



South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study

June 2003

Publication No. 03-03-021

printed on recycled paper



This report is available on the Department of Ecology home page on the World Wide Web at <http://www.ecy.wa.gov/biblio/0303021.html>

For additional copies of this publication, please contact:

Department of Ecology Publications Distributions Office

Address: PO Box 47600, Olympia WA 98504-7600

E-mail: ecypub@ecy.wa.gov

Phone: (360) 407-7472

Refer to Publication Number 03-03-021.

Any use of product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the author or the Department of Ecology.

The Department of Ecology is an equal-opportunity agency and does not discriminate on the basis of race, creed, color, disability, age, religion, national origin, sex, marital status, disabled veteran's status, Vietnam-era veteran's status, or sexual orientation.

If you have special accommodation needs or require this document in alternative format, please contact Joan LeTourneau at 360-407-6764 (voice) or 711 or 1-800-833-6388 (TTY).



WASHINGTON STATE
DEPARTMENT OF
E C O L O G Y

South Prairie Creek Temperature and Bacteria Total Maximum Daily Loads

by
Mindy Roberts

Environmental Assessment Program
Olympia, Washington 98504-7710

June 2003

Waterbody Numbers:
WA-10-1085/VC19MO and WA-10-1087/NX07HW

Publication No. 03-03-021
printed on recycled paper



This page is purposely blank for duplex printing

Table of Contents

	<u>Page</u>
List of Figures	iii
List of Tables	iv
Abstract	v
Acknowledgements	vi
Introduction	1
Scope and Purpose of the South Prairie Creek TMDLs	1
Pollutants and Surrogate Measures	2
Background	5
Geographic Setting	5
Basin Characteristics	5
Pollutant Sources	7
South Prairie Creek Fecal Coliform Bacteria TMDL	9
Applicable Water Quality Criteria	9
Water Quality and Resource Impairments	9
Seasonal Variation	11
Technical Analyses	12
Loading Capacity	14
Load Allocations	16
Wasteload Allocations	20
Summary of Load and Wasteload Allocations	21
Margin of Safety	21
Recommendations for Monitoring	23
South Prairie Creek Temperature TMDL	25
Applicable Water Quality Criteria	25
Water Quality and Resource Impairments	25
Seasonal Variation	27
Technical Analyses	27
Loading Capacity	44
Load Allocations	48
Wasteload Allocations	51
Summary of Load and Wasteload Allocations	55
Margin of Safety	56
Recommendations for Monitoring	56
References	57
Appendices	
A. Water Quality Data for South Prairie Creek and Tributaries	
B. Example of Vegetation GIS Data Layer Developed for South Prairie Creek	

This page is purposely blank for duplex printing

List of Figures

	<u>Page</u>
1. South Prairie Creek watershed with 303(d) listings	2
2. Historical discharge at USGS gage 12095000 on South Prairie Creek	6
3. Stations not meeting the fecal coliform water quality standard, based on 2000-2001 monitoring data.....	10
4. Time series of instantaneous fecal coliform loads at South Prairie Creek monitoring stations	12
5. Significant increases in fecal coliform bacteria loads during 2000-2001 monitoring ..	13
6. Fecal coliform bacteria loading capacity of South Prairie Creek represented as concentration	15
7. Current and allocated bacteria loads along South Prairie Creek.....	22
8. Summary of Ecology temperature monitoring results along South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch to 18°C temperature standard from 2001 monitoring	26
9. Plum Creek Timber Company temperature monitoring in the South Prairie Creek watershed (2000).	28
10. Heat flux components for South Prairie Creek downstream of South Prairie for 7Q10 conditions	33
11. Riparian vegetation sampling example using TTOOLS	35
12. Longitudinal profile of effective shade for South Prairie Creek estimated using Shadealator.....	37
13. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the calibration period August 9 through 15, 2001	40
14. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the warm validation period of July 29 through August 4, 2000	41
15. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the cool validation period of August 1 through 7, 2001	42
16. Predicted temperatures in South Prairie Creek under current, typical (7Q2), and extreme (7Q10) hydrologic conditions	43
17. Vegetation present during 1936 vegetation survey.....	44
18. Predicted daily maximum temperature in South Prairie Creek under critical conditions for the TMDL.....	45
19. Effective shade provided by riparian vegetation of varying heights, stream aspect, and NSDZ width	50
20. South Prairie wastewater treatment plant wasteload allocation.....	52
21. Wilkeson wastewater treatment plant wasteload allocation	54
22. Current and allocated temperature along South Prairie Creek, distinguishing nonpoint source and point source contributions	55

List of Tables

	<u>Page</u>
1. Streams addressed in the fecal coliform bacteria and temperature TMDLs	3
2. Monitoring locations for the South Prairie Creek watershed bacteria study	11
3. Load reduction factors summary by season.....	16
4. Load reductions necessary to meet water quality standards during the growing season (May through October).....	17
5. Load reductions necessary to meet water quality standards during the non-growing season (November through April)	18
6. South Prairie wastewater treatment plant fecal coliform load estimates	19
7. Monitoring locations for the South Prairie Creek watershed temperature study.....	26
8. Hydraulic geometry relationships for South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch	30
9. Flow statistics for USGS gage (12095000) on South Prairie Creek.....	31
10. Air temperature statistics for South Prairie Creek	32
11. Riparian vegetation codes and characteristics used for South Prairie Creek.....	36
12. QUAL2K model input data summary.....	39
13. Management scenarios and decreases in peak temperatures in South Prairie Creek for extreme hydrologic conditions (7Q10)	46
14. Effective shade, solar flux, and load allocations for South Prairie Creek	49
15. South Prairie wastewater treatment plant and receiving water characteristics	52
16. Wilkeson wastewater treatment plant and receiving water characteristics.....	54

Abstract

The South Prairie Creek watershed covers 90.7 mi² (235 km²) and includes all or portions of the towns of Wilkeson, Buckley, South Prairie, and Burnett. The creek, a Class A water body, is a tributary to the Carbon River, located in the Puyallup River watershed. Segments of South Prairie Creek or its tributaries were placed on the 303(d) list of impaired waters for fecal coliform, temperature, and copper.

Historical fecal coliform bacteria concentrations along lower South Prairie Creek exceeded water quality standards, resulting in inclusion on the 1996 and 1998 303(d) lists. The present study identifies and quantifies the sources of fecal coliform bacteria from Spiketon Road in Buckley to the confluence with the Carbon River. The South Prairie Creek load allocations call for fecal coliform bacteria load reductions downstream of the town of South Prairie. In addition, fecal coliform loads must be reduced in Spiketon Creek/Ditch and in the unnamed tributary leaving the town of South Prairie.

Continuous temperature monitoring in 2000 and 2001 indicated that some segments of South Prairie Creek and its tributaries exceed the Class A temperature standard. Wilkeson/Gale Creek was placed on the 303(d) list for temperature based on monitoring conducted in 1997 by the Muckleshoot Tribe. The temperature assessment uses effective shade as a surrogate measure of heat flux to fulfill the requirements of the federal Clean Water Act. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. The present study recommends load allocations equivalent to mature riparian vegetation throughout the watershed. The South Prairie and Wilkeson wastewater treatment plants should not increase stream temperatures significantly at the edge of the mixing zone.

A recent re-evaluation of the copper listing on Wilkeson Creek found that waters are within water quality standards for copper during critical conditions (Golding and Johnson, 2001) and recommended that the listing be removed. Therefore, no TMDL analysis was conducted.

Acknowledgements

We would like to thank the following people for their contribution to this study:

- Jeannette Barreca, Karol Erickson, Greg Pelletier (Ecology) and Laurie Best-Mann (EPA) for review of the draft report.
- Stephanie Brock, Sarah O’Neal, Dustin Bilhimer, Debby Sargeant, Lynel Rabago, Dana Mock, Trevor Swanson, Jim Garner, Chris Peredney, Jodie Beall, Anita Stohr, Greg Pelletier, Morgan Roose, Tara Galuska, John Summers VII, and the Stream Hydrology Unit (Ecology) for field assistance.
- Aspen Madrone (Ecology) for GIS support and delineation of vegetation.
- Larry Harter (South Prairie Utilities) for identifying discharge location and local information.
- KC Crusaders Paintball, the Britschgi residence, Inglin Dairy, and the Tait residence for allowing access to monitoring locations.
- Russ Ladley and Char Naylor (Puyallup Tribe) for background information on the system and access to results of ongoing data collection programs.
- Jeffrey Light (Plum Creek Timber Company, Inc.) for providing temperature monitoring data within private forest lands.
- John Collins (Pierce County Water Programs) and Margaret Hill (Ecology) for assistance in evaluating potential sources of contamination in Spiketown Creek/Ditch.
- Adriana Franz and Betsy Dickes (Ecology) for coordination with dairies.

Introduction

Section 303(d) of the federal Clean Water Act mandates that states establish Total Maximum Daily Loads (TMDLs) for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991) for establishing TMDLs.

Under the Clean Water Act, each state develops standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as cold water biota and drinking water supply, and criteria, usually numeric values, to achieve those uses. When a lake, river or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the water body on a list of “impaired” water bodies, referred to as the 303(d) list after the Clean Water Act section number, and to prepare an analysis called a Total Maximum Daily Load.

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of both water quality problems and sources of the problems. The TMDL determines the loading capacity, which is the amount of a given pollutant that can be discharged to the water body and still meet standards, and the load and wasteload allocated among various sources. If the pollutant comes from a discrete source (referred to as a point source) such as a wastewater treatment plant discharge, that facility’s share of the loading capacity is called a wasteload allocation. If it comes from a diffuse source (referred to as a nonpoint source) such as a residential development, that 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 regarding the causes of the water quality problem or a water body’s loading capacity. The sum of the load and wasteload allocations and the margin of safety must be equal to or less than the loading capacity of the system.

Scope and Purpose of the South Prairie Creek TMDLs

This report presents TMDL analyses and recommendations for fecal coliform bacteria and temperature in South Prairie Creek and its tributaries. Figure 1 shows the study area. The 1996 and 1998 303(d) lists identify South Prairie Creek or its tributaries as impaired by fecal coliform bacteria, temperature, and copper. The fecal coliform bacteria listing was based on historical ambient monitoring conducted by Ecology. The original temperature listings on South Prairie Creek and its tributaries were based on data collected by the Muckleshoot Tribe. Subsequent monitoring by Ecology conducted under the present study indicates that much of the lower watershed exceeds the temperature standard. Finally, the copper listing for Wilkeson Creek, originally based on estimates rather than field data, was reevaluated in 2001. Golding and Johnson (2001) concluded that the creek remains in compliance with water quality standards during critical conditions and recommended that Wilkeson Creek no longer be listed for copper.

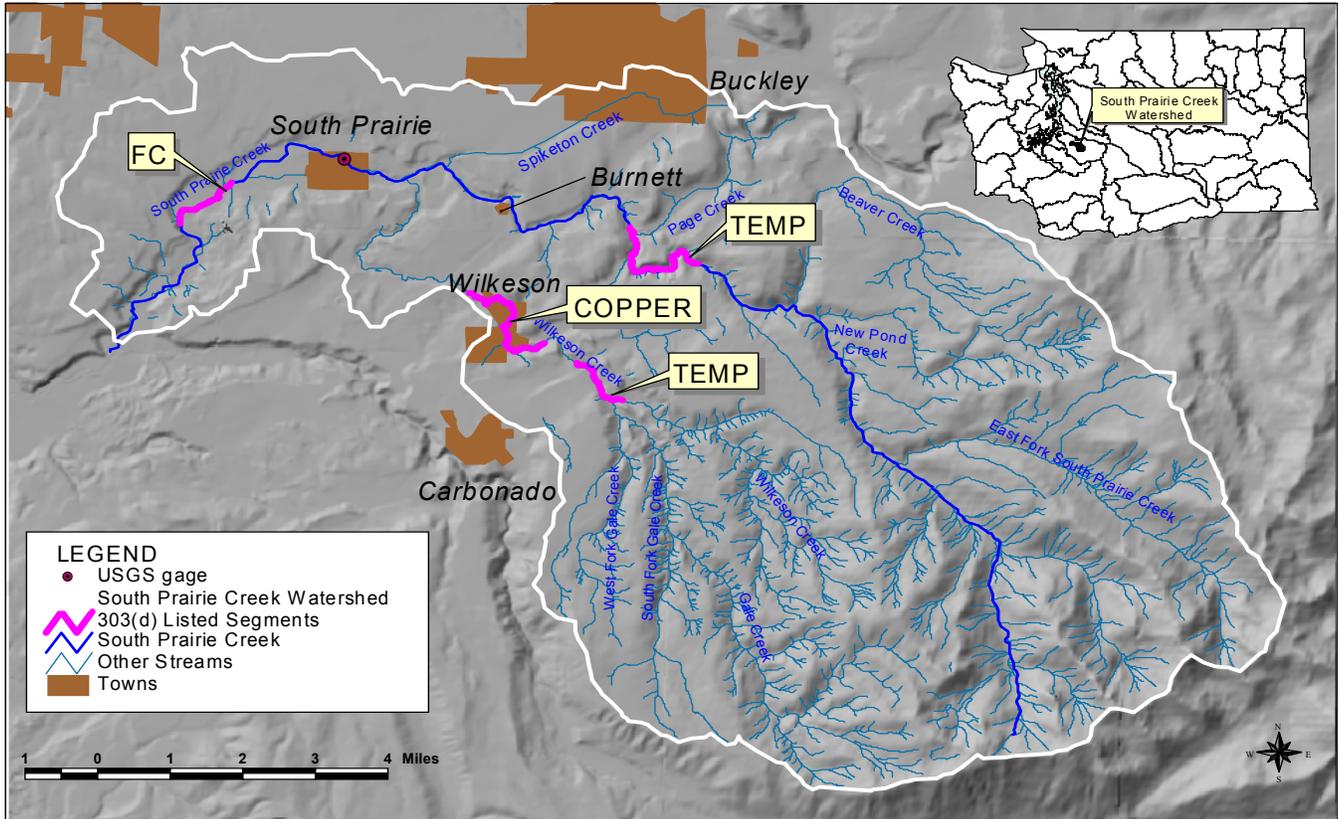


Figure 1. South Prairie Creek watershed with 303(d) listings.

Therefore, no copper TMDL was conducted. The fecal coliform bacteria and temperature analyses are presented in following sections of this report. Table 1 summarizes the water bodies addressed in this study.

Pollutants and Surrogate Measures

Fecal coliform bacteria are used by the State of Washington as indicators of pathogens associated with fecal contamination. Fecal pathogens are microorganisms capable of causing disease through ingestion or skin contact. Other indicators, such as *E. coli* and enterococci, have been evaluated as alternative or additional surrogates for pathogens under the triennial review of state water quality standards. However, at the time of publication, fecal coliform bacteria remain the designated indicator.

Table 1. Streams addressed in the fecal coliform bacteria and temperature TMDLs

Name	Parameter	Old ID	New ID	1996 303(d) list	1998 303(d) list	Impaired but not listed
South Prairie Creek	Fecal coliform bacteria	WA-10-1085	VC19MO	Yes	Yes	
Spiketon Creek	Fecal coliform bacteria	(none)	(none)	No	No	Yes
Wilkeson Creek	Fecal coliform bacteria	WA-10-1087	NX07HW	No	No	No
Unnamed Tributary	Fecal coliform bacteria	(none)	(none)	No	No	Yes
South Prairie Creek	Temperature	WA-10-1085	VC19MO	Yes*	Yes*	Yes*
Spiketon Creek	Temperature	(none)	(none)	No	No	Yes
Wilkeson/Gale Creeks	Temperature	WA-10-1087	NX07HW	Yes**	Yes**	Yes**

*South Prairie Creek was monitored by the Muckleshoot Tribe and subsequently placed on the 303(d) list in error by comparison with the Class AA water quality standards. South Prairie Creek is a Class A water body, and the historical monitoring data met the Class A water quality standards. However, monitoring conducted in 2000-2001 indicates that much of lower South Prairie Creek exceeds the Class A temperature standard; therefore, a TMDL was conducted.

**Wilkeson Creek, downstream of the confluence with Gale Creek, was monitored by the Muckleshoot Tribe and subsequently placed on the 303(d) list in error by comparison with the Class AA water quality standards. Wilkeson Creek is a Class A water body, and the historical monitoring data met the Class A water quality standards. Gale Creek, above the confluence with Wilkeson Creek, was also monitored by the Muckleshoot Tribe and was placed on the 303(d) list because it exceeded Class A water quality standards. Monitoring conducted in 2000-2001 indicates that the mouth of Wilkeson Creek exceeds Class A standards; therefore, a TMDL was conducted.

Temperature represents the equivalent of heat concentration within a water body. Thus, the present study evaluates and allocates the load of heat received by South Prairie Creek and its tributaries while comparing the resultant instream temperature to the water quality standards. Processes that affect water temperatures in the South Prairie Creek watershed include riparian vegetation disturbance that affects stream surface shading, reduced groundwater exchange that decreases heat exchange in the gravels, channel widening due to upstream sediment sources that increases the stream surface area exposed to solar radiation, reduced summer baseflows that reduce the volume of water available to absorb heat, and two point source discharges from wastewater treatment plants that introduce warm water. This study uses riparian shade as a surrogate measure of solar heat flux to water bodies. 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; thus, effective shade includes interception of solar radiation by topographic features as well as vegetation.

This page is purposely blank for duplex printing

Background

Geographic Setting

The South Prairie Creek watershed (Figure 1) covers 90.7 mi² (235 km²) and ranges in elevation from 5,933 ft (1800 m) at Pitcher Mountain to 285 ft (87 m) above mean sea level (Mastin, 1998), spanning the Puget Lowlands and Cascades ecoregions. The river flows 21.7 miles (34.8 km) from its headwaters within the Mt. Baker-Snoqualmie National Forest near the northwest corner of Mt. Rainier National Park to its confluence with the Carbon River, itself a tributary of the Puyallup River. The South Prairie Creek watershed includes three tributaries, of which Wilkeson Creek is the largest, with a watershed of 28 mi² (73 km²). Spiketon Creek, also known as Spiketon Ditch, flows to South Prairie Creek upstream of the Wilkeson Creek confluence and has a watershed area of 3.2 mi² (8.2 km²). A small unnamed ditch with a watershed of 0.7 mi² (1.8 km²) originates in the town of South Prairie and discharges to South Prairie Creek downstream of the town; the ditch is part of Pierce County's stormwater infrastructure. The shape of the watershed is such that only very small tributaries other than these three enter the main stem of South Prairie Creek.

Basin Characteristics

Climate in the basin follows patterns typical of the Puget Lowlands and Cascades ecoregions, with wet, mild winters and dry, cool summers. Mean annual average precipitation in the watershed varies from 85 in/yr (2.2 m/yr) at the higher elevations to 38 in/yr (1.0 m/yr) at the mouth (DNR, 1995; Miller et al., 1973). Most of the average annual precipitation occurs between November and April. Winter precipitation falls as rain in the lowlands and a mix of rain and snow at higher elevations.

Streamflow also varies seasonally. Highest flows occur between November and February, while the lowest flows occur in August and September, based on the U.S. Geological Survey (USGS) stream gage located at the town of South Prairie (Figure 2). Average discharge for the water years¹ 1988 to 2001 is 223 cfs (6.31 m³/s). Minimum 7-day average flows have ranged from 25 to 42 cfs (0.71 to 1.19 m³/s).

The watershed is composed of well compacted glacial till and stratified drift deposits. The upper watershed is characterized by steeper gradients, but the local channel slope in the lowlands study area varies from 0.03 to 0.003. The Osceola mudflow spilled into the South Prairie Creek valley near the confluence of Spiketon Creek/Ditch. The low-permeability valley bottom includes the developed areas of South Prairie, Wilkeson, Buckley, and Burnett (USDA SCS, 1979).

¹ Water year 2001 refers to the period October 1, 2000 through September 30, 2001.

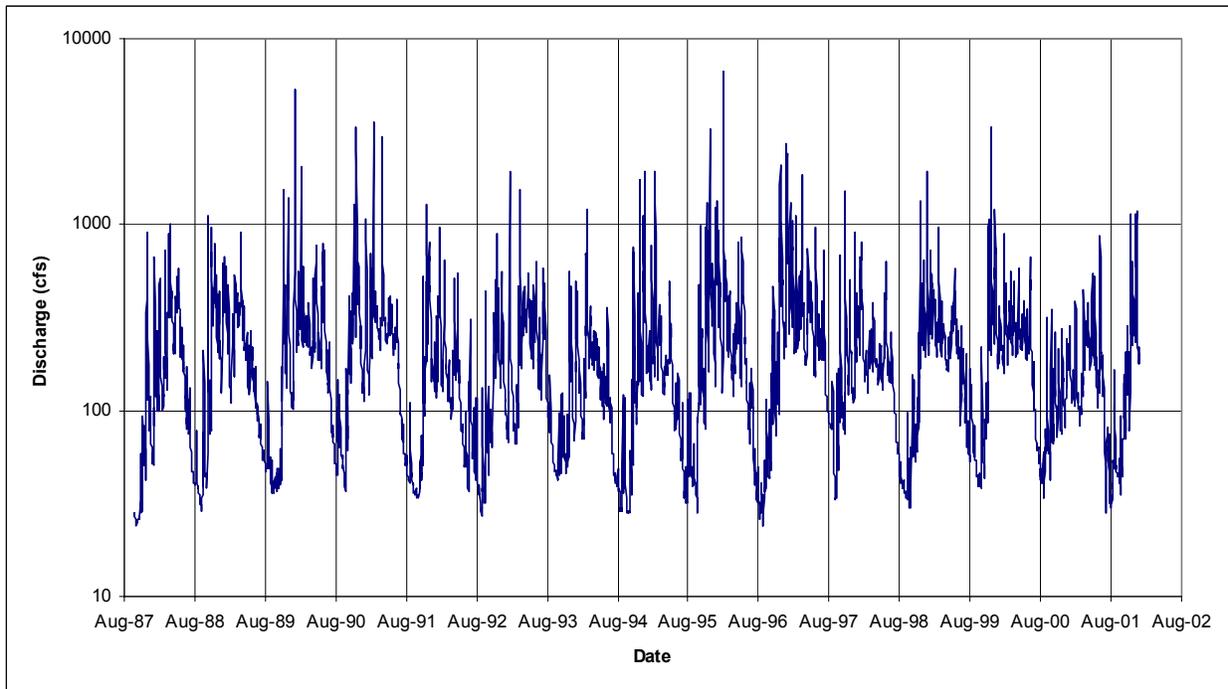


Figure 2. Historical discharge at USGS gage 12095000 on South Prairie Creek.

Current land use includes forestry operations in the higher elevations. The Mount Baker-Snoqualmie National Forest, administered by the White River Ranger District, includes 27 mi² (70 km²; Mastin, 1998) of the headwaters of South Prairie Creek. The area is not included in the present modeling analysis, since no impairment has been identified. In addition, the U.S. Forest Service is required to develop forest plans under the National Forest Management Act. Private timber companies, including Plum Creek, own land within the South Prairie Creek watershed. The area falls under the jurisdiction of the Timber Fish and Wildlife (TFW) Agreement. The 1987 agreement and the subsequent Forests and Fish Report, presented to the Forest Practices Board of Washington of the Department of Natural Resources and the Governor's Salmon Recovery Office in 1999, establish the following goals: provide compliance with the Endangered Species Act for aquatic and riparian-dependent species on non-federal forest lands, restore and maintain riparian habitat to support a harvestable fish supply, meet the requirements of the Clean Water Act, and keep the timber industry economically viable.

Two dairy facilities located near the town of South Prairie are the only commercial agriculture operations in the watershed. However, small non-commercial farms occur throughout the lower watershed.

Residential land use includes both small urban centers and rural residential parcels. Wilkeson is the largest town in the watershed, with a population of 395, based on the 2000 census. Local springs provide drinking water. The town owns and operates a wastewater treatment plant that discharges to Wilkeson Creek. South Prairie is the next largest town with a population of 332, based on the 2000 census. The town relies on local wells for drinking water and operates a

wastewater treatment plant that discharges to South Prairie Creek. Burnett is the site of a large on-site wastewater demonstration project that relies on various emerging technologies (Creveling, 2002). The project replaced direct wastewater discharges to the creek.

Buckley has a water right for 2 cfs (0.057 m³/s) and diverts a portion of upper South Prairie Creek for its water supply but did not gage the volume during the study period. The Department of Social and Health Services (DSHS) shares the diversion and has a water right for 3.5 cfs (0.10 m³/s) to serve the Rainier State School and Washington State University Dairy Forage Facility². The combined diversion passes through a sand filter as part of Buckley's drinking water supply infrastructure. When the infiltration capacity of the filters is exceeded, the overflow is diverted to South Prairie Creek via Spiketown Creek/Ditch. However, the portion used by Buckley for drinking water is transferred out of the watershed, since Buckley discharges wastewater to the adjacent White River watershed.

Other scattered residential developments throughout the lower watershed rely on private wells and septic systems. One septic system serving a residential property near the South Prairie wastewater treatment plant failed during the February 28, 2001 Nisqually earthquake (Pieritz, 2002). The system has been repaired. The Tacoma/Pierce County Health Department has determined that soils in the area are unsuitable for septic systems.

Pollutant Sources

Two facilities have permits for domestic wastewater discharge, which contribute both fecal coliform bacteria and heat loads to the receiving waters. The Wilkeson wastewater treatment plant (NPDES permit number WA0023281) discharges to Wilkeson Creek about 4.2 mi. (6.7 km) upstream of the confluence with South Prairie Creek. The current permit limits do not include limits for discharge rate or temperature, although the facility reports both. Fecal coliform bacteria concentrations must not exceed 200/100 mL as the monthly geometric mean or 400/100 mL for a weekly geometric mean. The South Prairie wastewater treatment plant (NPDES permit number WA0040479) limits maximum daily inflow to the plant to 38,200 gpd (0.059 cfs or 0.0017 m³/s); the permit does not limit temperature, although the facility reports effluent temperature. Fecal coliform bacteria must meet a monthly geometric mean of 200/100 mL and weekly geometric mean limit of 400/100 mL.

Nonpoint sources of fecal coliform bacteria include septic systems, dairy operations, domestic animals, and wildlife. Loads are released directly to water bodies or indirectly through subsurface loads or surface loads. These sources were quantified geographically in the data collection program by isolating the various sources.

Nonpoint sources also influence stream temperature by decreasing effective shade, reducing surface water discharge, reducing groundwater exchange, or increasing stream surface area through channel widening. Local riparian vegetation removal reduces the amount of shortwave radiation absorbed by leaves in the canopy, which increases the incident shortwave radiation to the stream. These disturbances result in elevated temperatures that propagate downstream.

² The WSU facility ceased dairy operations as of July 2000 but continues farming operations.

As the amount of water in the stream decreases, the volume of water capable of absorbing the heat decreases and temperature increases. Also, if the amount of groundwater discharging to surface water or the volume of mixed surface/groundwater that recirculates through the gravels decreases, surface water temperature increases. No evidence of channel widening was identified in the present study, and Mastin (1998) found no evidence of increased flood frequency or changes in channel geometry over the period 1965 to 1990. However, widening would result in higher stream surface area and more solar radiation absorbed in a given stream reach.

South Prairie Creek Fecal Coliform Bacteria TMDL

Applicable Water Quality Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

South Prairie Creek discharges to the Carbon River, which is a tributary to the Class A portion of the Puyallup River. Neither South Prairie Creek nor the Carbon River are classified separately from the Puyallup River in the water quality standards. Therefore, South Prairie Creek and its tributaries are classified as Class A from the confluence with the Carbon River upstream to the Mt. Baker-Snoqualmie National Forest boundary. All streams within the National Forest are classified as Class AA. The present study focuses on the Class A portions of the South Prairie Creek watershed.

Characteristic uses for Class A (excellent) water bodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Numeric criteria for particular parameters are intended to protect designated uses.

For Class A freshwater bodies,

“...fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.”

[WAC 173-201A-030 (2)(c)(i)(A)]

Fecal coliform bacteria, while not disease-causing organisms, have been adopted as indicator organisms for other pathogens with a fecal pathway that could impact human health. During the technical studies for South Prairie Creek, the water quality standards were under review. Potential changes included use of *E. coli* or enterococci as indicators of fecal pathogenic organisms. Therefore, *E. coli* and enterococci were included in the monitoring program. However, at the time of publication, fecal coliform bacteria remain the indicator organism on which the present TMDL is based. Appendix A includes data for all three potential indicators should the indicator organism change in the future.

Water Quality and Resource Impairments

Data collected by Ecology under the ambient monitoring program at station 10F090 (3.8 miles, or 6.1 km from the mouth; station SPCB4 of present study) from October 1992 through

September 1993 have a geometric mean concentration of 133/100 ml. Four of 12 samples (33%) exceeded 200/100 ml. Therefore, South Prairie Creek did not meet either of the two parts of the fecal coliform bacteria standard. The impaired use is recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment).

Additional sampling conducted as part of the present study shows that South Prairie Creek downstream of station 10F090, Spiketon Creek/Ditch, and the unnamed tributary/stormwater ditch near the town of South Prairie (stations T1 and T1ID) do not meet water quality standards. Figure 3 summarizes recent fecal coliform monitoring data. Table 2 describes monitoring locations.

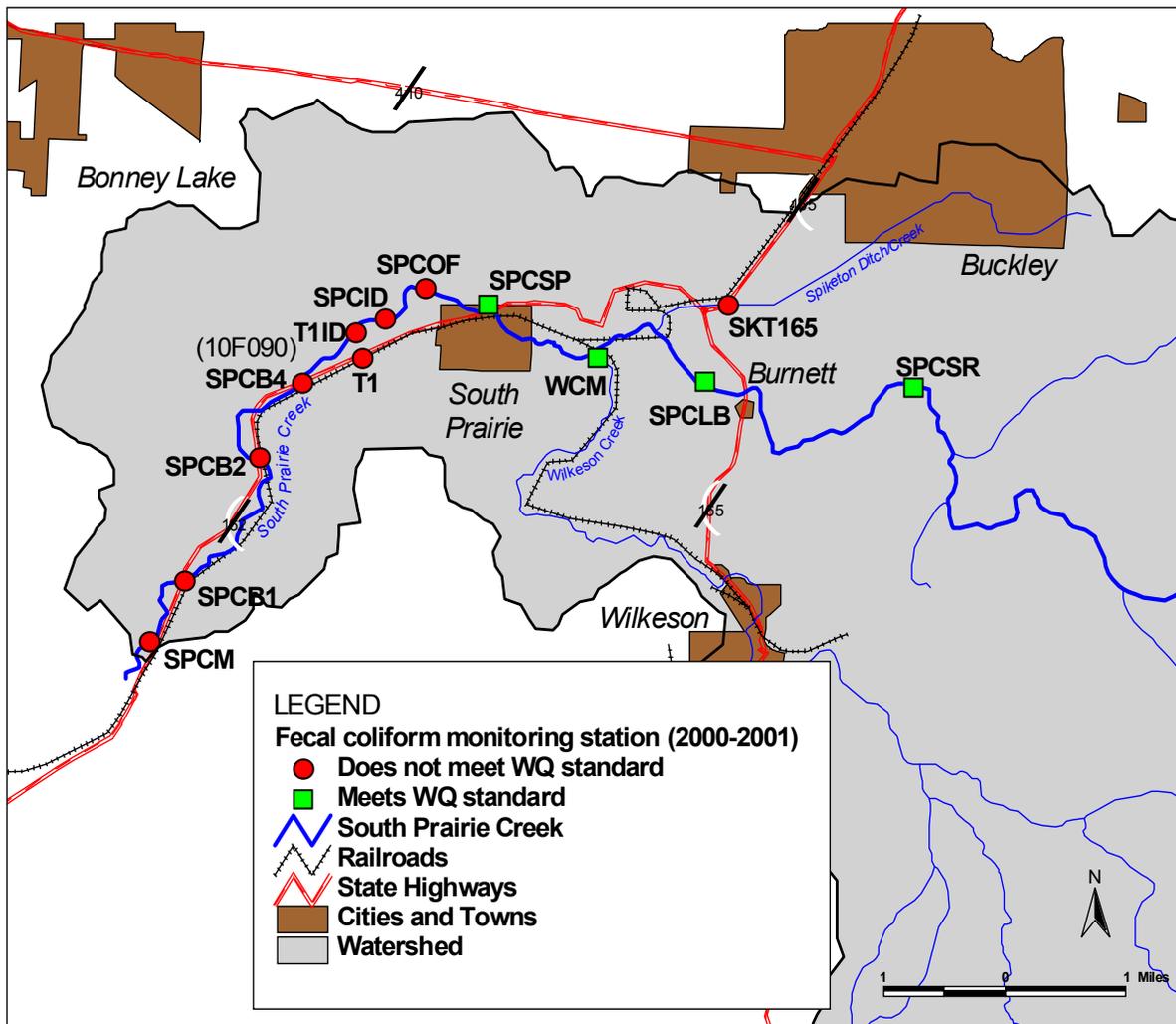


Figure 3. Stations not meeting the fecal coliform water quality standard, based on 2000-2001 monitoring data.

Table 2. Monitoring locations for the South Prairie Creek watershed bacteria study.

ID	Water Body	Description
SPCM	South Prairie Creek	At mouth, from South Prairie Creek Road
SPCB1	South Prairie Creek	At Route 162, first bridge north of Carbon River
SPCB2	South Prairie Creek	At Route 162, second bridge north of Carbon River
SPCB4	South Prairie Creek	At Route 162, fourth bridge north of Carbon River
SPCID	South Prairie Creek	At Inglin Dairy bridge
SPCOF	South Prairie Creek	At South Prairie wastewater treatment plant outfall; access from road by cabinet factory
SPCSP	South Prairie Creek	At South Prairie; access from fire station
SPCLB	South Prairie Creek	At Lower Burnett Road, downstream of Route 165 bridge
SPCSR	South Prairie Creek	At Spiketon Road, south of Buckley
T1	Unnamed tributary	At Route 162 culvert for ditch from South Prairie
TIID	Unnamed tributary	At mouth of ditch from South Prairie; access from Inglin Dairy
WCM	Wilkeson Creek	At mouth; access from KC Crusaders Paintball
SKTM	Spiketon Creek/Ditch	At mouth; access from Lower Burnett Road

Seasonal Variation

Clean Water Act Section 303(d)(1)(C) requires that TMDLs “be established at a 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 stream flow, loading, and water quality parameters” [40 CFR 130.7(c)(1)]. Fecal coliform bacteria concentrations and loads show seasonal variations, particularly in the lower watershed. Higher fecal coliform loads tend to coincide with wet winter conditions (Figure 4); however, elevated concentrations occur throughout the year and at a range of discharges. There was no statistically significant difference in fecal coliform bacteria concentrations in dry and wet conditions³ (P=0.646).

The non-growing season (November through April) tends to coincide with wet-weather conditions in the Puget Lowlands. For South Prairie Creek main stem stations, concentrations are higher during the non-growing season than the growing season. At other stations, the growing season concentrations are greater than the non-growing season levels. Therefore, the load allocations include both growing season and non-growing season reductions.

³ Dry is defined as <0.1 in of rain on the day of sampling or <0.2 in rain in the three days preceding. Wet conditions occur if at least 0.1 in fell on the day of sampling and at least 0.2 in fell in the previous days. Days where one condition is met but not the other were not included in the analysis.

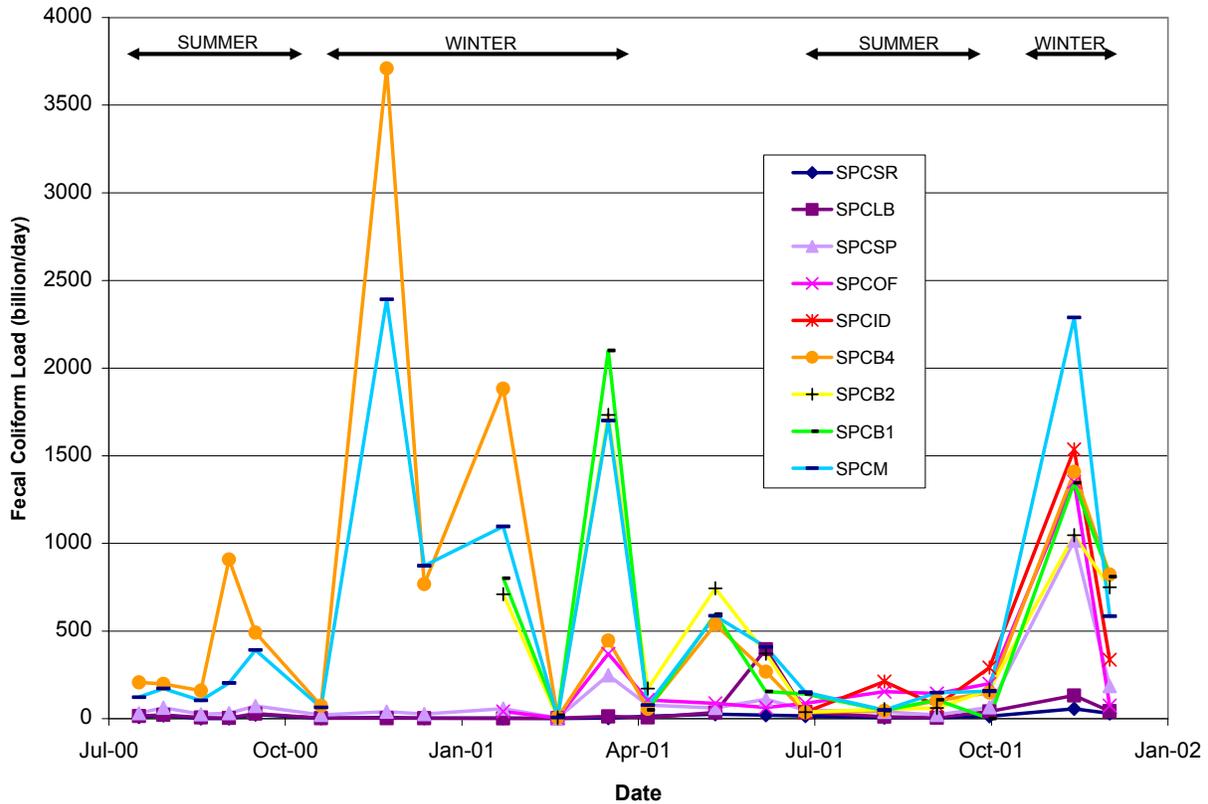


Figure 4. Time series of instantaneous fecal coliform loads at South Prairie Creek monitoring stations.

Technical Analyses

The technical analyses are based on historical and recent field and laboratory data collection, statistical analysis, and statistical modeling. The Quality Assurance Project Plans (Roberts, 2000 and 2001) describe the data collection program and methods.

Data Used in the Analysis

Water quality samples were collected and analyzed for fecal coliform twice monthly or monthly from July 2000 through December 2001. Nine monitoring stations were established over the 10.4-mi (16.8-km) study area to isolate potential sources. Instantaneous flows were measured at all accessible and appropriate stations using standard velocity-area methods (Ecology, 1993). The USGS stream gage at the town of South Prairie provides a continuous flow record since October 1, 1987. Appendix A includes all monitoring data.

Data were compiled and analyzed using Microsoft Excel®. Instantaneous loads were calculated using instantaneous flow measurements where available. Where not available, flows were

calculated using relationships with the USGS gage site or other instantaneous sites. Loads are analyzed as billion fecal coliform per day.

Critical Conditions

Elevated fecal coliform levels occur throughout the year and under different flow regimes. Critical conditions vary by station, as described above. Therefore, the TMDL analysis includes load reduction targets for both the growing season and the non-growing season.

Statistical Analysis

Sources of bacteria were identified and quantified by calculating the differential load entering a reach as the difference between the downstream and upstream loads using the pooled datasets. Both concentrations and loads were compared using one-tailed t-tests to identify whether loads at downstream stations were significantly greater than loads at the upstream station. Significant load increases ($\alpha=0.05$) occurred between stations SPCSP and SPCB4, and between SPCSP and SPCOF (Figure 5). No significant load increases occurred downstream of SPCB4.

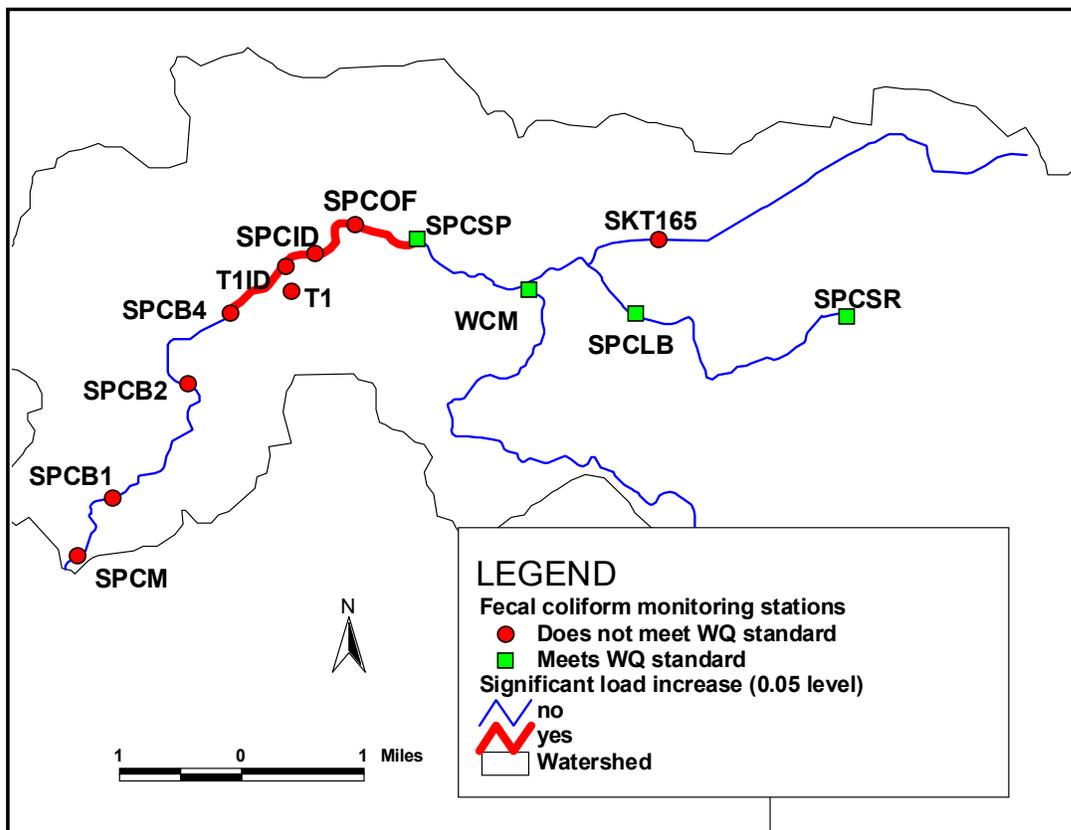


Figure 5. Significant increases in fecal coliform bacteria loads during 2000-2001 monitoring.

Modeling Approach

The modeling approach uses the statistical rollback method to determine the load reduction necessary to achieve the fecal coliform water quality standard in South Prairie Creek, Spiketon Creek/Ditch, and the unnamed tributary at the town of South Prairie. The statistical rollback method (Ott, 1995) has been used by Ecology to determine the necessary reduction for both the geometric mean value (GMV) and 90th percentile bacteria concentration (Joy, 2000) to meet water quality standards. Compliance with the most restrictive of the dual fecal coliform criteria determines the bacteria reduction needed. Fecal coliform sample results for each site in this study were found to follow lognormal distributions, and the 90th percentile was calculated as the antilog of the mean of the log-transformed data plus 1.28 times the standard deviation of the log-transformed data.

The rollback method uses the statistical characteristics of a known data set to predict the statistical characteristics of a data set that would be collected after pollution controls have been implemented and maintained. In applying the rollback method, the target fecal coliform GMV and the target 90th percentile are set to the corresponding water quality standard. The reduction needed for each target value to be reached is determined. The rollback factor, f_{rollback} , is

$$f_{\text{rollback}} = \text{minimum} \{ (100/\text{sample GMV}), (200/\text{sample } 90^{\text{th}} \text{ percentile}) \}$$

The percent reduction ($f_{\text{reduction}}$) needed is

$$f_{\text{reduction}} = (1 - f_{\text{rollback}}) \times 100\%$$

which is the percent reduction that allows both GMV and 90th percentile target values to be met. The result is a revised target value for both the GMV or the 90th percentile. In most cases, a reduction of the 90th percentile is needed and application of this reduction factor to the study GMV yields a target GMV that is usually less (i.e., more restrictive) than the water quality criterion. The 90th percentile is used as an equivalent expression to the “no more than 10%” criterion found in the second part of the water quality standards for fecal coliform bacteria. The reduction factors and description of sources are included under Load Allocations.

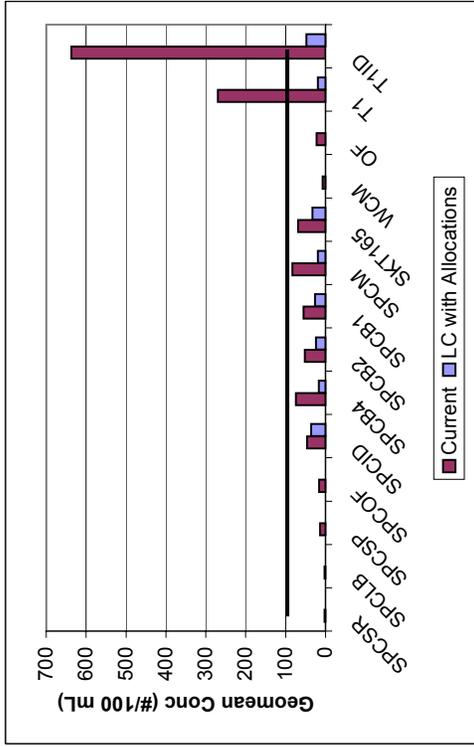
Loading Capacity

The loading capacity is the maximum load that can be assimilated by the receiving waters without violating water quality standards. Because fecal coliform has a two-part water quality standard for concentration, the load capacity also has two parts:

$$\begin{aligned} LC_{\text{GMV}} &= Q \cdot 100/100 \text{ mL} \cdot f_{\text{convert}} \\ LC_{90\%ile} &= Q \cdot 200/100 \text{ mL} \cdot f_{\text{convert}} \end{aligned}$$

where LC is the load capacity in billion fecal coliform per day, Q is discharge in cfs, and f_{convert} is 0.0245 to convert cfs • #/100 mL to billion fecal coliform per day. Load allocations are based on the reduction factors discussed above. Figure 6 compares current conditions with the loading capacity for geometric mean and 90th percentile fecal coliform bacteria concentrations. Loads must be reduced such that no bar extends above the water quality standards.

Non-growing season



Growing Season

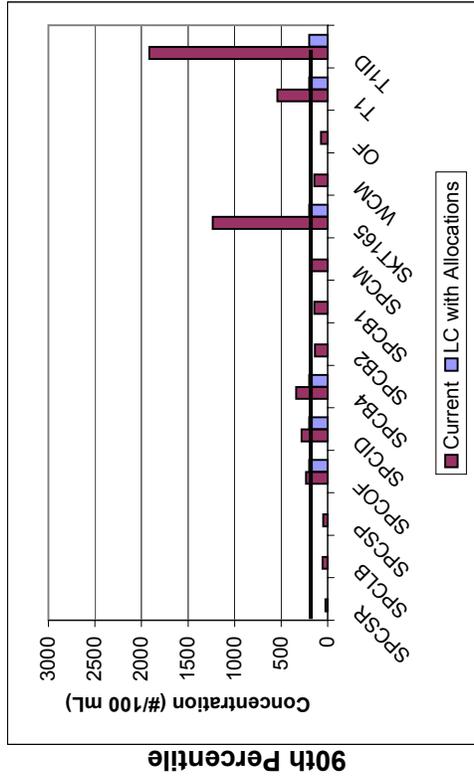
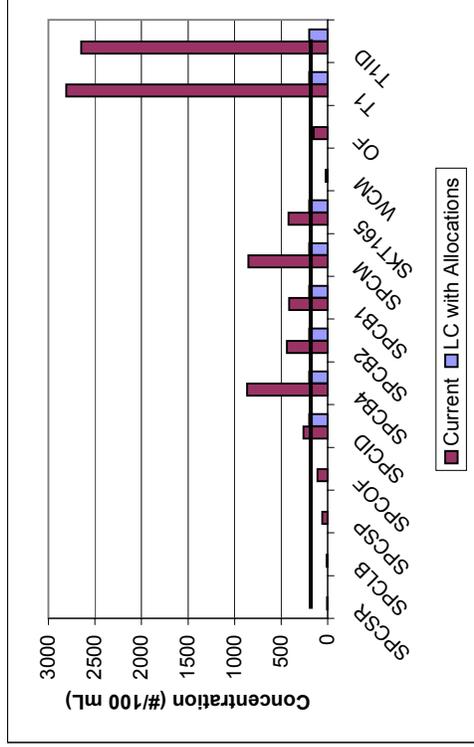
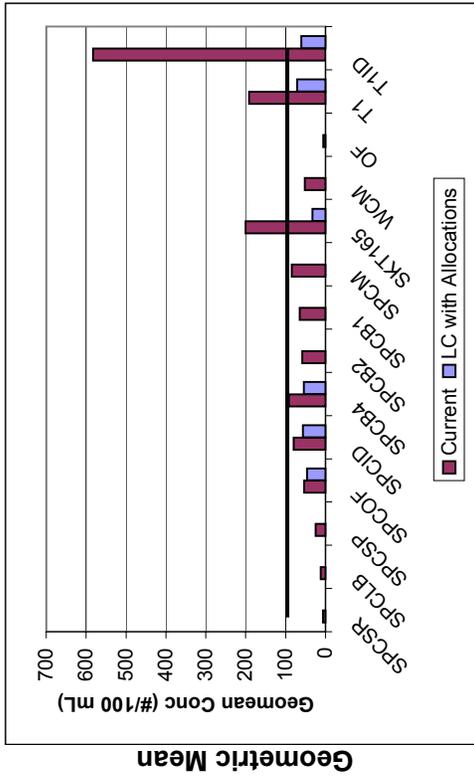


Figure 6. Fecal coliform bacteria loading capacity of South Prairie Creek represented as concentration.

Load Allocations

Load allocations are set for South Prairie Creek downstream of the town of South Prairie (station SPCSP), Spiketon Creek/Ditch, and the unnamed tributary/stormwater ditch from the town of South Prairie using the rollback method to determine the reduction factors necessary to meet both parts of the water quality standard for fecal coliform. Reduction factors are calculated for two periods, the growing season (May through October) and the non-growing season (November through April), and load allocations are set for both. Only the recent monitoring data (July 2000 through December 2001) were used, since older historical data may not represent current conditions.

All load reduction factors are summarized in Table 3. Station reduction factors include all upstream reductions. The Spiketon Creek reduction factor includes the entire subwatershed. Wilkeson Creek meets the bacteria standard and does not require load allocations. The South Prairie wastewater treatment plant outfall also met the bacteria standard at the point of discharge.

Table 3. Load reduction factors summary by season.

Station	Growing Season	Non-growing Season
Main Stem of South Prairie Creek		
SPCSR	NA	NA
SPCLB	NA	NA
SPCSP	NA	NA
SPCOF	14%	NA
SPCID	28%	23%
SPCB4	41%	77%
SPCB2	NA	54%
SPCB1	NA	52%
SPCM	NA	77%
Tributaries to South Prairie Creek		
Spiketon Creek/Ditch (SKT165)	84%	52%
Wilkeson Creek (WCM)	NA	NA
SP WWTP outfall	NA	NA
Unnamed tributary at SR162 (T1)	63%	93%
Unnamed tributary at mouth (T1ID)	90%	92%

NA: not applicable; station meets water quality criterion

The unnamed tributary/stormwater ditch did not meet the water quality standard at either of two monitoring locations. Because the ditch is part of Pierce County’s stormwater infrastructure, the reduction is included in the Wasteload Allocation section that follows, but is presented here for completeness. The reduction factor at the downstream station (T1ID at the mouth) is greater than the reduction factor for the upstream station (T1 at State Route 162). Thus, while loads must be reduced 63% in the growing season upstream of SR 162, additional load reductions are necessary between T1 and T1ID for a total of 90% reduction in bacteria levels for the entire tributary to meet water quality standards.

Table 4 presents the data on which the load reductions necessary during the growing season are based, while Table 5 presents the data for load reductions during the non-growing season. Several stations meet the water quality standards during the growing season but not during the non-growing season.

Table 4. Load reductions necessary to meet water quality standards during the growing season (May through October). Bold values exceed water quality standards.

Station	Number of Samples	Meets Std?	Geo-mean	90 th %ile	f _{rollback} for GMV (target to meet std)	f _{rollback} for 90 th %ile (target to meet std)	f _{reduction} (reduction to meet std)	Target geo-mean	Target 90 th %ile
Main Stem of South Prairie Creek									
SPCSR	12	YES	6	24	NA	NA	NA		
SPCLB	12	YES	12	54	NA	NA	NA		
SPCSP	12	YES	25	49	NA	NA	NA		
SPCOF	6	NO	54	234	NA	86%	14%	46	200
SPCID	4	NO	80	280	NA	72%	28%	57	200
SPCB4	12	NO	92	340	NA	59%	41%	54	200
SPCB2	6	YES	58	138	NA	NA	NA		
SPCB1	5	YES	64	142	NA	NA	NA		
SPCM	12	YES	84	192	NA	NA	NA		
Tributaries to South Prairie Creek									
SKT165	12	NO	200	1234	50%	16%	84%	32	200
WCM	12	YES	52	145	NA	NA	NA		
OF	6	YES	6	72	NA	NA	NA		
T1	6	NO	192	542	52%	37%	63%	71	200
T1ID	4	NO	583	1916	17%	10%	90%	61	200

NA: not applicable; station meets water quality criterion

From Table 3, loads entering South Prairie Creek between SPCSP and SPCB4 should be reduced by 41% in the growing season and 77% in the non-growing season. Slightly greater reduction is required during the non-growing season to meet water quality standards for that period because concentrations are greater. Potential sources include stormwater runoff from the town of South Prairie via the unnamed tributary (sampled at stations T1 and T1ID), the South Prairie wastewater treatment plant, failed septic systems, wildlife, or the dairy.

Table 5. Load reductions necessary to meet water quality standards during the non-growing season (November through April). Bold values exceed water quality standards.

Station	Number of Samples	Meets Std?	Geo-mean	90th %ile	f _{rollback} for GMV (target to meet std)	f _{rollback} for 90th %ile (target to meet std)	f _{reduction} (reduction to meet std)	Target geo-mean	Target 90%ile
Main Stem of South Prairie Creek									
SPCSR	8	YES	2	7	NA	NA	NA		
SPCLB	8	YES	2	9	NA	NA	NA		
SPCSP	8	YES	13	58	NA	NA	NA		
SPCOF	6	YES	16	110	NA	NA	NA		
SPCID	2	NO	46	259	NA	77%	23%	36	200
SPCB4	8	NO	74	865	NA	23%	77%	17	200
SPCB2	6	NO	52	439	NA	46%	54%	24	200
SPCB1	6	NO	55	413	NA	48%	52%	27	200
SPCM	8	NO	83	851	NA	23%	77%	19	200
Tributaries to South Prairie Creek									
SKT165	8	NO	68	420	NA	48%	52%	33	200
WCM	8	YES	7	22	NA	NA	NA		
OF	5	YES	22	149	NA	NA	NA		
T1	6	NO	270	2809	37%	7%	93%	19	200
TIID	2	NO	637	2649	16%	8%	92%	48	200

NA: not applicable; station meets water quality criterion

The unnamed tributary/stormwater ditch enters South Prairie Creek within this reach and requires significant load reductions to meet water quality standards before discharging to South Prairie Creek. Upstream of Route 162, as identified by station T1, the tributary fecal coliform loads should be reduced by 63% during the non-growing season and during high-flow conditions. The mouth of the tributary, identified as station TIID, requires an overall reduction of 90%, which is required in both the growing and non-growing seasons and at both high- and low-flow conditions. Load reductions achieved upstream of Route 162 (station T1) will reduce loads at the mouth (station TIID), but additional load reductions are necessary between Route 162 and the mouth of the tributary. Upstream of Route 162, land use is moderately dense residential development, with some commercial. Between Route 162 and the mouth, land use is agricultural with limited rural residential.

The unnamed tributary originates in the town of South Prairie and conveys groundwater and stormwater. The tributary had very high concentrations of fecal coliform bacteria during the 2001 monitoring program. Flow was not measured in the very small ditch. For a typical condition of a trapezoidal channel with 1:2 side slopes, bottom width of 3 ft, flow depth of 0.5 ft, channel slope of 0.005, and Manning's roughness of 0.35, Manning's equation estimates a flow of 0.3 cfs (0.008 m³/s):

$$Q = A * (1.49/n) * R^{2/3} S^{1/2},$$

where Q is discharge in cfs, A is cross-sectional area in ft², n is Manning's roughness, R is the hydraulic radius (equal to the cross-sectional area divided by the wetted perimeter), and S is channel slope. Peak flows were estimated to be on the order of 1 cfs (0.03 m³/s). The highest concentration was 2200/100 ml; with a flow of 1 cfs, the tributary may have contributed on the order of 50 billion fecal coliform/day, which could include failing septic system contributions. However, the average difference in loads between these upstream and downstream monitoring stations in South Prairie Creek was 300 billion fecal coliform per day; therefore, at most, T1 represents 17% of the incremental load to South Prairie Creek between SPCSP and SPCB4 and is not the only significant source.

Samples collected from the South Prairie wastewater treatment plant during the present study met the water quality standards with a geometric mean of 9/100 mL and a maximum of 80/100 mL (12 samples), without considering a mixing zone. The plant submits monthly reports of daily monitoring data. Table 6 presents low, medium, and high estimates of daily loads for each month of the monitoring program. The highest single-day load from the plant was 1.1 billion fecal coliform/day on 9/19/00, a monitoring day along the creek. The instantaneous load upstream at SPCSP was 73 billion fecal coliform/day, while the load downstream at SPCB4 was 490 billion fecal coliform/day. The treatment plant contributed <0.5% of the differential load upstream of SPCB4 and is responsible for only a small portion of the increase.

Table 6. South Prairie wastewater treatment plant fecal coliform load estimates.

Month	Low ¹ (10 ⁹ fcb/day)	Medium ² (10 ⁹ fcb/day)	High ³ (10 ⁹ fcb/day)
Jul-00	0.003	0.006	0.036
Aug-00	0.003	0.029	0.123
Sep-00	0.002	0.072	1.140
Oct-00	0.002	0.002	0.003
Nov-00	0.002	0.005	0.022
Dec-00	0.004	0.012	0.079
Jan-01	0.002	0.005	0.022
Feb-01	0.002	0.004	0.014
Mar-01	0.003	0.017	0.099
Apr-01	0.002	0.003	0.006
May-01	0.001	0.007	0.323
Jun-01	0.005	0.028	0.300
Jul-01	0.002	0.005	0.121
Aug-01	0.002	0.003	0.010
Sep-01	0.002	0.005	0.016
Oct-01	0.002	0.002	0.002
Nov-01	0.002	0.005	0.044
Dec-01	<0.001	<0.001	<0.001

1 Monthly average flow x min weekly fecal coliform concentration

2 Monthly average flow x geomean weekly fecal coliform concentration

3 Monthly average flow x max weekly fecal coliform concentration

With the exception of the failure during the Nisqually earthquake, no septic system failures have been located. However, the Tacoma/Pierce County Health District does not believe the soils in the South Prairie Creek valley are suitable for septic systems. At least ten homes in the area are served by septic systems. Assuming a per capita contribution of 2 billion fecal coliform/day (Metcalf and Eddy, 1991) and four people per household, failing septic systems could contribute 8 billion fecal coliform/day/system, or as much as 80 billion fecal coliform/day for ten homes. Thus, failing septic systems could contribute a significant portion of the load increase between SPCSP and SPCB4.

A synoptic survey, conducted in August 2001, found no other inflows with elevated fecal coliform concentrations. Several pipes and seeps were located between SPCSP and SPCB4 and sampled.

Wildlife contributions were not quantified explicitly in the study. However, using literature values for gull contributions of 0.1 billion fecal coliform/day (Gould and Fletcher, 1978; Nixon and Oviatt, 1973), 2,500 gulls would be necessary to contribute the differential fecal coliform load between SPCSP and SPCB4. There is no evidence that wildlife frequent this reach more than other reaches. Due to the level of development, wildlife are likely less prevalent between SPCSP and SPCB4.

Using literature values for cow contributions of 5.4 billion fecal coliform/day/cow (Metcalf and Eddy, 1991), waste from 46 cows would be sufficient to account for the differential load. While no direct discharges of waste from the dairy to South Prairie Creek were identified, field applications of manure were witnessed, and the dairy waste tank abuts South Prairie Creek. Both potential transport pathways could account for a significant proportion of the highly concentrated source entering South Prairie Creek between SPCSP and SPCB4. Either pathway could account for the intermittent nature of very high loads.

Load reductions achieved between SPCSP and SPCB4 will decrease the loads downstream of SPCB4. Travel time estimates were developed during low-flow conditions in 2001, which represent the slowest transport conditions over the year. Travel time from SPCSP to the mouth varies from 5 to 10 hours at a discharge of 40 cfs, and will be faster for higher flow rates. Therefore, there is little time for significant die-off to occur in this reach, meaning that upstream loads are not significantly attenuated. Unless the high bacteria loads masked low-level sources downstream of SPCB4, load reductions achieved between SPCSP and SPCB4 will cause downstream reaches to meet the water quality standards as well.

Wasteload Allocations

Wilkeson Creek met the fecal coliform bacteria water quality standard during the 2000-2001 monitoring period. Therefore, Wilkeson wastewater treatment plant (WA0023281) permit limits should remain at the current level of 200/100 mL for a monthly geometric mean and 400/100 mL for a weekly geometric mean, which are technology-based limits (Pieritz, personal communication, 2003). No further reduction in wasteload allocation is recommended, given that the plant contributes <1% of the load increase in the system, and the current permit limits represent the wasteload allocation for the Wilkeson wastewater treatment plant.

The South Prairie wastewater treatment plant (WA0040479) discharges to an impaired section of South Prairie Creek. Nonpoint sources contribute the vast majority of the bacteria load to South Prairie Creek. The point source contribution could increase the concentration at the edge of the mixing zone by 0 to 5 fecal coliform bacteria/100 mL, depending on the background contribution. Therefore, the permit limits should remain at 200/100 mL for a monthly geometric mean and 400/100 mL for a weekly geometric mean. If monitoring shows that the creek downstream of the treatment plant is still not meeting water quality standards by 2008, then the South Prairie wastewater treatment plant should receive water quality-based permit limits of 100/100 mL for a monthly geometric mean and 200/100 mL for a weekly geometric mean.

The TMDL submittal report to EPA, which will be based on the present technical report, must include reasonable assurance that implementation of nonpoint source management practices will occur and will reduce the bacteria load such that the creek meets the fecal coliform standard. Where reasonable assurance is not met, “the entire load reduction must be assigned to point sources,” (EPA, 1991), meaning that point sources cannot discharge any bacteria load. This analysis recommends no additional reductions in the wasteload allocations through 2008, given that the South Prairie plant contributes <0.5% of the load increase between stations SPCSP and SPCB4.

As discussed under Load Allocations, the unnamed tributary sampled under the present study at State Route 162 (T1) and at the confluence with South Prairie Creek (T1ID) is part of Pierce County’s stormwater conveyance system, covered under NPDES permit number WASM11002. Therefore, the reduction is considered a wasteload allocation. Bacteria levels must be reduced by 63% at State Route 162 and by 90% at the mouth. Details are presented under Load Allocations.

Summary of Load and Wasteload Allocations

Figure 7 compares the current conditions to the nonpoint source loading allocation and point source wasteload allocation for South Prairie Creek for the 90th percentile condition⁴. Current conditions exceed water quality standards, which is the loading capacity. The nonpoint load reductions discussed above will result in the load allocations shown. The point sources (shown multiplied by 10 or 100 to be visible in the figures) contribute small loads relative to the nonpoint sources, without considering die-off of the bacteria downstream of the discharge.

Margin of Safety

A margin of safety to account for scientific uncertainty must be considered in the TMDL in order for wasteload and load allocations to remain protective. The margin of safety for this TMDL is implicit; it is contained within conservative assumptions used to develop the TMDL. The rollback method assumes that the variance of the post-management data set will be equivalent to the variance of the pre-management data set. As pollution sources are managed, the frequency

⁴ Instream loads are based on average flows estimated for the growing and nongrowing seasons, while wastewater treatment plant wasteload allocations are based on peak monthly flows from the period of record of the DMRs.

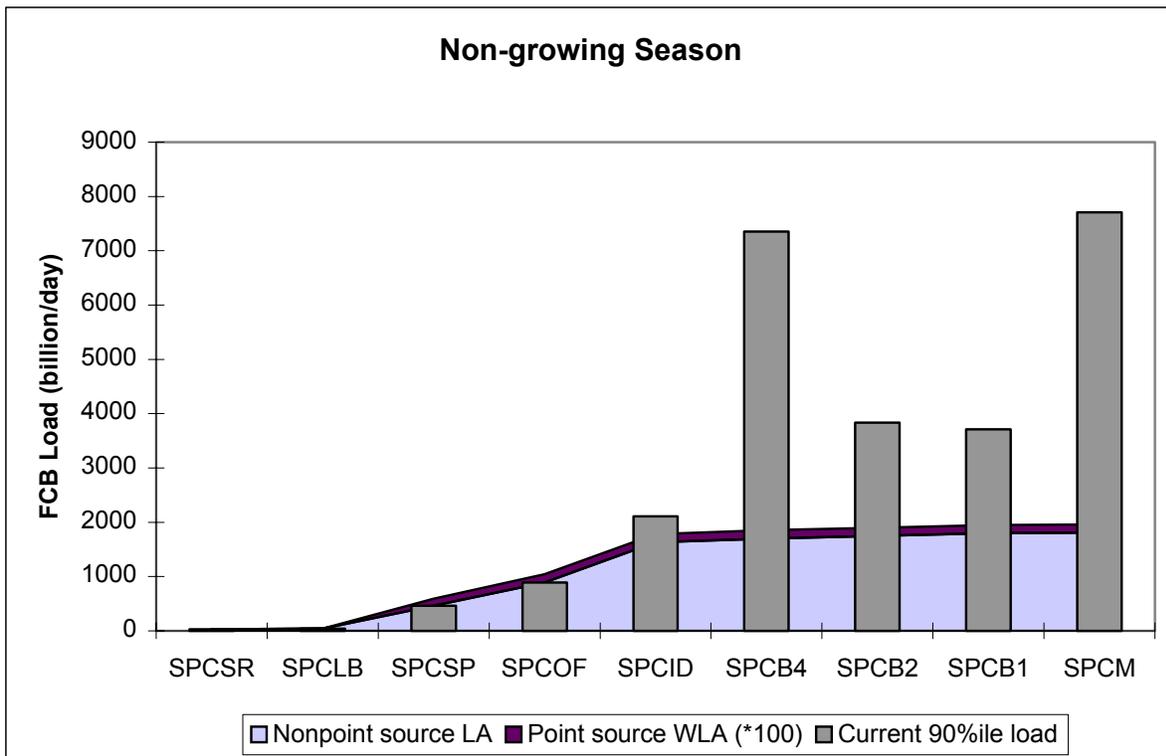
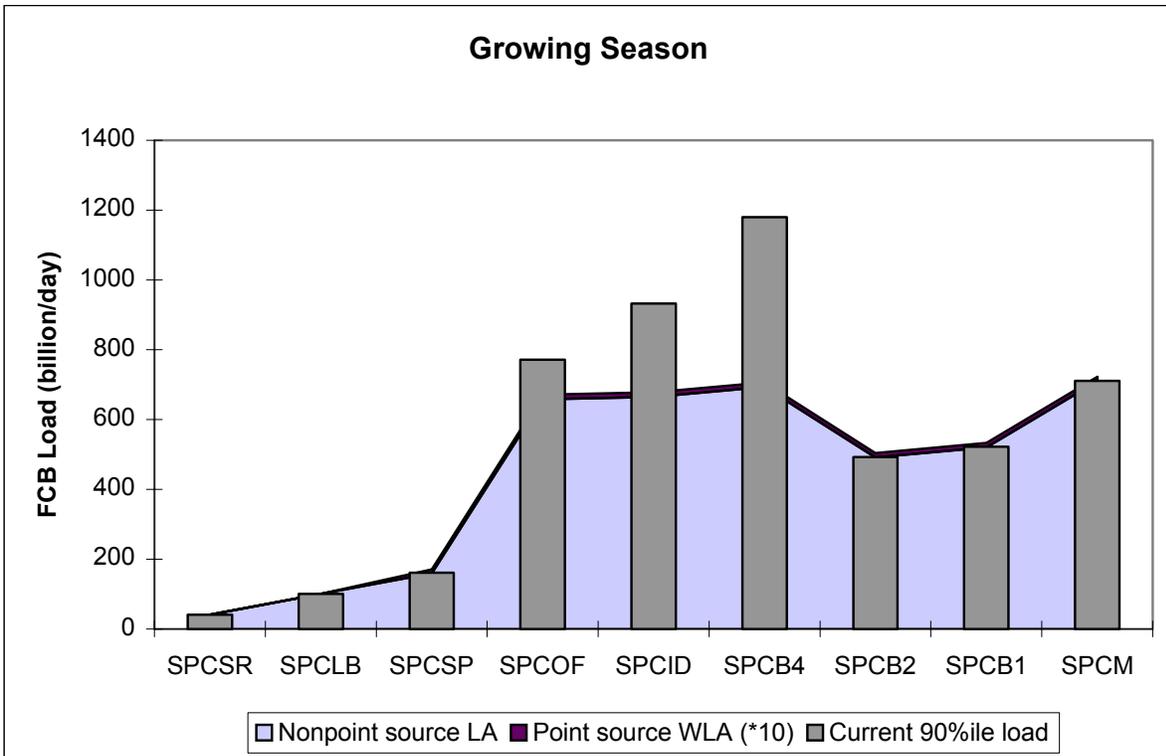


Figure 7. Current and allocated bacteria loads along South Prairie Creek. Point sources are multiplied by 10 and 100 to be visible in the charts.

of high fecal coliform values is likely to decrease, which should reduce the variance and 90th percentile of the post-management condition. Finally, differential reduction factors do not take into account bacterial decay.

Recommendations for Monitoring

To determine the success of fecal coliform control strategies, regular monitoring is recommended. Because stations SPCSP and upstream met the bacteria standards, SPCSP should be the upstream extent of regular monitoring. At a minimum, ten sites (SPCSP, SPCOF, SPCID, SPCB4, SPCB2, SPCB1, SPCM, SKTM, T1, and T1ID) should be monitored.

This page is purposely blank for duplex printing

South Prairie Creek Temperature TMDL

Applicable Water Quality Criteria

The water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, classifications, numeric criteria, and narrative standards for surface waters of the state.

South Prairie Creek discharges to the Carbon River, which is a tributary to the Class A portion of the Puyallup River. Neither South Prairie Creek nor the Carbon River are classified separately from the Puyallup River in the water quality standards. Therefore, South Prairie Creek and its tributaries are classified as Class A to the Mt. Baker-Snoqualmie National Forest boundary. All streams within the National Forest are classified as Class AA. The present study focuses on the Class A portions of the South Prairie Creek watershed.

Characteristic uses for Class A (excellent) water bodies include water supply (domestic, industrial, agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, harvesting), wildlife habitat, recreation (primary-contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Numeric criteria for particular parameters are intended to protect designated uses.

For Class A freshwater bodies,

“Temperature shall not exceed 18.0°C ... due to human activities. When natural conditions exceed 18.0°C ... no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C.”

[WAC 173-201A-030 (2)(c)(iv)]

Surface water temperatures reflect the heat load to a given water body. Therefore, the South Prairie Creek watershed temperature TMDL is based on heat, considered a pollutant under Section 502(6) of the Clean Water Act. Heat loads are modeled as point sources from the wastewater treatment plants and tributaries, distributed sources from groundwater inflows, and incoming solar radiation to South Prairie Creek and its tributaries. Factors that affect solar radiation heat loads include topographic shade (from adjacent hillslopes), riparian shade (from vegetation), stream surface area and volume, and groundwater exchange.

Water Quality and Resource Impairments

Data collected by the Muckleshoot Indian Tribe in 1997 at a location upstream of SPCSR peaked at 16.5°C but did not exceed the Class A water quality standard of 18°C. The creek was placed on the 303(d) list in error, based on comparison with the Class AA standards. However, monitoring indicates that all of South Prairie Creek from the town of South Prairie downstream exceeds 18°C during the 2000-2001 study period. Figure 8 summarizes the 2001 (warmest) temperature monitoring data for South Prairie Creek. Table 7 describes the monitoring locations.

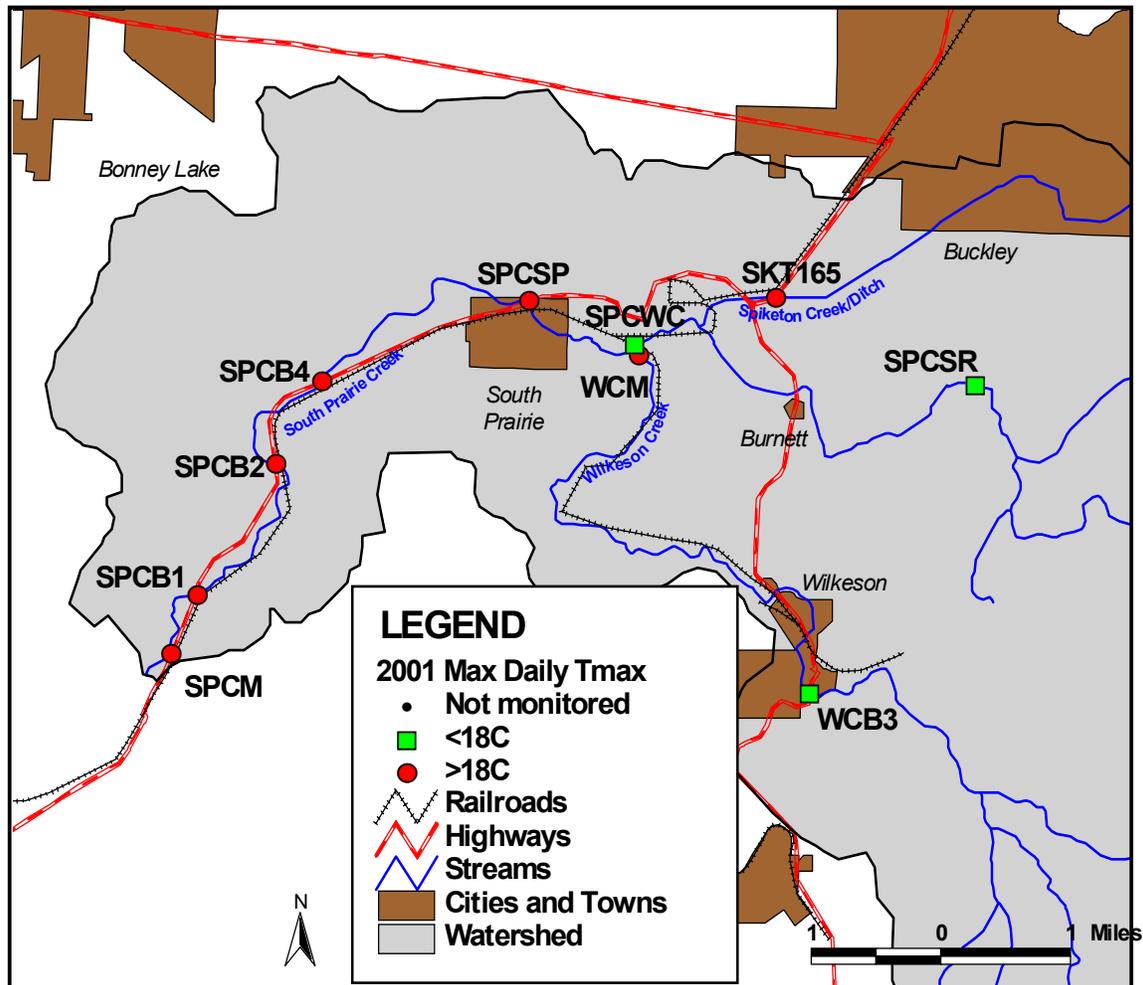


Figure 8. Summary of Ecology temperature monitoring results along South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch to 18°C temperature standard from 2001 monitoring.

Table 7. Monitoring locations for the South Prairie Creek watershed temperature study.

ID	Water Body	Description
SPCM	South Prairie Creek	At mouth, from South Prairie Creek Road
SPCB1	South Prairie Creek	At Route 162, first bridge north of Carbon River
SPCB2	South Prairie Creek	At Route 162, second bridge north of Carbon River
SPCB4	South Prairie Creek	At Route 162, fourth bridge north of Carbon River
SPCSP	South Prairie Creek	At South Prairie; access from fire station
SPCWC	South Prairie Creek	At Wilkeson Creek confluence near train trestle; access through KC Crusaders Paintball
SPCSR	South Prairie Creek	At Spiketon Road, south of Buckley
WCM	Wilkeson Creek	At mouth; access from KC Crusaders Paintball
WCB3	Wilkeson Creek	Upstream of town of Wilkeson, third bridge
SKT165	Spiketon Creek/Ditch	At Route 165 culvert

The Muckleshoot Indian Tribe also monitored two locations in the Wilkeson Creek watershed (including Gale Creek). The downstream location peaked at 17.1°C but did not exceed the Class A water quality standard of 18°C. The creek was placed on the 303(d) list in error, based on comparison with the Class AA standards. The upstream location peaked at 19.0°C and exceeded the Class A water quality standards. The upstream area is owned by Plum Creek Timber Company, Inc. and falls under the jurisdiction of the TFW Agreement. Monitoring conducted under the present study (Figure 10) indicates that while Wilkeson Creek met the 18°C standard at both locations in 2001, the station at the mouth (WCM) exceeded the standard in 2000.

Plum Creek recorded temperature continuously at numerous stations in the upper reaches of South Prairie Creek and Wilkeson/Gale Creek in 2000. As shown in Figure 9, although the four sites in upper South Prairie Creek met the 18°C standard, two sites on Gale Creek exceeded the standard. The area was not monitored by Ecology but is included in the narrative portion of the present TMDL; implementation is through the TFW Agreement.

In addition, Ecology monitored the temperature of Spiketon Creek/Ditch in 2000 and 2001. Results in Figure 8 indicate that Spiketon Creek/Ditch peaked at 19.7°C in 2001 and does not meet the 18°C Class A temperature standard.

Seasonal Variation

Clean Water Act Section 303(d)(1)(C) requires that TMDLs “be established at a 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 stream flow, loading, and water quality parameters” [40 CFR 130.7(c)(1)]. Finally, Section 303(d)(1)(D) suggests that the “total maximum daily thermal load required to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife ... shall take into account the normal water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters....”

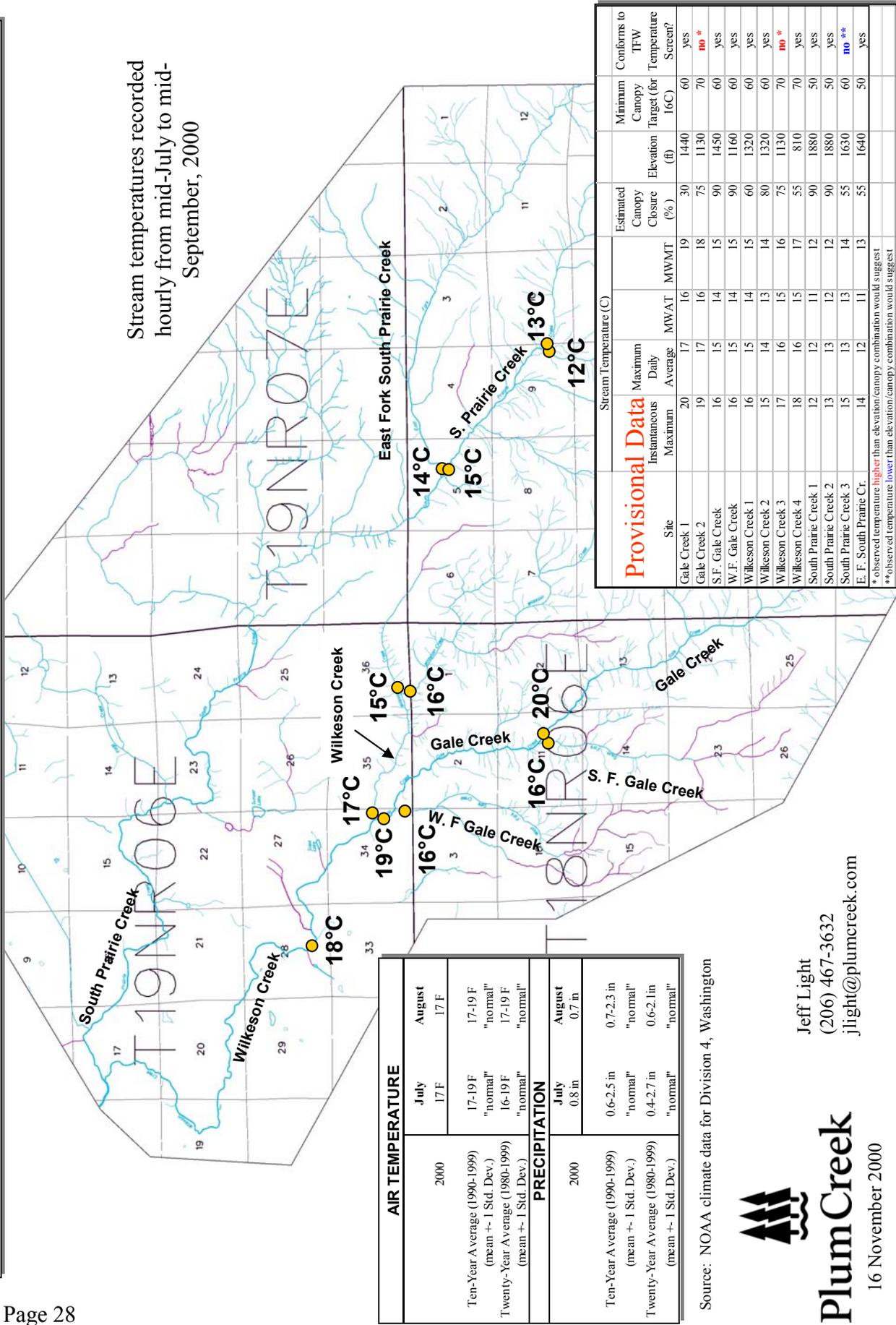
Existing water temperature conditions in the South Prairie Creek watershed reflect seasonal variation. Cooler temperatures occur in the winter, while warmer temperatures are observed in the summer. Highest temperatures typically occur in July and August, which is the critical period for temperature TMDL development.

Technical Analyses

Technical analyses are based on recent field data collection and temperature modeling. The Quality Assurance Project Plans (Roberts, 2000 and 2001) describe the data collection program and methods.

Figure 9.

Plum Creek Timber Company temperature monitoring in the South Prairie Creek watershed (2000).



Source: NOAA climate data for Division 4, Washington



Plum Creek

16 November 2000

Jeff Light
(206) 467-3632
jlight@plumcreek.com

Data Used in Analysis

Water Temperature, Air Temperature, and Relative Humidity

Water temperature, air temperature, and relative humidity were monitored continuously during the summer months in 2001, and partial records are available for 2000. Ten temperature monitoring stations were established over the 10.4-mi (16.8-km) study reaches. Appendix A includes the monitoring data. Data were compiled and analyzed using Microsoft Excel®.

Discharge Data, Hydraulic Geometry, and Channel Characteristics

Historical discharge data from the USGS station on South Prairie Creek at the town of South Prairie were used for statistical analyses. Only data from October 1, 1987 through December 31, 2001 were used in the present study, although the gage data include the period 1950 to 1979.

Ecology supplemented the continuous discharge records with instantaneous flows at eight locations between July 2000 and December 2001. Geometry and velocity data were used to generate relationships between discharge (Q) and channel width (w), average channel depth (d), and average velocity (u) using hydraulic geometry coefficients. Width, depth, and velocity can be related to discharge (Q) by power functions:

$$\begin{aligned}w &= a Q^b \\d &= c Q^f \\u &= k Q^m\end{aligned}$$

By continuity of mass,

$$Q = w d u = a Q^b * c Q^f * k Q^m$$

and

$$\begin{aligned}a * c * k &= 1 \\b + f + m &= 1\end{aligned}$$

Coefficients were determined for individual stations 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. Table 8 summarizes these equations. Relationships for a particular station were assumed to hold for reaches half the distance to the upstream station and half the distance to the downstream discharge station.

Additional channel characteristics were provided by habitat surveys, which were conducted in August 2001 at each temperature monitoring location. Ten cross sections were established, beginning at the monitoring station at 100-ft (33-m) intervals. At each cross section, the wetted width, bankfull width, width of near-stream disturbance zone, channel incision, and bankfull depth were recorded.

Table 8. Hydraulic geometry relationships for South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch (discharge, Q, in m³/s)

Station	Width (m)	Depth (m)	Velocity (m/s)
SPCLB	$W = 17.571 Q^{0.0976}$	$D = 0.177 Q^{0.3597}$	$U = 0.3215 Q^{0.5427}$
SPCSP	$W = 15.316 Q^{0.1101}$	$D = 0.3401 Q^{0.2267}$	$U = 0.192 Q^{0.6632}$
SPCB4	$W = 15.443 Q^{0.1916}$	$D = 0.3101 Q^{0.2509}$	$U = 0.2088 Q^{0.5574}$
SPCB2	$W = 11.679 Q^{0.4347}$	$D = 0.2474 Q^{0.1989}$	$U = 0.346 Q^{0.3664}$
SPCB1	$W = 15.96 Q^{0.0152}$	$D = 0.3088 Q^{0.376}$	$U = 0.2029 Q^{0.6088}$
SPCM	$W = 18.903 Q^{0.0798}$	$D = 0.2095 Q^{0.4809}$	$U = 0.2525 Q^{0.4393}$

Topographic Shade, Aspect, and Gradient

Shade angles from topographic features were calculated to the east, south, and west based on solar azimuth and a 10-m digital elevation model (DEM). The channel centerlines were used to estimate reach aspect. Channel gradient was averaged for each reach from electronic USGS quadrangle maps.

Riparian Vegetation and Effective Shade

Current vegetation characteristics, including height and density, are used to estimate effective shade from the riparian zone. No vegetation data layer was available for the watershed, however. Vegetation polygons were estimated from the most recent orthophotos⁵ within 500 ft (150 m) of the centerline of South Prairie Creek, Wilkeson Creek, and Spiketon Creek/Ditch. Vegetation height, type, and canopy cover categories were assigned to each polygon, based on visual interpretation and field observations collected in the habitat surveys described above. Polygon attributes were verified or refined in the field using observations of vegetation type and a laser range finder for vegetation height at all accessible locations.

Habitat surveys also provided densiometer readings at ten cross sections upstream of each temperature monitoring location. Hemispherical photography was used to record canopy cover at monitoring stations. Photos were evaluated using HemiView Canopy Analysis Software version 2.1 (Delta-T Devices Ltd., 1999) based on the path of the sun for a date.

Critical Conditions

Seasonal estimates for stream flow, solar flux, and climatic variables are taken into account to develop critical conditions. During the July 2000 through December 2001 monitoring period, daily water temperature in South Prairie Creek peaked on August 1, 2000 and August 10, 2001,

⁵ South Prairie Creek riparian zone orthophotos were available from 7/20/98 for the upstream model boundary to SPCB2; for the mouth to SPCB2, 7/18/90 was the most recent imagery. For Wilkeson Creek, orthophotos were available from 7/20/98 for the 1.6 mi (2.6 km) upstream of the mouth; for the headwaters to 1.6 mi (2.6 km), data were available from 7/15/90. The 7/20/98 imagery covered nearly the entire Spiketon Creek/Ditch riparian zone, from the mouth to a point 4.9 mi (6.2 km) upstream.

with highest 7-day average of daily maximum temperatures occurring July 29 through August 4, 2000 and August 9 through August 15, 2001 for each summer. Thus, the critical period for temperature monitoring occurs in late July to early August, and the 7-day averages were used in the analysis.

Critical stream flows for the temperature TMDL were evaluated as the lowest 7-day average flows with a 2-year recurrence interval (7Q2) and 10-year recurrence interval (7Q10) for the months of July and August. The 7Q2 stream flow represents conditions that occur during a typical climatic year, and the 7Q10 stream flow represents a reasonable worst-case climatic year at the South Prairie USGS gage. WQHYDRO (Aroner, 1994) was used to calculate 7Q2 and 7Q10 using a variety of distributions, as shown in Table 9. Flows selected to represent the critical conditions are 40 cfs (1.1 cms) for 7Q2 and 28 cfs (0.79 cms) for 7Q10.

Table 9. Flow statistics for USGS gage (12095000) on South Prairie Creek.

Statistic	Distribution	Discharge	95% C.I.
7Q2	Distribution free	39 cfs 1.1 cms	
	Log Pearson III (no bias correction)	40 cfs 1.1 cms	33 to 49 cfs 0.92 to 1.4 cms
	Weibull	41 cfs 1.2 cms	30 to 52 cfs 0.84 to 1.5 cms
	Log-Normal (3 parameter)	39 cfs 1.1 cms	33 to 48 cfs 0.94 to 1.4 cms
7Q10	Distribution free	29 cfs 0.82 cms	
	Log Pearson III (no bias correction)	28 cfs 0.80 cms	20 to 35 cfs 0.57 to 0.98 cms
	Weibull	27 cfs 0.75 cms	18 to 35 cfs 0.50 to 1.0 cms
	Log-Normal (3 parameter)	29 cfs 0.81 cms	26 to 32 cfs 0.72 to 0.91 cms

Air temperature is available for the USGS meteorology station at South Prairie since 1999. Because the South Prairie air temperatures are highly correlated with the SeaTac Airport temperatures ($R^2 = 0.92$ for the 7-day average of daily maximum temperatures), the long-term SeaTac Airport record was used to develop statistics from the period 1948 to 2001. The annual maximum values of the 7-day running average of daily maximum temperatures were ranked. The median (50th percentile) was used for typical hydrologic conditions, while the daily maximum temperature exceeded 10% of the time (90th percentile) was used for extreme hydrologic conditions. Table 10 summarizes the values from the SeaTac record and estimated for the South Prairie station.

Table 10. Air temperature statistics for South Prairie Creek.

	Typical Hydrologic Condition (exceeded 50% of time)		Extreme Hydrologic Condition (exceeded 10% of time)	
	(°C)	(°F)	(°C)	(°F)
SeaTac Airport (National Weather Service)	28.7	83.7	30.5	86.9
South Prairie Creek from regression with SeaTac record	28.6	83.5	30.4	86.7

Analytical Framework for Linking Shade and Instream Temperature

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. Stream temperature represents the concentration of heat. If heat loads gained by a stream reach exceed losses, the temperature increases. The change in heat is generally small compared with the heat entering from upstream. The heat budget expresses this in mathematical form:

$$J_{\text{net}} = J_{\text{longwave}} + J_{\text{solar}} + J_{\text{convection}} + J_{\text{evaporation}} + J_{\text{bed}} + J_{\text{hyporheic}} + J_{\text{in}} + J_{\text{out}}$$

where J represents the flux of each component, which can be positive or negative. Objects emit absorbed heat in the form of long-wave radiation (J_{longwave}). The atmosphere provides some long-wave radiation to water bodies, but more tends to be emitted by the water bodies, generally resulting in a net loss of heat. Solar, or short-wave radiation, (J_{solar}) tends to dominate the heat budget where effective shade is low. Solar radiation inputs peak at mid-day and do not occur at night. Heat can be transferred through convection ($J_{\text{convection}}$). If a stream is hotter than the air temperature above it, heat is transferred from the stream to the air, resulting in a decreased water temperature. Wind transfers that heat horizontally and dissipates air temperature gains next to the stream surface, which maintains the gradient of temperature that drives convection losses from the stream. If air temperature exceeds water temperature, heat is transferred into the stream. However, this term tends to be small relative to other heat fluxes. Evaporation ($J_{\text{evaporation}}$) results in a transfer of latent heat from the water body to the air (Dingman, 1994), although it is small relative to other terms in the heat budget equation. Finally, heat can be transferred to or from the bed through advective exchange of water containing heat ($J_{\text{hyporheic}}$) or by conduction (J_{bed}) with the sediments (Beschta et al., 1987). In addition, heat is advected in (J_{in}) and out (J_{out}) of a reach via surface water transport. Figure 10 provides an example of the heat flux components for a reach downstream of the town of South Prairie under 7Q10 hydrologic conditions.

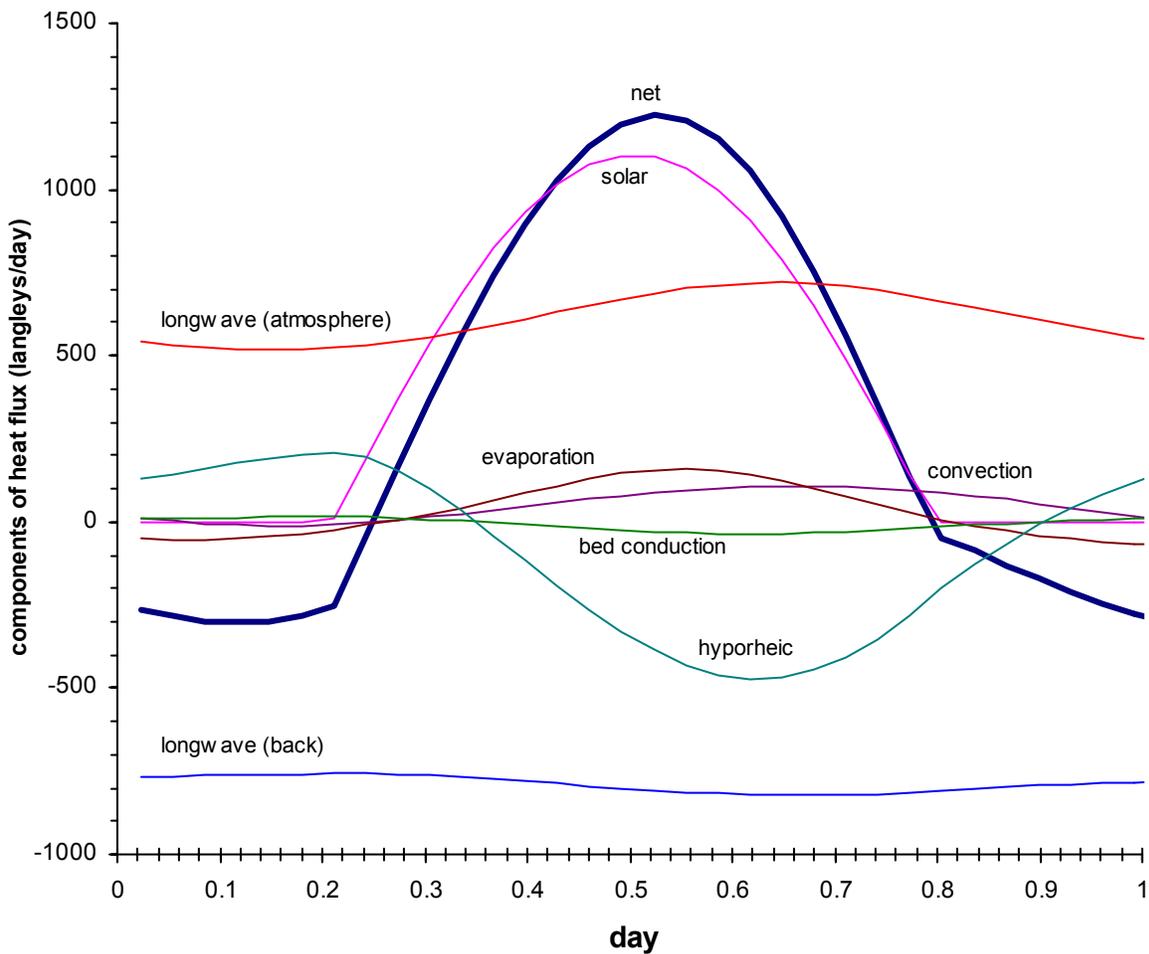


Figure 10. Heat flux components for South Prairie Creek downstream of South Prairie for 7Q10 conditions.

While climate and geographic location are outside of direct human control, riparian condition, channel morphology, and hydrology are affected by land use activities. Specifically, the elevated summer stream temperatures attributed to anthropogenic sources in the South Prairie Creek basin result from the following:

- Riparian vegetation disturbance reduces stream surface shading by decreasing riparian vegetation height, width, and density, thereby increasing the amount of solar radiation reaching the stream surface. Timber harvest, residential development, and agricultural activities decrease shade.
- Point source discharges from two wastewater treatment plants contribute heat loads to receiving water bodies.
- Channel widening (increased width to depth ratios) increases the stream surface area exposed to solar radiation.

- Reduced summer base flows may result from instream withdrawals and hydraulically connected groundwater withdrawals or hydrologic effects of timber harvesting. Reducing the amount of water in a stream can increase stream temperature (Brown, 1972).
- Reduced surface water/groundwater interaction, also called hyporheic exchange flow, increases surface water temperatures by reducing heat loss to gravels and cool groundwater discharges. This can result from decreased channel complexity and/or clogging of the gravels by fine material.

The present study includes the effects of reduced shade, point source heat discharges, channel widening, typical and extreme baseflow conditions, and the effect of hyporheic exchange flow. The analysis includes flow as a fixed variable only, since flows do not fall under the jurisdiction of the TMDL program. However, any activities that increase water withdrawals or decrease groundwater discharge or hyporheic exchange flow will exacerbate the temperature exceedances on South Prairie Creek and its tributaries. Similarly, channel widening will increase the channel surface area exposed to solar radiation and increase the surface water temperature of South Prairie Creek and its tributaries.

Effective Shade Definition

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. Effective shade is a function of several landscape and stream geometric relationships. Some of the factors that influence effective shade include the following:

- latitude and longitude
- time of year
- stream aspect and width
- vegetation buffer height, width, overhang, and canopy density
- topographic shade angles

In the Northern Hemisphere, the earth tilts on its axis toward the sun during the summer months allowing increased day length and higher solar altitude, both of which are functions of solar declination⁶. Geographic position (e.g., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream orientation. Riparian vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation, which results in shade. The solar position has a vertical component (altitude) and a horizontal component (azimuth) that are both functions of time/date (solar declination) and the earth's rotation (hour angle). Relatively simple geometry describes the relationships using methods developed by the solar energy industry.

Percent effective shade is the most straightforward stream parameter to monitor and calculate, and it is easily translated into quantifiable water quality management and restoration objectives. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The measured solar load at the stream surface can be measured with hemispherical photography or estimated using mathematical shade simulation computer programs.

⁶ measure of the earth's tilt toward the sun

Development of Effective Shade for South Prairie Creek and its Tributaries

The TTOOLS extension for ArcView, developed by Oregon Department of Environmental Quality (ODEQ, 2001) and modified by Ecology, samples and processes GIS data needed to calculate effective shade. First, South Prairie Creek and its tributaries were broken into 100-ft (30.5-m) segments. At the upstream end of each segment, TTOOLS develops the following attributes: stream aspect, elevation, gradient, topographic shade angle to the east, south, and west, channel width, distance from each channel bank to the edge of the nearstream disturbance zone (NSDZ), and the riparian vegetation code at varying distances from the edge of the NSDZ. The NSDZ is the active stream channel area without riparian vegetation, and includes features such as gravel bars.

Riparian vegetation is sampled at nine locations to either side of the channel (Figure 11). The sampling interval is every 15 ft (4.6 m) for a total of 135 ft (41 m) to each side of the NSDZ. Attributes for each riparian code include a unique combination of vegetation type, height, density and overhang. Overhang is generally assumed to be 10% of the vegetation height in the absence of other information. Table 11 lists the riparian vegetation codes used for the South Prairie Creek study. Appendix B presents an example of the vegetation datalayer developed for South Prairie Creek, with the current distribution of vegetation types within a 500-ft (150-m) buffer of the stream centerline.

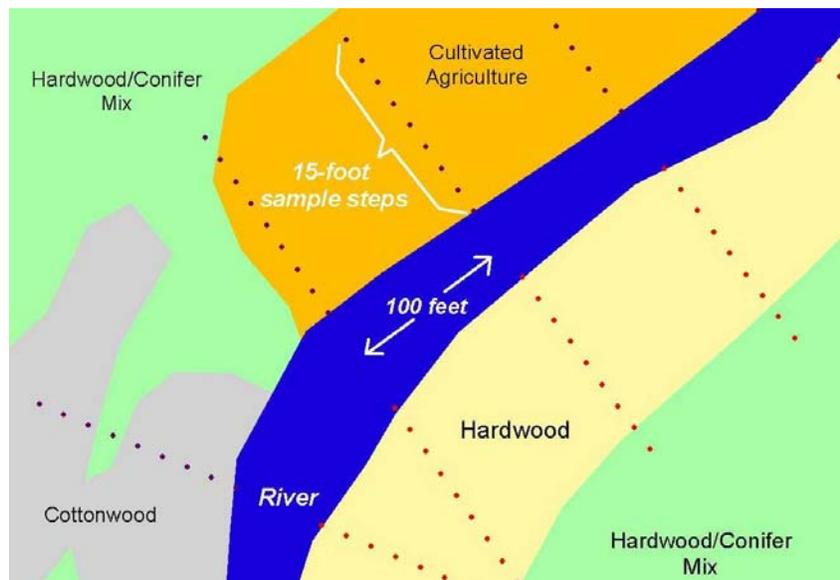


Figure 11. Riparian vegetation sampling example using TTOOLS (ODEQ, 2001).

Table 11. Riparian vegetation codes and characteristics used for South Prairie Creek.

Code	Description	Height		Density	Overhang	
		(ft)	(m)	(%)	(ft)	(m)
302	Pasture, field, lawn	2	0.5	75%	0	0.0
400	Road, barren land	0	0.0	0%	0	0.0
500	Mixed forest	120	36.6	90%	8	2.4
502	Mixed forest	150	45.7	95%	15	4.6
550	Mixed forest	80	24.4	25%	8	2.4
551	Mixed forest	40	12.2	25%	4	1.2
600	Hardwood forest	90	27.4	90%	9	2.7
601	Hardwood forest	60	18.3	90%	4	1.2
700	Conifer forest	100	30.5	95%	10	3.1
800	Shrubs	15	4.6	75%	2	0.5
3011	Floodplain, river bottom	0	0.0	0%	0	0.0

The effective shade algorithm, modified from Boyd (1996) using the methods of Chen et al. (1998a and 1998b), uses the riparian vegetation codes in each zone, stream aspect, and topographic shade angles, together with a selected date and latitude/longitude to estimate effective shade for each of the 100-ft (30.5-m) segments. Results are averaged for ten segments to create shade characteristics for 1000-ft (305-m) reaches, which are used by the computer model QUAL2K, discussed below.

Figure 12 presents effective shade predicted along South Prairie Creek from SPCSR downstream to SPCM. Effective shade ranges from 45 to 70% due to a combination of vegetation removal, a wide NSDZ, and relatively little topographic shade from SPCSR to just upstream of SPCLB. South Prairie Creek flows through a narrow canyon with mature vegetation interrupted with some vegetation removal from SPCLB to just downstream of the Wilkeson Creek confluence (SPCWC). From the town of South Prairie downstream, residential and agricultural land use practices have removed or reduced riparian vegetation to a narrow buffer.

HemiView results and densiometer readings from August 2001 generally support the predicted trends in effective shade from Shadealator. The high HemiView shade calculated at SPCSP and SPCB1 are likely due to interference from bridge structures.

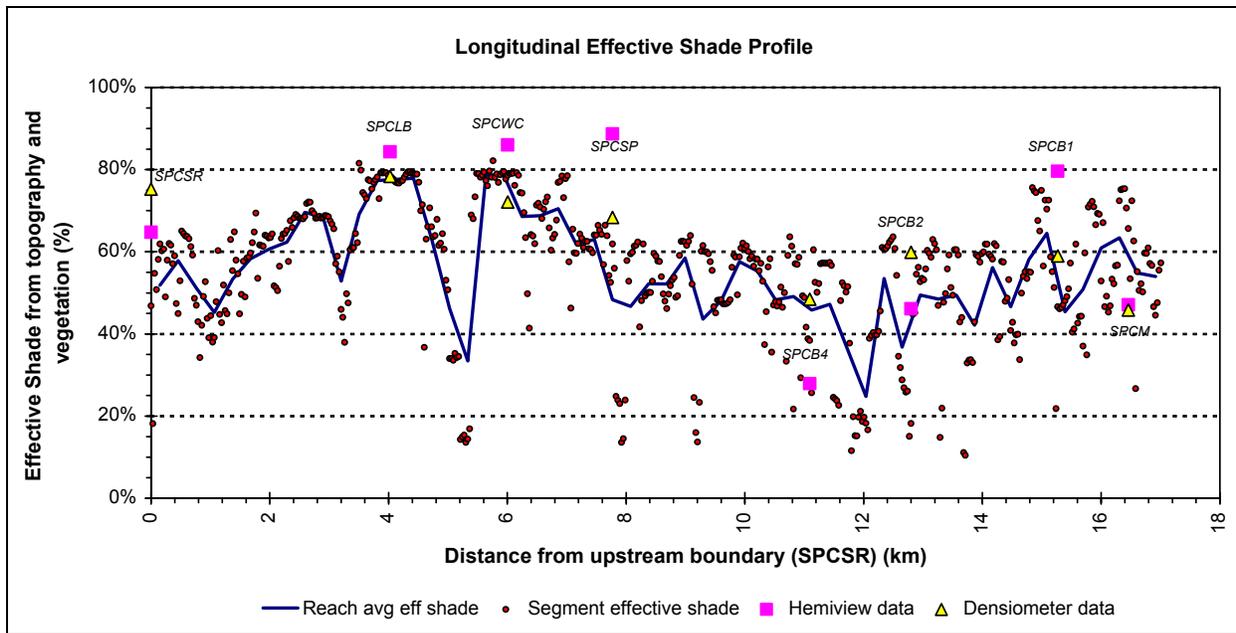


Figure 12. Longitudinal profile of effective shade for South Prairie Creek estimated using Shadealator.

Model Approach

QUAL2K Temperature Model Development

The QUAL2K model (Chapra, 2001) was used to calculate the components of the heat budget and to simulate water temperatures. QUAL2K, a Visual Basic application in a Microsoft Excel® environment, uses the kinetic formulations for the surface water heat budget described above and presented in Chapra (1997). In summary, QUAL2K is a steady-state, one-dimensional model that simulates diurnally varying water temperature using a finite-difference numerical method. Therefore, a single flow condition is selected to represent a given condition, such as a 7-day average flow. For temperature simulation, solar radiation, air temperature, relative humidity, headwater temperature, and point source/tributary water temperatures are specified as diurnally varying functions with a minimum and maximum value and time of the maximum value.

Heat flux components were calculated along the main stem of South Prairie Creek, with Wilkeson Creek, Spiketon Creek/Ditch, and the South Prairie wastewater treatment plant included as point sources. The model was calibrated using data collected during the hottest conditions of 2001 (August 9 through August 15) and verified with two different data sets: hottest water temperatures of 2000 (July 29 through August 4) and coolest steady-state maximum temperatures of 2001⁷ (August 1 through August 7).

⁷ The coolest 7-day average of maximum daily temperatures occurred August 22-28, 2001. However, these temperatures occurred during a storm, and unsteady conditions cannot be modeled using QUAL2K. Therefore, the coolest peak temperatures during steady-state conditions were used for the second validation data set.

Table 12 summarizes model input data specified for any model run. Following are descriptions of how specific input parameters were developed:

- Differential flows along South Prairie Creek were calculated for calibration and validation runs using field measurements. Flows were estimated for ungaged locations using the ratio of watershed areas with a measured flow location. For 7Q2 and 7Q10 analyses, the distribution of flows throughout the watershed was based on regression equations between the USGS gage at South Prairie and instantaneous flow measurements recorded during the present study. Differential inflows are specified as total inflow rate over a specified distance.
- Headwater temperature boundary conditions were established using monitoring data for the calibration and validation data sets from station SPCSR.
- Reach hydraulic geometry coefficients were established for monitoring stations and were assumed to hold over half the distance to stations upstream and downstream. The hydraulic geometry used in calibration and validation runs was also used for 7Q2 and 7Q10 runs. Calibration flows (36 cfs or 1.0 cms at SPCSP) were close to 7Q2 conditions (40 cfs or 1.1 cms).
- Sediment thermal properties were based on literature values for wet sand with a porosity of 0.7.
- Hyporheic exchange flow was a calibration parameter held constant for the validation, 7Q2, and 7Q10 runs.
- Air temperatures for the calibration run were based on monitoring data. Minimum daily air temperatures increased slightly downstream from 10.9 to 11.9°C at the mouth with a peak of 12.3°C at SPCSP, but maximum daily air temperatures increased significantly from 23.9 to 29.0°C at the mouth with SPCB2 exhibiting a peak of 30.5°C. The variation is equivalent to a lapse rate of 50°C/km, which is far greater than that explained by the adiabatic lapse rate of 6.5°C/km under dry conditions. The distribution for the calibration period was used to relate temperature at each site to the SPCSP riparian air temperature measured in the 2001 data collection program. Station SPCSP is closest to the USGS meteorology gage. Tidbit data were correlated with the USGS meteorological station data ($R^2 = 0.92$) but were slightly cooler, likely due to the riparian microclimate. The 2000 validation period uses USGS meteorological station data to generate the SPCSP riparian temperatures and the longitudinal air temperature profile. The USGS meteorological data were related to the SeaTac Airport record. Thus, the longitudinal air temperature profiles were developed for 7Q2 and 7Q10 conditions based on the SeaTac air temperature data, corrected for South Prairie conditions.
- Relative humidity values for the calibration and validation runs were based on 2001 data for the mouth of Wilkeson Creek (WCM) to characterize reaches from the upstream boundary (SPCSR) to the town of South Prairie (SPCSP) and 2001 data from the mouth of South Prairie Creek (SPCM) for the remainder of the study area. Minimum relative humidity occurs in late afternoon, while nearly 100% relative humidity occurs just before sunrise, even in summer conditions. The 2000 validation, 7Q2, and 7Q10 runs use 2001 monitoring results of approximately 60% minimum relative humidity and 100% maximum relative humidity.

- Wind speed was recorded near the South Prairie wastewater treatment plant in summer 2001, and data from the calibration and validation time periods were used. The 2000 validation uses the SeaTac data. The calibration values were used for 7Q2 and 7Q10 runs. Pollution index was set to 2 (clear) for all runs.
- Tributary point source inputs were developed from monitoring data at the mouth of Wilkeson Creek (WCM) and the mouth of Spiketon Creek/Ditch (SKT165/SKTM) for the 2001 calibration and validation and 2000 validation runs. For 7Q2 and 7Q10 conditions, maximum temperatures were assumed to be 18°C, with minimum temperatures set to the calibration run values.
- The South Prairie wastewater treatment plant point source inputs were developed from monitoring data reported in the Daily Monitoring Reports submitted to Ecology by the plant operator. Only one daily temperature is reported; 7-day average values of this temperature were used for both the maximum and minimum effluent temperature, essentially holding the temperature constant throughout the day.
- Diffuse source temperatures were assigned the average annual temperature (10.9°C), based on SeaTac mean daily air temperatures for the period October 1999 through September 2001⁸. The shape of the watershed is such that only very small surface tributaries other than Wilkeson Creek, Spiketon Creek/Ditch, and the unnamed tributary from the town of South Prairie enter the main stem of South Prairie Creek. Therefore, differential flows are assumed to be dominated by groundwater, and groundwater temperatures are often similar to the mean annual air temperature (Theurer et al., 1984).

Table 12. QUAL2K model input data summary

Category	Model Input Data
Run Information	Date, sunrise
Headwater	Latitude, longitude, elevation, discharge, discharge coefficients of upstream reach, minimum temperature, maximum temperature, time of maximum temperature
Reach	Reach labels, length, latitude, longitude, hydraulic geometry coefficients, effective shade, sediment thermal properties, hyporheic exchange flow
Meteorology	Minimum air temperature, maximum air temperature, time of maximum air temperature, minimum relative humidity, maximum relative humidity, time of maximum relative humidity, wind speed, cloud cover, pollution index (all specified by reach)
Point Sources	Name, location of inflow point, discharge, maximum temperature, minimum temperature, time of maximum temperature
Diffuse Sources	Upstream extent of source, downstream extent of source, discharge, temperature

⁸ The long-term (1948 to 2001) mean daily air temperature is similar at 10.7°C.

Model Calibration

Figure 13 presents the calibration run for South Prairie Creek for the 7-day average conditions for the period August 9 through August 15, 2001. The model appropriately represents the maximum temperature profile for the calibration conditions. The uncertainty of the temperatures predicted by the QUAL2K model can be assessed using the root mean square error⁹ (RMSE) of the predicted versus observed maximum and minimum temperatures. For the calibration period, the RMSE is 0.54°C.

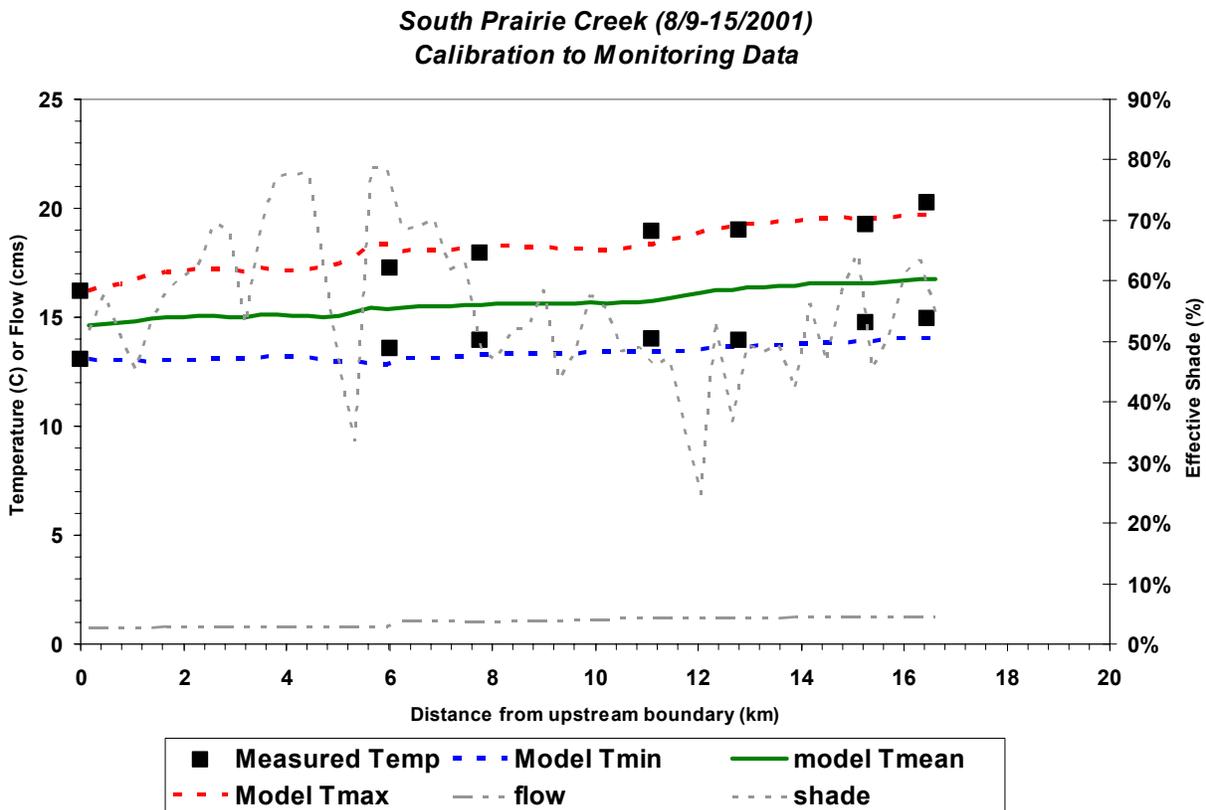


Figure 13. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the calibration period August 9 through 15, 2001 (RMSE = 0.54°C)

⁹ RMSE is the square root of the sum of the squared differences between observed and predicted values.

Model Validation

Two additional data sets were evaluated to verify that the model appropriately represents the temperature processes important to South Prairie Creek. Figure 14 compares the temperatures predicted by the QUAL2K model with measured data for the warm validation period, July 29 through August 4, 2000, using the effective shade and hyporheic exchange flows calibrated for the 2001 calibration period. Model uncertainty is relatively low, with a RMSE of 0.64°C. Similarly, Figure 15 compares predicted temperatures with measured data for the cool validation period, August 1 through August 7, 2001, using the calibration values for effective shade and hyporheic exchange flows. The RMSE is slightly higher at 0.91°C, but the model still appropriately represents cool peak temperature conditions.

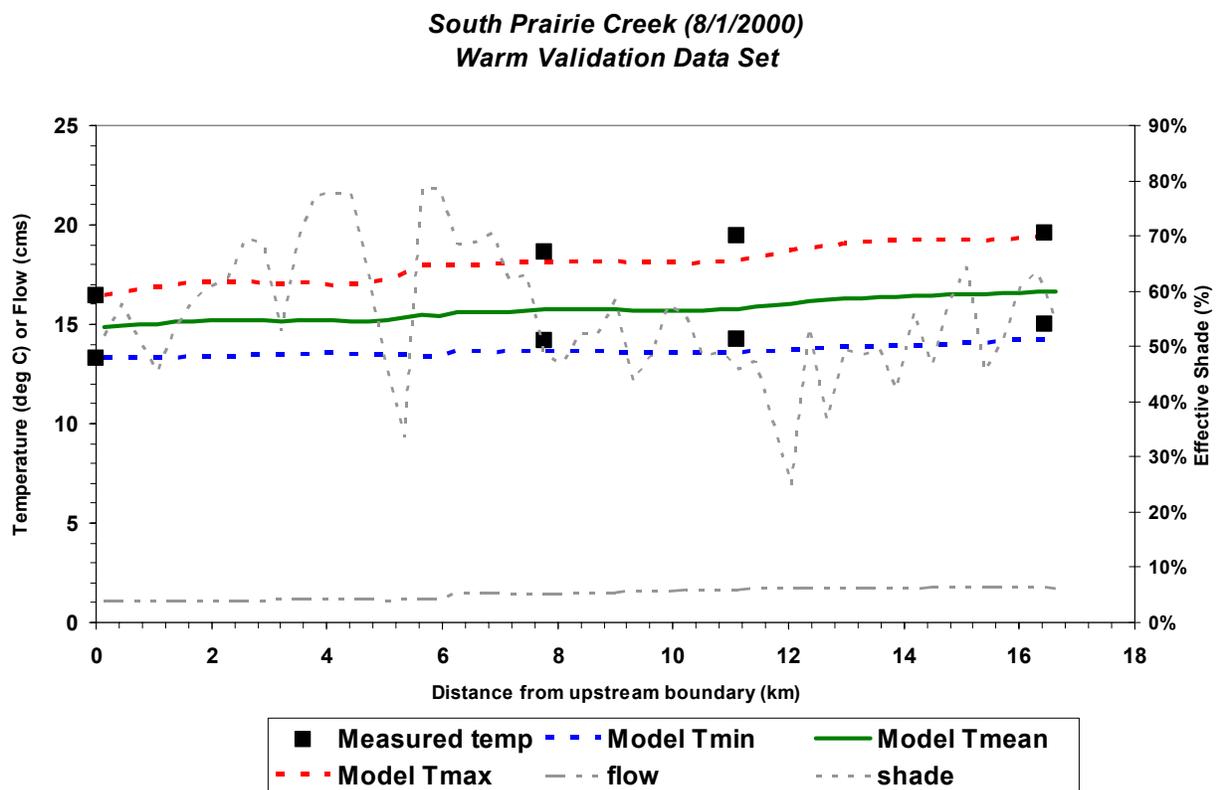


Figure 14. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the warm validation period of July 29 through August 4, 2000 (RMSE = 0.64°C).

**South Prairie Creek (8/1-7/2001)
Cool Validation Data Set**

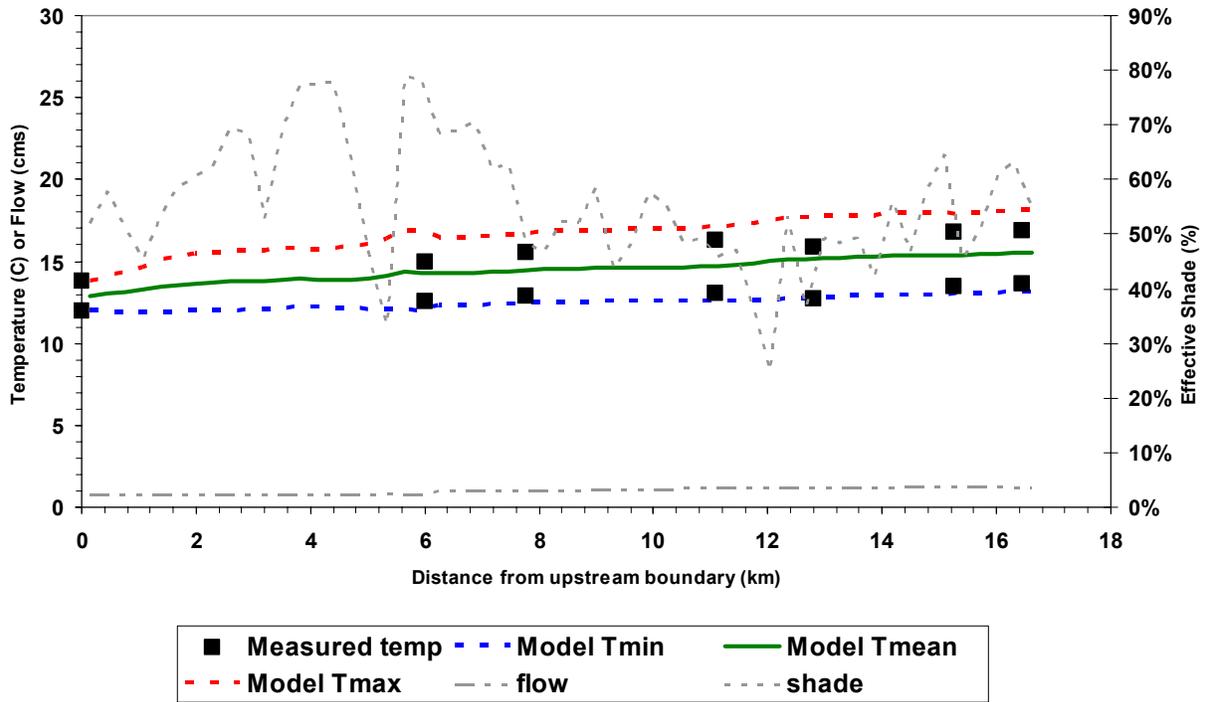


Figure 15. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the cool validation period of August 1 through 7, 2001 (RMSE = 0.91°C).

7Q2 and 7Q10 Conditions

Predicted daily maximum temperatures for typical and extreme hydrologic conditions are presented in Figure 16 with the calibration results. Because calibration air temperature and flow conditions were close to 7Q2 conditions, the predicted temperatures are similar. However, the higher air temperatures and lower flow conditions expected under 7Q10 conditions result in significantly increased water temperatures along the entire length of South Prairie Creek. Lengths of stream exceeding the 18°C standard are 6.9 and 9.2 mi (11.1 and 14.8 km) for typical and extreme hydrologic conditions, respectively.

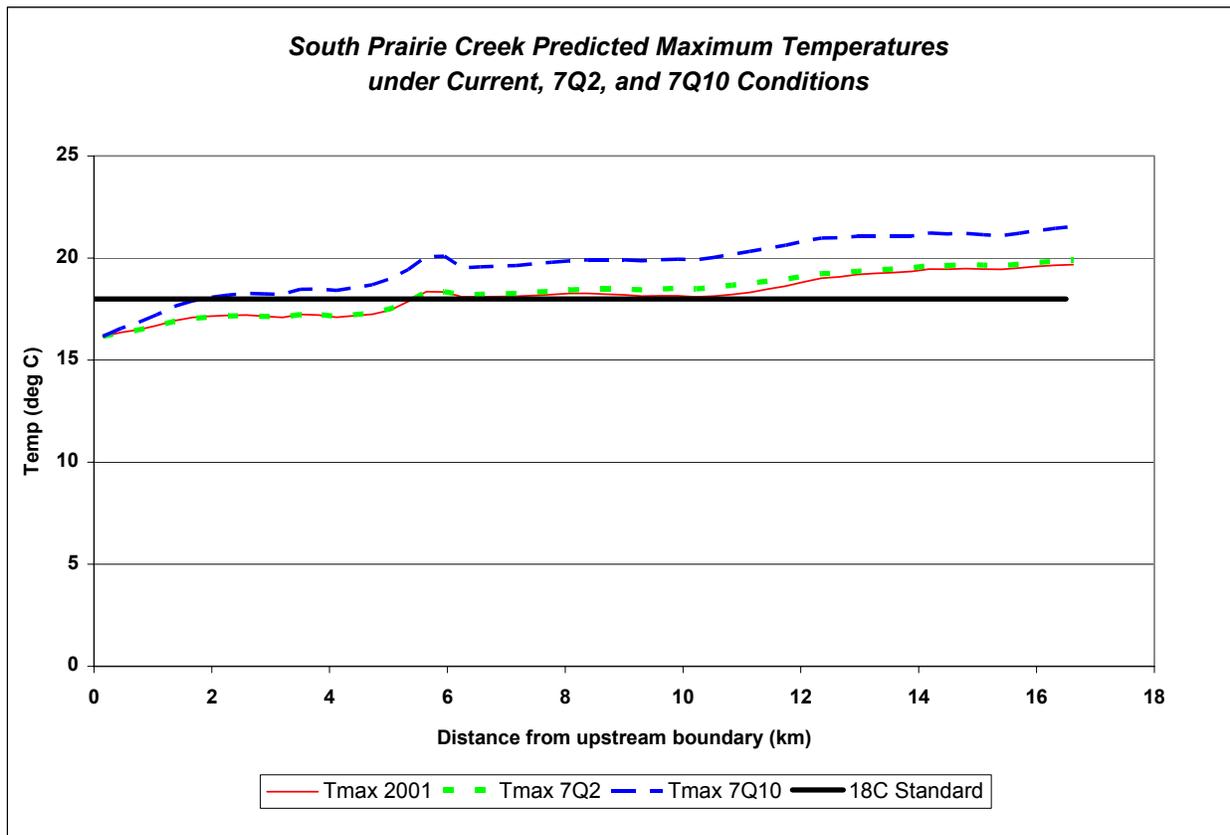


Figure 16. Predicted temperatures in South Prairie Creek under current, typical (7Q2), and extreme (7Q10) hydrologic conditions.

Loading Capacity

The calibrated QUAL2K model was used to determine the loading capacity for effective shade for South Prairie Creek from the upstream boundary at Spiketon Road (SPCSR) to the mouth. 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 7Q2 low flow was selected to represent a typical climatic year, and the 7Q10 low flow was selected to represent a reasonable worst-case condition for the July-August summer period.

The site potential vegetation is a cedar/hemlock/Douglas fir forest. A tree height of 55 m (180 ft) and canopy density of 90%, based on the current vegetation found along South Prairie Creek at the Wilkeson Creek confluence (SPCWC) and at the Lower Burnett Road crossing (SPCLB) (see Figure 12), was used to define maximum potential effective shade from mature riparian vegetation. The DNR soils datalayer indicates the area has a site index of 129, which represents the height in feet of the dominant or co-dominant vegetation at a stand age of 50 years for forests west of the Cascades. This is close to the highest site index value for all of WRIA 10 (132 ft, or 40 m). Much of the South Prairie Creek riparian area had been modified prior to the 1936 vegetation survey (USFS, 1996), which indicates older trees near the confluence with Wilkeson Creek (Figure 17). Thus, the current vegetation does not represent undisturbed conditions. The parameters representing mature riparian conditions exceed the height expected within 50 years, based on the site index from soil surveys, and are within the values for mature western Washington forests documented in Beschta et al. (1987).

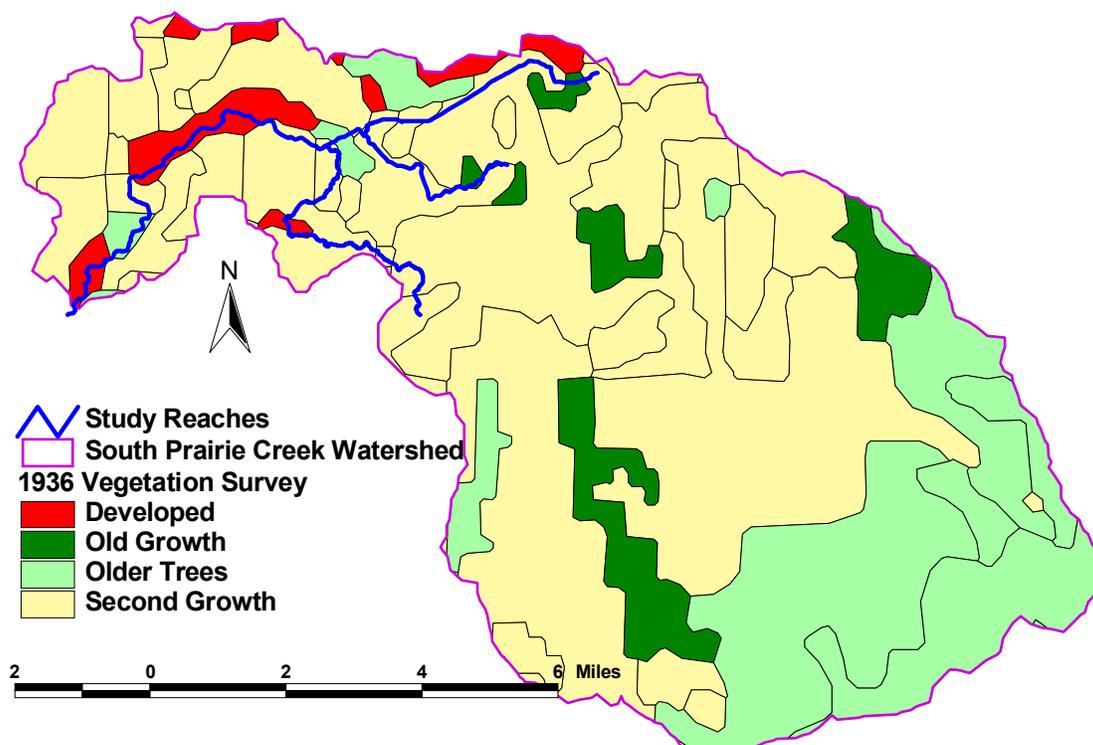


Figure 17. Vegetation present during 1936 vegetation survey.

Figure 18 presents the predicted water temperature in South Prairie Creek for the lowest 7-day average discharge during July and August with a two-year recurrence interval (7Q2) and a ten-year recurrence interval (7Q10). The increase in effective shade from mature riparian vegetation has the potential to significantly decrease water temperature under both typical and extreme hydrologic conditions.

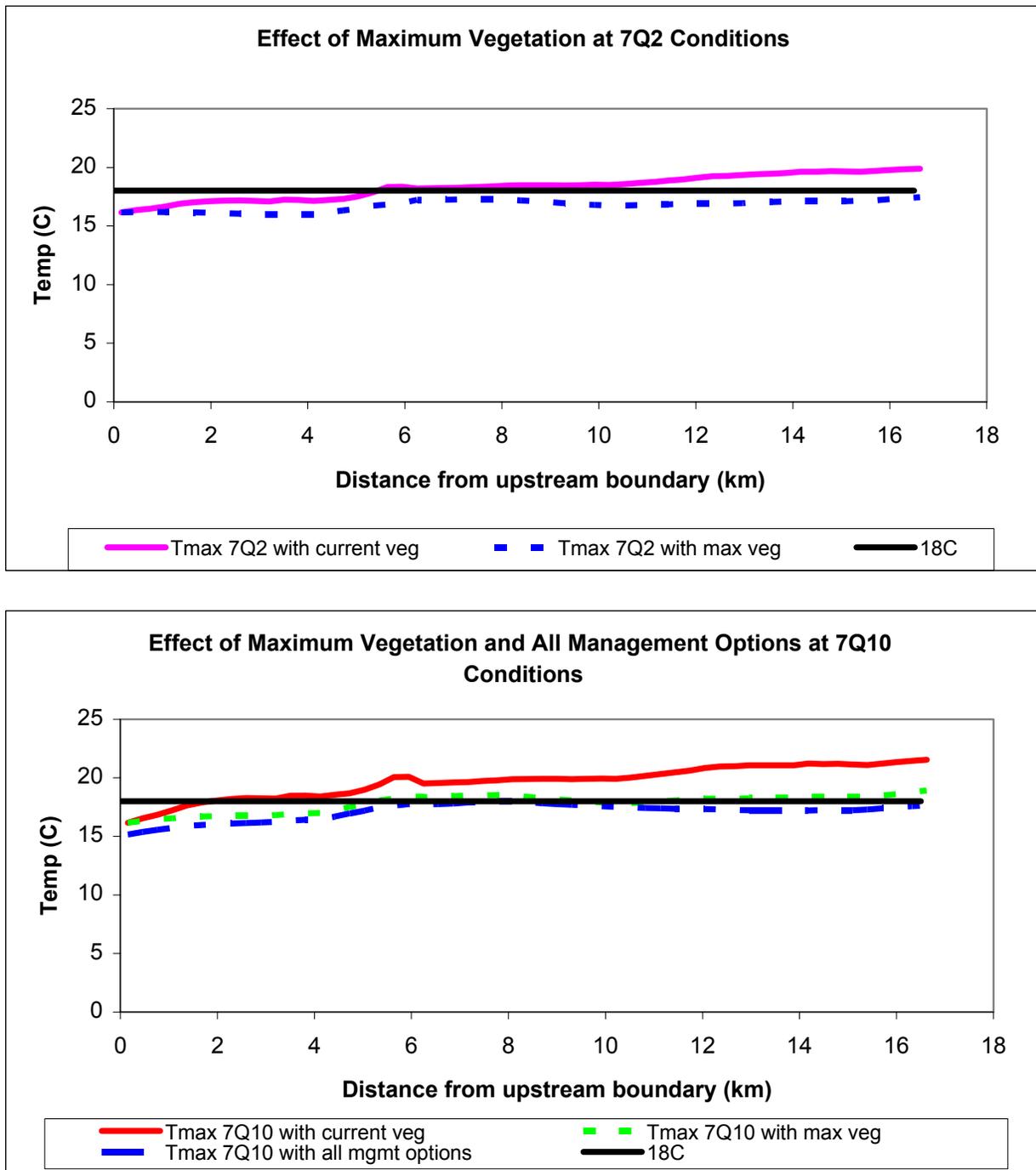


Figure 18. Predicted daily maximum temperature in South Prairie Creek under critical conditions for the TMDL.

With current vegetation, South Prairie Creek exceeds the numeric standard in the lower 11.1 km during 7Q2 conditions. Under mature vegetation conditions within the modeled area, South Prairie Creek should meet numeric standards along the entire length. Under 7Q10 conditions, current vegetation produces water temperatures that exceed 18°C for the lower 14.8 km of the creek with a peak temperature of 21.5°C. For the same flow conditions with mature vegetation within the model area, solar radiation is significantly attenuated such that an additional 7.8 km meets the 18°C criterion and temperatures peak at 18.9°C.

The background temperature expected within the study area was determined using the upstream boundary condition measured in 2001. The area was simulated with no upstream water withdrawals, mature riparian vegetation throughout the model area, and an intact riparian microclimate that reduces air temperatures. Temperature peaks at 18.2°C, as shown in Figure 18. Therefore, 18.2°C represents the background temperature against which anthropogenic impacts and management strategies are compared. Human activities cannot increase the temperature by >0.3°C above this, or 18.5°C.

Maximum vegetation alone will significantly decrease daily maximum temperatures, but South Prairie Creek may exceed 18°C under extreme hydrologic events, represented by 7Q10 conditions. Several additional ongoing and potential management strategies were simulated as a series of scenarios: increased baseflow, decreased upstream boundary condition temperatures, decreased channel widths, and decreased air temperatures. Table 13 summarizes the results.

Table 13. Management scenarios and decreases in peak temperatures in South Prairie Creek for extreme hydrologic conditions (7Q10). [± 0.6 to 0.9 °C for model uncertainty]

Scenario	T _{max} (°C)	Δ T _{max} *	Length <18°C	
Current vegetation**	21.5	(2.6)	2.0 km	12%
Mature riparian vegetation	18.9	0.0	7.0 km	42%
No DSHS withdrawal (increase headwater discharge by 3.5 cfs = 0.10 m ³ /s)	18.8	0.1	8.2 km	49%
No DSHS withdrawal and augment flows another 6.5 cfs	18.5	0.4	13.1 km	78%
No DSHS withdrawal and cool headwater boundary condition T _{max} by 1°C to 15.16°C	18.7	0.2	10.7 km	64%
No DSHS withdrawal and cool headwater boundary condition T _{max} by 2°C to 14.16°C	18.5	0.4	14.0 km	84%
No DSHS withdrawal and cool Wilkeson Creek T _{max} to 17°C	18.7	0.2	9.8 km	58%
No DSHS withdrawal and decrease channel width near mouth by 15% from 19m to 16m	18.6	0.3	8.2 km	49%
No DSHS withdrawal and keep SPCSP T _{air} constant downstream to mimic riparian microclimate	18.3	0.6	12.5 km	75%
No DSHS withdrawal, T _{air} constant from SPCSP downstream, decrease width, decrease SPC upstream boundary by 1°C, decrease Wilkeson Creek by 1°C	18.0	0.9	16.6	100%

* compared with maximum potential vegetation

** current vegetation produces peak temperatures 2.6°C greater than mature riparian vegetation

First, the streamflow at the upstream model boundary was increased under 7Q10 conditions to simulate a retired water right or other flow augmentation. DSHS may no longer exercise its water right of 3.5 cfs (0.10 cms). Adding the equivalent volume to the headwater boundary condition reduces the peak temperature to 18.8°C compared with 18.9°C for maximum potential vegetation; 8.2 km or 49% of the model study area would have surface water temperatures less than 18°C. If the upstream boundary discharge increased by another 6.5 cfs, or a total of 10 cfs including the DSHS water right, peak temperatures would decrease further to 18.5°C, and 78% of the study area would not exceed 18°C.

Second, to simulate the results of the TFW Agreement, the daily maximum temperature at the upstream boundary in South Prairie Creek was decreased by 1°C and 2°C to 15.16°C and 14.16°C, respectively. Peak temperatures would decrease from 18.9 in South Prairie Creek to 18.7 in South Prairie Creek and the length of stream not exceeding 18 in South Prairie Creek would increase from 8.2 to 10.7 km. A 2°C increase would result in a decrease in peak temperature from 18.9°C to 18.5°C, and 14.0 km (84%) of the study area would not exceed 18°C. Similarly, the Wilkeson Creek discharge was reduced to 17°C. This results in a similar decrease in peak temperature from 18.9°C to 18.7°C and increase in length of stream not exceeding 18°C from 8.2 to 9.8 km.

Third, by decreasing the channel width near the mouth by 15% from 62 ft to 53 ft (19 m to 16 m), peak temperatures decrease from 18.9°C to 18.6°C; the length of stream not exceeding 18°C would not change.

Finally, the model was used to simulate the effects of potential air temperature decreases due to a riparian microclimate that could result from continuous mature riparian vegetation. As described under Model Approach, longitudinal air temperatures varied from a maximum of 23.9°C during 2001 at the upstream boundary (SPCSR) to 29.0°C at the mouth (SPCM). This increase is far greater than can be explained by the dry adiabatic lapse rate to account for changes of elevation. The 2001 distribution of peak temperatures was used to relate air temperatures at the USGS meteorology station to riparian air temperatures upstream and downstream. The lack of continuous, mature riparian vegetation downstream of the town of South Prairie likely contributed to the 6.1°C increase in air temperatures as compared with the upstream area, where topography and vegetation likely create cool riparian microclimates. If the air temperature at the town of South Prairie is held constant downstream, temperature peaks at 18.3°C compared with 18.8°C, and 75% of the model area does not exceed 18°C.

In summary, increased shade from mature riparian vegetation significantly reduces peak water temperatures and increases the length of stream not exceeding 18°C. The secondary beneficial impacts of the riparian microclimate to air temperatures further reduces peak temperatures and increases the length of stream not exceeding 18°C. Increasing baseflow, decreasing upstream boundary temperatures, and decreasing stream width near the mouth also decrease peak temperatures. If all activities coincide, the model predicts that no part of South Prairie Creek will exceed 18°C. However, common practice (Pelletier, 2002; Brock and Stohr, 2002) in temperature TMDLs is to use model uncertainty (RMSE of 0.64°C and 0.91°C, from validation runs) as part of the margin of safety. While peak temperatures will exceed 18°C minus the uncertainty, or 17.1°C to 17.4°C, for all ongoing and potential management strategies, these

practices significantly decrease daily maximum temperatures during critical conditions and increase the length of stream not exceeding 18°C. This attenuation of the diurnal thermal range is beneficial to salmonids and other aquatic species using the creeks for refugia.

Load Allocations

The Load Allocations for effective shade in the South Prairie Creek watershed are as follows:

- For all perennial streams in the South Prairie Creek watershed, the load allocation for effective shade is the maximum potential effective shade that would occur from mature riparian vegetation.

Load Allocations for effective shade are quantified for the modeled reaches of South Prairie Creek in Table 14 as an example. For all other perennial streams in the watershed, the Load Allocation for effective shade is the maximum potential effective shade that would occur from mature riparian vegetation.

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

- For U.S. Forest Service land, the riparian reserves in the Northwest Forest Plan are recommended for establishment of mature riparian vegetation.
- For privately owned forest land, the riparian vegetation prescriptions in the Forests and Fish Report are recommended for all perennial streams. Load allocations are included in this TMDL for forest lands in the South Prairie Creek watershed in accordance with the section of Forests and Fish entitled “TMDLs produced prior to 2009 in mixed use watersheds,” using the shade curve methodology developed in the Upper White River Watershed Temperature TMDL (Ketcheson et al., 2003). Figure 19 presents the effective shade provided to streams of different NSDZ widths, varying stream aspects, and varying tree heights to represent an aging riparian forest. For example, for an east-west stream segment (aspect 90°) with a width of 66 ft (20 m) effective shade can be expected to increase from 18% to 35% to 62% to 80% as riparian tree height increases from 30 ft (9 m) to 60 ft (18 m) to 120 ft (37 m) to 180 ft (55 m).
- Instream flows and water withdrawals are managed through regulatory avenues separate from TMDLs. However, stream temperature is directly related to the amount of instream flow, and reductions in flow result in increases in temperatures. Given the temperature exceedance in South Prairie Creek and the inability to meet the temperature standard under full mature riparian vegetation, no further water withdrawals should be permitted. Voluntary retirement of existing water rights should be encouraged.
- While this study did not find evidence of channel widening in the South Prairie Creek watershed and a previous study found no evidence of changes in channel geometry (Mastin, 1998), future development and management activities should control potential channel widening processes.

Table 14. Effective shade, solar flux, and load allocations for South Prairie Creek.

Station	Reach	Distance from upstream boundary to middle of stream reach (km)	Distance from mouth to middle of stream reach (km)	Reach-average effective shade for current conditions (%)	Reach-average solar radiation received at the water surface on August 1 with current vegetation (langley/day)	Reach-average effective shade with mature riparian vegetation (%)	Reach-average solar radiation received at the water surface on August 1 with mature riparian vegetation (langley/day)	Load allocation for effective shade assuming mature riparian vegetation (180 ft and 90% canopy density)
SPCSR	1	0.15	16.6	52%	316	71%	193	71%
	2	0.46	16.3	58%	279	72%	191	72%
	3	0.76	16.0	51%	318	74%	186	74%
	4	1.07	15.7	45%	353	72%	167	72%
	5	1.37	15.4	53%	304	77%	185	77%
	6	1.68	15.1	58%	274	76%	153	76%
	7	1.98	14.8	61%	260	77%	156	77%
	8	2.29	14.5	62%	248	78%	152	78%
	9	2.59	14.2	70%	202	78%	146	78%
	10	2.90	13.9	68%	211	73%	149	73%
	11	3.20	13.6	53%	310	75%	177	75%
	12	3.51	13.3	69%	203	77%	165	77%
SPCLB	13	3.81	13.0	77%	147	78%	147	78%
	14	4.12	12.7	78%	148	78%	148	78%
	15	4.42	12.4	78%	148	71%	148	78%
	16	4.73	12.0	63%	242	74%	193	74%
SKTM	17	5.03	11.7	46%	346	66%	167	66%
	18	5.34	11.4	33%	433	79%	223	79%
	19	5.64	11.1	79%	139	79%	139	79%
SPCWC	20	5.95	10.8	79%	141	69%	141	79%
	21	6.25	10.5	69%	206	76%	220	76%
	22	6.56	10.2	69%	202	75%	156	75%
	23	6.86	9.9	70%	187	74%	161	74%
	24	7.17	9.6	62%	252	77%	174	77%
SPCSP	25	7.47	9.3	63%	244	78%	150	78%
	26	7.78	9.0	48%	336	76%	145	76%
	27	8.08	8.7	47%	349	78%	160	78%
	28	8.39	8.4	52%	313	78%	146	78%
SPCOF	29	8.69	8.1	52%	312	76%	147	76%
	30	9.00	7.8	58%	274	78%	155	78%
	31	9.30	7.5	44%	369	76%	149	76%
	32	9.61	7.2	48%	336	77%	154	77%
	33	9.91	6.9	58%	279	75%	154	75%
	34	10.22	6.6	55%	293	76%	162	76%
	35	10.52	6.3	48%	335	75%	158	75%
SPCB4	36	10.83	5.9	49%	334	71%	167	71%
	37	11.13	5.6	46%	354	76%	190	76%
	38	11.44	5.3	47%	345	72%	160	72%
	39	11.74	5.0	36%	413	72%	183	72%
	40	12.05	4.7	25%	485	72%	180	72%
	41	12.35	4.4	53%	307	75%	184	75%
SPCB2	42	12.66	4.1	37%	414	71%	162	71%
	43	12.96	3.8	49%	331	64%	189	64%
	44	13.27	3.5	48%	338	70%	237	70%
	45	13.57	3.2	49%	332	73%	196	73%
	46	13.88	2.9	42%	374	72%	178	72%
	47	14.18	2.6	56%	290	74%	184	74%
	48	14.49	2.3	47%	348	74%	170	74%
	49	14.79	2.0	58%	276	73%	169	73%
SPCB1	50	15.10	1.7	64%	232	70%	179	70%
	51	15.40	1.4	45%	355	64%	193	64%
	52	15.71	1.1	51%	324	67%	235	67%
	53	16.01	0.8	61%	256	72%	218	72%
SPCM	54	16.32	0.5	63%	239	73%	184	73%
	55	16.62	0.2	55%	293	73%	178	73%

Hyporheic exchange flows and groundwater discharges are important to maintain the current temperature regime and reduce maximum daily instream temperatures. Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the conductivity of the bed sediments. Therefore, activities that reduce groundwater elevations could hamper the exchange of water through the hyporheic zone, which would result in raised stream temperatures. Similarly, activities that reduce the conductivity of bed sediments could increase stream temperatures. Therefore, future development and management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.

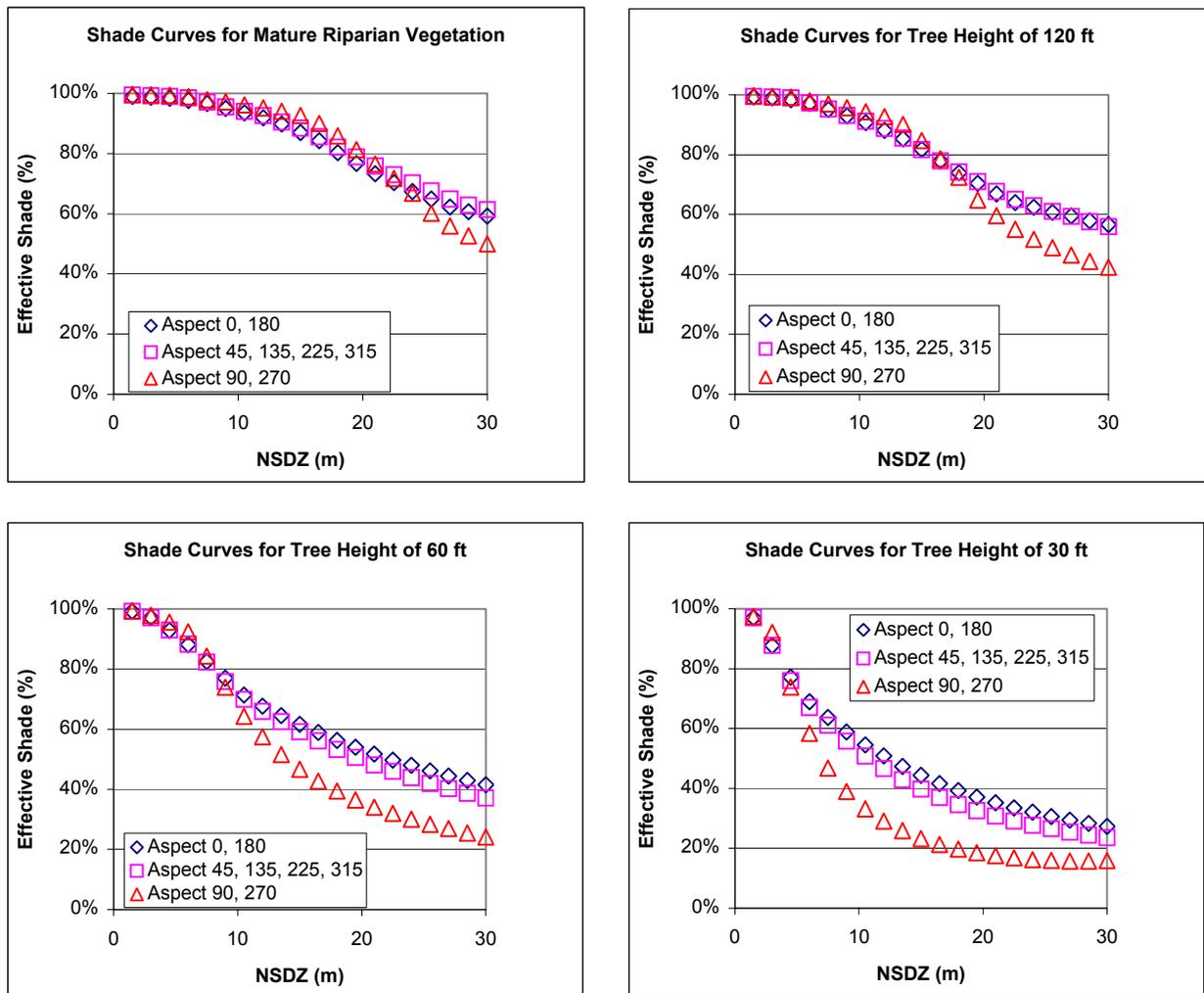


Figure 19. Effective shade provided by riparian vegetation of varying heights, stream aspect, and NSDZ width.

Wasteload Allocations

South Prairie Wastewater Treatment Plant

The South Prairie wastewater treatment plant discharges to South Prairie Creek under NPDES permit number WA0040479. The permit does not have an effluent limit for temperature. Because South Prairie Creek currently exceeds the 18°C standard near the discharge, based on the monitored conditions of 2000 and 2001 and predicted 7Q2 and 7Q10 conditions, the water quality standards stipulate that "...no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C," which includes point source and nonpoint source contributions.

No mixing zone analysis was conducted for the South Prairie wastewater treatment plant. In the absence of a previously defined mixing zone, the effluent can mix with one-quarter of the stream discharge at the point of comparison with the water quality standards (Bailey, 2002).

Table 15 summarizes the information for the South Prairie wastewater treatment plant. When the plant discharges at the maximum summer flow reported in DMRs during the period January 1995 through December 2001, the resultant temperature increase in South Prairie Creek is 0.03°C, less than the 0.3°C maximum increase in the water quality standards. Even if the South Prairie WWTP discharged at the maximum daily rate reported in the DMRs¹⁰ at the maximum temperature, the resultant temperature increase is 0.07°C, still less than the incremental increase allowed in the water quality standards. Therefore, the load allocation is set as a function of flow rate. Effluent temperature cannot exceed

$$T_{\text{wwtp}} (\text{°C}) < [0.452 / Q_{\text{wwtp}} (\text{mgd})] + 18.1$$

where Q_{wwtp} is the effluent flow rate in mgd and T_{wwtp} is the effluent temperature in °C. Figure 20 illustrates the effect. The wasteload allocation does not permit the facility to exceed an effluent temperature of 33°C at any time.

¹⁰ Flows exceeded the permit limit of 0.0382 mgd (0.59 cfs or 0.0017 cms) in the DMRs. This analysis is presented for information purposes only and does not constitute an increase in the permit limit for flow.

Table 15. South Prairie wastewater treatment plant and receiving water characteristics.

Item	mgd	cfs	cms	°C
South Prairie Creek critical conditions at WWTP discharge				
7Q10 discharge	18.10	28.0	0.79	
Allowable mixing volume				
25% 7Q10 discharge	4.52	7.00	0.198	
Theoretical temperature increase (maximum summer discharge and maximum summer temperature)				
Summer peak effluent discharge	0.0354	0.055	0.0016	
Summer peak effluent temperature				21.8
Temperature at edge of mixing zone				18.03
Theoretical temperature increase (permit limit and maximum summer temperature)				
Permit limit for discharge	0.0382	0.059	0.0017	
Summer peak effluent temperature				21.8
Temperature at edge of mixing zone				18.03
Theoretical temperature increase (maximum annual discharge and maximum summer temperature)				
Peak discharge in DMRs	0.083	0.13	0.0036	
Summer peak effluent temperature				21.8
Temperature at edge of mixing zone				18.07

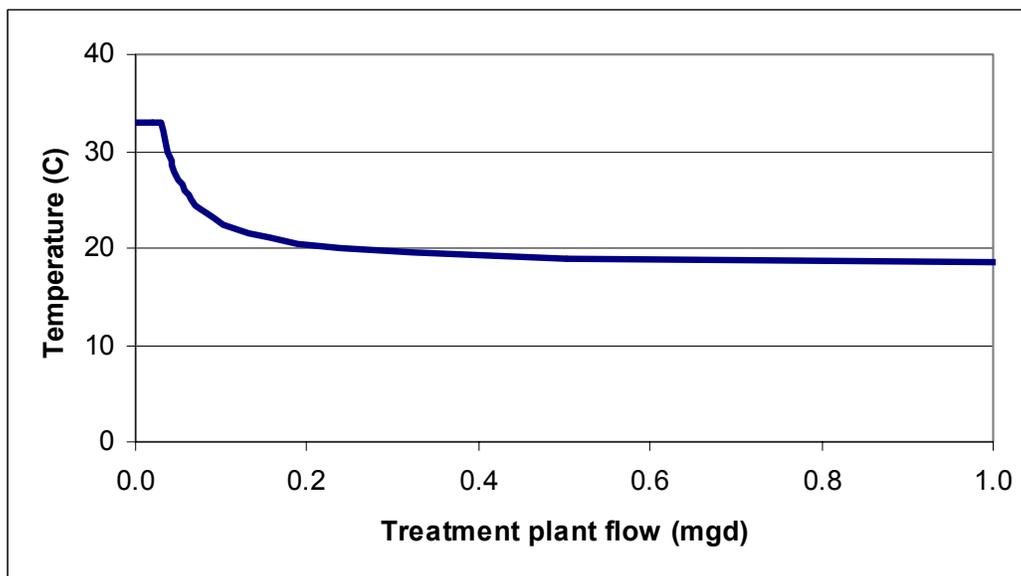


Figure 20. South Prairie wastewater treatment plant wasteload allocation.

Wilkeson Wastewater Treatment Plant

The Wilkeson wastewater treatment plant discharges to Wilkeson Creek under NPDES permit number WA0023281. The permit does not have an effluent limit for temperature. Wilkeson Creek currently meets the 18°C standard near the discharge, based on the monitored conditions of 2000 and 2001, but exceeds the standard at the mouth. The water quality standards stipulate that "...no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C," which includes point source and nonpoint source contributions.

No mixing zone analysis was conducted for the Wilkeson wastewater treatment plant. In the absence of a previously defined mixing zone, the effluent can mix with one-quarter of the stream discharge at the point of comparison with the water quality standards (Bailey, 2002). No 7Q10 has been developed for Wilkeson Creek at the wastewater treatment plant. However, using the 2000 and 2001 flow monitoring data together with the long-term discharge record on South Prairie Creek, 7Q10 flow conditions are estimated to be 6.4 cfs (0.18 cms) based on the relationship between flows at the mouth of Wilkeson Creek to those recorded at the South Prairie USGS gage, then scaled to the tributary area upstream of the discharge point.

Table 16 summarizes the information for the Wilkeson wastewater treatment plant. When the plant discharges at the maximum summer flow reported in DMRs during the period February 1991 through December 2001, the resultant temperature increase in Wilkeson Creek is 0.05°C, less than the 0.3°C maximum increase in the water quality standards. Even if the plant discharged at the maximum daily rate reported in the DMRs at the maximum temperature, the resultant temperature increase is <0.3°C. Therefore, the load allocation is set as a function of flow rate. Effluent temperature cannot exceed

$$T_{\text{wwtp}} (\text{°C}) < [0.104 / Q_{\text{wwtp}} (\text{mgd})] + 18.1$$

where Q_{wwtp} is the effluent flow rate in mgd and T_{wwtp} is the effluent temperature in °C. Figure 21 illustrates the effect. The wasteload allocation does not permit the facility to exceed an effluent temperature of 33°C at any time.

Table 16. Wilkeson wastewater treatment plant and receiving water characteristics.

Item	mgd	cfs	cms	°C
Wilkeson Creek critical conditions at WWTP discharge				
7Q10 discharge	4.2	6.4	0.18	
Allowable mixing volume				
25% 7Q10 discharge	1.04	1.61	0.046	
Theoretical temperature increase (maximum summer discharge and maximum summer temperature)				
Summer peak effluent discharge	0.028	0.043	0.0012	
Summer peak effluent temperature				20
Temperature at edge of mixing zone				18.05
Theoretical temperature increase (maximum annual discharge and maximum summer temperature)				
Peak discharge in DMRs	0.118	0.18	0.0052	
Summer peak effluent temperature				20
Temperature at edge of mixing zone				18.21

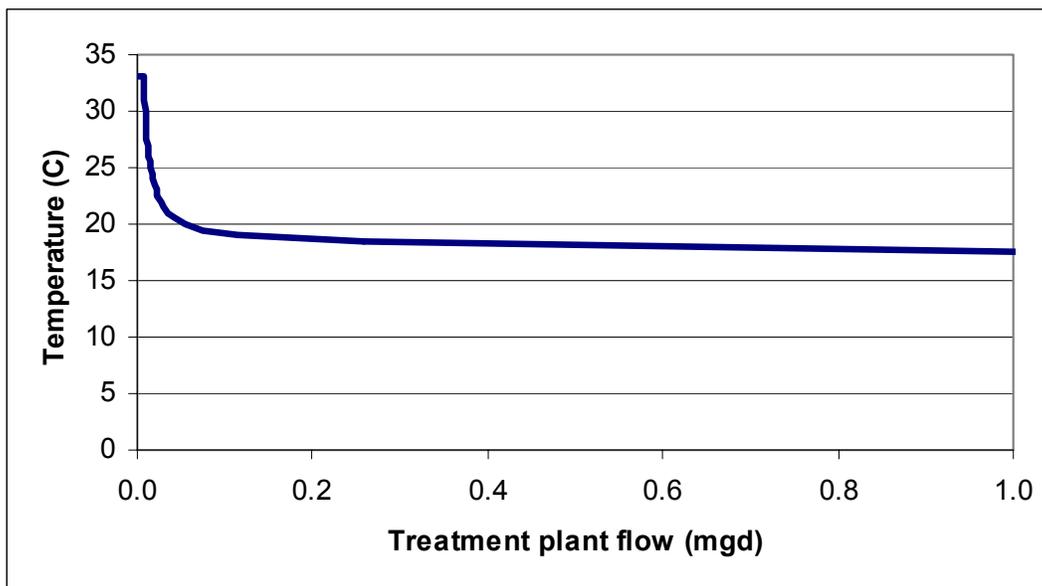


Figure 21. Wilkeson wastewater treatment plant wasteload allocation.

Summary of Load and Wasteload Allocations

Figure 22 compares current water temperature with the nonpoint source wasteload allocations and the point source load allocations for South Prairie Creek under 7Q10 conditions. Current conditions exceed water quality standards, which is the loading capacity. The effective shade allocations will decrease stream heating. The point sources contribute small thermal loads relative to the nonpoint influences on stream heating.

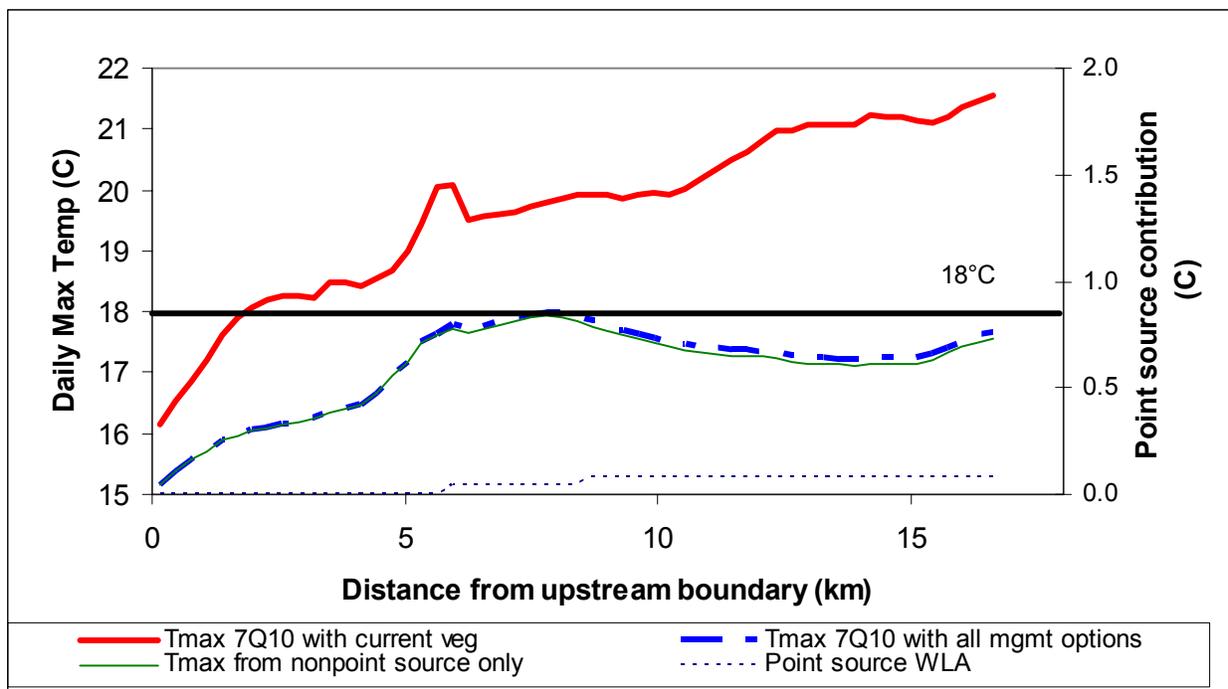


Figure 22. Current and allocated temperature along South Prairie Creek, distinguishing nonpoint source (thin green solid line) and point source (thin blue dashed line on secondary axis) contributions.

Margin of Safety

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

- The 90th percentile of air temperatures recorded at SeaTac Airport were used to develop reasonable worst case conditions air temperatures at South Prairie Creek.
- 7Q10 low-flow conditions were used to evaluate reasonable worst-case conditions. Typical conditions were evaluated using 7Q2 low flow conditions.

Model uncertainty was assessed by estimating the root-mean-square error (RMSE) of model predictions compared with observed temperatures during model validation. The warm validation data set resulted in a RMSE of 0.64°C, while the cool validation data set resulted in a RMSE of 0.91°C.

The load allocations are set to the effective shade provided by full mature riparian shade, which are the maximum values achievable in the South Prairie Creek system.

Recommendations for Monitoring

To determine the effects of management strategies within the model area and upstream in both South Prairie Creek and Wilkeson Creek, regular monitoring is recommended. The model predicts local temperature maxima at two locations: the mouth of South Prairie Creek and at the confluence with Wilkeson Creek (Figure 16). At a minimum, continuous temperature monitors should be installed at the following sites: SPCSR, SPCWC, SPCSP, SPCB2, SPCM, WCM, and SKT165. Probes should be deployed from June through September to capture the critical conditions. Shade management practices involve the development of mature riparian vegetation, which requires more than five years to become established. Interim monitoring is recommended, however, perhaps at five-year intervals.

References

- Aroner, Eric R. 1994. WQHYDRO. Water Quality/Hydrology/Graphics/Analysis System.
- Bailey, Gary. 2002. Permit Writer's Manual. Washington State Department of Ecology, Water Quality Program. Publication No. 92-109. <http://www.ecy.wa.gov/pubs/92109.pdf>
- Beschta, Robert L., Robert E. Bilby, George W. Brown, L. Blair Holtby, and Terry D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. In: *Streamside management: Forestry and Fishery Interactions*, edited by Ernest O. Salo and Terrance W. Cundy, University of Washington, Institute of Forest Resources, Contribution No. 57.
- Boyd, M.S. 1996. Heat source: stream, river, and open channel temperature prediction. Oregon State University. M.S. thesis.
- Brock, Stephanie and Anita Stohr. 2002. Little Klickitat River Watershed Temperature Total Maximum Daily Load. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-031.
- Brown, G.W. 1972. An improved temperature prediction model for small streams. *Water Resources Research*, 6(4):1133-1139.
- Chapra, S.C. 1997. *Surface Water Quality Modeling*. McGraw-Hill Companies, Inc.
- Chapra, S.C. 2001. Water-Quality Modeling Workshop for TMDLs, Washington State Department of Ecology, Olympia, WA. June 25-28, 2001.
- Chen, Y.D., Robert F. Carsel, Steven C. McCutcheon, and Wade L. Nutter. 1998a. Stream temperature simulation of forested riparian areas: I. Watershed-scale model development. *Journal of Environmental Engineering*, 124(4):304.
- Chen, Y.D., Steven C. McCutcheon, Douglas J. North, and Wade L. Nutter. 1998b. Stream temperature simulation of forested riparian areas: II. Model application. *Journal of Environmental Engineering*, 124(4):316.
- Creveling. 2002. Tacoma/Pierce County Health Department. Personal communication.
- Delta-T Devices, Ltd. 1999. HemiView Canopy Analysis Software, version 2.1.
- Dingman, S. Lawrence. 1994. *Physical Hydrology*. Prentice Hall, NJ.
- DNR, Forest Practices Division. 1995. Statewide precipitation isohyets GIS data layer, digitized from 1:2,000,000 source documents (Miller et al., 1973). Washington State Department of Natural Resources, Olympia, WA.

Ecology. 1993. Field Sampling and Measurement Protocols for the Watershed Assessments Section. Washington State Department of Ecology, Olympia, WA. Publication No. 93-e04.

EPA. 1991. Guidance for Water Quality-based Decisions: The TMDL Process. U.S. Environmental Protection Agency. EPA 440/4-91-001.

Golding, S. and A. Johnson. 2001. Re-Evaluation of Copper Impact from Wilkeson Wastewater Treatment Plant on Wilkeson Creek. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-021.

Gould, D.J. and M.R. Fletcher. 1978. Gull droppings and their effects on water quality. *Water Research*, 13:665-672.

Joy, J. 2000. Lower Nooksack River Basin Bacteria Total Maximum Daily Load Evaluation. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-006.

Ketcheson, G., P. Leinenbach, J. Schuett-Hames, T. Whiley, and C. James. 2003. Mt. Baker Snoqualmie National Forest, Upper White Watershed Sediment and Temperature TMDL for Aquatic Habitat (Public Comment Draft). Washington State Department of Ecology, Olympia, WA. Publication No. 03-10-032.

Mastin, M.C. 1998. Flood Potential of South Prairie Creek, Pierce County, Washington. Water-Resources Investigations Report 98-4009. Prepared in cooperation with Pierce County Department of Public Works, Tacoma, WA.

Metcalf & Eddy. 1991. *Wastewater Engineering*. Third Edition. McGraw-Hill, Inc., NY.

Miller et al. 1973. Precipitation-frequency Atlas of the Western United States, Volume IX, Washington, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration.

Nixon, S.W. and C.A. Oviatt. 1973. Ecology of a New England salt marsh. *Ecological Monographs*, 43:463-498.

ODEQ. 2001. Ttools 3.0 User Manual. Oregon Department of Environmental Quality, Portland, OR. <http://www.deq.state.or.us/wq/TMDLs/WQAnalTools.htm>.

Ott, W. 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

Pelletier, Greg. 2002. Wind River Watershed Temperature Total Maximum Daily Load. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-010.

Pieritz, Glenn. 2002. Water Quality Program, Southwest Regional Office, Washington State Department of Ecology, Olympia, WA. Personal communication.

Roberts, M.L. 2000. South Prairie Creek Total Maximum Daily Load Phase I Assessment Quality Assurance Project Plan. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-081.

Roberts, M.L. 2001. South Prairie Creek Total Maximum Daily Load Phase II Evaluation Quality Assurance Project Plan. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-064.

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model, Instream Flow Information Paper 16. Western Energy and Land Use Team, Division of Biological Services, Research and Development, U.S. Fish and Wildlife Service. FWS/OBS-84/15.

United States Forest Service. 1996. Historical vegetation of Oregon and Washington. Results of 1936 vegetation survey. <http://www.icbemp.gov/spatial/veg>.

United States Department of Agriculture, Soil Conservation Service. 1979. Soil Survey of Pierce County Area, Washington. In cooperation with the Washington Agricultural Experiment Station.

This page is purposely blank for duplex printing

Appendices

This page is purposely blank for duplex printing

Appendix A

Water Quality Data for South Prairie Creek and Tributaries

This page is purposely blank for duplex printing

Table A1. Phase I Assessment Water Quality Data (Ecology)

	Date	Station	Flow (cfs)	Fecal Coliform (#/100 ml)	E. coli (#/100 ml)	Enterococci (#/100 ml)	TPN (mg/L)	Ammonia (mg/L)	Nitrite/ Nitrate (mg/L)	Nitrite (mg/L)	Total Phosphorus (mg/L)	Ortho-phosphate (mg/L)	TSS (mg/L)	pH	Temp (C)	DO (mg/L)	
Main Stem Stations	7/19/2000	SPCSR		8											13.65		
	8/1/2000	SPCSR		20	20	4	0.255	0.010 U	0.201	0.010 U	0.015	0.005 U	1 U	7.6	14.6	9.9	
	8/21/2000	SPCSR		1										7.9	10.95		
	9/5/2000	SPCSR		2	2	44	0.208	0.010 U	0.179	0.010 U	0.017	0.005 U	2	8.3	9.9	10.8	
	9/19/2000	SPCSR		22										8.1	12.4		
	10/24/2000	SPCSR		1	1		0.288	0.010 U	0.277	0.010 UJ	0.012	0.005 U	1 U		6.2	11.7	
	12/18/2000	SPCSR													2.9		
	7/5/2000	SPCLB	90.9		11											14.65	
	7/19/2000	SPCLB	54.8		21	20	10	0.273	0.010 U	0.207	0.010 U	0.013	0.005 U		7.8	15.35	10
	8/1/2000	SPCLB	40.6		6										7.7	12.4	
	8/21/2000	SPCLB	39.1		4	4	32	0.225	0.010 U	0.190	0.010 U	0.018	0.005		7.5	11	10.8
	9/5/2000	SPCLB	37.2		26										7.6	12.85	
	9/19/2000	SPCLB	45.8		1	1		0.271	0.010 U	0.281	0.010 UJ	0.013	0.005 U		6.4	11.65	
	10/24/2000	SPCLB	87.4														
	11/28/2000	SPCLB	126.0													3.1	
	12/18/2000	SPCLB	103.9														
	7/12/2000	SPCSP			20											13.85	
	7/19/2000	SPCSP	51.6		49	45	24	0.305	0.010 U	0.239	0.010 U	0.020	0.006		8.1	14.55	10.25
	8/1/2000	SPCSP	47.1		22										7.7	16.85	
	8/21/2000	SPCSP	44.6		29	23	89	0.248	0.010 U	0.204	0.010 U	0.020	0.007		8.0	13.75	
	9/5/2000	SPCSP	59.4		50										7.6	12.4	10.9
	9/19/2000	SPCSP	110.6		8	8		0.336	0.010 U	0.357	0.010 UJ	0.015	0.006		7.4	14.05	
	10/24/2000	SPCSP	201.8													7.4	11.5
	11/28/2000	SPCSP															
	12/18/2000	SPCSP														3.4	
	7/12/2000	SPCB4			120											13	
	7/19/2000	SPCB4			140	130	19	0.523	0.013	0.426	0.010 U	0.028	0.012		8.3	13.85	
	8/1/2000	SPCB4	54.5		120										7.9	19	9.4
	8/21/2000	SPCB4	48.8		760 J	740	73	0.504	0.010 U	0.461	0.010 U	0.029	0.013		7.8	15.8	
	9/5/2000	SPCB4	66.8		300										7.6	12.7	10.7
	9/19/2000	SPCB4	103.3		29	17		0.468	0.010 U	0.440	0.010 UJ	0.018	0.008		7.6	14.7	
	10/24/2000	SPCB4														8.1	11.45
	12/18/2000	SPCB4														3.95	
	7/5/2000	SPCM	165.8													12.8	
	7/12/2000	SPCM			65											13.6	
	7/19/2000	SPCM	77.0		110	92	20	0.493	0.010 U	0.398	0.010 U	0.026	0.009	2	7.9	19.3	9.7
	8/1/2000	SPCM	63.9		77										7.6	16.05	
	8/21/2000	SPCM	54.7		160 J	140	86	0.498	0.010 U	0.432	0.010 U	0.028	0.010	2	7.7	13	10.5
	9/5/2000	SPCM	66.7		240										7.4	15.2	
	9/19/2000	SPCM	112.7		23	14		0.412	0.010 U	0.441	0.010 UJ	0.018	0.007	1 U	8.4	8.4	11.15
	10/24/2000	SPCM	207.9														
	11/28/2000	SPCM	169.6														
	12/18/2000	SPCM															
	Tributary Stations	7/5/2000	SD165	1.8												14.8	
		7/12/2000	SD165													15.05	
		7/19/2000	SD165	1.2	800										7.3	16.1	9.3
		8/1/2000	SD165	1.2	760	760	130	0.287	0.010	0.143	0.010 U	0.029	0.010		7.4	11.6	
		8/21/2000	SD165	1.4	670										7.9	10.1	10.7
9/5/2000		SD165	1.3	240	210	260	0.153	0.010 U	0.089	0.010 U	0.022	0.007		7.4	13.55		
9/19/2000		SD165	1.4	880											6.4	11.05	
10/24/2000		SD165	1.5	40	37		0.222	0.010 U	0.156	0.010 UJ	0.021	0.007					
11/28/2000		SD165	2.4														
12/18/2000		SD165	2.8													2.8	
7/12/2000		WCM														15.75	
7/19/2000		WCM	14.6	29												16.45	
8/1/2000		WCM	11.7	41	39	37	0.441	0.011	0.356	0.010 U	0.029	0.011	1	8.0	17.8	9.5	
8/21/2000		WCM	10.3	37											8.0	13.75	
9/5/2000		WCM	10.4	76	73	88	0.391	0.010 U	0.328	0.010 U	0.028	0.011	1	7.8	11.9	10.85	
9/19/2000		WCM	14.9	170											7.6	13.9	
10/24/2000	WCM	31.4	29	26		0.616	0.010 U	0.572	0.010 UJ	0.019	0.008	1		6.6	11.4		
11/28/2000	WCM	76.3															
12/18/2000	WCM	66.3													3.4		
Miscellaneous Locations	8/21/2000	SD1		39													
	8/21/2000	SD2		680 J													
	9/5/2000	SDSR		59													
	9/19/2000	SPC246		57													
	11/1/2000	SPCUS		7													
	9/19/2000	14309		1400													
10/24/2000	EMERY1		8														

Sampling stations are identified in Figures 3 and 8.

U Not detected at or above the reported detection limit.

J Estimated values; very high density of organisms on plate, and actual concentration may be greater than or equal to reported results.

Table A2. Phase II Assessment Water Quality Data (Ecology)

	Date	Station	Measured Streamflows (cfs)	Fecal Coliform (#/100 ml)	FC Qualifier	Enterococci (#/100 ml)	EC Qualifier	Temperature (°C)
Main Stem Stations	1/29/2001	SPCSR		2	J	1	UJ	3.6
	2/27/2001	SPCSR		1	UJ	1	UJ	2.2
	3/26/2001	SPCSR		1	UJ	1	J	5.4
	4/16/2001	SPCSR		5	J	1	UJ	6.2
	5/22/2001	SPCSR		7	J	1	J	8.6
	6/18/2001	SPCSR		6	J	1	UJ	8.6
	7/9/2001	SPCSR		12	J	2	J	12
	8/20/2001	SPCSR		9	J	5	J	11.8
	9/17/2001	SPCSR		13	J	45	J	11.6
	10/15/2001	SPCSR		7	J	41	J	7.4
	11/29/2001	SPCSR		10	J	2	J	5.7
	12/18/2001	SPCSR		3	J	4	J	4.3
	1/29/2001	SPCLB	68	1	UJ	2	J	3.6
	2/27/2001	SPCLB	50	2	J	3	J	2.3
	3/26/2001	SPCLB	163	3		1		6.2
	4/16/2001	SPCLB	125	2	J	1	UJ	6.8
	5/22/2001	SPCLB	153	9	J	5	J	9.1
	6/18/2001	SPCLB	158	110		100		9.4
	7/9/2001	SPCLB	53	28	J	6	J	12.6
	8/20/2001	SPCLB	30	16	J	4	J	12.2
	9/17/2001	SPCLB	22	8	J	150	J	12.1
	10/15/2001	SPCLB	89	19	J	35	J	7.8
	11/29/2001	SPCLB	245	22		19		5.8
	12/18/2001	SPCLB	430	4	J	3	J	4.5
	1/29/2001	SPCWC						3.9
	2/27/2001	SPCWC						3
	3/26/2001	SPCWC						6.8
	4/16/2001	SPCWC						7.3
	5/22/2001	SPCWC						10.2
	6/18/2001	SPCWC	149					
	7/9/2001	SPCWC						13.5
	8/20/2001	SPCWC						12.7
	9/17/2001	SPCWC						12.5
	10/15/2001	SPCWC	80					
	11/29/2001	SPCWC						5.8
	12/18/2001	SPCWC						4.5
	1/29/2001	SPCSP	111	21		10		4.1
	2/27/2001	SPCSP	79	2		6		3.9
	3/26/2001	SPCSP		39		60		7.3
	4/16/2001	SPCSP	227	14		5		7.9
	5/22/2001	SPCSP	209	12		8		11.2
	6/18/2001	SPCSP	215	21		11		12.1
	7/9/2001	SPCSP	70	28		16		14.5
	8/20/2001	SPCSP	39	41		16		14.4
	9/17/2001	SPCSP	29	29		41		12.8
	10/15/2001	SPCSP	111	24		60		8.6
	11/29/2001	SPCSP	597	83		270		5.8
	12/18/2001	SPCSP	759	10		11		4.8
1/29/2001	SPCOF		15		80		4.2	
2/27/2001	SPCOF		2	J	80	J	3.4	
3/26/2001	SPCOF		58		89		7.7	
4/16/2001	SPCOF		19		14		7.9	
5/22/2001	SPCOF		17		19		11.2	
6/18/2001	SPCOF		12		17		12.2	
7/9/2001	SPCOF		50		43		14.3	
8/20/2001	SPCOF		160		39		13	
9/17/2001	SPCOF		200		150		12.8	
10/15/2001	SPCOF		74		81		8.6	
11/29/2001	SPCOF		110		380		5.8	
12/18/2001	SPCOF		4		3		4.8	

Table A2. Phase II Assessment Water Quality Data (Ecology)

	Date	Station	Measured Streamflows (cfs)	Fecal Coliform (#/100 ml)	FC Qualifier	Enterococci (#/100 ml)	EC Qualifier	Temperature (°C)
Main Stem Stations	7/9/2001	SPCID		18		25		16.4
	8/20/2001	SPCID		200	J	61		13
	9/17/2001	SPCID		92		170		12.8
	10/15/2001	SPCID		110		270		9.1
	11/29/2001	SPCID		120		440		
	12/18/2001	SPCID		18		20		5
	1/29/2001	SPCB4		690	J	970		4.3
	2/27/2001	SPCB4	82	3	U	40		5
	3/26/2001	SPCB4		68		70		7.8
	4/16/2001	SPCB4		10		27		8.9
	5/22/2001	SPCB4	185	120	J	230		13.2
	6/18/2001	SPCB4		51		11		13.1
	7/9/2001	SPCB4		19		21		16.2
	8/20/2001	SPCB4	50	37		51		15.1
	9/17/2001	SPCB4	38	110		100		12.8
	10/15/2001	SPCB4	110	55		150		9.6
	11/29/2001	SPCB4		110		850	J	
	12/18/2001	SPCB4		44		110		5
	1/29/2001	SPCB2		260	J	930	J	4.4
	2/27/2001	SPCB2		3		23		5.2
	3/26/2001	SPCB2		260	J	220	J	7.8
	4/16/2001	SPCB2		31		34		9.1
	5/22/2001	SPCB2		150	J	200		14.1
	6/18/2001	SPCB2	215	71		29		13.3
	7/9/2001	SPCB2		19		21		16.6
	8/20/2001	SPCB2	44	48		110		15.7
	9/17/2001	SPCB2	40	71		120		13.1
	10/15/2001	SPCB2	118	57		140		9.8
	11/29/2001	SPCB2		80		890	J	
	12/18/2001	SPCB2		40		88		5.1
	1/29/2001	SPCB1	126	260	J	770	J	4.4
	2/27/2001	SPCB1		9		14		5.4
	3/26/2001	SPCB1		310		300		7.9
	4/16/2001	SPCB1	225	9		26		9.2
	5/22/2001	SPCB1	202	120		52		14.6
	6/18/2001	SPCB1	220	29		37		13.6
	7/9/2001	SPCB1	81	71		21		17.5
	8/20/2001	SPCB1	46	41		35		15.6
	9/17/2001	SPCB1	40	110		180	J	13
	10/15/2001	SPCB1	118					9.8
	11/29/2001	SPCB1	550	100		900	J	
	12/18/2001	SPCB1	700	43		71		5.1
	1/29/2001	SPCM	112	400	J	770		4.6
	2/27/2001	SPCM	83	3		6		5.3
	3/26/2001	SPCM	278	250	J	160		8.3
	4/16/2001	SPCM		14		23		9.3
	5/22/2001	SPCM	200	120		81		15
6/18/2001	SPCM	209	80		25		13.6	
7/9/2001	SPCM	86	72		11		17.9	
8/20/2001	SPCM	48	41		75		15.7	
9/17/2001	SPCM	38	160	J	390		13.1	
10/15/2001	SPCM	106	60		120		10.2	
11/29/2001	SPCM		170		1000	J		
12/18/2001	SPCM		31		80		5.1	

Table A2. Phase II Assessment Water Quality Data (Ecology)

	Date	Station	Measured Streamflows (cfs)	Fecal Coliform (#/100 ml)	FC Qualifier	Enterococci (#/100 ml)	EC Qualifier	Temperature (°C)
Tributary Stations	1/29/2001	SKT165	2.1					
	2/27/2001	SKT165	1.8					
	3/26/2001	SKT165	13	680		280		7
	4/16/2001	SKT165						
	5/22/2001	SKT165	1.7					10.9
	6/18/2001	SKT165	3.7					10.3
	7/9/2001	SKT165	0.9					13.5
	8/20/2001	SKT165	0.8					11.6
	9/17/2001	SKT165	1.0					11.9
	10/15/2001	SKT165	3.2					8
	11/29/2001	SKT165	21					
	12/18/2001	SKT165	14					4
	1/29/2001	SKTM		28	J	63	J	3.9
	2/27/2001	SKTM		48	J	36	J	2.5
	3/26/2001	SKTM						
	4/16/2001	SKTM		92	J	49	J	8.3
	5/22/2001	SKTM		320		13		11
	6/18/2001	SKTM		7		6		10.3
	7/9/2001	SKTM		180	J	140	J	12.7
	8/20/2001	SKTM		230	J	300	J	11.7
	9/17/2001	SKTM		94		330		11.9
	10/15/2001	SKTM		140		130		8.4
	11/29/2001	SKTM		500		1900	J	5.8
	12/18/2001	SKTM		26	J	54	J	4.3
	1/29/2001	WCM	36	11	J	5	J	3.9
	2/27/2001	WCM	25	3	J	8	J	2.75
	3/26/2001	WCM	79	5		29		7.1
	4/16/2001	WCM		8		15		7.6
	5/22/2001	WCM	47	19		11		11.4
	6/18/2001	WCM	56	19		23		11.8
	7/9/2001	WCM	20	53	J	32	J	14.2
	8/20/2001	WCM	12	130	J	57	J	12.4
	9/17/2001	WCM	8.6	46		140		12.6
	10/15/2001	WCM	27	200		140		8.9
	11/29/2001	WCM	168	34		74		5.9
	12/18/2001	WCM	247	8		7		4.9
	1/29/2001	T1		15		8	U	
	2/27/2001	T1		68		650	J	
	3/26/2001	T1		950	J	840		
	4/16/2001	T1		1100		210		
	5/22/2001	T1		540		210		
	6/18/2001	T1		210		69		15.3
	7/9/2001	T1		83		130		13.5
	8/20/2001	T1		84		84		12.2
	9/17/2001	T1		450		240		11.7
	10/15/2001	T1		140		140		10.4
	11/29/2001	T1		1500		13000	J	
	12/18/2001	T1		240		220		6.1
7/9/2001	T11D		340		200		15.9	
8/20/2001	T11D		2200	J	2100	J	13	
9/17/2001	T11D		280		230		12.2	
10/15/2001	T11D		550		230		11.4	
11/29/2001	T11D		1400		14000	J		
12/18/2001	T11D		290		380		6.2	

Table A2. Phase II Assessment Water Quality Data (Ecology)

	Date	Station	Measured Streamflows (cfs)	Fecal Coliform (#/100 ml)	FC Qualifier	Enterococci (#/100 ml)	EC Qualifier	Temperature (°C)
Point Source	1/29/2001	OF		37		8		
	2/27/2001	OF		7		3		
	3/26/2001	OF		80		57		
	4/16/2001	OF		1		4		
	5/22/2001	OF		25		7		
	6/18/2001	OF		76		22		
	7/9/2001	OF		19		10		
	8/20/2001	OF		1		1	U	
	9/17/2001	OF		1	U	2		
	10/15/2001	OF		3		1		
	11/29/2001	OF		82		39		
	12/18/2001	OF		1	U	2		

Sampling stations are identified in Figures 3 and 8.

U Not detected at or above the reported detection limit.

J Estimated values; very high density of organisms on plate, and actual concentration may be greater than or equal to reported results.

Table A3. Puyallup Tribe Water Quality Data

Parameter	Site	2/9/2001	3/12/2001	3/26/2001	5/2/2001	5/22/2001	6/18/2001	7/25/2001	8/21/2001	9/26/2001
FIELD DATA										
D.O. (mg/L)	SPC-1	13.27	12.87	12.70	13.90	11.90	11.52	9.66	11.06	10.16
D.O. (mg/L)	SPC-2	13.70	13.60	12.71	14.04	12.78	11.27	9.46	10.79	10.29
D.O. (mg/L)	SPC-3	13.14	14.04	11.74	14.17	11.14	10.70	10.84	12.22	9.59
D.O.%	SPC-1	99.7	106.5	103.2	105.8	105.6		95.1	103.7	94.3
D.O.%	SPC-2	103.9	112.7	103.7	113.8	114.2		93.6	102.3	95.9
D.O.%	SPC-3	99.5	14.0	97.9	116.0	100.3		107.7	117.1	89.8
Temp. (C)	SPC-1	3.39	7.82	6.54	6.94	10.19	10.04	14.69	13.17	12.05
Temp. (C)	SPC-2	3.58	7.39	6.89	7.18	10.54	10.95	15.16	13.15	12.16
Temp. (C)	SPC-3	3.71	7.36	7.66	7.44	11.01	11.36	15.15	13.47	12.38
Cond. (µs/cm)	SPC-1	62.6	94.5	66.9	55.9	64.8	64.6	111.1	127.6	122.9
Cond. (µs/cm)	SPC-2	75.2	103.8	76.3	61.5	71.4	72.4	125.2	143.0	135.7
Cond. (µs/cm)	SPC-3	75.5	104.7	87.6	62.6	77.4	73.8	123.8	139.1	133.7
pH	SPC-1	7.19	7.28	7.04	7.13	7.36	6.97	7.63	7.03	7.73
pH	SPC-2	7.04	7.28	6.84	7.08	7.34	6.89	7.87	7.17	7.65
pH	SPC-3	7.12	7.43	6.94	7.13	7.29	6.96	7.75	7.31	7.62
TDS (mg/L)	SPC-1	0.0401	0.0606	0.0428	0.0358	0.0415		0.7120	0.0815	0.0787
TDS (mg/L)	SPC-2	0.0481	0.0664	0.0488	0.0394	0.0458		0.0803	0.0913	0.0869
TDS (mg/L)	SPC-3	0.0483	0.0670	0.0523	0.0401	0.0497		0.0792	0.0890	0.0856
Salinity (ppt)	SPC-1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salinity (ppt)	SPC-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salinity (ppt)	SPC-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LABORATORY DATA										
Ortho (mg/L)	SPC-1									
Ortho (mg/L)	SPC-2									
Ortho (mg/L)	SPC-3									
Total Phos. (mg/L)	SPC-1			0.04			0.06			
Total Phos. (mg/L)	SPC-2									
Total Phos. (mg/L)	SPC-3			0.09			0.07			
Nitrate + Nitrite (mg/L)	SPC-1						0.24			
Nitrate + Nitrite (mg/L)	SPC-2									
Nitrate + Nitrite (mg/L)	SPC-3						0.35			
TSS (mg/L)	SPC-1			3			ND			
TSS (mg/L)	SPC-2									
TSS (mg/L)	SPC-3			4			10			
Fecal Coliform (col/100mL)	SPC-1			70			31			
Fecal Coliform (col/100mL)	SPC-2									
Fecal Coliform (col/100mL)	SPC-3			800			80			
Ammonia (mg/L)	SPC-1			ND			ND			
Ammonia (mg/L)	SPC-2									
Ammonia (mg/L)	SPC-3			0.1			ND			

Station Descriptions

SPC-1 (Puyallup Tribe) SPCSP (Ecology/TMDL)
 SPC-2 (Puyallup Tribe) SPCB4 (Ecology/TMDL)
 SPC-3 (Puyallup Tribe) SPCM (Ecology/TMDL)

ND = Not Detected

Table A4. Daily Minimum and Maximum Temperature Monitoring Data (2000)

Date	SPCSR		SPCSP		SPCB4		SPCM		WCM		SKT165	
	Tmin	Tmax	Tmin	Tmax								
7/12/00	12.31	14.01	13.66	15.86	13.09	16.71	12.92	17.16	14.11	15.85	14.11	15.21
7/13/00	11.07	12.93	11.79	14.91	12.01	15.76	12.61	16.21	12.09	14.89	12.09	14.73
7/14/00	11.38	12.78	12.41	14.43	12.63	14.97	13.23	15.57	13.03	14.58	12.71	14.42
7/15/00	9.98	14.01	10.7	15.86	10.92	16.87	11.52	17.16	11.01	15.85	10.69	14.89
7/16/00	10.92	14.95	11.63	16.82	11.85	17.83	12.45	18.12	11.94	16.8	11.62	16.01
7/17/00	11.84	15.11	12.57	16.97	12.78	17.99	13.38	18.12	13.03	17.12	12.87	16.64
7/18/00	12.47	13.39	13.34	14.91	13.56	15.6	14.15	16.37	13.65	15.37	13.64	15.21
7/19/00	12	15.27	13.03	17.13	13.09	18.15	13.53	18.44	13.34	16.96	13.33	16.32
7/20/00	12.31	15.59	13.19	17.61	13.41	18.63	13.99	18.77	13.49	17.43	13.49	16.96
7/21/00	12.62	16.38	13.5	18.26	13.72	19.29	14.31	19.43	13.96	18.08	13.79	17.92
7/22/00	12.93	14.48	13.97	16.02	14.18	16.56	14.62	17.8	14.11	16.48	14.26	16.64
7/23/00	12.62	14.48	13.34	16.34	13.56	17.19	13.99	16.84	13.49	15.85	13.64	16.17
7/24/00	11.53	15.43	12.41	17.29	12.47	18.15	13.07	18.44	12.56	16.96	12.24	16.32
7/25/00	12.47	13.71	13.34	15.54	13.41	16.08	14.15	16.84	13.65	15.53	13.64	15.69
7/26/00	12.47	14.17	13.5	15.86	13.56	17.03	14.15	17.8	13.8	15.69	13.64	16.01
7/27/00	12.31	15.27	13.34	17.46	13.41	17.83	14.15	18.12	13.65	17.12	13.49	17.12
7/28/00	13.24	14.32	14.59	15.86	14.66	16.56	15.42	17.16	15.06	16.01	15.21	16.48
7/29/00	12.93	16.22	13.97	18.42	14.03	19.45	14.62	19.43	14.27	18.24	14.42	17.92
7/30/00	13.39	16.86	14.28	19.07	14.49	20.11	15.26	20.23	14.74	18.73	14.58	18.56
7/31/00	13.86	17.17	14.75	19.39	14.81	20.27	15.57	20.39	15.06	19.05	15.05	18.73
8/1/00	14.48	16.86	15.7	18.74	15.76	19.45	16.52	19.59	15.69	18.4	15.53	18.08
8/2/00	12.78	16.22	13.5	18.26	13.56	18.96	14.31	19.1	13.49	17.59	13.02	16.8
8/3/00	12.78	15.59	13.5	17.77	13.56	18.63	14.31	18.77	13.49	17.12	13.18	17.12
8/4/00	12.78	16.38	13.66	18.58	13.56	19.45	14.46	19.43	13.65	18.08	13.49	17.59
8/5/00	13.39	16.54	14.28	18.42	14.49	19.12	15.26	19.1	14.42	17.76	14.26	17.43
8/6/00	13.39	16.07	14.28	17.93	14.34	18.63	15.09	18.61	14.27	17.28	14.26	17.12
8/7/00	13.71	15.43	14.43	16.97	14.49	17.51	15.26	17.32	14.42	16.17	14.58	16.64
8/8/00	12.93	16.22	13.66	18.09	13.72	18.8	14.62	18.77	13.49	17.43	13.33	16.96
8/9/00	13.24	15.91	13.97	17.29	14.03	17.99	14.93	17.8	13.96	16.64	13.95	16.8
8/10/00	13.24	14.48	14.12	15.86	14.18	16.08	14.93	16.68	13.8	15.21	14.11	15.85
8/11/00	12.16	14.17	13.03	15.7	13.09	15.92	13.84	16.05	12.87	15.06	12.87	15.21
8/12/00	11.23	14.48	11.79	16.34	11.69	17.19	12.45	17	11.63	15.69	10.85	14.89
8/13/00	11.23	14.01	11.79	15.7	11.85	16.56	12.76	16.68	11.63	15.06	11.01	14.89
8/14/00	11.69	13.55	12.26	15.22	12.16	15.92	12.92	15.89	12.09	14.58	11.62	14.11
8/15/00	10.92	13.71	11.48	15.86	11.38	16.56	12.14	16.52	11.17	15.06	10.54	13.79
8/16/00	10.92	14.17	11.32	15.86	11.38	16.71	12.14	16.68	11.17	15.37	10.38	14.26
8/17/00	11.07	14.32	11.63	16.02	11.69	17.03	12.45	16.84	11.47	15.37	10.69	14.58
8/18/00	11.84	12.78	12.57	14.28	12.94	14.81	13.53	15.42	12.41	13.8	12.24	13.79
8/19/00	11.69	13.24	12.41	14.43	12.63	14.97	13.23	15.42	12.41	14.27	12.24	13.79
8/20/00	11.53	13.86	12.26	15.38	12.32	16.24	12.92	16.21	12.25	15.06	11.93	14.58
8/21/00	11.07	14.01	11.63	15.7	11.69	16.71	12.61	16.68	11.47	15.37	11.16	14.73
8/22/00	11.38	14.48	11.94	16.34	12.01	17.51	12.92	17.32	11.94	15.85	11.47	15.37
8/23/00	11.84	14.95	12.57	16.66	12.78	17.83	13.53	17.64	12.72	16.17	12.56	16.17
8/24/00	12.47	15.27	13.19	16.82	13.41	17.83	14.15	17.64	13.34	16.48	13.18	16.17
8/25/00	13.39	14.48	14.28	16.49	14.49	17.19	15.26	17.48	14.27	16.01	14.58	16.17
8/26/00	13.09	14.17	13.97	15.38	14.03	15.76	14.78	16.21	13.96	15.06	13.64	14.89
8/27/00	12.16	13.55	12.88	15.07	12.78	15.28	13.53	15.89	12.72	14.42	12.4	14.11
8/28/00	10.76	13.71	11.01	15.22	11.08	16.08	11.83	15.89	10.86	14.58	10.23	13.95

Table A4. Daily Minimum and Maximum Temperature Monitoring Data (2000)

Date	SPCSR		SPCSP		SPCB4		SPCM		WCM		SKT165	
	Tmin	Tmax	Tmin	Tmax								
8/29/00	10.92	12.78	11.48	14.12	11.54	14.18	12.29	14.46	11.32	13.8	11.01	13.49
8/30/00	12.16	12.78	13.03	14.12	13.25	14.49	13.69	14.93	13.03	13.8	12.87	13.79
8/31/00	11.84	13.09	12.72	14.28	12.78	14.49	13.38	14.93	12.56	14.11	12.24	13.79
9/1/00	10.61	12.78	11.01	13.81	11.08	14.66	11.83	14.62	10.86	13.49	10.38	12.71
9/2/00	10.76	12	11.48	13.19	11.54	13.72	12.14	14.31	11.32	12.87	10.69	12.24
9/3/00	10.14	11.69	10.7	12.88	10.77	13.41	11.52	13.84	10.54	12.72	9.91	12.09
9/4/00	10.14	12.31	10.7	13.81	10.77	14.66	11.36	14.78	10.7	13.65	10.07	12.71
9/5/00	9.98	11.69	10.39	12.72	10.46	13.09	11.21	13.38	10.39	12.56	9.6	11.93
9/6/00	11.07	12	11.94	13.19	12.16	13.56	12.61	13.99	11.94	12.87	11.47	13.02
9/7/00	9.98	11.84	10.39	13.03	10.46	13.56	11.21	13.84	10.39	13.03	9.76	12.4
9/8/00	10.14	11.23	11.01	12.72	11.23	13.41	11.67	13.84	11.63	12.87	11.47	12.4
9/9/00	9.98	10.92	10.54	11.63	10.77	12.01	11.06	12.29	11.17	12.09	10.69	11.78
9/10/00	10.14	10.61	10.86	11.32	10.92	11.69	11.21	12.14	11.47	11.94	11.16	12.09
9/11/00	9.98	11.38	10.7	12.57	10.77	12.94	10.9	13.38	11.17	13.03	11.01	13.02
9/12/00	9.83	11.84	10.39	13.03	10.46	13.41	10.74	13.99	10.86	13.34	10.38	13.18
9/13/00	10.14	12.16	10.7	13.34	10.77	13.87	10.9	14.31	11.17	13.65	10.69	13.49
9/14/00	11.07	13.09	11.63	14.43	11.69	15.13	12.14	15.57	12.09	14.74	11.93	14.42
9/15/00	12.16	13.24	12.88	14.75	12.94	15.6	13.23	15.57	13.34	15.06	13.33	15.05
9/16/00	12.16	13.09	12.88	14.43	13.09	14.81	13.53	15.09	13.49	14.58	13.33	14.73
9/17/00	11.84	13.39	12.72	14.75	12.94	15.6	13.23	15.89	13.18	15.06	13.02	14.89
9/18/00	12.16	12.78	13.03	14.28	13.25	14.66	13.69	15.09	13.49	14.58	13.49	14.58
9/19/00	12.31	13.71	13.34	14.91	13.56	15.92	13.99	15.89	13.65	15.37	13.49	15.53
9/20/00	11.38	12.31	11.94	13.19	11.85	13.56	12.45	14.15	12.09	13.65	11.78	13.33
9/21/00	11.07	12.47	11.94	13.5	12.16	14.34	12.76	14.46	12.09	13.65	11.62	13.18
9/22/00	9.52	11.38	10.23	12.1	10.3	12.94	10.74	13.07	10.23	12.25	9.76	11.47
9/23/00	8.13	10.29	8.21	11.17	8.28	12.01	8.72	11.98	8.06	11.17	7.58	10.54
9/24/00	8.13	10.29	8.37	11.48	8.28	12.32	8.87	12.14	8.37	11.47	7.58	10.54
9/25/00	8.43	10.61	8.83	11.63	8.74	12.47	9.18	12.45	8.99	11.78	8.36	10.85
9/26/00	8.59	10.76	8.99	11.79	8.9	12.78	9.34	12.61	9.14	12.09	8.52	11.01
9/27/00	9.05	11.07	9.46	12.1	9.37	12.94	9.81	12.92	9.77	12.41	9.29	11.62
9/28/00	9.36	10.76	9.92	11.79	9.99	12.01	10.59	12.29	10.23	11.78	9.44	11.62
9/29/00	10.29	11.38	11.01	12.41	11.08	12.94	11.52	13.07	11.17	12.56	11.16	13.33
9/30/00	11.07	11.69	11.79	12.57	12.01	12.94	12.14	13.23	12.25	13.03	12.56	13.49
10/1/00	10.14	11.23	10.7	11.79	10.77	12.01	11.06	12.14	11.17	12.56	11.01	12.56
10/2/00	9.05	10.14	9.61	11.01	9.83	11.23	10.28	11.52	9.77	11.17	9.13	11.01
10/3/00	7.97	9.21	8.21	10.08	8.28	10.46	8.57	10.74	8.37	10.08	7.27	10.38
10/4/00	7.19	8.59	7.43	9.46	7.5	9.99	7.64	10.28	7.44	9.46	5.87	9.29
10/5/00	7.04	8.59	7.12	9.46	7.19	9.99	7.48	10.28	7.13	9.61	5.72	9.44
10/6/00	7.19	8.89	7.28	9.77	7.19	10.46	7.48	10.59	7.44	10.08	6.81	10.69
10/7/00	7.51	9.21	7.9	10.08	7.81	10.92	7.95	11.06	7.91	10.39	8.52	12.09
10/8/00	7.97	9.67	8.21	10.54	8.28	10.77	8.57	10.9	8.37	10.54	8.67	11.01
10/9/00	9.21	9.67	9.77	10.39	9.83	10.61	10.28	10.74	9.92	10.54	10.23	10.69
10/10/00	9.36	9.52	9.92	10.23	10.14	10.3	10.43	10.59	10.23	10.39	10.23	10.38

Table A5. Daily Minimum and Maximum Temperature Monitoring Data (2001)

Date	SPCSR		SPCWC		SPCSP		SPCB4		SPCB2		SPCB1		SPCM		WCB3		WCM		SKT165	
	Tmin	Tmax	Tmin	Tmax																
6/8/01			10.74	12.91	11.49	13.67	11.73	14.37	11.68	14.61	11.82	14.93	11.86	14.97	11.16	12.87	12.21	14.22	12.73	14.43
6/9/01			9.65	11.19	10.26	11.81	10.48	12.19	10.75	12.45	11.04	12.75	11.08	12.79	10.38	12.09	11.27	12.83	11.49	13.04
6/10/01			8.87	10.27	9.32	10.72	9.55	11.11	9.66	11.37	9.79	11.51	9.84	11.55	9.13	10.54	10.03	11.27	9.94	11.8
6/11/01			8.1	9.49	8.39	9.94	8.62	10.17	8.74	10.28	8.86	10.58	8.92	10.62	7.89	9.91	8.78	10.65	9.78	11.95
6/12/01			7.48	7.95	7.62	8.39	7.84	8.62	7.81	8.74	7.94	8.86	7.84	8.76	7.58	8.21	7.86	8.63	9.17	10.41
6/13/01			7.64	9.65	7.93	10.1	8.16	10.33	8.12	10.44	8.25	10.58	8.14	10.62	8.05	9.91	8.32	10.34	9.63	13.19
6/14/01			8.1	9.65	8.39	9.94	8.62	10.33	8.58	10.44	8.71	10.58	8.76	10.47	8.21	10.07	8.78	10.49	10.26	12.11
6/15/01			8.57	10.12	8.86	10.41	9.08	10.64	9.04	10.91	9.17	11.2	9.23	11.24	8.67	10.23	9.25	10.65	10.26	12.26
6/16/01			8.1	10.27	8.39	10.57	8.62	11.11	8.74	11.21	8.86	11.35	8.76	11.24	8.21	10.23	8.94	10.96	9.63	11.8
6/17/01			8.57	11.35	9.01	11.65	9.24	11.88	9.36	12.14	9.48	12.28	9.38	12.48	8.82	10.85	9.56	11.74	10.1	12.11
6/18/01			8.87	16.83	9.32	15.07	9.55	15.79	9.66	14.61	9.79	16.2	9.84	16.07	8.98	11.93	9.87	13.14	9.78	14.43
6/19/01			9.03	13.37	9.32	13.67	9.55	14.37	9.66	14.61	9.95	14.77	9.84	14.81	8.98	17.12	10.03	15.96	9.63	13.81
6/20/01			10.12	14.3	10.57	14.76	10.79	15.48	10.91	15.72	11.04	15.88	10.93	15.92	10.38	13.95	11.27	15.17	10.88	15.22
6/21/01			10.74	14.93	11.34	15.54	11.42	16.12	11.52	16.36	11.82	16.52	11.86	16.55	11.16	14.58	12.05	15.96	12.11	15.69
6/22/01			11.35	12.76	11.81	13.36	12.19	13.59	12.29	13.84	12.44	14.3	12.48	15.44	11.62	13.49	12.36	14.85	12.42	14.27
6/23/01			10.43	12.91	10.72	13.51	10.95	14.06	10.91	14.3	11.2	14.46	11.08	14.49	10.69	12.56	11.12	13.61	11.49	13.96
6/24/01			10.27	11.35	10.72	11.81	10.95	12.04	11.06	12.14	11.35	12.59	11.39	13.41	10.38	11.78	10.96	12.83	11.18	12.57
6/25/01			9.65	12.91	9.94	13.51	10.17	14.21	10.28	14.46	10.42	14.62	10.47	14.49	9.6	12.24	10.34	13.61	10.26	13.04
6/26/01			10.27	13.07	10.72	13.51	10.79	14.06	10.91	14.3	11.2	14.62	11.24	14.65	10.54	12.71	11.12	13.91	11.49	13.5
6/27/01			11.19	11.97	11.65	12.58	11.88	13.13	11.99	13.38	12.13	13.53	12.17	13.57	11.62	12.4	12.36	13.14	12.26	13.04
6/28/01			10.89	11.82	11.19	12.27	11.42	12.66	11.52	12.92	11.82	13.37	11.71	13.41	11.01	11.62	11.74	12.67	12.26	13.04
6/29/01			9.65	12.44	9.94	12.89	10.17	13.74	10.28	13.99	10.58	14.14	10.47	14.18	9.76	11.78	10.34	13.29	10.41	13.66
6/30/01			9.81	13.22	10.26	13.51	10.48	14.06	10.59	14.46	10.73	14.62	10.78	14.81	10.07	12.56	10.65	13.91	10.88	13.5
7/1/01			10.89	14.46	11.34	14.92	11.57	15.79	11.68	16.04	11.97	16.2	11.86	16.07	11.16	13.79	11.89	15.01	11.64	14.43
7/2/01			10.43	14.93	10.72	15.54	10.95	16.27	11.06	16.67	11.35	16.68	11.39	16.71	10.54	14.11	11.27	15.64	10.88	15.06
7/3/01			10.89	15.41	11.34	16.02	11.57	16.75	11.68	16.99	11.97	17.31	12.02	17.18	11.16	14.58	11.89	16.12	11.8	15.85
7/4/01			11.97	16.19	12.42	16.66	12.66	17.39	12.76	17.78	13.06	18.12	12.95	17.99	12.4	15.53	12.83	16.76	13.04	16.96
7/5/01			12.28	15.09	12.58	15.54	12.82	16.27	12.92	16.51	13.37	16.52	13.41	16.87	12.4	14.42	12.98	15.96	13.04	15.22
7/6/01			10.89	14.93	11.19	15.39	11.42	16.12	11.52	16.51	11.82	16.52	11.86	16.39	10.85	13.95	11.27	15.17	11.03	15.37
7/7/01			11.04	15.56	11.34	16.02	11.57	16.91	11.68	17.31	11.97	17.31	12.02	17.18	11.01	14.42	11.43	15.96	11.34	15.22
7/8/01			11.51	16.19	11.81	16.82	12.04	17.55	12.14	18.11	12.44	18.12	12.48	17.83	11.47	15.05	11.89	16.59	11.8	15.85
7/9/01	13.24	15.75	12.13	16.99	12.58	17.61	12.82	18.36	12.76	18.92	13.22	18.93	13.26	18.63	12.24	15.85	12.83	17.39	12.88	17.27
7/10/01	12.31	16.07	12.76	16.99	13.2	17.61	13.28	18.36	13.38	18.59	13.83	18.76	13.87	18.63	12.87	16.17	13.45	17.56	13.66	17.75
7/11/01	12.62	16.07	13.07	17.31	13.51	17.93	13.74	18.68	13.68	19.24	14.14	19.25	14.18	18.96	13.18	16.32	13.61	17.56	13.81	17.27
7/12/01	12.62	15.12	13.07	16.19	13.51	16.66	13.59	17.39	13.68	17.94	14.14	17.79	14.18	17.99	13.02	15.53	13.61	16.44	13.66	16.48
7/13/01	12.31	14.64	12.76	15.88	13.04	16.34	13.28	17.07	13.22	17.78	13.68	17.47	13.72	17.51	12.56	15.05	13.14	15.96	13.04	15.85
7/14/01	12.16	13.24	12.6	13.83	12.89	14.29	12.97	14.53	12.92	14.77	13.22	15.25	13.26	16.39	12.4	13.33	12.98	14.85	13.04	14.27
7/15/01	11.69	12.31	12.13	13.07	12.42	13.36	12.51	13.44	12.61	13.53	12.91	13.99	12.95	14.34	11.93	12.56	12.36	13.45	12.42	13.66
7/16/01	11.22	12.62	11.66	13.22	11.81	13.51	12.04	13.9	11.99	13.99	12.28	14.14	12.33	14.18	11.47	12.56	11.89	13.45	11.64	13.19
7/17/01	11.07	12.31	11.66	13.22	11.96	13.67	12.04	14.06	12.14	13.99	12.44	14.3	12.48	14.18	11.47	12.56	12.05	13.61	11.8	13.34
7/18/01	11.07	13.24	11.66	13.99	11.96	14.29	12.19	14.84	12.29	15.25	12.44	15.57	12.48	15.28	11.62	13.33	12.21	14.22	11.95	14.27
7/19/01	10.91	13.55	11.51	15.09	11.81	15.54	11.88	15.96	11.99	16.51	12.28	16.52	12.33	16.39	11.62	13.49	12.05	15.17	11.8	15.06
7/20/01	11.22	12.47	11.51	13.68	11.96	14.29	12.19	15	12.45	15.72	12.75	15.41	12.79	15.6	11.78	12.71	12.36	14.53	11.8	13.96
7/21/01	11.38	12.16	11.97	12.91	12.42	13.36	12.66	13.74	12.76	13.99	13.06	14.3	13.11	14.81	12.09	12.56	12.67	13.61	12.42	13.34
7/22/01	11.38	12.93	11.97	14.14	12.27	14.6	12.51	15.16	12.61	15.57	12.91	15.57	12.95	15.44	12.09	13.49	12.67	14.38	12.42	14.43
7/23/01	11.38	15.12	11.66	16.36	12.12	16.82	12.35	17.71	12.45	18.27	12.75	18.12	12.79	17.99	11.93	15.37	12.52	16.44	12.26	16.16
7/24/01	12.62	14.02	13.22	15.09	13.67	15.39	13.74	16.12	14.14	16.36	14.3	16.36	14.34	17.02	13.18	14.58	13.91	15.64	14.12	16.16
7/25/01	12.31	15.59	12.91	16.99	13.36	17.61	13.44	18.52	13.68	18.75	13.83	19.09	13.87	18.96	12.71	15.85	13.61	17.07	13.66	16.79
7/26/01	12.16	14.8	12.6	15.88	12.89	16.49	13.13	17.23	13.84	17.46	13.68	17.63	13.41	17.83	12.4	15.05	13.14	15.96	13.04	15.85
7/27/01	12.16	14.02	12.44	14.93	12.73	15.54	12.97	15.96	13.53	16.51	13.37	16.52	13.11	16.71	12.24	14.42	12.83	15.17	12.57	15.06
7/28/01	12.31	13.55	12.91	14.3	13.36	14.92	13.59	15.79	13.68	16.04	13.99	16.36	14.03	16.39	12.87	14.26	13.61	15.17	13.34	15.06
7/29/01	11.53	12.93	12.13	13.99	12.42	14.44	12.66	15	12.76	15.25	12.91	15.57	12.95	15.6	12.09	13.33	12.67	14.53	12.42	14.27
7/30/01	11.07	12.62	11.35	13.68	11.65	14.6	11.88	16.12	11.83	16.04	12.28	17.47	12.33	16.07	11.47	13.18	11.89	15.96	11.49	16.63
7/31/01	11.53	12.62	12.13	13.68	12.42	14.13	12.51	14.68	12.76	15.09	12.91	15.57	12.95	15.44	12.09	12.87	12.67	14.07	12.26	13.81
8/1/01	10.61	12.93	11.04	13.83	11.34	14.29	11.42	15	11.52	15.41	11.82	15.41	12.02	15.28	11.01	13.02	11.43	14.38	10.88	13.96
8/2/01	11.69	13.71	12.44	15.41	12.73	16.02	12.97	17.07	13.22	17.62	13.37	18.12	13.57	17.99	12.4	14.73	13.14	15.96	13.04	15.69
8/3/01	12.16	13.4	12.76	14.61	13.2	15.07	13.28	15.64	13.53	15.88	13.83	15.88	14.03	15.92	13.02	14.26	13.76	14.85	13.66	15.53
8/4/01	12.31	13.55	12.91	14.14	13.2	14.76	13.28	15.48	13.38	15.88	13.68	16.04	13.72	16.39	12.87	13.64	13.61			

Table A5. Daily Minimum and Maximum Temperature Monitoring Data (2001)

Date	SPCSR		SPCWC		SPCSP		SPCB4		SPCB2		SPCB1		SPCM		WCB3		WCM		SKT165	
	Tmin	Tmax	Tmin	Tmax																
8/15/01	13.24	15.75	13.68	16.52	13.98	16.97	14.21	17.71	14.46	18.11	14.77	18.12	14.97	19.12	13.33	15.85	14.07	16.44	13.96	17.11
8/16/01	13.55	14.33	13.83	15.41	14.13	15.71	14.21	16.27	14.46	16.51	14.77	16.68	14.97	17.02	13.33	14.26	14.07	15.33	14.12	15.69
8/17/01	12.93	14.17	13.37	15.09	13.51	15.54	13.59	15.79	13.68	16.04	13.99	16.52	14.03	16.87	12.71	14.11	13.29	14.69	13.5	15.53
8/18/01	12.78	14.02	13.22	14.93	13.51	15.39	13.44	15.64	13.68	15.88	13.99	16.04	14.03	16.39	12.71	13.79	13.45	14.85	13.66	15.06
8/19/01	11.84	14.17	12.13	15.41	12.27	15.71	12.35	16.43	12.61	16.67	12.91	16.68	12.95	17.83	11.78	14.11	12.21	15.17	11.95	14.9
8/20/01	11.38	14.48	11.66	15.24	11.81	15.71	11.73	16.43	11.83	16.67	12.28	16.52	12.33	17.34	11.32	14.26	11.74	15.17	11.18	14.9
8/21/01	11.69	12.93	12.13	13.68	12.27	13.98	12.35	13.9	12.45	14.3	12.75	14.93	12.95	14.97	11.62	12.71	12.21	13.61	11.8	13.5
8/22/01	12.31	12.78	12.91	13.37	13.04	13.67	13.13	13.9	13.38	13.99	13.53	14.14	13.57	14.18	12.4	13.18	12.98	13.61	12.42	13.5
8/23/01	12.16	12.93	12.44	13.53	12.58	13.67	12.82	13.9	12.92	14.14	13.06	14.46	12.95	14.34	12.24	13.02	12.83	13.45	12.57	13.81
8/24/01	11.69	13.86	11.97	14.61	12.12	14.92	12.35	15.79	12.45	15.88	12.59	16.04	12.64	16.07	11.78	13.49	12.21	14.53	12.11	14.27
8/25/01	11.22	14.02	11.51	15.09	11.65	15.39	11.73	16.43	11.83	16.67	12.13	16.83	12.17	16.55	11.32	13.79	11.74	15.01	11.49	14.9
8/26/01	11.69	14.64	11.97	15.72	12.27	16.02	12.35	17.07	12.61	17.46	12.91	17.47	12.95	17.18	11.93	14.58	12.36	15.64	12.26	15.53
8/27/01	12	14.64	12.28	15.56	12.73	16.02	12.82	16.91	13.07	17.14	13.37	17.31	13.41	17.67	12.24	14.58	12.83	15.33	12.42	15.22
8/28/01	12.78	15.12	13.53	16.19	13.82	16.66	14.06	17.71	14.3	18.11	14.62	17.96	14.65	18.79	13.18	15.21	14.07	16.28	13.96	16.48
8/29/01	12.47	14.96	12.91	15.88	13.2	16.34	13.44	17.07	13.68	17.62	14.14	17.63	14.18	18.79	12.87	15.05	13.29	15.81	13.19	16.16
8/30/01	12.62	15.43	13.07	16.19	13.36	16.82	13.59	17.71	13.68	18.11	14.14	17.96	14.34	18.79	12.87	15.37	13.61	16.28	13.34	16.32
8/31/01	13.24	15.27	13.99	15.88	14.29	16.66	14.37	17.07	14.61	17.46	14.77	17.47	14.97	18.31	13.49	14.89	14.38	16.12	14.43	16.01
9/1/01	12.62	13.86	13.22	14.61	13.51	14.92	13.74	15.16	13.99	15.57	14.46	15.88	14.49	16.07	12.71	13.79	13.45	14.85	13.19	14.58
9/2/01	11.53	14.02	11.82	14.93	12.12	15.23	12.04	15.96	12.29	16.36	12.59	16.52	12.64	17.02	11.62	13.95	11.89	14.85	11.49	14.43
9/3/01	12.31	13.4	12.76	14.61	13.04	14.92	13.13	15	13.38	15.25	13.53	15.41	13.72	15.44	12.24	13.33	12.98	14.38	12.73	14.12
9/4/01	12.31	14.02	12.91	14.77	13.04	15.23	13.13	15.79	13.38	16.04	13.53	16.04	13.57	16.87	12.56	13.79	13.14	14.85	12.88	14.58
9/5/01	11.53	12.78	11.97	13.53	12.12	13.82	12.19	13.9	12.45	14.14	12.75	14.62	12.79	14.97	11.47	12.87	12.05	13.61	11.49	13.19
9/6/01	10.91	12.62	11.35	13.53	11.34	13.98	11.42	14.21	11.37	14.61	11.51	14.77	11.55	15.13	10.85	12.71	11.27	13.45	10.88	12.88
9/7/01	11.38	13.24	11.97	14.3	12.27	14.6	12.35	15.79	12.61	16.04	12.91	16.04	12.79	17.18	11.62	13.33	12.21	14.22	11.64	13.81
9/8/01	10.45	13.09	10.74	13.99	10.88	14.44	10.95	15.48	11.06	15.88	11.51	15.73	11.55	16.55	10.54	13.18	10.96	13.91	10.26	13.34
9/9/01	10.45	13.09	10.74	13.83	11.03	14.29	10.95	15.48	11.21	15.72	11.51	15.57	11.55	16.55	10.54	13.18	10.96	13.91	10.26	13.5
9/10/01	10.29	12.93	10.58	13.68	10.72	14.29	10.79	15.16	10.91	15.57	11.35	15.41	11.39	16.39	10.38	13.02	10.81	13.76	10.1	13.34
9/11/01	10.61	13.24	10.89	13.99	11.19	14.44	11.11	15.48	11.37	15.88	11.66	15.73	11.55	16.71	10.69	13.33	11.12	14.07	10.57	13.66
9/12/01	10.91	13.55	11.19	14.3	11.34	14.76	11.42	15.79	11.52	16.2	11.97	16.04	11.86	16.87	11.01	13.64	11.58	14.38	10.88	14.27
9/13/01	11.07	13.71	11.35	14.3	11.65	14.92	11.73	16.12	11.83	16.36	12.13	16.2	12.17	17.02	11.32	13.79	11.74	14.53	11.34	14.43
9/14/01	11.38	13.86	11.82	14.61	11.96	15.23	12.04	16.27	12.14	16.67	12.44	16.36	12.48	17.51	11.62	13.95	12.21	14.85	11.8	14.9
9/15/01	11.69	14.02	12.13	14.77	12.27	15.39	12.35	16.27	12.61	16.67	12.91	16.36	12.95	17.51	11.93	14.11	12.52	15.01	12.11	15.06
9/16/01	11.53	12.93	11.97	13.68	12.27	13.98	12.51	14.37	12.61	14.61	12.91	14.93	12.95	15.44	11.62	12.87	12.36	13.91	11.8	13.66
9/17/01	11.69	16.54	12.13	12.6	12.27	12.89	12.35	12.82	12.45	13.07	12.75	13.53	12.79	13.72	11.62	11.93	12.21	12.52	11.95	12.42
9/18/01	10.61	11.84	11.04	12.6	11.34	12.89	11.42	13.13	11.68	13.38	11.97	13.37	12.02	13.72	10.69	11.78	11.12	12.52	10.41	12.11
9/19/01	11.07	12.62	11.51	13.22	11.65	13.51	11.73	14.37	11.83	14.46	12.13	14.93	12.02	15.76	11.01	12.56	11.58	13.14	11.03	12.73
9/20/01	9.67	12	9.81	12.6	9.94	12.89	10.02	13.74	10.13	13.99	10.42	13.83	10.47	14.65	9.6	12.09	9.87	12.36	9.01	11.95
9/21/01	10.45	12	10.89	12.76	11.03	13.2	11.11	13.59	11.21	13.84	11.51	13.83	11.55	14.34	10.38	12.09	10.96	12.98	10.57	12.42
9/22/01	10.45	12.78	10.74	13.37	11.03	13.82	10.95	15	11.21	15.41	11.51	15.09	11.55	15.92	10.69	13.02	10.96	13.61	10.41	13.34
9/23/01	10.76	13.09	11.19	13.68	11.34	14.13	11.42	15.32	11.68	15.57	11.97	15.25	12.02	16.23	11.16	13.33	11.58	14.07	11.03	13.81
9/24/01	11.22	12.93	11.66	13.53	11.81	13.82	11.88	14.21	12.14	14.3	12.28	14.3	12.48	14.97	11.47	13.02	12.05	13.76	11.64	13.81
9/25/01	11.38	12.16	11.97	12.91	12.27	13.2	12.35	13.28	12.61	13.38	12.91	13.53	12.95	14.03	11.47	12.24	12.21	13.14	12.11	12.88
9/26/01	10.45	11.69	10.89	12.44	11.19	12.58	11.42	12.66	11.52	12.92	11.66	13.06	11.71	13.26	10.69	11.93	11.27	12.52	10.88	12.26
9/27/01	9.06	10.61	9.34	11.19	9.48	11.34	9.39	11.57	9.51	11.83	9.79	11.97	9.69	11.86	8.98	10.54	9.41	11.12	8.71	10.88
9/28/01	9.06	10.91	9.18	11.35	9.32	11.65	9.39	12.66	9.51	12.92	9.64	12.75	9.69	12.64	8.98	11.01	9.25	11.58	8.55	11.18
9/29/01	8.9	11.07	9.18	11.66	9.32	11.96	9.24	12.82	9.36	12.82	9.79	12.59	9.69	13.26	8.98	11.32	9.41	11.89	8.86	11.8
9/30/01	9.21	10.76	9.49	11.35	9.63	11.49	9.71	12.04	9.82	12.14	10.27	12.13	10.16	12.79	9.29	11.01	9.72	11.43	8.86	10.88
10/1/01	9.21	11.22	9.34	11.51	9.48	11.96	9.86	12.82	10.13	12.92	10.42	12.75	10.31	14.03	9.29	11.32	9.56	11.89	8.71	11.49
10/2/01	8.74	10.76	8.87	11.04	9.01	11.49	9.08	12.35	9.2	12.61	9.64	12.44	9.69	13.57	8.82	10.85	9.09	11.27	8.24	10.72
10/3/01	8.44	10.14	8.57	10.43	8.7	10.72	8.77	11.11	8.89	11.21	9.17	11.2	9.07	12.17	8.52	10.23	8.78	10.65	7.78	9.94
10/4/01	8.13	10.14	8.1	10.43	8.24	10.72	8.46	11.73	8.58	11.99	9.02	11.82	8.76	12.79	8.21	10.38	8.17	10.65	7.01	9.94
10/5/01	7.82	9.98	7.95	10.43	7.93	10.72	7.84	11.57	7.97	11.83	8.25	11.51	8.14	12.17	7.89	10.23	8.01	10.65	8.4	11.34
10/6/01	8.44	10.29	8.87	10.58	8.86	10.88	8.93	11.57	9.04	11.83	9.17	11.82	9.23	12.17	8.52	10.38	8.94	10.81	9.01	10.72
10/7/01	8.74	9.83	8.87	10.27	9.01	10.41	9.08	10.64	9.2	10.75	9.48	10.73	9.38	10.78	8.82	9.76	9.09	10.34	8.55	9.78
10/8/01	9.21	10.29	9.81	10.89	9.94	11.19	10.02	11.73	10.13	11.99	10.27	11.97	10.16	12.64	9.44	10.38	9.87	10.96	9.32	10.26
10/9/01	8.59	9.67	9.03	10.27	9.32	10.57	9.39	11.11	9.51	11.21	9.79	11.2	9.69	11.08	8.82	10.07	9.25	10.49	8.4	9.94
10/10/01	7.82	8.59	7.95	9.03	7.9															

Appendix B

Example of Vegetation GIS Data Layer Developed for South Prairie Creek

This page is purposely blank for duplex printing

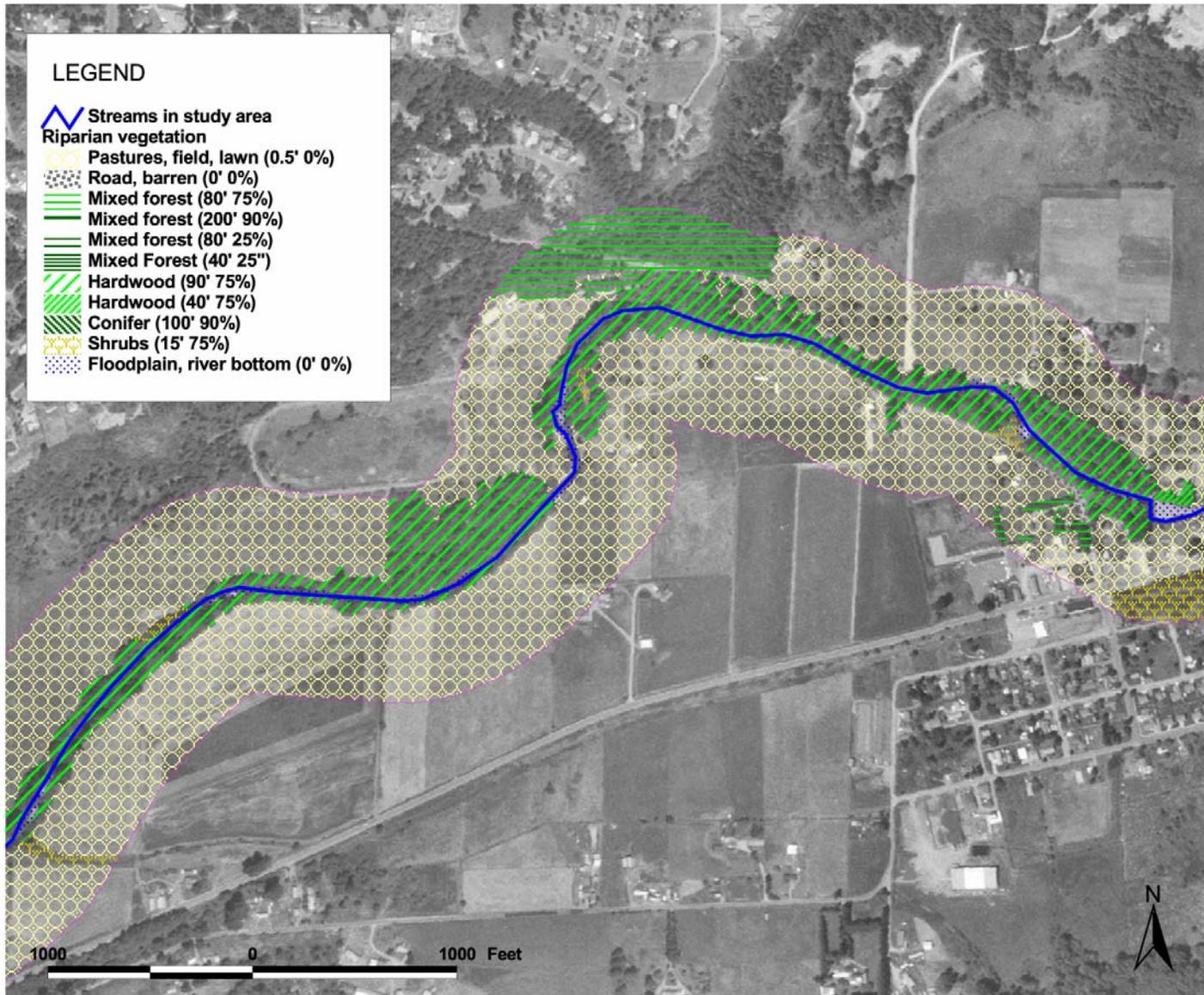


Figure B-1. Digital orthophoto, with overlay of vegetation polygons derived from orthophotos and habitat surveys.