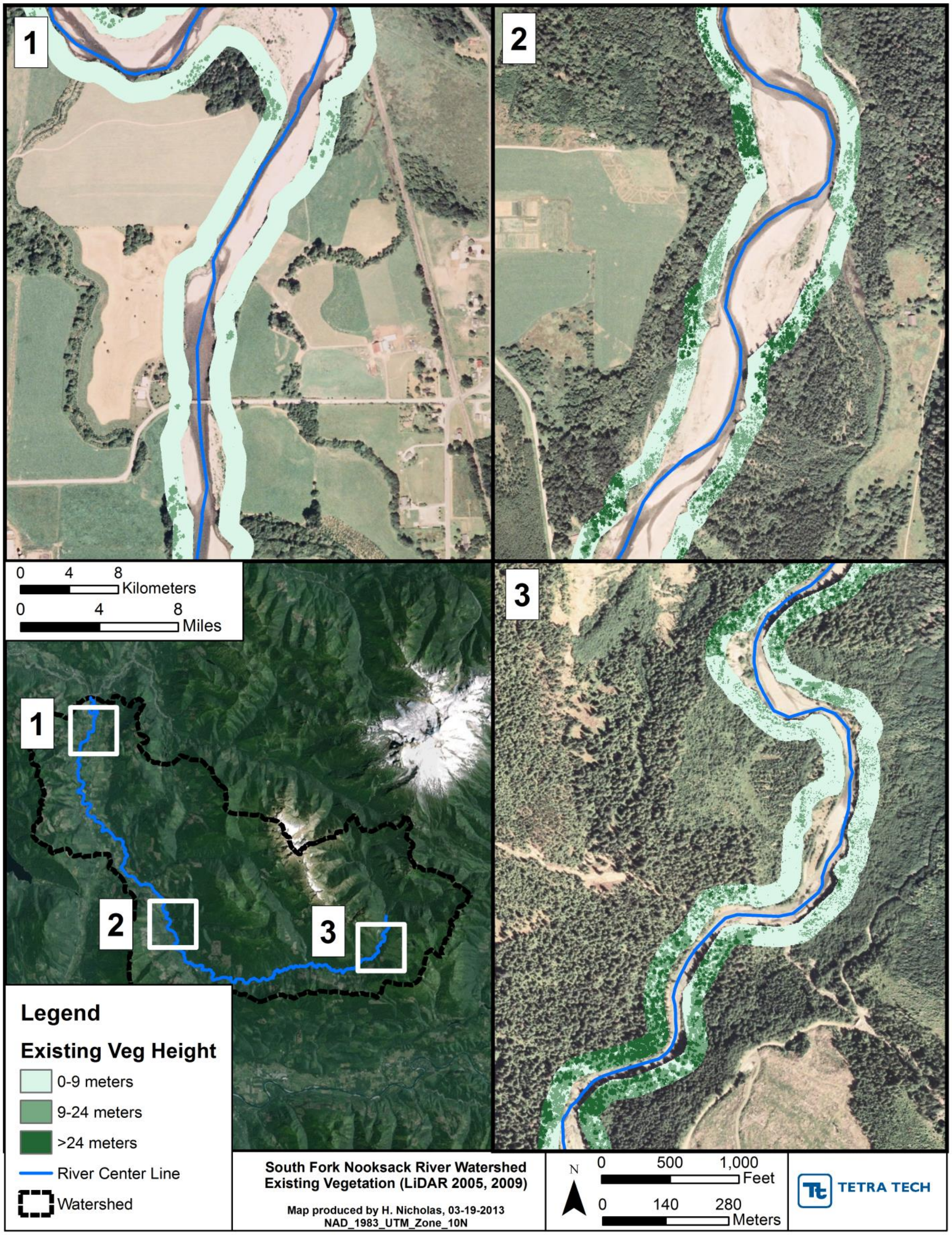


Figure 35. Example of existing vegetation height classifications for the South Fork Nooksack watershed (using 2005, 2009 LiDAR).

Shade calculations for current conditions

The effective shade produced by the current riparian vegetation was estimated using the Shade model. The model quantifies the solar radiation that is received along each reach of the channel at each hour in the day, while taking into account shading provided to the mainstem by vegetation canopy and topographic features such as hills. First, TTools was used to sample the channel and riparian information along the mainstem of the SFNR, to use as input for the Shade model. This sampling involved taking a snapshot of the riparian vegetation at equal intervals across the buffer width along the entire length of the model channel.

The following settings were used when running TTools:

- Sampling was conducted at 100-m intervals along the mainstem to capture the average behavior along each stream reach (Stohr et al., 2011).
- LiDAR was used to determine the stream gradient using a 25-cell sample size, (cell sample size is dictated by the input raster; therefore, 6-ft by 6-ft cells).
- The 10-m digital elevation model was used for topographic shade angles because it had a larger extent beyond the riparian area compared to the LiDAR data, sampled to 10 km away in seven directions.
- Vegetation sampling occurred at 5-m intervals into the riparian buffer (nine samples total within the 150-ft buffer width) perpendicular to the stream aspect. These sample intervals were chosen similar to the Snoqualmie TMDL (Stohr et al., 2011) because it appears to capture most vegetation changes in the riparian area while still allowing the model to run with some efficiency. Sampling occurred for both left and right banks.

In addition to the vegetation information, TTools was also used to sample each 100-m interval for channel wetted width, NSDZ width, stream aspect, stream elevation, and topographic shade angles in all directions. Where the NSDZ channel width was artificially high because of large forested islands, manual changes were made to the widths before the Shade model was run (outliers were checked for being more than two standard deviations away from the mean NSDZ width for the entire reach). Note that forested islands of this nature were included in the TTools sampling for Shade model input when the vegetation was deemed significant enough to provide a substantial amount of shade to the stream. The relevant information from TTools sampling was then used as input into the Shade model to calculate effective shade.

These settings were specified in the Shade model:

- Channel incision depth was calculated as the elevation difference between the NSDZ line and the wetted width line using LiDAR bare-earth elevations. Incision depth was averaged for each 1,000-m segment of the mainstem. The average incision depth is about 1 m along the mainstem.
- Riparian Extinction[6] was turned *on* in the model.

[6] Riparian Extinction when "on" calculates shadow density as it relates to the size and magnitude of vegetation in the canopy using light attenuation employed by Beer's Law (Beer, 1852).

- The Bras Method[7] was selected for the solar radiation model.
- The Chen Method[8] for shade calculation.

The Shade model requires identification of a specific day and year, which affects daylight hours and angle of the sun, and the earth's orbital characteristics. Models were run for 8/2/2007 and 8/16/2010, the chosen dates for the QUAL2Kw model. Tests were conducted to determine the sensitivity of the model to day and year. Not surprisingly, year had an insignificant effect (e.g., running the *2007* model on 8/2/2006). Day of year had a minor influence with more shading on 8/16/2010 primarily because of differences in solar aspect and topographic shading.

Figure 36 shows results of two Shade model runs: the 8/2/2007 run, which is largely based on 2006 imagery, and the model run for 8/16/2010 using the 2009 imagery. The effective shade calculated by the two model runs is different because of changes in stream geomorphology (sedimentation deposits, altered meanders, and such), some changes in land use along the riparian area, and the time of year (8/2 vs. 8/16). Aside from changes in vegetation, land use, wetted width/NSDZ width taken from the aerial imagery, and the date of interest specified in the Shade model run, all other Shade model inputs were held constant between the 2007 and 2010 model run.

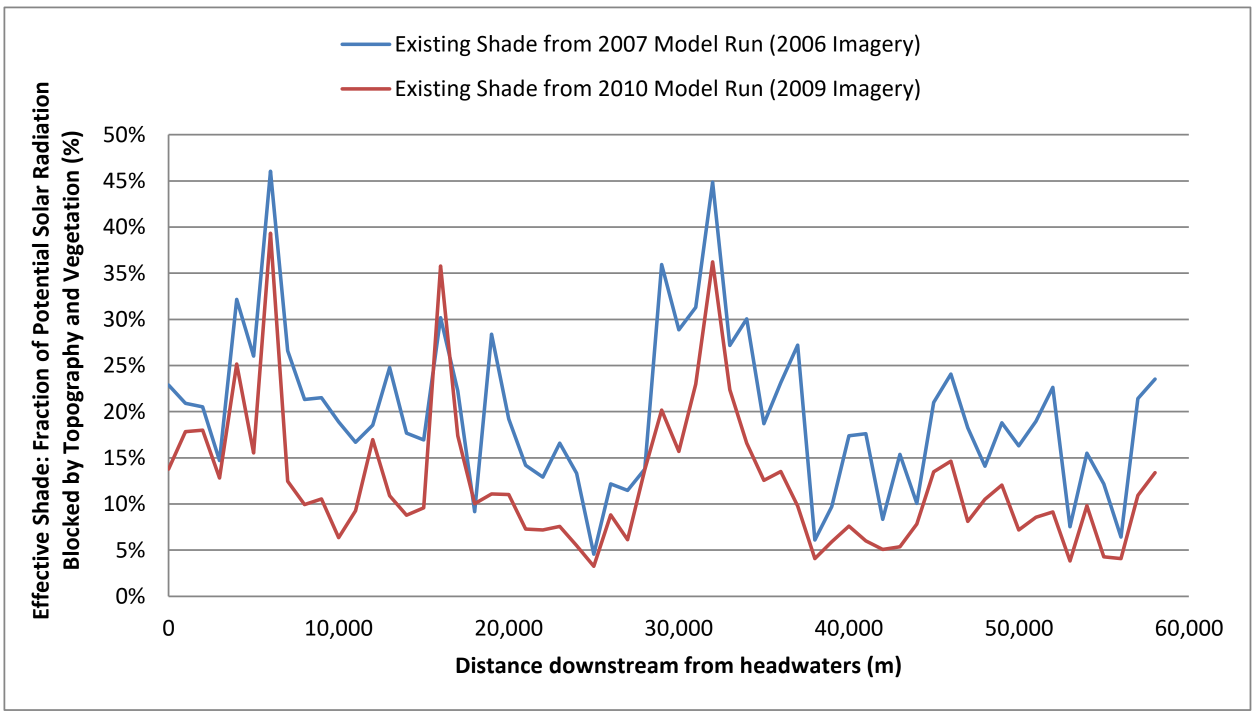


Figure 36. Modeled effective shade during daylight hours under channel and vegetation conditions for 8/2/2007 (using 2006 imagery) and 8/16/2010 (using 2009 imagery).

[7] The Bras Method calculates net longwave solar radiation during the day at the ground surface (Bras, 1990).
[8] The Chen Method calculates shade as a combined effect of topography, vegetation, and reflection as it relates to solar inputs (Chen, 1996; Chen et al., 1998a; Chen et al. 1998b).

Note that while the Shade model was developed for the mainstem only, a shade curve was developed to show how much effective shade can be achieved in streams with different widths and aspects (for a given SPV height and density). This information will be presented later and will be used to represent the load allocations for all tributaries/streams in the rest of the watershed.

Potential near-stream vegetation cover and effective shade

System potential vegetation (SPV) is defined as the vegetation that would occur if the riparian corridor had native vegetation of 100 years age. Ecology prepared a guidance document for calculating SPV (Mohamedali and Stohr, 2011). In this document, the following concept is introduced:

> System potential shade, which is the natural maximum level of shade that a given stream is capable of attaining with the growth of system potential mature riparian vegetation (from here on, "SPV"). This is defined as the vegetation that would naturally grow and reproduce on a site, given climate, elevation, soil properties, plant biology and hydrologic processes.

SPV is used to estimate natural riparian conditions that could exist at 100 years of growth. SPV is used as an indicator of vegetation as riparian conditions approach natural conditions. Data for tree height associated with the 100-year site index is readily available on the west side of the Cascade Mountains.

For input into the Shade Model, SPV must be assigned height, density, and overhang. SPV parameters for overhang and density were based on assumptions made in completed TMDLs in adjacent/similar watersheds. As an appendix to Ecology's guidance document, a list of temperature TMDLs completed throughout Washington State has been provided. Assumptions made for SPV overhang were determined on the basis of the *Snoqualmie Watershed Temperature TMDL* (Stohr et al., 2011), a nearby Puget Sound watershed. For the Snoqualmie area, old-growth conifer trees were measured and averaged about 3 m of overhang, so because the South Fork Nooksack area system potential trees are entirely coniferous, the 3-m overhang was applied to all SPV, and the density applied to these tree communities was 85% because it reflects the similar conditions in the Snoqualmie watershed (Stohr et al., 2011).

For purposes of the TMDL, SPV species and heights along the SFNR were determined based on soils which were analyzed spatially using the soil surveys and SSURGO datasets. Detailed below is the process used to determine the 100-year SPV height:

1. The WDNR digitized soil shapefile was used to identify the dominant soils within the riparian corridor along the mainstem of the SFNR. The dominate soils were Saxon, Puyallup, Pilchuck, Cokedale, Larush, and Dystric Xerorthents.
2. The dominant tree species for the dominant soil types were taken from the county soil surveys (Goldin, 1992; Klungland and McArthur, 1989), and were determined to be western hemlock and Douglas fir.
3. The 100-year site indices (SPV height for a given soil type at 100 years of age) for western hemlock and Douglas fir trees were taken from the county soil surveys for each of the dominant soil types.

4. The 90th percentile of all the site indices was determined, resulting in an SPV height of 50.66 meters (166.21 feet).

Following are some additional notes regarding SPV heights:

- **Red alder.** Historically, streamside vegetation in the Acme Valley was dominated by red alder and red cedar prior to logging (Collings and Sheikh, 2004a; 2004b). However, due to historical logging, burning, and agriculture in the area, the SPV composition of the riparian area of the SFNR is considered to be a combination of Douglas fir, western hemlock, and to a smaller degree, red alder (Goldin, 1992; Klungland and McArthur, 1989). Red alder is a relatively short-lived, early successional tree or pioneer species which would likely not persist in an SPV scenario along these near-stream forests (Harrington, 1965). The WDNR soils listed the 100-year system potential vegetation as red alder on only 4% of the riparian soils in this study area, therefore that tree type was excluded from the analysis.

- **Other tree species.** The soil surveys mentioned the presence of other trees to a limited extent such as red cedar, bigleaf maple, grand fir, ponderosa pine, western larch, western white pine, etc. These trees were not indicated as the dominant tree type for any of the soil types, therefore they were excluded from the analysis.

- **Climax community.** SPV does not represent the climax height of riparian vegetation. Western hemlock and Douglas fir can commonly achieve heights of 60-80 m, which are taller than the value used to represent 100-year SPV in the model (Moore, 2002; Anderson, 2003). The effect of using taller climax vegetation height beyond the 100-year SPV was evaluated and is discussed later in this report. An examination of the LiDAR data revealed existing maximum individual tree heights present in the riparian area of as much as 250 feet (76 meters).

The criteria used for assigning 100-year SPV classes (within the 150-ft riparian zone) were as follows (Table 15):

- Areas considered *river bottom* in the existing vegetation scheme remain in that class.
- Using 100-year site indices associated with Whatcom and Skagit County Soil Survey reports in the riparian area, currently vegetated areas were allowed to reach a 100-year system potential height of 50.66 m.
- Current vegetation that is forest, grassland, cropland, and pasture were all allowed to reach 100-year system potential height.
- Areas that the CCAP data source defined as *wetland soils* composed about 4% of the total riparian area. Most of these areas were already forested; therefore, these areas were also allowed to achieve 100-year SPV growth.

Table 15. Riparian vegetation classification scheme for the 100-year system potential land use/land cover in the South Fork Nooksack River watershed.

Code	Riparian Feature Description	Height (m)	Density (%)	Overhang[a] (m)
911	rb - river bottom, floodplain, sandy areas which cannot support SPV	0	100%	0.0
711	Developed (buildings) – no potential for vegetation	6.1	100%	0.6
613	Developed (roads) – no potential for vegetation	0	100%	0
888	Currently vegetated areas, including wetland soils which will reach system potential	50.66	85%	3

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

The shade scenarios in Figure 37 were then developed on the basis of the above criteria using the 2007 model year:

1. 100-year SPV was applied *throughout* the riparian zone for all land uses and land cover types except for sand/gravel/riverbed, which were maintained as sand/gravel/riverbed.
2. Same as the previous scenario, except 100-year SPV was *not* applied in areas considered *developed* (e.g., roads, buildings, parking lots, and other impervious surfaces). This scenario was used for load allocations.

F

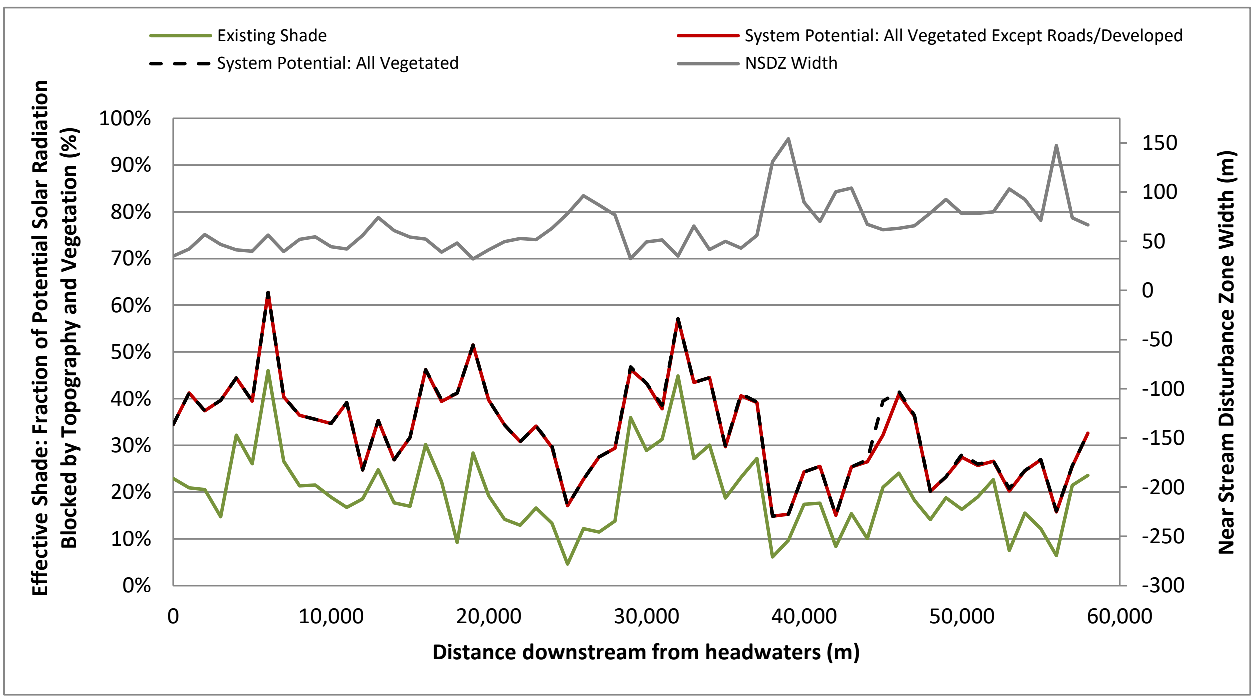


Figure 37. Modeled effective shade (fraction of potential solar radiation blocked by topography and vegetation) for each of the key modeled scenarios:

Existing Vegetation in 2007, 100-year SPV with all land reaching 100-year system potential, and 100-year SPV with developed lands not reaching system potential. NSDZ shown for comparison.

The modeled effective shade increases from the existing conditions in all locations along the river in the scenario of the 100-year system potential. The greatest NSDZ width corresponds to the lowest effective shade in both current and system potential conditions. This is because when the NSDZ is large, the vegetation is set back farther from the stream banks and more shade falls on the gravel bars associated with a very large NSDZ, rather than on the wetted stream channel.

NSDZ width changes as the stream meanders over time due to pulses of sediment input from logging and other human impacts, as well as natural processes (Collins and Sheikh, 2004a; 2004b). Collins and Sheikh (2004a; 2004b) digitized maps from the late 1800s and mapped several large forested islands from the mouth to just below Skookum Creek. There were occasions when pulses of sediment input, especially after heavy logging began, would have increased active channel width (or NSDZ) until the vegetation recovered.

The South Fork Nooksack model captures only a moment in time by characterizing the NSDZ under current conditions, and retains this character for the 100-year system potential scenario, and therefore may not be fully representative of historical equilibrium conditions. Later in this document, an attempt to measure the sensitivity of several unmeasured parameters is made in order to provide an estimate of how much cooler the water might be under Natural Conditions. The factors considered were cooler headwater and tributary temperatures, decreased channel width, and increased shade from larger taller riparian forests and enhanced hyporheic exchange.

The impact of crop and pasture land reaching SPV is seen most at the downstream end of the mainstem where crop land is concentrated (see difference between red line and black dashed line between 40,000 and 50,000 meters from headwaters in Figure 37). On the whole, crop and pasture land account for 6.0% of the riparian buffer area along the entire mainstem of the South Fork Nooksack. For reference, 1.6% of the riparian area is developed/roadways, and the remaining 92% of the riparian buffer is already forested to some capacity. Note that key differences between the upper and lower halves of the watershed are revealed within a statistical analysis of land cover/land use of the existing vegetation within the buffer area. The upper half of the watershed is 46% coniferous trees while the lower half is 2%, the upper half is 4% deciduous trees while the lower half is 57%, and the upper half is <1% agricultural lands while the lower half is 16% agricultural.

The Shade model for the SFNR was developed using the best available information for model inputs (e.g., aerial imagery, LiDAR, and GIS layers for soils and vegetation). There were not, however, field or observed data (e.g., on the ground data of effective shade using a Solar Pathfinder or hemispherical photography) to calibrate or check the model against. In the absence of these data, visual checks were performed to ensure that the Shade model results were realistic in terms of on-the-ground conditions and characteristics that determine stream shading as demonstrated by Figure 38. In this figure, two sites along the mainstem are shown: one with a high current shade value (69.7%) and one with a low current shade value (5.1%) as well as their system potential shade values respectively. Comparing the riparian vegetation between the two panels (area between the red and yellow lines), it is apparent that the lack of vegetation for the panel on the left contributes to the low shade percentage. The converse holds true for the right panel.

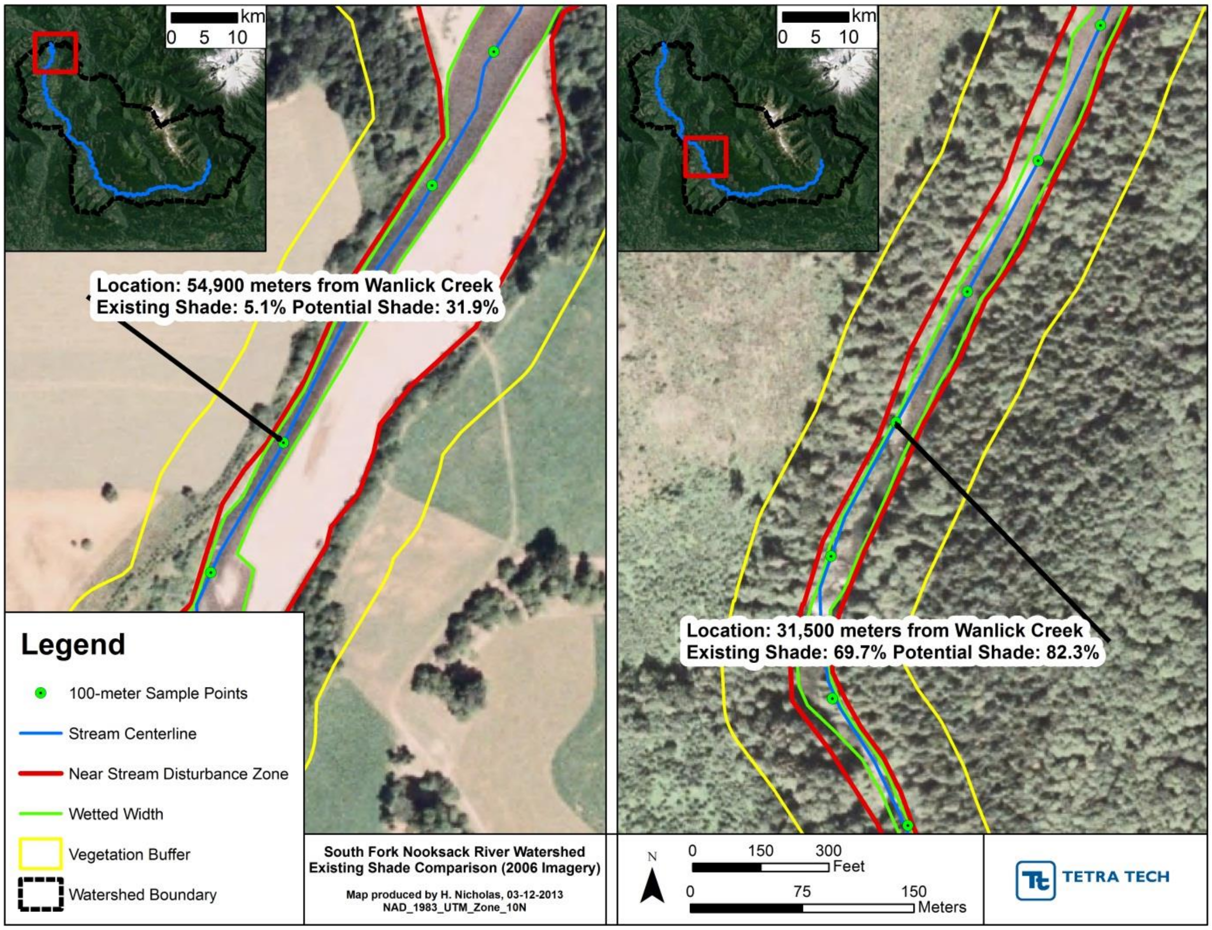


Figure 38. Comparison of low shade area and high shade area along the South Fork Nooksack River.

QUAL2Kw model calibration and validation

A QUAL2Kw model of the SFNR was developed to determine the components of the heat budget and simulate water temperatures under observed and critical conditions. The model was calibrated to observed conditions for a critical day in 2007 using the available data and was validated using a critical day in 2010. The QUAL2Kw model was applied by assuming that flow remains constant (i.e., steady flows) for a given condition over the one-day period (using daily average flows). Key variables other than flow were allowed to vary with time over the course of a day. Solar radiation, air temperature, dew point, cloud cover, shade, headwater temperature, tributary temperatures were specified as diurnally varying functions. Sensitivity analyses were conducted to determine the model's sensitivity to key parameters.

Model setup

Stream segmentation

For QUAL2Kw input, the SFNR was segmented into 58 reaches of 1 km each (Figure 39). The upstream boundary was at the confluence with Wanlick Creek.

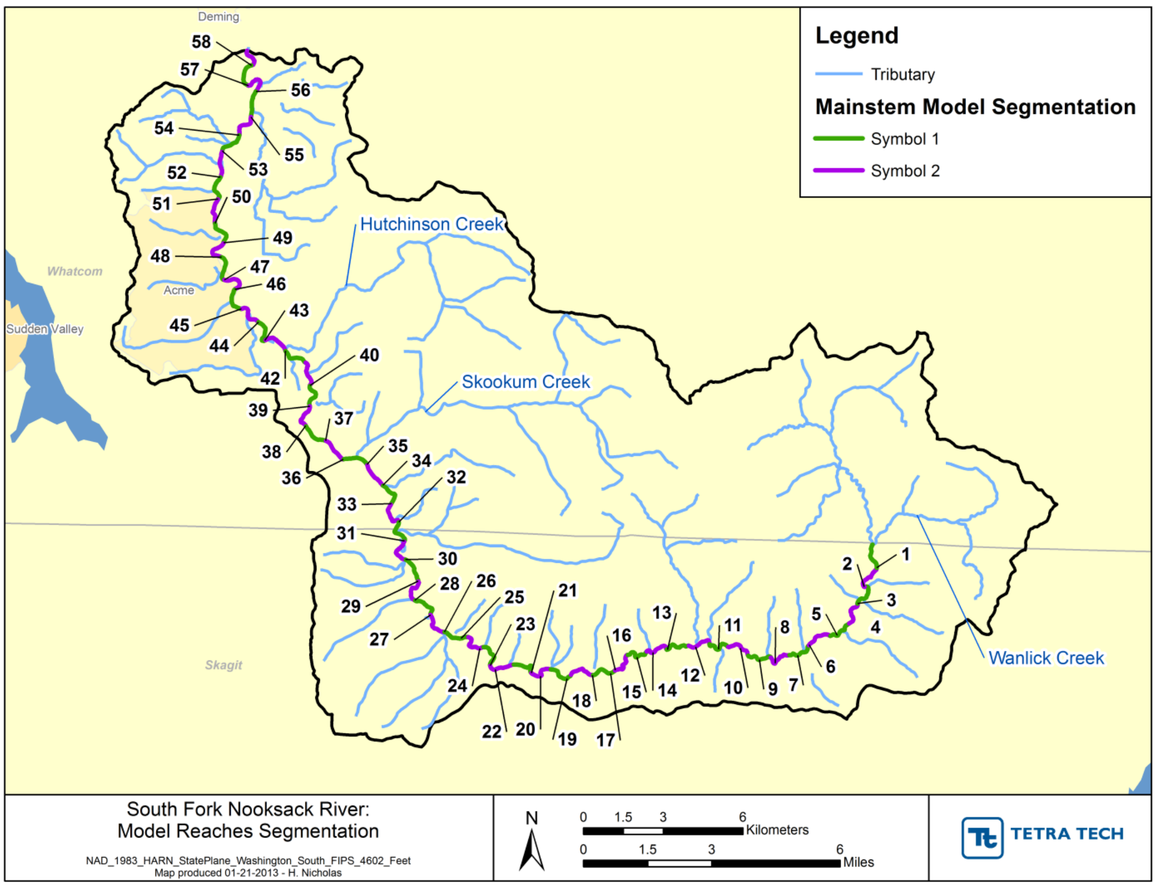


Figure 39. QUAL2Kw model reaches for the South Fork Nooksack River mainstem.

Flow boundary conditions

Flow boundary conditions for the headwater, tributary, and groundwater inputs were based on steady-state flows during low-flow conditions in the calibration and validation periods. Observed flow data in the watershed included a limited amount of data from USGS and Ecology gages; much of the mainstem and tributaries are not gaged. Therefore, flow values were estimated for ungaged portions of the watershed using the following approach:

- Local studies of low-flow conditions were reviewed for data/information that could be used to estimate flow from ungaged tributaries and direct groundwater input.
- Observed flow monitoring data was tabulated for the selected simulation dates.
- A methodology was developed to synthesize data/findings from the studies with observed flow on the simulation dates to estimate cumulative tributary and groundwater contribution from the headwaters, all major and minor tributaries, and all remaining land areas adjacent to the mainstem. From here on, this method is referred to as the Flow Boundary Model and is discussed further.

Low-flow studies in the Nooksack River Basin

Curran and Olsen (2009) performed an in-depth analysis of low-flow hydrology and statistics for 25 gaging sites in the Nooksack River Basin and developed regional regression equations for estimating 12 critical low-flow statistics at ungaged locations. The low-flow statistics all have the form of average flow over a given *number of days*, with a *recurrence interval* of a set number of years. For example, one of the most commonly cited critical low-flow statistics is 7Q10, which represents 7-day average low flow with an occurrence interval of 10 years. Their statistics include a broad suite of low-flow measures, using consecutive-day average flows for 1, 3, 7, 15, 30, and 60 days, and recurrence intervals of 2 and 10 years. Numerous basin attributes of the gaged sites were tabulated, including area, precipitation statistics, topographic measures, geology, and land use. In developing the low-flow statistics, explanatory variables were limited to avoid unnecessary complexity and cross-correlation. The final regression equations—all of which have the same form—were based on basin area and mean basin elevation:

$$LFS = b_1 DA^{b_2} \times 10^{b_3 E} \qquad \text{(Equation 3)}$$

where *LFS* is the estimated low-flow frequency statistic, *DA* is the drainage area in square miles, *E* is the mean basin elevation in thousands of feet, and b_1, b_2, and b_3 are coefficients.

Mean elevation is essentially a proxy for orographic increase in rainfall; they found that elevation was a better predictor than gridded annual precipitation estimates from PRISM. As mean elevation increases, the low-flow statistic increases—in other words, given two basins of the same size, the one with the higher mean elevation is predicted to have higher discharge for a given low-flow statistic. Likewise, the low-flow statistic increases as basin area increases.

An independent analysis of the mathematical relationship between contributing basin area and the predicted critical low-flow statistic reveals a nonlinear response between changes in basin area and predicted low flow, independent of elevation. While flow is expected to increase as drainage area increases, the increase is linear only if the unit-area flow (i.e., cfs/mi^2) is static when precipitation (imputed from elevation) is the same. However, this is not the case—as basin area increases, the unit-area low-flow increases as well. This is likely because of the accumulated contribution of groundwater as basin area increases; groundwater that infiltrates in smaller drainages emerges below their mouths into larger systems downstream.

As a caution to applying statistical inference of this study to other basins, the predictive statistics developed by Curran and Olsen (2009) were from a limited pool of regional data. Many of the stations had relatively brief periods of record, the regression was limited to two explanatory variables, and uncertainty associated with each statistic is fairly large. In many cases the error between predicted low-flow statistics and the observed values is substantial. In addition, their analysis focused on the whole Nooksack River Basin, and was not specifically optimized to the SFNR basin. Three gages within the South Fork Nooksack basin were included in their analysis – Skookum Creek (USGS 12209490), South Fork Nooksack at Wickersham (USGS 12209000), and Hutchinson Creek (Ecology 01C070) – and observed critical low flow statistic values tend to be higher across the board than predicted values for all three of these gages. Even so, the study provides useful information when monitoring data are otherwise absent.

Regression equations from the Curran and Olsen (2009) study were incorporated into the Flow Boundary Model to estimate flow boundary conditions for the QUAL2Kw models (discussed further below).

Kemblowski et al., Groundwater Quantity Report for WRIA 1, Phase II

Kemblowski et al. (2001) summarized the state of knowledge of aquifer systems in the WRIA 1 region, and discussed the results of two seepage study runs on the SFNR conducted in August and September 1998. The data indicated the river is typically a gaining system, although some short losing reaches were thought to be present. The report did not provide an analysis to distinguish between direct groundwater gains and inflows from tributaries. The seepage run data are previously introduced in the Historic Data section and include data collected in October 1999 that were not discussed in Kemblowski et al. Data were also collected for select tributaries, and flow was measured at the Skookum Creek Fish Hatchery outfall.

The Kemblowski et al. (2001) data and findings were used to inform development of the Flow Boundary Model for estimated flow boundary conditions for the QUAL2Kw models. The data were also used to assist with the calibration of the QUAL2Kw model.

Flow Monitoring Data on Model Simulation Dates

Development of the Flow Boundary Model and calibration of the QUAL2Kw models required monitored stream flow data for the QUAL2Kw model simulation days. Table 16 provides observed flows on August 2, 2007, and August 16, 2010. USGS suspended gaging of flow at 12209000 (South Fork Nooksack at Wickersham) in the summer of 2007 and began monitoring at 12210000 (South Fork Nooksack at Saxon Bridge). Stage was monitored and reported in early August 2007 before the inception of flow and stage monitoring a short time later, so flow at 12210000 was estimated for August 2, 2007, using reported stage, paired with flow-stage measurements from fall 2007.

Table 16. Average daily flow at gages on model simulation days.

Location	Gage ID	Flow (cfs)	
		8/2/2007	8/16/2010
Skookum Creek	12209490	44	35
South Fork Nooksack at Wickersham	12209000	190	n/a
South Fork Nooksack at Saxon Bridge	12210000	224*	140
SFNR at Potter Road	01F070	267	90**
Hutchinson Creek	01C070	7.9	7.2

* Estimated from stage
** Flow reported as more than 50% below the lower end of the rating curve

Flow reporting at Ecology 01F070 appeared to become impaired over the course of 2009, a conclusion supported by technical notes for the gage for WY2009 which indicated cumulative potential error of plus or minus 30%, and documented several problems including erratic drift in stage measurements and damage to the staff gage for half of the water year. The contributing area to Ecology 01F070 is about 182 mi^2, nearly 50% greater than the area draining to USGS 12210000, which is approximately 126 mi^2. In theory, flow at 01F070 should be higher than at 12210000, at least in periods of elevated flow. During low flow, it is possible that South Fork Nooksack becomes a losing reach below 1221000, but the pattern between 01F070 and 1221000 at low flow should be consistent.

As seen in Figure 40, in WY2009 the flow at 01F070 is consistently higher than at 1221000 when discharge exceeds 300 cfs. However, the opposite is true in WY2010, when flow at 01F070 is consistently lower than at 1221000, even when flows are similarly elevated during the same seasons. Of course, it is possible that either gage, or both gages, are impaired. However, in much of August 2010, flow at 01F070 was reported as being less than 50% below the lowest value on the gage rating curve. USGS 12210000 shows decreasing flow during the same period, while reported flow at Ecology 01F070 is a flat line at 90 cfs (Figure 40). Given the reported error on low flow, the flat line at 90 cfs, and the suspension of monitoring at the gage following WY2010, it is more likely that 01F070 is impaired. As a result, the Ecology 01F070 value of 90 cfs for August 16, 2010, was excluded from further analysis.

It is important to note that all the USGS and Ecology gages showed numerous modifications to the gage rating curves throughout their periods of record. Shifting channel forms add a degree of uncertainty to all flow measurements, especially during low flows.

To illustrate temporal variation in flow, Figure 41 and Figure 42 provide observed flows in the two weeks preceding and two weeks following the two QUAL2Kw model simulation days.

Available data are shown for the SFNR gages and for the Skookum Creek gage. Hutchinson Creek was omitted because flow in both periods averaged less than 10 cfs and was never greater than 16 cfs. SFNR at Potter Road (01F070) was excluded from Figure 41 because its record in the latter period is assumed to be impaired.

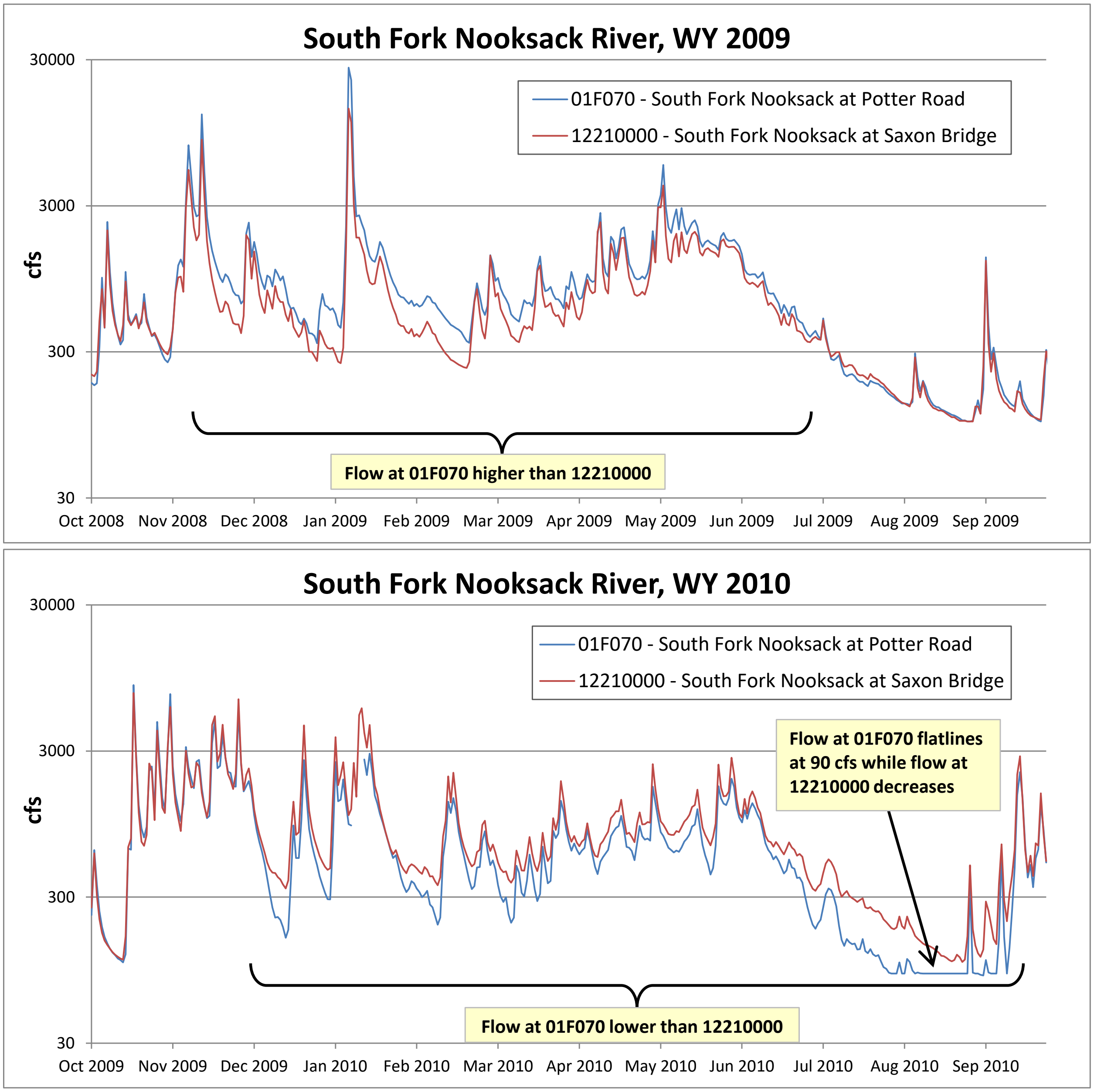


Figure 40. Comparison of gaged flow on South Fork Nooksack River in WY2009-WY2010.

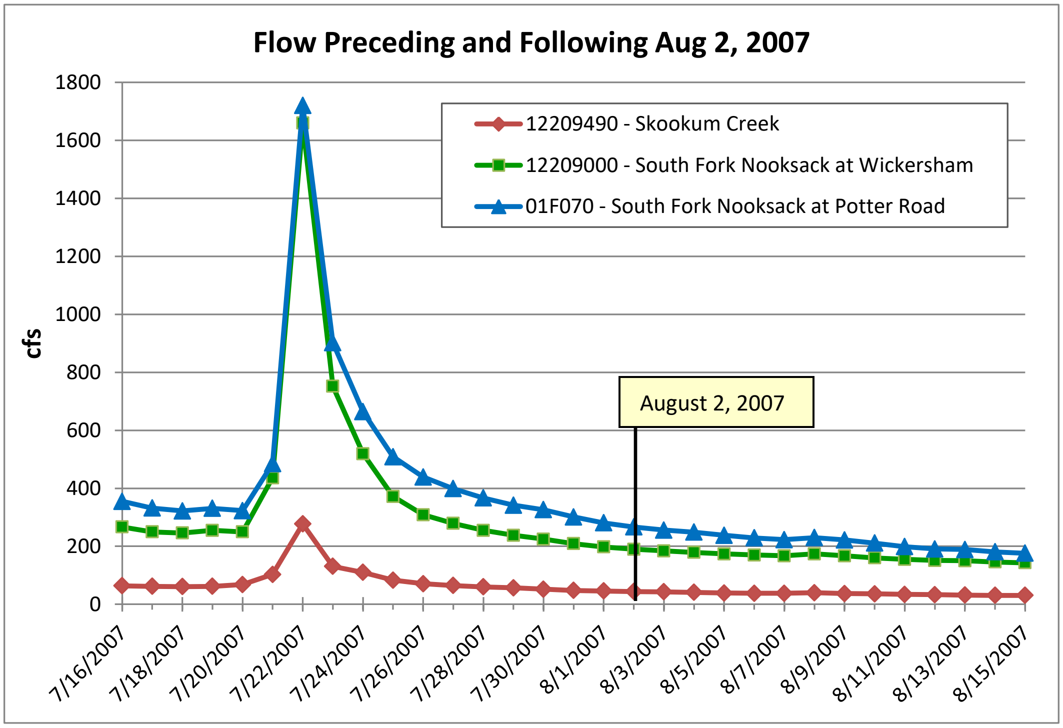


Figure 41. Temporal variation in flow before and after calibration QUAL2Kw model simulation day.

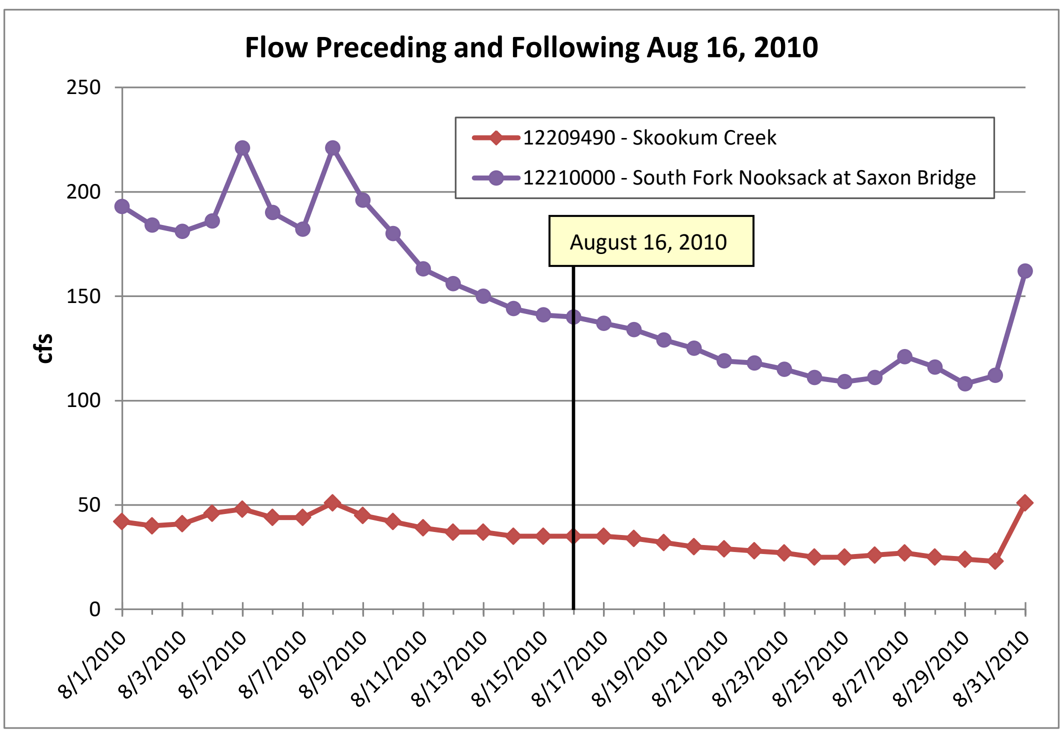


Figure 42. Temporal variation in flow before and after validation QUAL2Kw model simulation day.

Flow boundary model and estimation of flow boundary conditions for model simulation days

Flow boundary conditions in the QUAL2Kw model were estimated by using regression equations for critical low flow statistics from Curran and Olsen (2009), with adjustments to account for differences between observed flow at the gages during the simulation days and the low-flow statistic assumed to represent those days. Further refinements were made to distribute flows between tributaries (assumed to carry perennial flow) and direct groundwater inputs to SFNR. A schematic of the Flow Boundary Model is shown in Figure 43.

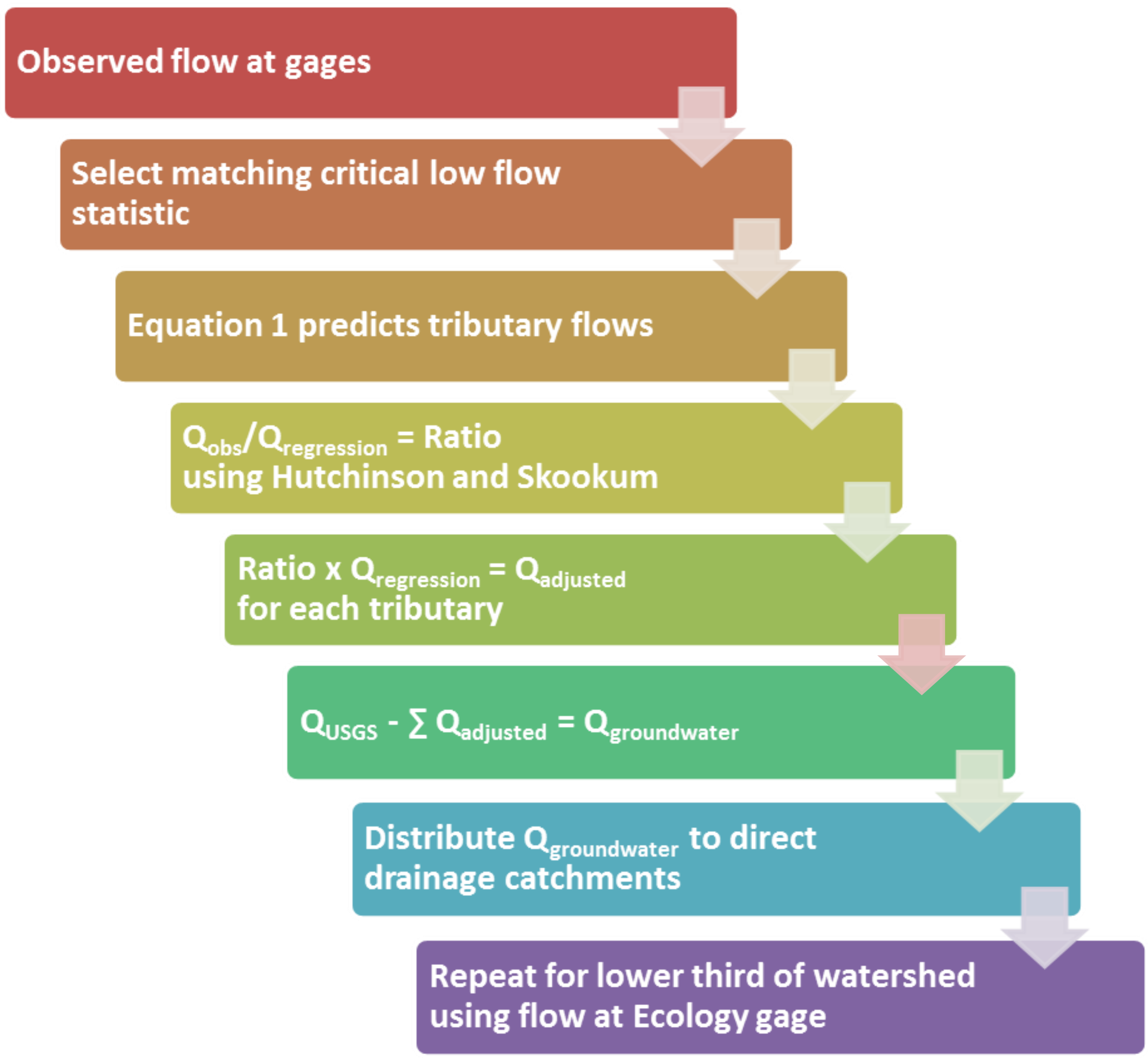


Figure 43. Flow Boundary Model schematic.

Curran and Olsen regression equations were developed from a large cross section of contributing drainage areas, ranging from 1.1 square miles to 786 square miles. The gaged sites capture flow from perennial streams, so it is reasonable to assume that Curran and Olsen regression equations are applicable to even the smallest tributary drainages. As noted previously, observed critical low-flow statistics for gages in the South Fork Nooksack basin were higher than predictions using the regression equations, so low flow estimates for ungaged tributaries were scaled up to be consistent with observed critical statistic values. (Note that variation between observed values and predictions from the regression is expected, since any regression represents a central tendency among a pool of observations and possesses quantifiable error.) Data from the 1998/1999 seepage studies were used to validate the Flow Boundary Model (discussed in Hydraulics section that follows).

Following is a more detailed summary of the calculations associated with the Flow Boundary Model.

1. The watershed was subdivided into its constituent NHDPlus V2 (2012) catchments. Tributaries identified as having perennial flow in NHDPlus V2 were modeled as *point source* inputs to the mainstem, while catchments along the mainstem with intermittent tributaries were modeled as a *diffuse source* as direct groundwater inputs to the mainstem (Figure 44). While the mainstem catchments did have intermittent tributaries, it is likely that these tributaries would be dry during periods of low flow and groundwater inputs would dominate. The location of both point source tributaries and diffuse source groundwater inputs were estimated to 0.1 km relative to the mouth of the SFNR, which was necessary for representing them within the QUAL2Kw model. Inflow from Wanlick Creek and the headwaters of SFNR were assigned as the upstream boundary.

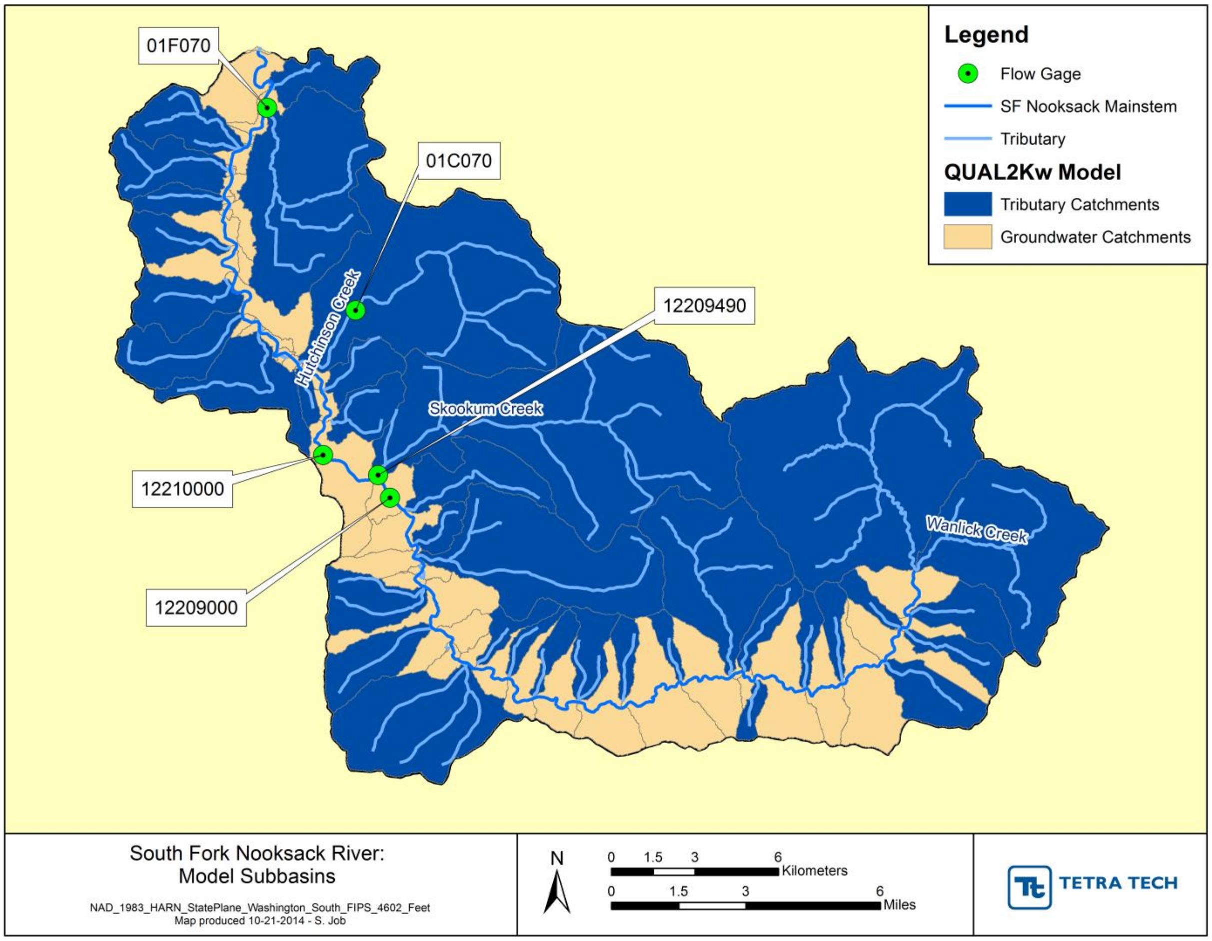


Figure 44. Groundwater sources (diffuse sources), tributary sources (point sources), and streamflow gages for the model.

2. Curran and Olsen provided low-flow statistics for three of the flow gages in the South Fork Nooksack Basin—Skookum Creek (USGS 12209490), South Fork Nooksack at Wickersham (USGS 12209000), and Hutchinson Creek (Ecology 01C070). The 60Q2 statistic (i.e., the 60-day average low flow with an occurrence interval of 2 years) for each of these represents the highest flow among the pool of 12 critical low flow statistics. The 60Q2 flows are somewhat less than flows reported on the model simulation days, but are reasonably close. The 60Q2 regression was therefore selected as being the most representative of flow conditions for ungaged locations for the two simulation days. Note that in the next step, estimated flows were scaled to match observed conditions; the role of the 60Q2 equation is to provide a basis for estimating ungaged flow using GIS inputs of basin area and mean elevation.

3. For each tributary, basin area and mean elevation were calculated using GIS. The 60Q2 flow (using equation 3) was then calculated using basin area and mean elevation. The 60Q2 values calculated for Skookum Creek and Hutchinson Creek were compared to the observed flows on the model simulation days (shown in Table 16 previously), which were much higher than the regression values. (As noted previously, the Curran and Olsen *observed* 60Q2 values for Skookum Creek and Hutchinson Creek were also much higher than the regression values. This indicates that tributaries in the South Fork Nooksack contribute greater than average flow during low-flow conditions compared to the Nooksack River Basin as a whole.).

   The ratio of simulation day observed flow to regression 60Q2 was calculated separately for Skookum Creek and Hutchinson Creek, and the two ratios were averaged. This ratio was then used to rescale ungaged tributaries to be consistent with observed conditions in the gaged tributaries. As an example, the ratio for the 2007 simulation was 2.16; 60Q2 flow for Wanlick Creek was estimated to be 6.7 cfs and was rescaled to 14.2 cfs to represent 2007 model conditions. The 2010 ratio was lower at 1.82, and Wanlick Creek flow was rescaled to 12.0 cfs for the 2010 model simulation.

4. Next, cumulative estimated tributary flow was summed up to the USGS monitoring stations—12209000 for 2007 and 1221000 for 2010. The difference between observed flow and cumulative tributary flow was assumed to represent the groundwater contribution along the mainstem up to that point. The difference was positive in both cases, indicating gaining flow.

5. The groundwater contribution was assigned to the diffuse source catchments by area; a weighting factor was also applied to each catchment to account for orographic precipitation variation. The factors were calculated using the Curran and Olsen 60Q2 regression equation but with the area factor excluded so as to account for elevation differences only.

6. Steps 3 and 4 were repeated for the portion of the mainstem from the USGS station 1221000 to the mouth, using Ecology 01F070 for observed flow. For 2010, the impaired flow value was replaced by an estimate derived using the ratio of Ecology 01F070 to USGS 1221000 in 2007 (267 cfs to 224 cfs, or 1.19, applied to 2010 USGS 1221000 flow (140 cfs). The resulting 2010 flow for Ecology 01F070 was 166.9 cfs.

A comparison of Flow Boundary Model results to observed mainstem flows is shown for 2007 (Figure 45) and 2010 (Figure 46).

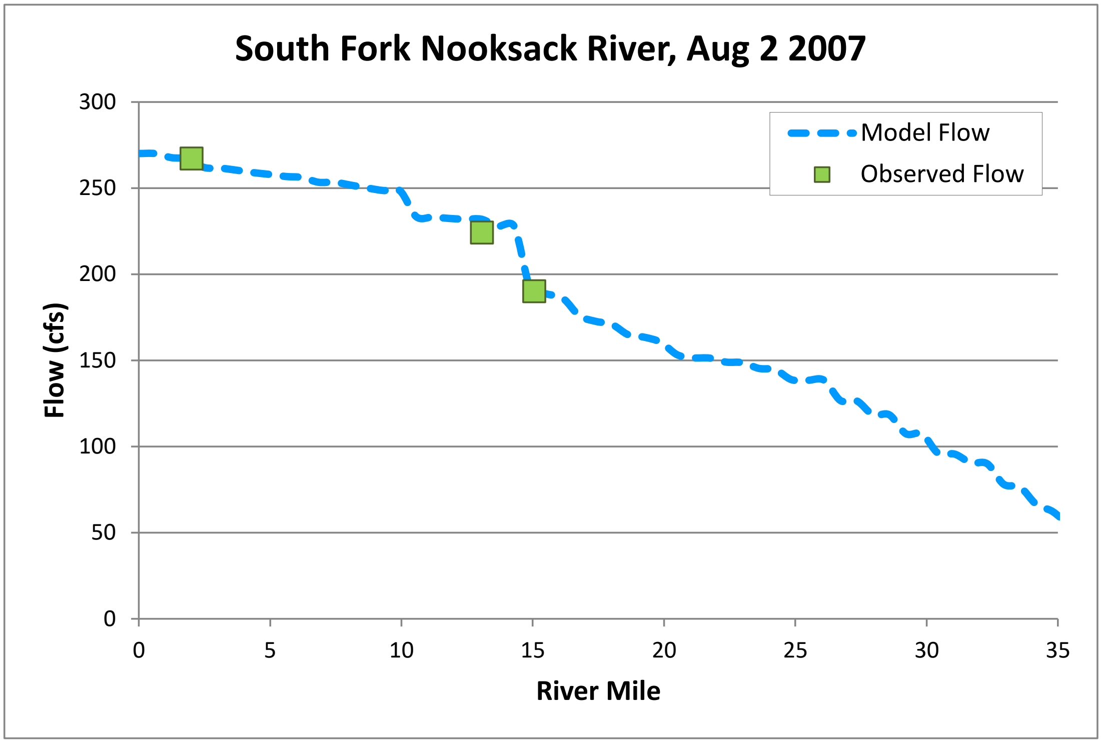


Figure 45. Comparison of observed and simulated flows for the calibration period.

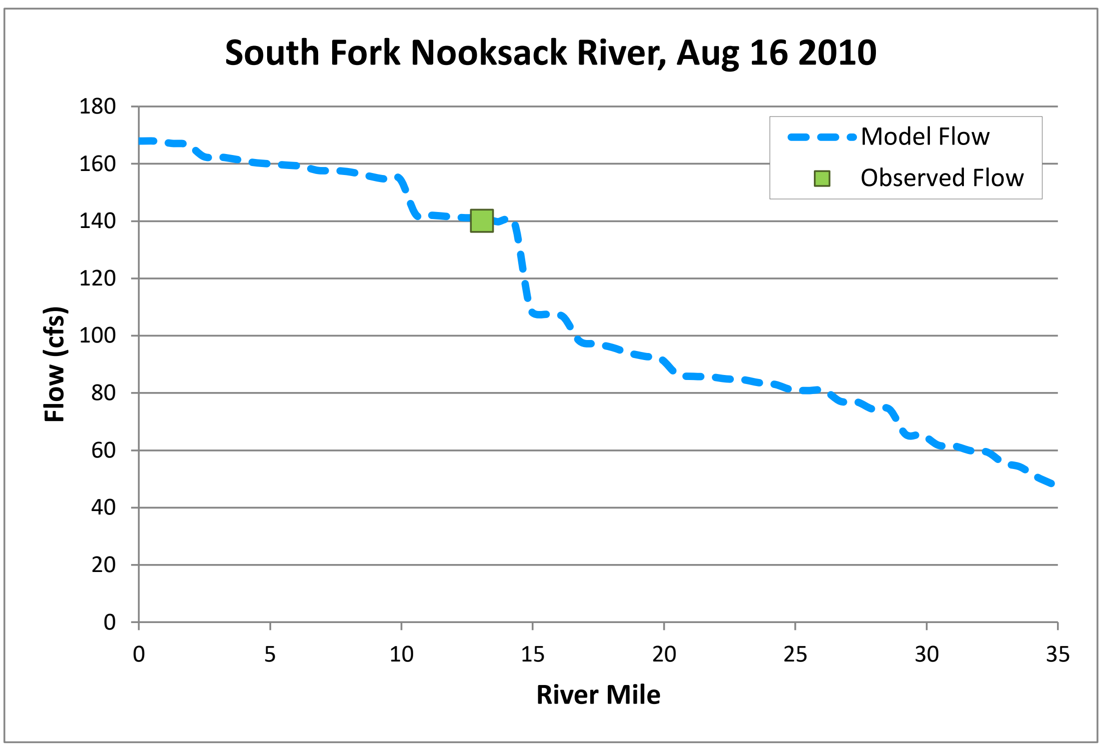


Figure 46. Comparison of observed and simulated flow for the validation period.

It is important to consider that significant uncertainty is associated with flow predictions using the Curran and Olson equations, and that flow measurements at the USGS and Ecology gages are themselves uncertain (as are any observed flow measurements). Ultimately, the cumulative contributions of flow from headwaters, tributaries, and direct groundwater inflow to the mainstem are not known for the two model simulation days. However, the Curran and Olsen research reflects local conditions and provides an empirical method for estimating a critical input to QUAL2Kw—the magnitude and distribution of flows.

Hydraulics

Hydraulic parameters required by QUAL2Kw were determined using the Manning's equation approach. Required QUAL2Kw inputs, for each reach, include bottom width, channel slope, and Manning's n (roughness index). Bottom width was assumed to be equal to wetted width and estimated from 2006 aerial imagery (the same imagery used for the Shade model). Channel slope was estimated from LiDAR data as described previously for the Shade model. The version of QUAL2Kw used requires zero side slopes when using the Manning's approach.[9] Finally, Manning's n values were estimated by reach using the following steps.

A number of stream cross sections and accompanying data along the mainstem were measured in the late 1990s during three separate periods as part of the USGS seepage study (described in the Historic Data section previously). These data were used to develop the necessary stream channel hydraulic characteristics, even though they do not coincide in time with the calibration and validation periods used for the QUAL2Kw model (similar data for the calibration and validation periods were not available). Because the South Fork Nooksack channel has a tendency to move and change in shape over time, this approach does introduce uncertainty in the model representation of hydraulics. Some of this uncertainty was assessed using a sensitivity analysis. However, while the channel is dynamic and lateral movement occurs often, the general form and relationship of pools, runs, riffles, and such, are expected to be less variable, particularly in the low-flow conditions that will be simulated in the model.

To develop a set of optimized Manning's n values by reach, QUAL2Kw models for flow were developed for each of three days of the USGS seepage study. Flows required for the model (i.e., headwater, tributaries, and groundwater) were developed from the seepage study data using the Flow Boundary Model discussed in the previous section. For each of the three periods of the seepage study, flows coincident with gaged locations were compared to observed low-flow statistics from Curran and Olsen (2009). Each of the seepage study dates was assumed to be best represented by the following low-flow statistic:

- August 25, 1998 – 30Q10
- September 29, 1998 – 7Q10
- October 5, 1999 – 60Q2

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[9] Following initial model development, a test was performed using an earlier version of the model that allows greater than zero side slopes. A test of 1:1 side slopes resulted in no discernible difference in simulated temperatures (on average, daily temperatures changed by 0.18 °C). The calibrated model is, therefore, not sensitive to the side slope, so even if actual side slopes were known and used, the effect on temperature would be minimal, if any at all.

The seepage study flows were scaled to the Curran and Olsen regression equations corresponding to the statistics shown in the previous bullets. Observed seepage study flows and the estimated flows are shown in Figure 47. As before, flows predicted by the regressions were rescaled to match observed flows from the seepage runs, thus providing inflow distributed throughout the model. The seepage study flows were not used directly since most of the tributary flow was not reported, preventing attribution of flow to tributary versus groundwater sources. In addition, better consistency was achieved by estimating hydraulic parameters using the same structure for the Flow Boundary Model as was used for QUAL2Kw model for the two simulation days.

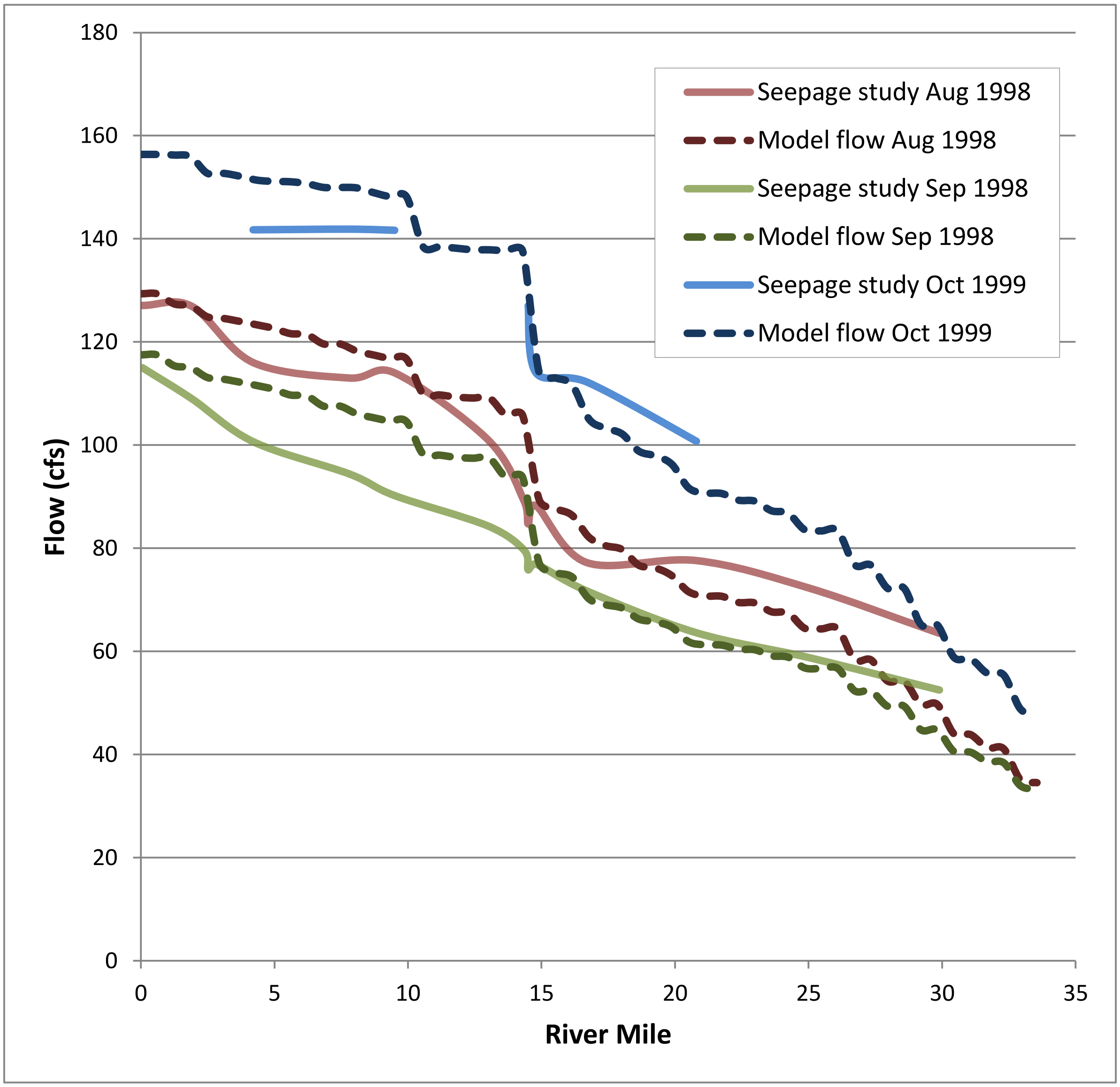

Figure 47. Comparison of 1998-1999 seepage study flow with estimated flows using the flow boundary model.

Next, the seepage study data from the mainstem was input into Ecology's Manning's calculator (available at https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Models-tools-for-TMDLs) to develop initial Manning's n values for the surveyed reaches. Calculated values using the seepage study data ranged from 0.02 to 0.39. These were applied as initial values to the reaches in the QUAL2Kw model and assigned on the basis of general trends in channel slope, which decreases from upstream to downstream. Other channel characteristics required by the model (e.g., channel slope, channel width) were based on the same representation used for the 2007 Shade runs and subsequent 2007 QUAL2Kw model. Manning's n values were adjusted for the three dates to fit the ranges of observed depths and velocities during the seepage study, and resulted in one optimized set that were used during the temperature modeling calibration (2007) and validation (2010) periods.

Table 17 compares observed and modeled depths and velocities. The table demonstrates that modeled values were within the range of observed values. Fit was optimized for depth because it is likely to have a greater effect on water temperature than velocity. Therefore, velocity tends to be under-predicted. Note that the rectangular channel form required by the model affects the ability to fit both depth and velocity well in this exercise. Also this procedure would be expected to produce some amount of deviation in model fit because the stream geometry was based on a different time period (2006 imagery; 2005/2009 Lidar) than the seepage study data. However, the results provide general consistency and give a reasonable amount of confidence in the hydraulic properties applied for 2007 and 2010.

Final Manning's n values ranged from 0.04 to 0.23 and followed a general decreasing trend from upstream to downstream. The average values for reaches upstream and downstream of Cavanaugh Creek were 0.196 and 0.068, respectively. Lower Manning's n values generally represent straighter, smoother stream bed conditions; higher values represent more winding streams with variable conditions (e.g., riffles and pools, or presence of stones, wood, and weeds).

Some of the values for Manning's n selected for the model are higher than values often used in traditional application of the roughness coefficient. Traditional uses are typically not focused on low-flow conditions as in this TMDL, but on higher flows such as bank full. Typical values for these traditional uses range from about 0.025 to 0.15 for natural main channels (Chow, 1959). Those developing previous TMDLs focused on critical low-flow conditions in the region have acknowledged the need to use higher values in some cases (Coffin and Lee, 2011; Zalewsky and Bilhimer, 2004). In addition, since the values selected were based on measured data from the seepage study at locations along the river and their use in the QUAL2Kw seepage study runs resulted in a reasonable fit of velocity and depth, they were deemed appropriate for use in the temperature model calibration.

Table 17. Results of model simulation to optimize Manning's n values.

Reach	Observed	Modeled	Observed	Modeled
	Depth (m)		Velocity (m/s)	
September 29,1998				
31	0.26	0.26	0.82	0.35
37	0.42	0.41	0.37	0.21
46	0.34	0.26	0.30	0.42
51	0.42	0.32	0.24	0.26
55	0.29	0.27	0.43	0.37
58	0.28	0.30	0.76	0.33
Average	*0.34*	*0.30*	*0.49*	*0.32*
Average for all 58 reaches	--	*0.29*	--	*0.29*
August 25, 1998				
10	0.48	0.31	0.34	0.22
18	0.64	0.34	0.27	0.25
25	0.36	0.32	0.44	0.22
31	0.38	0.28	0.28	0.37
34	0.26	0.33	0.40	0.34
46	0.25	0.27	0.57	0.44
51	0.40	0.34	0.41	0.27
55	0.32	0.29	0.50	0.39
58	0.32	0.32	0.71	0.34
Average	*0.32*	*0.31*	*0.48*	*0.36*
Average for all 58 reaches	--	*0.31*	--	*0.30*
October 5,1999				
25	0.53	0.37	0.20	0.25
31	0.35	0.33	0.62	0.41
34	0.28	0.39	0.44	0.37
35	0.35	0.38	0.37	0.44
37	0.45	0.51	0.28	0.25
43	0.36	0.48	0.49	0.45
46	0.24	0.31	0.32	0.48
51	0.36	0.38	0.47	0.29
Average	*0.34*	*0.41*	*0.40*	*0.38*
Average for all 58 reaches	--	*0.36*	--	*0.33*

Meteorology

Meteorological data are needed by the QUAL2Kw model to estimate stream temperatures using real solar and weather forcing. The weather parameters used in the model are air temperature, wind speed, cloud cover, solar radiation, and dew point.

Observed hourly weather data for the calibration and validation dates were supplied by the same sources to be consistent between model runs. The breakdown of weather data sources, stations, and explanation for each parameter are presented in Table 18. Stations were chosen on the basis of proximity to the watershed, data availability for both calibration and validation dates, and reported quality assurance. The stations listed above can be seen in the map below for their relative location to the SFNR watershed (Figure 48).

Table 18. Weather stations and data for each parameter.

Weather Parameter	Weather Station	Explanation/Description
Wind Speed	AgWeatherNet: Nooksack Station	Hourly data from this station were used for 8/2/2007 and 8/16/2010.
Cloud Cover	NCDC: Station 24217	Hourly data from this station were used for 8/2/2007 and 8/16/2010. Cloud cover data were not measured at the AgWeatherNet Nooksack Station.
Solar Radiation	AgWeatherNet: WSU Station	Hourly data from this station were used for 8/2/2007 and 8/16/2010.
Air Temperature	Ecology: Station 01F070 SNOTEL: Station 910	Hourly data 8/2/2007 and 8/16/2010 from these two stations were used to estimate air temperatures at each reach along the river using linear interpolation based on elevation.
Dew Point	AgWeatherNet: Nooksack Station Ecology: Station 01F070 SNOTEL: Station 910	Hourly dew point temperatures were measured at the Nooksack Station, and the relative difference between dew points and the minimum daily temperature at this station were calculated. Next, hourly dew points were calculated for each reach in the model on the basis of the relative differences calculated for the Nooksack Station applied to the minimum daily air temperatures measured at station 01F070 and station 910.

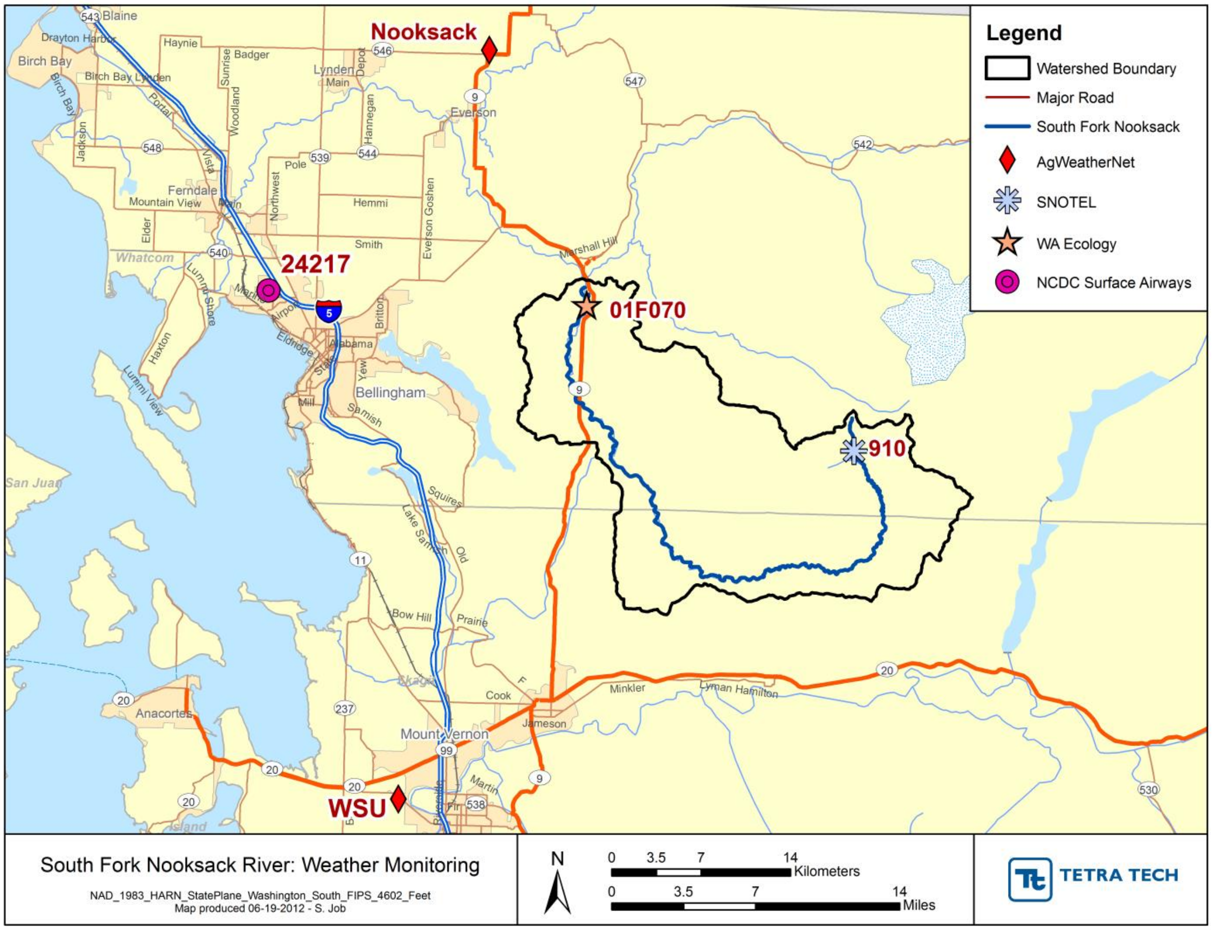

Figure 48. Weather monitoring station locations used for weather data input in QUAL2Kw for the South Fork Nooksack River.

Reach thermal properties

Both hyporheic and surface transient storage were simulated in the models. Default or recommended values (according to QUAL2Kw model guidance; Pelletier and Chapra, 2008) were used in most cases. Sediment thermal conductivity was set to 1.6 W/m-°C, and sediment thermal diffusivity was 0.0064 cm^2/s. The proportion of hyporheic exchange flow and the flow fraction for the surface storage zone were each kept at defaults of 5%. Hyporheic sediment porosity was set to 40%. Finally, the only value adjusted from default was the sediment/hyporheic layer thickness; this was considered a calibration parameter, and final values ranged from 10 to 25 cm (the default is 10 cm). The higher thickness values were applied in the upper reaches of the river.

Headwater settings

Headwater flows were calculated as described previously in the flow boundary model section. Temperatures assigned to the headwater flows were based on observed values on the simulation day.

For 2007, temperatures were specified using flow weighted values from SF0200 (located on the mainstem) and SF0210 (at the mouth of Wanlick Creek) (e.g., temperature at each station is multiplied by the fraction of the total flow—SF0200+SF0210- for each station, and then combined). The US Wanlick station on the mainstem was used for 2010.

Tributary and groundwater temperatures

Observed stream temperature data were also available for a number of tributaries along the mainstem of the SFNR, which were added as *Point Sources* in the model. A total of 35 tributaries join the SFNR along this study reach. Temperature data were available for a subset of these streams (Table 19; Table 20; stations are shown later on Figure 49 and Figure 50). Where two stations were co-located on the same tributary, an average of their temperature data was used.

For unmonitored tributaries, average values from the monitored tributaries were applied according to differences in elevation (i.e., monitored stations were grouped into high- and low-elevation sets, and average temperatures from each set were applied to unmonitored tributaries by mean elevation, high or low, of the unmonitored tributary). This method does not capture any differences in land cover or riparian cover. Unmonitored tributaries in 2007 included 19 unnamed tributaries, McGinnes, Howard, Canyon, Plumbago main tributary, Fobes, Pond, Jones, McCarty, Standard, Hard Scrabble Falls, Sygitowicz, and Black Slough. Unmonitored tributaries in 2010 included 19 unnamed tributaries, McGinnes, Howard, Canyon, Fobes, Pond, Jones, McCarty, Standard, Hard Scrabble Falls, and Sygitowicz.

Table 19. Observed temperature data for 2007 for tributaries.

Tributary Name	Observed Stream Temperature Station	Distance from Downstream (km)
Wanlick Creek	SF0210	Headwater trib
Deer Creek	SF0135	Trib to Plumbago
Cavanaugh Creek	SFT016	30.65
Edfro Creek	SFT015	26.95
Skookum Creek	SF0130	26.55
Hutchinson Creek	01C070	18.15
McCarty Creek	SF0033	14.25

Table 20. Observed temperature data for 2010 for tributaries.

Tributary Name	Observed Stream Temperature Station	Distance from Downstream (km)
Wanlick Creek	Wanlick10	Headwater trib
Plumbago Creek	411	34.85
Cavanaugh Creek	410	30.65
Edfro Creek	409	26.95
Skookum Creek	413 2209490	26.55
Hutchinson Creek	408 01C070	18.15
Black Slough Creek	407	6.15

Groundwater temperatures associated with flows in the *Diffuse Sources* tab of the model were initially determined on the basis of average annual air temperature (at Ecology and SNOTEL stations) and varied by elevation. Final calibration values ranged from 10 to 13.9 °C. These same values were used for the validation run.

Shade input

Shade hourly time series from the Shade model (discussed earlier) represents the fraction of solar radiation reaching each stream segment blocked by vegetation and topography. Shade model runs for 2007 and 2010 were used as input to the calibration and validation simulations, respectively.

Permitted point sources

The Lummi Nation operates the Skookum Creek Fish Hatchery, on Saxon Rd, at the mouth of Skookum Creek. The hatchery operates under a General Hatchery Permit issued by EPA and diverts water from Skookum Creek downstream from the gaging station location. This water is discharged (along with groundwater pumped from six wells) to the SFNR upstream from the Saxon Road gaging station. Average daily flow for 2007 was 7.7 mgd. The permit requires monitoring of flow, settleable solids, TSS, and chlorine and therefore there is no requirement to monitor temperature or dissolved oxygen in the discharged water. Additionally, temperature data were not available for 2007. As hatchery outflow is on the order of 5% or less of the SFNR mainstem flow, it is not modeled explicitly. The hatchery is discussed further in the wasteload allocation section.

Observed data for model calibration and validation

Observed stream temperature data were used to calibrate and validate the model. Stream temperature was measured at several different locations along the mainstem of the SFNR on the calibration and validation dates. The stations used for observed data along the river are seen below (Table 21; Figure 49; Figure 50). Note that where a single reach has multiple temperature stations, the data were averaged for model comparisons where needed (e.g., the diel tab data in the model).

Table 21. Observed temperature data for 2007 and 2010 along the mainstem.

Observed Stream Temperature Station	Distance from Downstream (km)	Reach unit to which this distance corresponds	Available Stream Temperature Data
2007 Calibration Data			
Nooksack Tribe: SF0200	57.75	1	Hourly
Nooksack Tribe: SF0190	50.50	8	Hourly
Nooksack Tribe: SF0180	41.40	17	Hourly
Nooksack Tribe: SF0153	33.93	24	Hourly
Nooksack Tribe: SF0134	29.55	29	Hourly
USGS: 12209000	24.20	34	Min, Max, Mean only
USGS: 12210000	21.10	37	Min, Max, Mean only
Nooksack Tribe: SF0075	15.38	43	Hourly
Nooksack Tribe: SF0031	10.75	48	Hourly
Nooksack Tribe: SF0030	9.50	49	Hourly
Ecology: 01F070[a]	3.30	55	Hourly
2010 Validation Data			
Nooksack Tribe: DSWanlick	57.65	1	Hourly
Nooksack Tribe: 406	50.60	8	Hourly
Nooksack Tribe: 405	41.43	17	Hourly
USGS: 12210000	21.05	37	Min, Max, Mean only
Nooksack Tribe: 403	21.10	37	Hourly
Nooksack Tribe: 402	15.53	43	Hourly
Nooksack Tribe: KALSUS10	10.68	48	Hourly
Nooksack Tribe: TENASKUS10	5.73	53	Hourly
Ecology: 01F070[b]	3.30	55	Hourly
Nooksack Tribe: VANZANUS10S	2.60	56	Hourly
Nooksack Tribe: VANZANDS10S	1.35	57	Hourly

[a] Data from this station in 2007 was inconsistent (i.e., lower mean and smaller range) with other nearby data, however it was retained for comparison purposes.
[b] Data from this station in 2010 were inconsistent with other nearby data. Because the mean was more than 30% lower than stations upstream and downstream and there was little range in values, it was *not* used for comparison purposes.

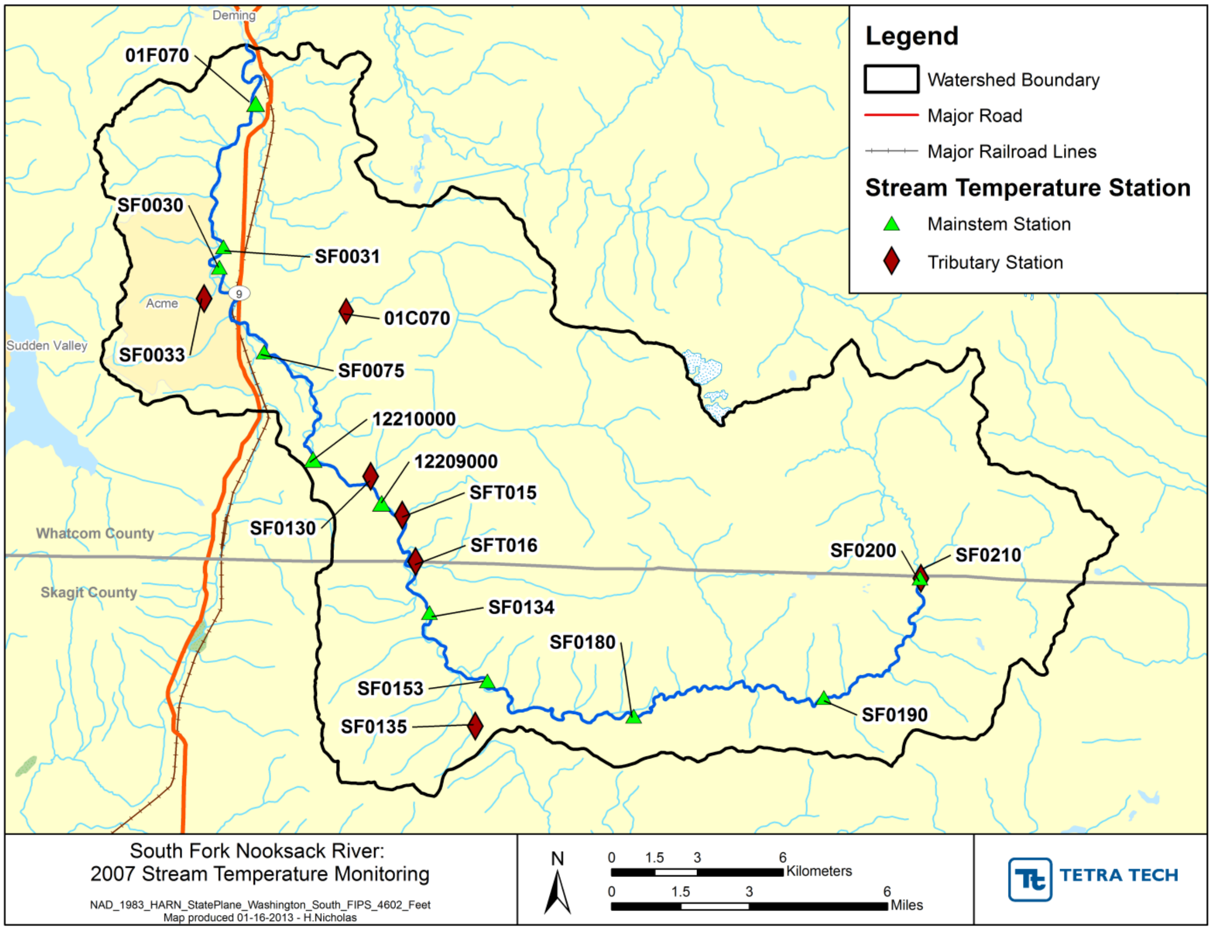

Figure 49. Locations of observed stream temperature monitoring sites for 2007 used for model calibration.

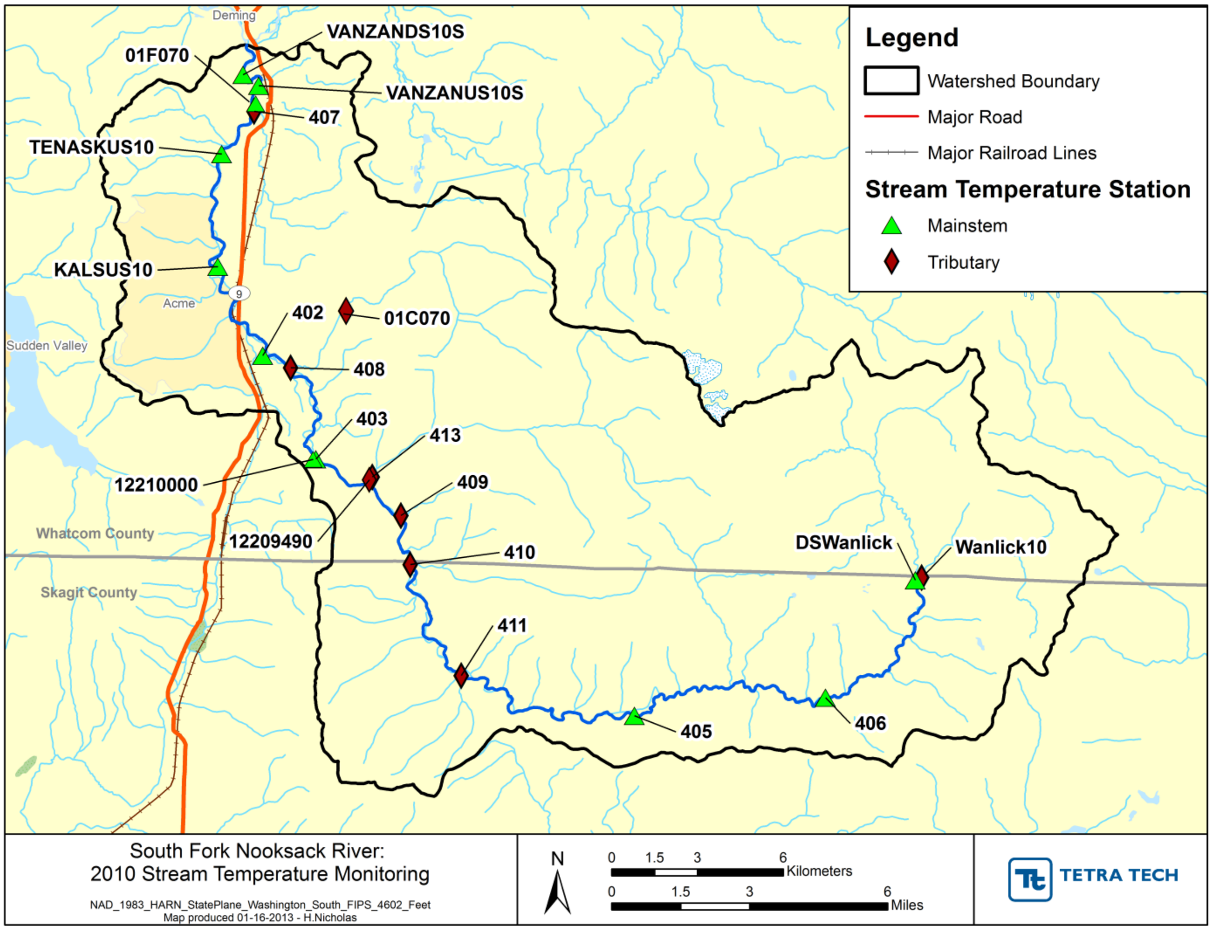

Figure 50. Locations of observed stream temperature monitoring sites for 2010 used for model validation.

Calibration and validation results

Results for 2007 calibration

Figure 51 provides the longitudinal profile of observed and predicted temperature for the calibration period. Tabular comparisons of predicted and observed values for the min, max, mean, and 90th percentile temperature are shown in Table 22. Temperatures follow a general increasing trend from upstream to downstream. The minimums, maximums, and means are predicted reasonably well with varying amounts of under- and over-prediction. Note that the observed data for reach 55 (Ecology: 01F070) are somewhat inconsistent with the other observed data showing a much smaller range and lower mean. Model deviation near this point is therefore acceptable given uncertainty in the data. Example diel series are provided for three reaches representing upstream (Figure 52; reach 17), mid-stream (Figure 53; reach 24), and downstream locations (Figure 54, reach 49). The patterns are generally replicated with better fit (e.g., reach 24) for some than others.

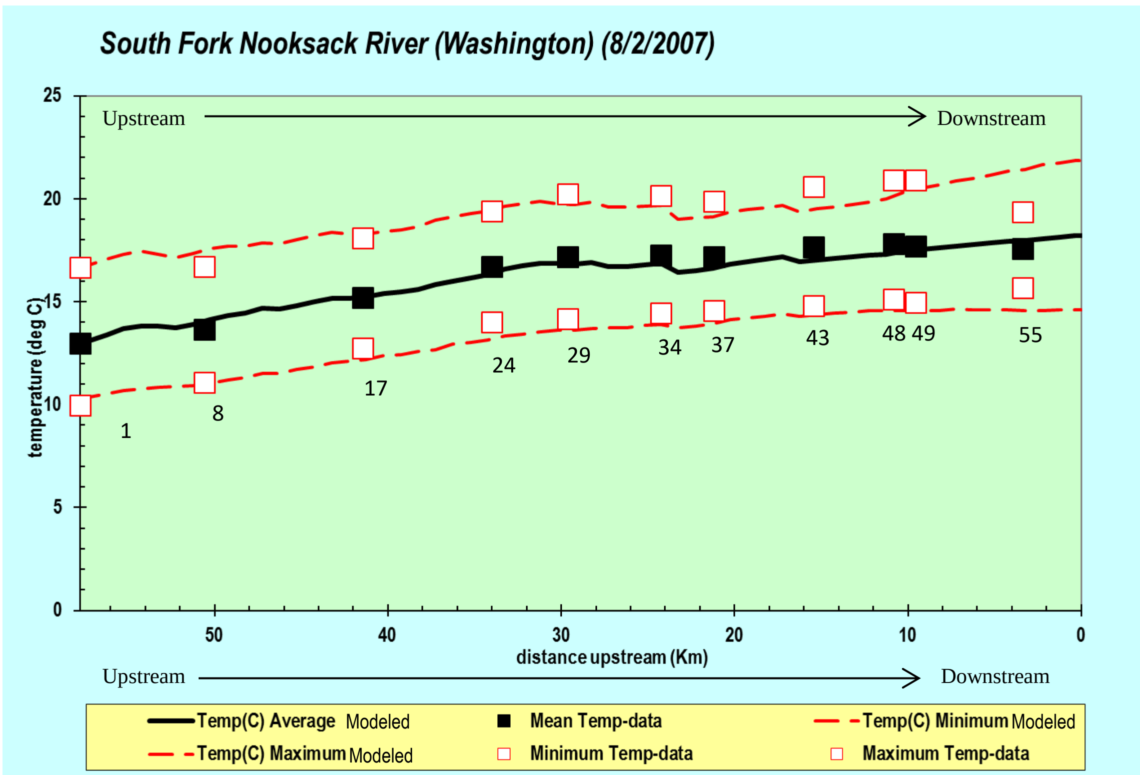

Figure 51. Longitudinal temperature comparison (observed data and modeled) for the calibration period. Labels for observed data correspond to Reach Numbers in the following table.

Table 22. Comparison of model results for the 2007 calibration – temperature (°C)

Reach	Observed Data				Modeled Data			
	Min	Max	Mean	90th Percentile	Min	Max	Mean	90th Percentile
1	9.91	16.62	12.85	16.33	10.37	16.79	13.10	16.49
8	11.03	16.64	13.54	16.36	11.04	17.63	14.16	17.40
17	12.67	18.03	15.17	17.71	12.18	18.38	15.29	18.17
24	13.93	19.35	16.66	19.03	13.18	19.40	16.34	19.21
29	14.12	20.18	17.12	20.02	13.69	19.70	16.87	19.56
43	14.75	20.51	17.58	20.24	14.36	19.52	17.05	19.37
48	15.06	20.83	17.76	20.56	14.59	20.31	17.47	20.15
49	14.90	20.83	17.65	20.55	14.58	20.52	17.54	20.33
55	15.60	19.30	17.42	19.20	14.57	21.43	17.97	21.22

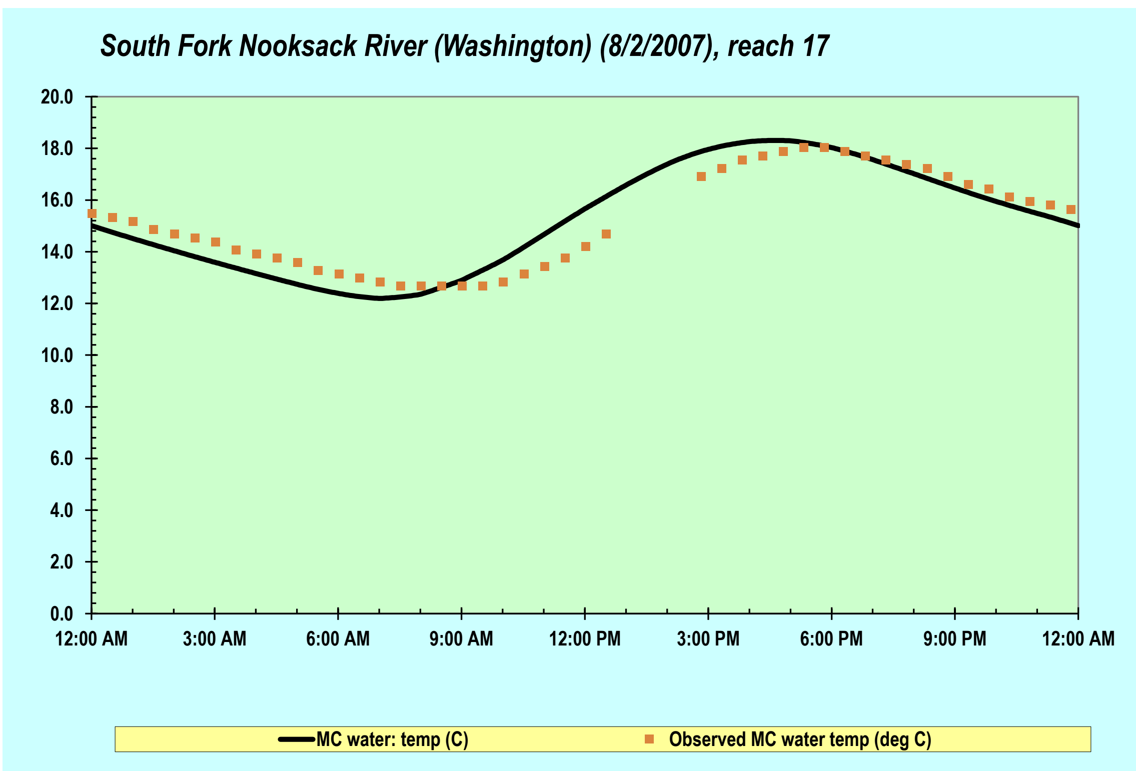

Figure 52. Diel temperature data (dashed line) vs. modeled (solid line) at reach 17 during the calibration period.

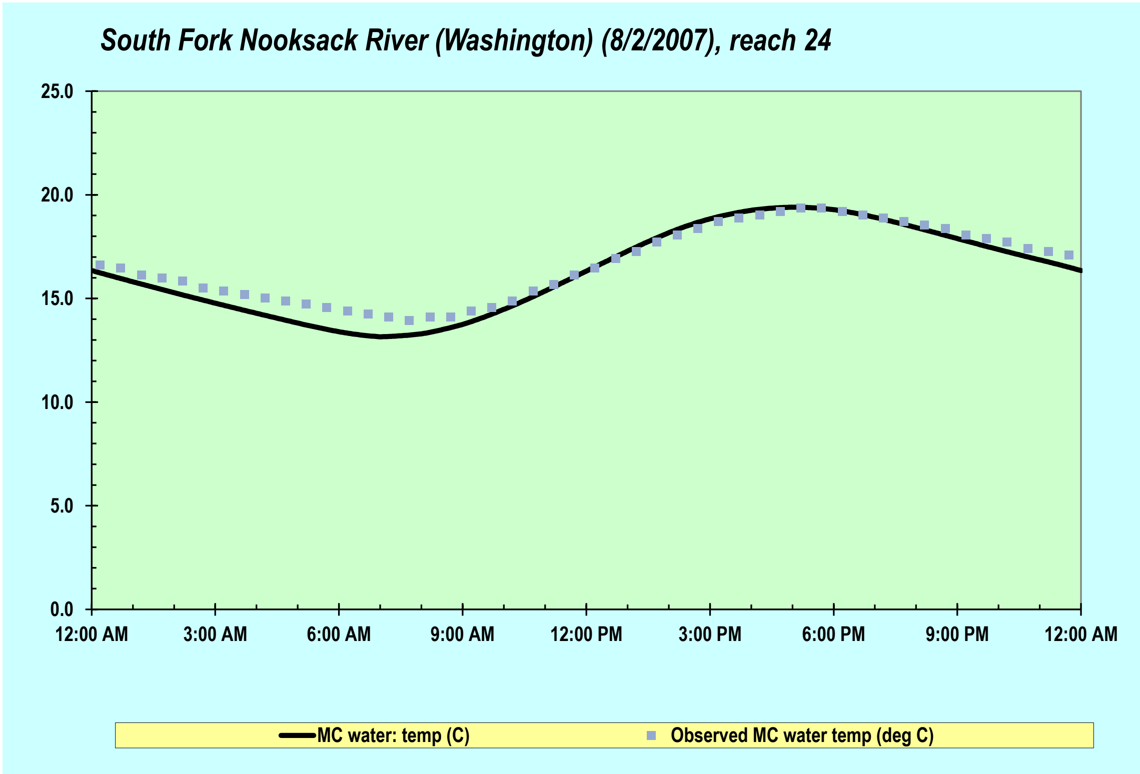

Figure 53. Diel temperature data (dashed line) vs. modeled (solid line) at reach 24 during the calibration period.

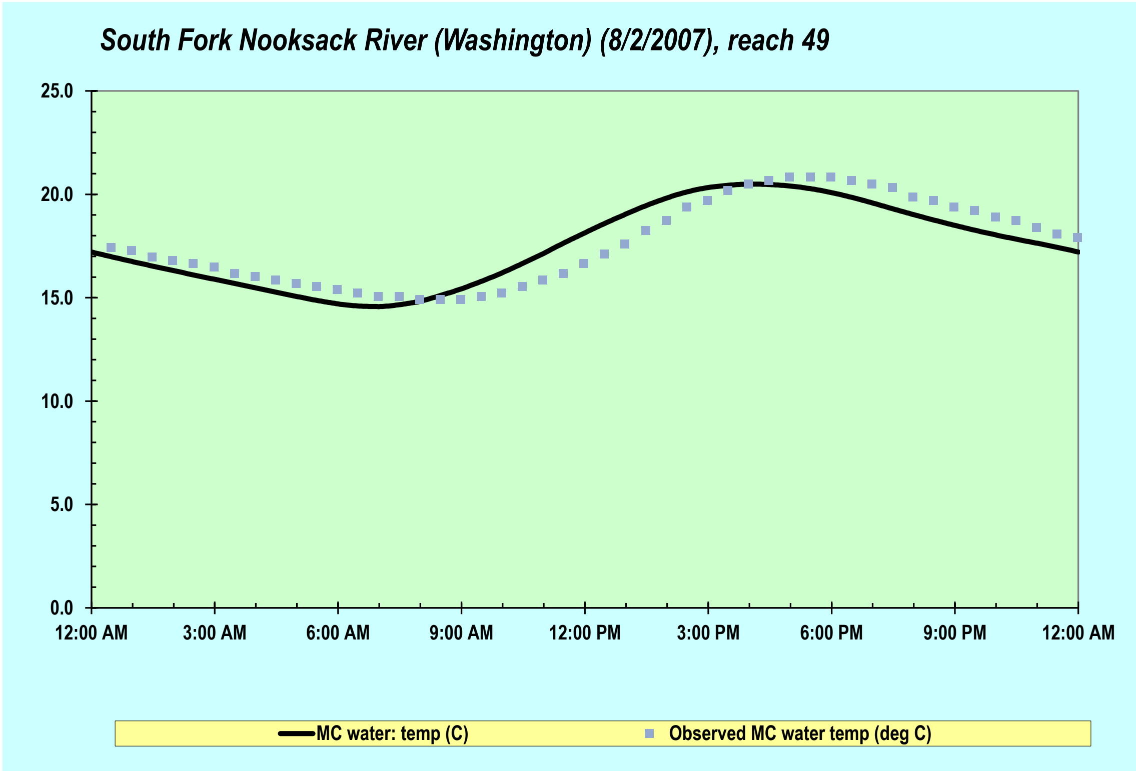

Figure 54. Diel temperature data (dashed line) vs. modeled (solid line) at reach 49 during the calibration period.

Error statistics for the calibration model are provided in Table 23. RMSE for maximum and minimum values are less than 1° C except for the maximum in reach 55 (see the previous note regarding observed data at this station). The average RMSE over these reaches is 0.47 and 0.34 for maximums and minimums, respectively. RPD values range from -5.5% to +5.8% (excluding reach 55). Both under- and over-prediction occur suggesting no consistent bias in the model.

Table 23. Error statistics for the 2007 calibration.

Reach	RMSE for Maximums (°C)	RMSE for Minimums (°C)	RPD for Maximums	RPD for Minimums
1	0.12	0.33	1.02%	4.54%
8	0.70	0.01	5.78%	0.09%
17	0.25	0.35	1.92%	-3.94%
24	0.04	0.53	0.26%	-5.53%
29	0.34	0.30	-2.41%	-3.09%
43	0.70	0.28	-4.95%	-2.68%
48	0.37	0.33	-2.53%	-3.17%
49	0.22	0.23	-1.50%	-2.17%
55	1.51	0.73	10.46%	-6.83%

Results for 2010 validation

The 2010 validation provides a test of the calibrated model parameters under a different set of conditions. Reach properties such as slope, width, Manning's n, and other associated parameters were unchanged from the calibration run. Other inputs were based on observed data in 2010. Groundwater temperatures, for which there were no direct observed data, were unchanged because they are not expected to vary greatly.

Figure 55 provides the longitudinal profile of observed and predicted temperature for the validation period. Associated tabular data are shown in Table 24. There are some differences between modeled and observed mean and maximum temperatures in reach 8 as well as in reaches 37 through 57. Modeled temperatures in other reaches compare well to observed temperatures. Means and minimum values are generally under-predicted, but the relative differences between observed and modeled values are largely consistent. Maximum values show greater consistency at most downstream stations (except for reaches 43 and 48).

Error statistics are provided in Table 25. Average RMSE for the comparison stations was 0.51 and 0.82 °C for maximum and minimum temperatures, respectively. RMSE values greater than 1 occurred at two of nine stations for maximum temperatures and three of nine for minimum temperatures. RPD values ranged from -10.7% to +11.7%.

Example diel series are provided for three reaches representing upstream (Figure 56; reach 17), mid-stream (Figure 57; reach 37), and downstream locations (Figure 58, reach 48).

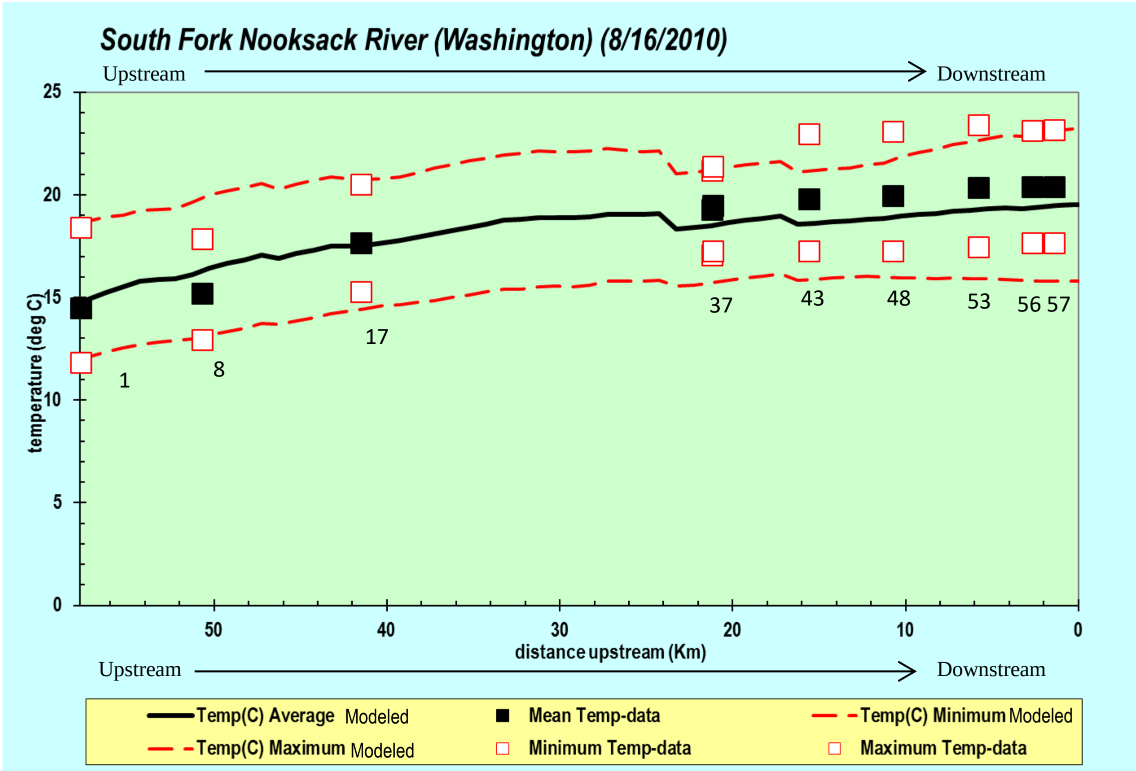

Figure 55. Longitudinal temperature comparison (observed data and modeled) for the validation period.

Labels for observed data correspond to Reach Numbers in the following table.

Table 24. Comparison of model results for the 2010 validation - temperature (°C).

Reach	Observed Data				Modeled Data			
	Min	Max	Mean	90th Percentile Temp	Min	Max	Mean	90th Percentile Temp
1	11.76	18.34	14.44	17.84	12.11	18.74	14.90	18.38
8	12.87	17.80	15.13	17.65	13.12	20.00	16.41	19.75
17	15.22	20.44	17.58	20.19	14.35	20.74	17.50	20.51
37	17.01	21.13	19.20	20.98	15.71	21.19	18.49	21.01
43	17.20	22.90	19.73	22.51	15.88	21.19	18.62	21.02
48	17.20	23.04	19.89	22.70	15.96	21.87	18.99	21.70
53	17.39	23.33	20.29	22.95	15.92	22.75	19.32	22.53
56	17.61	23.06	20.34	22.82	15.81	23.03	19.43	22.80
57	17.58	23.11	20.34	22.93	15.80	23.12	19.49	22.91

Table 25. Error statistics for the 2010 validation.

Reach	RMSE for Maximums	RMSE for Minimums	RPD for Maximums	RPD for Minimums
1	0.28	0.25	2.14%	2.94%
8	1.56	0.18	11.66%	1.92%
17	0.21	0.62	1.48%	-5.90%
37	0.04	0.92	0.30%	-7.95%
43	1.21	0.93	-7.74%	-7.99%
48	0.83	0.88	-5.21%	-7.48%
53	0.41	1.04	-2.51%	-8.83%
56	0.02	1.27	-0.15%	-10.74%
57	0.01	1.26	0.03%	-10.68%

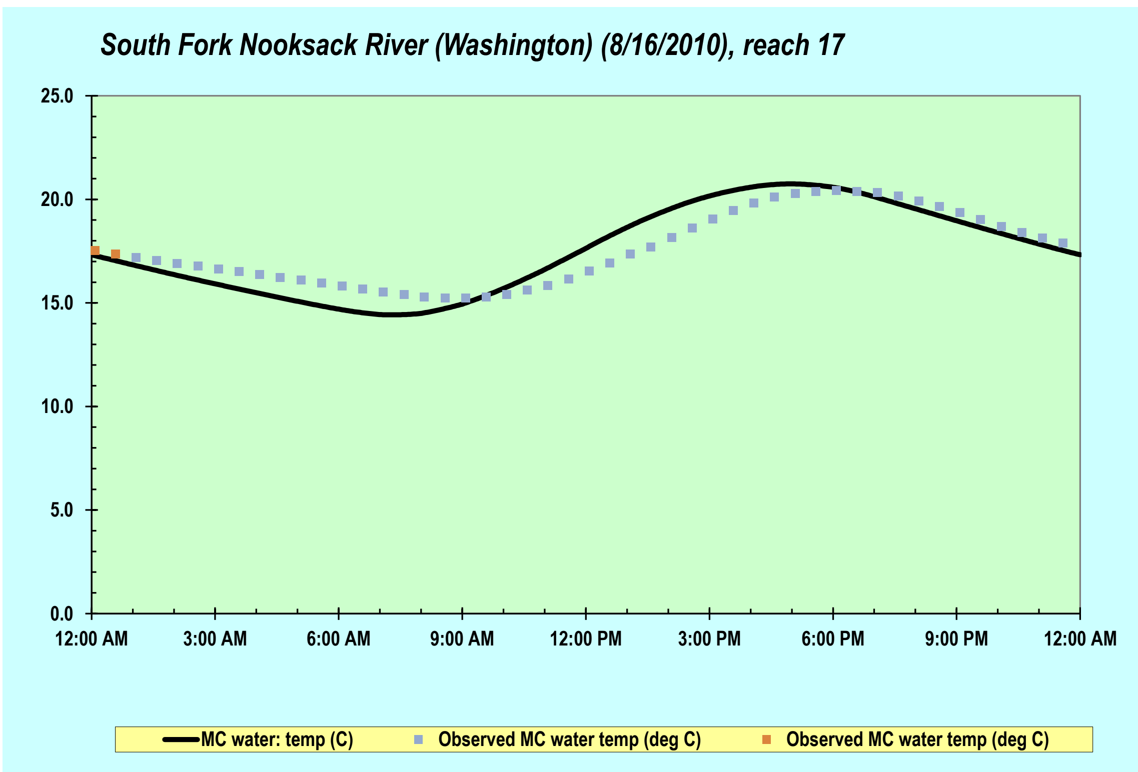

Figure 56. Diel temperature data (dashed line) vs. modeled (solid line) at reach 17 during the validation period.

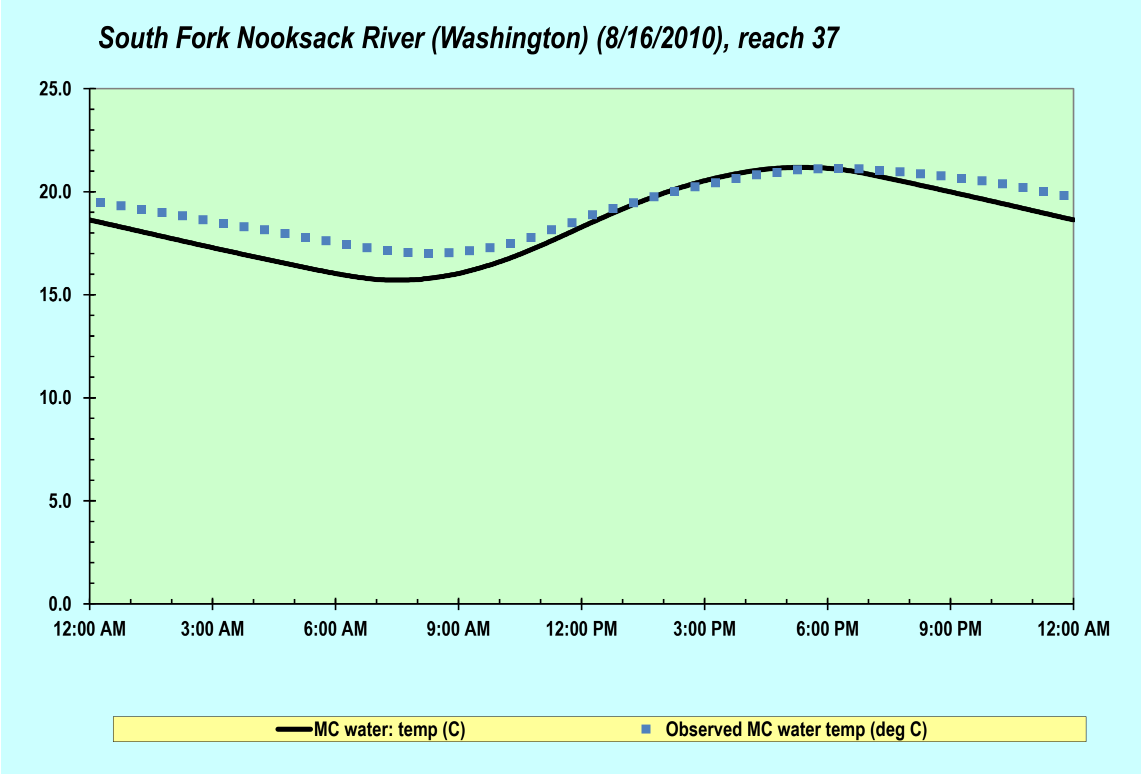

Figure 57. Diel temperature data (dashed line) vs. modeled (solid line) at reach 37 - validation.

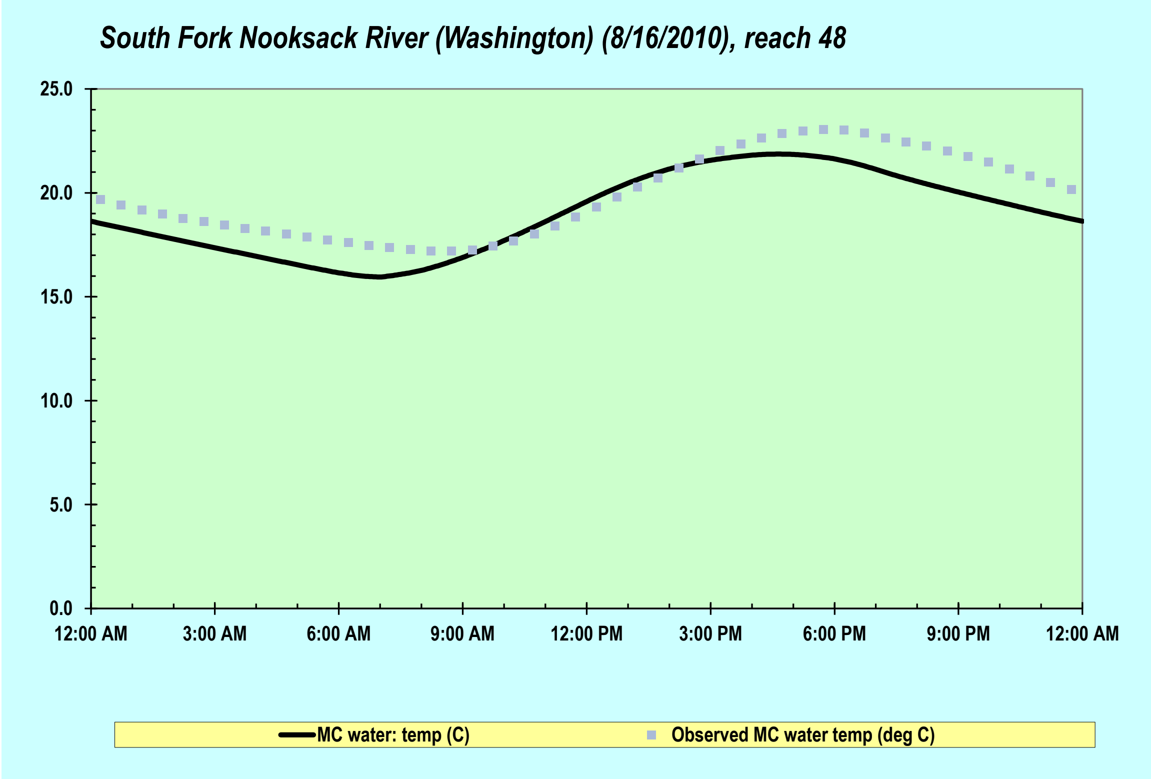

Figure 58. Diel temperature data (dashed line) vs. modeled (solid line) at reach 48 - validation.

Sensitivity analysis

A sensitivity analysis was conducted to test the calibration model's sensitivity to key model inputs. The parameters tested include boundary conditions (flow and temperature), Manning's n values, stream bottom width, shade, and air temperature. The relative sensitivity of each of the parameters was determined by calculating the variance associated with the change in modeled temperature at a critical station (reach 48, which had the highest max and mean temperature on the calibration date) by increasing and decreasing the parameter input by +/- 10%.

The results from sensitivity model runs are compiled in Table 26 by reporting the average, minimum, and maximum temperature output for reach 48.

Table 26. Sensitivity analyses conducted on QUAL2Kw model to determine impact on modeled stream temperature statistics.

Sensitivity Analysis	Mean Water Temperature (C)	Minimum Water Temperature (C)	Maximum Water Temperature (C)
Manning's n increased by 10%	17.47 (+0.003)	14.72 (+0.130)	20.20 (-0.110)
Manning's n decreased by 10%	17.47 (-0.004)	14.44 (-0.150)	20.45 (+0.140)
Bottom width increased by 10%	17.76 (+0.287)	14.71 (+0.120)	20.78 (+0.470)
Bottom width decreased by 10%	17.16 (-0.314)	14.44 (-0.150)	19.81 (-0.500)
Air temperature increased by 10%	17.91 (+0.434)	14.96 (+0.370)	20.79 (+0.480)
Air temperature decreased by 10%	17.04 (-0.432)	14.22 (-0.370)	19.84 (-0.470)
Hourly shade increased by 10%	17.32 (-0.148)	14.47 (-0.120)	20.15 (-0.160)
Hourly shade decreased by 10%	17.62 (+0.150)	14.70 (+0.110)	20.48 (+0.170)
Flow inputs increased by 10% (headwaters, tributaries, groundwater)	17.17 (-0.298)	14.44 (-0.150)	19.84 (-0.470)
Flow inputs decreased by 10% (headwaters, tributaries, groundwater)	17.80 (+0.331)	14.74 (+0.150)	20.85 (+0.540)
Temperature inputs increased by 10% (headwaters, tributaries, groundwater)	18.12 (+0.649)	15.24 (+0.650)	20.96 (+0.650)
Temperature inputs decreased by 10% (headwaters, tributaries, groundwater)	16.82 (-0.656)	13.92 (-0.670)	19.66 (-0.650)
Model output at reach 48 without sensitivity analyses applied	**17.47**	**14.59**	**20.31**

Normalized sensitivity coefficients were calculated to determine how a change in parameter impacts a change in that parameter's response. The formula for this calculation is as follows:

$$\boldsymbol{Normalized\ Sensitivity\ Coefficient} = \frac{\Delta\, response}{base\ model\ response} \Big/ \frac{\Delta\, parameter}{base\ parameter\ value} \quad \text{(Equation 4)}$$

The denominator is always in the range of +/- 10%, therefore 0.2. The base model response is the corresponding model output from the last row in the table above, and the Δ response is the absolute difference between the model being run at -10% and +10% for a single parameter.

The normalized sensitivity coefficient (Table 27) reveal which parameters have the greatest model response to change, and those responses are also presented as tornado diagrams (Figure 59, Figure 60, Figure 61).

Table 26 shows for each percentage point change in a parameter, the model will see the corresponding change in response. Change in headwater and tributary boundary temperature has the greatest impact on temperature. Air temperature has the second largest impact on the model output with average and minimum temperature. The second and third largest impact on maximum temperature is derived from boundary flow and bottom width. Changes in Manning's n and shade have the least impact on the model outputs.

Table 27. Normalized sensitivity coefficients calculated for each parameter.

Sensitivity Analysis	Normalized Sensitivity Coefficient		
	Average	Minimum	Maximum
Manning's n changed +/- 10%	0.2%	9.6%	-6.2%
Bottom width changed +/- 10%	17.2%	9.3%	23.9%
Air temperature changed +/- 10%	24.8%	25.4%	23.4%
Hourly shade changed +/- 10%	-8.6%	-7.9%	-8.1%
Boundary flow inputs changed +/- 10%	-18.0%	-10.3%	-24.9%
Boundary temperature inputs changed +/- 10	37.3%	45.2%	32.0%

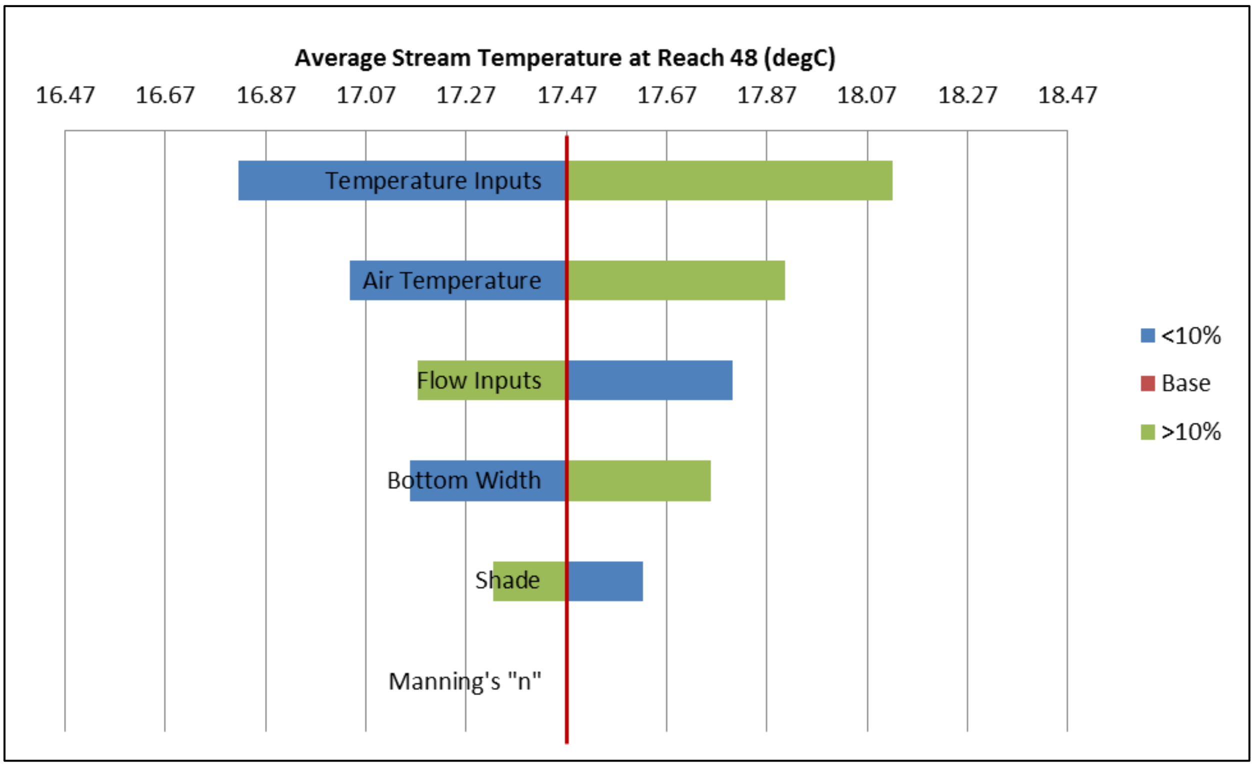

Figure 59. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled average temperature output at reach 48.

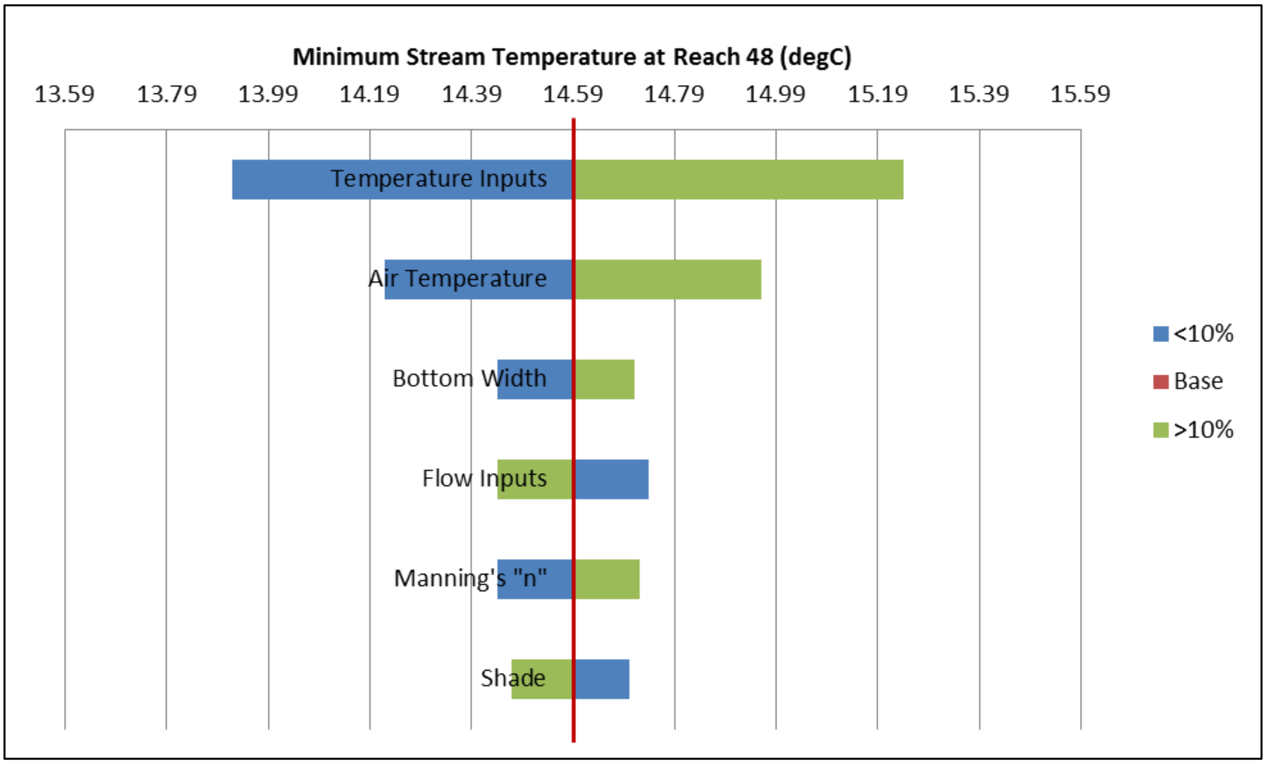

Figure 60. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled minimum temperature output at reach 48.

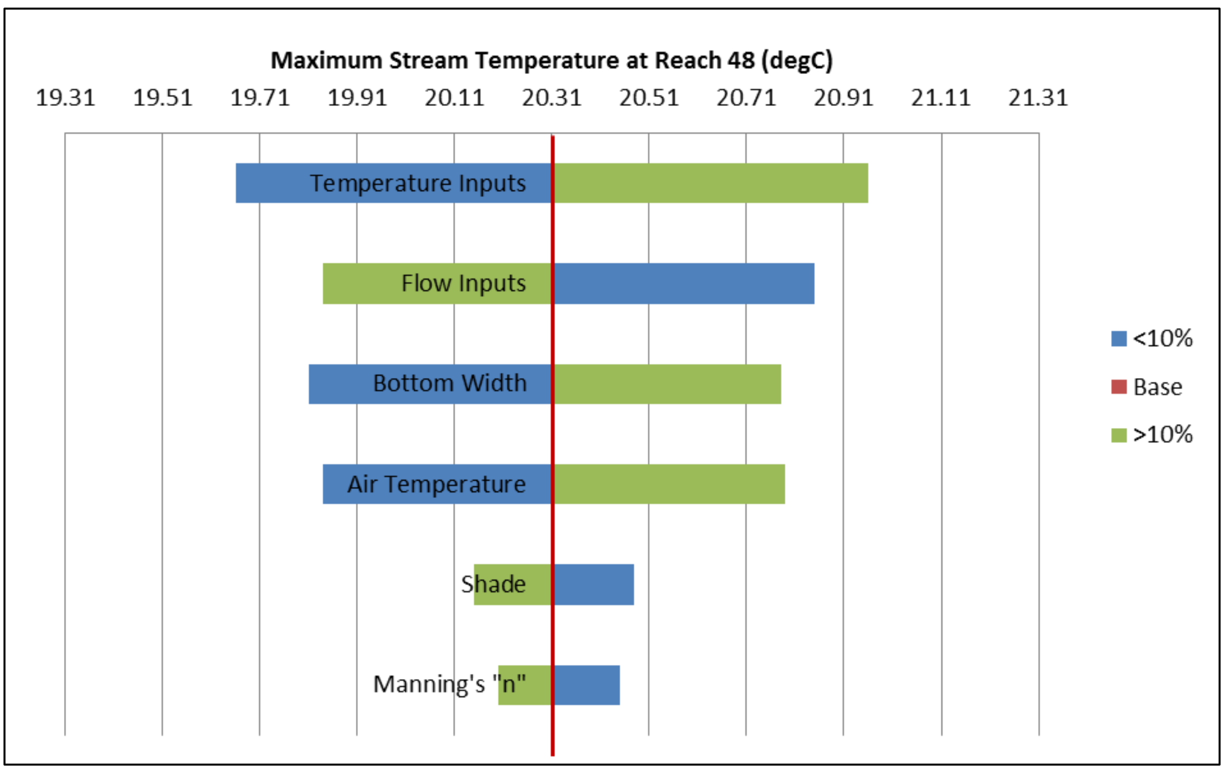

Figure 61. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled maximum temperature output at reach 48.

TMDL modeling scenarios

A series of six TMDL modeling scenarios were developed to evaluate stream temperatures on the mainstem of the SFNR realized under various typical and critical summer conditions. The key differences between each scenario are provided in Table 28, relative to the 2007 calibration model (Table 28). Typical low-flow conditions represent 7Q2 flows and 50th percentile air temperatures based on a ranking of the hottest week for each year of record. Critical low-flow conditions represent 7Q10 flows and 90th percentile air temperatures based on a ranking of the hottest week for each year of record. For all six scenarios, the following inputs or parameters were unchanged from the 2007 calibration model: groundwater temperature, wind, hyporheic flow, and transient storage. Additional modified input variables and parameters relative to the 2007 calibration model are described in the *Scenario input data processing* section.

Table 28. South Fork Nooksack River TMDL modeling scenarios summarized by overall description.

Scenario	Scenario Type	Flow Regime	Meteorological Conditions[a]	Headwater and Tributary Temperatures	Mainstem Shade Condition
1	Typical Low Flow/Temperature with Existing Vegetation	7Q2	50th Percentile Air Temperature	Same as 2007	Existing Vegetation
2	Typical Low Flow/Temperature with 100-year SPV	7Q2	50th Percentile Air Temperature + microclimate effect	At the water quality criteria or current temperature if cooler	100-year SPV (except existing developed land uses)
3	Critical Low Flow/Temperature with Existing Vegetation	7Q10	90th Percentile Air Temperature	Same as 2007	Existing Vegetation
4	Critical Low Flow/Temperature with Existing Vegetation	7Q10	90th Percentile Air Temperature	At the water quality criteria or current temperature if cooler	Existing Vegetation
5	Critical Low Flow/Temperature with 100-year SPV	7Q10	90th Percentile Air Temperature + microclimate effect	At the water quality criteria or current temperature if cooler	100-year SPV (except existing developed land uses)
6	Critical Low Flow/Temperature with 100-year SPV	7Q10	90th Percentile Air Temperature + microclimate effect	At the water quality criteria or current temperature if cooler	100-year SPV Everywhere

[a] Based on ranking of highest 7-DADMax values from each year of the historical record.

Scenario input data processing

Hydraulics

The 2007 calibration model used the Manning's n approach to specify hydraulics. While the general approach is unchanged, for the 7Q2 and 7Q10 scenarios the bottom width of each reach (used as input for the Manning's n approach) was adjusted (decreased in both cases) to reflect expected changes in geometry based on changes in flow, especially reduced width expected under the lower flow conditions. Baseline values from the calibration model for flow, cross-sectional area, width, and depth were used to determine adjustments to the bottom width using equations provided in EPA's technical guidance (EPA, 1997; p A-16). This process began by running the calibration model with the 7Q10 (or 7Q2) flow inputs for the headwaters, tributaries, and groundwater. These resulting flows for the mainstem by reach were then combined with the baseline stream depth and cross-sectional area to determine a new depth and cross-sectional area using the following equations:

$$Depth: \quad \frac{H_{7Q2,7Q10}}{H_{Baseline}} = \left(\frac{Q_{7Q2,7Q10}}{Q_{Baseline}}\right)^{0.45} \quad \text{(Equation 5)}$$

$$Cross-sectional\ area: \quad \frac{A_{7Q2,7Q10}}{A_{Baseline}} = \left(\frac{Q_{7Q2,7Q10}}{Q_{Baseline}}\right)^{0.43} \quad \text{(Equation 6)}$$

where H is depth, Q is flow, and A is cross-sectional area.

The revised width by reach for each corresponding flow condition (7Q2, 7Q10) was then calculated as cross-sectional area divided by depth. Resulting values were used as inputs for the scenario models, while retaining the other baseline inputs for the Manning's n approach.

Headwater, tributary, and groundwater flows

The Flow Boundary Model used to develop boundary conditions in the calibration model was also used to estimate all inflows to the 7Q2 and 7Q10 conditions for the six scenarios. In the previous applications of the Flow Boundary Model, observed flows from specific simulation days were used to scale Curran and Olsen (2009) low-flow regression relationships, thus allowing for the estimation of flows from the headwaters, ungaged tributaries, and direct groundwater inflows. In contrast, the 7Q2 and 7Q10 flows do not represent flow from a specific day, but rather flows relating to a statistical measure. Gaged flows in the Flow Boundary Model were therefore used to calculate 7Q2 and 7Q10 values at each of the observed flow input locations, rather than flows from a single calendar day.

To develop the low-flow regression relationships, Curran and Olsen calculated 7Q2 and 7Q10 statistics for three of the gaged sites in the SFNR watershed using various criteria USGS methods, as shown in Table 29. The other two gages were excluded from the analysis, presumably because of insufficient periods of record. For reference, the 2007 calibration flows were 44 cfs for the Skookum Creek gage, 190 cfs for South Fork Nooksack at Wickersham, and 7.9 cfs for the Hutchinson Creek gage.

Table 29. Calculated 7Q2 and 7Q10 flows (Curran and Olsen, 2009).

Location	Gage ID	Flow (cfs)	
		7Q2	7Q10
Skookum Creek	12209490	20.6	15.3
South Fork Nooksack at Wickersham	12209000	102	75.8
Hutchinson Creek	01C070	4.92	4.37

The Flow Boundary Model requires specification of flow at the Ecology 01F070 gage, but the period of record at this gage is not long enough to allow for calculation of 7Q2 and 7Q10 values using statistical methods. The low-flow statistics were therefore estimated using USGS 12209000 (South Fork Nooksack at Wickersham) as a proxy, during overlapping periods of record (WY2004–WY2008). The following steps describe the process.

1. Daily flows at 01F070 and 12209000 were compared to determine whether any impairment in gaging was discernible, noting that 01F070 was likely impaired during 2009–2010 as discussed in the calibration model setup section. No new issues were identified in the review.
2. Flows at 12209000 were ranked from smallest to largest and paired with flows at 01F070 occurring on the same day. The 7Q2 flow at 12209000 is 102 cfs, which occurs on four days during the overlapping periods of record. The flows at 01F070 on the same days were variable, ranging from 118 cfs to 158 cfs with a mean of 132.25 cfs and a median of 126.5 cfs. Larger time periods of flow data around 102 cfs at 12209000 were examined (i.e., 101 through 103 cfs, and 100 through 104 cfs). The corresponding median flows at 01F070 were found to converge to 133 cfs, which was selected as the representative 7Q2 flow for 01F070.
3. A similar process as described in step #2 was used for estimating 7Q10, and 97.9 cfs was selected as the representative 7Q10 flow for 01F070.
4. The observed and estimated 7Q2 and 7Q10 values were entered into separate Flow Boundary Models, each with corresponding low-flow regression coefficients from Curran and Olsen.
5. Headwater, tributary, and groundwater flows were calculated throughout the model domain for 7Q2 and 7Q10 conditions.

Negative groundwater flux was predicted for 7Q2 and 7Q10 for direct drainage to the SFNR downstream of 12209000 to the mouth. Kemblowski et al. (2001) found evidence suggesting that losing reaches were present at low-flow conditions downstream of confluence with Skookum Creek (near 12209000), while Cox et al. (2005) performed groundwater monitoring in the lower Nooksack basin and reported periods where some creeks became losing reaches during low flow conditions. It is therefore not unreasonable for the Flow Boundary Model to predict groundwater loss. The losses were relatively small, about -3 cfs for 7Q2 and -6 cfs for 7Q10. The losses were specified in the QUAL2Kw model as abstractions.

Headwater and tributary temperatures

For several model scenarios (#2, 4 through 6), the input for tributary and headwater temperatures was dictated by the water quality standard. For the time period being modeled, the Core Summer Salmonid Habitat (16 °C) water quality criteria applies in most of the lower half of the watershed, and the Char Spawning and Rearing (12 °C) applies to most of the upper half of the watershed, with some exceptions (note that the criteria changes to 13 °C on September 1). For model scenarios #2, 4, 5, and 6 (see Table 28 for list of model scenarios), if the existing tributary temperature in the 2007 calibration model was cooler than the water quality criteria, the existing temperature was retained in scenarios. If existing tributary temperatures were warmer than water quality criteria, then the water quality criteria was used as the maximum tributary temperature (Table 30).

To adjust temperatures to the applicable water quality criteria, QUAL2Kw inputs of tributary mean temperature and range were altered. If the mean temperature (used in the 2007 calibration run) did not exceed the criteria but the range exceeded the criteria, then the mean temperature was preserved but the range was altered keep temperatures below the criteria over the course of the day (affected 12 tributaries). If the mean temperature exceeded the criteria, as is the case for 5 of the 35 tributaries, the mean was adjusted to the water quality criteria and the range was reduced to zero (a sensitivity analysis revealed that removing the diel temperature range of tributaries had a negligible impact on mainstem temperatures). The breakdown of monitored and unmonitored tributaries which exceeded the temperature criteria with average or maximum water temperatures is in Table 30.

Table 30. Master list of South Fork Nooksack tributaries, water quality criteria, monitoring status, average and maximum water temperatures, and criteria exceedances (2007 data only).

Tributary	WQ Criteria (°C)	Average Water Temperature, 2007 (°C)	Maximum Water Temperature, 2007 (°C)	Status of Data (Source)	Average Exceeds Criteria	Maximum Exceeds Criteria
SFN Headwaters and Wanlick Creek	12	12.65	16.13	Monitored	Yes	Yes
Unnamed Trib 22	12	11.41	12.68	Estimated		Yes
Unnamed Trib 21	12	11.41	12.68	Estimated		Yes
Unnamed Trib 20	12	11.41	12.68	Estimated		Yes
Unnamed Trib 19	12	11.41	12.68	Estimated		Yes
Unnamed Trib 18	12	11.41	12.68	Estimated		Yes
Unnamed Trib 17	12	11.41	12.68	Estimated		Yes
Unnamed Trib 16	12	11.41	12.68	Estimated		Yes
McGinnes	12	11.41	12.68	Estimated		Yes
Howard	12	11.41	12.68	Estimated		Yes
Unnamed Trib 15	12	11.41	12.68	Estimated		Yes
Unnamed Trib 14	12	11.41	12.68	Estimated		Yes
Canyon	12	13.49	14.64	Estimated	Yes	Yes
Unnamed Trib 12	12	11.41	12.68	Estimated		Yes
Unnamed Trib 11	12	13.49	14.64	Estimated	Yes	Yes

Tributary	WQ Criteria (°C)	Average Water Temperature, 2007 (°C)	Maximum Water Temperature, 2007 (°C)	Status of Data (Source)	Average Exceeds Criteria	Maximum Exceeds Criteria
Unnamed Trib 10	12	13.49	14.64	Estimated	Yes	Yes
Deer Creek (trib of Plumbago)	12	13.45	15.09	Monitored	Yes	Yes
Fobes	16	11.41	12.68	Estimated		
Unnamed Trib 8	16	13.49	14.64	Estimated		
Cavanaugh	16	13.26	14.27	Monitored		
Unnamed Trib 7	16	13.49	14.64	Estimated		
Edfro Creek	16	13.85	14.62	Monitored		
Skookum	12	13.45	14.69	Monitored	Yes	Yes
Unnamed Trib 6	16	13.49	14.64	Estimated		
Pond Creek	16	13.49	14.64	Estimated		
Unnamed Trib 5	16	13.49	14.64	Estimated		
Hutchinson	12	10.96	11.11	Monitored		
Unnamed Trib 4	16	13.49	14.64	Estimated		
Jones	16	11.41	12.68	Estimated		
McCarty	16	13.43	14.52	Monitored		
Standard	16	13.49	14.64	Estimated		
Hard Scrabble Falls Creek	16	13.49	14.64	Estimated		
Sygitowicz Creek	16	13.49	14.64	Estimated		
Unnamed Trib 2	16	13.49	14.64	Estimated		
Black Slough	16	13.49	14.64	Estimated		
Unnamed Trib 1	16	13.49	14.64	Estimated		

Air temperatures

The 50th and 90th percentile 7-day annual maximum air temperature conditions (based on rankings of the hottest week for each year of record) were calculated using the historical record from two air temperature stations, representing lower and upper elevations. Initial candidate stations were those used for air temperature in the calibration model. SNOTEL station 910 with available data from August 1995 through 2012 was retained as the upper elevation station; however, Ecology station 01F070 had a much shorter period of record beginning in 2003. Therefore, an alternate station, NCDC Summary of the Day Station WA457507, farther downstream in the town of Sedro-Woolley, WA was selected for the lower elevation station due to its relative proximity to the watershed centroid.

Using the period of record at SNOTEL 910 and data from 1959 to 2009 at WA457507, 50th and 90th percentiles were calculated by ranking the hottest week for each year of record (Table 31). The WA457507 values were then scaled by a factor of 0.47 °C by the relationship to station 01F070 (determined using the average difference between air temperatures from July/August of paired years between the two stations). Next, those percentile values were used to linearly interpolate air temperatures for each reach on the basis of elevation, similar to the approach used for specifying air temperatures in the calibration model. Finally, the hourly data series used for the calibration series were adjusted by difference to arrive at the new air temperature series.

Table 31. Air temperature statistics for South Fork Nooksack region.

Condition	SNOTEL Station 910 (1996-2012)		Adjusted SOD Station WA457507[a] (1959-2009)	
	(°F)	(°C)	(°F)	(°C)
90th percentile of annual maximum 7-DADMax	83.64	28.69	86.13	30.07
50th percentile of annual maximum 7-DADMax	80.19	26.77	82.42	28.01

[a] Station WA457507 was scaled by 0.47 °C to align with available data from Ecology station 01F070.

Microclimate effect

The microclimate effect reflects a cooling of air temperature near the stream channel as a result of the presence of mature riparian vegetation. Brosofske et al. (1997) reported that buffer width of at least 150 ft was required to maintain natural riparian microclimate environments in small forest streams in western Washington in Douglas-fir/western hemlock forests. The average impact of clear cutting on ambient mean daily air temperature was an increase of 2 °C according to a literature review provided in Bartholow (2000). Using the aggregated results of this study, it was concluded that an opposite impact could be expected from reforesting an area, such that the full microclimate impact of a mature riparian forest would decrease ambient air temperature by 2 °C.

As specified by Ecology, this microclimate effect is simulated by a drop in temperature of 2 °C at every hour of the day for several scenarios in which SPV occurs (Scenarios 2, 5, and 6 from Table 28). Note that because much of the SFNR is wider than the streams discussed in Brosofske et al. (1997) (and because the stream is largely forested and not clear cut), the application of this assumption has additional uncertainty. On the basis of the Lower Skagit TMDL, dew point was held at 90th and 50th percentile conditions during microclimate runs (unless it exceeded air temperature) to preserve increased relative humidity expected during the microclimate scenarios (Zalewsky and Bilhimer, 2004).

Dew point temperatures

For the calibration model, the relationship between minimum air temperature and hourly dew point temperatures at AgWeatherNet Station Nooksack was used to estimate hourly dew point temperatures for each reach. To capture changing dew points in the 50th and 90th percentile scenarios, the difference between the calibration model air temperature maximum and the 50th or 90th percentile air temperature maximum at each reach was used to scale the dew point temperatures to preserve relative humidity.

Cloud cover

Cloud cover is set to zero in all scenarios to represent critical summer conditions.

TMDL modeling scenario results

Results for the TMDL scenarios for typical low flow and weather conditions and critical low flow and weather conditions are presented in Table 32, Figure 62 and Figure 63. In the figures, the following temperature benchmarks are shown for comparison:

- The 12 °C water quality criteria which applies to the mainstem headwater down to reach 28 (or 27.5 km from the confluence with Wanlick Creek.
- The 16 °C water quality criteria which applies from reach 28 to the outlet.
- The 1-day maximum temperature of 23 °C which represents the threshold for fish lethality based on WAC 173-201A-200(1)(c)(vii)(A) and an Ecology study (Hicks, 2002) that evaluated lethal temperatures for coldwater fish.
- The 7-day average of daily maximum temperature of 22 °C which represents the threshold of fish lethality.

Table 32. Modeling scenario results for typical low-flow and critical low-flow conditions.

Scenario	Condition	Maximum Stream Temperature (°C) (averaged across select reaches)		
		All Reaches	Headwaters to Reach 28[a]	Reach 28[a] to Outlet
Typical Low Flow Conditions (7Q2 flows; 50th percentile air temperature)				
1	Current Conditions: 7Q2	19.00	18.44	19.66
2	100-year System Potential except where developed: 7Q2	16.99	16.22	17.55
Critical Low Flow Conditions (7Q10 flows; 90th percentile air temperature)				
3	Current Conditions: 7Q10	21.00	20.11	21.88
4	Current Conditions with cooler tributaries: 7Q10	20.77	19.66	21.66
5	100-year System Potential except where developed: 7Q10	18.77	17.88	19.66
6	100-year System Potential everywhere: 7Q10	18.77	17.88	19.66

[a] the water quality criteria is 16 °C during the modeling period.

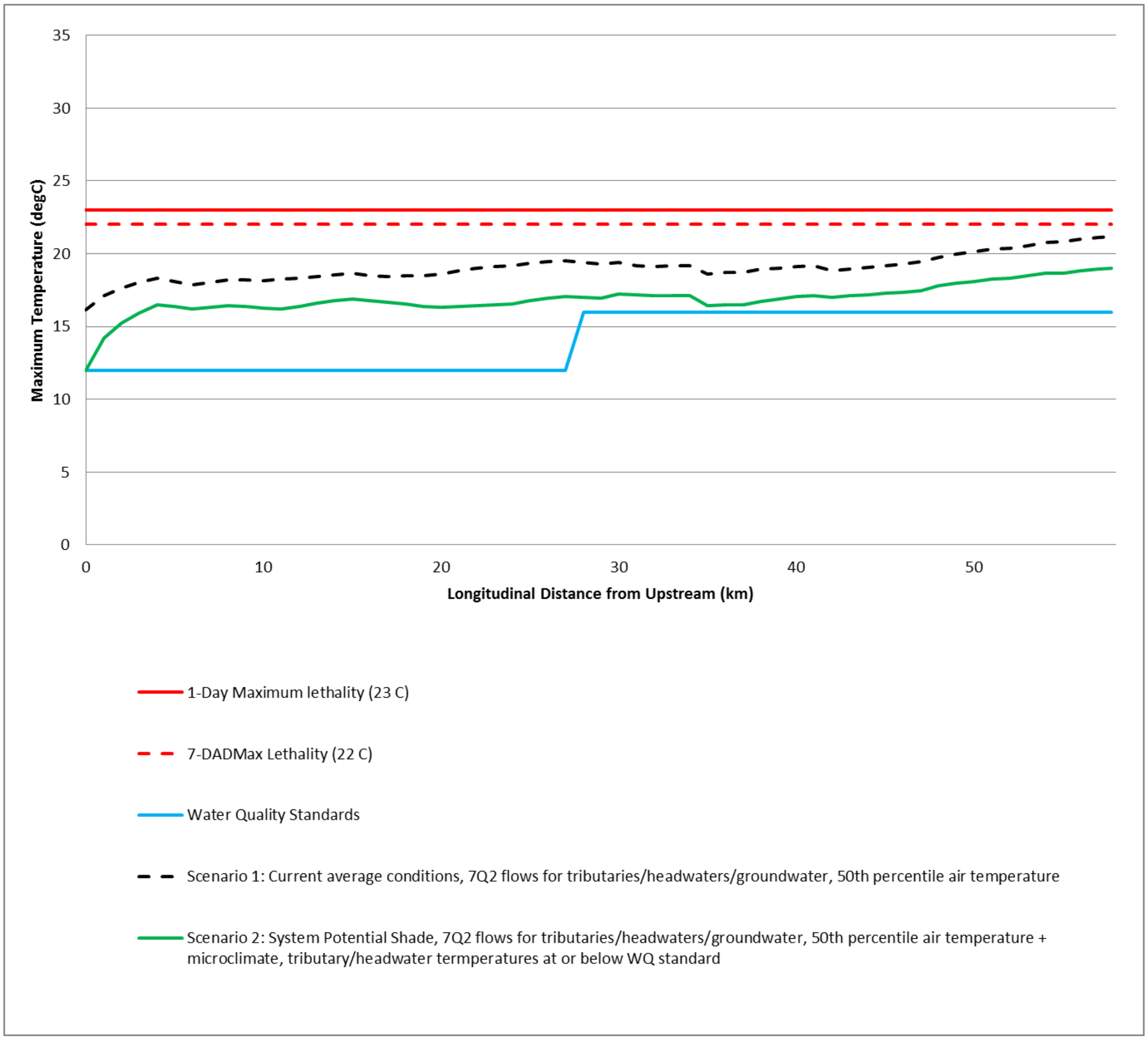

Figure 62. Predicted maximum water temperatures for typical low-flow (7Q2) and meteorological (50 percentile) conditions for current and 100-year system potential scenarios along the mainstem of the South Fork Nooksack River.

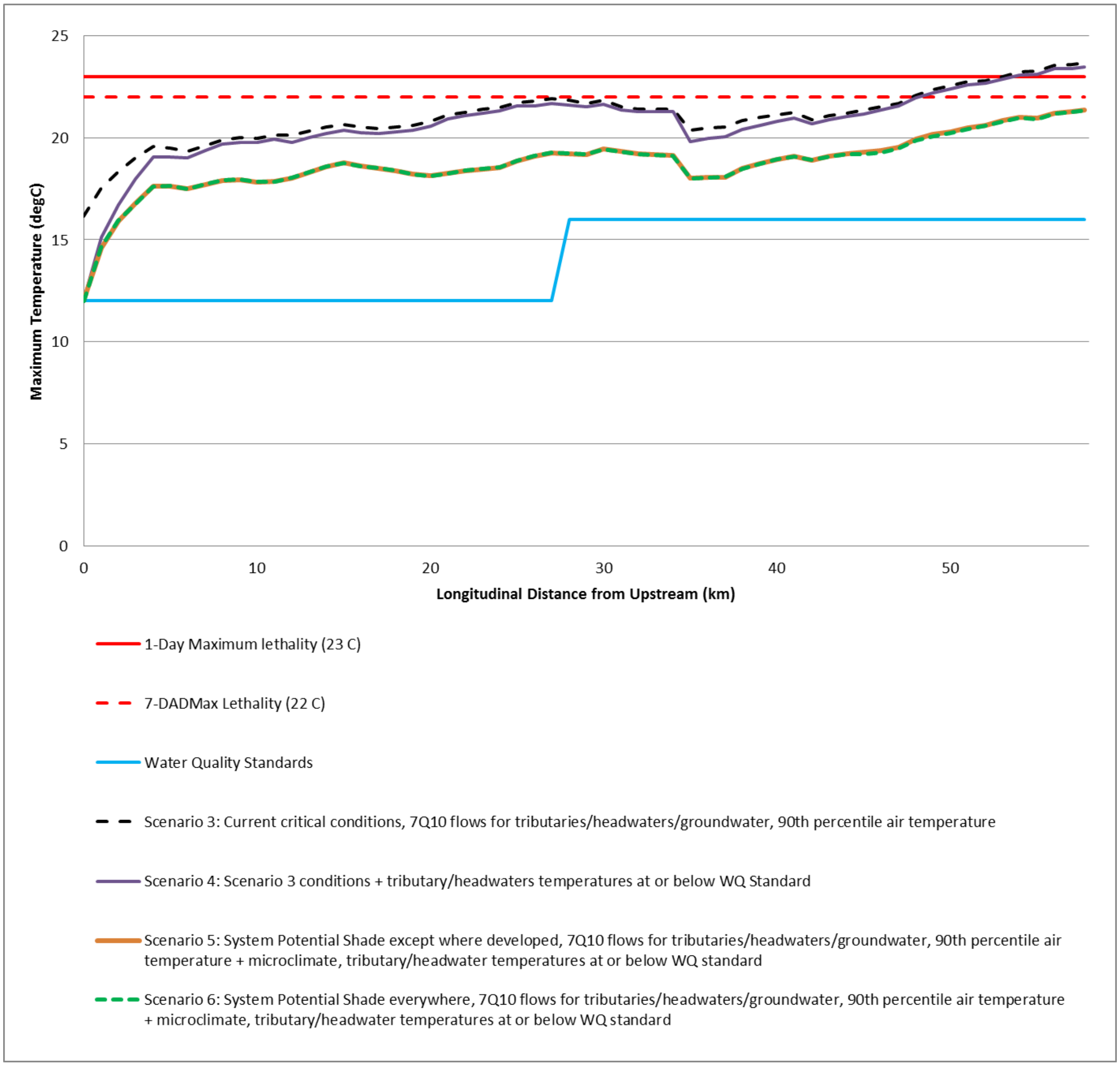

Figure 63. Predicted maximum water temperatures for critical low-flow (7Q10) and meteorological (90 percentile) conditions for current and 100-year system potential scenarios along the mainstem of the South Fork Nooksack River.

Discussion of current conditions (Scenarios 1,3,4)

During both typical low-flow (Figure 62; scenario 1) and critical low-flow conditions (Figure 63; scenario 3), and corresponding meteorological conditions in the summer, the model estimates that the SFNR exceeds the numeric water quality criteria of 12 °C (headwaters to reach 28) and 16 °C (reach 28 to outlet) in all instances. Maximum temperatures estimated for scenario 1 averaged 18.4 and 19.6 °C for the upstream and downstream reaches, respectively (Table 32), which exceeds the numeric criteria by 3.6 to 6.4 °C. Comparison to the lethality benchmarks suggests temperatures for the 7Q2 scenario #1 remain well below these values.

For scenario 3, temperatures in all reaches exceed the numeric criteria by nearly 6 to 8 °C. Stream temperatures are above lethal temperatures at the most downstream end near reach 48 and below. Indeed in the summer of 2009, were close to critical conditions (coincident 7Q10 flow and 90th percentile temperature), and maximum stream temperatures approached or exceeded these benchmarks at several stations. Note that scenario 4 estimated an average decrease in temperature of 0.23 °C when compared to scenario 3 as a result of tributaries and the headwater temperatures being set at (or below, if cooler at current conditions) the water quality criteria (Table 32).

Discussion of system potential (Scenarios 2,5,6)

To estimate what the mainstem of the SFNR might experience under certain "natural conditions", the models were run with 100-year SPV, associated microclimate effects, and tributaries and headwaters at or below the numeric water quality criteria. Under both typical and critical 100-year system potential scenarios (scenarios 2 and 5), the stream continues to exceed the numeric water quality criteria, though it remains below lethal temperature benchmarks. Averaged over reaches upstream of Fobes Creek, the temperatures are 4.2 and 5.8°C above the criteria for the 7Q2 and 7Q10 scenarios. The exeedances below the point where the numeric criteria changes to 16 °C (for the simulation dates) averaged 1.5 to 3.6°C.

Scenario 5 estimates water temperatures under shade levels provided by 100-year SPV. Adding 100-year SPV (with the associated microclimate effect) cools down stream temperatures by an average of 2.11 °C relative to existing vegetation. Further addition of 100-year SPV in the developed areas under critical conditions (scenario 6) did not have a noticeable effect since the change applied to a relatively small area (1.6%) of the riparian buffer area.

The estimate of stream temperatures under 100-year SPV (scenario 5), is used in this analysis to represent an approximation of the stream's natural background temperature and therefore, its loading capacity. In the case of the SFNR, this estimate of natural background temperature from scenario 5 is warmer than the numeric criteria. The natural conditions provision of the water quality standards (WAC 173-201A-260(1)(a)) states "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." Therefore, if a water body does not meet its assigned numeric criteria due to natural climatic or landscape attributes, then the natural conditions constitute the water quality criteria and become the TMDL target. As discussed in the Water Quality Standards section of this TMDL, Ecology may consider a formal rule change to adopt site-specific criteria only after the allocations in this TMDL are significantly implemented and an updated analysis of natural conditions and legacy impacts take place.

Using the results of Scenario 5 as our initial estimate of the stream's natural temperatures and as the TMDL target assumes the following:

- Shade is a significant and manageable mechanism influencing stream temperatures, and the growth of 100-year SPV provides a reasonable approximation of progress toward natural conditions.
- Under Scenario 5 conditions, tributary temperatures were either at the water quality criteria, or at current temperatures (for tributaries that are currently cooler than the criteria).
- The effect of human activities on stream hydrology and channel geomorphology (e.g. geometry, hydraulics, hyporheic exchange, groundwater flow) on stream temperatures are not accounted for. The next section identifies the significance of these additional forcing functions.

In order to assess this sensitivity of our natural condition estimate to the above assumptions/limitations, an additional set of model runs were conducted. These are discussed in the following section.

Sensitivity analysis for natural conditions

For this TMDL, an assessment of the uncertainty of Scenario 5 as an estimate of the natural condition was performed by assessing the temperature model's sensitivity to a number of changes. These scenarios modify some of the parameters of the summer critical condition SPV model run (TMDL Scenario 5). These scenarios assess the effect of the following variations to the estimated natural condition based on the analysis from Nooksack Indian Tribe:

- Cooler headwater and tributary temperatures.
- Decreased channel width.
- Increased effective shade due to increased vegetation height and riparian buffer width.
- Enhanced hyporheic exchange.
- The combined impact of all four alterations.

To the extent that these influences on temperature existed over large or small spatial extents, or can be implemented in the future, these sensitivity analyses provide estimates of variability associated with the natural condition estimates. This variability can be considered when making future impairment, land use, permitting, and restoration decisions.

The results of the sensitivity analysis are shown in Table 32. The largest effect was seen from increased vegetation height and wider buffers. Combining all scenarios results in meeting numeric water quality criteria in portions of the river.

Scenario development

Each scenario has the following parameter inputs: 90th percentile air temperatures and dew point with microclimate effect, 7Q10 flows for headwaters and tributaries with associated decreased channel bottom width, no clouds, shade based on SPV (except where alternative riparian cover is described), and headwater/tributary temperatures set at or below the water quality criteria. The data used to develop these scenarios were based on information provided by Maudlin et al. (2014) and subsequent personal communication and technical analysis provided by scientists from the Nooksack Tribe Natural Resources Department (Treva Coe, 2012, Oliver Grah, 2014, personal communication). These scenarios are valuable in assessing how these factors (e.g. cooler headwater temperatures) influence stream temperatures, and can be used to help prioritize restoration actions (e.g. should we prioritize restoration of the historic channel or shading tributary streams?).

Cooler headwaters and tributaries

All headwater and tributary water temperatures were decreased by 20% of the temperature in degrees C to explore the impact on temperature along the main stem. This scenario is intended to estimate the potential effect of intact riparian vegetation in tributary catchments (e.g. if there were no forestry activities in upland areas of the watershed). An intact riparian corridor in these catchments would potentially cool down tributary and headwater inputs. In the absence of a watershed model we cannot estimate the exact magnitude of stream temperature cooling. The 20% reduction is used to simply assess the effect of cooler temperatures beyond the range used in the original sensitivity analysis.

Decreased channel width

In order to capture potential variations in natural channel geometry, the Shade Model was modified using historical data provided by 1890 Government Land Office (GLO) surveys. Channel wetted width and NSDZ widths were decreased to reflect a reverse of what has been documented as a pattern of historic channel widening in response to land use activities in the watershed (Kirtland 1995, Maudlin et al 2002, Soicher at al 2006, Brown and Maudlin 2007). In general, widening the channel sets back riparian vegetation from the stream bank and reduces the amount of shade received by the stream – therefore, narrowing the channel in places can translate into an increase in effective shade.

The results of the altered channel width on the Shade Model (Figure 64) were input into the QUAL2Kw model. Since simulated flow conditions were at low 7Q10 levels, wetted widths directly within the QUAL2Kw model were unchanged. It was assumed that flow occupies a smaller, pilot channel in both cases and that only the NSDZ areas would vary.

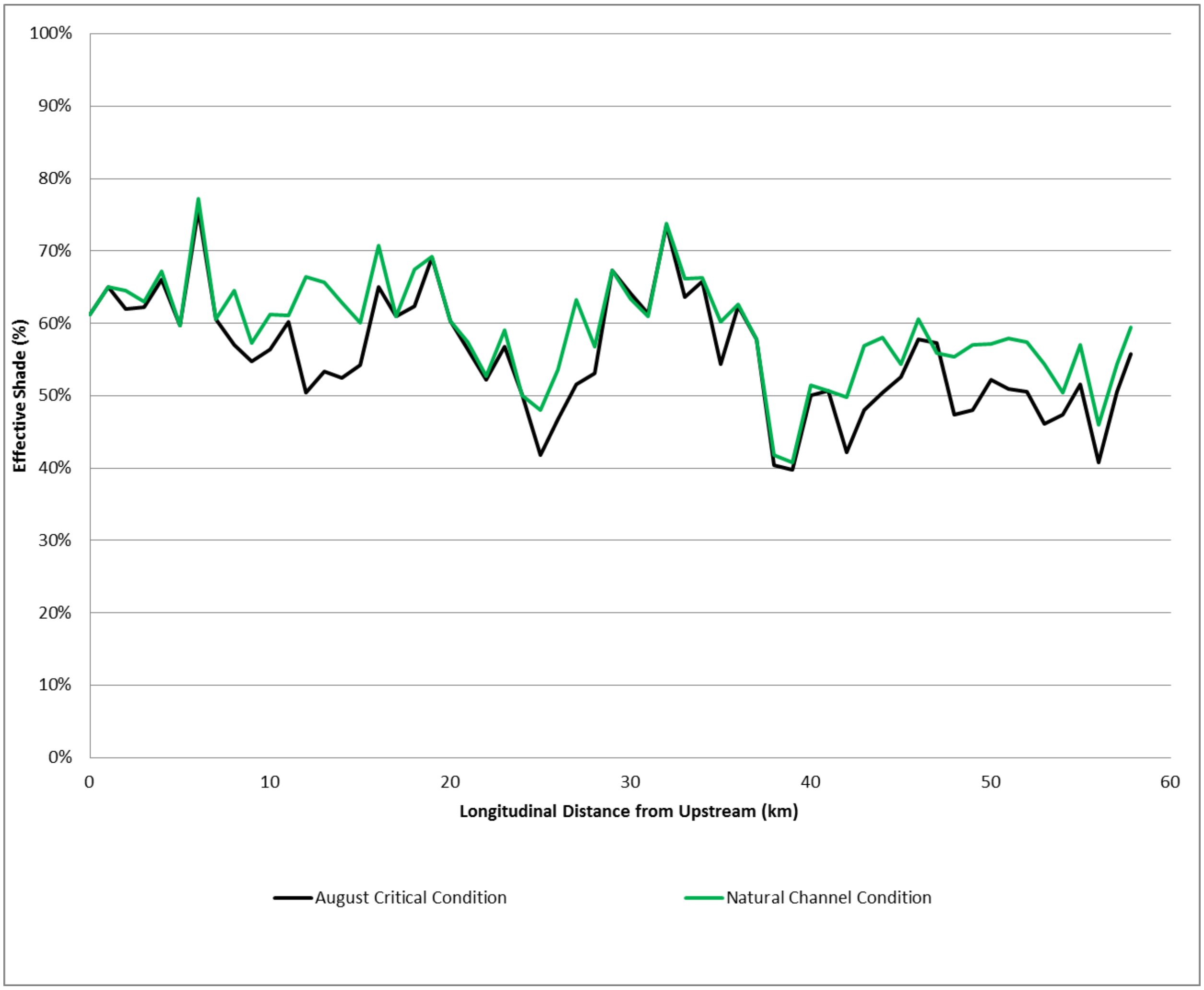

Figure 64. Comparison of Shade Model effective shade results for the August critical condition and narrower near-stream disturbance zone.

Altered riparian buffer and vegetation

Based on recommendations from the Nooksack Tribe, the Shade Model inputs were altered to assume that climax vegetation, with a vegetation height of 290 ft., was achieved everywhere within a 218-foot buffer (TMDL Scenario 5, which is being used to estimate the TMDL allocations, assumes a150-ft buffer and 166-ft SPV tree height). The climax vegetation height of 290 ft (88.4 mm) was chosen to represent not the 100-year site potential value, but rather the estimated natural/old-growth/climax conditions for a fully forested natural riparian buffer of primarily Douglas fir trees. This climax vegetation height is applied to all riparian vegetation and was chosen based on an analysis of Douglas fir heights from field work across the state of Washington (Grah, 2014).

An increase in the buffer width from 150-218 ft. (75% of the new vegetation height) was also included in this scenario based on expert input from the Nooksack Tribe scientists, and based on information derived from FEMAT (1993). Figure 65 shows the comparison of Shade Model effective shade results for the August critical condition and a scenario with increased buffer and vegetation height.

The extent to which the larger tree heights are applicable should be verified as part of implementation, and Load Allocations should be adjusted to include taller trees and wider buffers where applicable as an adjusted estimate of natural conditions.

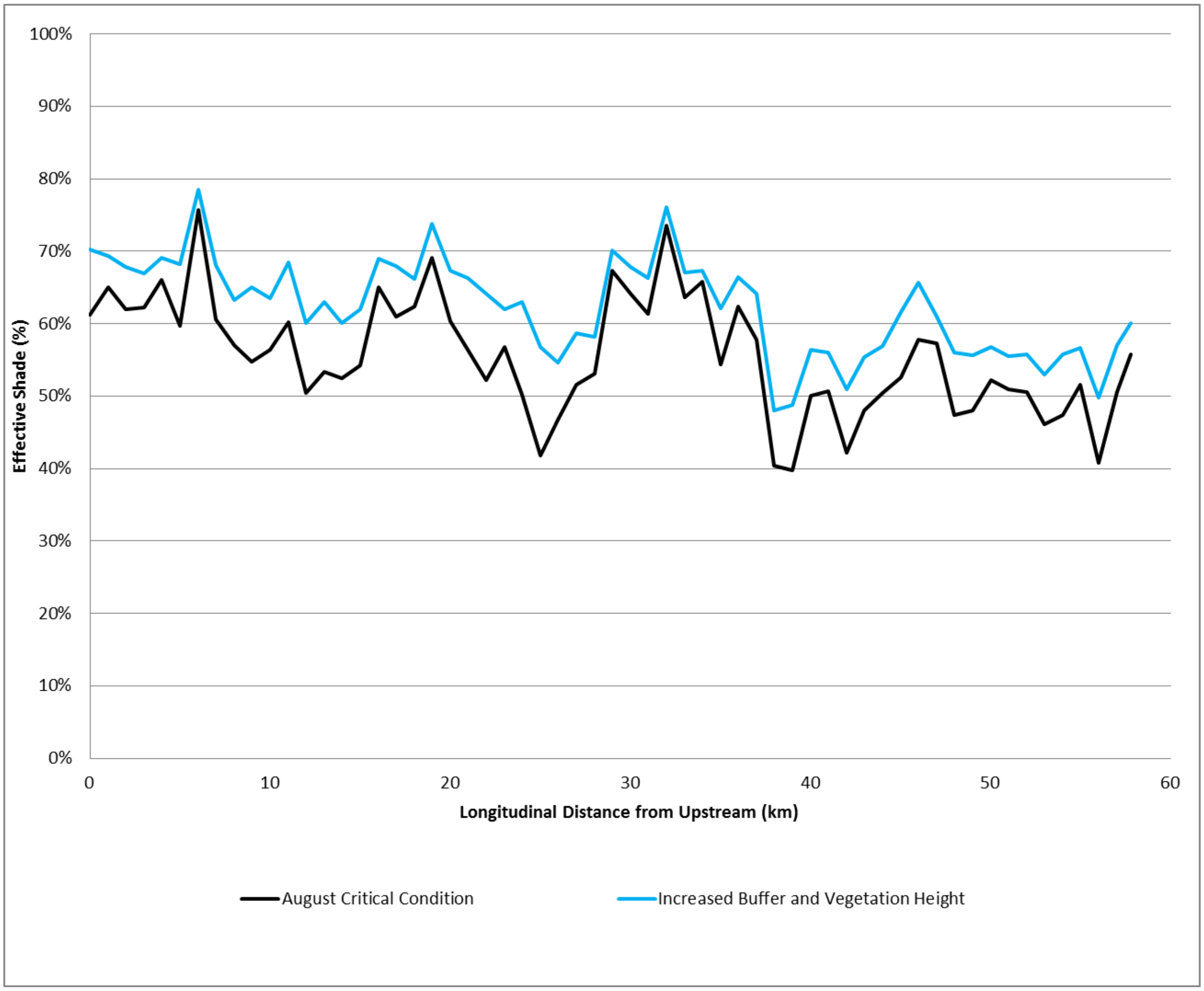

Figure 65. Comparison of Shade Model effective shade results for the August critical condition and a scenario with increased buffer and vegetation height.

Enhanced hyporheic exchange

A modeling scenario incorporating information from Laenen and Bencala (2001) was implemented to understand the potential impact of enhanced hyporheic exchange (Maudlin et al., 2014). Altering the hyporheic exchange parameters in the model included simulating diffusive exchange using the OTIS (One-dimensional Transport with Inflow and Storage) exchange coefficient method, applying OTIS coefficients along the mainstem based on sediment type and location along the mainstem, and also revising the hyporheic zone thickness as a ratio of surface water depth.

The set of hyporheic exchange parameters applied to the most downstream third of the mainstem were: OTIS exchange coefficient of 44 days-1, and hyporheic zone thickness of 41% of water depth (ranging from 14 to 27 cm). The parameters applied to the upstream two thirds of the mainstem were: OTIS exchange coefficient of 12 days-1, and hyporheic zone thickness of 21% of water depth (ranging from 6 to 14 cm). Note that the TMDL scenario 5 modeled hyporheic exchange as a unitless fraction of flow at 0.05 (rather than OTIS) for the entire mainstem. Also in scenario 5, the hyporheic zone thickness were not set as a function of flow as described previously: the upper third of the mainstem was 25 cm and the downstream two thirds of the mainstem was set to 10 cm based on the model calibration.

Scenario results

Results from each model scenario representing variations in natural conditions each result in cooler mainstem temperatures along the mainstem, with an average combined decrease in maximum temperature of about 2.9 °C (Table 33). Even with a potential combined temperature decrease of 2.9 °C, the estimated variation in the natural condition during summer critical conditions is typically warmer than the numeric criteria in many areas and particularly in the upper reaches, as illustrated in Figure 66. However, there are areas of the mainstem (Rkm 35-45) where model results show that the combined variations in the natural condition would result in summer critical condition temperatures which are cooler than or equivalent to the numeric criterion. Individually, increased vegetation height and buffer width had the largest effect while enhanced hyporheic exchange had the smallest effect.

Table 33. Estimated maximum stream temperatures along the mainstem for natural condition variation model runs.

Condition	Average Maximum Stream Temperature (°C)		
	All Reaches	Headwaters to Reach 28 (WQS Change[10])	Reach 28 to Outlet
TMDL Scenario 5 -7Q10 Critical conditions	18.7	17.8	19.6
Cooler headwater and tributaries	18.0 (- 0.7)	16.9 (-0.9)	19.0 (-0.6)
Decreased Channel Width	18.1 (-0.6)	17.2 (-0.6)	18.9 (-0.7)
Increased SPV height and buffer width	17.5 (-1.2)	16.7 (-1.1)	18.2 (-1.4)
Enhanced hyporheic exchange	18.6 (-0.1)	17.8 (-0.0)	19.3 (-0.3)

[10] At reach 28 the water quality standards change. There are different uses and associated criteria to protect the uses.

Condition	Average Maximum Stream Temperature (°C)		
	All Reaches	Headwaters to Reach 28 (WQS Change[10])	Reach 28 to Outlet
Combined natural condition variations	*15.8 (-2.9)*	*15.1 (-2.7)*	*16.4 (-3.2)*

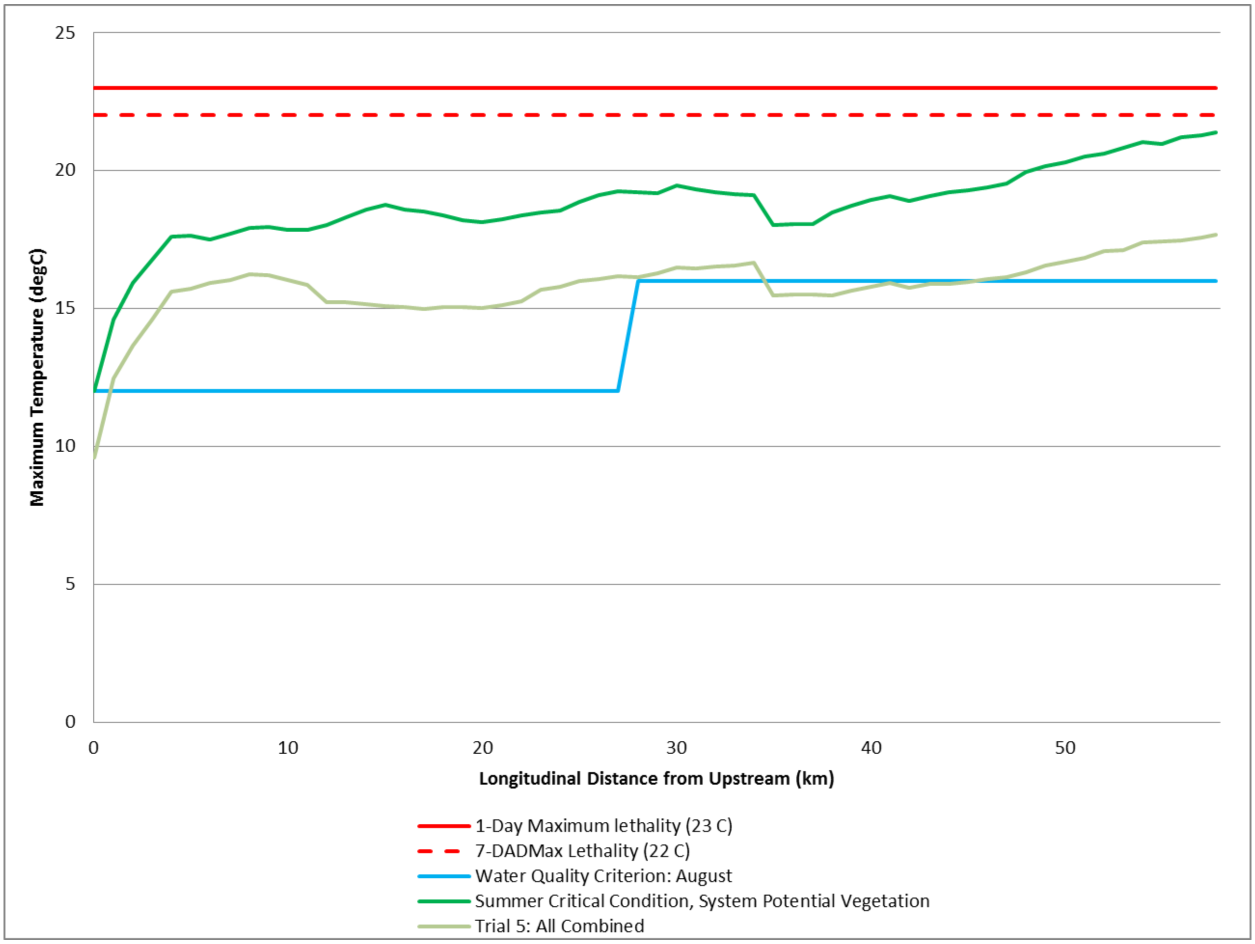

Figure 66. Comparison of temperature model results for TMDL Scenario 5 and a combination of natural condition scenarios.

Evaluation of Scenario 5 during period of supplemental spawning criteria

The model calibration and scenarios discussed so far were focused on the August time period when the Char Spawning and Rearing criterion (12° C) and the Core Summer Salmonid Habitat criterion (16° C) were in effect. The supplemental criterion for the SFNR mainstem for salmonid spawning and incubation protection is 13° C, applicable from September 1 - July 1. An analysis was therefore conducted to evaluate critical conditions when this supplemental criterion applies.

Consistent with methods used to select the model days for the model calibration and validation time periods, a critical day during the September 1 - July 1 timeframe within the calibration year (2007) was selected based on maximum stream temperature. For the mainstem, the 7-day average maximum daily temperatures (7-DADMax) were calculated based on monitored stream temperature (Figure 67). The month of September contained higher 7-DADMax temperatures relative to other months during the September 1 - July 1 timeframe. Of all the stations with data during this time period in 2007, station SF0031 had the highest 7-DADMax (18.73 °C) on both September 9 and 10. The highest instantaneous maximum temperature contributing to these 7-DADMax values was 19.54 °C on September 11. Therefore, September 11, 2007 was chosen to represent the most critical simulation day for modeling the supplemental spawning criterion.

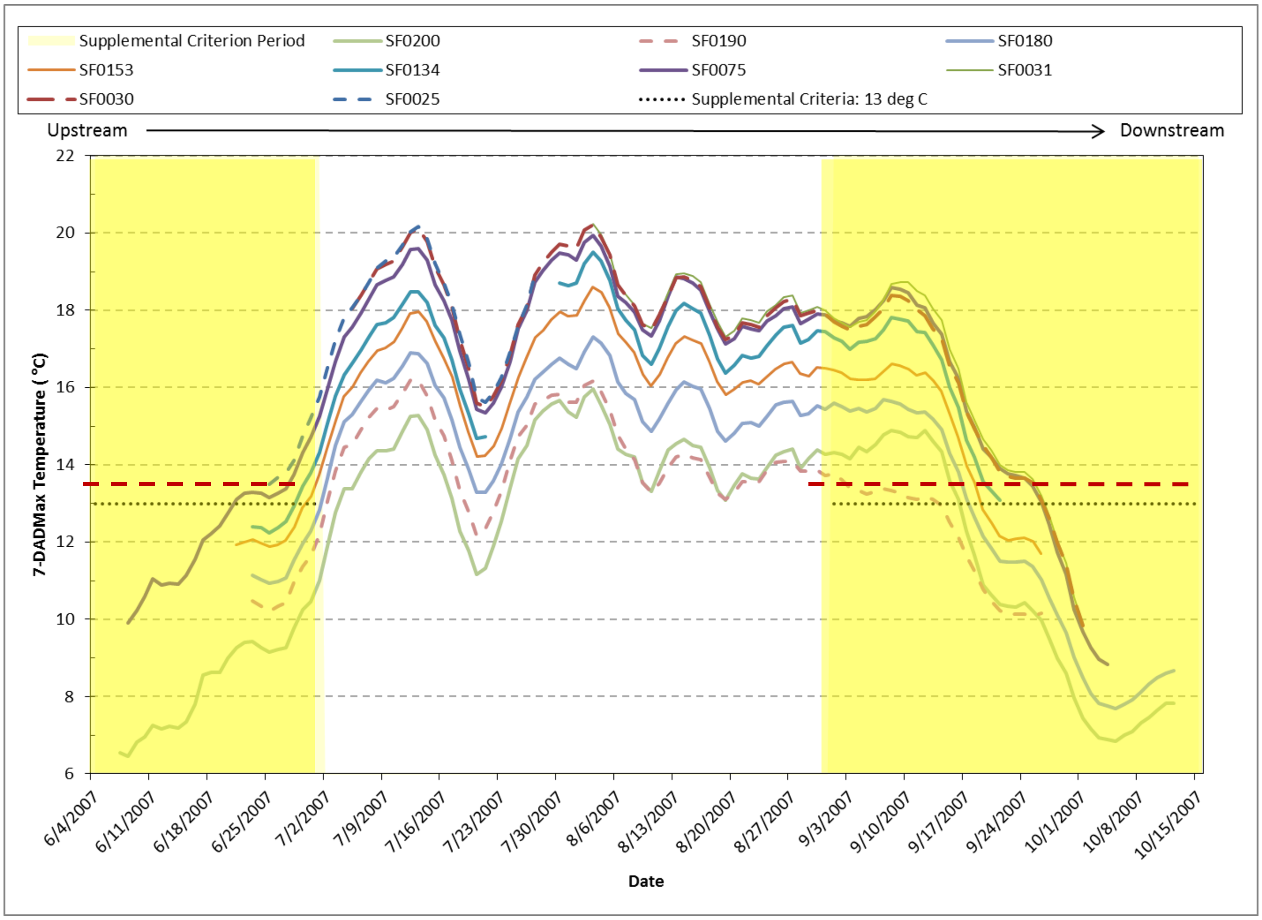

Figure 67. South Fork Nooksack River mainstem 7-DADMax temperature for 2007 summer and early fall period.

For the September model run, many elements and parameters of the model remained from the calibration period, but a number of inputs were changed to reflect September 11 conditions, including flow and temperature boundary conditions, shade, and meteorological data. These are discussed in detail in the following section.

Unaltered inputs and parameters

The following parameters and inputs from the calibration QUAL2Kw model remained unchanged for the September model run:

- The Shade model was run on the new date; however, other features of the analysis, TTools results from digitized landcover, channel incision, vegetation height, density and overhang, remained unchanged.
- Channel geometry (NSDZ width, wetted width, buffer width, stream segmentation, roughness). *Note here that width was modified as a function of flow according to the approach described in the previous phase of the SFNR TMDL project (see draft TMDL documentation).*
- Reach thermal properties (e.g., hyporheic and surface transient storage)
- Groundwater temperature

Meteorological inputs

To represent conditions on September 11, 2007, QUAL2Kw needs meteorological data coincident with this date. Data for this time period were available from the same stations that were used to develop meteorological inputs for the August 2, 2007 calibration (Table 34).

Table 34. Weather stations for each meteorological parameter for September 2007.

Weather Parameter	Agency	Station ID
Wind Speed	AgWeatherNet	Nooksack
Cloud Cover	NCDC	24217
Solar Radiation	AgWeatherNet	WSU Mt. Vernon
Air Temperature	Ecology / SNOTEL / NOAA SOD	01F070 / 910 / WA457507
Dew Point	AgWeatherNet / Ecology / SNOTEL	Nooksack / 01F070 / 910

Wind speed and solar radiation from September 11, 2007 were used directly in the new model, however to reflect critical conditions, cloud cover was set at zero percent.

Similarly to the 7Q10 TMDL scenario, air temperature and dew point temperature were developed to represent a 90th percentile condition with a microclimate effect due to the presence of SPV. First, hourly air temperatures were estimated for each reach based on elevation and the linear interpolation between air temperature stations with available data on the model day. Next, the 90th percentile of the maximum 7-day average maximum air temperatures (Max(7-DADMax)) were developed for the period of record of September data for the SNOTEL 910 station (1996-2012).

Just as in the calibration model, NOAA SOD station WA4574507 was used to calculate the 90th percentile Max(7-DADMax) air temperatures for Septembers of record (1959-2009) which was used to scale the Ecology station 01F070 with a period of record only 2003-2009. Hourly air temperatures were calculated as a function of elevation for each reach based on the linear interpolation of the Max(7-DADMax) station data. Using the estimated daily maximum temperature and the 90th percentile maximum temperature for each reach, the hourly data for September 11, 2007 was converted to a 90th percentile scenario. Lastly, 2 degrees were subtracted from every hourly temperature to reflect the generalized impact of microclimate due to SPV as was applied in the TMDL.

Dew point temperatures across the SFNR watershed were estimated from the AgWeatherNet Nooksack station as a function of the relative difference between minimum air temperature and hourly dew point data at that station. Dew point was estimated as a function of elevation. If calculated dew point for any hour was greater than the 90th percentile air temperature with microclimate, the dew point was decreased to be equal to the air temperature at those hours (morning and evening).

Stream temperature inputs

The temperature monitoring stations used to specify headwater and tributary temperature in the QUAL2Kw model during the calibration period were also used for the new model period (Table 35).

Table 35. Weather stations for each meteorological parameter for September 2007.

Station Location Type	Agency	Observed Stream Temperature Station	Distance from Downstream (km)
Mainstem/Headwater	Nooksack Tribe	SF0200	57.75
Tributary (Wanlick Creek)	Nooksack Tribe	SF0210	Headwater trib
Tributary (Deer Creek)	Nooksack Tribe	SF0135	Plumbago trib
Tributary (Cavanaugh Creek)	Nooksack Tribe	SFT016	30.65
Tributary (Edfro Creek)	Nooksack Tribe	SFT015	26.95
Tributary (Skookum Creek)	Nooksack Tribe	SF0130	26.55
Tributary (Hutchinson Creek)	Ecology	01C070	18.15
Tributary (McCarty Creek)	Nooksack Tribe	SF0033	14.25

Tributary and headwater temperatures were developed for this model run using each of the listed stations as was done in the calibration model. For the purposes of this critical condition run with SPV, headwater and tributary temperatures were set at the supplemental spawning criterion of 13 °C unless measured data was lower (this was the case for about half of the tributaries).

Flow boundary conditions

The September run requires modified flow boundary conditions for headwater, tributary, and groundwater inputs. Boundary conditions were developed to be representative of historic critical low flow conditions occurring in the watershed during September. The Flow Boundary Model approach earlier was used to estimate tributary flows and groundwater exchange with the river mainstem. The first input to the Flow Boundary Model is flow at gaged locations in the watershed. To estimate historic September critical low flows, 7Q10 values were calculated from gaged flow records using September flow data only. The lowest 7-day average flow during the month of September was calculated for each year available in a flow record. September 7Q10 values were then calculated from the series of annual minima using the method of Arnes (2006).

There were sufficient periods of record at three locations – SFNR at Wickersham (12209000), Skookum Creek (12209490), and Hutchinson Creek (01C070). The resulting September critical values were calculated as 76.7, 16.8, and 4.49 respectively for Wickersham, Skookum, and Hutchinson. The values are slightly higher than full-year 7Q10 values reported by USGS (Curran and Olsen, 2009) of 75.8, 15.3, and 4.92 respectively, which would be expected since full-year values include low-flow periods outside of September.

As described earlier, station 01F070 has impaired records during periods of low flow in the late 2000s calling into question the use of Arnes' method. Instead, overlapping periods-of-record were identified between 01F070 and USGS Wickersham (years 2003-2008) for September dates only. The lowest flows at Wickersham were isolated (about 76 – 100 cfs) and a power regression was performed for flows occurring on the same date at 01F070 versus the lowest flows at USGS Wickersham. The Wickersham September 7Q10 value of 76.7 was entered into the regression equation, yielding a predicted value of 94.8 at 01F070.

Flow estimates from the analyses are shown in Table 36. Flow was not needed at SFNR at Saxon Bridge (12210000) in the Flow Boundary Model, since flow was available at the Wickersham gage located a few miles upstream.

Table 36. September low flow critical values used in Flow Boundary Model.

Location	Gage ID	Flow (cfs)	Method for Estimation
Skookum Creek	12209490	16.8	Arnes (2006)
South Fork Nooksack at Wickersham	12209000	76.7	Arnes (2006)
South Fork Nooksack at Saxon Bridge	12210000	n/a [a]	n/a
SFNR at Potter Road	01F070	94.8	Regression
Hutchinson Creek	01C070	4.49	Arnes (2006)

a. Flow not needed at this location since flow is available at the Wickersham gage a few miles upstream

The second input into the Flow Boundary Model was the set of regression coefficients corresponding to the assumed low-flow frequency statistic (e.g., 1Q10, 3Q2). Reported flow statistics for 7Q10 from Curran and Olsen (2009) were the closest to the September critical values in Table 36, so the regression coefficients corresponding to 7Q10 were used in the Flow Boundary Model. The updated model provided predictions of headwater, tributary, and diffuse groundwater flows for the entire South Fork Nooksack mainstem. Estimated flow along the mainstem is shown in Figure 68.

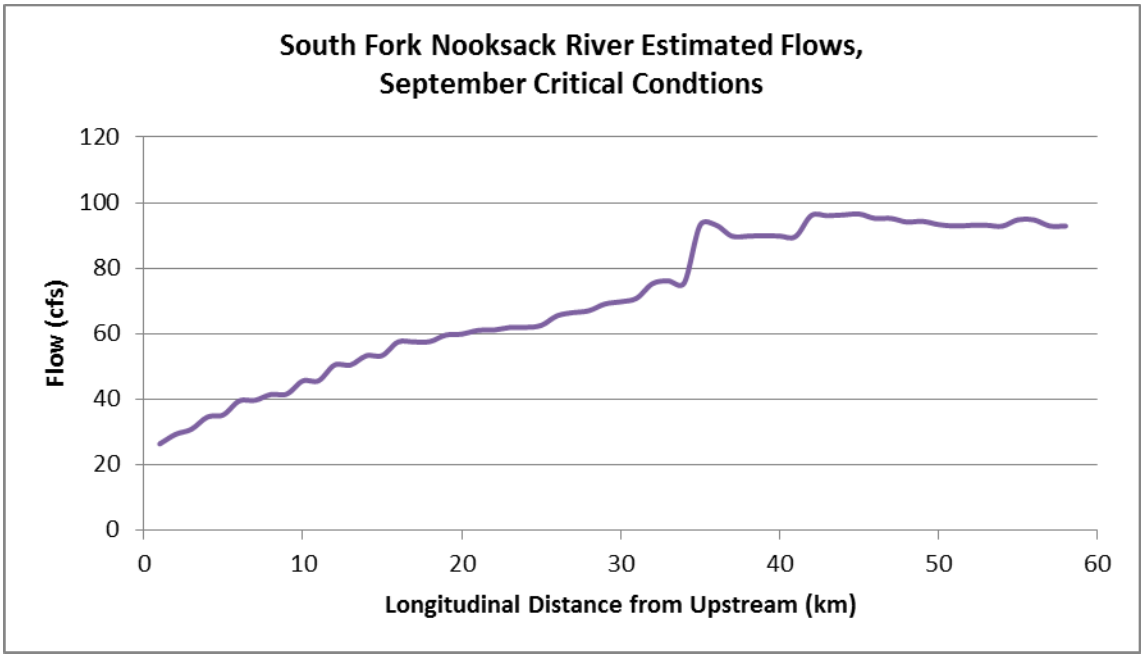

Figure 68. Estimated flow in South Fork Nooksack River, September 11, 2007.

As was the case for the TMDL modeling scenarios, the Flow Boundary Model predicts groundwater loss along the lower portion of the SFNR mainstem downstream of the Wickersham gage to the South Fork Nooksack mouth. The loss was relatively large at about 13 cfs. A comparison of the September low flow critical values used as inputs to Flow Boundary Model shows that the combined estimated flows from Wickersham, Skookum, and Hutchinson are 98 cfs, which is higher than the estimated flow of 94.8 cfs at 01F070 located downstream near the mouth. Losses are modeled in QUAL2Kw as groundwater abstractions.

Shade inputs

Input and settings for the Shade model, which is run independently to generate input for the QUAL2Kw model, were kept identical to the calibration run except for the day-of-year, which was changed to September 11. The change of date for the Shade model impacted the solar aspect which is calculated using the Julian day. Depending on latitude and Julian day, changes in the angle of sun can greatly impact direct solar radiation, as well as shade from topography and vegetation. Results of the run are provided below, and compared to the August calibration date values (Figure 69).

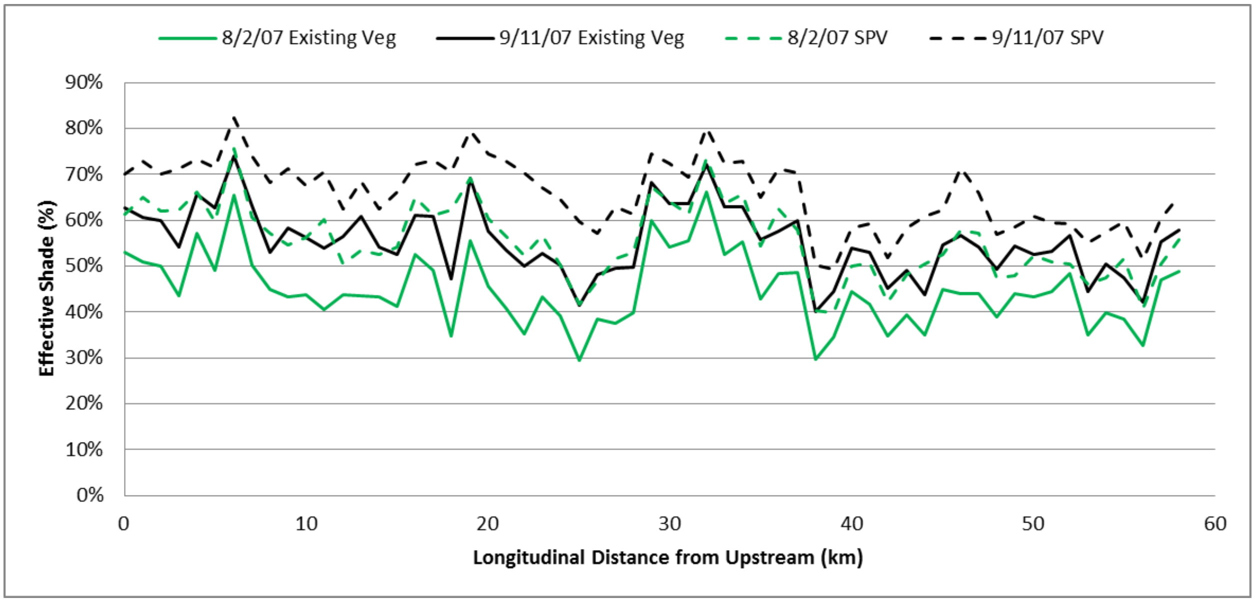

Figure 69. Effective Shade model results for current and SPV on August 2, 2007 (calibration period) and September 11, 2007.

Model results

The model results for the system potential, critical condition run for September 11, 2007 are shown in Figure 70 and Table 37. The model shows that the SFNR mainstem exceeds the supplemental spawning criterion of 13 °C in some locations. The average exceedance is less than one degree. Predicted stream temperatures for September are cooler than those predicted for August due to increased effective shade as a result of reduced solar radiation as well as cooler air temperatures. Based on this analysis, load allocations based on full SPV will also be needed to be protective of the stream during the supplemental spawning criteria.

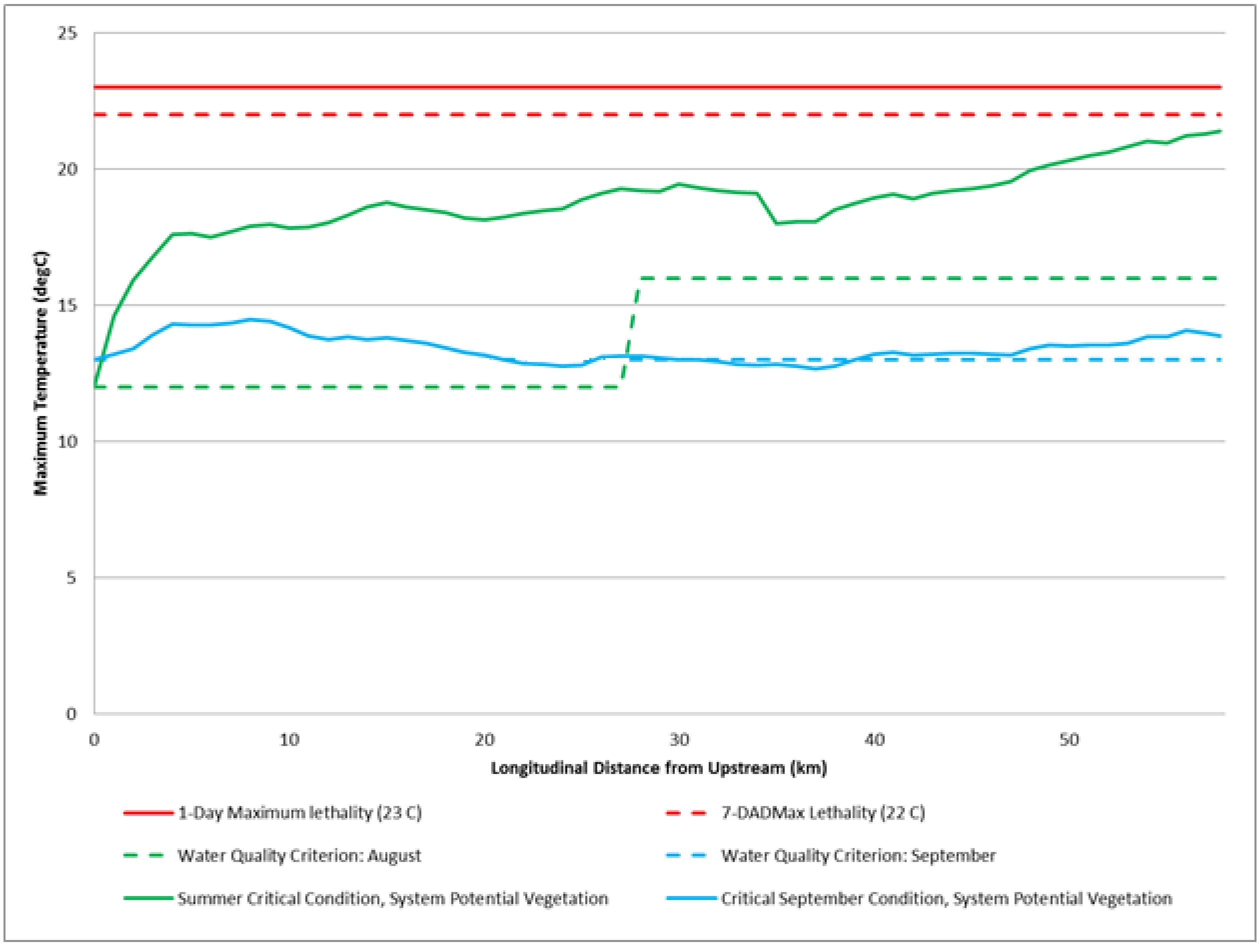

Figure 70. Model results for the critical September run and August TMDL scenario paired with their respective water temperature criteria.

Table 37. Stream temperature model results for critical condition run for September.

Condition	Average Maximum Stream Temperature (°C)		
	All Reaches	Headwaters to Reach 28	Reach 28 to Outlet
Critical conditions: September	13.4	13.6	13.3

Loading capacity

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

Loading capacity for the mainstem of the SFNR can be approximated using the 100-year system potential scenario (scenario 5) under critical low-flow (7Q10) and air temperature conditions (90th percentile of the hottest week for each year of record). This scenario assumes 100-year SPV within the 150-ft buffer, tributaries and headwaters at or below the numeric water quality criteria, and microclimate effects of reduced air temperature.

Using the 100-year system potential scenario, load allocations were developed for both shade and heat load. These are provided in the allocations section of the report.

The loading capacity also includes a 0.3 °C increase above natural temperature conditions as described in the Water Quality Standards section.

Load and Wasteload Allocations

The temperature TMDL for the SFNR represents the maximum amount of a heat that a water body can receive and still meet the temperature standards, and an allocation of that amount to the contributing sources. The allocations take the form of a load allocation for nonpoint sources and a wasteload allocation for point sources.

Load allocations

Shade load allocations

Load allocations for the South Fork Nooksack temperature TMDL establish limits on the allowable heat load from nonpoint sources. The TMDL quantifies head loads in terms of Watts/m^2 and as effective shade. Effective shade allocations control delivery of direct solar radiation to the stream, both to the mainstem and its tributaries. This is considered the largest source of heat. Load allocations (both effective shade and heat load) for the mainstem are provided in Appendix C in 1,000-m increments. The effective shade deficit along the mainstem beginning at the confluence with Wanlick Creek by 1,000-m increments is shown graphically in Figure 71. Shade deficits range from 4.0 to 32.0%, with an average of 13.4%.

For the tributaries to the SFNR, which are not modeled individually, the load allocations for effective shade are represented as shade curves in Figure 72 and Appendix D. These allocations are based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum 100-year SPV conditions. The shade curves were developed by running the Shade model with prescribed combinations of channel widths and aspects with buffer zones at full 100-year SPV conditions. This analysis used the same criteria for SPV as previously in the model, i.e. allowing a 150-ft riparian buffer to become vegetated with trees that are 50.66 m tall, with a 3-m overhang, and 85% density. The goal was to capture the characteristics of any tributary over a range of channel widths and aspects that occur in the SFNR watershed.

Figure 72 shows the amount of effective shade under 100-year system potential conditions, decreasing as the width of the channel increases. For tributaries with a bankfull channel width less than 6 m, the shade begins to level off because the SPV overhang of 3 m is assumed to meet and cover the entire stream width with shade. Note that the creation of the shade curves assumes that topographic shade is equal to zero – this is a conservative assumption since topographical features would provide additional effective shade beyond that provided by the growth of SPV.

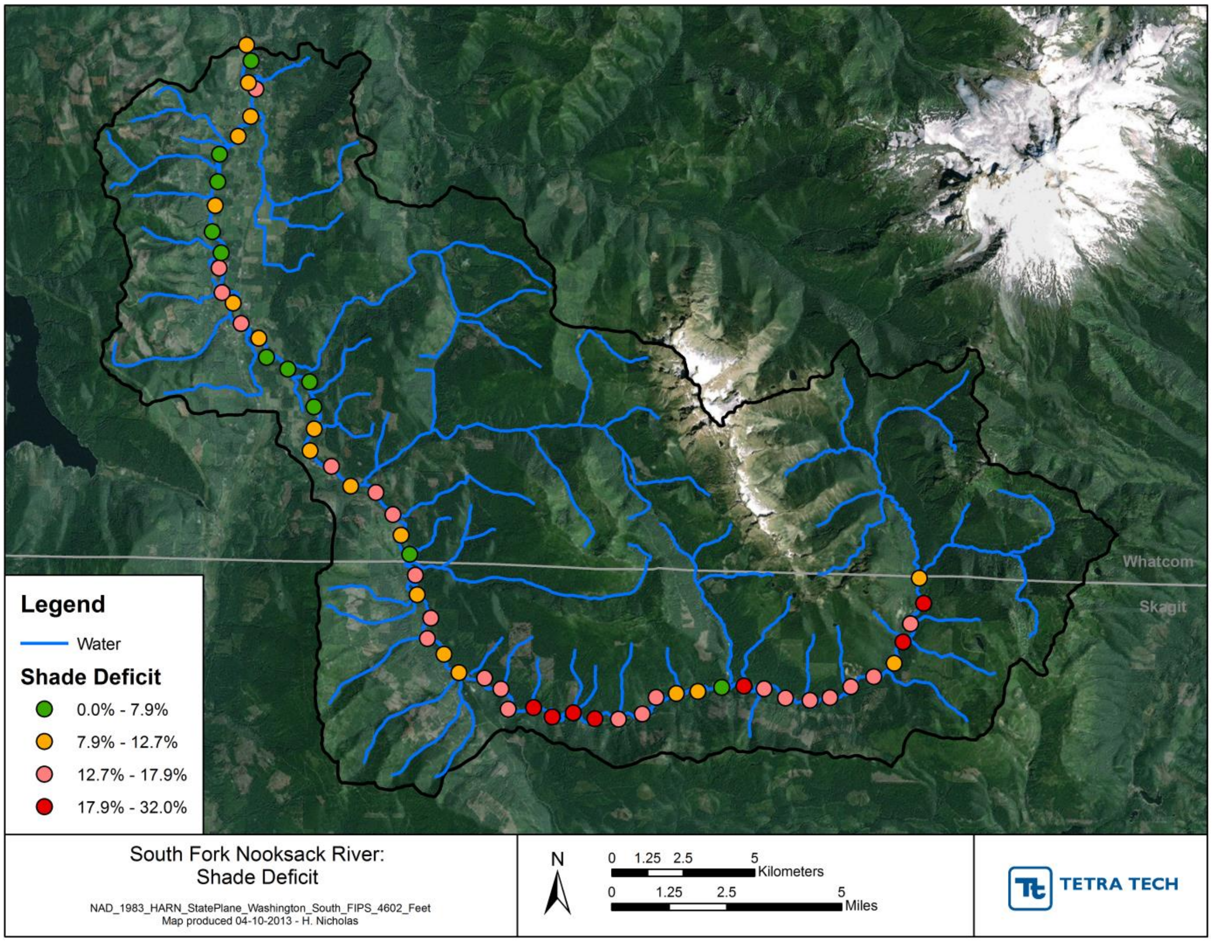

Figure 71. Effective shade deficit by 1,000-m increments.

The deficit represents the difference in effective shade between system potential and current vegetation conditions, as estimated by the Shade model.

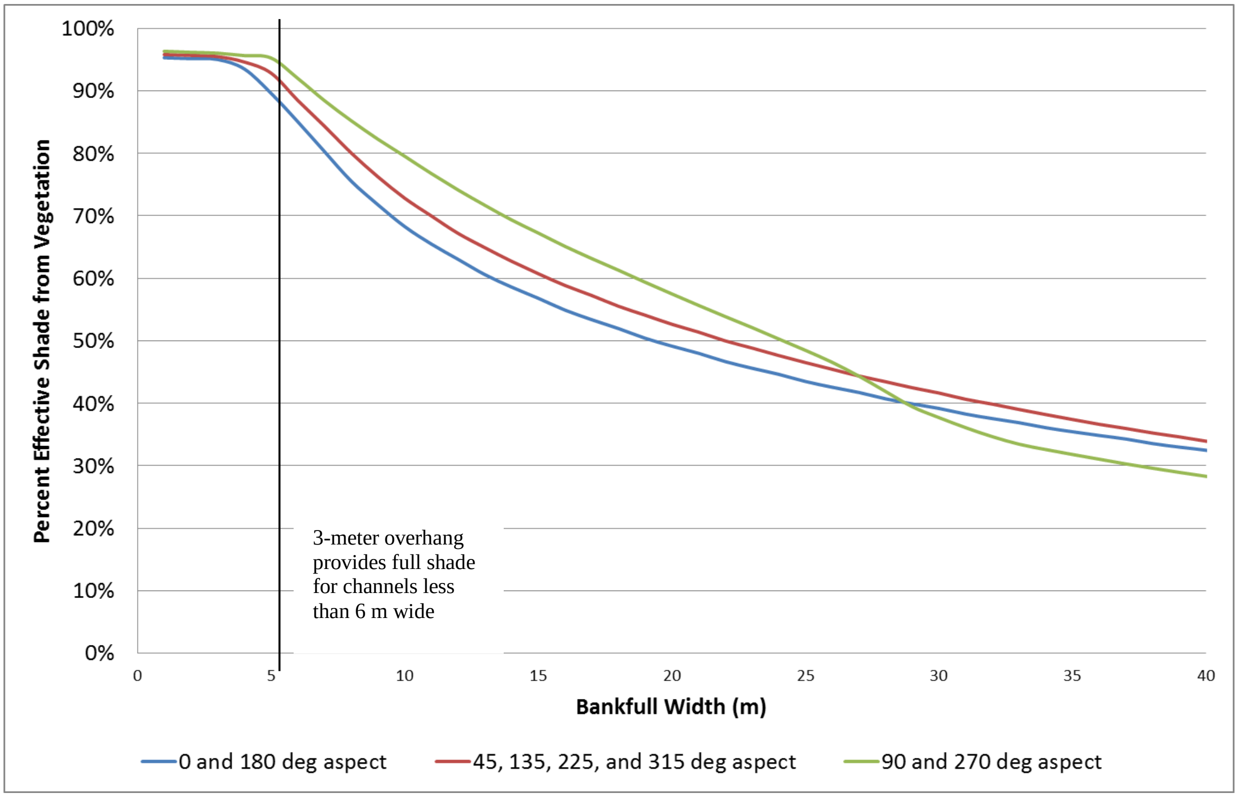

Figure 72. Shade Curve for determining load allocations of effective shade for tributaries.

Curves are based on generalized output of the Shade model in the 100-year SPV scenario (all riparian area reaches 50.66m tall, 85% density, 3-m overhang).

The shade allocations for the SFNR watershed represent shade levels produced by 100-year riparian vegetation. The riparian vegetation will reduce direct solar radiation to the mainstem and tributaries resulting in lower stream temperatures. An additional benefit of an improved microclimate is also expected. There might also be indirect benefits of a more stable channel because of the protection that a mature buffer would provide.

Load allocations are calculated assuming shade levels provided by 100-year SPV, which should result in water temperatures that approximate temperatures that would occur under natural conditions, acknowledging the limitations in modeling natural conditions for this TMDL (listed in the subsections on *Discussion of system potential scenarios* and *Sensitivity analysis for natural conditions*). When streams have attained their natural background temperatures, they will have cooled to meet or be cooler than the numeric criterion, or the stream will have cooled to its natural temperature, which may or may not be warmer than the numeric criterion.

When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the standards state that the natural conditions constitute the water quality criteria (WAC 173-201A-260 (1)(a)). Under this circumstance, the ability of the assumed system potential scenario to realistically represent natural conditions must be fully evaluated before this standard is applied. This provision of the water quality standards is implemented by using the modeled natural condition as the TMDL target. Ecology will consider a formal rule change to adopt site-specific criteria in the future only after significant implementation has occurred, as provided by WAC 173-201A-430, at which point the natural condition, determined by empirical and modeled data, will be used to set new water quality criteria through a public rule-making process.

Although this temperature TMDL is heavily focused on the impact of stream shading, other management actions such as geomorphology changes, sensitive land cover, reducing sediment loading, increasing groundwater inflows, and hyporheic exchange are also recommended to reduce stream temperatures.

Stormwater load allocations

Stormwater that is not covered by an NPDES permit is a non-point source of heat loading. There are two municipally owned stormwater collection systems in the drainage. Neither one is covered by an NPDES permit. Whatcom County has a Phase II permit that covers urbanized areas, and urban growth areas. None of Whatcom County's stormwater system in the South Fork of the Nooksack is in the area covered by the Phase II permit. 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 discharges to any water body in the state for which there is an EPA-approved TMDL with load allocations and associated implementation documents specifying actions for WSDOT stormwater discharges. Stormwater discharges in this watershed, from municipally owned stormwater collection systems, do not occur in the critical season, so neither system is considered a significant contributor to the impairment.

Because stormwater is not discharged during critical conditions, no additional BMPs are needed to meet a load allocation of zero. If a stormwater source is identified as a significant discharger in the future, it will receive a wasteload allocation using the "Reserve for future permits" section under Wasteload Allocation.

Wasteload allocations

Discharges to state waters are regulated through the NPDES permit system. Facilities with an NPDES permit are considered point sources. 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 anthropogenic 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 33 °C to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life. The load allocations for 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.

Two potential active point sources were identified in the SFNR watershed (Table 38). Concrete Norwest Saxon Pit has a sand and gravel general permit; stormwater generated by the facility discharges to groundwater so no waste load allocation is necessary. The Lummi Nation operates the Skookum Creek Fish Hatchery, on Saxon Road, at the mouth of Skookum Creek. The hatchery operates under a General Hatchery Permit issued by EPA and diverts water from Skookum Creek downstream from the gaging station location. This water is discharged (along with groundwater pumped from six wells) to the SFNR upstream from the Saxon Road gaging station. Temperature measurements are not a requirement of the permit. The average reported discharge for the hatchery in 2007 was 7.7 mgd.

Table 38. Active point sources in the South Fork Nooksack watershed.

Permit number	Facility name	Type	Parameters monitored
WAG503013	Concrete Norwest Saxon Pit	Sand and Gravel General Permit	Oil and Grease
WAG130017	Skookum Creek Fish Hatchery	EPA Fish Hatchery General Permit	Flow, TSS, Settleable Solids, and Chlorine

Saxon Pit is not considered a concern for water temperature because they do not discharge to surface water.

Skookum Creek Fish Hatchery has the potential to affect water temperature in the SFNR. The hatchery diverts water from Skookum Creek and discharges the water into the Nooksack River a few hundred feet downstream from the Skookum Creek Confluence. Wasteloads for point sources are typically set by limiting the temperature to that which would cause the temperature at the edge of the mixing zone to increase by no more than 0.3 °C when the receiving water is at the criteria, using the following equation:

$$T_{NPDES} = [16^o C (or 13^o C) - 0.3] + [chronic\_dilution\_factor] \times 0.3 \quad \text{(Equation 7)}$$

Where:

T_{NPDES} is effluent temperature,

$$\text{Chronic\_dilution\_factor} = (Q_{eff} + 0.25 \times Q_{7Q10})/Q_{eff},$$

Q_{eff} is effluent flow,

Q_{7Q10} is 7Q10 river flow (cfs), and assumes 25% by volume mixing allowance.

However in this case the Hatchery intake water is often well above the numeric water quality criteria. The hatchery has not been able to cool the water before it enters the hatchery and likewise at this time could not cool the water after it leaves the hatchery. Even if the hatchery did not divert the warm water, that warm water would still be flowing into the South Fork. In this TMDL we are setting a wasteload allocation that limits the heat added to the water during hatchery operations. The hatchery is limited to discharging water no warmer than the criteria when the influent water is 0.3 °C cooler than the numeric criteria. When the influent temperature is warmer than the numeric criteria, the wasteload allocation is influent temperature plus 0.3 °C. With a mixing zone which has a dilution factor greater than 3 this allows a temperature increase of less than 0.1 °C at the edge of the mixing zone. The increase will be less than 0.1 °C on the overall river. This wasteload allocation is to be applied as a 7-day average of the daily maximum temperatures (7-DADMAX). These limits are summarized in Table 39.

Table 39. Wasteload allocations for dischargers in the watershed covered by NPDES permits.

NPDES facility; permit #	7Q10[a] (cfs)	Effluent Flow - Current[b] (cfs)	Effluent Flow - Design (cfs)	Water Quality Criteria (°C)	Chronic Dilution Factor	T_{NPDES} (°C)
Skookum Creek Fish Hatchery; WAG130017	91.1	10.2 (6.6 mgd)	Not Available (assume equals current)	16 (Jul 1 to Sept 1) 13 (Sept 1 to Jul 1)	3.2	16.0 or influent temperature + 0.3 (Jul 1 to Sept 1) 13.0 or influent temperature + 0.3 (Sept 1 to Jul 1)

[10a] Hatchery discharges upstream from USGS station at Saxon Road. Value used for wasteload allocation is assumed to be the 7Q10 flow from USGS 12209000 at Wickersham plus from USGS 12209490 at Skookum.
[b] Based on the highest average monthly summer flow for 2010 and 2011, which occurred in September.

Reserve for future permits

Ecology's 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 7-DADMax values. To be both consistent with these temperature criteria and practical (a receiving water could be affected by multiple stormwater outfalls with wide spatial distribution and controlled discharge rates), this TMDL expresses cumulative stormwater wasteload allocations as a 7-day average daily (7-DAD) loading value as measured at the TMDL monitoring points established in the TMDL study. Although the wasteload allocations incorporate seven daily values, they are expressed as a daily value and are consistent with the state's 7-DADMax criteria.

The following criteria express the cumulative temperature wasteload allocation for any future permittees:

- When a water body's temperature is warmer than state criteria due to natural conditions (or within 0.3 °C), the cumulative discharge from all permitted sources may not cause the 7-DADMax receiving water temperature under those conditions to increase more than 0.1 °C. That allowable 0.1 °C increase is quantified using the following equation, which provides a numeric daily loading value to assess compliance with the aggregate wasteload allocation. The remaining incremental warming allowance is reserved for unpermitted stormwater, 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.

$$Teff = T + 0.1 * \frac{Q+Qeff}{Qeff} \quad \text{(Equation 8)}$$

Where

T = Background Temperatures
Q = Stream Flow before discharge
Qeff = Stormwater discharge
Teff = Temperature of allowable stormwater discharge

Seasonal variation

CWA 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 SFNR 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 late-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 model was calibrated to a date (August 2) in 2007 where stream temperature data showed that the SFNR was warmest around this day. Next, the calibrated model was modified to represent 90th percentile air temperatures (based on a ranking of the hottest week for each year of record) and critical stream flows (i.e., lowest 7-day average flows with 10-year recurrence interval or 7Q10).

Load allocations from the summer model runs resulted in requiring the maximum riparian protection to the stream. A fall scenario was conducted and confirmed that allocations will be protective both during August critical conditions and during the fall when supplemental criteria apply. For point sources, seasonal variation is taken into account, as described in the Wasteload Allocation section.

Margin of Safety

The margin of safety accounts for uncertainty about pollutant loading and water body response.

Some of the sources of uncertainty have to do with limitations of the model and the assumptions it is based on such as:

- A number of modeling assumptions were necessary, such as those regarding forested islands, Manning's n and other hydraulic parameters, hyporheic exchange, inflow estimates, and temperature for unmonitored tributaries and groundwater, among others. These assumptions contribute to uncertainty in the modeling results.
- Upland watershed processes have not been directly modeled within the TMDL. Their effect is captured implicitly within the model calibration and validation. Management of upland processes to restore stream temperature may not be fully captured in the system potential scenarios.
- Tributaries are not modeled directly within the Shade and QUAL2Kw models. A number of tributaries did not have monitoring data during the calibration and validation periods and therefore temperatures had to be estimated. This treatment and these assumptions add uncertainty to the attribution of sources of heat load.
- The "system potential" modeling assumes that readily available information can be used to represent "natural conditions."
- Load allocations are based on 100-year SPV and may differ from historical riparian and are not equivalent to climax vegetation communities, which were taller.
- The 100-year system potential described in this TMDL report does not capture potential changes to the stream channel, both from indirect benefits of a mature riparian buffer or other watershed management practices such as constructed log jams, which could result in a more natural geomorphology under undisturbed conditions (e.g., geometry, sediment dynamics, woody debris) and greater hyporheic exchange. It is uncertain how this type of change might affect stream temperature.
- The load allocations assume tributaries can meet temperature standards. It is unclear whether the streams are cooler or warmer than the criteria under natural conditions.

This TMDL contains an explicit margin of safety 0.1 °C which has not been reserved or allocated.

There is also an implicit margin of safety in this TMDL because of the following:

- The 90th percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the SNOTEL station 910 and NCDC Summary of the Day Station WA457507 (scaled to the Ecology station 01F070 gage) was combined with the lowest 7-day average flows with recurrence intervals of 10 years (7Q10) to represent a reasonable worst-case condition for prediction of water temperatures in the SFNR watershed.

- Typical summer conditions were represented by the 50th percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the aforementioned weather stations was combined with the lowest 7-day average flows in July–August with recurrence intervals of 2 years (7Q2).
- The lowest 7-day average annual flows 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 validation of maximum temperatures was less than 0.5 °C.
- Model bias evaluation shows no evidence of systematic over- or under-prediction 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 100-year-old riparian vegetation.
- Implementation will include additional measures beyond riparian shade that should contribute to reduced stream temperatures, such as instream structures creating pools that connect with hyporheic flow, and wetland restoration creating improved groundwater connection.

Reasonable Assurance

When establishing a TMDL, reductions of a pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. For the SFNR watershed temperature TMDL, both point and nonpoint sources exist. TMDLs must show *reasonable assurance* that these sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance, implementation of voluntary protective measures, permit administration, and enforcement will all be used to ensure that the goals of this TMDL project are met.

The goal of the TMDL is to help the waters of the basin meet the state's water quality standards. The following rationale helps provide reasonable assurance that the South Fork Nooksack River (SFNR) TMDL goals will be met by 2120 if implementation happens immediately. Implementation should happen as soon as possible to minimize how rapidly water temperatures will be rising due to climate change.

Ecology and EPA will control point source thermal loadings from NPDES-permitted facilities as part of engineering plan review and approval as well as basic permit administration activities. There is also considerable interest and local involvement in riparian and in-stream restoration actions that will help reduce stream temperatures in the watershed. Ecology believes that the following activities already support this TMDL and add to the assurance that 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.

- **Nooksack Indian Tribe**: technical assistance, watershed monitoring activities, climate change studies, research and problem identification, and special projects support for riparian and in-stream improvement projects.
- **Lummi Nation:** technical assistance and special project support for riparian and in-stream improvement projects and watershed monitoring activities.
- **Ecology:** technical assistance, project development and coordination, Centennial and 319 Grant funding, State Revolving Fund Loan program, wetlands and shorelines protection, regulation of NPDES permitted discharges, water quality assurance to DNR.
- **Whatcom and Skagit counties:** enforcement of Critical Areas and Shoreline Master Plan ordinances.

The WRIA 1 Salmonid Recovery Plan, adopted by the WRIA 1 Salmon Recovery Board in 2005, constitutes the WRIA 1/SFNR watershed chapter of the ESA recovery plan for Puget Sound Chinook. Many of the actions are focused on improving water temperature or providing refugia from water that fails to meet water temperature criteria. Progress to date for Chinook salmon habitat restoration in the Nooksack River Basin includes: detailed habitat assessment and restoration planning for 78 miles of the Nooksack forks, construction of 227 log jams, acquisition of 758 priority acres within the historic migration zone, and 300 feet of passage restored at Canyon Creek. Design work has also been advanced for reconstruction of the Middle Fork diversion dam to facilitate fish passage. Fifteen restoration projects have been completed in the SFNR and 99 engineered log jams constructed.

Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards. However, it is the goal of all participants in the TMDL process to achieve clean water through cooperative efforts.

In addition, as implementation and monitoring for this TMDL occur into the future, stream temperatures will be evaluated regularly. An adaptive management approach will be used to fine tune management and expectations over time.

Implementation Plan

Introduction

This Implementation Plan (IP) was developed jointly by Ecology, EPA, Nooksack Indian Tribe, Tetra Tech, and interested and responsible parties. It describes recommended actions to improve water quality. It explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, or direct responsibility for cleanup), along with the programs or other means through which they will address these water quality issues, timeframes, and funding sources. It prioritizes specific actions planned to improve water quality and achieve water quality standards.

This IP describes how water temperatures will be reduced to meet water quality standards. TMDL reductions should be achieved by 2120 in the SFNR watershed. The success of this TMDL project will be assessed using monitoring data from streams in the watershed and adaptive monitoring will be implemented to adjust and ensure pollution reduction measures are effective.

Who needs to participate in implementation?

A number of local, tribal, state, and federal organizations will coordinate and help to implement this TMDL. They include:

1. Washington Department of Natural Resources (DNR) (regulatory authority): forest practices regulations.
2. Whatcom County (regulatory authority): enforcement of Critical Areas and Shoreline Master Program regulations.
3. Skagit County (regulatory authority): enforcement of Critical Areas and Shoreline Master Program regulations.
4. Nooksack Indian Tribe: technical assistance, watershed monitoring activities, research and problem identification, and special projects support for riparian and in-stream improvement projects.
5. Lummi Nation: technical assistance and special project support for riparian and in-stream improvement projects and watershed monitoring activities.
6. Ecology (regulatory authority): technical assistance, project development and coordination, Centennial and 319 Grant funding, State Revolving Fund Loan program, wetlands protection, regulation of NPDES permitted discharges, and when necessary, enforcement of water quality laws.
7. EPA (regulatory authority): technical assistance, regulation of NPDES permitted discharges, CWA oversight.

8. USFS: technical assistance, management of forest service lands.
9. U.S. Fish and Wildlife Service: participant in WRIA 1 Salmonid Recovery Plan
10. WDFW: participant in WRIA 1 Salmonid Recovery Plan.
11. NOAA: participant in WRIA 1 Salmonid Recovery Plan.

Pollution sources and organizational actions, goals, and schedules

Activities to address pollution sources

A wide range of implementation activities will be necessary to achieve compliance with water quality standards in the SFNR watershed. Temperature is directly affected by the removal of riparian zone vegetation, which increases solar radiation reaching the stream surface. This reduction of riparian zone vegetation reduces the available shade, which increases sunlight to the stream surface and subsequently increases water temperature.

Groundwater influences, in-stream flows, water withdrawals, and stream channel geometry also influence stream temperature. Where significant volumes of groundwater discharge to a stream or river, groundwater can warm a stream in winter and cool it in summer (Gendaszek, 2014). Conversion of forest to developed and open agricultural land, and removal of forest cover through harvesting operations, can affect watershed hydrology and sediment loading. These land conversions contribute to upland sediment load. They can also reduce natural infiltration (leading to less cold baseflow) and contribute to loss of wetlands (potentially reducing thermal buffering capacity).

Land use and management in the watershed has likely caused an increase in upland sediment load. This, in turn, could contribute to loss of wetlands, filling of deep pools, and aggradation and widening of the channel. In turn, these impacts can result in reduced thermal buffering capacity and increased direct solar radiation. Filling of stream gravels with fine sediment can also reduce cooler hyporheic flows. Sediment loading has been identified as a limiting factor to the existence and recovery of native salmon stocks (Nooksack Indian Tribe, 2011).

Key implementation actions include:
Restoration of full system potential shade. Achieving system potential shad will have a significant impact on whether or not the system can achieve water quality standards. Planting native vegetation where buffers are lacking is a priority. Buffers provide not only shading with direct temperature benefit to streams, but also indirect benefits related to air cooling, source of woody debris, and eventual narrowing and deepening of the stream channel.

Address erosion and sedimentation. Streams that are wide and shallow because of 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.

Depending on the severity of the erosion stream bank stabilization projects could range from simple riparian buffer plantings to full scale bank contouring and plantings. The *Integrated Streambank Protection Guidelines* describes many methods for addressing this problem (Washington State Aquatic Habitat Guidelines Program, 2002).

Encourage residents next to streams to reduce water use during late-summer, low flow conditions. Instream flows and water withdrawals are managed under a state regulatory program. There may be opportunities to transfer surface withdrawals to groundwater wells, which could create a lag time of effects of those withdrawals to the river.

Promote restoration activities that increase groundwater discharge to streams. Groundwater inflow to streams could increase if recharge is increased as a result of renewed channel-floodplain connectivity. Years ago, some creeks were channelized to reduce flooding. However, this reduced the amount of time floodwaters spend on the floodplain and also reduced infiltration of floodwaters to the surface aquifer and reduced summer baseflow.

Table 40 lists implementation activities. As implementation occurs, Ecology is committed to making a better estimate of the temperature attainable under natural conditions. Additionally, Ecology would welcome periodic updates to the implementation plan establishing short-term and long-term priorities as knowledge about the river system improves. Integration of the planning effort of the Nooksack Indian Tribe and South Fork Watershed Group, which lead to the South Fork Nooksack River Watershed Conservation Plan and the South Fork Watershed Education Committee, would be an effective means of updating the implementation plan.

Table 40. Implementation activities for the South Fork Nooksack River.

Implementation Goal	Implementation Activity
Increased tree height and buffer width	Preservation and enhancement of riparian shade. Planting native vegetation where buffers are lacking with a goal of providing shade consistent with a climax forest.
Decreased headwater and tributary temperatures	Preservation and enhancement of riparian shade. With a goal of providing, shade consistent with a climax forest where there is flowing water during critical periods
Decreased Channel Width	Increase stability of disturbance zone with log jams
	Implement stream bank stabilization projects
Enhanced hyporheic exchange - also includes enhanced ground water inflow	Form deep pools with log jambs
	Reconnect floodplains
	Integrate salmon recovery into floodplain management
	Investigate changes in land cover effect on summer base flows, forest and wetland.
Other -Provide access to refugia	Restore passage at salmon barriers
Other – Comply with Permit	Point source requirements are detailed under the WLA section.

Forestry practices

The state's forest practices regulations will be relied on to bring waters into compliance with the load allocations established in this TMDL project on private and state forest lands. This strategy, referred to as the CWA Assurances, was established as a formal agreement to the 1999 Forests and Fish Report.

The state's forest practices rules were developed with the assumption that the stream buffers and harvest management prescriptions 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.

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 10-year review of the forest practices and adaptive management programs in 2009: https://fortress.wa.gov/ecy/publications/summarypages/0910101.html

Ecology noted numerous areas where improvements were needed, but it also recognized the state's forest practices program provides a substantial framework for bringing the forest practices rules and activities into full compliance with the water quality standards. Therefore, Ecology decided to conditionally extend the CWA assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific milestones for program accomplishment and improvement. These milestones were designed to provide Ecology and the public with confidence that forest practices in the state will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

The USFS manages land in the uppermost portions of the watershed. Management practices in this area will be coordinated by that agency.

There are several additional voluntary measures that commercial forestry operators can implement to further ensure there is no water quality impairment due to harvest activities. These include leaving wider riparian areas over longer lengths of the stream, inter-planting with conifers in hardwood dominated riparian areas and stabilizing hillsides and shorelines that have been destabilized by historic forest practices.

State Environmental Policy Act and land use planning

TMDLs should be considered during State Environmental Policy Act (SEPA) and other local land use planning reviews.

If the land use action under review is known to potentially impact stream temperature as addressed by this TMDL project, 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 project to help prevent new land uses from violating water quality standards. Ecology published a focus sheet on how TMDLs play a role in SEPA impact analysis, threshold determinations, and mitigation. Additionally, the TMDL should be considered in the issuance of land use permits by local authorities.

Critical Area ordinance for Whatcom and Skagit counties

The Whatcom County Critical Areas code (Title 16.16 of Whatcom County Code) and the Skagit County Critical Areas code (Title 14.24 of Skagit County Code) were adopted in 2005 and 2006 respectively under the authority of the Whatcom County Comprehensive Plan, the Skagit County Comprehensive Plan, and the State of Washington Growth Management Act (Chapter 36.70A RCW). The codes establish rules for designating and classifying critical areas. Furthermore, the codes seek to protect the ecological functions of the critical areas while protecting public safety and allowing for the economically viable use of property. Critical area categories regulated by the codes include geologically hazardous areas, frequently flooded areas, critical aquifer recharge areas, wetlands, and fish and wildlife habitat conservation areas.

Several of the critical area categories relate to preserving existing vegetated land, the most relevant to this TMDL being the “wetlands, and fish and wildlife habitat conservation areas.” The code designates variable protective buffer widths for all state-classified streams which fall under the categories: shoreline streams (Class S), fish-bearing streams (Class F), and non-fish-bearing streams (Class N). The Whatcom County Critical Areas Code designates 150-ft buffers for Class S streams, 100-ft buffers for Class F streams, and 50-ft buffers for Class N streams. Skagit County designations are somewhat different with a 200-ft buffer for Class S. Also, Class F and N requirements are similar except for Class F streams greater than 5 feet in width: for those the buffer is 150-ft. Figure 73 depicts the classes of all streams in the SFNR watershed.

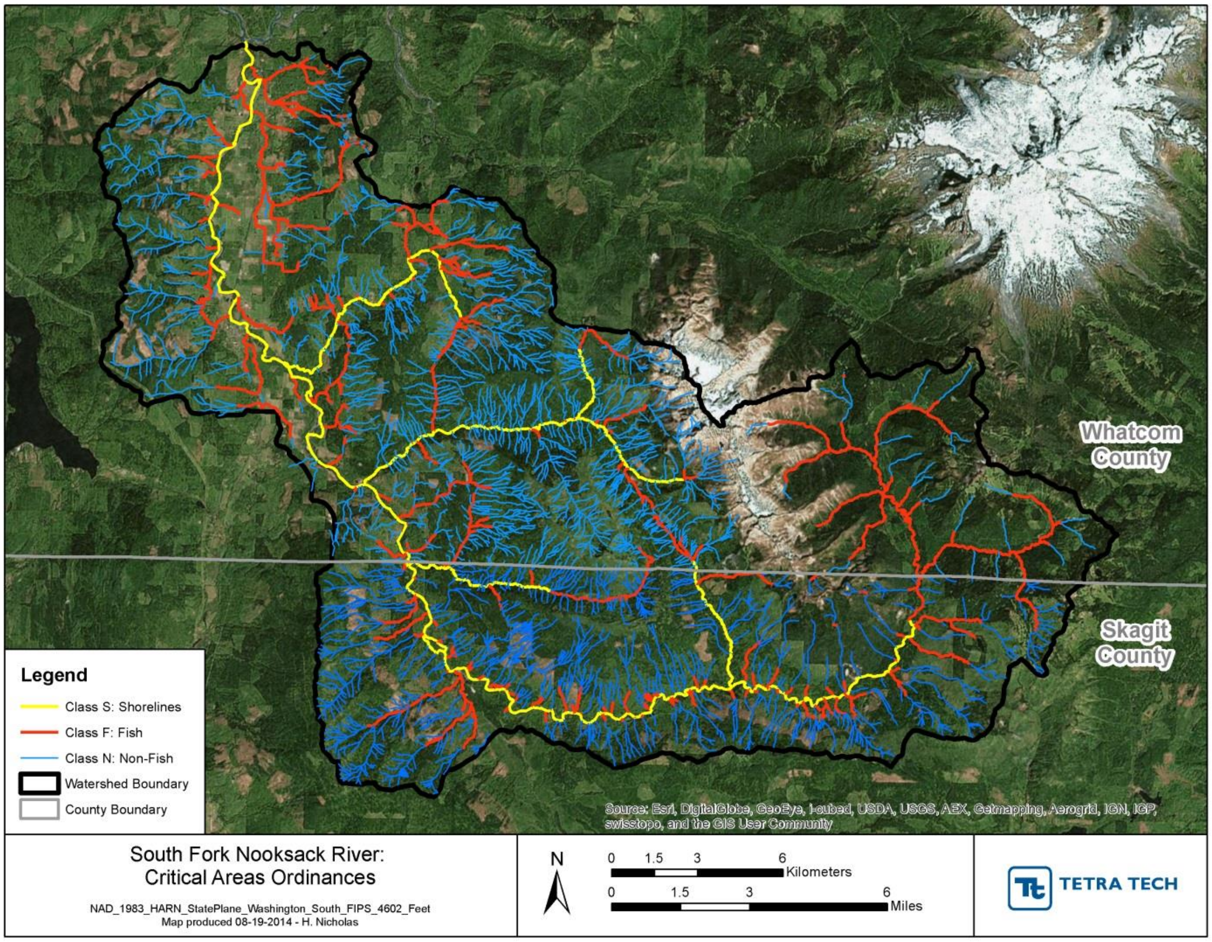

Figure 73. Habitat Conservation Areas (subject to protected buffers variable by county)**.**

A number of activities within the critical areas are allowed, including but not limited to, certain forestry practices, vegetation maintenance, some recreational activities, maintenance of already-established buildings, utilities, and the cutting of hazard trees. When a development is proposed that would impact a critical area, a critical areas assessment report is typically required, in which the developer proposes alternative mitigation and protective measures. The code states that complete avoidance of impacts is the highest priority, and in order for some impact to be allowed the applicant must demonstrate that all reasonable efforts to avoid impacts have been taken. The critical areas assessment report contains an analysis of how critical area impacts or risks will be avoided or minimized, and an analysis of the proposed measures to prevent or minimize impacts. When impacts cannot be avoided, the developer includes a mitigation plan for replacing critical area functions and values that would be altered by the development.

In both Whatcom and Skagit Counties, existing agricultural operations are allowed to continue within critical areas with an approved conservation plan. Conservation plan requirements vary depending on the type of agricultural operation and land zoning, and are more extensive for operations classified as moderate to high impact. Among the standard conservation plan requirements, existing native vegetation within critical area buffers (which includes riparian areas) are required to be maintained to practical extent. Clearing activities cannot be authorized within critical areas unless the clearing would occur on existing agricultural land and is considered an essential part of the ongoing agricultural use. The conservation plans are subject to monitoring, adaptive management, and enforcement by the counties.

Critical Areas code and TMDL implementation

The Critical Areas Codes for both counties support TMDL implementation through current language, and future revisions to the codes could provide additional support. At a minimum, the codes protect existing shade along the applicable reaches and help prevent further temperature impairment. Considering that the load allocations are quantified in terms of shade levels provided by 100-year SPV, as noted the existing critical areas code supports TMDL implementation. While the land within the buffer areas is already vegetated, some of the vegetation will not be fully matured, and protection from development would allow the riparian vegetation to eventually reach full potential shade.

If disturbance is allowed under the code, mitigation must occur (e.g., restoration of another riparian area), and this mitigation could be directed at areas that would support TMDL implementation. While not all critical areas overlap with riparian areas, those that do, regardless of the category, would provide support to TMDL implementation through their existing and potential riparian shade. Figure 74 provides an example of how the critical areas code can support TMDL implementation. In this example, 150-ft and 200-ft stream buffer requirements along the entire mainstem indicate that the protected buffers support future increases in shade. Note that a large number of tributaries are also classified to receive either 50-ft or 100-ft buffer widths.

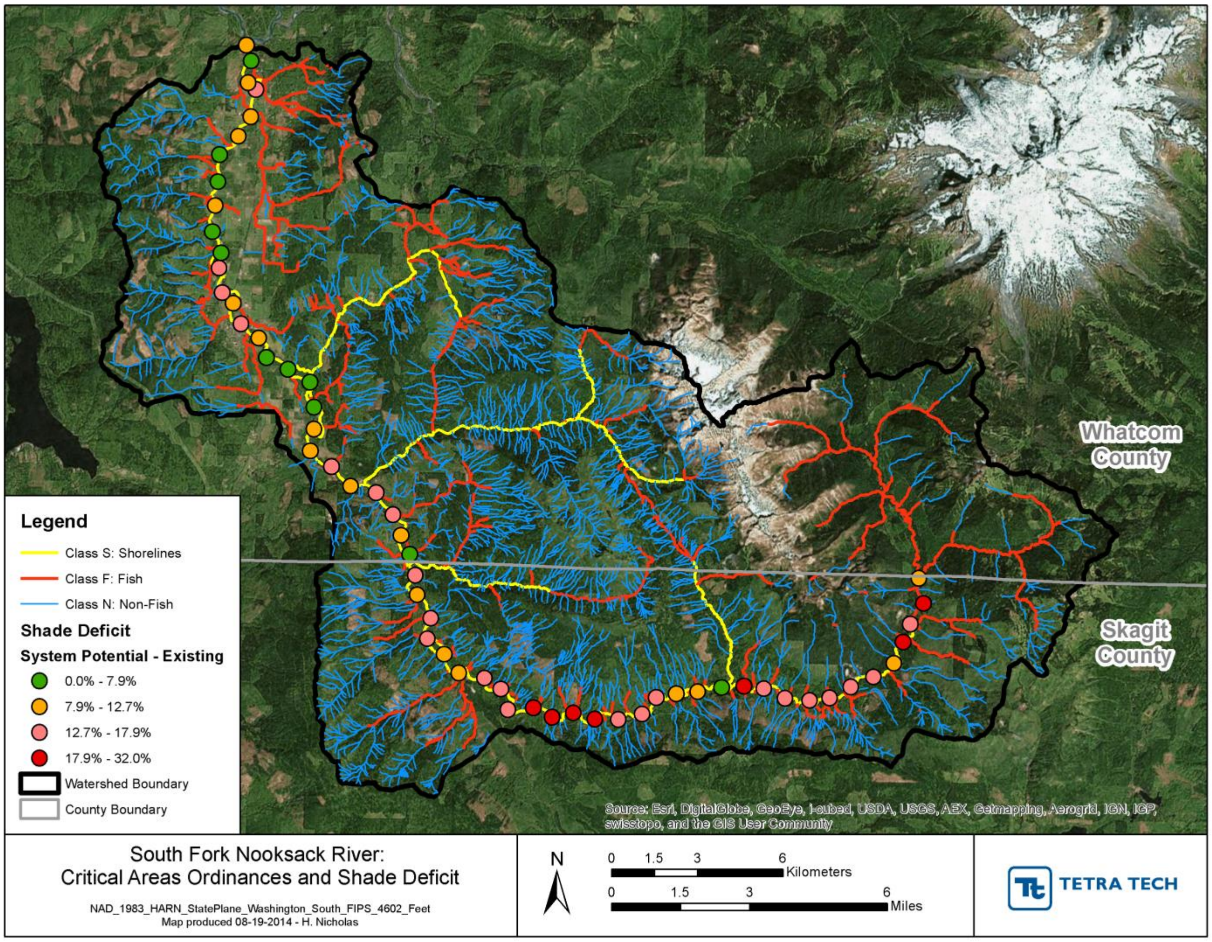

Figure 74. Comparison of Shade Deficit to Habitat Conservation Areas (subject to protected buffers – variable by county).

In addition to protecting existing and potential riparian shade, several critical areas categories (e.g., geologically hazardous areas) include land that may not be vegetated and could be restored to provide further riparian shade. These areas provide promising opportunities for TMDL implementation. Compared to land outside of critical areas, landowners may be more willing to participate in a restoration project on critical area land because development or other uses may not be allowed.

The abandoned lands clause of the code presents another opportunity for riparian restoration. Under the code, the code administrator may require restoration of the critical area or buffer as a condition of permit approval if a nonconforming building or structure on the parcel has been intentionally abandoned for a period of 12 months or more (Whatcom County code:16.16.275 E; Skagit County Shoreline Master Program draft code: 14.26.640).

When assessing the extent that the critical areas code supports the TMDL, it is important to consider the exemptions and mitigation allowances within the code. While TMDL implementation would progress best by preventing further disturbance and maintaining existing riparian vegetation, where mitigation is necessary, it will be important to require mitigation within the same watershed. Specific to the SFNR watershed, any disturbance to riparian critical areas should be mitigated on riparian land within the watershed boundaries. To further support implementation, mitigation could be directed towards restoration opportunities that would provide the best progress towards TMDL implementation. The Whatcom County critical areas ordinance states that mitigation plans "should be compatible with watershed and recovery planning goals" for the county, and the Skagit County code elaborates that mitigation plans "must be maintained over the life of the use or development."

Once the TMDL is approved, specific language could be added to the code that includes TMDL implementation among the watershed and recovery planning goals. Precedence exists for including TMDL language in the code since TMDLs are mentioned under the Habitat Conservation Areas section of the Whatcom County code in relation to stormwater discharges (16.16.720 F4). The Skagit County code includes language about TMDL development in its Shoreline Master Program spring 2014 working draft (14.24.550 4) which directly states that critical area site assessments must discuss water quality exacerbation potential associated with established pollutant TMDLs for the area in question.

While the provisions for agriculture in the code do not provide further restoration of critical areas, the conservation plans, if implemented and enforced successfully, provide protection of existing riparian vegetation and potential for increased shading in the future. To support TMDL implementation, monitoring and enforcement could be emphasized on priority riparian areas within the SFNR watershed.

Finally, the code provides support for the use of incentives and funding mechanisms that could lead to restoration of riparian vegetation in critical areas (16.16.295). These include open space taxation assessment, establishment of conservation easements, and use of the Conservation Futures Property Tax Fund by the County for the acquisition of properties containing significant critical areas and associated buffers.

Summary – Whatcom County and Skagit County Critical Areas codes

Overall, the county Critical Areas codes support the preservation and restoration of riparian vegetation and associated shade along the mainstem and many key tributaries of the SFNR through the following provisions:

- Protection of existing riparian vegetation within designated critical areas.
- Restoration potential for critical areas without existing vegetation, including potential for landowner willingness to participate in conservation easements or restoration.
- Possible requirement for vegetation restoration where nonconforming buildings or structures have been abandoned.
- Support for the use of incentives and funding towards protecting and restoring critical areas, including riparian areas.

The following additional provisions, if added to the code, would provide further support to TMDL implementation as well as reduce the risk of further degradation:

- Requirement that mitigation be performed within the same watershed as the impact.
- Prioritization of mitigation sites that would provide the best progress towards TMDL implementation.
- Additional language that refers to the TMDL as a specific watershed and recovery planning goal to be addressed in the mitigation plans.
- Targeted monitoring and enforcement of agricultural conservation plans within the riparian portion of SFNR watershed critical areas.

Coordination among EPA, Ecology, the Nooksack Indian Tribe, the Lummi Nation, Whatcom County, and Skagit County will help ensure realization of the multiple benefits provided by the code. Partnerships between agencies and departments could help facilitate efforts to monitor and enforce the code and enhance the code language to augment its support for TMDL implementation.

WRIA 1 Salmonid Recovery Plan

The WRIA 1 Salmonid Recovery Plan, adopted by the WRIA 1 Salmon Recovery Board in 2005, constitutes the WRIA 1/SFNR watershed chapter of the ESA recovery plan for Puget Sound Chinook. Many of the actions are focused on improving water temperature or providing refugia from water that fails to meet water temperature criteria. Near term species priorities identified in the plan include:

- Focus and prioritize salmon recovery efforts to maximize benefit to North Fork/Middle Fork Nooksack spring Chinook and South Fork Nooksack spring Chinook salmon.
- Address fall Chinook through adaptive management, focusing in the near-term on identifying hatchery- versus naturally-produced population components.
- Facilitate recovery of WRIA 1 bull trout by:
  - Implementing actions with mutual benefit to both spring Chinook salmon and bull trout.
  - Removing fish passage barriers in presumed bull trout spawning and rearing habitats in the upper Nooksack River watershed.
- Address other salmonid populations by:
  - Protecting and restoring salmonid habitats and habitat-forming processes throughout WRIA 1 through regulatory and incentive-based programs (*the focus of this qualitative assessment*).
  - Encouraging and supporting voluntary actions that benefit other WRIA 1 salmonid populations without diverting attention from spring Chinook recovery.

A 10-year Action Plan was developed to assist in the prioritization and implementation of near-term recovery actions in the Nooksack River Basin. These actions include the following:

1. Restore passage at major spring Chinook salmon barriers.
2. Restore Nooksack spring Chinook salmon freshwater habitat.
3. Integrate salmon recovery into floodplain management planning.
4. Integrate salmon recovery into regulatory updates.
5. Establish a South Fork Nooksack spring Chinook salmon hatchery population rebuilding program.
6. Establish new instream flows in WRIA 1.
7. Protect and restore estuarine and near-shore areas.
8. Protect and restore functioning riparian and water quality conditions and reconnect isolated habitat in lowland tributaries and independent tributaries to the Fraser River and Strait of Georgia.
9. Continue to manage harvest and harvest-oriented hatchery programs to not impede recovery.

The current high priority strategies in the SFNR include the following voluntary actions:

- Log jams to form deep complex pools: cool-water inflow areas (RM 0-20.6).
- Log jams to form deep complex pools: other areas (RM 0-20.6).
- Setback or remove riprap embankments (RM 0-10.9).
- Lower artificial levees to native bank/floodplain elevations (RM 7.2-8.6).
- Relocate river-adjacent infrastructure outside the 100-year erosion hazard area (RM 7.2-8.6).
- Reconnect floodplains (RM 20.6-22) and other reaches if applicants provide sufficient justification.
- Acquisition of properties necessary to facilitate restoration (RM 0-12.8).
- Acquisition of properties at risk of degradation to protect high quality habitat and habitat-forming processes (RM 8.6-20.6).

Progress to date for Chinook salmon habitat restoration in the Nooksack River Basin includes: detailed habitat assessment and restoration planning for 78 miles of the Nooksack forks, construction of 227 log jams, acquisition of 758 priority acres within the historic migration zone, and 300 feet of passage restored at Canyon Creek. Design work has also been advanced for reconstruction of the Middle Fork diversion dam to facilitate fish passage. Fifteen restoration projects have been completed in the SFNR and 99 engineered log jams constructed.

Nooksack Indian Tribe

The Nooksack Indian Tribe has been instrumental in the development of this TMDL. The tribe has many studies underway and plans for additional work to implement the TMDL. This is a list of ongoing efforts that either implement the TMDL or will inform improvements to future implementation plans:

- Act on recommendations of EPA's Climate Change Pilot Research Project
- Development and update of the South Fork Nooksack River Watershed Conservation Plan, including public outreach and stakeholder engagement
- Instream habitat restoration – engineered log jams
- Hard bank armoring removal
- Wetland hydrology restoration
- Stream buffer protection and restoration
- Water quantity and quality monitoring including low flow season gaging of tributaries, stream temperature, sediment transport, turbidity, and general water quality
- Update of climate change hydrologic modeling, including flow, sediment, and stream temperature
- Evaluating the relative influence of forest stand age on late summer streamflow and stream temperature
- Evaluate and identify forest harvest strategies that promote snow accumulation and facilitate later season snowmelt as a resilience tool against climate change

Climate change pilot – qualitative assessment and recommendations

During the development of this TMDL report, the U.S. Environmental Protection Agency (EPA) Region 10, EPA's Office of Research and Development (ORD) and Office of Water (OW), the Washington Department of Ecology (Ecology), and the Nooksack Indian Tribe launched a Pilot Research Project to consider how projected climate change impacts can be incorporated into the implementation plan for the South Fork Nooksack Temperature TMDL. One element of the Pilot Research Project was a qualitative assessment of the impacts of climate change on endangered species recovery actions. The focus of the analysis was to determine what actions provided the greatest resiliency for salmon to the changes resulting from climate change (EPA 2016). The following is the executive summary from the study. The entire report can be found on EPA's website.

The South Fork Nooksack River (South Fork) is located in northwest Washington State and is home to nine species of Pacific salmon, including Nooksack early Chinook (aka, spring Chinook salmon), an iconic species for the Nooksack Indian Tribe. Segments of the South Fork and its tributaries are identified as being impaired by elevated temperature on Washington's 2010 Clean Water Act (CWA) 303(d) list. These segments exceed the temperature criteria established to protect aquatic life uses for the support of cold-water salmonid populations. High water temperatures in the South Fork are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. Populations of Nooksack salmon, especially Nooksack early Chinook, have dramatically declined from historic levels. Growing evidence shows that climate change will exacerbate legacy impacts to temperature, hydrologic, and sediment regimes of the South Fork.

The Total Maximum Daily Load (TMDL) program, established by Section 303(d) of the CWA, is used to establish limits on loading of pollutants from point and nonpoint sources necessary to achieve water quality standards. One important use of the TMDL is to bring impaired waters back into compliance with water temperature criteria established for the protection of cold-water fisheries as a primary designated use of the South Fork. The U.S. Environmental Protection Agency's (EPA) Region 10, Office of Research and Development (ORD) and Office of Water (OW), the Washington Department of Ecology (Ecology), and the Nooksack Indian Tribe have launched a Pilot Research Project to explore how projected climate change impacts could be considered in the implementation of a CWA 303(d) temperature TMDL and influence restoration actions in an Endangered Species Act (ESA) Salmonid Recovery Plan. The Pilot Research Project uses a temperature TMDL being developed by Ecology for the South Fork in Washington, as the pilot TMDL for climate change vulnerability analysis. However, the collaborative framework and coordinated research components developed as part of the Pilot Research Project have provided the opportunity to focus more directly on the impact of climate change, primarily increased stream temperatures, on salmon that inhabit the river. Therefore, the pilot also provides the opportunity to move beyond the South Fork temperature TMDL and assess how climate change might influence salmon recovery plans, including ESA recovery plans.

This qualitative assessment is a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork. It also evaluates the effectiveness of restoration tools that address Pacific salmon recovery. The objective of the assessment is to identify and prioritize climate change adaptation strategies or recovery actions for the South Fork that explicitly include climate change as a risk. The qualitative assessment's findings will inform development of the CWA South Fork temperature TMDL Implementation Plan, updates to the Endangered Species Act (ESA) Water Resource Inventory Area 1 (WRIA 1) Salmonid Recovery Plan, and other land-use and restoration planning efforts. A companion document, the Quantitative Assessment, compares projected increases in stream temperature with the thermal tolerances and requirements of various salmonids to inform the CWA TMDL numeric cold-water temperature water quality standard (Butcher et al. 2016).

This qualitative assessment used a stakeholder-centric involvement process that benefited from the engagement of knowledgeable scientists and informed lay-persons alike. The stakeholder process has included several stakeholder involvement events to date (i.e., nine workshops, meetings, webinars) and will include additional opportunities for stakeholder engagement to refine this assessment and present key findings. It is hoped that the qualitative assessment will serve as a pilot project whereby the methods can be applied to other drainages with similar species, limiting factors, and restoration planning, including the Middle Fork and North Fork Nooksack rivers.

The qualitative assessment methodology is based on Restoring Salmon Habitat for a Changing Climate (Beechie et al. 2013). In that paper, Beechie et al. present a methodology to provide a systematic, stepwise approach to analyzing climate change impacts; we refer to that methodology herein as the Beechie method. The qualitative assessment applies the Beechie method to the South Fork context, including evaluation per climate risk, per salmonid species, and per restoration action.

The qualitative assessment evaluates historic conditions (or natural conditions in the South Fork temperature TMDL) and the changes, or legacy impacts, resulting from those conditions due to past land management. The cumulative effects of legacy impacts from timber harvest, flood control, transportation facilities, and conversion of forested land to agricultural uses in the South Fork have substantially altered the nature of the South Fork channel, floodplain, and watershed, and has resulted in degraded habitat conditions, including excessive stream temperatures and increased sediment loading that threaten the survival of salmonids. Climate change has and will exacerbate those cumulative effects. Water temperature is highly correlated with air temperature. Recorded air temperature monitoring in the vicinity of the South Fork has suggested a 1.3 °C increase from 1905 through 2010.

Modeling results from the quantitative assessment presented in Section 5.1 (Evaluate Impacts by Climate Risk) show that climate change will have a significant effect on water temperature in the South Fork. South Fork water temperatures, without restoration of riparian shade, are projected to rise by amounts ranging from 3.5 to almost 6 °C during critical low-flow conditions by the 2080s; which could substantially impact fish and reduce the amount and quality of preferred salmon habitat. Table 41 summarizes the distribution and severity of climate change impacts through the South Fork reaches and subbasins.

As part of this qualitative assessment, the potential magnitude of the impact that climate change could have on Pacific salmon species and life stages in the South Fork was evaluated (see Section 5.2 Evaluate Per Salmonid Species the qualitative assessment). Of the nine salmon species assessed, three salmon species have been listed as threatened under the federal ESA and are of high priority in the South Fork—spring Chinook salmon, summer steelhead trout, and bull trout. For all species, the life stages with the greatest potential to be impacted by the changing climate were during spawning and intra-gravel development stages, with high potential also recorded for several species during upstream migration/holding and rearing.

Salmon recovery actions and the ability of each action to ameliorate climate change effects were then evaluated (see Section 5.3 Evaluate Per Salmon Recovery Actions the qualitative assessment). Restoration actions were prioritized by reach and subbasins based on ability to ameliorate various climate change impacts and/or increase salmon resilience, and the potential effectiveness of each restoration action (see Table 5-8 and Table 5-9 in EPA 2016).

From a watershed scale perspective, channel conditions and legacy impacts today are directly related to intensive and extensive land management. Forestry dominates the watershed and timber harvest and logging road construction are likely the largest contributors to the legacy impacts. The South Fork temperature TMDL project has indicated that restoring the riparian zone of the mainstem of the South Fork alone is not enough to ameliorate excessive temperatures in the river. This strongly suggests that additional focus needs to be given to watershed-scale actions that will address both legacy impacts and future continued climate change.

The following is a list of actions that should be considered that address both legacy impacts and climate change:

Longitudinal Connectivity

- Evaluate feasibility of improving passage at South Fork River Mile (RM) 25 barrier and implement feasible projects.

Floodplain Reconnection

- Increase the pace of broader-scale floodplain reconnection projects by acquiring conservation easements or fee simple title to property in the floodplain or otherwise working with existing landowners to increase stewardship. In addition, work with land owners and develop plans that facilitate floodplain reconnection on specific parcels.

Restoring Stream Flow Regimes

- Enforce water rights and incentivize water conservation in the lower South Fork valley to the extent possible (e.g., water banking).
- Develop a groundwater-flow model coupled with a watershed model for the South Fork basin to evaluate future development/restoration scenarios to inform land use decisions and identify and prioritize floodplain wetland restoration projects.

Riparian Functions

- Continue to implement and expand the Conservation Reserve Enhancement program (CREP) through the lower South Fork and seek funding to extend 15-year lease terms and/or otherwise work to protect existing CREP buffers over the long-term.
- Increase opportunity and funding for riparian/wetlands protection and restoration along the lower South Fork through purchase of conservation easements, development rights, and/or fee simple title and/or working with landowners to foster stewardship.

Instream Rehabilitation

- Continue and increase the pace of instream restoration projects in high priority reaches of the South Fork that create cold-water refuges, increase effective shading, promote hyporheic exchange, reconnect floodplain channels, reduce redd scour, and create flood refuge habitat.

Planning

- Incorporate climate change into updates to WRIA 1 Salmonid Recovery Plan and development and prioritization of projects for Salmon Recovery Funding Board/Puget Sound Acquisition and Restoration Account funding.
- Develop a watershed management/conservation plan that facilitates the South Fork temperature TMDL implementation plan and comprehensively addresses the impacts of land management and climate change on the ecological health of the South Fork.

Monitoring, Research, and Adaptive Management

- Develop life cycle models for South Fork salmonid populations to identify limiting life stages and support quantitative assessment of climate change impacts on salmon recovery.

Most of these recommendations will require substantial planning, including a watershed conservation plan, project feasibility assessments, agency consultation, landowner cooperation, stakeholder involvement, and funding, if they are to be implemented in a manner that will effectively address the cumulative effects of legacy impacts and climate change on salmonids and ESA recovery. These parameters will require a substantial amount of time to work through and become effective. Thus, it is important that the recommendations previously presented are considered.

Table 41. Distribution and Severity of Climate Change Impacts through the South Fork Reaches and Subbasins.

Reach or Subbasin	Climate Impact: Reduced Spring Snowmelt (percentSD+HL)	Elevated Summer Temperature	Reduced Summer Low Flow	Increased Winter Peak Flow	Sediment
Reaches					
1 (RM 0-14.3)	Moderate (43 percent of basin)	High (Currently exceeds 7-DAD Max lethal limit of 22 °C)	High (Potentially a reach that loses surface water to groundwater recharge)	High (Floodplain artificially confined and incised)	Moderate (Floodplain artificially confined and incised, loss of floodplain sediment storage)
				Low (Floodplain unconfined)	Moderate (Rapid channel migration- increase in bank erosion)
		High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change)		Moderate (Floodplain naturally confined)	Low (Floodplain naturally confined/ channel migration limited)
2 (RM14.3- 18.5)	High (60 percent of basin)		Moderate		
3 (RM 18.5-25.4)	High (66 percent of basin)			Low (Floodplain unconfined)	Moderate (Rapid channel migration)
				Moderate (Floodplain naturally confined)	Moderate (Abundant stream-adjacent landslides and unstable slopes could increase sediment sources)
4 (RM 25.4-31)	High (73 percent of basin)				
5 (Upstream of RM 31)	High (77 percent of basin)	Moderate (Expected to remain below lethal)			
Subbasin					
Hutchinson	Moderate (18 percent of basin)	High	High	Moderate	Moderate
Skookum	High (67 percent of basin)	Moderate	Moderate	Moderate	Moderate
Acme Valley	Low (2 percent of basin)	High	High	Moderate	Moderate
Plumbago and Deer	Moderate (29 percent of basin)	Moderate	Moderate	Moderate	Moderate
Edfro and Cavanaugh	Moderate (39 percent of basin)	Moderate	Moderate	Moderate	Moderate
Howard	High (55 percent of basin)	Low	Low	Moderate	Moderate
Upper South Fork	High (84 percent of basin)	Low	Low	Moderate	Moderate

Impact Potential	
(blue)	Low Impact
(yellow)	Moderate Impact
(orange)	High Impact

Measuring progress toward goals

The load/wasteload allocations for the SFNR TMDL are expected to allow the river to meet standards by 2116. This section includes plans to measure whether implementation activities have been completed and if water quality standards are being met.

Local governments evaluate the Critical Areas ordinance and Shoreline Master Programs that regulate the riparian corridors every five years. It is expected that the shade targets established in this TMDL report will help inform their decision-making on the updates to those regulations. Periodically, it would be helpful to survey the streams to monitor progress toward meeting shade targets to help with the reevaluation.

Entities with enforcement authority are responsible for following up on any enforcement actions. NPDES permittees are responsible for meeting the requirements of their permits. Those conducting restoration projects or installing BMPs are responsible for maintenance of improvements, structures and fencing and for monitoring plant survival rates.

Long term monitoring will be conducted by the Nooksack Indian Tribe, the Lummi Nation, Ecology, DNR, and its partners to help assess the hydrologic and water quality conditions in the SFNR.

Performance measures and targets

The Nooksack Indian Tribe is developing a SFNR restoration plan which may supplement these measures in the future. This plan will work with stakeholders to establish attainable targets.

Shade targets will be met through growth of existing shade producing riparian vegetation. Shade producing riparian vegetation will be established where it does not currently exist.

Effectiveness monitoring plan

Effectiveness monitoring will be expected to include:

- Water temperature monitoring.
- Flow monitoring.
- Shade canopy assessments to evaluate progress towards system potential.

Monitoring to determine the quality of water after implementation has occurred will be needed when water quality standards are believed to be achieved. The existing temperature stations will be used.

Every five years those parties that have been working to implement the South Fork Nooksack TMDL will gather to determine the state of implementation. If data does not exist to update the shade model to current conditions, the meeting will be used to assign the responsibility to collect the data in the next year. If resources allow, the QUAL2Kw model will re-validated, and if necessary re-calibrated to the new data. The model will be used to assess if improved riparian condition is having the desired improvement in temperatures.

Adaptive management

Natural systems are complex and dynamic. The way a system will respond to human management activities is often unknown and can be described only as probabilities or possibilities. 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 TMDL projects, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. As we implement these actions, the system will respond, and it will also change. Adaptive management allows for actions to be fine-tuned to be more effective, and allows for trying new strategies if there is evidence that new approaches could help achieve compliance.

TMDL reductions should be achieved by 2116. If water quality standards are achieved, but wasteload and load allocations are not met, the TMDL project will be considered satisfied. Partners will work together to monitor progress toward these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the implementation strategy as needed.

Ecology will use adaptive management when water monitoring data show that the TMDL project targets are not being met or implementation activities are not producing the desired result. A feedback loop (Figure 75) consisting of the following steps will be implemented:

Step 1. The activities in the water quality IP are put into practice.

Step 2. Programs and BMPs are evaluated for technical adequacy of design and installation.

Step 3. The effectiveness of activities are evaluated by assessing new monitoring data and comparing it to the data used to set the TMDL project targets.

- Step 3a. If the goals and objectives are achieved, the implementation efforts are adequate as designed, installed, and maintained. Project success and accomplishments should be publicized and reported to continue project implementation and increase public support.
- Step 3b. If not, then BMPs and the IP will be modified or new actions identified. The new or modified activities are then applied as in Step 1.

It is ultimately Ecology's responsibility to assure that implementation is being actively pursued and water standards are achieved.

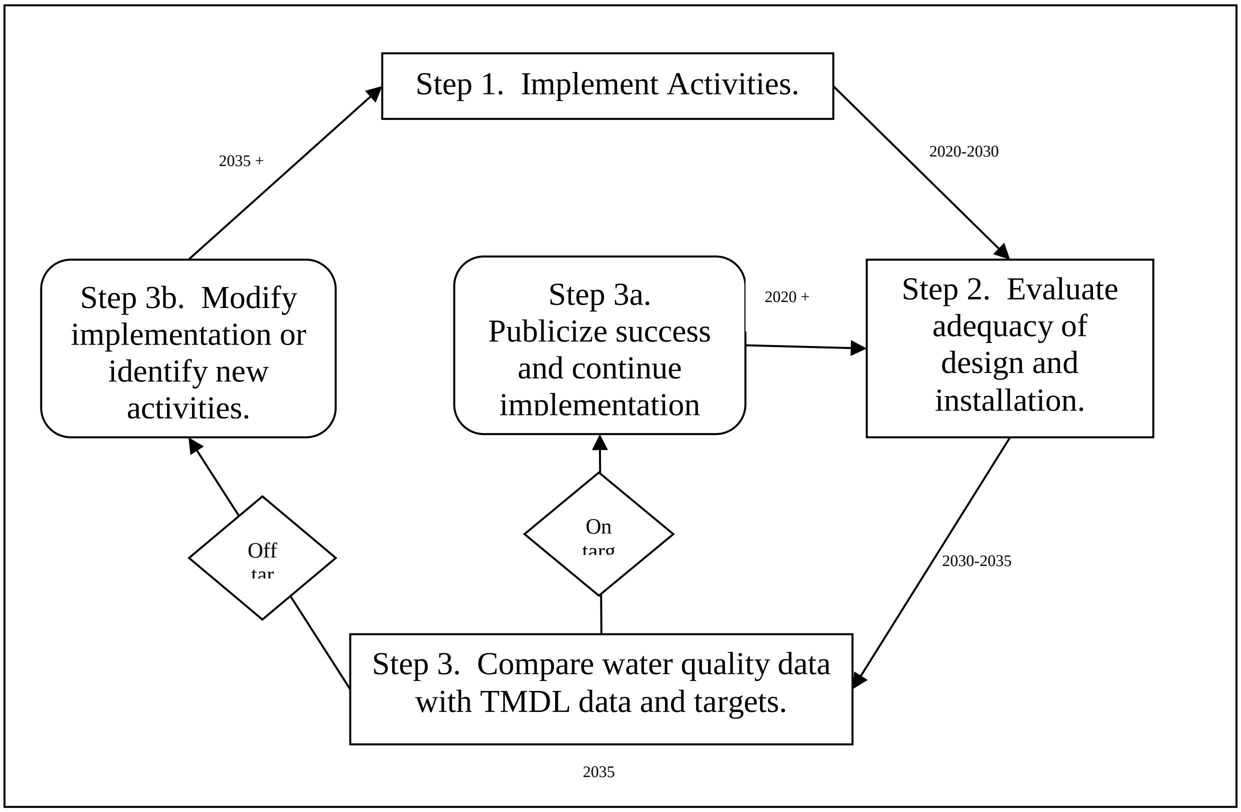

Figure 75. Feedback loop for determining need **for adaptive management.**

Dates are estimates and could change depending on resources and implementation status.

Funding opportunities

Multiple sources of financial assistance for water cleanup activities are available through Ecology's grant and loan programs, local conservation districts, and other sources. A list and descriptions of several funding sources is provided in Table 42.

Table 42. Potential funding sources to help support TMDL implementation.

Sponsoring Entity	Funding Source	Fund Uses
Natural Resources Conservation Service	Conservation Programs www.nrcs.usda.gov/programs	www.wa.nrcs.usda.gov/programs/wrp/wrp.html These programs "....help people reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters.".
	Emergency Watershed Protection https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/ewpp/	NRCS purchases land vulnerable to flooding to ease flooding impacts.
	Wetland Reserve Program	Landowners may receive incentives to enhance wetlands in exchange for retiring marginal agricultural land.
Office of Interagency Committee, Salmon Recovery Board	Salmon Recovery Funding Board www.rco.wa.gov/grants/eval_results.shtml Scroll down to "Salmon Recovery"	Provides grants for habitat restoration, land acquisition and habitat assessment.
Washington State Conservation Commission	https://scc.wa.gov/grants/	Various environmental program grants.
Ecology: Water Quality Program (WQP)	Centennial Clean Water Fund, Section 319, and State Revolving Fund https://ecology.wa.gov/About-us/How-we-operate/Grants-loans/Find-a-grant-or-loan/Water-Quality-Combined-Funding-Program	Facilities and water pollution control-related activities; implementation, design, acquisition, construction, and improvement of water pollution control. Priorities include: implementing water cleanup plans; keeping pollution out of streams and aquifers; modernizing aging wastewater treatment plants (WWTP); reclaiming and reusing waste water.
Ecology: Shorelands and Environmental Assistance Program	Coastal Zone Protection Fund	Some funding is available through a program that taps into penalty monies collected by the WQP.

Sponsoring Entity	Funding Source	Fund Uses
U.S. Department of Agriculture	Farm Service Agency (FSA): Conservation Reservation Program (CRP)	CRP helps agricultural producers protect environmentally-sensitive land.
EPA	Watershed Funding: https://www.epa.gov/nps/funding-resources-watershed-protection-and-restoration	Provides tools, databases, and information on funding sources that can be used to protect watersheds.

Climate Change Considerations

Global climate change has the potential for significant impacts on freshwater ecosystems through changes in both the hydrologic and thermal regime. Stream temperatures are projected to increase in most rivers, resulting in increased stress on cold water fish species such as salmon. Changes in hydrology, such as reduction in summer baseflow, and an increase in peak flows during winter, could potentially exacerbate these impacts. To date, the supporting analyses for temperature TMDLs have generally assumed a stationary climate under which historical data on flow and air temperature are assumed to be an adequate guide to future conditions. Projected changes in climate over the 21st century suggest, however, that temperature is expected to increase in most parts of the US, accompanied in many areas by seasonal shifts in the timing and amount of precipitation, which in turn will alter stream flow. This section describes the urgency of immediate implementation of the TMDL to slow the increases in stream temperature for a water body that is already impaired.

Climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth and Fifth Assessment Reports (IPCC, 2007, 2013) confirm observations of increasing temperatures in the Pacific Northwest (PNW) over the 20th century and consistently project accelerated warming in the 21st century. Across the PNW, the overall average across all analyzed climate models yields increases in mean annual air temperature of 2.0 °F (1.1 °C) by the 2020s, 3.2 °F (1.8 °C) by the 2040s, and 5.3 °F (2.9 °C) by the 2080s compared to a baseline of 1970 to 1999 (Mote and Salathé, 2010). Precipitation changes are less certain, but most climate model simulations project changes toward wetter falls and winters and drier summers in the PNW, with reduced summer flow further increasing water temperature maxima. Together these factors could significantly increase temperature stress on salmonid populations (Butcher et al., 2016).

EPA Region 10 and EPA's Office of Research and Development (ORD) and Office of Water (OW) conducted a pilot research project to consider how projected climate change impacts can be incorporated into the SFNR TMDL, and how climate change considerations might affect restoration plans. Portions of one of two resulting reports (Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River under Future Climates using QUAL2Kw; Butcher et al., 2016 and EPA, 2016) are excerpted here.

In the Quantitative Assessment, the findings of modeling tools used to develop the temperature TMDL were reevaluated under a range of potential future climate conditions. The Quantitative Assessment calculated altered boundary conditions for the QUAL2Kw TMDL modeling under the IPCC A1B greenhouse gas emissions storyline (which speculates a balance of fossil and non-fossil fuel energy sources) and for three time horizons (2020s, 2040s, and 2080s). These boundary conditions were used to conduct additional QUAL2Kw modeling analyses of system response under potential future climate conditions. Model results provide important information on the potential future response of the system to future climate, with and without riparian shading implementation actions called for in the TMDL.

The Quantitative Assessment is one part of a larger research plan that is described in the *EPA Region 10 Climate Change and TMDL Pilot Research Plan* (Klein et al., 2013). The Research Plan provided for developing both a Quantitative Assessment and a Qualitative Assessment. The Qualitative Assessment complements the modeling investigations of the TMDL provided in the Quantitative Assessment and evaluated additional restoration actions and strategies beyond riparian shading to enhance salmon recovery under climate change in the SFNR (EPA 2016). Management strategies developed in the Qualitative Assessment are discussed in the Implementation Plan section of this document.

Modeling approach

In the Quantitative Assessment, the calibrated QUAL2Kw stream temperature model developed for the TMDL study was used to estimate the impacts of potential future climate changes on the stream temperature with and without the growth of 100-year system potential vegetation (SPV). To evaluate climate change in the SFNR, a new set of boundary conditions were developed for QUAL2Kw representing conditions forecast for the 2020s, 2040s, and 2080s.

Climate projections

The climate-altered boundary conditions for the QUAL2Kw modeling of the SFNR were derived from the work conducted by the Climate Impacts Group (CIG) at the University of Washington (e.g., Mauger and Mantua, 2011; Hamlet et al., 2010). CIG assembled output from multiple Global Climate Models (GCMs) and used statistical downscaling to translate these global model projections to a finer spatial scale over the Pacific Northwest (PNW). CIG also used the downscaled climate data to predict future hydrology using a grid-based macro-scale hydrologic model known as the Variable Infiltration Capacity (VIC) model.

Different GCMs provide different results for the PNW, although all agree on an increase in air temperatures – with an increase in summer air temperatures of as much as 6 °C or more over the SFNR watershed. Evaluation of the risk of adverse temperatures under future climates needs to take into account the range of predictions among different climate models. We selected three climate model products that approximately span a range of low, medium, and high emissions scenarios simulating conditions in the 2020s, 2040s, and 2080s – resulting in a total of nine climate change scenarios.

Selection of specific GCMs span the range of potential impacts and consider factors other than average annual temperature increase. Maximum risk is expected to coincide with increases in summer temperatures accompanied by decreases in summer baseflow. The USFS North Cascadia Adaptation Partnership (NCAP) in ongoing work suggested that the following elements of climate change have potential impacts on aquatic habitat:

- Longer duration, higher stream temperatures, and lower summer baseflow.
- Transitions among the three basic PNW streamflow patterns (snow-dominant, transient, and rain-dominant hydrographs). The lower SFNR is now classified as transient, but is expected to transition to rain-dominant by the 2020s under the A1B emissions scenario.

The upper reaches of the SFNR are currently snow-dominant, but are expected to transition to transient as early as the 2020s.

- Precipitation is expected to increase annually primarily because of earlier, more intense fall rainfall and increased winter rainfall. This is likely to increase winter flooding in sensitive transient river basins such as the SFNR.

Selection of specific GCMs is complicated by the fact that rankings (of low, medium, or high impact scenarios) can switch for different time periods. Nonetheless, three GCMs were identified that meet the general criteria for low, medium, and high warming while also demonstrating consistency with the NCAP storyline. These specific climate models are discussed in detail in the Quantitative Assessment report.

The downscaled climate model projections and VIC hydrologic application are still too coarse in spatial scale to directly drive a local, site-specific model such as the SFNR QUAL2Kw model. Therefore, a delta change method was applied in which the observed historical climate data for the SFNR were modified by the amount of change predicted by the downscaled climate models to obtain a projection of future conditions specific to the SFNR. The climate inputs for which change factors were calculated include several which are analyzed directly from VIC model outputs, such as air temperature and flow, as well as inputs for parameters that are indirectly calculated from VIC output such as dew point, headwater, tributary, and ground water temperatures.

QUAL2Kw boundary conditions

The TMDL analysis is based on a quasi-steady state simulation of critical conditions of high air temperature, high water temperature, and low flow. For the climate change scenarios, meteorological boundary conditions are developed from the downscaled climate projections discussed in the previous section. Appropriate representations of the tributary flow and water temperature boundary conditions were also needed. Physical conditions such as channel structure and bulk hyporheic flow were assumed to be unchanged under future climate conditions.

Mainstem and Tributary Flow Boundary Conditions

Flow boundary conditions under future climates were based on an estimate of the effect of climate on low-flow conditions. To do this, the climate change application incorporates predicted changes in summer baseflow derived from assessments conducted by CIG with the VIC hydrologic model. For each grid cell, the VIC produces daily outputs of surface and subsurface flow. In the critical low-flow periods for the TMDL, the total flow was nearly equivalent to the subsurface baseflow.

The VIC model is a large-scale model that is not explicitly calibrated to the SFNR and does not exactly reproduce the current conditions represented in the TMDL. Therefore, mapping/extrapolation of CIG estimates to the QUAL2Kw domain was necessary.

Specifically, the CIG output was applied using a delta change method in which the TMDL 7Q10 flow at the model headwaters and for all tributary and diffuse inflows is modified by the ratio of CIG estimates of low flows of a similar return period under future and current climate conditions.

Specifically, the VIC model output for recent historical conditions was converted to unit-area 7-day flows, and the 7-day flows analyzed to determine the empirical 7-day flow with 2- and 10-year recurrence intervals. The same procedure was followed for each of the future climate scenarios and the ratio between future climate and current conditions for 7Q10 flows was calculated for each VIC grid cell, area-weighted to estimate a ratio for each tributary watershed, and applied to the boundary inflow to yield the climate-modified inflow estimate for the critical condition.

The resulting ratios vary strongly by elevation, with greater reductions at higher elevations and larger reductions for the 7Q2 than for the 7Q10 flow. For example, in the 2080s under the high impact scenario, the predicted 7Q2 at the eastern ridgeline of the watershed was only 26% of the existing 7Q2, while the baseflow of tributaries near the mouth was 90% of the existing 7Q2. This reflects a shift away from snow-dominant runoff at higher elevations. For the 7Q10 flows, the corresponding ratios were 53 and 94%.

Flows for direct groundwater inputs were analyzed in the same manner as the tributary flows, except that the ratio-based (or multiplicative) deltas are based on VIC output for subsurface flow only. For the portion of the lower SFNR that is a losing stream under low-flow conditions, the rates of water loss (which sum to about 6% of the total flow) were left unchanged.

Water Temperature Boundary Conditions

For future climate conditions the diel pattern or shape of the curve between the daily maximum and daily minimum temperature was assumed to remain unchanged; however, the daily maximum and daily minimum temperature were modified. These changes were represented by an additive delta change approach. That is, an absolute estimated change (in °C) is applied to both the maximum and minimum tributary water temperature.

The CIG climate analysis provides daily minimum and maximum air temperature; however, the VIC model does not predict stream water temperature. Therefore, an approach was developed to predict observed water temperatures using a regression model with CIG/VIC model output as explanatory variables. We fit the regression model by predicting observed temperatures in a number of SFNR tributaries monitored during the 2007 – 2012 period. The final predictive model combined the non-linear temperature regression model format used by Flint and Flint (2008, 2011) for the Klamath River Basin in northern California with additional findings from stepwise regression analysis of SFNR data. The final model (described in detail in the Quantitative Assessment) used drainage area, solar radiation, vapor pressure deficit, mean temperature, elevation, fraction of watershed in forest cover, and a day-of-year function to predict observed 7-day average minimum water temperature and 7-day average maximum water temperature in the SFNR tributaries.

The QUAL2Kw model also includes direct groundwater discharge to the SFNR, and the temperature of this discharge has an important impact on the heat balance in the river. Under future climate conditions, the groundwater inflow temperature was modified using an additive delta. To derive the delta, it is assumed that groundwater temperatures are ultimately proportional to annual average air temperatures with the superposition of an annual cycle that results in discharge temperatures that are a few degrees warmer than the annual average air temperature in the late-summer critical period. Therefore, the delta in the annual average air temperature was used to modify the groundwater inflow temperature.

Results of future climate simulations

In the Quantitative Assessment (Butcher et al., 2016), EPA developed a total of 18 climate scenarios using scenarios 3 (Existing Vegetation) and 5 (100-year SPV plus microclimate effect)) from the TMDL as starting templates to combine with high, medium, and low impact GCMs for climate conditions of the 2020s, 2040s, and 2080s (2 x 3 x 3 scenarios).

The QUAL2Kw model simulations suggest that, without restoration of riparian shade, maximum water temperatures during critical summer low-flow conditions could increase by between 3.4 to 5.9 °C (averaged across all river reaches) by the 2080s. Restoration of full system potential riparian shading (i.e., desired future conditions) can help buffer against temperature increases; however, even with system potential shade, the critical condition maximum 7-day average stream water temperatures are expected to increase by 1.1 to 3.6 °C by the 2080s. In conjunction with this increase, the percent of stream miles in which critical condition water temperatures exceed levels identified as potentially lethal to salmon is predicted by the model simulations to increase dramatically—from about 18% at present to between 60% and 94% in the 2080s, depending on the climate model.

Figure 76 shows projections of spatially averaged maximum water temperatures over time for the climate change scenarios with SPV. This indicates that the additional shading called for in the TMDL has the potential to buffer the effects of climate change on critical condition water temperature through the 2020s, but that a steady increase in water temperature is predicted to occur in future decades even with SPV. (This figure also shows that the ranking of climate scenarios as high, medium, and low impact is appropriate for the 2080s, but that in the 2020s the impacts are slightly greater under the “medium” impact scenario.)

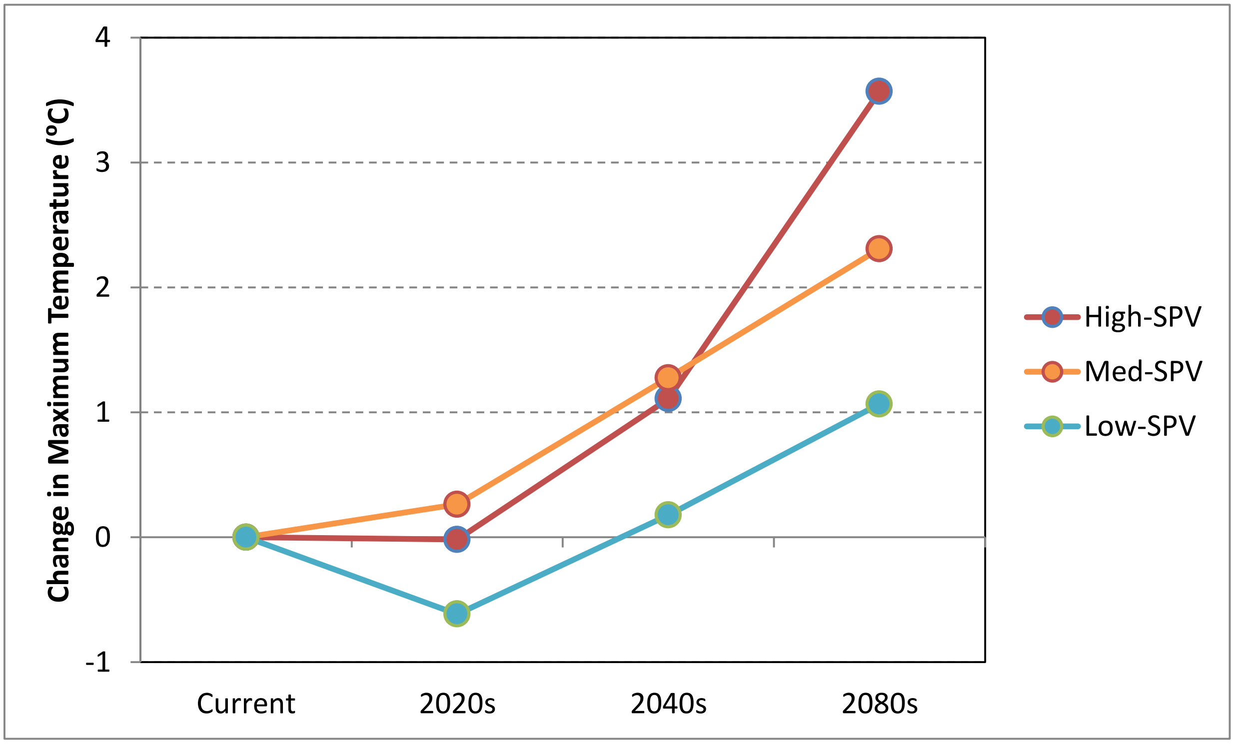

Figure 76. Change in spatially averaged maximum water temperature in the South Fork Nooksack River mainstem at critical conditions with SPV for three future climate emissions scenarios compared to existing TMDL conditions and vegetation.

Comparison of paired runs with and without SPV shows that the response to increased shade is not strongly dependent on climate. That is, increasing shade to SPV reduces 7-DADMax water temperature by about the same amount under existing climate as it does under future climate conditions. The climate change scenario, however, represents a new baseline against which this reduction occurs. In the end, the projected impacts of climate change do not change the shade allocation requirements, but do change the predicted critical condition water temperature that can be achieved.

The TMDL program intentionally focuses on infrequent, worst-case, or "critical" conditions, using 7-day average low flows that are expected to occur on average once every 10 years (7Q10 flows) and the 90th percentile of projected annual 7-day maximum air temperatures, as a way of ensuring that standards are met at almost all times. To estimate more typical summer periods of maximum stress, additional simulations evaluated responses to the 7-day average low flow that occurs once every two years (7Q2 flow) and the median projected annual 7-day maximum air temperature. Under these less stringent conditions, water temperatures through the 2080s, while increasing, are projected to generally remain below lethal thresholds when SPV is in place, with the possible exception of the most downstream reaches of the SFNR.

Discussion of climate change considerations for the TMDL

Climate change is projected to increase the maximum water temperatures in the watershed. Because the TMDL already calls for implementing system potential shade, incorporation of climate change into the TMDL analysis does not change the TMDL allocations. However, the climate change analysis does suggest the need for maximizing riparian shading beyond SPV assumptions.

While the climate analysis does not change the TMDL allocations for the SFNR, it does have implications for TMDL implementation as well as for broader watershed planning to support habitat for endangered salmonids. A TMDL is a regulatory requirement for addressing specific identified impairments and is not necessarily a complete strategy for preserving and enhancing valued resources. A TMDL's focus on critical conditions could obscure the need for practical management strategies that enhance and protect the resource under less extreme, but more frequently encountered conditions.

Evaluation of climate change vulnerability helps inform the implementation of the TMDL. Climate change is time dependent. The pace (timing/rate) and priorities of restoration actions for TMDL implementation to ameliorate potential impacts of climate change is a key component of an iterative risk management strategy, as recommended by the National Climate Assessment (Figure 77). A key finding of the Quantitative Assessment for the SFNR is that SPV can likely provide substantial resiliency into the future that will help protect designated uses, especially if combined with other actions that provide cold water refuges during high-temperature events.

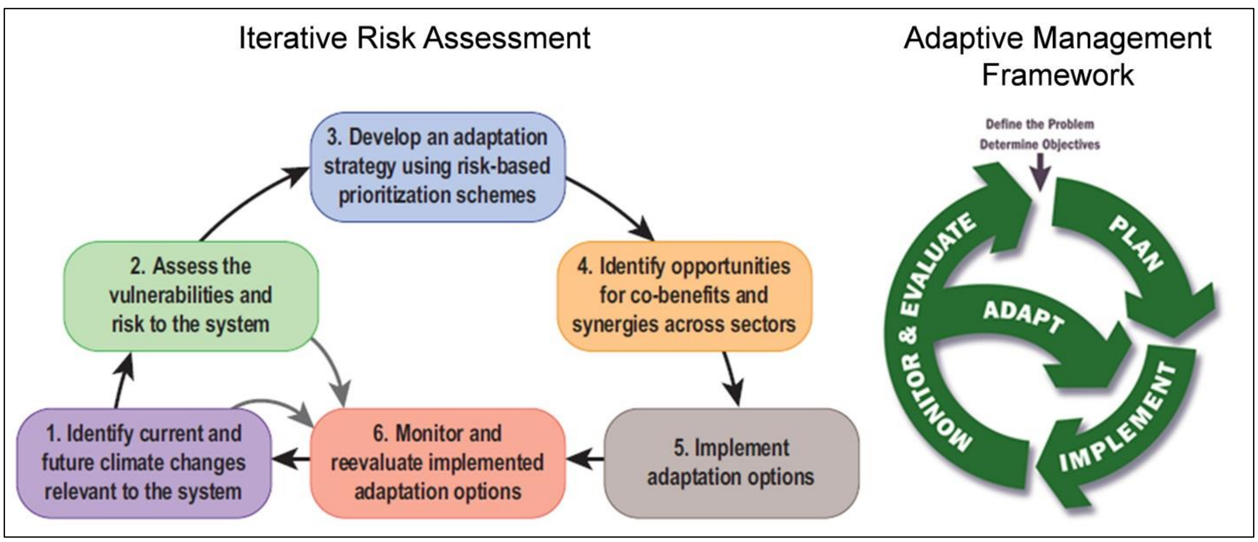

Figure 77. Climate change adaptation and iterative risk management (Yohe, 2011).

Several implications for restoration and management strategies are suggested in EPA's Quantitative Assessment. The modeling scenarios show that restoring system potential shade will have a strong beneficial impact on the summer temperature regime in the SFNR. Despite the benefits of increased riparian shade, future climate scenarios suggest that water temperature regimes will shift from those that are ideal for providing salmon habitat.

The model, however, predicts reach-average temperature on an approximately 1-km scale. The impact of occasional high-temperature events is in large part determined by whether the fish can find sufficient cold water refuges that are cooler than the reach-averaged conditions, and within their physiological tolerance ranges (Hannah et al., 2014). Thus, habitat management at a scale smaller than the spatial scale of the QUAL2Kw model segments can have an important role in protecting the resource. Therefore, the implementation plan combines system potential shade with other options that provide localized cooler habitat. In addition, watershed management that increases stream stability (and thus resulted in a narrowing of the treeless riparian zone) would further increase effective shade on the river and mitigate warming.

Beechie et al. (2012) addressed the question of protecting salmon habitat in the face of anticipated climate change for the 2080s, considering conditions similar to those projected for the SFNR—a decrease in summer low flows, an increase in maximum monthly flows, and stream temperature increases of between 2 and 6 ºC. They concluded that restoring floodplain connectivity, restoring streamflow regimes, and re-aggrading incised channels are most likely to ameliorate streamflow and temperature changes and increase habitat diversity and population resilience. EPA's Qualitative Assessment (summarized in the Implementation Plan section of this report) evaluates the extent to which these conclusions apply to the SFNR.

Summary of Public Involvement Methods

Ecology published in the Bellingham Herald, notification of the public comment period ending November 20. We also published a similar notice in the Cascadia Weekly. Both publications were printed on September 19, 2018,

Whatcom County Council was notified of the comment period at their meeting September 25, 2018 and an offer to present to the Natural Resources Committee will be extended.

Ecology made a presentation in the watershed in a forum open to the public, and publicly advertised as part of Whatcom Water Week. There were several requests for additional presentation to specific groups.

A copy of the document was available at Ecology's office and at the reference desk at the Deming Branch of the Whatcom County Library System.

Comments were collected using the Ecology E-comment web application.

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Appendices

Appendix A Glossary, acronyms, and abbreviations

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

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to 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 water bodies (ocean waters, estuaries, lakes, and streams) that fall short of state surface water quality standards and are not expected to improve within the next two years.

60Q2: the 60-day average low flow with an occurrence interval of 2 years.

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

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

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

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.
Anadromous: A term describing fish which migrate upstream to spawn.

Bankfull stage: Formally defined as the stream level that "corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels" (Dunne and Leopold, 1978).

Best management practices (BMPs): Physical, structural, 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.

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

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 (see definition) flow event unless determined otherwise by the department.

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.

Digitize: to convert an image to a digital format to allow for computer processing.

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-400.
https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-400

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 (for example, 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.

Exceeded criteria: Did not meet criteria.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

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

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

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

Longitudinal Connectivity: Connectivity of habitat along the length of a river.

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

Microclimate: local atmospheric zone where the climate is different from the surrounding area, namely in this case due to the impact of the stream.

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

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

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

Near-stream disturbance zone (NSDZ): The active channel area without 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.

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

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

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

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

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

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

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

Reach: A specific portion or segment of a stream.

Refugia: Isolated areas of protection provided to a species of interest. In context of this report, “cold water refugia” refers to the refuges created by unique factors along a river, such as root systems, eddies, etc.

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

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

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

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

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 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.

System potential: The design condition used for TMDL analysis.

System potential channel morphology: The more stable configuration that would occur with less human disturbance.
S**ystem potential mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

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

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

Thalweg: The line of lowest elevation within a river.

Total maximum daily load (TMDL): 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.

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

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

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

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

Acronyms and abbreviations

BMP	best management practice
CCAP	Coastal Change Analysis Program
CFR	Code of Federal Regulations
CID	Climate Information Group
CWA	Clean Water Act
DPS	distinct population segment
DTS	distributed temperature sensors
Ecology	Washington State Department of Ecology
ELJ	engineered log jam
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
ESU	evolutionarily significant unit
EVH	existing vegetation height
EVT	existing vegetation type
FEMAT	Forest Management Assessment Team
FLIR	Forward Looking Infrared thermal imagery
GCM	global climate model
GIS	geographic information system software
HPD	hourly precipitation data
IGAP	Indian General Assistance Grant
IP	implementation plan
IPCC	International Panel on Climate Change
LFS	low-flow frequency statistic
LiDAR	Light Detection and Ranging
MS4	municipal separate storm sewer systems
NAIP	National Agricultural Imagery Program
NCAP	North Cascadia Adaptation Partnership
NCDC	National Climatic Data Center
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSDZ	near-stream disturbance zone
ODEQ	Oregon Department of Environmental Quality
ORD	Office of Research and Development
OTIS	One-dimensional transport with inflow and storage
OW	Office of Water
Precip	precipitation
PNW	Pacific Northwest
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RCU	riparian condition units
RCW	Revised Code of Washington
RM	river mile

RMSE	root mean square error
RPD	relative perfect difference
SEPA	State Environmental Policy Act
SFNR	South Fork Nooksack River
SNOTEL	SNOwpack and TELemetry
SOD	summary of the day
SPV	system potential vegetation
SSURGO	Soil Survey Geographic database
TIR	thermal infrared radiation
TMDL	total maximum daily load (water cleanup plan)
Trib	tributary stream
TSS	total suspended solids
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
VIC	variable infiltration capacity
WAC	Washington Administrative Code
WDNR	Washington Department of Natural Resources
WQ	water quality
WQA	water quality assessment
WQIR	water quality improvement report
WQS	water quality standard
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WSU	Washington State University
WWTP	wastewater treatment plant

Units of Measurement

%	percent
#	number, count
°C	degrees centigrade
°F	degrees Fahrenheit
cfs	cubic feet per second
cm	centimeter
cm^2/s	square centimeter per second
ft	feet
ft/s	feet per second, velocity
m/s	meters per second, velocity
kcfs	1,000 cubic feet per second
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mi	mile
mi^2	square mile
mg	million gallons
mgd	million gallons per day

RM	river mile, distance along river from mouth
WY	water year, 12-month period from October 1 to September 30
W/m^2	Watts per square meters, heat load units

Appendix B Stream temperatures and criteria exceedances

Table B-1. 7-DADMax of stream temperatures in 2007 in the South Fork Nooksack River subbasin (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (°C)		# Days Exceeding Criteria	# Days Monitored	Temperature (°C)		# Days Exceeding Standard	# Days Monitored	Temperature (°C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2007 Monitoring														
SF0200	SFNR	Upstream of Wanlick Creek	25	11.0	12	0	61	16.0	12	56	42	14.9	12	17
SF0210	Wanlick Creek	Near SFNR confluence	25	10.1	12	0	61	14.3	12	50	42	13.0	12	15
SF0190	SFNR	Seattle City Light bridge	9	12.2	12	1	61	16.2	12	61	26	13.8	12	16
SF0180	SFNR	200 Rd Bridge	9	12.8	12	2	61	17.3	12	61	42	15.7	12	19
SF0153	SFNR	Larson`s bridge	11	13.7	12	6	61	18.6	12	61	26	16.6	12	25
SF0135	Deer Creek	140 Rd Bridge	11	13.3	12	3	61	16.3	12	61	36	13.7	12	16
SF0134	SFNR	New Bridge	9	14.3	13	3	53	19.5	16	47	21	17.8	13	21
SFT016	Cavanaugh Creek	1000 Puddles Trail	18	12.1	13	0	61	15.7	16	0	41	13.3	13	6
SFT015	Edfro Creek	1000 Puddles Trail	18	12.9	13	0	61	15.7	16	0	41	13.9	13	15
SF0130	Skookum Creek	USGS gage station	10	12.4	12	1	61	15.5	12	61	24	13.5	12	16
SF0075	SFNR	Downstream of Hutchinson Creek	24	15.2	13	11	61	19.9	16	57	34	18.6	13	26
SF0033	McCarty Creek	Upstream of Turkington Rd. bridge	24	12.8	16	0	61	15.8	16	0	34	13.5	16	0
SF0031	SFNR	Upstream of Kalsbeek along riprap	not monitored	--	13	--	29	20.2	16	29	31	18.7	13	26
SF0030	SFNR	Kalsbeek above culvert-downstream end	not monitored	--	13	--	58	20.2	16	55	31	18.4	13	26
SF0025	SFNR	Upstream of Todd Creek	7	15.8	13	7	26	20.2	16	23	not monitored	--	13	--

Table B-2. 2007 exceedances of water quality criteria (WQC) by location (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2007 Monitoring					
SF0200	SFNR	Upstream of Wanlick Creek	73	128	57%
SF0210	Wanlick Creek	Near SFNR confluence	65	128	51%
SF0190	SFNR	Seattle City Light Bridge	78	96	81%
SF0180	SFNR	200 Rd Bridge	82	112	73%
SF0153	SFNR	Larson's Bridge	92	98	94%
SF0135	Deer Creek	140 Rd Bridge	80	108	74%
SF0134	SFNR	New Bridge	71	83	86%
SFT016	Cavanaugh Creek	1000 Puddles Trail	6	120	5%
SFT015	Edfro Creek	1000 Puddles Trail	15	120	13%
SF0130	Skookum Creek	USGS gage station	78	95	82%
SF0075	SFNR	Downstream of Hutchinson Creek	94	119	79%
SF0033	McCarty Creek	Upstream of Turkington Rd. Bridge	0	119	0%
SF0031	SFNR	Upstream of Kalsbeek along riprap	55	60	92%
SF0030	SFNR	Kalsbeek above culvert-downstream end	81	89	91%
SF0025	SFNR	Upstream of Todd Creek	30	33	91%

[a] Percent Exceedance = (number of days exceeding WQC) / (total days monitored) x 100

Table B-3. Stream temperature as 7-DADMax for 2008 in the South Fork Nooksack subbasin (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description[a]	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2008 Monitoring														
08SF01	SFNR	Kalsbeek ELJ#1	3	13.2	13	1	61	19.8	16	33	21	18.8	13	21
08SF02	SFNR	Downstream of Kalsbeek ELJ#1	3	13.2	13	1	61	20.1	16	33	21	16.1	13	20
08SF03	SFNR	Kalsbeek side channel	3	13.3	13	3	14	17.9	16	7	not monitored	--	13	--
08SF04	SFNR	Kalsbeek ELJ#3	3	13.0	13	1	61	19.3	16	8	21	15.8	13	20
08SF06	SFNR	Kalsbeek bank roughness structure	3	13.2	13	1	61	19.8	16	33	21	15.8	13	20
08SF08	SFNR	Upstream of Todd Creek ELJ site	not monitored	--	13	--	52	20.0	16	34	9	15.9	13	9
08SF07	SFNR	Downstream of Todd Creek	3	13.4	13	2	61	20.0	16	34	21	15.4	13	20

[a] ELJ = engineered log jam projects that were implemented by the Nooksack Indian Tribe and designed in part to create temperature refuges for holding spring Chinook.

Table B-4. 2008 exceedances of Water Quality Criteria (WQC) by location (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description[b]	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2008 Monitoring					
08SF01	SFNR	Kalsbeek ELJ#1	55	85	65%
08SF02	SFNR	Downstream of Kalsbeek ELJ#1	54	85	64%
08SF03	SFNR	Kalsbeek side channel	10	17	59%
08SF04	SFNR	Kalsbeek ELJ#3	29	85	34%
08SF06	SFNR	Kalsbeek bank roughness structure	54	85	64%
08SF08	SFNR	Upstream of Todd Creek ELJ site	43	61	70%
08SF07	SFNR	Downstream of Todd Creek	56	85	66%

[a] Percent Exceedance = (number of days exceeding WQC) / (total days monitored) x 100

[b] ELJ = engineered log jam projects that were implemented by the Nooksack Indian Tribe and designed in part to create temperature refuges for holding spring Chinook.

Table B-5. Stream temperature as 7-DADMax for 2009 in the South Fork Nooksack subbasin (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2009 Monitoring														
405	SFNR	200 Rd Bridge	21	13.4	12	7	17	18.3	12	17	15	17.8	12	8
09SF01	SFNR	Downstream right bank erosion area (RM 24.2)	21	15.5	12	13	61	22.4	12	61	14	17.8	12	14
412	Deer Creek	140 Rd Bridge	21	14.0	12	16	61	18.0	12	61	14	14.1	12	14
09KB01	South Fork Nooksack River	Right bank at Kalsbeek on ELJ	not monitored	--	13	--	44	24.4	16	44	31	19.6	13	28
09KB02	SFNR	Right bank at Kalsbeek on small wood pile	not monitored	--	13	--	44	24.3	16	44	31	19.5	13	28
09TK02	SFNR	Right bank Tenaska at ELJ	not monitored	--	13	--	44	25.2	16	44	11	20.5	13	11
09TK03	SFNR	Left bank at Tenaska at ELJ 3	not monitored	--	13	--	44	13.7	16	0	31	13.7	13	11
09TK01	SFNR	Left bank at Tenaska at ELJ 1 in eddy	not monitored	--	13	--	32	23.8	16	32	31	19.9	13	28

Table B-6. 2009 exceedances of water quality criteria (WQC), by location (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2009 Monitoring					
405	SFNR	200 Rd Bridge	32	53	60%
09SF01	SFNR	Downstream right bank erosion area (RM 24.2)	88	96	92%
412	Deer Creek	140 Rd Bridge	91	96	95%
09KB01	SFNR	Right bank at Kalsbeek on ELJ	72	75	96%
09KB02	SFNR	Right bank at Kalsbeek on small wood pile	72	75	96%
09TK02	SFNR	Right bank Tenaska at ELJ	55	55	100%
09TK03	SFNR	Left bank at Tenaska at ELJ 3	11	75	15%
09TK01	SFNR	Left bank at Tenaska at ELJ 1 in eddy	60	63	95%

[a] Percent Exceedance = (number of days exceeding WQC) / (total days monitored) x 100

Table B-7. Stream temperature as 7-DADMax for 2010 in the South Fork Nooksack subbasin (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2010 Monitoring														
USWanlick	SFNR	Upstream of Wanlick Creek	not monitored	--	12	--	45	18.3	12	45	33	13.1	12	9
Wanlick10	Wanlick Creek	Wanlick Creek	not monitored	--	12	--	45	15.9	12	43	33	11.9	12	0
DSWanlick	SFNR	Downstream of Wanlick Creek	not monitored	--	12	--	45	17.4	12	45	33	12.7	12	3
406	SFNR	South Fork at Seattle City Light property	34	11.6	12	--	54	17.2	12	50	31	12.9	12	9
405	SFNR	South Fork at 200 Road Bridge	34	12.8	12	6	54	19.5	12	51	31	12.4	12	1
412	Deer Creek	Deer Creek	33	12.9	12	7	54	16.5	12	52	31	13.0	12	23
411	Plumbago Creek	Plumbago Creek	4	8.8	12	--	25	16.6	12	25	31	12.5	12	11
410	Cavanaugh Creek	Cavanaugh Creek	not monitored	--	13	--	44	22.3	16	44	34	16.5	13	27
409	Edfro Creek	Edfro Creek	32	12.3	13	--	59	16.3	16	4	48	13.4	13	8
413	Skookum Creek	Skookum Creek	25	11.6	12	--	54	14.7	12	50	53	12.2	12	3
403	SFNR	South Fork Nooksack Upstream Saxon Br.	35	13.6	13	5	54	20.2	16	45	27	15.5	13	19
408	Hutchinson Creek	Hutchinson Creek	34	12.8	12	8	54	15.2	12	52	27	12.9	12	20
402	SFNR	SF Nooksack DS of Hutchinson Creek	25	14.3	13	9	54	21.7	16	49	27	17.1	13	20
KALSUS10	SFNR	Kalsbeek Upstream of upper most ELJ	not monitored	--	13	--	51	22.0	16	51	40	17.4	13	28
KALSELJ110S	SFNR	Kalsbeek at upper logjam SURFACE	not monitored	--	13	--	51	22.2	16	51	39	17.3	13	30
KALSELJ110D	SFNR	Kalsbeek at upper logjam DEPTH	not monitored	--	13	--	51	21.4	16	51	39	16.9	13	29
KALSBA210S	SFNR	Kalsbeek #2 Bank Armor SURFACE	not monitored	--	13	--	51	21.6	16	51	39	16.9	13	30
KALSBA210D	SFNR	Kalsbeek at #2 Bank Armor DEPTH	not monitored	--	13	--	51	21.6	16	51	39	16.8	13	29
KALSBA410	SFNR	Kalsbeek #4 Bank Armor	not monitored	--	13	--	51	21.7	16	51	39	16.9	13	30

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2010 Monitoring														
KALSBA610S	SFNR	Kalsbeek #6 Bank Armor SURFACE	not monitored	--	13	--	51	21.6	16	51	39	16.8	13	30
KALSBA610D	SFNR	Kalsbeek #6 Bank Armor DEPTH	not monitored	--	13	--	51	21.6	16	51	39	16.9	13	20
TENASKUS10	SFNR	Tenaska Right bank Upstream of ELJ cabled to root wad	not monitored	--	13	--	51	22.4	16	51	41	17.6	13	34
TENASKELJ310S	SFNR	Tenaska cabled to 3rd ELJ in back water SURFACE	not monitored	--	13	--	51	17.6	16	35	38	15.4	13	30
TENASKELJ310D	SFNR	Tenaska cabled to 3rd ELJ in backwater DEPTH	not monitored	--	13	--	51	12.5	16	0	38	14.2	13	7
TENASKELJ110D	SFNR	Tenaska cabled to 1st ELJ in back water Depth	not monitored	--	13	--	51	18.7	16	42	38	15.4	13	29
VANZANUS10S	SFNR	Van Zandt Upstream of ELJ site SURFACE	not monitored	--	13	--	46	22.1	16	46	48	17.3	13	34
407	Black Slough	Black Slough	35	15.0	13	23	50	16.7	16	12	39	14.6	13	30
VANZANDS10S	SFNR	Van Zandt Downstream of ELJ sites SURFACE	not monitored	--	13	--	46	25.7	16	46	39	17.4	13	34
VANZANDS10D	SFNR	Van Zandt Downstream of ELJ sites Depth	not monitored	--	13	--	46	22.1	16	46	48	17.3	13	33
SF	SFNR	Van Zandt Downstream of ELJ sites DEPTH	not monitored	--	13	--	46	22.3	16	46	14	17.5	13	14

Table B-8. 2010 exceedances of water quality standards (WQC), by location (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2010 Monitoring					
USWanlick	SFNR	Upstream of Wanlick Creek	54	78	69%
Wanlick10	Wanlick Creek	Wanlick Creek	43	78	55%
DSWanlick	SFNR	Downstream of Wanlick Creek	48	78	62%
406	SFNR	South Fork at Seattle City Light property	59	119	50%
405	SFNR	South Fork at 200 Road Bridge	58	119	49%
412	Deer Creek	Deer Creek	82	118	69%
411	Plumbago Creek	Plumbago Creek	36	60	60%
410	Cavanaugh Creek	Cavanaugh Creek	71	78	91%
409	Edfro Creek	Edfro Creek	12	139	9%
413	Skookum Creek	Skookum Creek	53	132	40%
403	SFNR	South Fork Nooksack Upstream Saxon Br.	69	116	59%
408	Hutchinson Creek	Hutchinson Creek	80	115	70%
402	SFNR	SF Nooksack DS of Hutchinson Creek	78	106	74%
KALSUS10	SFNR	Kalsbeek Upstream of upper most ELJ	79	91	87%
KALSELJ110S	SFNR	Kalsbeek at upper ELJ SURFACE	81	90	90%

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2010 Monitoring					
KALSELJ110D	SFNR	Kalsbeek at upper ELJ DEPTH	80	90	89%
KALSBA210S	SFNR	Kalsbeek #2 Bank Armor SURFACE	81	90	90%
KALSBA210D	SFNR	Kalsbeek at #2 Bank Armor DEPTH	80	90	89%
KALSBA410	SFNR	Kalsbeek #4 Bank Armor	81	90	90%
KALSBA610S	SFNR	Kalsbeek #6 Bank Armor SURFACE	81	90	90%
KALSBA610D	SFNR	Kalsbeek #6 Bank Armor DEPTH	71	90	79%
TENASKUS10	SFNR	Tenaska Right bank Upstream of ELJ cabled to root wad	85	92	92%
TENASKELJ310S	SFNR	Tenaska cabled to 3rd ELJ in back water SURFACE	65	89	73%
TENASKELJ310D	SFNR	Tenaska cabled to 3rd ELJ in backwater DEPTH	7	89	8%
TENASKELJ110D	SFNR	Tenaska cabled to 1st ELJ in back water Depth	71	89	80%
VANZANUS10S	SFNR	Van Zandt Upstream of ELJ site SURFACE	80	94	85%
407	Black Slough	Black Slough	65	124	52%

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2010 Monitoring					
VANZANDS10S	SFNR	Van Zandt Downstream of ELJ sites SURFACE	80	85	94%
VANZANDS10D	SFNR	Van Zandt Downstream of ELJ sites Depth	79	94	84%
SF	SFNR	Van Zandt Downstream of ELJ sites DEPTH	60	60	100%

[a]Percent Exceedance = (# days exceeding WQC) / (total days monitored) x 100

Table B-9. Stream temperature as 7-DADMax for 2011 in the South Fork Nooksack subbasin (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C) Highest 7-DADMax	Temperature (C) WQ Criteria	# Days Exceeding Criteria	# Days Monitored	Temperature (C) Highest 7-DADMax	Temperature (C) WQ Criteria	# Days Exceeding Criteria	# Days Monitored	Temperature (C) Highest 7-DADMax	Temperature (C) WQ Criteria	# Days Exceeding Criteria
2011 Monitoring														
SFDSHUTC11	SFNR	Downstream of Hutchinson	not monitored	--	13	--	39	18.1	16	27	51	18.2	13	27
KALSBA711D	SFNR	Kalsbeek KBA7Depth	not monitored	--	13	--	34	17.6	16	31	52	18.1	13	28
KALSBA311S	SFNR	Kalsbeek KB03 Surface	not monitored	--	13	--	27	18.3	16	25	40	16.5	13	16
KALSBA311D	SFNR	Kalsbeek KB03 Depth	not monitored	--	13	--	34	18.4	16	32	52	18.0	13	28
KALSUS11	SFNR	Kalsbeek US 11	not monitored	--	13	--	34	18.5	16	32	52	18.2	13	28
KALSBA111S	SFNR	Kalsbeek ELJ 1 Surface	not monitored	--	13	--	34	19.0	16	32	52	18.8	13	28
KALSDS11	SFNR	Kalsbeek DS	not monitored	--	13	--	34	18.4	16	31	52	18.0	13	28
KALSBA111D	SFNRSFNR	Kalsbeek ELJ 1 Depth	not monitored	--	13	--	40	19.0	16	33	54	18.8	13	29
KALSBA711S	SFNRSFNR	Kalsbeek KBA7 Surface	not monitored	--	13	--	34	18.5	16	32	52	18.2	13	28
HRDSBLUS11	SFNR	Hardscrabble US	not monitored	--	13	--	33	18.7	16	32	53	18.1	13	28
HRDSBLDS11	SFNR	Hardscrabble DS	not monitored	--	13	--	33	18.6	16	32	53	18.1	13	28
TENASKUS11	SFNR	Tenaska US ELJ #5	not monitored	--	13	--	32	18.6	16	32	53	18.1	13	29
TENASKB411S	SFNR	Tenaska B4 Surface	not monitored	--	13	--	32	18.6	16	32	52	18.2	13	28
TENASKB411D	SFNR	Tenaska B4 Depth	not monitored	--	13	--	32	18.6	16	32	53	18.1	13	28
TENASKA711S	SFNR	Tenaska A7 Surface	not monitored	--	13	--	32	18.7	16	32	52	18.3	13	29
TENASKA711D	SFNR	Tenaska A7 Depth	not monitored	--	13	--	32	18.6	16	32	52	18.3	13	28

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria	# Days Monitored	Temperature (C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
2011 Monitoring														
TENASKA111S	SFNR	Tenaska A1 Surface	not monitored	--	13	--	32	18.1	16	17	52	19.9	13	29
TENASKA111D	SFNR	Tenaska A1 Depth	not monitored	--	13	--	32	14.9	16	0	51	15.8	13	26
TENASKDS11	SFNR	Tenaska DS 11	not monitored	--	13	--	32	18.8	16	32	52	18.4	13	29
BLKZANT11	SFNR	Van Zandt upper/lower Black Slough BLKZANT	not monitored	--	13	--	40	18.7	16	32	54	18.6	13	29
CTNWOOD11S	SFNR	Van Zandt Cottonwood Surface	not monitored	--	13	--	40	19.1	16	33	53	18.7	13	29
CTNWOOD11BW	SFNR	Van Zandt Cottonwood Backwater	not monitored	--	13	--	40	18.5	16	33	53	17.7	13	28
CTNWOOD11D	SFNR	Van Zandt Cottonwood Depth	not monitored	--	13	--	40	19.0	16	33	54	18.6	13	29
ELJ4VAN11S	SFNR	Van Zandt ELJ 4 Surface	not monitored	--	13	--	34	18.7	16	32	52	18.5	13	28
ELJ4VAN11D	SFNR	Van Zandt ELJ 4 Depth	not monitored	--	13	--	40	19.0	16	33	54	18.7	13	29
ELJ6VAN11S	SFNR	Van Zandt ELJ6 Surface	not monitored	--	13	--	40	19.1	16	33	54	18.7	13	29
ELJ6VAN11D	SFNR	Van Zandt ELJ6 Depth	not monitored	--	13	--	40	18.8	16	33	54	18.4	13	28
ELJ8VAN11S	SFNR	Van Zandt ELJ8 Surface	not monitored	--	13	--	40	19.0	16	33	54	18.7	13	29
ELJ8VAN11D	SFNR	Van Zandt ELJ8 Depth	not monitored	--	13	--	40	19.0	16	33	54	18.7	13	29
DSVANZAN11	SFNR	Van Zandt downstream	not monitored	--	13	--	40	19.0	16	33	53	18.7	13	32

Table B-10. 2011 exceedances of water quality standards (WQC), by location (collected by the Nooksack Indian Tribe).

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2011 Monitoring					
SFDSHUTC11	SFNR	Downstream of Hutchinson	54	90	60%
KALSBA711D	SFNR	Kalsbeek KBA7Depth	59	86	69%
KALSBA311S	SFNR	Kalsbeek KB03 Surface	41	67	61%
KALSBA311D	SFNR	Kalsbeek KB03 Depth	60	86	70%
KALSUS11	SFNR	Kalsbeek US 11	60	86	70%
KALSBA111S	SFNR	Kalsbeek ELJ 1 Surface	60	86	70%
KALSDS11	SFNR	Kalsbeek DS	59	86	69%
KALSBA111D	SFNR	Kalsbeek ELJ 1 Depth	62	94	66%
KALSBA711S	SFNR	Kalsbeek KBA7 Surface	60	86	70%
HRDSBLUS11	SFNR	Hardscrabble US	60	86	70%
HRDSBLDS11	SFNR	Hardscrabble DS	60	86	70%
TENASKUS11	SFNR	Tenaska US ELJ #5	61	85	72%

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2011 Monitoring					
TENASKB411S	SFNR	Tenaska B4 Surface	60	84	71%
TENASKB411D	SFNR	Tenaska B4 Depth	60	85	71%
TENASKA711S	SFNR	Tenaska A7 Surface	61	84	73%
TENASKA711D	SFNR	Tenaska A7 Depth	60	84	71%
TENASKA111S	SFNR	Tenaska A1 Surface	46	84	55%
TENASKA111D	SFNR	Tenaska A1 Depth	26	83	31%
TENASKDS11	SFNR	Tenaska DS 11	61	84	73%
BLKZANT11	SFNR	Van Zandt upper/lower Black Slough BLKZANT	61	94	65%
CTNWOOD11S	SFNR	Van Zandt Cottonwood Surface	62	93	67%
CTNWOOD11BW	SFNR	Van Zandt Cottonwood Backwater	61	93	66%
CTNWOOD11D	SFNR	Van Zandt Cottonwood Depth	62	94	66%
ELJ4VAN11S	SFNR	Van Zandt ELJ 4 Surface	60	86	70%

Station ID	Stream Name	Station Description	Total Days Exceeding WQC	Total Days Monitored	Percent Exceedance[a]
2011 Monitoring					
ELJ4VAN11D	SFNR	Van Zandt ELJ 4 Depth	62	94	66%
ELJ6VAN11S	SFNR	Van Zandt ELJ6 Surface	62	94	66%
ELJ6VAN11D	SFNR	Van Zandt ELJ6 Depth	61	94	65%
ELJ8VAN11S	SFNR	Van Zandt ELJ8 Surface	62	94	66%
ELJ8VAN11D	SFNR	Van Zandt ELJ8 Depth	62	94	66%
DSVANZAN11	SFNR	Van Zandt downstream	65	93	70%

[a]Percent Exceedance = (# days exceeding WQC) / (total days monitored) x 100

Table B-11. Stream temperature summary for USGS gage stations.

Station ID	Station Description	Year	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (°C)		# Days Exceeding Criteria	# Days Monitored	Temperature (°C)		# Days Exceeding Criteria	# Days Monitored	Temperature (°C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
12209000	SFNR near Wickersham, WA	2001	0	0	13	0	41	20.9	16	32	119	16.1	13	26
		2002	180	12.9	13	0	61	19.7	16	40	118	16.9	13	26
		2003	180	16.6	13	25	61	22.3	16	61	118	19.1	13	31
		2004	173	18.2	13	16	61	23.0	16	53	119	14.9	13	11
		2005	180	16.6	13	26	61	21.2	16	52	118	16.6	13	23
		2006	180	16.9	13	11	61	21.5	16	56	62	18.3	13	26
		2007	180	15.1	13	4	61	19.3	16	55	119	17.6	13	20
		2008	180	12.6	13	0	61	19.0	16	5	27	15.0	13	16
12209490	Skookum Creek above diversion near Wickersham, WA	2008	73	12.4	12	3	61	15.2	12	44	119	11.8	12	0
		2009	179	12.8	12	8	61	18.3	12	61	119	14.9	12	24
		2010	179	11.6	12	0	61	15.6	12	57	91	12.3	12	4
		2011	179	9.6	12	0	61	13.7	12	32	87	13.3	12	20
12210000	SFNR at Saxon Bridge, WA	2007	0	0	13	0	60	19.0	16	54	119	16.9	13	20
		2008	179	12.7	13	0	61	19.3	16	19	103	14.6	13	16
		2009	179	17.1	13	17	61	23.9	16	56	119	19.0	13	27
		2010	179	13.8	13	6	61	20.4	16	52	119	15.6	13	23
		2011	179	10.8	13	0	61	17.2	16	11	104	16.6	13	26
		2012	33	5.0	13	0	0	0	16	0	0	0	13	0

Table B-12. Stream temperature summary for Ecology gage stations.

Station ID	Station Description	Year	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (°C)		# Days Exceeding Criteria	# Days Monitored	Temperature (°C)		# Days Exceeding Criteria	# Days Monitored	Temperature (°C)		# Days Exceeding Criteria
				Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria			Highest 7-DADMax	WQ Criteria	
01C070	Hutchinson Creek near Acme	2003	16	12.4	12	5	61	12.7	12	30	119	11.2	12	0
		2004	168	13.0	12	15	61	13.5	12	61	119	12.7	12	7
		2005	179	12.4	12	7	61	13.2	12	45	119	11.0	12	0
		2006	165	13.6	12	13	61	13.6	12	49	119	11.4	12	0
		2007	179	10.7	12	0	61	11.6	12	0	119	10.4	12	0
		2008	180	10.9	12	0	61	11.4	12	0	119	10.6	12	0
		2009	179	10.6	12	0	61	11.4	12	0	119	10.1	12	0
		2010	179	10.5	12	0	61	11.4	12	0	119	11.0	12	0
		2011	179	10.8	12	0	61	11.7	12	0	27	10.4	12	0
01F070	SFNR at Potter Road	2003	16	18.1	13	16	61	23.1	16	61	119	20.7	13	37
		2004	174	19.5	13	22	61	23.7	16	54	119	15.9	13	23
		2005	179	18.0	13	45	61	22.6	16	54	119	18.2	13	29
		2006	179	18.9	13	12	61	23.0	16	61	119	19.8	13	40
		2007	179	15.1	13	12	61	19.2	16	49	119	15.7	13	24
		2008	180	12.9	13	0	61	18.0	16	16	119	14.0	13	15
		2009	179	15.6	13	31	61	14.9	16	0	119	14.2	13	18
		2010	179	11.8	13	0	61	13.9	16	0	28	12.9	13	0

Appendix C : Load allocations - South Fork Nooksack River

Table C-1. Load allocations for the effective shade in the South Fork Nooksack River for the condition of mature riparian vegetation for the calibration period (8/2/2007).
Note that the System Potential scenario here represents the condition in which the entire riparian area reaches SPV except currently developed areas/roads.

Reach	Significant Tributary or Landmarks	Reach Location as Distance from Headwaters (km)	Current Shade Conditions (%)	System potential shade (%)	Increase in shade needed	Load allocation for shortwave solar (watts/m^2)[a]
1	Wanlick Creek	0-1	51.0%	65.1%	14.1%	174.2
2		1-2	50.0%	62.0%	12.0%	185.5
3		2-3	43.6%	62.3%	18.7%	178.9
4		3-4	57.2%	66.1%	8.9%	164.8
5		4-5	49.1%	59.6%	10.5%	179.4
6		5-6	65.6%	75.7%	10.1%	110.3
7		6-7	50.2%	60.5%	10.3%	176.7
8		7-8	44.9%	57.1%	12.2%	188.5
9		8-9	43.3%	54.7%	11.4%	191.0
10		9-10	43.8%	56.3%	12.6%	193.6
11		10-11	40.6%	60.2%	19.5%	180.3
12		11-12	43.9%	50.4%	6.5%	223.0
13		12-13	43.5%	53.4%	9.8%	191.6
14		13-14	43.4%	52.5%	9.1%	216.8
15		14-15	41.2%	54.2%	13.1%	202.5
16		15-16	52.6%	65.0%	12.4%	159.5
17		16-17	49.0%	61.0%	12.0%	179.7
18		17-18	34.9%	62.3%	27.5%	174.4
19		18-19	55.6%	69.1%	13.4%	143.9
20		19-20	45.5%	60.4%	14.8%	178.7
21		20-21	40.7%	56.4%	15.7%	194.6
22		21-22	35.1%	52.2%	17.1%	205.1
23		22-23	43.3%	56.7%	13.4%	195.2
24		23-24	39.1%	50.2%	11.1%	208.6
25		24-25	29.5%	41.8%	12.3%	245.8
26		25-26	38.4%	46.8%	8.4%	229.0
27		26-27	37.6%	51.6%	14.0%	214.8
28		27-28	39.8%	53.1%	13.3%	209.3
29		28-29	60.0%	67.3%	7.3%	159.2
30		29-30	54.1%	64.2%	10.1%	168.1

Reach	Significant Tributary or Landmarks	Reach Location as Distance from Headwaters (km)	Current Shade Conditions (%)	System potential shade (%)	Increase in shade needed	Load allocation for shortwave solar (watts/m^2)[a]
31		30-31	55.5%	61.3%	5.8%	184.3
32		31-32	66.2%	73.5%	7.4%	127.0
33		32-33	52.6%	63.6%	11.0%	167.6
34		33-34	55.3%	65.8%	10.5%	164.6
35		34-35	42.9%	54.4%	11.5%	208.3
36	Skookum Creek	35-36	48.3%	62.4%	14.1%	176.1
37		36-37	48.7%	57.8%	9.1%	180.3
38		37-38	29.7%	40.4%	10.7%	252.5
39		38-39	34.6%	39.7%	5.1%	251.2
40		39-40	44.5%	50.0%	5.5%	224.3
41		40-41	41.7%	50.7%	9.0%	220.8
42	Hutchinson Creek	41-42	34.7%	42.1%	7.5%	251.9
43		42-43	39.4%	48.1%	8.6%	221.1
44		43-44	35.1%	50.4%	15.3%	217.8
45		44-45	45.0%	52.6%	7.6%	200.8
46		45-46	44.1%	57.8%	13.7%	175.0
47	Acme	46-47	44.0%	57.2%	13.2%	189.1
48		47-48	39.0%	47.4%	8.4%	236.6
49		48-49	44.0%	47.9%	3.9%	227.4
50		49-50	43.2%	52.2%	9.0%	214.9
51		50-51	44.4%	50.9%	6.5%	220.3
52		51-52	48.3%	50.6%	2.3%	217.6
53		52-53	34.9%	46.0%	11.1%	236.4
54		53-54	39.7%	47.4%	7.7%	223.5
55	Black Slough	54-55	38.4%	51.6%	13.2%	216.7
56		55-56	32.7%	40.8%	8.2%	249.7
57		56-57	47.0%	50.5%	3.5%	220.7
58		57-57.8	48.8%	55.7%	6.9%	199.7

[a] These results are based on Shade Model outputs of daily average solar radiation below riparian vegetation.

Appendix D : Load allocations - South Fork Nooksack River tributaries

Table D-1. Load allocations for effective shade based on 100-year potential vegetation: height=50.66 m, density=85%, overhang = 3 m.

Bankfull width (meters)	Effective shade from vegetation (%) at the stream center at various stream aspects (degrees from N)			Daily average global solar shortwave radiation (W/m^2) at the stream center at various stream aspects (degrees from N)		
	0 to 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 to 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
1	97.3%	97.9%	98.3%	8	6	5
2	97.1%	97.8%	98.1%	9	7	6
3	97.0%	97.6%	97.9%	9	7	6
4	96.3%	97.0%	97.5%	11	9	7
5	95.5%	96.2%	97.2%	13	11	8
6	94.3%	95.2%	96.8%	17	14	9
7	92.6%	94.4%	96.2%	22	17	11
8	90.7%	93.4%	95.7%	28	19	13
9	88.6%	91.8%	94.6%	34	24	16
10	85.9%	89.2%	92.8%	42	32	21
11	82.8%	86.3%	90.8%	51	41	27
12	79.6%	83.7%	88.7%	61	48	34
13	76.9%	81.1%	86.4%	68	56	40
14	74.3%	78.7%	84.0%	76	63	48
15	72.1%	76.5%	81.6%	83	70	55
20	62.7%	66.6%	69.3%	111	99	91
25	55.6%	58.9%	56.2%	132	122	130
30	50.1%	52.5%	43.9%	148	141	166
35	45.3%	47.2%	38.4%	162	156	183
40	41.5%	42.7%	34.2%	173	170	195

Note: For streams with a channel width less than 6 m, 100-year vegetation of 50.66 m, 85% canopy cover, and 3 m overhanging vegetation provide the required shading because the assumed overhanging vegetation will cover the stream.

Appendix E Record of public participation

Display advertisements in the Bellingham Herald (Figure E1) and Cascadia Weekly (Figure E2) notified the public about the availability of the comment period for the Draft South Fork Nooksack River Temperature Total Maximum Daily Load. The advertisements provided links to a description of the project and instructions on how to submit comments using the E-comment web application.

Steve Hood spoke during the Open Session (Figure E3) of the council meeting held on September 25, 2018. He advised the Whatcom County Council of the comment period, and offered to return to address the Natural Resources Committee if invited. The council clerk received a copy of the document.

The Whatcom County Library Deming Branch kept a copy in the Reference section for public access by residents of the South Fork Nooksack River.

Steve Hood made presentations (see copy of slides in figure E4) to several groups on the dates identified in Table E1. At each presentation, the group received a copy of the document. The first presentation to the South Fork Watershed Education Committee Community Forum (figure E5) was advertised as part of Whatcom Water Week (figure E6) a week of events (September 14 to September 22) promoted by the Whatcom Water Information Network, on education about water issues.

Table E1 – Groups, Dates, and Locations of presentations

Group	Date	Location
South Fork Watershed Education Committee Community Forum	September 19, 2018	Van Zandt Community Center
WRIA 1 Staff Team	September 23, 2018	Civic Building, Garden Room
Nooksack Indian Tribe, Natural Resources Staff	October 15, 2018	Nooksack Indian Tribe, Natural Resource Office
Lummi Nation Natural Resources	October 23, 2018	Lummi Indian Business Council Office

Oregon hiker likely killed by cougar, authorities say

BY GILLIAN FLACCUS
Associated Press

PORTLAND, ORE.

Authorities say a dead hiker whose body was recovered this week was likely killed by a cougar, marking the first fatal attack by a wild cougar in Oregon and the second in the Pacific Northwest this year.

Search and rescue teams found the body of Diana Bober, 55, on Monday off a trail in the Mount Hood National Forest in Welches, about 40 miles southeast of Portland. Her body was several miles from where searchers found her car last week near a ranger station.

In May, a mountain biker in Washington state was killed by a cougar on a trail east of Seattle, the first fatal attack in that state in 94 years.

Bober, an avid hiker who often trekked in the Mount Hood and Columbia River Gorge area, was last heard from by family and friends on Aug. 29. She was reported missing Friday and it's still unclear when she started her hike, said Sgt. Brian Jensen of the Clackamas County Sheriff's Office.

Her body had injuries consistent with a cougar attack and a medical examiner ruled out the possibility that she was mauled after she died of another cause, Jensen said. DNA samples collected at the scene were being flown by the Oregon State Police to a U.S. Fish and Wildlife Service laboratory for further analysis, he said.

Authorities warned a local school district of the attack and advised hikers to stay out of the area.

Oregon wildlife officials are trying to find and kill the animal, he said.

"This is an unprecedented event in Oregon," said Brian Wolfer, watershed manager for the Department of Fish and Wildlife. "We don't know what risk it poses to the public."

Cougar sightings are relatively common in Oregon, particularly in more rural areas, but Bober's death appears to be the first fatal attack.

There are about 6,600 cougars - also called commonly called mountain lions or pumas - throughout Oregon. State wildlife officials get about 400 complaints about the animals each year, authorities said.

Cougars can be killed by landowners or law enforcement officials when they pose a threat to human safety. Over the past decade, about 20 cougars have been killed each year in the area where Bober's body was found.

DEPARTMENT OF ECOLOGY

Comments requested on South Fork of the Nooksack River water quality report

The South Fork of the Nooksack River is home to all [illegible] native Pacific Northwest salmon and trout species. In the summer, the water is too warm to be healthy for these fish.

Ecology, with the help of contractors hired by EPA and the Nooksack Indian Tribe, studied what would restore cooler temperatures to the river. Now Ecology is seeking public review and comments on the report before submitting it to the U.S. Environmental Protection Agency.

Your written comments are encouraged during the public comment period ending November 20, 2018.

Public comment period Sep. 12 to Nov 20, 2018

Review the plan at:
- Department of Ecology [illegible] Way, [illegible] Bellingham Washington
- Deming Public Library
- Ecology website [illegible]
- Enter your comments at [illegible]

Written comments may also be mailed to Steve Hood, Department of Ecology, [illegible] Way, Suite [illegible], Bellingham, WA [illegible], or email at [illegible]

- Following the public comment period, Ecology will submit the water quality improvement report to EPA for approval. This approved plan will guide subsequent cleanup activities.
- A summary of the project, providing some of the background material, is available at [illegible]
- For more information, please call Steve Hood at 360 [illegible], or e-mail [illegible]

OBITUARIES

Figure E1 – Cut sheet from Bellingham Herald September 9, 2018

citizens that we enjoy will be our children as well, that they :xperience life, liberty and pur- ppiness.

; represented well, and now we ıpport her. That's why I'm voting e Van Werven Nov. 6.

—*Sally Mickley, Lynden*

ƦSHIP FOR VE CHANGE

ting for James Erb to be our next County Prosecuting Attorney. secuting Attorney's office repre- nty government in all civil and natters and is one of the most and powerful elected positions ınty. Here are two reasons why I for James:

of experience: James has 14 ıerience in several different ju- ; prosecuting criminal misde- nd serious felonies and advising/ ng local governments and train- ɔn complex civil matters. His op- s 25 years' experience in criminal , and his professional working life in only one jurisdiction working umbent prosecuting attorney.

hip for positive change: From the his campaign, James addressed jail" issue (twice rejected by the identifying the expense of lock- nviolent people, and proposing :-effective alternatives like full ı of the Drug Court, better men- services and bail reform. Only se alternatives are established ɔw the true size and cost of the ʋe need. His opponent has dem-

DEPARTMENT OF ECOLOGY State of Washington

Comments requested on South Fork of the Nooksack River water quality report

The South Fork of the Nooksack River is home to all nine native Pacific Northwest salmon and trout species. In the summer, the water is too warm to be healthy for those fish.

Ecology, with the help of contractors hired by EPA and the Nooksack Indian Tribe, studied what would restore cooler temperatures to the river. Now Ecology is seeking public review and comments on the report before submitting it to the U.S. Environmental Protection Agency.

Your written comments are encouraged during the public comment period ending November 20, 2018.

- Following the public comment period, Ecology will submit the water quality improvement report to EPA for approval. This approved plan will guide subsequent cleanup activities.
- A summary of the project, providing some of the background material, is available at https://ecology.wa.gov/southNooksack
- For more information, please call Steve Hood at 360-255-4396, or e-mail steve.hood@ecy.wa.gov.

Public comment period Sep. 12 to Nov 20, 2018

Review the plan at:

- Department of Ecology 919 Squalicum Way, #101 Bellingham Washington
- Deming Public Library
- Ecology website: **https://fortress.wa.gov/ecy/publications/summarypages/1810021.html**
- Enter your comments at: **http://ws.ecology.commentinput.com/?id=SMW9f**

Written comments may also be mailed to Steve Hood, Department of Ecology, 919 Squalicum Way, Suite 101, Bellingham, WA 98225, or email at steve.hood@ecy.wa.gov.

Figure E2 – Cut Sheet from Cascadia Weekly September 9, 2018

COUNCIL AGENDA

REGULAR COUNCIL MEETING
7 p.m. Tuesday, September 25, 2018
Council Chambers, 311 Grand Avenue

CALL TO ORDER
ROLL CALL
FLAG SALUTE
ANNOUNCEMENTS

If you will be handing out paperwork to councilmembers, please give one copy to the clerk for our office files. Thank you.

MINUTES CONSENT

1. Committee of the Whole for September 11, 2018
   Pages 256-257
2. Special Committee of the Whole for September 11, 2018
   Pages 258-261
3. Regular County Council for September 11, 2018
   Pages 262-270

PUBLIC HEARINGS
Audience members who wish to address the council during a public hearing are asked to sign up at the back of the room before the meeting begins. The council chair will ask those who have signed up to form a line at the podium. Each speaker should state his or her name for the record and will be given three minutes to address the council. Council staff will keep track of time limits and inform speakers when they have thirty seconds left to conclude their comments. When a large group of individuals supports the same position on an issue, we encourage the selection of one or two representatives to speak on behalf of the entire group.

1. Resolution authorizing the sale of Whatcom County surplus property pursuant to Whatcom County Code 1.10 (AB2018-211A)
   Pages 271-276
2. Ordinance adopting amendments to the Whatcom County Comprehensive Plan and Whatcom County Code Title 24, Health Code (relating to water resources and the implementation of ESSB 6091) (AB2018-253)
   Pages 277-295
3. Request for public comment and Council action on a request to authorize the County Executive to enter into an interlocal agreement between Whatcom County and the City of Bellingham to purchase inclement weather protective gear from funds provided by the Edward Byrne Memorial Justice Assistance Grant Program, in the amount of $13,223 (AB2018-257)
   Pages 296-307
4. Resolution approving the Whatcom County Six-Year Transportation Improvement Program for the years 2019 through 2024 (AB2018-250)
   Pages 308-435

OPEN SESSION (20 MINUTES)
During open session, audience members can speak to the council on any issue not scheduled for public hearing. Each speaker should state his or her name for the record and will be given three minutes to address the council. Council staff will keep track of time limits and inform speakers when they have thirty seconds left to conclude their comments.

5

Figure E3 – Council agenda from September 25, 2018

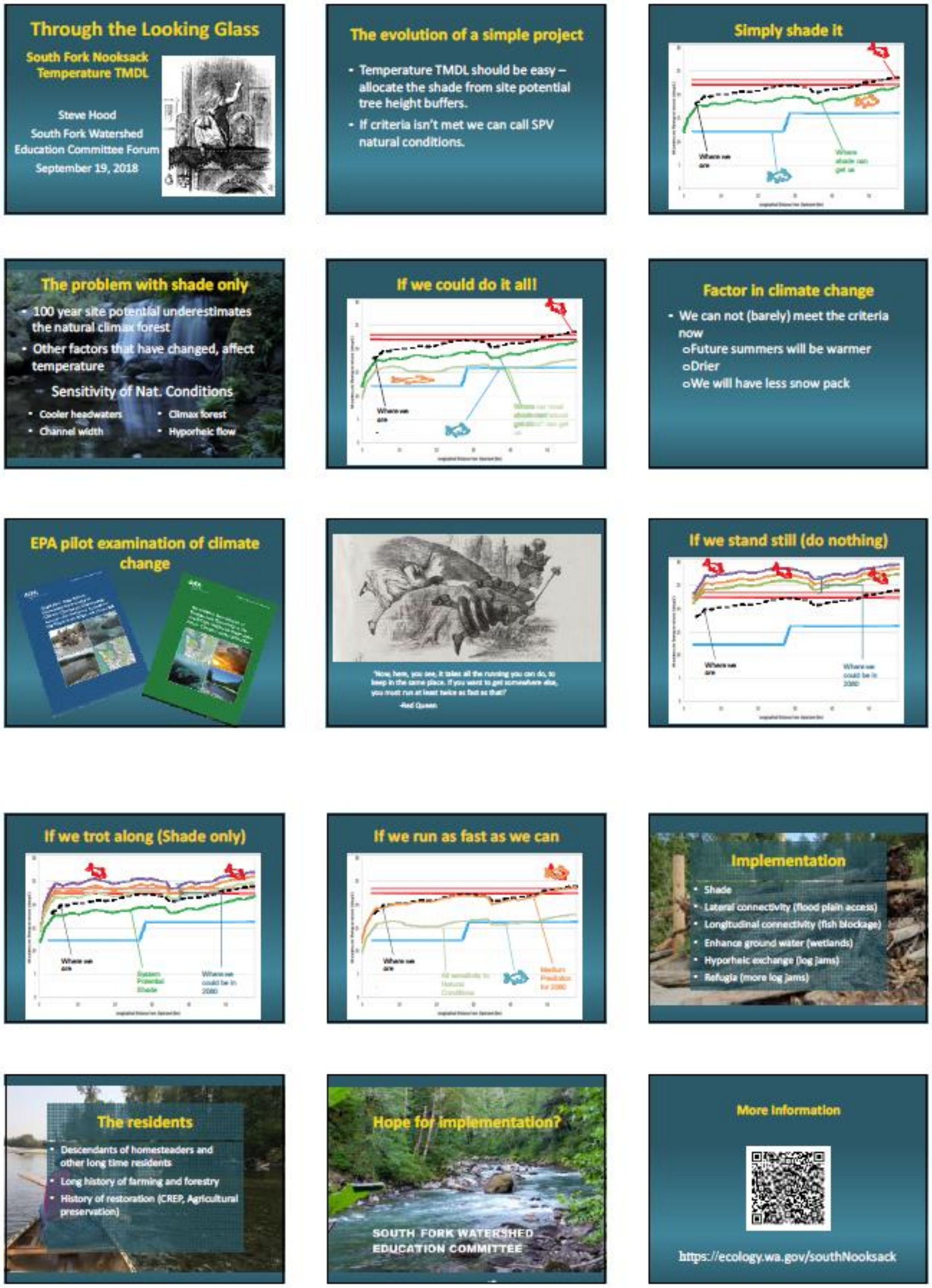


Figure E4 – Copy of presentation slides

Today's Program

6:30 – Doors Open
6:45 – Opening Remarks
7:00– Steven L. Hood, P.E.
8:00 – Q&A
8:25 – Closing Remarks

The South Fork Community Forum Series provides quarterly educational events bringing knowledgeable speakers together with local residents to explore the challenges that threaten our South Fork Nooksack Watershed. Watch out for future forums on other topics and let us know what issues you are interested in by filling out the feedback section!

Today's Speaker

Steven L. Hood, P.E.
Water Quality Engineer
WA Dept. of Ecology

Steve Hood is an environmental engineer who has worked for the Department of Ecology for 20 years. He has worked on cleanup plans for bacteria in the Nooksack watershed, and phosphorus in Lake Whatcom. His work in the South Fork of the Nooksack goes back nearly 30 years to when he worked for Crown Pacific, Ltd. as a forest engineer. As a multi-generation native of Whatcom County he shares and appreciates the sense of place with the residents of the South Fork.

This Community Forum Series made possible by:

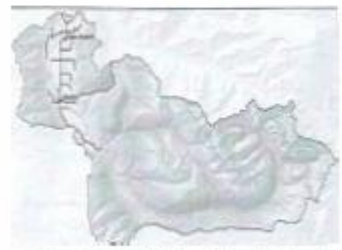
Whatcom Community Foundation Project Neighborly Grant

We'd also like to recognize the following for their help with this event:
Acme Diner
Three Rivers Educational Cooperative
South Fork Valley Community Association
Mt. Baker School District
Deming Library
Acme Elementary
All volunteers of the SFWEC

South Fork Watershed Education Committee
Community Forum Series

Water Temperature In the South Fork

September 19, 2018
6:30 pm - 8:30 pm

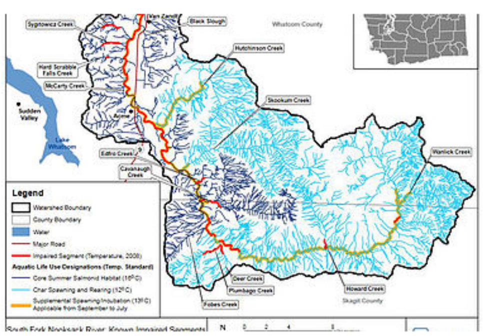


Picture: South Fork Nooksack River Watershed

Mission Statement

Our intent is to educate ourselves and our community concerning watershed topics for the South Fork of the Nooksack River in order to increase self-determination related to current and future water use and quality issues.

Figure E5 – Simplified program for South Fork Watershed Education Committee Community Forum on September 19, 2018



September 19, 2018

Education Forum: Temperature TMDL on the South Fork

6:30pm, Van Zandt Community Hall

The South Fork Watershed Education Committee is pleased to host the next forum in our ongoing watershed education series. Steve Hood from the Department of Ecology (DOE) will present information on DOE's recommendations for temperature total maximum daily load (TMDL) on the South Fork of the Nooksack River. Adults and children are welcome. Childcare available. Event at the Van Zandt Community Hall.

September 19, 6:30pm, Van Zandt Community Hall. Contact Cindy Fabbri cfabbri1081@gmail.com

Figure E6 – Clip from https://www.whatcomwaterweeks.org/events on 12-12-2018

Appendix F Response to public comment

Ecology received comments from two individuals, one agency and one Tribe. The full text of the comment is reproduced below. Salutations and closings have been removed and formatting where appropriate has been reproduced. Ecology's response follows the comment.

Comment From: Anonymous - Individual

I-1-1

The South Fork Nooksack River TMDL publication has no information answering the question: Why should someone bother to address all of the suggested areas to reduce water temperature if those efforts aren't going to reduce river temperature enough anyway to get the river back to where it needs to be for the salmon.

Response To: Anonymous - Individual

I-1-1

Information on why we can hope that salmon can adapt if we give them a chance will be included in the introductory background section of the document.

Comment From: Donna Gawron - Individual

I-2-1

I strongly urge the EPA to approve the recommendations put forward in this report and begin implementation of the measures without delay. I am 67 years old. If only my generation had listened to Rachel Carson in the 60's and Bill McKibben in the 80's, and how many others that I don't even know about. If only we had acted then on what they discovered and predicted. Decades lost. Species lost. I am so sorry we didn't do better. We've been living beyond our means – beyond the ability of this beautiful planet to heal itself and support the inconceivably diverse, magnificent life forms that grace us. The salmon didn't cause this problem. We did. The salmon can't fix this problem. We can – at least we can start by restoring the habitat that is essential to their survival. Approve these measures. Act now. Do more. Not for me, but for the salmon and for our future generations so that they may experience at least some of the beauty and bounty of this land that my generation so casually squandered. I am so sorry we didn't do better.

Response To: Donna Gawron - Individual

I-2-1

Thank you for your response. EPA has been a close partner and Ecology believes that EPA will approve the TMDL.

Comment From: Elsa Pond/Kenneth M. Stone - WSDOT

A-1-1

While we understand thermal loading from stormwater running off state highways is minimal during the critical period in this watershed, interagency coordination during Total Maximum Daily Load (TMDL) development remains important to prevent confusion. TMDLs affect the Washington State Department of Transportation (WSDOT) National Pollutant Discharge Elimination System and State Waste Discharge Municipal Stormwater General Permit (Permit). WSDOT works to coordinate with Ecology TMDL Leads to ensure consistent and appropriate language is used to prevent confusion. Currently there are 28 TMDLs in WSDOT's Permit and three more will be added to our 2019 Permit. WSDOT is also attempting to track over 30 TMDLs or related efforts currently under development statewide. Tracking developing TMDL efforts is challenging due to limited resources and variabilities in Ecology's TMDL development processes. Proactive stakeholder coordination by Ecology is essential.

WSDOT’s Environmental Services Office has been checking in with Ecology annually requesting updates on the development status of the South Fork Nooksack River Temperature TMDL. The last annual update we received in December of 2017 stated that Ecology was awaiting review of a communication plan and then stakeholder outreach would begin. Ecology also stated, "we should not be including WLA for stormwater dischargers" due to the minimal stormwater discharges during the critical season. Based on these annual updates, and the fact that the watershed boundary is fully outside permit coverage area, WSDOT had been tracking this TMDL as a low priority. WSDOT understands that TMDL strategies often change during the development process, which is why stakeholder outreach and coordination is important. Unfortunately, we were not invited to participate in stakeholder meetings for this TN-IDL nor were we notified when the draft 'IMDL was released for public comment. WSDOT became aware that the draft TMDL was out for public comment during Ecology's annual TMDL Prioritization webinar. We would like to provide the following specific comments on the draft TMDL:

1) Page 24, second paragraph:

The Washington State Department of Transportation (WSDOT) holds a Phase I MS4 permit in the watershed. In March 2012, Ecology issued a new modified permit to WSDOT. This permit addresses stormwater discharges from WSDOT MS4s in areas covered by the Phase I Municipal Stormwater Permit, the Eastern Washington Phase II Municipal Stormwater Permit, and the Western Washington Phase II Municipal Stormwater permit. WSDOT highways, maintenance facilities, rest areas, park and ride lots, and ferry terminals are covered by this permit when a WSDOT-owned MS4 conveys the discharges.

Comment: This language is incorrect. WSDOT does not hold a Phase I MS4 permit in the watershed. WSDOT holds a General MS4 permit which applies in NPDES Phase I and II permit coverage areas. Additionally, our current permit was issued in March 2014 not 2012.

Recommendation: Edit the draft language above to state:

WSDOT's MS4 permit does not cover stormwater discharges in the watershed because it is fully outside WSDOTs permit coverage area.

2) Page 24, third paragraph:

WSDOT has a 2011 Highway Runoff Manual that provides tools for designing stormwater collection, conveyance, and treatment systems for transportation-related facilities. This manual has been approved by Ecology as functionally equivalent to the Stormwater Management Manual for Western Washington and is at www.wsdot. wa.gov/Environment/WaterQuality/RunoffHighwayRunoffManual. htm

Comment: This information is relevant because we implement the HRM statewide, regardless of permit coverage. The HRM instructs our designers to select best management practices that will minimize impacts to impaired waters based on the pollutant of concern. Our current HRM was published in 2016, but we require new projects to use the most recent version. Additionally, the link provided in the draft does not work.

Recommendation: Edit the draft language to state:

WSDOT implements the Highway Runoff Manual statewide. The manual provides tools for designing stormwater collection, conveyance, and treatment systems for transportation-related facilities. This manual has been approved by Ecology as functionally equivalent to the Stormwater Management Manual for Western Washington. The most recent version can be found: https://www.wsdot.wa.gov/Publications/Manuals/M31-16.htm

3) Page 144, second paragraph:

Wasteload allocations are necessary for permitted stormwater discharges if they are a source of pollutant loading to the stream when receiving water temperatures are impaired The SFNR watershed has permitted stormwater sources discharging into its mainstem or tributaries. ***The largest Source of permitted stormwater is WSDOT.*** *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 discharges to any water body in the state for which there is an EPA-approved TMDL with* ***load allocations*** *and associated implementation documents specifying actions for WSDOT stormwater discharges.*

Comment: The bolded information from the draft TMDL referenced above is incorrect. WSDOT agrees that wasteload allocations are necessary for permitted stormwater discharges if they are a source of pollutant loading. However, as stated in comment 1, WSDOT's MS4 permit does not cover this watershed and therefore cannot be the largest source of permitted stormwater. As such, WSDOT should not be issued a WLA especially if there is no data to suggest we are a significant contributor. This comment is supported by past TMDLs (e.g. „ Palouse River Temperature TMDL) as well as the directive from the Environmental Protection Agency commonly known as the "Wayland memo" which states, "EPA expects TMDL authorities to make separate allocations to NPDES-regulated storm water discharges (in the form of WLAs) and unregulated storm water (in the form of LAs)." Furthermore, the reference to "load allocations" in the last sentence is not correct (it should be wasteload allocations).

Recommendation: Delete all references to WSDOT in this paragraph in the subsection titled "Stormwater Wasteload Allocations" it inaccurately described WSDOT permit and is inappropriate.

If Ecology believes WSDOT's MS4 permit should be described in the TMDL it should be described correctly in an appropriate section. Refer to the language found in WSDOT's MS4 permit Special Condition S1.B.

4. **Comment**: As consistent with comment 3 above, WSDOT should be assigned a load allocation (LA) instead of WLA.

Recommendation: Assign WSDOT a LA and delete references to WSDOT being assigned a WLA.

Response To: Elsa Pond/Kenneth M. Stone - WSDOT

A-1-1

The intent on the overall stormwater WLAs was to remove assigning a WLA to all stormwater permittees. The failure to remove the language regarding WSDOT was an oversight. Ecology has moved discussion of WSDOT stormwater to the load allocation and nonpoint sections and explained why WSDOT is not a point source.

The failure to notify WSDOT prior to the public comment period for clarification is entirely the fault of the primary author. Please accept my apologies.

Comment From: Oliver Grah - Nooksack Indian Tribe

T-1-1

The Nooksack Indian Tribe appreciates this opportunity to provide these technical comments on the DRAFT SFNR temperature TMDL.

The Tribe initiated technical engagement in the TMDL project in August 2011. At that time we offered the following comments. If the TMDL is applied as a tool to address pollution in the SFNR, in order for the TMDL to be effective it must address the following:

- Climate change
- Upland watershed processes
- Realistic natural conditions
- Focus on impacts to fish - the designated or beneficial use; not just the CWA numeric criteria

We provided at least two sets of comprehensive review comments on earlier preliminary drafts of the TMDL, the most recent was on June 3, 2015. We incorporate those comments by reference.

We worked with the EPA Region 10, EPA-ORD, and Ecology to address these comments from August 2011 through until October 2016 when our involvement on EPA's Climate Change Pilot Research Project was completed. That pilot research project was designed and executed to support the TMDL, even though the three EPA reports on the pilot project were issued well before the date of issuance of the Draft TMDL in September 2018. In general, we believe the regulatory agencies did a reasonable job of addressing our comments except as noted below.

We appreciate the close positive collaborative relationship we developed with Ecology, EPA Region 10, EPA-ORD and their consultant Tetra Tech, Inc. on this important project.

We offer the following comments specific to the Draft SFNR Temperature TMDL:

- The hydrologic modeling conducted utilizing Qual2k (sic) did not resolve and was not sensitive to forest harvest history and patterns in the SFNR watershed. Although, the draft TMDL discusses land use in general and does identify forestry as a major land use, the TMDL holds the influence of forestry on the SFNR hydrograph and the water quality of the river constant - in other words assumes that forest practices has no impact on flow and quality. This assumption is not realistic. It has been well known for well over 100 years that manipulating forest cover has a subsequent change to the hydrograph. Typically, forest harvest increases annual runoff from a watershed, but that additional water runs off during the "wet months" (November through May) when flow quantity is not a limiting factor to fish and fish habitat. However, the other impact of forest harvest is a narrowing of the hydrograph with resulting lowered late-summer and early-fall flows in the river at a time most critical to several species of Pacific salmon, including the SFNR spring Chinook salmon. Perry and Jones (2016) (see excerpts below) showed through the application of a paired watershed study on the west slope of the Cascade Mountains in Oregon that forest harvest may reduce late season streamflows by up to 50 percent when compared to adjacent watersheds with mature and/or old growth forest stand structure.

- Water quantity and quality are intrinsically connected. Reduced flows in the late summer-early fall period will exacerbate and compound heat loading of the river. By ignoring the impacts of forest harvest on river flows and quality results in an incomplete picture of the dynamics of land management and runoff and water quality.

- Although climate change was addressed in the TMDL through completion of the climate change pilot research project, the cumulative impact of climate change and the impacts of land use (e.g., forest practices) were not adequately addressed for the reasons stated above. Taking projected climate change impacts into consideration is good; however, not linking those impacts with the impact of forestry on river flow and quality is an inadequacy of the TMDL.

- Although the TMDL primarily addresses non-point source pollution and therefor (sic) is not regulated, the TMDL needs to more fully consider the importance of full watershed management in the TMDL implementation plan, not just a focus on the river and its riparian buffer. Modifying land use through voluntary action is also needed. The Tribe has initiated a pilot research project to evaluate the impacts of forest practices on late season river flows and what voluntary actions might be implemented to ameliorate those impacts through modified forest harvest prescriptions and land management. The pilot project will address the cumulative impact of land management and climate change on the hydrology of the river. Through this effort we hope to identify measures that can maintain resilience of the watershed to continued projected climate change as well as the impacts of land management.

- We are pleased that the sensitivity analysis conducted at the request of the Tribe suggested that the current numerical standards are reasonably protective of what should be a "truer" natural condition. As such, there is no reason to update or modify the numerical criteria through a legislative process.

- We expect the TMDL to act on every feasible and reasonable tool to reduce temperature and sediment loading to the SFNR so as to support salmon recovery efforts, promote watershed resiliency, and to attain a harvestable surplus of salmon that the Tribe relies on for cultural, heritage, subsistence, and commercial uses.

Perry, T.D., and J.A. Jones. 2016. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. Ecohydrology 2016:1-13. DOI 10.1002/eco.1790. Excerpts from that study:

- Updating an earlier (Jones and Post 2004) synthesis of long-term paired watershed studies in western Oregon, Perry and Jones (2016) reported in this paper that logged watersheds still show no sign of recovery from prolonged depletion of low streamflows by ca. 50% in watersheds logged 40-50 years ago, compared to unlogged watersheds.
- The study summarizes results of long-term paired logged and unlogged watersheds in experimental forests in the central Oregon Cascades and southwest Oregon. The data from the 12 instrumented watersheds are among the only time extended series of data available in the Pacific Northwest to measure the long-term effects of logging and post-logging forest succession on stream conditions.
- The watersheds in this study are considered representative of a vast population of watersheds across western Oregon and the Pacific Northwest where Douglas-fir is the dominant tree species. The relatively consistent and sustained response of low flow deficits among the study basins supports the applicability of the results to watersheds across the Pacific Northwest.
- Mature and old growth Douglas-fir forests appear to be exceedingly efficient in water use and produce steady streamflows compared to second-growth forest plantations.
- Low flow deficits of 50% or greater occurred in all streams where greater than 50 percent of watershed area was logged.
- Low flow deficits caused by logging and post-logging forest regrowth persist for at least 40-50 years, without evidence of recovery to re-logging flows.
- Low flow deficits occur from late June, through July, August, September, and October.
- Flow deficits are caused by more wasteful water use by rapidly-growing trees and other vegetation in post-logging plantations, compared to the much more efficient regulation of water use in mature and old growth forests.
- The results suggest that reported trends of streamflow reduction in recent decades (e.g., Luce and Holden 2009) could be caused as much or more by cumulative effects of logging than by climate change.
- The study also showed that logging treatments produced peak flow increases that still persist decades post-harvest.

- Past widely-cited textbooks and agency plans and assessments reporting 10-15 years for "hydrologic recovery" after clearcutting are fundamentally incorrect, and were based on an erroneous and short-sighted view of experimental watershed data. This longer-term analysis shows that neither peak flow increases nor low-flow deficits return to pre-harvest conditions within 40-50 years of logging.
- Of foremost concern, small low flow increases observed in the first decade post-logging gave way to prolonged flow deficits, with summer, fall and early winter flows depleted to half or less of their pre-logging value persisting at least several decades.
- Because low flow deficits in logged forests are apparently caused by fundamental physiological inefficiency of water use by vegetation in re-growing forests, it appears unlikely that any modification of logging practices can reduce or mitigate the cumulative impact on depletion of streamflows--other than greatly restricting the area and frequency (reducing harvest rotation) of logging.
- Staggering the timing of logging did not and likely will not reduce the adverse depletion of low flows. Sustained low flow depletion occurred in all catchments that were more than 50 percent harvested within the 40-50-year time frame of observations. The flow deficit effect persists for at least 4-5 decades with no measured recovery, so staggering logging within this time frame is ineffective.
- The long-term low flow depletion effect can be reduced and sometimes avoided if half or more of a catchment is retained in mature, natural forested condition. In cases where between 25% and 50% of the basin was harvested, with 50-75% remaining in natural mature forest condition, the long-term low flow depletion effects were substantially reduced in magnitude. By contrast, short-term peak flow increases were not ameliorated and were similar in magnitude and persistence to peak flows in 100% harvested basins.
- Thinning of post-harvest plantations did not measurably ameliorate the long-term low flow depletion effect. Apparently the growth flush of vegetation "released" by thinning increases water demand and quickly consumes any soil water gain made available by thinning. I.e., water used efficiency remains low relative to unlogged forests.
- The great majority of forested watersheds in the Pacific Northwest are likely experiencing severe, but previously unrecognized streamflow deficits caused by past and ongoing logging. From a landscape or regional perspective, it can be concluded that any watershed with greater than half its forested area impacted by logging in the preceding 4-5 decades (and probably longer) is highly likely suffering severe and sustained depletion of summer, fall and early winter stream flows (on the order of 50 percent) compared to its historical, pre-logging condition.
- Most private industrial and small woodlot forest ownerships are found in watersheds where more than 50 percent of the landscape has been logged within the past 50 years. On such lands, any additional harvest exerts harm by prolonging and perpetuating the condition of low flow deficit.
- Where private forests and public forest lands are comingled, reduced and limited harvest rates and fully protected mature forest reserves on federal lands could partially offset and mitigate the flow depletion effects of logging on private lands. However, the degree to which such a mitigation effect scales up from small catchments to larger watershed areas remains unresolved, and may depend in part on the specific spatial pattern of logging relative to affected streams.

- There may be something akin to a "tipping point" when less than 50 percent of a watershed or landscape of watersheds remains in mature and old growth forest; disturbed beyond this point by logging, severe wildfire, or other catastrophic disturbance. Beyond this point, sustained low flow depletion is highly likely to be expressed in most if not all but a few smaller streams. Below 50% area logged, depending on the specific distribution of vegetation disturbance, many individual streams could experience severe and prolonged flow depletion, but the effects would likely be ameliorated in at least some areas of the watershed.
- Reduced low flows cause elevated summer stream temperatures and restrict movement and reduce cover for young and returning adult fish, compounding the stress of crowding in reduced habitat area.
- Logging-driven low flow deficits could be among the principle causes of lagging recovery of Endangered Species Act-listed and other depressed salmon and steelhead populations across the region.
- Summer low flows also limit withdrawals for domestic, urban and industrial uses, potentially stalling future economic growth.
- Watersheds and river basins with more than 50% of forest area logged in the preceding 50 or more years are likely to experience further loss of low flows in response to warming and drying of climate in the coming decades.
- Streams draining watershed areas dominated by natural, unlogged mature and old growth forests are more likely to retain low flows similar to their historical conditions, thus maintaining resilience to climate change better than harvested areas.

Response To: Oliver Grah – Nooksack Indian Tribe

T-1-1

Ecology thanks you and the staff at the Natural Resources Department of the Nooksack Indian Tribe for all of your efforts. The information you gathered, the efforts on estimating the effects of climate change and the implementation activities you have coordinated make a real difference. Without your valuable help, we would not be able to submit this TMDL to EPA and expect an approval letter.

Your information on the effects of forestry on base flows and the resulting effect on Temperature does raise an interesting issue but not one that we are able to address through implementation plans in this TMDL. We rely on the regulations in WAC 222 to prevent ill effects to water quality from forestry. The regulations protecting water quality in WAC 222 are stronger than other sectors, and there is a formal adaptive management process to examine those regulations to ensure that water quality is preserved. As a cooperator to forest practices adaptive management program, the Nooksack Indian Tribe and the Northwest Indian Fish Commission could encourage the direct examination of whether rotation age should be adjusted through regulation to protect water quality.

The potential ability to increase base flows by creating programs that encourage retention of older forests also suggests a potential opportunity for voluntary implementation under RCW 90.94 funding opportunities.

To the extent the increased flow benefits can be quantified, projects that permanently protect mature forests from being logged may be eligible to compete for grant funding under RCW 90.94 in the context that the preserved stream flow can be used to offset impacts from new domestic wells expected to be drilled in the watershed over the coming twenty years.

Additionally, in this TMDL Ecology has committed to estimating natural conditions, once significant progress on implementation has taken place. Continued research in this area would also help us more accurately quantify the effects so that we can make an accurate estimate of natural conditions.

Appendix G Additional information (Alt Text) for Figures

Figure ES-1. 303(d) listed segments in the South Fork Nooksack River watershed.
This map shows the segments identified as impaired for temperature on the 303(d) list. Most of the lower mainstem South Fork Nooksack is impaired. A few segments in the upper mainstem are impaired. Segments on Howard Creek, Deer Creek, Plumbago Creek, in the upper watershed are impaired. In the lower watershed, segments of Cavanaugh Creek, Edfro Creek, Hardscrabble Creek, Sygitowicz Creek and Todd Creek are impaired.

Figure ES-2. Effective Shade deficit by 100-m increments.
This map has fifty-nine markers on the South Fork Nooksack River (every kilometer) representing Shade Deficits divided into 4 categories. The categories are 0% to 7.9%, 7.9% to 12.7%, 12.7% to 17.9% and 17.9% to 32%. The longest string (four in a row) of the lowest category is just upstream of the confluence of Hutchinson Creek and the South Fork Nooksack. The longest string (4 in a row) of the highest category is 3 km upstream of the confluence of Plumbago Creek. In general the upper watershed has a majority of the markers in the two highest deficit categories and the lower watershed has most of the markers in the lowest deficit categories.

Figure 1. Study area and temperature standards for the South Fork Nooksack River watershed
This map shows the study area straddles Whatcom, Skagit boundary line in northwest Washington. Lake Whatcom is within 4 miles to the west of the study area. In the upper watershed (above Fobes Creek) , Skookum Creek, Hutchinson Creek their tributaries support Char spawning and Rearing with a criterion of 12 ˚C. The lower mainstem and remaining tributaries support Core Summer Salmonid Habitat with a criterion of 16 ˚C. The mainstem South Fork, Hutchinson Creek and lowest reaches of Skookum Creek have supplemental spanning use with criteria of 13 ˚C from September to July.

Figure 2. 303(d) listed segments in the South Fork Nooksack River watershed
This map shows the segments identified as impaired for temperature on the 303(d) list. Most of the lower mainstem South Fork Nooksack is impaired. A few segments in the upper mainstem are impaired. Segments on Howard Creek, Deer Creek, Plumbago Creek, in the upper watershed are impaired. In the lower watershed, segments of Cavanaugh Creek, Edfro Creek, Hardscrabble Creek, Sygitowicz Creek and Todd Creek are impaired.

Figure 3. Mean monthly hydrograph showing range of monthly averages measured.
This graph shows flows in July, August and September with a minimum in August of about 300 CFS. The August range is about 100 to 700. November and January are the highest values at about 2000 CFS with a range from about 1000 to nearly 3000 CFS.

Figure 4. South Fork Nooksack River land cover (2006 NLCD).
This map shows forest over most of the watershed. Evergreen forests dominate the forestland, with patches of deciduous forest and scrub/shrub. The notable exceptions are the barren land and small perennial ice/snow on the summit of the Twin Sisters, and the pasture/Hay in the lower valley.

Figure 5. South Fork Nooksack River land cover (LANDFIRE). LANDFIRE 2008 land use/land cover using preliminary vegetation groups.

This map shows conifer forest dominates the land cover in the basin. There are ribbons of deciduous forest. The exceptions are agriculture along the lower valley bottom, and barren land with patches of Snow-Ice at the summer of the Twin Sisters.

Figure 6. Comparison of LANDFIRE and NLCD land use/land cover estimates for the South Fork Nooksack watershed

There is a pie chart for Landfire Existing Vegetation Type and a pie chart for NLCD 2006 Land Cover. Forest types dominate the two pie charts showing land cover. The notable difference is that LANDFIRE shows 80 % Conifer, 10% hardwood and 1% Shrubland. NLDC shows 56% Evergreen, 3% hardwood and 18.9% shrubland. The other big difference is LANDFIRE shows 1% developed vs nearly 3% developed in NLCD. Both show about 2.5% in agriculture.

Figure 7. South Fork Nooksack River land cover (CCAP 2006).

This map shows Evergreen Forest with patches of shrub/scrub, deciduous and mixed forest, dominate the watershed with the exception of the summit of the Twin Sisters where the land is barren with small patches of Snow/Ice and Agriculture in the lower valley bottom.

Figure 8. Forest disturbance from fires and timber harvest.

This map shows there are small patches (less than 50 acres) representing active Timber Harvest scattered over the watershed. The exception to the distribution is that, No fires are in the USFS area above the confluence of Wanlick creek and the mainstem South Fork Nooksack River. There are five locations showing where fires have occurred within or near the watershed. The fire locations are not to scale, but are labeled with the year and size. The years range from 1979 to 2004 and the sizes range from eight to 130 acres.

Figure 9. Forest zoning in the watershed.

This map shows the portion of the watershed above the confluence of Wanlick Creek and mainstem South Fork Nooksack River is managed by USDA Forest Service without a designated zone. This covers about 25% of Whatcom County watershed and well under 10% of the Skagit County watershed. In Whatcom County, there is a small ring of Rural Forest surrounding the lower valley bottom (between Acme and Van Zandt) in Whatcom County. Uphill from the small ring of Rural Forest is Commercial Forest which covers most of the Whatcom County portion of the watershed. In Skagit County the dominant zoning is Industrial Forest. The other zone is Public Open Space buffering the upper mainstem by 0 to 2 km.

Figure 10. Nooksack Indian Tribe stream temperature monitoring station locations – Map 1.

This map shows temperature monitoring stations identified by year. The years shown are 2007 through 2011. The stations are distributed along the mainstem of the South Fork Nooksack with a few tributaries being monitored more than one kilometer from the confluence with the South Fork Nooksack.. There is a higher density of stations in the lower river.

Figure 11. Nooksack Indian Tribe stream temperature monitoring station locations – Map 2.

This map enlarges the lower watershed (below Hutchinson Creek) and provides the same information as the figure 10.

Figure 12. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2007 in the South Fork Nooksack.

This box plot shows the stations arranged from upstream on the left to downstream on the right. Mainstem stations and tributary stations are differentiated using color.

Temperatures ranges are higher in stations further downstream. Tributary temperatures tend to be cooler than nearby mainstem stations. Only three stations have a median cooler than the year round criteria and they are all tributary stations. Only one station is below the supplemental criterion.

Figure 13. Box-and-whisker plots with the 25th, 50th, and 75th percentiles of the 7-DADMax stream temperature for 2008 in the South Fork Nooksack.

This boxplot shows the stations arranged from upstream on the left to downstream on the right. Mainstem stations, log jam stations and one tributary station are differentiated using color. There is not a district trend with distance. The log jam station have the most variability with one station median above the criteria of 16 ˚C, and one below the supplemental criteria of 13 ˚C. One mainstem station has a median above 16 ˚C. The rest of the stations have medians between 13 ˚C and 16 ˚C.

Figure 14. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2009 in the South Fork Nooksack.

This boxplot shows the stations arranged from upstream on the left to downstream on the right. Mainstem stations and tributary stations are differentiated using color. Temperatures ranges are higher in stations further downstream. Tributary temperatures tend to be cooler than nearby mainstem stations. The only station to have a median below the water quality criteria is a tributary station. That station also has a median at the supplemental criterion.

Figure 15. Box-and-whisker plots with the 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2010 in the South Fork Nooksack.

This boxplot shows the stations arranged from upstream on the left to downstream on the right. Mainstem stations and tributary stations are differentiated using color. Temperatures ranges are higher in stations further downstream. Tributary temperatures tend to be cooler than nearby mainstem stations. Station 410 (Cavanaugh Creek) is an exception. The median temperature is more than 5˚ C warmer than the nearest mainstem stations.

Figure 16. Monitoring locations for USGS and Ecology gages.

This map shows Ecology and USGS gages. All are located in Whatcom County. They are along the mainstem of the South Fork Nooksack River, at the mouth of Skookum Creek and in the middle of Hutchinson Creek.

Figure 17. Seasonal box and whiskers plots of 7-DADMax at Nooksack Stations at River Mile 6.5, South Fork Nooksack River.

This boxplot shows temperatures for five stations, each representing a different year. The temperatures for 2007 to 2011 are broken down by Core Summer and Supplemental Spawning seasons for each year. All of the core summer median temperatures are above the 16˚C criterion. All of the supplemental spawning season medians are above the 13˚C criterion.

Figure 18. Seasonal box and whiskers plots of 7-DADMax at Nooksack Stations at River Mile 3, South Fork Nooksack River.

This boxplot shows temperatures for five stations, each representing a different year. The temperatures for 2007 to 2011 are broken down by Core Summer and Supplemental Spawning seasons for each year. All of the core summer median temperatures are above the 16˚C criterion. All of the supplemental spawning season medians are above the 13˚C criterion.

Figure 19. Seasonal box and whiskers plots of 7-DADMax at USGS Station 12210000 (2008-2011), South Fork Nooksack River.

This boxplot shows temperatures at one station over four years. The temperatures for 2009 to 2011 are broken down by Core Summer and Supplemental Spawning seasons for each year.

The year 2008 only has supplemental spawning season data. Core summer medians for 2009 and 2010 are above the 16°C criterion and 2011 is below the criterion. All of the supplemental spawning season medians are below the 13˚C criterion.

Figure 20. Seasonal box and whiskers plots of 7-DADMax at Ecology Station 01F070 (2003-2010), South Fork Nooksack River.

This boxplot shows temperatures at one station over eight years, separated into core summer and supplemental. Core summer medians for 2003 to 2007 are above the 16°C criterion and 2008 to 2010 are below the criterion. All of the supplemental spawning season medians are below the 13˚C criterion.

Figure 21. Average annual flow (complete water years only) and 7-day low flow at USGS 12209000.

This time series shows average annual flow and 7-day low flow for the period from early 1930s to 2008. Average annual flow ranges from 500 to 1000 CFS. The average annual flow time series has a gap from late 1970s to mid-1990. The 7-day low flows range from 100 to 200 CFS. The 7-day low flow time series has a gap near the end of the 1970s.

Figure 22. Average annual flow at all locations (complete water years only, beginning 1996)

This time series shows average annual flow for five stations. None of the stations are complete over the time period shown (1996 to 2011). Average flow for station 12209000 ranges from 500 to 1000 CFS in the years 1996 to 2008. Average flow for station 12209490 ranges from 100 to 200 CFS in the years 1999 to 2011. Average flow for station 12210000 ranges from 800 to 1000 in the years 2009 to 2011. Average flow for station 01F070 ranges from 800 to 1200 CFS for the years 2004 to 2010. Average flow for station 01C070 is near 50 in the years 2004 to 2011. Between 2009 and 2010, station 01F070 drops from 1000 CFS to 800 CFS and station 1221000 rises from 800 CFS to 1000 CFS. There is no obvious trend among stations with overlapping periods.

Figure 23. Meteorology monitoring stations near the watershed.

This map shows the type of meteorological stations by map symbol. The types are AgWeatherNet, SNOTEL, WA Ecology, Coop SOD, NCDC HPD, and NCDC Surface Airways. The station locations are from near the Canadian Border in the north, Mount Vernon to the south, Anacortes to the west, and Marblemount to the east.

Figure 24. Subset of assessment units from riparian function assessment (based on 1991 and 1995 aerial imagery).

This map shows canopy closure in ranges from 0 to 20%, 20% to 40%, 40% to 70%,70 to 90% and greater than 90%. The only segments greater than 90% are a few tributaries and a side channel of the mainstem. All ranges are present in the tributaries. The mainstem is dominated by the 0%-20% and 20%-40% ranges. The map is centered on the confluence of Deer and Plumbago creeks with the South Fork Mainstem.

Figure 25. Existing vegetation height along the South Fork Nooksack River from LiDAR data collected in 2005 and 2009

This map has a band along the South Fork Nooksack showing vegetation heights in ranges from 0m to 5m, 5m to 10m, 10 to 25m, 25m to 50m and greater than 50m. The upper watershed was flown in 2005 and the lower watershed in 2009. Most of the 0 to 5m area is in the lower watershed, but there are areas along the entire length in that class. It is difficult to find any greater than 50m areas. In the upper watershed, there are patches in the 20m to 50m class near the river.

Figure 26. Subset of FLIR images captured for the South Fork Nooksack River.
This figure shows a thermal infrared image and a true color image for two locations. The thermal infrared image has a scale from less than 12.5˚C to 22˚C. Bare ground greater than 22˚C. The coolest temperatures are where surfaces (both canopy and water) in deep shade are visible. The upper image shows the South Fork Nooksack River (19.4˚C) at RM 2.0. The inflow of Black Slough (14.6˚C) is visible, except where obscured by vegetation, along the right bank of the South Fork Nooksack River. The lower image shows the downstream end of a gravel bar on the South Fork Nooksack River (19.1˚C) at RM 7.1. Water temperatures are cooler in the side channel where surface water emerges from the gravel, evidence of hyporheic upwelling.
Figure 27. Cross-section locations along the South Fork Nooksack River and tributaries.
This map shows the 24 cross-sections. Most of the cross sections are in the lower watershed. Four of the cross-sections are upstream of Cavanagh Creek. Cross-sections 4, 5 and 9 are the only sites that are more than a hundred meters from the South Fork Nooksack River. Those cross-sections are on Todd, Sygitowicz and McCarty Creeks respectively.
Figure 28. Cross-section survey measurements for Site 2.
This figure shows two cross-sections for 8/25/1998 and 9/29/1998. Both are about 80 feet wide. The 8/25/1998 cross section shows a steep left bank and uniform depth of 1.2 feet to 50 feet from the left bank. The right bank is nearly constant gradient from 50 to 80 feet. The 9/29/1998 cross section shows a consistent gradient from the left bank to 50 feet where the depth is 1 foot. The last 30 feet to the right banks has a "U" shape with maximum depth of 2.4 at 10 feet from the right bank,
Figure 29. Cross-section survey measurements for Site 22.
This figure shows three cross-sections from 8/25/1998, 9/29/1998 and 10/5/1999. The two from 1998 are similar with a width of 45 (9/29/1998) to 50 (8/25/1998) feet. The bottom of both is rough and ranges from 1.4 to 1.8 in the 15 feet to 35 feet from the left bank. The 1999 cross-section is nearly twice as wide (85 feet), and 30% deeper at nearly 2.4 feet from 35 to 65 feet from the left bank. The right bank is very steep with a drop of 1.6 foot drop in less than 2 feet.
Figure 30. Historic channel positions of the South Fork Nooksack River.
This is a map of the South Fork Nooksack from just below Fobes Creek to just below Larson's Bridge. The map shows historic channel locations for 1885, 1940, 1956, 1966, 1991, 2001, 2002, and 2005. Above Deer and Plumbago Creeks all of the meanders since 1885 are tightly grouped (within 0.5 km of the migration zone centerline), and have migrated downstream from the 1885 location. Below the confluence of Plumbago and Deer creeks the historic channels fill a meander zone about 1 km wide. Migration patterns are not readily apparent to this observer.
Figure 31. South Fork Nooksack River mainstem 7-DADMax temperature for 2007.
Time series of 7-DADMax for nine stations are shown for the period June 4, 2017 to October 15, 2007. The upstream stations are generally about 5˚C cooler than the downstream stations. There are two peak temperatures one in early July and one in late July Both with temperatures 20°C upstream and less than 16° at the upstream stations. Temperatures drop 4°C in in mid-July. From the lake July peak to the second week in August temperatures occasionally, drop below 18°C at the most downstream stations and below 14°C at the upstream station. In the third and fourth weeks of September and the first week October temperatures consistently drop 8°C.
Figure 32. South Fork Nooksack River mainstem 7-DADMax temperature for 2010.
7-DADMax for 11 stations is shown for the period 5/25/2010 to 10/19/2010. Before the second week of July only four upstream stations are shown. The highest temperatures shown are for VANZANDS10S.

Temperatures of 23°C to 26°C from August 3 to August 17 are four degrees warmer than other stations. The VANZANUS and SF are the next most warm. They peak at just under 22°C at the end of July, drop to 19°C on 8/10/2010 and reach a new peak of 22°C on 8/17/2010 and then cool to 10°C or less by 10/12/2010. Other stations are up to 6°C cooler.

Figure 33. Generalized curves of riparian ecological functions (FEMAT, 1993).

This is a graph with an x-axis distance from channel scaled in tree height from 0 to 1. The y-axis is Cumulative Effectiveness and runs from 0 to 100%. Three curves, Litter Fall; Shading; and Coarse Wood Debris to Stream, all are approximately linear up to .5 to 0.7 tree height, with progressively lower slopes and longer near linear response. They curves then flatten and asymptotically approach 100%. Root strength has a sigmoid shape with rapid increase from 10% cumulative effectiveness and 0.2 tree height to 90% effectiveness at 0.4 tree height. The curve ends near 100% cumulative effectiveness at 0.5 tree height.

Figure 34. Examples of digitized river center line, NSDZ and 150-ft riparian buffer (which starts at the NSDZ) created using ortho imagery from 2006.

Aerial photography from three sites has lines added to show River Center Line (CL), Near Shore Disturbance Zone (NSDZ) and the 150 foot Riparian Buffer (RB). Site 1 is the most downstream site and near Van Zandt, the Potter Road Bridge is in the view. It has an NSDZ that appears to be constrained. The CL straight down the center of the NSDZ or right up against one edge. Much of the RB is not forest but cultivated land. Site 2 is in the part of the river near the confluence with Cavanagh Creek. It has the widest NSDZ. The CL meanders across the NSDZ and does not stay attached to either edge for long. The RP is mostly forested. Site 3 is the upstream site, just downstream from the confluence with Wanlick Creek. It has the narrowest NSDZ. The NSDZ is the most sinuous of the three sites and matches the sinuosity of the river. Forest cover fills the RB.

Figure 35. Example of existing vegetation height classifications for the South Fork Nooksack watershed (using 2005, 2009 LiDAR).

Aerial photographs of three sites shown in Figure 34 have shading showing vegetation height classes in ranges 0 to 9 m, 9-24m and greater than 24m covering the 150 foot Riparian Buffer (RB). Site 1 (near Van Zandt) has more than 90% of the RB in the 0 to 9 m class. Site 2 has patches of buffer in the greater than 24m and in the 9-24m class. About half is in the 0-9m class. Site 3 about 20% in the greater than 24m class and about a third in 0 to 9 m class.

Figure 36. Modeled effective shade during daylight hours under channel and vegetation conditions for 8/2/2007 (using 2006 imagery) and 8/16/2010 (using 2009 imagery).

Two scenarios are shown together as a shade profile. The x-axis is distance downstream from the headwaters in m from 0 to 60,000 m. The y-axis is Effective Shade expressed as fraction on Potential Solar Radiation blocked by topography and vegetation, from 0 to 50%. The 2007 scenario generally has higher Effective Shade. At 7,500 m the 2007 scenario peaks with 46% shade; the 2010 scenario peaks at 40% shade. There is another peak at 15,000 m at 35% and 30% shade and a third peak at 33,000 m with 45% and 35% shade. Between the peaks, the 2007 scenario has a range of 5% to 25%. The 2010 scenario has a range of 15% to 5% between the peaks.

Figure 37. Modeled effective shade (fraction of potential solar radiation blocked by topography and vegetation) for each of the key modeled scenarios:

Four lines are drawn in this figure. Near Stream Disturbance Zone is shown. At the head waters it is near 30 m. It reaches a peak at 40,000 and 58,000 of about 150 meters. Between the peaks it is 60m to 100m.

Effective Shade is shown for Existing Shade, System Potential: All Vegetated and System Potential: All Vegetated except Roads/Developed. Both system potential are almost identical. The main departure is at 45,000 m the All Vegetated scenario raises from 30% top 40% Effective shade over 500 m and levels off. The All Vegetated Except Roads/ Developed raises from 30% to 40% and meets the All Vegetated scenario in 1,000 m. The existing shade is 10% to 20% lower than the System Potential scenarios. Peaks in NSDZ are matched by dips in effective shade.

Figure 38. Comparison of low shade area and high shade area along the South Fork Nooksack River.

Two aerial photographs are shown with lines delineating the stream centerline, near stream disturbance zone (NSDZ), stream wetted width, and 150-foot buffer on the NSDZ. Sample points are marked every 100 m along the stream centerline. In the left photo, the text "Location: 54,900 meters from Wanlick Creek, Existing Shade: 5.1% Potential Shade 31.9%" is associated with a sample point. At that sample point, the stream centerline is near the left (West) edge of the near stream disturbance zone, there is a narrow band of trees (30 feet) and then grass vegetation to the left (west). To the right is about 200 feet of bare ground (exposed river bottom) and then vegetation similar to the left bank. In the right photograph, there is text that reads "Location: 31500 meters from Wanlick Creek, Existing Shade: 67.7% Potential Shade: 82.3%", at this station the stream centerline is close (10 feet) to the left side of the NSDZ. The right side of the NSDZ is 80 feet east of the sample point. Vegetation on both sides of the stream is mature trees to the width of the 150-foot buffer zone that is marked.

Figure 39. QUAL2Kw model reaches for the South Fork Nooksack River mainstem.

The map shows, The South Fork Nooksack River and tributaries. Along the mainstem of the South Fork, alternating bands of color long identify 1 km long model reaches. Reaches are marked at the downstream end with a number. The first number (1) is 1 km from the confluence of Wanlick Creek and the South Fork Nooksack. The last numbered segment is 58 and there is an unlabeled segment about ½ km at the end. Skookum Creek has a label and enters reach 36 near the mid-point. Hutchinson Creek has a label and enters near the beginning of segment 43.

Figure 40. Comparison of gaged flow on South Fork Nooksack River in WY2009-WY2010.

This figure shows a comparison between gages 01F070 – South Fork Nooksack at Potter Road and 12210000 – South Fork Nooksack at Saxon Bridge for water years 2009 and 2010. In WY 2009 flow at 01F070 is 10% to 30% higher than gage 12210000 from November 2008 to July 2009. In WY 2010 gage 01F070 is 10% to 30% lower than gage 12210000 from December 2009 to July 2010. In July 2010 gage 01F070 drops rapidly to a minimum value of 90 CFS which is maintained most of August. Gage 12210000 descends more slowly to a minimum of 150 CFS near the end of August.

Figure 41. Temporal variation in flow before and after calibration QUAL2Kw model simulation day.

There are lines showing flow at three different gages. At the beginning of the time series (7/16/2007) gage 12209000 (250 CFS) is 2/3 of the flow at gage 01F070 (375 CFS). The gage 12209490 starts the time series at 50 CFS. All three peak on 7/22/2007. Gages 01F07 and 12209000 have peaks at 1700 CFS. Gage 12209490 peaks at 350 CFS. Four days after the peak 12209000 (350 CFS) is about 75% of 01F070 (>400 CFS), and 1220940 is down to the initial level. All three gradually decline keeping approximately the same ratio to the end of the time series at 8/15/2007 when 01F070 is at 150 CFS.

The calibration day August 2, 2007 is in the middle of this time span, 11 days after the peak flow. All gages are still smoothly declining. Gage 01F070 is at 300 CFS; gage 12209000 is at 200 CFS and 12209490 is at 25 CFS.

Figure 42. Temporal variation in flow before and after validation QUAL2Kw model simulation day.

Two lines shows follow from two gages for the period 8/1/2010 to 8/31/2010. Gage 12210000 starts at 200 CFS with two peaks of 220 CFS on 8/5/2010 and 8/8/2010 and drops to 180 CFS between the peaks. The flow gradually descends past a flow of 140 CFS on August 16, 2010 and continues to descend until a minimum of 110 CFS on 8/29/2010. Flow for gage 12209490 follows a similar pattern but with about a quarter of the flow. It starts at 45 CFS the peaks are more modest at about 50CFS. On August 16, 2010 flow is 40 CFS and the minimum flow is about 25 CFS the 8/30/2010. On 8/31/2010 the flow rises back to 50 CFS.

Figure 43. Flow Boundary Model schematic.

This figure shows seven steps leading down. The steps are coded to smoothly transition from Red to Violet which I thought would be very important to share with the visually impaired. The steps are (RED) Observed flow at gages,(ORANGE) Select matching critical low flow statistic, (YELLOW-ORANGE) Equation 1 predicts tributary flows, (GREENISH_YELLOW) $Q_{obs}/Q_{regression}$ = Ratio using Hutchinson and Skookum, (YELLOWISH-GREEN) Ratios X (times) $Q_{regression} = Q_{adjusted}$, (GREEN) $Q_{USGS}-Q_{adjusted} = Q_{groundwater}$, (BLUE) Distribute $Q_{groundwater}$ to direct drainage catchments, (VIOLET) repeat for lower third of watershed using Ecology gate.

Figure 44. Groundwater sources (diffuse sources), tributary sources (point sources), and streamflow gages for the model.

This map shows the watershed. Areas that drain directly to the Mainstem (diffuse sources) are distinguished from the areas that drain to tributaries (point sources). Some diffuse sources extend as far as 3 km from the river. Along the southern boundary of the watershed there is a 14 km stretch where the diffuse sources extend from the river to the watershed boundary, broken by only one small tributary (2km long by .5 km wide).

Figure 45. Comparison of observed and simulated flows for the calibration period.

This chart shows modeled flow for South Fork Nooksack River, August 2, 2007, as a continuous line from River Mile (RM) 0 to RM 35. Flow descends from 270 CFS at RM 0 to 50 CFS at RM 35. The decent is gradual except for two steps down. The first step down is at RM 11 where flow drops from 250 CFS to 230 CFS. The second step is at RM 15 with where flow drops abruptly from 225 CFS to 190 CFS. After RM 15 the descent is fairly uniform. (NOTE to listeners - the authors have switch from metric distance (meters and kilometers) downstream from Wanlick Creek confluence to Miles downstream from Wanlick Creek, not conventional River Miles measured moving upstream - end of NOTE) Observed flow is marked for three gages. The marks are 0.8 miles wide, by 12 CFS tall and all touch the model flow line. The gage marks are at RM 2 (270 CFS), RM 13 (225 CFS), and RM 15 where as previously noted flow is about 190 CFS.

Figure 46. Comparison of observed and simulated flow for the validation period.

This chart shows modeled flow for South Fork Nooksack River, August 16, 2010, as a continuous line from River Mile (RM) 0 to RM 35. Flow descends from 168 CFS at RM 0 to 45 CFS at RM 35. There decent is gradual except for two steps down. The first step down is at RM 11 where flow drops from 155 CFS to 140 CFS. The second step is at RM 15 with where flow drops abruptly from 140 CFS to 105 CFS. After RM 15 the descent is fairly uniform.

(NOTE to listeners - the authors have switch from metric distance (meters and kilometers) downstream from Wanlick Creek confluence to Miles downstream from Wanlick Creek, not conventional River Miles measured moving upstream - end of NOTE) Observed flow is marked for one gage. The mark is 0.8 miles wide, by 12 CFS tall and centered on the model flow line. The gage marks is at RM 13 where flow is at 140 CFS.

Figure 47. Comparison of 1998-1999 seepage study flow with estimated flows using the flow boundary model.

The figure shows three pairs of flow profiles. Each pair consists of modeled flow, from River Mile (RM) 0 to RM 35, and seepage study profiles that have different end points. The highest flows are for the October 1999 pair. The seepage study data starts at RM 5 and is level to RM10. The modeled flow is 15 to 20 CFS higher. There is a gap in seepage study data to RM15 where both seepage study data and model data drop from 130 CFS to 115 CFS. Seepage study data shows a steady decline from 115 CFS to 100 CFS at RM 21. The model data drops to 90 CFS over the same interval.

The next highest flows are from the August 1998 Seepage study. Model data drops from 130 CFS to 50 CFS in the RM0 to RM35 interval. Seepage study data is provided for RM 0 to RM 30. The seepage study data is matching to 10 CFS less up to RM 17, and then gradually departs from modeled results until it is 15 CFS at RM 30. The modeled steep drop at RM 15 is largely smoothed out starting earlier and lasting later.

The lowest flows are from the seepage study of September 1995. Model data descends from 120 CFS at RM 0 to 35 CFS at RM 35. The seepage study data shows a smooth decline. Readings at RM 0 and RM 15 are very close (within 2 CFS). The modeled drop at RM 15 represent the largest departure when modeled flows goes from 15 CFS over prediction to matching the predictions. There is a very good match from RM 15 to 25, and then the seepage study data starts to depart from modeled data. At RM 30 there is greater than 5 CFS difference.

One other feature to note about a mile before (downstream of) RM 15, just before modeled and measured data match, the modeled flow descends and rises back up about 1 CFS.

OK that was definitely more than 150 words but there are three dang pairs of lines to compare.

Figure 48. Weather monitoring station locations used for weather data input in QUAL2Kw for the South Fork Nooksack River.

This map shows western Whatcom and Skagit counties. The AgWeatherNet stations, Nooksack and WSU are shown. They are north of Everson, and West of Mount Vernon. SNOWTEL site 910 is in the upper watershed near the South Fork Nooksack upstream of the Wanlick Creek confluence. Ecology station 01F070 is within 3 km of the confluence of the South Fork Nooksack and the Mainstem Nooksack River. NCDC Surface Airways station 24217 is shown North West of Bellingham at the Airport.

Figure 49. Locations of observed stream temperature monitoring sites for 2007 used for model calibration.

This map of the watershed has locations of both mainstem and tributary stations. Tributary stations SF0210, SFT016, SFT015 and SF0130 are so close to the mainstem that the .5 km symbols touch the mainstem. SF0135, 01C070 and SF0033 are tributary station set back (2 to 5 km) from the mainstem. There are 11 mainstem stations. The mainstem stations are more space in the upper, and lower watershed. The middle third has the greatest density.

Figure 50. Locations of observed stream temperature monitoring sites for 2010 used for model validation.

This map of the watershed has locations of both mainstem and tributary stations. Tributary stations Wanlick10, 411, 410, 409, 413, 408, and 407 are so close to the mainstem that the .5 km symbols touch the mainstem. Tributary station 01C070 is the only tributary station set back (5 km) from the mainstem. There are 10 mainstem stations. The mainstem stations are more spaced in the upper watershed, and very tightly spaced in the lower watershed. There are three mainstem station in the last 3 km.

Figure 51. Longitudinal temperature comparison (observed data and modeled) for the calibration period. Labels for observed data correspond to Reach Numbers in the following table.

Profiles of modeled daily temperature Maxima, Average and Minima are compared to measured values at eleven stations. Modeled data is represented by a line. The eleven station measurements are represented by squares 1km wide by 1 degree tall. All of the measured average temperature marks touch the average line. Most of the daily maximum temperature boxes touch the line. One maximum is above the line and one is below. They are both within ½ degree of touching the line. Most of the daily minimum temperature boxes are centered above the minimum temperature line but touching the line. Two of the marks are above the line and do not touch. They are within ½ degree of touching.

Figure 52. Diel temperature data (dashed line) vs. modeled (solid line) at reach 17 during the calibration period.

The observed minimum is about 0.4 °C warmer than the modeled minimum. The observed maximum is about 0.4°C cooler than the modeled maximum. The time of the observed temperatures extremes lags the time of the modeled extremes by about 2 hours.

Figure 53. Diel temperature data (dashed line) vs. modeled (solid line) at reach 24 during the calibration period.

The observed minimum is about 0.3 °C warmer than the modeled minimum. The observed maximum is matches the modeled maximum. The time of the observed temperatures extremes lags the time of the modeled extremes by less than one hour.

Figure 54. Diel temperature data (dashed line) vs. modeled (solid line) at reach 49 during the calibration period.

The observed minimum matches the modeled minimum. The observed maximum is less than 0.1 °C warmer than the modeled maximum. The time of the observed temperatures extremes lags the time of the modeled extremes by one hour.

Figure 55. Longitudinal temperature comparison (observed data and modeled) for the validation period.

Profiles of modeled daily temperature Maxima, Average and Minima are compared to measured values at nine stations. Modeled data is represented by a line. The nine station measurements are represented by squares 1km wide by 1 degree tall. Two (Reach 1 and Reach 17) of the measured average temperature marks touch the average line. The Reach 8 measurement is below the line. Averages for Reaches 37, 43, 48, 53, 56 and 57 are all above the line. The centers of all of the average marks are within 1°C of the modeled average temperature. Five of the daily maximum temperature boxes touch the line. One (Reach 8) maximum is below the line and three (Reaches 43, 48 and 53) are above the line. Reach 8 is centered 2°C below the modeled maximum temperature. Reach 43 is 2°C above the modeled maximum. Minimum observed temperatures for reach 1 and 8 touch the line for modeled minimum temperature. The rest of the observed minimum temperatures are .5°C (Reach 17) to 2°C (Reaches 56 and 57) above the modeled minimum.

Figure 56. Diel temperature data (dashed line) vs. modeled (solid line) at reach 17 during the validation period.
The observed minimum is about 0.5 °C warmer than the modeled minimum. The observed maximum is about 0.5°C cooler than the modeled maximum. The time of the observed temperatures minimum lags the time of the modeled minimum by about 2 hours. The time of the observed temperatures maximum lags the time of the modeled maximum by about 1 hour.
Figure 57. Diel temperature data (dashed line) vs. modeled (solid line) at reach 37 - validation.
The observed minimum is about 1.5 °C warmer than the modeled minimum. The observed maximum matches the modeled maximum. The time of the observed temperatures extremes lags the time of the modeled extremes by about 1 hour.
Figure 58. Diel temperature data (dashed line) vs. modeled (solid line) at reach 48 - validation.
The observed minimum is about 1.5 °C warmer than the modeled minimum. The observed maximum is about 1.5 °C warmer than the modeled maximum. The time of the observed temperatures minimum lags the time of the modeled minimum by about 2 hour. The time of the observed temperatures minimum lags the time of the modeled minimum by about 3 hour.
Figure 59. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled average temperature output at reach 48.
The six parameters are shown with the temperature effect on decreasing the parameter 10% and increasing the parameter by 10%. Parameters with the greater ranges are shown on top of parameters with smaller ranges. The ranges may not be symmetrical about the 0% chance or base scenario (17.49 °C), thus the diagram is expected to resemble a tornado in shape. In this case the parameters in order from top to bottom are Temperature Inputs, Air Temperature, Flow Inputs, Bottom Width, Shade and Manning's "n". Air Temperature has a range from less than 16.87°C to more than 18.07°C. Manning's 'n' caused no detectable change. The 10% lower parameters of Temperature Inputs, Air Temperature, and Bottom Width decreased average stream temperature. The 10% increase for parameters Flow Inputs and Shade decreased average stream temperature. The least symmetrical parameter is Bottom Width, decreasing bottom width reduced average temperature about 0.35°C more than increasing Bottom Width increased the average temperature.
Figure 60. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled minimum temperature output at reach 48.
The six parameters are shown with the temperature effect on decreasing the parameter 10% and increasing the parameter by 10%. Parameters with the greater ranges are shown on top of parameters with smaller ranges. The ranges may not be symmetrical about the 0% chance or base scenario (14.59 °C), thus the diagram is expected to resemble a tornado in shape. In this case the parameters in order from top to bottom are Temperature Inputs, Air Temperature, Bottom Width, Flow Inputs, Manning's "n" and Shade. Air Temperature has a range from less than 13.99°C to more than 15.19°C. Shade has a range more than 14.39°C to less than 14.79°C. The 10% lower parameters of Temperature Inputs, Air Temperature, Bottom Width, and Manning's "n" decreased average stream temperature. The 10% increase for parameters Flow Inputs and Shade decreased average stream temperature. The least symmetrical parameters is Bottom Width, and Manning's "n" decreasing bottom width reduced average temperature about 0.03°C more than increasing Bottom Width increased the average temperature.

Figure 61. Tornado diagram representing sensitivity analysis results conducted on QUAL2Kw comparing modeled maximum temperature output at reach 48.
The six parameters are shown with the temperature effect on decreasing the parameter 10% and increasing the parameter by 10%. Parameters with the greater ranges are shown on top of parameters with smaller ranges. The ranges may not be symmetrical about the 0% chance or base scenario (20.31 °C), thus the diagram is expected to resemble a tornado in shape. In this case the parameters in order from top to bottom are Temperature Inputs, Flow Inputs, Bottom Width, Air Temperature, Shade and Manning's "n. Air Temperature has a range from less than 19.71°C to more than 20.91°C. Manning's "n" has a range from 20.2°C to less than 20.51°C. The 10% lower parameters of Temperature Inputs, Bottom Width, and Air Temperature decreased average stream temperature. The 10% increase for parameters Flow Inputs, Shade and Manning's "n" decreased average stream temperature. All of the parameters are near symmetric.
Figure 62. Predicted maximum water temperatures for typical low-flow (7Q2) and meteorological (50 percentile) conditions for current and 100-year system potential scenarios along the mainstem of the South Fork Nooksack River.
Two temperature profiles are shown. Three Thresholds are provided to give reference to the temperatures. The highest threshold is 1-Day Maximum lethality at 23°C, the next is 7-DADMax Lethality (capitalization matches figure) at 22°C. The lowest threshold is Water Quality Standards at 12°C from 0 to 27 km from Upstream where the Water Quality Standard jumps to 16°C the rest of the way downstream. Both temperature profiles are above the Water Quality Criteria and below both lethality thresholds. The Scenario 1 (can copy long text description if necessary) profile starts at 16°C rises to 18° in the first 5 km and then gradually rises to 19°C at 27 km where it is more or less stable until a small drop to at km 35 to 18 ½ °C (if this value is converted to decimal change to just over 18.5 + up to .2 to reflect imprecision of estimate by eye). Below km 35 the temperature climbs to the maximum of 21°C at the end of the profile. Scenario 2 (can copy long text description if necessary) mimics the shape of Scenario 1 but at lower temperatures. Scenario 2 starts at 12°C drops to 16.5°C at km 35 and ends at 18°C.
Figure 63. Predicted maximum water temperatures for critical low-flow (7Q10) and meteorological (90 percentile) conditions for current and 100-year system potential scenarios along the mainstem of the South Fork Nooksack River.
Four temperature profiles are shown. Three Thresholds are provided to give reference to the temperatures. The highest threshold is 1-Day Maximum lethality at 23°C, the next is 7-DADMax Lethality (capitalization matches figure) at 22°C. The lowest threshold is Water Quality Standards at 12°C from 0 to 27 km from Upstream where the Water Quality Standard jumps to 16°C the rest of the way downstream. All four temperature profiles are above the Water Quality Criteria. Scenario 3 (long description if necessary) and Scenario 4 exceed 7-DADMax lethality at km 47 and 1-Day Maximum lethality at km 52. Scenario 3 start at 16°C at km 0, and Scenarios 4, 5 and 6 all start at 13°C. All three rise strongly in the first 5 km. Scenario 4 approaches Scenario 3. Scenarios 5 and 6 remain about 2.5°C below Scenario 3. For the rest of the profile Scenarios 3 and 4 are very close with Scenario 4 just a bit cooler than Scenario 3. Scenarios 5 and 6 are nearly identical. They are completely overlapped up to km 42 where Scenario 6 is less than 0.1°C lower than Scenario 5. Scenarios 3 and 4 approach but do not exceed the 1-DADMax lethality near km 27. Scenarios 5 and 6 are about 19.5 degrees at km 27. Scenarios 3 and 4 end above 22°C and Scenarios 5 and 6 end at about 21.5 °C.

Figure 64. Comparison of Shade Model effective shade results for the August critical condition and narrower near-stream disturbance zone.

Profiles of effective shade are shown for the August Critical Condition and the Natural Channel Condition. The profiles run from km 0 to km 56 as distance from Upstream. All of the data is in the range of 40% to 80% Effective shade. Both profiles nearly match in several segment, km 0 to km 8, km 20 to km 25, 29 to km 41. In all other locations but one the Natural Channel Condition has more shade (an increase of 5% to 15% of effective shade). The only location where August Critical Condition has a higher effective shade than the Natural Channel Condition is km 47 where the where both conditions have about 57% effective shade but the August Condition is slightly higher. The two locations with the highest effective shade (km 6 and km 33) are in locations where both conditions match.

Figure 65. Comparison of Shade Model effective shade results for the August critical condition and a scenario with increased buffer and vegetation height.

Profiles of effective shade are shown for the August Critical Condition and the Increased Buffer and Vegetation Height. The profiles run from km 0 to km 56 as distance from Upstream. All of the data is in the range of 40% to 80% Effective shade. Both profiles follow a similar rise and fall pattern, but the August Critical Condition falls further than the Increased Buffer and Vegetation Height profile. There is a very close match at peak effective shade at location km 6 (75% vs 77% effective shade) and km 33 (74% vs. 76%). Where the August critical condition approaches 40% shade the Increased Buffer and Vegetation Height profile is close to 50% effective shade.

Figure 66. Comparison of temperature model results for TMDL Scenario 5 and a combination of natural condition scenarios.

Two temperature profiles are shown. Three Thresholds are provided to give reference to the temperatures. The highest threshold is 1-Day Maximum lethality at 23°C, the next is 7-DADMax Lethality (capitalization matches figure) at 22°C. The lowest threshold is Water Quality Criterion: August at 12°C from 0 to 27 km from Upstream where the Water Quality Standard jumps to 16°C the rest of the way downstream.

The Summer Critical Condition, System Potential Vegetation profile starts at 16°C rises to 18° in the first 5 km and then gradually rises to 19°C at 27 km where it is more or less stable until a small drop to at km 35 to 18 ½ °C (if this value is converted to decimal change to 18.5 to 18.7 reflect imprecision of estimate by eye). Downstream of km 35 the temperature climbs to the maximum of 21°C at the end of the profile.

The Trial 5: All Combined profile mimics the shape of Summer Critical Conditions profile but at lower temperatures. Trial 5 starts at 10°C and stays below the water quality criteria for the 1 km (thumbs up emoji). At km 27 when the water quality standard rises to 16°C Scenario 5 is just over the criteria. At km 35 it drops below 16°C (thumbs up emoji) and does not rise above 16°C until km 47.

Figure 67. South Fork Nooksack River mainstem 7-DADMax temperature for 2007 summer and early fall period.

As described in Figure 31, Time series of 7-DADMax for nine stations are shown for the period June 4, 2017 to October 15, 2007. The upstream stations are generally about 5˚C cooler than the downstream stations. There are two peak temperatures one in early July and one in late July Both with temperatures 20°C upstream and less than 16° at the upstream stations. Temperatures drop 4°C in in mid-July.

From the lake July peak to the second week in August temperatures occasionally, drop below 18°C at the most downstream stations and below 14°C at the upstream station. In the third and fourth weeks of September and the first week October temperatures consistently drop 8°C. The period at the beginning of the time series to the end of June, and the period from the beginning of September to the end of the time series are highlighted to indicate it is the time when supplemental criteria (12°C) apply. All of the series show local maxima on September 11, and that is the highest temperatures in the period and is well above the supplemental criteria.

Figure 68. Estimated flow in South Fork Nooksack River, September 11, 2007.

This figure shows a flow profile. Flow increases from 22 CFS at km 0 to 75 CFS at km 35. At km 36 there is a steep climb to 95 CFS, a small dip to 90 CFS between km 37 to km 40. From km 42 to 58 the flow is near 95 CFS.

Figure 69. Effective Shade model results for current and SPV on August 2, 2007 (calibration period) and September 11, 2007.

This figure shows effective shade profiles for two different days (8/2/2007 and 9/11/2007) and two different vegetation conditions (Existing and System Potential Vegetation (SPV)) for each day. All of the data in in the range of 30% effective shade to 82% effective shade. All profiles follow the same pattern of multiple local maxima and minima at the same locations. At all locations. The 9/11/2010 SPV profile is higher than all other profiles. At all locations, the 8/2/2007 Existing Vegetation profile is lower than all other profiles. The 9/11/2010 Existing Vegetation and 8/2/207 SPV profile cross each other many times.

Figure 70. Model results for the critical September run and August TMDL scenario paired with their respective water temperature criteria.

Two temperature profiles are shown. Four Thresholds are provided to give reference to the temperatures. The highest threshold is 1-Day Maximum lethality at 23°C, the next is 7-DADMax Lethality (capitalization matches figure) at 22°C. The lowest two thresholds are Water Quality Criteria. One of the water quality standards is base water quality criterion applicable in August, 12°C from 0 to 27 km from Upstream where the Water Quality Standard jumps to 16°C the rest of the way downstream. The other water quality criteria applicable in September is 13°C along the length of the river.

The Summer Critical Condition, System Potential Vegetation profile starts at 16°C rises to 18° in the first 5 km and then gradually rises to 19°C at 27 km where it is more or less stable until a small drop at km 35 to 18 ½ °C (if this value is converted to decimal change to 18.5 to 18.7 reflect imprecision of estimate by eye). Downstream of km 35 the temperature climbs to the maximum of 21°C at the end of the profile.

The Critical September Condition, System Potential Vegetation profile is 13°C at km 0. At km 8 it reaches a peak of 14°C. Temperatures reach a low just under 13°C from km 33 to km 39. From km 39 to km 56 temperatures rise to about 14°C.

Figure 71. Effective shade deficit by 1,000-m increments.

This map has fifty-nine markers on the South Fork Nooksack River (every kilometer) representing Shade Deficits divided into 4 categories. The categories are 0% to 7.9%, 7.9% to 12.7%, 12.7% to 17.9% and 17.9% to 32%. The longest string (four in a row) of the lowest category is just upstream of the confluence of Hutchinson Creek and the South Fork Nooksack. The longest string (4 in a row) of the highest category is 3 km upstream of the confluence of Plumbago Creek. In general the upper watershed has a majority of the markers in the two highest deficit categories and the lower watershed has most of the markers in the lowest deficit categories.

Figure 72. Shade Curve for determining load allocations of effective shade for tributaries.
Shade curves are provided for bankfull width from 0 m to 40 m at three aspects, 1) 0° and 180°(North-South), 2) 45°, 135°, 225° and 135° (intercardinal), and 3) 90° and 270°(East-West). All of them start near 95% Effective shade. All are concave downward from 3m to 6m. After 6m all curves are concave up. From 6m to 26m the East-West curve has the highest effective shade, and North-South has the least effective shade. From 28m to 40m, East-West has the least effective shade, and the intercardinal curve has the highest effective shade.

Figure 73. Habitat Conservation Areas (subject to protected buffers variable by county).
This map shows the stream classification under Forest Practice regulations. Class S: Shorelines covers the South Fork Nooksack from km 2 downstream to the confluence with the Mainstem Nooksack River. Class S also covers 4 main tributaries (not labeled for sighted readers => do we need to list Howard, Skookum, Cavanaugh, and Hutchinson creeks). Dozens of tributaries are in Class F: Fish. The final Class F: Non-Fish contains too many streams to count.

Figure 74. Comparison of Shade Deficit to Habitat Conservation Areas (subject to protected buffers – variable by county).
This map has fifty-nine markers on the South Fork Nooksack River (every kilometer) representing Shade Deficits divided into 4 categories. The categories are 0% to 7.9%, 7.9% to 12.7%, 12.7% to 17.9% and 17.9% to 32%. The longest string (four in a row) of the lowest category is just upstream of the confluence of Hutchinson Creek and the South Fork Nooksack. The longest string (4 in a row) of the highest category is 3 km upstream of the confluence of Plumbago Creek. In general the upper watershed has a majority of the markers in the two highest deficit categories and the lower watershed has most of the markers in the lowest deficit categories.

This map also shows the stream classification under Forest Practice regulations. Class S: Shorelines covers the South Fork Nooksack from km 2 downstream to the confluence with the Mainstem Nooksack River. Class S also covers 4 main tributaries (not labeled for sighted readers => do we need to list Howard, Skookum, Cavanaugh, and Hutchinson creeks). Dozens of tributaries are in Class F: Fish. The final Class F: Non-Fish contains too many streams to count.

Figure 75. Feedback loop for determining need for adaptive management.
This flow chart nominally has three steps with estimated dates to move from one step to the next. Step 1 is Implement activities. The dates to move to step 2 are 2016-2020. Step 2 is Evaluate adequacy of design and installation. Progress to step 3 has years 2020-2025 assigned. Step 3 is Compare to water Quality Targets. This step is the only step assigned a year. It is assigned 2025. If "on target" we move to Step 3a. Publicize success and continue implementation. From this leads back to Step 2 for years 2013 onward. If at step 3 it is determined that status is "off target" the next pseudo step is step 3b. Modify implementation or identify new activities. Step 3b leads back to step 1 and is assigned years 2030+

Figure 76. Change in spatially averaged maximum water temperature in the South Fork Nooksack River mainstem at critical conditions with SPV for three future climate emissions scenarios compared to existing TMDL conditions and vegetation.
This figure shows 3 lines. The vertical axis is Change in Maximum Temperature °C), the horizontal axis has for points: Current, 2020's, 2040s 2080s. The three lines are for High-SPV, Med-SPV, and Low-SPV. All start at 0°C change for Current. Low-SPV drops to -.5°C at 2020s, and then steadily climbs to 1°C in the 2080s. Med-SPV rises to 1/4°C in the 2020s, and then rises more steeply and steadily to 2 ¼°C in the 2080s.

The High-SPV stays level at 0°C to 2020s, it is then concave upward to reach 3.5°C in the 2080s, crossing the Med-SPV shortly after the 2040s. (Scale not linear so no interpolation)

Figure 77. Climate change adaptation and iterative risk management (Yohe, 2011).

This figure show two colorful but excessively looped flow diagrams with different styles.

The first is Iterative Risk Assessment. There are six step. Step 1 "Identify current and future climate changes relevant to the system", can lead to step 6 or step 2. Step 2 "Assess the vulnerabilities and risk to the system", can lead to step 6 or step 3. Step 3 "Develop an adaption strategy using risk-based prioritization schemes" leads to step 4. Step 4 "Identify opportunities for co-benefits and synergies across sectors" leads to step 5. Step 5 "Implement options" leads to step 6. Step 6 "Monitor and reevaluate implemented adaption options, leads to step 1. Steps 1, 2 and 5 all lead to step 6.

The second flow has arrows with activities labeled on the arrows leading to each other. At the top is an arrow to enter "Define the Problem, Determine Objectives". This is followed by "PLAN" that leads to "IMPLEMENT". "IMPLEMENT" leads to "MONITOR & EVALUATE". "MONITOR & EVALUATE" has a fork, "ADAPT" that leads back to "IMPLEMENT", and the main stem continues back to the entry point where "PLAN" picks up.