South Fork Nooksack River Temperature Total Maximum Daily Load

Water Quality Study Design (Quality Assurance Project Plan)

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Publication and Contact Information

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

The plan for this study is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1203126.html

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Federal Clean Water Act 2010 303(d) Listings Addressed in this Study

(See next page.)

Cover photo: South Fork Nooksack River, http://www.fishermanoutofwater.com

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South Fork Nooksack River	35244	36N-7E-3
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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	36846	38N-5E-8
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	42105	37N-5E-16
South Fork Nooksack River	42111	38N-5E-18
Edfro Creek	35238	37N-5E-26
Cavanaugh Creek	7064	37N-5E-35
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

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EPA: U.S. Environmental Protection Agency
WQP: Washington State Department of Ecology Water Quality Program

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Abstract

Segments of South Fork Nooksack River and some of its tributaries were included on the Washington State 2008 and 2010 303(d) list of impaired water bodies for temperature violations of water quality standards. The Washington State Department of Ecology (Ecology) is required under Section 303(d) of the federal Clean Water Act to develop and implement total maximum daily loads (TMDLs) for impaired waters of the state. As a part of the TMDL for South Fork Nooksack River, this technical study will evaluate 303(d) listed parameters in the watershed by modeling temperature using a combined Shade-QUAL2Kw modeling approach. Data generated through the modeling analyses will form the basis for allocating heat loads to pollutant sources.

The goal of this TMDL project is to ensure that the South Fork Nooksack River and its associated tributaries attain water quality standards for stream temperature. After completion of the study, a final report describing the results will be posted to the Internet.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act Requirements

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

The Water Quality Assessment (WQA) and the 303(d) List

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

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribal governments, industries, and citizen monitoring groups. These data are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment.

The Washington State 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 – Waters that meet standards for parameter(s) for which they have 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 an approved TMDL being implemented.
- 4b. – Have a pollution-control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, culverts.

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

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

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

TMDL Process Overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. A TMDL study identifies existing pollution problems in the watershed, and specifies how much pollution needs to be reduced or eliminated to achieve applicable water quality standards. Ecology, with the assistance of local governments, tribal governments, agencies, and the community then develops a strategy to control and reduce pollution sources and a monitoring plan to assess the effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *Water Quality Improvement Report* (WQIR).

Once the U.S. Environmental Protection Agency (EPA) approves the WQIR, a *Water Quality Implementation Plan* (WQIP) is developed within one year. The WQIP identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving applicable water quality standards.

Who Should Participate in this TMDL?

Nonpoint source pollutant load targets will likely be established in this TMDL. Because non-point pollution comes from diffuse sources, all upstream watershed areas have potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. Similarly, all point source dischargers in the watershed must also comply with the TMDL. The area that will be subject to the South Fork Nooksack River Temperature TMDL is shown in Figure 1.

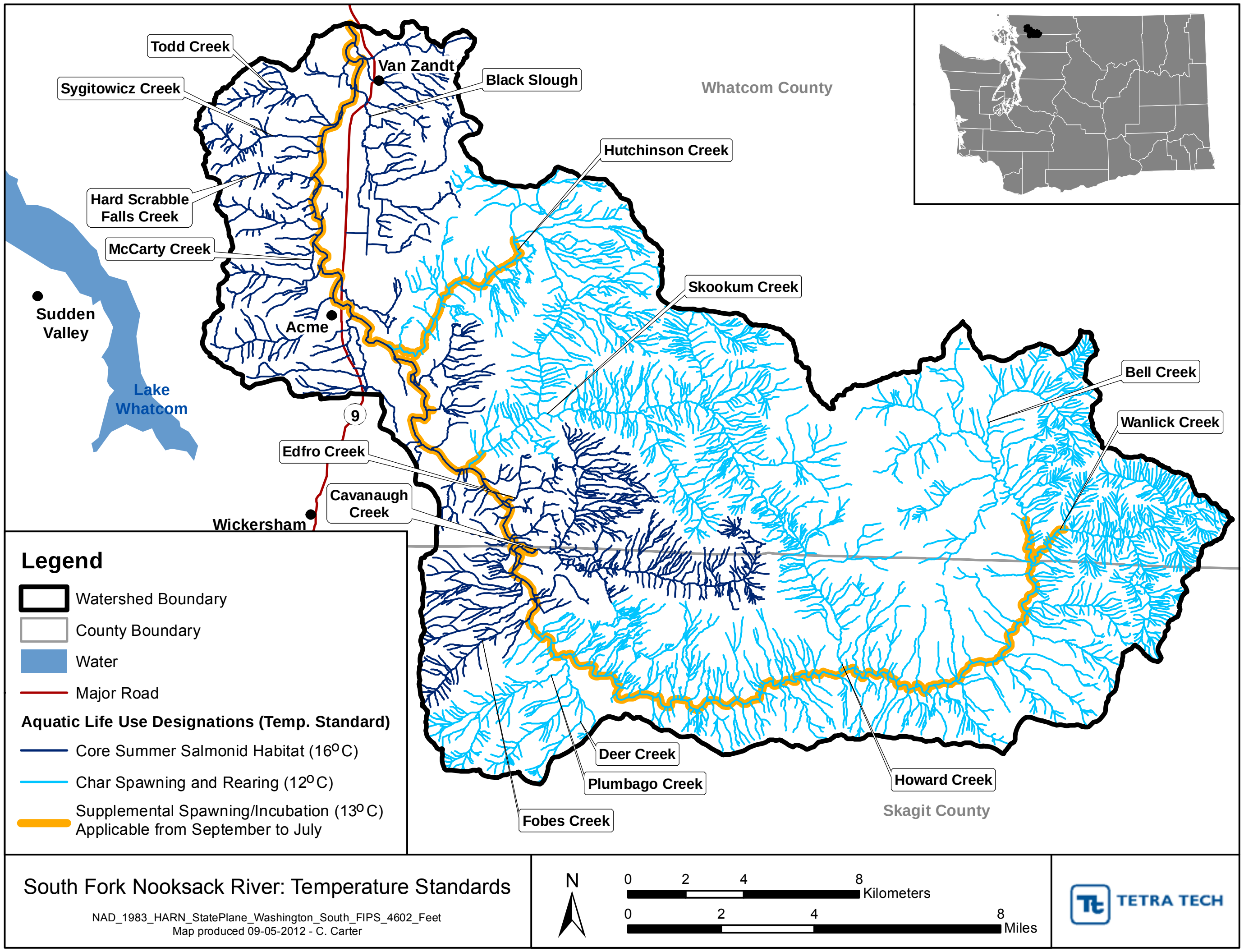

Figure 1. Study area and temperature standards for the South Fork Nooksack River Watersheds TMDL study.

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 the water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the pollution reduction needed to bring the water body into compliance with the applicable water quality standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to 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, residential, agricultural, timber harvest operation runoff, the cumulative share is called a *load allocation*.

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

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

Why is Ecology Conducting a TMDL Study in This Watershed?

Background

The South Fork Nooksack River 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 Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), Nooksack Indian Tribe, and the Lummi Nation are cooperating on the development of a temperature Total Maximum Daily Load (TMDL) for the South Fork Nooksack River.

The TMDL study area encompasses the South Fork Nooksack River watershed, which is located in Whatcom and Skagit counties of Washington (Figure 1). The river flows to the mainstem Nooksack River, which flows through the Lummi Indian 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 migration spawning, incubation, rearing, and foraging habitats for all native Pacific Northwest salmon and trout species. These fish species are highly valued by the many state residents that depend upon them for cultural, recreational, or economic reasons. Salmon in the Nooksack River watershed are relied on by the Lummi Nation and Nooksack Indian Tribe for ceremonial, subsistence, and commercial purposes. Despite this reliance on salmon by Lummi and Nooksack tribal members and other residents in the watershed, abundances of many salmonid populations have diminished substantially from historic levels. Nooksack River early run (aka 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 South Fork Nooksack River watershed is necessary to support the recovery of threatened cold water fish species that migrate, spawn, rear, or live there.

Each study conducted by Ecology requires an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. The goal of this Quality Assurance Project Plan is to characterize water temperatures and the watershed processes that affect water temperatures to establish load and wasteload allocations for the heat sources. 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 Water Quality Improvement Report and Implementation Plan. The Improvement Report and Implementation Plan will help guide Ecology and other stakeholders in our work to restore and protect aquatic life uses.

Study Area

The study area for this TMDL is the South Fork Nooksack River and its tributaries, encompassing approximately 186 mi^2 (Figure 1). This watershed falls within Washington State's Water Resources Inventory Area No. 1 (WRIA 1) and the United States Hydrologic Unit Code (HUC) No. 17110004.

Beneficial Uses

In the water quality standards, aquatic-life-use categories are described using key species (e.g., salmon versus warm-water species) and life-stage conditions (e.g., spawning versus rearing) (WAC 173-201A-200; 2003 edition). The beneficial uses to be protected within the South Fork Nooksack River watershed include Core Summer Salmonid Habitat below the junction at Fobes Creek, Char spawning and rearing above the junction at Fobes Creek (WAC 173-201A-602), and further protection for salmonid spawning and egg incubation along the South Fork Nooksack River and some tributary reaches below Wanlick Creek (DOE, 2011) (Figure 1).

Impairments Addressed by this TMDL

Washington State has established water quality standards to protect these beneficial uses. Based on existing data, there are fourteen segments on the South Fork Nooksack River and eight tributary segments that are identified as being impaired for temperature on Washington's proposed 2010 303(d) list (Table 1; Figure 2). These impairments are addressed in this TMDL.

Limited sampling data indicate that temperature impairments may 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 proposed 2010 303(d) list. Figure 2 shows the distribution of 303(d) listed segments in the South Fork Nooksack watershed. Other impaired reaches may be identified as this study progresses.

To meet the temperature standards, thermal heat loading must be decreased.

Table 1. Study area water bodies on the proposed 2010 303(d) list for temperature

Water Body	Listing ID	Township – Range – Section
South Fork Nooksack River	7112	38N-5E-7
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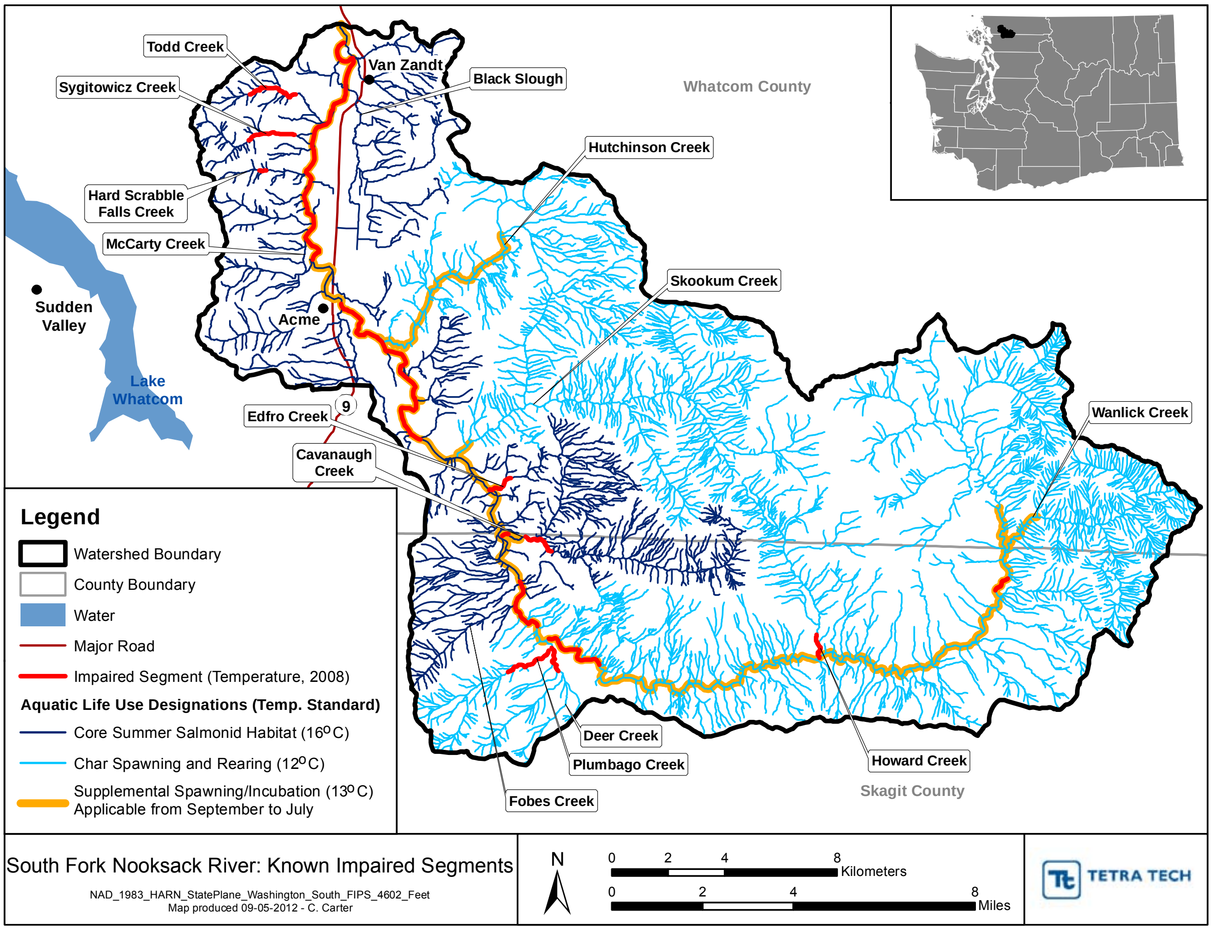


Figure 2. 303(d) listed segments in the South Fork Nooksack River watersheds.

How Will the Results of This Study be Used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve the applicable water quality standards. This is done by assessing the situation and then recommending practices to reduce pollution, and by establishing limits for facilities that have permits. Since the study may also identify the main sources or source areas of pollution, Ecology and local partners use these results to decide where to focus water quality improvement activities. Or, sometimes the study suggests areas for follow-up sampling to further pinpoint sources for cleanup or restoration.

Water Quality Standards and Numeric Targets

The Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state. This section provides Washington State water quality information and those standards applicable to the South Fork Nooksack River watershed.

In July 2003, Ecology made significant revisions to the state's surface water quality standards (Chapter 173-201A WAC). These changes included eliminating the classification system the state used for decades 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, warm water fish habitat).

Ecology submitted the revised water quality standards regulation to the EPA for federal approval in July 2003. These standards were approved by EPA on February 11, 2008. The revisions to the existing standards are online at Ecology's water quality standards website: www.ecy.wa.gov/programs/wq/swqs.

Segments of South Fork Nooksack River and its tributaries were included on the Washington State 2008 303(d) list of impaired water bodies for temperature. In 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 applicable water quality criteria for these parameters are summarized in Table 2.

Table 2. Washington State temperature criteria for impaired parameters in the South Fork Nooksack River watershed.

Use Classification	Criteria
Core summer salmonid habitat, spawning, rearing, and migration	<16°C 7-DADMax[1,2]
Char spawning and rearing	<12°C 7-DADMax[1,2]
Supplemental salmonid spawning and incubation	<13°C 7-DADMax[1,2] (Sept 1 – Jul 1)

1. 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
2. A human-caused variation within the above range of less than 0.3°C for temperature is acceptable.

Temperature affects the physiology and behavior of fish and other aquatic life as well as the physical and biological properties of the water body. For example, in general, the higher the stream temperature, the lower the amount of dissolved oxygen in the water. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

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

In the water quality standards, 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; 2003 edition]. The temperature criteria established to protect these uses are described in Table 200 (1)(c) of the water quality standards, and include numeric criteria of 12°C for Char Spawning and Rearing; 16°C for Core Summer Salmonid Habitat; both of which are effective throughout the entire year. 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 September 1 to July 1 (Ecology, 2011). The criteria are based on the highest seven-day average of daily maximum temperatures (7-DADMax). Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average (WAC 173-201A-200 (1)(c)(iii)).

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, the state provides a small allowance for additional warming due to human activities. When the background condition is cooler than the criteria, the temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (WAC 173-201A-200 (1)(c)(ii)). If a water body's temperature is warmer than the criteria (or within 0.3°C of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (WAC 173-201A-200 (1)(c)(i)).

Whether or not the water body is naturally high in temperature is determined using a computer model. The model roughly approximates natural conditions, and is appropriate for determining the implementation of the temperature criteria. This model results in what is called the "system thermal potential" or "system potential" of the water body.

Global Climate Change

Changes in global climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005).

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

The predicted changes to our region's climate highlight the importance of protecting and restoring the mechanisms that help to cool stream temperatures. Stream temperature improvements obtained by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help to minimize the changes anticipated from global climate change. It will take considerable time, however, to reverse human actions that contribute to elevated stream temperatures. The sooner such restoration actions begin and the more complete they are, the more effective the program will be in offsetting some of the detrimental effects on our stream resources.

Restoration efforts may not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species.

Ecology is conducting this TMDL to meet the state's surface water quality standards based on current climatic patterns. In association with the TMDL, a pilot climate change study is being conducted including evaluation of a number of scenarios. This feature is discussed later in this QAPP. Potential changes in stream temperatures associated with global climate change may require further modifications to human-source allocations at some future time.

Watershed Description

The South Fork Nooksack River watershed is located in Whatcom and Skagit counties, Washington in WRIA 1 and HUC 17110004 (Figure 1). The South Fork Nooksack River watershed is approximately 186 square miles in size. It originates in the snow-dominated Twin Sisters Mountain of the Cascade Mountain Range and discharges into the Nooksack River mainstem approximately 36 river miles (RM) upstream from where the Nooksack River mainstem discharges to Bellingham Bay.

The South Fork Nooksack River watershed is dominated by forest and shrubland with small amounts of agriculture and development in the lower portion. It includes portions of the cities of Van Zandt and Acme, and counties of Whatcom and Skagit. The Lummi Nation operates a salmon hatchery and established the Arlecho Creek Preserve within the watershed. The Nooksack Indian Tribe also owns land and other facilities within the watershed. The headwaters are lands managed by the US Forest Service. 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 South Fork Nooksack River is fed by numerous tributaries as it flows down from the Cascade Mountains. Major tributaries include 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 gaging station 01F070 (WY 2004-2010) located on the left bank of the South Fork Nooksack River at the Potter Road Bridge crossing near the town of Van Zandt.

The upstream portion of the South Fork Nooksack River 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 South Fork Nooksack River, sorted combinations of silt, sand, and gravel dominate in streambeds and alluvial fans. The Lower South Fork Nooksack River 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 material consisting of graphite, muscovite, quartz, and phylite, 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 South Fork Nooksack River) is dominated by the Twin Sisters Range. The Twin Sisters mountains are 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, 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 are generally easier to erode 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 GIS grid-based product for the entire United States. The data are based on interpretation of multi-seasonal Landsat satellite images (30-meter 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 datasets are updated about every five years. Year 2006 land use/land cover is shown in Figure 3. The most prevalent land covers in the watershed are three forest types (Deciduous, Evergreen, and Mixed), and Shrub/Scrub (Figure 3).

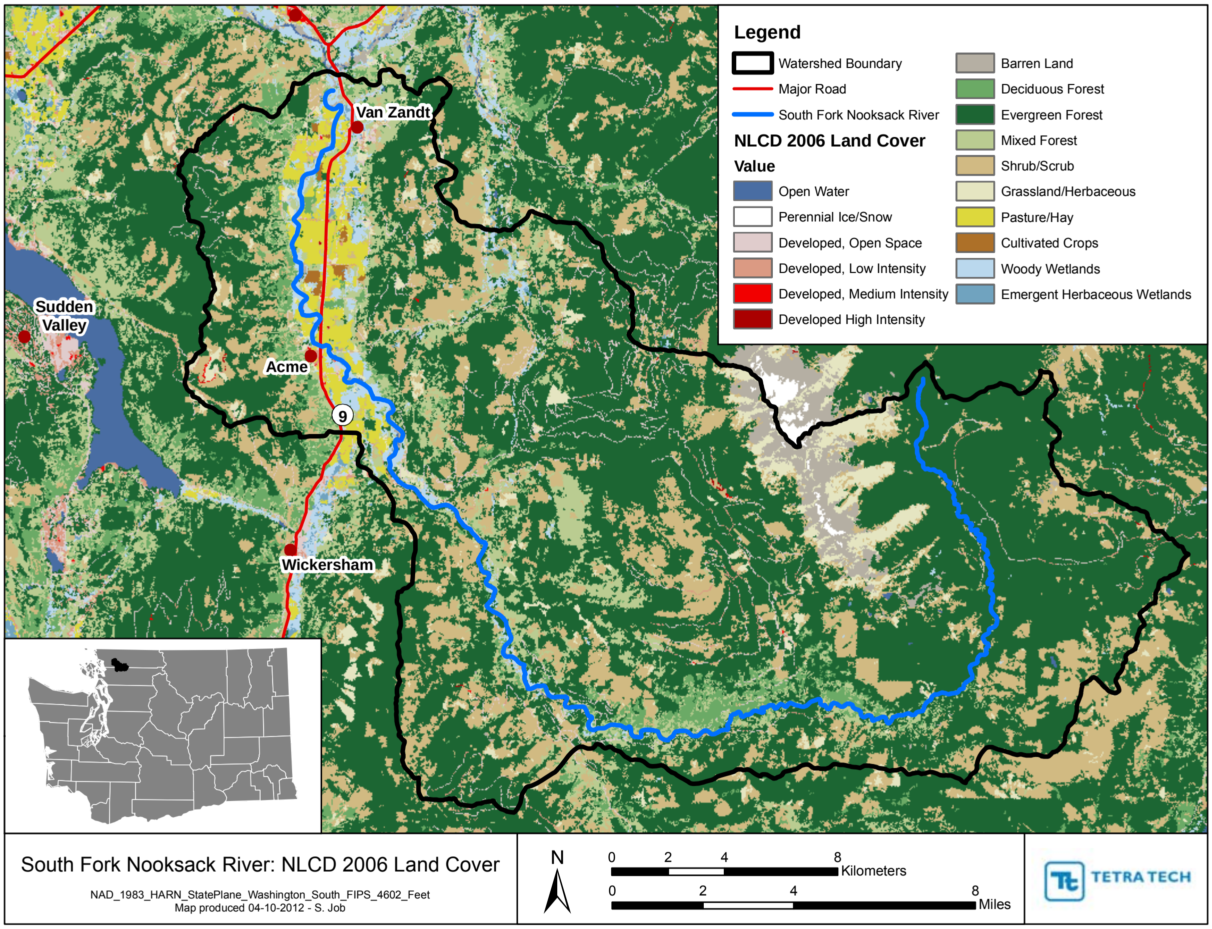


Figure 3. South Fork Nooksack River land cover (2006 NLCD).

The USFS/DOI LANDFIRE dataset, 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 meter grid cells. LANDFIRE provides several data products including vegetation height, vegetation cover (percent canopy), vegetation type, and others. The first LANDFIRE dataset (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) dataset 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 4).

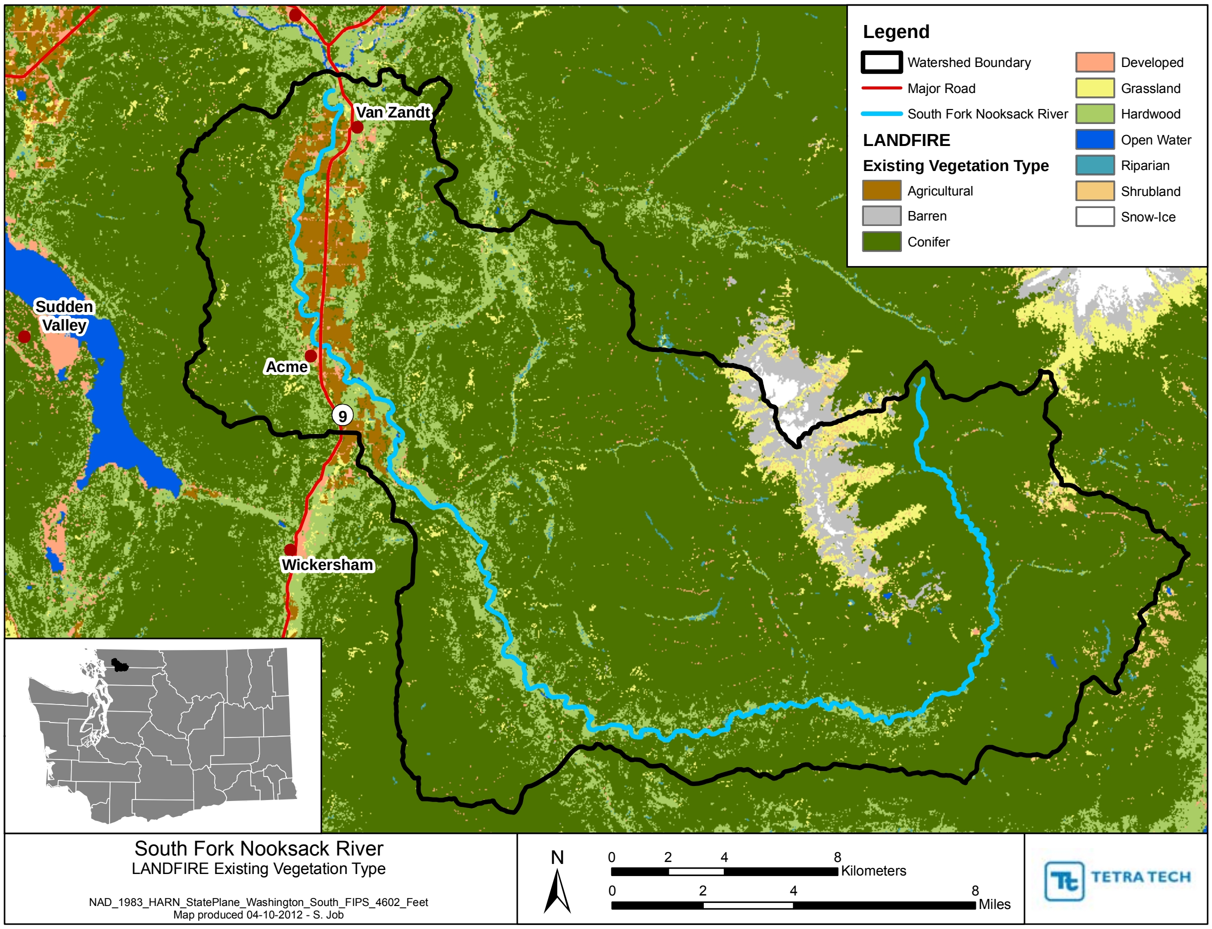


Figure 4. South Fork Nooksack River land cover (LANDFIRE). LANDFIRE 2008 land use/land cover using preliminary vegetation groups

LANDFIRE and NLCD differ markedly in their interpretation of forest types and shrubland (Figure 5). 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 meters 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 meters) tend to overlay on areas with EVT tree height of more than 10 meters.

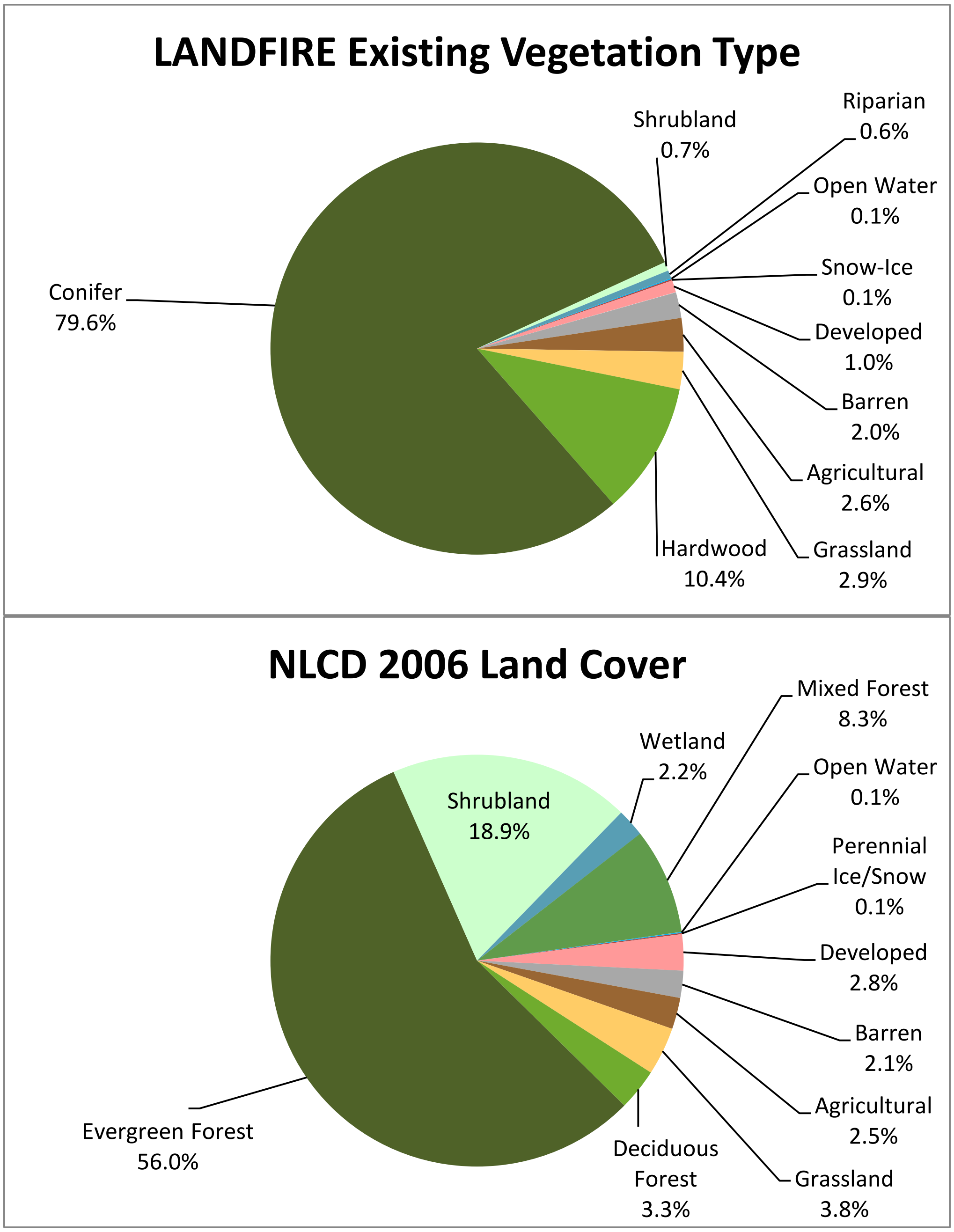


Figure 5. Comparison of LANDFIRE and NLCD land use/land cover estimates for the South Fork Nooksack watershed.

The NOAA Coastal Change Analysis Program (CCAP) produces land cover and land cover change data products for coastal areas of the US. The South Fork Nooksack watershed lies within the regional land cover zone, where 30 meter grid cell resolution is available. Datasets 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 dataset classifies both palustrine and estuarine wetlands separately and further classifies each of these as either forested, scrub/shrub, or emergent wetlands. Within the watershed, CCAP 2006 is almost identical to NLCD 2006 outside of wetland areas. **Figure 6** displays the CCAP land cover dataset in which forested and scrub/shrub wetlands are combined into a woody wetlands category for a spatial comparison with the NLCD dataset. There is a small amount of variation between the two datasets at a local scale, but the overall spatial distribution of land cover is essentially the same as NLCD 2006.

The CCAP land cover dataset has been previously selected for use in studies of the Lower Nooksack River and it is advisory to rely on the same dataset for this piece of work. Therefore, CCAP is the selected land cover dataset 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 the determination of system potential shade).

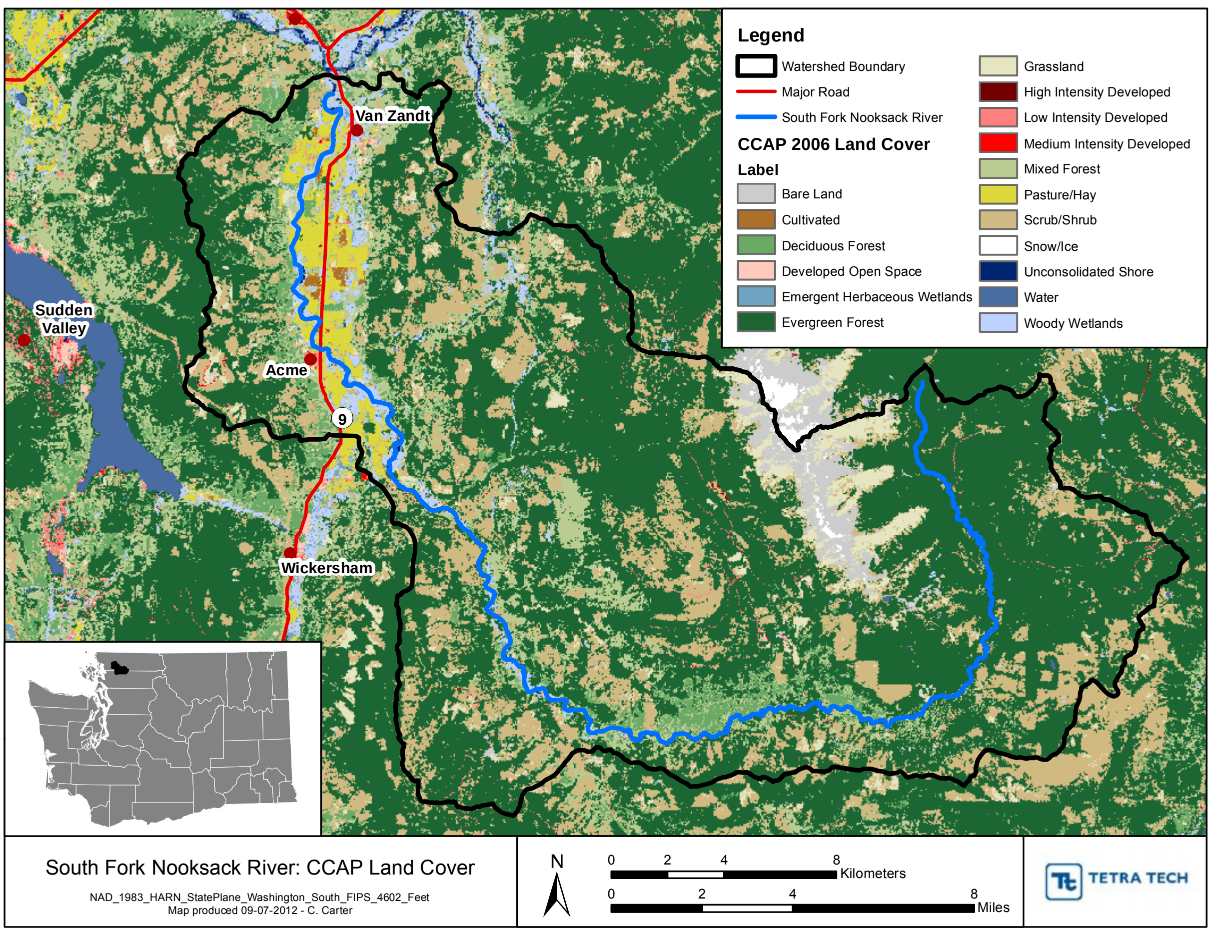


Figure 6. South Fork Nooksack River land cover (CCAP 2006)

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 dataset includes Forest Practices Application/Notification harvest unit boundaries as well as the number of acres associated with active Forest Practices Application/Notifications. The number of acres for all active Forest Practices Application/Notifications within the South Fork Nooksack River watershed equal 3,387 acres of land over the 2003 to 2012 period, with expiration dates ranging from 2012 to 2014. Figure 7 provides the spatial distribution of active timber harvesting throughout the watershed for this approximately 10 year period. This dataset does not include forest practices that were active in the past and that are currently inactive.

There have been five significant forest fires in the watershed during the last 30 years (Figure 6). The largest fire occurred in 1979 when 130 acres of forest burned during a debris burn. Another major debris burn occurred in 2004 just outside of the watershed boundary, affecting 100 acres. Aside from these five primary fire events, all other fire events occurring within the last 30 years individually burnt less than three acres.

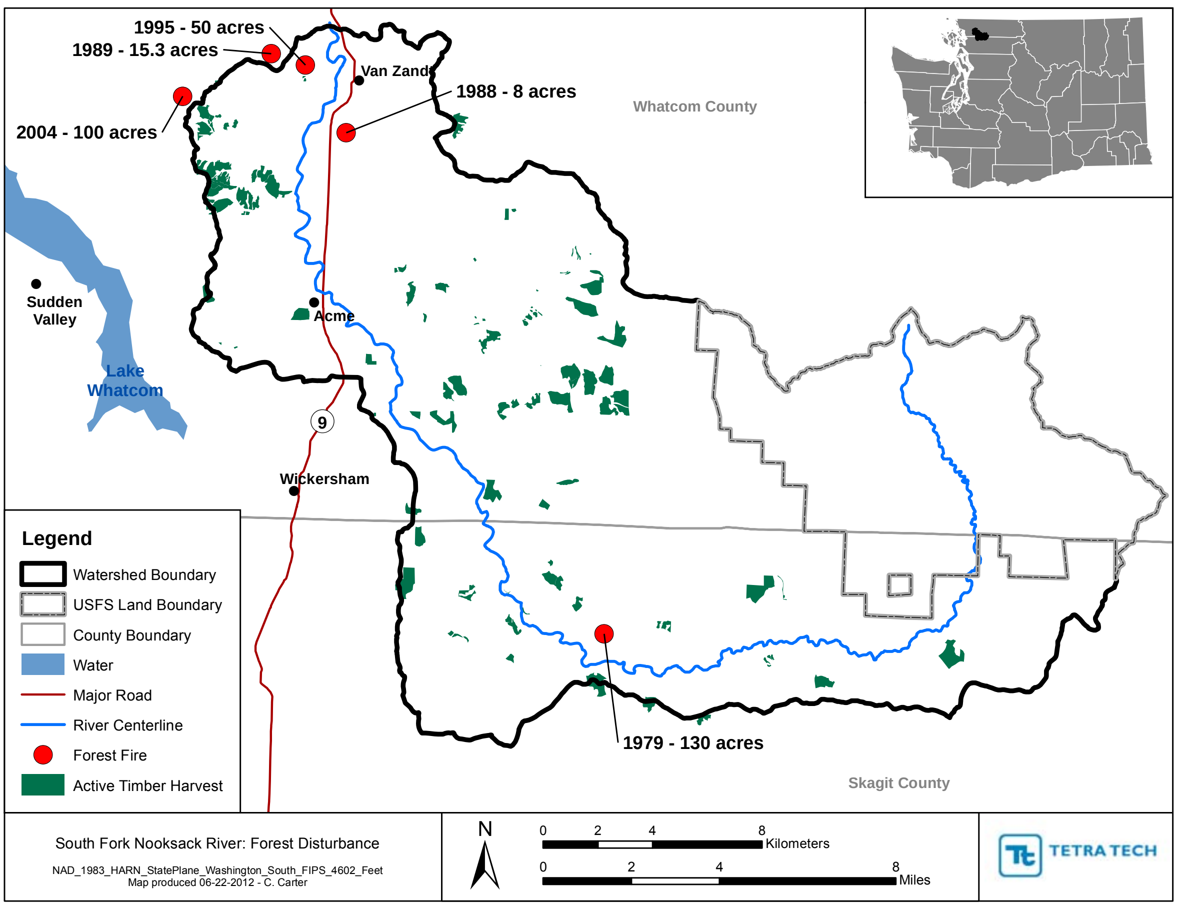


Figure 7. Forest disturbance from fires and timber harvest

In a recent study performed by Pollock et al. (2009), 42 subbasins located 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. And the “total basin forest area” was defined as the entire area of the basin, upstream and downstream of the temperature loggers.

Results showed that the percentage of the “total basin forest area” harvested (within the past 40 years) explained 39 percent of the variation in the average daily maximum temperature, and the percentage of harvested “riparian forest network” upstream from temperature monitoring locations explained 33 percent 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. These results suggest that “total basin forest area” harvest and “riparian forest network” harvest were much better predictors of stream temperature regimes when compared to “near upstream riparian forest” harvest.

The researchers observed a relatively strong relationship between maximum daily stream temperatures and the total amount of harvest in the “total basin forest area”, and strong but slightly weaker relationship between maximum daily stream temperatures and the total amount of harvest in the “riparian forest network” of a basin. Based on 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 cannot be entirely mitigated through the reestablishment of riparian buffers. Their findings have important implications for South Fork Nooksack watershed. While most of the harvested areas shown in Figure 8 are not directly adjacent to temperature-impaired reaches, there is a higher proportion of harvesting in the drainages in the vicinity of the impaired reaches. The potential for future impacts is also significant, given the large proportion of the watershed zoned for commercial or private forest harvesting (Figure 8). In addition to impacts of active harvest, previously harvested areas recovering from canopy removal may also affect stream temperature.

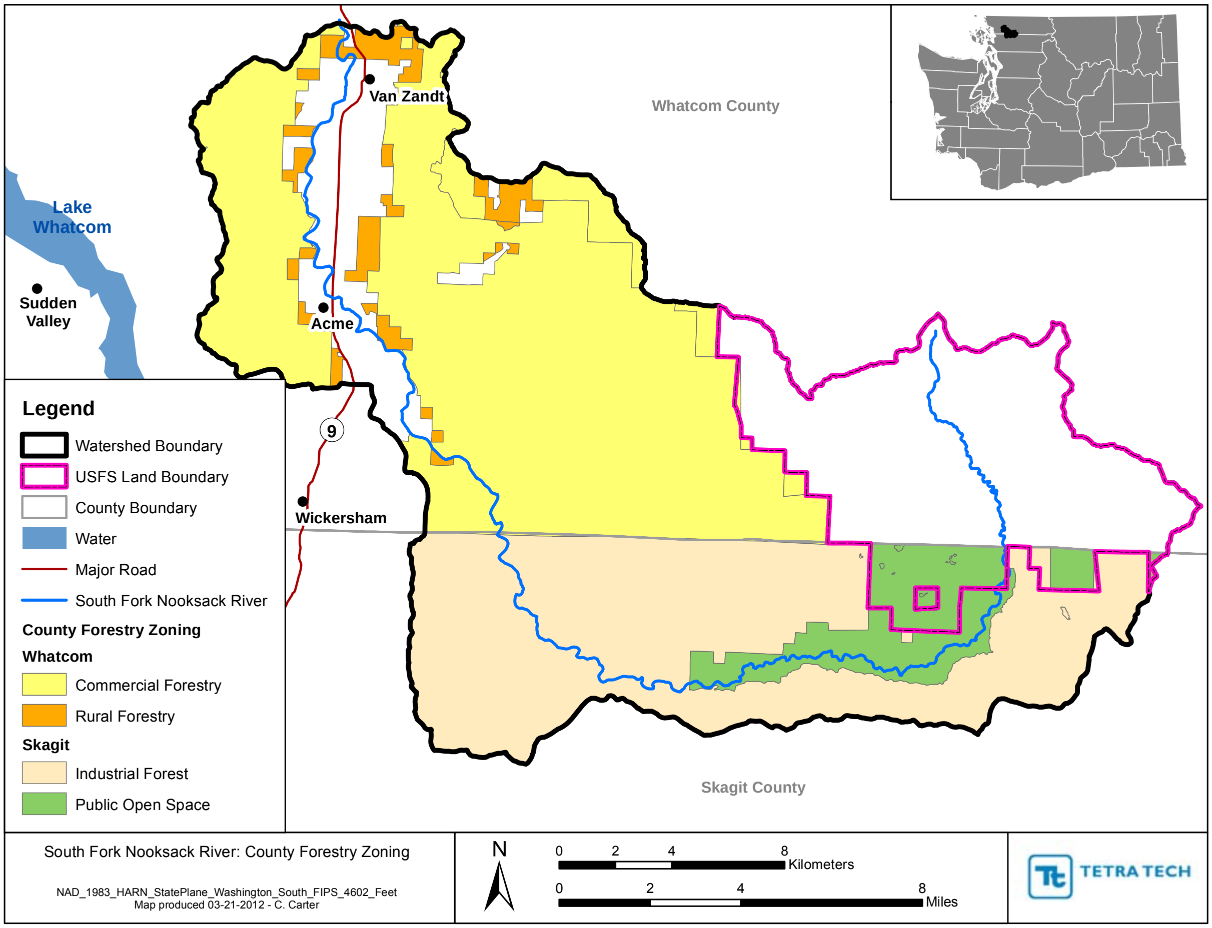


Figure 8. Forest zoning in the watershed

Climate

The South Fork Nooksack watershed lies within a convergence zone of Arctic weather from the north and Pacific weather systems from the south (USFS, 1995). In the summer months, 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 within the watershed, annual average precipitation ranges from 60 and 125 inches (USGS, 2000a). Monthly average precipitation is at its highest during November through January; however, extreme storm events resulting in more than 4 inches of precipitation per day have occurred outside of 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 run-off 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 South Fork Nooksack River have limited access for anadromous salmonids due to the steep terrain, the river's and channel blockages, major tributaries contain accessible habitat and 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 South Fork Nooksack River salmonids require cold, clean water and a complex, connected habitat structure to survive. Both early run (spring) Chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*) are federally listed as threatened under the Endangered Species Act.

The riparian corridors of the South Fork Nooksack River 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 South Fork Nooksack 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 located west of the Cascade Mountains crest. Agricultural fields along the South Fork Nooksack River provide foraging and wintering areas for a resident herd of Rocky Mountain 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 within the South Fork Nooksack River 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 Contamination

Non-Stormwater Point Source Pollutions

Three active point sources were identified within the South Fork Nooksack River watershed (Table 3). Jacqueline Ridge is located south of Acme and west of Hwy 9, next to the watershed border. Concrete Norwest Saxon Pit is located about five miles southeast of Acme, and is also on the watershed border, about a ½ mile west of South Fork Nooksack River; stormwater generated by the facility currently discharges to groundwater. 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 South Fork Nooksack River 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 MGD, equivalent to 8.7 cfs.

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

Permit Number	Facility Name	Type	Parameters Monitored
WAR010717	Jacqueline Ridge	General Construction Stormwater Permit	Turbidity and pH
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

Agricultural Irrigation

Surface water and groundwater withdrawals support agricultural irrigation in the watershed. About 775 acres are currently irrigated, according to information from Whatcom Farm Friends and 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 (personal communication, Thomas Buroker, May 29, 2012). The 7Q10 value for U.S. Geological Survey (USGS) gage 12209000 over the past 24 years is about 75.8 cfs based on USGS calculations; 2.8 cfs represents less than 4 percent of the 7Q10 flow. The 2.8 cfs value is likely overestimated, since some irrigation use is from groundwater.

Point Source Stormwater Pollution

During 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. Ecology issues NPDES permits to larger entities that operate municipal separate storm sewer systems

(MS4s) responsible for collecting, treating, and discharging stormwater to local streams and rivers.

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.

More information on the WSDOT permit can be found at
www.ecy.wa.gov/programs/wq/stormwater/municipal/wsdot.html

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 available at
www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm

Nonpoint Pollution Sources

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

- Loss of vegetation within the riparian zone
- Human activities that have changed stream channel morphology and geometry
- Reduction in baseflows, instream flows, groundwater flows and hyporheic exchange flows
- Urban stormwater (not regulated through NPDES)
- Forest practices

Nonpoint source contributions are important to understand because they have impact on stream water quality, and they also are a major component of stormwater runoff. Temperature is directly impacted 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, instream 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.

Conversion of forest to developed and open agricultural land, as well as removal of forest cover through harvesting operations, can have impacts on watershed hydrology and sediment loading. These land conversions contribute to upland sediment load. They may 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 may 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 may also reduce cooler hyporheic flows.

Historic logging appears to have resulted in increased landslides and a shortage of large woody debris. Subsequent scour of landslide toes contributes to filling of pools, while the lack of wood also contributes to channel instability. More generally, these effects may have set off a channel evolution process leading to wider, shallower channels that absorb more solar radiation.

Historical Data Review

The South Fork Nooksack River watershed is monitored regularly by the USGS, the Nooksack Indian Tribe, 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. Available and pertinent data on existing water temperatures and river flows from these agencies sources are described below. Data included in this QAPP are presented to characterize historical and recent flow and 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 QA/QC. The data have been checked against Ecology's Credible Data Policy (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf).

Stream Temperature Data

Stream temperature monitoring data collected by the Nooksack Indian Tribe, USGS, and Ecology were analyzed for comparison with water quality standards. Three time periods were selected for analysis for each year, based on the effective dates for the supplemental standard for spawning and incubation of salmonid species (September 1 through July 1). The three time 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 water temperatures in Chinook salmon habitats of the Nooksack River watershed. This ongoing work is funded through EPA Clean Water Act Sections 106 and 319, and Indian General Assistance Grant (IGAP) grant programs that constitute a component of the Nooksack Indian Tribe's Performance Partnership Grant with the 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 during the months of June through October (every 30 minutes). In this section, continuous data have been summarized as highest seven-day average of daily maximum temperatures (7-DADMax) in order to be consistent with the water quality standard. The 7-DADMax for any individual day was 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.

In 2007, nine locations were monitored for temperature along the South Fork Nooksack River and six locations were monitored on tributaries to the South Fork (Figure 9, Figure 10, and Table 4). Sites were selected to monitor water temperature throughout the range of Nooksack early run Chinook salmon habitats. In 2007, there is a general increase in stream temperature 7-DADMax from upstream to downstream monitoring locations. The boxplots in Figure 10 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 11). Temperatures recorded at the South Fork station locations show that these waters exceeded the applicable water quality standard 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 8 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 (Table 5).

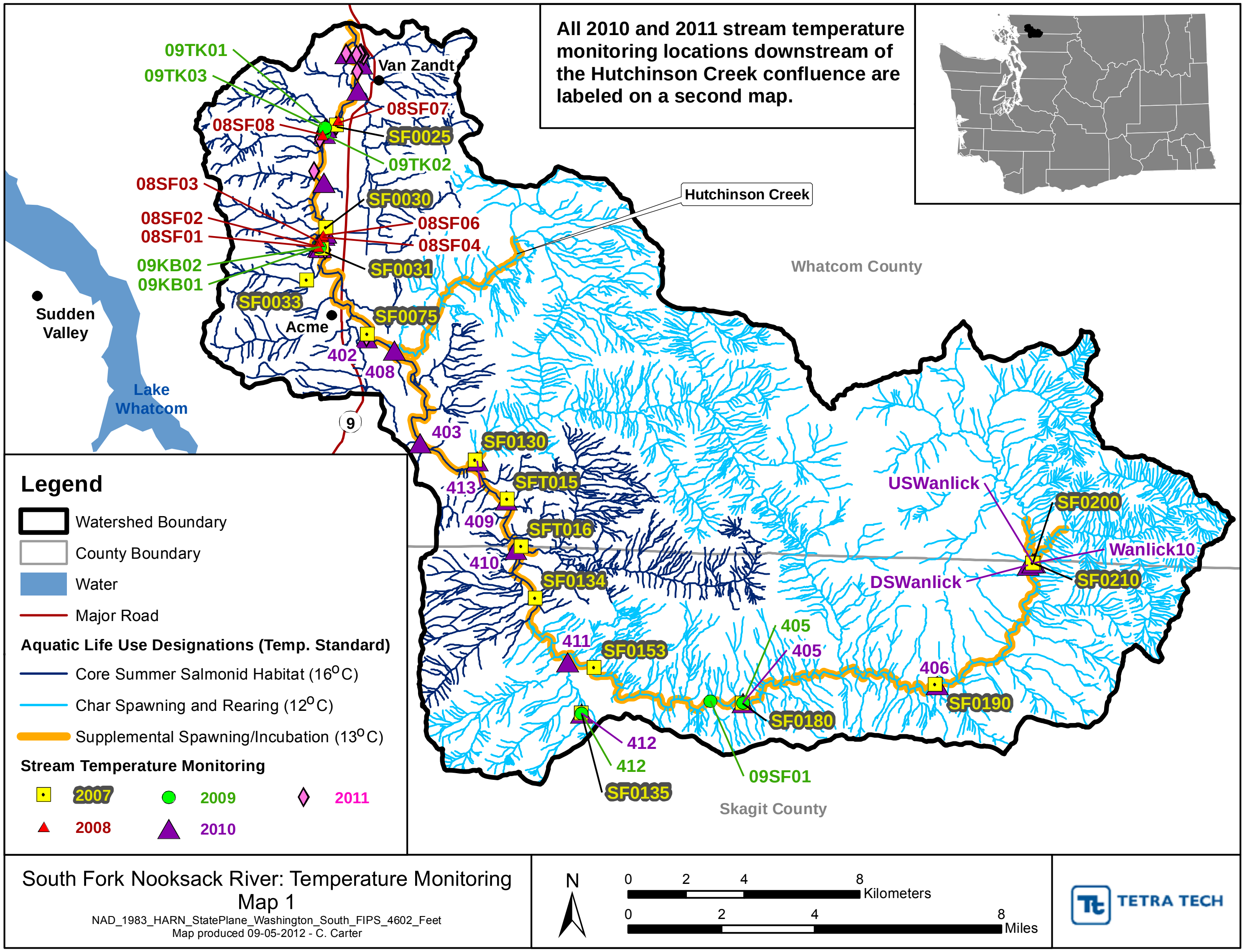


Figure 9. Nooksack Indian Tribe stream temperature monitoring station locations – Map 1

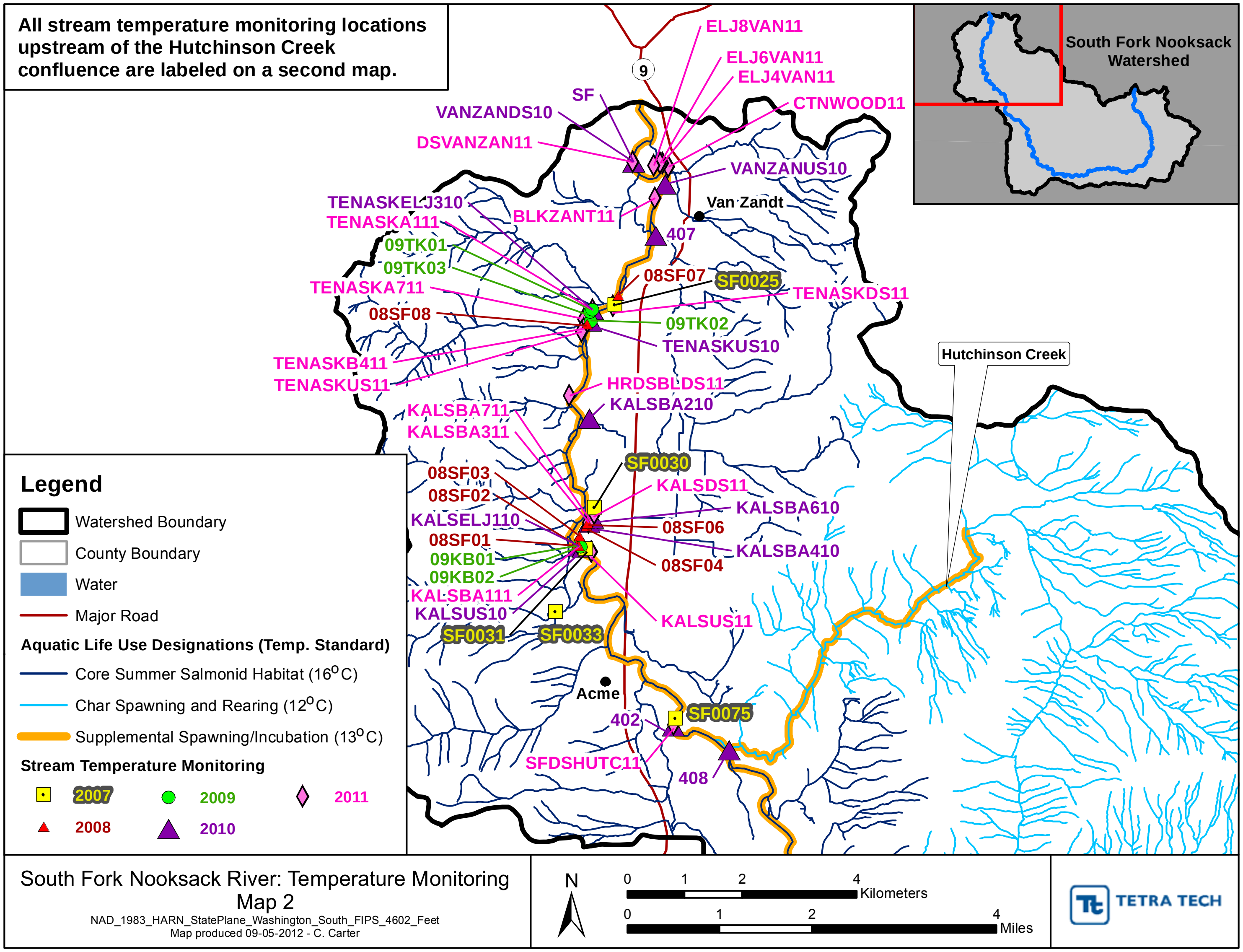


Figure 10. Nooksack Indian Tribe stream temperature monitoring station locations – Map 2

Table 4. 7-DADMax of stream temperatures in 2007 in the South Fork Nooksack subbasin

Station ID	Stream Name	Station Description	January 1- July 1				July 2 - August 31				September 1 - December 31			
				Temperature (°C)				Temperature (°C)				Temperature (°C)		
			# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard	# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard	# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard
2007 Monitoring														
SF0200	South Fork Nooksack River	Upstream of Wanlick Creek	25	11.0	12	0	61	16.0	12	56	42	14.9	12	17
SF0210	Wanlick Creek	Near South Fork Nooksack River confluence	25	10.1	12	0	61	14.3	12	50	42	13.0	12	15
SF0190	South Fork Nooksack River	Seattle City Light bridge	9	12.2	12	1	61	16.2	12	61	26	13.8	12	16
SF0180	South Fork Nooksack River	200 Rd Bridge	9	12.8	12	2	61	17.3	12	61	42	15.7	12	19
SF0153	South Fork Nooksack River	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	South Fork Nooksack River	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	South Fork Nooksack River	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	South Fork Nooksack River	Upstream of Kalsbeek along riprap	0	0	13	0	29	20.2	16	29	31	18.7	13	26
SF0030	South Fork Nooksack River	Kalsbeek above culvert-downstream end	0	0	13	0	58	20.2	16	55	31	18.4	13	26
SF0025	South Fork Nooksack River	Upstream of Todd Creek	7	15.8	13	7	26	20.2	16	23	0	0.0	13	0

Table 5. 2007 exceedances of Water Quality Standards (WQS) by location

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2007 Monitoring					
SF0200	South Fork Nooksack River	Upstream of Wanlick Creek	73	128	57%
SF0210	Wanlick Creek	Near South Fork Nooksack River confluence	65	128	51%
SF0190	South Fork Nooksack River	Seattle City Light bridge	78	96	81%
SF0180	South Fork Nooksack River	200 Rd Bridge	82	112	73%
SF0153	South Fork Nooksack River	Larson`s bridge	92	98	94%
SF0135	Deer Creek	140 Rd Bridge	80	108	74%
SF0134	South Fork Nooksack River	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	South Fork Nooksack River	Downstream of Hutchinson Creek	94	119	79%
SF0033	McCarty Creek	Upstream of Turkington Rd. bridge	0	119	0%
SF0031	South Fork Nooksack River	Upstream of Kalsbeek along riprap	55	60	92%
SF0030	South Fork Nooksack River	Kalsbeek above culvert-downstream end	81	89	91%
SF0025	South Fork Nooksack River	Upstream of Todd Creek	30	33	91%

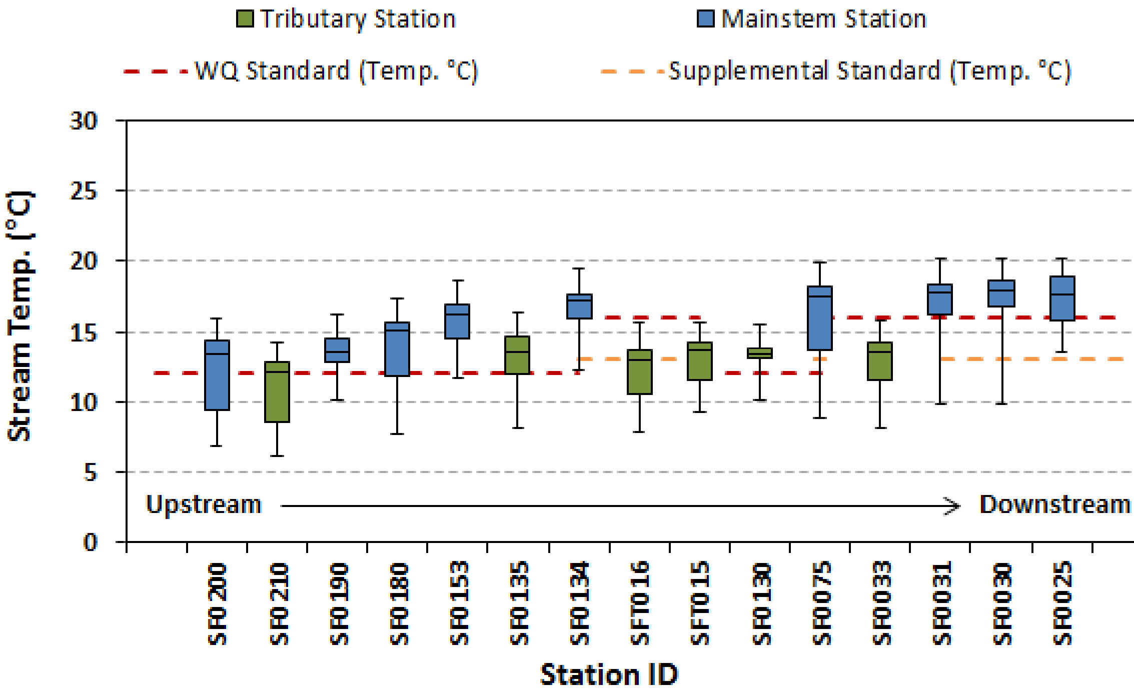


Figure 11. 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2007 in the South Fork Nooksack

In 2008, the Nooksack Indian Tribe's site selection shifted to implement their 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 South Fork Nooksack River (Figure 9 and Figure 10) were placed in the deepest sections of the log jam-associated pools. As a result, the spatial variation in 2008 (Figure 12) temperature monitoring is not as great as it was in 2007; the 2008 stations are clustered within two reaches where the Tribe had constructed log jam projects and all are located on the downstream portion of the South Fork where the 13 or 16°C water quality standards apply (depending on location and date).

All stations show exceedances of the applicable temperature standard throughout the 2008 monitoring period; the total number of monitored days that temperatures exceeded the standard ranged from 10 to 56 (Table 6 and Table 7). Given that these stations were selected to represent the enhanced condition (pools formed in areas of cool-water influence) rather than reach-average conditions, such data should be interpreted with caution.

Table 6. Stream temperature as 7-DADMax for 2008 in the South Fork Nooksack subbasin

Station ID	Stream Name	Station Description[1]	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
2008 Monitoring														
08SF01	South Fork Nooksack River	Kalsbeek ELJ#1	3	13.2	13	1	61	19.8	16	33	21	18.8	13	21
08SF02	South Fork Nooksack River	Downstream of Kalsbeek ELJ#1	3	13.2	13	1	61	20.1	16	33	21	16.1	13	20
08SF03	South Fork Nooksack River	Kalsbeek side channel	3	13.3	13	3	14	17.9	16	7	0	0	13	0
08SF04	South Fork Nooksack River	Kalsbeek ELJ#3	3	13.0	13	1	61	19.3	16	8	21	15.8	13	20
08SF06	South Fork Nooksack River	Kalsbeek bank roughness structure	3	13.2	13	1	61	19.8	16	33	21	15.8	13	20
08SF08	South Fork Nooksack River	Upstream of Todd Creek ELJ site	0	0	13	0	52	20.0	16	34	9	15.9	13	9
08SF07	South Fork Nooksack River	Downstream of Todd Creek	3	13.4	13	2	61	20.0	16	34	21	15.4	13	20

[1] ELJ stands for 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 7. 2008 exceedances of Water Quality Standards (WQS) by location

Station ID	Stream Name	Station Description[1]	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2008 Monitoring					
08SF01	South Fork Nooksack River	Kalsbeek ELJ#1	55	85	65%
08SF02	South Fork Nooksack River	Downstream of Kalsbeek ELJ#1	54	85	64%
08SF03	South Fork Nooksack River	Kalsbeek side channel	10	17	59%
08SF04	South Fork Nooksack River	Kalsbeek ELJ#3	29	85	34%
08SF06	South Fork Nooksack River	Kalsbeek bank roughness structure	54	85	64%
08SF08	South Fork Nooksack River	Upstream of Todd Creek ELJ site	43	61	70%
08SF07	South Fork Nooksack River	Downstream of Todd Creek	56	85	66%

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

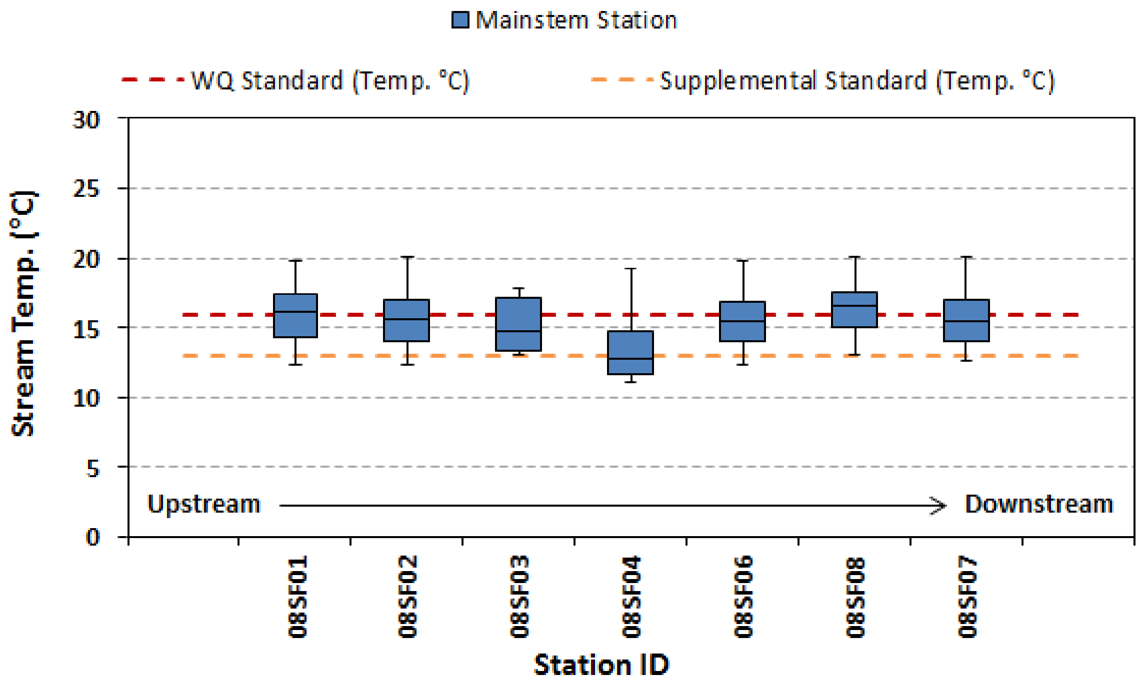


Figure 12. 25th, 50th, and 75th percentiles of the 7-DADMax stream temperature for 2008 in the South Fork Nooksack

In 2009, seven locations were monitored for temperature along the South Fork Nooksack River, and one station was located on the Deer Creek tributary at the same location as station SF0135 from the 2007 monitoring period (Table 8, Table 9, and Figure 13). As in 2007, there is a general increase in stream temperature from upstream to downstream locations. However, station 09TK03, located 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 located 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 and/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 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.

Table 8. Stream temperature as 7-DADMax for 2009 in the South Fork Nooksack subbasin

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
2009 Monitoring														
405	South Fork Nooksack River	200 Rd Bridge	21	13.4	12	7	17	18.3	12	17	15	17.8	12	8
09SF01	South Fork Nooksack River	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 log jam	0	0	13	0	44	24.4	16	44	31	19.6	13	28
09KB02	South Fork Nooksack River	Right bank at Kalsbeek on small wood pile	0	0	13	0	44	24.3	16	44	31	19.5	13	28
09TK02	South Fork Nooksack River	Right bank Tenaska at enhanced log jam	0	0	13	0	44	25.2	16	44	11	20.5	13	11
09TK03	South Fork Nooksack River	Left bank at Tenaska at log jam three	0	0	13	0	44	13.7	16	0	31	13.7	13	11
09TK01	South Fork Nooksack River	Left bank at Tenaska at log jam one in eddy	0	0	13	0	32	23.8	16	32	31	19.9	13	28

Table 9. 2009 exceedances of Water Quality Standards (WQS), by location

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2009 Monitoring					
405	South Fork Nooksack River	200 Rd Bridge	32	53	60%
09SF01	South Fork Nooksack River	Downstream right bank erosion area (RM 24.2)	88	96	92%
412	Deer Creek	140 Rd Bridge	91	96	95%
09KB01	South Fork Nooksack River	Right bank at Kalsbeek on log jam	72	75	96%
09KB02	South Fork Nooksack River	Right bank at Kalsbeek on small wood pile	72	75	96%
09TK02	South Fork Nooksack River	Right bank Tenaska at enhanced log jam	55	55	100%
09TK03	South Fork Nooksack River	Left bank at Tenaska at log jam three	11	75	15%
09TK01	South Fork Nooksack River	Left bank at Tenaska at log jam one in eddy	60	63	95%

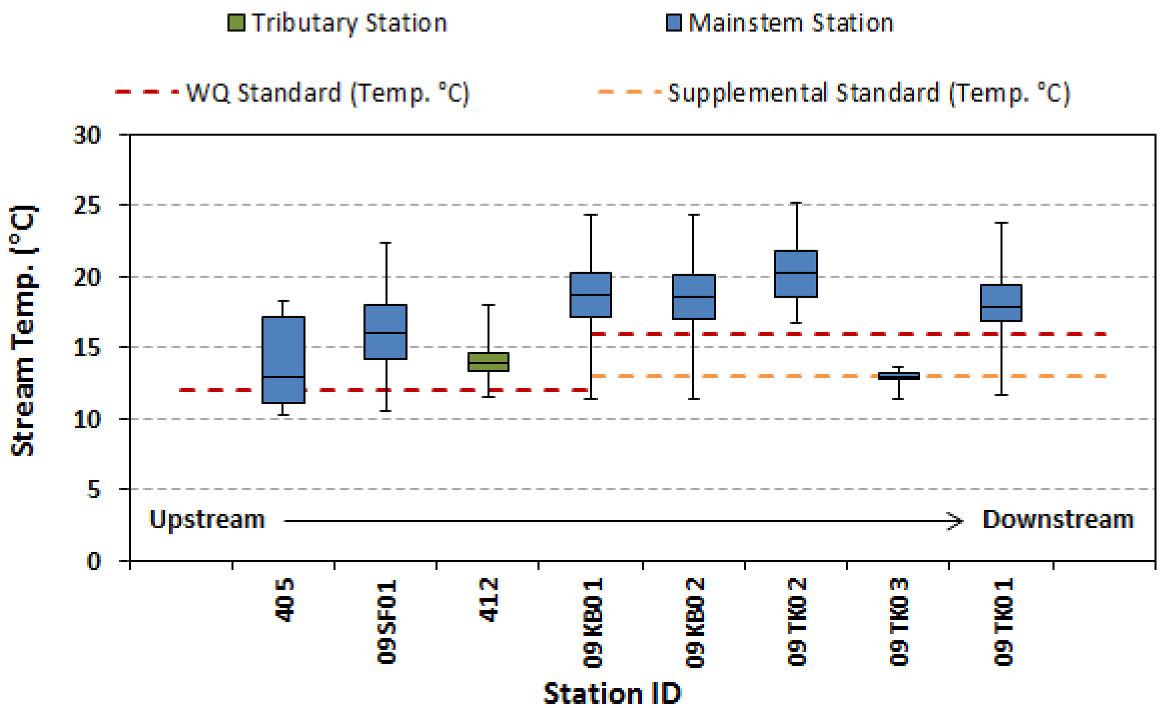


Figure 13. 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2009 in the South Fork Nooksack

In 2010, River 22 locations on the South Fork 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 (Table 10 and Table 11). The box and whisker plot for 2010 (Figure 14) supports the upstream to downstream warming trend that was 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.

Table 10. Stream temperature as 7-DADMax for 2010 in the South Fork Nooksack subbasin

			January 1 - July 1				July 2 - August 31				September 1 - December 31			
				Temperature (C)				Temperature (C)				Temperature (C)		
Station ID	Stream Name	Station Description	# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard	# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard	# Days Monitored	Highest 7-DADMax	WQ Standard	# Days Exceeding Standard
2010 Monitoring														
USWanlick	South Fork Nooksack River	Upstream of Wanlick Creek	0	0	12	0	45	18.3	12	45	33	13.1	12	9
Wanlick10	Wanlick Creek	Wanlick Creek	0	0	12	0	45	15.9	12	43	33	11.9	12	0
DSWanlick	South Fork Nooksack River	Downstream of Wanlick Creek	0	0	12	0	45	17.4	12	45	33	12.7	12	3
406	South Fork Nooksack River	South Fork at Seattle City Light property	34	11.6	12	0	54	17.2	12	50	31	12.9	12	9
405	South Fork Nooksack River	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	0	25	16.6	12	25	31	12.5	12	11
410	Cavanaugh Creek	Cavanaugh Creek	0	0	13	0	44	22.3	16	44	34	16.5	13	27
409	Edfro Creek	Edfro Creek	32	12.3	13	0	59	16.3	16	4	48	13.4	13	8
413	Skookum Creek	Skookum Creek	25	11.6	12	0	54	14.7	12	50	53	12.2	12	3
403	South Fork Nooksack River	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	South Fork Nooksack River	SF Nooksack DS of Hutchinson Creek	25	14.3	13	9	54	21.7	16	49	27	17.1	13	20
KALSUS10	South Fork Nooksack River	Kalsbeek Upstream of upper most ELJ	0	0	13	0	51	22.0	16	51	40	17.4	13	28
KALSELJ110S	South Fork Nooksack River	Kalsbeek at upper logjam SURFACE	0	0	13	0	51	22.2	16	51	39	17.3	13	30
KALSELJ110D	South Fork Nooksack River	Kalsbeek at upper logjam DEPTH	0	0	13	0	51	21.4	16	51	39	16.9	13	29
KALSBA210S	South Fork Nooksack River	Kalsbeek #2 Bank Armor SURFACE	0	0	13	0	51	21.6	16	51	39	16.9	13	30
KALSBA210D	South Fork Nooksack River	Kalsbeek at #2 Bank Armor DEPTH	0	0	13	0	51	21.6	16	51	39	16.8	13	29
KALSBA410	South Fork Nooksack River	Kalsbeek #4 Bank Armor	0	0	13	0	51	21.7	16	51	39	16.9	13	30

Station ID	Stream Name	Station Description	January 1 - July 1 # Days Monitored	January 1 - July 1 Temperature (C) Highest 7-DADMax	January 1 - July 1 Temperature (C) WQ Standard	January 1 - July 1 # Days Exceeding Standard	July 2 - August 31 # Days Monitored	July 2 - August 31 Temperature (C) Highest 7-DADMax	July 2 - August 31 Temperature (C) WQ Standard	July 2 - August 31 # Days Exceeding Standard	September 1 - December 31 # Days Monitored	September 1 - December 31 Temperature (C) Highest 7-DADMax	September 1 - December 31 Temperature (C) WQ Standard	September 1 - December 31 # Days Exceeding Standard
2010 Monitoring														
KALSBA610S	South Fork Nooksack River	Kalsbeek #6 Bank Armor SURFACE	0	0	13	0	51	21.6	16	51	39	16.8	13	30
KALSBA610D	South Fork Nooksack River	Kalsbeek #6 Bank Armor DEPTH	0	0	13	0	51	21.6	16	51	39	16.9	13	20
TENASKUS10	South Fork Nooksack River	Tenaska Right bank Upstream of log jams cabled to root wad	0	0	13	0	51	22.4	16	51	41	17.6	13	34
TENASKELJ310S	South Fork Nooksack River	Tenaska cabled to 3rd log jam in back water SURFACE	0	0	13	0	51	17.6	16	35	38	15.4	13	30
TENASKELJ310D	South Fork Nooksack River	Tenaska cabled to 3rd log jam in backwater DEPTH	0	0	13	0	51	12.5	16	0	38	14.2	13	7
TENASKELJ110D	South Fork Nooksack River	Tenaska cabled to 1st log jam in back water Depth	0	0	13	0	51	18.7	16	42	38	15.4	13	29
VANZANUS10S	South Fork Nooksack River	Van Zandt Upstream of ELJ site SURFACE	0	0	13	0	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	South Fork Nooksack River	Van Zandt Downstream of ELJ sites SURFACE	0	0	13	0	46	25.7	16	46	39	17.4	13	34
VANZANDS10D	South Fork Nooksack River	Van Zandt Downstream of ELJ sites Depth	0	0	13	0	46	22.1	16	46	48	17.3	13	33
SF	South Fork Nooksack River	Van Zandt Downstream of ELJ sites DEPTH	0	0	13	0	46	22.3	16	46	14	17.5	13	14

Table 11. 2010 exceedances of Water Quality Standards (WQS), by location

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2010 Monitoring					
USWanlick	South Fork Nooksack River	Upstream of Wanlick Creek	54	78	69%
Wanlick10	Wanlick Creek	Wanlick Creek	43	78	55%
DSWanlick	South Fork Nooksack River	Downstream of Wanlick Creek	48	78	62%
406	South Fork Nooksack River	South Fork at Seattle City Light property	59	119	50%
405	South Fork Nooksack River	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	South Fork Nooksack River	South Fork Nooksack Upstream Saxon Br.	69	116	59%
408	Hutchinson Creek	Hutchinson Creek	80	115	70%
402	South Fork Nooksack River	SF Nooksack DS of Hutchinson Creek	78	106	74%
KALSUS10	South Fork Nooksack River	Kalsbeek Upstream of upper most ELJ	79	91	87%
KALSELJ110S	South Fork Nooksack River	Kalsbeek at upper log jam SURFACE	81	90	90%

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2010 Monitoring					
KALSELJ110D	South Fork Nooksack River	Kalsbeek at upper log jam DEPTH	80	90	89%
KALSBA210S	South Fork Nooksack River	Kalsbeek #2 Bank Armor SURFACE	81	90	90%
KALSBA210D	South Fork Nooksack River	Kalsbeek at #2 Bank Armor DEPTH	80	90	89%
KALSBA410	South Fork Nooksack River	Kalsbeek #4 Bank Armor	81	90	90%
KALSBA610S	South Fork Nooksack River	Kalsbeek #6 Bank Armor SURFACE	81	90	90%
KALSBA610D	South Fork Nooksack River	Kalsbeek #6 Bank Armor DEPTH	71	90	79%
TENASKUS10	South Fork Nooksack River	Tenaska Right bank Upstream of log jams cabled to root wad	85	92	92%
TENASKELJ310S	South Fork Nooksack River	Tenaska cabled to 3rd log jam in back water SURFACE	65	89	73%
TENASKELJ310D	South Fork Nooksack River	Tenaska cabled to 3rd log jam in backwater DEPTH	7	89	8%
TENASKELJ110D	South Fork Nooksack River	Tenaska cabled to 1st log jam in back water Depth	71	89	80%
VANZANUS10S	South Fork Nooksack River	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 WQS	Total Days Monitored	Percent Exceedance
2010 Monitoring					
VANZANDS10S	South Fork Nooksack River	Van Zandt Downstream of ELJ sites SURFACE	80	85	94%
VANZANDS10D	South Fork Nooksack River	Van Zandt Downstream of ELJ sites Depth	79	94	84%
SF	South Fork Nooksack River	Van Zandt Downstream of ELJ sites DEPTH	60	60	100%

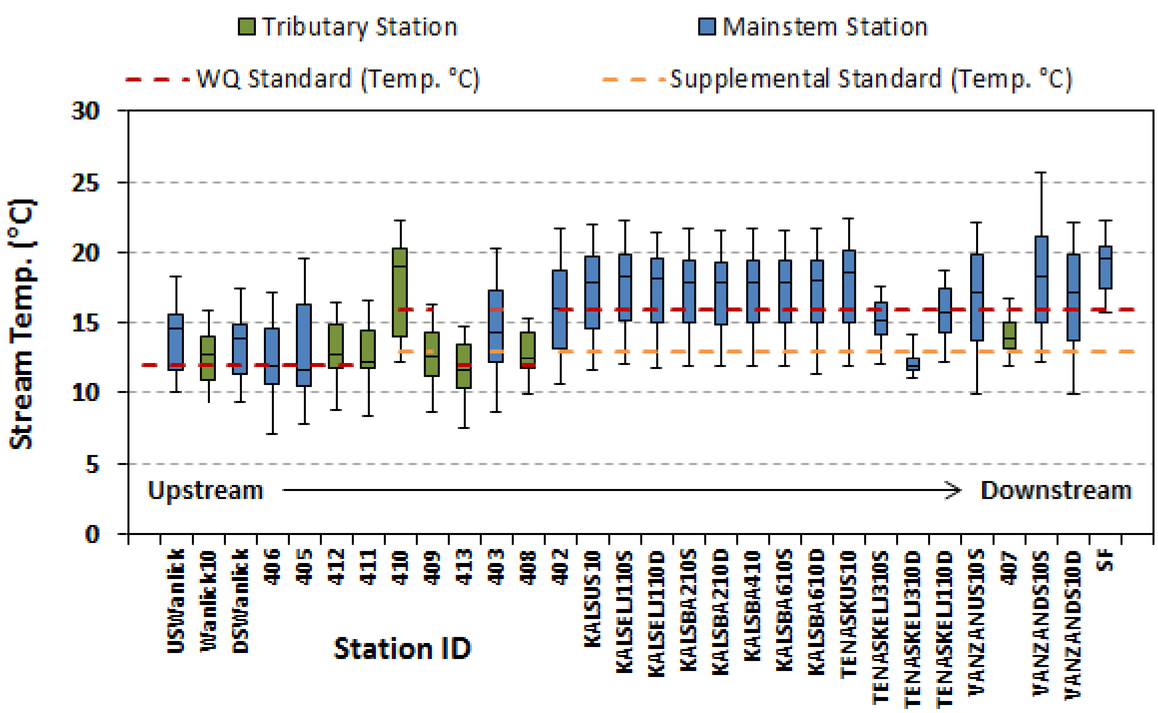


Figure 14. 25th, 50th and 75th percentiles of the 7-DADMax stream temperature for 2010 in the South Fork Nooksack

In 2011, a total of 30 locations, most locations differing from those monitored in 2010, were monitored for stream temperature along the South Fork Nooksack River. 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 (Table 12 and Table 13).

Table 12. Stream temperature as 7-DADMax for 2011 in the South Fork Nooksack subbasin

Station ID	Stream Name	Station Description	January 1 - July 1				July 2 - August 31				September 1 - December 31			
			# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
2011 Monitoring														
SFDSHUTC11	South Fork Nooksack River	Downstream of Hutchinson	0	0	13	0	39	18.1	16	27	51	18.2	13	27
KALSBA711D	South Fork Nooksack River	Kalsbeek KBA7Depth	0	0	13	0	34	17.6	16	31	52	18.1	13	28
KALSBA311S	South Fork Nooksack River	Kalsbeek KB03 Surface	0	0	13	0	27	18.3	16	25	40	16.5	13	16
KALSBA311D	South Fork Nooksack River	Kalsbeek KB03 Depth	0	0	13	0	34	18.4	16	32	52	18.0	13	28
KALSUS11	South Fork Nooksack River	Kalsbeek US 11	0	0	13	0	34	18.5	16	32	52	18.2	13	28
KALSBA111S	South Fork Nooksack River	Kalsbeek ELJ 1 Surface	0	0	13	0	34	19.0	16	32	52	18.8	13	28
KALSDS11	South Fork Nooksack River	Kalsbeek DS	0	0	13	0	34	18.4	16	31	52	18.0	13	28
KALSBA111D	South Fork Nooksack River	Kalsbeek ELJ 1 Depth	0	0	13	0	40	19.0	16	33	54	18.8	13	29
KALSBA711S	South Fork Nooksack River	Kalsbeek KBA7 Surface	0	0	13	0	34	18.5	16	32	52	18.2	13	28
HRDSBLUS11	South Fork Nooksack River	Hardscrabble US	0	0	13	0	33	18.7	16	32	53	18.1	13	28
HRDSBLDS11	South Fork Nooksack River	Hardscrabble DS	0	0	13	0	33	18.6	16	32	53	18.1	13	28
TENASKUS11	South Fork Nooksack River	Tenaska US ELJ #5	0	0	13	0	32	18.6	16	32	53	18.1	13	29
TENASKB411S	South Fork Nooksack River	Tenaska B4 Surface	0	0	13	0	32	18.6	16	32	52	18.2	13	28
TENASKB411D	South Fork Nooksack River	Tenaska B4 Depth	0	0	13	0	32	18.6	16	32	53	18.1	13	28
TENASKA711S	South Fork Nooksack River	Tenaska A7 Surface	0	0	13	0	32	18.7	16	32	52	18.3	13	29
TENASKA711D	South Fork Nooksack River	Tenaska A7 Depth	0	0	13	0	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 Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard	# Days Monitored	Temperature (C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
2011 Monitoring														
TENASKA111S	South Fork Nooksack River	Tenaska A1 Surface	0	0	13	0	32	18.1	16	17	52	19.9	13	29
TENASKA111D	South Fork Nooksack River	Tenaska A1 Depth	0	0	13	0	32	14.9	16	0	51	15.8	13	26
TENASKDS11	South Fork Nooksack River	Tenaska DS 11	0	0	13	0	32	18.8	16	32	52	18.4	13	29
BLKZANT11	South Fork Nooksack River	Van Zandt upper/lower Black Slough BLKZANT	0	0	13	0	40	18.7	16	32	54	18.6	13	29
CTNWOOD11S	South Fork Nooksack River	Van Zandt Cottonwood Surface	0	0	13	0	40	19.1	16	33	53	18.7	13	29
CTNWOOD11BW	South Fork Nooksack River	Van Zandt Cottonwood Backwater	0	0	13	0	40	18.5	16	33	53	17.7	13	28
CTNWOOD11D	South Fork Nooksack River	Van Zandt Cottonwood Depth	0	0	13	0	40	19.0	16	33	54	18.6	13	29
ELJ4VAN11S	South Fork Nooksack River	Van Zandt ELJ 4 Surface	0	0	13	0	34	18.7	16	32	52	18.5	13	28
ELJ4VAN11D	South Fork Nooksack River	Van Zandt ELJ 4 Depth	0	0	13	0	40	19.0	16	33	54	18.7	13	29
ELJ6VAN11S	South Fork Nooksack River	Van Zandt ELJ6 Surface	0	0	13	0	40	19.1	16	33	54	18.7	13	29
ELJ6VAN11D	South Fork Nooksack River	Van Zandt ELJ6 Depth	0	0	13	0	40	18.8	16	33	54	18.4	13	28
ELJ8VAN11S	South Fork Nooksack River	Van Zandt ELJ8 Surface	0	0	13	0	40	19.0	16	33	54	18.7	13	29
ELJ8VAN11D	South Fork Nooksack River	Van Zandt ELJ8 Depth	0	0	13	0	40	19.0	16	33	54	18.7	13	29
DSVANZAN11	South Fork Nooksack River	Van Zandt downstream	0	0	13	0	40	19.0	16	33	53	18.7	13	32

Table 13. 2011 exceedances of Water Quality Standards (WQS), by location

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2011 Monitoring					
SFDSHUTC11	South Fork Nooksack River	Downstream of Hutchinson	54	90	60%
KALSBA711D	South Fork Nooksack River	Kalsbeek KBA7Depth	59	86	69%
KALSBA311S	South Fork Nooksack River	Kalsbeek KB03 Surface	41	67	61%
KALSBA311D	South Fork Nooksack River	Kalsbeek KB03 Depth	60	86	70%
KALSUS11	South Fork Nooksack River	Kalsbeek US 11	60	86	70%
KALSBA111S	South Fork Nooksack River	Kalsbeek ELJ 1 Surface	60	86	70%
KALSDS11	South Fork Nooksack River	Kalsbeek DS	59	86	69%
KALSBA111D	South Fork Nooksack River	Kalsbeek ELJ 1 Depth	62	94	66%
KALSBA711S	South Fork Nooksack River	Kalsbeek KBA7 Surface	60	86	70%
HRDSBLUS11	South Fork Nooksack River	Hardscrabble US	60	86	70%
HRDSBLDS11	South Fork Nooksack River	Hardscrabble DS	60	86	70%
TENASKUS11	South Fork Nooksack River	Tenaska US ELJ #5	61	85	72%
TENASKB411S	South Fork Nooksack River	Tenaska B4 Surface	60	84	71%
TENASKB411D	South Fork Nooksack River	Tenaska B4 Depth	60	85	71%
TENASKA711S	South Fork Nooksack River	Tenaska A7 Surface	61	84	73%
TENASKA711D	South Fork Nooksack River	Tenaska A7 Depth	60	84	71%

Station ID	Stream Name	Station Description	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
2011 Monitoring					
TENASKA111S	South Fork Nooksack River	Tenaska A1 Surface	46	84	55%
TENASKA111D	South Fork Nooksack River	Tenaska A1 Depth	26	83	31%
TENASKDS11	South Fork Nooksack River	Tenaska DS 11	61	84	73%
BLKZANT11	South Fork Nooksack River	Van Zandt upper/lower Black Slough BLKZANT	61	94	65%
CTNWOOD11S	South Fork Nooksack River	Van Zandt Cottonwood Surface	62	93	67%
CTNWOOD11BW	South Fork Nooksack River	Van Zandt Cottonwood Backwater	61	93	66%
CTNWOOD11D	South Fork Nooksack River	Van Zandt Cottonwood Depth	62	94	66%
ELJ4VAN11S	South Fork Nooksack River	Van Zandt ELJ 4 Surface	60	86	70%
ELJ4VAN11D	South Fork Nooksack River	Van Zandt ELJ 4 Depth	62	94	66%
ELJ6VAN11S	South Fork Nooksack River	Van Zandt ELJ6 Surface	62	94	66%
ELJ6VAN11D	South Fork Nooksack River	Van Zandt ELJ6 Depth	61	94	65%
ELJ8VAN11S	South Fork Nooksack River	Van Zandt ELJ8 Surface	62	94	66%
ELJ8VAN11D	South Fork Nooksack River	Van Zandt ELJ8 Depth	62	94	66%
DSVANZAN11	South Fork Nooksack River	Van Zandt downstream	65	93	70%

USGS Stream Temperature Monitoring

Three USGS streamflow gage locations within the South Fork Nooksack River watershed have continuous monitoring data for stream temperature, even during non-summer months, between 2001 and 2011 (though specific years differ among these stations). Two stations are located along the South Fork Nooksack River and the third is located on Skookum Creek, a tributary to the South Fork (Figure 15). The South Fork stations are located 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 located near Wickersham, WA (12209000). The confluence of Skookum Creek is located between the two South Fork gage locations. The Skookum Creek station (12209490) is located 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 period during 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 (Table 14).

The Skookum Creek station (12209490) showed signs of exceedance of the water quality standard 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 standard from 2007 through 2011. Waters monitored at 12209000 (on the South Fork upstream from 12210000) exceeded the water quality standard for all monitored years, 2001 through 2008 (Table 15).

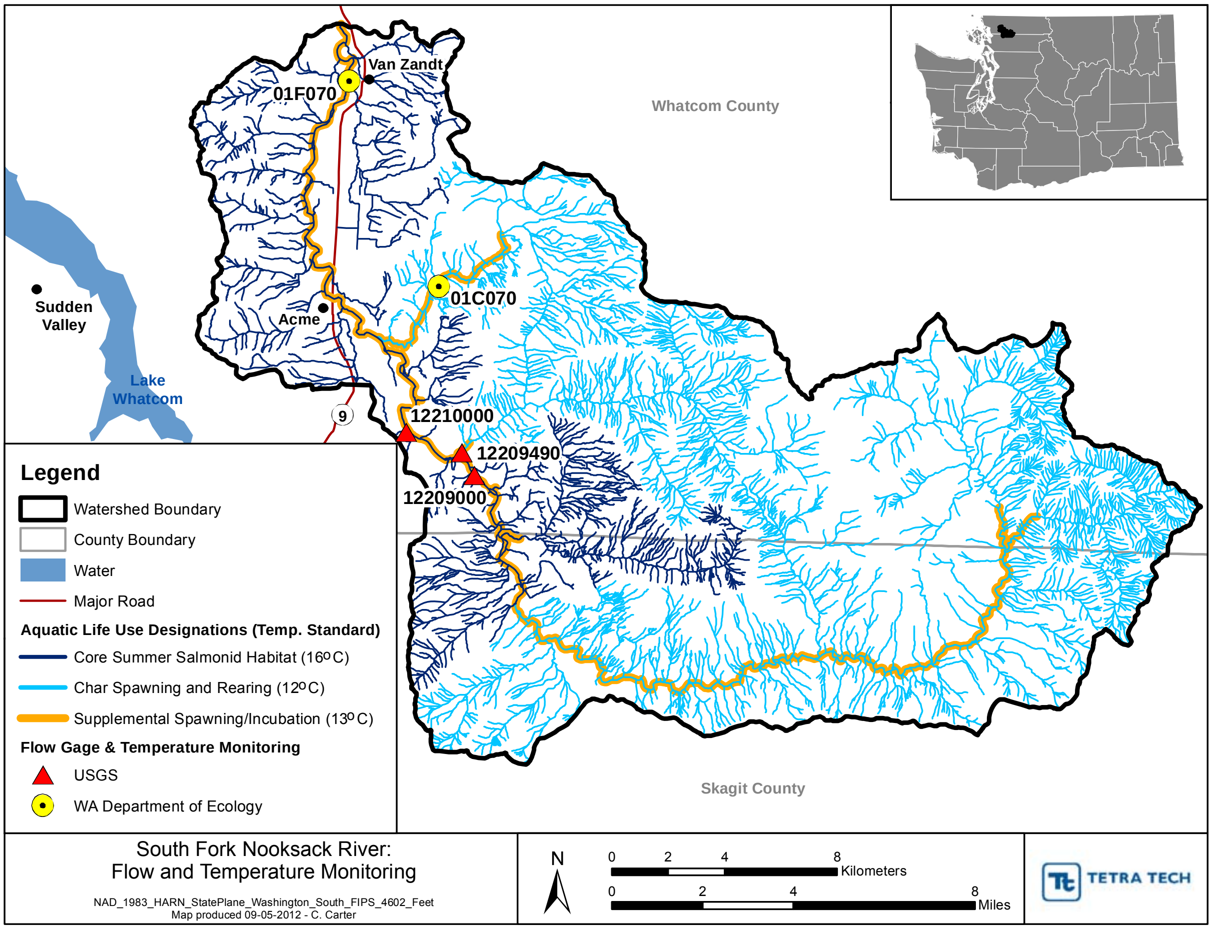


Figure 15. Monitoring Locations for USGS and Ecology Gages

Table 14. 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 Standard	# Days Monitored	Temperature (°C)		# Days Exceeding Standard	# Days Monitored	Temperature (°C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
12209000	South Fork Nooksack River 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	South Fork Nooksack River 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 15. USGS gage exceedances of Water Quality Standards (WQS), by location

Station ID	Station Description	Year	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
12209000	South Fork Nooksack River 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	South Fork Nooksack River 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%

Ecology Stream Temperature Monitoring

Two Ecology gage locations within the South Fork Nooksack River watershed were monitored continuously for stream temperature between 2003 through 2010 or 2011. One station is located along the South Fork Nooksack River at the Potter Road bridge (RM 1.8, Site 01F070) and the second is located on Hutchinson Creek (Site 01C070). Station 01F070 is located on waters designated for Core Summer Salmonid Habitat where the temperature criteria are 13 or 16°C depending on the date. Station 01C070 is located 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 (Table 16 and Table 17).

The waters monitored by the Hutchinson Creek gage location near the town of Acme, WA (01C070) showed no sign of exceeding the water quality standard for the years from 2007 to 2011; however, there were periodic exceedances of the applicable temperature standard from 2003 to 2006. The South Fork gage (01F070), located farthest downstream along the South Fork in relation to other stream temperature monitoring stations in the watershed, provides evidence of exceedance of the temperature water quality standard for years 2003 through 2009. There was no sign of exceedance of the temperature standard for waters monitored by this gage in 2010.

Table 16. Stream temperature summary for Washington State Department of 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 Standard	# Days Monitored	Temperature (°C)		# Days Exceeding Standard	# Days Monitored	Temperature (°C)		# Days Exceeding Standard
				Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard			Highest 7-DADMax	WQ Standard	
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	South Fork Nooksack River 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

Table 17. Ecology gage exceedances of Water Quality Standards (WQS), by location

Station ID	Station Description	Year	Total Days Exceeding WQS	Total Days Monitored	Percent Exceedance
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	South Fork Nooksack River 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%

Streamflow Data

Recent streamflow monitoring on a daily or sub-daily basis is available from the three USGS and the two Ecology monitoring stations, shown previously in Figure 15. As shown in Table 18, the periods of record for these stations vary. Monitoring ended at the 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 located farther down the South Fork, 1.8 miles upstream of the South Fork Nooksack River 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 seven-day average low flow at 12209000 appear relatively stable with no apparent trends (Figure 16). A comparison of average annual flow across all the gages can be seen in Figure 17. Flow statistics are generally consistent with contributing drainage areas, noting that different time periods were used to generate the measures (Table 19). 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 during fall 2009. Ecology reported extensive scour at the site following 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 percent for water year 2009. No technical notes were available for water year 2010 when the change in rank occurred.

Table 18. Streamflow monitoring periods of record

Agency	Station ID	Station Name	Beg. Date	End Date
USGS	12209000	South Fork Nooksack River near Wickersham, WA	5/1/1934	9/30/2008
USGS	12209490	Skookum Creek above diversion near Wickersham, WA	6/13/1998	Current
USGS	12210000	South Fork Nooksack River at Saxon Bridge, WA	10/1/2008	Current
WA Ecology	01C070	Hutchinson Creek near Acme	6/13/2003	Current
WA Ecology	01F070	South Fork Nooksack River at Potter Road	6/14/2003	9/30/2010

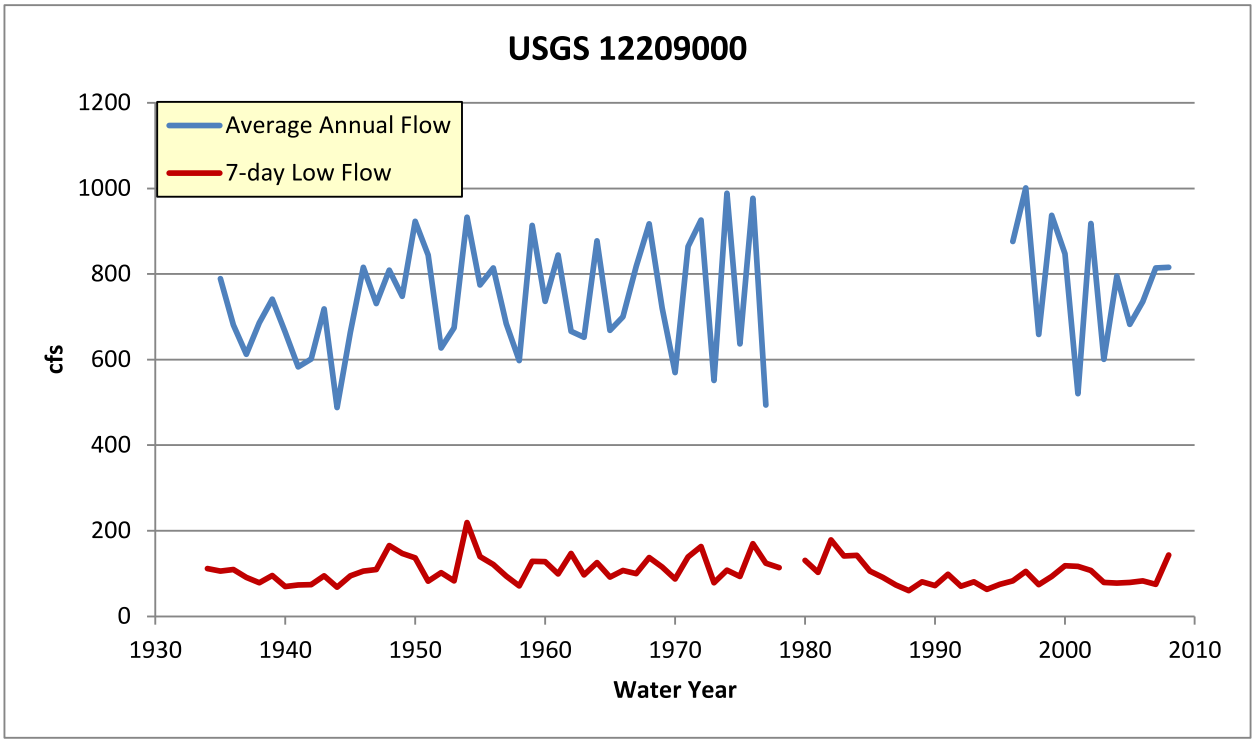


Figure 16. Average annual flow at USGS 12209000 (complete water years only)

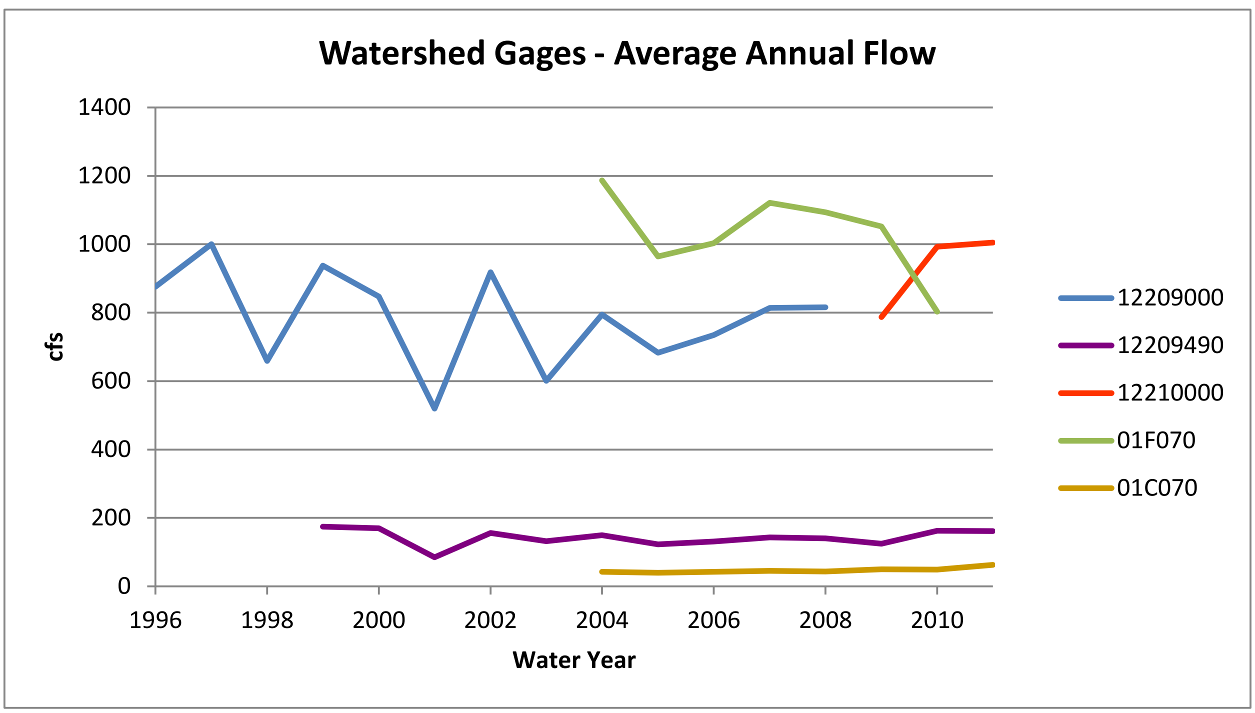


Figure 17. Average annual flow at all locations (complete water years only, beginning 1996)

Table 19. Flow statistics for monitoring stations

Station ID	Time Period	Mean flow for Time 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 South Fork Nooksack River conducted in August and September 1998 by the USGS. The data indicate the river is typically a gaining system, though some short losing reaches were thought to be present. The report did 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

QUAL2Kw utilizes observed meteorological data during calculation of surface heat flux for the temperature model. 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 since 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 18 and presented in Table 20. A brief description of each follows.

- 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 Western US.
- 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 located at National Weather Service, Federal Aviation Administration, and cooperative observer stations.
- Surface Airways stations are major weather data collection stations generally located 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 meteorology data will depend on a number of factors including data quality, proximity to the watershed, period of record, and available parameters.

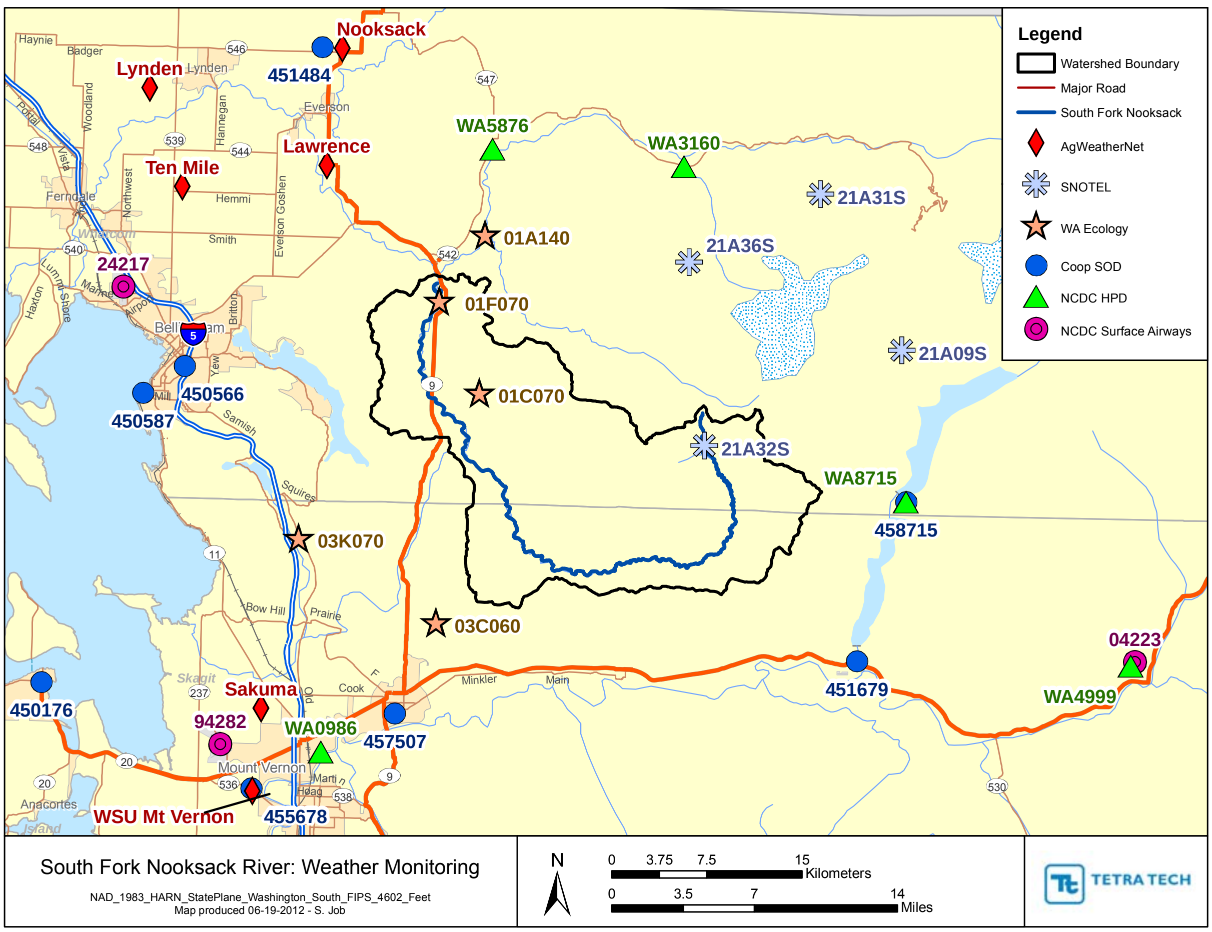


Figure 18. Meteorology monitoring stations near the watershed

Table 20. 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	
WA 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

Riparian Function Assessment

The Nooksack Indian Tribe Natural Resources Department provided data on riparian characteristics for the South Fork River and major tributaries throughout the South Fork Nooksack 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-foot-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 may not reflect more current conditions being analyzed for the TMDL tools. Figure 19 displays percent canopy shading derived for assessment units for a subset of the watershed.

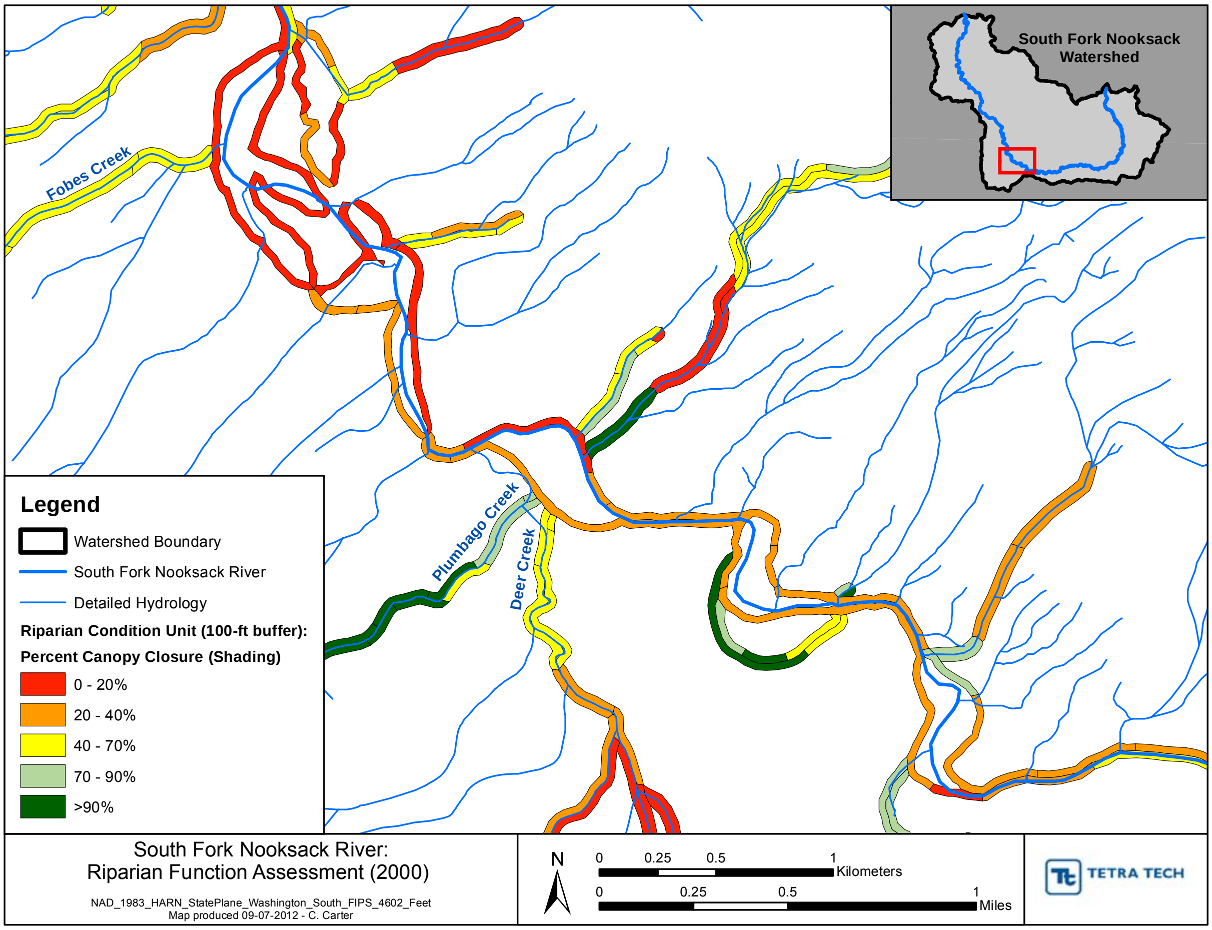


Figure 19. Subset of assessment units from riparian function assessment (based on 1991 and 1995 aerial imagery)

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 may occur in slow, deep channels or upstream of impoundments (Oregon DEQ, 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 8-12 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 (Oregon DEQ, 2001).

A spatial tool called TTools can be used to sample FLIR temperature data to develop longitudinal temperature profiles. 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, river miles 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 21 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 21. 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	5000	1763	≈2.9	Mouth to mile 13.7
SF Nooksack River Floodplain	2:44 - 4:37	1500	528	≈0.9	Multiple flight lines; river mile 0 to 11.2
SF Nooksack River	4:46 - 5:43	1500	528	≈0.9	Mouth to mile 38.5

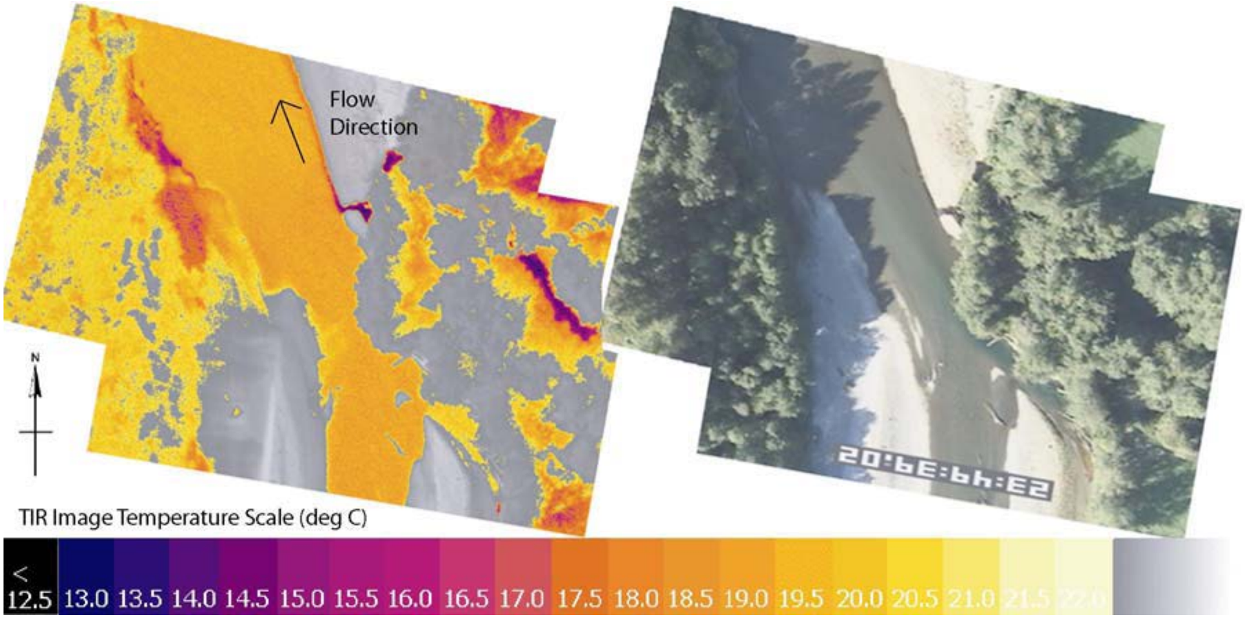
Higher altitude surveys are generally conducted on larger rivers in order to capture floodplain features of wide rivers. Low altitude surveys are ideal for smaller, narrower rivers where floodplain features can still be captured while producing higher resolution images.

Watershed Sciences, LLC (2002), verified the accuracy of radiant temperatures measured by the thermal infrared (TIR) sensor using instream temperature data loggers at 17 locations throughout the Nooksack River Basin. Their findings suggest that on the high altitude survey (5,000 feet) of the South Fork Nooksack River, no significant difference was observed between the three instream sensors and the radiant temperatures. However, a larger range of differences was noted on the low altitude survey (1,500 feet) of the South Fork Nooksack River where differences between instream 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 explained that the difference between radiant temperatures and temperatures measured by instream 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.

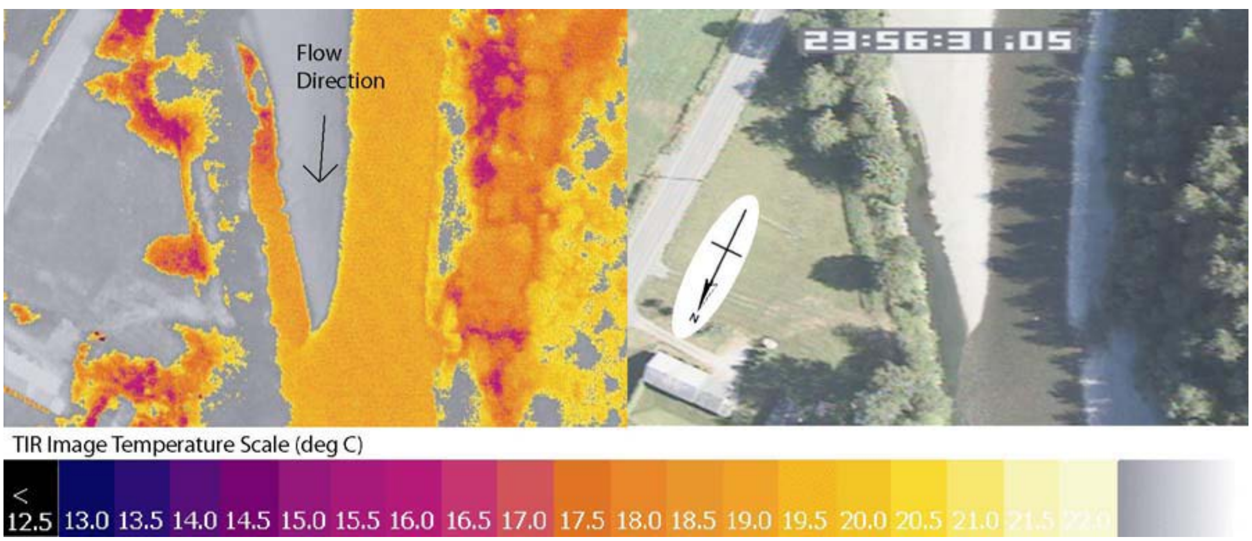
Watershed Sciences, LLC (2002), summarized FLIR survey results for the South Fork Nooksack as follows:

> *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.*

The following images illustrate thermal infrared (FLIR image results) and visible band color images showing features observed in the South Fork Nooksack River basin. The stream temperatures presented with the images represent the median of ten sample points taken longitudinally at the center of the apparent thalweg in the thermal infrared image. The given tributary temperatures are the median of ten sample points taken at the mouth of the tributary (Watershed Sciences, LLC, 2002). The survey report provides longitudinal profiles of median channel temperatures versus river mile for the low altitude survey (1,500 feet) of the South Fork Nooksack River (mouth to river mile 38.5) and of the high altitude survey (5,000 feet) of the lower 13.5 river miles of the South Fork Nooksack River. The profiles include median temperatures and river mile location 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 South Fork Nooksack River (i.e., mouth to river mile 13.5), median surface water temperatures from the two surveys are generally within approximately 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 river mile zero to river mile 8, after which (from river mile 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 approximately 1°C or less.



Frame: sfn0103-104: TIR/visible band images showing the South Fork Nooksack River (19.4°C) at river mile 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 South Fork Nooksack River (19.1°C) at river mile 7.1. Water temperatures are cooler in the side channel where surface water emerges from the gravel, evidence of hyporheic upwelling.

Figure 20. Subset of FLIR images captured for the South Fork Nooksack River

Channel Morphology

Channel cross sections of South Fork Nooksack River 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 (f/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 only collected for the two dates in 1998. Figure 21 displays the location of each cross section within the South Fork Nooksack watershed. Table 22, Figure 22 and Figure 23 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 South Fork Nooksack River (Collins and Sheikh, 2004) and from 1885 to 2005 for the upstream portion of the river (Brown and Maudlin, 2007). Data were generated from historic survey maps prior to 1990 and aerial photographs for the remaining years. Figure 24 displays channel positions for a small section of the river, using data generated in support of Brown and Maudlin (2007).

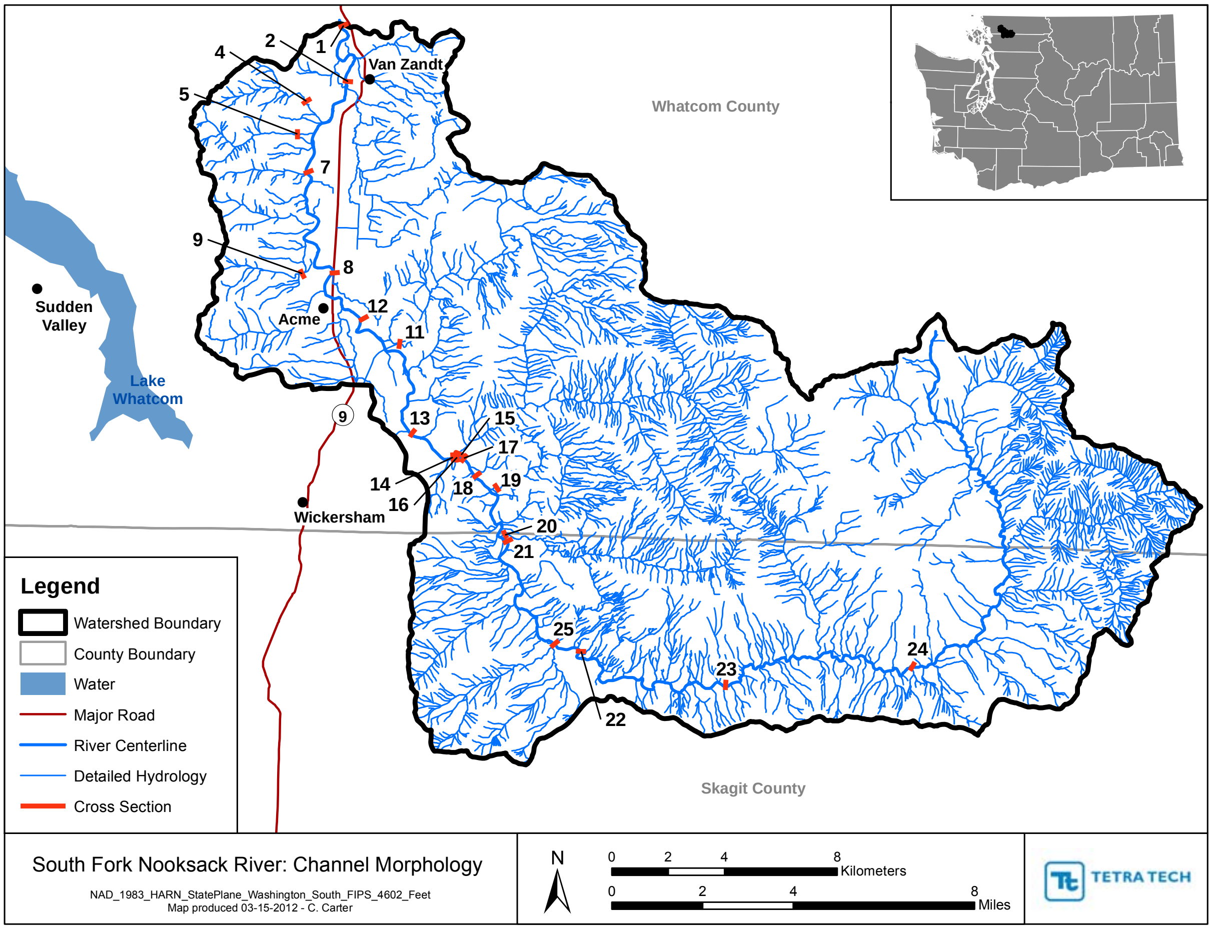


Figure 21. Cross section locations along the South Fork Nooksack River and tributaries

Table 22. 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

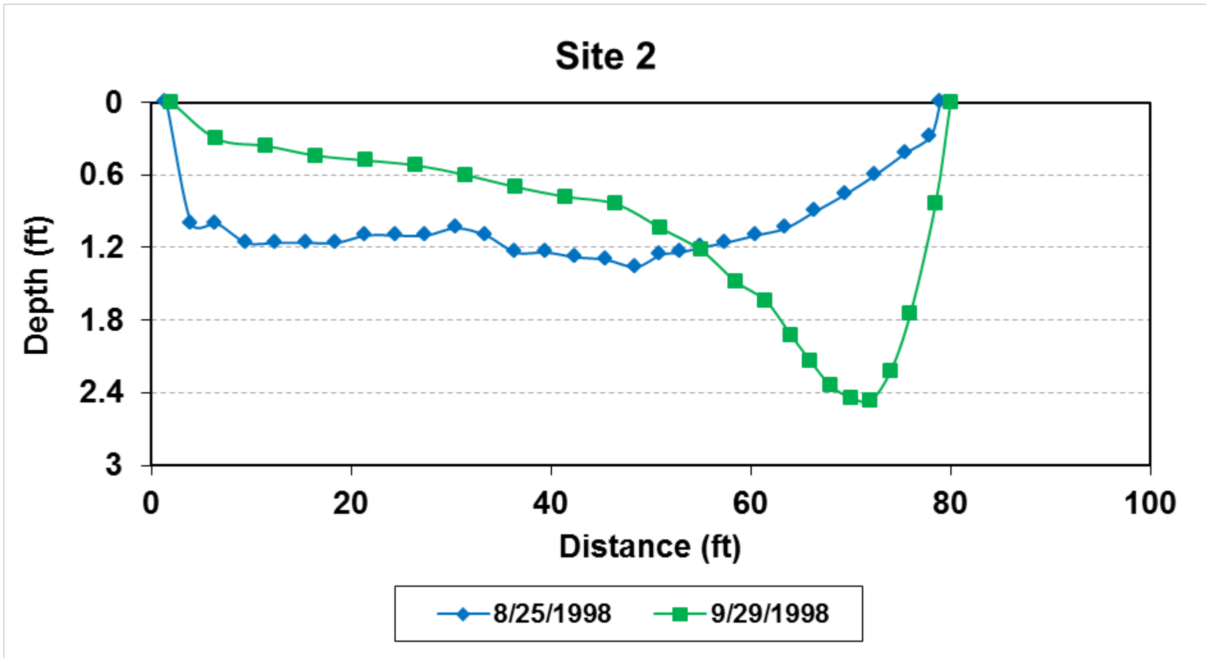


Figure 22. Cross section survey measurements for Site 2

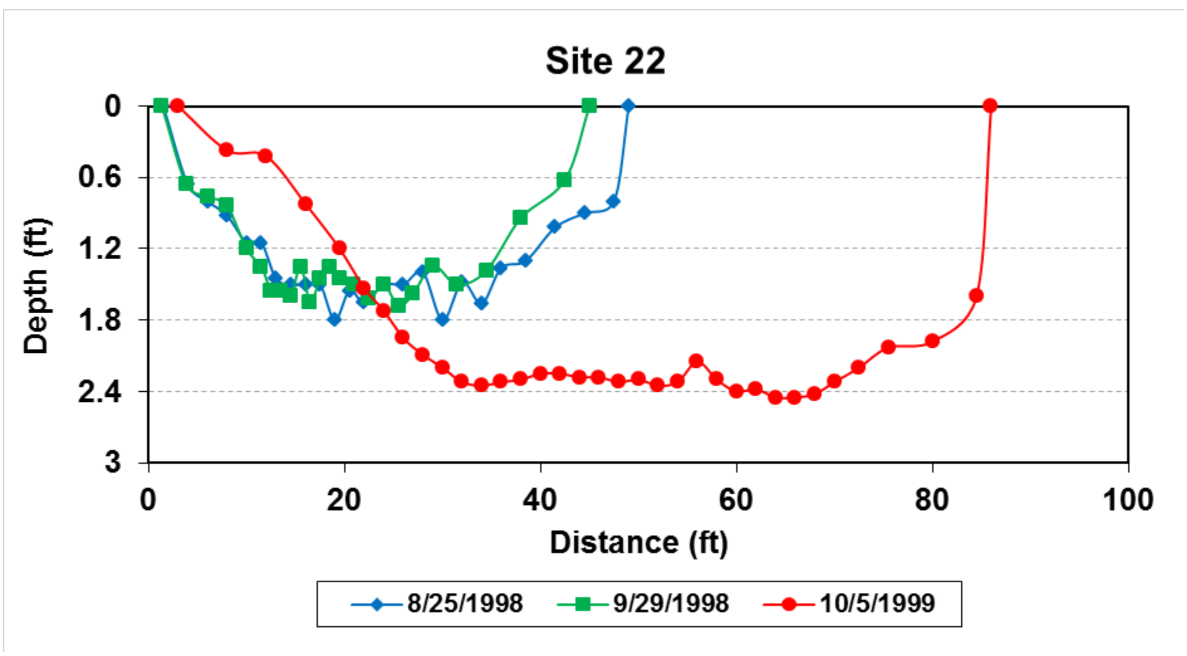


Figure 23. Cross section survey measurements for Site 22

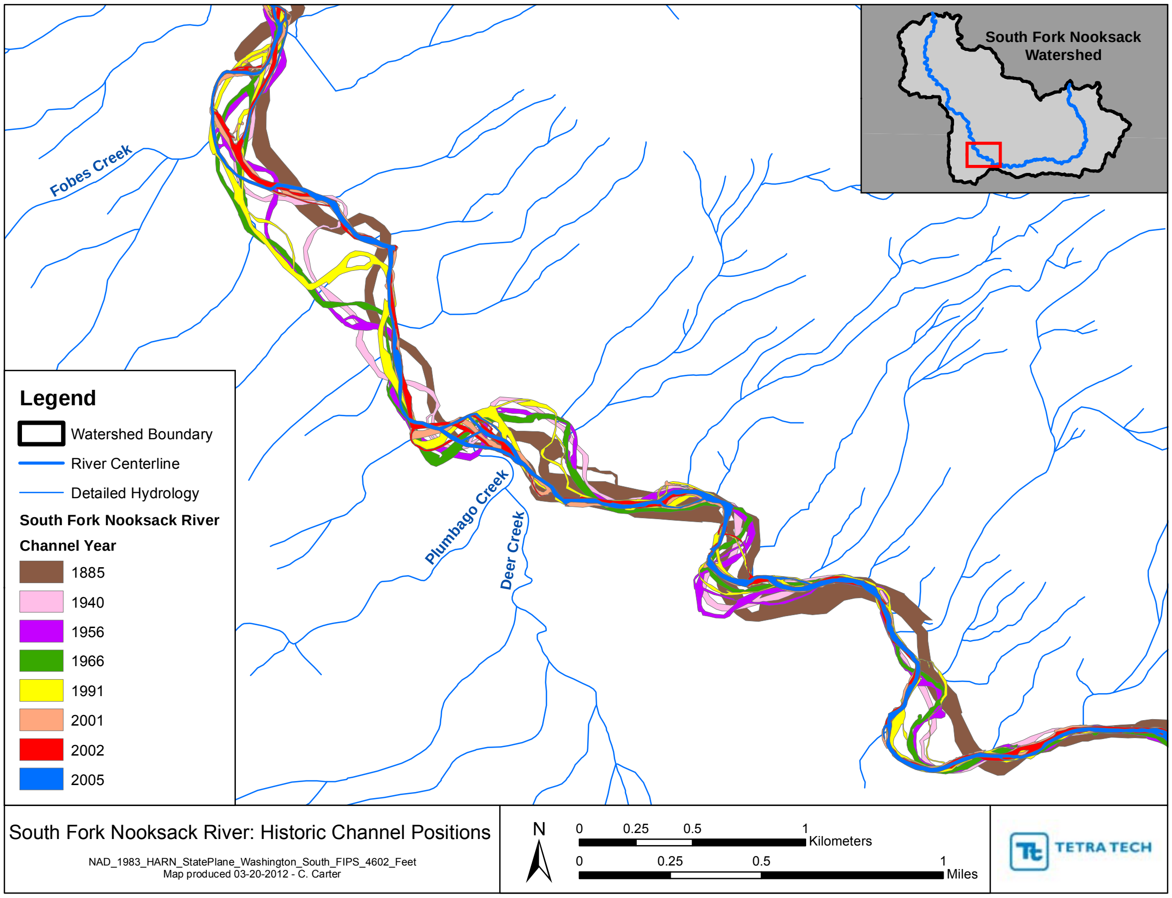


Figure 24. Historic channel positions of the South Fork Nooksack River

System Potential Vegetation

There are many factors that contribute to warmer instream temperatures, including reduced shading from riparian vegetation, reduced baseflow/groundwater, changes in hydrology and streamflow, and reduced channel complexity (Mohamedali and Stohr, 2011). The following section provides a brief discussion of data and methods that may be used to conduct initial steps in an approach to assess shading from riparian vegetation and its influence on instream temperature in the South Fork Nooksack watershed.

Ecology prepared a guidance document for calculating system potential vegetation (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, "system potential vegetation ."). 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.

Ecology then presents a series of steps for evaluating system potential vegetation and discusses the importance of incorporating system potential vegetation results into a model that encompasses all factors that may contribute to warmer instream temperatures.

Three parameters are presented that define system potential vegetation: riparian buffer width, vegetation density, and vegetation height. Ecology recommends a 150-ft riparian buffer to assess system potential vegetation and potential vegetation height, which will be determined from soils data, either from Washington Department of Natural Resources (DNR) soils or Soil Survey Geographic Database (SSURGO) soils data (NRCS, 2012). In any areas of the watershed where there are data gaps from either of these two soils data sources, LIDAR vegetation height data from 2005 or 2009 can be used to provide insight on what can grow within the riparian zone of the South Fork Nooksack River and its major tributaries. Collection of LIDAR data for 2005 and 2009 was commissioned and funded by the Nooksack Indian Tribe and Lummi Nation; vegetation height derived from these data is displayed in Figure 25.

Ecology explains that vegetation density can typically be determined from similar work that has been conducted in adjacent watersheds (Mohamedali and Stohr, 2011). As an appendix to Ecology's guidance document, a list of temperature TMDLs completed throughout Washington State has been provided. These can be used to support selection of approximate vegetation density for the South Fork Nooksack watershed.

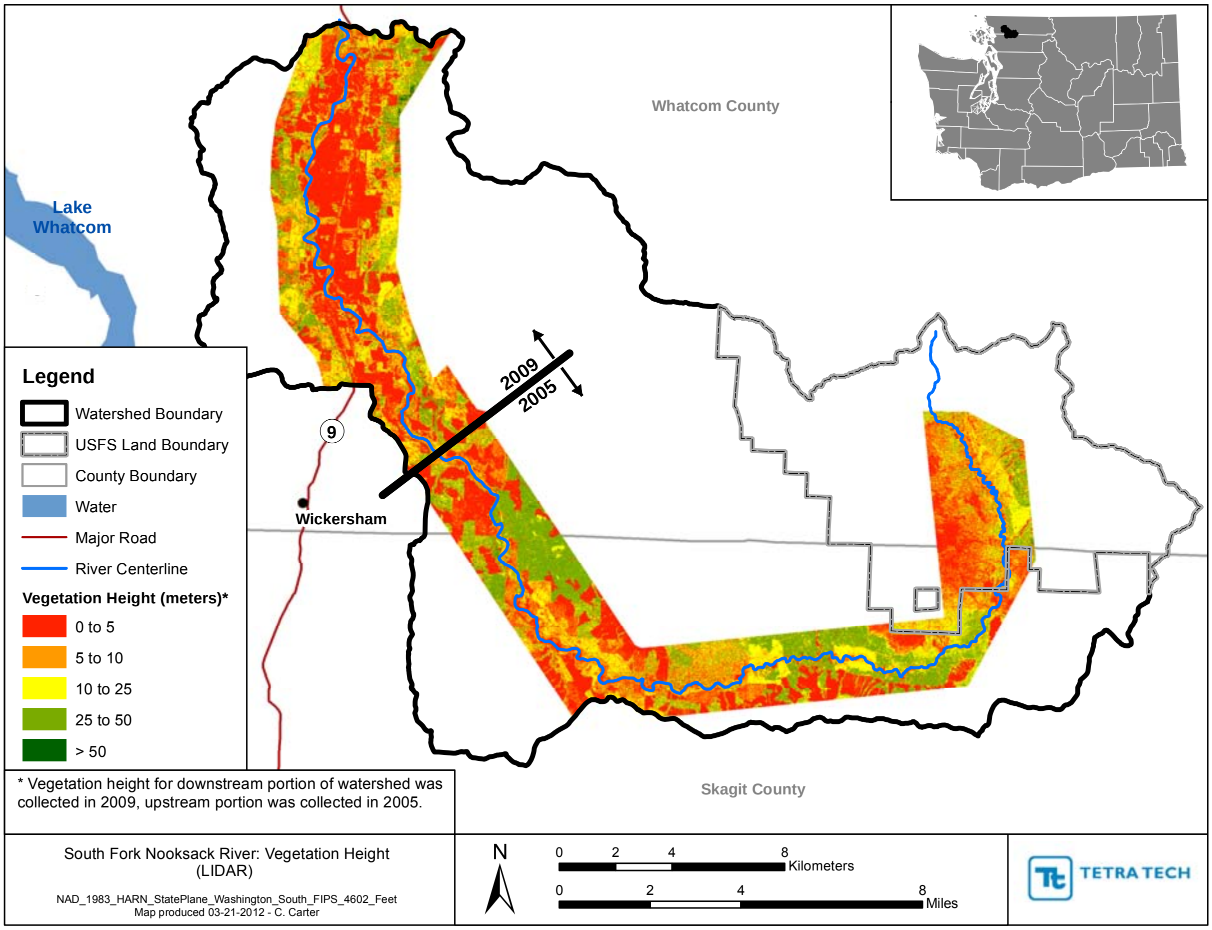


Figure 25. Vegetation height along the South Fork Nooksack River from LIDAR data

Historic Cover Datasets

Several datasets are available representing historic conditions in the vicinity of the watershed from 1880 - 1938, using a combination of survey notes and land use maps, early topographic maps, and aerial photographs (Coe, T., 2012). A historical conditions dataset was also created in support of the WRIA1 Watershed Management Project (Winkelaar, 2004). Historic conditions datasets can be used to support modeling of natural conditions during TMDL development and to compare with system potential vegetation 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 suggested there were five reaches of the river 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 South Fork 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 may identify reaches in other locations where groundwater discharge may be occurring.

Ongoing Studies

Two complementary studies are underway in the project area. These projects are described below. Though each project has a different schedule and specific goals from the South Fork Nooksack River Temperature TMDL project, there may be opportunity for information sharing that can be mutually beneficial.

Water Resource Inventory Area 1 Model

A hydrologic modeling effort (i.e., water budget for the lower basin) is being conducted by Silver Tip Solutions, Christina Bandaragoda to update the Water Resource Inventory Area (WRIA) 1 model previously developed by Utah State University (Tarboton et al., 2007a; Tarboton et al., 2007b). The South Fork Nooksack River 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 will be used to establish drainage-based estimates of precipitation, evapotranspiration, streamflow, and groundwater infiltration. Report completion is planned for December 2012 according to the project website.

While the South Fork Nooksack River 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 South Fork Nooksack 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 time 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. The updates underway may address some of these issues.

Nooksack Tribe and USGS Groundwater Study, beginning 2012

A groundwater modeling study is expected to begin in spring 2012 involving the USGS and the Nooksack Indian Tribe. The goal is to refine the characterization of groundwater processes in the South Fork Nooksack valley. The USGS will develop an exploratory MODFLOW groundwater flow model and hydrogeological framework for the watershed, collect water elevation data to support model calibration, and investigate groundwater/surface water interactions through deployment of a distributed temperature sensor (DTS) cable and through monitoring of piezometers in wetlands and riparian areas adjacent to the South Fork Nooksack River. A draft version of the study dataset is scheduled to be available in August 2012, so the data may be available for use in TMDL development.

Goals and Objectives

Project Goal

The goal of the proposed TMDL study is to evaluate compliance with state water quality standards for temperature in the South Fork Nooksack River watershed and to support development of a Water Quality Improvement Report and Implementation Plan.

Study Objectives

Objectives of the TMDL study are as follows:

- Characterize stream temperatures and processes governing the thermal regime. This includes 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 South Fork Nooksack River's capacity to assimilate heat, and evaluate the system potential temperature (approximate natural temperature conditions) for the river.
- Determine the loading capacity that meets temperature water quality criteria and protect beneficial uses.
- Present potential alternative pollutant allocation scenarios for point and nonpoint sources that meet the loading capacity.
- Use the calibrated model to evaluate future water quality management decisions.

Study Design

Overview

The water quality model will be calibrated to the available field data. Any water quality data used in the TMDL analysis will meet the requirements of Ecology's credible data policy (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf.). The calibrated model will be used to evaluate the water quality in response to various alternative scenarios of pollutant loading and calculate the loading capacity of the South Fork Nooksack River.

Load allocations for nonpoint sources and wasteload allocations for point sources will also be evaluated. The models will be used to determine how much effective shade is necessary to bring stream temperature into compliance with water quality criteria. Components and descriptions of the models are summarized in the Modeling and Analysis Framework section. In addition, potential management scenarios will be evaluated with the selected models to determine implementation opportunities to achieve the required load reductions.

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 characteristics and topography, a combined Shade-QUAL2Kw modeling approach will be applied.

This modeling approach consists of a geographical information system (GIS)-based Shade model linked to the QUAL2Kw water quality model. The selected models are based on data that are already available and on the analysis needed to meet study objectives.

QUAL2Kw serves as the model to perform instream temperature simulations. The steady-state QUAL2Kw model is appropriate for evaluating impairments and determining specific conditions during the summer low-flow period. The GIS-based Shade model will simulate shading factors based on topography and riparian vegetation coverage, which will feed into the QUAL2Kw instream model.

Model Selection

The work described in this QAPP does not involve creating new simulation modeling software. Rather, it involves developing a base conceptual model and data collection for the watersheds and applying that information to existing models—Shade.xls and QUAL2Kw. The rationale for selecting proposed modeling framework components is described below in the model-specific sections.

Shade Model

The Shade model was selected to evaluate solar radiation along the streams using watershed-specific GIS-based data derived with the TTools ArcView extension, developed by Oregon Department of Environmental Quality (ODEQ). It uses input coverages and grids to develop vegetation and topography data perpendicular to the stream channel, and samples longitudinal stream channel characteristics such as the near-stream disturbance zone and elevation. TTools can sample spatial data within the riparian zone. Typically, these include LiDAR, digital elevation models (DEMs), riparian vegetation digitized from aerial imagery (digital orthophoto quadrangles and rectified aerial photos), and FLIR temperature data. For this project, TTools will be used to sample stream width, aspect, topographic shade angles, elevation, and riparian vegetation for incorporation into the Shade model. The riparian vegetation coverage will contain 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 for download at http://www.ecy.wa.gov/programs/eap/models.html; Ecology, 2003a) was adapted from a program that ODEQ developed as part of its HeatSource model version 6. Shade.xls 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 located at http://www.heatsource.info and http://www.deq.state.or.us/wq/TMDLs/TMDLs.htm.

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 easily available (e.g., aerial imagery and digital elevation models), and additional data (e.g., vegetation height) can be estimated from data sources discussed in the historic data review section. TTools output will be used as input for the Shade model 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) will be used as input into the QUAL2Kw model, which is discussed below.

QUAL2Kw Model

The steady-state QUAL2Kw model (Chapra and Pelletier, 2003; Ecology 2003b) will be 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 temperature TMDLs. The model simulates daily temperature and heat budget with hourly variations in input parameters and boundary conditions. QUAL2Kw is well matched to the short-period, intensive/continuous monitoring work conducted by local agencies. QUAL2Kw will be used to address specific specialized processes (e.g., hyporheic flow).

Meteorological conditions have strong influences on water temperature. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, headwater and tributary temperature, and hyporheic flow temperature. These parameters are calculated (e.g., effective shade from Shade model), obtained from weather station information, or interpreted from FLIR data and other sources. These factors will be specified or simulated as time-varying functions.

Point sources may also be an important input if they can impact receiving stream temperature with effluent. Among the current active point sources in the watershed, the Skookum Creek Fish Hatchery has the potential to influence stream temperature to the degree that their operations affect temperature between withdrawal and discharge; they monitor temperature periodically as part of their NPDES permit. Concrete Norwest Saxon Pit currently has a permit to discharge to groundwater only, but any proposed changes to their permit including direct discharge to the river could be evaluated by QUAL2Kw.

QUAL2Kw will be applied to conduct focused analyses of critical conditions (e.g., late summer low flow, clear sky, high air temperature conditions) that impact temperature impairments from which TMDL targets can be determined directly. Model input will include flow and temperature boundary conditions developed from available data. The QUAL2Kw model will be used for evaluating TMDL loading capacity and developing allocations under critical conditions.

Summary of the Modeling Framework

The Shade-QUAL2Kw models will be used to predict steady-state instream thermal balance under critical conditions. QUAL2Kw will be run hourly for shorter date ranges during a critical summer period, coinciding with the best available data for calibration (see modeling calibration/assessment procedures). The modeling system will be used to develop prescriptive TMDLs for temperature including various scenarios. Table 23 summarizes the modeling components and their role in the proposed technical approach.

Table 23. Shade-QUAL2Kw modeling components

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

Careful consideration was given to model selection. Disadvantages of QUAL2Kw are that it does not consider the land use-based processes required to perform scenarios for prescriptive TMDL development (e.g., forest practices). There are also strong advantages for including a QUAL2Kw model to address impairments associated with low-flow critical conditions:

- QUAL2Kw is Ecology's standard tool for low-flow critical condition TMDLs and has a high degree of familiarity for both Ecology staff and stakeholders.
- QUAL2Kw enables a focused analysis of critical conditions from which TMDL targets can be determined directly, rather than through analysis of dynamic time series, which is often not necessary and is resource intensive.
- QUAL2Kw is well matched to the short-period intensive/continuous monitoring.
- QUAL2Kw addresses some specialized processes (such as hyporheic flow).
- QUAL2Kw has automated calibration and sensitivity capabilities.
- Because QUAL2Kw can be run quickly, it is a useful tool for efficient assessment of the sensitivity of model results to boundary conditions and parameters.

Model Calibration and Assessment

Environmental simulation models are simplified mathematical representations of complex real-world systems. Models cannot accurately 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 corroboration (CREM, 2009).

Objectives of Model Calibration Activities

Model calibration is designed to ensure that the model is adequate to provide appropriate input to answer the study questions. The objective of this TMDL is to develop temperature TMDLs, which include implementation strategies to address the required load reductions. The principal study questions to be addressed by modeling in this project are:

1. What are the sources of increased temperature during critical summer low-flow conditions?
2. What are the TMDL allocations—such as riparian shade and heat loading to the South Fork River and its tributaries—needed in order to meet temperature standards?

To address those questions, the model must be able to provide credible representations of the movement of water, and the generation and transport of thermal loads.

In addition, the model can also be used to assess other management actions such as enhanced groundwater interactions, changes in the flow regime, effective buffers along the South Fork and tributaries, etc. A more refined list of potential scenarios to evaluate will be determined during TMDL development.

Model Setup, Calibration/Validation, and Assessment Procedures

The QUAL2Kw and Shade models will be developed for the mainstem of the river beginning at approximately the confluence with Wanlick Creek (just upstream of the first impaired segment) and extending to the confluence with the Nooksack River. Tributaries are represented as follows: they are included at the point they enter the mainstem in QUAL2Kw and are represented in using a shade curve in the Shade model as discussed below.

Ecology's Shade Model will be used to estimate effective shade along the mainstem segments. Effective shade will be calculated at appropriate intervals along the streams, and then averaged over appropriate intervals for input to the temperature model. Estimated system potential shade will also be developed. The TTools extension for ArcView will be used to sample and process GIS data for input to the shade and temperature models.

While the Shade model will be developed only for the mainstem, a shade curve (an output of the Shade Model) showing how much effective shade can be achieved in streams with different widths and aspects (for a given system potential vegetation height and density), will be used to represent the load allocations for all tributaries/streams in the rest of the watershed. The TMDL and shade load allocations therefore cover the entire watershed (listed + unlisted segments).
The QUAL2Kw model will be 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 will be calibrated to observed conditions for year 2007 using the available data and will be validated using year 2010. These are the years with the greatest spatial and temporal coverage of temperature data. Sensitivity analyses will be conducted to determine the model's sensitivity to key parameters.

The QUAL2Kw model will be applied by assuming that flow remains constant (i.e., steady flows) for a given condition over a 1-day period (using daily average flows), but key variables other than flow will be allowed to vary with time over the course of a day. For QUAL2Kw temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions.

Flow boundary conditions for the main stem and tributary inputs will be based on steady-state flows during low-flow conditions of the calibration and validation periods. Flow data from USGS gages will be used; however, not all of the main stem or tributaries are gaged. Therefore, flow will be prorated for the headwater boundary (to the downstream gages in the watershed) and for the tributaries based on drainage area with some weighting to changes in precipitation (e.g., orographic effects) if needed. If available and deemed appropriate, data from the WRIA hydrologic model updates will supplement this approach.

Cross sections help to inform relationships of flow, depth, width, and velocity used in the QUAL2Kw and are important for the Shade model set up as well. A number of cross sections along the main stem were measured in the late 1990s as part of the USGS seepage study (described in the Historic Data section previously). Data from additional sources – such as historic channel data and aerial photos – will be integrated to develop best representations of channel dimension. For example, aerial photos during the calibration and validation periods can be used to modify channel widths. The available channel morphology data do not coincide in time with the stream temperature data that will be used to calibrate the QUAL2Kw model and the channel does move and change in shape over time. These factors will result in fundamental uncertainty during modeling. Some of this uncertainty can be assessed by doing a sensitivity analysis on the channel geometry properties required by QUAL2Kw to see how sensitive the model is to these parameters. While the channel is dynamic and lateral movement occurs often, the general form and relationship of pools, runs, riffles, etc. is expected to be less variable, particularly during the low-flow conditions that will be simulated in the model. The effects of this and other sources of uncertainty will be discussed in the TMDL.

Once the model is calibrated and validated, it is anticipated that model runs will be conducted to estimate the temperature in the South Fork Nooksack River under the following scenarios:

1. Estimating the temperature under critical low flow (7Q10) and meteorological (90 percentile air temperature) with both current riparian shading and system potential riparian shading.
2. Estimating the temperature under typical low flow (7Q2) and meteorological (50 percentile air temperature) with both current riparian shading and system potential riparian shading.
3. Estimating the temperature under current stream channel dimensions.
4. Estimating the temperature under historical channel dimensions based on available information from the Tribes and other sources.
5. Estimating the sensitivity of temperature to increases or decreases in streamflow.
6. Estimating the levels of expected heat load reductions (expressed as daily loads and changes in stream temperature) from improved riparian buffers, as well as other modeling scenarios which include alternative ways to reduce or eliminate stream temperature impairments (such as: enhancing near-stream wetlands, hyporheic flow, transient storage and other in-channel restoration activities, setting tributary boundary conditions to the water quality standard) based on input from the Project Team and based on what QUAL2Kw has the capability to simulate.
7. Conducting additional overall sensitivity analyses and potential future climate change scenarios to be defined by the Project Team. The climate change scenarios are discussed more fully in the next section.

Climate Change Scenarios

Once the QUAL2Kw TMDL model setup is completed and the model provides acceptable predictions of current temperature conditions, it can be applied to answer a variety of questions. One area of inquiry will be an EPA pilot project to examine potential climate change impacts on South Fork Nooksack River temperatures. One option for estimation of climate change effects on river temperature is to use climate-altered boundary conditions in the QUAL2Kw to predict future conditions. Tetra Tech, under a separate EPA-funded research project, will be assessing available information and developing alternative boundary conditions for the South Fork Nooksack River QUAL2Kw model. A suite of boundary conditions will be developed to capture the uncertainties in future greenhouse gas emission rates and the climate response to those emissions. These “scenarios” will be run through QUAL2Kw to acquire predictions of river streamflow and temperature changes due to climate change. The goal of the pilot project is to incorporate the results of this assessment into the TMDL.

QUAL2Kw is a physically based, steady-state (but with diurnal variability) model that simulates temperature, dissolved oxygen, and nutrient-algal response in streams. Evaluation of the TMDL under potential changes to climate requires an evaluation of potential changes in the boundary conditions that force the model. The following outline identifies specific boundary conditions in the QUAL2Kw that are expected to change in response to climate, proposed sources of information on the extent of change, and some of the issues that may arise in translating disparate types of information into appropriate QUAL2Kw inputs.

Climate Model Scenarios

Climate model scenarios will be taken from the work conducted and served by the Climate Impacts Group (CIG) at the University of Washington. CIG has taken output from global circulation models (GCMs) and downscaled the meteorological output to a 1/16 degree scale for the region using quantile mapping on historical meteorological time series (see Polebitski et al., 2007a). This has been done for ten GCMs and multiple emission scenarios for the period through 2099. Downscaling is also done in two different ways: a composite delta method in which there is a single average change (delta) for each month calculated from a time slice of the GCM for the region that is applied to every day in that month, and a hybrid delta approach that uses statistical bias correction to maintain the probability distribution. There is also a composite delta run that represents the central tendency of the ten hybrid delta GCMs for a given emission scenario.

A total of 79 climate products are available from CIG for the Nooksack. Initial work for this project will focus on a limited subset. Specifically, three runs will be conducted using the composite delta results for the A1B emissions scenario for three future time periods (2020s, 2040s, and 2080s). This will serve as an effective test of the method, although not covering the full range of variability in the GCMs. Additional runs may be added in the future to evaluate the ensemble variability, given sufficient resources.

Tributary and mainstem flows

The QUAL2Kw "core model" (existing condition for TMDL) will represent gaged and/or estimated flows in the mainstem and significant tributaries. The TMDL application will scale the flow to a 7Q10 critical low-flow condition (or other low-flow condition if a 7Q10 cannot be calculated). The climate change application can incorporate predicted changes in summer baseflow from assessments conducted with CIG. CIG has paired climate scenarios with the Variable Infiltration Capacity (VIC) hydrologic model, operating at 1/16 degree resolution. For each grid cell, the VIC produces daily outputs of surface and subsurface flow. During the critical low-flow periods for the TMDL it is likely that all flow will be baseflow.

The VIC model is a large-scale model that is not explicitly calibrated to the South Fork Nooksack and cannot be expected to exactly reproduce either current or future conditions for the TMDL. Therefore, mapping/extrapolating CIG estimates to the QUAL2Kw domain will be necessary. Specifically, the CIG output will be applied using a change method in which the TMDL 7Q10 flow is modified by the ratio of CIG estimates of low flows of a similar return period under current and future climate conditions.

Boundary water temperatures

The QUAL2Kw model application will encompass the mainstem (only) of the South Fork Nooksack River, beginning upstream of the first impaired segment. QUAL2Kw provides a process-based simulation of temperature changes within the simulated reaches; however, it requires specification of water temperatures for all influent boundary conditions.

Boundary temperatures will be documented for critical conditions used in the TMDL model. For the climate scenarios, these boundary temperatures will be altered using a delta change method, in which an incremental change is imposed on the existing temperatures.

The temperature deltas will be assessed using a regression approach based on CIG output. CIG provides daily minimum and maximum air temperature and daily surface and subsurface flow. These will be used as independent variables (along with other variables such as elevation and tributary shading) to develop multiple regression equations for current climate tributary stream temperatures. The regression equations will then be applied to future climate conditions and the difference between future and current condition predictions will be used as the temperature delta. Development of the regression relationships will be documented, including an analysis of model fit uncertainty. Output of this process will be a 24-hour time series for QUAL2Kw.

Weather

Air temperature

Boundary air temperature is defined as a 24-hour time series in QUAL2Kw. The QUAL2Kw core model will use meteorological data from a nearby station for the existing air temperature on the simulation date. The TMDL application will likely scale the air temperature to a critical condition such as the 90th percentile. The climate change application can incorporate predicted changes in summer air temperature from assessments conducted by the CIG. Mapping/extrapolation of CIG estimates to the QUAL2Kw domain will be handled using a delta change method in which the existing time series is modified by the predicted arithmetic change between current and future conditions.

Cloud cover

The QUAL2Kw core model will use meteorological data from a nearby station for the existing cloud cover on the simulation date. The TMDL application will likely adjust the cloud cover to zero (clear sky) as a critical condition. There will be no climate change adjustment for cloud cover.

Relative humidity and wind

These conditions will be set to existing conditions for all model setups, including climate change scenarios. While relative humidity and wind are likely to change under future conditions, downscaled analysis of these variables is not available from CIG. Note that relative humidity (rather than dew point) will be kept constant to represent a conservative condition (as evaporation cools the stream). These variables are not expected to have a major impact on water temperature predictions. However, their potential influence will be investigated using sensitivity analyses on the range of potential change predicted from GCMs.

Other Boundary Conditions

Riparian shade

The QUAL2Kw core model will use estimates of existing shade on the mainstem river based on observations (e.g., LIDAR, field sampling) and the Shade model. The TMDL application will likely include alternative shade conditions, including the natural condition of full potential shade. There will be no climate change adjustment in riparian shade outside the range of conditions to be evaluated for the TMDL.

Channel structure (width/depth by segment)

The channel structure will be set to existing conditions for all model setups, including climate change scenarios.

Hyporheic Exchange

Warmer land temperatures associated with climate change scenarios have the potential to impact the cooling influences of hyporheic exchanges. A sensitivity analysis will be performed to evaluate the importance of hyporheic exchange as needed for model calibration purposes.

Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to address project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. Quality objectives apply to laboratory and field data though no new data collection is proposed, therefore, quality objectives for modeling are relevant to this QAPP.

Quality Objectives for Modeling

To help guide the interpretation of the technical information provided by the water quality models, several methods can be used to compare observed measurement and model results. These methods include:

- Graphical comparison for visual inspection.
- Statistical methods quantifying the comparison.

This section presents options for evaluating model performance that may be used in the TMDL analysis. In addition, performance target ranges associated with some of the statistical tests are presented. The performance targets are based on generally accepted values from the literature and experience with previous projects. Numeric acceptance criteria are not specified for the model; rather *performance target ranges* are identified. These ranges provide a guide and a goal for model evaluation; however, several factors will be considered when determining overall model acceptance (i.e., modeling will not be disqualified based on any single departure). Appropriate uses of the model will be determined by the project team after assessing the types of decisions to be made, the model performance, and the available resources.

Acceptance Criteria for Model Calibration

The intended uses of the model focus on the effectiveness. As such, the ability of the models to represent the relative contributions of different source areas and the relative performance of different management measures is of greatest importance, while obtaining a precise estimate of loading time series is of less direct interest. Ideally, the models should attain tight calibration to observed data; however, a less precise calibration can still be useful.

In light of these uses of the models, it is most informative to specify performance target ranges of precision that characterize the model results as *very good*, *good*, *fair*, or *poor*. These characterizations inform appropriate uses of the model: Where a model achieves an excellent fit it can generally assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit it should assume a much less prominent role in the overall weight-of-evidence evaluation of management options.

The general acceptance criterion for models to be applied in this project is *to achieve a quality of fit of good or better*. If that level of quality is not achieved on some or all measures, the model might still be useful; however, a detailed description of its potential range of applicability will be provided.

Model Performance Measurements

To conduct the model calibration process, a visual comparison along with a set of basic statistical methods will be used to compare model predictions and observations. These methods are presented below for the QUAL2Kw model.

Visual Comparisons of Model Results

Model results (hydrology and water quality) will be compared with associated observed measurements using graphical presentations. Such visual comparisons are useful in evaluating model performance over the appropriate temporal range. For example, continuous monitoring data can be compared with continuous modeling results to ensure diurnal variation and minimum/maximum values are well represented.

Statistical Tests of Model Results

Model performance can also be evaluated using statistical tests. This section presents a suite of tests that may be used during calibration of the QUAL2Kw model. The exact statistical tests will be determined during model calibration and may include any of the following. In addition, if determined necessary and appropriate, additional tests of model fit may also be applied.

QUAL2Kw model resolution and performance will be measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986).

Root-Mean-Square Error Statistic. The root-mean-square error (E_{rms}) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O - P)^2}{n}} .$$

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

A root-mean-square error of zero is ideal. The root-mean-square error 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.

Model bias will be assessed both mathematically and graphically. Bias is the systematic deviation between a measured (i.e., observed) and a computed (i.e., modeled) value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration.

Mathematically, bias is calculated as the relative percent difference (RPD). This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

$$RPD = (| P_i – O_i | *2) / (O_i + P_i),$$

where

P_i = ith prediction
O_i = ith observation

QUAL2Kw graphically represents observed and measured values along the length of the modeled stream segment. Therefore, bias will also be evaluated by observing modeled trends and over- or under-prediction between computed vs. measured values.

Means, maximums, minimums, and 90th percentiles will be determined from the data collected at each monitoring location. For temperature, the maximum, minimum, and daily average will be determined. Estimates of groundwater inflow may be calculated by constructing a water mass balance from continuous and instantaneous streamflow data and piezometer studies. Estimates may also be compared to where FLIR data indicate groundwater influences.

Model Performance Targets for Select Statistical Tests

Because QUAL2Kw uses steady-state flow, only one flow condition can be considered for one model run. For model flow calibration and validation, two modeled results will be output. The flow balance of QUAL2Kw is mainly governed by specified boundary inflows. For other parameters such as velocity, statistics can be calculated if data are available. Statistics become meaningful when sufficient data are available. It is not expected that sufficient data will be available for the QUAL2Kw hydrology calibration; therefore, it is anticipated that statistics will not be calculated on QUAL2Kw flow simulations. Any statistics that are calculated must be used cautiously in combination with visual inspection.

The QUAL2Kw model runs under steady-state flow conditions. The water quality in that selected day can vary. Statistics will be calculated using continuous data for comparison in addition to the visual comparison described above. The statistics described for the QUAL2Kw model include RMSE and RPD. As a general evaluation of model performance, the HSPF criteria (Donigian et al., 1984; Lumb et al., 1994; and Donigian, 2000) may be applied to the QUAL2Kw model; however, these performance targets were originally developed for assessing relative error (RE) for conventional water quality parameters.

For the RMSE comparisons, the statistics will be expressed in actual units (i.e., degrees Celsius, mg/L) and may be performed not just on average values, but also on minimum and maximum of daily values to capture diurnal variation in the continuous data. Several statistical tests should be used cautiously in combination with visual inspections to assess model performance.

Data Management Procedures

Contractor's Management of Modeling Data

The modeling software to be used for this project consists primarily of the QUAL2Kw model. Executables for the QUAL2Kw and Shade models are available as part of Ecology's Environmental Assessment Program Models for Total Maximum Daily Load Studies (www.ecy.wa.gov/programs/eap/models.html). Use of output from models developed by others (e.g., models for input of boundary conditions under future climate scenarios) is addressed in the Secondary Data section.

The contractor will maintain and provide the final version of the model, including input, output, and executables, to Ecology and EPA for archiving at the completion of the task. Electronic copies of the data, GIS, and other supporting documentation (including records documenting model development) will be supplied to EPA Region 10 with the final report. The contractor will maintain copies in a task subdirectory (subject to regular system backups) and on disk for a period of 3 years after task termination, unless otherwise directed by EPA.

Most work conducted by the contractor for this task requires the maintenance of computer resources. The contractor's computers are either covered by on-site service agreements or serviced by in-house specialists. When a problem with a microcomputer occurs, in-house computer specialists diagnose the problem and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. For other computer equipment requiring outside repair and not covered by a service contract, local computer service companies are used on a time-and-materials basis.

Routine maintenance of microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes.

All contractor computer users have been instructed on the importance of routinely archiving work assignment data files from hard drive to compact disc or server storage. The office network server is backed up on tape nightly during the week. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems have been placed on all contractor computer systems and are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software is performed to keep up with evolutionary changes in computer storage, media, and programs.

Audits and Reports

Reports will follow technical direction from EPA and include the final TMDL report.

Data Quality (Usability Assessment)

Usability of Results from Modeling

From a decision context, the primary function of the calibrated water quality model is to predict the response of pollutant loads to changes in management. As such, an important input to the decision-making process is information on the degree of uncertainty that is associated with model predictions. In some cases, the risks or *costs* of not meeting water quality standards could be substantially greater than the costs of over-protection, creating an asymmetric decision problem in which there is a strong motivation for risk avoidance. Further, if two scenarios produce equivalent predicted results, the scenario with the smaller uncertainty is often preferable. Therefore, an uncertainty analysis of model predictions is essential.

As with any mathematical approximation of reality, a water quality model is subject to significant uncertainties. Direct information on the aggregate prediction uncertainty will arise from the model corroboration exercise; however, further diagnostics are needed to understand the sources and implications of uncertainty.

The major sources of model uncertainty include the mathematical formulation, boundary conditions data uncertainty, calibration data uncertainty, and parameter specification. In many cases, a significant amount of the overall prediction uncertainty is due to boundary conditions (e.g., uncertainty in estimation of rainfall from point gage measurements, uncertainty in specifying point source loading time series) and uncertainty in the observed data used for calibration and validation. These sources of uncertainty are largely unavoidable, but they do not invalidate the use of the model for decision purposes. Uncertainties in the mathematical formulation and model parameters are usually of greater concern for decision purposes because they describe the relationships in the calibrated model.

The model code for QUAL2Kw has history of testing and application, so outright errors in the coding of the models are unlikely. A simulation model, however, is only a simplified representation of the complexities of the real world. The question is not whether the model is *right* in the sense that it represents all processes, but rather whether it is useful, in the sense that it represents the important processes to a sufficiently correct degree to be useful in answering the principal study questions.

Additional aspects of model quality assessment are described below, including model development, software development, surveillance of project activities, and overall model output assessment and model usability.

Model Development Quality Assessment

This QAPP and other supporting materials will be distributed to all personnel involved in the work assignment. The designated contractor Modeling QC Officer will ensure that all tasks described in the work plan are carried out in accordance with the QAPP. The contractor will review staff performance throughout each development phase of each case study to ensure adherence to task protocols.

Quality assessment is defined as the process by which QC is implemented in the model development task. All modelers will conform to the following guidelines:

- All modeling activities including data interpretation, load calculations, or other related computational activities are subject to audit or peer review. Thus, the modelers are instructed to maintain careful written and electronic records for all aspects of model development.
- If historical data are used, a written record on where the data were obtained and any information on their quality will be documented in the final report. A written record on where this information is on a computer or backup media will be maintained in the task files.
- If new theory is incorporated into the model framework, references for the theory and how it is implemented in any computer code will be documented and peer-reviewed.
- Any modified computer codes will be documented, including internal documentation (e.g., revision notes in the source code) and external documentation (e.g., user's guides and technical memoranda supplements).

The QC Officer will periodically conduct surveillance of each modeler's work. Modelers will be asked to provide verbal status reports of their work at periodic internal modeling work group meetings. The contractor Task Order Leader (TOL) or his/her designee will make monthly detailed modeling documentation available to members of the modeling work group.

Software Development Quality Assessment

New software development is not anticipated for this project. If any such development is required, the QC Officer (or designee) will conduct surveillance on software development activities to ensure that all tasks are carried out in accordance with the QAPP and satisfy user requirements.

Surveillance of Project Activities

Internal peer reviews within the contractor's organization will be documented in the project file and QAPP file. Documentation will include the names, titles, and positions of the peer reviewers; their report findings; and the project management's documented responses to their findings. The contractor TOL could replace a staff member if it is in the best interest of the task to do so.

Performance audits are quantitative checks on different segments of task activities. The contractor QC Officer (or designee) will be responsible for overseeing work as it is performed and for periodically conducting internal assessments during the data entry and analysis phases of the task. The contractor TOL will perform surveillance activities throughout the duration of the task to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in the data review and technical approach documentation. These surveillance activities will include assessing how task milestones are achieved and documented; corrective actions are implemented; budgets are adhered to; peer reviews are performed; data are managed; and whether computers, software, and data are acquired in a timely manner.

Output Assessment and Model Usability

Departures from Acceptance Criteria

The model developed for the project will be used to assess a series of study objectives, as summarized in the “Goals and Objectives” section above. Acceptance criteria for the model are described in the “Quality Objectives for Modeling” section.

Written documentation will be prepared under the direction of the relevant QC officer addressing the calibrated model’s ability to meet the specified acceptance criteria and provided to the TOL and QA officer for review. If a model does not meet acceptance criteria, the QC officer will first direct efforts to bring the model into compliance. If, after such efforts, the model still fails to meet acceptance criteria, the contractor will conduct a thorough exposition of the problem and potential corrective actions (e.g., additional data collection or modification of model code) and provide them to Ecology and EPA. The contractor will also provide an analysis of the degree to which any model that does not fully meet acceptance criteria might still be useful for addressing study questions.

Reconciliation with User Requirements

In the *Quality Objectives for Modeling* described above, acceptable performance target ranges for the models are presented (not specific numeric acceptance criteria). Appropriate uses of the model will be determined by the project team on the basis of an assessment of the types of decisions to be made, the model performance, and the available resources.

If the project team determines that the quality of the model calibration is insufficient to address the project goal and study objectives, the contractor will consult with Ecology, EPA, and other team members, as appropriate, as to whether the levels of uncertainty present in the models can allow user requirements to be met, and, if not, the actions needed to address the issue.

A detailed evaluation of the ability of the modeling tools to meet user requirements will be provided in either the TMDL report or in internal technical memoranda between the contractor and Ecology, which may ultimately be included as an appendix to the TMDL report.

External Data Usability

Any water quality data from outside this study that will be used in the TMDL analysis will meet the requirements of Ecology's credible data policy (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf). Note that this requirement does not apply to non-quality data such as flow or meteorological data.

External data (also referred to as secondary data) are data previously collected under an effort that are used for water body assessment as well as model development and calibration. Other secondary data will be assembled from other sources. Table 24 lists the secondary sources that are anticipated to be used as part of this project. The sections below provide details regarding how such secondary data will be identified, acquired, and used for this task.

Table 24. Sources of key secondary data

Data type	Source
Flow data	USGS gaging station (National Water Information System)
Meteorology data	National Climatic Data Center (NCDC)
Water quality observations	Ecology; Nooksack Indian Tribe; USGS; Lummi Nation
Reach hydraulics	USGS
Point source data	Discharge Monitoring Reports (Ecology)
Land cover	NOAA Coastal Change Analysis Program (CCAP)

Flow Data

Reliable streamflow data are important to model development and calibration and validation. The USGS maintains streamflow gages in the South Fork Nooksack River watershed. Data from the gage are readily available through the USGS National Water Information System, accompanied by related QC information. Additional flow measurements in the watershed have been collected and are available through the Lummi Nation and the Nooksack Indian Tribe.

Meteorological Data

Meteorological conditions have strong influences on water temperature. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, and headwater temperature. Some of these parameters are calculated (e.g., effective shade from Shade model), and others obtained from weather station information. All relevant precipitation and temperature stations will be reviewed for applicability to the model. Data will be obtained from NOAA's National Climatic Data Center (NCDC). NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States. Data from the University of Washington Land Surface Hydrology Research Group will also be explored for potential use.

COOP stations record hourly or daily rainfall data, while airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover. All data compiled and maintained by NCDC are stored with associated QC tags that identify data quality and missing intervals.

Water Quality Observations

Water quality observations are required for calibration of the QUAL2Kw model in addition to overall water body assessment (see Historical Data Review section). Temperature is the parameter of interest.

Tetra Tech (EPA contractor for QAPP development) has compiled and reviewed monitoring data. Specifically, as noted in the Historical Data Review, monitoring included in situ continuous data and instantaneous values as well as grab samples collected for laboratory analysis.

It is assumed that data collected and provided by Ecology, Nooksack Indian Tribe, Lummi Nation, and others have undergone appropriate QA/QC procedures, but if data from other sources are used, the project team will review the relevant QA protocols and document the results in the final TMDL report. This ensures that the data for the TMDL analyses can be combined, compared, and analyzed comprehensively, resulting in a complete suite of data and information to characterize the study area.

Reach Hydraulics

Stream geometry information is a required input to QUAL2Kw models. This information includes stream channel width, depth, and available cross-section estimates. This information is necessary to best represent the physical system in the models. Basic stream geometry data will be used from existing sources as described in the Historic Data Review section. These data will be the primary source of stream geometry information. Other data sources will be investigated, as necessary. Other stream geometry information will be compiled from available reports and will be used as a secondary source of information, if necessary.

Point Source Discharges

Several types of NPDES permitted facilities or activities exist in the watershed, as described above in the Watershed Description section. DMR data will be incorporated into the model as needed. Ecology will incorporate any NPDES permit reporting data that indicates an effluent discharge, or category of dischargers, affecting temperature levels during a critical period. If the data are determined not to be representative of a discharger or category of dischargers then Ecology may choose not to incorporate that information into its models.

Quality Control for Secondary Measurements

The majority of the secondary measurements, data collected by outside agencies, will be obtained from quality-assured sources. Associated water quality data will be verified using Ecology's Credible Data Policy before inclusion in TMDL analyses. For non-water quality data, it is assumed that data obtained from EPA, USGS, Ecology, or Whatcom County documents and databases have been screened and meet specified measurement performance criteria. Such criteria might not be reported for the parameters of interest in the documents or databases. The project team will determine how much effort should be made to find reports or metadata that might contain that measurement performance criteria information. The team will also perform general quality checks on the transfer of data from any source databases to another database, spreadsheet, or document.

Where non-water quality data are obtained from sources lacking an associated quality report, the contractor Project Manager will evaluate data quality of such secondary data before using it. Additional methods that might be used to determine the quality of secondary data are:

- Verifying values and extracting statements of data quality from the raw data, metadata, or original report.
- Comparing data to a checklist of required factors (e.g., analyzed by an approved laboratory, used a specific method, met specified DQOs, validated).

If it is determined that such searches are not necessary or that no quality requirements exist or can be established, but the non-water quality data must be used in the task, a statement will be included in the final report indicating that the quality of the specified secondary data is unknown.

Use of External Modeling Products

For the climate sensitivity analyses, various boundary conditions to the QUAL2Kw model will be established using output provided by the University of Washington's Climate Impact Group (CIG). CIG provides gridded estimates of future climate (precipitation, temperature, etc.) and streamflow (using the Variable Infiltration Capacity or VIC model) under different emission scenarios and time frames. Results are served online at a 1/16-degree resolution.

Projections of future climate are subject to many uncertainties, which will be acknowledged in the report. CIG has worked to ensure that the uncertainties in their projections reflect uncertainties in the science and are not contaminated by additional uncertainty due to data management and processing errors. The CIG climate projections were developed under a QAPP, as described in Polebitski et al. (2007a). Similarly, the VIC watershed model applications were developed under a QAPP (Polebitski et al., 2007b). The project team will rely on these QAPPs to ensure the quality of modeling output from CIG used to support the current project. As with other secondary data, representative subsample spot checks will be deployed to ensure that the data entered into the QUAL2Kw model are consistent with the CIG model output.

Project Organization

Table 25 shows the roles and responsibilities of Ecology and contractor staff.

Table 25. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Steve Hood Ecology, WQP, BFO Phone: (360) 715-5211	Ecology Project Lead	Acts as point of contact between EAP staff and interested parties. Coordinates information exchange. Forms technical advisory team and organizes meetings. Reviews and approves the QAPP.
Teizeen Mohamedali Ecology, EAP, BFO Phone: (360) 715-5209	Ecology Project Manager, Technical Lead	Helps define project objectives, scope, and study design. Provides modeling and technical expertise and oversight for the project. Reviews the QAPP.
Chuck Springer Ecology, EAP, HQ Phone: (360) 407-6997	Ecology Hydrogeologist	Deploys and maintains continuous flow gages and staff gages. Produces records of streamflow data at sites selected for this study.
Laurie Mann EPA Region 10 Phone: (206) 553-1583	EPA Technical Lead	Serves as technical lead for the contracting agency.
Jayne Carlin EPA Region 10 Phone: (206) 553-8512	EPA Task Order Manager	Serves as contract manager for the project.
Gina Grepo-Grove EPA Region 10 Phone: (206) 553-1632	EPA Quality Assurance Manager	Ensures products meet quality objectives.
J. Todd Kennedy Tetra Tech, Inc. Phone: (919) 485-2067	Tetra Tech QAPP Author/ Project Manager	Writes sections of the QAPP. Leads, coordinates, and conducts technical analyses to support TMDL development.
Jonathan Butcher Tetra Tech, Inc. Phone: (919) 485-2060	Tetra Tech Modeling Quality Control Officer	Provides quality control on technical aspects of the project, including modeling and data analyses. Approves the final QAPP.
John O'Donnell Tetra Tech, Inc. Phone: (703) 385-6000	Tetra Tech Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

EAP: Environmental Assessment Program.
QAPP: Quality Assurance Project Plan.
BFO: Bellingham Field Office.
HQ: Headquarters.
EPA: US Environmental Protection Agency

Project Schedule

Table 26 shows the anticipated project schedule for the South Fork Nooksack River TMDL project.

Table 26. Proposed schedule for completing reports.

Final TMDL (WQIR) report: To be declared by EPA and the contractor.

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

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

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

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

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.

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are “indicator” organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

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.

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

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, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

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 NPDES 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).

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: Source of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: 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.

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

Salmonid: Fish that belong to the family *Salmonidae*. Basically, 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.

System potential: The design condition used for TMDL analysis.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

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

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

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
NPDES	(See Glossary above)
QAPP	Quality Assurance Project Plan
QC	Quality Control
RM	River mile
TMDL	(See Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mm	milliliter
mg	milligrams
mg/L	milligrams per liter (parts per million)
mL	milliliters
NTU	nephelometric turbidity units
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity