Upper Naches River Temperature Total Maximum Daily Load

Volume 1. Water Quality Study Findings

December 2008

Publication No. 08-03-036

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and Contact Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/0803038.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search User Study ID, STEB0001.

Ecology's Study Tracker Code for this study is 04-002-01.

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Cover photo: Upper Naches River (taken by Michael LeMoine, May 2004).

Upper Naches River Temperature Total Maximum Daily Load

Volume 1. Water Quality Study Findings

by

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Waterbody Numbers: See Table 1

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Abstract

The study area for the upper Naches River Temperature Total Maximum Daily Load (TMDL) consists of the mainstem Naches River from the confluence with the Tieton River (river mile 17.6) to the U.S. Forest Service (USFS) boundary (RM 38.8), all major tributaries along this reach, and Cowiche Creek.

The Naches River watershed is located within Watershed Resource Inventory Area (WRIA) 38. The Federal Clean Water Act Section 303(d) listings for temperature in the study area include 26 listed segments.

The Washington State Department of Ecology conducted field work for this study in 2004. This report presents (1) an analysis of the spatial and temporal stream temperature patterns of streams within the Naches River basin and (2) results of a QUAL2Kw stream temperature model used to investigate possible thermal behaviors of the upper Naches River for different meteorological, shade, and flow conditions.

Reductions in water temperatures are predicted for hypothetical conditions with mature riparian vegetation, channel width reductions, and improvements in riparian microclimate. Model simulations show an expected 2.7°C reduction in temperature compared to current conditions for the upper Naches River (RM 38.8 to 17.6). Potential reduced temperatures are predicted to be lower than the threshold for fish lethality of 23°C, but greater than 16°C in all the stream segments evaluated.

This technical assessment uses effective shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d) for a TMDL for temperature.

This TMDL sets effective shade load allocations for the upper Naches River study area. The TMDL also incorporates the allocations developed for USFS lands in the *Wenatchee National Forest Water Temperature TMDL Technical Report*. In addition to the load allocations for effective shade, other management activities are recommended for compliance with the Washington State water quality standards for water temperature. These include measures to increase channel stability and complexity.

Acknowledgements

The author of this report would like to thank the following people for their contribution to this study:

- U.S. Geological Survey staff for assistance during the seepage flow survey.
- Dave Ragsdale, US Environmental Protection Agency, for assistance with field surveys, review of the draft report, and many valuable comments.
- Staff with the Washington State Department of Ecology:
  - James Kardouni and Michael LeMoine for extensive field work and analysis of environmental data.
  - Nuri Mathieu and Sara Livingston for assistance with field surveys.
  - Barb Carey for groundwater work and analysis.
  - James Kardouni and Sara Livingston for data analysis, data Quality Assurance, and input to Ecology's EIM database.
  - George Onwumere, Anita Stohr, Teizeen Mohamedali, Gary Arnold, Mark Hicks, and Susan Braley for review of the draft report and many valuable comments.
  - Mark Peterschmidt for review of the draft report and coordination of the public review process for the study.
  - Chuck Springer and the Stream Hydrology Unit for continuous streamflow data collection.
  - Joan LeTourneau and Cindy Cook for formatting and editing this report.

Executive Summary

Introduction

The federal Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the waterbodies on the Section 303(d) list. The TMDL identifies pollution problems in the watershed, and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology then works with the local community to develop: (1) an overall approach to control the pollution, called the *Implementation Strategy*, and (2) a monitoring plan to assess the effectiveness of the water quality improvement activities.

This document establishes the loading capacity and load allocations necessary to improve stream temperatures and meet water quality standards. Ecology's Central Regional Office prioritized the watersheds needing TMDLs in central Washington. Addressing a TMDL in the upper Naches River watershed is in accordance with that prioritization.

The study area for this TMDL consists of the mainstem Naches River from the confluence with the Tieton River (River Mile (RM) 17.6) to the U.S. Forest Service (USFS) boundary (RM 38.8), all major tributaries along this reach, and Cowiche Creek (Figure ES1). The Naches River watershed is located within Watershed Resource Inventory Area (WRIA) 38.

Ecology developed a temperature TMDL technical report for the Wenatchee National Forest that established load allocations for shade on USFS designated lands in WRIA 38 (Whiley and Cleland, 2003). Therefore, this temperature TMDL will not develop load allocations for USFS lands, but will incorporate the load allocations from the Wenatchee National Forest Water Temperature TMDL Technical Report (Figure ES1). In the near future, Ecology will develop separate water quality improvement projects to take care of the remaining temperature impairments in WRIA 38.

This TMDL addresses stream temperature exceedances located within the study area. The Naches River subbasin is part of the Yakima River drainage basin. The Naches River flows east from the Cascades to the city of Yakima where it converges with the Yakima River.

Project goals include:

- Characterizing summer (June-October) stream temperature of the Tieton River, Naches River, Rattlesnake Creek, and Cowiche Creek.
- Developing a predictive computer temperature model for the upper mainstem Naches River from the Wenatchee National Forest Boundary to the confluence with the Tieton River.
- Developing shade curves for Cowiche Creek and selected Naches River tributaries not located on USFS lands.
- Establishing a TMDL for temperature in the upper Naches River watershed and Cowiche Creek.

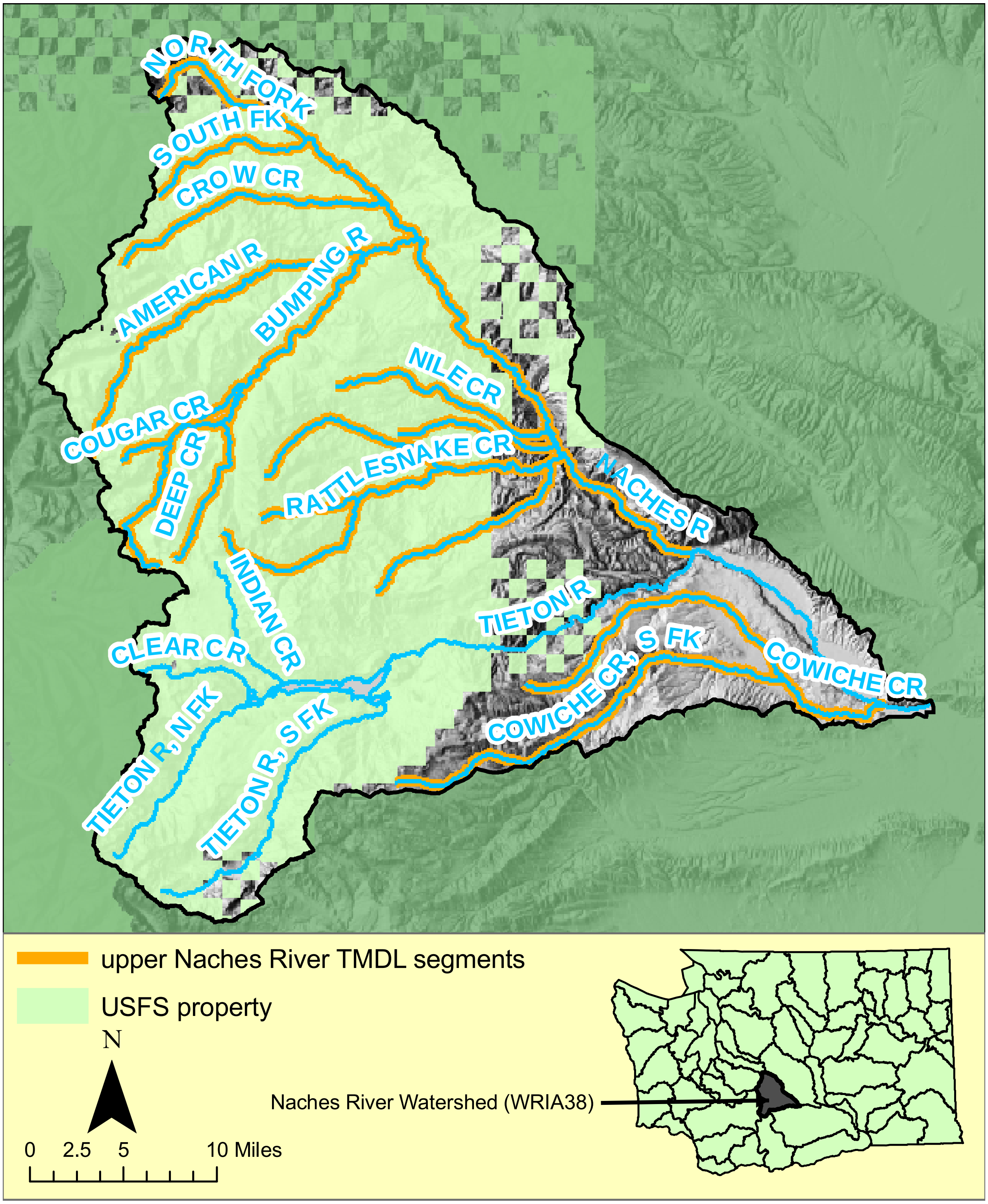

Figure ES1. Segments in the Naches River basin studied for developing a temperature TMDL.

Water quality standards

Water temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life. Water temperature 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, these criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a waterbody.

In the Washington State water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2006 edition].

The beneficial uses designated within the Naches River basin include Char Spawning and Rearing, Core Summer Salmonid Habitat, and Salmonid Spawning, Rearing and Migration. The applicable temperature criteria for the designated uses are contained in 173-201A-200(c) as:

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

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

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

The state uses the criteria described above to ensure that where a waterbody 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 waterbody is naturally warmer than the above-described criteria, the state provides an allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition.

Special consideration is also required to protect spawning and incubation of salmonid species. Where Ecology determines the temperature criteria established for a waterbody would likely not result in protective spawning and incubation temperatures, the following criteria apply: (1) Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and (2) Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Figure ES2 illustrates the applicable beneficial uses, supplemental spawning/incubation criteria, and associated temperature criteria for all waterbodies within the Naches River watershed. In cases where the supplemental spawning criteria are more or less stringent than the designated beneficial use temperature criteria, the more stringent temperature criteria should be applied.

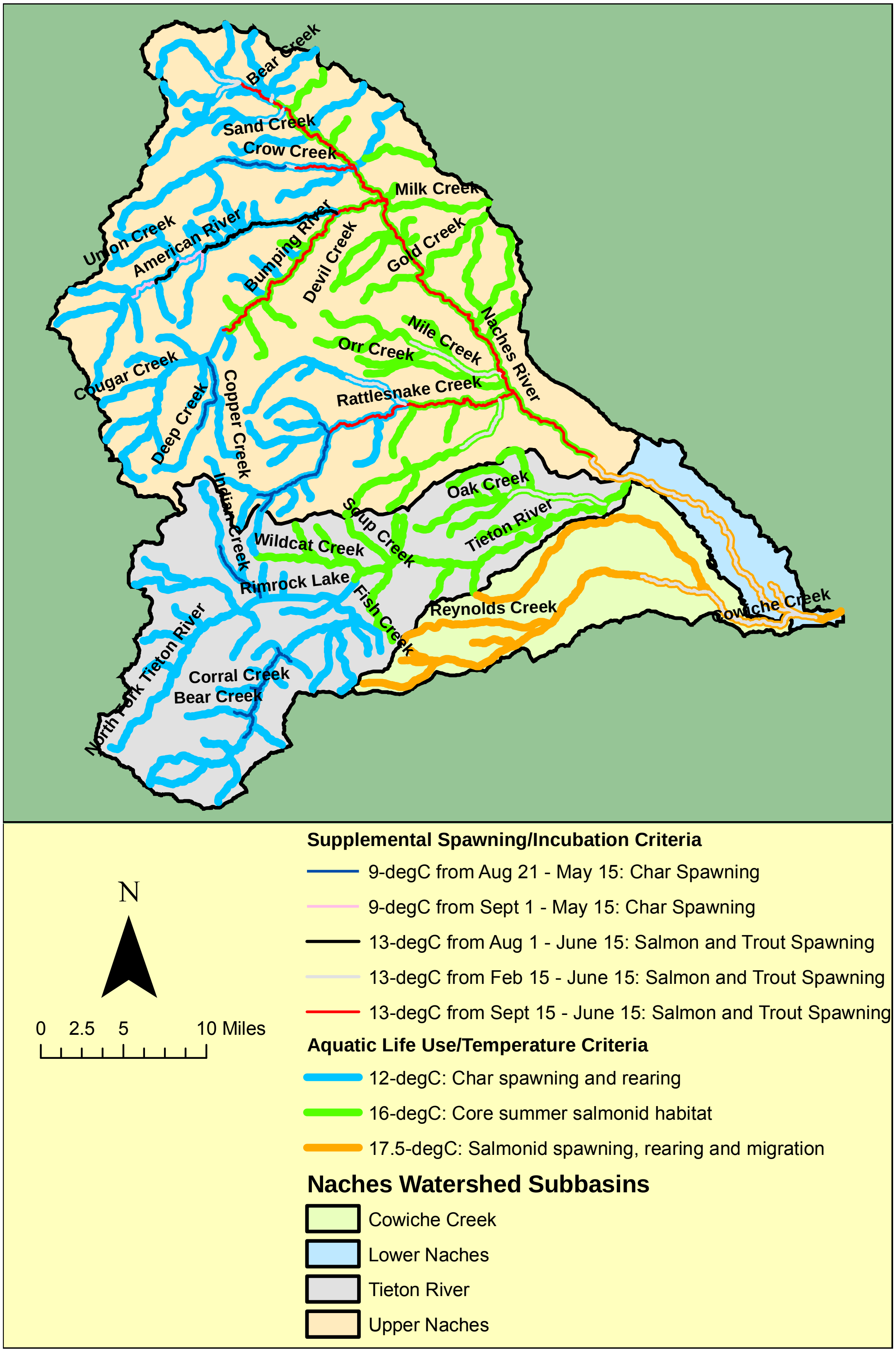

Figure ES2. Applicable beneficial uses and temperature criteria for the Naches River watershed.

Summary of allocations

Load allocations (for nonpoint sources) and wasteload allocations (for point sources) are established in this TMDL to meet both (1) the numeric threshold criteria, and (2) the allowances for human warming under conditions that are naturally warmer than those criteria.

Load allocations

Modeling for the TMDL indicates that system-potential water temperatures would not meet numeric water quality standards during the hottest period of the year on the upper Naches River. Hence, there is a widespread need to provide maximum protection from direct solar radiation. The load allocation for the upper Naches River from the USFS boundary (RM 38.8) to the confluence with the Tieton (RM 17.6) is the effective shade that would occur from system-potential mature riparian vegetation and a 10% reduction in channel width.. *System-potential mature riparian vegetation* is defined as: *that vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes.*

The load allocation for surface waters located from the USFS boundary (RM 38.8) to the headwaters was developed in the Wenatchee National Forest Temperature TMDL Technical Report (Whiley and Cleland, 2003) based on a channel classification system. The allocations consist of (1) the *TMDL load allocations*, or the effective shade levels required to meet the temperature standard, and (2) the *load allocation*, or the effective shade level provided by site potential vegetation. For the Cowiche Creek system and all tributaries flowing into the upper Naches River (RM 38.8 to 17.6), the load allocations for shade are based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum riparian vegetation condition.

The load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural conditions. Therefore, the load allocations are expected to result in water temperatures that meet the water quality standard.

Establishing mature riparian vegetation is expected to also have a secondary benefit of reducing channel widths and improving microclimate conditions to address those influences on the loading capacity. An adaptive management strategy is recommended to address other influences on stream temperature such as sediment loading, groundwater inflows, and hyporheic exchange.

Wasteload allocations

The state water quality standards (WAC 173-201A) restrict the amount of warming that point sources can cause when temperatures are warmer than water quality criteria. At times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times.

Maximum effluent temperatures should also be no greater than 33°C to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life (WAC 173-201A-200).

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

Maximum temperatures (T_{NPDES}) for the NPDES[1] effluent point source discharges into Cowiche Creek, including the Cowiche POTW[2] and six fruit packing facilities, were calculated from the following mass balance equation (Ecology, 2007), in recognition that the system-potential upstream temperature is greater than 17.5ºC.

Salmonid spawning, rearing and migration:

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

A summary of the wasteload allocations developed for this TMDL are listed in Table ES1.

Table ES1. Wasteload allocations (WLA) for point sources located in the study area for the upper Naches River Temperature TMDL.

NPDES facility	Permit number	Monitoring point	Chronic dilution factor	Water quality standard for temperature (°C)	Allowable increase in temperature at the mixing zone boundary (°C)	T_{NPDES} = Maximum allowable effluent temperature WLA (°C)
Cowiche POTW	WA-005239-6		1	17.5	0.3	17.5
Strand Apples Inc Marley Bldg	WAG435036C	1	20	17.5	0.3	23.2
Strand Apples Inc Main Plant	WAG435044C	3	2	17.5	0.3	17.8
Cowiche Growers Inc	WAG435046C	5	2	17.5	0.3	17.8
Ackley Fruit Company LLC	WAG435070C	1	3	17.5	0.3	18.1
Strand Apples Forney	WAG435283A	1	2	17.5	0.3	17.8
Lloyd Garretson, Co.	WAG435210C	1	4	17.5	0.3	18.4

[1] NPDES = National Pollutant Discharge Elimination System.
[2] POTW = Publicly Owned Treatment Works.

Conclusions and management recommendations

Conclusions

Reductions in water temperature are predicted for hypothetical conditions with mature riparian vegetation, improvements in riparian microclimate, and reduction of channel width. Current temperatures in some sections of the upper Naches River (RM 38.8 to 17.6) are above the 23°C lethal limit for salmonids during the summer months (June – October). Potential reduced maximum temperatures under critical conditions are predicted to be greater than the 16°C numeric standard in the upper mainstem Naches River, but below the lethal limit of 23°C for salmonids. Further reductions are likely if all tributaries and channel complexity are restored.

The best estimate of potential summer stream temperature reductions for the upper Naches River (RM 38.8 to the confluence with the Tieton River) is 2.7°C. This estimate is based on implementing 2-zone system-potential vegetation, microclimate reductions, 10% reduction in channel width, and restoring the headwaters and tributaries to the water quality numeric criterion of 16°C. Most of the system has the ability to achieve temperatures in the range of 18-23ºC during the hottest portions of the summer (Table ES2).

The QUAL2Kw model simulations indicated that:

- A buffer of mature riparian vegetation along the banks of the rivers is expected to decrease the average daily maximum temperatures slightly. At 7Q10 flow conditions, a 0.7°C reduction is expected for the upper Naches River.
- A 10% reduction of the channel width would result in an expected reduction of 1°C. A 25% reduction in channel width may result in a 1.5°C reduction of the average maximum temperatures.
- The changes in microclimate conditions associated with mature riparian vegetation could further lower the daily average maximum water temperature by about 0.5°C.
- With all management scenarios in place and the assumption that the headwaters and the tributaries are in compliance with the water quality criterion, the overall decrease in the average maximum temperature for the simulated critical condition is 2.7°C.

Table ES2. Summary of daily water temperatures (ºC) during critical conditions in the upper Naches River (RM 38.8 to 17.6).

Scenario	Upper Naches River	
	Tave (average daily average of all reaches)	Tmax (average daily maximum of all reaches)
7Q2		
Current condition	18.06	21.35
Average system-potential vegetation	17.90	21.03
Maximum system-potential vegetation	17.82	20.87
2-zone maximum system-potential vegetation	17.72	20.67
2-zone maximum system-potential vegetation, 10% width reduction	17.69	20.41
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions	17.53	20.16
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions, tributary and headwaters to water quality numeric criteria	16.16	18.64
7Q10		
Current condition	18.41	21.93
Average system-potential vegetation	18.24	21.59
Maximum system-potential vegetation	18.14	21.39
2-zone maximum system-potential vegetation	18.07	21.24
2-zone maximum system-potential vegetation, 5% width reduction	18.04	21.09
2-zone maximum system-potential vegetation, 10% width reduction	18.00	20.93
2-zone maximum system-potential vegetation, 25% width reduction	17.90	20.44
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions	17.81	20.64
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions, tributary and headwaters to water quality numeric criteria	16.46	19.20

7Q2 = flow representing the 7-day average low-flow having a two-year reoccurrence.
7Q10 = flow representing the 7-day average low-flow having a ten-year reoccurrence interval.

Management recommendations

In addition to the wasteload and load allocations for effective shade in the upper Naches River basin, the following management activities are recommended for compliance with water quality standards throughout the watershed:

- For USFS managed lands in the Wenatchee National Forest, continue implementing riparian reserves and maintaining mature riparian vegetation as established by the Northwest Forest Plan.

- Load allocations are included in this TMDL for non-federal forest lands in accordance with Section M-2 of the Forests and Fish Report. The report can be found at: www.dnr.wa.gov/forestpractices/rules/forestsandfish.pdf. Consistent with the Forests and Fish agreement, implementation of the load allocations established in this TMDL for private and state forestlands will be accomplished via implementation of the revised forest practices regulations.

- For areas that are not managed by the USFS or in accordance with the state forest practices rules, such as private non-forest areas, voluntary programs to increase riparian vegetation should be developed. An example voluntary program would be riparian buffers or conservation easements sponsored under the U.S. Department of Agriculture Natural Resources Conservation Service's Conservation Reserve Enhancement Program.

- Instream flows and water withdrawals are managed through regulatory avenues separate from TMDLs. However, stream temperature is related to the amount of instream flow, and increases in flow generally result in decreases in maximum temperatures. Future projects that have the potential to increase groundwater or surface water inflows to streams in the watershed and have the potential to decrease stream temperatures should be encouraged.

- Management activities that would reduce the loading of sediment to the surface waters from upland and channel erosion are also recommended.

- Hyporheic[3] exchange flows and groundwater discharges are important to maintaining the current temperature regime and reducing maximum daily instream temperatures. Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the hydraulic conductivity of the streambed sediments. Activities that reduce the hydraulic conductivity of streambed sediments could result in increased stream temperatures. Management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.

- Management activities that increase the amount of large woody debris in the Naches River system will assist in pool-forming processes and will assist in reducing flow velocities that wash out spawning gravels and contribute to channel downcutting. Increased sinuosity will also help dissipate flow energy, allowing water to better enter the hyporheic zone.

[3] Hyporheic = The area under and along the river channel where surface water and groundwater meet.

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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 Clean Water Act requires each state and tribe 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.

Every two years, states and tribes are required to prepare a list of waterbodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list. To develop the list, Ecology compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before the data are used to develop the 303(d) list. The 303(d) list is part of the larger Water Quality Assessment.

The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. This list divides waterbodies into five categories:

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

Category 2 – Waters of concern.

Category 3 – Waters with no data available.

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

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

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

TMDL process overview

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) or water cleanup plan be developed for each of the waterbodies on the 303(d) list. The TMDL identifies pollution problems in the watershed and then specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology then works with the local community to develop (1) an overall approach to control the pollution, called the *Implementation Strategy*, and (2) a monitoring plan to assess effectiveness of the water quality improvement activities. The document that combines all of these elements is called a water quality implementation report.

Once the Environmental Protection Agency (EPA) approves the TMDL, a *Water Quality Implementation Plan* must be developed within one year. This plan identifies specific tasks, responsible parties, and timelines for achieving clean water.

Elements required in a TMDL

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

Identifying the pollutant loading capacity for a waterbody is an important step in developing a TMDL. EPA defines the loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source, 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 a set of diffuse (nonpoint) sources such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider seasonal variations, and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future loads from growth pressures is sometimes included as well. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

TMDL = Loading Capacity = sum of all wasteload allocations + sum of all load allocations + margin of safety

What part of the process are we in?

This document establishes the loading capacity and load allocations necessary to improve stream temperatures and meet water quality standards.

Why is Ecology Conducting a TMDL Study in this Watershed?

Overview

Ecology is conducting a TMDL study in the upper Naches River watershed because the federal Clean Water Act requires that impaired waterbodies be restored to meet water quality standards through a TMDL process. Ecology's Central Regional Office prioritized the watersheds needing TMDLs in Central Washington. Addressing a TMDL in this watershed is in accordance with that prioritization.

Study area

The study area for this TMDL consists of the mainstem Naches River from the confluence with the Tieton River (river mile 17.6) to the USFS boundary (RM 38.8), all major tributaries along this reach, and Cowiche Creek (Figure 1). The Naches River watershed is located within Watershed Resource Inventory Area (WRIA) 38. The lower Naches and Tieton River systems were monitored during the technical study. However, a TMDL on these reaches will be developed in a future TMDL development project.

The Washington State Department of Ecology (Ecology) has developed a temperature TMDL technical report for the Wenatchee National Forest that established load allocations for shade on USFS designated lands in WRIA 38 (Whiley and Cleland, 2003). Therefore, this temperature TMDL will not develop load allocations for USFS lands, but will incorporate the load allocations from the Wenatchee National Forest Water Temperature TMDL Technical Report (Figure 1).

Pollutants addressed by this TMDL

This TMDL addresses temperature exceedances located within the study area and on Wenatchee National Forest lands.

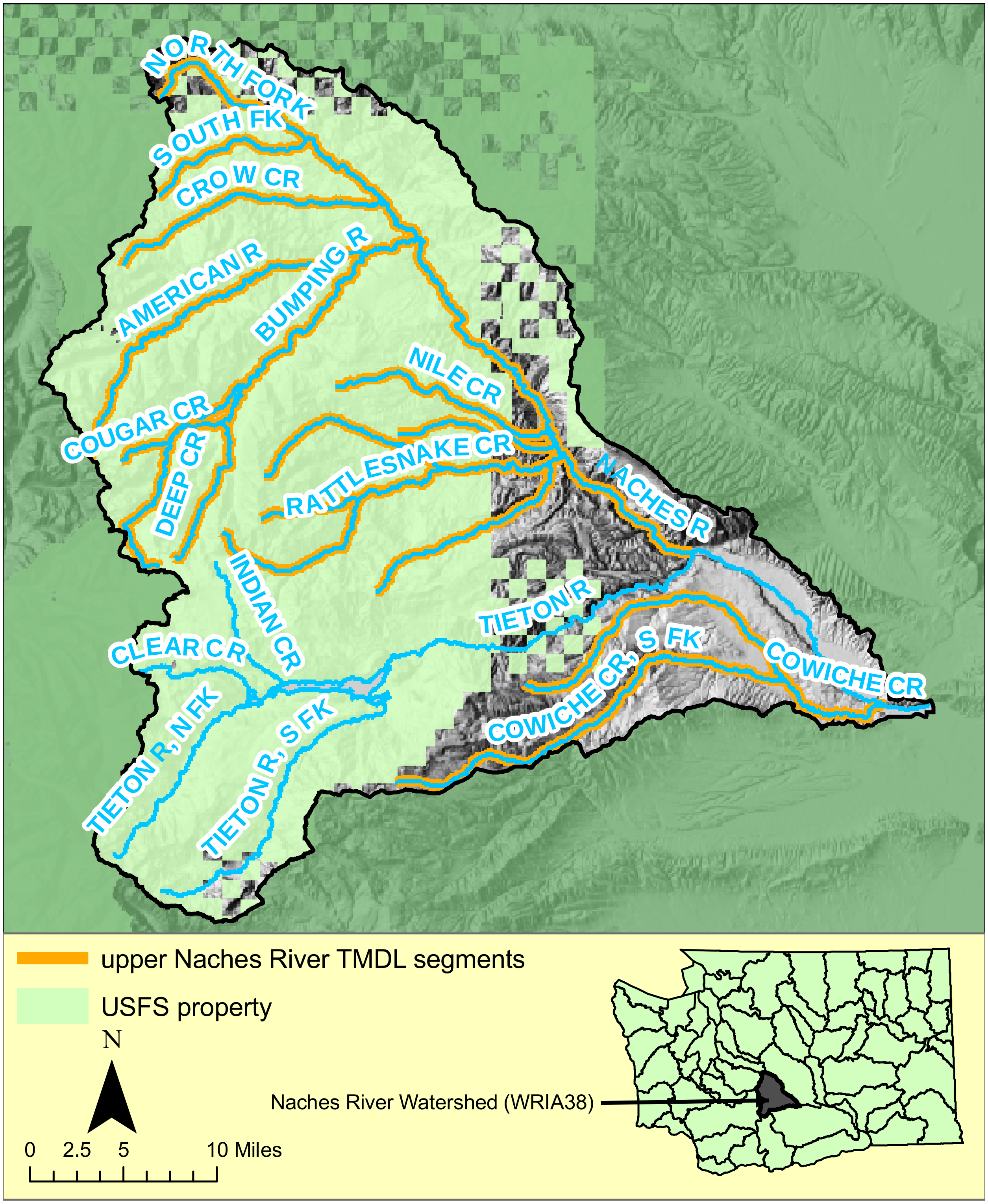

Figure 1. Segments in the Naches River basin (WRIA 38) studied for developing a temperature TMDL.

Impaired beneficial uses and waterbodies on Ecology's 303(d) list of impaired waters

The main beneficial use to be protected by this TMDL is Aquatic Life Uses, including core summer salmonid habitat and salmonid spawning, rearing, and migration. The Naches watershed is used by the following salmonid species: Spring Chinook Salmon (*Oncorhynchus tshawytscha*), Rainbow/Steelhead Trout (*Oncorhynchus mykiss*), and Bull Trout (*Salvelinus confluentus*). The lower reaches of the basin are mainly used by these species for migration, rearing, and spawning habitat. Pacific lamprey, kokanee salmon, cutthroat trout, and mountain whitefish have also been documented within the basin (YSFWPB, 2004).

Washington State has established water quality standards to protect these beneficial uses. Table 1 lists the waterbodies within the study area that exceed temperature criteria established by the water quality standards. These temperature impairments are addressed in this TMDL.

Table 2 inventories additional 303(d) listings for parameters other than temperature that occur in the basin. In addition to one temperature exceedances on the South Fork Tieton River, the Naches River watershed has additional water quality issues other than temperature. These impairments are outside of the scope of this study and will be addressed separately.

Why are we doing this TMDL now?

Several factors contribute to the timing of the Upper Naches River Temperature TMDL. Ecology maintains a listing of water quality impaired waterbodies in Washington State. These impaired waterways are considered geographically and selected for initiation of TMDL projects due to the severity of the impairment, the resource available to conduct the TMDL, and interest from the watershed community.

The Upper Naches Temperature TMDL was begun due to:

- Ranking of the impairment compared to other potential TMDL projects in the region.
- Ability to combine resources and incorporate the Wenatchee National Forest Water Temperature TMDL Technical Report for the upper watershed.
- Interest from within the watershed community, particularly in working with water quality improvement for salmon recovery goals.
- Local stakeholders already making great strides toward implementation of this TMDL, including riparian restoration throughout the project area and water conservation to increase instream flows.

Ecology wants to support the above efforts through development of this TMDL.

Table 1. Study area waterbodies on the 2004 303(d) list for temperature.

Waterbody	Listing ID	Township	Range	Section	Waterbody Number	Old Waterbody ID	1996 List?	1998 List?	Category
American River	8314	17N	13E	12	QX86IU	WA-38-1060	Y	Y	5
Bear Creek	8315	19N	13E	32	JJ42VM	WA-38-1088	Y	Y	5
Bear Creek	40927	18N	13E	05	JJ42VM	WA-38-1088	N	N	2
Blowout Creek	8316	19N	12E	35	OL73EW	WA-38-1091	Y	Y	5
Blowout Creek	40929	19N	12E	36	OL73EW	WA-38-1091	N	N	2
Bumping River	39332	17N	13E	12	XR40PP	WA-38-1070	Y	Y	5
Cowiche Cr, N.F.	8321	14N	17E	18	TY98TL	WA-38-1016	Y	Y	5
Cowiche Cr, S.F.	8325	13N	17E	03	VD04IL	WA-38-1017	Y	Y	5
Cowiche Cr, S.F.	8318	13N	15E	22	VD04IL	WA-38-1015	Y	Y	5
Crow Creek	8329	18N	14E	30	TL45HC	WA-38-1081	Y	Y	5
Gold Creek	8330	17N	14E	36	CR82VL	WA-38-1041	Y	Y	5
Little Naches R.	8331	17N	14E	04	JR85ZB	WA-38-1080	Y	Y	5
Little Naches R.	8333	18N	14E	32	JR85ZB	WA-38-1080	Y	Y	5
Little Naches R.	40762	18N	14E	30	JR85ZB	WA-38-1080	N	N	5
Little Naches R.	40763	18N	13E	14	JR85ZB	WA-38-1080	N	N	5
Little Naches R.	40757	18N	13E	09	JR85ZB	WA-38-1080	N	N	5
Little Naches R.	40755	18N	13E	05	JR85ZB	WA-38-1080	N	N	5
Little Naches R.	8332	19N	13E	31	JR85ZB	WA-38-1080	Y	Y	5
Little Naches R, N.F.	40770	19N	12E	36	VR66RV	--	N	N	5
Little Rattlesnake Cr.	8334	15N	15E	01	FD68UD	WA-38-1036	Y	Y	5
Mathew Creek	40775	18N	13E	09	LW85BJ	WA-38-1086	N	N	5
Mathew Creek	8335	18N	13E	10	LW85BJ	WA-38-1086	Y	Y	5
Nile Creek, N.F.	8338	16N	15E	03	IN37QB	WA-38-2110	Y	Y	5
Rattlesnake Creek	8340	15N	15E	09	MB08QY	WA-38-1037	Y	Y	5
Rattlesnake Creek	8339	15N	14E	10	MB08QY	WA-38-1035	Y	Y	5
Reynolds Creek	8341	13N	15E	15	BI05EL	WA-38-1018	Y	Y	5

Category 2 = Waters of concern.
Category 5 = Polluted waters that require a TMDL – the 303(d) list.

Table 2. Additional 2004 303(d) listings not addressed by this report.

Waterbody	Parameter	Medium	Listing ID	Township	Range	Section	Category	Waterbody Number	Old Waterbody ID
Cowiche Creek, N.F.	Fecal Coliform	Water	8323	13N	17E	03	5	TY98TL	WA-38-1016
Cowiche Creek, S.F.	Fecal Coliform	Water	8326	14N	16E	35	5	VD04IL	WA-38-1017
Deep Creek	pH	Water	11801	15N	12E	10	2	QG55YA	WA-61-7000
Dog Lake	Invasive Exotic Species	Habitat	4876	14N	12E	32	4C	368CDZ	--
Myron Lake	Ammonia-N	Water	8913	13N	18E	10	5	130UZL	WA-38-9080
Naches River	Copper	Water	8916	14N	17E	04	2	NK19LR	WA-38-1010
Naches River	Instream Flow	Habitat	14286	15N	16E	36	4C	NK19LR	--
Tieton River	Dissolved oxygen	Water	16106	14N	14E	31	2	AB82ZA	--
Tieton River, N.F.	Dissolved oxygen	Water	11814	12N	11E	01	2	XM55AK	--
Tieton River, S.F.	Temperature	Water	39334	13N	13E	13	5	NV27KW	WA-38-3000

Overview of stream heating processes

The temperature of a stream reflects the amount of heat energy in the water. The exchange of heat energy between the water and the surrounding environment in a particular stream segment influences the water temperature within that segment. If there is more heat energy entering the water in a stream segment than there is leaving, the temperature will increase. If there is less heat energy entering the water in a stream segment than there is leaving, then the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer) and stream temperature change is outlined in Figure 2.

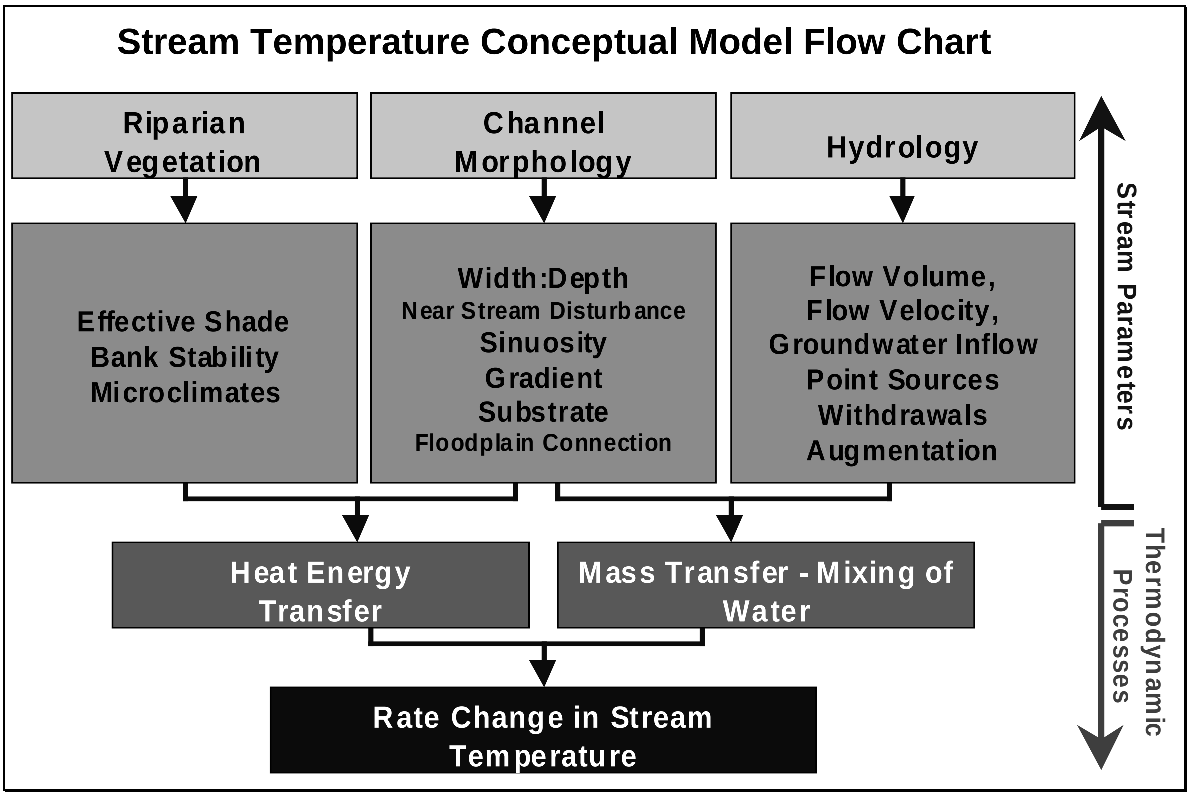

Figure 2. Conceptual model of factors that affect stream temperature.

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

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

Heat budgets and temperature prediction

Heat exchange processes occur between the waterbody and the surrounding environment. These processes control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure 3 shows the major heat energy processes or fluxes across the water surface or streambed.

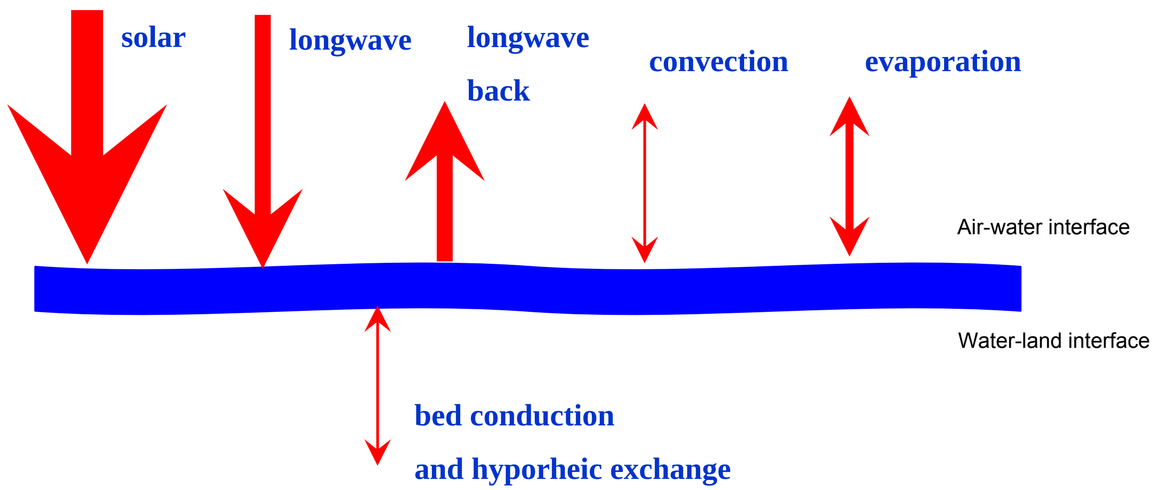

Figure 3. Surface heat exchange processes that affect water temperature (net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed). Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

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

- **Shortwave solar radiation**. Shortwave solar radiation is the radiant energy which passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range between 0.14 μm and about 4.00 μm. At the Washington State University's (WSU) TreeForest Research and Extension Center (TFREC) station in Wenatchee, the daily average global shortwave solar radiation for August 2002 was 259 W/m^2. The peak values during daylight hours are typically about 3 times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear.
- **Longwave atmospheric radiation.** The longwave radiation from the atmosphere ranges in wavelength from about 4 to 120 μm. Longwave atmospheric radiation depends primarily on air temperature and humidity, and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974).
- **Longwave back radiation from the water to the atmosphere.** Water sends heat energy back to the atmosphere in the form of longwave radiation in the wavelength range from about 4 to 120 μm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

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

- **Evaporation flux at the air-water interface** is influenced mostly by the wind speed and the vapor pressure gradient between the water surface and the air. When the air is saturated, the evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation, the reversal of evaporation takes place. This term then becomes a gain component in the heat balance.
- **Convection flux at the air-water interface** is driven by the temperature difference between water and air, and by the wind speed. Heat is transferred in the direction of decreasing temperature.
- **The Bed conduction flux and hyporheic exchange** component of the heat budget represents the heat exchange through conduction between the bed and the waterbody and the influence of hyporheic exchange. The magnitude of bed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher. This transfer usually affects the temperature diel profile, rather than affecting the magnitude of the maximum daily water temperature.

  Hyporheic exchange recently received increased attention as a possible important mechanism for stream cooling (Johnson and Jones, 2000; Poole and Berman, 2000; Johnson, 2004). The hyporheic zone is defined as the region located beneath the channel characterized by complex hydrodynamic processes that combine stream water and groundwater. The resulting fluxes can have significant implications for stream temperature at different spatial and temporal scales.

Figures 4 and 5 show surface heat flux in a relatively unshaded and a more heavily shaded stream reach, respectively.

Figure 4 shows an example of the estimated diurnal pattern of the surface heat fluxes in one of Washington's coastal rivers for the week of August 8-14, 2001. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar shortwave heat flux (Adams and Sullivan, 1989). The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream.

Figure 5 shows an example of the estimated diurnal pattern of the surface heat fluxes in a more heavily shaded location in the same river. Shade that is produced by riparian vegetation or topography can reduce the solar shortwave flux. Other processes, such as longwave radiation, convection, evaporation, bed conduction, or hyporheic exchange, also influence the net heat flux into or out of a stream.

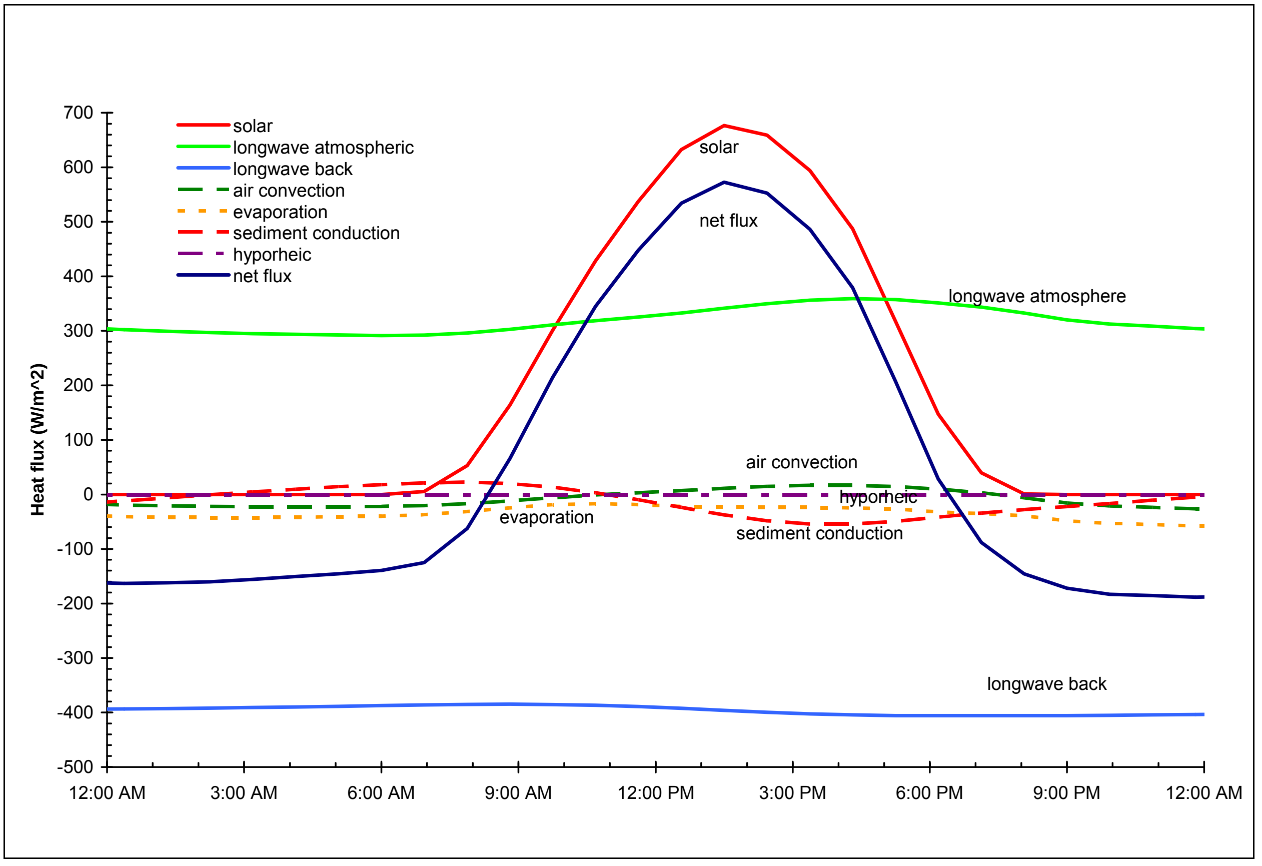

Figure 4. Estimated heat fluxes in an unshaded segment of a river during August 8-14, 2001 (net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

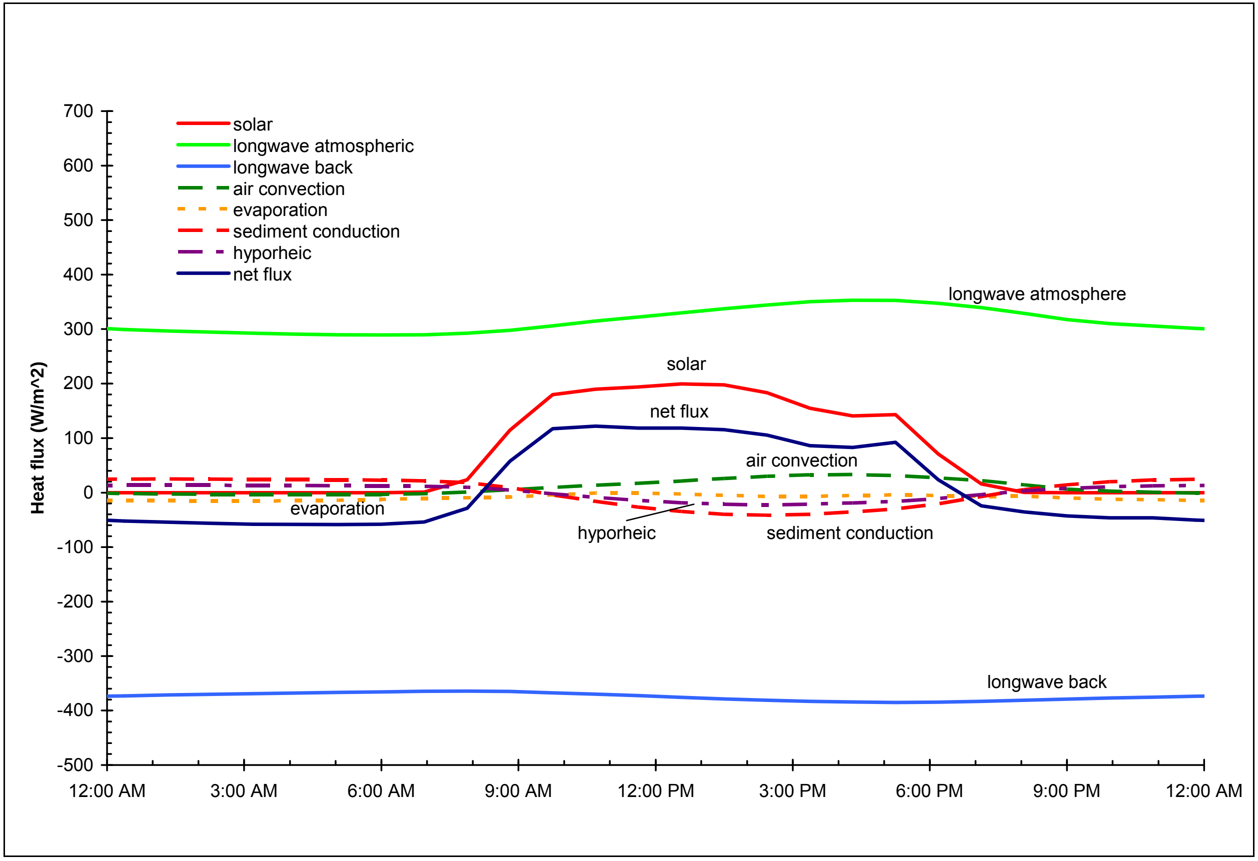

Figure 5. Estimated heat fluxes in a more shaded section of the river during August 8-14, 2001 (net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Heat exchange between the stream and the streambed has an important influence on water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the daylight hours (Figure 6). Heat is typically transferred from the water into the streambed during the day then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

The bulk temperature of a vertically mixed volume of water in a stream segment, under natural conditions, tends to increase or decrease with time during the day according to whether the net heat flux is either positive or negative. When the sun is not shining, the water temperature tends toward the dew-point temperature (Edinger et al., 1974; Brady et al., 1969). The equilibrium temperature of a natural body of water is defined as the temperature at which the water is in equilibrium with its surrounding environment, and the net rate of surface heat exchange would be zero (Edinger et al., 1968; Edinger et al., 1974).

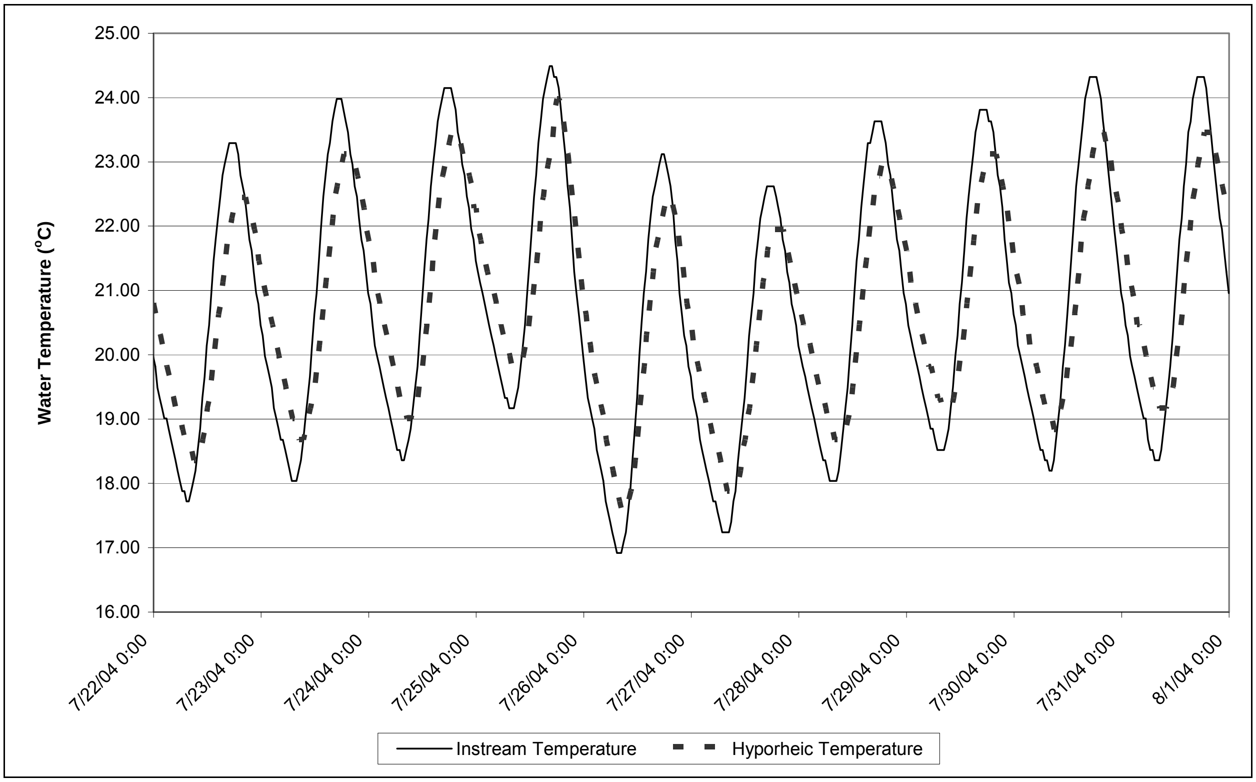

Figure 6. Water and streambed temperatures in late July in the Naches River near the mouth (RM 0.5).

The dominant contribution to the seasonal variations in the equilibrium temperature of water is from seasonal variations in the dew-point temperature (Edinger et al., 1974). The main source of hourly fluctuations in water temperature during the day is solar radiation. Solar radiation generally reaches a maximum during the day when the sun is highest in the sky unless cloud cover or shade from vegetation interferes.

The complete heat budget for a stream also accounts for the mass transfer processes which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a stream segment. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries and groundwater inflows and outflows. Mass transfer relates to transport of flow volume downstream, instream mixing, and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water.

Thermal role of riparian vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation is well documented (e.g., Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier

(1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al., 1992; Beschta et al., 1987; Bolton and Monahan, 2001; Castelle and Johnson, 2000; CH2M Hill, 2000; GEI, 2002; Ice, 2001; and Wenger, 1999. All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. The list of important benefits provided by riparian vegetation includes:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Bank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land-cover type and condition by affecting flood plain and instream roughness, contributing coarse woody debris, and influencing sedimentation, stream substrate compositions, and streambank stability.

The warming of water temperatures as a stream flows downstream is a natural process. However, the rates of heating can be dramatically reduced when high levels of shade exist and heat flux from solar radiation is minimized. The overriding justification for increases in shade from riparian vegetation is to minimize the contribution of solar heat flux in stream heating. There is a natural maximum level of shade that a given stream is capable of attaining, and the importance of shade decreases as the width of a stream increases.

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

Effective shade

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

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

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

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

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summer months, allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun) (Figure 7). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation (direction of streamflow). Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade) (Table 3). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation.

While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, (Ice, 2001; OWEB, 1999; Boyd, 1996; Teti, 2001; Teti and Pike, 2005). These methods include:

- Hemispherical photography
- Angular canopy densitometer (ACD)
- Solar pathfinder

Hemispherical photography is generally regarded as the most accurate method for measuring shade, although the equipment that is required is significantly more expensive compared with other methods.

ACD and Solar pathfinders provide a good balance of cost and accuracy for measuring the importance of riparian vegetation for preventing increases in stream temperature (Teti, 2001; Beschta et al., 1987; Teti and Pike, 2005). Whereas canopy density is usually expressed as a vertical projection of the canopy onto a horizontal surface, the ACD is a projection of the canopy measured at an angle above the horizon at which direct beam solar radiation passes through the canopy. This angle is typically determined by the position of the sun above the horizon during that portion of the day (usually between 10 A.M. and 2 P.M. in mid to late summer) when the potential solar heat flux is most significant. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80% to 90%.

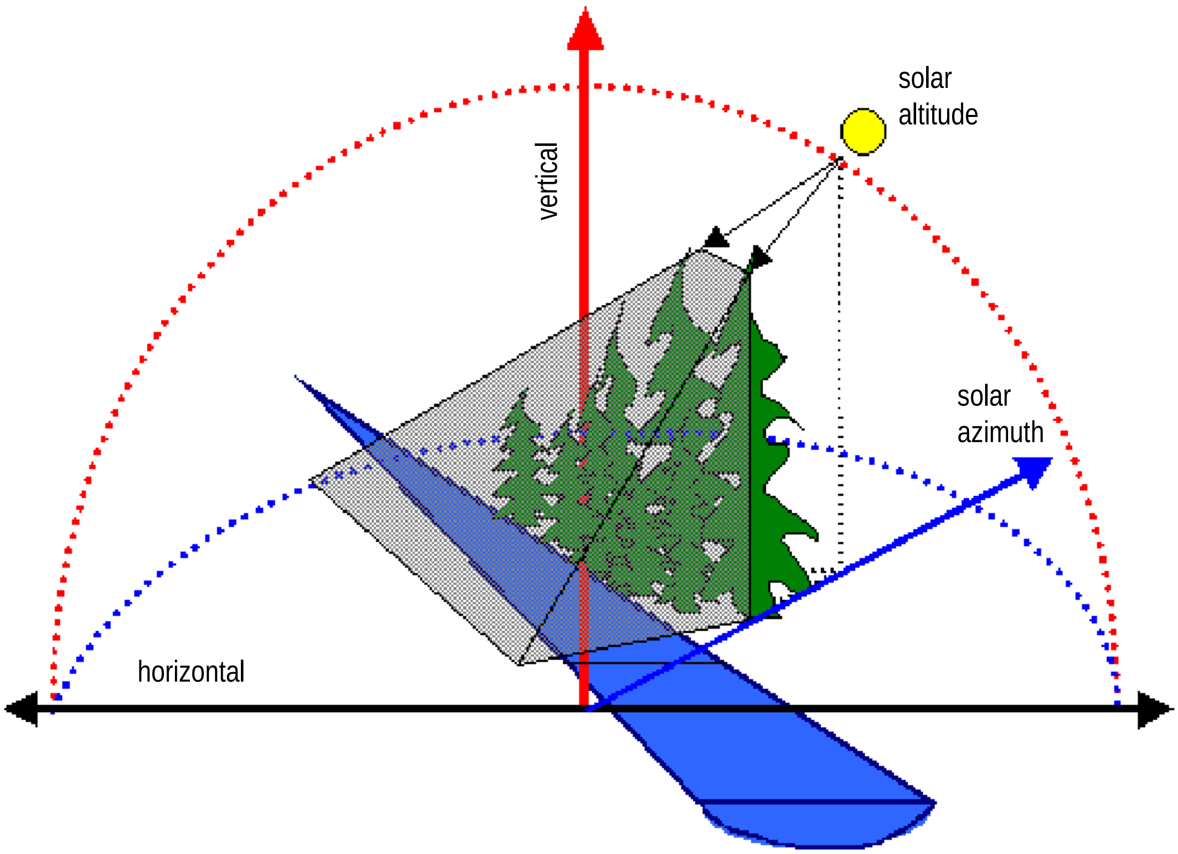

Figure 7. Parameters that affect shade and geometric relationships. Solar altitude is a measure of the vertical angle of the sun's position relative to the horizon. Solar azimuth is a measure of the horizontal angle of the sun's position relative to north. (Boyd and Kasper, 2003.)

Table 3. Factors that influence stream shade.

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

Bold indicates influenced by human activities.

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table 3 (Ecology, 2003a; Chen, 1996; Chen et al., 1998; Boyd, 1996; Boyd and Park, 1998).

Riparian buffers and effective shade

Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown, 1973; Steinblums et al., 1984). The shading effectiveness of riparian vegetation is correlated to riparian area width (Figure 8).

The shade as represented by ACD for a given riparian buffer width varies temporally and spatially because of differences among site potential vegetation, forest development stages (e.g., height and density), and stream width. For example, a 50-foot-wide riparian area with fully developed trees could provide from 45 to 72% of the potential shade in the two studies shown in Figure 8.

The Brazier and Brown (1973) shade data show a stronger relationship between ACD and buffer strip width than the Steinblums et al. (1984) data. The r^2 correlation for ACD and buffer width was 0.87 and 0.61 in Brazier and Brown (1973) and Steinblums et al. (1984), respectively. This difference supports the use of the Brazier and Brown curve as a base for measuring shade effectiveness under various riparian buffer proposals. These results reflect the natural variation among old-growth sites studied, and show a possible range of potential shade.

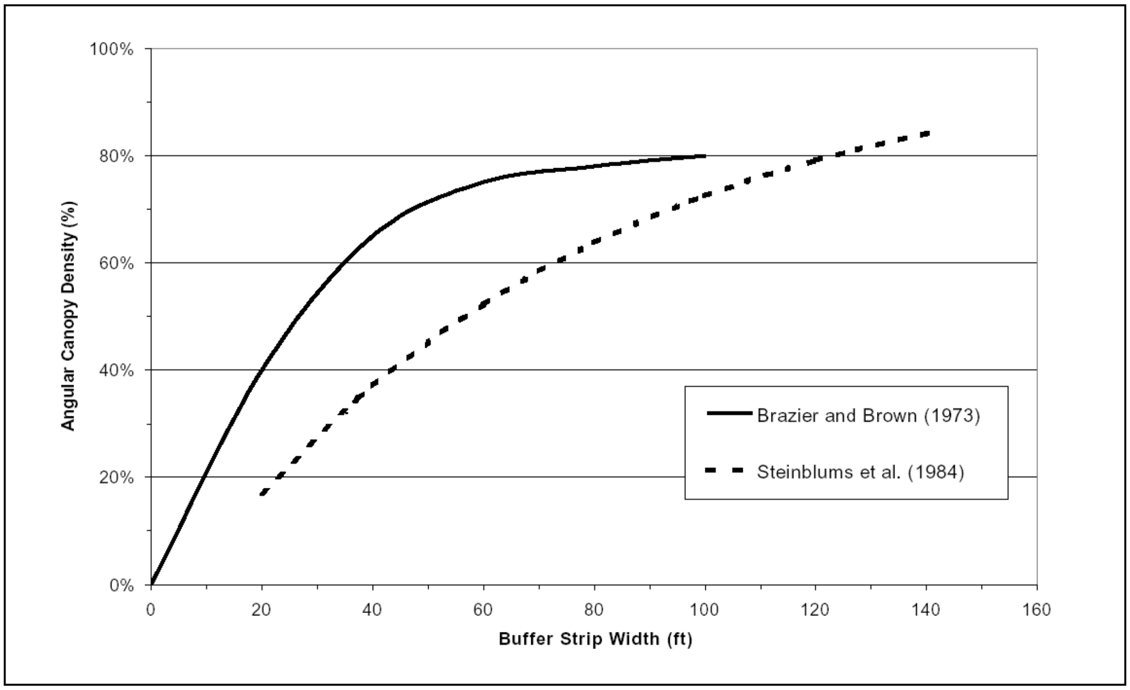

Figure 8. Relationship between angular canopy density and riparian buffer width for small streams in old-growth riparian stands (Beschta et al., 1987; CH2M Hill, 2000).

Several stream shading studies report that most of the potential shade comes from the riparian area within about 75 feet (23 meters) of the channel (CH2M Hill, 2000; Castelle and Johnson, 2000):

- Beschta et al. (1987) report that a 98-foot-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-foot (24-m) buffer provides maximum shade to streams.
- Corbett and Lynch (1985) concluded that a 39-foot (12-m) buffer should adequately protect small streams from large temperature changes following logging.
- Broderson (1973) reported that a 49-foot-wide (15-m) buffer provides 85% of the maximum shade for small streams.
- Lynch et al. (1984) found that a 98-foot-wide (30-m) buffer maintains water temperatures within 2°F (1°C) of their former average temperature in small streams (channel width less than 3 m).

GEI (2002) reviewed the scientific literature related to the effectiveness of buffers for shade protection in agricultural areas in Washington. They concluded that buffer widths of 10 meters (33 feet) provide nearly 80% of the maximum potential shade in agricultural areas. Wenger (1999) concluded that a minimum continuous buffer width of 10-30 meters (33-98 feet) should be preserved or restored along each side of all streams on a municipal or county-wide scale to provide stream temperature control and maintain aquatic habitat. GEI (2002) considered the recommendations of Wenger (1999) to be relevant for agricultural areas in Washington.

Steinblums et al. (1984) concluded that shade could be delivered to forest streams from beyond 75 feet (22 meters) and potentially out to 140 feet (43 meters). In some site-specific cases, forest management practices between 75 and 140 feet (22 and 43 meters) of the channel have the potential to reduce shade delivery by up to 25% of maximum. However, any reduction in shade beyond 75 feet would probably be relatively low on the horizon, and the impact on stream heating would be relatively low because the potential solar radiation decreases significantly as solar elevation decreases.

Microclimate - surrounding thermal environment

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

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet

(45 meters) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams. This study was specific to channel widths less than 4 meters in the foothills of the western slope of the Cascade Mountains in western Washington with predominantly Douglas-fir and western hemlock vegetation.

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

- **Air temperature**. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (Cervus canadensis) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7ºC for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima. Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988).

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

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

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

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

Thermal role of channel morphology

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

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

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

- Building streambanks. Traps suspended sediments, encourages deposition of sediment in the flood plain, and reduces incoming sources of sediment.
- Maintaining stable streambanks. High rooting strength and high streambank and flood- plain roughness prevents streambank erosion.
- Reducing flow velocity (erosive kinetic energy). Supplies large woody debris to the active channel, provides a high pool-to-riffle ratio, and adds channel complexity that reduces shear stress exposure to streambank soil particles.

Surrogate measures

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

The upper Naches River Temperature TMDL incorporates measures other than “daily loads” to fulfill the requirements of Section 303(d). This TMDL allocates other appropriate measures, or “surrogate measures” as provided under EPA regulations [40 CFR 130.2(i)]. The “Report of the

Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program" (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

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

This technical assessment for the upper Naches River basin temperature TMDL uses riparian effective shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Other factors influencing heat flux and water temperature were also considered, including microclimate, channel geometry, groundwater recharge, and instream flow.

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Water Quality Standards and Beneficial Uses

Designated beneficial uses

The 2006 Water Quality Standards for Surface Waters of the State of Washington Chapter 173-201A WAC (Ecology, 2006) designate the following uses within the Naches River watershed: Char spawning and rearing; Core summer salmonid habitat; and Salmonid spawning, rearing, and migration. Table 4 lists the use designations by waterbody.

The key identifying characteristics for each applicable use are as follows (WAC 173-201A-200):

- **Char spawning and rearing:** This use protects spawning or early juvenile rearing by native char, or use by other species similarly dependent on such cold water. This use also protects summer foraging and migration of native char; and spawning, rearing, and migration by other salmonid species.
- **Core summer salmonid habitat:** This use protects summer season, defined as June 15 through September 15, salmonid spawning or emergence, or adult holding; summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other protected uses include spawning outside of the summer season, rearing, and migration by salmonids.
- **Salmonid spawning, rearing, and migration:** This use protects salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 – June 14). Other uses include rearing and migration by salmonids.

In some waters, special considerations are necessary to protect spawning and incubation of char and salmonid species. Supplemental spawning/incubation criteria have been established for specified time periods to protect these special uses. Figure 9 illustrates where the beneficial and supplemental spawning/incubation uses apply within the Naches River watershed.

Each beneficial use designation has associated water quality criteria. This TMDL addresses the temperature impairments in the basin. The following section describes the applicable temperature criteria for the designated uses within the basin.

Table 4. Use designations for waterbodies in the Naches River watershed (WRIA 38).

Waterbody	Aquatic Life Uses		
	Char spawning and rearing	Core summer salmonid habitat	Salmonid spawning, rearing, and migration
Upper Naches Subbasin			
American River and all tributaries	X		
Barton Creek and all tributaries	X		
Bumping Lake's unnamed tributaries at latitude 46.8850 longitude -121.2779	X		
Bumping River's unnamed tributaries at latitude 46.9317 longitude -121.2067 (outlet of Flat Iron Lake).	X		
Bumping River and tributaries downstream of the upper end of Bumping Lake (except where designated Char)		X	
Bumping River (and tributaries) upstream of Bumping Lake.	X		
Cedar Creek and all tributaries	X		
Crow Creek and all tributaries	X		
Deep Creek and all tributaries	X		
Goat Creek and all tributaries	X		
Granite Creek and all tributaries	X		
Little Naches River and Bear Creek: All waters (including tribs) above the junction	X		
Little Naches River, South Fork and all tributaries	X		
Naches River and tributaries from latitude 46.7640 longitude -120.8286 (just upstream of Cougar Canyon) to Snoqualmie National Forest boundary (river mile 35.7) (except where designated Char).		X	
Naches River from Snoqualmie National Forest boundary (river mile 35.7) to headwaters (except where designated Char).		X	
Pileup Creek and all tributaries	X		
Quartz Creek and all tributaries	X		
Rattlesnake Creek, North Fork, all waters above latitude 46.8107 longitude -121.0694 (from and including the unnamed tributary just above junction with mainstem).	X		
Rattlesnake Creek: All waters above the junction with North Fork Rattlesnake Creek	X		
Sand Creek and all tributaries	X		
Sunrise Creek (latitude 46.9042 longitude -121.2431) and all tributaries.	X		
Tieton River Subbasin			
Clear Creek and tributaries (including Clear Lake)	X		
Indian Creek and all tributaries	X		
Tieton River and tributaries (except where otherwise designated).		X	
Tieton River, North Fork (including tributaries) above the junction at Clear Lake	X		
Tieton River, South Fork, and all tributaries	X		
Lower Naches Subbasin			
Naches River and tributaries from latitude 46.7640 longitude -120.8286 (just upstream of Cougar Canyon) to mouth (confluence with Yakima River)			X

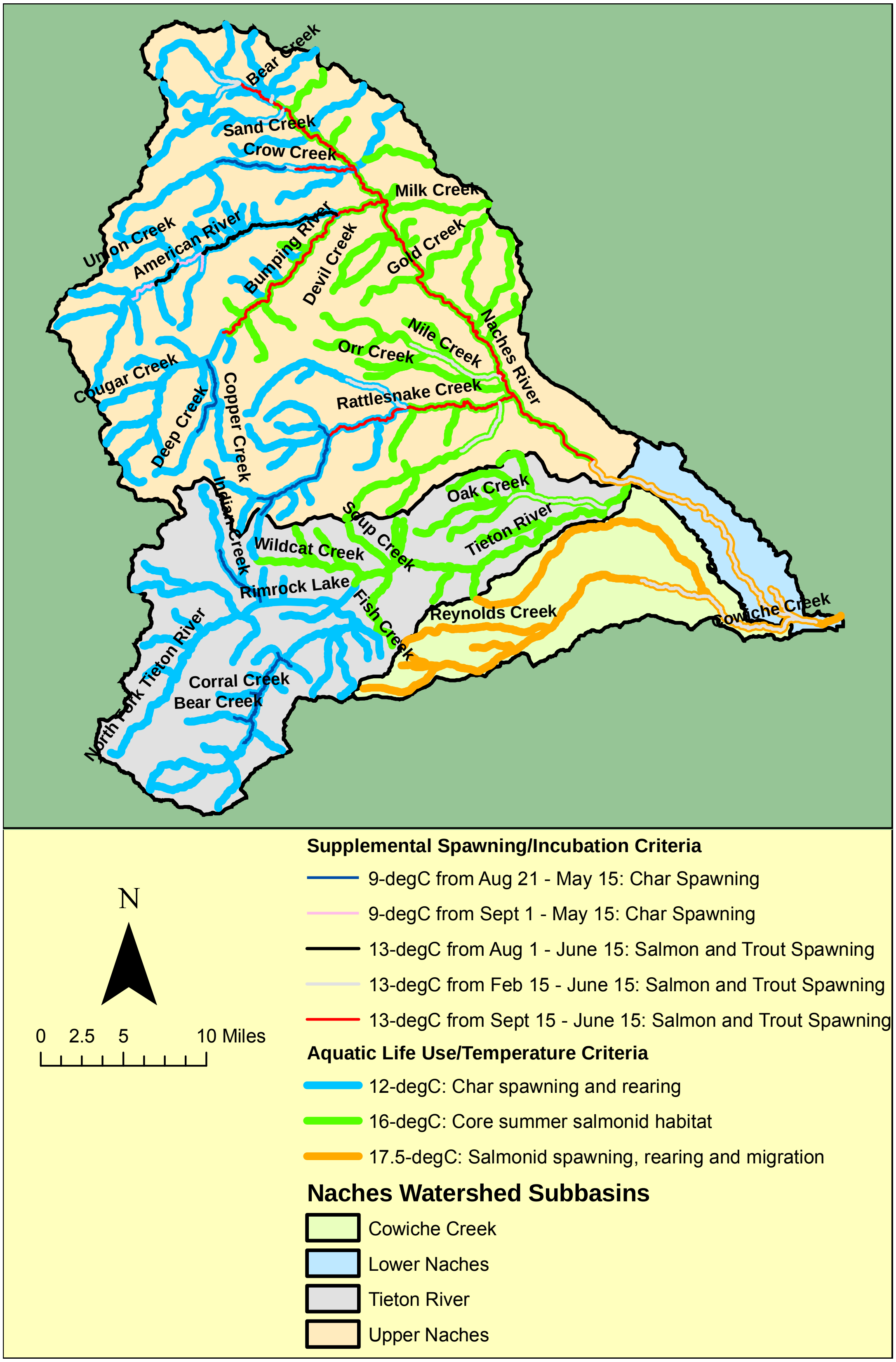

Figure 9. Applicable beneficial uses and temperature criteria for the Naches River watershed.

Temperature criteria

Fresh waters

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

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

In the Washington State water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2006 edition].

The beneficial uses designated within the Naches River basin include Char Spawning and Rearing, Core Summer Salmonid Habitat, and Salmonid Spawning, Rearing and Migration. The applicable temperature criteria for the designated uses are contained in 173-201A-200(c) as:

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

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

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

The state uses the criteria described above to ensure that where a waterbody 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 waterbody is naturally warmer than the above-described criteria, the state provides an additional allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition.

In addition to the maximum criteria noted above, compliance must also be assessed against criteria that limit the incremental amount of warming of otherwise cool waters due to human activities. When water is cooler than the criteria noted above, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted to: (1) incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/T+7 as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge), and (2) incremental temperature increases resulting from the combined effect of all nonpoint source activities in the waterbody must not at any time exceed 2.8°C (5.04°F).

Special consideration is also required to protect spawning and incubation of salmonid species. Where Ecology determines the temperature criteria established for a waterbody would likely not result in protective spawning and incubation temperatures, the following criteria apply: (1) Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and (2) Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Figure 9 illustrates the applicable beneficial uses, supplemental spawning/incubation criteria, and associated temperature criteria for all waterbodies within the Naches River watershed. In cases where the supplemental spawning criteria are more or less stringent than the designated beneficial use temperature criteria, the more stringent temperature criteria should be applied.

Global warming

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

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global warming (Hamlet and Lettenmaier, 1999).

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

These efforts may not 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. As global warming progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

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

Watershed Description

The study area consists of the entire Naches River Watershed. The watershed is divided into four distinct subbasins:

- Upper Naches River, which consists of the mainstem Naches River from the confluence with the Tieton River (river mile 17.6) to the USFS boundary (RM 38.8) and all major tributaries along this reach.
- Lower Naches River, which includes the mainstem Naches River from RM 17.6 to the confluence with the Yakima (RM 0), and all of the tributaries along this reach.
- Cowiche Creek and all the tributaries along the creek.
- Tieton River and all of its tributaries (Figure 9).

This TMDL developed load and wasteload allocations for the upper Naches River and Cowiche Creek subbasins. Ecology developed a temperature TMDL technical report for the Wenatchee National Forest that established load allocations for shade on USFS designated lands in WRIA 38 (Whiley and Cleland, 2003). The load allocations developed for USFS lands are incorporated into this report (Figure 1). In the near future, Ecology will develop separate water quality improvement projects to address the remaining temperature impairments in the Tieton and lower Naches River subbasins.

The Naches River watershed (WRIA 38) is part of the Yakima River drainage basin. The Naches River flows east from the Cascades to the city of Yakima where it converges with the Yakima River. The Naches River has four major tributaries: Bumping, American, Tieton, and Little Naches Rivers. There are two reservoirs located within the basin: Rimrock Lake (approximately 198,000 acre-feet) is located on the Tieton River, and Bumping Lake (approximately 33,700 acre-feet) is located on the Bumping River.

The climate of the basin ranges from cool and moist in the mountains to warm and dry in the valleys. Most of the precipitation falls during November to January. Annual precipitation in the mountains ranges from 80 to 140 inches at the cascade crest to less than 10 inches in the eastern part of the basin. Average summertime temperatures range from 55°F in the mountains to 82°F in the valleys. These conditions are formed by predominately westerly winds coming over the Cascade crest and the rain shadow effect in the valleys below.

The Naches River basin lies mainly in the Cascade Mountain province with only a small portion near the mouth falling in the Columbia Plateau. The Cascade Mountains consist of continental formations of Eocene-age sandstone, shale, and some coal layers, and pre-Miocene volcanic, intrusive, and metamorphic formations. Tertiary and quaternary andesite and dacitic lavas, tuff, and mudflows form a broad north-south arch (Tri-County, 2000). The Columbia Plateau is a series of basalt flows that cover older rock of the Cascade Mountains. Much of the fertile soils in the basin come from glacier and river transported soils.

The vegetation of the basin is a complex blend of forest, shrub steppe, and grasslands. The forests are located in the mountainous areas where precipitation is greater, and along the riparian edges of streams and rivers. Ponderosa pine, Douglas fir, and Grand and Noble fir form the majority of complex heterogeneous forests at the higher elevations (Haring, 2001). White oak, cottonwood, birch, and alder are found along the riparian zones in the valleys (Haring, 2001). Most of the land in the lower reaches is populated with fragile shrub and grassland that is highly susceptible to erosion if disturbed.

Spring chinook salmon (*Oncorhynchus tshawytscha*), rainbow/steelhead trout (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*) are the salmonid species present in the Naches River basin. The lower reaches of the basin are mainly used by these species for migration, rearing, and spawning habitat. Pacific lamprey, kokanee salmon, cutthroat trout, and mountain whitefish have also been documented within the basin (YSFWPB, 2004).

Land ownership in WRIA 38 is predominantly public. The USFS owns and manages the majority of land in the basin. The Washington State Department of Natural Resources and Washington State Department of Fish and Wildlife own and manage the next largest proportion of public lands. The private lands of the upper watershed consist of small recreational cabins and small resorts. The valleys of the mainstem Naches River and Cowiche Creek are predominantly irrigated agricultural croplands. The major crops raised in the basin are apples, pears, and cherries. There are four municipalities located within the lower Naches Watershed: Naches, Tieton, Cowiche, and Yakima.

The U.S. Bureau of Reclamation manages the Yakima reservoirs system, which includes the reservoirs located within the Naches Watershed, using a management policy termed “flip-flop.” In practice, flip-flop, which was conceived and initiated in 1981, consists of releasing virtually all water needed by the Wapato Irrigation Project and the Sunnyside Valley Irrigation District from the upper Yakima reservoirs until September. During this time, releases from Rimrock and Bumping Reservoirs are minimized. In early September, the release pattern reverses and the majority of the flow is provided from Rimrock and Bumping Reservoirs and the upper Yakima releases are curtailed (YSFWPB, 2004).

The purpose of the flip-flop operation is to encourage chinook, returning to the upper Yakima in the fall, to spawn at lower river stages. This ensures that the flows required to keep the redds watered and protected during the incubation period (November through March) are minimized; it is also consistent with the “normative” flow concept for the upper Yakima arm of the basin (Bureau of Reclamation, 2004). Based on historical records, flip-flop actually occurred sooner than normal in 2004 with release of storage flows from the Naches Reservoir system increasing in late August to early September.

Point sources in the basin include two municipal wastewater treatment plants located on the Naches River and Cowiche Creek. There are 21 fruit packing facilities and one fish hatchery within the watershed. Table 5 summarizes the point sources, type of applicable National Pollutant Discharge and Elimination System (NPDES) permit, and any temperature water quality criteria exceedances at the facilities.

Table 5. Point sources located within the Naches River basin.

Facility	NPDES Permit Number	Type of Discharge	Exceedances of Temperature Water Quality Criteria
Individual Permits			
Naches Sewage Treatment Plant	WA0022586C	Municipal wastewater	Exceeded between May - Sept 2004
Cowiche Sewage Treatment Plant	WA0052396A	Municipal wastewater	No exceedances between May - Oct 2004
General Permits			
Fruit Packers	general; 21 facilities	Surface water discharge from operations	6 facilities – exceeded at least once between May - Oct 2004
Fish Hatchery	general; 1 facility	Surface water discharge from flow through ponds	No temperature data reported
Stormwater/ Construction	general; 1 facility	Construction site stormwater	No temperature data reported

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Goals and Objectives

Project goals

1. Characterize summer (June-October) stream temperature of the Tieton River, Naches River, Rattlesnake Creek, and Cowiche Creek.

2. Develop a predictive computer temperature model for the upper mainstem Naches River from the Wenatchee National Forest Boundary to the confluence with the Tieton River.

3. Develop shade curves for Cowiche Creek and selected Naches River tributaries not located on USFS lands.

4. Establish a TMDL for temperature in the upper Naches River and Cowiche Creek subbasins.

Study objectives

For goal 1 above:

- Compile existing data, including:
  - Data collected by USFS, Washington Department of Fish and Wildlife (WDFW), U.S. Bureau of Reclamation (USBR), United States Geological Survey (USGS), and other potential data sources found during the study.
  - Qualitative historical data on stream temperature, stream channel characteristics, and riparian vegetation.
- Collect additional data in cooperation with USFS, WDFW, and other watershed groups.

For goals 2 and 3 above:

- Model the stream temperature regime at average and critical conditions.
- Evaluate the ability of various watershed *Best Management Practices* (BMPs) to reduce water temperature to meet water quality standards.

For goal 4 above:

- Develop the loading capacity for thermal load to the stream (usually expressed as incoming solar radiation in units of W/m^2).
- For ease of implementation, report load allocations in terms of surrogates for solar radiation such as shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, channel width-to-depth ratio, or miles of active eroding streambanks.

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Collection of Field Data

Data collection, compilation, and assessment were governed by the data set requirements of the computer temperature model (Table 6). The data were assembled from local third-party studies and Ecology field surveys. Local third-party studies include investigations by USFS, WDFW, USBR, USGS, and other potential data sources.

Five types of Ecology field surveys were conducted: (1) continuous flow monitoring at selected gaging stations, (2) continuous monitoring of water and air temperature and relative humidity, (3) riparian surveys of the streams and rivers, (4) groundwater monitoring, and (5) remote sensing of surface temperatures using thermal infrared (TIR) technology.

Streamflow monitoring

Three on-site, continuous-flow monitoring stations were established by Ecology's Environmental Assessment Program's in the study area for the sampling season, June through October 2004 (Figure 10). The standard protocols for the on-site, continuous data loggers followed those established by the Stream Hydrology Unit (Sullivan, 2007).

There are two USGS continuous-flow monitoring stations located on the mainstem Naches River and one located on the American River. The USBR maintains ten stations throughout the basin to monitor their flow management operations. USFS operates one station on the Little Naches River and another on Oak Creek.

All continuous flow monitoring stations located within the Naches River Basin are shown on Figure 10.

Ecology, in cooperation with USGS, performed a seepage run on the Naches River on July 20-21, 2004. Instantaneous flow measurements were taken at 35 sites along the Tieton, Naches, and tributary mouths (Appendix E). The Naches seepage run extended from the confluence of the Little Naches and American Rivers in the upper watershed (RM 43) to the mouth of the Naches River (RM 0.5). The Tieton seepage run extended from below Tieton Canal Headworks (RM 14) to the confluence of the Tieton River with the Naches River (RM 0.4).

Duplicate or replicate flows were measured at 15 sites to evaluate precision. The purpose of the seepage run was to develop a mass balance on all the measurable inflows and outflows as close to the same time as possible. In this way, differences in flow between consecutive gaging sites not attributable to surface inflows or outflows could be identified, and groundwater influences could be investigated in those areas.

Table 6. Model data requirements and collection source.

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

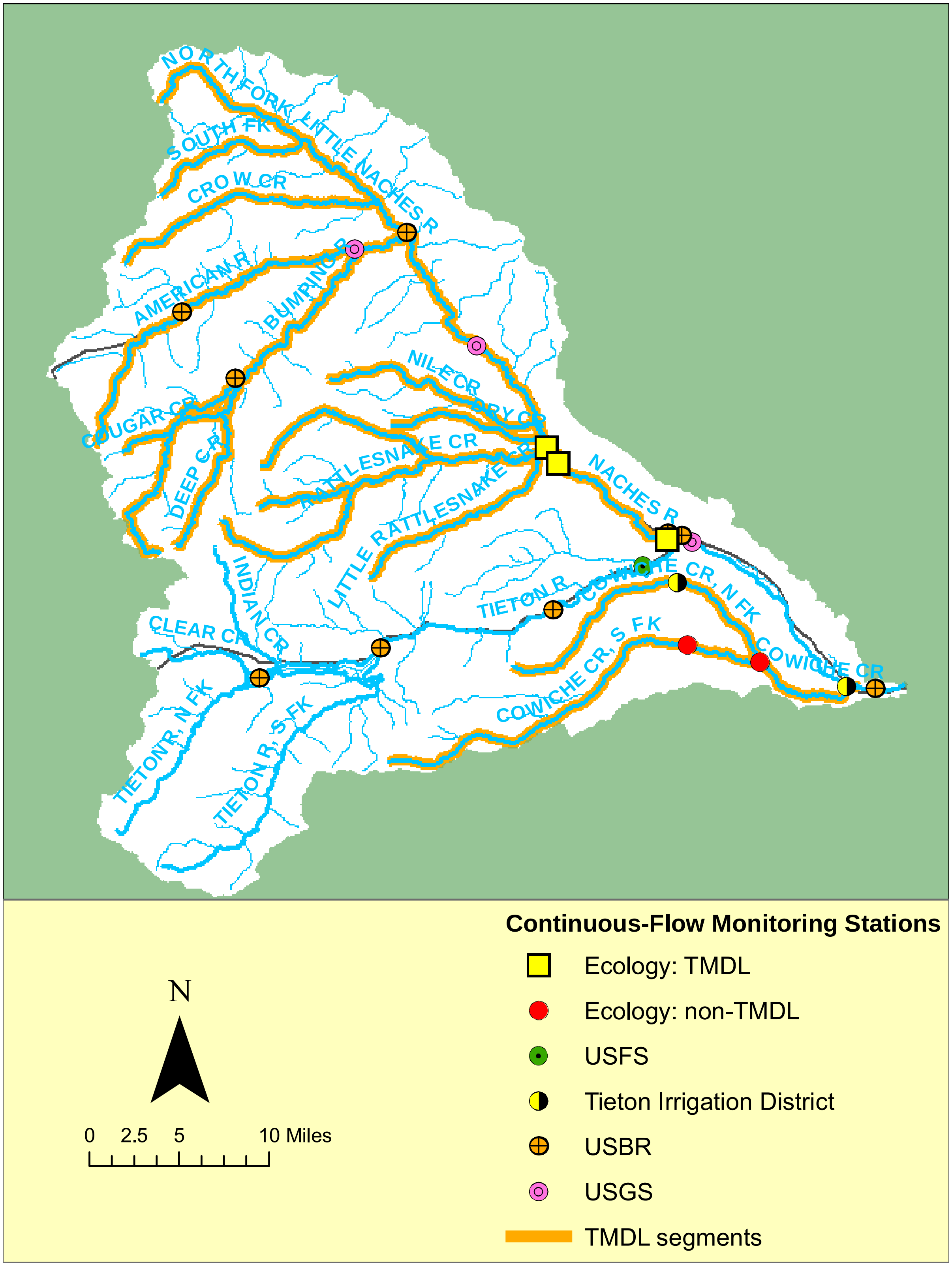

Figure 10. Continuous-flow monitoring stations for the Naches River Temperature TMDL.

Temperature sites

Water temperature sites were established at 35 locations throughout the study area (Figure 11). Air temperature was monitored at 16 of these sites, and relative humidity was monitored at 3 of these sites (Figure 11 and Appendix E). Water and air temperature was measured with Onset StowAway Tidbits. Relative humidity was measured with an Onset H8 Pro RH/temperature data logger.

The temperature data loggers were installed in a location in the stream or riparian forest, which was shaded from direct sunlight. They were placed in an area representative of the surrounding environment. The water temperature logger was installed at approximately one-half of the water depth and as close to the center of the thalweg as possible. The installation site was located where there was obvious water mixing and at a depth that would not become exposed if the water level dropped and would not be affected by groundwater inflow or stratification. The air temperature data loggers were installed adjacent to the water temperature probe about one to three meters into the riparian zone from the edge of the bankfull channel and about one meter off the ground.

Climate stations

Hourly air temperature, humidity, wind speed, and either solar radiation or cloud cover were measured at four weather stations located throughout the Naches River basin. In addition to these stations, Ecology installed 15 data loggers to continuously measure near-stream air temperature and three data loggers to monitor near-stream relative humidity. Figure 12 illustrates the locations of all climate stations used for this study.

Riparian stream and habitat surveys

An adapted form of the Timber-Fish-Wildlife Stream Temperature Survey methodology was followed for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys were conducted July to October 2004 at the temperature sites established by Ecology (Appendix E). Field measurements were taken longitudinally (approximately every ½ mile) along the Naches River. Sites were dispersed evenly from the USFS boundary to the mouth of the Naches River. The Wapatox Reach was not surveyed because of instream safety hazards from water diversions. Field surveys were completed on 1000-foot reaches above all the temperature monitoring locations on the Tieton River during the low-flow period.

Data collection consisted of bankfull width and depth, wetted width and depth, effective shade (using hemispherical photography and a Solar Pathfinder), and channel substrate composition. Riparian Management Zone (RMZ) characteristics, such as active channel width, cover, size, density, and bank erosion, were recorded during the surveys. Hemispherical photography was used to measure effective shade and canopy density at all water temperature stations to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos. Channel data collected during these surveys are reported in Appendix C.

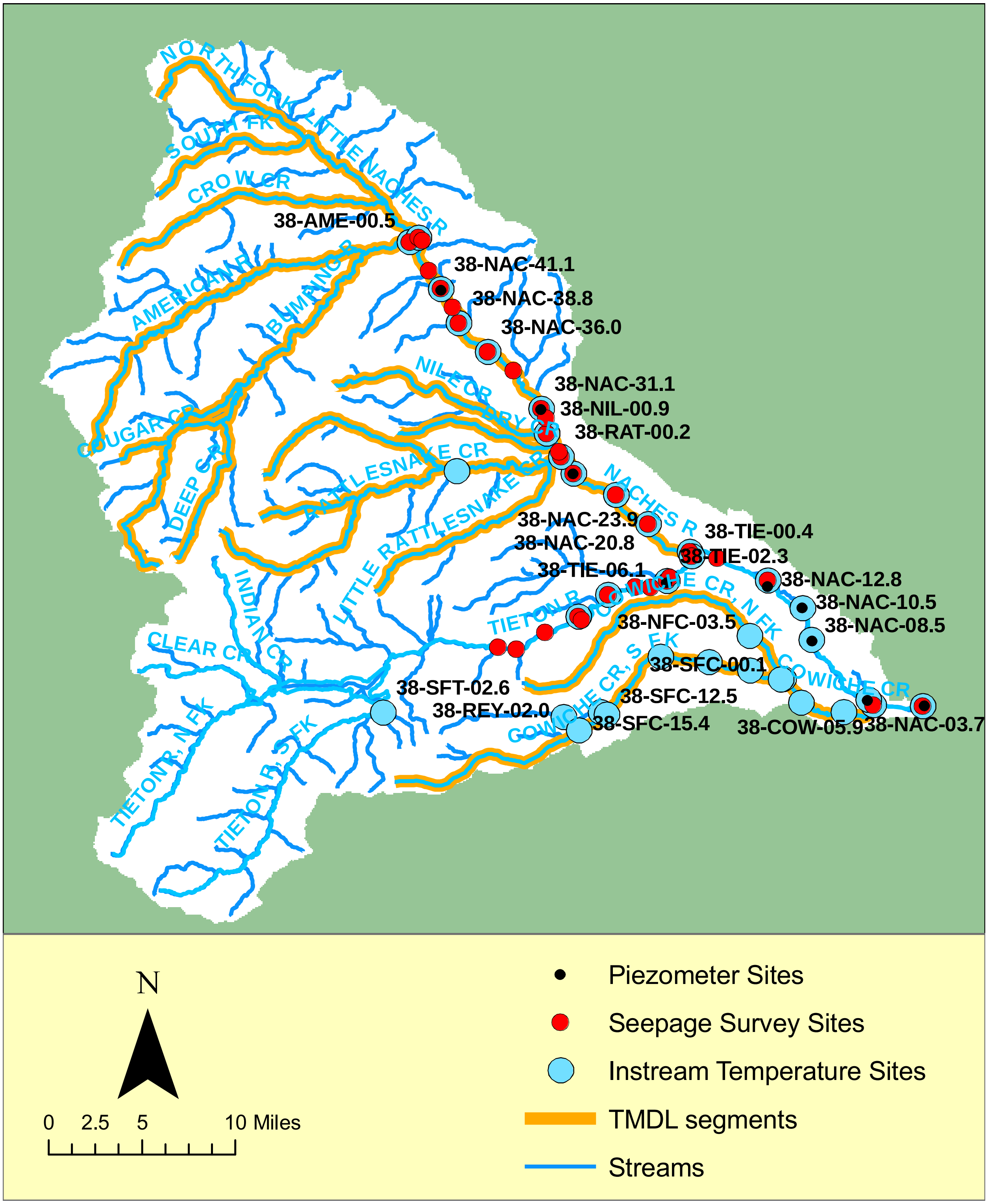

Figure 11. Monitoring stations for the Naches River Temperature TMDL.

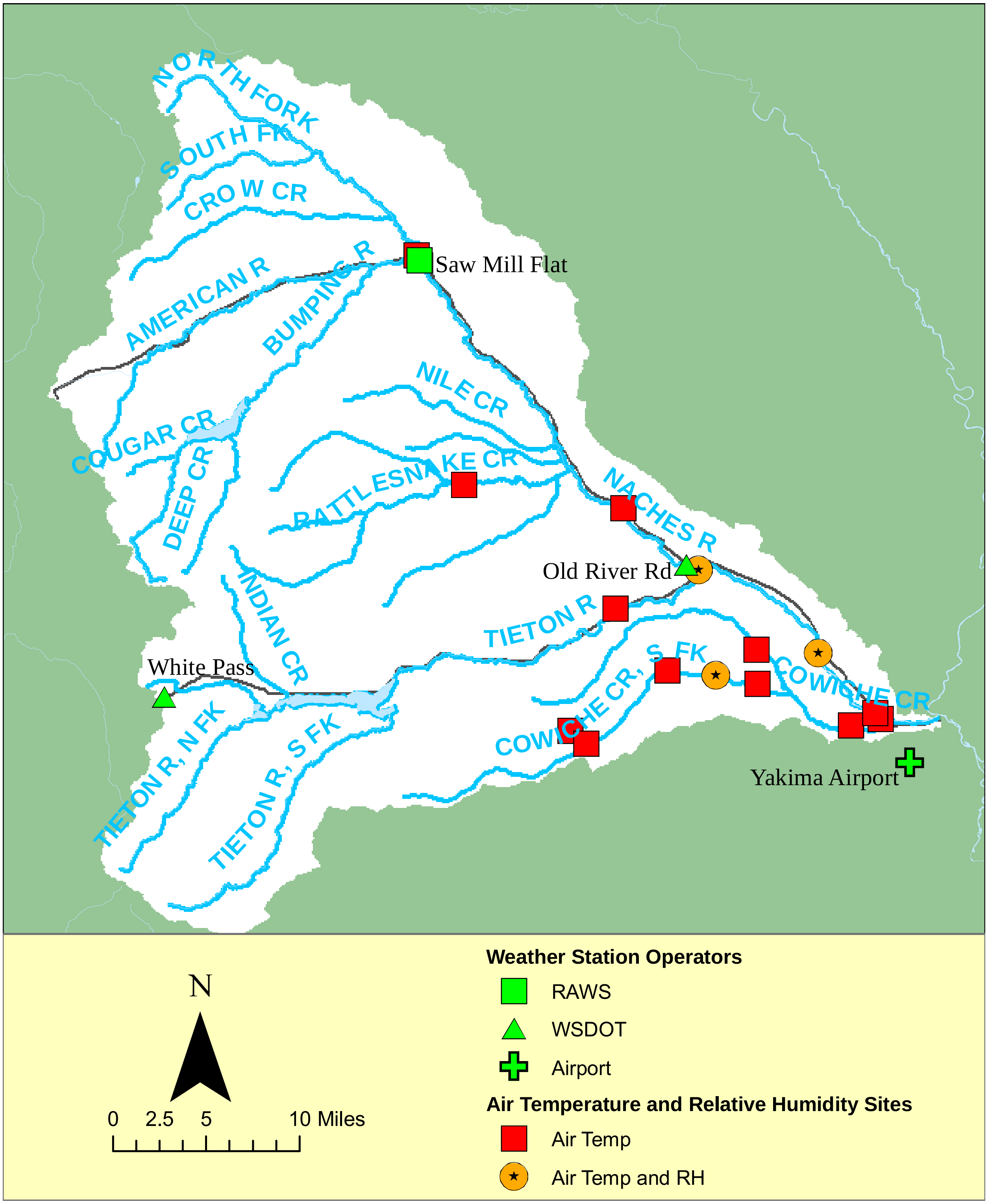

Figure 12. Climate stations located within the Naches River basin.

Groundwater survey

Mini-instream piezometers were installed near nine temperature stations on the Tieton River and Naches River to define the vertical hydraulic gradient between area streams and the water-table aquifer (Figure 11). The piezometers consist of a seven-foot length of one-half inch diameter galvanized pipe, one end of which is crimped and slotted. The piezometers were hand driven into the streambed to a depth of approximately five feet. The piezometers were used to characterize groundwater influences within the watershed.

Water levels in the piezometers were measured twice, between July and September 2004, using a calibrated electric well probe or steel tape in accordance with standard USGS methodology (Stallman, 1983). The head difference between the internal piezometer water level and the external creek stage provides an indication of the vertical hydraulic gradient and the direction of flow between the creek and groundwater. When the piezometer head exceeds the creek stage, groundwater discharge into the creek can be inferred. Similarly, when creek stage exceeds the head in the piezometer, loss of water from the creek to groundwater storage can be inferred.

Surface and piezometer water temperatures were measured during each of the piezometer surveys. Stream reaches with significant groundwater input (especially during low-flow periods) should exhibit stream water temperature similar to the groundwater temperature. Measurements were made with properly maintained and calibrated field thermometers in accordance with standard USGS methodology.

Hyporheic tidbits, placed at a depth of one foot and three feet below the river bottom, were installed at seven sites to measure thermal transfer of heat through the surface and hyporheic zones. The hyporheic tidbits logged temperatures every one-half hour to measure changes in hyporheic temperatures. In addition, temperature was measured during the habitat surveys to assess the presence, or absence, of groundwater discharge longitudinally along the Naches and Tieton Rivers.

Thermal infrared surveys

Approximately 45 miles of the Naches River (Figure 13) was flown on August 14, 2004 between 13:55 and 15:15 to provide simultaneous TIR and visible video coverage. Images and TIR data are geographically linked through a Global Positioning System (GPS) and geo-referenced through a Geographic Information System (ArcView GIS). Each thermal image covered a ground width of approximately 270 meters with a spatial resolution of approximately 0.84 meters per pixel. The thermal imagery was calibrated to measured water temperatures with an accuracy of approximately +/- 0.4°C (Watershed Sciences, Inc., 2004).

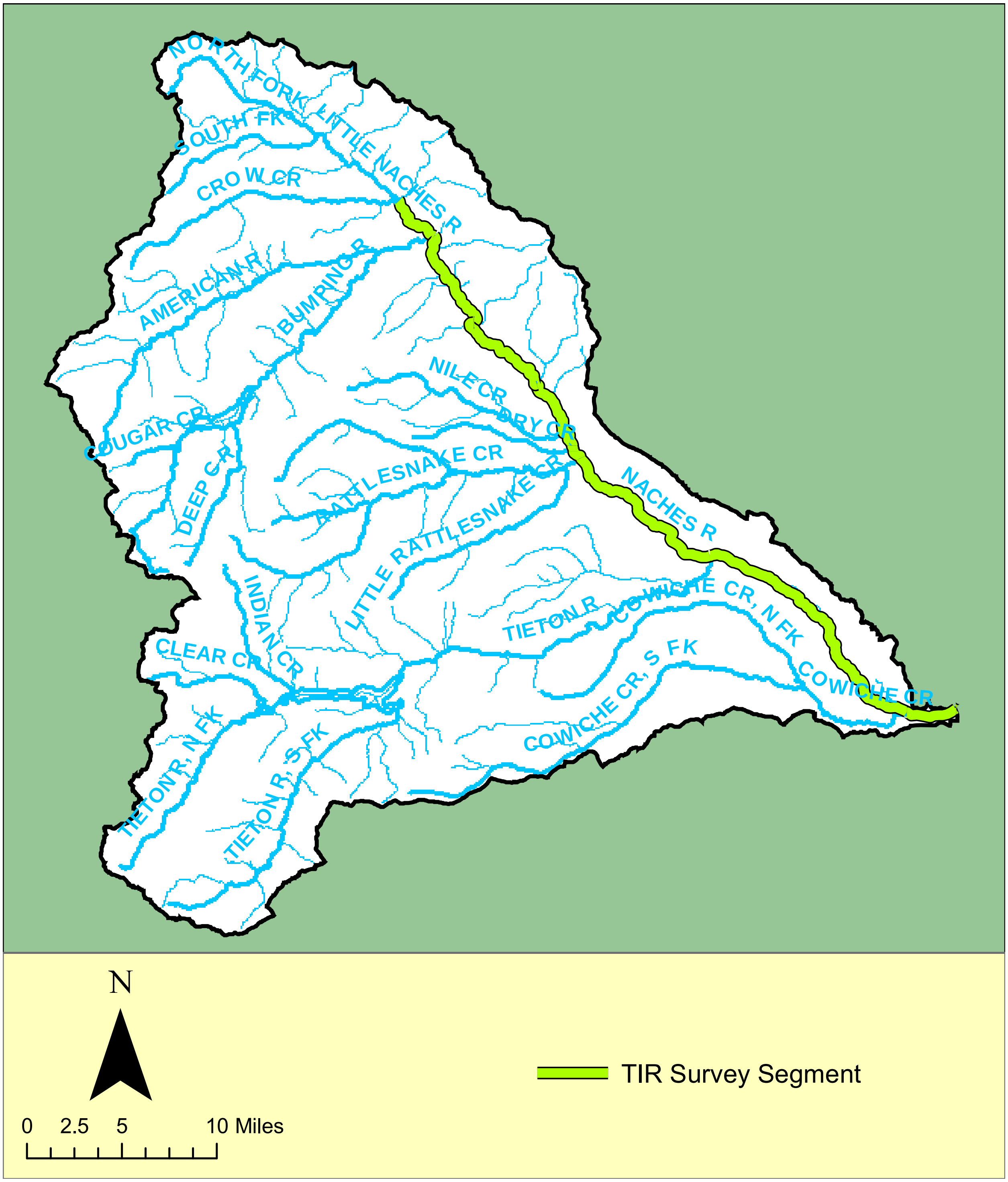

Figure 13. TIR Survey for the Naches River Temperature TMDL.

Results and Discussion

Current conditions

Continuous temperature data

Temperature data collected by continuous instream thermistors throughout the Naches River watershed during the 2004 field season are reported in Table 7. Data from 2004 show that water temperatures in excess of the 2006 water quality standards are common throughout the watershed between June and October (Appendix B). Seven-day average daily maximum water temperatures of 23°C were observed at stations between RM 20.8 and 0.5 on the mainstem Naches River. Generally, the tributary stations had 7-DADMax temperatures which were slightly higher than those recorded on the mainstem Naches River.

Maximum temperatures above 23°C were observed throughout the watershed. The highest observed temperature (27.69°C) was recorded on Cowiche Creek at RM 2.7 on July 25, 2004. The hottest 7-day period of 2004 occurred from (1) August 11 to 17 for stations located on the mainstem Naches above the confluence with the Tieton, and (2) July 28 to August 3 for stations located on the tributaries and the mainstem Naches River below the confluence with the Tieton.

Aerial temperature data (TIR survey)

The August 14, 2004 TIR flight occurred after the start of flip-flop flow in the basin, so streamflow was higher than previous weeks. The survey also occurred during the second warmest 7-day average maximum water temperature period of the summer. The day of the survey, the weather conditions were fair in the morning with blue skies, but deteriorated throughout the day to cloudy skies with rain showers at the conclusion of the survey. A high temperature of 90.2°F was recorded at 3:00 PM; this was slightly cooler than air temperatures measured on previous days.

The median water temperatures recorded longitudinally along the Naches River during the TIR survey are plotted linearly in Figure 14. The points on the graph show the temperatures and locations (river mile) of tributaries, springs, and other inflows along the mainstem Naches (Watershed Sciences, Inc., 2004). Figure 15 can be used to show which areas of the watershed are cooler, which are hotter, and how some of these waters mix. Both figures clearly illustrate the cooling impact that the Tieton River has on the Naches during flip-flop and where in the basin springs have the greatest influence on the mainstem temperatures. All of the TIR images and a video can be viewed at:
www.ecy.wa.gov/apps/watersheds/temperature/tir/Naches/index.html.

Table 7. Temperature data collected during 2004 for the Naches River Temperature TMDL.

Station ID	Station Description	Temperature (°C)		
		7-DADMax	Daily Maximum	Water Quality Standard
Upper Naches River Mainstem Stations (above confluence with Tieton River)				
38-NAC-41.1	Naches at Boulder Cave Rd	20.61	21.19	16
38-NAC-38.8	Naches at Lower Old River Rd	20.93	21.45	16
38-NAC-36.0	Naches at FS Chinook (Cottonwood) Camp	21.51	22.03	16
38-NAC-31.1	Naches at Upper Nile Rd	21.24	21.88	16
38-NAC-26.8	Naches at Lower Nile Rd	21.89	22.57	16
38-NAC-23.9	Naches 2.5 miles below Nile Rd	22.22	22.96	16
38-NAC-20.8	Naches above Horseshoe Bend	23.09	23.65	16
38-NAC-17.6	Naches at Y (SHU Station)	22.94	23.70	17.5
Upper Naches River Tributary Stations (above confluence with Tieton River)				
38-LIT-00.1	Little Naches at Hwy 410 bridge	20.58	21.21	16
38-AME-00.5	American River at Halfway Flat Campground	20.44	21.49	16
38-NIL-00.9	Nile Creek at Nile Rd	23.60	24.81	16
38-RAT-07.3	Rattlesnake at FS 119 Rd	18.53	19.13	16
38-RAT-00.2	Rattlesnake near mouth (SHU)	22.20	22.90	16
Lower Naches River Mainstem Stations (below confluence with Tieton River)				
38-NAC-12.8	Naches at South Naches Road	20.59	21.13	17.5
38-NAC-10.5	Naches downstream of Naches at Public Fishing	20.83	21.68	17.5
38-NAC-08.5	Naches at Eschach Park	19.69	22.19	17.5
38-NAC-03.7	Naches at Powerhouse Rd	23.65	23.97	17.5
38-NAC-00.5	Naches at BOR Station near mouth	23.91	24.49	17.5
Lower Naches River Tributary Stations (below confluence with Tieton River)				
38-SFT-02.6	South Fork Tieton	18.10	18.61	12
38-TIE-09.0	Tieton near Windy Pt (upstream Hwy 12 bridge)	16.92	17.61	16
38-TIE-06.1	Tieton at 2nd turnout above Mile Marker 180	19.40	19.79	16
38-TIE-02.3	Tieton above Oak Creek	18.71	19.34	16
38-TIE-00.4	Tieton near mouth	20.65	21.36	16
38-REY-02.0	Upper Reynolds past Van Wyke Prop	17.87	18.72	17.5
38-REY-00.2	Reynolds near mouth	19.45	20.05	17.5
38-SFC-15.4	SF Cowiche where road ends	20.09	20.69	17.5
38-SFC-12.5	SF Cowiche at Cowiche Ranger's bridge	20.43	21.28	17.5
38-SFC-07.6	SF Cowiche at 1st bridge on Cowiche Mill Rd	22.81	23.56	17.5
38-SFC-02.1	SF Cowiche at Pioneer Way	23.75	24.53	17.5
38-NFC-00.0	NF Cowiche near confluence with SFC	22.69	23.12	17.5
38-COW-05.9	Cowiche above Cowiche Canyon	22.96	23.76	17.5
38-COW-02.7	Cowiche below Cowiche Canyon	26.88	27.69	17.5
38-COW-00.5	Cowiche at West Powerhouse Rd	23.29	24.22	17.5

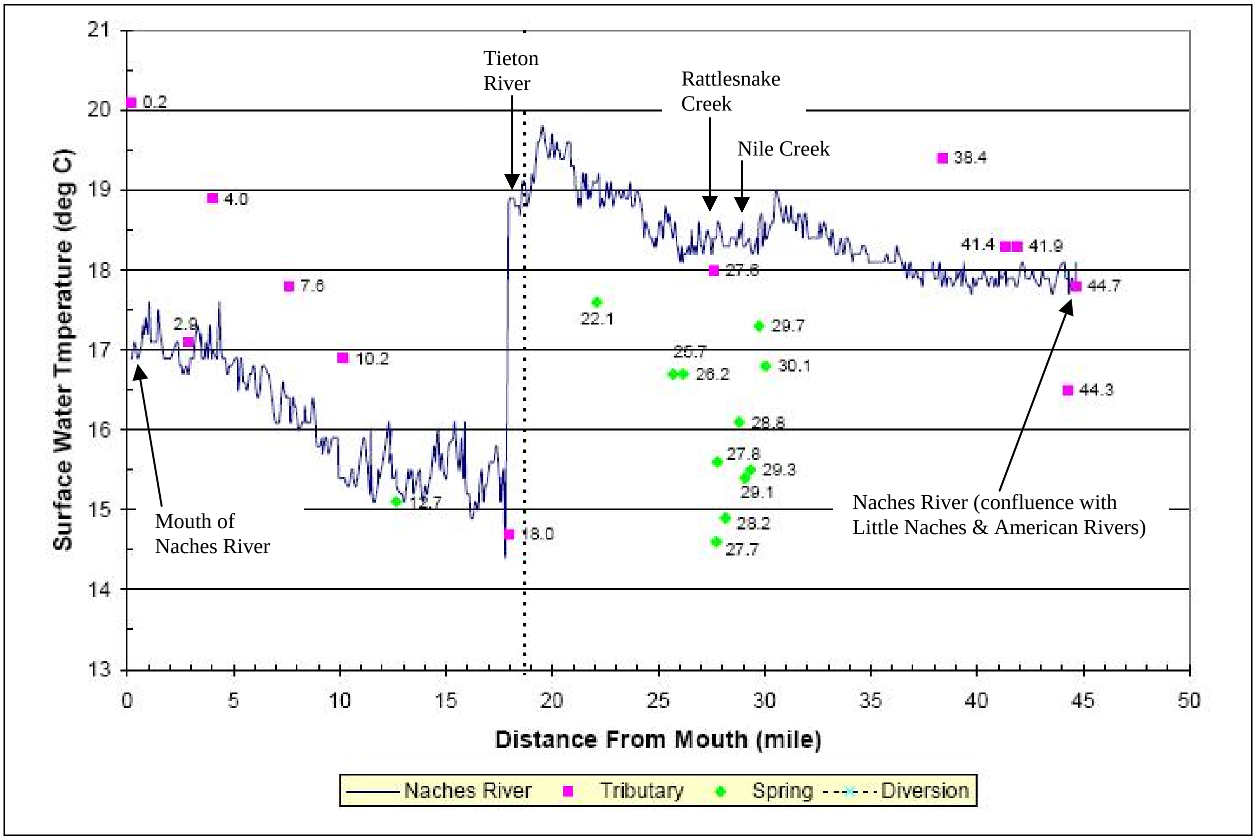

Figure 14. Median temperatures recorded on the mainstem Naches River during the 2004 TIR Survey (Watershed Sciences, Inc., 2004).

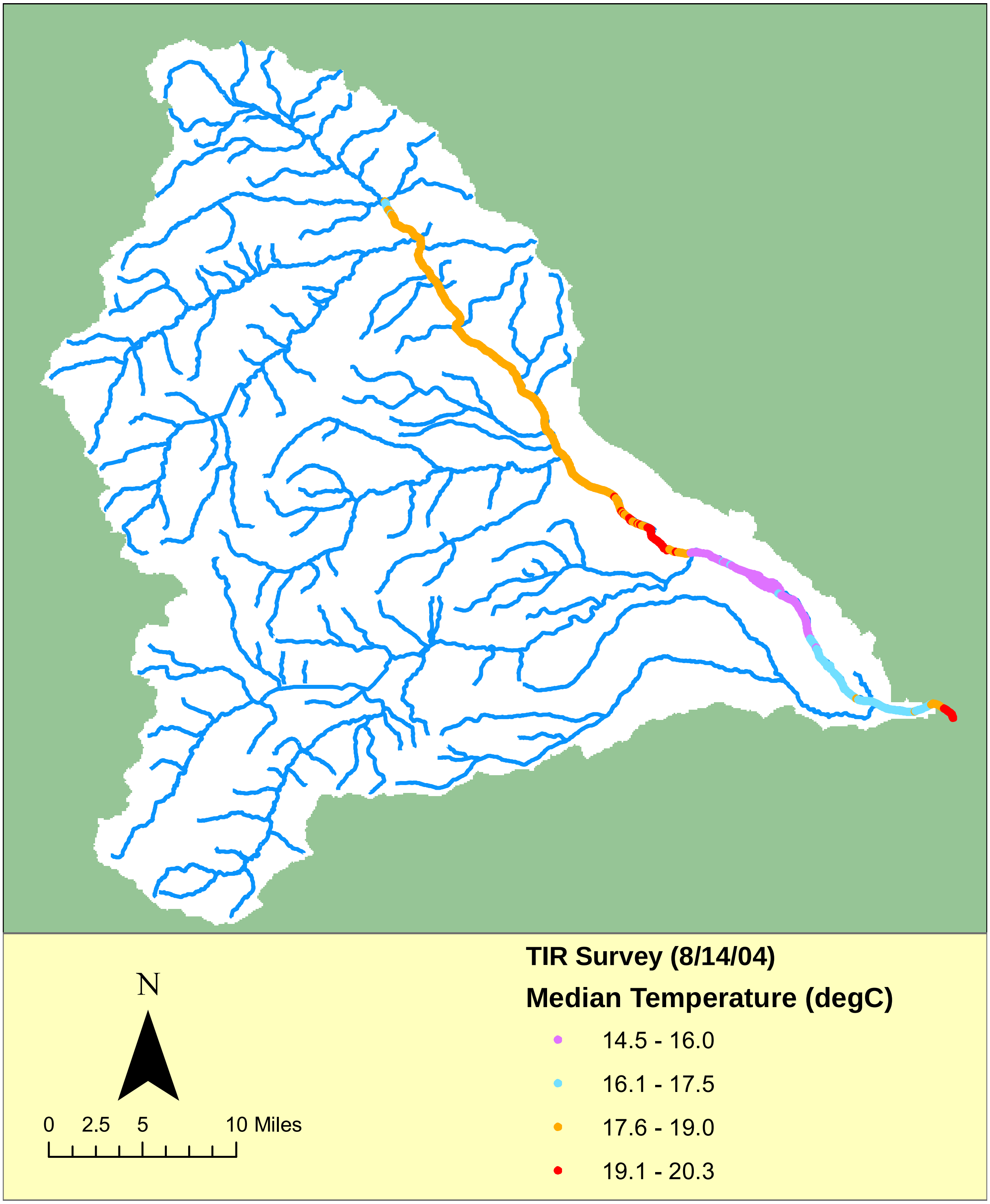

Figure 15. TIR Profile for the Naches River.

Streamflow data

Flow statistics for selected long-term USBR and USGS streamflow gages in the Naches River basin are reported in Table 8. Typically in a TMDL analysis, the lowest 7-day average flow with a 2-year recurrence interval (7Q2) is selected to represent an average condition year. The lowest 7-day average flow with a 10-year recurrence interval (7Q10) is selected to represent a reasonable worst-case condition for the July-August period. The 7Q10 streamflow is typically considered the critical condition for steady-state discharges in riverine systems (WAC 173-201A-200).

Table 8. Low-flow statistics for long-term flow gages in the Naches River basin.

Location	Gage ID	Owner	Period of record used	7-day, 10-yr low-flow for July-August (7Q10, cfs)	7-day, 2-yr low-flow for July-August (7Q2, cfs)
Naches River near mouth (RM 0.5)	NRYW	USBR	1982-2005	252.4	362.6
Naches River near Naches (RM 16.8)	NACW	USBR	1977-2005	122.3	191
Naches River below Tieton River (RM 16.8)	12494000	USGS	1909-1979	155.7	501.2
Naches River at Oak Flat (RM 19.4)	12489500	USGS	1905-1917	243.3	351
Naches River near Cliffdell (RM 36.0)	CLFW	USBR	1909-1914, 1977-2005	206.8	287.2
Tieton River at Tieton Canal Headworks (RM 14.2)	TIWC	USBR	1977-2005	92.1	173.7
Tieton River at Headworks (RM 14.2)	12492500	USGS	1908-1978	43.6	323.1
Tieton River at Tieton Dam (RM 20.9)	12491500	USGS	1909-1978	314	633.1
Naches Selah Canal	NSCW	USBR	1953-2005	113	126.1
Wapatox Power Canal	WOPW	USBR	1974-2005	132.9	263.9
South Naches Canal	SOUW	USBR	1977-2005	31	49.8

Groundwater data

Seepage run flow measurements, TIR survey results, vertical hydraulic gradient measurements, and information on geologic and fluvial characteristics of the area were used to estimate groundwater gains and losses along the Naches and Tieton Rivers. The Naches River was aggregated into six larger reaches based on geologic and fluvial characteristics.

Table 9 outlines the gaining and losing reaches on the Naches and Tieton Rivers. More information on the analysis is available in *Groundwater-Surface Water Interactions along the Naches and Tieton Rivers, Summer and Fall 2004* (Carey, 2007).

Table 9. Groundwater gains and losses along the Naches and Tieton Rivers.

River	Reach	Reach length (miles)	Percent gain/loss	Net seepage gain/loss (cfs/mile)
Naches	43.0-38.8	4.2	8.0	6.4
	31.1-26.8	4.3	7.0	6.2
	26.8-17.6	9.2	11.2	5.7
	17.6-12.8	4.8	-16.1	-12.4
	12.8-0.5	12.3	25.9	7.7
Tieton	6.1-4.0	2.1	-5.8	-7.7
	4.0-3.0	1	6.4	16.9
	2.3-1.5	0.6	-6.5	-22.6
	1.5-0.4	1.1	9.7	23.1

Hydraulic geometry

The channel width, depth, and velocity have an important influence on the sensitivity of water temperature to the flux of heat. At different discharges, the observed mean velocity, mean depth, and width of flowing water reflect the hydraulic characteristics of the channel cross-section. Graphs of these three parameters as functions of discharge at the cross-section constitute a part of what Leopold (1994) called the hydraulic geometry of stream channels. Width, depth, and velocity can be related to discharge (Q) by power functions:

$W=aQ^b$; $d=cQ^f$; $u=kQ^m$

where w is width, Q is discharge, d is mean depth, and u is mean velocity. The letters b, f, and m are exponents, and a, c, and k are coefficients.

Exponents and coefficients were determined for individual flow measurement sites by fitting power curves to data collected for instantaneous discharge measurements. The curves are used to estimate width and depth for flow regimes not specifically measured (e.g., 7Q2 or 7Q10). Tables 10 and 11 summarize these equations.

During modeling, coefficients for stream segments that were not located at a flow site were adjusted with results from the travel-time study.

Table 10. Summary of hydraulic geometry relationships with flow (Q) for all stations in the Naches River watershed, summer 2004.

Station	Station name	Width (m) = a Q (m^3/sec) ^ b		Velocity (m/sec) = c Q (m^3/sec) ^ d	
		Width "a"	Width "b"	Velocity "c"	Velocity "d"
38-NAC-17.6 (SHU)	Naches near confluence with Tieton "Y"	20.58	0.13	0.14	0.63
38-NAC-20.8	Naches above Horseshoe Bend	28.28	0.05	0.30	0.35
38-NAC-23.9	Naches 2.5 road miles down from Nile Rd	25.70	0.07	0.29	0.31
38-NAC-26.8 (SHU)	Naches at Lower Nile Road	23.22	0.24	0.19	0.47
38-NAC-31.1	Naches at Upper Nile Road	29.28	0.06	0.21	0.41
38-NAC-36.0	Naches at USFS Cottonwood Camp (USBR)	29.46	0.08	0.06	0.90
38-NAC-38.8	Naches at Lower Old River Road	12.16	0.47	0.16	0.68
38-NAC-41.1	Naches at Boulder Cave Road	27.87	0.05	0.21	0.57
38-TIE-00.4	Tieton near mouth	14.04	0.26	0.32	0.39
38-TIE-02.3	Tieton at Hwy 12 above Oak Creek	17.73	0.10	0.29	0.47
38-TIE-9.0	Tieton at Hwy 12 near Windy Point Campgrnd	15.81	0.22	0.22	0.63
38-RAT-00.2 (SHU)	Rattlesnake Creek near mouth	22.43	0.04	0.42	0.40
38-RAT-07.3	Rattlesnake Creek near FS Road 119	14.03	0.08	0.16	0.71
38-COW-02.7	Cowiche Creek below Cowiche Canyon	4.72	0.07	0.62	0.73
38-COW-05.9	Cowiche Creek above Cowiche Canyon	5.47	0.20	0.39	0.52

Table 11. Summary of average hydraulic geometry relationships with flow for the Naches River, Tieton River, Rattlesnake Creek, and Cowiche Creek, summer 2004.

Average of	Rivers/Reaches	Width (m) = a Q (m^3/sec) ^ b		Velocity (m/sec) = c Q (m^3/sec) ^ d	
		Width "a"	Width "b"	Velocity "c"	Velocity "d"
All Stations	Naches, Tieton, Rattlesnake, and Cowiche	19.39	0.14	0.27	0.55
All Naches Stations	Naches: RM 17.6-38.8	24.10	0.16	0.19	0.54
All Tieton Stations	Tieton: RM 0.4-2.3, and 0.9	15.86	0.19	0.28	0.49
All Rattlesnake Stations	Rattlesnake: RM 00.2-07.3	6.35	0.14	0.95	0.66
All Cowiche Stations	Cowiche: RM 00.5-05.9	9.69	0.07	0.40	0.46

Climate data

Air temperature and relative humidity data for the basin are available from four weather stations located within the Upper Naches River basin. These data were collected by Ecology in 2004 at several sites throughout the basin (Figure 12). Comparison of data collected at the Yakima Airport with data collected near-stream by Ecology and at RAWS and WSDOT stations show that all stations measure similar air temperature and relative humidity, except for the airport station. Near-stream weather stations established by RAWS and WSDOT were used exclusively for air temperature and relative humidity for the QUAL2Kw temperature model of the Naches River.

The Yakima Airport weather station was used to determine which were hot and cold years and to derive the typical (50% percentile) and the extreme (90% percentile) years for climate conditions. Then actual data from the RAWS/WSDOT stations was used for near-stream temperature and relative humidity.

The Yakima Airport weather station has 59 years of climate data available, 1948-2006. This long-term record was used to calculate the 90th and 50th percentile conditions on the highest 7-day average of daily maximum air temperatures. The corresponding median and 90th percentile air temperature conditions for the near-stream conditions along the mainstem Naches River were calculated from measurements taken at the Old River Road WSDOT station (near RM 17.6) and the Saw Mill Flats RAWS weather station (near RM 43). Table 12 outlines the air temperature statistics calculated for the Naches River temperature model.

Table 12. Air temperature statistics calculated for the QUAL2Kw temperature model.

Condition	Yakima Airport		NAC-41.1		NAC-3.7		Saw Mill Flats		Old River Road	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Calibration Period (hottest water temperatures in the basin): 7/28 to 8/3/2004	34.1	17.4	28.1	11.2	32.0	19.0	29.0	11.8	29.6	13.4
Verification Period (hottest water temperatures in the basin after flip flop occurs) and Extreme Climate Conditions (90th percentile): 8/11 to 8/17/2004	36.7	17.8	31.3	12.4	32.7	17.5	34.1	13.1	32.4	12.8
Average Climate Conditions (50th percentile): 8/4 to 8/10/2005	35.6	14.5	No data		No data		30.2	10.2	32.0	12.1

NAC = Ecology monitoring site on the Naches River.

In most watersheds, as elevation increases, air and dew-point temperatures decrease (Figure 16). Hourly air temperatures for the headwater of the model (RM 38.8) and the downstream end of the model (RM 17.6) were calculated from the air thermistors located at RM 41.1 and 3.7, respectively. Air temperatures for intermediate locations between the Naches River at RM 17.6 and the headwaters at RM 38.8 were calculated by using an interpolation with stream elevation. Relative humidity was interpolated with stream elevation using data measured at the Saw Mill Flats RAWS station and the relative humidity probe installed at RM 8.5.

The wind speeds measured at the RAWS, WSDOT, and Yakima Airport stations were averaged to calculate the near-stream wind speed for all locations in the model. Cloud cover/solar radiation data were only available at the Yakima Airport. Therefore, as an explicit margin of safety, cloud cover data collected at the airport were used for all model scenarios.

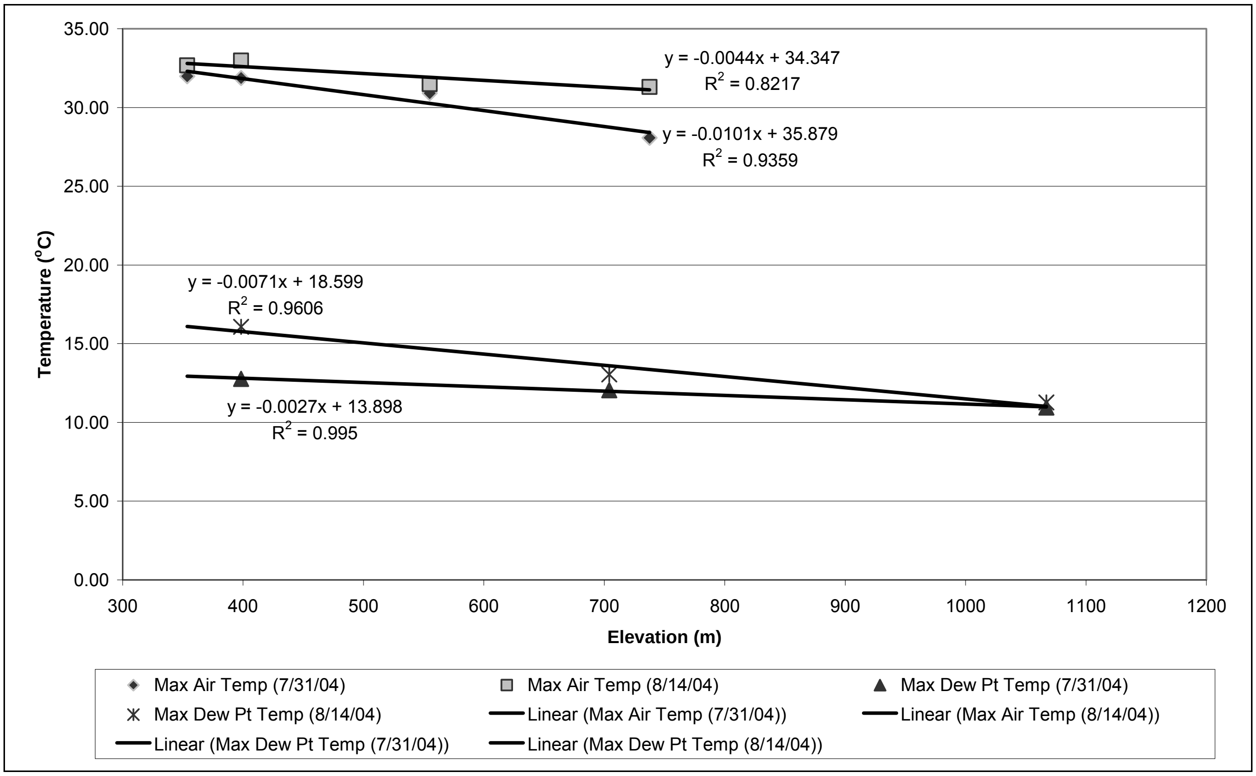

Figure 16. Maximum dew point and air temperature versus elevation trends in the Naches River basin.

Riparian vegetation and effective shade

Current near-stream vegetation

Near-stream vegetation cover, along with channel morphology and stream hydrology, represent the most important factors that influence stream temperature. To obtain a detailed description of the existing riparian conditions in the Naches River basin, a combination of GIS analysis and aerial photography interpretation was used.

The ArcView GIS dynamic segmentation method was used to produce 100 meter (approximately 328 ft) stream segments. In addition, a 50 ft (15.2 m), 100 ft (30.5 m), and 150 ft (45.7 m) buffer from each side of a creek was delineated as shown in Figure 17. Vegetative polygons made up of stream segment lengths and the buffers were mapped at 1:3000 scale. A vegetation type code that combines information about the average tree height, canopy density, and overhang was assigned to different vegetation types present along the Naches River (Table 13) using full-color digital orthophoto quadrangles (DOQs) 1:24000.

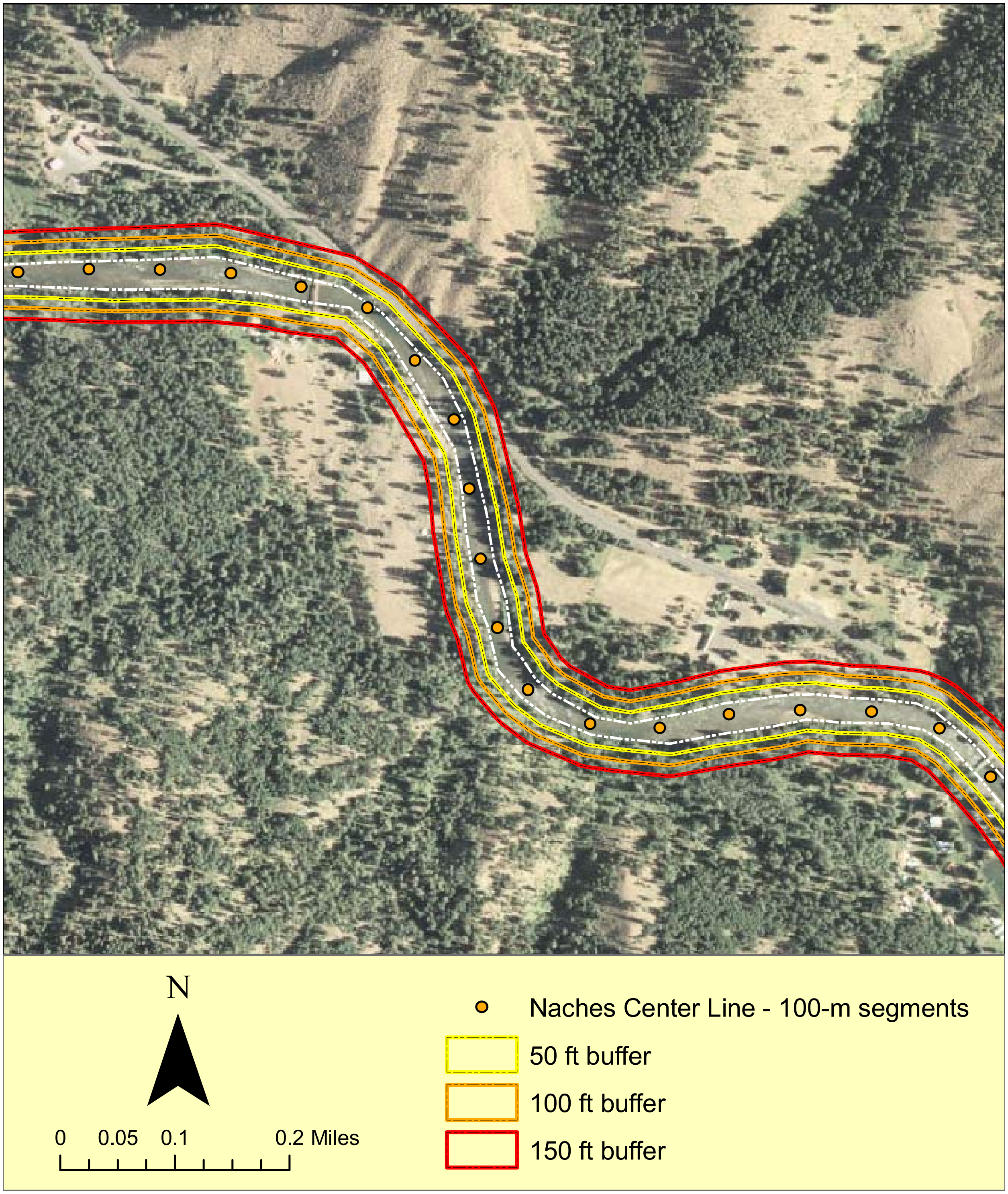

Figure 17. Example of color digital orthophotographs (DOQs), channel segmentation, and digitized channel buffers for the mainstem Naches River.

Table 13. Riparian codes and vegetation characteristics for the Naches River Temperature TMDL.

Code	Description	Height (meter)	Density (%)	Overhang (meter)
111	conifer, small, sparse	9.0	25%	1.0
112	conifer, small, dense	9.0	75%	1.0
113	conifer, small, medium	9.0	50%	1.0
114	**System-Potential Average**	**24.0**	**62%**	**2.4**
115	**System-Potential Maximum**	**34.0**	**62%**	**3.4**
121	conifer, large, sparse	30.5	25%	3.0
122	conifer, large, dense	30.5	75%	3.0
123	conifer, large, medium	30.5	50%	3.0
131	conifer, medium, sparse	20.0	25%	1.5
132	conifer, medium, dense	20.0	75%	1.5
133	conifer, medium, medium	20.0	50%	1.5
211	deciduous, small, sparse	9.0	25%	1.0
212	deciduous, small, dense	9.0	75%	1.0
213	deciduous, small, medium	9.0	50%	1.0
221	deciduous, large, sparse	32.0	25%	4.0
222	deciduous, large, dense	32.0	75%	4.0
223	deciduous, large, medium	32.0	50%	4.0
231	deciduous, medium, sparse	22.0	25%	2.0
232	deciduous, medium, dense	22.0	75%	2.0
233	deciduous, medium, medium	22.0	50%	2.0
311	mixed, small, sparse	9.0	25%	1.0
312	mixed, small, dense	9.0	75%	1.0
313	mixed, small, medium	9.0	50%	1.0
321	mixed, large, sparse	32.0	25%	3.0
322	mixed, large, dense	32.0	75%	3.0
323	mixed, large, medium	32.0	50%	3.0
331	mixed, medium, sparse	22.0	25%	2.0
332	mixed, medium, dense	22.0	75%	2.0
333	mixed, medium, medium	22.0	50%	2.0
400	riparian scrub/ shrub	2.0	75%	0.2
401	scrub/ shrub upland	2.0	25%	0.2
500	grass/ rush/ sedge riparian	0.5	75%	0.1
600	barren	0.0	100%	0.0
700	water	0.0	100%	0.0
800	developed	6.1	100%	0.6
850	pastures, cultivated (lawn)	0.0	100%	0.0
870	orchard	3.0	75%	0.0
1000	water flows under bridge	50.0	100%	0.0
2000	water flows under road, thru culvert		100%	0.0

Bold = Vegetation codes used for modeling system potential conditions.

Field observations of vegetation type, height, and density were also compared against the digitized GIS data.

To increase the accuracy of the image interpretation (riparian vegetation type, height, and density), an additional set of aerial photographs was used: digital photographs acquired during the TIR survey. These photos (about 1800 images with about 40% overlap) were taken from low altitude (approximately 300 m) and provided a higher level of detail than the orthophotos. The images are more accurate, and specific details such as tree shadows helped in deciphering the species composition and height.

The near-stream vegetation cover for the Naches River was mapped using the ArcView GIS dynamic segmentation method which proved to be more cost-effective and sufficiently accurate compared to the polygon delineation method (Cristea, 2004).

System-potential vegetation

The height and density of site-potential riparian vegetation (at mature stages) were estimated based on various GIS existing coverages and information compiled in the *Wenatchee National Forest Water Temperature TMDL Technical Report*, as described below.

DNR soils coverage (www3.wadnr.gov/dnrapp6/dataweb/dmmatrix.html#Soils) provides digitized soil delineations and soil attributes. Site index data – a designation of the quality of a forest site based on the height of the dominant and co-dominant tallest trees in a stand – is one of the polygon attributes in the DNR soils coverage.

Eastern Washington site conditions are estimated by using an index age of 100 years. The site index height is the average height attained by the tallest trees in a fully stocked stand at the applicable index age. Tree heights for the tallest trees from the DNR data are summarized for the Naches River basin in Table 14. The average tree height of 24 meters (79 ft) was calculated as the weighted average height by coverage area. The maximum tree height found in the basin was 34 meters (112 ft).

The Natural Resources Conservation Service (NRCS) SSURGO soil layers consist of digital soil survey data and a related Access database file that provide information on vegetation characteristics for given soil types. Tree height information for the SSURGO data was found by linking the “component” table to the “coforprod” table. The site index height (height of vegetation after 100 years) and plant species estimated from the SSURGO data are listed in Table 15. The average tree height of 78 ft was calculated as a weighted average of the site index height by coverage area. The maximum tree height found in the SSURGO data was 105 ft.

Table 14. Potential tree heights estimated from DNR soil coverage.

Tree Height (m)	Coverage Area (m^2)	Percent of Total Area	Weighted Average Height (m)	Weighted Average Height (ft)
15	4450711	2%	0.3	1
19	3951514	2%	0.4	1
20	16179385	8%	1.6	5
20	12517753	6%	1.2	4
21	27184237	13%	2.7	9
23	1881220	1%	0.2	1
24	45752858	22%	5.3	17
24	1894	0%	0.0	0
25	4388056	2%	0.5	2
25	52998147	25%	6.4	21
27	6037038	3%	0.8	3
27	7709681	4%	1.0	3
27	1419745	1%	0.2	1
28	9352915	4%	1.3	4
29	2157086	1%	0.3	1
31	563792	0%	0.1	0
32	3775	0%	0.0	0
32	8931419	4%	1.4	5
33	2818112	1%	0.4	1
34	8926	0%	0.0	0
		Average Height	24	79
		Maximum Height	34	112

Table 15. Potential tree heights calculated from SSURGO soil coverages.

Species	Average Height		Maximum Height	
	(m)	(ft)	(m)	(ft)
Alaska cedar	23	75	23	75
Douglas-fir	23	77	32	105
Engelmann spruce	23	74	23	74
Grand fir	23	75	23	75
Lodgepole pine	27	89	27	89
Mountain hemlock	20	65	21	70
Oregon white oak	21	70	21	70
Pacific silver fir	20	65	20	65
Ponderosa pine	24	79	30	100
Quaking aspen	17	55	17	55
Western hemlock	24	80	29	95
TOTAL	24	78	32	105

Riparian vegetation characteristics measured during field surveys show that the near-stream vegetation tends to be a deciduous-conifer mix with a lower average tree height but higher canopy density. Therefore, riparian vegetation used in the Shade model to predict system-potential temperature consists of two zones of vegetation on each side of the river (Table 16). The inner-near-stream zone is a conifer-deciduous mix with a maximum tree height of 32 meters (105 feet). A tree height of 34 meters (110 feet) was used for the outer riparian zones.

The maximum potential density of trees along the stream corridor will vary depending primarily on the presence of roads and tributaries. A 75% and 62% density was assumed as an estimate of riparian vegetation density-potential for the inner and outer riparian zones, respectively. This estimate is equal to the density calculated in the Wenatchee National Forest Temperature Study (Whiley and Cleland, 2003). In addition, an overhang equal to 10% of the tree height was assumed for both zones.

Table 16. System-potential vegetation recommendations for the upper Naches River Temperature TMDL.

Scenario	ZONE 1					ZONE 2				
	Species	Tree Ht (m)	Density *	Over-hang (m)	Zone Width (m)	Species	Tree Ht (m)	Density *	Over-hang (m)	Zone Width (m)
Maximum 2-Zone System-potential Tree	Mixed - Conifer and Deciduous	32	75	3	5	Conifer (ponderosa pine/ douglas-fir)	34	62	3	41

*Density assumed equal to density cited in Wenatchee National Forest Temperature Study.
System-potential Recommendations derived from DNR soil data and SSURGO data.

Effective shade calculations

Vegetation data were input into a shade model (Ecology, 2003a). The vegetation codes required for input in this model were assigned manually at 100-meter intervals using color orthophotographs, TIR survey color photographs, and riparian characteristics collected during field habitat surveys. Stream aspect and topographic shade angles to the west, south, and east were sampled with Ttools 3.3 ArcView extension developed by the Oregon Department of Environmental Quality (ODEQ, 2001). The shade calculation method chosen was the method developed by Chen (1996).

Effective shade is defined as the fraction of incoming solar shortwave radiation above the vegetation and topography that is blocked from reaching the surface of the stream. Effective shade levels provided by vegetation and topography were estimated for the upper Naches River (RM 38.8 to the confluence with the Tieton River) for five scenarios:

- Current vegetation and topography.
- Average system-potential riparian vegetation with characteristics presented in Table 17.

- Maximum 1-zone system-potential vegetation with characteristics presented in Table 17.
- Maximum 2-zone system-potential vegetation with characteristics presented in Table 17.
- Maximum 2-zone system-potential vegetation with characteristics presented in Table 17 and a 10% reduction of channel width.

Each of the vegetation scenarios accounts for the presence of Highway 410. Note: trees were grown from bankfull width to a width equivalent to the height of the potential vegetation, but not in the right-away of Highway 410.

Table 17. System-potential vegetation scenarios for the upper Naches River Temperature TMDL.

Scenario	ZONE 1					ZONE 2				
	Species	Tree Ht (m)	Den-sity *	Over-hang (m)	Zone Width (m)	Species	Tree Ht (m)	Den-sity *	Over-hang (m)	Zone Width (m)
Average System-potential Tree	Conifer (ponderosa pine/ douglas-fir)	24	62	2	5	Conifer (ponderosa pine/ douglas-fir)	24	62	2	41
Maximum 1- zone System-potential Tree	Conifer (ponderosa pine/ douglas-fir)	34	62	3	5	Conifer (ponderosa pine/ douglas-fir)	34	62	3	41
Maximum 2- Zone System-potential Tree	Mixed - Conifer and Deciduous	32	75	3	5	Conifer (ponderosa pine/ douglas-fir)	34	62	3	41

*Density assumed equal to density cited in Wenatchee National Forest Temperature Study.
System-potential Recommendations derived from DNR Soil data and SSURGO data.

Figure 18 presents the effective shade calculated by the Shade model and estimated in the field by hemispherical photography and a Solar Pathfinder. Figure 19 presents the effective shade calculated by the Shade model for each of the system-potential vegetation scenarios. Finally, Figure 20 illustrates the deficit in effective shade levels in the Naches River basin.

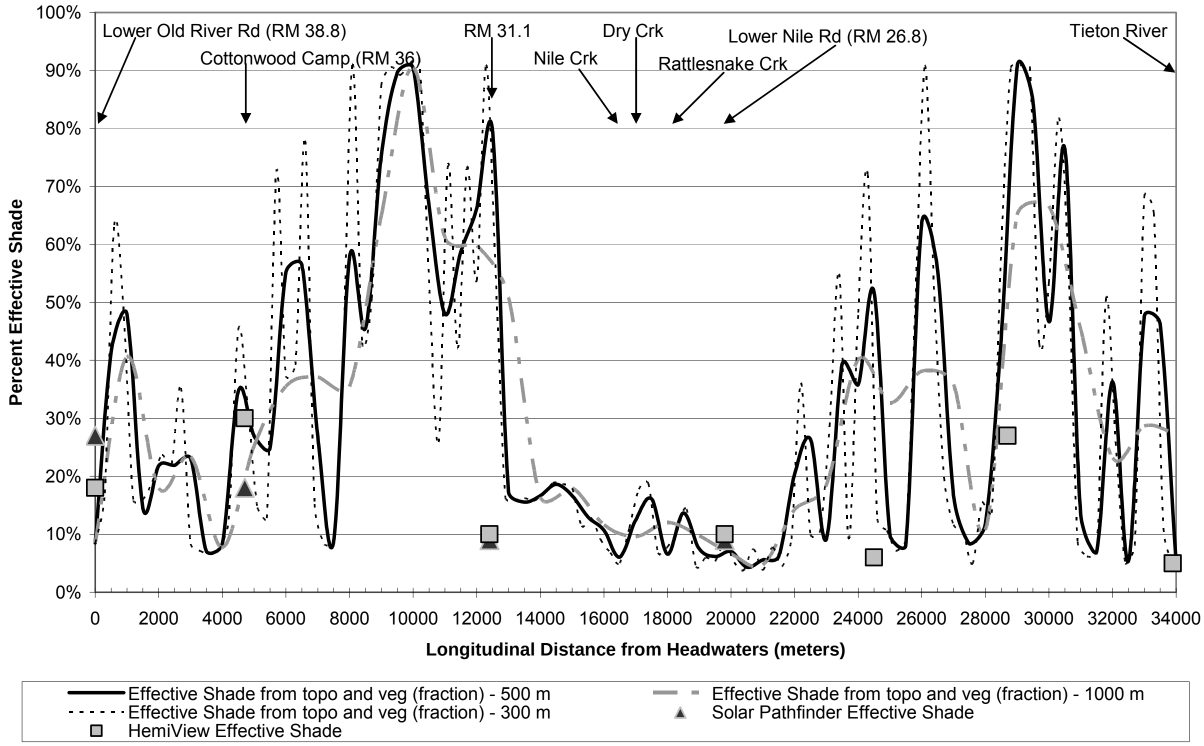

Figure 18. Comparison of effective shade calculated by the Shade model to shade estimated by field measurements for the upper Naches River between RM 38.8 to 17.6.

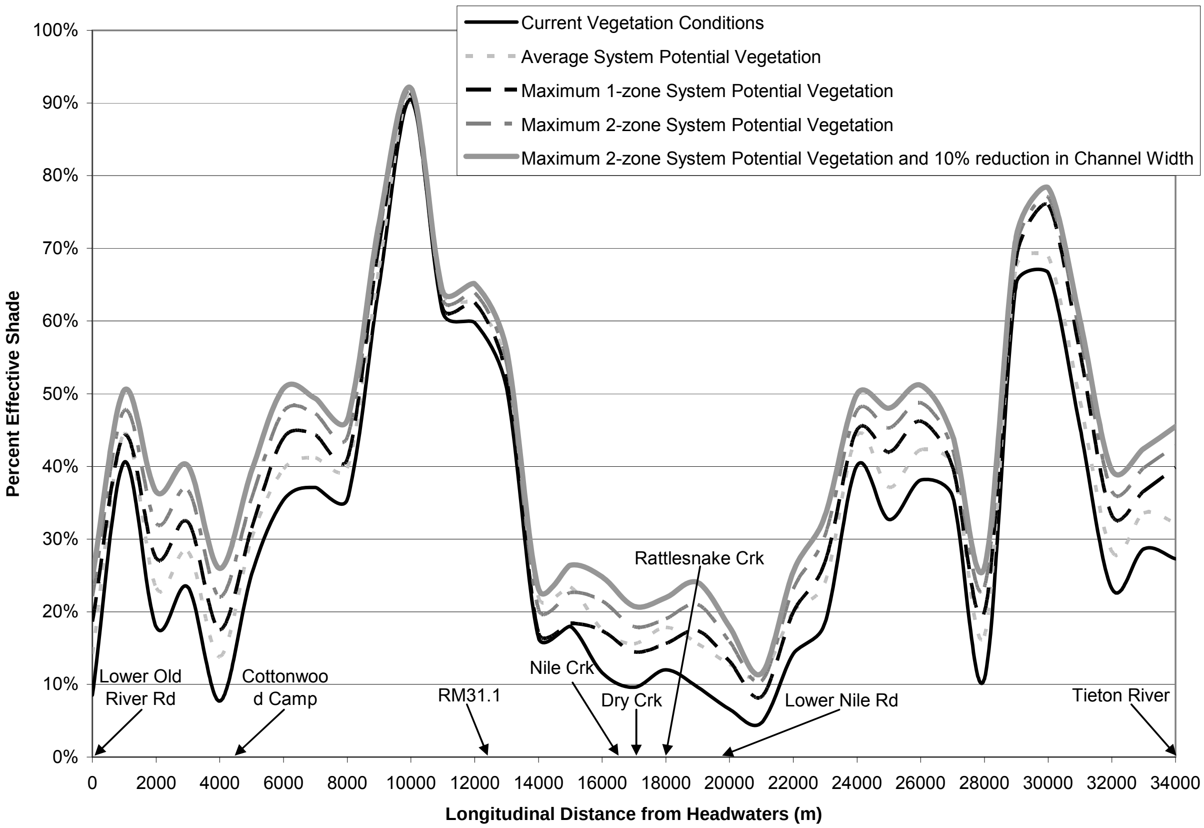

Figure 19. Effective shade calculated for system-potential vegetation scenarios for the upper Naches River (RM 38.8 to 17.6).

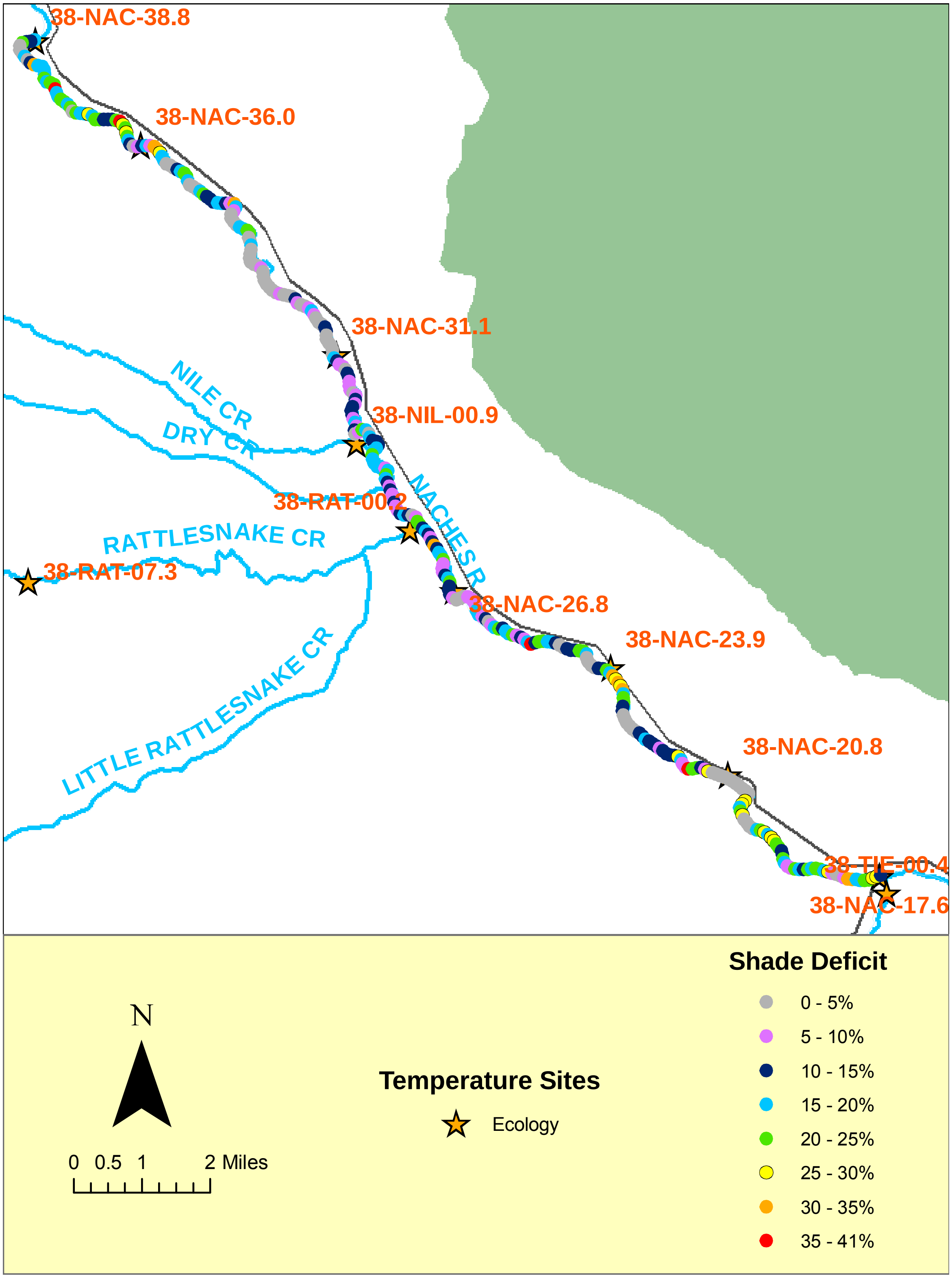

Figure 20. Shade deficit between current conditions and system-potential vegetation and channel conditions for the upper Naches River (RM 38.8 to 17.6).

Seasonal variation

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

Existing conditions for stream temperatures in the Naches River watershed reflect seasonal variation. Cooler temperatures occur in the winter, while warmer temperatures occur in the summer. Figures 21 and 22 summarize the highest 7-day average maximum water temperatures and the highest daily maximum for 2004. The highest temperatures typically occur from mid-July through mid-August. This timeframe is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The critical period for evaluation of solar flux and effective shade was assumed to be July 31 because it is the mid-point of the period when water temperatures are typically at their seasonal peak.

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

Study quality assurance evaluation

The quality assurance for the field work followed the protocols established in the Quality Assurance Project Plan contained in LeMoine and Brock (2004). Pre- and post-calibration of the instream and air thermistors in both an ice-water and warm-water bath indicates that all equipment met manufacturer specifications. The average difference between continuously collected instream temperature and thermometer field checks was 0.2°C (Table 18). The average percent difference between replicate and duplicate flows taken during the seepage run is 4.3% (Table 19). The overall margin of error for discharge data collected by Ecology's Stream Hydrology Unit at three continuous flow monitoring sites ranged from 5 to 20% (Springer, 2007). Data collected were deemed to be of sufficiently high quality to be used for development of this temperature TMDL.

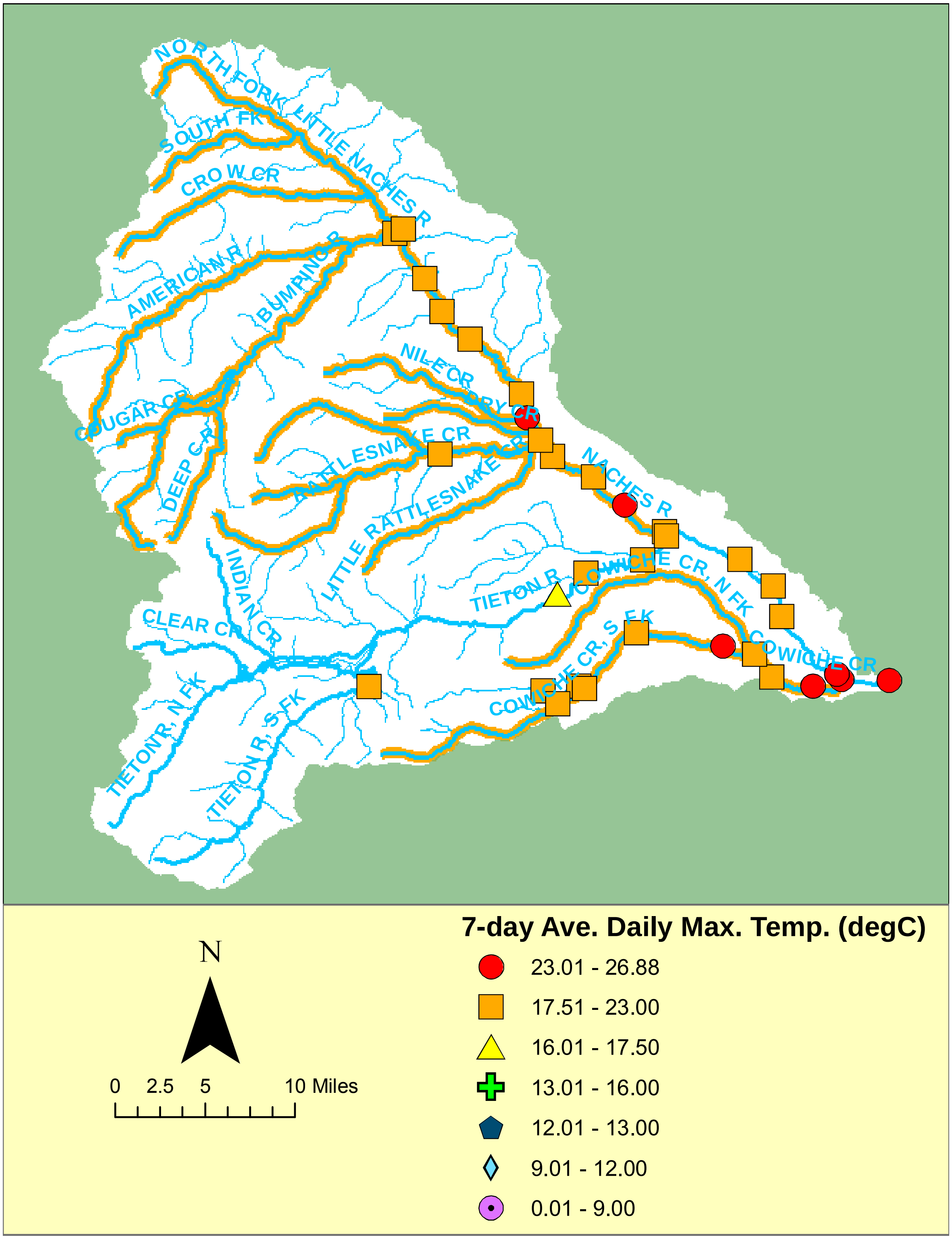

Figure 21. Highest 7-day instream average daily maximum temperatures observed in the Naches River watershed during the summer 2004 field season.

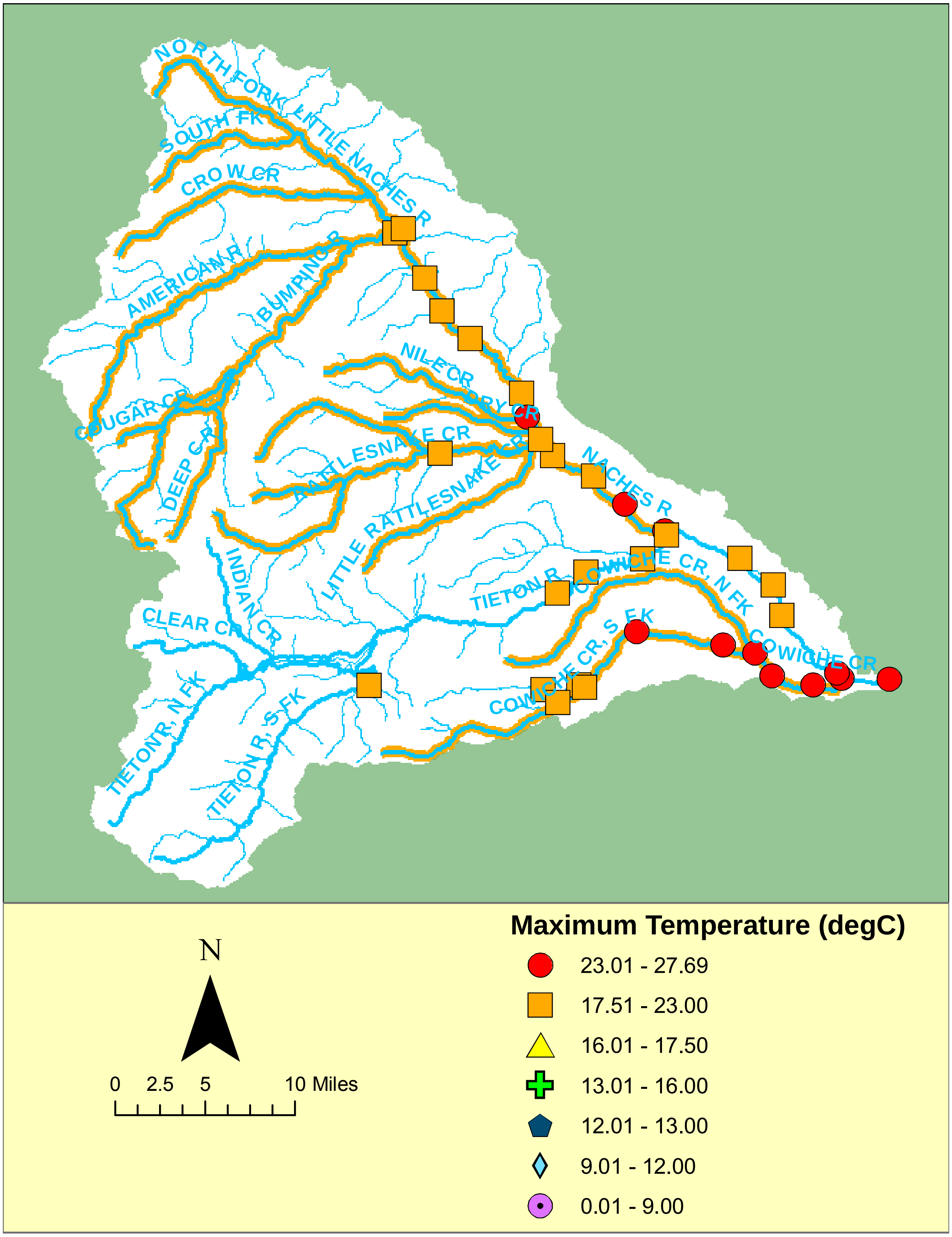

Figure 22. Maximum instream temperatures observed in the Naches River watershed during the summer 2004 field season.

Table 18. Quality control results (^{o}C) for instream temperatures collected for the 2004 upper Naches River Temperature TMDL.

Station	Thermistor Accuracy
38-AME-0.5	0.2
38-LIT-0.1	0.1
38-NAC-41.1	0.3
38-NAC-38.8	0.3
38-NAC-36.0	0.2
38-NAC-31.1	0.1
38-NAC-26.8	0.1
38-NAC-23.9	0.1
38-NAC-20.8	0.3
38-NAC-12.8	0.1
38-NAC-10.5	0.1
38-NAC-8.5	0.3
38-NAC-3.7	0.2
38-NAC-0.5	0.2
38-RAT-7.3	0.2
38-NIL-0.9	0.2
38-SFT-2.6	0.2
38-TIE-9.0	0.2
38-TIE-6.1	0.5
38-TIE-2.3	1.1
38-TIE-0.4	0.1
38-REY-2.0	0.1
38-REY-0.2	0.2
38-SFC-15.4	0.2
38-SFC-12.5	0.1
38-SFC-7.6	0.2
38-SFC-2.1	0.1
38-NFC-3.5	0.2
38-NFC-0.0	0.2
38-COW-5.9	0.3
38-COW-2.7	0.3
38-COW-0.5	0.4
Average Difference	0.2

Table 19. Quality control results for the seepage run completed for the 2004 Naches River Temperature TMDL.

Station	Flow (cfs)	Percent Difference
38-LIT-0.1	62.1	5.7
38-LIT-0.1R	65.8	
38-NAC-42	366.3	6.8
38-NAC-42D1	393.0	
38-NAC-42D1	393.0	9.0
38-NAC-42D2	431.7	
38-NAC-42	366.3	15.2
38-NAC-42D2	431.7	
38-NAC-41.1	390.3	1.9
38-NAC-41.1R	397.8	
38-NAC-31.1	385.3	1.8
38-NAC-31.1D	378.4	
38-RAT-0.2div	15.4	0.2
38-RAT-0.2divR	15.5	
38-NAC-26.8	458.3	2.7
38-NAC-26.8D	470.9	
38-NAC-20.8	463.1	3.1
38-NAC-20.8R	477.8	
38-NAC-12.8	368.9	1.0
38-NAC-12.8R	365.3	
38-NAC-0.5	431.1	0.5
38-NAC-0.5R	433.3	
Average Percent Difference		4.3

R = replicate (flow taken at same location by same flow team)
D = duplicate (flow taken at same location by different flow team)

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TMDL Analyses for Temperature

Analytical framework

Data collected during this TMDL effort has been used to simulate temperatures continuously along streams using a methodology that is both spatially continuous and spans full-day timeframes. The GIS and modeling analysis was conducted using three specialized software tools:

1. ODEQ's Ttools extension for ArcView (ODEQ, 2001) was used to sample and process GIS data for input to the QUAL2Kw model.
2. Ecology's Shade model (Ecology, 2003a) was used to estimate effective shade along the mainstem of the upper Naches River (Figure 18 - 20). Effective shade was calculated at 100-meter intervals along the streams and then averaged over 1000-meter intervals for input to the QUAL2Kw model.
3. The QUAL2Kw model (Chapra, 2001; Chapra and Pelletier, 2003; and Pelletier and Chapra, 2003) was used to calculate the components of the heat budget and simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady-flow condition. QUAL2Kw was applied by assuming that flow remains constant for a given condition such as a 7-day or 1-day period, but key variables are allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures were specified or simulated as diurnally varying functions.

   QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget that are shown in Figure 3 and described in Chapra (1997). Complete model documentation and software can be found at www.ecy.wa.gov/programs/eap/models/index.html. Diurnally varying water temperatures at 1000-meter intervals along the streams in the upper Naches River basin were simulated using a finite difference numerical method. The water temperature model was calibrated to, and confirmed by, instream data.

All input data for the Shade and QUAL2Kw models are longitudinally referenced, allowing spatial and/or continuous inputs to apply to certain zones or specific river segments. Model input data were determined from available GIS coverages using the Ttools extension for ArcView, or from data collected by Ecology or other data sources. Detailed spatial data sets were developed for the following parameters for model calibration and confirmation:

- Rivers and tributaries were mapped at 1:3,000 scale from 3-foot resolution color Digital Orthophoto Quads (DOQs) flown in 2003 for the portions of the watershed within Yakima County. The portion of the upper Naches River that lies above the confluence with the Tieton was mapped at 1:4,800 scale from 1-meter-resolution, color-infrared DOQs collected by the U.S. Bureau of Reclamation (USBR) in 2000 during LiDAR flights in the Yakima basin (UCAO, 2003b).

- Riparian vegetation size and density were mapped at 1:3,000 scale from the DOQs and sampled from the GIS coverage along the stream at 100-meter intervals. Effective shade was calculated from vegetation height, density, and overhang with Ecology's Shade model. The effective shade values calculated from the Shade model were found to be highly correlated with solar pathfinder field measurements taken during the summer 2004 stream surveys (Figure 18).
- Near-stream disturbance zone (NSDZ) widths were digitized at a scale of 1:3000.
- West, east, and south topographic shade angle calculations were made from the 10-meter Digital Elevation Model (DEM) grid using ODEQ's Ttools extension for ArcView.
- Stream elevation was sampled from the 10-meter DEM grid with the Milagrid ArcView extension. Gradient was calculated from USGS 1:24,000 quad maps. Incision was calculated from bare earth LiDAR data (UCAO, 2003a) with the Milagrid ArcView extension.
- Aspect (streamflow direction in decimal degrees from north) was calculated by the Ttools extension for ArcView.
- The hourly observed temperatures for the boundary conditions at the headwaters and the daily minimum and maximum observed temperatures for the tributaries were used as input to the QUAL2Kw model for the calibration and confirmation periods. The QUAL2Kw model of the upper Naches River was calibrated using data collected during July 28 – August 3, 2004, and confirmed using data from August 11 – 17, 2004.
- Flow balances for the calibration periods were estimated from field measurements and gage data of flows made by Ecology, USGS, and USBR. The lowest 7-day average flows during July-August with recurrence intervals of 2 years (7Q2) and 10 years (7Q10) were calculated for four long-term USBR gaging stations in the upper Naches River basin (Table 8). Water balance for the remainder of the upper Naches River system was calculated using continuous flow data from 2004 and from seepage run (synoptic flow) data collected in the watershed by Ecology and USGS in 2004. Typical gains and losses between stations for the low-flow period in July and August, estimation of actual water withdrawals from USBR canals, and estimate of groundwater input from July and August were used to construct the complete water balance for the upper Naches River.
- Hydraulic geometry (wetted width, depth, and velocity as a function of flow) for the mainstem upper Naches River was estimated using relationships between wetted width, wetted depth, average velocity, and flow. Travel-time data from the 2004 dye study and the channel survey were used to augment these relationships to represent entire reaches instead of static flow points.
- The temperature of groundwater in the upper Naches River mainstem was set to 17.4°C for the reach between RM 31.1 to 26.8, and 17.9°C for the reach between RM 26.8 to 17.6. Groundwater temperatures were based on temperature data collected in 2004 by spot temperature measurements within instream piezometers and continuous hyporheic tidbits buried in the substrate (Carey, 2007).

- Air temperature, relative humidity, and cloud cover were estimated from meteorological data. The observed minimum and maximum air temperatures and relative humidity collected at Ecology, RAWS, and WSDOT stations during the study year were used to represent the conditions for the calibration and verification periods. Cloud cover data came from the Yakima Airport station located near the mouth of the Naches River. Wind speed measured at the Old River Road, Sawmill Flats, and Yakima Airport stations was averaged to calculate the wind speed used for upper Naches River temperature modeling.

- Heat exchange between the water and the streambed is simulated in QUAL2Kw by two processes: (1) conduction according to Fick's law is estimated as a function of the temperature gradient between the water and surface sediment, thickness of the surface sediment layer, and the thermal conductivity, and (2) hyporheic exchange is estimated as a function of the temperature gradient between the water and surface sediment and the bulk diffusive flow exchange between the water and the streambed, the thickness of the surface sediment layer, the density and heat capacity of water.

  Calibration of the QUAL2Kw model involved specification of the thickness of the surface sediment layer in the range of 50 to 100 cm and specification of the bulk diffuse flow exchange between the water and the streambed between 0 and 100% of the surface flow in a stream reach. A typical constant value for the thermal conductivity of the surface sediment of 1.57 to 3.53 W/(m°C) (0.0035 cal/sec/cm/°C) was assumed (Chapra, 2001). This is in the typical range of 1 to 4.18 W/(m°C) in the literature values summarized by Sinokrot and Stefan (1993) for typical streambed materials.

Calibration of the QUAL2Kw model

Model calibration with different values of parameters within the ranges discussed in this section was accomplished using the genetic algorithm for automatic QUAL2Kw calibration (Pelletier et al., 2005). During model verification, all parameter values were set to those values used for model calibration except field and weather data specific to the verification period.

The hottest 7-day period of 2004 occurred from July 28 – August 3 and was used for calibration of the upper Naches River QUAL2Kw temperature model (Figure 23). The next warmest week occurred from August 11 – 17 and was used as the verification period for the QUAL2Kw temperature model. This time period corresponded to the TIR Flight, which is compared to the model predicted temperatures in Figure 24.

The goodness-of-fit for the QUAL2Kw model was summarized using the root mean squared error (RMSE) as a measure of the deviation of model-predicted stream temperature from the measured values. The RMSE represents an estimation of the overall model performance and |was calculated as:

$$RMSE = \sqrt{\sum \frac{\left(T_{measured} - T_{calculated}\right)^2}{n}}$$

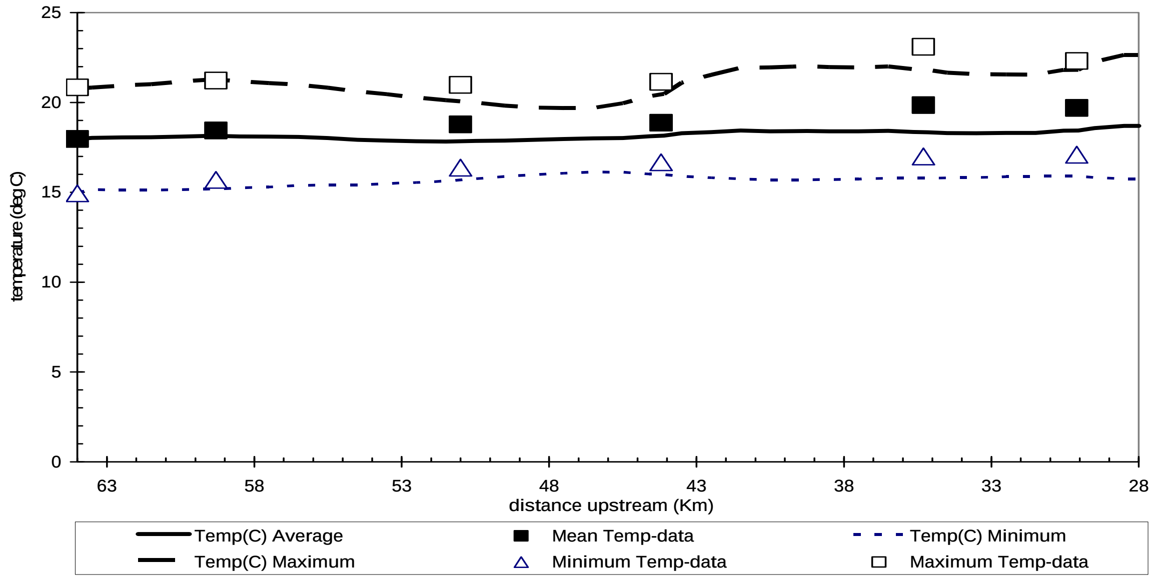

Figure 23. Modeled and observed instream temperatures for the calibration period (July 28-August 3, 2003) for the upper Naches River.

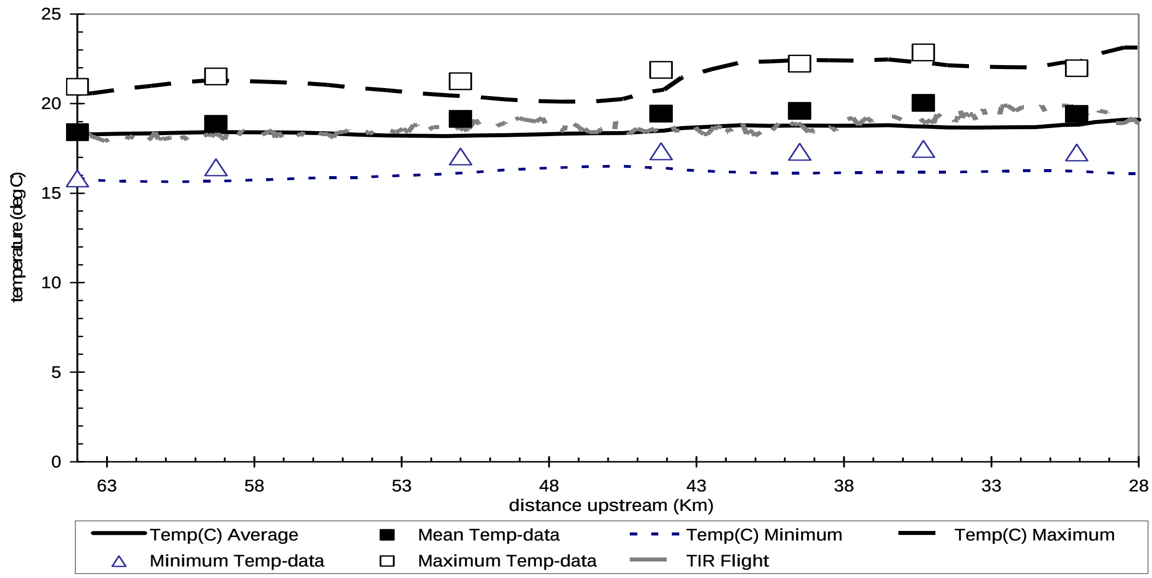

Figure 24. Modeled and observed instream temperatures for the verification period (August 11-17, 2004) for the upper Naches River.

For the calibration and verification periods, the RMSE of the predicted versus observed daily maximum temperatures in the upper Naches River averaged around 0.59°C (Table 20). The RMSE of the combined maximum and minimum predicted daily temperatures was similar.

Table 20. Summary root mean square error (RMSE) of differences between the predicted and observed daily maximum temperatures and combined maximum and minimum temperatures in the upper Naches River (RM 38.8 to 17.6).

Watercourse	Statistic	RMSE for July 28–Aug 3, 2004 (ºC)	RMSE for Aug 11–17, 2004 (ºC)
Upper Naches River	Maximum	0.73	0.45
Upper Naches River	Total (max + min)	0.78	0.55

Loading capacity

Upper Naches River

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (40 CFR § 130.2(f)). Loading capacities in the upper Naches River are solar radiation heat loads based on potential land cover (primarily vegetation) and channel width.

The calibrated QUAL2Kw model was used to determine the loading capacity for effective shade for the mainstem upper Naches River (RM 38.8 to 17.6). Loading capacity was determined based on prediction of water temperatures under typical and extreme flow and climate conditions combined with a range of effective shade conditions.

The lowest 7-day average flow with a 2-year recurrence interval (7Q2) was selected to represent a typical climatic year. The lowest 7-day average flow with a 10-year recurrence interval (7Q10) was selected to represent a reasonable worst-case condition for the July-August period.

Air temperature values for the 7Q2 condition were assumed to be represented by the average of the hottest week of August 2005, which was the median condition from the historical record at Yakima Airport (Table 12). The air temperature values for the 7Q10 condition were the average of the hottest week of 2004, which was the 90th percentile condition from Yakima. The corresponding median and 90th percentile air temperature conditions for the near-stream conditions near the Naches River at RM 38.8 were calculated from measurements taken at the WSDOT Saw Mill Flats weather station during August 2005 and August 2004, respectively. The median and 90th percentile air temperatures for the near-stream conditions near the Naches River at RM 17.6 were calculated from measurements taken at RAWS Old River Road weather station.

Critical and average air temperatures for the remainder of the upper Naches River were calculated using a linear regression equation based on elevation.

The following scenarios for effective shade were evaluated for the 7Q2 and 7Q10 flow and climate conditions:

- The effective shade produced by the current riparian vegetation condition.
- Effective shade from average mature riparian vegetation that would naturally occur in the upper Naches River. Mature vegetation was represented by height and densities reported earlier, in Table 17, and by a riparian vegetation width of 150 feet on each side of the stream.
- Effective shade from maximum mature riparian vegetation that would naturally occur in the upper Naches River (Table 17).
- Effective shade from 2-zone maximum mature riparian vegetation that would naturally occur in the upper Naches River (Table 17).

The system-potential vegetation scenarios account for the presence of Highway 410. Additional critical scenarios were evaluated to test the sensitivity of predicted water temperatures to changes in riparian microclimate, decreases in channel width, and reduction of tributary temperatures:

- **Microclimate.** Increases in vegetation height, density, and riparian zone width are expected to result in decreases in air temperature. To evaluate the effect of this potential change in microclimate on water temperature, the daily maximum air temperature was reduced by 2°C for reaches modeled with deciduous or conifer trees based on the summary of literature presented by Bartholow (2000).
- **Channel width.** Channel banks are expected to stabilize and become more resistant to erosion as the riparian vegetation along the stream matures. The sensitivity of predicted stream temperatures to reduction of channel width was tested by predicting stream temperatures that would occur if channel width were reduced by 5, 10, and 25%.
- **Reduced tributary temperatures.** A scenario was evaluated with the assumption that all tributaries flowing into the upper Naches River meet the applicable water quality criterion (16°C) during the critical period. This scenario also assumed that the water quality criterion of 16°C was met at the model headwater boundary (RM 38.8).

The results of the model runs for the critical 7Q2 and 7Q10 conditions are presented in Figures 25 through 27. The current condition in the Naches River watershed is expected to result in daily maximum water temperatures that are greater than 16°C in all of the evaluated reaches. Portions of the evaluated streams could be greater than the threshold for lethality of a 7-DADMax temperature at or below 22°C and a 1-day maximum temperature at or below 23°C under current riparian conditions. The "lethality" limit or "threshold for lethality" in Figures 25-27 is referring to the following excerpt from WAC 173-201A-200(1)(c)(vii)(A) and an Ecology study (Hicks, 2002) that evaluates lethal temperatures for coldwater fish:

"For evaluating the effects of discrete human actions, a 7-day average of the daily maximum temperatures greater than 22°C or a 1-day maximum greater than 23°C should be considered lethal to cold water fish species such as salmonids. Barriers to migration should be assumed to exist anytime daily maximum water temperatures are greater than 22°C and the adjacent down-stream water temperatures are 3°C or more cooler."

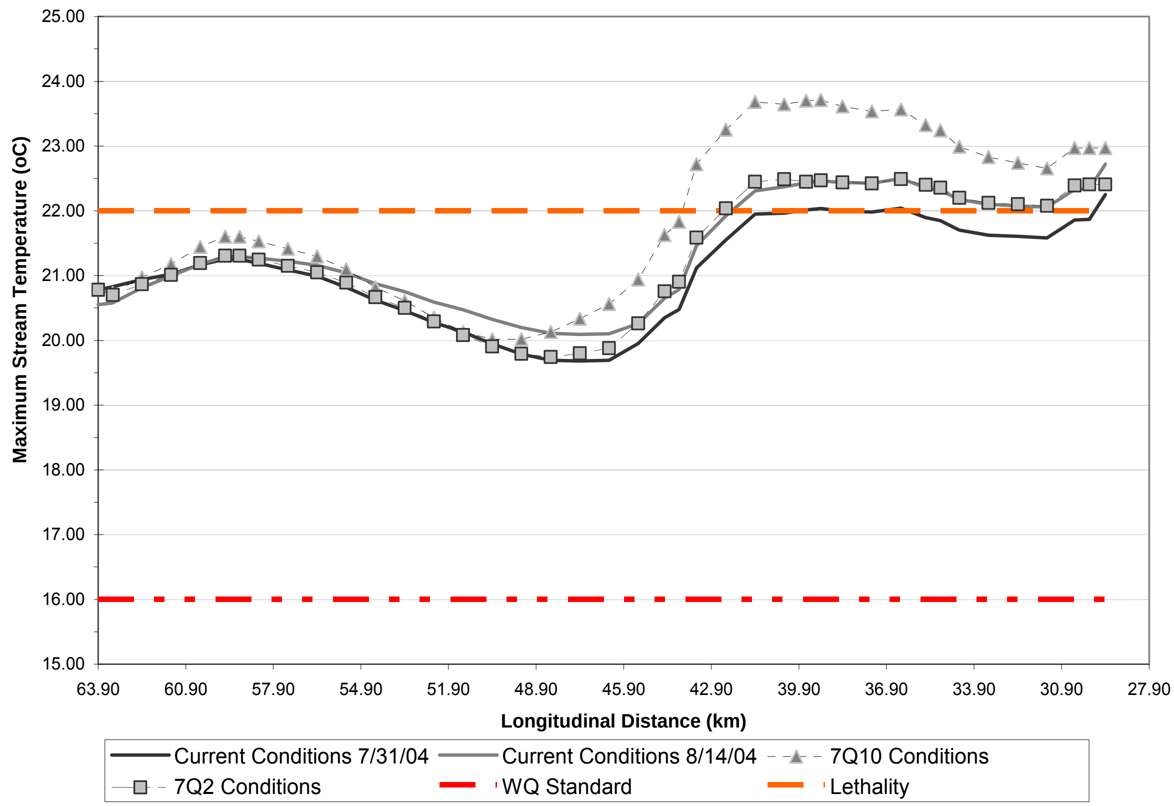

Figure 25. Model calibration, 7Q10, and 7Q2 scenarios with current vegetation, flow, and channel for the upper Naches River.

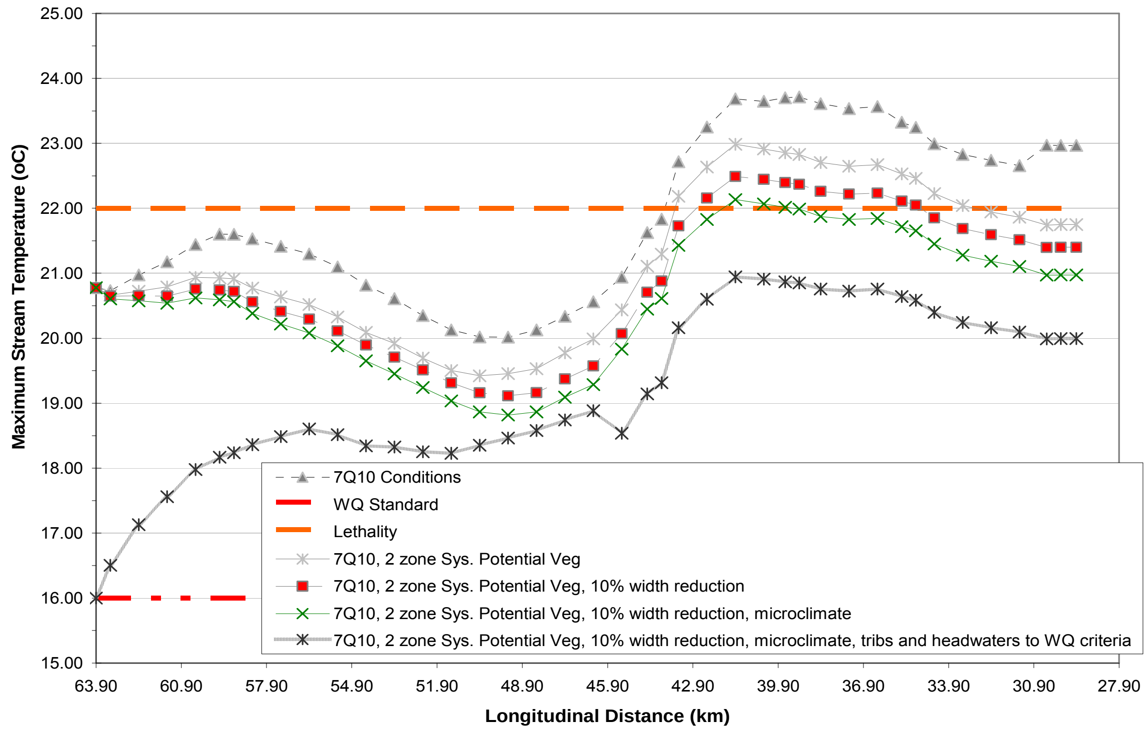

Figure 26. 7Q10 model scenarios for the upper Naches River.

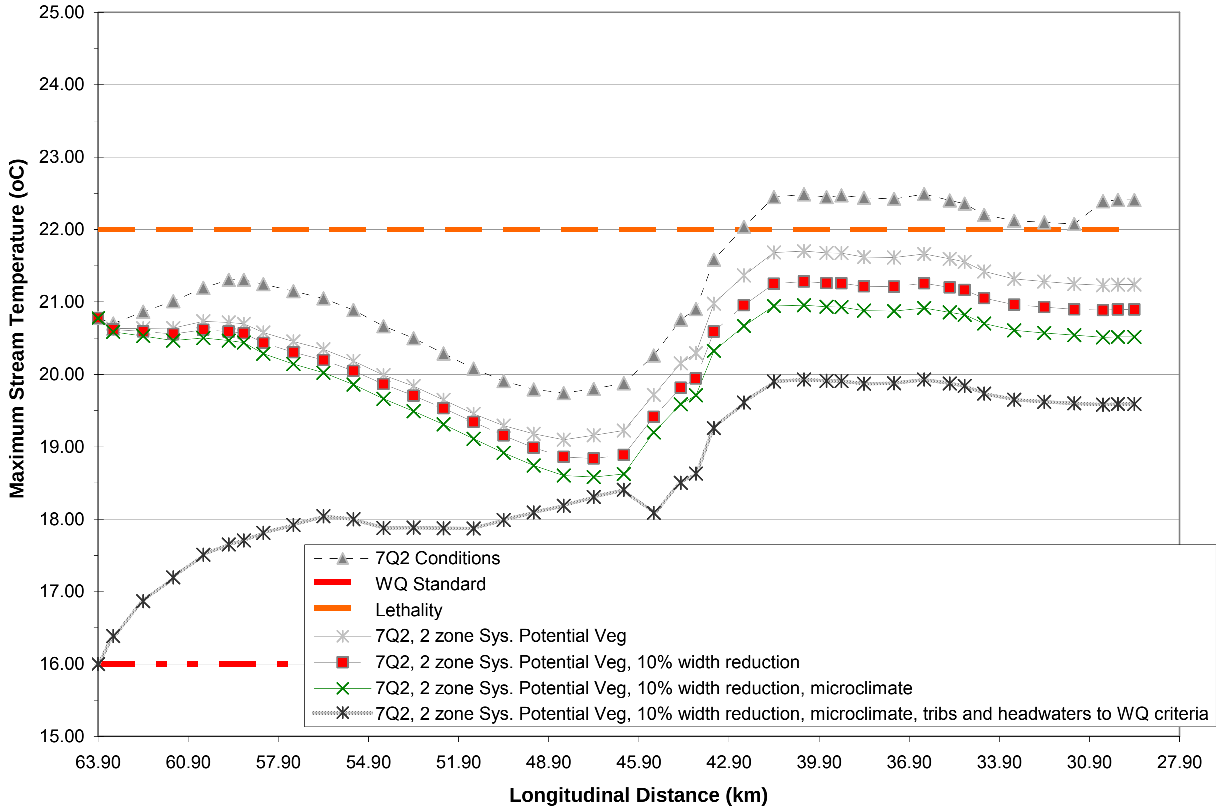

Figure 27. 7Q2 model scenarios for the upper Naches River.

Reductions in water temperature are predicted for hypothetical conditions with mature riparian vegetation, improvements in riparian microclimate, and reduction of channel width. Current temperatures in some sections of the upper Naches River are above the 23°C lethal limit for salmonids during the summer months. Potential reduced maximum temperatures under critical conditions are predicted to be greater than the 16°C numeric standard in the upper mainstem Naches River, but below the lethal limit of 23°C for salmonids. Further reductions are likely if all tributaries and channel complexity are restored (WAC 173-201A-200).

The best estimate of potential summertime stream temperature reductions for the upper Naches River (RM 38.8 to 17.6) is 2.7°C. This estimate is based on implementation of 2-zone system-potential vegetation, microclimate reductions, 10% reduction in channel width, and restoration of the headwaters and tributaries to the water quality numeric criteria of 16°C. Most of the system has the ability to achieve temperatures in the range of 18-23°C during the hottest portions of the summer (Table 21).

Table 21. Summary of daily water temperatures (^oC) during critical conditions in the upper Naches River.

Scenario	Tave (average daily average of all reaches)	Tmax (average daily maximum of all reaches)
7Q2		
Current condition	18.06	21.35
Average system-potential vegetation	17.90	21.03
Maximum system-potential vegetation	17.82	20.87
2-zone maximum system-potential vegetation	17.72	20.67
2-zone maximum system-potential vegetation, 10% width reduction	17.69	20.41
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions	17.53	20.16
2-zone maximum Vegetation, 10% width reduction, microclimate reductions, tributary and headwaters to WQ numeric criteria	16.16	18.64
7Q10		
Current condition	18.41	21.93
Average system-potential vegetation	18.24	21.59
Maximum system-potential vegetation	18.14	21.39
2-zone maximum system-potential vegetation	18.07	21.24
2-zone maximum system-potential vegetation, 5% width reduction	18.04	21.09
2-zone maximum system-potential vegetation, 10% width reduction	18.00	20.93
2-zone maximum system-potential vegetation, 25% width reduction	17.90	20.44
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions	17.81	20.64
2-zone maximum system-potential vegetation, 10% width reduction, microclimate reductions, tributary and headwaters to WQ numeric criteria	16.46	19.20

It is important for stream water quality throughout the year to promote a robust, diverse riparian condition because *"…the degree of shading of streams is a function of the structure and composition of riparian vegetation. Dense, low, overhanging canopies greatly reduce light intensity at the water's surface, but high, relatively open canopies allow greater amounts of light to reach the stream. Deciduous riparian vegetation shades streams during summer, but modifies light conditions only slightly after leaf fall, whereas evergreen riparian zones shade stream channels continuously (Montgomery, 1996)."*

Cowiche Creek

Cowiche Creek was not modeled with QUAL2Kw to determine the temperature reductions required or the loading capacity for solar radiation. Therefore, loading capacities in Cowiche Creek are solar radiation heat loads based on shade curves generated for varying channel width and aspect at system-potential vegetation defined in Table 17.

Surface waters on Wenatchee National Forest lands

In the *Wenatchee National Forest Lands Temperature TMDL Technical Report*, identification of loading capacity targets used the landscape stratification system developed specifically for that TMDL analysis. The loading capacities reflected the range variation in geologic setting and associated physical processes that occurred across the Wenatchee National Forest. Channel classes were based on three attributes, which included:

- Subsection Mapping Units (SMU) that reflect the geologic setting
- Watershed size
- Channel morphology

Existing data collected by the USFS was used in a heat budget analysis to determine loading capacity targets. More information about the analysis and the loading capacity targets by landscape stratification is available in the *Wenatchee National Forest Lands Temperature TMDL Technical Report* (Whiley and Cleland, 2003).

Results and discussion

The QUAL2Kw model simulations indicated that:

- A buffer of mature riparian vegetation along the banks of the rivers is expected to decrease the average daily maximum temperatures slightly. At 7Q10 flow conditions, a 0.7ºC reduction is expected for the upper Naches River.
- A 10% reduction of the channel width would result in an expected reduction of 1ºC. A 25% reduction in channel width may result in a 1.5ºC reduction of the average maximum temperatures.
- The changes in microclimate conditions associated with mature riparian vegetation could further lower the daily average maximum water temperature by about 0.5ºC.
- With all management scenarios in place and the assumption that the headwaters and the tributaries are in compliance with the water quality criterion, the overall decrease in the average maximum temperature for the simulated critical condition is 2.7ºC.

Other discussion and recommendations

A sensitivity analysis of Highway 410's impact on maximum temperatures in the upper Naches River indicates that replacement of the highway with mature riparian vegetation would only result in an overall temperature reduction of 0.01ºC. This is likely because the Naches is a wide river, and there is approximately 50 feet of land between the road and the river on which to grow vegetation.

Load allocations

Numeric threshold temperature criteria are established in the Washington State water quality standards (WAC 173-201A-200). These numeric criteria are designed to ensure specific communities of aquatic life will be fully protected whenever and wherever the numeric criteria are met. The state standards recognize, however, that some waterbodies may not be able to meet the numeric criteria at all places and all times.

WAC 173-201A-200 states that: *"Temperature shall not exceed [the numeric criteria] due to human activities. When natural conditions exceed [the numeric criteria], no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°."* (WAC 173-201A-200(1)(c)(i))

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

In addition to placing a limit on the amount of human warming allowed when temperatures exceed the numeric criteria, the state standards restrict the amount of warming point and nonpoint sources can cause when temperatures are cooler than the numeric criteria.

For fresh waters, WAC 173-201A-200(c)(ii) states that*: "Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge). . . Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the waterbody must not, at any time, exceed 2.8°C (5.04°F)."*

Load allocations (for nonpoint sources) and wasteload allocations (for point sources) are established in this TMDL to meet both (1) the numeric threshold criteria, and (2) the allowances for human warming under conditions that are naturally warmer than those criteria.

The *system-potential temperature* is an approximation of the temperature that would occur under natural conditions during specified conditions of air temperature and streamflow. The system-potential temperature is estimated using analytical methods and computer simulations proven effective in modeling and predicting stream temperatures in Washington. The system-potential temperature is based on our best estimates of the *mature riparian vegetation, natural channel shape, and riparian microclimate.*

A system-potential temperature is estimated for both an *average* year (50^{th} percentiles of climate and low streamflows) and a *critical condition* year (upper 90^{th} percentile air temperature and low flows that occur only once every ten years). The system-potential temperature does not, however, replace the numeric criteria, nor invalidate the need to meet the numeric criteria at other times of the year and at other less extreme low flows and warm climatic conditions.

At locations and times where the system-potential temperature is greater than the numeric criterion assigned to the waterbody (Figure 9), the loading capacity and load allocations in this TMDL should be established such that human activities/sources do not increase water temperatures more than an additional 0.3°C. In all waters where the system-potential temperature is higher than the assigned criterion, maximum riparian shade and best the channel and flow conditions possible are needed.

Upper Naches River

For the upper Naches River (RM 38.8 to 17.6), predicted system-potential water temperatures will not meet numeric water quality standards during the hottest period of the year. Hence, there is a widespread need to achieve maximum protection from direct solar radiation. The load allocation for the upper Naches River from the USFS boundary (RM 38.8) to the confluence with the Tieton (RM 17.6) is the effective shade that would occur from system-potential mature riparian vegetation and a 10% reduction in channel width (Appendix F).

System-potential mature riparian vegetation is defined as: that vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes.

Upper Naches River tributaries and Cowiche Creek

For the Cowiche Creek system and all tributaries flowing into the upper Naches River, the load allocations for shade are represented in Figure 28 based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum riparian vegetation condition defined in Table 17. Appendix D presents the data in table format. Figure 28 shows that the importance of shade decreases as the width of the channel increases.

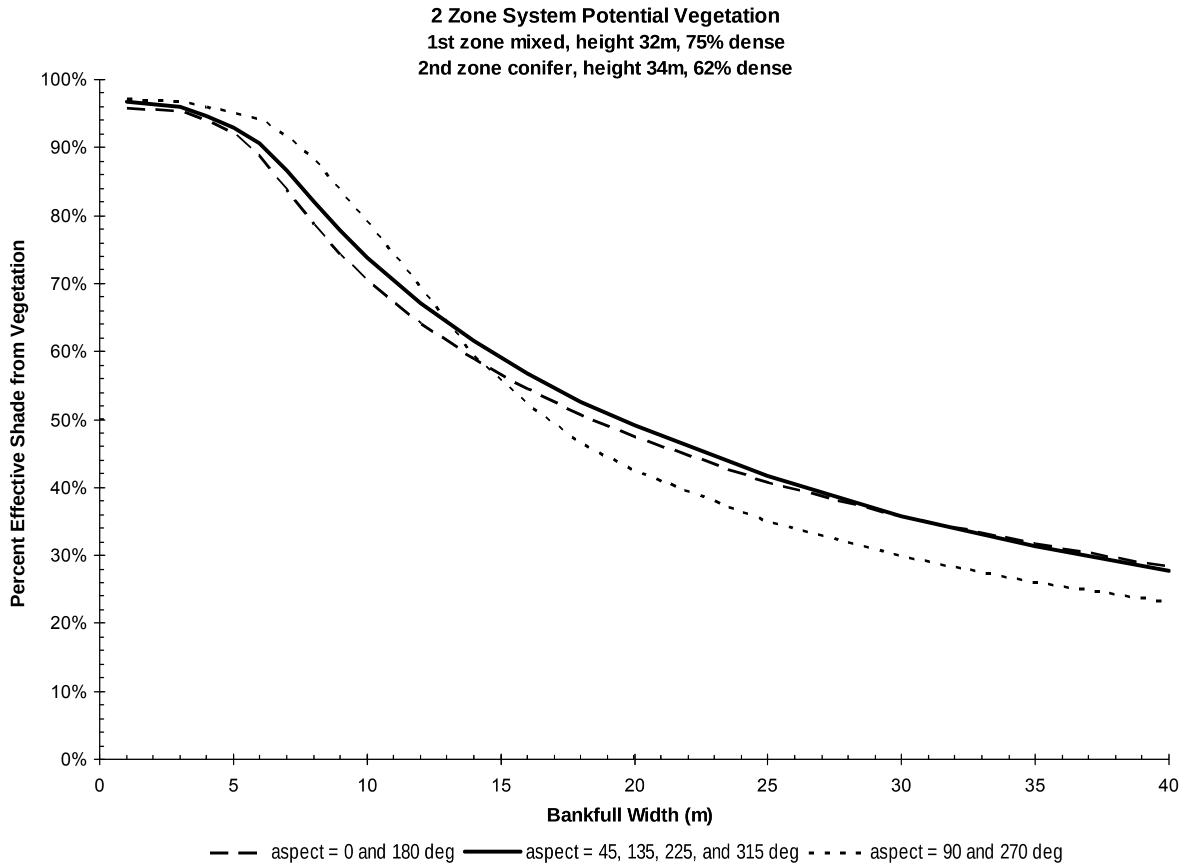

Figure 28. Load allocations for effective shade for various bankfull width and aspect of the un-simulated Cowiche Creek system and tributaries to the upper Naches River.

Surface waters on Wenatchee National Forest lands

The Wenatchee National Forest Temperature TMDL Technical Report developed load allocations based on a channel classification system developed for surface waters within the Wenatchee National Forest. Table 22, in conjunction with Figure 29, outlines the TMDL load allocations, or the effective shade levels required to meet the temperature standard, and the load allocation, or the effective shade level provided by site potential vegetation. Direct application of Table 23 to the listed and impaired streams is provided in Table 23 (Whiley and Cleland, 2003).

Table 22. Wenatchee National Forest Temperature TMDL Technical Report load allocations by channel class for M242Cp Naches Mountains.

Classification	Flow (cfs)	W:D (wetted)	TMDL Allocation Effective Shade (%)	Load Allocation (System Potential) Effective Shade (%)		
				Group a	Group b	Group c
Cp-1A	1	10	70	48	61	70
Cp-1B	1	15	70	48	61	70
Cp-2B	2	15	70	47	61	69
Cp-2C	2	15	70	47	61	69
Cp-3B	4	20	60	46	58	67
Cp-3C	4	30	65	46	58	67
Cp-4C	8	35	60	43	55	63
Cp-5C	16	40	55	39	51	58
Cp-6C	32	45	50	33	44	51

W:D = width:depth.

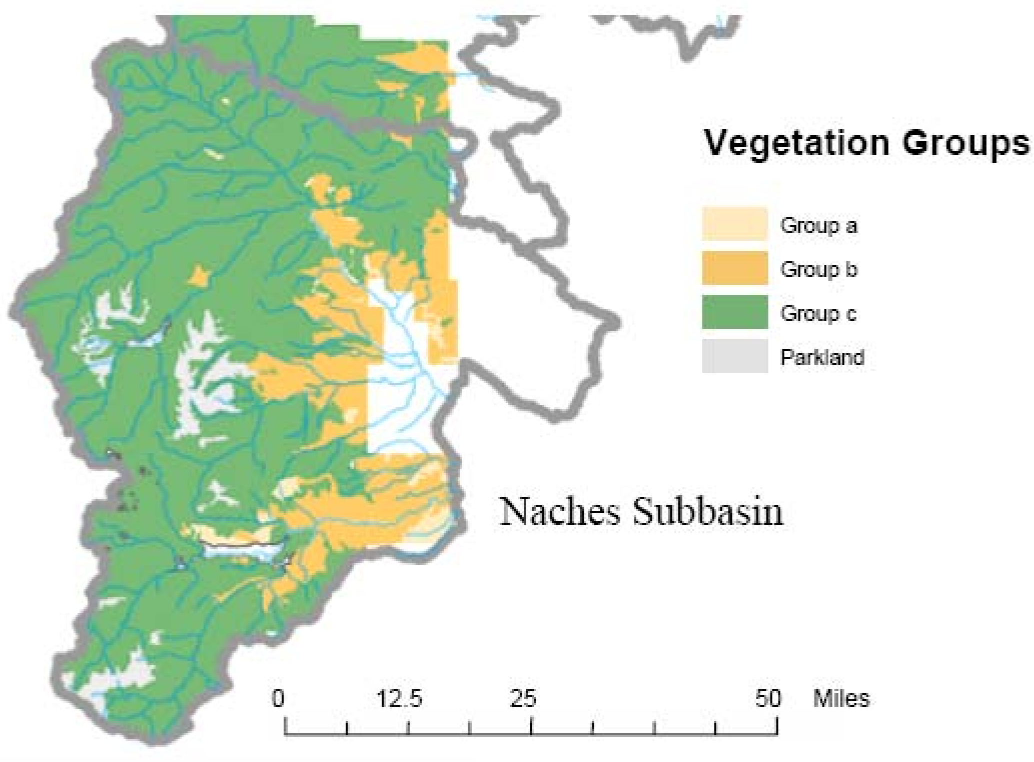

Figure 29. Wenatchee National Forest vegetation groups for the Naches River subbasin.

Table 23. Allocations developed in the Wenatchee National Forest Temperature TMDL Technical Report.

Stream Name	1996 Waterbody ID	Township, Range, Section	Stream Classification	TMDL Allocation Effective Shade (%)	Load Allocation Effective Shade (%)
American River	WA-38-1060	17N,13E,12	Cp-5Cc	55	58
Bear Creek	WA-38-1088	19N,13E,32	Cp-2Bc	70	69
NF Nile Ck. (Benton)	WA-38-2110	16N,15E,03	Cp-1Ab	70	61
Bumping River	WA-38-1070	17N,13E,12	Cp-5Cc	55	58
Crow Creek	WA-38-1081	18N,14E,30	Cp-4Cc	60	63
Gold Creek	WA-38-1041	17N,14E,36	Cb-2Aa	70	47
Mathew Creek	WA-38-1086	18N,13E,10	Cp-2Bc	70	69
SF Tieton River	WA-38-3000	13N,13E,13	Cp-5Cc	55	58
Rattlesnake Creek	WA-38-1035	15N,14E,10	Cp-5Cb	55	51
Hause Creek	-	14N, 14E, 21	Cp-2Bb	70	61
Little Rattlesnake Ck.	-	15N, 14E, 25	Cp-3Cb	65	58
Little Naches River	-	17N, 14E, 4	Cp-6Cc	50	51
Little Naches River	-	18N, 14E, 30	Cp-5Cc	55	58
Little Naches River	-	18N, 13E, 14	Cp-5Cc	55	58
Little Naches River	-	18N, 13E, 9	Cp-4Cc	60	63
Little Naches River	-	18N, 13E, 5	Cp-4Cc	60	63
Sand Creek	-	18N, 13E, 14	Cp-2Bc	70	69
Bumping River	-	17N, 14E, 4	Cp-6Cc	50	51
Bumping River	-	16N, 11E, 36	Cp-4Cc	60	63
Quartz Creek	-	18N, 14E, 30	Cp-3Cc	65	67
Grey Creek	-	13N, 13E, 29	Cp-1Ab	70	61

Results and discussion

The load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural conditions. Therefore, the load allocations are expected to result in water temperatures that meet the water quality standard.

Establishment of mature riparian vegetation is expected to also have a secondary benefit of reducing channel widths and improving microclimate conditions to address those influences on the loading capacity. An adaptive management strategy is recommended to address other influences on stream temperature such as sediment loading, groundwater inflows, and hyporheic exchange.

Wasteload allocations

The water quality standards (WAC 173-201A) restrict the amount of warming that point sources can cause when temperatures are warmer than water quality criteria. At times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times.

Maximum effluent temperatures should also be no greater than 33ºC to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life (WAC 173-201A-200).

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

Maximum temperatures (T_{NPDES}) for the NPDES effluent point source discharges into Cowiche Creek, including the Cowiche Regional Publicly Owned Treatment Works (POTW) and six fruit packing facilities, were calculated from the following mass balance equation (Ecology, 2007), in recognition that the system-potential upstream temperature is greater than 17.5ºC.

Salmonid spawning, rearing and migration:

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

Cowiche Regional POTW

The Cowiche POTW discharges water to the North Fork Cowiche Creek about two miles upstream of the confluence with the mainstem Cowiche Creek. Table 24 presents the maximum effluent temperature allowable for the reported dilution factor for the Cowiche POTW Permit No WA-005239-6. The permit does not allow a mixing zone for the Cowiche POTW for the following reasons:

- The effluent discharge point occurs in the vicinity of a segment listed as impaired on Ecology's 303(d) list.
- The Cowiche Canyon Conservancy (a sensitive area) is three miles downstream of the outfall, and potential impacts to downstream sensitive habitat have not been adequately addressed.
- The critical flow is too low to authorize a mixing zone.
- The current outfall configuration does not minimize the size of the mixing zone or concentrations of pollutants as required by the NPDES permit.

The Cowiche Creek system was not modeled to determine the system-potential conditions. Therefore, the system-potential temperature upstream from the NPDES discharger may be greater than the water quality criteria of 17.5ºC and will vary depending on the river flow and weather conditions. The wasteload allocation expressed in the permit limit must ensure the discharge does not exceed the water quality standards under all but the most critical conditions (7Q10 flows).

Table 24. Wasteload allocation for the Cowiche Regional Publicly Owned Treatment Works.

NPDES Facility	Chronic dilution factor	Water quality standard for temperature (degrees C)	Allowable increase in temperature at the mixing zone boundary (degrees C)	T_{NPDES} = Maximum allowable effluent temperature WLA (degrees C)
Cowiche POTW	1.0	17.5	0.3	17.5

Discharge Monitoring Report (DMR) data from the Cowiche POTW for November 2002-June 2007 show that maximum discharge temperatures in June, July, August, and September range between 14.2ºC (57.6°F) and 21.2°C (70.2°F). The design criterion for the POTW is an effluent discharge temperature of 18ºC. The NPDES permit was due for renewal in 2007 at which time the discharge temperature limit would need to be adjusted to 17.5º C.

Fruit packing facilities

Five fruit packing facilities discharge to the North Fork Cowiche Creek between the Cowiche POTW and the confluence with the mainstem Cowiche Creek. One fruit packing facility, Lloyd Garretson Co., discharges to Cowiche Creek near the mouth. Table 25 presents the maximum effluent temperature allowable for the dilution factor for each facility. The dilution factor for each facility was calculated as the ratio between the 7Q10 flow at the mouth of the North Fork Cowiche Creek (0.26-cfs) or the mouth of Cowiche Creek (0.5-cfs) and the maximum DMR reported effluent flow between January 2000 and June 2007.

Each facility is held to the water quality standard of 17.5°C plus 0.3°C at the edge of their mixing zone. This conservative calculation should ensure that cumulatively the facilities do not cause an increase of more than 0.3°C above the waterbody's system-potential temperature.

Table 25. Wasteload allocations for fruit packing facilities that discharge to the North Fork Cowiche Creek.

NPDES Facility	Permit Number	Monitoring Point	Chronic dilution factor	Water quality standard for temperature (˚C)	Allowable increase in temperature at the mixing zone boundary (˚C)	T_{NPDES} = Maximum allowable effluent temperature WLA (˚C)
Strand Apples Inc Marley Bldg	WAG435036C	1	20	17.5	0.3	23.2
Strand Apples Inc Main Plant	WAG435044C	3	2	17.5	0.3	17.8
Cowiche Growers Inc	WAG435046C	5	2	17.5	0.3	17.8
Ackley Fruit Company LLC	WAG435070C	1	3	17.5	0.3	18.1
Strand Apples Forney Warehouse	WAG435283A	1	2	17.5	0.3	17.8
Lloyd Garretson, Co.	WAG435210C	1	4	17.5	0.3	18.4

The Fresh Fruit Packing General NPDES permit is due for renewal in 2009. At that time, the discharge temperature limits will need to be adjusted for each of the above permittees. Expansion or reduction in facility size can affect effluent temperature limits in the future.

Other dischargers

Several NPDES permittees that discharge to the lower Naches River were not give wasteload allocations in this TMDL because they are outside of, and downstream from, the study area for this TMDL. All of these point sources will be addressed in a later temperature TMDL. NPDES dischargers in the Naches River basin that are not given temperature wasteload allocations in this TMDL include the Naches Sewage Treatment Plant (STP), Naches Hatchery, and six fruit packing facilities that discharge to the lower Naches River.

The Naches STP (permit WA-002258-6) and Naches Hatchery (permit WAG135003D) were not addressed in this TMDL because the outfalls from both facilities discharge to the lower Naches River (RM 17.6 to 0). These point sources should be addressed in a later TMDL.

Wasteload allocations were not developed for six fruit packing facilities that discharge to the lower Naches River (Table 26). These were not addressed because they discharge to a river segment which was not addressed in this TMDL. These facilities will be addressed in a later temperature TMDL.

Table 26. Fruit packing facilities along the lower Naches River.

Facility	Permit #	Outfall ID
Allan Brothers Gleed CA 2	WAG435015C	1
Upper Valley Fruit	WAG435016C	1
Price Cold Storage Gleed Rd	WAG435034C	1
Allan Brothers	WAG435051C	1
Rowe Farms Inc	WAG435095C	3
Apple King LLC	WAG435160C	1 and 4

Allocation for future growth

EPA *guidance* suggests considering anticipated *future growth* when allocating loadings for point sources. However, the North Fork Cowiche Creek is an effluent-dominated stream, and the current NPDES permit for the Cowiche POTW does not allow for a mixing zone for the plant. Therefore, the wasteload allocation was set to 17.5°C. Hence, future plant expansions will need to continue to adhere to the 17.5°C effluent temperature limit.

Additionally, there is no reserve loading for future expansions of existing dischargers or new dischargers.

Margin of safety

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

- The 90th percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the Yakima Airport represents a reasonable worst-case condition for prediction of water temperatures in the upper Naches River watershed. Typical conditions were represented by the median of the highest 7-day averages of daily maximum air temperatures for each year of record.

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

- Model uncertainty for prediction of maximum daily water temperature was assessed by estimating the root-mean-square error (RMSE) of model predictions compared with observed temperatures during model validation. The average RMSE for model calibration and confirmation was 0.6°C.

- The load allocations are set to the effective shade provided by fully mature riparian shade. These allocations are the maximum values achievable in the upper Naches River (RM 38.8 to 17.6) basin.

The margin of safety is also explicit because:

- Cloud cover collected at the airport was used for all model scenarios run for the upper Naches River segments. In addition, a cloud cover of 0% was used for the critical condition model runs.

- The wasteload allocations for the point sources were developed using the maximum reported DMR facility flows and 7Q10 streamflows to calculate the dilution factors.

Management recommendations

In addition to the load allocations for effective shade in the study area, the following management activities are recommended for compliance with Washington State water quality standards throughout the watershed:

- For USFS managed lands in the Wenatchee National Forest, continue implementation of riparian reserves and maintenance of mature riparian vegetation as established by the Northwest Forest Plan.

- Load allocations are included in this TMDL for non-federal forest lands in accordance with Section M-2 of the Forests and Fish Report. The report can be found at: www.dnr.wa.gov/forestpractices/rules/forestsandfish.pdf. Consistent with the Forests and Fish agreement, implementation of the load allocations established in this TMDL for private and state forestlands will be accomplished via implementation of the revised forest practices regulations.

- For areas that are not managed by the USFS or in accordance with the state forest practices rules, such as private non-forest areas, voluntary programs to increase riparian vegetation should be developed. Example voluntary programs are riparian buffers or conservation easements sponsored under the U.S. Department of Agriculture Natural Resources Conservation Service's Conservation Reserve Enhancement Program.

- Instream flows and water withdrawals are managed through regulatory avenues separate from TMDLs. However, stream temperature is related to the amount of instream flow, and increases in flow generally result in decreases in maximum temperatures. Future projects that have the potential to increase groundwater or surface water inflows to streams in the watershed, and decrease stream temperatures, should be encouraged.

- Management activities that would reduce the loading of sediment to the surface waters from upland and channel erosion are also recommended.

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

- Management activities that increase the amount of large woody debris in the Naches River system will assist in pool forming processes and reducing flow velocities that scour spawning gravels and contribute to channel incision.

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Appendices

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Appendix A. Glossary and acronyms

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.

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 waterbody and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for July and August as these typically represent the critical months for temperature in our state.

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

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

7-DADMax or *7-day average of the daily maximum temperatures* is 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.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Angular Canopy Density (ACD): A measure of the density of canopy actually capable of shading the stream. At a given point on a stream, ACD is the percentage of time that a stream will be shaded between 10 AM to 2 PM local solar time.

Best management practices (BMPs): Physical, structural, and/or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Chronic critical effluent concentration: The maximum concentration of effluent during critical conditions at the boundary of the mixing zone assigned in accordance with WAC 173-201A-100. The boundary may be based on distance or a percentage of flow. Where no mixing zone is allowed, the chronic critical effluent concentration shall be one hundred percent effluent.

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

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

Critical period: Mid-July through mid-August.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each waterbody or segment, regardless of whether or not the uses are currently attained.

Diel: Of, or pertaining to, a 24-hour period.

Dilution Factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of an mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100. http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

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

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

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

Hyporheic: The area under and along the river channel where surface water and groundwater meet.

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

Loading capacity: The greatest amount of a substance that a waterbody 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 waterbody.

Morphology: River cross-sectional shape.

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): (i) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, storm water, or other wastes and (ii) designed or used for collecting or conveying stormwater; (iii) which is not a combined sewer; and (iv) 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.

Near Stream Disturbance Zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

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

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

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

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or is 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: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

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

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

System potential: The design condition used for TMDL analysis.

System-potential channel morphology: The more stable configuration that would occur with less human disturbance.

System-potential **mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

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

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

Thalweg: The deepest and fastest moving portion of a stream.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation (WLA): 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

ACD	Angular canopy densitometers
DMR	Discharge Monitoring Report
DNR	Washington State Department of Natural Resources
d/s	Downstream
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
GIS	Geographic Information System software
N.F.	North Fork
POTW	Publicly Owned Treatment Works
RAWS	Remote Automated Weather Station
RM	River Mile
S.F.	South Fork
SHU	Stream Hydrology Unit
TIR	Thermal infrared radiation
u/s	Upstream
USBR	U.S. Bureau of Reclamation
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
W/m2	Watts per square meter
WDFW	Washington Department of Fish and Wildlife
WAC	Washington Administrative Code
WRIA	Water Resources Inventory Area
WSDOT	Washington State Department of Transportation
WQ	Water Quality

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Appendix B. 7-DADMax and maximum temperature graphs

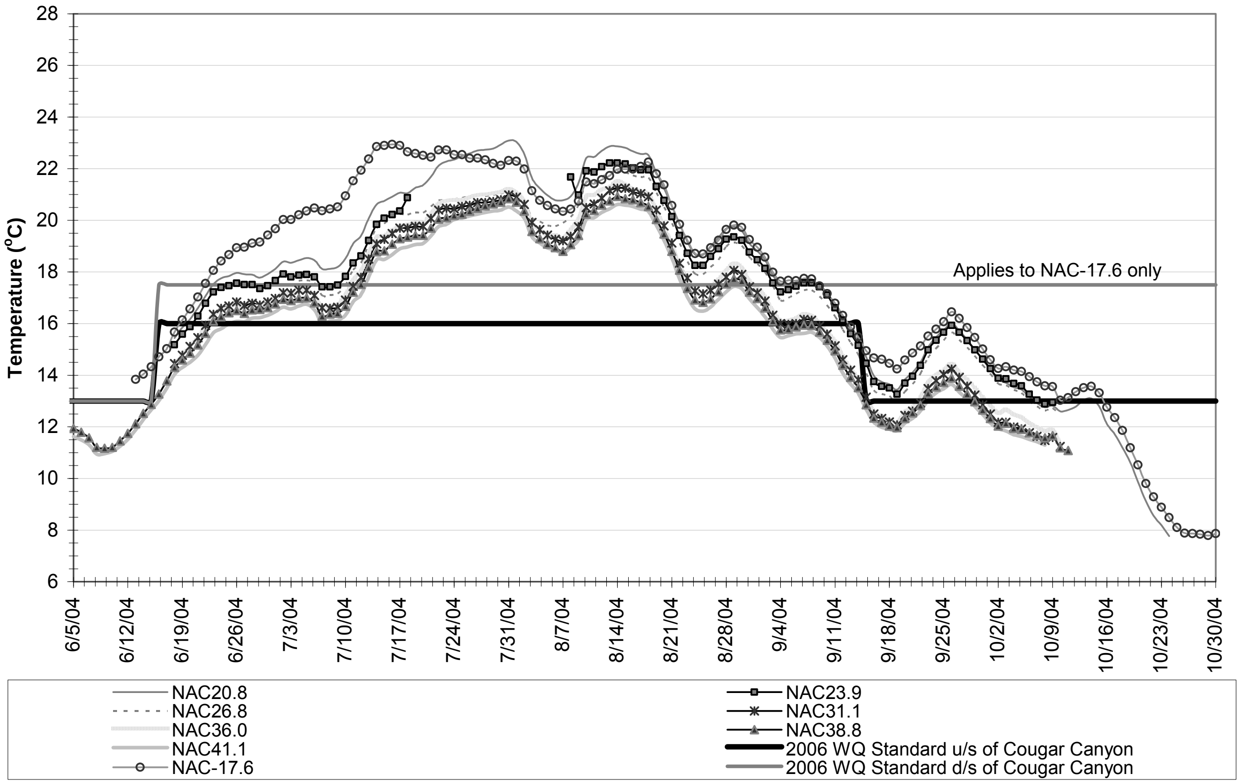

Figure B-1. 7-day average maximum temperatures observed at upper Naches River mainstem stations.

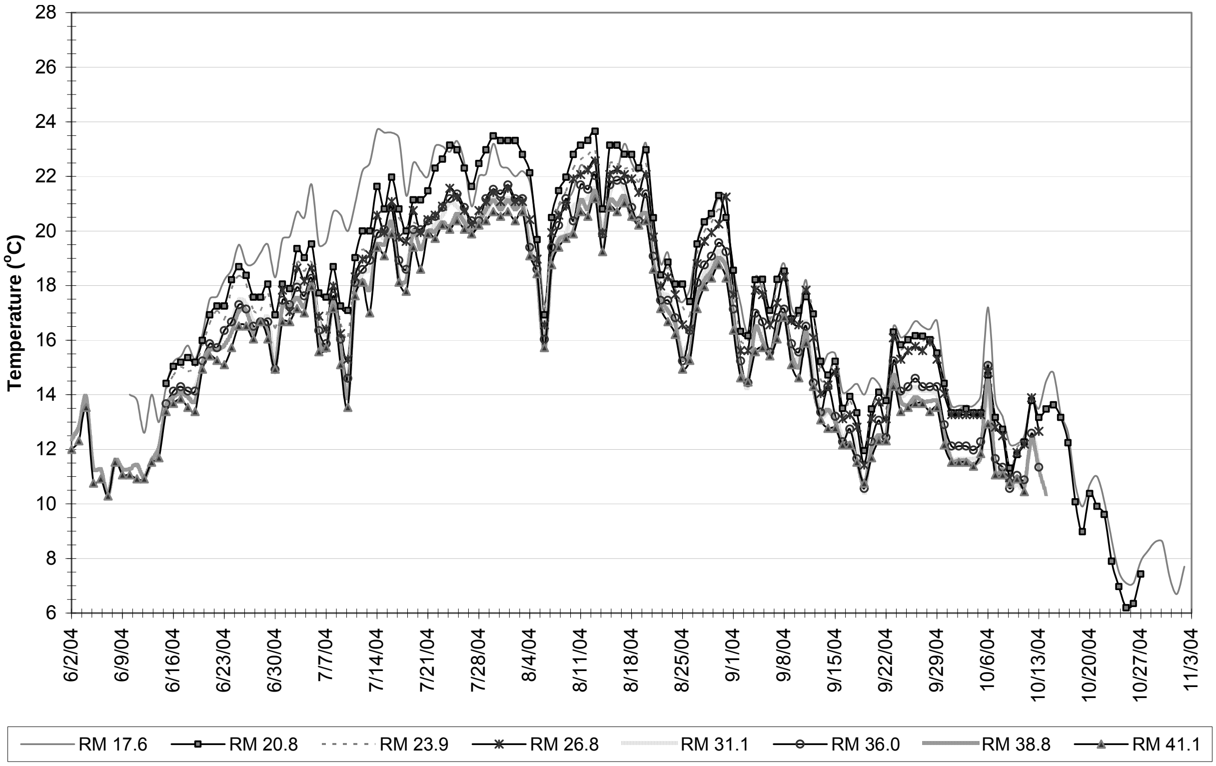

Figure B-2. Maximum temperatures observed at upper mainstem Naches River stations.

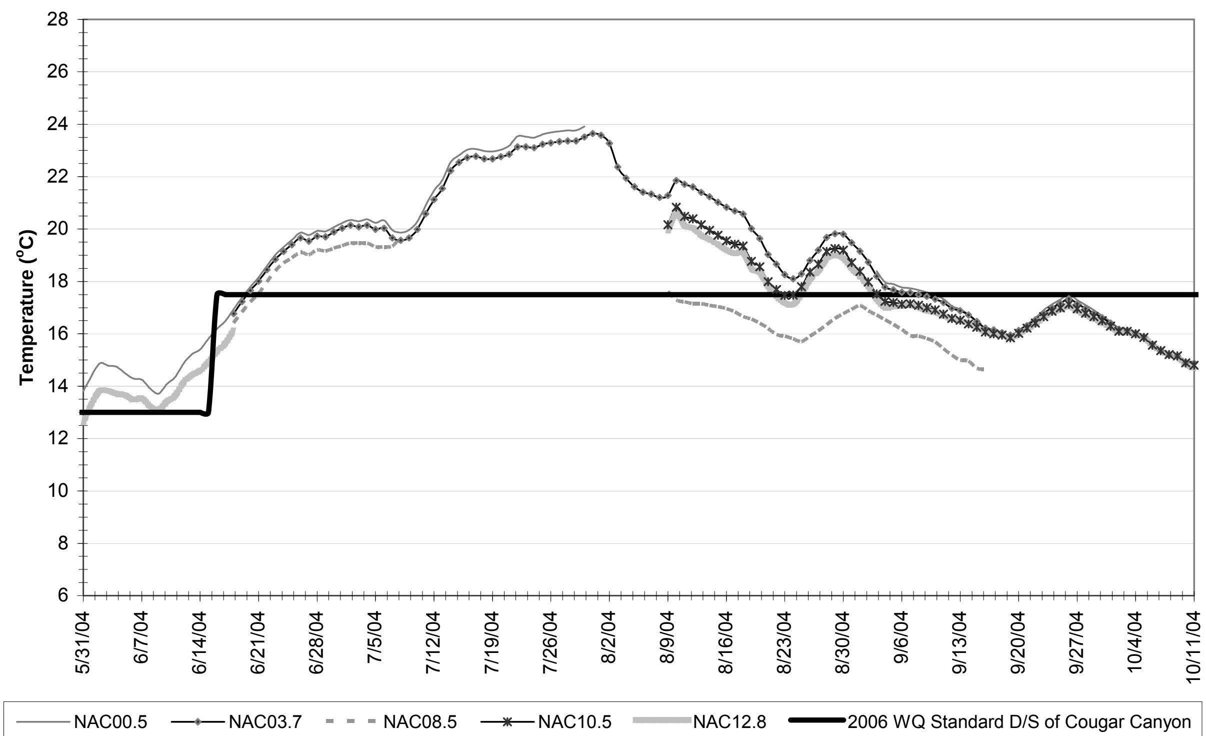

Figure B-3. 7-day average maximum temperatures observed at lower Naches River stations.

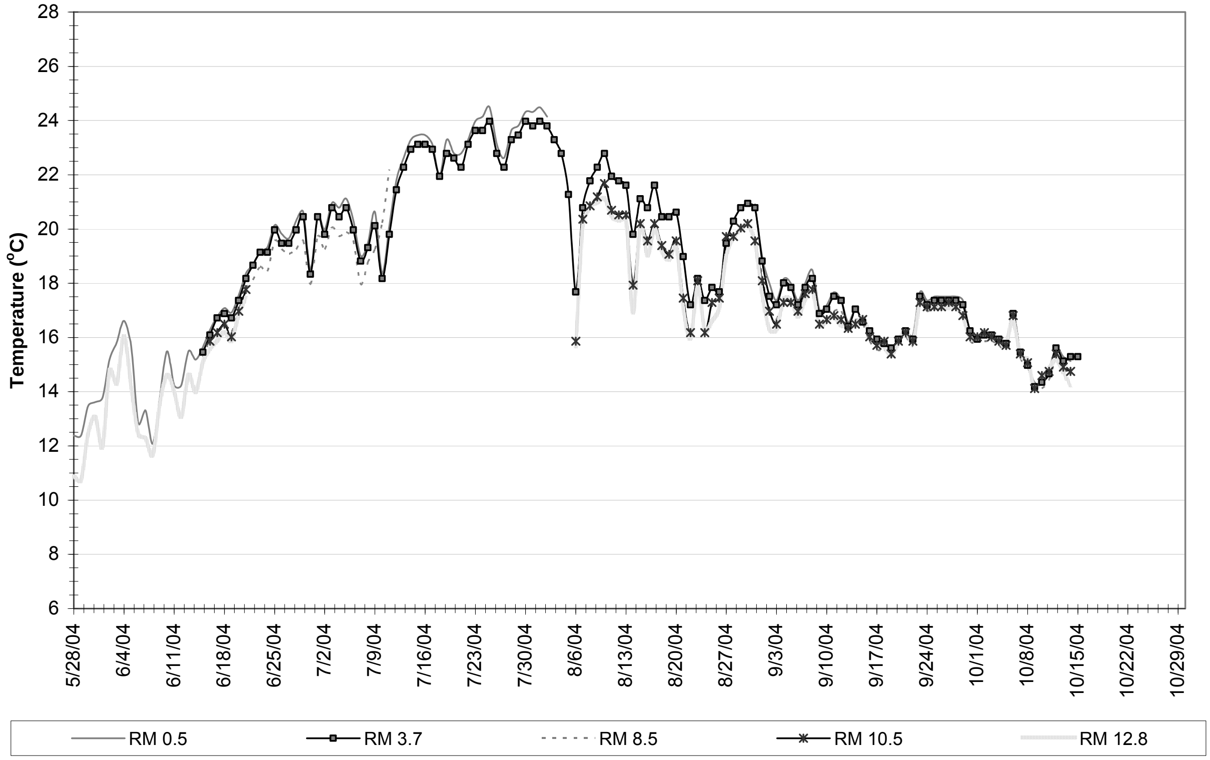

Figure B-4. Maximum temperatures observed at lower Naches River stations.

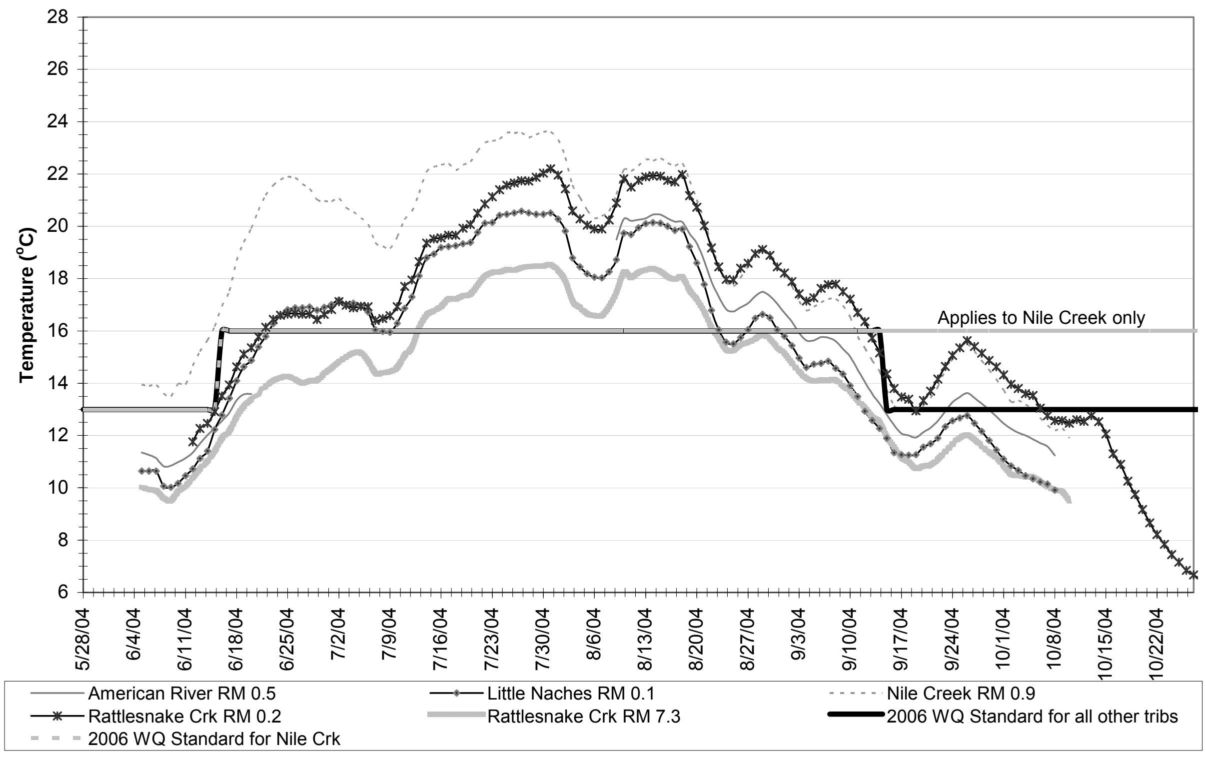

Figure B-5. 7-day average maximum temperatures observed at tributary stations in the upper Naches River basin.

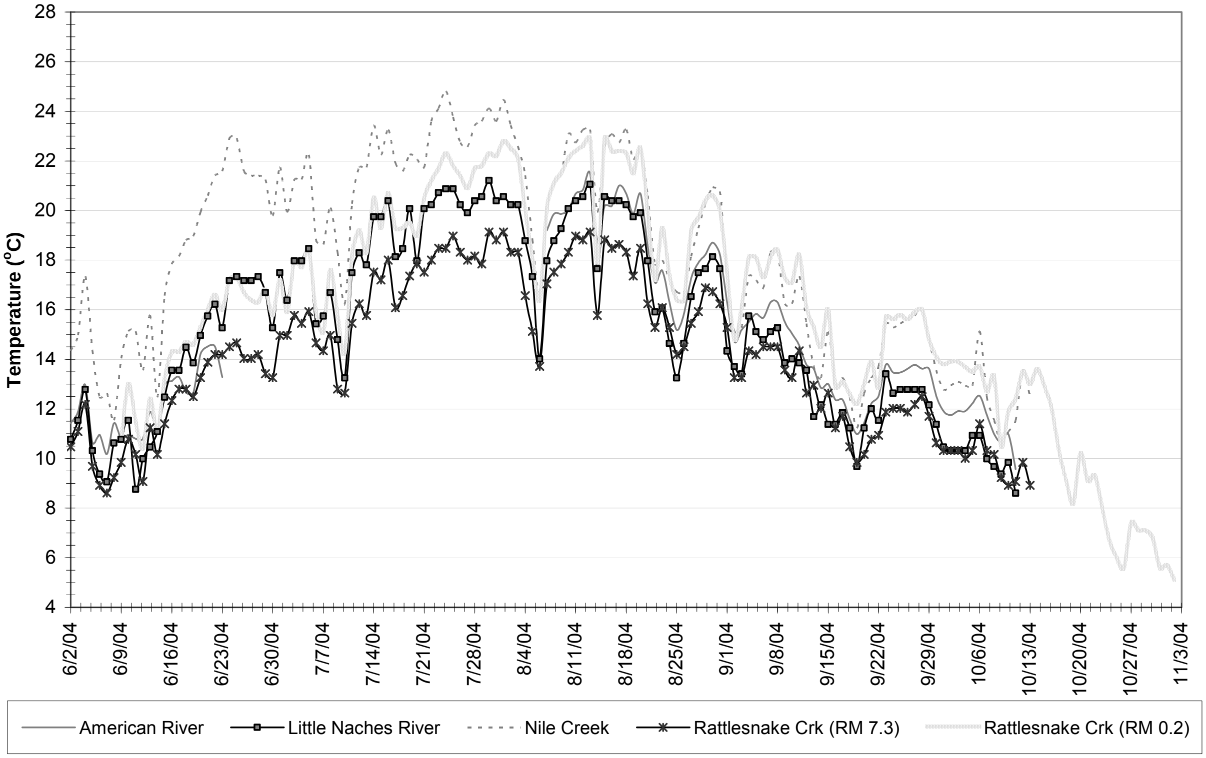

Figure B-6. Maximum temperatures observed at tributary stations in the upper Naches River basin.

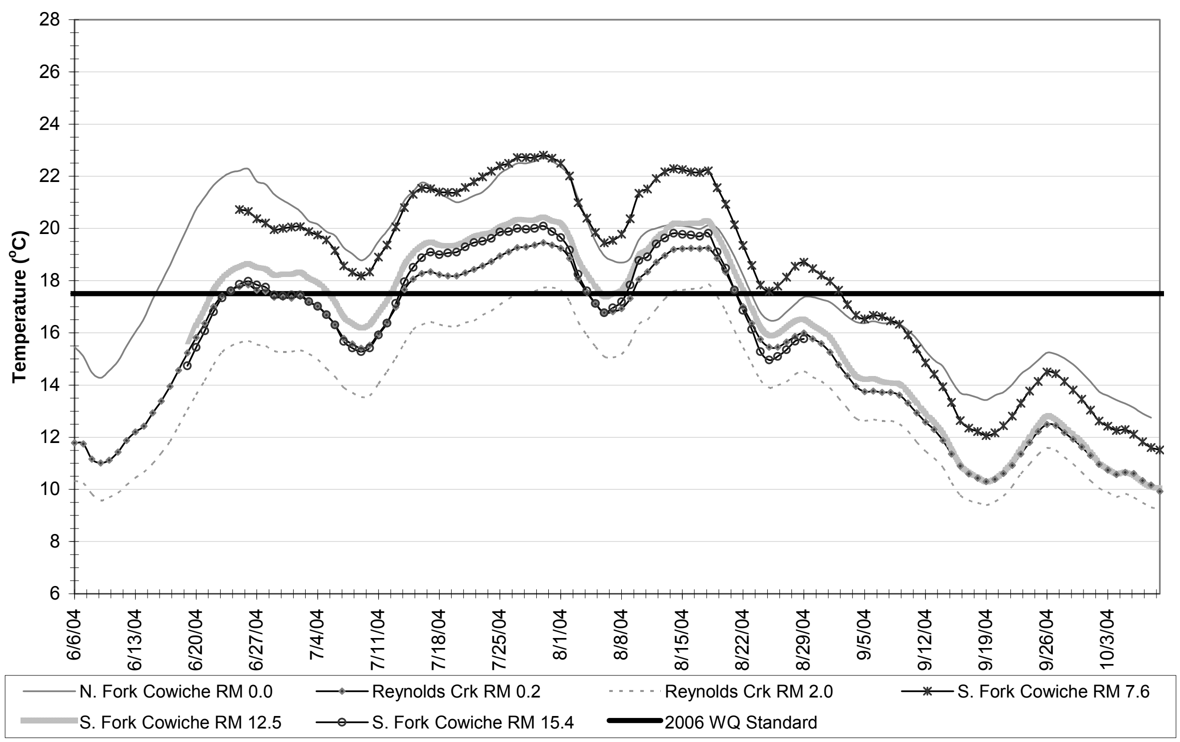

Figure B-7. 7-day average maximum temperatures observed at tributary stations in the lower Naches River basin (Chart 1 of 2).

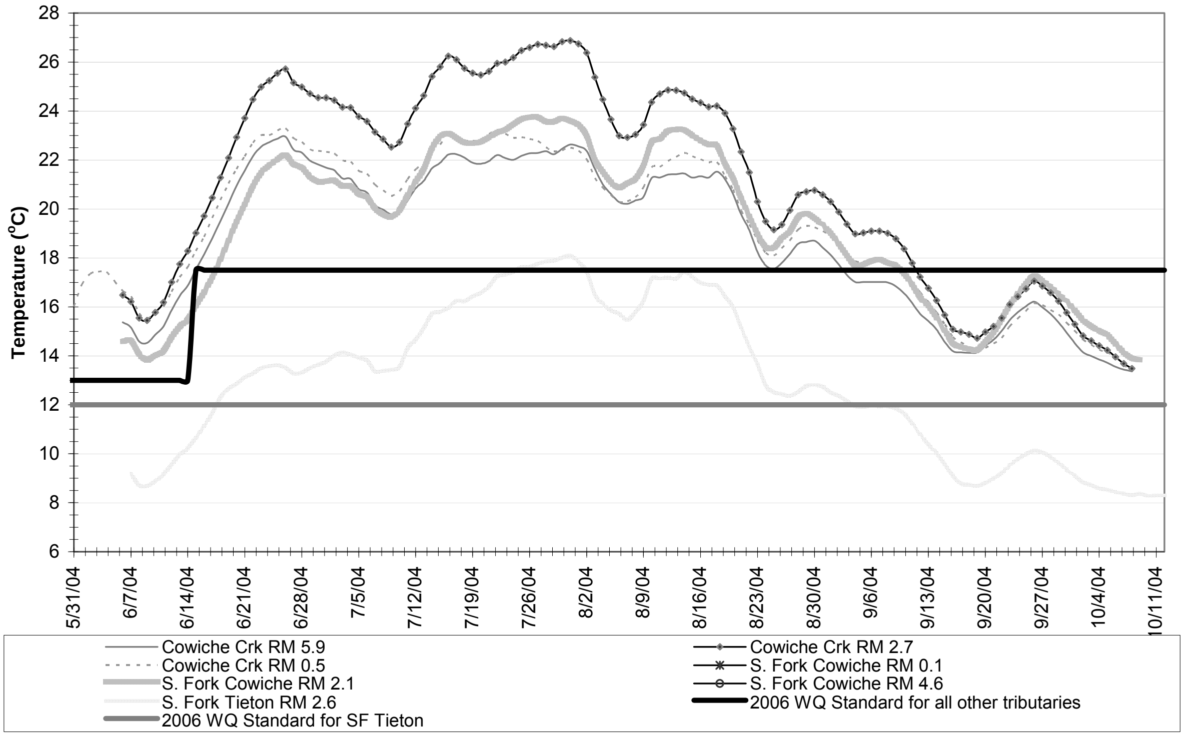

Figure B-8. 7-day average maximum temperatures observed at tributary stations in the lower Naches River basin (Chart 2 or 2).

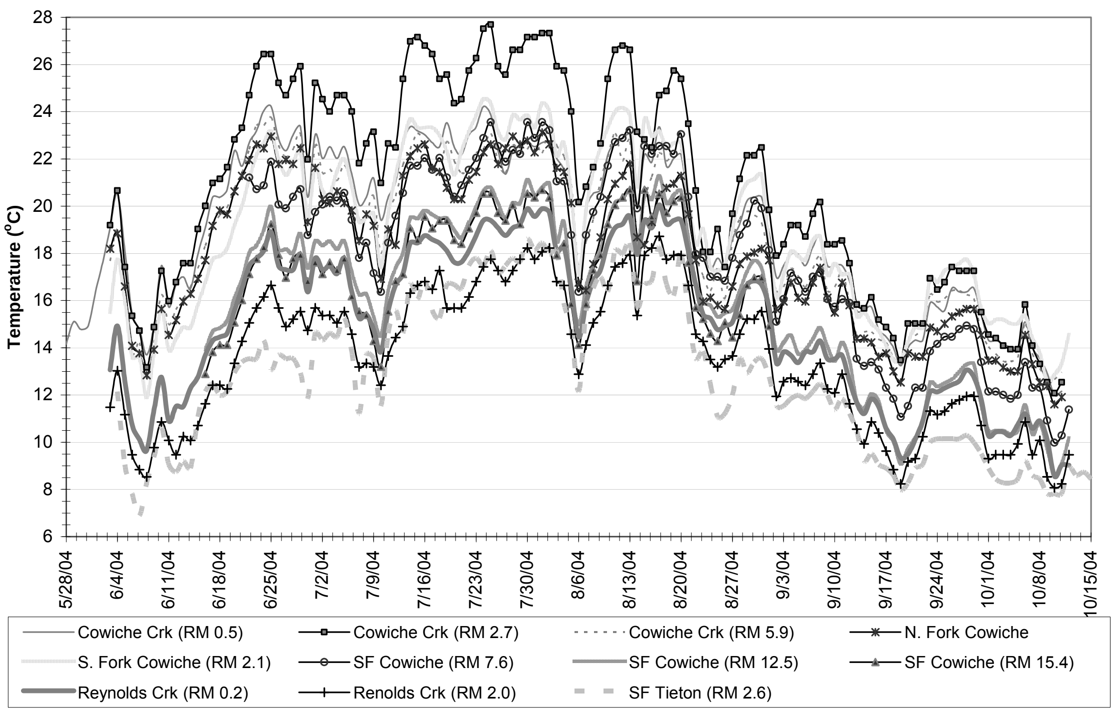

Figure B-9. Maximum temperatures observed at tributary stations in the lower Naches River basin.

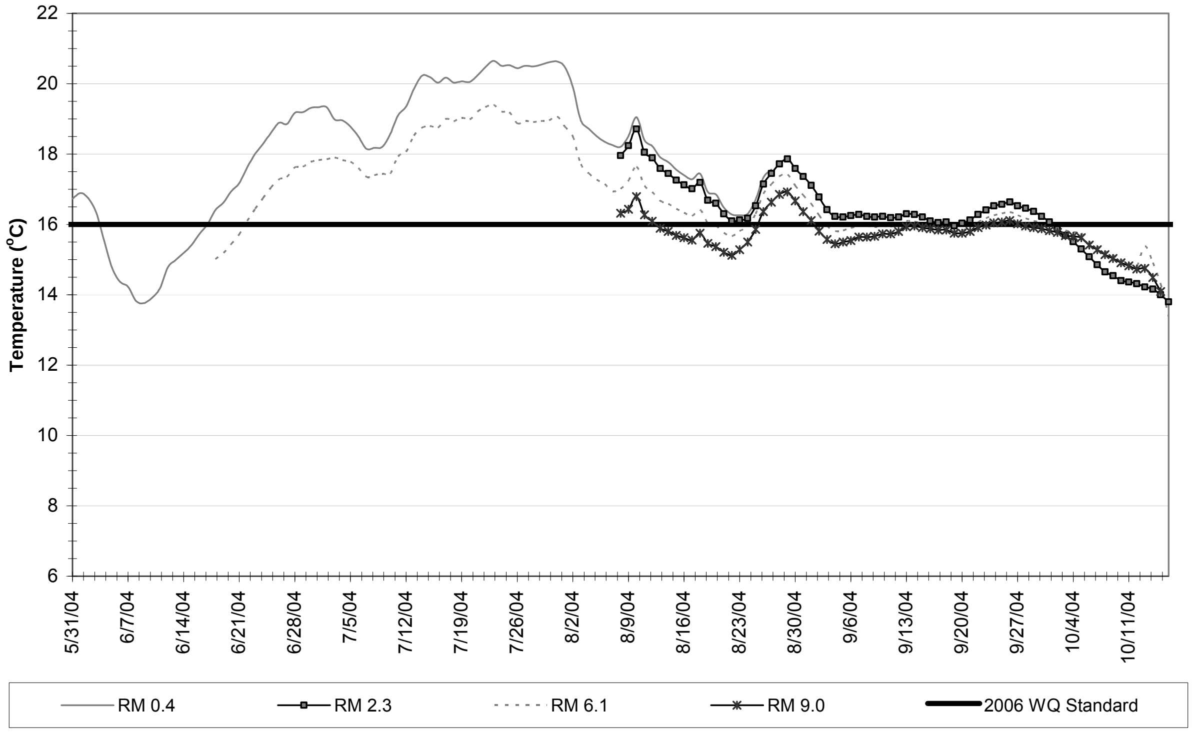

Figure B-10. 7-day maximum rolling average temperatures observed at mainstem Tieton River stations.

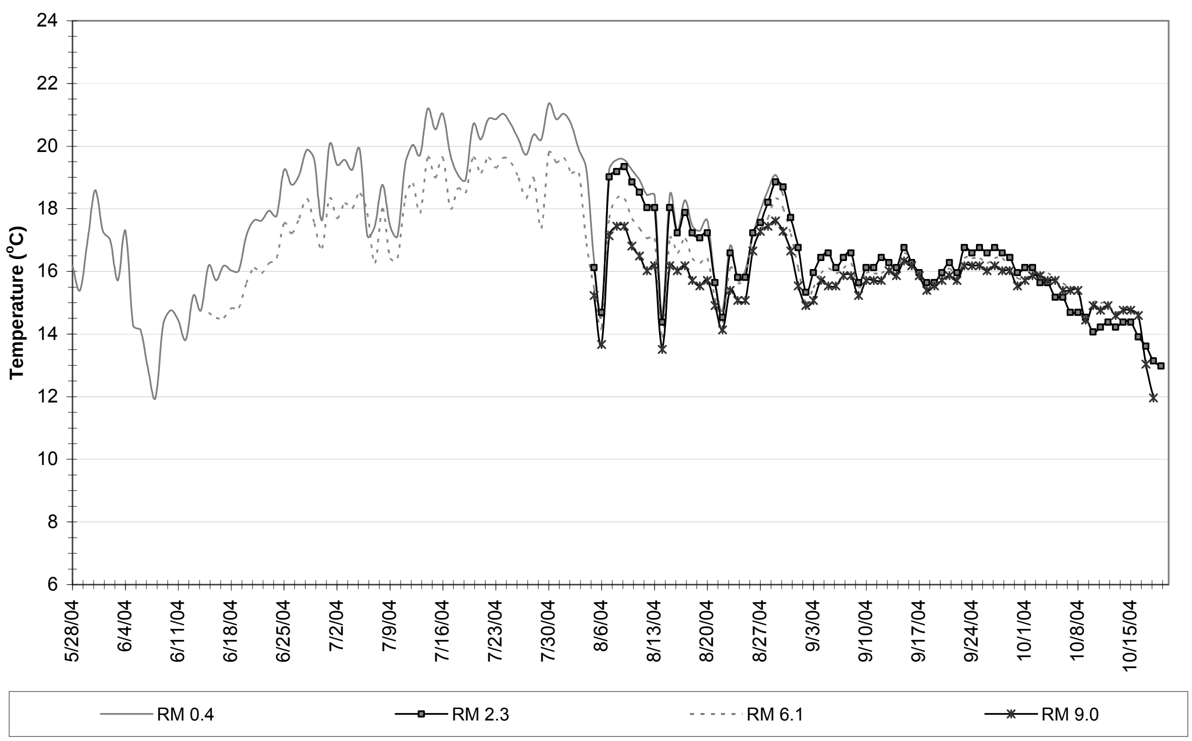

Figure B-11. Maximum temperatures observed at mainstem Tieton River stations.

Appendix C. Channel survey data

Table C-1. Channel data collected during the Naches River Temperature TMDL field surveys.

Site	Wetted Width		Bankfull Width		NSDZ			Wetted Depth			Bankfull Depth			Flood-plain Width	Incision		
	Ave	Std Dev	Ave	Std Dev	Ave	Std Dev	n	Ave	Std Dev	n	Ave	Std Dev	n		Ave	Std Dev	n
Upstrm of NAC 41.1	36	6	45	3	49	5	3	0.4	0.2	3	0.6	0.3	3	99	2	1	4
Btwn NAC 41.1 - 38.8	36	8	41	10	57	12	4	0.5	0.1	3	0.7	0.2	3	90	2	1	6
Btwn NAC 38.8 - 36.0	36	10	44	16	58	19	4	0.7	0.4	4	0.7	0.2	4	80	3	4	8
Btwn NAC 31.1 - 26.8	38	11	46	10	90	27	9	0.4	0.1	9	0.6	0.2	9	101	2	3	18
38-NAC-23.9	20	21	21	22	63	9	4	0.4	0.1	5	0.4	0.1	5	29	1	1	10
38-NAC-17.6	38	26	40	27	91	36	7	0.3	0.1	7	0.4	0.1	7	87	1	0	14
38-TIE-0.4	20	3	25	4	40	11	10	0.3	0.1	10	0.8	0.2	10	55	4	13	20
38-TIE-2.3	24	5	29	5	44	9	10	0.2	0.0	10	0.7	0.1	10	64	3	2	20
38-TIE-06.1	18	4	24	4	48	13	10	0.3	0.1	10	0.8	0.1	10	44	1	1	20
38-TIE-09.0	22	13	30	14	40	14	11	0.2	0.1	11	0.8	0.1	11	53	1	1	22
38-TIE-16.2	70	15	105	14	168	38	10	0.9	0.1	10	3.2	0.5	10	189	1	1	20
38-RAT-0.2	64	22	82	22	267	36	10	0.6	0.5	10	1.8	0.5	10	181	11	6	20
38-RAT-07.3	46	15	86	42	161	39	10	1.0	0.6	10	3.0	1.0	10	121	81	91	20
38-COW-00.5-06.3	2	2	3	4	8	1	4	0.1	0.0	4	0.4	0.1	4	4	2	1	8
38-SFC-00.1-15.4	3	2	5	3	12	7	8	0.1	0.1	8	0.4	0.1	8	8	1	1	16

NSDZ = near stream disturbance zone
Ave = average
Std Dev = standard deviation
N = number
Upstrm = upstream
Btwn + between

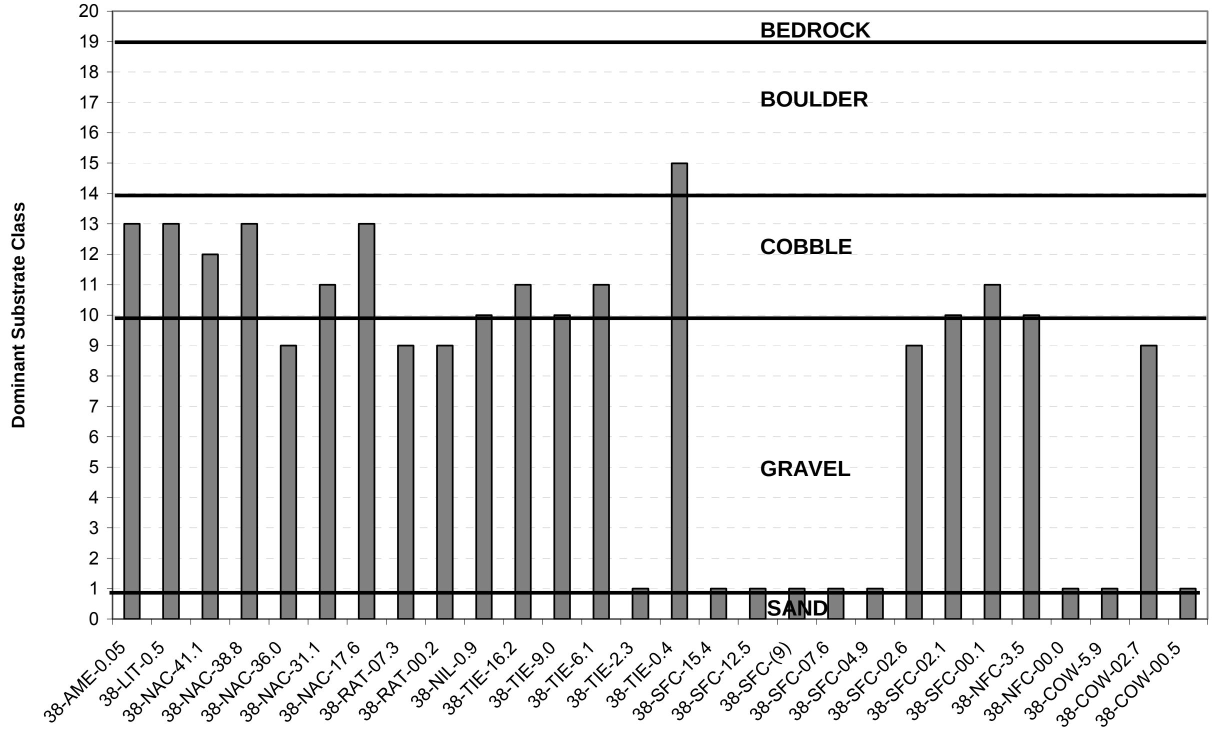

Figure C-1. Dominant substrate class by station.

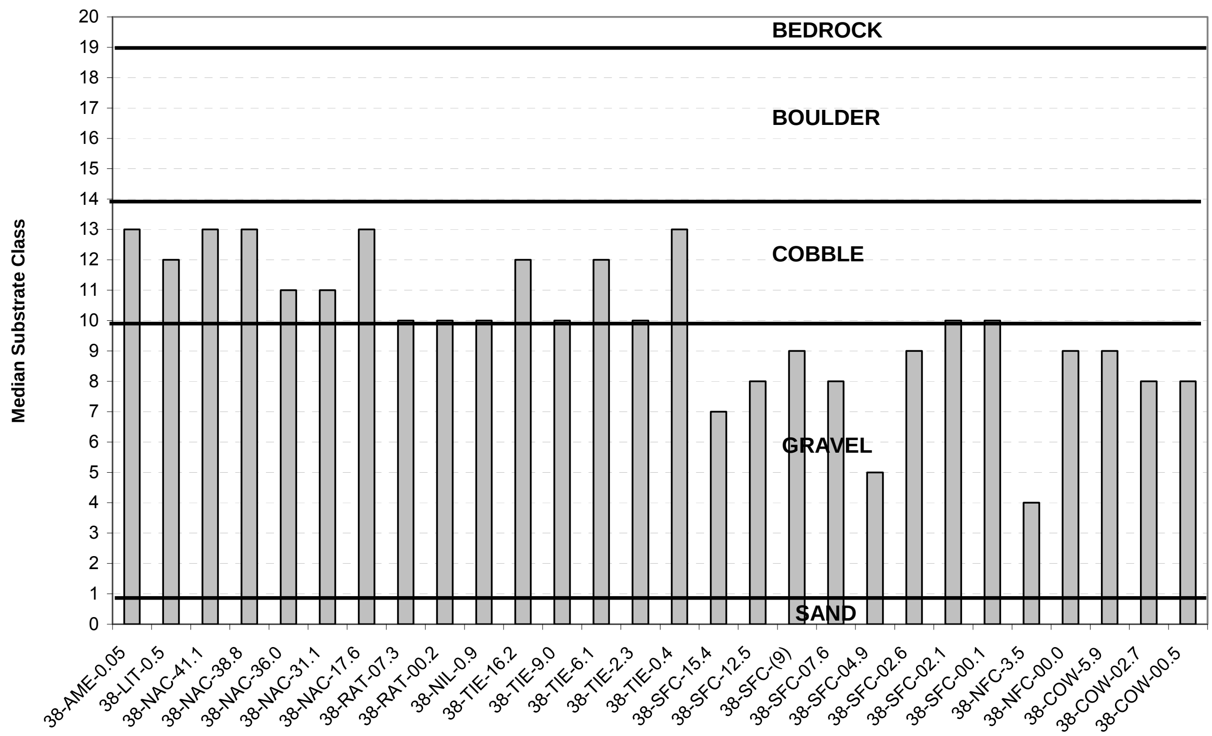

Figure C-2. Median substrate class by station.

Appendix D. Load allocation table for upper Naches River tributaries and Cowiche Creek

Table D-1. Effective shade and solar shortwave radiation load allocations for upper Naches River tributaries and Cowiche Creek. This table is derived from the shade curves shown in Figure 28.

Bankfull width (m)	Percent Effective Shade from vegetation at the stream center at various stream aspects (degrees from N)			Daily average global solar shortwave radiation (W/m2) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
1	95.8%	96.7%	97.2%	12.6	10.1	8.6
2	95.6%	96.3%	96.9%	13.3	11.2	9.5
3	95.4%	96.0%	96.7%	13.9	12.2	10.1
4	94.0%	94.6%	96.1%	18.2	16.3	11.9
5	92.1%	92.9%	95.3%	24.0	21.5	14.3
6	88.7%	90.6%	94.3%	34.2	28.6	17.2
7	83.7%	86.6%	91.6%	49.4	40.7	25.5
8	78.5%	82.1%	88.3%	65.2	54.3	35.5
9	74.1%	77.7%	83.6%	78.5	67.4	49.6
10	70.3%	73.9%	79.0%	90.1	79.2	63.7
12	64.0%	67.1%	69.4%	109.2	99.6	92.8
14	58.8%	61.6%	59.3%	124.8	116.5	123.2
16	54.4%	56.8%	52.1%	138.2	130.9	145.1
18	50.6%	52.6%	46.5%	149.8	143.5	162.2
20	47.3%	49.1%	42.4%	159.6	154.4	174.4
25	40.8%	41.6%	35.0%	179.5	177.0	197.1
30	35.7%	35.8%	29.8%	194.8	194.6	212.7
35	31.6%	31.3%	26.1%	207.1	208.3	224.1
40	28.3%	27.7%	23.1%	217.1	219.1	232.9

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Appendix E. Monitoring stations for the Naches River Temperature Study

Station ID	Station Description	Instream Temperature	Air Temperature	Relative Humidity	Piezometer	Hyporheic Temperature	Instream Flow
38-AME-00.5	American R at Halfway Flat Campground	X	X				I
38-COW-00.5	Cowiche Crk at W. Powerhouse Rd	X	X				I
38-COW-02.7	Cowiche Crk below Cowiche Canyon	X	X				I
38-COW-05.9	Cowiche Crk above Cowiche Canyon	X					I
38-LIT-00.1	Little Naches R at Hwy 410 bridge	X					I
38-NAC-00.5	Naches R at BOR Station near mouth	X			X	X	I
38-NAC-03.7	Naches R at Powerhouse Rd	X	X		X	X	
38-NAC-08.5	Naches R at Eschach Park	X	X	X	X	X	
38-NAC-10.5	Naches R d/s of Naches at Public Fishing	X			X	X	
38-NAC-12.8	Naches R at S. Naches Road	X			X		I
38-NAC-16.0	Naches R below confluence with Tieton						I
38-NAC-17.6	Naches R at Y (SHU Station)	X				X	C
38-NAC-20.8	Naches R above Horseshoe Bend	X					I
38-NAC-23.9	Naches R 2.5 miles below Nile Rd	X	X				I
38-NAC-26.8	Naches R at Lower Nile Rd (SHU Station)	X			X	X	C
38-NAC-28.0	Naches R downstream of Rattlesnake Crk						I
38-NAC-30.5	Naches R 0.35 miles below Upper Nile Rd						I
38-NAC-31.1	Naches R at Upper Nile Rd	X			X		I
38-NAC-34.0	Naches R 3 miles upstream of Upper Nile Rd						I
38-NAC-36.0	Naches R at FS Chinook (Cottonwood) Camp	X					I
38-NAC-38.8	Naches R at Lower Old R Rd	X					I
38-NAC-40.0	Naches R downstream of Boulder Cave Rd						I
38-NAC-41.1	Naches R at Boulder Cave Rd	X			X		I
38-NAC-42.0	Naches R 1 mile upstream of Boulder Cave Rd						I
38-NAC-43.0	Naches R 0.5 miles upstream of 410 bridge						I
38-NFC-03.5	North Fork Cowiche Crk at Danner Rd	X	X				I
38-NFC-00.0	North Fork Cowiche Crk near confluence with SFC	X					I
38-NIL-00.9	Nile Crk at Nile Rd	X					I
38-RAT-00.2	Rattlesnake Crk near mouth (SHU)	X					C
38-RAT-07.3	Rattlesnake Crk at FS 119 Rd	X	X				I
38-REY-00.2	Reynolds Crk near mouth	X					I

Station ID	Station Description	Instream Temperature	Air Temperature	Relative Humidity	Piezometer	Hyporheic Temperature	Instream Flow
38-REY-02.0	Upper Reynolds Crk past Van Wyke Prop	X	X				I
38-SFC-00.1	SF Cowiche Crk near confluence (SHU)	X					C
38-SFC-02.1	SF Cowiche Crk at Pioneer Way	X	X				I
38-SFC-04.6	SF Cowiche Crk at Oak Crk CWR		X	X			
38-SFC-07.6	SF Cowiche Crk at 1st bridge on Cowiche Mill Rd	X	X				I
38-SFC-12.5	SF Cowiche Crk at Cowiche Ranger's Bridge	X					I
38-SFC-15.4	SF Cowiche Crk where road ends	X	X				I
38-SFT-02.6	SF Tieton R	X					I
38-TIE-00.4	Tieton R near mouth	X	X	X			I
38-TIE-01.5	Tieton R at Tom's Pond						I
38-TIE-02.1	Tieton R downstream of Oak Crk						I
38-TIE-02.3	Tieton R above Oak Crk	X			X	X	I
38-TIE-03.0	Tieton R upstream of Oak Crk Road Mile 183						I
38-TIE-04.0	Tieton R near Road Mile 182						I
38-TIE-06.1	Tieton R at 2nd turnout above Mile Marker 180	X	X				I
38-TIE-08.5	Tieton R upstream of Windy Point Camp						I
38-TIE-09.0	Tieton R near Windy Pt (u/s Hwy 12 bridge)	X					I
38-TIE-11.0	Tieton R 2.5 miles below Rimrock Retreat						I
38-TIE-13.0	Tieton R downstream of Rimrock Retreat						I
38-TIE-14.0	Tieton R upstream of Rimrock Retreat						I
38-TIE-16.2	Tieton R at Willows campground		X				I

I = instantaneous flow measurement
C = continuous flow measurement
d/s – downstream
BOR = U.S. Bureau of Reclamation
SHU = Stream Hydrology Unit (Ecology)
SFC – South Fork Cowiche

Appendix F. Loading capacity and load allocations for the upper Naches River

			Load Allocation		
Longitudinal Distance (km)	Current Effective Shade (%)	Current Solar Load (W/m^2)	Target Solar Load (W/m^2)	Required Solar Reduction (%)	Target Effective Shade (%)
Headwaters - Lower Old River Rd (38-NAC-38.8)					
63.9	9%	277	209	24%	25%
62.9	41%	180	132	27%	52%
61.9	18%	249	169	32%	39%
60.9	23%	232	160	31%	43%
59.9	8%	280	199	29%	29%
Forest Svc Cottonwood Camp (38-NAC-36.0)					
59.2	31%	210	151	28%	46%
58.9	25%	227	162	29%	42%
57.9	35%	196	131	33%	53%
56.9	37%	191	136	29%	51%
55.9	35%	195	144	26%	48%
54.9	65%	106	71	33%	75%
53.9	90%	29	22	25%	92%
52.9	61%	118	98	17%	65%
51.9	60%	122	95	22%	66%
50.9	51%	149	119	20%	57%
49.9	16%	253	208	18%	25%
48.9	18%	249	198	20%	29%
47.9	12%	268	202	25%	27%
46.9	10%	274	214	22%	23%
45.9	12%	267	211	21%	24%
44.9	10%	274	205	25%	26%
Lower Nile Rd SHU station (38-NAC-26.8)					
44.1	7%	281	220	22%	21%
43.9	7%	283	224	21%	20%
42.9	5%	289	243	16%	13%
41.9	14%	260	202	22%	27%
40.9	18%	247	180	27%	35%
39.9	40%	181	135	26%	52%

			Load Allocation		
Longitudinal Distance (km)	Current Effective Shade (%)	Current Solar Load (W/m^2)	Target Solar Load (W/m^2)	Required Solar Reduction (%)	Target Effective Shade (%)
2.5 miles downstream of Nile Rd (38-NAC-23.9)					
39.4	52%	146	110	25%	61%
38.9	33%	204	139	32%	50%
37.9	38%	188	132	30%	53%
36.9	36%	194	151	22%	46%
35.9	11%	270	200	26%	28%
Upstream of horseshoe bend (38-NAC-20.8)					
35.2	55%	135	98	28%	65%
34.9	65%	106	76	28%	73%
33.9	67%	101	58	42%	79%
32.9	45%	166	107	35%	62%
31.9	23%	233	163	30%	42%
30.9	29%	216	155	28%	44%
Upstream of Tieton River (38-NAC-17.6)					
30	30%	213	138	35%	50%
29.9	27%	220	146	34%	47%