Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Technical Report

Water Quality Study Findings

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Water Quality Study Findings

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(See Tables 1 and 2 for complete list of water bodies addressed.)

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Abstract

Portions of the Deschutes River, Capitol Lake, and Budd Inlet do not meet the water quality standards and are on the Clean Water Act Section 303(d) list for one or more of the following parameters: fecal coliform bacteria, temperature, dissolved oxygen (DO), pH, or fine sediment. This report summarizes the technical basis for a water cleanup plan (Total Maximum Daily Load study), which was conducted to determine the targets that enable water bodies to meet standards. The project involved data collection to characterize the sources and processes relevant to the impairments as well as analytical tool development, including computer models, that will be used to simulate the potential benefits of various management strategies.

Fecal coliform bacteria concentrations must be reduced during both the summer growing season and winter non-growing season. The highest reductions are needed in the small tributaries to Budd Inlet.

Mature riparian shade must be established throughout the Deschutes River and Percival Creek watersheds. While restoring mature riparian vegetation and channel conditions would not result in temperature meeting the numeric criteria throughout the system, the actions would cool peak temperatures up to 6.9°C, reduce the number of reaches above lethal temperatures, increase minimum DO by 1.2 mg/L, and decrease maximum pH by 0.5 standard units under critical conditions.

The combined effects of nonpoint and point sources currently exceed the pollutant loading capacity of Budd Inlet and Capitol Lake for nutrients. Pollutant load reductions are required to meet water quality standards for DO.

Water quality improvement targets were quantified for each water body except Capitol Lake and Budd Inlet. The Water Quality Improvement Report will be prepared at a future date and will establish numeric load and wasteload allocations.

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- Susan Burke (Northern Economics) consulted with Ecology on the net benefits analysis related to water quality in Capitol Lake under the Deschutes Estuary Feasibility Study.
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Study in the 1990s funded by LOTT. ERM, Inc. (formerly J.E. Edinger and Associates) provided initial model runs from the earlier Budd Inlet Scientific Study under contract to Ecology.

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Executive Summary

Introduction

The Washington State Department of Ecology (Ecology), in cooperation with the Squaxin Island Tribe, Thurston County, City of Olympia, and others, conducted this technical basis for the Total Maximum Daily Load (TMDL) study, also called a Water Cleanup Plan, because several water bodies do not meet the Washington State water quality standards. Portions of the Deschutes River, Capitol Lake, Budd Inlet, and their tributaries are on the Clean Water Act Section 303(d) list of impaired waters for at least one of the following parameters: fecal coliform bacteria, temperature, dissolved oxygen (DO), pH, or fine sediment. The study involved data collection to characterize the sources and processes relevant to the impairments as well as analytical tool development, including computer models, that will be used to simulate the potential benefits of various management strategies.

The federal Clean Water Act requires that a TMDL be developed for each water body on the 303(d) list. TMDL studies identify pollution sources in the watershed and specify how much pollution must be reduced to achieve clean water. Ecology is working with the local community to develop the overall approach to controlling pollution (Water Quality Improvement Report) and detailed steps to meet the goals (Water Quality Implementation Plan).

TMDLs determine the amount of a given pollutant that can be discharged to a water body under critical conditions and still meet water quality standards, allocating loads among the various contributors. Point sources, or discrete sources covered by a permit, receive wasteload allocations; nonpoint sources, or diffuse sources, receive load allocations. The sum of all load and wasteload allocations plus a margin of safety or any reserve capacity must be equal to or less than the loading capacity of the system.

The goals of this study were to (1) develop the loading capacity for fecal coliform bacteria, temperature, DO, pH, and fine sediment in portions of the watershed and (2) recommend loading reductions targets to meet water quality standards. This report constitutes the Technical Report to support the Water Quality Improvement Report. The Water Quality Improvement Report will develop load and wasteload allocations for Capitol Lake and Budd Inlet.

Budd Inlet, Capitol Lake, and Deschutes River Watershed

The 186-mi^2 (480-km^2) study area extends from the headwaters of the Deschutes River northward through Capitol Lake and Budd Inlet and lies entirely within Water Resource Inventory Area (WRIA) 13 (Figure ES-1). The study includes portions of Thurston County and Lewis County, the cities of Olympia, Lacey, and Tumwater, and the town of Rainier. Residents rely on groundwater from the Deschutes watershed or the adjacent McAllister Springs for drinking water. Land cover includes a mix of forested lands, agricultural uses, rural, residential, and urban lands.

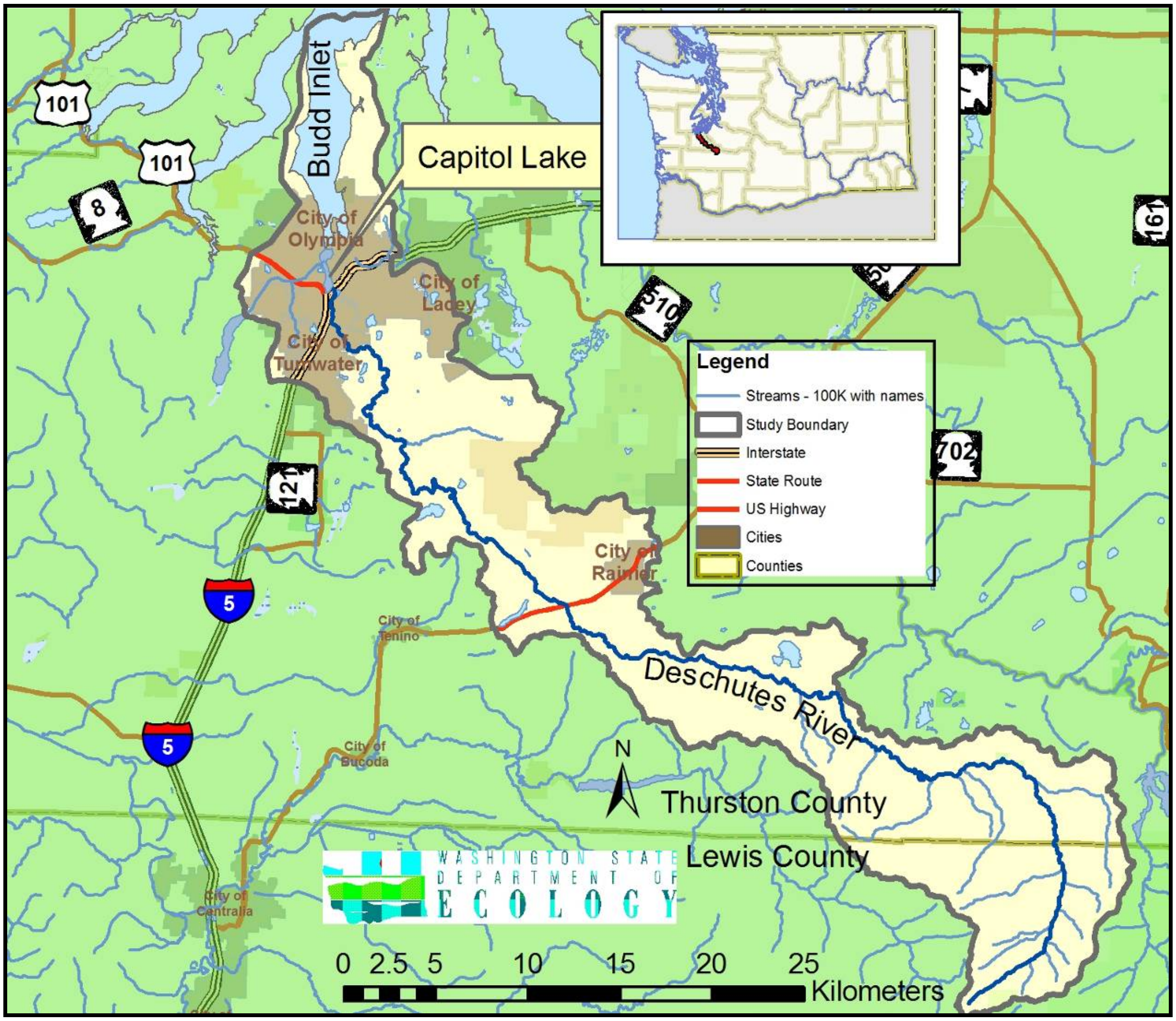

Figure ES-1. Deschutes River, Capitol Lake, and Budd Inlet TMDL study area.

The Lacey, Olympia, Tumwater, and Thurston County (LOTT) Clean Water Alliance provides secondary wastewater treatment before discharging to Budd Inlet, as well as advanced treatment (nitrogen removal) from April through October. Other domestic wastewater treatment plant discharges include Boston Harbor, Seashore Villa, and Tamoshan. These plants all operate under individual National Pollutant Discharge Elimination System (NPDES) permits managed by Ecology. In addition, Ecology regulates stormwater from the Washington State Department of Transportation (WSDOT) through an NPDES Phase I permit.

Ecology regulates municipal, industrial, and construction stormwater through general permits. Sand and gravel facilities also operate under general permits. Two dairies operate within the watershed with nutrient management plans certified by the Thurston Conservation District. Historically, the Washington Department of Fish and Wildlife (WDFW) operated four net pens within Capitol Lake, but these were discontinued in 2007. The WDFW operates the Tumwater Falls Hatchery as a seasonal salmonid rearing facility.

Potential pollutant sources include a variety of point and nonpoint sources. Lack of riparian vegetation, deteriorating sewer infrastructure, domestic animals, septic systems, fertilizers, recreational users, road building, and natural phenomena contribute to water quality impairments.

Water Quality Standards

Water quality standards define the goals for a water body by designating beneficial uses, setting criteria to protect those uses, and establishing provisions to protect water bodies from pollutants. The beneficial uses to be protected by this TMDL are recreation, aquatic life, water supply, and miscellaneous (wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics). The water quality standards include numeric criteria for different parameters that vary by designated use.

The current configuration of Capitol Lake is designated as Lake Class, based on the mean detention time and mean annual minimum storage. Because Percival Creek discharges to Capitol Lake, it must meet stringent aquatic life and recreation use standards. The Washington State Department of General Administration (GA), now part of the Department of Enterprise Services (DES), convened an independent, parallel process to evaluate management alternatives for Capitol Lake that include reverting to an estuary. If the dam were removed, the Deschutes estuary would be an extension of Budd Inlet, which would fall under the aquatic uses defined for marine areas south of latitude 47° 04' N (south of Priest Point Park). In this circumstance, the designated uses to be protected in Percival Creek would switch to those of other tributaries to Budd Inlet.

Whether Capitol Lake reverts to an estuary in the future affects the applicable water quality standards and nutrient targets for Capitol Lake and Budd Inlet, and possibly for the Deschutes watershed. This report presents the loading capacity for both scenarios but does not recommend an alternative. Pollutant targets for Percival Creek are based on the more stringent designated use based on discharge to a lake, but alternatives are discussed under the estuary scenario.

The water quality standards also protect waters of higher quality than the numeric criteria, and the antidegradation process prevents unnecessary lowering of water quality.

Technical Approach

The study supplemented historical data collected by a variety of organizations with targeted data collection programs conducted primarily from July 2003 through December 2004 as well as computer models and other analytical tools.

- Fecal coliform bacteria levels were established using a combination of monthly or twice monthly grabs and targeted stormwater sampling at a fine spatial scale throughout the study area. The monitoring data were used to quantify loading capacity and bacteria reduction targets for the summer growing season (May through September) and winter non-growing season (October through April).

- Existing water temperatures were recorded along the Deschutes River, Percival Creek, and tributaries. The QUAL2Kw model was applied to the mainstem of the Deschutes River to assess the influence of current and potential future riparian shade and channel characteristics on water temperatures. A related hydrogeology study evaluated groundwater influences. Effective shade, defined as the fraction of incoming solar radiation that is blocked from reaching the water surface by vegetation and topography, was used as a surrogate measure of heat flux to fulfill the requirements of Section 303(d) for a temperature TMDL. The Percival Creek watershed analysis was based on current and potential effective shade.
- DO, pH, and nutrient concentrations in grab samples were quantified, and continuous DO and pH probes were installed in August 2004 to characterize Deschutes River daily minimum and maximum values. Detailed mainstem instantaneous DO and pH were recorded in August 2003 as well. The data were used to calibrate and confirm the QUAL2Kw model to simulate the interaction of nutrients, DO, and pH. Alternative management scenarios were evaluated, including increased shade and decreased nutrient inputs.
- Fine sediment targets were based on healthy habitat values for salmonid spawning. Reductions from current levels quantified by the Squaxin Island Tribe were calculated from current and target concentrations. The sediment budget was used to establish the anthropogenic contribution.
- The GEMSS computer model was applied to Capitol Lake and Budd Inlet under both the current configuration and a potential estuary alternative with a 500-ft (150-m) opening to Budd Inlet. Natural, current, and permitted point and nonpoint sources were evaluated.

Load Reduction Targets

Loading targets for fecal coliform bacteria were based on reductions needed to meet the water quality standards during both summer and winter seasons, and targets were expressed as percent reduction from current conditions. No wasteload reductions for fecal coliform bacteria were evaluated for the wastewater treatment plants discharging to Budd Inlet, because Budd Inlet was not on the 303(d) list for fecal coliform bacteria at the time this study began. Numeric load reduction targets were established for areas covered by municipal stormwater general permits and WSDOT's stormwater permit based on the targets established by subwatershed. No additional targets were recommended for facilities covered by the industrial and construction stormwater or sand and gravel general permits beyond adhering to the terms of the general permits.

Loading targets for temperature were based on the effective shade achievable from full mature riparian vegetation and improved channel conditions. System potential temperature would not meet the numeric standards upstream of Offutt Lake, but establishing mature vegetation would reduce peak temperatures up to 6.9°C and reduce the length of river above the lethality limit of 22°C during critical conditions from 63 km to 5 km. No numeric load targets for heat were established for facilities covered under general permits in the Deschutes River watershed. Loading targets for DO and pH in the Deschutes River, Percival Creek, and their tributaries also were based on the effective shade achieved from full mature riparian vegetation and improved channel conditions. System potential DO could meet the numeric criteria in the Deschutes River downstream but not upstream of Offutt Lake under critical conditions. Reductions are needed in areas where the combined effect of human activities decreases DO by more than 0.2 mg/L. Portions of the Deschutes River do not meet the maximum pH or pH range standards. Improving temperature would also benefit those sections, but additional actions may be needed to reduce human influences to <0.2 standard units (SU) upstream of Offutt Lake and <0.5 SU downstream of Offutt Lake.

Additional nutrient load reductions may be needed in the Deschutes River and Percival Creek watersheds to meet standards in Capitol Lake and Budd Inlet. These will be revisited in the subsequent Water Quality Improvement Report.

New permitted facilities cannot increase fecal coliform bacteria, heat/temperature, nutrients, pH, or fine sediment and cannot decrease DO beyond natural conditions.

Fine sediment targets for the Deschutes River were based on reductions needed to meet healthy habitat levels to protect salmonid spawning. Because the reductions were equal to or greater than the anthropogenic contributions to sediment levels, the natural condition may be higher than the healthy habitat levels in some areas. Facilities covered under general permits may not increase sediment contributions over natural conditions.

The future Water Quality Improvement Report will establish load and wasteload allocations for Capitol Lake and Budd Inlet and will revisit Deschutes River and Percival Creek watershed nutrient reductions under both lake and estuary scenarios.

Conclusions and Recommendations

Continued source identification and remediation is needed for fecal coliform bacteria, primarily in tributaries to Budd Inlet.

Programs that preserve and restore riparian vegetation and restore stream channel characteristics should be established and strengthened throughout the Deschutes River and Percival Creek watersheds. Establishing mature riparian vegetation would benefit temperatures directly through reduced solar radiation and indirectly through the establishment of channel complexity that enhances water exchange with gravels, producing a cooling effect. Effective shade from mature vegetation also is necessary to meet the water quality standards for DO and pH, since cooler water temperatures hold more oxygen and riparian shade reduces the growth of aquatic plants that affect DO and pH. Deschutes River tributary and groundwater nutrient concentrations should be reduced to natural conditions.

Anthropogenic sources of fine sediment include unpaved roads and landslides associated with roads, and continued adaptive management is recommended. In addition, other anthropogenic sources, such as off-road vehicle use, domestic animals, and facilities covered under general permits, should be identified and reduced.

The combined effects of current nonpoint and point sources exceed the loading capacity of both Budd Inlet and Capitol Lake for nutrients with the lake in place. With Capitol Lake in place, more of Budd Inlet and Capitol Lake would violate standards for DO under critical conditions than with a restored Deschutes estuary. If the lake were to revert to an estuary, a smaller portion of Budd Inlet would violate standards for DO, and the geographic area that is currently Capitol Lake would meet marine water quality standards for DO under all nutrient loading alternatives. Load reductions are needed under either alternative and will be developed in the Water Quality Improvement Report.

Next Steps

Ecology convened the Deschutes Advisory Group to develop the next steps. The information contained in this technical report will be the basis for committee discussions on wasteload and load allocations. Once allocations have been determined, a strategy for implementation will be developed. Information on this approach will be compiled with this technical report and allocations into a Water Quality Improvement Report. The Water Quality Improvement Report will be submitted to the U.S. Environmental Protection Agency for approval. Ecology again will work with the advisory group to establish specific details for implementation actions, and this information will be compiled into a Water Quality Implementation Plan.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act requirements

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

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

The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. The Water Quality Assessment divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list.

Category 1 – Waters that meet standards for parameter(s) for which they have been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

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

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

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

TMDL Process Overview

The Clean Water Act requires that a TMDL, also referred to as a water cleanup plan, be developed for each of the water bodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology works with the local community to develop (1) a strategy to control the pollution and (2) a monitoring plan to assess effectiveness of the water quality improvement activities.

TMDLs involve five major steps for development (Figure 1).

1. Existing data are reviewed and data gaps are identified.
2. A Quality Assurance Project Plan is prepared and additional field data collection is performed to fill data gaps and collect additional environmental information.
3. Data are evaluated to establish water quality relationships and computer modeling is performed to identify pollutant reduction needs.
4. Stakeholders explore options and assignment of wasteload and load allocations. In addition, an implementation strategy is developed, identifying who needs to do what, appropriate implementation actions, and responsible entities. The technical evaluations, wasteload and load allocations, and implementation strategy are compiled into a Water Quality Improvement Report that is submitted to the U.S. Environmental Protection Agency (EPA) for approval.
5. A Water Quality Implementation Plan is developed, specifying when, where, and how implementation will occur, acknowledging detailed information for necessary actions, and including a schedule for implementing actions.

This report documents the results from the first three steps.

Figure 1. Five steps in TMDL development.

Elements Required in a TMDL

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

If the pollutant comes from a discrete (point) source such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from a set of diffuse (nonpoint) source such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

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

The present study includes recommended load and wasteload reduction targets for all parameters except marine dissolved oxygen (DO). The future Water Quality Improvement Report will establish load and wasteload allocations for all parameters, including nutrient loads to Budd Inlet and Capitol Lake.

Total Maximum Daily Load Analyses: Loading capacity

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

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Why is Ecology Conducting a TMDL Study in this Watershed?

Overview

Ecology, in cooperation with the Squaxin Island Tribe, Thurston County, the city of Olympia, and others, is conducting a TMDL study in the Budd Inlet watershed because the Deschutes River, Capitol Lake, Budd Inlet, and some of their tributaries are on the Clean Water Act 303(d) list for at least one of the following parameters: fecal coliform bacteria, temperature, DO, pH, or fine sediment. The study involved data collection to characterize the sources and processes relevant to the impairments as well as analytical tool development, including computer models, to simulate the potential benefits of various management strategies.

Study Area

The study area for this TMDL (Figure 2) extends from the headwaters of the Deschutes River northward through Capitol Lake and Budd Inlet, entirely within Water Resource Inventory Area (WRIA) 13. The study area includes portions of Thurston County and Lewis County, as well as the cities of Olympia, Lacey, and Tumwater, and the town of Rainier.

Capitol Lake was created in 1951 as an impoundment of the Deschutes estuary to create a reflecting pool for the State Capitol building. The dam, located under 5th Avenue in downtown Olympia, consists of two radial gates, a fish weir, and a siphon to stabilize the lake level, maintain freshwater conditions, and control flooding. The Washington Department of General Administration (GA), now part of the Department of Enterprise Services, is the state agency that manages the facilities of the Capitol Campus, and operates the dam.

A separate process that concluded in 2010 evaluated the scientific, technical, economic, and cultural significance of maintaining the lake as is or reverting it to an estuary by removing the dam. Because the presence or absence of Capitol Lake will affect the implementation of water quality targets for Capitol Lake, Percival Creek, the Deschutes River, and Budd Inlet, this study includes two potential future scenarios: (1) Capitol Lake as it now exists and (2) a simple representation of the Deschutes estuary with a 500-ft (150-m) opening under 5th Avenue. Under the estuary alternative, marine waters are expected to extend through the north basin, central basin, and into the south basin of Capitol Lake.

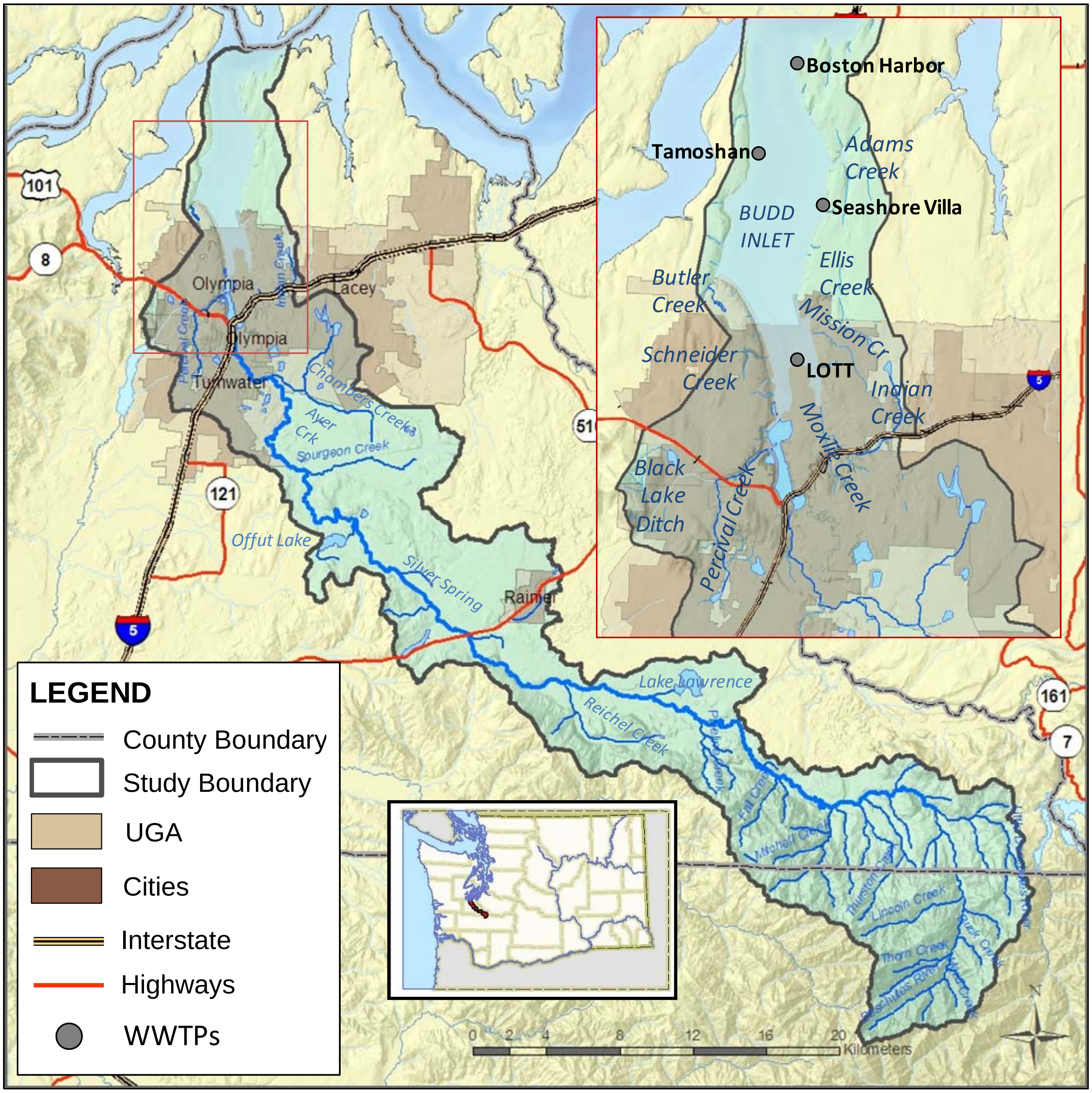

Figure 2. **Deschutes River, Capitol Lake, and Budd Inlet TMDL study area.**

Pollutants Addressed by this TMDL

This TMDL addresses temperature, DO, pH, and fine sediment in the mainstem of the Deschutes River; fecal coliform bacteria, temperature, DO, and pH in Percival Creek and Black Lake Ditch; fecal coliform bacteria in several tributaries to the Deschutes River and Budd Inlet; DO and pH in Ayer (Elwanger) Creek; DO in Reichel Creek; temperature in Huckleberry Creek and unnamed tributary to the Deschutes River; fecal coliform, total phosphorus, and DO in Capitol Lake; and DO in Budd Inlet. While some parameters are not direct pollutants, such as DO, they are the measures by which water bodies are compared with the water quality standards.

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

The beneficial uses to be protected by this TMDL are recreation, aquatic life, and water supply. Table 1 details the 303(d) listings established in 2004 within the study area covered by this TMDL. In addition, several water bodies evaluated as part of the present project did not meet the water quality standards and are on the 303(d) list submitted in 2008 to EPA for approval (Table 2). While the Deschutes River is listed as Category 1 or 2 for pH on the 303(d) list submitted in 2008, this TMDL addresses Deschutes River pH as well. The Deschutes River was on the 303(d) list submitted in 1998 for pH when the study was initiated.

Table 1. Study area marine water bodies on the 2008 303(d) list addressed by this TMDL.

Marine Water Bodies	Parameter	Listing ID
Budd Inlet (Inner)	Dissolved Oxygen	5852
	Dissolved Oxygen	5853
	Dissolved Oxygen	5863
	Dissolved Oxygen	5864
Budd Inlet (Outer)	Dissolved Oxygen	3769
	Dissolved Oxygen	5862
	Dissolved Oxygen	7582
	Dissolved Oxygen	7583
	Dissolved Oxygen	7584
	Dissolved Oxygen	7585
	Dissolved Oxygen	7586
	Dissolved Oxygen	7587
	Dissolved Oxygen	10188

Table 2. Study area fresh water bodies on the 2008 303(d) list addressed by this TMDL.

Name	Parameter	Listing id
Capitol Lake		
Capitol (South Arm) Lake	Total Phosphorus	22718
Capitol (South Arm) Lake	Fecal Coliform	40588
Deschutes River		
Deschutes River	Fecal Coliform	9881
Deschutes River	Fecal Coliform	46210
Deschutes River	Fecal Coliform	46499
Deschutes River	Fecal Coliform	46500
Deschutes River	Temperature	6576
Deschutes River	Temperature	7588
Deschutes River	Temperature	7590
Deschutes River	Temperature	7592
Deschutes River	Temperature	7593
Deschutes River	Temperature	7595
Deschutes River	Temperature	9439
Deschutes River	Temperature	48710
Deschutes River	Temperature	48711
Deschutes River	Temperature	48712
Deschutes River	Temperature	48713
Deschutes River	Temperature	48714
Deschutes River	Temperature	48715
Deschutes River	Temperature	48717
Deschutes River	Temperature	48718
Deschutes River	Temperature	48720
Deschutes River	Temperature	48721
Deschutes River	Temperature	48724
Deschutes River	Temperature	48726
Deschutes River	Dissolved Oxygen	10894
Deschutes River	Dissolved Oxygen	47753
Deschutes River	Dissolved Oxygen	47754
Deschutes River	Dissolved Oxygen	47756
Deschutes River	Fine Sediment	6232
Deschutes River Tributaries		
Ayer (Elwanger) Creek	Fecal Coliform	5849
Ayer (Elwanger) Creek	Dissolved Oxygen	5851
Chambers Creek	Fecal Coliform	45560
Huckleberry Creek	Temperature	3757
Lake Lawrence Creek	Dissolved Oxygen	47696
Reichel Creek	Fecal Coliform	3763
Reichel Creek	Fecal Coliform	45566
Reichel Creek	Temperature	48666
Reichel Creek	Dissolved Oxygen	47714
Spurgeon Creek	Fecal Coliform	46061
Tempo Lake Outlet	Temperature	48696

Name	Parameter	Listing id
Unnamed Creek (Trib to Deschutes River)	Temperature	7591
Unnamed Spring (Trib to Deschutes River)	Temperature	48923
Percival Creek Watershed		
Percival Creek	Fecal Coliform	46103
Percival Creek	Fecal Coliform	46108
Percival Creek	Temperature	42321
Percival Creek	Temperature	48249
Percival Creek	Temperature	48727
Percival Creek	Temperature	48729
Percival Creek	Dissolved Oxygen	48085
Percival Creek	Dissolved Oxygen	48086
Black Lake Ditch	Temperature	48733
Black Lake Ditch	Temperature	48734
Black Lake Ditch	Temperature	48735
Black Lake Ditch	Temperature	42337
Black Lake Ditch	pH	50990
Black Lake Ditch	Dissolved Oxygen	47761
Black Lake Ditch	Dissolved Oxygen	47762
Budd Inlet Tributaries		
Adams Creek	Fecal Coliform	45462
Adams Creek	Fecal Coliform	45695
Butler Creek	Fecal Coliform	45471
Butler Creek, SW.F.	Fecal Coliform	45342
Ellis Creek	Fecal Coliform	45480
Indian Creek	Fecal Coliform	3758
Indian Creek	Fecal Coliform	45213
Indian Creek	Fecal Coliform	46410
Mission Creek	Fecal Coliform	45212
Mission Creek	Fecal Coliform	46102
Moxlie Creek	Fecal Coliform	3759
Moxlie Creek	Fecal Coliform	3761
Moxlie Creek	Fecal Coliform	45252
Moxlie Creek	Fecal Coliform	46432
Schneider Creek	Fecal Coliform	45559

Trib: Tributary
SW.F: Southwest Fork

This watershed has other water quality issues that will not be addressed in this TMDL (Table 3). In particular, the following additional 303(d) listings for parameters other than those listed above occur in the study area, but are not addressed in this report.

Table 3. Additional 2008 303(d) listings not addressed by this report.

Water Body	Parameter	Listing ID	Category	Medium
Budd Inlet				
Budd Inlet (Inner)	Benzo[b]fluorene	8685	5	Tissue
Budd Inlet (Inner)	Benzo[k]fluorene	8686	5	Tissue
Budd Inlet (Inner)	Benzo[a]anthracene	8688	5	Tissue
Budd Inlet (Inner)	Chrysene	8689	5	Tissue
Budd Inlet (Inner)	PCB	8690	5	Tissue
Budd Inlet (Outer)	Fecal Coliform	45317	5	Water
Budd Inlet (Outer)	Fecal Coliform	45829	5	Water
Budd Inlet (Inner)	2,4-Dimethylphenol	509166	4B	Sediment
Budd Inlet (Inner)	2-Methylphenol	509167	4B	Sediment
Budd Inlet (Inner)	4-Methylphenol	509168	4B	Sediment
Budd Inlet (Inner)	Pentachlorophenol	509169	4B	Sediment
Budd Inlet (Inner)	Cadmium	509170	4B	Sediment
Budd Inlet (Inner)	Chromium	509171	4B	Sediment
Budd Inlet (Inner)	Copper	509172	4B	Sediment
Budd Inlet (Inner)	Lead	509173	4B	Sediment
Budd Inlet (Inner)	Phenol	509174	4B	Sediment
Budd Inlet (Inner)	Zinc	509175	4B	Sediment
Capitol Lake				
Capitol (South Arm) Lake	Invasive Exotic Species	4698	4C	Habitat
Deschutes River				
Deschutes River	Instream Flow	6194	4C	Habitat
Deschutes River	Instream Flow	6195	4C	Habitat
Deschutes River	Large Woody Debris	6224	4C	Habitat
Deschutes River	Large Woody Debris	6225	4C	Habitat
Deschutes River Watershed				
Ayer (Elwanger) Creek	pH	5850	5	Water
Lawrence Lake	Total Phosphorus	6348	5	Water
Offutt Lake	PCB	52676	5	Tissue
Ward Lake	PCB	7022	5	Tissue
Budd Inlet Watershed				
Adams Creek	pH	50965	5	Water

Budd Inlet toxics listings are associated with the Cascade Pole site and are addressed by the remediation efforts of Ecology's Toxics Cleanup Program. Budd Inlet (outer) was listed for fecal coliform after this TMDL began; these listings were not evaluated as part of this study. Lawrence Lake total phosphorus should be addressed in a future lake TMDL. Ward Lake and

Budd Inlet are listed for polychlorinated biphenyls (PCBs), but source identification and reduction must be part of a future regional study. The two pH listings are for low pH and will be addressed through other processes. Both systems include wetland soils, which may be contributing to the low levels.

The Deschutes River has Category 4C listings for lack of large woody debris (LWD) and insufficient instream flow; however, these parameters are not considered “pollutants” under the Clean Water Act and are not candidates for TMDL allocations as per Ecology policy. However, large woody debris is likely to be improved indirectly through allocations for fine sediment and temperature and should be part of the management strategies implemented to address other load allocations.

Instream flows may be determined through watershed planning under the Watershed Planning Act (90.82). The Deschutes Watershed Planning Unit (WPU) completed a final draft watershed plan in September 2004. However, the WPU was unable to reach consensus on their plan at the October 29, 2004 meeting when the Squaxin Island Tribe, an initiating government, voted against approval of the plan. No minimum instream flows were determined for the Deschutes River.

This report does not establish numeric instream flows or large woody debris targets. However, the TMDL analyses for temperature in the Deschutes River quantified the effects of varying low flow discharges on the temperature regime, and the recommendations for temperature, DO, and pH TMDLs in the Deschutes River include enhancing instream large woody debris to improve temperature, nutrient dynamics, and habitat value in general.

Why Are We Doing This TMDL Now?

In the fall of 2001, Ecology’s Water Quality Program began an annual planning process to identify potential TMDL development projects, TMDL effectiveness monitoring projects, and ambient water quality monitoring needs. In this scoping process, the 303(d) list of impaired water bodies in 1998 was reviewed to identify water bodies in Ecology’s Southwest Region that were not meeting Washington State water quality standards. In this review, it was noted that numerous standards violations were occurring in the Deschutes River watershed. Elevated stream temperatures, fecal coliform bacteria concentrations, and fine sediment values were documented along with low DO concentrations. Water quality standards violations also were noted in the marine waters of Budd Inlet and in Capitol Lake.

As part of this TMDL project evaluation and decision process, tribes and local entities were consulted and local support for potential projects was determined. The Southwest Regional Office endorsed a new TMDL for the Deschutes River and Budd Inlet, considering needs across the entire region. The Water Quality Program requested that Ecology’s Environmental Assessment Program develop a data collection and modeling approach for completing a TMDL assessment.

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Water Quality Standards

Water Quality Standards define the water quality goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. A water quality standard consists of three elements:

1. Designated uses of the water body (for example, aquatic life or recreation).
2. Water quality criteria to protect designated uses (numeric pollutant concentrations and narrative requirements).
3. Antidegradation policy to maintain and protect existing uses and high quality waters.

Designated Uses

Water quality standards are established by Washington State to protect the designated uses within water bodies. Table 602, established in WAC 173-201A-602, lists use designations for fresh water bodies, while Table 612, established in WAC 173-201A-612, lists use designations for marine water bodies. In addition, lakes are defined in WAC-173-201A-020. Designated uses for tributaries to lakes are established in WAC-173-201A-600(1)(a)(ii), while fresh water bodies not specifically named in Table 602 are assigned uses in WAC-173-201A-600(1). Table 4 summarizes designated uses for the water bodies included in this study.

Under the water quality standards, the current configuration of Capitol Lake is considered Lake Class. Lakes and reservoirs with a mean detention time of greater than 15 days are distinguished from riverine systems in WAC 173-201-020. WAC 173-201-020 further defines mean detention time as the time obtained by dividing a reservoir's mean annual minimum total storage by the 30-day, 10-year low flow (30Q10) from the reservoir.

The U.S. Geological Survey (USGS) estimated the 30Q10 flows for the Deschutes River at E Street (gage 12080010), based on monitoring data from 1991-2001 at 59.8 cfs (1.69 cms; D. Kresch, personal communication, 2003). Mean annual minimum total storage is difficult to estimate, given that the water level may be drawn down prior to an event expected to produce high river discharge. The typical lake volume is estimated at 1800 ac-ft (2,220,000 m^3), calculated from information presented in CH2M Hill (2001). The resulting detention time is 15.2 days. Therefore, Capitol Lake is considered Lake Class.

Under the scenario with the dam removed, the Deschutes estuary would be an extension of Budd Inlet, which would fall under the aquatic uses of a marine water body south of latitude 47º 04’ N (south of Priest Point Park). Because the area currently part of Capitol Lake would become an estuary in this circumstance, the designated use to be protected in Percival Creek, a tributary to Capitol Lake, would switch from a tributary to a Lake Class water body to a tributary to Budd Inlet, shifting the designated uses to those associated with other waters not specifically listed.

Table 4. Designated uses for freshwater and marine water bodies in the study.

Fresh Water bodies	Aquatic Life Uses		Recreation Uses		Water Supply Uses	Miscellaneous Uses
	Core summer salmonid habitat	Salmonid spawning, rearing, and migration	Extraordinary primary contact	Primary contact	Domestic, agricultural, industrial, stock watering	Wildlife habitat, harvesting, commerce/navigation, boating, aesthetics
Deschutes River, from mouth to, and including, tributary from Offutt Lake		X		X	X	X
Deschutes River and tributaries, upstream from Offutt Lake within national forest boundary (no samples were collected within this portion of the watershed)	X		X		X	X
Deschutes River and tributaries, upstream from Offutt Lake below national forest boundary	X			X	X	X
Tributaries to lakes (Percival Creek)	X		X		X	X
Other waters not specifically listed (tributaries to Budd Inlet)		X		X	X	X
Marine Water bodies	Aquatic Life Uses		Recreation Uses		Shellfish Harvest	Miscellaneous Uses
	Excellent	Good	Primary contact	Secondary contact		Wildlife habitat, harvesting, commerce/ navigation, boating, aesthetics
Budd Inlet south of latitude 47º 04’ N (south of Priest Point Park)		X		X		X
South Puget Sound (except southern Budd Inlet)	X		X		X	X

Criteria to Protect Designated Uses

Numeric criteria are developed to protect designated uses. Individual numeric criteria are based on specific data and scientific assessment of adverse effects. The numeric criteria are numbers that specify limits or ranges of chemical concentrations, such as oxygen, or physical conditions, such as water temperature. A typical numeric criterion for aquatic life protection usually contains a concentration and an averaging period (for example, 5 mg/L once every ten years). The criteria are values that should be exceeded rarely if uses are to be supported.

The water quality standards contain numeric criteria for both marine and freshwaters.

Bacteria

Freshwaters

Bacteria criteria are set to protect people who work and play in and on the water from waterborne illnesses. In the Washington State water quality standards, fecal coliform is used as an "indicator bacteria" for the state's freshwaters (for example, lakes and streams). Fecal coliform in water "indicates" the presence of waste from humans and other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The fecal coliform criteria are set at levels that have been shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

The Deschutes River and its tributaries are designated as *Primary Contact* recreation. Because Capitol Lake is designated as Lake Class, Percival Creek and its tributaries are designated as *Extraordinary Primary Contact* recreation. Budd Inlet south of Priest Point Park is designated *Secondary Contact*, while the rest of Budd Inlet is designated *Primary Contact* recreation. While marine bacteria levels are not included in this TMDL because Budd Inlet was not on the 303(d) lists for fecal coliform bacteria at the time this study began, tributaries to Budd Inlet are included and are classified as *Primary Contact* recreation under WAC 173-201A-600(1). In addition, Capitol Lake would be subject to the marine waters provisions of the water quality standards for bacteria should it revert to an estuary. Under this scenario, Percival Creek would be a tributary to marine waters and would be classified as *Primary Contact* recreation.

(1) The *Extraordinary Primary Contact* use is intended for waters capable of "providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas." To protect this use category: Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL" [WAC 173-201A-200(2)(b), 2006 edition].

(2) The *Primary Contact* use is intended for waters "where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving,

swimming, and waterskiing." More to the point, however, the use is to be designated to any waters where human exposure is likely to include exposure of the eyes, ears, nose, and throat. Since children are also the most sensitive group for many of the waterborne pathogens of concern, even shallow waters may warrant primary contact protection. To protect this use category: "Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200 colonies/100 mL" [WAC 173-201A-200(2)(b), 2006 edition].

Compliance is based on meeting both the geometric mean criterion (Part 1) and the 10% of samples (or single sample if less than ten total samples) limit (Part 2). These two measures used in combination ensure that bacterial pollution in a water body will be maintained at levels that will not cause a greater risk to human health than intended. While some discretion exists for selecting sample averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal (summer versus winter) data sets.

The criteria for fecal coliform are based on allowing no more than the pre-determined risk of illness to humans that work or recreate in a water body. The criteria used in the state standards are designed to allow seven or fewer illnesses out of every 1,000 people engaged in primary contact activities. Once the concentration of fecal coliform in the water reaches the numeric criterion, human activities that would increase the concentration above the criteria are not allowed. If the criterion is exceeded, the state will require that human activities be conducted in a manner that will bring fecal coliform concentrations back into compliance with the standard.

If natural levels of fecal coliform (from wildlife) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution further. While the specific level of illness rates caused by animal versus human sources has not been quantitatively determined, warm-blooded animals (particularly those that are managed by humans and thus exposed to human-derived pathogens as well as those of animal origin) are a common source of serious waterborne illness for humans.

Temperature

This TMDL is based on surface water quality standards that were adopted in December 2006 and approved by EPA in February 2008. The Deschutes River and its tributaries from the mouth to and including the tributary from Offutt Lake are designated as *Salmonid Spawning, Rearing, and Migration* for Aquatic Life. The designated use of the Deschutes River and its tributaries upstream of the Offutt Lake tributary to the national forest boundary are classified as *Core Summer Salmonid Habitat.* Capitol Lake is designated Lake Class under the scenario where the dam remains in place; if the dam were removed, the Deschutes estuary would be designated as *Good Aquatic Life*, described below under Marine Waters. With Capitol Lake in place, Percival Creek is classified as *Core Summer Salmonid Habitat* as a tributary to a lake; however, if the area reverts to an estuary, Percival Creek would be classified for *Salmonid Spawning, Rearing, and Migration.*

The 2006 water quality standards can be found at Ecology's website: www.ecy.wa.gov/programs/wq/swqs.

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

Freshwaters

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

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

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

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

The criteria described above are used to ensure that, where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, an additional allowance is provided for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition.

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

Global Climate Change

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

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the 10 models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

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

These efforts may cause streams not to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

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

Dissolved Oxygen

Aquatic organisms are very sensitive to reductions in the level of DO in the water. The health of fish and other aquatic species depends upon maintaining an adequate supply of oxygen dissolved in the water. Growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants are all affected by oxygen levels. While direct mortality due to inadequate oxygen can occur, the state's criteria are designed to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are expressed as the lowest 1-day minimum oxygen concentration that occurs anywhere in a water body and is not applied as a water-column average.

Freshwaters

In the Washington State water quality standards, freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2006 edition]. In this TMDL, the following designated aquatic life uses and criteria are to be protected.

The Deschutes River and its tributaries from the mouth to and including the tributary from Offutt Lake are designated as *Salmonid Spawning, Rearing, and Migration* for Aquatic Life. The designated use of the Deschutes River and its tributaries upstream of the Offutt Lake tributary to the national forest boundary are classified as *Core Summer Salmonid Habitat*. Capitol Lake is designated Lake Class under the scenario where the dam remains in place, and Percival Creek is designated *Core Summer Salmonid Habitat*. If the dam is removed, the Deschutes estuary would be designated as *Good Aquatic Life*, described below under Marine Waters, and Percival Creek would be designated *Salmonid Spawning, Rearing, and Migration.*

(1) To protect the designated aquatic life use of *Core Summer Salmonid Habitat*, the lowest 1-day minimum oxygen level must not fall below 9.5 mg/l more than once every 10 years on average between June 15 and September 15.

(2) To protect the designated aquatic life use of *Salmon and Trout Spawning, Rearing, and Migration*, the lowest 1-day minimum oxygen level must not fall below 8.0 mg/l more than once every 10 years on average.

The criteria described above are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a water body is naturally lower in oxygen than the criteria, an additional allowance is provided for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/l decrease below that naturally lower (inferior) oxygen condition.

While the numeric criteria generally apply throughout a water body, they are not intended to apply to discretely anomalous areas such as in shallow, stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason the standards direct that measurements be taken from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously oxygen rich areas. For example, in a slow moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that is erroneous for comparing to the criteria.

Lakes are treated differently for protecting DO conditions. For all lakes, and for reservoirs with a mean annual retention time of greater than 15 days, human actions considered cumulatively may not decrease the 1-day minimum oxygen concentration more than 0.2 mg/l below estimated natural conditions. WAC-201A-020 states that lakes "shall be distinguished from riverine systems as being water bodies, including reservoirs, with a mean detention time of greater than fifteen days." The storage volume of Capitol Lake divided by the 30Q10 low flow is greater than 15 days, and Capitol Lake is considered Lake Class.

Marine Waters

Budd Inlet south of Priest Point Park is designated *Good Quality Aquatic Life*, while the rest of Budd Inlet is *Excellent Quality Aquatic Life*. In addition, Capitol Lake would be subject to the marine waters provisions of the water quality standards for DO should it revert to an estuary, and it would be designated *Good Quality Aquatic Life.*

(1) To protect the designated Excellent Quality category of aquatic life use, the lowest 1-day minimum oxygen level must not fall below 6.0 mg/l more than once every 10 years on average.

(2) To protect the designated Good Quality category of aquatic life use, the lowest 1-day minimum oxygen level must not fall below 5.0 mg/l more than once every 10 years on average.

The standard is applied to the lowest concentration within the water column and not a water-column average. The criteria described above are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a water body is naturally lower in oxygen than the criteria, an additional allowance is provided for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/l decrease below that naturally lower (inferior) oxygen condition.

pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. pH is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species. The degree of dissociation of weak acids or bases is affected by changes in pH. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. While some compounds (for example, cyanide) increase in toxicity at lower pH, others (for example, ammonia) increase in toxicity at higher pH. While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, at the extremes of pH lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient carbon dioxide (CO_2) from bicarbonate in the water to be directly lethal to fish.

While the pH criteria in the state water quality standards are primarily established to protect aquatic life, they also serve to protect waters as a source for domestic water supply. Water supplies with either extreme pH or that experience significant changes of pH even within otherwise acceptable ranges are more difficult and costly to treat for domestic water purposes. pH also directly affects the longevity of water collection and treatment systems, and low pH waters may cause compounds of human health concern to be released from the metal pipes of the distribution system.

In the state water quality standards for freshwater systems, two different pH criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2006 edition].

The Deschutes River and its tributaries from the mouth to and including the tributary from Offutt Lake are designated as *Salmonid Spawning, Rearing, and Migration* for Aquatic Life. The designated use of the Deschutes River and its tributaries upstream of the Offutt Lake tributary to the national forest boundary are classified as *Core Summer Salmonid Habitat*. Capitol Lake is designated Lake Class under the scenario where the dam remains in place; if the dam were removed, the Deschutes estuary (marine waters) would be designated as *Good Aquatic Life.*

(1) To protect the designated aquatic life uses of *Core Summer Salmonid Habitat*, pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

(2) To protect the designated aquatic life uses of *Salmonid Spawning, Rearing, and Migration,* pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

Fine Sediment

Fine sediment is governed by the narrative standards, and no numeric targets have been established in the water quality standards. The characteristic use to be protected is *Aquatic Life Habitat,* which is impaired by harmful fine sediment levels. Both *Salmonid Spawning, Rearing, and Migration* and *Core Summer Salmonid Habitat* uses would require healthy levels of fine sediment.

WAC-173-201A-260(2) includes protection from fine sediment levels that would be construed as deleterious. “Toxic, radioactive, or deleterious material concentrations must be below those which have the potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters….”

The original impairment was based on several reports documenting habitat alterations and human-caused contributions. Schuett-Hames and Flores (1993) used the Timber Fish and Wildlife Watershed Analysis Manual (Washington Forest Practices Board, 1997) and rated fine sediment “poor” in reach 22 (RM 28.5, near Lake Lawrence). Squaxin Island Tribe (SIT) data submitted by Jeff Dickison (1996) show fine sediment ranging from 15.5% to 22.5%, above the threshold for good habitat. Dickison (1996) documented a stock of coho salmon, while Baranski (1996) reclassified coho stocks as depressed. Toth (1991) documented human-caused contributions to these habitat alterations.

Antidegradation

The Clean Water Act requires that TMDLs be established to protect existing uses in state waters not meeting the state’s numeric water quality criteria. The standards also protect those waters of a higher quality than the numeric criteria. The concept of keeping high quality waters from being degraded is known as *antidegradation*. The antidegradation policy in the state’s water quality standards helps prevent unnecessary lowering of water quality, and provides a framework to identify those waters that are designated as an *outstanding resource* by the state. Washington State’s antidegradation policy follows the federal regulation guidelines and has three tiers of protection:

- Tier I: WAC 173-201A-310 is used to ensure existing and designated uses are maintained and protected. Tier I applies to all waters and all sources of pollution.
- Tier II: WAC 173-201A-320 is used to ensure that waters of a higher quality than the criteria assigned in the standards are not degraded unless such lowering of water quality is necessary and in the overriding public interest.
- Tier III: WAC 173-201A-330 is used when a high-quality water is designated as an “outstanding resource water.” The water quality and uses of these waters must be maintained and protected against all sources of pollution. (There are no Tier III waters identified in this TMDL area.)

This TMDL identifies areas where water quality is not being met and load and wasteload reductions are needed to bring the water back into compliance with the standards, consistent with Tier I Antidegradation goals. This TMDL also identifies areas where water is of a higher quality than the numeric criteria. These areas provide an opportunity to keep waters of a high quality by specifying actions to prevent reductions in water quality. Opportunities for these actions will be explored with stakeholders as part of developing the implementation strategy for this TMDL. The results of this report will provide the background for that discussion.

Watershed Description

Watershed Characteristics

The Budd Inlet watershed occupies a total of 186 mi^2 (480 km^2) including the 8.3-mi^2 (22-km^2) surface area of Budd Inlet. Elevations range from 3870 ft (1180 m) at Cougar Mountain in the Bald Hills to sea level. The watershed averages 5 miles (8 km) in width, and very few large tributaries discharge to the Deschutes River mainstem. The two largest by summer discharge rates are Spurgeon Creek and the spring at State Route 507.

Budd Inlet is one of several terminal inlets in South Puget Sound. Depths range from 100 ft (30 m) in the north to mudflats in the shallow East and West Bays. Much of the inlet varies from 15 to 50 ft (5 to 15 m) in depth. The tide range is 14.6 ft (4.5 m), based on the difference between mean higher high water and mean lower low water; however, spring tides can exceed 18 ft (5.5 m).

Black Lake sits at the drainage divide between WRIA 13 and WRIA 23 and contributes flow to both watersheds. Black Lake Ditch was excavated in 1922 to drain potential agricultural land. Thurston County owns the ditch and an easement that varies from 25 to 50 ft (7.6 to 15.2 m) on both sides. The ditch flows into Percival Creek, which is a tributary to Capitol Lake.

Precipitation varies from over 90 in (230 cm) at the headwaters to 45 in (115 cm) between Tumwater and Rainier (Miller et al., 1973). The USGS has gaged discharge on the mainstem of the Deschutes River at Rainier (gage 12079000) and near the mouth at the E Street bridge (gage 12080010) from the 1940s to 1960s and from 1990 to the present. Average annual discharge is 263 cfs (7.5 cms) at Rainier and 406 cfs (11.5 cms) at the E Street bridge. Because of the relatively low elevation of the headwaters, nearly all precipitation falls as rain, reflected in the streamflow patterns where the highest discharges occur following large winter storms.

The southern watershed headwaters are composed largely of Tertiary age bedrock consisting of basalt, andesite flows, and volcaniclastic deposits of the Northcraft Formation. The rocks generally yield little groundwater. The northern study area is underlain largely by Vashon age deposits of glacial outwash gravel and sand, interspersed with deposits of Vashon till in complex, heterogeneous patterns. The outwash gravels and sands are both capable of yielding significant groundwater volumes. The watershed includes the southern terminus of the Vashon glaciation.

Land Cover

Land cover includes a mix of forested lands, agricultural uses, and rural, residential, and urban lands. Weyerhaeuser Company, the Washington State Department of Natural Resources (DNR), and the U.S. Forest Service (USFS) own and manage public and private timberlands primarily in the southern headwaters. Commercial and non-commercial agricultural operations occur primarily in the central Deschutes River watershed and include dairy, sheep, and non-commercial livestock. Three major highways traverse the watershed. Interstate 5 crosses near Olympia, Tumwater, and Lacey, dividing Capitol Lake into the middle and south basins. Highway 101 connects with Interstate 5 along Capitol Lake. State Route 507 crosses the watershed through the town of Rainier.

The largest population centers within the watershed include most of Olympia and Tumwater, a portion of Lacey, and the town of Rainier, comprising over 50,000 people. All rely on groundwater systems for drinking water sources, and except for Olympia's nearby McAllister Springs source, the groundwater sources are within the watershed. The Deschutes River is closed to further water withdrawals (Kavanaugh, 1980).

Wastewater treatment for watershed residents includes both onsite sewage systems and centralized treatment facilities. Four plants discharge to Budd Inlet. These serve the region around Olympia and Tumwater as well as on the east and west sides of Budd Inlet (Figure 2). The rest of the watershed is served by onsite sewage systems.

Regulatory Activities

EPA is responsible for implementing the federal Clean Water Act. EPA designated the Washington State Department of Ecology (Ecology) to administer the Clean Water Act, including writing permits, developing water quality standards, and conducting water cleanup studies. EPA must review and approve all TMDLs developed in Washington.

The tribes of the 1854 Treaty of Medicine Creek ceded land encompassing this watershed to the United States while reserving their rights to take fish in their "usual and accustomed" areas and hunt on "open and unclaimed land" within their traditional hunting territories. The Deschutes River and Budd Inlet watershed is within the Squaxin Island Tribe's treaty "usual and accustomed" fishing area and within the Tribe's aboriginal hunting grounds.

Forestry Activities

Recommendations for load targets are included in this TMDL technical report for non-federal forest lands in accordance with Section M-2 of the Forests and Fish Report (USFWS et al., 1999). Expectations for TMDL implementation on non-federal forest lands will be discussed in the subsequent Water Quality Improvement Report.

As part of the Forests and Fish Report (Schedule M-2), Ecology provided assurances to landowners that the new regulations would be relied on to protect water quality for a 10-year period through June 30, 2009. On July 15, 2009, Ecology extended the Clean Water Act assurances, contingent upon meeting a series of corrective milestones for the forest practices operational and adaptive management programs (Hicks, 2009). If the programs meet the milestones, then the state's forest practices program can continue to be relied on to protect water quality and to bring degraded waters into compliance with state water quality standards and the federal Clean Water Act.

NPDES Individual Permits

Ecology administers several permits under the National Pollutant Discharge Elimination System (NPDES), including individual wastewater, municipal stormwater Phase I, and general permits for municipal stormwater Phase II, industrial stormwater, construction stormwater, and sand and gravel operations. In addition, Ecology administers general permits for upland fin-fish hatching and rearing. General permits apply to a group of dischargers as a whole and implement both the federal Clean Water Act and state Water Pollution Control Act.

Table 5 lists the four domestic wastewater facilities that discharge to Budd Inlet. The Boston Harbor and Tamoshan plants are batch reactors with extended aeration, activated sludge, and ultraviolet disinfection, while the Seashore Villa package plant included activated sludge with extended aeration and chlorine disinfection until November of 2007 when it was upgraded to a membrane bioreactor with ultraviolet disinfection. Annual discharges average 0.01 to 0.03 million gallons per day (mgd) for the period 1999-2008 (Mohamedali et al., 2011). A small facility at Beverly Beach previously discharged to Budd Inlet, but the wastewater has since been routed to an upgraded facility at Tamoshan.

Table 5. Individual wastewater permits issued with the study area.

Water Body	Facility Name	Permit No.	Parameter Limits	Reporting Parameters
Budd Inlet	LOTT Budd Inlet Treatment Plant	WA0037061	BOD5 and TIN, with seasonal variation, FC, pH, TSS	Q, BOD5, TSS, pH, FC, Temp, NH4N, NO23N, TKN
Budd Inlet	Boston Harbor	WA0040291	BOD5, TSS, FC, pH	Q, BOD5, TSS, FC, NH4N, DO, pH
Budd Inlet	Seashore Villa	WA0037273	BOD5, TSS, FC, pH	Q, BOD5, TSS, pH, FC
Budd Inlet	Tamoshan	WA0037290	BOD5, TSS, FC, pH	Q, BOD5, TSS, pH, FC

Abbreviations are defined in Appendix B.

The Lacey, Olympia, Tumwater, and Thurston County (LOTT) Clean Water Alliance Budd Inlet Treatment Plant includes activated sludge and seasonal advanced treatment for nutrient removal. Annual discharge averages 11.1 mgd with lower flows in the summer. The plant provides secondary wastewater treatment as well as denitrification from April through October before discharging to Budd Inlet. Effluent is discharged through an outfall off the north end of the Port peninsula.

A portion of Olympia, primarily the downtown area, is served by combined sewers that flow to the Budd Inlet Treatment Plant. When excessive stormwater discharges exceed the hydraulic capacity of the plant, a portion of the combined stormwater and wastewater may be discharged through the Fiddlehead outfall, which serves as an emergency outfall. A discharge from the Fiddlehead outfall has occurred once in the last 16 years (Dougherty, personal communication, 2007). The excess volume of combined stormwater and wastewater that could not be treated was screened prior to emergency release.

Two combined sewer outfalls are within the City of Olympia jurisdiction as well at State and Chestnut Streets and at the Water Street Pump Station. These two combined sewer outfalls have not been used for years, but other overflows from manholes or pump stations have occurred during major storm events (Dougherty, personal communication, 2007). Separate storm sewers serve the remaining developed areas.

NPDES Municipal Stormwater Permits

Table 6 lists the municipal stormwater permittees in the study area. Ecology issued the current Phase II Municipal Stormwater Permit for Western Washington in January 2007 to cover discharges to waters of the state from municipal separate storm sewers (MS4s). Ecology is in the process of issuing a new permit, with public comment on the draft through February 2012. Ecology proposes to extend the current permit through July 2013 and issue the new permit effective August 2013.

Table 6. Western Washington municipal stormwater permits

Water Body	Facility Name	Permit No.	Parameter Limits	Reporting Parameters
Western Washington Phase II Municipal Stormwater Permit				
(citywide)	City of Olympia	WAR04-5015	(not required)	Annual report with Stormwater Management Program
(citywide)	City of Lacey	WAR04-5011	(not required)	Annual report with Stormwater Management Program
(citywide)	City of Tumwater	WAR04-5020	(not required)	Annual report with Stormwater Management Program
*	Thurston County	WAR04-5025	(not required)	Annual report with Stormwater Management Program
Capitol Lake	Department of Enterprise Services	WAR04-5210**	(not required)	Annual report with Stormwater Management Program
WSDOT Phase I Municipal Stormwater Permit				
(multiple)	WSDOT	WAR043000	(not applicable)	Annually submit Stormwater Management Program Progress Report

* For all counties required to have coverage under this permit, the geographic area of coverage is the urbanized areas and urban growth areas associated with cities under the jurisdictional control of the county. The geographic area of coverage also includes any urban growth area contiguous to urbanized areas under the jurisdictional control of the county.

** Washington State Department of Enterprise Services, previously known as General Administration, is a secondary permittee with coverage under the Phase II permit for the Capitol Campus.

The existing permit stipulates that permittees have in place the following components of the Stormwater Management Program:

1. Public education and outreach.
2. Public involvement/participation.
3. Illicit discharge detection and elimination.
4. Construction site stormwater runoff control.
5. Post construction stormwater management in new development and re-development.
6. Pollution prevention and good housekeeping for municipal operations.

In addition, the programs must include

1. Compliance with approved TMDLs or equivalent analysis, where appropriate.
2. Evaluation and assessment of program compliance.

Phase II municipal stormwater permittees must implement actions necessary to achieve pollutant reductions in TMDLs that are approved by EPA prior to the issuance date of the permit. For TMDLs approved after the permit issuance date, Ecology may establish TMDL-related permit requirements through a formal permit modification or through the issuance of an administrative order.

The Washington State Department of Transportation (WSDOT) permit regulates stormwater discharges from municipal storm sewer systems (MS4s) owned or operated by WSDOT within the Phase I and II Municipal Stormwater Permit designated boundaries excluding federal and tribal lands. Ecology issued the current permit to WSDOT on February 4, 2009. This permit covers stormwater discharges to any water body in Washington State for which there is an EPA-approved TMDL with load allocations and associated implementation documents specifying actions for WSDOT stormwater discharges (applicable TMDLs listed in Appendix 3 of the WSDOT permit).

As a result of a settlement agreement between Ecology, WSDOT, and Puget Soundkeeper Alliance, Ecology is in the process of modifying the permit to add new TMDL-related permit requirements every 18 months. This modification will also update references to the 2011 updated Highway Runoff Manual and update the Stormwater Management Program Plan.
The public comment period closed December 23, 2011, and the modified permit was issued in March 2012. The modified draft permit requires compliance with applicable approved TMDLs listed in Appendix 3 of the permit. Ecology will modify the permit and/or issue an administrative order establishing new TMDL-related permit requirements for TMDLs approved by EPA during the preceding 18 months after the final modification is issued.

Other General Permits

Table 7 lists the general permits currently issued for activities within the Deschutes River watershed. These include industrial stormwater, construction stormwater, sand and gravel operations, and other permits.

Table 7. General permits within the study area.

Water Body	Facility Name	Permit No.	Reporting Parameters
General Industrial Stormwater			
Deschutes River	O'Neill and Sons	SO3001404	Annual report of stormwater sampling for turbidity, pH, oil sheen, total copper, total zinc
Deschutes River	Tumwater Lumber Co	SO3004272	
Budd Inlet	BMT-Northwest	SO3004476	
Budd Inlet	Dunlap Tow Olympia Log Yard/Chip Reld	SO3000106	
Budd Inlet	Holbrook Inc Olympia Public Yard	SO3003855	
Budd Inlet	Port of Olympia Ocean Terminal	SO3001168	
General Construction Stormwater			
(study area)	(varies*)	(varies*)	
General Sand and Gravel Operations			
Deschutes River	Waldrick Road Pit	WAG501231	Quarterly reporting; parameters vary by facility
Deschutes River	Alpine Sand and Gravel	WAG501037	
Deschutes River	Olympia Airport Asphalt Plant	WAG501042	
Black Lake Ditch	Jones Quarry	WAG501118	
Black Lake Ditch	Concrete Recyclers	WAG501507	
Other facilities			
Deschutes River	WDFW Tumwater Falls Hatchery	**	Not applicable

* Facilities covered under the Construction Stormwater General Permit change monthly, but projects often include residential and commercial development.
** The Washington Department of Fish and Wildlife (WDFW) has applied for a permit for the Tumwater Falls hatchery but was not granted a permit, pending the outcome of the present TMDL study.

The current Industrial Stormwater General Permit was effective January 1, 2010 with a modification to become effective July 1, 2012. The permit was appealed in November 2009; however, the Pollution Control Hearings Board validated the permit as written in April 2011, except that Ecology was ordered to modify permit conditions related to sampling and corrective actions. That order does not affect permit section S6, Discharges to 303(d)-Listed or TMDL Waters. Discharges to 303(d)-listed waters that do not have an EPA-approved TMDL must meet effluent limits established in section S6(c) Table 5. The table includes fecal coliform, total phosphorus, and ammonia and stipulates that limits will be assigned at the time of permit coverage. For discharges to waters with applicable TMDLs, Ecology will list requirements to comply with the TMDL.

Reductions recommended in this report and to be established in the future Water Quality Improvement Report would apply to new permit applications only. Additional requirements of existing permittees associated with TMDLs completed after the issuance date of the general permit will only become effective if they are imposed through an administrative order by Ecology. Several facilities discharging to the Deschutes River or Budd Inlet currently operate under the Industrial Stormwater General Permit.

The current Construction Stormwater General Permit was issued in 2010, with an effective date of January 1, 2011. The general permit covers all sites that disturb one or more acres and discharge stormwater to surface waters of the state. Facilities covered under the permit must not cause or contribute to a violation of surface water quality standards. Specifically, site operators must develop stormwater pollution prevention plans and implement sediment, erosion, and pollution prevention control measures.

Any discharges to waters on the 303(d) list for turbidity, fine sediment, high pH, or phosphorus must monitor and comply with effluent limits in Special Condition S8, subsections C and D. This includes pH sampling for discharges to water bodies listed as impaired for high pH as well as turbidity monitoring for those that discharge to water bodies listed as impaired for turbidity, fine sediment, or phosphorus.

Further, any discharges to water bodies subject to TMDLs for those parameters must comply with any specific wasteload allocations. Where an applicable approved TMDL has established a general wasteload allocation for construction stormwater discharges but without specific requirements, compliance with conditions of the permit will be assumed to be consistent with the approved TMDL. Where an applicable TMDL has not specified a wasteload allocation but has not excluded these discharges, compliance with the permit will be assumed consistent with the TMDL. Where an applicable TMDL specifically precludes or prohibits discharges from construction activity, the operator is not eligible for coverage under this permit.

The requirements in the subsequent Water Quality Improvement Report will apply to future permittees. TMDLs completed after the operator’s complete permit application is received by Ecology become applicable to the permittee only if they are imposed through an administrative order by Ecology or through modification of permit coverage. The number of facilities discharging to the Deschutes River or Budd Inlet currently operating under the Construction Stormwater General Permit varies.

The current Sand and Gravel General Permit was issued in 2010 with an effective date of October 1, 2010. The permit was appealed and modified, effective October 1, 2011. Facilities covered under the permit must monitor effluent based on the type of facility. Discharges must not cause or contribute to a violation of surface water quality standards, as described in Special Condition S3.B. The general permit cannot cover discharges to waters with a TMDL for turbidity, fine sediment, pH, or temperature unless the facility complies with requirements in Special Section S3.G.3-5, and the general permit requirements are adequate. The general permit also cannot cover facilities that discharge to 303(d)-listed waters at a concentration or volume that will cause or contribute to violations of applicable water quality standards.

New and existing facilities must comply with TMDL wasteload allocations completed prior to the date permit coverage was issued. New facilities that would discharge to an impaired water body without a completed TMDL cannot discharge the listed pollutant at a concentration or volume that will cause or contribute to a violation of the applicable water quality standard. Facilities also cannot increase loading or concentrations over the duration of the permit cycle or until a wasteload allocation is approved by EPA. Table 7 lists facilities operating under the Sand and Gravel General Permit that discharge to water bodies in the Deschutes River watershed. Historically, the Washington Department of Fish and Wildlife (WDFW) operated four net pens in Percival Cove within Capitol Lake, but these were discontinued in 2007. The WDFW operates the Tumwater Falls Hatchery as a seasonal rearing facility. Ecology determined that the facility is not covered under the Upland Fin-Fish Hatching and Rearing General NPDES Permit. The WDFW previously proposed a Deschutes Watershed Center with both rearing facilities and public education opportunities, but the project is currently on hold, pending budget constraints.

Fisheries

The Deschutes River and Budd Inlet watershed supports important shellfish and anadromous fish populations. Five salmonid species use the study area for spawning and rearing – steelhead trout, sea-run and resident cutthroat trout, coho salmon, hatchery chinook, and chum salmon (Haring and Konovsky, 1999) – although, historically, Tumwater Falls presented a natural barrier to fish passage. The Washington Department of Fisheries constructed a fish ladder in 1954 (General Administration, 2002). Chum salmon primarily rely on small, low-gradient streams feeding directly into Budd Inlet. Chinook salmon primarily use the lower and middle mainstem of the Deschutes River and Percival Creek. The middle and upper reaches of the watershed are used by coho salmon, steelhead trout, and sea-run and resident cutthroat trout. Resident trout are common in the tributaries above barriers to anadromous salmonids.

Salmonids from the Deschutes River now constitute a substantial portion of the South Puget Sound sport and Native American fishery. Several synoptic surveys of fish species and habitat distribution have been performed by the Washington Department of Fisheries (Williams et al., 1975) and Weyerhaeuser Company (Dinicola, 1979; Bisson et al., 1985; Sullivan et al., 1987).

Other fish species that occur within the Budd Inlet watershed include Pacific lamprey, large-scale suckers, speckled dace, longnose dace, redside shiners, torrent sculpin, and shorthead sculpin (Sullivan et al., 1987).

Species of shellfish known to occur within Budd Inlet include geoducks, manila, native littleneck, butter clams, cockles, mussels, squid, red rock crabs, and oysters (Zulauf et al., 1990). The Washington State Department of Health (DOH) has closed most of Budd Inlet (south of

Burfoot County Park) to bivalve shellfish harvest due to the presence of treated wastewater discharges (DOH, 2008), and Burfoot County Park currently has a harvest advisory because potential pollution sources have not been evaluated.

Potential Pollutant Sources

Potential pollutant sources include a variety of point sources and nonpoint sources. Point-source discharges include domestic wastewater, combined sewer, and separate storm sewer systems operating under NPDES permits. Other potential permitted discharges include those operating under general permits for municipal stormwater, industrial stormwater, construction stormwater, and sand and gravel operations. Nonpoint sources are those traditionally more diffuse in origin that cannot be identified with a discrete discharge location. Examples of nonpoint sources can include livestock having direct access to streams, lack of riparian vegetation, onsite sewage systems, pet wastes, ditches or channeled surface waters, sheet flows, land cover activities, and wildlife contributions.

Temperature

Potential sources of temperature impairments in streams include the lack of riparian shade that would otherwise block incoming solar radiation to water surfaces, low summer streamflows due to natural conditions and anthropogenic (related to humans) activities, elevated temperatures from stormwater runoff, and increased stream surface area due to natural and anthropogenic activities. Except for stormwater runoff, these potential anthropogenic contributors to elevated temperatures are all considered nonpoint sources. Temperature point sources include activities covered under general permits for municipal stormwater, industrial stormwater, construction stormwater, and sand and gravel operations.

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature (Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; Levno and Rothacher, 1967, Brown and Krygier, 1970, Adams and Sullivan, 1989). The important benefits that riparian vegetation has upon stream temperature include the following:

- Near-stream vegetation height, width, and density combine to intercept shortwave radiation that reduces solar heat flux to the water surface.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperature, higher relative humidity, lower wind speed, and cooler ground temperature along stream corridors.
- Bank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land cover type and condition, affecting floodplain and instream roughness, contributing large woody debris, and influencing sedimentation, stream substrate composition, and streambank stability.

Streamflows influence water temperatures by varying the volume over which heat is dissipated. As the volume of water decreases, the temperature, equivalent to the concentration of heat, increases. Natural contributors to low streamflows include seasonally varying meteorology and hydrogeology. Potential anthropogenic contributors include water withdrawals and altered hydrogeology due to land surface processes that increase the heat load of stormwater runoff and decrease groundwater recharge.

Stream depth and width affect water temperature by varying the volume over which heat is dissipated and by increasing the surface area over which the heat load is applied. Stream widths can increase due to sediment deposition from natural and anthropogenic sources. For example, natural decreases in the channel slope reduce the sediment transport capacity of the river. Anthropogenic activities may increase overall sediment in the system, leading to enhanced sediment deposition.

Lakes and wetlands can be sources of heat to downstream water bodies. Shallow lakes and wetlands occupy the headwaters of many tributaries of the Deschutes River, as well as Percival Creek and Black Lake Ditch. These streams cool in a downstream direction due to groundwater inflow, as well as inputs from cooler spring-fed tributaries.

This study uses riparian shade as a surrogate measure of heat flux. Effective shade is defined as the fraction of the potential solar shortwave radiation blocked by vegetation or topography before it reaches the stream surface.

Fecal Coliform Bacteria, Nutrients, Dissolved Oxygen, and pH

Fecal Coliform Bacteria and Nutrients

Potential sources of fecal coliform bacteria and nutrients that could affect DO and pH include humans, domestic animals, agricultural activities, and wildlife.

Human waste can reach streams directly or indirectly through deteriorating or improperly connected sewer infrastructure. Leaks in sewer systems occur as the infrastructure ages and as surrounding soils are disturbed by construction or by tree roots. During construction or redevelopment, wastewater pipes may be inadvertently connected to stormwater infrastructure. Infrastructure-related sources are generally considered nonpoint sources unless the effluent reaches stormwater infrastructure covered by a general permit. Recreational users or homeless populations may contribute waste, including bacteria and nutrients, to surface waters through improper waste disposal practices.

Humans may contribute to nonpoint-source fecal or nutrient contamination via improperly maintained, poorly located, or failing septic systems. Properly functioning septic systems allow solids to settle to the bottom of a tank where they are partially decomposed (Thurston County Public Health and Social Services Department, 2004). If solids accumulate and the tank is not pumped on a regular basis, the settling capacity of the tank is reduced and solids may flow out of the tank with the effluent. In a conventional septic system, the septic tank effluent flows to a drainfield, which is a network of perforated pipes set in gravel-filled trenches. Final treatment of the effluent occurs through biological activity and physical filtration within the gravel trenches and in the unsaturated soil beneath the drainfield. Inadequate inspection and maintenance of a septic system, overuse, and physical disturbance can contribute to system failure.

Septic systems are not designed to remove nitrogen from the wastewater, and even functioning systems contribute nitrogen. Septic system sources are generally considered nonpoint sources unless the effluent reaches stormwater infrastructure covered by a general permit.

Domestic animals, such as dogs and cats, may contribute to nonpoint-source bacteria and nutrient contamination when owners fail to clean up after pets. Stormwater runoff may suspend fecal matter in impervious areas and transport it to the stormwater infrastructure or in pervious areas as overland flow to surface waters.

Livestock such as horses, cows, and sheep may contribute via overland flow during storms, unmanaged animal access, or from improper manure storage and disposal. Livestock are considered nonpoint sources unless the effluent reaches stormwater infrastructure covered by a general permit or unless a Confined Area Feeding Operation (CAFO) permit coverage is required. Other agricultural activities that could contribute to high fecal coliform bacteria levels include animal waste fertilizers improperly applied to growing areas. Non-livestock agricultural activities are generally considered nonpoint sources unless runoff reaches stormwater infrastructure covered by permits.

There are no permitted livestock operations within the Deschutes River watershed. Two dairies continue within the watershed, but currently are not required to obtain CAFO permit coverage. Mahan Ranch LLC (Dairy License 2079) is located near Route 507 along the Deschutes and Plowman Dairy (Dairy License 5979) is located east of Lake Lawrence. The Washington State Department of Agriculture (WSDA) conducts routine inspections and does enforcement under RCW 90.64. Dairies must have a dairy nutrient management plan certified by the local conservation district, which is the Thurston Conservation District for this watershed.

Historically, two other dairies operated within the watershed, but both had ceased operations by summer 2003. At least one facility (sheep) and possibly several smaller agricultural facilities operate within the Deschutes River watershed, although none require regular inspections under state law. Any complaints received by Ecology are referred to Ecology’s Southwest Regional Office nonpoint-source inspectors and WSDA for follow up. Ecology is responsible for regulatory enforcement under RCW 90.48 and for enforcement under general nonpoint-source pollution responsibilities.

Birds and other wildlife may contribute bacteria and nutrients directly to water bodies or indirectly via overland stormwater runoff. Unless wildlife populations have increased artificially due to anthropogenic activities, wildlife contributions are considered natural background conditions which may be quantified in a TMDL but not assumed to be decreased.

In addition to causing increased stream temperatures, lack of riparian vegetation also may reduce the filtering of nutrients from overland flow (NRC, 2002). Soils in riparian areas perform valuable functions and mitigate effects of upland disturbances. Plants, soil, and microorganisms can transform chemicals through processes such as denitrification.

Dissolved Oxygen and pH

Low DO and high pH levels may result from increased sunlight or nutrient loads that stimulate plant growth, referred to as primary productivity, above natural levels. Plant growth can include both macrophytes and algae that occur in freshwater and marine environments. Macrophytes can be emergent, submerged, or floating, and either rooted or unattached. Benthic algae that grow on stream substrates typically have a greater effect on streams than suspended phytoplankton. In marine systems, phytoplankton typically dominate primary production.

The natural diel cycle of plant growth produces DO during daylight hours as the plants photosynthesize, but reduces DO levels to a natural minimum around sunrise as respiration occurs. Algae and other aquatic plants also consume carbon dioxide during photosynthesis, reducing the amount of carbon dioxide and bicarbonate in the water. Because alkalinity remains constant, the pH level increases. Primary productivity generally produces the highest pH in the late afternoon and the lowest DO levels in the early morning hours. Enhanced algae growth due to increased sunlight or nutrient loads from human activities increases the daily variation, resulting in lower DO and higher pH levels than would have resulted under natural conditions.

Productivity may be limited by a specific nutrient, generally phosphorus in streams and nitrogen in marine water bodies, by sunlight to fuel photosynthesis or by retention time in a water body.

Residence time affects DO and pH as well. High residence time and high organic matter loading in wetlands, for example, produce low DO and pH levels. Many wetland complexes exist within the Deschutes River system and may contribute to the low levels recorded in the mainstem and tributaries.

Marine DO levels in Budd Inlet are affected by point-source discharges from facilities covered by individual and general permits. Treated domestic wastewater adds nutrient loads to the marine waters, enhancing primary productivity, as occurs in the freshwater systems described above. Stormwater from combined areas can also decrease treatment efficiency at the facility. Combined Sewer Outflows (CSOs) are a source of biological, chemical, and aesthetic pollution.

Marine DO levels also are affected by nonpoint-source nutrient loads from the Deschutes River and other direct tributaries, due to a combination of human and animal sources. In addition, high productivity within Capitol Lake – due to the combination of increased residence times compared with a free-flowing estuary, shallow water, warm water temperatures, and high nutrient loads from the Deschutes River and Percival Creek – produces high seasonal organic matter levels, particularly during algae blooms that occur in late summer.

Stream pH levels may be affected by natural sources, in addition to the diel effect of productivity described above. The pH of rain in western Washington is generally 4.8 to 5.1 (NADP/NATN, 2004). Therefore, stormwater may have a low pH due to regional atmospheric rather than local watershed conditions. Wetland systems also affect pH by enhancing natural decomposition processes, which results in acidic (low) pH levels.

Anthropogenic activities can lower pH as well. For example, decomposing organic material, such as that found in logging slash, and even acid deposition can lower pH below water quality standards. Some streams have a naturally low buffering capacity, which makes them more susceptible to pH changes. These streams can have both low and high pH in the same stretch, though often during different times of the year.

Fine Sediment

Stream sediment levels result from erosion that may be part of the natural processes or influenced by anthropogenic activities. River sediment processes reflect climate, geology, regional topography, soils, vegetation, and human land-use practices. Increased delivery of fine sediment can alter substrate composition and channel morphology, leading to degradation of spawning habitat for fish. Salmonid eggs require healthy DO levels for survival, which makes them particularly susceptible to degradation from fine sediment. Fine sediments may clog pores between gravel particles, impeding the exchange of oxygen between the stream and the underlying gravel beds (Johnson, 1980). Several studies have found a link between high fine sediment levels and elevated mortality rates of salmonid embryos (Chapman, 1988; Everest et al., 1985; Iwamoto et al., 1980; Koski, 1966).

Potential sources of fine sediment include (1) natural sources, such as landslides and bank erosion, or (2) anthropogenic sources from land disturbances, such as road building, timber harvest, agricultural activities, residential development, and increases in stormwater runoff resulting in downcutting.

Landslides constitute a natural part of the landscape, particularly in areas of steep slopes and abundant rainfall. The delivery of high sediment volumes can result from unstable slope failure, which can overwhelm the capacity of the channel to transport sediment downstream. These processes lead to channel widening, bank erosion, and shallower water depths. Clearcutting and road building substantially increase landslide rates (Jones and Grant, 1996; Naiman and Bilby, 1998; Robinson et al., 1999; Spence et al., 1996; Swanson et al., 1998).

Road building and improper drainage maintenance also can increase the likelihood of mass movements by further destabilizing hillslopes, often undercutting the lower part of a slide or adding weight to the top of a slide. Roads also create impervious surfaces and enhance the drainage connectivity. Water flowing through roadside ditches picks up sediment and delivers it to streams, considerably increasing the volume of sediment delivered. Undersized culverts may force water over roadways, potentially washing out the road.

Rivers naturally mobilize and transport sediment through bank erosion and downcutting. Sediment transport is directly proportional to the availability of eroded material and the stream power to move it (Bull, 1979). In headwater streams, steep gradients create sufficient stream power to undercut the toe of slopes and downcut through streambed surfaces. Down-gradient streams typically erode floodplain banks as they migrate laterally and downstream. Most of the material eroded from the floodplain banks settles in bars and overbank flood deposits. Bank erosion does not constitute a net sediment influx to the river unless channel widening occurs. However, natural equilibrium can be offset by increases in stream power or increases in sediment volume delivered to the stream. Increases in stream power can result from a variety of factors including natural storm events, clear-cut logging, and road building. The latter two activities increase stream power by decreasing natural infiltration rates, which increases overland flow and the volume and speed of water delivered to the stream (Bull, 1979; Jones and Grant, 1996).

Human activities such as agriculture and urbanization also can increase the delivery of sediment to stream channels. The physical manipulation of soils from agricultural activities can lead to increased soil erosion by both wind and water. The common practice of draining and adding tile drains to wet agricultural lands also increases the volume and speed of delivery of water to the river channel, increasing stream power. Straightening channel meanders through channelization further increases stream energy and erosive power. Large domestic animals may increase streamside erosion in areas in which they are allowed direct stream access by damaging streambanks and eliminating riparian vegetation and regeneration needed for bank stability.

Urban sources of sediment include runoff from paved surfaces, unpaved roads, disturbed hillslopes, and new excavation and construction activities. Impervious surface increases associated with urban and suburban development also increase overland flow and alter the timing of water delivered to the channel, again increasing stream power.

Fine sediments from both natural and anthropogenic sources can contribute phosphorus, often associated with weathered rock and soil particulate matter.

Goals and Objectives

Project Goals

The project goals were to determine the loading capacity for fecal coliform bacteria, temperature, DO, nutrients, pH, and fine sediment in portions of the Deschutes River, Capitol Lake, Budd Inlet, and their tributaries. This report also recommends load and wasteload reductions for various parameters throughout the study area. The future Water Quality Improvement Report will develop load and wasteload allocations for Capitol Lake and Budd Inlet marine DO and will re-evaluate load reduction targets for the Deschutes River, Percival Creek, and other tributaries.

Study Objectives

Study objectives included several technical elements designed to achieve the project goals.

Fecal Coliform Bacteria

- Characterize bacteria concentrations and identify major sources geographically to the Deschutes River, Mission Creek, Ayer (Elwanger) Creek, Indian Creek, Reichel Creek, Capitol Lake, Moxlie Creek, Adams Creek, Butler Creek, Chambers Creek, Ellis Creek, Percival Creek, Schneider Creek, and Spurgeon Creek.

Temperature

- Characterize stream temperatures and processes governing the thermal regime in the Deschutes River, Percival Creek, Black Lake Ditch, and tributaries, including the influence of lakes and wetlands.
- Develop predictive models of the Deschutes River under critical conditions. Apply the model to recommend load targets for effective shade and other surrogate measures to meet temperature water quality standards, identify the areas influenced by lakes and wetlands, and, if necessary, determine the natural temperature regime.
- Quantify the effective shade deficit in the Percival Creek watershed and recommend shade improvements without modeling water temperature in the system.

Dissolved Oxygen, Nutrients, and pH

- Conduct surveys for physical, chemical, and biological measures relevant to DO in the Deschutes River, and evaluate Ayer (Elwanger) Creek and Reichel Creek.
- Characterize pH and relevant physical, chemical, and biological measures in the Deschutes River, Ayer (Elwanger) Creek, Adams Creek, Butler Creek, Chambers Creek, Ellis Creek, Hard Creek, Lincoln Creek, Little Deschutes River, Percival Creek, Schneider Creek,

Spurgeon Creek, and Thurston Creek. If streams are impaired by anthropogenic activities, assess productivity.

- Determine DO, nutrient, and pH targets for the Deschutes River and its tributaries.
- Monitor DO, nutrients, pH, and parameters related to productivity in Capitol Lake.
- Model DO in Capitol Lake. Load reduction targets for all inflows to the lake will be established in the subsequent Water Quality Improvement Report.
- Utilize existing data and a refined model of Budd Inlet to establish targets and quantify overall load reductions necessary to meet the water quality standards. The subsequent Water Quality Improvement Report will establish point-source wasteload allocations and nonpoint-source load allocations for DO and related parameters.

Fine Sediment

- Identify and quantify the processes governing the generation, transport, and deposition of fine sediment in the Deschutes River watershed.
- Evaluate the relative contributions of natural and anthropogenic sources of fine sediment to the Deschutes River and its tributaries, and establish targets.

Study Methods

Data Collection Activities

The study was conducted under a Quality Assurance (QA) Project Plan that was reviewed by Ecology, EPA Region 10, the Squaxin Island Tribe, and local stakeholders. The QA Project Plan was approved after incorporating review comments in February 2004 (Roberts et al., 2004). A brief description of the 2003-2005 data collection and analysis activities is presented here. Interim data were provided in quarterly reports (www.ecy.wa.gov/programs/wq/tmdl/deschutes/technical.html).

Water quality and streamflow data were collected from monitoring sites distributed throughout the study area. The study design included a combination of continuous results, grab samples, synoptic surveys, and stormwater monitoring.

Temperature

Water temperature was recorded at 30-minute intervals at 25 locations in 2003, 20 locations in 2004, and has continued at a subset of three sites through the present (Figure 3). In addition, a thermal infrared survey was conducted in August 20, 2003 along the mainstem of the Deschutes River to identify cold water sources and to provide a validation data set. While the QA Project Plan included mainstem and tributary monitoring in both 2003 and 2004, tributary monitoring was inadvertently discontinued in 2004, and water temperatures were not recorded.

In addition, air temperature was recorded continuously at five locations in 2003 and 16 locations in 2004. Relative humidity was measured at one location in 2003 and two locations in 2004.

Because groundwater was expected to have a profound effect on instream temperatures, a network of piezometers was installed and co-located with continuous temperature monitors. Thirteen piezometers were installed along the mainstem of the Deschutes River in 2003 and an additional 10 piezometers were added in 2004. Piezometers consisted of 1- or 1.5-inch (2.5- or 3.8-cm) galvanized pipe extending approximately 1.5 m (5 ft) below the sediment surface and screened near the bottom with twelve 0.5-cm (3/16-in) holes. Vertical hydraulic gradient, or the difference in water levels within and outside the piezometers, was recorded monthly to establish the net direction of groundwater flow. In addition, the piezometers were instrumented with three continuous temperature monitors to provide hyporheic and groundwater temperatures within 0.3 m (1 ft) of the sediment surface, near the bottom of the piezometer, and approximately equidistant between the two. Grab samples collected from a subset of seven piezometers were analyzed for nutrient levels and in-situ parameters such as DO. The related study included VS2DHI modeling (Hsieh et al., 2000) to estimate hyporheic water and solute transport based on a best fit to the measured streambed sediment profiles. The hydrogeology results were summarized in a separate report (Sinclair and Bilhimer, 2007).

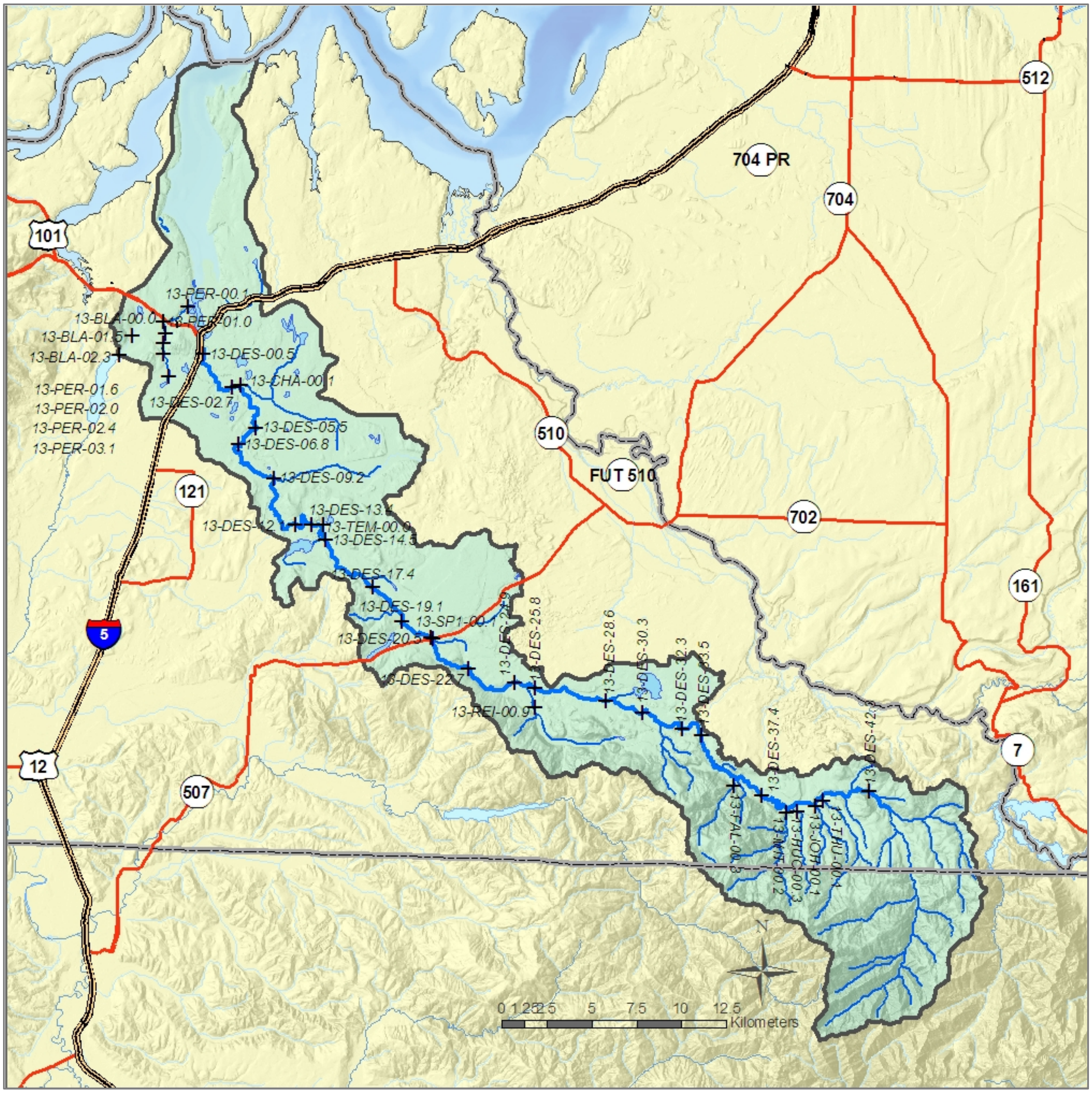

Figure 3. Temperature monitoring stations within the Deschutes River and Percival Creek watersheds.

To provide additional information on the distribution of flows within the Deschutes River watershed, Ecology monitored discharge continuously at three sites from July 2003 through February 2005 to supplement USGS stream gaging at E Street and Rainier and Weyerhaeuser Company gaging at 1000 Rd. A detailed seepage run was conducted on August 5, 2003, where teams measured discharge at 15 mainstem locations and 24 tributaries to the Deschutes River. A seepage study was conducted over six locations within the Percival Creek/Black Lake Ditch watershed on August 6, 2003. Figure 4 presents the locations of continuous discharge and synoptic survey station locations.

Figure 4. Continuous discharge monitoring (red shapes) and synoptic flow (black crosses) stations within the Deschutes River and Percival Creek watersheds.

Continuous and instantaneous flow measurements were supplemented with a time-of-travel survey conducted August 2-4, 2004. Rhodamine dye and fluorometers were used to track the plume from the Vail Cutoff Road to the E Street bridge, and travel times were determined for multiple river reaches.

Riparian vegetation was characterized using a combination of computer and field techniques. Vegetation polygons were digitized within the 328-ft (100-m) riparian corridor on both sides of the Deschutes River. LiDAR data available through the Puget Sound LiDAR Consortium were used to estimate vegetation height within polygons. Species type, height, and density were checked against field observations recorded during the August 11-15, 2003 stream walk. Shade estimates calculated from vegetation characteristics were compared with those measured using hemispherical digital photography at nine locations along the mainstem of the Deschutes River and six locations within the Percival Creek watershed.

Bankfull and wetted widths were digitized from color orthophotos supplemented with field observations.

The hydrogeology study (Sinclair and Bilhimer, 2007) used multiple field techniques to estimate direction, volume, and timing of surface water-groundwater interactions and to estimate the nutrient levels in both the Deschutes River and Percival Creek watersheds. Seepage runs were used to quantify groundwater inflows and outflows. In addition, the study included instream piezometers, groundwater quality, and streambed temperature patterns.

Fecal Coliform Bacteria, Nutrients, Dissolved Oxygen, and pH

To characterize bacteria, nutrient levels, and primary productivity within the Deschutes River, monthly or twice-monthly grab samples were collected along the mainstem and from tributaries from July 2003 through December 2004. Similarly, monthly or twice-monthly samples were collected from the Percival Creek watershed and within Capitol Lake. Bacteria levels were characterized in seven tributaries to Budd Inlet. Figure 5 shows the station locations. Total (persulfate) nitrogen, nitrate+nitrite, ammonium, total phosphorus, orthophosphate, and total and dissolved organic carbon were analyzed at a subset of sites. Samples were analyzed for alkalinity as well, and in-situ temperature, DO, and pH were recorded with a Hydrolab ® multi-probe instrument.

Continuous DO, pH, temperature, and conductivity levels were recorded at five locations along the mainstem of the Deschutes River during August 9-13, 2004 using Hydrolabs installed in-situ. Another Hydrolab was installed at the outlet of Capitol Lake near the dam from August 4-13, 2004, to monitor the effect of an herbicide application to control invasive milfoil within the lake, described below.

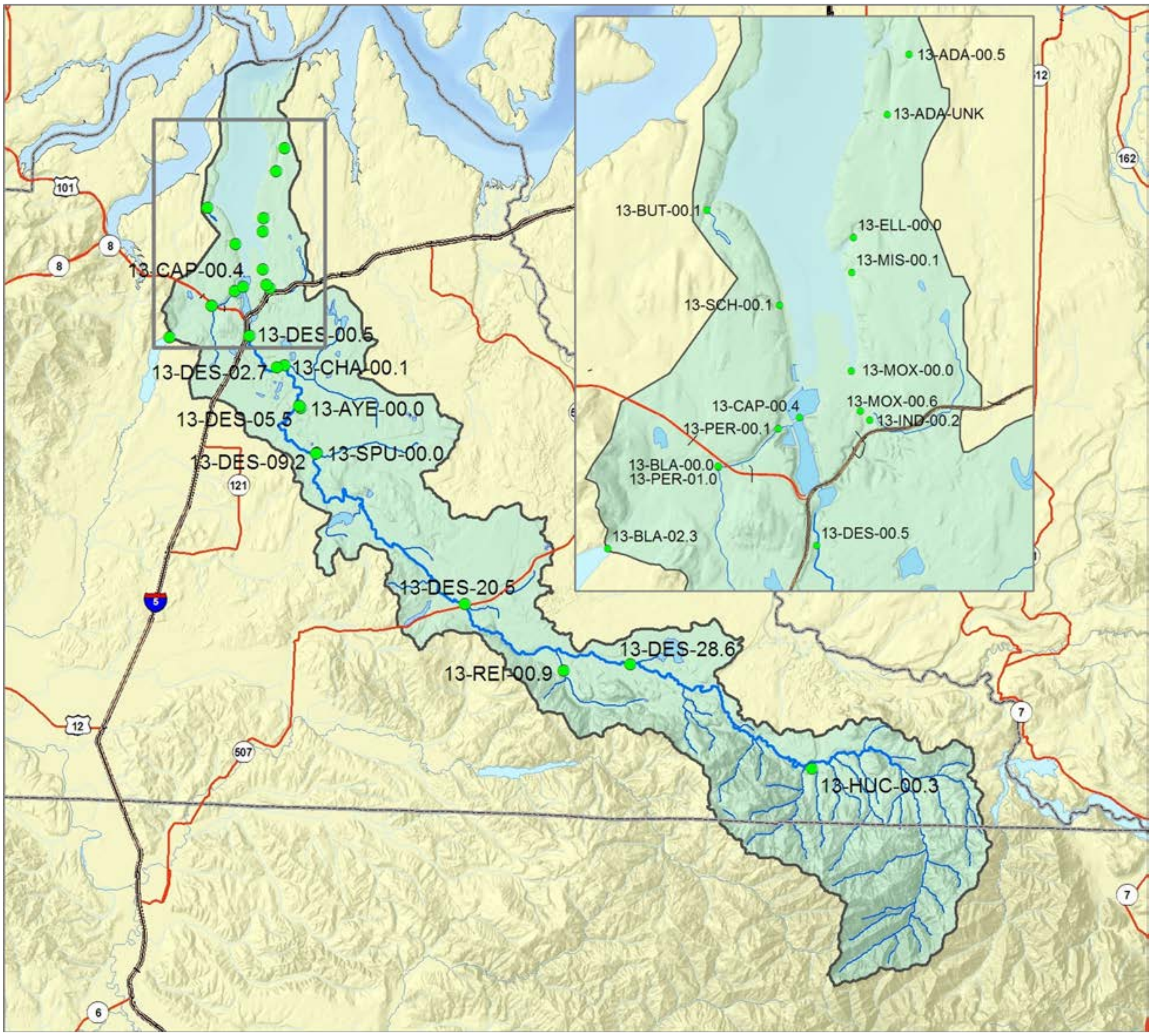

Figure 5. Monitoring stations within the Deschutes River and Percival Creek watersheds.

In addition, water column profiles were recorded within Capitol Lake in 2003 and 2004 (Figure 6). Grab samples were collected for nutrient analyses from two stations monthly. Profile parameters included temperature, DO, pH, conductivity, salinity, and light levels, while laboratory analyses included fecal coliform, nutrients, chlorophyll-a, and organic carbon. Grab samples from four locations were analyzed for dominant algae species, and both cell densities and biovolumes were reported. Originally the QA Project Plan included plans to install a water level monitor with the Washington Department of Enterprise Services (DES), formerly known as General Administration, but no monitor was installed during the project.

The QA Project Plan included a bathymetric survey of Capitol Lake to provide the current lake volume. Ecology contracted with USGS to develop this information using shipboard continuous data loggers. Bathymetry also was needed for the concurrent Deschutes Estuary Feasibility Study components related to hydraulic and sediment transport. Results were presented in George et al. (2006) and were provided to Ecology.

Figure 6. Capitol Lake monitoring stations for 2003 (small dots) and 2004 (open circles).
Benthic flux stations are indicated with a + symbol.

General Administration (GA), now known as DES, conducted herbicide applications to control invasive milfoil. Triclopyr was applied on July 19, 2004 (south and middle basins) and July 29, 2004 (north basin). The outlet structure was set to retain nearly all lake water for several days. As part of the surveys required by GA under Ecology's Aquatic Weeds Management Fund grant agreement to verify no adverse effect to non-target plants, aquatic plant surveys were conducted by Ecology (pre-application) and Thurston County (post-application).

Ecology quantified the macrophyte biomass above the sediment level in Capitol Lake on July 11-12, 2004, prior to the herbicide application, as described in the QA Project Plan. A stratified random approach was used to select sites from a 75-m grid, and biomass was determined within 0.1-m^2 quadrats. Thurston County conducted post-application monitoring during September 13-16, 2004, using the identical procedures as Ecology's pre-application biomass survey. A third survey was conducted by Thurston County in July/August 2005. Ecology presented the plant data in a preliminary summary of aquatic plant data in Parsons (2004) and Parsons (2005), included in Appendix B.

Finally, benthic flux chambers were installed in September 2004 at several locations in Capitol Lake. DO fluxes were recorded using Hydrolabs, and nutrient fluxes were quantified using grab samples collected over 24 to 48 hours.

To help isolate bacteria sources, detailed storm and dry-weather monitoring was conducted at 25 locations within seven watersheds, as detailed in Roberts (2004). Sites are shown in Figure 7. Originally the QA Project Plan called for two rounds of dry-weather monitoring in late summer 2004 and three to six storm events, two to four times over the course of the storm, in winter 2004. However, due to unusually dry conditions throughout the winter, only one storm event and one dry-weather monitoring round were performed. Storm samples were collected one to three times per event.

Figure 7. Stations evaluated for fecal coliform during intense dry- and wet-weather monitoring.

Fine Sediment

As described in the QA Project Plan, the Squaxin Island Tribe received a grant from EPA to conduct field investigations and develop a sediment source inventory. Field work was conducted by the Tribe, as described in Konovsky (2004). RainesTerra, LLC summarized historical sediment yields for 1972-1981 and 1981-1991 and estimated sediment yields for 1991-2003 by primary sediment sources, including high bank erosion, landslides, and unpaved roads (Raines, 2007).

Data Analytical Methods

Data Compilation and Availability

Interim data were released as a series of quarterly reports available at www.ecy.wa.gov/programs/wq/tmdl/deschutes/index.html. All project data are stored in Ecology's Environmental Information Management (EIM) system under the user study ID MROB0001 or the study name Deschutes River Watershed (WRIA 13), multi-parameter TMDL. The QA Project Plan originally referenced user study ID KSIN0009, but this was changed during the course of the project. The EIM system can be accessed on the internet at www.ecy.wa.gov/eim/. Appendix J summarizes station identification codes and descriptions, which may be used to access specific data within EIM.

In addition, streamflow data for the Deschutes River are available from the USGS at waterdata.usgs.gov/wa/nwis and from Ecology's Freshwater Monitoring Unit at fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp?historical=1&region.

The EIM database includes daily minimum and maximum values as well as the continuous temperature, DO, pH, and conductivity data.

Fecal Coliform Bacteria Approach

To develop targets for fecal coliform levels, the analytical approach relies on detailed data collection programs to characterize levels geographically and seasonally. The results are summarized statistically, and reduction factors are calculated from comparisons between data and water quality standards criteria.

Modeling Temperature

The temperature modeling approach, described in detail in the QA Project Plan (Roberts et al., 2004), includes a variety of tools:

- TTools is an ArcView extension originally developed by the Oregon Department of Environmental Quality (ODEQ, 2001) to quantify stream channel characteristics, topographic details, and vegetation characteristics for shade and temperature model development. Topography and vegetation height were developed from LiDAR data provided by the Puget Sound LiDAR Consortium. Current vegetation height was verified with field observations.

- Shade.xls was adapted from a program originally developed by ODEQ and enhanced with shade calculation methods described in Chen (1996) and Chen et al. (1998a and 1998b). The program uses topographic elevations and current or potential vegetation characteristics (height, type, and density) perpendicular to the channel to calculate solar radiation attenuation through the canopy. Model output includes percent shade by stream reaches and by hour of the day for a specific day of the year.
- QUAL2Kw is a one-dimensional, steady-state stream model that includes a diurnal heat budget (Pelletier and Chapra, 2006). The model simulates diurnally varying water temperatures using the kinetic formulations described in Chapra (1997). QUAL2Kw includes sediment-water fluxes of water and heat to simulate the effect of hyporheic interactions.

For the Deschutes River, all three tools were applied. For the Percival Creek watershed, TTools and Shade.xls were applied, but the QUAL2Kw model was not developed.

Modeling Dissolved Oxygen and pH

Modeling primary productivity, including DO and pH levels, also was described in the QA Project Plan (Roberts et al., 2004). The QUAL2Kw application developed for temperature was used to simulate biological productivity as a function of nutrient inputs and light levels in the Deschutes River. The model estimates diel fluctuations in primary productivity and resulting minimum and maximum DO and pH levels. In addition, the Delta Method (Chapra and DiToro, 1991; Chapra, 1997) was used to estimate stream reaeration, primary production, and respiration from continuous DO data recorded in the Deschutes River. A spreadsheet version of the Delta Method is available at www.ecy.wa.gov/programs/eap/models.html.

A separate tool was developed to simulate productivity within Budd Inlet, with the option to simulate the current Capitol Lake hydraulics or a potential future Deschutes estuary. The Generalized Environmental Modeling System for Surface Waters (GEMSS) comprises a suite of tools that includes three-dimensional hydrodynamics and water quality (Edinger and Buchak, 1980; Edinger and Buchak, 1985; Edinger and Buchak, 1995; Edinger et al., 1994; Edinger et al., 1997). GEMSS has evolved from previous models applied as part of the Budd Inlet Scientific Study (Aura Nova Consultants et al., 1998). The model simulates phytoplankton and nutrient cycling in a framework that includes point-source and tributary inflows.

Fine Sediment Approach

Data collected by the Squaxin Island Tribe and technical analyses performed by RainesTerra (Raines, 2007) were used to develop fine sediment reduction targets. Raines (2007) developed a fine sediment inventory for three primary sources: bank erosion, landslides, and unpaved roads. Recent bank erosion rates were calculated by comparing aerial photographs from 1991 and 2003, supplemented with LiDAR data, to determine the horizontal area lost and field measurements or extrapolations to quantify bank height. Contributions from landslides were developed from a provisional Weyerhaeuser Company inventory for 1966 to 2001 that included sediment volume. Raines (2007) accounted for attenuation prior to reaching the mainstem of the Deschutes River based on attrition rates developed by Collins (1994).

Sediment sources from unpaved road surfaces were estimated using the empirical Washington Road Surface Erosion Model (Dubé et al., 2004) that is part of the Standard Methodology for Conducting Watershed Analysis (Washington Forest Practices Board, 1997). The model uses physical road characteristics and was built in part on data collected from the Deschutes River watershed (Sullivan and Duncan, 1980; Bilby et al., 1989). Anthropogenic sources include all unpaved roads and landslides associated with roads. Landslides not associated with roads and bank erosion were assumed not to be anthropogenic in origin.

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Study Quality Assurance Evaluation

All environmental studies conducted by Ecology must have an approved project plan that documents study objectives and procedures for achieving those objectives (Lombard and Kirchmer, 2004). In addition to describing the sampling design and protocols, the Quality Assurance (QA) Project Plan also establishes data quality objectives. This section summarizes the quality control procedures for the data collection described in Roberts et al. (2004) and specifically reports the measurement quality objectives (MQOs). MQOs include field meter pre- and post-calibration results; laboratory blanks, spikes, and replicates; and field replicates.

Field and Laboratory Data

Table 14 of the QA Project Plan (Roberts et al., 2004) established MQOs for field and laboratory data, in addition to documenting the field and laboratory procedures. This study followed the field and laboratory procedures outlined in the QA Project Plan.

Field Meter Pre- and Post-Calibration

Several in-situ measurements were used to characterize field parameters. Discharge measurements relied on velocity flow meters, continuous temperature was recorded using Onset StowAway TidBits and i-buttons, and both continuous and discrete DO, pH, conductivity, and temperature were recorded using Hydrolabs.

All field meters were calibrated according to the manufacturers' recommendations. Velocity meters were factory calibrated, and streamflow measurements followed protocols in Ecology (1993). Onset StowAway TidBits and Dallas Semiconductor i-buttons (temperature) were calibrated in accordance with Timber-Fish-Wildlife (TFW) stream temperature survey protocols (Schuett-Hames et al., 1999), which include both pre-calibration and post-checking against a National Institute of Standards and Technology (NIST)-certified thermometer across the temperature range expected. Hydrolab measurements followed standard operating procedures (Swanson, 2007). All Hydrolabs passed pre- and post-deployment checks.

Any Onset StowAway TidBits that differed by more than 0.2°C or i-buttons that differed by more than 0.4°C from the NIST-certified thermometer were not used in the field. If in-situ readings or post-deployment comparisons with the NIST-certified thermometer were beyond the acceptance range, data were flagged as estimates in Ecology's Environmental Information Management (EIM) system.

Discrete DO samples analyzed using Winkler titrations were collected as a field check on the meter readings. The Winkler DO results were used to develop site-specific correction factors for the continuous DO data from the Deschutes River. Tributary samples were analyzed by Winkler titration as the fundamental method, except for two July 2003 and one October 2004 monitoring events. During these events, 12 sample pairs were used to check 47 values, or 26%. The Hydrolab results showed low variability when compared with Winkler results (4.0% mean RSD), including the Capitol Lake stations where very high DO values (20.0 mg/L) likely were beyond the capability of the instrument and drift, occurred over the long deployment. Measurement quality objectives were met for field data.

Laboratory Blanks, Spikes, and Replicates

All samples were analyzed by Ecology's Manchester Environmental Laboratory (MEL) using standard protocols (MEL, 2005). All samples were received and processed by MEL within accepted hold times, within the proper temperature range, properly preserved where applicable, and in good condition, except for several rounds of bacteria samples. Because these were not analyzed within 24 hours of sample collection, the results were flagged with a J to indicate the values are estimates. A few other fecal coliform results were flagged as estimates due to very high concentrations. Data reported with qualifiers should be used carefully, and data variability must be considered when interpreting results and using data for further analyses.

Table 8 summarizes laboratory quality control samples, including blanks, laboratory spiked samples, standards, and laboratory replicates. Measurement quality objectives (MQOs) were met for laboratory data, as detailed below.

Laboratory blanks were nearly entirely below the reporting limit throughout the monitoring period. Of the 553 laboratory blanks analyzed, only two (0.4%) were above the detection limit for the parameter, and both of these values were within 0.001 mg/L of the detection limit.

Mean laboratory control samples (standards) were within the acceptance criteria for the data sets. Of the 560 laboratory control samples analyzed, only one (0.2%) was beyond the acceptance criteria (one of three BOD5 results). Another BOD5 laboratory control sample analyzed the same month met the acceptance range.

Mean laboratory matrix spikes are samples spiked with a known parameter amount. Of the 281 matrix spikes analyzed, 280 (99.6%) were within the acceptance criteria.

MEL split 386 samples and analyzed them as laboratory replicates. Besides the bacteria results, which have different targets for acceptance, all data-set mean relative standard deviation (RSD) values were within the 10% acceptance limit. Of the 260 non-bacteria laboratory replicates, only 14 (5.4%) individual pairs were beyond the 10% acceptance limit for the entire data set.

Due to the inherent variability in bacteria concentrations, acceptance criteria are evaluated differently than for other parameters. For 64 laboratory pairs with a mean concentration >20/100 mL, 50% of the pairs had an RSD <20%, and 90% of the sample pairs had an RSD <50%. For the 62 laboratory replicates with a mean concentration ≤20/100 mL, 50% of the samples had <20% RSD. However, the 90th percentile of the RSD values for sample pairs with mean values ≤20/100 mL was 60%. The mean difference between the original and laboratory replicate samples with mean concentrations ≤20/100 mL was 0.6/100 mL, indicating no measurable biases, high or low, between the original values and laboratory replicates. For pairs

Table 8. Manchester Environmental Laboratory quality control results.

Parameter	Laboratory Blanks (mg/L)				Laboratory control samples (%)				Laboratory matrix spikes (%)				Laboratory replicates (%)			
	Count	Mean Value	Reporting Limit	Range	Count	Mean Value	Acceptance Criteria	Range	Count	Mean Value	Acceptance Criteria	Range	Count	Mean RSD	Target	Range
ALK	32	5	5	5 - 5	49	101.0	75 - 125	91.1 - 106					22	0.6%	10%	0.0 - 2.4
BOD5	4	0.63	2 (2)	0.07 - 2	3	71.0	75 - 125	37.8 (3) - 89.8					2	0.0%	10%	0.0 - 0.0
BODULT				-									5	NC		NC
CHLOROPH (1)	9	0.05	0.05	0.05 - 0.05									5	9.6%	10%	1.5 - 29.2 (6)
DOC	56	1	1	1 - 1	56	101.2	75 - 125	87.9 - 112	35	103.8	75 - 125	92.9 - 125	38	3.0%	10%	0.0 - 13.7
DTP	4	0.001	0.001	0.001 - 0.001	4	96.5	75 - 125	91.6 - 102	8	95.6	75 - 125	86.8 - 101				
DTPN	37	0.025	0.025	0.025 - 0.025	37	99.7	75 - 125	81.8 - 111	24	96.9	75 - 125	77 - 110	23	2.2%	10%	0.0 - 11.6
NH4N	64	0.01	0.01	0.01 - 0.01	64	100.2	75 - 125	86.6 - 115	30	93.2	75 - 125	72.6 (4) - 108	27	1.4%	10%	0.0 - 10.1
NO23N	62	0.01	0.01	0.01 - 0.01	62	100.0	75 - 125	89.3 - 108	29	96.2	75 - 125	80 - 109	26	0.4%	10%	0.0 - 3.3
OP	72	0.003	0.003	0.003 - 0.003	72	94.0	75 - 125	81.4 - 109	41	96.2	75 - 125	83.7 - 106	41	1.8%	10%	0.0 - 31.6 (5)
TOC	53	1	1	1 - 1	53	100.4	75 - 125	83.4 - 111	26	102.2	75 - 125	84.8 - 121	23	3.5%	10%	0.0 - 14.6
TP	48	0.001	0.001	0.001 - 0.005	48	99.0	75 - 125	90.4 - 107	56	101.0	75 - 125	93.3 - 114				
TPLL	12	0.001	0.001	0.001 - 0.0013	12	101.9	75 - 125	95.5 - 106	4	98.2	75 - 125	88.9 - 112	4	1.2%	10%	0.0 - 3.4
TPN	61	0.025	0.025	0.025 - 0.05	61	101.6	75 - 125	91.6 - 117	16	97.5	75 - 125	77.2 - 122	17	1.4%	10%	0.0 - 5.6
FC >20 50th percentile													62	10.0%	20%	
FC >20 90th percentile													62	34.1%	50%	
FC<20 50th percentile													64	17.7%	20%	
FC <20 90th percentile													64	60.0% (7)	50%	
Total	553				560				281				386			

(1) Units for chlorophyll samples are ug/L.
(2) Reporting limit is 2 mg/L for all but the December 2004 samples, which had a reporting limit of 4 mg/L.
(3) Two other BOD5 LCS results were >75% recovery, including one analyzed in the same month.
(4) Next lowest value was 76; two other LCS for NH4N on this date were >90%.
(5) Anomalously high lab replicate for OP occurred May 2004. Next highest value was 5.7% RSD.
(6) Anomalously high lab replicate for CHL occurred June 2004. Sample received a J flag as estimate. Original and replicate samples were <2 ug/L. Next highest value was 7.6 %.
(7) Acceptance criteria for bacteria levels <20/100 mL are determined by the project manager.
NC indicates that none of the five ultimate BOD laboratory replicates had a measurable value.

Abbreviations are defined in Appendix B.

with a mean concentration <20/100 mL, acceptance is governed by a project manager review of the data to determine data usability. These differences were determined to be inconsequential, and the entire bacteria data set met the laboratory replicate acceptance criteria.

Field Replicates for Discharge and Laboratory Analyses

Ecology performed replicate discharge measurements and collected replicate field samples for laboratory parameter analyses.

While replicate stream velocity measurements are generally not conducted in field programs, as part of the synoptic survey conducted August 5-6, 2003, field teams re-occupied discharge monitoring sites multiple times and with different teams to determine the replicability of discharge measurements. Five sites were monitored twice by the same team, and four sites were monitored by two separate teams. Table 9 summarizes the results. The within-team mean RSD was 4.1%, while the between-team RSD was 3.8%. No targets were established in the QA Project Plan, but overall replicability of discharge measurements was good.

Table 9. Discharge measurement field replicates.

Station	Date	Time 1	Time 2	Discharge 1 (cfs)	Discharge 2 (cfs)	RSD
Within Team					**Mean:**	**4.1%**
13-DES-00.5	8/5/03	16:18	16:52	79.3	79.0	0.3%
13-DES-13.4	8/5/03	11:53	12:27	41.6	47.6	9.5%
13-DES-19.1	8/5/03	13:12	14:09	29.4	28.7	1.6%
13-DES-24.9	8/5/03	13:00	14:00	23.8	23.8	0.1%
13-MIT-00.2	8/5/03	13:00	13:30	2.2	1.9	9.1%
Between Team					**Mean:**	**3.8%**
13-DES-14.5	8/5/03	10:23	16:51	42.2	40.8	2.4%
13-DES-20.5	8/5/03	15:06	11:42	30.5	31.0	1.1%
13-DES-28.6	8/5/03	15:15	9:23	17.9	17.6	1.1%
13-DES-37.4	8/5/03	15:00	13:05	17.2	14.8	10.6%
					Overall Mean:	***4.0%***

Field replicate samples were collected at a nominal rate of 11.4% for laboratory analysis, and results are shown in Table 10. Field replicates met the project target RSD for all parameters except total suspended solids (TSS) and bacteria. Sixteen of the 17 sample pairs analyzed for TSS were within five times the detection limit, and the project manager determines acceptance criteria and data usability (Mathieu, 2006). Because the mean difference between the original and field replicate value (0.4 mg/L) was well below the detection limit, the difference was considered inconsequential and the TSS data set was accepted in its entirety.

For bacteria field replicates, the data for values >20/100 mL were evaluated with a cumulative frequency distribution, and data usability for the data set of values ≤20/100 mL was based on a review by the project manager. For the 82 samples with mean pair values >20/100 mL, both the 50th percentile and 90th percentile RSDs meet those recommended in Mathieu (2006). For the 38 samples with mean pair values ≤20/100 mL, the average difference between the replicate and the original value was 0.8/100 mL. This difference was considered inconsequential, and the fecal coliform results were accepted.

Individual field replicate pairs fell outside the target, but these instances did not occur on the same date or from the same location to suggest a bias in the results. For the data analyses presented in the remainder of this document, average sample value was used.

Table 10. Field replicates analyzed by Manchester Environmental Laboratory.

Parameter	Count	Mean RSD	Target Mean Data Set RSD	Range
ALK	22	0.8%	10%	0.0 - 4.2
BOD5	3	0.0%	10%	0.0 - 0.0
CHLOROPH	3	6.5%	10%	4.0 - 10.9
DOC	40	4.2%	10%	0.0 - 17.0
DTPN	28	4.3%	10%	0.0 - 30.2
HARD	5	0.9%	10%	0.0 - 1.9
NH4N	44	1.7%	10%	0.0 - 12.9
NO23N	44	0.9%	10%	0.0 - 8.0
OP	45	3.3%	10%	0.0 - 75.0
TOC	37	4.6%	10%	0.0 - 35.4
TP	41	3.4%	10%	0.0 - 35.2
TPLL	4	2.5%	10%	0.0 - 4.2
TPN	37	2.5%	10%	0.0 - 16.4
TSS	17	16.5%[1]	10%	0.0 - 47.1
FC >20 50th percentile	82	14.5%	20%	
FC >20 90th percentile	82	47.0%	50%	
FC <20 50th percentile	38	8.9%	20%	
FC <20 90th percentile	38	70.7%[2]	50%	
Total	**493**			

Abbreviations are defined in Appendix B.

Model Calibration and Confirmation

Deschutes River Temperature, Dissolved Oxygen, and pH Model

Ecology's Shade.xls model was adapted from a program originally developed by the Oregon Department of Environmental Quality (ODEQ) but updated to include options for modeling the attenuation of solar radiation through the forest canopy (Chen et al., 1998a; Chen et al., 1998b).

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[1] Only one pair was beyond five times the detection limit (RSD = 0.0%).

[2] Acceptance criteria for bacteria levels <20/100 mL are determined by the project manager.

Riparian shade estimates predicted from Shade.xls were compared with in-situ estimates determined from discrete HemiView photos and processing software.

QUAL2Kw is a one-dimensional, steady-state model that simulates the diurnal heat budget and diurnal water quality kinetics (Pelletier and Chapra, 2006). To simulate temperature, the user specifies solar radiation and related parameters, meteorological conditions, and headwater, tributary, and diffuse groundwater volumes and temperature. The heat budget simulates the physics of shortwave and longwave radiation, convection, evaporation, and advective fluxes. To simulate DO and pH, the user builds from the flow and temperature model, adding nutrients and related parameters for the headwaters, tributaries, and diffuse groundwater. QUAL2K simulates the complex interactions of floating and attached plants (phytoplankton and periphyton), along with sediment-water fluxes. QUAL2Kw includes an option to simulate the effects of hyporheic exchange and sediment pore water quality on surface water constituents.

The root mean square error (RMSE) was used as a measure of the goodness-of-fit of the model predictions compared with the observed temperature and water quality data. Predicted minimum and maximum temperatures were compared with the 7-day average daily minimum or maximum temperatures at 13 stations along the Deschutes River for specific time periods selected for model calibration and confirmation, as summarized in Table 11. A genetic algorithm was used to assist calibration of the DO and pH model (Pelletier et al., 2006), and the calibrated model minimized the combined error in nutrient concentrations, DO, and pH by comparing predicted to observed average daily minimum and maximum values.

Table 11. Time periods used for Deschutes River model calibration and confirmation and related surveys.

Parameter	Run	Time Period	Description	Discharge at Rainier (cfs)	Discharge at E Street bridge (cfs)
Temperature	CAL	7/21-27/2004	Hottest 7-day average temperature in 2004	31.1	78.9
	VAL1	7/27-8/2/2003	Hottest 7-day average temperature in 2003	22.6	72.0
	VAL2	8/20/2003	Thermal infrared survey	24.0	65.0
	VAL3	8/5-11/2003	Cool, non-storm conditions	23.9	69.4
DO and pH	DOCAL	8/10-12/2004	Productivity surveys in Deschutes River	27.7	74.3
	Stream walk	8/11-15/2003	Stream walk	28.4	76.4
Hydrology	Synoptic survey	8/5-6/2003	Detailed flow distribution	22.5	70.0
	Tracer study	8/2-4/2004	Low flow travel time	27.3	72.3

Capitol Lake and Budd Inlet Model

J. E. Edinger Associates, Inc. (JEEAI) applied the 3-D hydrodynamic and water quality model GLLVHT (Generalized, Longitudinal-Lateral-Vertical Hydrodynamics and Transport model) to Budd Inlet during studies conducted from 1996-1998, with follow up work in 1999 and 2000. JEEAI was subsequently acquired by ERM Group Inc. (ERM). The GLLVHT modeling framework was updated by JEEAI and ERM and is currently called the Generalized Environmental Modeling System for Surfacewaters (GEMSS).

The GEMSS modeling framework was applied to the Budd Inlet and Capitol Lake regions of the model domain. There was no single calibration data set that included both the Budd Inlet and Capitol Lake regions. Therefore, each of the regions was calibrated separately. Calibration of the GEMSS model was accomplished using the following data sets:

- The Budd Inlet region of the model domain was calibrated using data collected during the LOTT Budd Inlet Scientific Study (Aura Nova et al., 1999). Data collected from January-September 1997 was used for calibration. Ecology re-calibrated the model using the January-September 1997 data following some corrections to the programming code.
- The Capitol Lake region of the model domain was calibrated using data collected by Ecology and Thurston County from May-September 2004. Confirmation of the model for the Capitol Lake region was based on data collected by Miller Brewing Co. (CH2M Hill, 2001) and Thurston County from April-June 2001.

Budd Inlet

Ecology's re-calibration of the model using the January-September 1997 data is described in Appendix G. The period of previous calibration (Aura Nova et al., 1999) was from June through September 1997 while the model verification was done for January through September 1997. During re-evaluation, only the verification period was considered since it was inclusive of the calibration period. The purpose of re-evaluation was to optimize the goodness-of-fit of model predictions compared with observed concentrations of water quality variables. Rate constants and sediment fluxes were compared with, and kept within, the literature values during the re-evaluation process.

The water quality parameter of primary concern to Ecology and the focus of the re-calibration effort was DO. In particular, re-calibration of the Budd Inlet model sought to accurately predict the low DO conditions observed in the lower water column of the Inner Inlet.

The root mean square error (RMSE) statistic was used to describe the unbiased goodness-of-fit of the predicted to the observed values. The RMSE is defined as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum(X_f - X_m)^2}$$

where X_f is the field-observed value, X_m is the model-predicted value, and N is the number of paired model and field data. The model bias was quantified using the mean standard deviation of the residuals (difference between predicted and observed values).

The process of calibrating a water quality model involves selection of values for the many parameters that represent various kinetic processes. Calibration of the model for this project involved running batches of about 100 model runs at a time. Critical parameters were varied and applied to a base model run that had the best skill from the previous batch. The parameter estimates were constrained to be within the ranges of prior distributions of expected reasonable values. The results of each batch of runs were examined to compare the relative model skill with different combinations of parameter values. Information about which combinations of parameters improved the model skill was used to guide the selection of parameter values for the base model run of the next batch and for the development of new parameter combinations for sensitivity analysis in the batch. This process was repeated for 15 batches of runs in this project, for a total of about 1500 model runs, and resulted in continuous improvement of the skill of the best model run from one batch to the next.

Earlier batches tended to focus on sensitivity of optimal parameters for the light and temperature limitation parameters to optimize the timing of phytoplankton blooms. Later batches focused on sensitivity to other parameters to optimize model skill for prediction of the magnitude of phytoplankton biomass and other water quality variables.

Two approaches were used to assess model skill for each batch during the parameter estimation process and to guide the selection of the base parameter set for the next batch of runs for sensitivity analysis:

- Graphical comparison of predicted and observed values using charts of time series and profiles of concentrations.
- Ranking of model runs based on a weighted average RMSE statistic that combined the skill for prediction of bottom DO, entire water column DO, dissolved inorganic nitrogen (DIN), and chlorophyll-a to describe the overall goodness-of-fit.

In general, both of these approaches tended to reinforce each other and indicate that the same parameter sets had the best overall skill for predicting the observed data. Usually one of the model runs within the top 5% ranking of the overall goodness-of-fit statistics for a batch also appeared to visually be the best match at representing major features of the observed data in charts of time series and profiles (e.g., timing and magnitude of blooms and trends in nutrient and DO concentrations).

The entire process of parameter optimization – including the selected base parameter values in each batch and the matrix of parameter variations that were used for sensitivity analysis in each batch, as well as the corresponding charts of model output comparing predicted and observed conditions and goodness-of-fit statistics for all 1500 model runs – is documented in a Web-based model output browser (https://fortress.wa.gov/ecy/spsdos/bicl/index.html). The use of a Web-based model output browser facilitated rapid comparison of model skill for various combinations of parameter values. The final re-calibration parameter set was the model run with the overall best skill in the last batch of runs.

Capitol Lake

The results of model calibration and confirmation by ERM and Ecology are presented in detail in Appendix H. The calibration period adopted for the study was May 18 to September 30, 2004. This period was adopted based on the availability of boundary condition and calibration data. The RMSE and mean of the residuals were used as the goodness-of-fit statistic. Graphical comparisons of observed and predicted time series and vertical profiles were also used to assess the calibration.

The overall goal of the calibration was to minimize RMSE. The calibration process included varying the rates and constants in the three GEMSS modules (WQCBM, WQADD and GAM) in successive batches with RMSE calculated for each run within a batch. The run with the lowest RMSE was considered for further improvement in the next batch of runs. Similarly, for temperature calibration, the following variables were varied during the calibration process: chezy friction coefficient, wind sheltering coefficient, wind speed function, transport scheme, and dispersion functions.

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Results and Discussion

Meteorology and Hydrology

During the data collection period (July 2003 through March 2005), summer meteorological conditions were warmer than usual. The nearest long-term monitoring station is at the National Weather Service site at the Olympia Airport, for which a long-term record exists for precipitation, air temperature, dewpoint temperature, wind speed and direction, and cloud cover. Figure 8 presents the 7-day average of daily maximum temperature and monthly precipitation values at the Olympia Airport since 1996. Summer 2004 precipitation amounts (5.04 inches) were wetter than average (2.1 inches for July through September totals from 1999-2007) and summer 2003 was drier (1.5 inches). Peak summer air temperatures were warmer in 2004 (7-day average of daily maximum temperature 30.2°C) than in 2003 (27.5°C).

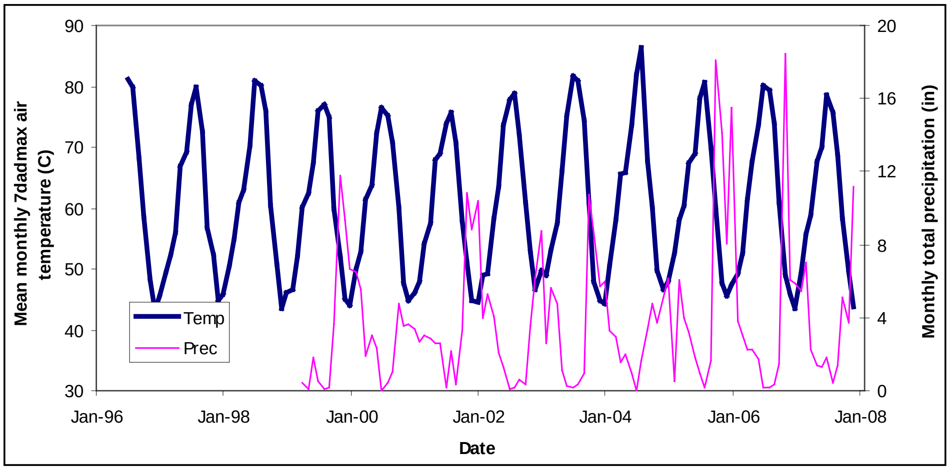

Figure 8. Mean monthly 7-day average of daily maximum air temperature and monthly precipitation at the Olympia Airport.

Air temperature was recorded at five Deschutes River stations in 2003 and 16 stations in 2004, but only three stations were common to both years. The hourly temperatures were averaged across all available sites to provide model input data for the various time periods of interest. The sites do not reflect a strong upstream-to-downstream pattern in air temperatures, and some hourly values may indicate direct sunlight affecting the results. Coolest temperatures were recorded at river miles (RMs) 5.6, 12.1, and 37.4, while warmest time series are for RMs 9.2 and 22.7, possibly due to stream aspect or riparian microclimate. Figure 9 summarizes air temperature monitored along the Deschutes River during the calibration time period. In general, peak air temperatures were cooler than those recorded at the Olympia Airport.

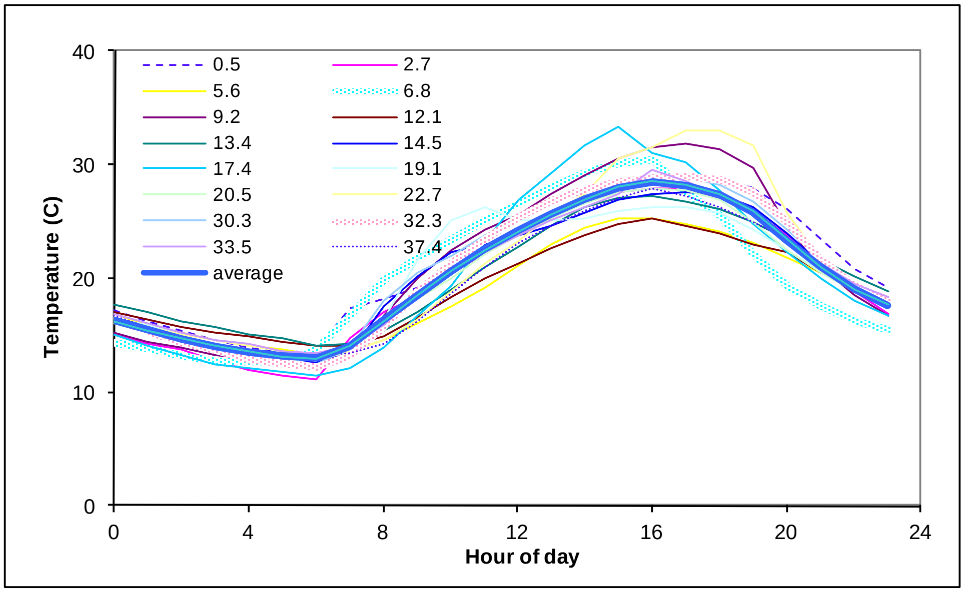

Figure 9. Air temperature monitoring in the Deschutes River watershed in July 21-27, 2004 by station identified by river mile and averaged across stations.

Dewpoint temperatures for the temperature model were developed from one station (RM 42.3) in 2003 and two stations (RM 0.5 and 37.4) in 2004. Figure 10 presents the hourly dewpoint temperatures recorded for the calibration period recorded at the two stations and the average used for the entire study area.

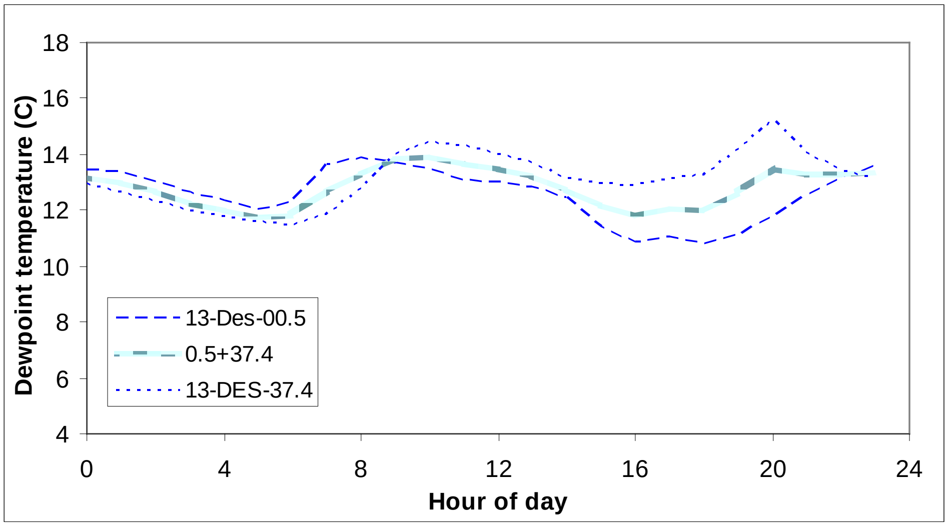

Figure 10. Dewpoint temperatures in the Deschutes River watershed for July 21-27, 2004 by station and averaged across both stations.

Winds from the Olympia Airport indicate that mean daily wind speed was quite low for both summers, but a few hourly wind speeds were measurable. Wind speed was set to zero for all warm-condition temperature periods. The VAL3 period was used to characterize cool, non-storm conditions, and zero wind speeds were not representative. For that time period, the average of the seven days, by hour, was used to establish wind speeds.

Cloud cover data from the Olympia Airport were used (Figure 11). The eighths of the sky covered with clouds was converted to a percentage by multiplying number of eighths by 12.5%. For each hour, the average of the 7-day calibration or validation time period was used. Overall cloud cover during warm periods was low but was not necessarily zero.

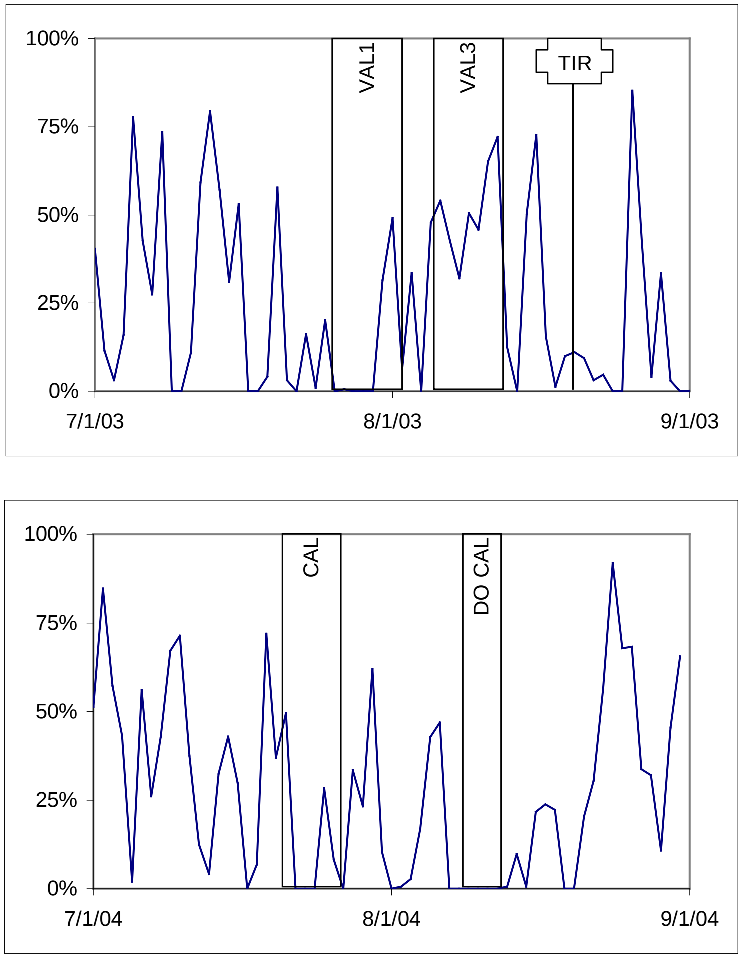

Figure 11. Cloud cover at the Olympia Airport for 2003-2004.

Figure 12 presents the historical mean, maximum, and minimum average monthly river discharge, as well as the 2003 and 2004 conditions, based on long-term monitoring conducted by USGS at the E Street bridge. Average monthly streamflows in July and August 2003 were nearly the lowest on record, as was July 2004. August 2004 flows were closer to average.

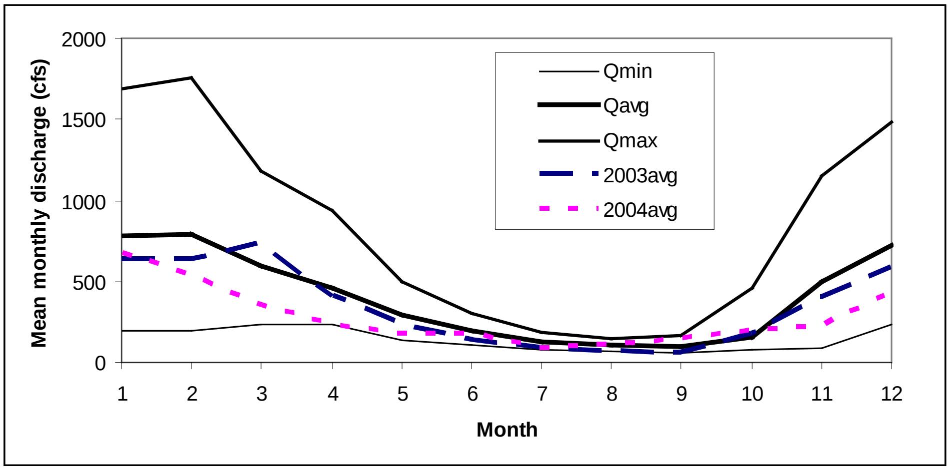

Figure 12. Historical minimum, mean, and maximum average monthly flows at the USGS station 12080010 (E Street bridge) compared with 2003 and 2004 conditions.

USGS estimated the 7-day average low flow with a 10-year recurrence interval (7Q10) at both the Rainer and E Street bridge stations based on historical gaging (D. Kresch, personal communication, 2003). Table 12 summarizes the values. Summer low flows have decreased recently, compared with the historical time period, likely due to the combined effects of climate cycles and increased water withdrawals. In 2003 and 2004, the lowest 7-day average daily discharge was 20 and 25 cfs, respectively, at Rainier and 49 and 63 cfs, respectively, at the E Street bridge. Summer low flows were near 7Q10 levels in both years.

Table 12. Historical 7Q10 discharge estimates for the two USGS gages.
(D. Kresch, personal communication).

Years	Period	Rainier (12079000)		Years	E Street (12080010)	
		(cfs)	(cms)		(cfs)	(cms)
1949 – 2001	All data	24.0	0.68	1946 - 2002	64.1	1.8
1949 – 1969	Historical only	26.0	0.74	1945-1964	78.3	2.2
1991 – 2001	Recent only	21.4	0.61	1991-2001	56.3	1.6

In addition, the Weyerhaeuser Company has maintained continuous flow gaging stations in the Deschutes River at 1000 Road and in upstream tributaries since 1945. The Weyerhaeuser Company provided flow and other data through 2004 (Heffner, personal communication).

The 2003 synoptic survey recorded instantaneous flows within the mainstem and tributaries. Groundwater inputs were calculated by difference. Figure 13 presents the longitudinal variation in flows from the upper falls (RM 42.3) to the E Street bridge (RM 0.5). Discharge remained nearly constant with some losing reaches for 15 miles downstream of the falls. Small increases in flow occurred between RM 25 and RM 5. Large groundwater discharges in the Tumwater area downstream of RM 5 significantly increased the flow in the Deschutes River.

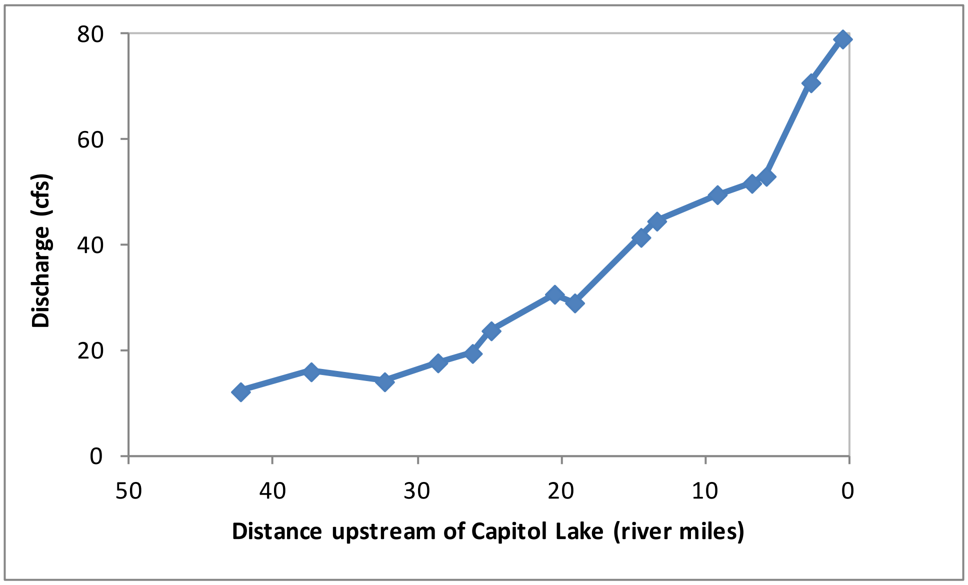

Figure 13. Longitudinal profile of flows in the Deschutes River recorded August 2-4, 2004.

The QA Project Plan included seepage runs in both the Deschutes River and Percival Creek watersheds. However, only the Percival Creek watershed flows were detailed in 2004, and the flow distribution in the Deschutes River is based on the 2003 seepage run, which was included in the QA Project Plan. The Percival Creek watershed seepage results are presented in the related hydrogeology report (Sinclair and Bilhimer, 2007).

A tracer study was conducted August 2-4, 2004, to quantify travel time in various reaches between the Vail Cutoff Road and the E Street bridge. Rhodamine dye was released at three locations, moving from downstream to upstream in approximately 5-km reaches. Fluorometers recorded dye concentrations at multiple locations downstream. A storm event on August 5, 2004, prevented the furthest upstream reach (Deschutes Falls to Vail Cutoff Road) from being characterized. Table 13 presents the incremental and cumulative travel time in the Deschutes River during summer baseflow conditions. Incremental reach velocities ranged from 0.14 to 0.21 m/s. Cumulative velocity is nearly constant downstream of the Vail Cutoff Road.

The table also presents estimates of Manning's n values derived from the reach-averaged velocities, channel slope and a characteristic depth to estimate the hydraulic radius. The calculated values are greater than values reported in traditional hydraulics textbooks for natural channels. However, these values are comparable to values found in other regional studies

(Mohamedali and Lee, 2008) for low-flow conditions in streams and rivers with high channel complexity.

The hydrogeology study (Sinclair and Bilhimer, 2007) water budget provided the basis for the flow balances used to model Deschutes River temperature, nutrients, DO, and pH during low-flow conditions. Point-based vertical hydraulic gradients and temperature profiles within the gravels at the piezometers locations generally confirmed the direction and magnitude of the seepage runs. While many piezometers exhibited constant positive or negative gradients, seasonal or short-term reversals occurred. Surface water-groundwater exchanges were evaluated using VS2DI, a one-dimensional fluid flow and energy transport model (Hsieh et al., 2000).

Table 13. Tracer study results for Deschutes River for August 2-4, 2004.

Discharge at the E Street bridge was 72 cfs. Release locations are indicated in italics.

Station	Name	River	Cumulative		Differential					
		km	Time (hr)	Vel (m/s)	Time (hr)	Vel (m/s)	Slope (m/m)	Bottom width (m)	Depth (m)	n
13-DES-28.6	*Vail Cutoff Rd.*	23	0.0							
13-DES-24.9	USGS gage	28.8	11.8	0.14	11.8	0.14	0.0026	11.7	0.35	0.18
13-DES-20.6	SR507	35.9	25.3	0.14	13.5	0.14	0.0022	14.6	0.35	0.16
13-DES-19.1	*Military Rd.*	38.1	29.7	0.14	4.3	0.15	0.0020	14.3	0.35	0.15
13-DES-17.4	Beans Rd.	40.5	33.2	0.15	3.6	0.21	0.0022	15.3	0.35	0.11
13-DES-14.5	Waldrick Rd.	45.5	39.9	0.16	6.7	0.19	0.0022	15.3	0.35	0.12
13-DES-12.7	Park at Cowlitz Dr.	48.4	44.7	0.16	4.8	0.17	0.0020	14.3	0.35	0.13
13-DES-9.6	*Rich Rd.*	53.4	52.9	0.16	8.2	0.17	0.0020	14.3	0.35	0.13
13-DES-6.8	Oly Fuel & Asphalt	58	59.9	0.16	7.0	0.18	0.0020	14.3	0.35	0.12
13-DES-02.7	Henderson Rd.	64.6	71.2	0.16	11.3	0.16	0.0019	15.3	0.35	0.13
13-DES-00.5	E St. bridge	68.3	75.8	0.17	4.7	0.21	0.0044	13.4	0.35	0.16

Groundwater samples collected from piezometers exhibited a range of nutrient and DO concentrations. Orthophosphate varied from 0.008 to 0.086 mg/L, nitrate+nitrite varied from 0.011 to 4.76 mg/L, and ammonium ranged from 0.032 to 0.206 mg/L. DO concentrations reflected varying atmospheric connectivity, ranging from <0.1 to 7.75 mg/L. The streambed temperature results indicated that the hyporheic zone extends over a meter into the gravel substrate.

Fecal Coliform Bacteria Results

Ecology maintains a long-term monitoring station on the Deschutes River at the E Street bridge (13A060) and has collected monthly grab samples to quantify fecal coliform concentrations. The geometric mean concentration for October 1999 through August 2007 was 22.6 colonies/ 100 mL. During July 2003 through December 2004, the geometric mean concentration was higher at 29.7 colonies/100 mL, due in part to the very high concentration recorded during flood conditions on October 20, 2003. Without that value, the geometric mean concentration at 13A060 would have been 22.4 colonies/100 mL, similar to the historical value.

Table 14 summarizes twice monthly bacteria results as the geometric mean of samples collected by station, as well as the percent of samples that were higher than Part 2 of the water quality standards. Results are presented for both the summer growing season (May through September) and winter non-growing season (October through April). These seasons were selected to distinguish potential sources evident during the low-flow summer season from those associated with the high-flow winter season. For example, bacteria associated with poorly functioning onsite sewage systems may only be distinguishable at low flows, while bacteria associated with stormwater runoff may only be transported in wet weather.

Geometric mean concentrations were higher during the growing season than in the non-growing season at most sites, although the overall load may have been lower due to the lower discharge in the summer months. Deschutes River concentrations are highest in the upstream segments and decrease in a downstream direction. Reichel, Spurgeon, and Chambers Creeks have the highest concentrations of the tributaries to the Deschutes River. In the Percival Creek watershed, Black Lake Ditch has lower levels than in Percival Creek. The highest bacteria concentrations found in the study were the tributaries to Budd Inlet. Concentrations were on average four times higher during the summer growing season than in the winter non-growing season.

Table 15 summarizes the targeted stormwater sampling conducted in several tributaries to the Deschutes River and Budd Inlet to further identify sources upstream of the mouths. No summer samples were collected at these stations. In several cases, multiple samples were collected on the same day to capture potential variation in concentrations through the duration of the storm event. The table summarizes these data overall but maintains multiple data points from a single day as distinct data. The data confirmed the high winter concentrations found at the mouth and generally indicated that the sources are located throughout the watershed.

In Butler Creek, the highest levels were found in the southwest fork. The Ellis Creek stormwater samples have a much higher geometric mean than the twice monthly data at the mouth during the winter season. The most upstream station of Indian Creek has the lowest concentrations, which increase in a downstream direction. The highest concentrations in the Indian Creek watershed were found at 13-IND-MART at 4th Avenue. In the Moxlie Creek portion of the watershed, lower levels were found at 13-MOX-PARK but were generally high throughout the system. Both upstream sites on Mission Creek also had high bacteria levels. An upstream location on Percival Creek also exhibited elevated levels that are consistent with the twice-monthly results. Finally, Spurgeon Creek had low stormwater concentrations consistent with winter twice-monthly monitoring; stormwater sampling did not address the high bacteria levels found in Spurgeon Creek in the summer season.

Additional monitoring was conducted throughout Capitol Lake to further identify sources. The geometric mean of 29 samples, collected from eight stations throughout the lake in summer 2003 and summer 2004, was very low (5.7 colonies/100 mL), and only one sample was higher than Part 2 of the criteria. Therefore, no clear source of the bacterial contamination found at 13-CAP-00.4 was identified.

Table 14. Fecal coliform bacteria results by season.

Station	Summer	Geomean	%>Part 2*	Winter	Geomean	%>Part 2*
	n			n		
Deschutes River						
13-DES-00.5	16	21.1	0.0%	18	9.1	0.0%
13-DES-02.7	16	16.9	0.0%	18	6.5	0.0%
13-DES-05.5	10	65.8	10.0%	14	13.2	0.0%
13-DES-09.2	10	81.5	10.0%	14	13.3	0.0%
13-DES-20.5	10	89.2	20.0%	14	6.5	0.0%
13-DES-28.6	12	56.1	16.7%	18	8.1	5.6%
Tributaries to Deschutes River						
13-AYE-00.0	16	24.2	0.0%	21	10.3	9.5%
13-CHA-00.1	16	71.5	18.8%	18	9.9	0.0%
13-HUC-00.3	10	10.0	0.0%	14	1.3	0.0%
13-REI-00.9	16	102.4	18.8%	18	24.8	5.6%
13-SPU-00.0	16	81.2	12.5%	22	11.2	0.0%
Capitol Lake						
13-CAP-00.4	16	3.9	6.3%	18	15.9	11.1%
Percival Creek Watershed						
13-BLA-00.0	15	21.3	0.0%	22	10.4	9.1%
13-BLA-02.3	16	5.6	0.0%	22	7.0	4.5%
13-PER-00.1	16	44.0	12.5%	22	13.4	4.5%
13-PER-01.0	16	93.5	43.8%	21	27.8	14.3%
Tributaries to Budd Inlet						
13-ADA-00.5	16	22.1	6.3%	21	53.5	23.8%
13-ADA-UNK	10	2667.7	90.0%	11	348.6	63.6%
13-BUT-00.1	16	60.7	6.3%	22	33.3	9.1%
13-ELL-00.0	16	132.5	25.0%	21	33.2	19.0%
13-IND-00.2	16	540.8	81.3%	22	104.3	31.8%
13-MIS-00.1	16	173.5	50.0%	22	65.7	27.3%
13-MOX-00.0	15	438.3	93.3%	22	330.6	68.2%
13-MOX-00.6	15	177.5	46.7%	22	62.8	22.7%
13-SCH-00.1	13	23.6	0.0%	17	15.2	11.8%

* Part 2 of the fecal coliform bacteria standards, where not more than 10% of the samples may exceed 100 or 200 organisms/100 mL, depending on the beneficial use to be protected.

Table 15. Targeted stormwater monitoring in tributaries to the Deschutes River and Budd Inlet.

Station	n	Geomean	%>Part 2*
13-BUT-NW	6	40.8	16.7%
13-BUT-SE	6	69.9	16.7%
13-BUT-SW	6	155.8	66.7%
13-ELL-33RD	6	103.9	66.7%
13-IND-12TH	5	34.3	0.0%
13-IND-BOUL	6	332.0	83.3%
13-IND-FRED	6	303.6	83.3%
13-IND-MART	6	846.2	100.0%
13-IND-SBAY	6	367.6	66.7%
13-IND-WHEE	6	393.0	100.0%
13-MIS-BETH	6	268.6	100.0%
13-MIS-ETHR	6	143.7	50.0%
13-MOX-5TH	12	103.0	58.3%
13-MOX-8TH	7	203.6	85.7%
13-MOX-PARK	6	38.3	50.0%
13-MOX-PLUM	6	99.1	66.7%
13-PER-54TH	6	62.0	33.3%
13-SPU-EQUU	6	18.4	0.0%
13-SPU-LATI	6	19.4	0.0%
13-SPU-MOOD	6	18.4	0.0%

Temperature Results

Long-term monitoring at Ecology’s ambient monitoring station includes monthly in-situ values for temperature. Continuous probes have been installed in the summer months since 2001. While historical ambient monitoring did not target late-afternoon peak temperatures, the long-term data do confirm that peak annual temperatures occur in July (Figure 14). Upper watershed water temperatures also peak at that time (Sullivan et al., 1987).

In 2003-2004, temperature probes were installed along the Deschutes River mainstem and tributaries. Figure 15 presents the peak 7-day average of daily maximum temperatures by site. Temperatures in the mainstem of the Deschutes River increased about 5ºC within 10 miles of the Deschutes Falls. Peak temperatures declined about 4ºC over the next 10 miles (16 km) downstream. Temperatures rose somewhat before a secondary peak in temperatures around RM 5.

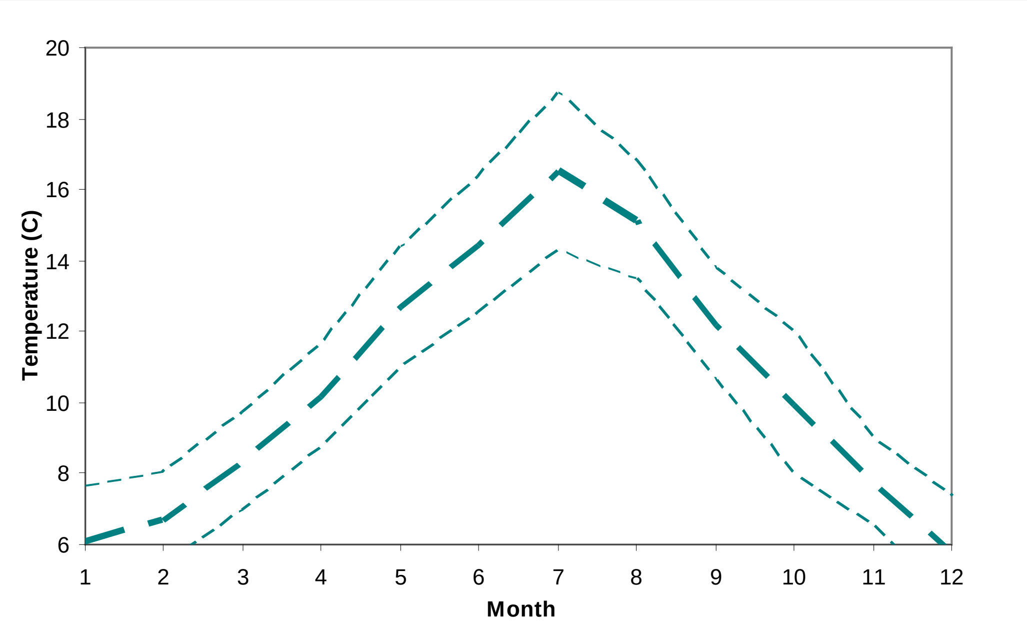

Figure 14. Peak instantaneous temperature (mean ± 1 SD) by month for Ecology ambient monitoring station 13A060 (1988 through 2007).

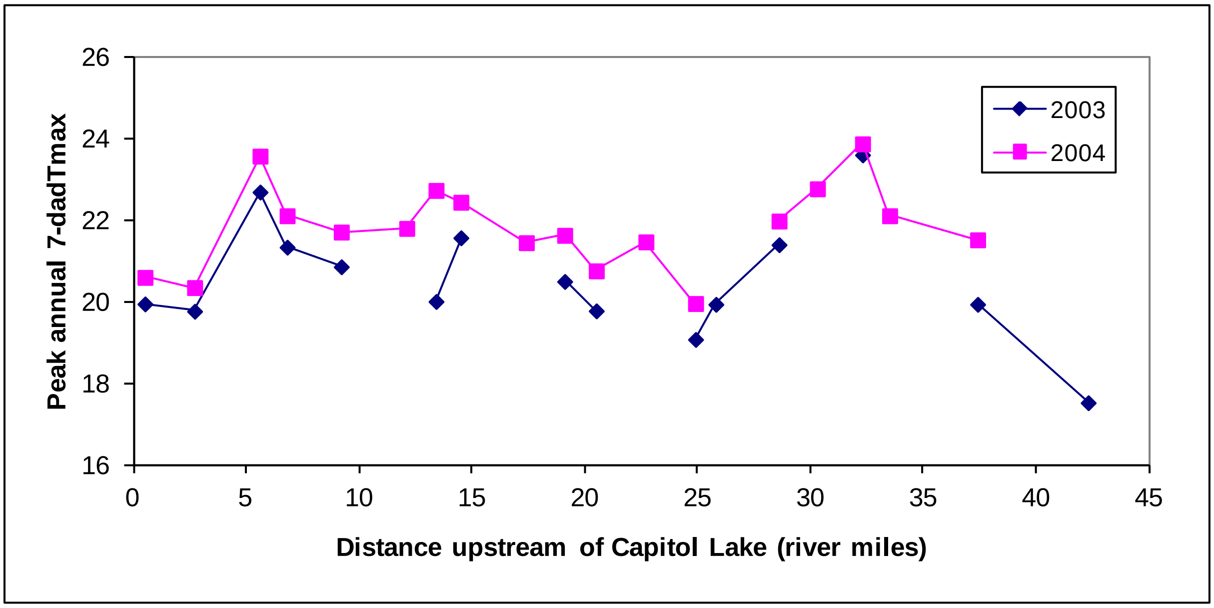

Figure 15. Profile of peak annual 7-day average of daily maximum temperatures in 2003 and 2004 along the Deschutes River from the Deschutes Falls (RM 42.3) to the E Street bridge (RM 00.5).

A thermal infrared (TIR) survey was conducted August 20, 2003 (Watershed Sciences, 2004) to characterize surface water temperatures from the Deschutes Falls downstream through the E Street bridge area. TIR images and visible band images were recorded from a helicopter for a swath of 150 m (500 ft) along the mainstem of the Deschutes River. The survey was conducted beginning near Capitol Lake at 13:41 and ending upstream of the Thurston Creek and the Deschutes upper falls at 14:50. Nineteen Tidbits were deployed along the mainstem (5) and tributaries (14) to calibrate the conversion of radiance from the images to temperature. Figure 16 presents example TIR and visible band images. TIR images do not account for water temperatures beneath vegetation or any stratification of the water column. The average error was 0.02ºC at the five mainstem Tidbit locations.

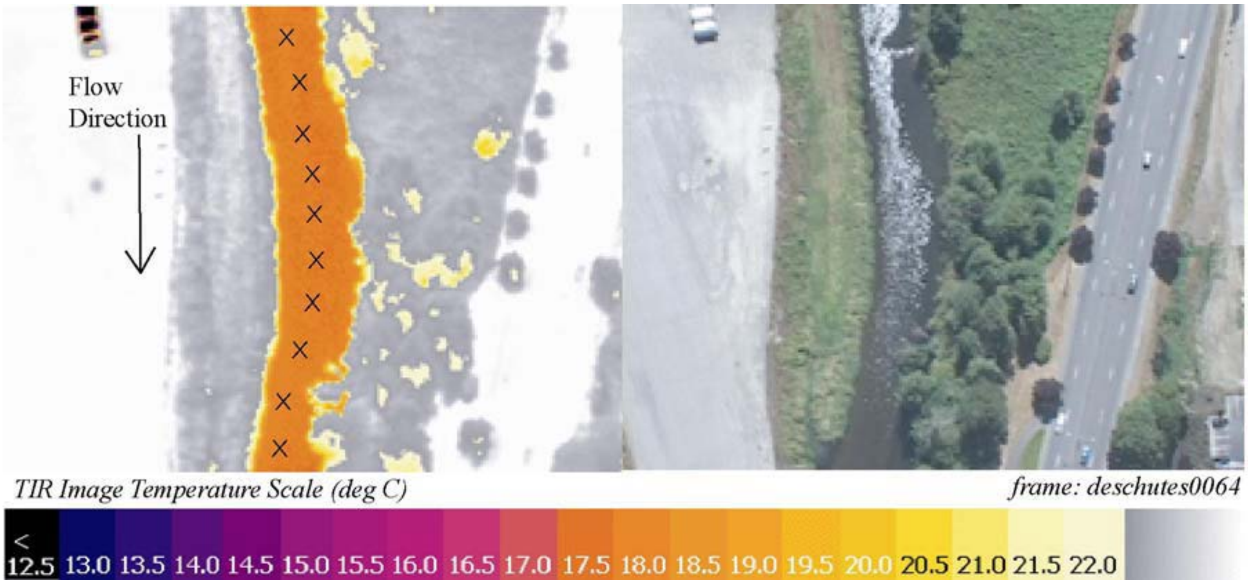

Figure 16. Example thermal infrared (left) and visible band (right) paired images from the TIR survey.

Source: Watershed Sciences (2004).

Figure 17 presents the longitudinal profile of centerline water temperatures together with in-situ temperatures recorded by Watershed Sciences. The longitudinal profile shows that peak water temperatures occurred 30 to 40 miles (48 to 64 km) upstream of Capitol Lake. Several areas exhibit strong warming or cooling of at least 1.0ºC, indicated with arrows in the figure, and rapid warming of 5ºC occurred near RM 40 (downstream of Deschutes Falls). The tributaries and springs were 2 to 6ºC cooler than the mainstem of the river. The detailed longitudinal and lateral temperatures can be found at www.ecy.wa.gov/apps/watersheds/temperature/tir/deschutes/index.html
The survey was flown earlier in the day than the peak temperatures identified in the mainstem (approximately 4 to 6 p.m.), but the TIR survey recorded the highly complicated longitudinal patterns in Deschutes River temperature.

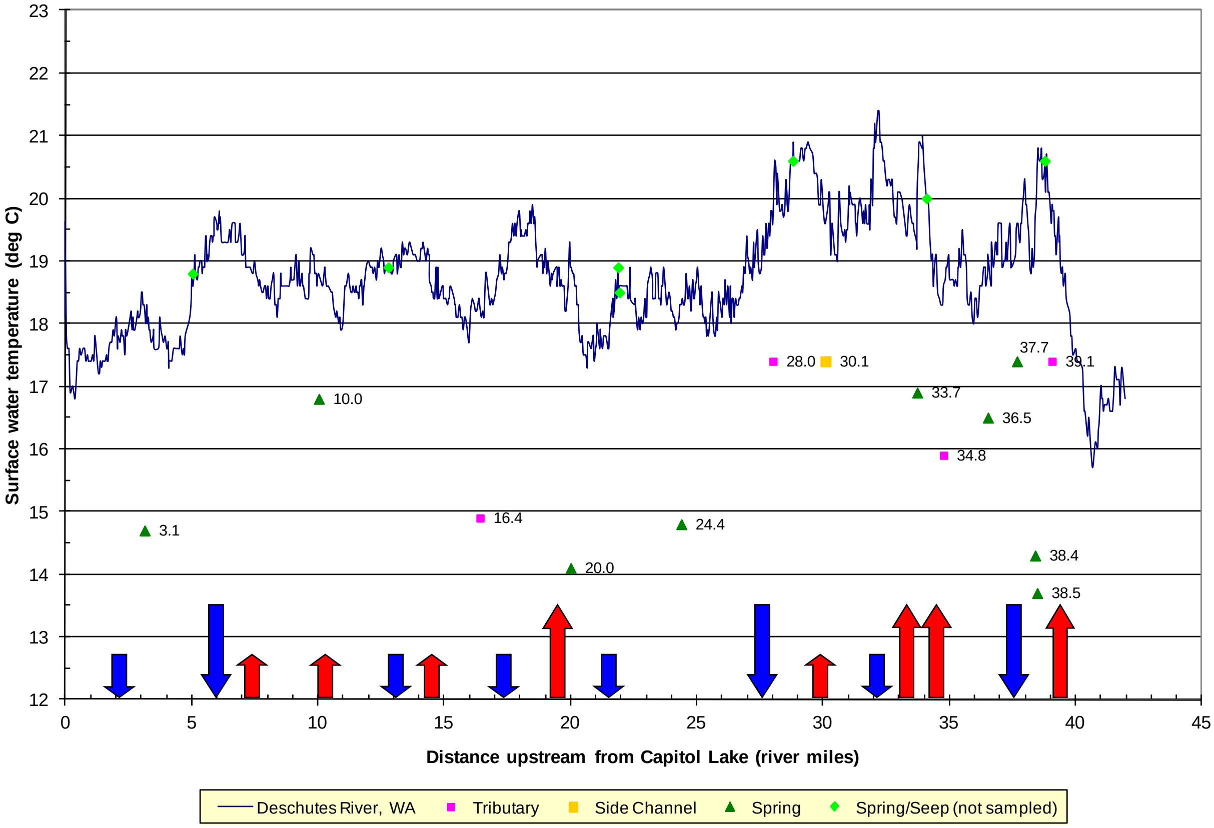

Figure 17. Detailed longitudinal profile from TIR survey for the mainstem Deschutes River, as well as measured and estimated tributary and spring temperatures.

Source: Watershed Sciences (2004). Arrows added to identify areas with warming or cooling of 1.0ºC (small arrows) to >2ºC (large arrows). Points represent tributary temperatures.

A storm event the previous week and cloudy conditions increased flows and decreased temperatures throughout the area. While the TIR survey captures the overall variability in temperatures and identified cool water inflows and hot water development, the survey was not conducted at critical conditions. Resulting temperatures likely reflected the transient effects of the storm.

The TIR imagery identified a number of cold water inputs to the mainstem of the Deschutes River that could represent important refugia during high-temperature periods. Locations are mentioned and identified in images in the report (Watershed Sciences, 2004). Watershed Sciences (2004) noted a water temperature decrease of 1.0ºC through a logjam near RM 5.3.

Nutrients, Dissolved Oxygen, and pH Results

The monitoring program included a combination of ambient and short-term targeted monitoring as well as grab samples and continuous monitoring. The Deschutes ambient monitoring data provide long-term data to evaluate trends. Targeted monitoring includes continuous DO and pH at several upstream locations and monthly grabs to evaluate longitudinal patterns within the Deschutes River system. Capitol Lake monitoring supplemented Thurston County historical monitoring. Finally, a stream walk assessed longitudinal patterns over 30 river miles.

Ambient Monitoring at 13A060

Long-term monitoring at Ecology's ambient monitoring station includes monthly samples analyzed for nutrients and in-situ values for DO and pH. The ambient monitoring program does not necessarily target critical sunrise or sunset time periods, but the data do provide context for seasonal variability.

Based on data collected over a 20-year period (October 1988 through September 2007), concentrations of total nitrogen and dissolved inorganic nitrogen have increased ($p<0.05$), as shown in Figure 18. The low R^2 values reflect seasonal and noisy data but do not address the significance of the trend. Ammonium concentrations have decreased significantly during the same time as high-concentration spikes diminished in recent years, but the decrease is more than offset by the increase in nitrate+nitrite.

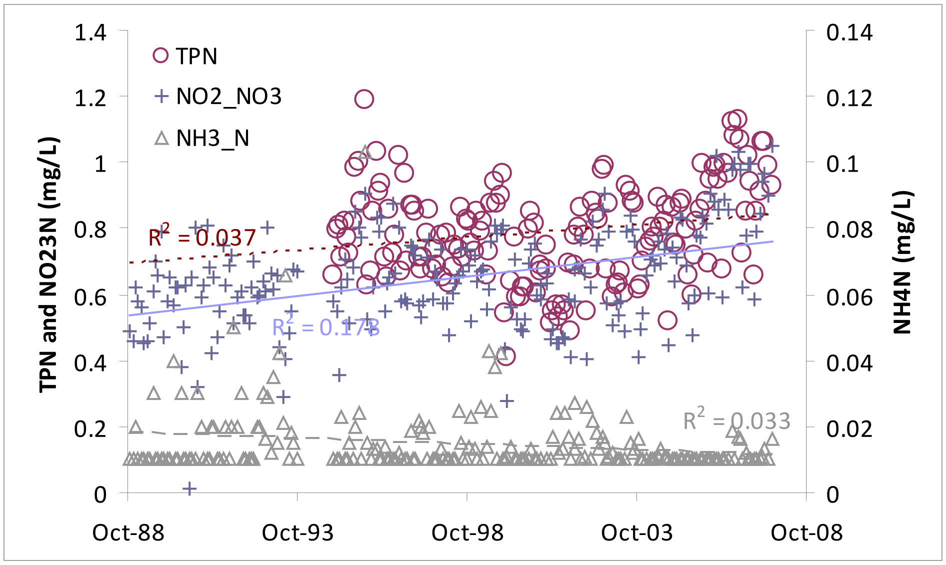

Figure 18. Long-term trends in nitrogen concentrations at Ecology's ambient monitoring station 13A060 at the E Street bridge.

Total phosphorus concentrations have declined significantly over the past 20 years, although it is unclear whether changes in analytical methods in 1999 and 2003 influence the results (Figure 19). Conversely, orthophosphorus concentrations have increased significantly, even with a decrease in the reported detection limit from 0.01 mg/L through 1993 to 0.005 mg/L since that time.

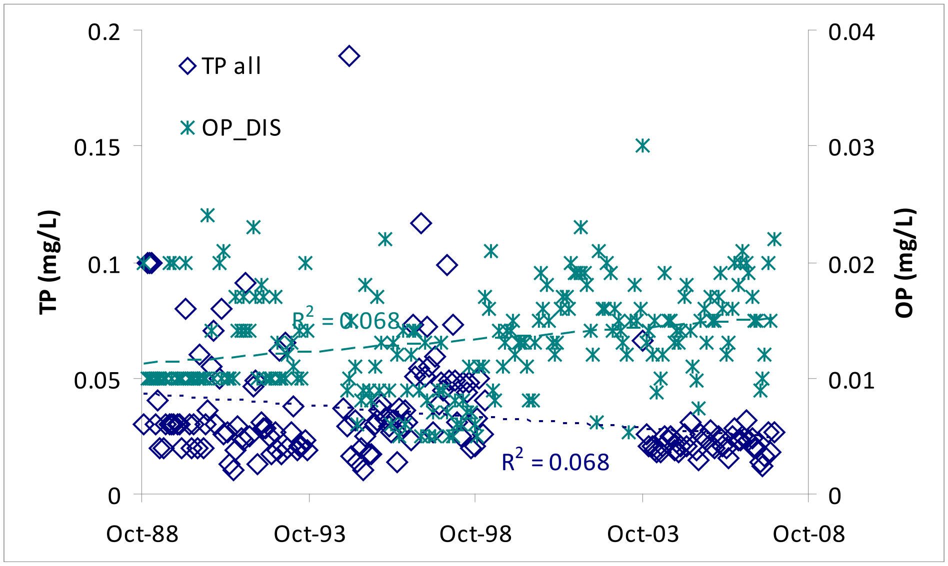

Figure 19. Long-term trends in phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge.

The ambient monitoring at the mouth of the Deschutes River shows distinct seasonal variation. Peak temperature and pH coincide with minimum DO levels in the month of July for the period 1988-2007 (Figure 20). Nutrient patterns are more complex but also show seasonal patterns (Figure 21). The highest monthly mean concentration of nitrate+nitrite, which is the primary component of dissolved inorganic nitrogen and total nitrogen, occurs in September, but a second peak occurs in February. Ammonium remains near the detection limit year-round, but highest levels also occur in September. Total phosphorus concentrations are highest in the winter months and likely are associated with high discharge events and particulates. Orthophosphate concentration patterns follow those of nitrate+nitrite.

Ratios of nitrogen to phosphorus indicate whether primary productivity is limited by one or both nutrients. The traditional Redfield ratio was developed for marine algae (Redfield, 1958) but is often applied to freshwater systems as well. More recently, Kahlert (1998) evaluated benthic algae molar ratios. The two compilations list optimal ratios of 16:1 and 18:1 molar ratios. Accounting for atomic mass, these are equivalent to 7.2:1 and 8.7:1, respectively. Deschutes River primary productivity is limited by phosphorus, since N:P generally exceeds 30:1 based on the bioavailable forms, dissolved inorganic nitrogen and orthophosphate.

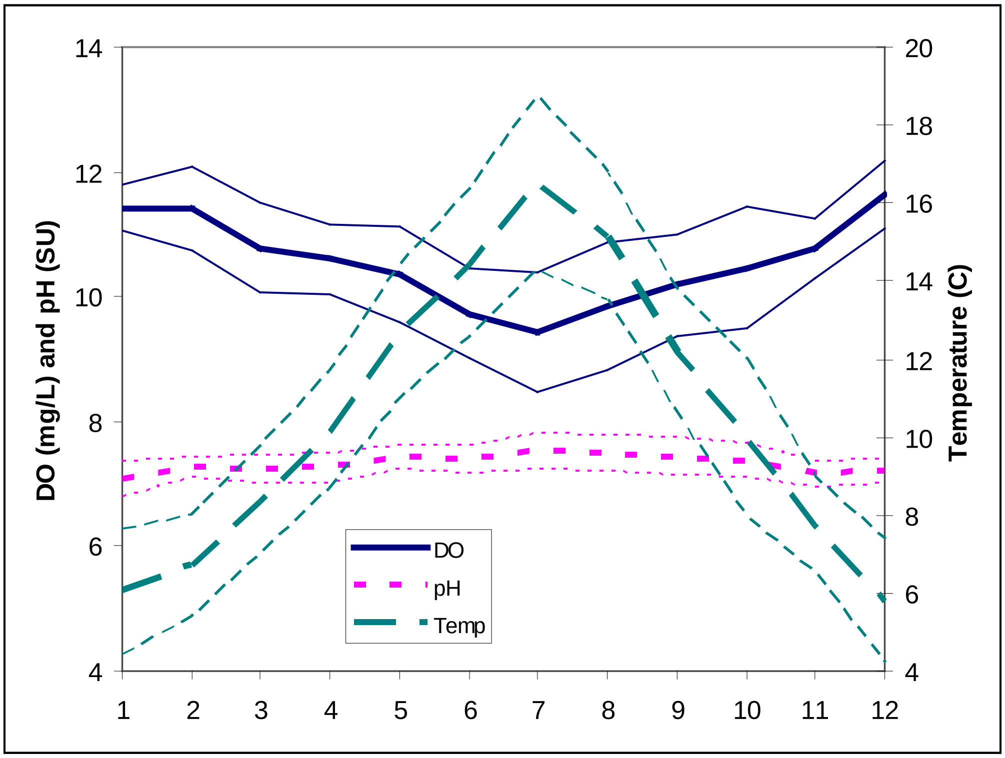

Figure 20. Monthly values (mean ± 1 SD) for DO, pH, and temperature at Ecology's ambient monitoring station 13A060 at the E Street bridge (1988 through 2007).

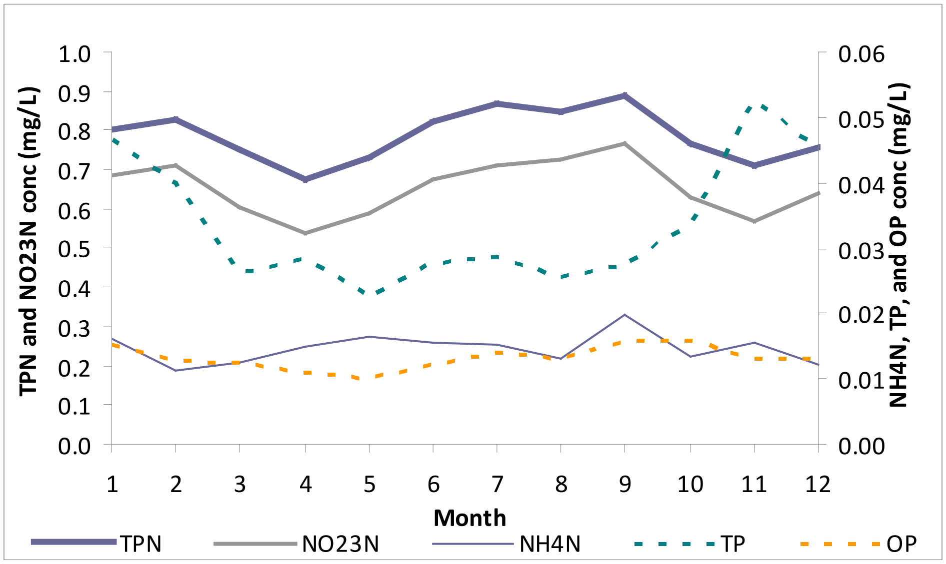

Figure 21. Monthly values for nitrogen and phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge.

Longitudinal Patterns in the Deschutes River

To distinguish patterns upstream of the ambient monitoring station near the mouth, the 2003-2004 monitoring program included both monthly grab samples and in-situ concentrations at seven locations along the mainstem of the river and from four tributaries to the Deschutes River. Hydrolabs installed at five locations from 13-DES-37.4 to 13-DES-00.5 recorded DO, pH, temperature, and conductivity at 15-minute intervals for approximately three days. Data from all sites were presented in quarterly reports. Figure 22 presents DO, DO saturation, and pH results for the five locations. DO and pH were highest in the late afternoon and lowest in the early morning, although the exact phasing varied by location and parameter. Station 13-DES-28.6 had the lowest minimum DO concentration, and station 13-DES-05.5 had the highest maximum pH levels. DO was supersaturated in late afternoon but decreased to 70-80% saturation near sunrise.

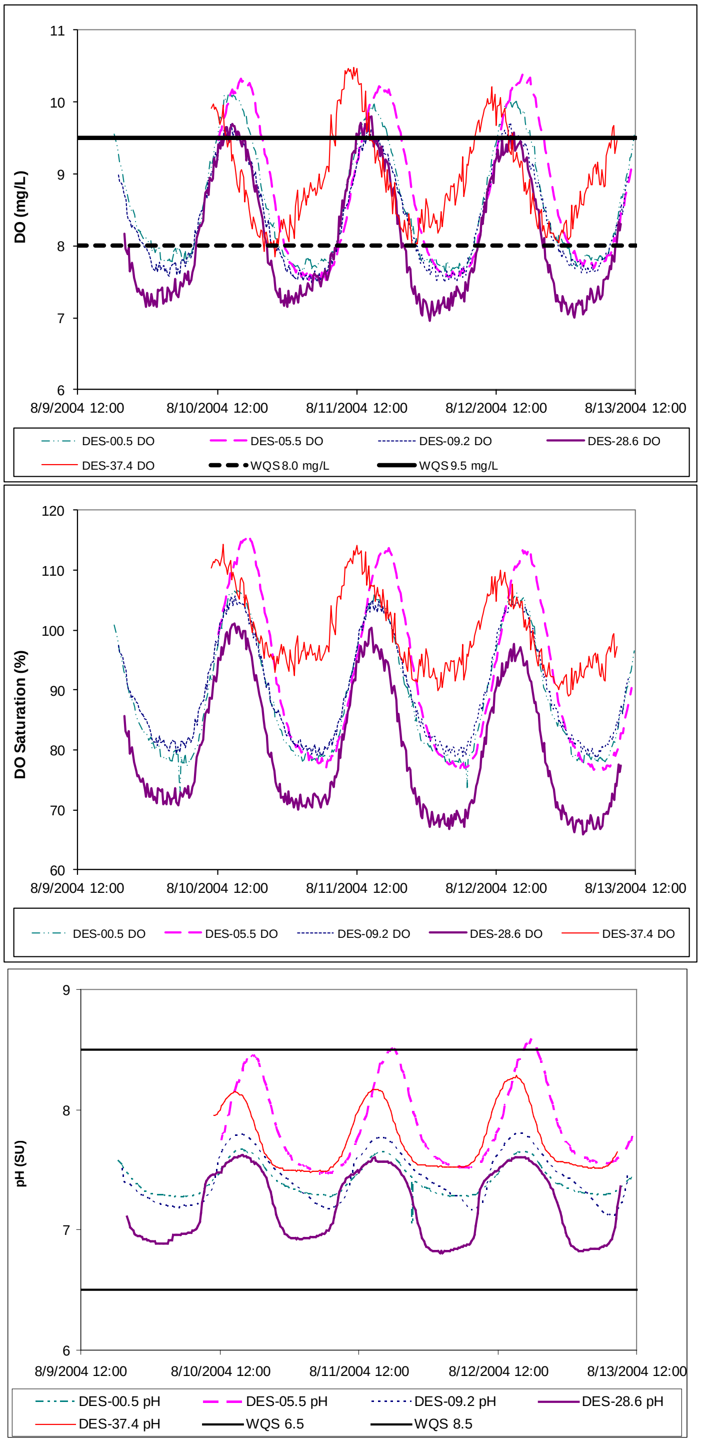

Figure 22. Continuous DO, DO saturation, and pH results from Hydrolab measurements at five stations.

Solid lines represent stations upstream of Offutt Lake, where the 9.5 mg/L standard shown as a solid line applies, while dashed lines represent sites downstream of Offutt Lake, where the 8.0 mg/L standard shown as a dashed line applies. The pH range criteria are the same for both designated uses.

In addition to providing the daily minimum and maximum concentrations for model calibration, the Hydrolab data were used to calculate several model parameters using the Delta Method (Chapra and DiToro, 1991; Chapra, 1997). The patterns in the data, including temporal offsets, were used to derive reaeration coefficients and average daily production and respiration, presented in Table 16.

Table 16. Reaeration coefficients, average daily production, and average daily respiration derived from the Hydrolab measurements.

Station	Reaeration (d^{-1})	Average daily production (mg-O_2/L/d)	Average daily respiration (mg-O_2/L/d)
13-DES-37.4	16.9	14.4	17.0
13-DES-28.6	9.2	11.0	18.7
13-DES-09.2	7.9	8.7	14.4
13-DES-05.5	3.2	8.3	9.1
13-DES-00.5	6.7	8.9	14.3

Figure 23 presents the profile of 2004 nitrogen concentrations from the upper falls through Capitol Lake. Total nitrogen and nitrate+nitrite concentrations steadily increased downstream before declining within Capitol Lake. Ammonium concentrations were low throughout the Deschutes River but were higher and more variable within Capitol Lake. Phosphorus followed similar patterns (Figure 24), with a steady increase in both total phosphorus and orthophosphate from upstream to downstream within the Deschutes River. Total phosphorus levels continued to rise within Capitol Lake, but mean orthophosphate levels declined somewhat.

The ratio of nitrogen to phosphorus (DIN to orthophosphate) indicates that the Deschutes River is phosphorus limited throughout the year (Figure 25). However, station 13-DES-37.4 (1000 Rd) was nitrogen limited or co-limiting in June and July 2004, which is not unusual near the headwaters.

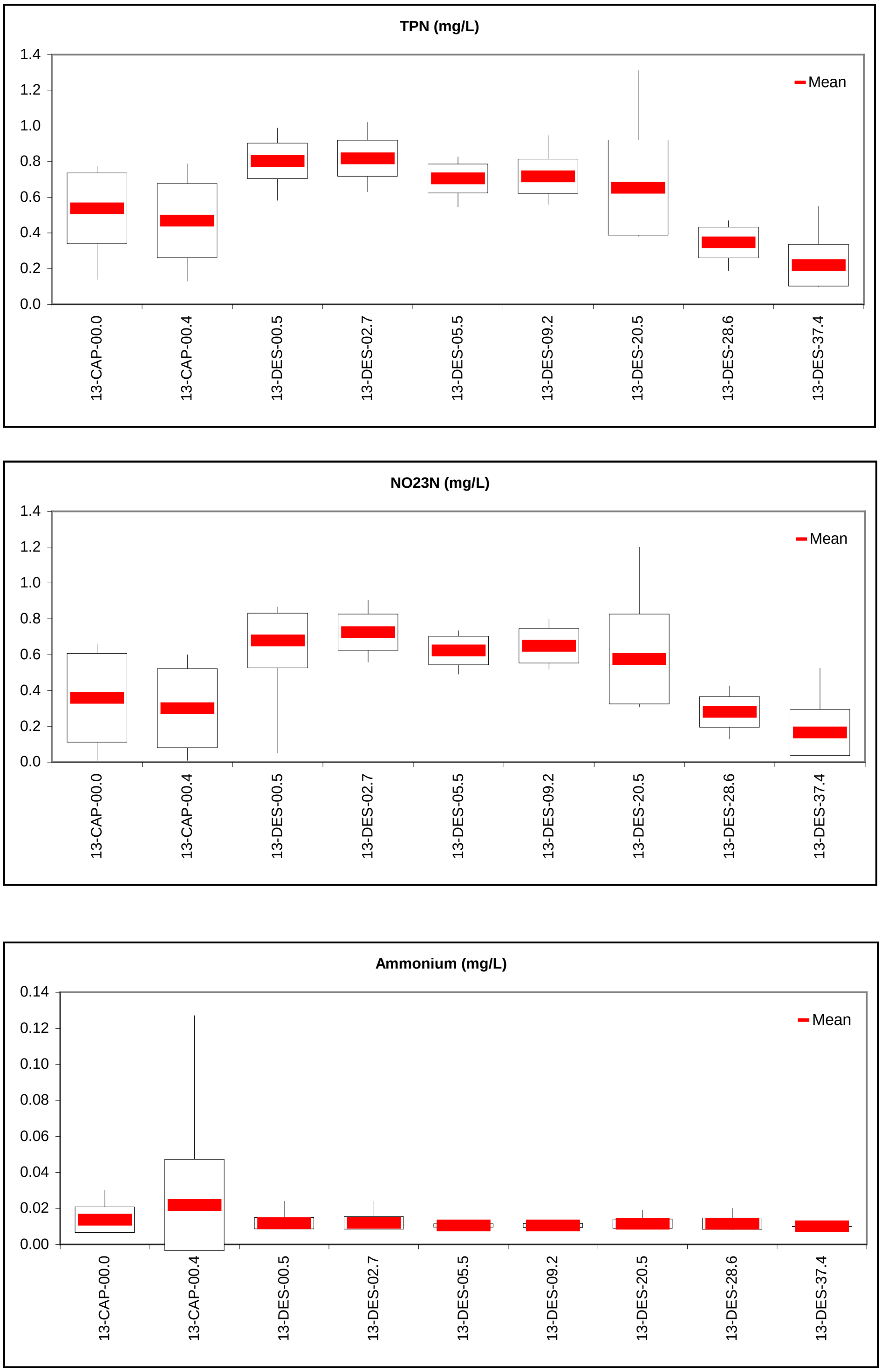

Figure 23. Longitudinal variation in monthly and twice-monthly nitrogen concentrations from the 1000 Road to the E Street bridge, from right to left.

Boxes indicate 25th and 75th percentiles, while whiskers extend to the minimum and maximum values.

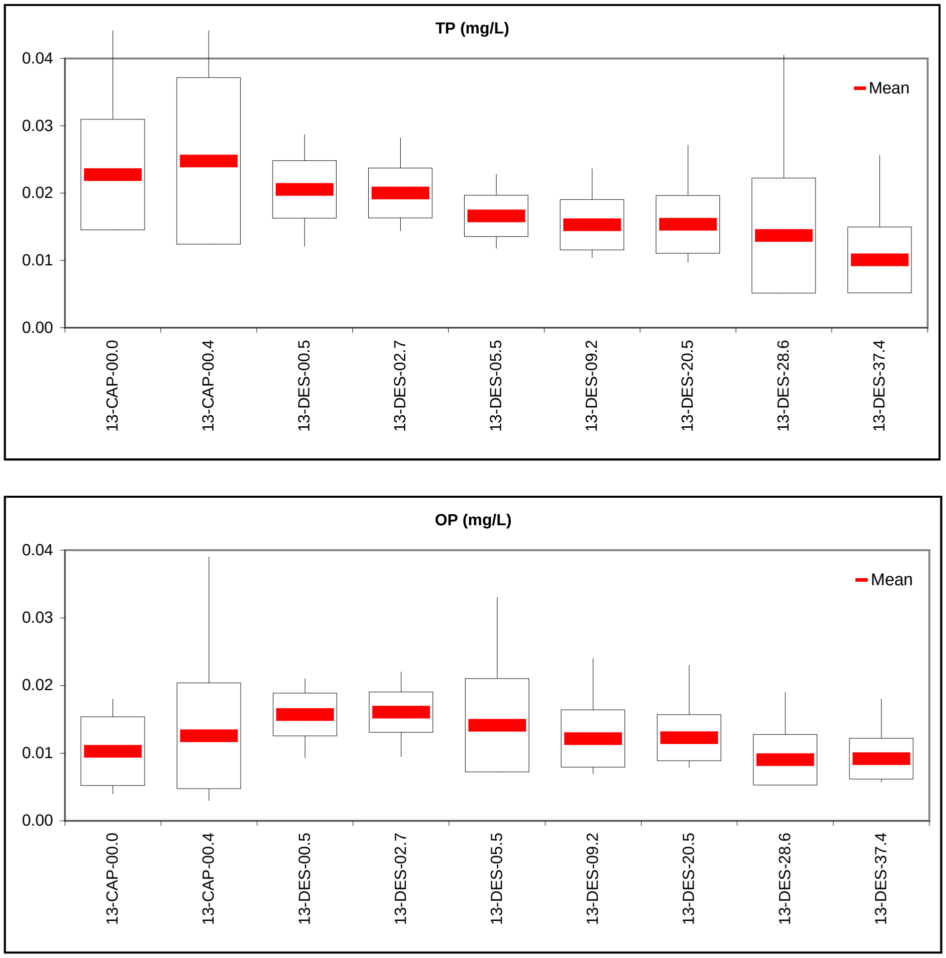

Figure 24. Longitudinal variation in monthly and twice-monthly phosphorus concentrations from the 1000 Road to the E Street bridge.

See previous figure for legend.

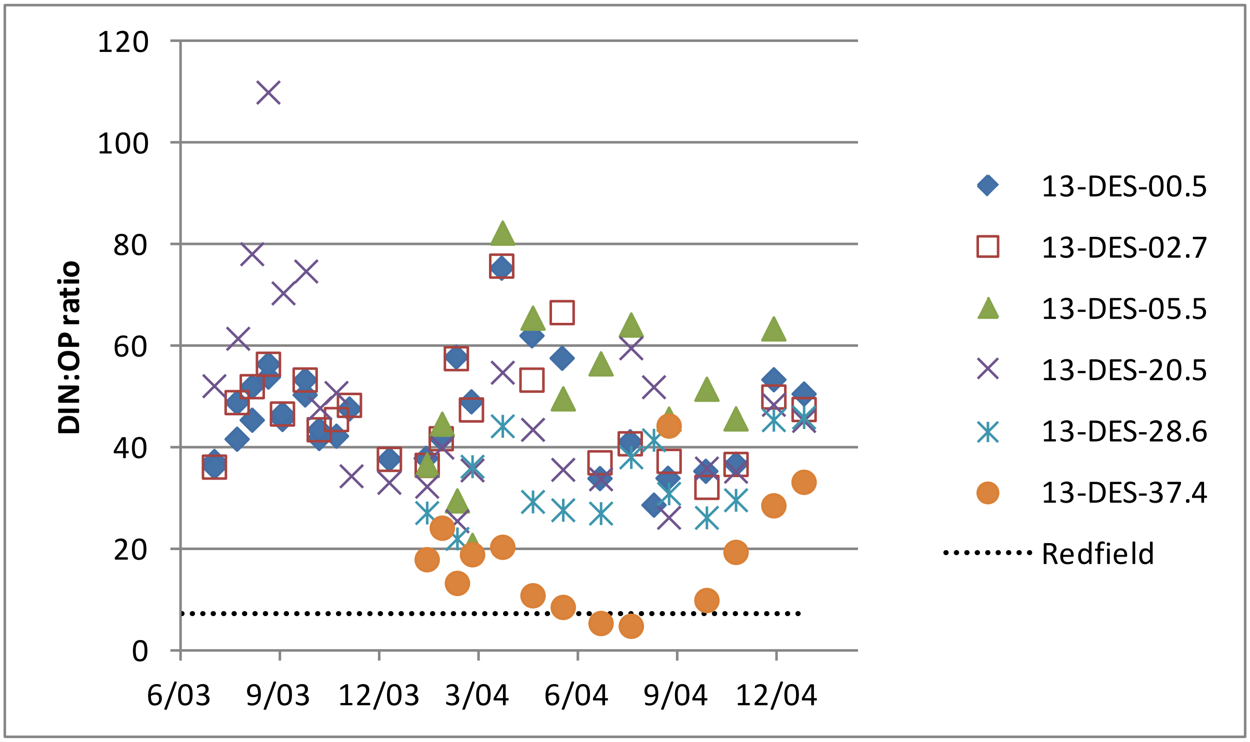

Figure 25. Nitrogen to phosphorus ratios expressed as DIN:OP.

The August 11-15, 2003 stream survey was conducted moving from upstream to downstream. Average daily discharge at the E Street bridge was 76.4 cfs. Temperature, DO, conductivity, and pH were recorded along 30 river miles over five days. Parameters varied by location and time, and the time series in Figure 26 represent values over several hours. Vertical offsets in the record indicate a change from afternoon to morning the next day, while horizontal gaps represent areas where access was not possible. Temperature, DO, and pH generally increased during each day of the survey, as expected with increasing solar radiation and primary productivity during the day-time survey. The survey also identified locations where decreases occurred, likely associated with groundwater inputs.

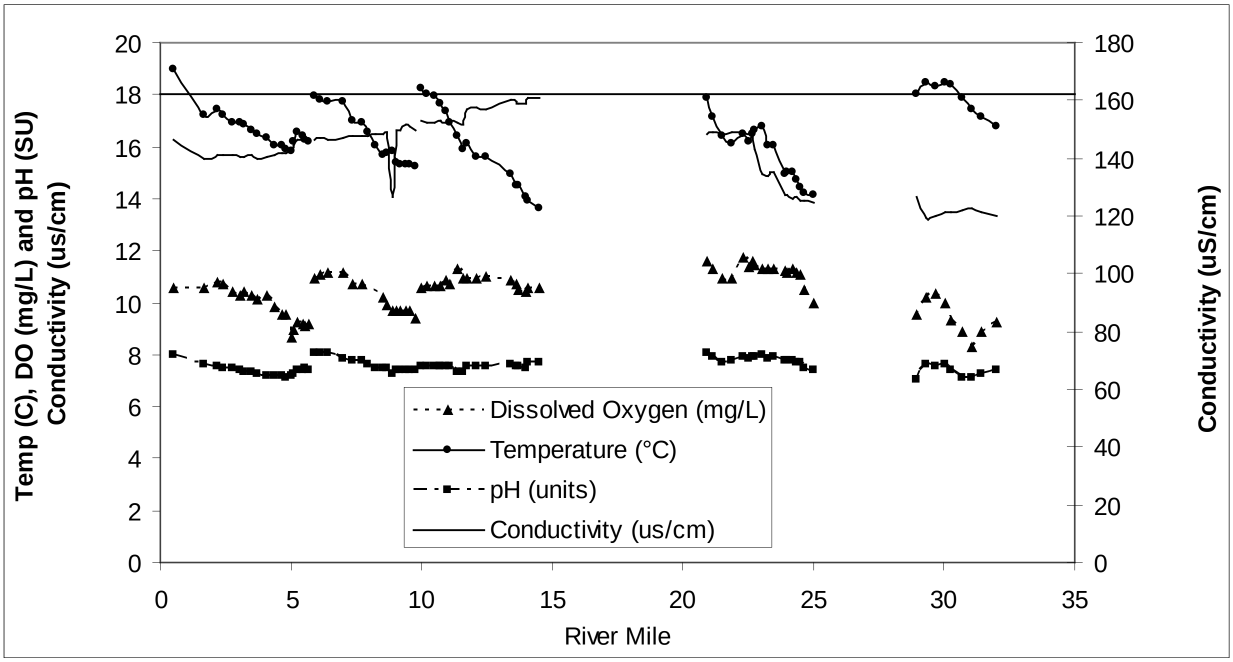

Figure 26. Temperature, DO, pH, and conductivity longitudinal profiles recorded August 11-15, 2003.

Capitol Lake

Surface water samples were collected from the south basin (13-CAP-01), railroad trestle (13-CAP-03), and outlet of Capitol Lake (13-CAP-04) monthly from July through September 2004. As shown in Figure 27, diatoms dominated the algal counts in the south basin throughout the period. While counts were relatively low in June at both the railroad trestle and lake outlet, a green algae bloom occurred in July when *Golenkinia paucispina* counts increased; diatoms (*Stephanodiscus hantzschii* and *Cyclotella stelligera*) also increased in July. By August, the blue-green algae *Anabaena circinalis* increased substantially, producing very high algal biovolume, which accounts for the size of the algae. By September, algal biomass had returned to July levels.

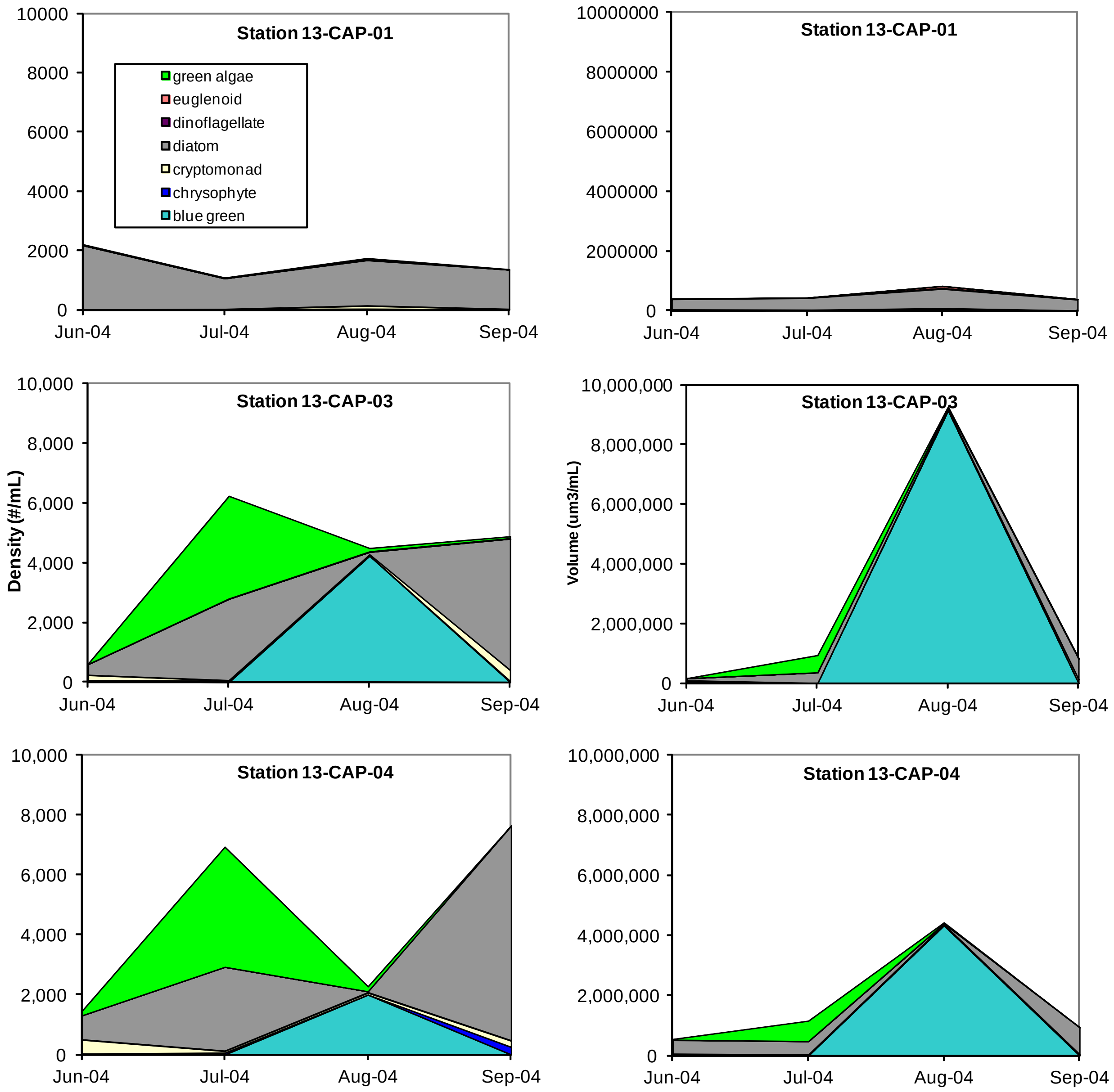

Figure 27. Capitol Lake phytoplankton density (#/mL) and volume (um^3/mL) in 2004.

During the August 2004 herbicide application, a Hydrolab recorded conditions at the outlet of Capitol Lake (Figure 28). Short-term intrusions of high-conductivity Budd Inlet water ceased as the lake was isolated during the application. As milfoil that dominated the macrophyte biomass died off, an algae bloom occurred, leading to daily peaks in DO that exceeded 160% saturation. Enhanced productivity also caused an increase in pH to over 10 standard units (SU). Winkler DO measurements were 4 to 6 mg/L higher than measured by the Hydrolab, and Hydrolab measurements were not corrected for this bias low.

Capitol Lake nutrient concentrations reflect seasonal influences. The lake is phosphorus limited fall through spring. During the summer months, primary productivity reduces both dissolved inorganic nitrogen (DIN) and orthophosphate to very low levels, to the point that nitrogen limited primary productivity in summer 2003. The 2004 nutrient levels reflect the transient influences of the August herbicide application. Decaying macrophyte biomass or sediment nutrient releases spurred by high pH may have lead to high DIN and orthophosphate values in late August. Concentrations stabilized to normal ranges by late October 2004. Summer 2004 nutrients were co-limiting.

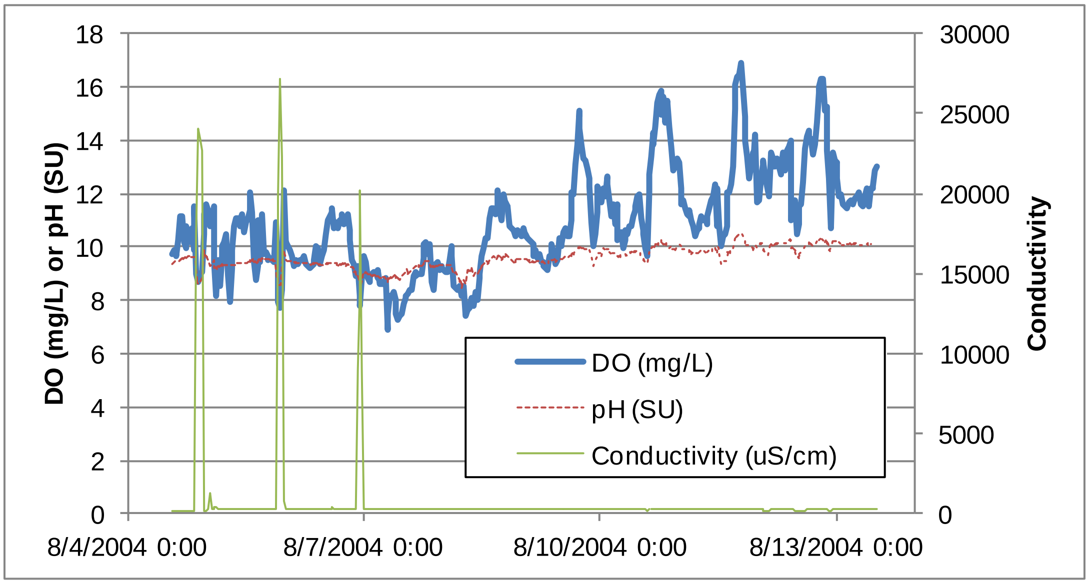

Figure 28. Continuous DO, pH, and conductivity measurements from Hydrolab installed at Capitol Lake outlet.

Benthic fluxes were measured using chambers deployed in the north, middle, and south basins of Capitol Lake. A partition in the middle of the 1-foot deep by 3-feet long clear acrylic aquariums separated light and dark chambers and provided a mount for two Hydrolabs (with stirrers) to record temperature, DO, pH, and specific conductance continuously over one to two days. Detailed results were presented in Quarterly Report #7.

The continuous DO measurements were used to calculate an equivalent sediment oxygen demand (SOD) for each chamber, based on the initial and final concentrations; the light chambers also included the superimposed effect of primary production. Similarly, the initial and final nutrient concentrations were used to calculate the simple net fluxes over the deployment period.

Table 17 summarizes the fluxes. The SOD rates averaged 1.5 g-O_2/m^2-d in the dark chambers. Fluxes were lower in light chambers where primary productivity partially offset the SOD. Nitrate fluxes into the sediments balanced ammonium fluxes from the sediments overall, but variability among sites was high. The sediments were a net source of phosphorus and carbon at most sites.

Table 17. Capitol Lake benthic fluxes (g/m^2-d) quantified in September 2004.
Italicized values are means over the light and dark chambers.
Positive values are fluxes from sediments to water.

Description	Station ID	DO	TN	NO23N	NH4N	TP	OP	TOC	DOC
Dark chambers (sediment fluxes only)		*-1.45*	*-0.016*	*-0.039*	*0.041*	*0.029*	*0.004*	*0.20*	*0.15*
Middle Basin, SW corner shallows	13-CPFX1B	-1.20	-0.023	-0.043	0.044	0.022	0.012	0.24	0.15
Middle Basin, east side	13-CPFX2B.1	-1.83	-0.007	-0.060	0.039	0.001	0.001	0.64	0.54
North Basin	13-CPFX2B.2	-1.57	0.008	-0.002	0.029	0.007	0.006	-0.63	-0.82
South Basin	13-CPFX3B	-1.19	-0.042	-0.049	0.051	0.085	-0.002	0.53	0.71
Light chambers (sediment fluxes and primary productivity)		*-0.54*	*-0.019*	*-0.031*	*0.024*	*0.003*	*0.002*	*0.12*	*0.03*
Middle Basin, SW corner shallows	13-CPFX1A	-0.91	-0.031	-0.039	0.021	0.0102	0.0048	0.17	0.09
Middle Basin, east side	13-CPFX2A.1	0.01	0.000	-0.025	0.009	-0.0020	-0.0015	0.27	0.22
North Basin	13-CPFX2A.2	-0.46	0.010	-0.008	0.033	0.0036	0.0056	-0.42	-0.39
South Basin	13-CPFX3A	-0.79	-0.057	-0.054	0.034	-0.0001	-0.0018	0.45	0.18

Abbreviations are defined in Appendix B.

Percival Creek and Black Lake Ditch

The QA Project Plan did not include extensive data collection in the Percival Creek watershed, Data collected during the present study resulted in portions of Black Lake Ditch and Percival Creek being added to the Category 5 303(d) listings. Figure 29 summarizes the DO, pH, and nutrient results for Black Lake Ditch at the outlet of Black Lake (13-BLA-02.3) and at the confluence with Percival Creek (13-BLA-00.0) as well as for Percival Creek downstream of the confluence with Black Lake Ditch (13-PER-01.0) and as it enters Percival Cove (13-PER-00.1).

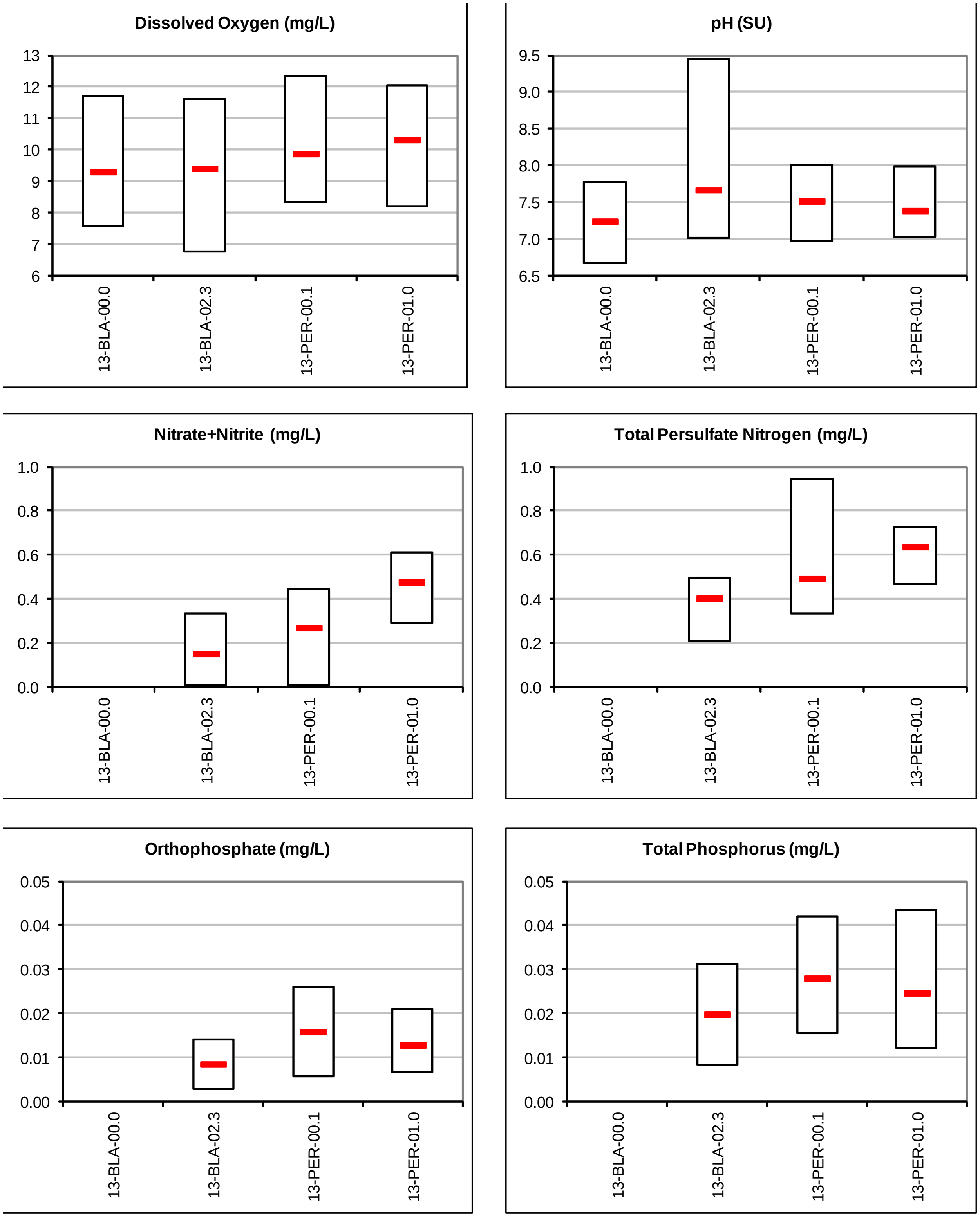

Figure 29. Monitoring results for the Percival Creek and Black Lake Ditch watershed.

Fine Sediment Results

In-situ Values

Konovsky and Puhn (2005) summarized the 2004 characterization of fine sediment levels, defined as <0.85 mm, both to establish current conditions and to evaluate trends in fine sediment levels. Data were collected using the methods described in Konovsky (2004). The study used the same standard methods (Schuett-Hames et al., 1999) and locations as the previous characterization of Deschutes River fine sediment levels (Schuett-Hames and Child, 1996). Figure 30 identifies the survey reaches.

Spawning sites and riffle crests were inventoried within each reach and a subset of the riffle crests (upstream extent of riffles) sampled. Sixty-nine gravel samples were collected and sieved to obtain the percent fines and compare with results for 90 samples collected in 1995 (Schuett-Hames and Child, 1996). Four of the five sites had fine sediment levels >17% and were rated as poor for spawning habitat quality based on Appendix F of the Timber, Fish, and Wildlife Watershed Analysis Manual (Washington Forest Practices Board, 1997).

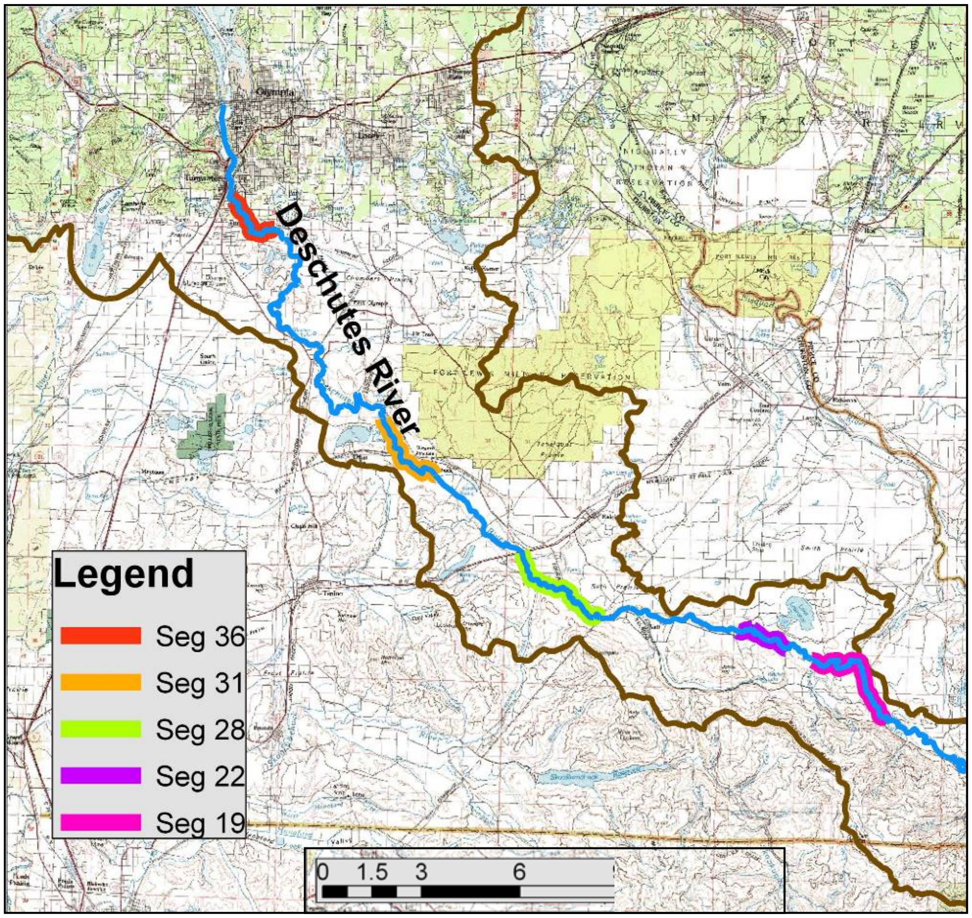

Figure 30. Fine sediment study reaches sampled in 2004.

Source: Konovsky and Puhn (2005). River kms are downstream of Deschutes Falls.

Figure 31 presents the percent fines by site for both 1995 and 2004. While values for some locations changed somewhat during that time, there was no statistically significant difference between years when all sites were pooled (ANOVA, p=0.475). A weak trend (decreasing fines in a downstream direction) is suggested, but only Sites 19 and 36 were significantly different (p<0.01). Higher levels at Site 19 may have been due to the January 1990 storm event or recreational off-road vehicle use, which is common in the area (Konovsky and Puhn, 2005).

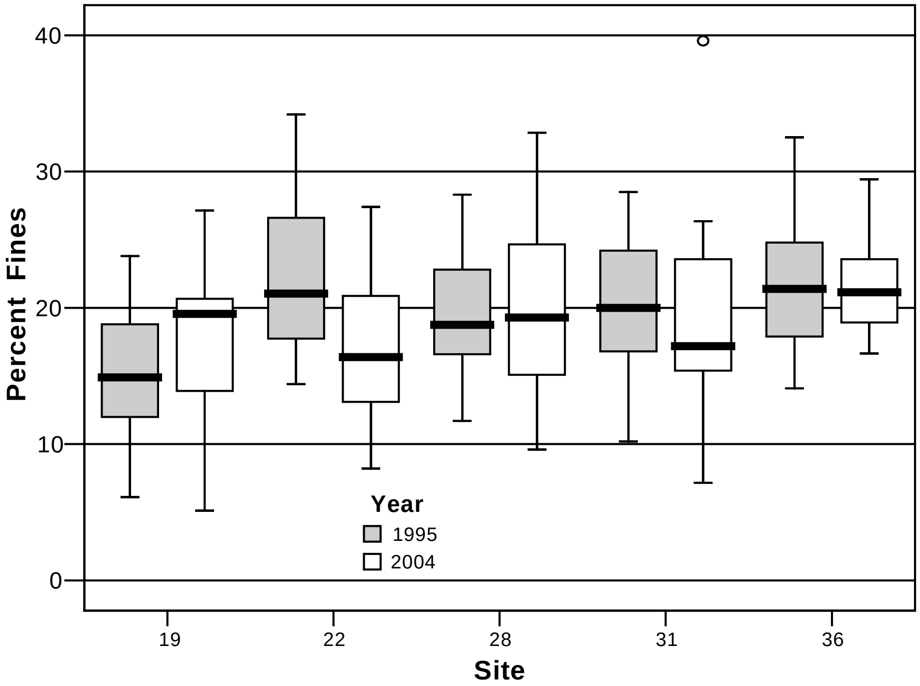

Figure 31. Fine sediment levels by study reach.

Source: Konovsky and Puhn (2005).
Bars indicate median values, boxes are the standard deviations, and whiskers are the minimum and maximum values of replicates.

A related study was based in part on the fine sediment levels determined by Konovsky and Puhn (2005). The analytical study of habitat condition influences on coho salmon production evaluated the effects of full and partial restoration of various habitat functions, including flows, water temperature, fine sediment, and large woody debris (LWD). Anchor Environmental (2008) found that a 2% decrease in fine sediment levels within all reaches of the Deschutes River would produce the biggest increase in coho production compared with the benefits of partial restoration of high and low flows, high water temperature, and LWD, as much as tripling annual returns. Full restoration to no more than 10% fine sediments in the system would increase coho production by an order of magnitude over current levels. The study identified the mainstem and tributaries between RM 31 and RM 41 as the most critical segments for restoration.

Anchor Environmental (2008) also evaluated the influence of LWD, a related parameter. Fox and Bolton (2007) summarized median and interquartile ranges of LWD abundance for rivers of varying widths in Washington State, and Anchor Environmental (2008) used the 25th percentile value for intermediate-sized rivers (29 pieces per 100 m) as the restoration target for the Deschutes River and the 25th percentile value for small streams (26 pieces per 100 m) as the restoration target for tributaries. Under current conditions, 60% of the tributaries between RM 31 and RM 41 meet the restoration target, while 0 to 2% of the mainstem meets the restoration target.

Partial restoration of LWD (70% in tributaries between RM 31 and RM 41 and 10% elsewhere) would produce some increase in coho returns. Full restoration of LWD availability would produce the highest coho increase of any habitat parameter in the Deschutes River watershed.

Sediment Budget

Raines (2007) quantified sediment yields in the Deschutes River watershed from high bank erosion, landslides, and unpaved roads for the period 1991-2003 and compared the values with historical estimates (Collins, 1994). Table 18 summarizes the sediment budget for all sources (Raines, 2007) and provides estimates of Capitol Lake inputs developed from historical dredging and bathymetric surveys (George et al., 2006). The identified sediment sources account for 68 to 78% of the estimated sediment loads to Capitol Lake. Based on a mean annual load to Capitol Lake of 36,000 yd^3/yr and identified sources of 26,000 yd^3, approximately 10,000 yd^3/yr of fine sediment is unaccounted in the mass balance. Raines (2007) used a fine sediment size fraction of <2 mm, which differs from the definition of <0.85 mm used by Konovsky and Puhn (2005).

Table 18. Sediment budget summary for the Deschutes River from all sources (yd^3/yr).
Source: Raines (2007).

Bank erosion from all sources	1972-81	1981-91	1991-2003	1972-2003
Fine	8,800	27,100	4,900	13,200
Coarse	3,200	6,100	3,500	4,300
Total	*12,000*	*33,200*	*8,400*	*17,500*
Landslides from all sources	1970-78	1978-90	1990-2001	1970-2001
Fine	5,300	5,600	2,600	4,500
Coarse	2,300	2,400	1,100	1,900
Total	*7,600*	*8,000*	*3,700*	*6,400*
Unpaved roads from all sources	1972-81	1981-91	1991-2003	1972-2003
Fine	1,300	900	3,000	1,800
Coarse	0	0	0	0
Total	*1,300*	*900*	*3,000*	*1,800*
Total identified sources	1972-81	1981-91	1991-2003	1972-2003
Fine	*15,400*	*33,600*	*10,500*	*19,500*
Coarse	*5,500*	*8,500*	*4,600*	*6,200*
Total	*20,900*	*42,100*	*15,200*	*25,700*
Sediment output	1974-83	1983-90	1990-98	1972-2003
Capitol Lake load	*55,000*	*35,000*	*29,000*	*33,000-38,000*

Erosion sites identified from aerial photos were coded by landform. Only erosion from high banks, either hillslopes or glacial terraces, was considered a net sediment input to the system; channel and floodplain erosion was considered remobilization of sediment from other sources and was not included in sediment inputs. Annual average erosion from high banks has declined somewhat over historical levels developed by Collins (1994), both for all sediment and for fine sediment. The highest rates were estimated for the period 1981 to 1991. Since then, average annual fine sediment inputs have declined to <20% of the 1981 to 1991 levels. Raines (2007) attributed the change to post-1990 storm sediment redistribution and higher frequency but lower magnitude discharge events in the recent period or to human armoring, particularly in the downstream reaches of the watershed. High bank erosion was not attributed to anthropogenic sources. Erosion of glacial terraces is the largest identified source of sediment to the system.

Recent and historical landslide inputs were based on an inventory of 110 landslides in the upper Deschutes River watershed provided by the Weyerhaeuser Company for the period 1966 to 2001 based on aerial photographs. Proximity to roads was included in the analysis, as were geology, soils, and terrain. Road-associated landslides constituted 73% of the landslide sediment inputs, and 79% of the 110 slides occurred in weathered bedrock terrain with deep, fine-textured soils.

Annual mean total and fine sediment inputs from landslides for the recent time period (1990 to 2001) were less than half the inputs estimated for 1970 to 1978 and 1978 to 1990. Three of the four highest discharges on record for the Deschutes River occurred between 1970 and 1990 (9600 cfs in January 1990, 7780 cfs in January 1974, and 7420 cfs in January 1972) and likely contributed to the high inputs. Raines (2007) noted that the second-highest flow (7850 cfs) occurred in February 1996, but sediment inputs declined, likely attributable to improvements in forest practices.

Sediment inputs from unpaved roads were based on a Level 1 screening application of the Washington Road Surface Erosion Model (WARSEM). Of the 1033 miles of road in the Deschutes River watershed, 59% are unpaved. Of the unpaved roads, 31% are directly connected to streams and another 16% are within 200 ft (60 m) of a stream, connectivity rates that are somewhat lower than found in previous studies, as reported in Raines (2007). WARSEM accounted for multiple traffic levels and geologic erosion factors. Two road surface categories were evaluated to give a range of potential erosion estimates of 12 to 25 tons per mile of unpaved road, similar to the estimates of Sullivan et al. (1987).

Raines (2007) quantified anthropogenic contributions to the sediment inputs (Table 19). Contributions from unpaved roads and from landslides associated with roads constitute the anthropogenic fraction of the sediment inputs, while high bank erosion and landslides not associated with roads do not. Overall, anthropogenic sources contribute 26 to 32% of the total sediment inputs to the Deschutes River system. Most of these sources are fine sediment, however. Anthropogenic contributions of fine sediment (<2 mm) constitute 25 to 32% of the fine sediment inputs to the system, as well.

Table 19. Sediment budget summary for the Deschutes River from anthropogenic sources (yd^3/yr).

Source: Raines (2007).
Low and high estimates are based on assuming only road-associated landslides or all landslides are anthropogenic in origin.

Bank erosion from anthropogenic sources	1972-81	1981-91	1991-2003	1972-2003
Fine	0	0	0	0
Coarse	0	0	0	0
Total	*0*	*0*	*0*	*0*
Landslides from anthropogenic sources	1970-78	1978-90	1990-2001	1970-2001
Fine	4,400 - 5,300	4,000 - 5,600	1,800 - 2,600	3,300 - 4,500
Coarse	1,900 - 2,300	1,700 - 2,400	800 - 1,100	1,400 - 1,900
Total	*6,300 - 7,600*	*5,700 - 8,000*	*2,500 - 3,700*	*4,700 - 6,400*
Unpaved roads from anthropogenic sources	1972-81	1981-91	1991-2003	1972-2003
Fine	1,300	900	3,000	1,800
Coarse	0	0	0	0
Total	*1,300*	*900*	*3,000*	*1,800*
Total Annual Averages				
Fine	5,700 - 6,600	4,900 - 6,500	4,800 - 5,600	5,100 - 6,300
Coarse	1,900 - 2,300	1,700 - 2,400	800 - 1,100	1,400 - 1,900
Total	*7.600 - 8,900*	*6,600 - 8,900*	*5,500 - 6,700*	*6,500 - 8,200*

Figure 32 summarizes the fine sediment and total sediment budget by primary source. Based on the long-term mean sediment load discharged to Capitol Lake, approximately 10,000 yd^3/yr (29%) are unaccounted for by the sediment budget developed by Raines (2007). Other potential fine sediment sources include runoff from facilities or areas covered by NPDES general permits, enhanced bank erosion from uncontrolled animal access or recreational river users, and land cover practices that produce soil erosion from upland sites.

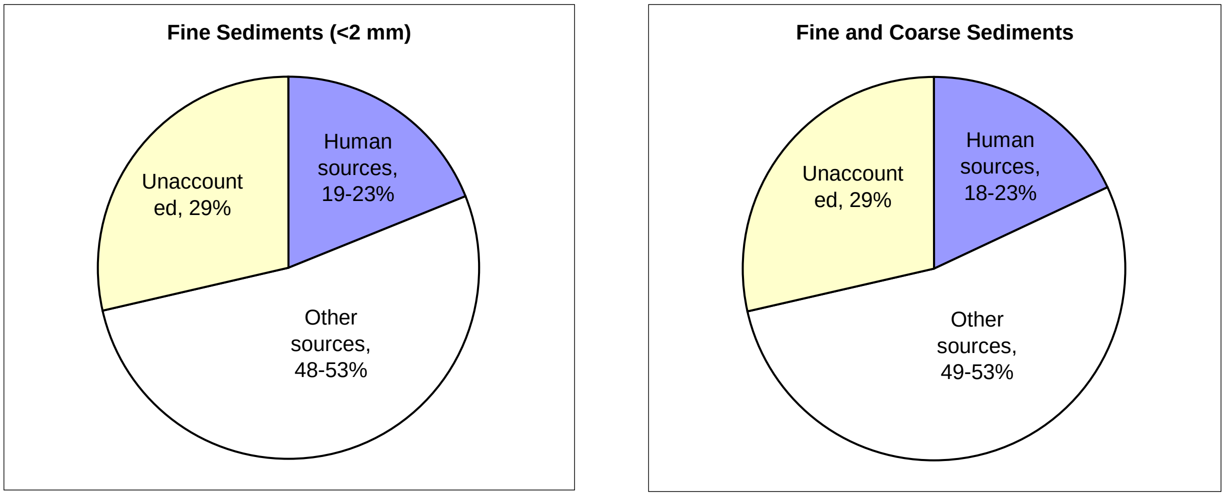

Figure 32. Sediment budgets for both fine sediments and the combination of fine and coarse sediments.

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TMDL Analyses

Fecal Coliform Bacteria

Analytical Framework

Fecal coliform load reduction targets are based on data collected from July 2003 through March 2005. Load reduction targets are based on the statistical rollback method, which compares in-situ data statistics to water quality standards. Reductions are calculated for both Part 1 and Part 2 of the bacteria water quality standards for any site that does not meet either one or both. This method has been applied for many previous studies (Ahmed and Rountry, 2007; Sargeant et al., 2005; Ahmed 2004a and 2004b; Roberts, 2003; Joy, 2000; Pelletier and Seiders, 2000).

Fecal coliform concentrations measured at a station over time follow a lognormal distribution, and distribution properties can be used to estimate the geometric mean and 90th percentile bacterial concentrations. When these estimates are higher than the water quality standards, the target reductions are estimated by rolling back the estimated geometric mean or 90th percentile concentrations (whichever is most restrictive) to the appropriate water quality standards.

The two parts of the bacteria criteria are applied separately. First, the geometric mean is calculated for each monitoring station for the period of interest. If the geometric mean is higher than the water quality standard, the station fails Part 1 of the criteria. Next, the percent of samples higher than the threshold, which varies with the water body class, is calculated. If >10% of samples are higher than the threshold, the station fails Part 2 of the criteria. Because the percentage cannot be rolled back directly, data must be translated into an equivalent 90th percentile, and the 90th percentile is rolled back to the threshold.

For lognormally distributed data, the 90th percentile can be estimated from the log-transformed data:

$$90th\ percentile = 10^{\overline{(l_1, l_2, \ldots l_n)} + 1.28 * stdev(l_1, l_2, \ldots l_n)}$$

where l_n is the log of value x_n and stdev is the standard deviation.

To calculate the reduction factors, the geometric mean or 90th percentile of the data is compared with the value in the standards (std):

$$GM_{reduction} = 1 - \frac{GM_{std}}{GM_{data}}$$

$$90th\ percentile_{reduction} = 1 - \frac{90th\ percentile_{std}}{90th\ percentile_{data}}$$

The overall reduction factor is whichever reduction factor is higher.

Depending on the nature of the sources, bacteria sources may cause high levels in the summer growing season, in the winter non-growing season, or in both. Therefore, data are summarized using both periods of interest to identify sources. Critical conditions are based on the two separate seasons.

Loading Capacity

The loading capacity is the maximum load received by a water body such that the water body still meets the water quality standards. In the case of fecal coliform bacteria, the loading capacity varies with beneficial use to be protected but is defined by both a numeric geometric mean and percent of samples higher than a specific value.

Figure 33 presents the geometric mean and 90th percentile of data collected for all stations with at least 10 samples for the summer season, and Figure 34 presents the results for the winter season. The loading capacity is indicated by numeric values for Part 1 and Part 2 of the water quality standards. Of the 25 stations, 10 did not meet Part 1 of the water quality standards, and 13 did not meet Part 2 of the water quality standards for the summer season. The mouth of Schneider Creek (13-SCH-00.1) violates Part 2 of the standards because >10% of samples were >200/100 mL; however, the 90th percentile estimated from the log-transformed data is below 200/100 mL. For the winter season, three stations monitored twice monthly did not meet Part 1 of the water quality standards, and 10 did not meet Part 2. In addition, of the stormwater monitoring stations, only the Spurgeon Creek stations met Part 1 and Part 2 of the standard.

The figures define the loading capacity for Percival Creek under the current, more stringent designated use. Similarly, the Capitol Lake loading capacity is based on the current Lake Class standard. If Capitol Lake reverts to an estuary, the Percival Creek watershed loading capacity for fecal coliform bacteria will increase to a geometric mean of 100 colonies/100 mL and no more than 10% of the samples >200 colonies/100 mL. The Capitol Lake/Deschutes estuary would be subject to the marine water quality standards, which use enterococcus as the indicator bacteria for *Secondary Contact* recreation (WAC 173-201A-210(3)(b)).

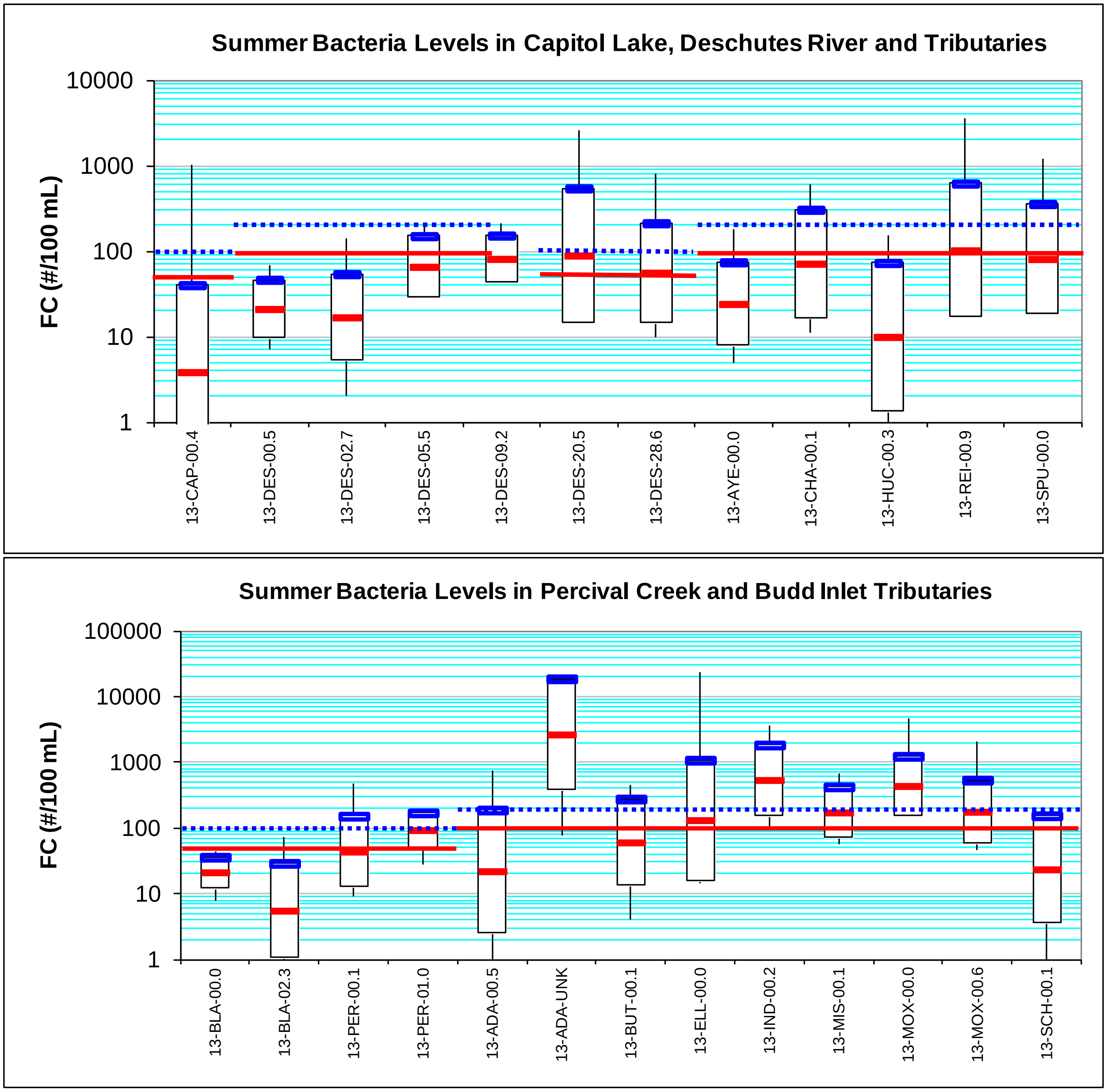


Figure 33. Fecal coliform concentrations and loading capacities for the summer growing season (May through September).

Box and whisker plots represent the median (red bar), 10th and 90th percentiles (box), and minimum or maximum values (whiskers).

Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use in the water quality standards.

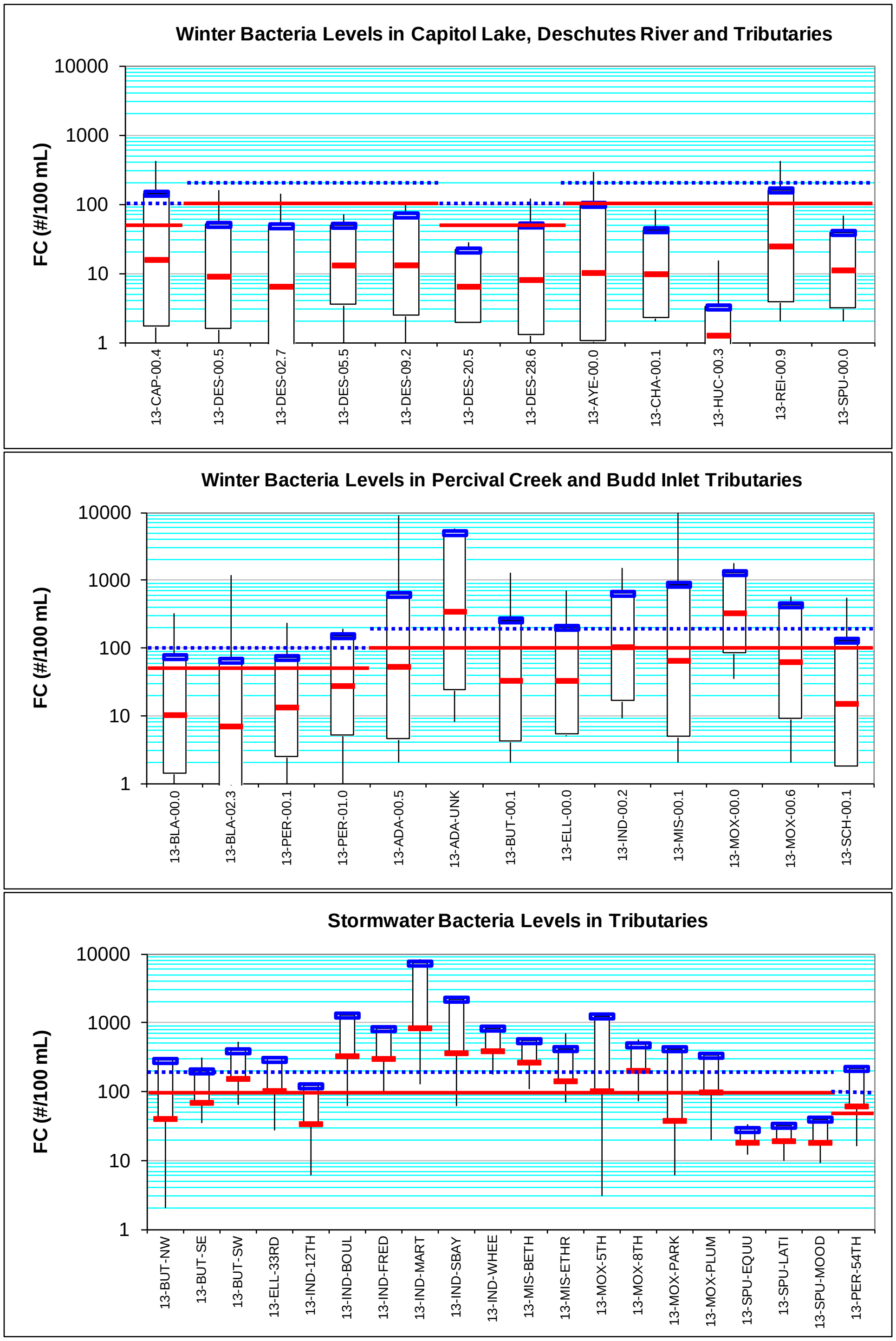


Figure 34. Fecal coliform concentrations and loading capacities for the winter non-growing season (October through April).

Box and whisker plots represent the median (red bar), 10th and 90th percentiles (box), and minimum or maximum values (whiskers).

Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use in the water quality standards.

Load and Wasteload Targets

Target reductions may be either in terms of concentration, or load, or both. This TMDL is expressed in terms of fecal coliform concentration, as allowed under 40 CFR 130.2(I) as “other appropriate measures.” The concentration is appropriate since the water quality standard can be directly compared to measured concentrations in the receiving water under various flow scenarios. The target reductions define what is necessary to achieve the water quality standard. Load reductions are developed for nonpoint sources, while wasteload reductions are established for point sources.

Wasteload reductions are recommended for all permitted point-source discharges, including stormwater, while load reductions are recommended for all nonpoint sources. While targeted stormwater monitoring was included in the study design, the program did not specifically isolate individual entities covered under NPDES Phase 2 stormwater permits. Instead, wasteload reductions for stormwater are defined as percent reduction targets, which are established for specific geographic areas that include areas served by municipal separate storm sewer systems.

Load Targets

Load targets are the nonpoint-source reductions recommended at each location. The targets are expressed as percent reduction from current conditions from either Part 1 or Part 2 of the standards, whichever requires a greater reduction. Future compliance with these targets will be based on comparison of measured data with the water quality standards; if a site meets both Part 1 and Part 2 of the water quality standards, the site will be in compliance with the target recommendations of this TMDL.

Table 20 summarizes the load reduction targets necessary to meet the water quality standards during the summer season. Figure 35 presents the same information spatially. Table 21 presents the targets for the winter season. Because Schneider Creek (13-SCH-00.1) violates Part 2 of the standards but the estimated 90th percentile is below the target, a nominal 10% reduction in bacteria loads are recommended to achieve compliance with Part 2 of the standards. In addition to the mouths of the creeks that were assessed twice monthly, the stormwater monitoring conducted upstream of the mouths provides supplemental reduction targets for the winter season only (Table 22). Figure 36 presents the winter reduction targets expressed spatially.

Table 20. Target reductions necessary to achieve water quality standards during the summer season (May through September).

Station	Count	Water Quality Standards Part 1				Water Quality Standards Part 2					Overall	
		Geo-mean	Target	Vio-lation?	Percent Re-duction	% >Target	Target	Vio-lation?	90%ile	Percent Re-duction	Meets WQS?	Percent Re-duction
Deschutes River												
13-DES-00.5	16	21.1	100			0%	200				meets	
13-DES-02.7	16	16.9	100			0%	200				meets	
13-DES-05.5	10	65.8	100			10%	200				meets	
13-DES-09.2	10	81.5	100			10%	200				meets	
13-DES-20.5	10	89.2	50	Part 1	44%	20%	100	Part 2	544	82%	fails both	82%
13-DES-28.6	12	56.1	50	Part 1	11%	17%	100	Part 2	213	53%	fails both	53%
Tributaries to Deschutes River												
13-AYE-00.0	16	24.2	100			0%	200				meets	
13-CHA-00.1	16	71.5	100			19%	200	Part 2	306	35%	fails Part 2	35%
13-HUC-00.3	10	10.0	100			0%	200				meets	
13-REI-00.9	16	102.4	100	Part 1	2%	19%	200	Part 2	620	68%	fails both	68%
13-SPU-00.0	16	81.2	100			13%	200	Part 2	357	44%	fails Part 2	44%
Capitol Lake												
13-CAP-00.4	16	3.9	50			6%	100				meets	
Percival Creek Watershed												
13-BLA-00.0	15	21.3	50			0%	100				meets	
13-BLA-02.3	16	5.6	50			0%	100				meets	
13-PER-00.1	16	44.0	50			13%	100	Part 2	152	34%	fails Part 2	34%
13-PER-01.0	16	93.5	50	Part 1	47%	44%	100	Part 2	171	41%	fails both	47%
Budd Inlet Tributaries												
13-ADA-00.5	16	22.1	100			6%	200				meets	
13-ADA-UNK	10	2668	100	Part 1	96%	90%	200	Part 2	18736	99%	fails both	99%
13-BUT-00.1	16	60.7	100			6%	200				meets	
13-ELL-00.0	16	132.5	100	Part 1	25%	25%	200	Part 2	1082	82%	fails both	82%
13-IND-00.2	16	540.8	100	Part 1	82%	81%	200	Part 2	1841	89%	fails both	89%
13-MIS-00.1	16	173.5	100	Part 1	42%	50%	200	Part 2	425	53%	fails both	53%
13-MOX-00.0	15	438.3	100	Part 1	77%	93%	200	Part 2	1239	84%	fails both	84%
13-MOX-00.6	15	177.5	100	Part 1	44%	47%	200	Part 2	538	63%	fails both	63%
13-SCH-00.1	13	23.6	100			0%	200				meets	

Table 21. Target reductions necessary to achieve water quality standards during the winter season (October through April).

Station	Count	Water Quality Standards Part 1				Water Quality Standards Part 2					Overall	
		Geo-mean	Target	Vio-lation?	Percent Re-duction	% >Target	Target	Vio-lation?	90%ile	Percent Re-duction	Meets WQS?	Percent Re-duction
Deschutes River												
13-DES-00.5	18	9.1	100			0%	200					meets
13-DES-02.7	18	6.5	100			0%	200					meets
13-DES-05.5	14	13.2	100			0%	200					meets
13-DES-09.2	14	13.3	100			0%	200					meets
13-DES-20.5	14	6.5	50			0%	100					meets
13-DES-28.6	18	8.1	50			6%	100					meets
Tributaries to Deschutes River												
13-AYE-00.0	21	10.3	100			10%	200				meets	
13-CHA-00.1	18	9.9	100			0%	200				meets	
13-HUC-00.3	14	1.3	100			0%	200				meets	
13-REI-00.9	18	24.8	100			6%	200				meets	
13-SPU-00.0	22	11.2	100			0%	200				meets	
Capitol Lake												
13-CAP-00.4	18	15.9	50			11%	100	Part 2	144	30%	fails Part 2	30%
Percival Creek Watershed												
13-BLA-00.0	22	10.4	50			9%	100				meets	
13-BLA-02.3	22	7.0	50			5%	100				meets	
13-PER-00.1	22	13.4	50			5%	100				meets	
13-PER-01.0	21	27.8	50			14%	100	Part 2	152	34%	fails Part 2	34%
Budd Inlet Tributaries												
13-ADA-00.5	21	53.5	100			24%	200	Part 2	617	68%	fails Part 2	68%
13-ADA-UNK	11	351.5	100	Part 1	72%	64%	200	Part 2	5069	96%	fails both	96%
13-BUT-00.1	22	33.4	100			9%	200				meets	
13-ELL-00.0	21	33.3	100			19%	200	Part 2	203	2%	fails Part 2	2%
13-IND-00.2	22	104.7	100	Part 1	5%	32%	200	Part 2	646	69%	fails both	69%
13-MIS-00.1	22	66.1	100			27%	200	Part 2	880	77%	fails Part 2	77%
13-MOX-00.0	22	330.6	100	Part 1	70%	68%	200	Part 2	1295	85%	fails both	85%
13-MOX-00.6	22	62.8	100			23%	200	Part 2	433	54%	fails Part 2	54%
13-SCH-00.1	17	15.2	100			12%	200	Part 2	130	nom 10%	fails Part 2	nom 10%

Table 22. Target reductions necessary to achieve water quality standards during storm events in the winter season (October through April).

Station	Count	Water Quality Standards Part 1				Water Quality Standards Part 2					Overall	
		Geomean	Target	Violation?	Percent Reduction	% >Target	Target	Violation?	90%ile	Percent Reduction	Meets WQS?	Percent Reduction
13-BUT-NW	6	40.8	100			16.7%	200	Part 2	283	29%	fails Part 2	29%
13-BUT-SE	6	69.9	100			16.7%	200	Part 2	200	nom 10%	fails Part 2	nom 10%
13-BUT-SW	6	155.8	100	Part 1	36%	66.7%	200	Part 2	392	49%	fails both	49%
13-ELL-33RD	6	103.9	100	Part 1	4%	66.7%	200	Part 2	294	32%	fails both	32%
13-IND-12TH	5	34.3	100			0.0%	200				meets	
13-IND-BOUL	6	332.0	100	Part 1	70%	83.3%	200	Part 2	1294	85%	fails both	85%
13-IND-FRED	6	303.6	100	Part 1	67%	83.3%	200	Part 2	822	76%	fails both	76%
13-IND-MART	6	846.2	100	Part 1	88%	100.0%	200	Part 2	7353	97%	fails both	97%
13-IND-SBAY	6	367.6	100	Part 1	73%	66.7%	200	Part 2	2201	91%	fails both	91%
13-IND-WHEE	6	393.0	100	Part 1	75%	100.0%	200	Part 2	837	76%	fails both	76%
13-MIS-BETH	6	268.6	100	Part 1	63%	100.0%	200	Part 2	549	64%	fails both	64%
13-MIS-ETHR	6	143.7	100	Part 1	30%	50.0%	200	Part 2	422	53%	fails both	53%
13-MOX-5TH	12	103.0	100	Part 1	3%	58.3%	200	Part 2	1257	84%	fails both	84%
13-MOX-8TH	7	203.6	100	Part 1	51%	85.7%	200	Part 2	479	58%	fails both	58%
13-MOX-PARK	6	38.3	100			50.0%	200	Part 2	421	52%	fails Part 2	52%
13-MOX-PLUM	6	99.1	100			66.7%	200	Part 2	337	41%	fails Part 2	41%
13-PER-54TH	6	62.0	50	Part 1	19%	33.3%	100	Part 2	217	54%	fails both	54%
13-SPU-EQUU	6	18.4	100			0.0%	200				meets	
13-SPU-LATI	6	19.4	100			0.0%	200				meets	
13-SPU-MOOD	6	18.4	100			0.0%	200				meets	

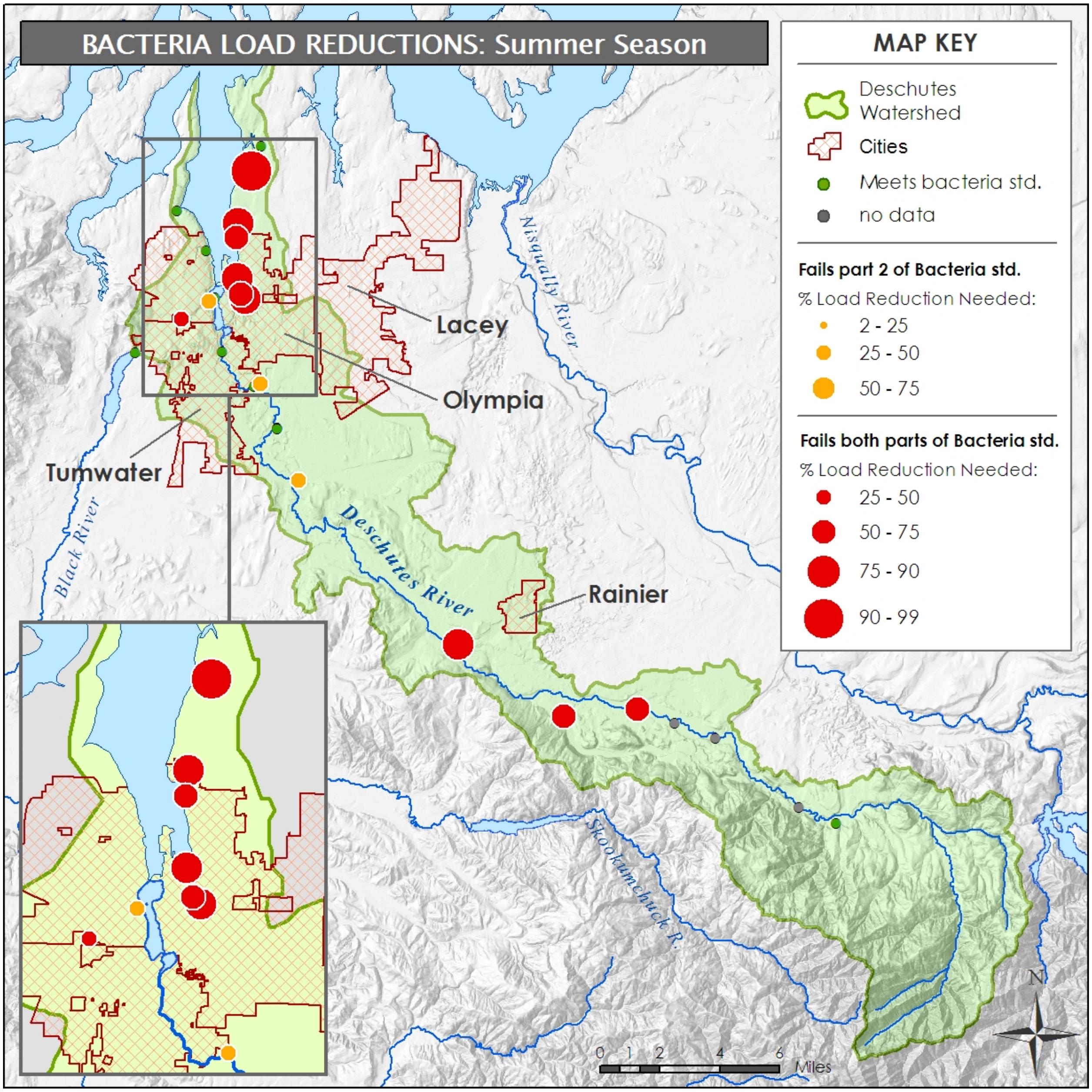


Figure 35. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the summer season (May through September).

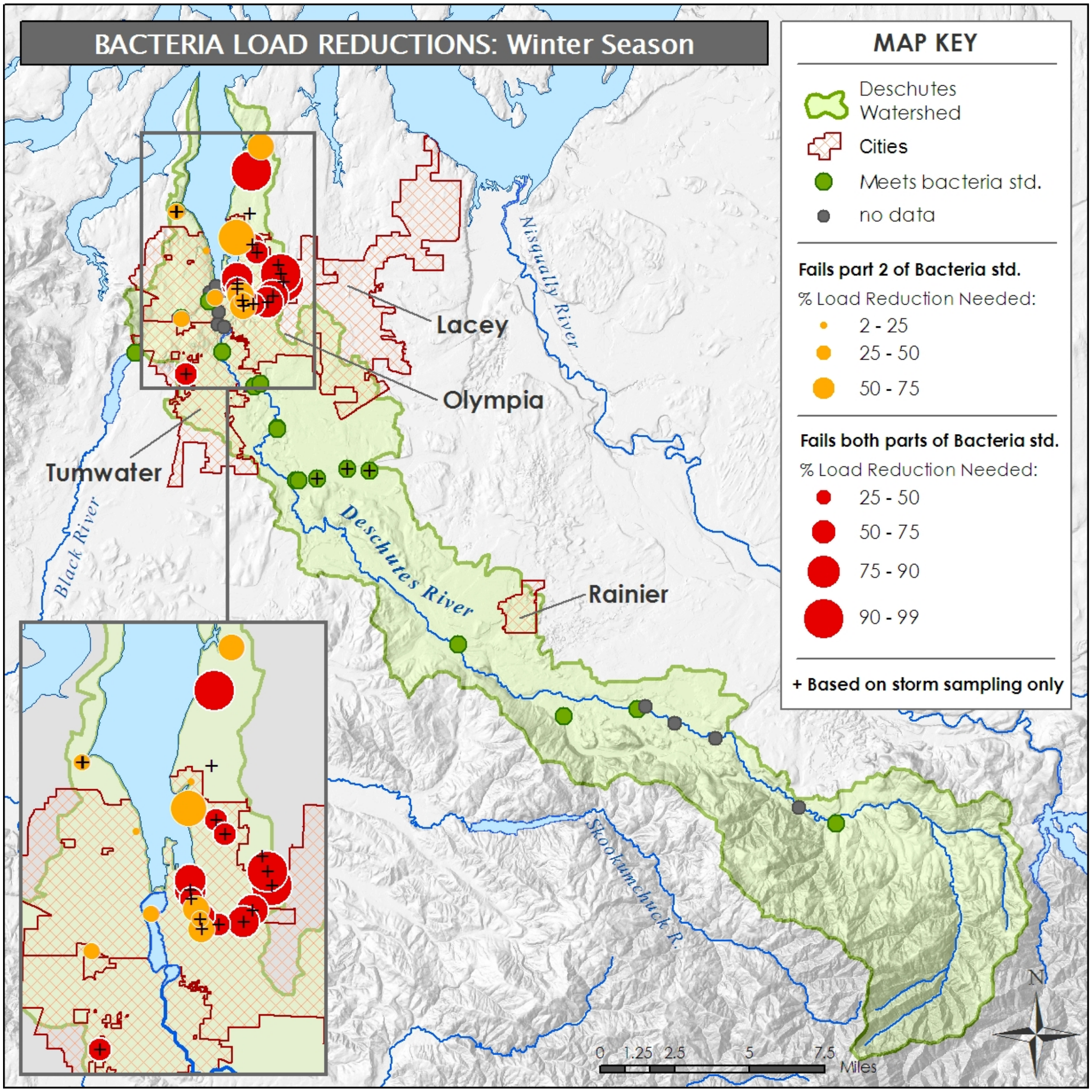


Figure 36. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the winter season (October through April).

Wasteload Targets

Wasteload targets represent the pollution reduction targets for point sources and other sources that are covered under a NPDES permit. No load reduction targets were developed for Budd Inlet because it was not on the 303(d) list for fecal coliform bacteria when the project began. Therefore, the NPDES permits for fecal coliform bacteria discharges from the four individual wastewater treatment plants listed in Table 5 are not affected by this study. However, facilities and jurisdictions covered by general permits are included in this study, and some have the potential to produce or transport fecal coliform bacteria.

Fecal coliform reduction areas include areas covered by the Phase II and WSDOT municipal stormwater NPDES permits. Elevated fecal coliform values in stormwater runoff from developed land, including highways, are well established (Pitt et al., 2004; White, 2005). During both routine monitoring and targeted stormwater monitoring, the tributaries to Budd Inlet with high development levels had bacteria levels that did not meet water quality standards. Ongoing efforts by Thurston County and the City of Olympia continue to identify sources of high levels within the study watersheds and elsewhere. In addition to the requirements outlined in the stormwater general permits, jurisdictions should focus source identification and management efforts in the areas with fecal coliform reduction targets identified in this study.

Facilities covered by the Sand and Gravel General Permit are not expected to contribute significant sources of fecal coliform bacteria. No additional permit requirements are recommended beyond the good housekeeping practices outlined in the current permit.

Facilities covered by the Industrial Stormwater General Permit or Construction Stormwater General Permit have a low potential for contributing or transporting fecal coliform bacteria. No additional permit requirements are recommended beyond the good housekeeping practices outlined in the current permits.

Conclusions and Recommendations

Bacteria levels do not meet the water quality standards during both the summer growing season and winter non-growing season. Reductions are needed in both seasons, as summarized in the tables above. Additional source identification is warranted in many locations.

Reductions are necessary throughout the watershed, but the highest reductions are needed in small tributaries to Budd Inlet. Immediate efforts should focus on identifying and reducing sources in the tributaries to Budd Inlet, building from past efforts by the City of Olympia and others. Urban areas include a variety of potential sources, including cross-connected infrastructure, failing septic systems, domestic animals, recreational users, and homeless populations. Stormwater should receive particular attention.

Two locations along the Deschutes River (13-DES-20.5 and 13-DES-28.6) did not meet Part 2 of the water quality standards, and further source identification is recommended. Bacteria concentrations decline further downstream, and downstream sources do not appear to cause violations.

Dairies have the potential to contribute fecal coliform bacteria to the Deschutes River. Both operations should be evaluated for overall facility management and manure applications in particular. Additional water quality monitoring may be warranted.

Ecology staff noted cows on the banks and fecal material in the river and on gravel bars between Old Camp Lane (13-DES-32.3) and the Lake Lawrence tributary (13-LLT-00.0). This site should be evaluated for fencing and waste management.

While Black Lake Ditch meets the water quality standards, Percival Creek does not, and additional source identification is warranted. Potential sources include recreational users and homeless populations.

While the railroad trestle at Capitol Lake (13-CAP-00.4) meets the water quality standards in the summer, it fails Part 2 in the winter. Additional monitoring and source identification is recommended. Summer 2003 and 2004 supplemental monitoring did not identify sources of concern.

If future source tracking surveys in the watershed identify sources other than wildlife in streams not meeting standards, future management programs should eliminate human and domestic animal sources.

In keeping with the antidegradation policy in the state's water quality standards, areas where the current water quality is better than the water quality criteria should be considered during development of the Implementation Strategy for this TMDL. Specific actions and/or institutional safeguards may be necessary to prevent a loss in current water quality conditions in these areas as further development or other changes occur in the watershed.

Recommendation for Future Growth

This fecal coliform bacteria TMDL does not include a specific reserve capacity for future growth. Future monitoring programs should quantify both the effect of growth since the study was conducted as well as the beneficial effect of ongoing management practices.

Margin of Safety

A margin of safety to account for scientific uncertainty must be considered in all TMDLs to ensure that the targets will protect water quality in cases when the data and other factors in the analysis are naturally variable or unknown. The margin of safety for this fecal coliform TMDL analysis is implicit through the use of conservative assumptions in project design and analysis.

Target reductions generally were based on the 90th percentile of fecal coliform concentrations. 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 of high fecal coliform values is likely to decrease, which should reduce the variance and 90th percentile of the post-management condition. In addition, the estimated targets do not account for any bacterial die-off in the water column during travel from the source.

Temperature

Analytical Framework

The QUAL2Kw model (Pelletier and Chapra, 2006) was used to simulate temperature within the mainstem of the Deschutes River based on data collected during this TMDL study. QUAL2Kw uses effective shade based on a GIS analysis of vegetation and channel characteristics. The Percival Creek watershed temperature load reduction targets are based on an assessment of current and potential future effective shade. Based on data collected in 2003, Huckleberry Creek meets the water quality standards and no temperature reductions are necessary. However, several other nearby tributaries do not meet the water quality standards, and targets are based on the need to meet the numeric criteria to improve temperatures in the Deschutes River, as well as within the tributaries.

QUAL2Kw is a one-dimensional, steady-state model with diel heat and water quality kinetics that simulates hourly temperatures for a single flow condition. Hydraulic parameters such as discharge and velocity vary from upstream to downstream in the one-dimensional system, but time-varying flows cannot be simulated. Flows and heat are well mixed both vertically and laterally within the 1-km computational elements. Temperature is the equivalent concentration of heat within the surface water. QUAL2Kw simulates the surface water heat budget, including the effects of solar radiation, atmospheric exchange, point sources, and diffuse sources (Chapra, 1997). Solar radiation, relative humidity, headwater temperature, and tributary water temperatures were based on diurnally varying functions.

The Shade.xls spreadsheet model (Ecology, 2003) estimates effective shade for the river surface based on the geometry of each reach and the attenuated shade through the riparian vegetation canopy (Chen, 1996; Chen et al., 1998a; Chen et al., 1998b). Shade.xls calculations are date specific because the solar azimuth angle varies with time of year, and the angle affects the shade calculations.

Deschutes River Physical Model Configuration

To represent longitudinal variation, the Deschutes River was divided into 100-m units using TTools (ODEQ, 2001) to sample and process GIS data for input to both the Shade.xls model and QUAL2Kw. The stream channel centerlines, left bank, right bank, and near-stream disturbance zone (encompassing exposed gravel bars within the channel migration zone) were digitized from color aerial photographs provided by Thurston County (1-ft resolution). TTools was used to segment the centerline into 692 point locations to simulate 69 km (43 mi) of the Deschutes River from the upper falls through the lower falls. Model distances were kilometers from the headwaters at the Deschutes Falls, rather than river miles from Capitol Lake upstream. Figure 37 presents a link between river miles and river kilometers for comparison.

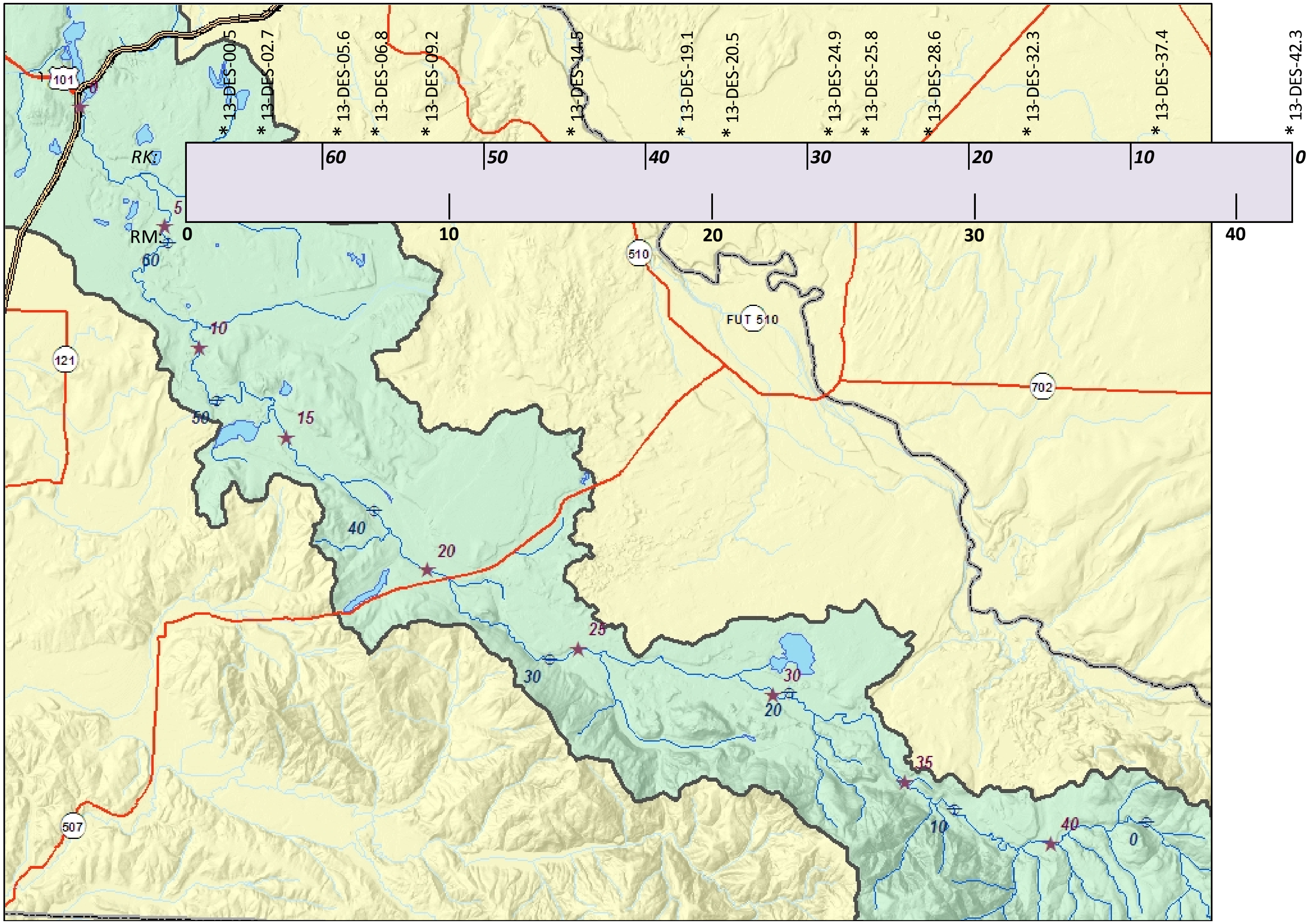


Figure 37. Deschutes river lengths as river miles (RM, purple circles and text) upstream of Capitol Lake and river kilometers (RK, purple stars and text) downstream of the upper Deschutes River falls. Scale bar includes stations.

Stream channel centerline elevations at each 100-m point were derived from LiDAR bare earth (surface) grids provided by the Puget Sound LiDAR Consortium. Channel elevations were smoothed in Excel to eliminate pits and valleys by interpolating over adjacent segments. The smoothed elevations were used to calculate slopes for the 1-km simulation reaches. Latitude and longitude for both Shade.xls and QUAL2Kw were based on values near the middle of the Deschutes River.

Riparian vegetation was digitized from digital color orthophotos. A LiDAR-based grid of vegetation heights was developed by subtracting the bare earth elevations from the first-return (top of vegetation) elevations. Vegetation polygons were assigned a characteristic height class based on the tallest dominant vegetation from the LiDAR-based vegetation heights. Forest type (conifer, deciduous, mixed) was derived from visual interpretation of aerial photographs confirmed with field observations, and percent cover was based on values previously used in western Washington. Table 23 summarizes riparian vegetation characteristics by code.

Table 23. Riparian vegetation codes and characteristics used for the Deschutes River watershed.

Code	Description	Height (m)	Density (%)	Overhang (m)
200	Water, gravel bars	0.0	25%	0.0
300	Pasture, open, agriculture, scattered trees	0.5	75%	0.0
302	Road, pavement, barren, buildings	0.0	25%	0.0
400	Gravel bars	0.0	75%	0.0
500	Shrub	2.0	75%	0.5
600	Small conifer	15.0	95%	1.5
601	Medium conifer	30.0	95%	3.0
602	Large conifer	50.0	95%	4.5
603	XL conifer	60.0	95%	5.5
700	Small deciduous	15.0	90%	1.5
701	Medium deciduous	30.0	90%	3.0
702	Large deciduous	50.0	90%	4.5
703	XS deciduous	10.0	90%	1.0
800	Small mixed	15.0	95%	1.5
801	Medium mixed	30.0	95%	3.0
802	Large mixed	50.0	95%	4.5
803	XS mixed	10.0	95%	1.0

XL = Extra large; XS = Extra small.

Vegetation type was sampled at nine 4.5-m (15-ft) intervals from the streambank perpendicular to the stream aspect. The hourly effective shade was calculated based on the geometry of the channel, vegetation, and solar position. Results were compared with the in-situ shade values determined from the processed HemiView photos. Vegetation heights were increased for the large and extra large categories from 45 to 50 m and from 50 to 60 m to match in-situ values more closely. Stream reach (100 m) aspect was calculated using TTools, and Shade.xls was used to calculate the topographic shade angles for all four cardinal directions using the 30-m (32.8-ft) statewide elevation grid.

Channel incision was calculated as the difference in the channel elevation and the first riparian vegetation sampling location, where the elevations of both points were determined from the LiDAR-based digital elevation models (DEMs). Results were smoothed to remove outliers.

Percival Creek Physical Model Configuration

Percival Creek and Black Lake Ditch were segmented into 100-m units. TTools was applied to develop channel and riparian vegetation using the same processes as for the Deschutes River. Because much of the stream channels were not visible in orthophotos, stream widths were set to constant values based on flow gaging values. Black Lake Ditch was set to 4.0 m, Percival Creek upstream of the Black Lake Ditch confluence to 2.3 m, and lower Percival to 5.0 m. Vegetation was digitized 50 m to either side of the streams. Similar vegetation codes were applied as for the Deschutes River, and the Shade.xls model was used to quantify effective shade under current vegetation. The National Wetland Inventory was used to identify wetlands.

Deschutes River Seasonal Variation and Critical Conditions

Temperature probes installed at two locations in the Deschutes River watershed have been operational since 2003 and include year-round water temperatures. The peak water temperatures occur in the summer months, as shown in Figure 38. In TMDL studies, critical conditions are selected for individual systems based on in-situ monitoring data. For the Deschutes River, peak 7-day averages of daily maximum temperatures occur between July 20 and August 10, based on five years of data (7 yrs at 13A060) and neglecting the 2007 values that were influenced by unusual July storm events. Peak temperatures and the dates of occurrence are presented in Table 24, including Ecology’s ambient monitoring station 13A060 at the E Street bridge.

The calibration and validation conditions were not unusual compared with the longer period of record at these three sites. For the five-year record at Vail Loop Road (13-DES-24.9), water temperature in summer 2006 was slightly hotter than 2004, the next hottest on record. At 13-DES-33.5, the hottest year on record was 2004, followed by 2006, and the same pattern was recorded at 13A060. Peak temperatures did not meet the water quality standards in any of the years monitored for any of the three stations.

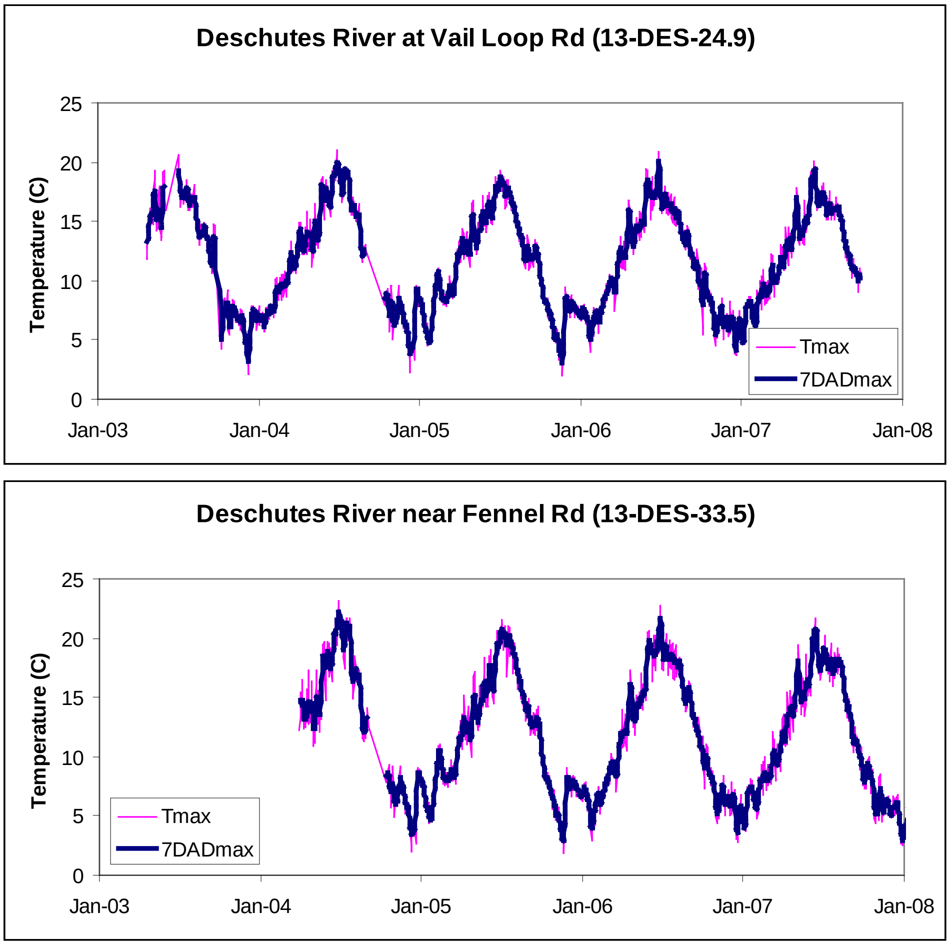


Figure 38. Long-term monitoring of surface water temperature in the Deschutes River watershed.

Table 24. Peak summer temperatures since 2003.

Year	13-DES-24.9		13-DES-33.5		13A060	
	7-DADMax	Date of peak	7-DADMax	Date of peak	7-DADMax	Date of peak
2001	NA	NA	NA	NA	19.4	8/10/01
2002	NA	NA	NA	NA	19.1	7/21/02
2003	19.28	8/1/03	NA	NA	19.9	7/20/03
2004	20.00	7/25/04	22.15	7/26/04	20.5	7/26/04
2005	18.81	7/30/05	20.77	7/28/05	19.6	7/28/05
2006	20.04	7/24/06	21.68	7/24/06	20.3	7/24/06
2007	19.36	7/13/07	20.75	7/12/07	18.2	7/30/07

Both 13-DES-24.9 and 13-DES-33.5 are within the *Core Summer Salmonid Habitat* designated use area. The Vail Loop Road site did not meet the 16ºC water quality standard for 306 days over five years or, typically, 61 days per year. The 7-day average of the daily maximum temperature also did not meet the water quality standard for an average of 61 days per year. At the upstream 13-DES-33.5 site, the water quality standard either in terms of daily maximum or 7-day average of the daily maximum temperature was not met during an average of 87 or 85 days, respectively, over the 2004-2007 sampling period at that site.

Calibration and Validation of Deschutes River QUAL2Kw Model

Calibration and the warm validation time periods were selected using annual peaks in the 7-day average of daily maximum temperatures in 2004 and 2003. Cool validation periods were selected to avoid storm events. Table 11 summarized the various calibration and validation time periods and conditions. Figure 39 illustrates the discharge patterns, survey timing, and the context for the calibration and validation time period selection.

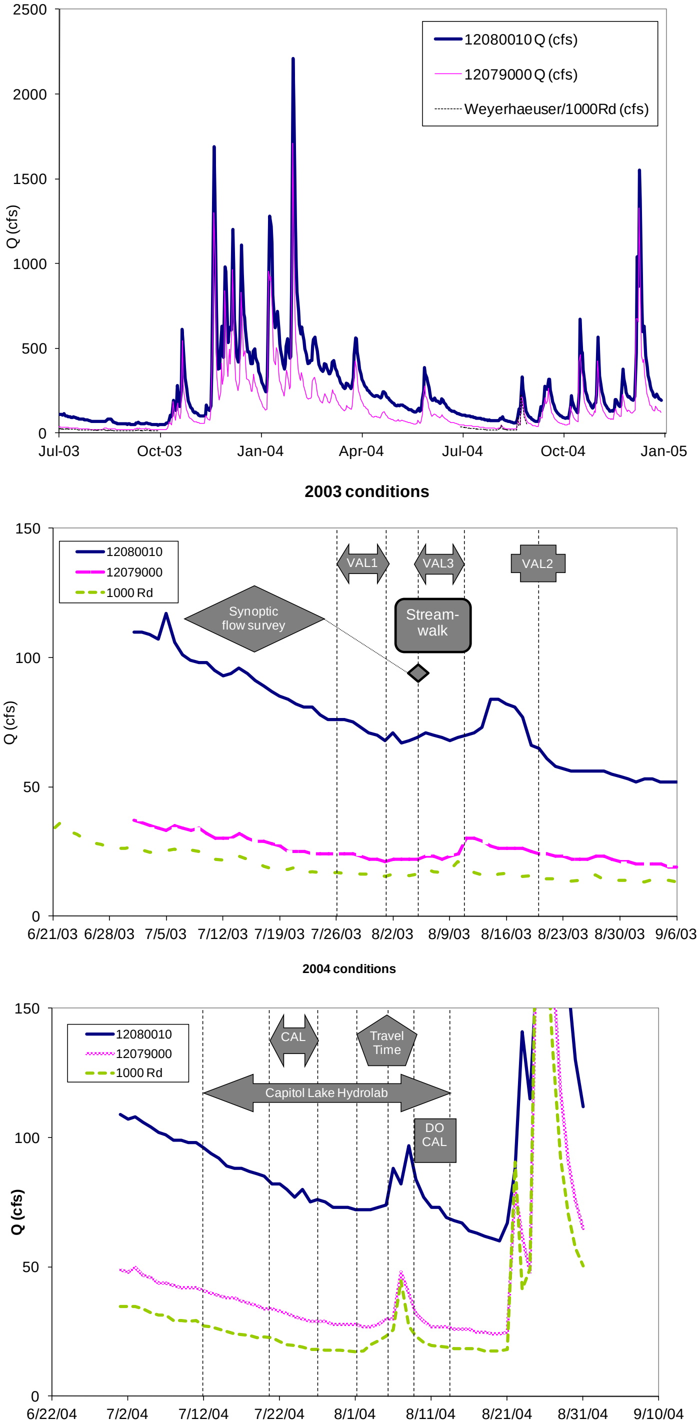


Figure 39. Discharge at the USGS and Weyerhaeuser long-term gaging sites for the 2003-04 study period, including the dates selected for calibration and validation of the QUAL2Kw model.

Dashed boxes in the top chart highlight the time periods plotted in the two lower charts.

QUAL2Kw Temperature Model Calibration

Input Parameters

Hydraulics

Manning's equation was used to describe hydraulic and transport properties within the Deschutes River. Manning's n values could be developed for most of the watershed from the tracer study, which quantified travel time and reach-averaged velocity for different segments of the Deschutes River.

Because most river channels are much wider than they are deep, the hydraulic radius (R) can be estimated as the water depth (d):

$$R = \frac{A}{P} = \frac{Wd}{W + 2d} \sim d$$

Where A is the cross-sectional area, P is the wetted perimeter, and W is the channel width.

Reach-averaged velocities for 10 river segments from the tracer study were presented in Table 13. During the synoptic survey, channel depths were consistent among sites and averaged 0.35 m, and wetted widths averaged 15 m, consistent with the values estimated using the GIS datalayer. Using the TTools-derived channel widths, there is no strong relationship with river distance; therefore, values from the GIS datalayer were used for bottom width in the hydraulic characteristics. Hydraulic characteristics are fairly insensitive to side slopes, and typical values of 3:1 were used. From the tracer study, calculated Manning's n values for the ten reaches between RM 28.6 and RM 0.5 ranged from 0.11 to 0.18, with an average of 0.16. The final calibration uses a constant Manning's n value of 0.14 throughout the system to provide the best fit to the travel time data.

Flow distribution was based on the detailed August 2003 synoptic survey, which was conducted at low flows (the USGS gages at Rainier and E Street were 22 and 69 cfs, respectively). During the tracer study, discharge was similar (the USGS gages at Rainier and E Street were 27 and 72 cfs, respectively) but slightly higher at 1000 Rd during a storm event. Discharge during the calibration time period also was slightly higher than during the synoptic flow study, and the synoptic flows were scaled accordingly. The synoptic survey flow distribution was scaled by the ratio of discharge at the 1000 Road gage (headwater), Rainier gage (upper), or the E Street bridge gage (lower) to simulate different low-flow time periods.

Reach Thermal Properties

QUAL2K guidance was used to select values for sediment thermal properties. Sediment thermal conductivity was set to 1.82 W/m-°C as the highest value for sand with 23% saturation. Similarly, sediment thermal diffusivity was set to 0.0126 cm^2/s.

The sediment hyporheic zone thickness was set to 50 cm, a typical value for a non-gaining reach from the hydrogeology study (Sinclair and Bilhimer, 2007). The value was established by evaluating frequency of temperature fluctuations at three depths below the sediment surface. The near-surface temperature probes generally recorded diel fluctuations in temperature, whereas those located 1 m below the surface generally demonstrated only seasonal fluctuations. The mid-depth temperature probe was the transition between daily and seasonal patterns.

Hyporheic exchange flow, or the proportion of surface discharge exchanged with the hyporheic zone within a simulation reach, was set to 10%, except for those reaches within geologic units with permeable soils, which were set to 30%. Hyporheic sediment porosity was set to 40%, as a value typical of cobble, sand, silt systems.

Meteorology

For the calibration time period, 16 riparian air temperature records were available (Figure 9). The hourly data show a typical summer pattern of minimum temperatures of 11.2 to 14.1ºC around 6:00 a.m. and peaks of 25.3 to 33.0ºC around 4:00 p.m. However, the data do not show a strong upstream to downstream pattern. The coolest temperatures occurred at RMs 5.6, 12.1 and 37.4, while the warmest occurred at RMs 9.2 and 22.7. Therefore, the average hourly air temperature across all 16 monitoring stations was used; the composite record had 7-day average hourly minimum and maximum temperatures of 12.9 and 28.5ºC, respectively.

The 7-day average of the hourly values for the two dewpoint monitoring stations (RM 00.5 and RM 37.4) was used throughout the model domain (Figure 10).

Olympia Airport meteorology data were used for winds and cloud cover (Figure 11). For the calibration period, the 7-day average of hourly wind speeds and cloud cover were used.

Shade.xls model

The Shade.xls model was used to estimate topographic and vegetation shade to the mainstem Deschutes River, based on the digitized stream and riparian vegetation characteristics.

Topographic shade quantifies the amount of solar radiation blocked by the surrounding landforms only and does not include the effect of riparian vegetation. Topographic shade angles were developed from TTools by sampling elevations of the LiDAR DEM. Topographic shade ranges from 0 to 35.5% of the incoming solar radiation, based on the solar position on July 24, 2004, but the average topographic shade between the upper and lower falls is 5%.

The Shade.xls model quantifies the solar radiation above and below the vegetation canopy and calculates effective shade as the reduction in solar radiation at the water surface. Estimates include the effect of channel incision. The attenuation of solar radiation is calculated sequentially through multiple riparian vegetation zones. The sum of topographic shade and vegetation shade ranged from 0.4 to 98.6% for each of the 100-m segments, while the 1-km smoothed shade curve followed the HemiView images and ranged from 15 to 89% (Figure 40). The average current effective shade is 47% over the length of the Deschutes River.

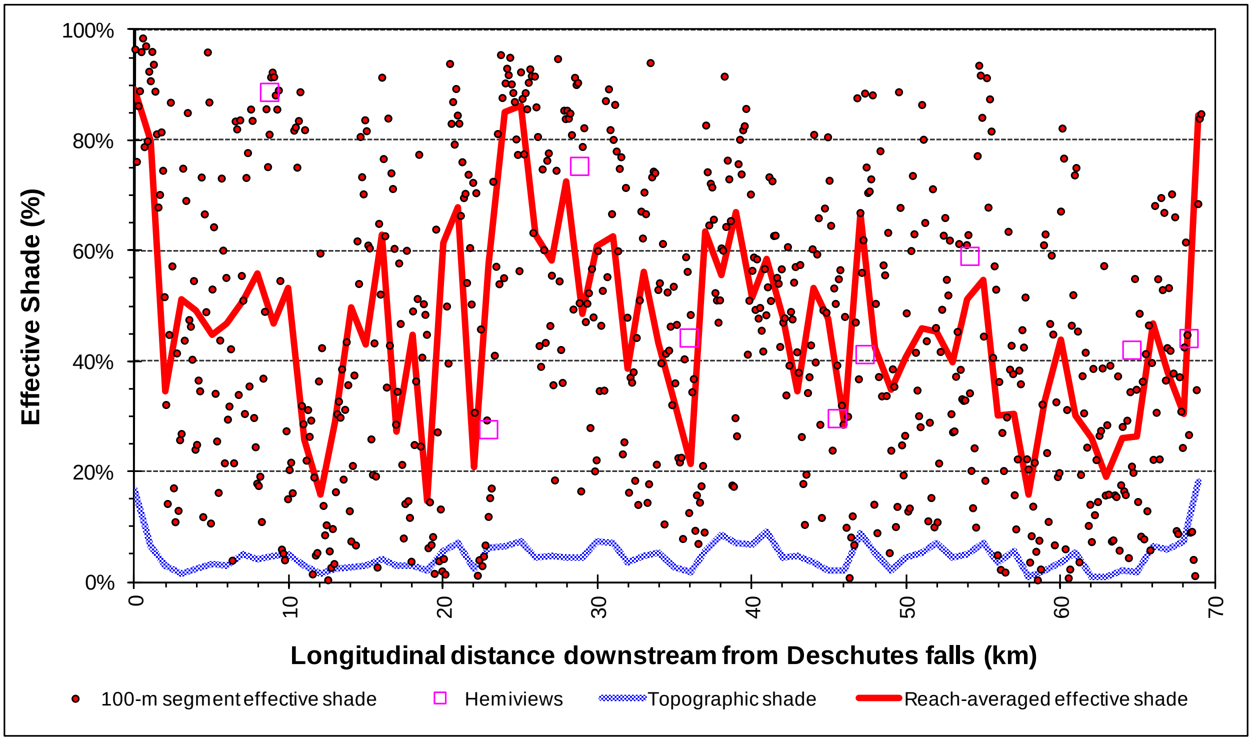


Figure 40. Effective shade based on current vegetation and July 24, 2004 solar characteristics.

Point Sources

Tributaries are represented as point sources that enter the mainstem Deschutes, and flows were scaled. Water temperatures were estimated from 2003 data, because no Tidbits were installed in tributaries in 2004. The 2003 and 2004 annual peak 7-day average of the daily maximum temperature throughout the mainstem of the Deschutes River were highly correlated (Figure 41), and the regression relationship was used to estimate 2004 annual peak 7-day average of the daily maximum tributary temperatures. The daily minimum temperatures also were correlated, and the relationship was used to estimate 2004 tributary daily minimum temperatures from 2003 data. The method was checked for three sites in the Percival Creek watershed with 2003 and 2004 data. The relative standard deviation (RSD) between the estimated and the measured values were minimal, ranging from 0.15% to 0.85%, and the approach was appropriate.

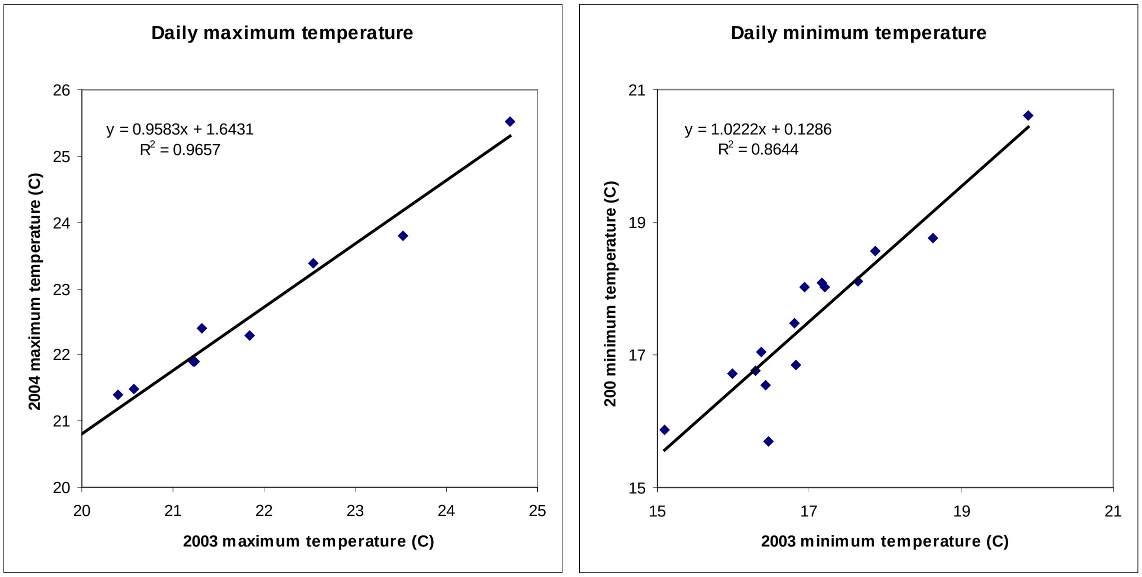


Figure 41. Relationships between 2003 and 2004 7-day average of daily maximum and minimum surface water temperatures in the mainstem of the Deschutes River.

Silver Spring's temperature profile was not well represented by the other monitored locations. The July and August water temperature at 13-SIL-00.4 ranged from 10 to 14ºC, typical of a spring-fed system with limited diel fluctuations. Therefore, the mean daily maximum and minimum temperatures from 2003 were used to estimate conditions for 2004.

In addition, several unnamed creeks were included in the synoptic survey, but no TidBits were installed; these temperatures were estimated from adjacent similar watersheds. The Lake Lawrence tributary had no continuous temperature data (the TidBit was lost in 2003). The temperature characteristics of Reichel Creek were used as an initial estimate for the Lake Lawrence tributary, although the tributary likely has a higher heat load than Reichel Creek because of the heat absorbed in the lake surface area. No temperature monitoring was conducted for the unnamed creek on the west side of the Deschutes River downstream of Chambers Creek, and the Percival Creek (above the Black Lake Ditch confluence) characteristics were used to estimate.

Diffuse Sources

For flow regimes other than the synoptic survey, the diffuse inflows were calculated by difference and were scaled based on the ratio of discharges at the USGS gages. Temperatures were assigned based on 2004 water temperatures in gaining reaches instrumented with piezometers. Temperatures were recorded with monthly nutrient grab samples. Originally the July 28, 2004 temperatures (average 11.2ºC; 10.7ºC at 13-DES-28.6, 11.2ºC at 13-DES-24.9, 11.6ºC at 13-DES-2.7) were used for all groundwater inflows and scenarios, but the value was calibrated to 13ºC.

Headwater

Station 13-DES-42.3 did not have a TidBit deployed in 2004 due to an error in the field program. However, the headwater temperature conditions were estimated from the 1000 Road station (13-DES-37.4) based on the 2003 temperature data. The average hourly temperatures for the period July 27 through August 21, 2003 were calculated for both stations, and the mean difference (1.6ºC cooler at 13-DES-42.3) was used to adjust the 13-DES-37.4 results. Variability related to the headwater temperature was revisited in the sensitivity analyses described below.

Calibration Results

The QUAL2Kw model was calibrated to minimize the root mean square error (RMSE) between the measured and predicted daily minimum and maximum temperatures for the period July 21-27, 2004. RMSE is a measure of the goodness-of-fit, calculated as the deviation of the model from measured values:

$$RMSE = \sqrt{\frac{\Sigma(T_{measured} - T_{predicted})^2}{n}}$$

The parameters varied to improve the RMSE of the calibration run include the hyporheic exchange flow, groundwater temperature, channel width between 13-DES-42.3 and 13-DES-37.4, and Manning’s n. Figure 42 presents the calibrated temperature model, which had a RMSE of 0.85ºC for the daily maximum temperature and 0.92ºC for the combined daily minimum and maximum values. The tributaries generally have a cooling effect on temperatures in the mainstem of the Deschutes River, and warm tributaries do not coincide with the peak temperatures in the Deschutes River. Overall, the model describes the temperature regime of the Deschutes River well.

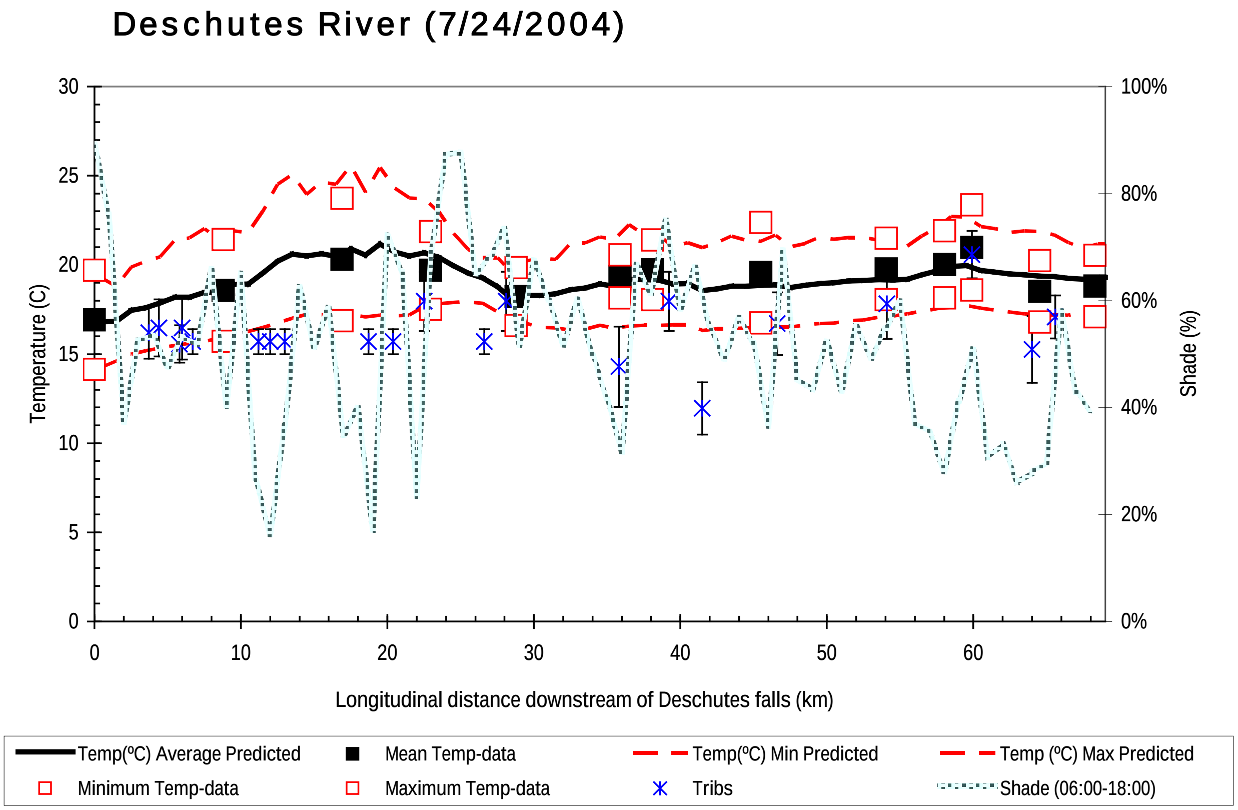


Figure 42. Predicted and observed water temperature in the Deschutes River for the July 21-27, 2004 calibration period.

From the headwaters at the Deschutes Falls, maximum temperatures increased to a peak between river kilometer (RK) 13 and RK 20 (from upstream to downstream), consistent with measured data at station 13-DES-32.3 (Old Camp Lane) and coincident with decreasing discharge in the river through the losing reach. The diel temperature change was largest in this area, both in the measured data and as predicted by the model, indicative of the influence of solar radiation. Peak temperatures and the diel swing decreased between RK 20 and RK 28, coinciding with increases in shade, groundwater inputs, and flow. Peak temperature remained somewhat constant downstream, but a secondary peak in maximum temperatures near RK 60 coincided with a losing reach. The large groundwater inputs downstream of this site produced a cooling effect on surface water temperatures.

QUAL2Kw Temperature Model Validation

The parameters calibrated to the July 21-27, 2004 conditions were held constant and applied to different time periods to validate (others use the terms *verify* or *confirm*) the model application. Three different conditions listed in Table 9 were evaluated, including the peak temperatures from 2003, a cool non-storm period, and the thermal infrared (TIR) survey, which provided highly detailed in-situ temperatures. While the warm and cool validation runs used 7-day average flows, meteorology, and boundary condition temperatures, the TIR validation run used values for the single day of the survey.

Input Parameters

For the validation applications, discharge and temperature were updated for the headwaters, tributaries, and diffuse inflows, as were the meteorology variables. The Shade.xls model was applied with an updated solar azimuth angle but with the same vegetation and channel characteristics used in the calibration.

Hydraulics: No changes were made to channel characteristics, and only the discharge was updated to reflect flow regimes within the three validation time periods. The same flow distribution was used, with the headwater, point sources, and diffuse sources scaled.

Meteorology: Air temperature, dewpoint temperature, wind speed, and cloud cover were updated to the conditions recorded at the Olympia Airport for the three validation time periods.

Shade: The Shade.xls model was applied to the different dates for the three validation time periods, with no changes to the vegetation or channel characteristics.

Point Sources: Tributary discharges were scaled from values recorded in the synoptic surveys based on the upper and lower watershed flow factors described above. Water temperatures recorded during each validation time period were used. Temperatures for several unnamed creeks on the southwest side of the Deschutes River were estimated from values for Fall Creek. Tributaries from Lake Lawrence and McIntosh Lake were assigned the temperatures recorded in Reichel Creek. The unnamed creek on the west side of the Deschutes River downstream of Chambers Creek was assigned the temperatures recorded in the nearby Percival Creek above the confluence with Black Lake Ditch.

Nonpoint Sources: Groundwater influences were calculated for individual reaches based on the scaled flows at the gages and the scaled tributary inflows. Because the overall flows were so similar between the synoptic survey, calibration, and validation time periods, groundwater diffuse sources also were similar but not identical. No changes to groundwater temperature were used in the validation runs.

Headwater: Headwater flow was based on scaling the Weyerhaeuser Company flow gage at 1000 Road for each of the three validation time periods. Actual temperatures recorded at the headwater were used for the three validation time periods.

Validation Results

Figure 43 presents the first validation model run, applied to the peak 7-day average of the daily maximum temperatures recorded in 2003. The RMSE was 0.90ºC for the maximum temperatures and 1.24ºC for the combined minimum and maximum temperatures. Minimum water temperatures were systematically under-predicted. System discharge was 10 to 25% lower than in the 2004 calibration period. Water temperatures in the mainstem Deschutes River averaged 0.8ºC cooler in 2003, compared with 2004, based on monitoring data, and the model simulated cooler conditions than peak 2004 conditions used for the calibration. Cloud cover was slightly greater than during calibration. The patterns in both the data and the model predictions are similar for 2003 and 2004.

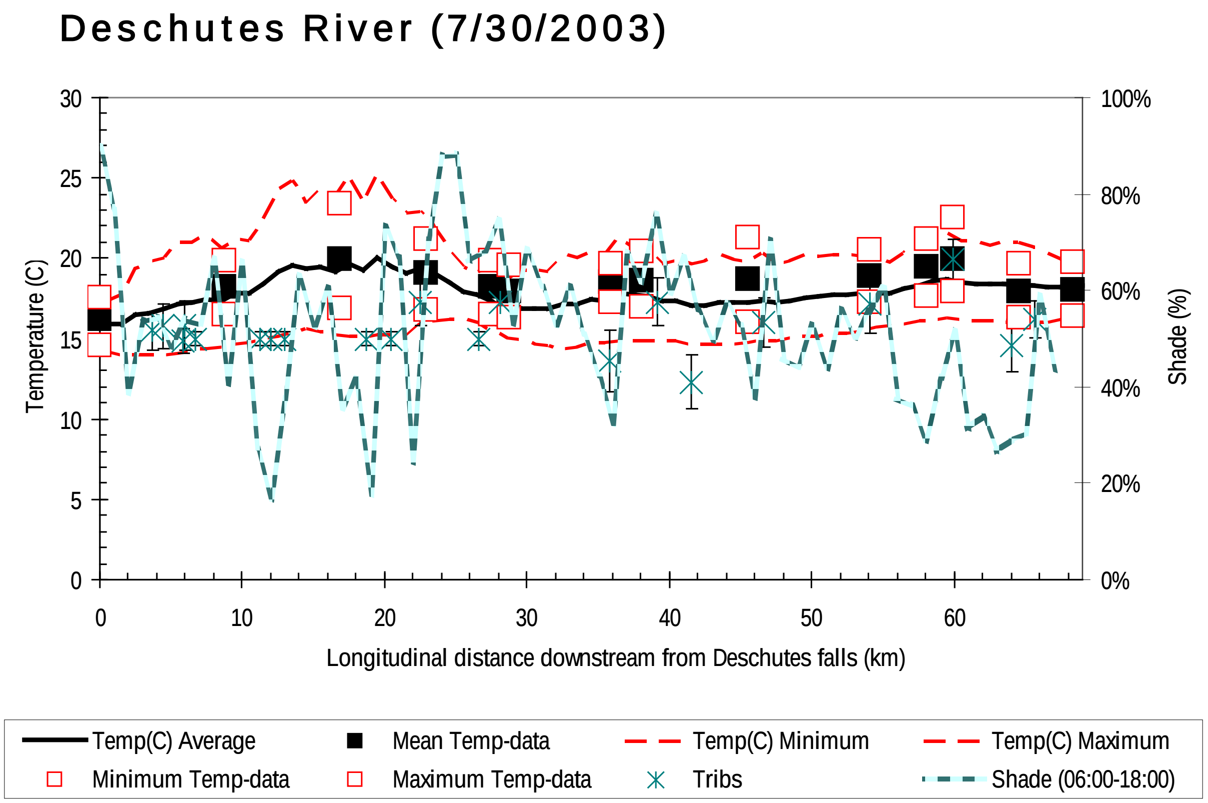


Figure 43. QUAL2Kw model run results for the July 27 through August 2, 2003 validation period (peak daily maximum surface water temperatures).

The TIR survey was conducted after an unusual summer storm had increased flow and cloudy conditions had decreased temperatures along the Deschutes River (Figure 39). River discharges nearly recovered to baseflow values prior to the storm but remained elevated at both USGS gages. In-situ temperatures recorded at Ecology's stations in the mainstem were 2 to 4ºC cooler than the 2004 calibration period. Winds also were stronger, averaging 0.24 m/s. Figure 44 illustrates that, while maximum temperatures were similar between observed data and predicted values, the application consistently under-predicted both the minimum and maximum temperatures in much of the system. Model RMSE was 1.51ºC for maximum values and 2.19ºC for the combined minimum and maximum values. Conditions were cooler throughout the system in both the observed data and model predictions.

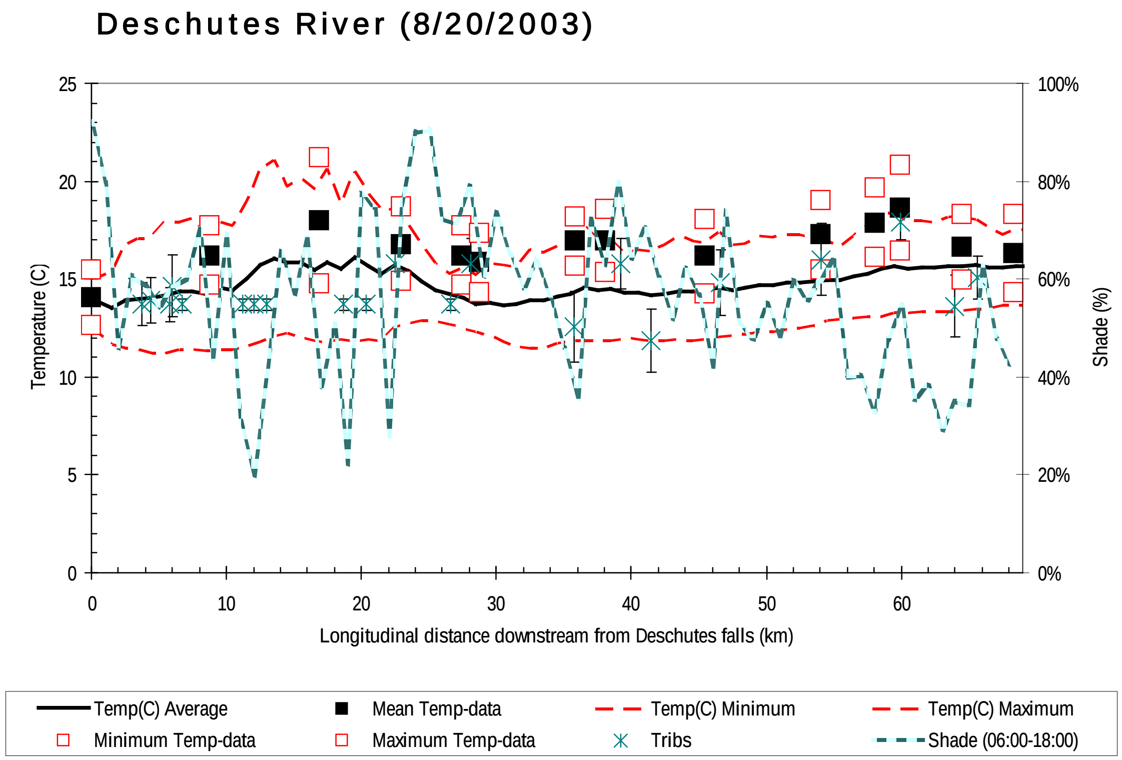


Figure 44. QUAL2Kw model run results for the August 20, 2003 validation period (TIR survey).

The detailed TIR data were smoothed and scaled to the 1-km reaches used in the model. Figure 45 presents the longitudinal profile for the reach-averaged temperature estimated in the TIR survey as well as the lowest and highest instantaneous values within each reach. While the TIR survey was conducted earlier in the day than peak temperatures generally occur, the survey found temperatures similar to those recorded by the Ecology Tidbits (0.1°C mean difference). Individual TIR data values within the smoothed reaches often were higher than recorded at Ecology's monitoring stations. Both programs adhered to quality assurance standards, so the differences likely result from variability within the 1-km reach. The detailed TIR profile also confirms many of the details predicted by the temperature model, including location and magnitude of heating and cooling.

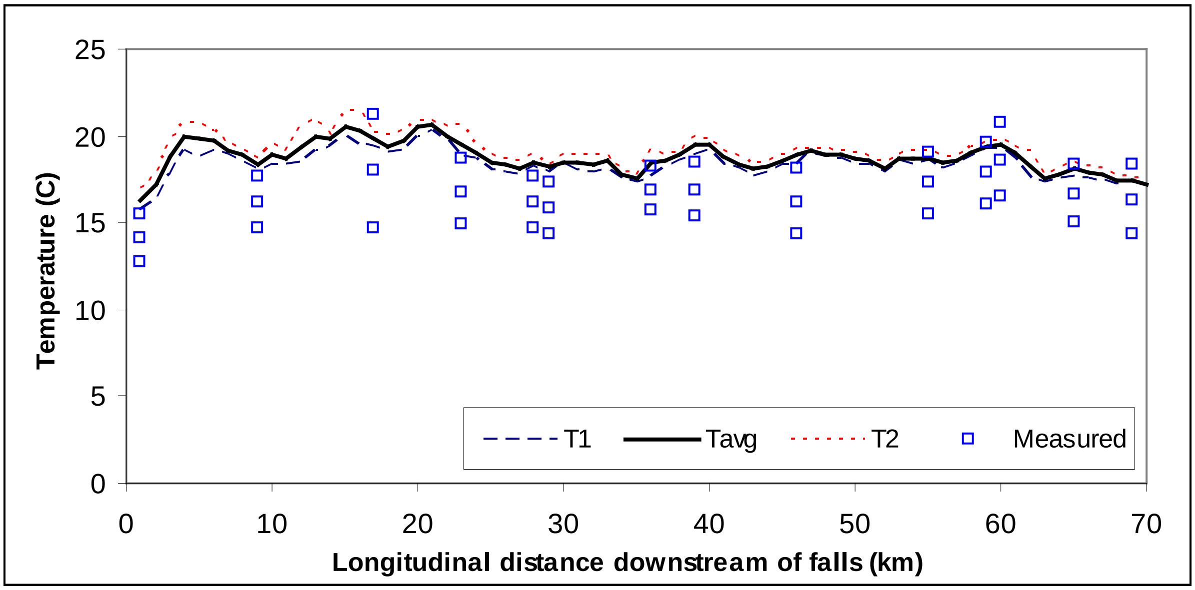


Figure 45. Smoothed TIR results scaled to the river kilometer length scale used in the model.

Data were smoothed over each river kilometer (Tavg), but the lowest (T1) and highest (T2) instantaneous values within each reach are identified.

Measured data include the daily minimum, maximum, and average temperatures recorded at the Ecology stations.

One feature in the TIR data was not predicted by the model. While the model predicted an increase in temperature from the headwater to the first monitoring station, the local high temperature of 20ºC near RK 4 was not simulated. Because groundwater inputs were calculated as the difference in flow between the two stations, groundwater was evenly distributed over the reach. The TIR profile suggests that most of the groundwater is concentrated in the second half of the reach between the headwaters and the first TidBit at 13-DES-37.4. The original calibration parameters were not adjusted, however, since the model fits the available Tidbit data at 13-DES-37.4.

A cool-weather period was selected specifically for validation from the 2003 data, since a summer storm influenced the 2004 late summer conditions (Figure 46). During the cool, non-storm validation time period, water temperatures in the mainstem Deschutes River were 3 to 4ºC cooler than the 2004 calibration period. Minimum daily temperatures also were much cooler, ranging from 14 to 16ºC, and cloud cover was much higher, averaging 41%. The QUAL2Kw model captured the daily minimum and maximum temperatures during this period. Model RMSE was 0.80ºC for maximum temperatures and 0.95ºC for the combined minimum and maximum temperatures.

The model was capable of reproducing the cool, non-storm conditions used for the third validation run. The difficulty in reproducing the conditions during the TIR survey likely reflected transient effects of the storm lingering in the system and may have been influenced by the use of 1-day versus 7-day average conditions for meteorology and hydrology.

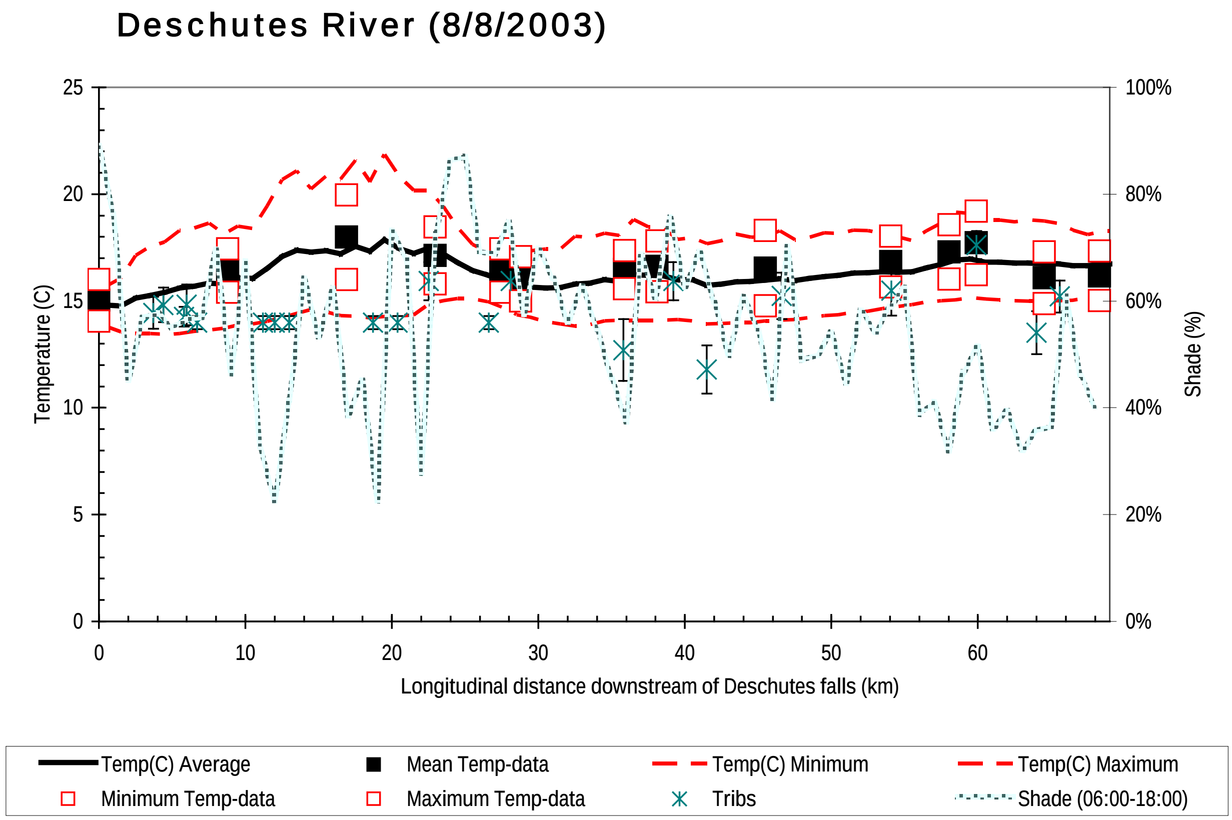


Figure 46. QUAL2Kw model run results for the August 5-11, 2003 validation period (low daily maximum surface water temperatures during non-storm conditions).

QUAL2Kw Temperature Model Sensitivity Analyses

Several sensitivity analyses were run to test various assumptions made during model calibration.

Adjusting the headwater temperature ±2ºC affects downstream values for several kilometers, due in part to the overall decreasing flow in this reach (Figure 47). The influence decreases to under 1ºC within 5 km and to 0.6ºC by the next downstream monitoring station at 13-DES-37.4, leading to an over-prediction, because the headwater was based on the measured temperature at 13-DES-37.4. Within the peak temperature region between RK 12 and RK 20, the effect is 0.3ºC. Because the peak temperature region is not strongly influenced by the headwater temperature, assumptions used to develop headwater temperature do not strongly influence the findings.

The lack of 2004 tributary temperatures warranted estimates based on tributary monitoring for 2003 and the mainstem of the Deschutes River 2003 and 2004 patterns. The tributary temperatures were increased and decreased by 2ºC to reflect potential errors in the assumption. From Figure 48, these assumptions increase or decrease the temperature in the mainstem of the Deschutes River by up to 0.5ºC approximately 6 km from the upper falls and by an average of 0.2ºC throughout the mainstem. Because Mitchell Creek and Thurston Creek have higher flow rates than the other tributaries reaching the upper Deschutes River below the falls, they have the greatest influence. Between RK 12 and RK 20, varying the tributary temperatures by up to 2ºC produces a change in predicted maximum temperatures of up to 0.3ºC.

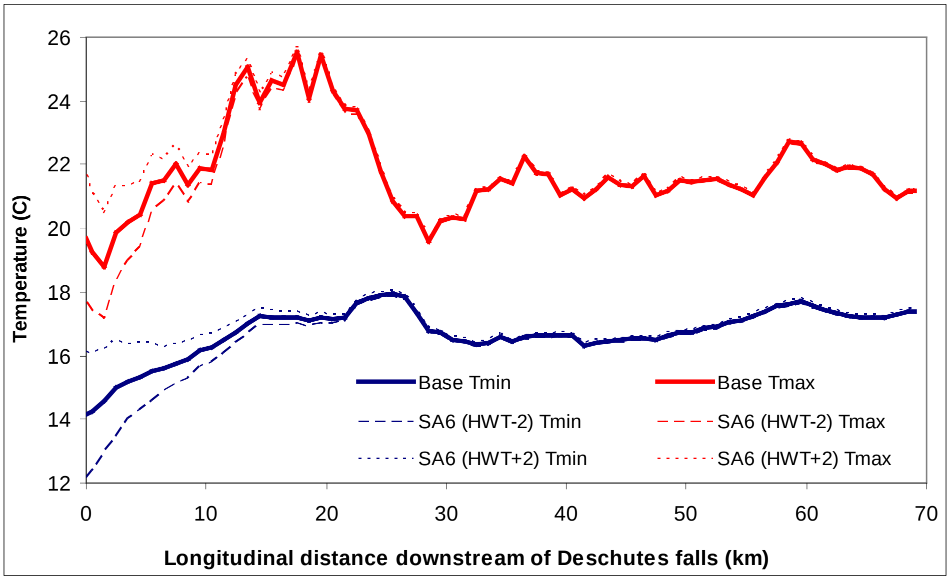


Figure 47. Effect of varying headwater temperature (HWT) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

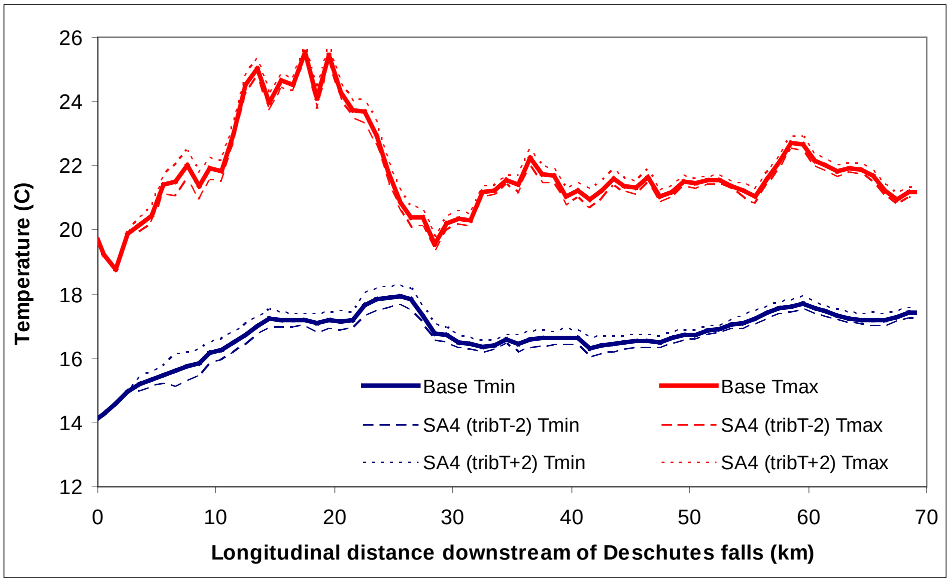


Figure 48. Effect of varying tributary temperature (tribT) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

Sensitivity analyses included varying groundwater temperature by 2ºC (increase and decrease) throughout the system (Figure 49). Because over 55% of the summer low flow is derived from groundwater entering the Deschutes River within the model domain in the calibration model run, groundwater temperatures moderately influence mainstem water temperature, but only downstream of RK 23. Upstream of RK 23, groundwater is a net loss from the system, so the assumed groundwater temperature does not influence the peak system temperatures between RK 12 and RK 20. The biggest influence is downstream of RK 65 where very high groundwater inflows occurred. Groundwater temperature was used as a calibration parameter.

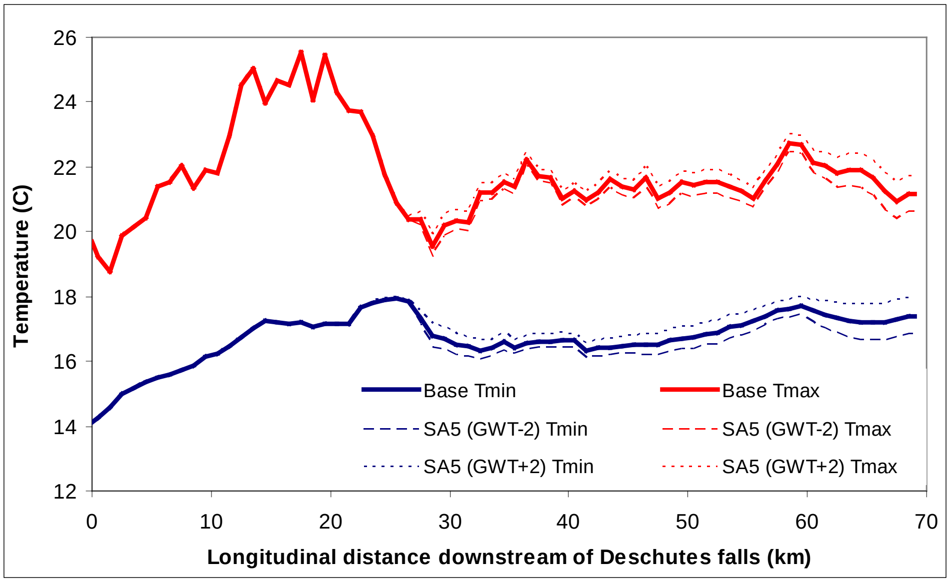


Figure 49. Effect of varying groundwater temperature (GWT) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

A single air temperature regime was used throughout the system because no upstream to downstream variation was evident in the measured air temperature data. Comparing daily maximum air temperatures measured at each of the 16 stations to the average used throughout the system, the absolute value of the residuals averaged 1.8ºC, with a maximum of 4.6ºC. Air temperatures were varied ±2 and ±5ºC throughout the system. From Figure 50, air temperature differences as high as 5ºC produce surface water temperature changes of as much as 1.8ºC, with an average of 1.5ºC. Changing the air temperature by 2ºC produces as much as a 0.7ºC change and an average 0.6ºC change in surface water temperature. A higher local air temperature may have been responsible for under-predicting peak temperatures between RK 12 and RK 20 in the calibration run, since these are sensitive to moderate changes in air temperature.

The watershed average air temperature was used as a boundary condition for the entire model domain, but the daily maximum values recorded during the calibration period for stations between RK 12 and RK 20 produced maximum values within 0.6ºC of the assumed system value. Therefore, while the area between RK 12 and RK 20 is sensitive to air temperatures, the region is not expected to produce air temperatures more than 2ºC or 5ºC above the assumed value.

River wetted widths do not show an increasing trend in a downstream direction. Given the variability in measured wetted widths defined using the GIS coverage, channel widths were varied ±10%. Channel width does affect peak mainstem Deschutes River temperatures. Within the peak temperature area between RK 12 and RK 20, increasing or decreasing the channel width by 10% changes predicted maximum temperatures by as much as 1.0ºC and an average of 0.8ºC, but 0.5ºC throughout the entire length of the Deschutes River, as evident in Figure 51. Minimum temperature is not sensitive to bottom width.

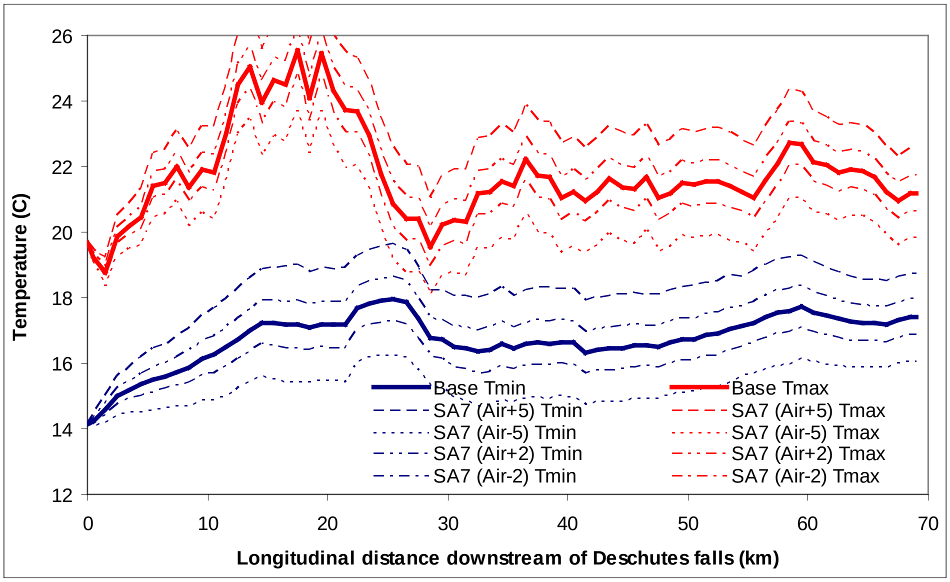


Figure 50. Effect of varying air temperature on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

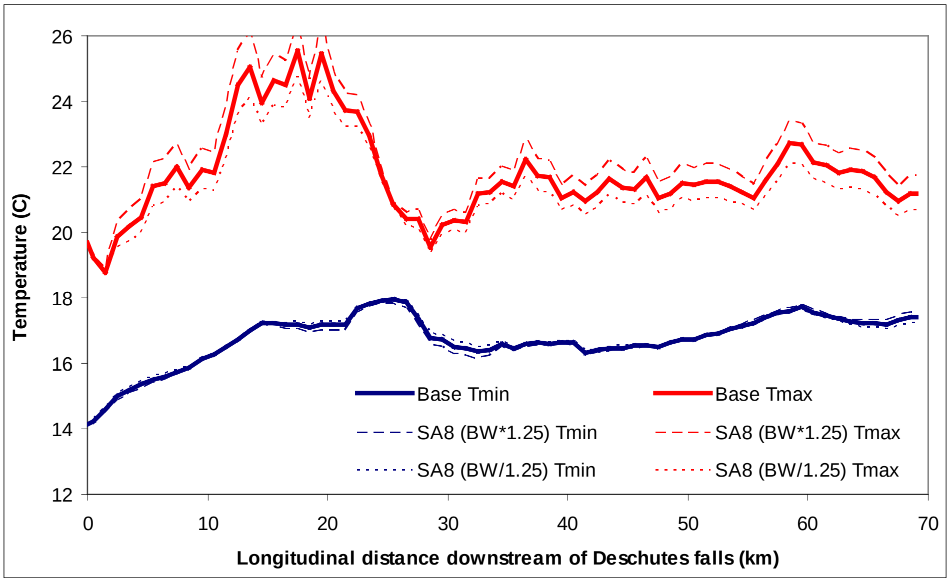


Figure 51. Effect of varying channel bottom width (BW) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

Figure 52 presents the effect of changing vegetation characteristics on shade predicted using the Shade.xls model. Increasing or decreasing the height for all categories by 10% changes the average shade along the entire Deschutes River from 47% for the base calibration to 48 and 45%, respectively. The effect on maximum temperature is muted, with a mean 0.2ºC throughout the system and maximum 0.3ºC effect within the critical area between RK 12 and RK 20. Decreasing the density for all forested categories to 90% and 80% decreases effective shade to 44% and 38%, respectively, producing an average change of 0.4 and 1.2ºC in the mainstem of the Deschutes River. Decreasing the density to 80% has a measurable effect, but otherwise uncertainty in vegetation characteristics has a small effect on predicted temperatures.

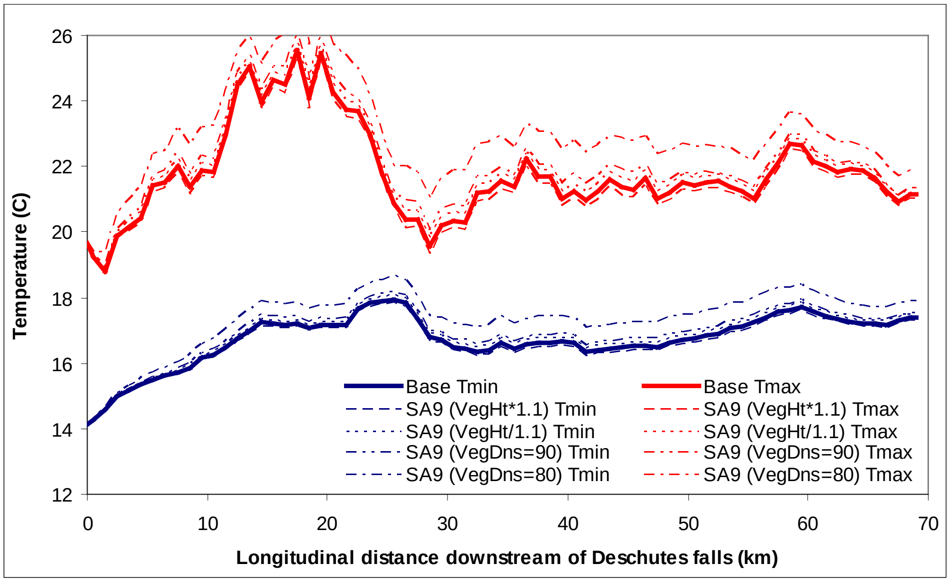


Figure 52. Effect of varying vegetation characteristics (height [Ht] and density [Dns]) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

Manning's n was calibrated to provide the best fit for the travel time, but a range of reach-based Manning's n values were developed. The minimum and maximum values were checked for effects on travel time and predicted temperature. Decreasing Manning's n increases the overall velocity, which decreases the travel time from the upper falls to the lower falls but also increases the water depth to achieve conservation of mass. While the faster transport time would decrease exposure time to solar radiation, it also alters interaction with the hyporheic zone. Without decreased buffering due to hyporheic interactions, faster velocity produces higher maximum temperatures. Similarly, increasing Manning's n decreases velocity and increases the travel time, and, while it increases the exposure to solar radiation, it also alters the interaction with the hyporheic zone, producing lower maximum temperatures.

In the sensitivity analysis, Manning's n was changed to 0.11 and 0.18 from the calibrated value of 0.14 to bracket the lowest and highest reach values estimated from the travel time survey. Decreasing Manning's n to 0.11 results in a faster travel time of 4.0 days compared with 4.7 days, decreasing the influence of the hyporheic zone, and increasing peak temperatures by 0.2ºC on average and as much as 0.5ºC within the critical area between RK 12 and RK 20 (Figure 53). Increasing Manning's n to 0.18 slows down the flow in the system, increasing the travel time to 5.4 days, increasing the interaction with the hyporheic zone, and decreasing peak temperatures by an average of 0.2ºC and as much as 0.5ºC between RK 12 and RK 20.

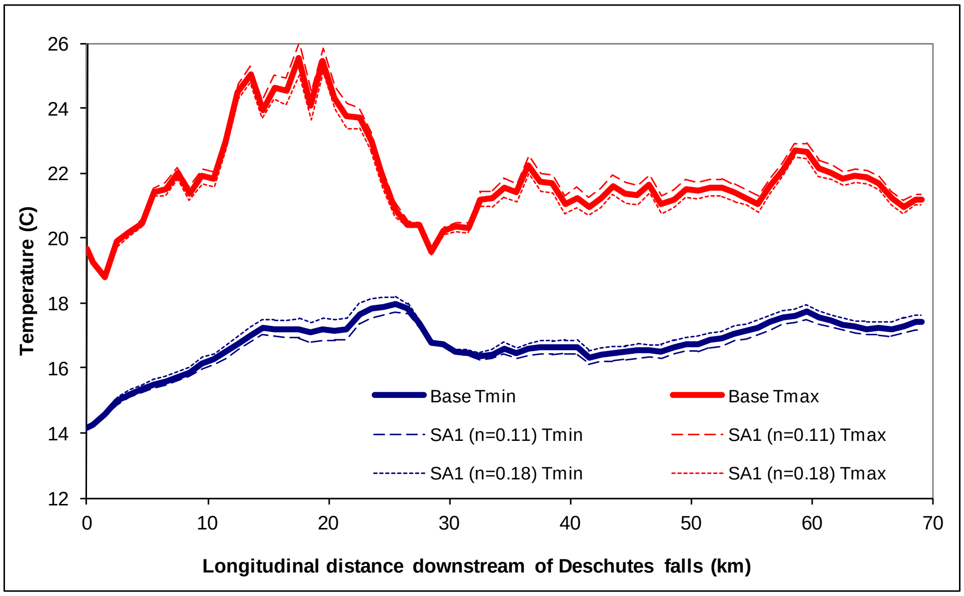


Figure 53. Effect of varying Manning's n on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

Sensitivity to the depth of the active hyporheic zone and the hyporheic exchange flow rate was evaluated. The active hyporheic zone was set to half and twice the value used in the calibration, which changed predicted maximum temperatures by as much as 0.5ºC within the critical area between RK 12 and RK 20 (Figure 54). The effect of the hyporheic exchange flow is more pronounced. Decreasing the hyporheic exchange flow by half would increase peak temperatures as much as 0.8ºC between RK 12 and RK 20, while doubling it would decrease peak temperatures by 0.9ºC.

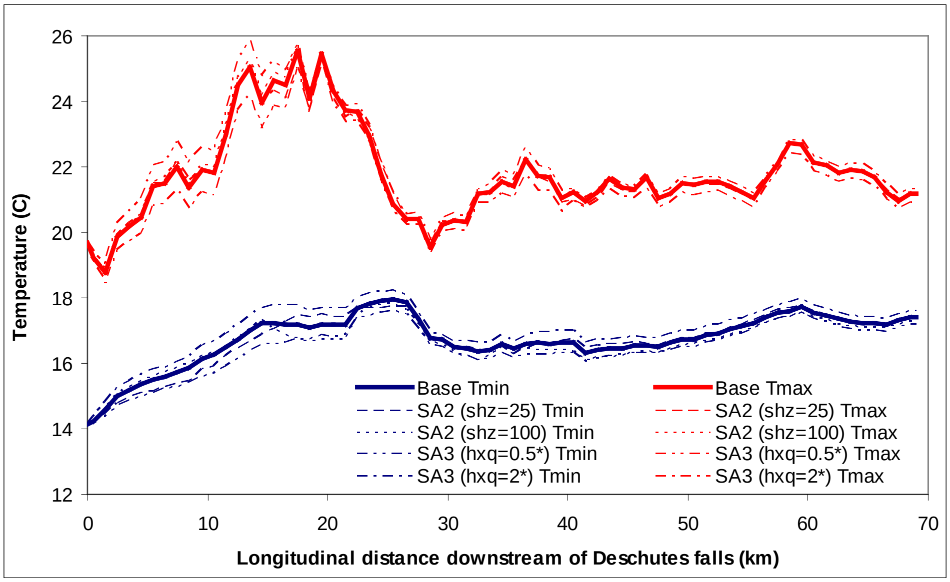


Figure 54. Effect of varying hyporheic zone thickness (shz) and exchange flow (hxq) on mainstem Deschutes River temperatures for the July 21-27, 2004 calibration period.

In summary, the Deschutes River temperature calibration, while sensitive to some parameters, is robust. Within the critical area of peak temperatures between RK 12 and RK 20, peak temperatures are most sensitive to air temperature, channel width, and hyporheic zone exchange flow, and less sensitive or not sensitive at all to headwater temperature, tributary temperatures, groundwater temperature, current vegetation characteristics, hyporheic zone active depth, and Manning's n.

Deschutes River Loading Capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards (40CFR §130.2(f))." Loading capacities for temperature in the Deschutes River watershed are expressed as solar radiation heat loads based on system potential vegetation. The calibrated QUAL2Kw model was used to determine the loading capacity for temperature based on effective shade for the mainstem of the Deschutes River.

The system potential temperature is an estimate of the temperature that would occur under natural conditions. The system potential temperature is estimated using analytical methods and computer simulations proven effective in modeling and predicting stream temperatures in Washington. The system potential temperature is based on the best estimates of the mature riparian vegetation, riparian microclimate, and natural channel characteristics that do not include human influences.

The system potential temperature does not replace the numeric criteria. It also does not invalidate the need to meet the numeric criteria at other times of the year and at other less extreme low flows and warm climatic conditions.

In this study, system potential temperatures in the Deschutes River were estimated for a critical condition defined as low flows that occur once every 10 years and by the 90th percentile of daily maximum air temperature. Low flows are the lowest 7-day average flows that occur, on average, once every 10 years (7Q10). However, 7Q10 discharges have declined over time. The lower, more recent 7Q10 value for the period 1991-2001 was evaluated as the base case, but the higher, historical 7Q10 value was used in a scenario described below.

Air temperatures were based on the long-term data at the Olympia Airport. The data were adjusted to the riparian climate of the Deschutes River by the mean scalar calculated from air temperature near the Deschutes River and at the airport for the calibration and validation time periods. For 1996-2007, the annual maximum of the 7-day average of the daily maximum air temperatures ranged from 26.4ºC in 1999 to 35.9ºC in 2004. The 90th percentile temperature was 33.0ºC, close to the actual conditions during the 7-day average conditions around July 23, 2006 (air temperature was 33.1ºC). Therefore, the actual hourly air and dewpoint temperatures for July 20-26, 2006, were used as critical conditions but scaled to the Deschutes watershed conditions (105% of the minimum and 93% of the maximum temperature at Olympia Airport). However, dewpoint temperatures from Olympia Airport were used without adjustment. Cloud cover and wind speeds were set to zero under this worst-case scenario.

The following scenarios were evaluated under 7Q10 flow and 90th percentile climate conditions:

- **Current shade**. The effective shade produced by the current riparian vegetation condition. [Base case]
- **Maximum potential shade**. Effective shade from the system potential maximum mature riparian vegetation that would naturally occur in the Deschutes River watershed. Mature vegetation was represented by maximum height and densities within 100 meters to either side of the near-stream disturbance zone. Height was based on the tallest existing vegetation in the system (50 m), excluding some very tall conifer stands (60 m). In this scenario, tributaries and the headwaters were assumed to be at current conditions. [SCEN1]

Additional scenarios were evaluated to quantify the effects of various potential management strategies:

- **Microclimate improvements**. Increases in vegetation height, density, and riparian zone width are expected to result in localized decreases in air temperature. To evaluate the effect of this potential change in microclimate on water temperature, the daily maximum air temperature was reduced by 2ºC, based on the summary of literature presented by Bartholow (2000). [SCEN2]
- **Reduced channel width**. Channel banks are expected to stabilize and become more resistant to erosion as the riparian vegetation along the stream matures and as fine sediment is controlled (see Fine Sediment section of this report). Portions of the Deschutes River floodplain have very wide near-stream disturbance zones, including areas over 30 m. These were reduced to 30 m and 20 m maximum [SCEN3A and SCEN3B]. In addition, the wetted width and NSDZ were decreased by 10% to calculate effective shade [SCEN3C], and the bottom width was reduced 10% in the reach hydraulics [SCEN3D].
- **Reduced headwater and tributary temperatures**. The headwater and all tributary temperatures were set to the water quality standards (16ºC upstream of Offutt Lake and 17.5ºC downstream of Offutt Lake) to quantify the effect on the mainstem of the Deschutes River [SCEN4 with SCEN3C channel changes].
- **Increased baseflows**. The historical 7Q10 conditions provided by Kresch (2003) were evaluated [SCEN5 includes historical 7Q10 flows in addition to SCEN4 channel, headwater, and tributary characteristics].

Figure 55 summarizes daily maximum water temperatures under current vegetation and the changes possible under various scenarios, while Figure 56 presents the information as deviations from current conditions. Under current vegetation, the entire Deschutes River is expected to reach daily maximum water temperatures above the 16ºC and 17.5ºC water quality standards. As much as 63 km (91%) of the reaches would exhibit temperatures in excess of the 22ºC threshold for lethality, as defined by WAC 173-201A-200(1)(c)(vii)(A) and Hicks (2002):

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

Substantial reductions in water temperatures are predicted with mature riparian vegetation, improvements in riparian microclimate, and reduction of channel width. While achieving mature riparian vegetation would not result in water temperatures that meet the water quality standards under critical conditions, maximum temperatures would cool by 4.5ºC across the system and as much as 6.9ºC in the warmest reaches (Scenario 1). In addition, all but 5 km (7%) would be below the 22ºC lethality limit. Riparian microclimate improvements would further decrease peak temperatures by 0.7ºC throughout the system (Scenario 2).

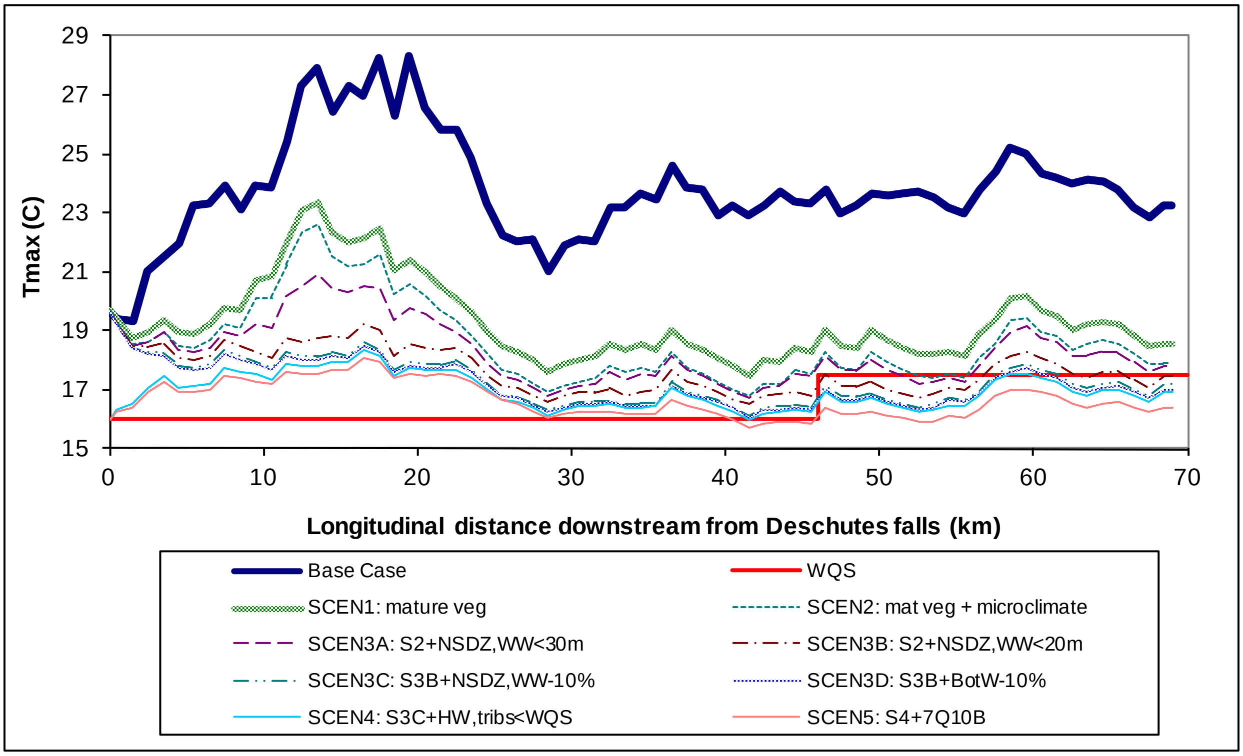


Figure 55. Predicted daily maximum water temperature in the Deschutes River for critical conditions under current conditions and various scenarios.

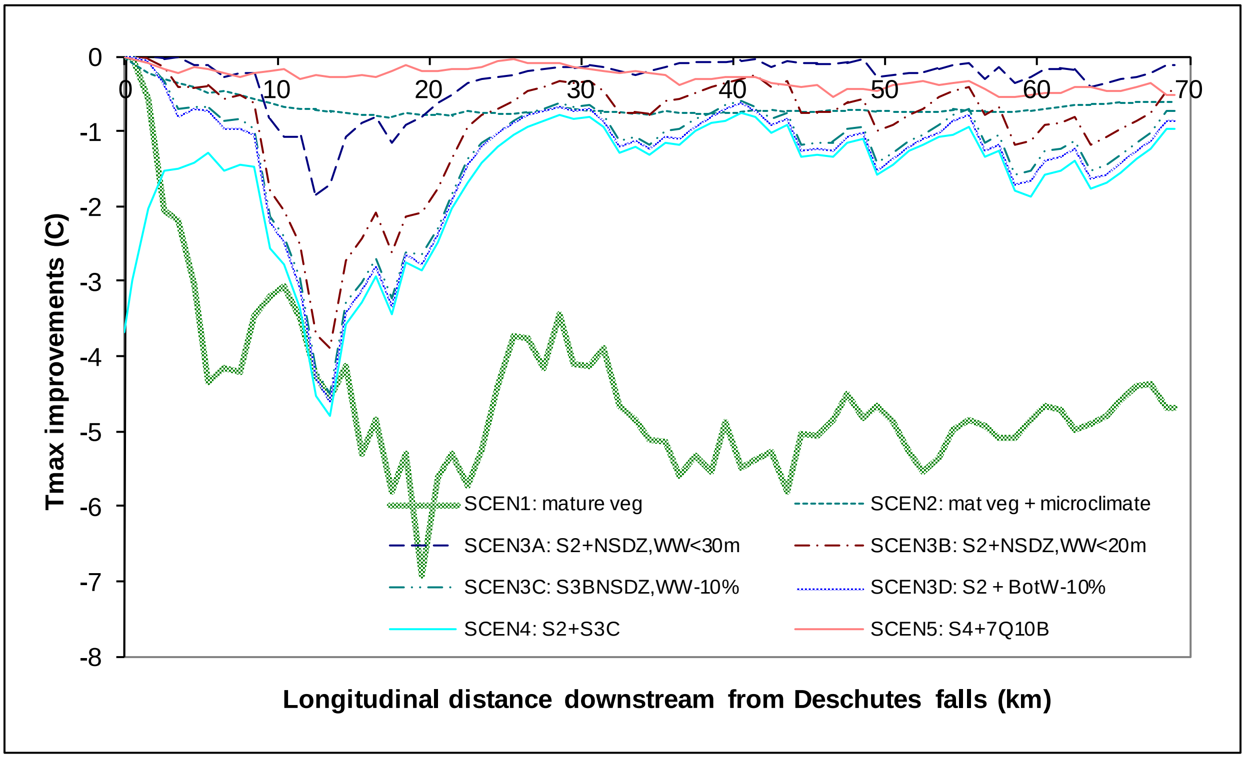


Figure 56. Decreases in peak temperature under various critical conditions scenarios by river reach.

Several scenarios related to channel characteristics were evaluated. The near-stream disturbance zone (NSDZ) is as wide as 35 m in 1-km average reaches and over 50 m in individual 100-m segments where extensive gravel bars are visible on the aerial imagery. Scenario 3A evaluated conditions if neither the NSDZ nor the wetted width was greater than 30 m, and Scenario 3B evaluated a maximum width of 20 m. Reducing the effective width to 30 m would decrease peak temperatures by 0.3ºC on average, while reducing to 20 m would decrease an additional 0.6ºC, based on improvements in shade alone. Scenario 3C evaluated conditions with both NSDZ and wetted width decreased by 10% throughout the system, which would produce an additional 0.4ºC. Finally, Scenario 3D used the shade of Scenario 3C but also decreased bottom widths for hydraulics, which would decrease peak temperatures by an additional 0.2ºC. Figure 57 presents the wetted width and NSDZ for each scenario.

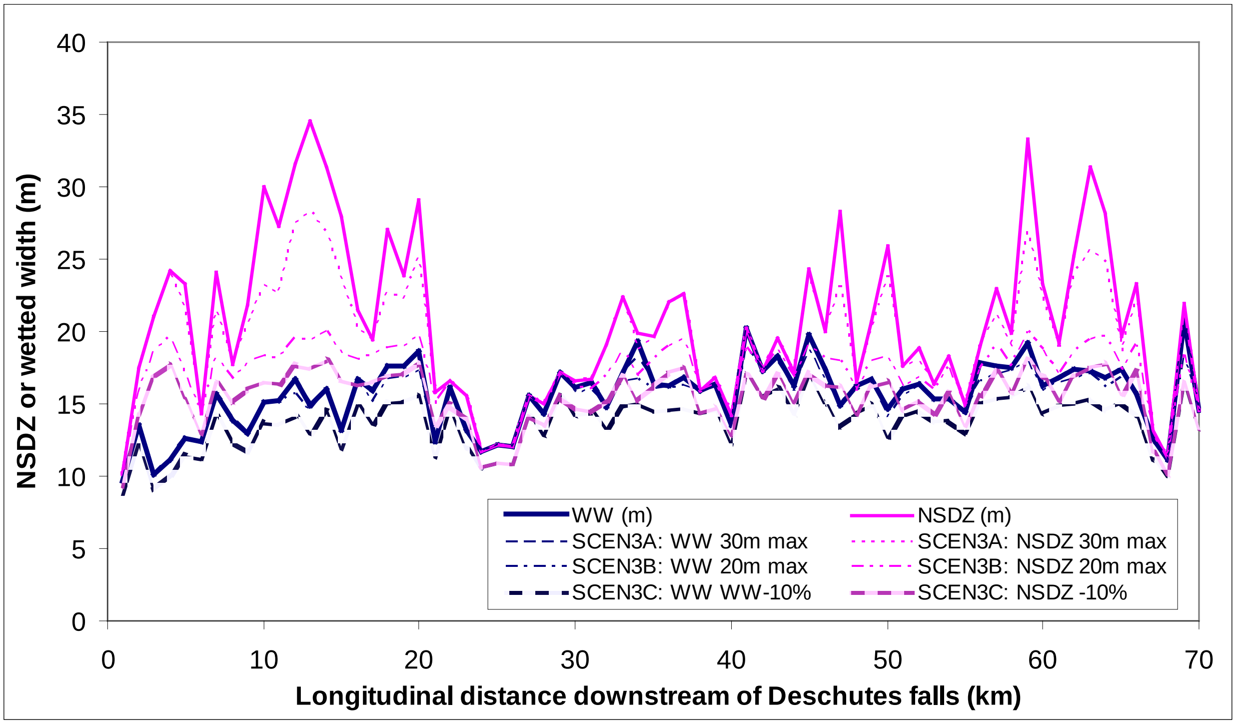


Figure 57. NSDZ and wetted width under current conditions and several scenarios.

The river lengths with the widest NSDZ coincide with several of the areas with the largest potential improvements to maximum temperatures in Figure 54. These include the areas around State Route 507 (RK 35.9), Waldrick Road (RK 45.5), and Henderson Road (RK 64.6), in addition to the peak temperature region between RK 12 and 20 near station 13-DES-32.3 at Old Camp Lane. Channel improvements in these areas could significantly improve peak temperatures.

The headwaters and tributaries have temperatures above the water quality standards. Scenario 4 evaluated mainstem Deschutes River temperatures if the headwaters and tributaries had peak temperatures no greater than the 16ºC water quality standard upstream of Offutt Lake and 17.5ºC standard below. This would provide an average decrease of 0.4ºC throughout the mainstem, with the greatest benefit directly downstream of the Deschutes Falls.

Finally, because the historical 7Q10 flow rates at the USGS gages were higher than the more recent value, the historical 7Q10 flows were evaluated as Scenario 5. Increasing baseflows by 20 to 40% (2 to 22 cfs throughout the system) would decrease peak temperatures by an average of 0.3ºC throughout the system.

Table 25 summarizes predicted decreases in daily maximum temperatures with the implementation of mature riparian vegetation, riparian microclimate, channel improvements, and increased flow under 7Q10 conditions. The table also provides the length of river meeting either the water quality standards or the lethality limit.

Table 25. Predicted decreases in 7-day average of daily maximum temperatures under critical conditions for current characteristics (base case) and various scenarios.

T_{max} is the highest in the system and mean.
T_{max} is the system-wide average maximum temperature.
ΔT_{max} refers to the incremental temperature benefit as the system-wide average for each scenario.

Scenario	T_{max}	Mean T_{max}	ΔT_{max}	Length of river in compliance with water quality standards				Lethality
	(ºC)	(ºC)	(ºC)	Upstream of Offutt Lake (16ºC)		Downstream of Offutt Lake (17.5ºC)		Portion of river above 22ºC
Base case (current vegetation, temperature, and channel widths under recent 7Q10 flows)	28.29	23.75	0.0	0 km	0%	0 km	0.0 %	63 km (91%)
Scenario 1 (mature riparian vegetation)	23.36	19.27	-4.48	0 km	0%	0 km	0 %	5 km (7%)
Scenario 2 (Scenario 1 with riparian microclimate)	22.63	18.6	-0.67	0 km	0%	3 km	4%	2 km (3%)
Scenario 3A (Scenario 2 with NSDZ and WW 30m max)	20.91	18.28	-0.33*	0 km	0%	5 km	7%	0 km (0%)
Scenario 3B (Scenario 2 with NSDZ and WW 20m max)	19.68	17.67	-0.93*	0 km	0%	15 km	22%	0 km (0%)
Scenario 3C (Scenario 2 with NSDZ and WW 20m max and reduce 10%, shade only)	19.68	17.31	-1.29	0 km	0%	19 km	28%	0 km (0%)
Scenario 3D (Scenario 2 with NSDZ and WW 20m max and reduce 10%, shade and hydraulics)	19.68	17.23	-1.37*	0 km	0%	21 km	30%	0 km (0%)
Scenario 4 (Scenario 3C with HW and tributaries = WQS)	18.34	16.93	-0.38	1 km	1%	22 km	32%	0 km (0%)
Scenario 5 (Scenario 4 + historical 7Q10)	18.07	16.64	-0.29	6 km	9%	24 km	35%	0 km (0%)

* Compared with Scenario 2. Only Scenario 3C is used to compare with Scenarios 4 and 5.

Abbreviations are defined in Appendix B.

Figure 58 summarizes the system-wide average maximum temperature, including contributions from anthropogenic changes. While the current 7Q10 flow conditions likely reflect the combined effects of climate and water withdrawals, the two cannot be distinguished. As a conservative approach, all of the change due to the decreased flow is assumed to be human-caused. The predicted natural condition is a system-wide average maximum temperature of 16.6ºC.

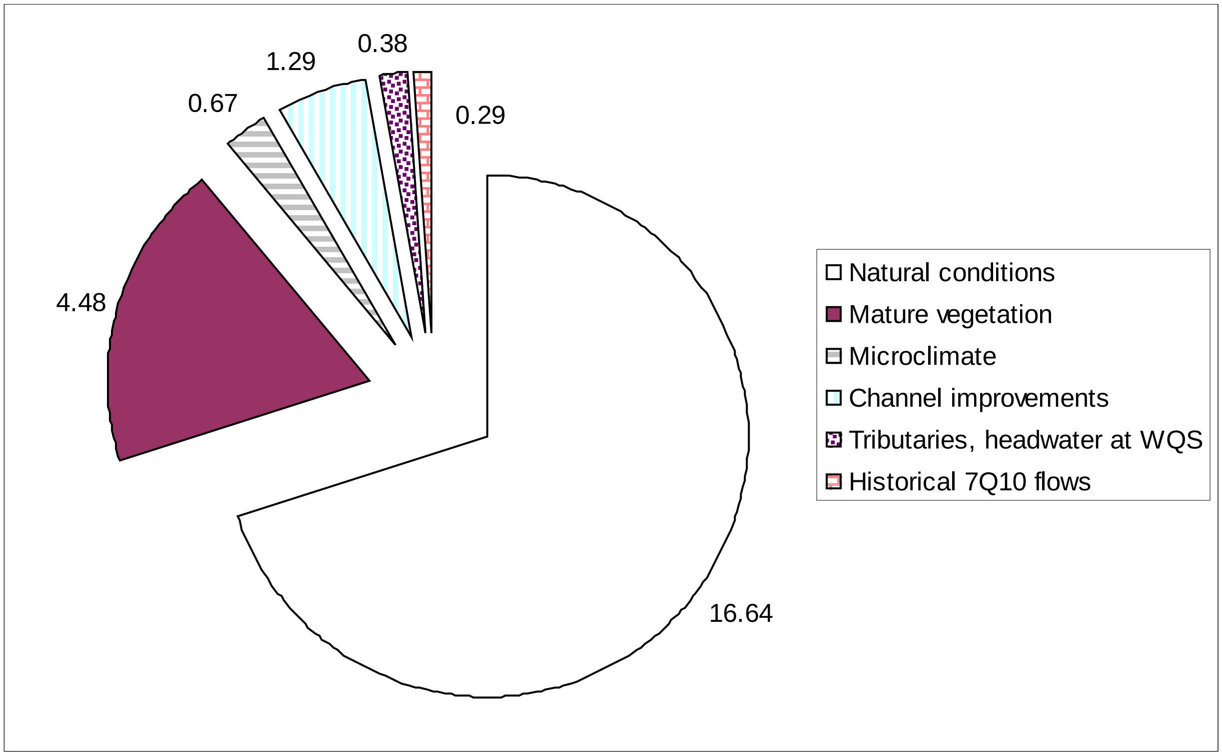


Figure 58. Temperature improvements (system-wide average Tmax ºC) associated with various management strategies.

Percival Creek and Black Lake Ditch Loading Capacity

Loading capacity for water temperature in the Percival Creek watershed is expressed as solar radiation heat loads based on system potential vegetation. The system potential temperature within the watershed was not determined using a QUAL2Kw model application. The temperature regime is highly influenced by Black Lake and wetlands at the headwaters in both branches. Groundwater inflows to the system cool the creeks in a downstream direction (Figure 59).

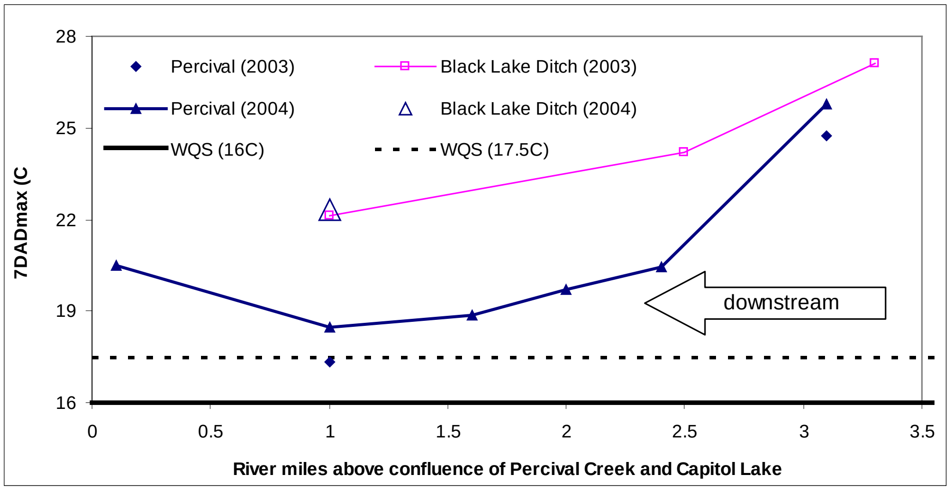


Figure 59. Temperature profiles in Percival Creek and Black Lake Ditch.

Load and Wasteload Targets

Deschutes River Load Targets

Load targets are recommended in this TMDL to meet both the numeric threshold criteria and the allowances for human warming under conditions that are naturally warmer than those criteria. Maximum temperatures predicted under mature riparian shade would not meet the 16 or 17.5ºC numeric water quality criteria during critical conditions throughout the Deschutes River but would substantially reduce peak temperatures below the lethality limit. Therefore, there is a need to achieve maximum protection from direct solar radiation throughout the system. The load target for the Deschutes River and all tributaries is the shade that would result from full mature riparian vegetation, including microclimate and channel improvements (see Fine Sediment). Figures 60 and 61 summarize the effective shade deficit, and solar heat load targets for potential vegetation are detailed in Appendix E.

Because the numeric criteria would not be met, the sum of all human influences cannot cause >0.3°C increase in peak temperatures. Given that the decrease in baseflows from historical values could cause a 0.29°C increase in peak temperatures, all other sources of anthropogenic warming must be controlled.

Several tributaries to the Deschutes River do not meet the water quality standards. To reduce temperatures in these tributaries, full mature riparian vegetation is needed along the creeks listed in Table 26. While Huckleberry Creek was on the 303(d) list in 2004, the creek did not violate water quality standards in 2003 (7-DADMax 15.6ºC). However, peak 7-DADMax temperatures could violate water quality standards under the critical conditions simulated in the Deschutes River, and full mature riparian vegetation is recommended.

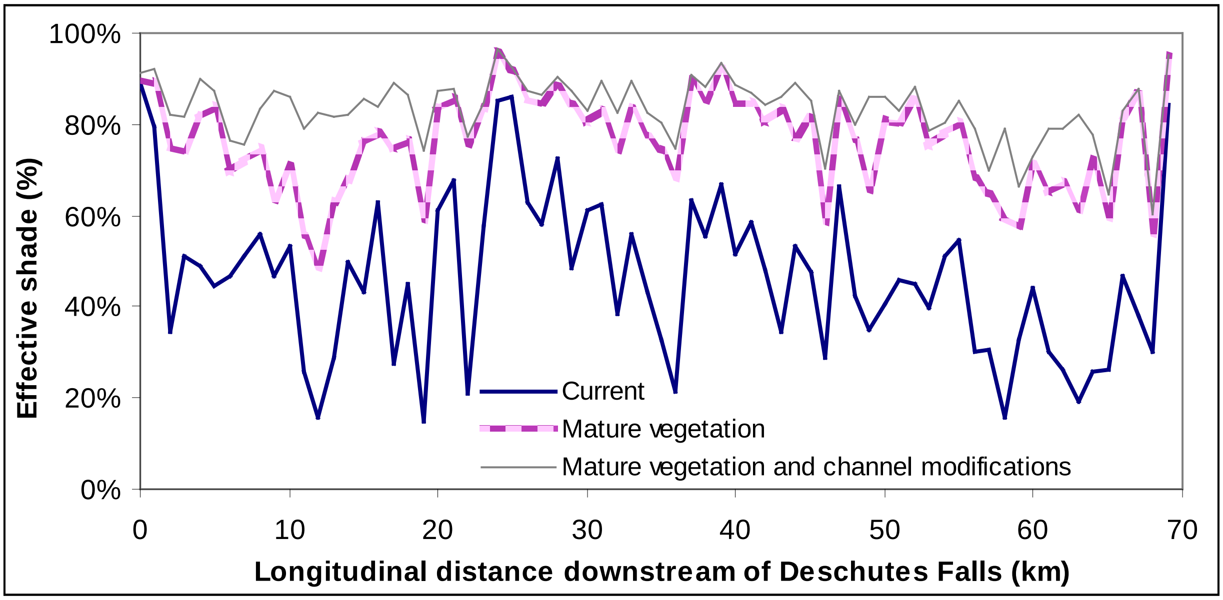


Figure 60. Effective shade targets for the Deschutes River with full mature riparian shade and with supplemental channel modifications.

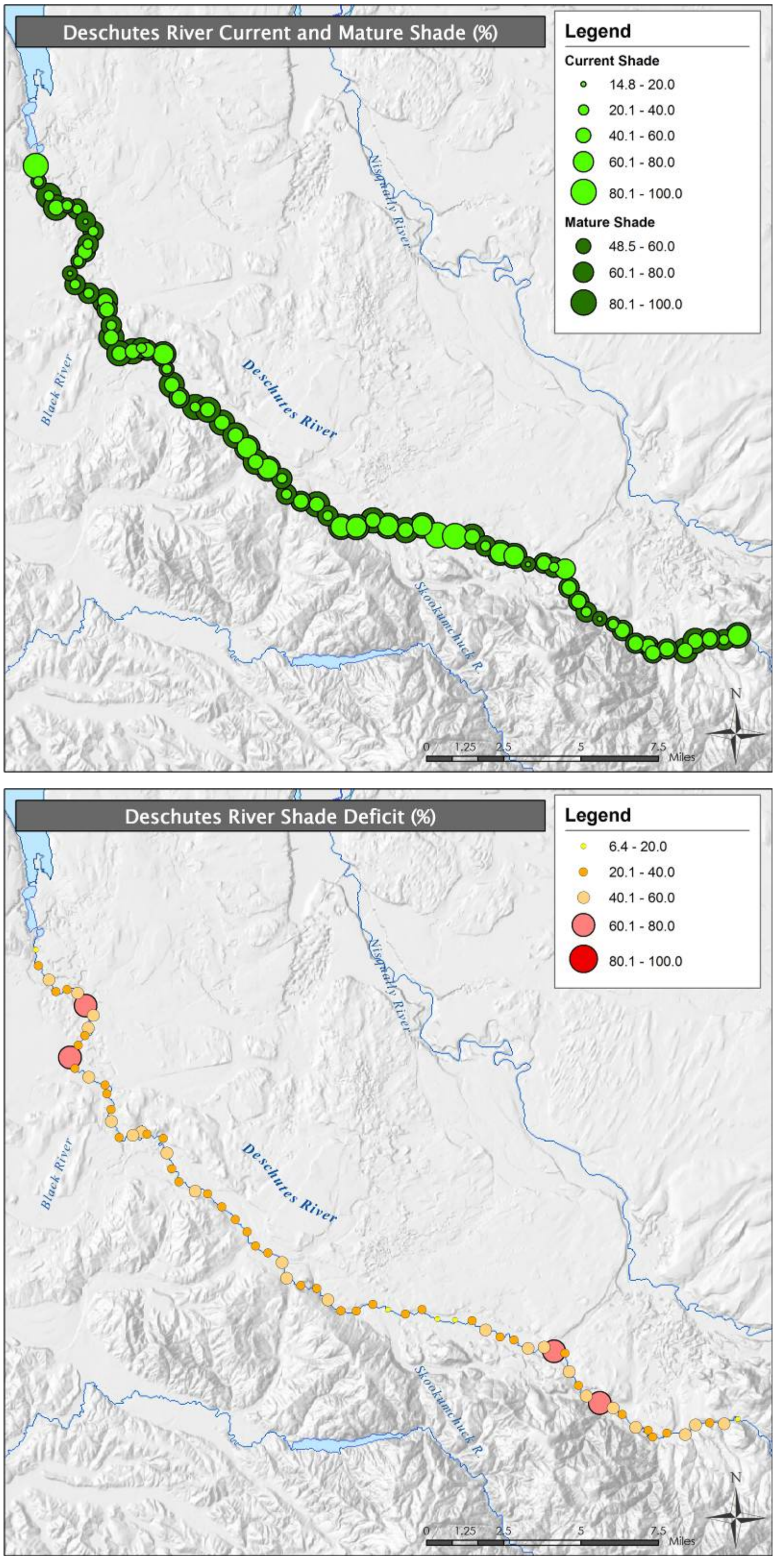


Figure 61. Shade from current and mature vegetation (top) and shade deficit (bottom) along the Deschutes River.

Table 26. Conditions in tributaries to the Deschutes River, including temperature load targets for streams that do not meet the water quality standards.

Deschutes River km	Station	Description	7-DADMax 2003 (ºC)	7-DADMax 2004 (ºC)	WQS	Meets WQS?	Target (ºC)	Load target
3.7	13-THU-00.1	Thurston Creek at 3000 Rd.	16.72		16.0	no	16.0	Full mature riparian shade
4.4	13-JOH-00.1	Johnson Creek at 3000 Rd.	17.14		16.0	no	16.0	Full mature riparian shade
5.8	13-HUC-00.3	Huckleberry Creek at 3000 Rd.	15.62*		16.0	yes	16.0	Full mature riparian shade
6	13-MIT-00.2	Mitchell Creek at 3000 Rd.	17.34		16.0	no	16.0	Full mature riparian shade
11.2	13-FAL-00.3	Fall Creek at 1000 Rd.	15.13		16.0	yes		
28.1	13-REI-00.9	Reichel Creek at Vail Loop Rd.	19.01		16.0	no	16.0	Full mature riparian shade
31.5	13-DES-22.7spr	Spring near Deschutes River 860 Rd.		11.81	16.0	yes		
35.8	13-SP1-00.1	Spring outlet at State Route 507	15.65		16.0	yes		
41.5	13-SIL-00.4	Silver Spring near mouth	14.00		16.0	yes		
46.5	13DES13.4spr	Spring near Cowlitz Dr.	17.71		17.5	no	17.5	Full mature riparian shade
46.6	13-TEM-00.0	Tempo Lake outflow at Stedman Rd.	23.14		17.5	no	17.5	Full mature riparian shade
54.1	13-SPU-00.0	Spurgeon Creek at Rich Rd.	18.94		17.5	no	17.5	Full mature riparian shade
59.9	13-AYE-00.0	Ayer Creek off Sienna Ct.	21.61		17.5	no	17.5	Full mature riparian shade
64	13-CHA-00.1	Chambers Creek off 58th Ave.	16.24		17.5	yes		

* Huckleberry Creek could violate water quality standards during critical conditions, although it did not violate in 2003. Full mature riparian shade is recommended.

In addition to the numeric load targets for effective shade in the Deschutes River watershed, the following narratives and management activities are recommended:

- Load targets are included in this TMDL for non-federal forest lands in accordance with Clean Water Act assurances established under Section M-2 of the Forests and Fish Report (USFWS et al., 1999). These assurances are contingent upon meeting a series of corrective milestones (Hicks, 2009). Consistent with the Forests and Fish Agreement, implementation of the load targets established in this TMDL for private and state forestlands will be accomplished via implementation of the revised forest practices regulations.
- These targets apply to the entire Deschutes River watershed, including the areas within the U.S. Forest Service (USFS) boundary.
- Tributaries also should achieve full mature riparian vegetation.
- For areas that are not managed by the USFS or in accordance with the Forests and Fish Agreement, such as private non-forest areas, voluntary programs to increase riparian vegetation should be developed. For example, riparian buffers or conservation easements may be sponsored by the U.S. Department of Agriculture, Natural Resources and Conservation Service, Conservation Reserve Enhancement Program. In particular, the area between RK 12 and RK 20 should be targeted for riparian and channel restoration.
- Instream flows and water withdrawals are managed through alternative regulatory structures and are not established in TMDLs. The designation of historical 7Q10 flows as the natural condition does not imply setting a minimum instream flow based on the analyses included in this report. However, stream temperature is affected by instream flow. Continued decreases in summer baseflows will have a detrimental effect on water temperatures in the Deschutes River, and enhancing baseflow by any means possible would decrease peak water temperatures in the river. Future projects that have the potential to increase groundwater or surface-water inflows to streams in the watershed should be encouraged and have the potential to decrease peak water temperatures.
- Management activities that would decrease the load of sediment to the Deschutes River would benefit water temperature, due to the subsequent improvement in channel characteristics. See the Fine Sediment TMDL section of this report for additional recommendations.
- While mature riparian vegetation eventually would provide large woody debris (LWD) to the channel, short-term restoration strategies should include increasing LWD abundance as one means to increase channel complexity. Increasing complexity would increase Manning’s n, which, together with greater water depth, would improve peak temperatures.
- Existing hyporheic exchange flows and groundwater inflows significantly buffer the effect of solar radiation on water temperature. Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the hydraulic conductivity of the streambed sediments. Activities that reduce the hydraulic conductivity, such as accumulation of fine sediment, could increase stream temperatures. Management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate. See the Fine Sediment TMDL section for additional recommendations.

- Management activities that increase the amount of LWD in the Deschutes River system would assist in pool formation and will mitigate peak flows that wash out spawning gravels and contribute to channel downcutting and enhanced bank erosion. See the Fine Sediment TMDL section of this report for additional recommendations.

Deschutes River Wasteload Targets

No numeric wasteload targets for heat were recommended for the Deschutes River temperature TMDL. Ecology regulates municipal, industrial, and construction stormwater facilities as point sources under various general permits. The conditions established in those permits, particularly activities promoting infiltration, may reduce the likelihood of future increases in heat loads from areas covered by the permits. Heat loads from existing development may be contributing to high temperatures during summer wet-weather events, but these are not necessarily covered by current stormwater permits.

Stormwater runoff could potentially contribute to thermal loading during summer storms, resulting in water temperatures above the water quality criteria. However, in temperature TMDLs conducted in western Washington by Ecology to date, the highest temperatures used to establish critical conditions occurred during dry weather (Ahmed and Hempleman, 2006; Mohamedali and Lee, 2008).

Sites covered by general permits, including both sand and gravel and stormwater, should emphasize infiltration of stormwater to the amount possible on site.

Percival Creek Watershed Load Targets

Load targets are developed in this TMDL based on effective shade needed to reduce direct solar radiation to free-flowing reaches of Percival Creek and Black Lake Ditch. The headwaters of both branches are the warmest in the system due to heating of Black Lake and wetland complexes. While temperatures decrease downstream because of increased cool groundwater inputs, no part of either branch meets the temperature criteria, either the current 16ºC with Capitol Lake in place or the potential 17.5ºC if the lake reverts to an estuary. Given that natural conditions likely are warmer than the numeric standards, full mature riparian vegetation is necessary to mitigate anthropogenic effects. The allowance for anthropogenic effects is set aside as a margin of safety.

The load target is the shade that would result from full mature riparian vegetation. Maximum vegetation height will be a function of soil type. Wetland soils present along several reaches could support vegetation up to 10 m high that would still shade the narrow stream channels (Mohamedali and Lee, 2008). Elsewhere, maximum vegetation was set to 40 m, which is the tallest vegetation currently within the riparian area. Figure 62 presents current and potential future shade, and load targets are detailed in Appendix F. Effective shade would increase from 47% to 84% on average in Black Lake Ditch and from 84% to 98% in Percival Creek. Figure 63 presents the current and mature vegetation and effective shade deficits throughout the Percival Creek system.

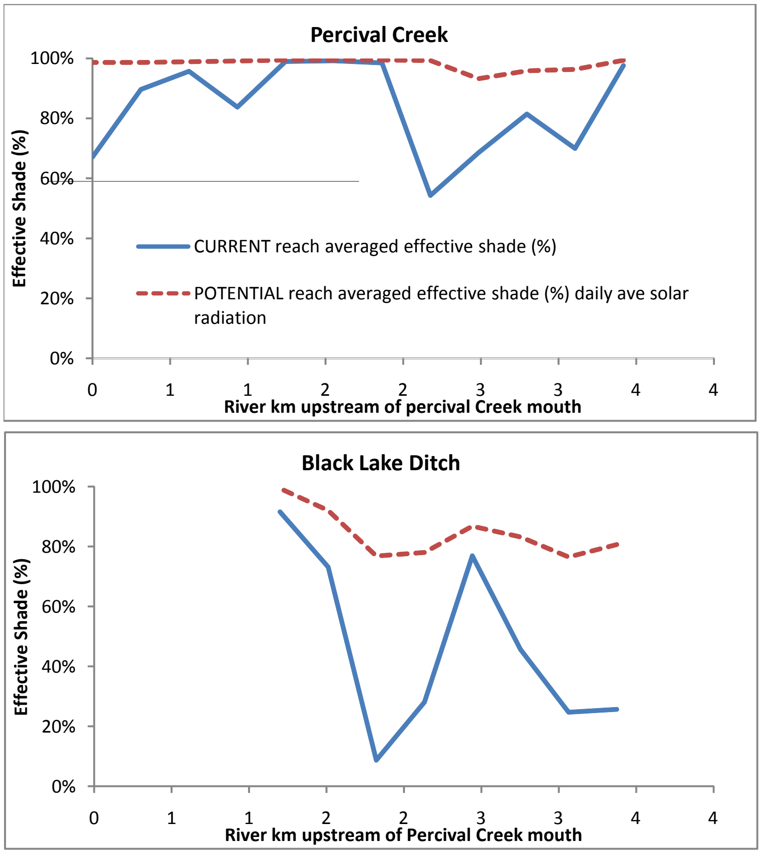


Figure 62. Percival Creek watershed effective shade targets.

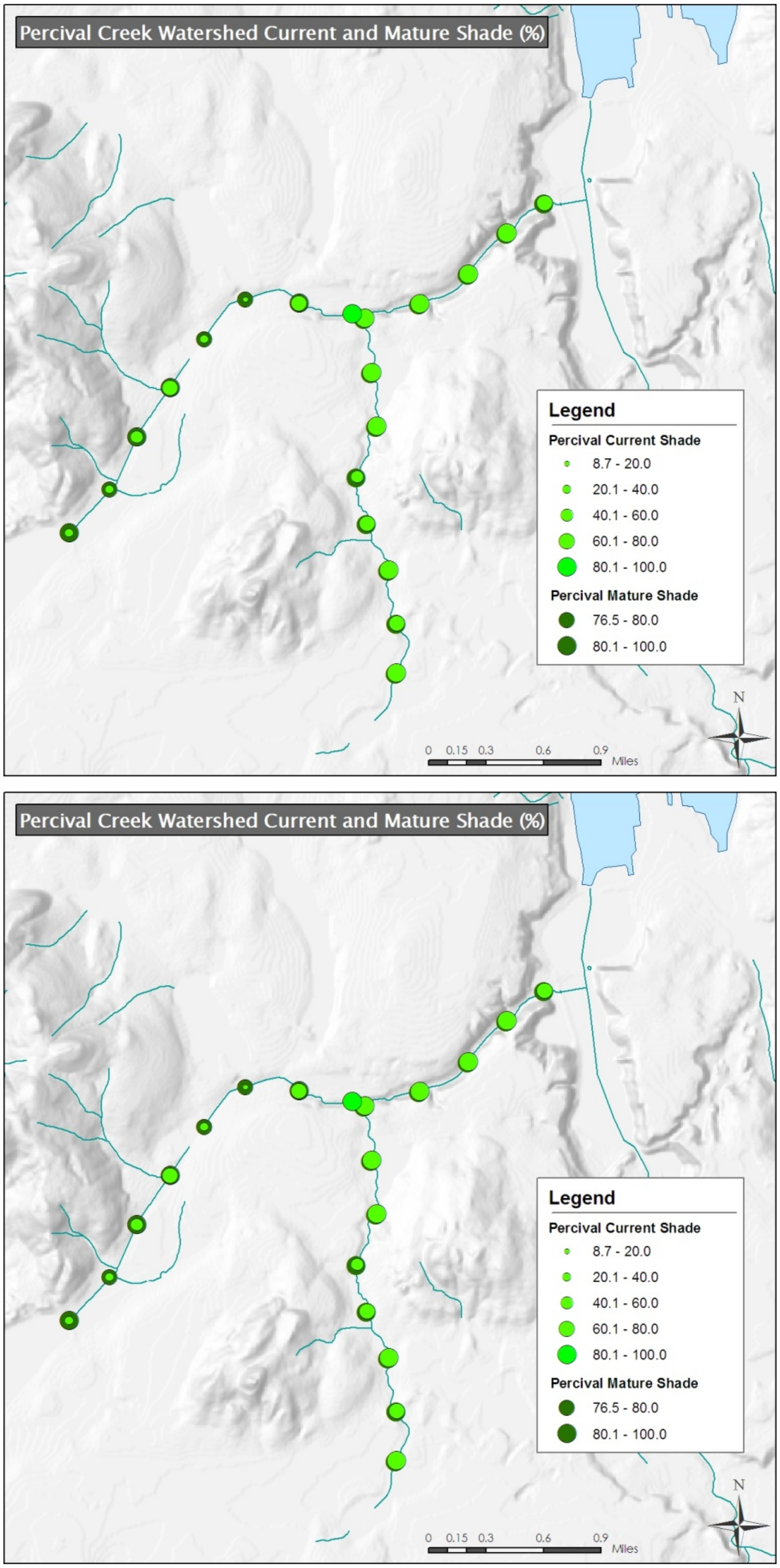


Figure 63. Shade from current and mature vegetation (top) and shade deficit (bottom) along Percival Creek and Black Lake Ditch.

In addition to the numeric load targets for effective shade in the Percival Creek watershed, the following narratives and management activities apply:

- Voluntary programs to increase effective shade should be developed that provide incentives to landowners. The initial focus should be the area with the greatest shade deficit.
- Existing groundwater inflows and likely hyporheic exchanges buffer the effect of solar radiation and have a strong cooling effect (5ºC in Black Lake Ditch and 7ºC in Percival Creek above the confluence with Black Lake Ditch). Management activities should maintain or improve groundwater inputs and enhance hyporheic exchange by increasing channel complexity through restoration programs and minimizing fine sediment inputs that could clog gravels.

Percival Creek Watershed Wasteload Targets

No numeric wasteload targets for heat were recommended for this Percival Creek temperature TMDL. Ecology regulates municipal, industrial, and construction stormwater facilities within the watershed as point sources under general permits. The conditions established in those permits, particularly activities promoting infiltration, may reduce heat loads from areas covered by the permits. Facilities covered by stormwater general permits should maximize infiltration, buffer peak flows that could affect channel structures, and eliminate the discharge of fine sediment above natural conditions. No visible accumulation of fine sediment should occur within water bodies downstream of the facilities.

Conclusions and Recommendations

The QUAL2Kw model was used to simulate the heat budget and water temperatures of the Deschutes River under varying conditions. The models reproduced monitoring data under a variety of solar radiation conditions, with a root mean square error (RMSE) of 0.8 to 0.9ºC for daily maximum temperatures for the calibration period and the various validation runs. The thermal infrared (TIR) survey RMSE was 1.5ºC for peak temperatures; the data likely were influenced by a summer storm and cloudy conditions.

Based on modeling critical conditions under existing vegetation, channel characteristics, and recent 7Q10 flows, peak temperatures throughout the entire Deschutes River would be warmer than the water quality criteria, and many areas would be above the lethality threshold of 22ºC. The highest temperatures in the Deschutes River occurred between stations 13-DES-37.4 and 13-DES-28.6, roughly 12 to 20 km downstream of the Deschutes Falls.

Establishing system potential shade from mature riparian vegetation would decrease peak temperatures by an average of 4.5ºC throughout the Deschutes River. However, the model predicts that while water quality criteria would not be met under critical conditions. Improving shade would reduce the length of river above the lethality limit from 63 km (91%) under current vegetation to 5 km (7%) under mature vegetation. With effects of microclimate, channel modifications, and the headwaters and tributaries meeting the temperature standards, 23 km (33%) would meet the water quality standards, and peak temperatures along the entire river would be below the lethality temperature.

Mature riparian vegetation would have several secondary benefits to temperature, DO, pH, and fine sediment (see separate Fine Sediment and Freshwater DO and pH TMDL sections of this report). Greater canopy cover establishes a continuous riparian microclimate that reduces air temperatures near the water surface and also reduces water temperatures. A mature riparian forest also provides large woody debris (LWD) that protects river banks from enhanced erosion, increases the channel complexity, enhances hyporheic exchanges, and reduces transport of fine sediment. Over 98% of the Deschutes River watershed contains very little LWD, in the lowest quartile for intermediate-sized rivers in western Washington (Fox and Bolton, 2007). Previous accumulations of large quantities of LWD that contributed to localized flooding are a symptom of the system-wide depletion of LWD. Restoration strategies should consider the system as a whole. Decreasing the amount of light reaching the streambed would decrease periphyton growth, with benefits to DO and pH.

Temperature reductions are needed in several tributaries to the Deschutes River, and full mature riparian vegetation should be established. The hottest conditions are in the Tempo Lake outflow, due in part to solar heating of the lake surface. The lake outlet should be evaluated for hydraulic modifications that enhance subsurface connection or cooler water. Ayer Creek also should be targeted for enhanced riparian restoration appropriate to the soils.

Other management activities could further improve surface water temperature in the Deschutes River. Controlling anthropogenic sediment sources (see separate Fine Sediment TMDL section) would benefit temperature, as described in the narrative section under the Load Targets. Enhancing LWD also would improve temperature and other habitat factors. Watershed Sciences (2004) noted a 1ºC decrease in temperatures in the mainstem of the Deschutes River during the TIR survey through a logjam and attributed it to enhanced hyporheic exchanges.

The Deschutes River watershed, similar to other areas in the Puget Lowland, is subject to intense development pressure, both near and away from existing urban growth areas. With no change in development from previous practices, future growth is expected to reduce riparian vegetation further, increase impervious surfaces, and increase the demand for groundwater. All of these factors will worsen existing temperature impairments in the Deschutes River watershed.

In addition, climate change is expected to intensify winter storms and increase summer air temperatures, two of the various climate-related factors that would further exacerbate impairments. Accommodating climate change will entail maximizing controllable factors that influence surface water temperature. Under modeling scenarios, restoring mature riparian vegetation would decrease water temperature by 4.5ºC, whereas increasing air temperature by 2 to 5ºC would increase water temperature by 0.6 to 1.5ºC. Therefore, restoring riparian vegetation will make a significant difference even under future climate changes.

Surface water temperatures are influenced by instream flows, and reducing summer baseflows will exacerbate temperature impairments. Separate regulatory authorities establish instream flows and regulate groundwater withdrawals, and TMDLs do not establish flows. Drinking water is a use to be protected under WAC 173-201(A) 600. This TMDL does not modify any legal water rights within the Deschutes River watershed.

However, opportunities exist to mitigate the effects of current and potential future withdrawals. Reclaimed water facilities are currently in operation, and others are planned for the region. Use of reclaimed water with appropriate management practices would reduce the need for potable water or groundwater but should not lead to increased nutrient loads to surface water (see Freshwater DO TMDL section). Maximizing stormwater infiltration would mitigate erosion during high flows and would enhance summer baseflows. Water conservation programs should be strengthened to reach urban, suburban, and rural water users from residential, industrial, commercial, agricultural, and forestry sectors. Successful methods of reaching and assisting exempt well users should be evaluated.

Specifically, water withdrawals should be quantified for all watershed users. Illegal withdrawals should be identified, and agencies should work with landowners. If needed, enforcement actions should be taken to eliminate them.

In the Percival Creek system, establishing full mature riparian vegetation, with heights governed by soil type, would increase effective shade from 47% to 84% on average in Black Lake Ditch and from 84% to 98% in Percival Creek. While numeric water quality criteria may not be met even with full shade, due in part to the headwater lake and wetland complexes, mature shade should reduce stream temperatures significantly. Hydraulic modifications may be made at the outlet from Black Lake to enhance subsurface water connections and minimize the surface water connectivity. The lake outlet should be evaluated further.

The following activities are recommended:

- Preserve existing riparian vegetation, and restore areas with young or no vegetation. Plantings should include both deciduous trees and shrubs, which grow quickly, and conifer trees. Conifers follow deciduous trees in forest succession and are the dominant vegetation under natural conditions in most areas.
- Enhance channel complexity. Enhanced restoration should include LWD within the active river bed to promote bank stabilization and pool formation and within riparian zones to provide self-armoring elements as banks are eroded. Key locations include the areas around Henderson Blvd, Waldrick Road, State Route 507, and Old Camp Lane.
- Investigate opportunities to enhance groundwater recharge through low impact development (LID) practices for new development and redevelopment, infiltration of existing stormwater wherever possible, and possibly reclaimed water such that surface water nutrient levels are not impacted (see separate Freshwater Dissolved Oxygen TMDL section).
- Consider a water management strategy that recognizes the benefits of maintaining summer baseflows while meeting the community’s need for water. Strategies should consider projected future growth and increases in water demand.
- Maintain the current status that the Deschutes River watershed is closed to further withdrawals, eliminate illegal withdrawals, and quantify and mitigate the effect of exempt wells.
- Encourage water conservation throughout the watershed and particularly residents served by exempt wells.

- Restore and protect natural wetlands in areas such as Ayer/Elwanger, Reichel, and Spurgeon Creeks. While all three tributaries also have elevated temperatures, the creek temperatures would benefit from restoration of riparian zones with plantings appropriate to the soils present. Even wetland shrubby vegetation would reduce solar heating of these streams.
- The Lake Lawrence tributary also has high water temperatures, due in part to the solar radiation received by the surface of the lake. The lake outlet should be evaluated for existing hydraulic modifications that could be altered to decrease downstream temperatures.
- The Deschutes River between 1000 Road and Vail Cutoff Road SE is the warmest, and therefore the most sensitive, part of the river. Future development and management should be conditioned to (1) prevent further degradation of those areas already not meeting standards (prevent riparian vegetation removal, reduce groundwater withdrawal, or enhance groundwater recharge), and (2) protect those areas currently meeting standards, as required by the antidegradation portions of the water quality standards.
- Once mature riparian vegetation is established, runoff from sites covered by general permits should be evaluated for the potential to contribute heat loads that cause the receiving water temperatures to increase above the water quality standards.
- Cool-water sources identified in the TIR imagery should be protected from flow depletion or temperature increases. Future fisheries surveys may characterize these sites further as thermal refugia.

The long-term temperature monitoring conducted at the two sites on the Deschutes River should continue, as should summer continuous temperature monitoring at station 13A060. These data will prove invaluable in tracking trends and evaluating interannual variability. The portion of the river with the highest water temperatures is between 1000 Road (13-DES-37.4) and Vail Cutoff Road SE (13-DES-28.6), and continued monitoring at the 13-DES-33.5 (Fennel Road) site will track conditions at a key location. Future detailed monitoring for temperature improvements could occur at intervals of 5 to 10 years, given the need to establish riparian vegetation and the relatively slow growth of riparian vegetation.

In keeping with the antidegradation policy in Washington State’s water quality standards, areas where the current water quality is better than the water quality criteria should be considered during development of the Implementation Strategy for this TMDL. Specific actions and/or institutional safeguards may be necessary to prevent a loss in current water quality conditions in these areas, as further development or other changes occur in the watershed.

Recommendation for Future Growth

This temperature TMDL does not include a specific reserve capacity for future growth in the Deschutes River or Percival Creek watersheds. Future development should not increase heat loads to the Deschutes River, Percival Creek, or tributaries, particularly the sensitive area between 1000 Road (13-DES-37.4) and Vail Cutoff Road SE (13-DES-28.6). Future growth within the Percival Creek watershed should include management activities that maintain intact riparian vegetation and restore degraded areas.

Margin of Safety

The margin of safety accounts for uncertainty in pollutant loading or water body response, and may be either explicit or implicit. For this TMDL, the margin of safety is implicit through the use of conservative assumptions:

- The 90th percentile of the highest 7-day averages of daily maximum air temperatures represents a reasonable worst-case condition for predicting water temperatures in the Deschutes River.
- The 7-day average low flows occurring on average once every 10 years based on the recent gage data by the USGS were used. This conservative assumption uses the year-round data set, including September discharges that tend to be lower than those experienced in July and August. The 7Q10 values for the entire gaging record are higher but represent some combination of wetter climate and fewer domestic water withdrawals during the historical gaging period (1945 to 1969).
- The likelihood of both 7Q10 flows and 90th percentile air temperatures coinciding is lower than either condition occurring individually and adds to the margin of safety.
- Conservative model assumptions of zero cloud cover and wind speed were used for critical condition model runs.
- The entire 0.3°C allowance in the Deschutes River is recommended to be assigned to potential human impacts on baseflow and subsequent warming.
- The 0.3°C allowance in the Percival Creek watershed is recommended as a margin of safety.

Freshwater Dissolved Oxygen and pH

Analytical Framework

The QUAL2Kw model (Pelletier and Chapra, 2006) was used to simulate nutrients and DO within the mainstem of the Deschutes River. The analytical framework of QUAL2Kw was presented in the Temperature section. In addition to evaluating current and potential future temperature regimes, QUAL2Kw was used to evaluate the influence of nutrients and benthic algae on DO concentrations and pH in the Deschutes River. The Percival Creek watershed DO and pH analytical framework is based on an assessment of current and potential future effective shade that was completed for the Temperature TMDL of this report. The Ayer Creek DO and pH and Reichel Creek DO analytical framework is based on the loading capacity and natural conditions in the Deschutes River watershed.

DO and pH are functions of plant photosynthesis in water. The Deschutes River, like many lotic (flowing water) systems, has relatively low levels of floating plants, or phytoplankton. Instead, the periphyton that coats the rocks and sediment is the primary organic matter process that governs instream DO and pH levels. Periphyton increases DO and pH during the day, resulting in peak concentrations in late afternoon. At night, the plants reduce DO and pH, leading to the lowest levels near sunrise. If DO is over the saturation level, oxygen is lost to the atmosphere. Reaeration occurs if DO is under the saturation level, and oxygen is gained from the atmosphere.

QUAL2Kw was calibrated to instream data collected along the mainstem of the Deschutes River on August 10-12, 2004. As described in the Temperature section, while QUAL2Kw simulates steady-state, single flow conditions, the model simulates diel changes that result from biological processes such as photosynthesis with distinct day/night cycles. A stream survey performed August 11-15, 2003 was used to confirm that the model simulates processes appropriately.

Deschutes River Physical Model Set Up

The DO and pH application is based on the same 69 one-kilometer reaches as in the temperature model of the Deschutes River. DO and pH were calibrated for a different time period than for temperature.

Percival Creek Physical Model Set Up

The Percival Creek DO and pH analysis is based on the Shade.xls model configuration used in the Percival Creek temperature TMDL.

Deschutes River Seasonal Variation and Critical Conditions

DO and pH levels are governed by biological processes that vary seasonally and hourly. Based on ambient monthly data collected by Ecology at the mouth of the Deschutes River (13A060), the lowest DO levels and highest pH levels occur from June through August (Figure 20). The pattern was confirmed by detailed monitoring, which also found lowest DO and highest pH between June and August at nearly all stations. Monthly low DO coincides with the peak monthly temperature in July.

The ambient data collection program does not target early morning DO or late afternoon pH, times of the day when critical conditions are expected. The seasonal trends in ambient monitoring are assumed to represent seasonal trends in daily minimum or maximum values. The continuous data from August 10-12, 2004 (the month when DO was lowest over the entire study period) confirmed that, in a given day, the lowest DO levels generally occur near sunrise and the highest pH in late afternoon. Therefore, the Deschutes River was calibrated to morning DO and afternoon pH in early August.

Critical conditions were evaluated as morning DO and afternoon pH at 7Q10 streamflow and 90th percentile air temperature. The water quality standards also stipulate that humans cannot cause more than a 0.2 or 0.5 SU change in the pH range. This requires a modeling analysis to distinguish human influences, which were evaluated during the critical condition for maximum pH.

Calibration and Confirmation of Deschutes River QUAL2Kw model

Calibration uses the available in-situ continuous DO and pH data in the mainstem of the Deschutes River. Flows were similar for this time period compared with both the temperature calibration and validation time periods and the synoptic flow survey (Table 9). The synoptic flow survey was used to scale flows throughout the watershed. Because detailed continuous DO data were available for only one time period, the stream walk survey was used as a check of the overall patterns.

QUAL2Kw DO and pH Model Calibration

Once the flow distribution, hyporheic exchanges, and shade were calibrated to the continuous temperature data, the model was calibrated to DO and pH in the mainstem, after updating the meteorology, flow, and shade inputs for the DO calibration period. The values and process are as described for the Deschutes River temperature model. Point-source (tributary) flows were scaled using the 2003 synoptic survey flow distribution, and diffuse sources were estimated from the flow balance at the gaged locations. Tributary, headwater, and diffuse temperatures were estimated as described in the Temperature TMDL section.

The QUAL2Kw model was calibrated to minimize the root mean square error (RMSE) between the measured and predicted daily minimum and maximum values for a variety of parameters. The RMSE is a measure of the goodness-of-fit calculated as the deviation of the model from measured values:

$$RMSE = \sqrt{\frac{\Sigma(X_{measured} - X_{predicted})^2}{n}}$$

where X is the DO, pH, or other parameter and n is the number of comparison locations.

The rates that govern chemical and biological processes were auto-calibrated using several iterations of the genetic algorithm (Pelletier et al., 2006). The genetic algorithm applied within QUAL2Kw finds the combination of multiple kinetic rates and constants within a range of values to optimize the fit of the predicted values against observations. The process mimics natural selection and evolution, where the user selects the population size and number of generations to simulate. Based on the goodness-of-fit, pairs of model runs (parents) are selected from the current population. The parent model runs breed to produce two offspring applications where the kinetic rate parameters can mutate or cross over between the parent models.

The goodness-of-fit is evaluated for a user-specified function that includes the option to weight different constituents, such as in-situ DO or ammonium concentrations. For the Deschutes River DO and pH application, the fitness function includes measured nutrient, DO, and pH parameters.

The genetic algorithm was applied multiple times to establish a family of potential parameter values. The rate parameters for each run were archived and compared from run to run to identify which rate constants varied the most. Results were reviewed to determine whether large changes to small values occurred or if the rate constant cycled within the established range. Table 27 lists rate constants with high variability (>50% between successive model runs). Other rate constants exhibited low or moderate variability between successive runs.

Table 27. Rate constants with high variability between applications of the genetic algorithm to Deschutes River DO and pH.

Rate constants	Constrained range
Denitrification	0 to 2 /d
Sediment denitrification transfer coefficient	0 to 1 m/d
Inorganic phosphorus settling velocity	0 to 2 m/d
Plant respiration rate	0 to 0.5 /d
Plant external nitrogen half saturation	0 to 300 ug-N/L
Plant inorganic carbon half saturation	1.30E-06 to 1.30E-04 moles/L
Plant light constant	1 to 100 langleys/d
Plant ammonia preference	1 to 100 ug-N/L
Subsistence quota for nitrogen	0.0072 to 7.2 mg-N/mg-algae
Subsistence quota for phosphorus	0.001 to 1 mg-P/mg-algae
Internal phosphorus half saturation	1.05 to 5 (unit less)
Detritus settling velocity	0 to 5 m/d

Groundwater inflow volumes were calculated as the difference in flows between stations, but this value does not account for groundwater that enters and exits the same reach. Groundwater nutrient concentrations were higher than surface water values. Groundwater nitrate concentrations were calibrated using the genetic algorithm, constrained by the observed range.

Figure 64 presents the calibrated DO model, which had a RMSE of 0.64 mg/L for the daily minimum DO and 0.53 mg/L for the combined daily minimum and maximum values. The pH model had a RMSE of 0.58 SU for the daily maximum and 0.47 SU for the combined daily minimum and maximum values. Diel swings in DO were under-predicted in general, with a mean fluctuation of 2.3 mg/L for the data and 1.7 mg/L for the model, and the model tended to over-predict minimum DO concentrations. The pH model characterized the highest maximum pH in the system but consistently over-predicted peak pH values at other locations and did not reflect the decline in peak pH at RK 23. The stream walk data, described below, confirmed the predicted decline in pH near RK 28.

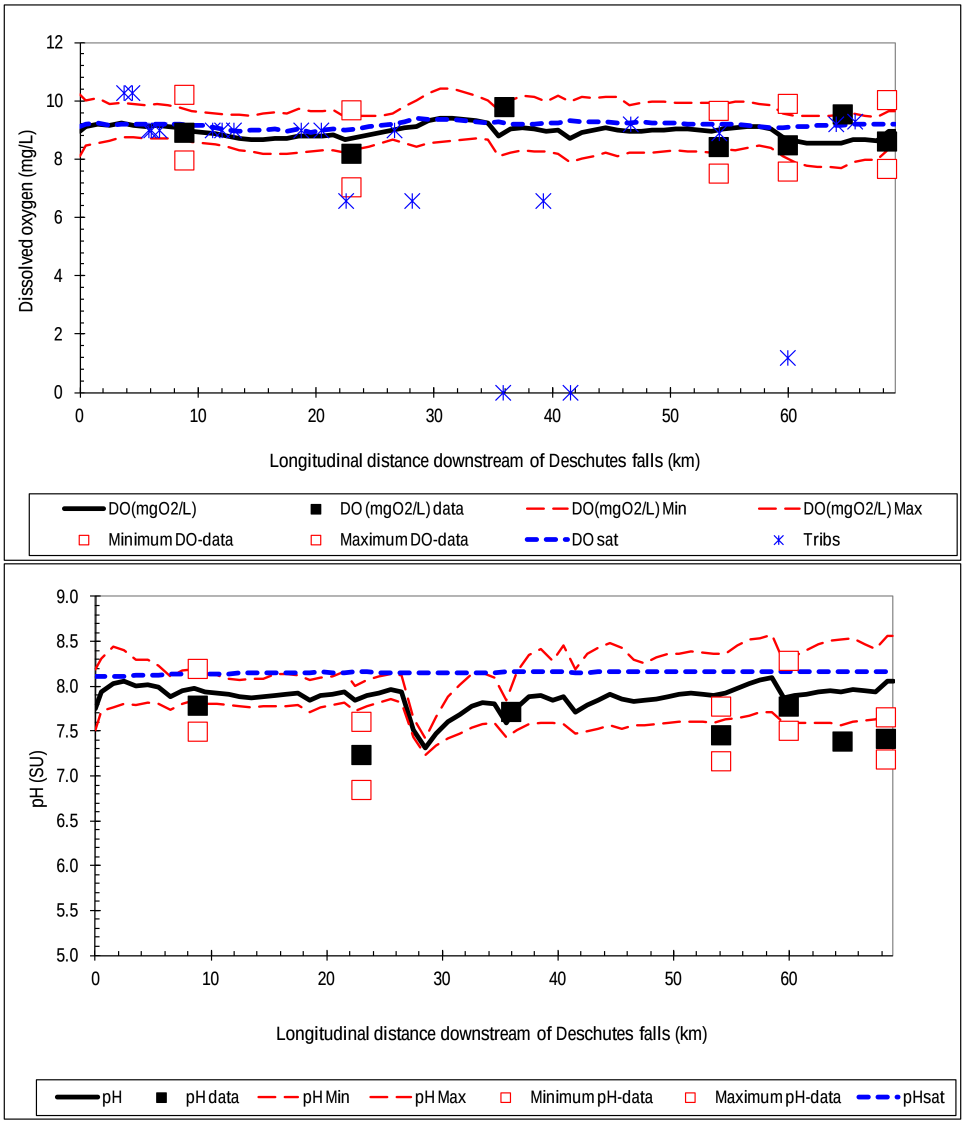


Figure 64. Predicted and observed DO and pH in the Deschutes River for the August 10-12, 2004 calibration period.

Figure 65 presents the simulated longitudinal profile of nitrogen and phosphorus species in the mainstem, tributaries, and groundwater. Nitrate+nitrite increased in a downstream direction, consistent with the observed data. Groundwater and some tributaries entered with higher concentrations than in the mainstem of the Deschutes River. Inorganic phosphorus was low throughout the system, except within 10 km of Capitol Lake near Henderson Blvd. Tributaries had higher concentrations of ammonium and inorganic phosphorus than the mainstem Deschutes River, although tributary nitrate+nitrite concentrations were lower.

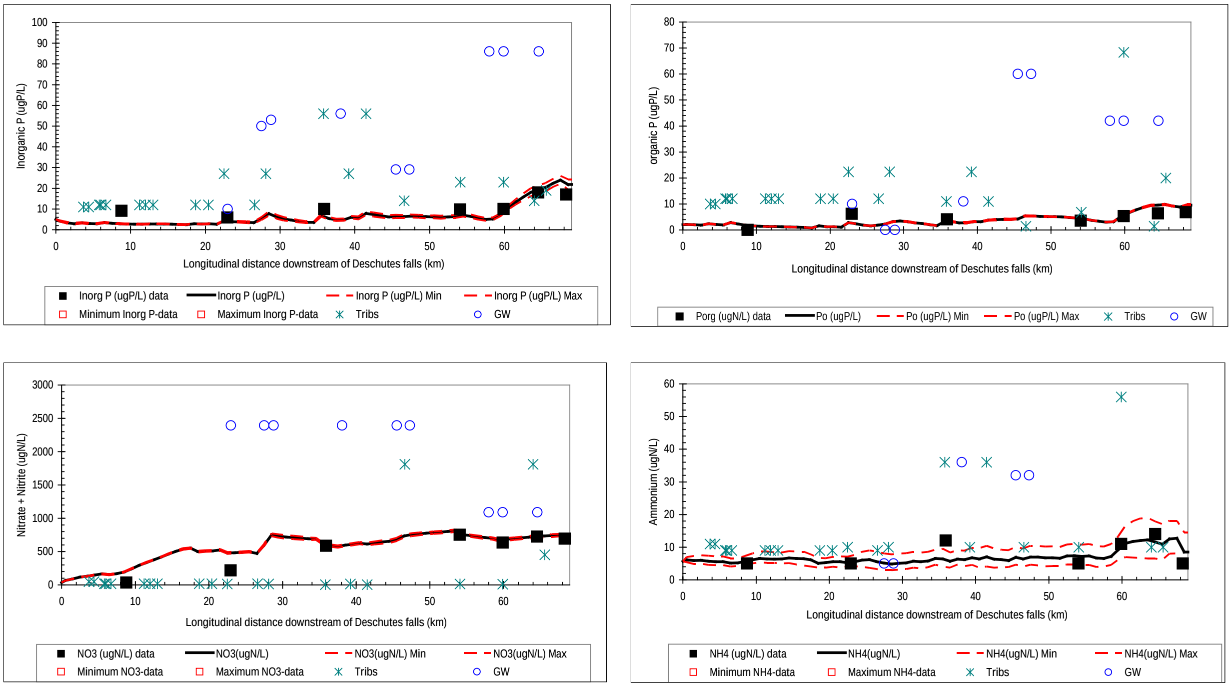


Figure 65. Predicted and observed nitrogen and phosphorus concentrations along the Deschutes River for the August 10-12, 2004 calibration period.

Predicted periphyton concentrations were close to values measured in other western Washington streams. Appendix D in Mohamedali and Lee (2008) indicates periphyton values of 2 to 10 g-algae/m^2, with one site up to 23 g-algae/m^2. No periphyton data were collected from the Deschutes River during the 2003-2004 monitoring period (Figure 66). Detritus concentrations also were predicted to be low. All Deschutes River total organic carbon (TOC) results were below the reporting limit of 1.0 mg/L. No detailed comparison of detritus was performed. Overall, the model describes the DO, pH, and nutrient variations in the Deschutes River.

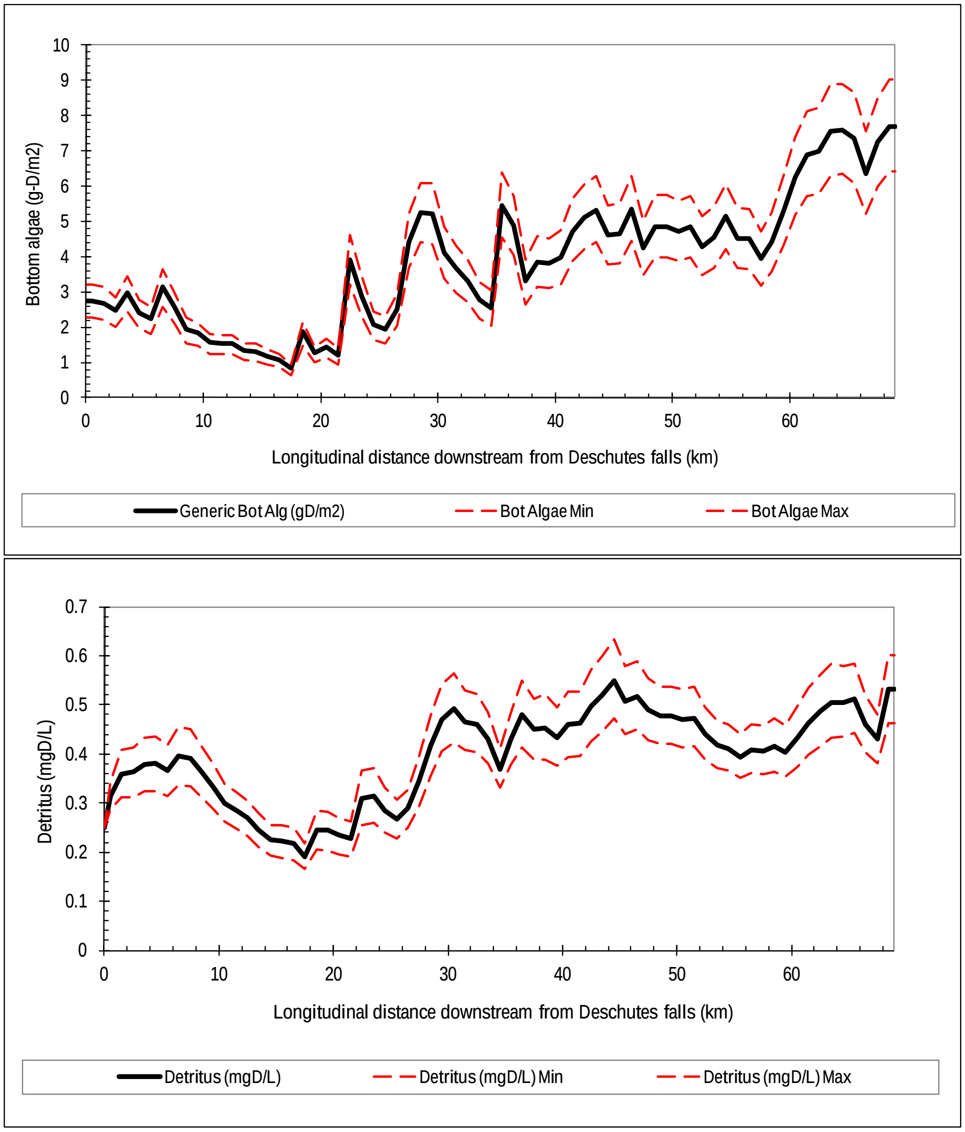


Figure 66. Predicted bottom algae and detritus concentrations along the Deschutes River for the August 10-12, 2004 calibration period.

All TOC results, a proxy for detritus, were <1.0 mg/L.

QUAL2Kw DO and pH Model Confirmation

The stream walk survey conducted August 11-15, 2003 provided model comparison information, although daily minimum and maximum DO and pH data were not available nor were nutrient concentrations. Twice-monthly nutrient data for the Deschutes River were available for the following week, and these values were used in the model comparison.

Predicted minimum DO concentrations were very close to the values measured during the stream walk. Because the surveys began each day at mid morning, the daily minimum values were not captured. The model underestimated the maximum DO concentrations (Figure 67). The model generally overestimated the pH values. While the model characterized pH fluctuations very well near RK 30, the model overestimated maximum pH at RK 20 and downstream of RK 50.

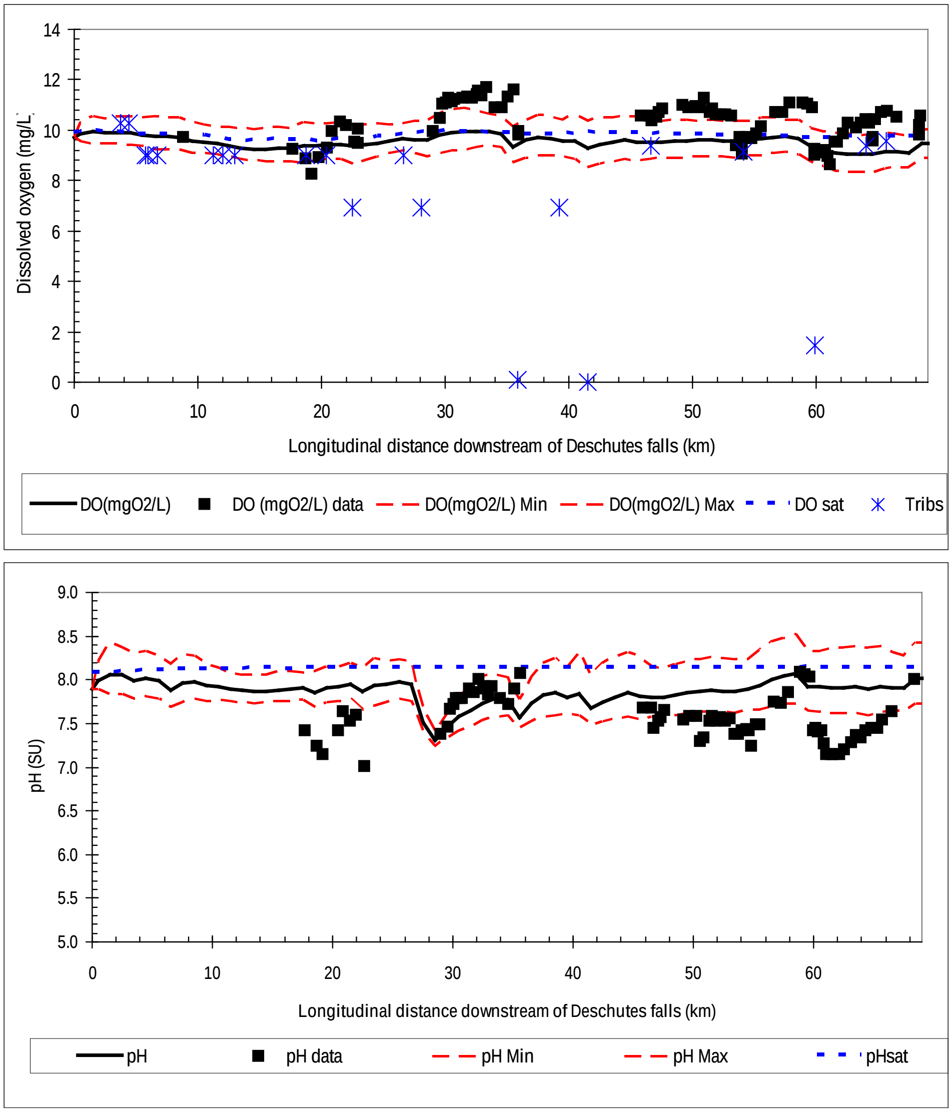


Figure 67. Predicted and observed DO and pH in the Deschutes River for the August 11-15, 2003 stream walk survey.

To simulate conditions during the stream walk survey, nutrient concentrations for the tributaries and groundwater were set to the values used in the calibration for August 2004, since no August 2003 data were available. Longitudinal variations were similar to those found in the DO calibration (Figure 68), as were bottom algae and detritus (Figure 69).

Although the stream walk survey was limited by the lack of nutrient concentrations, the survey confirmed the overall patterns in the Deschutes River.

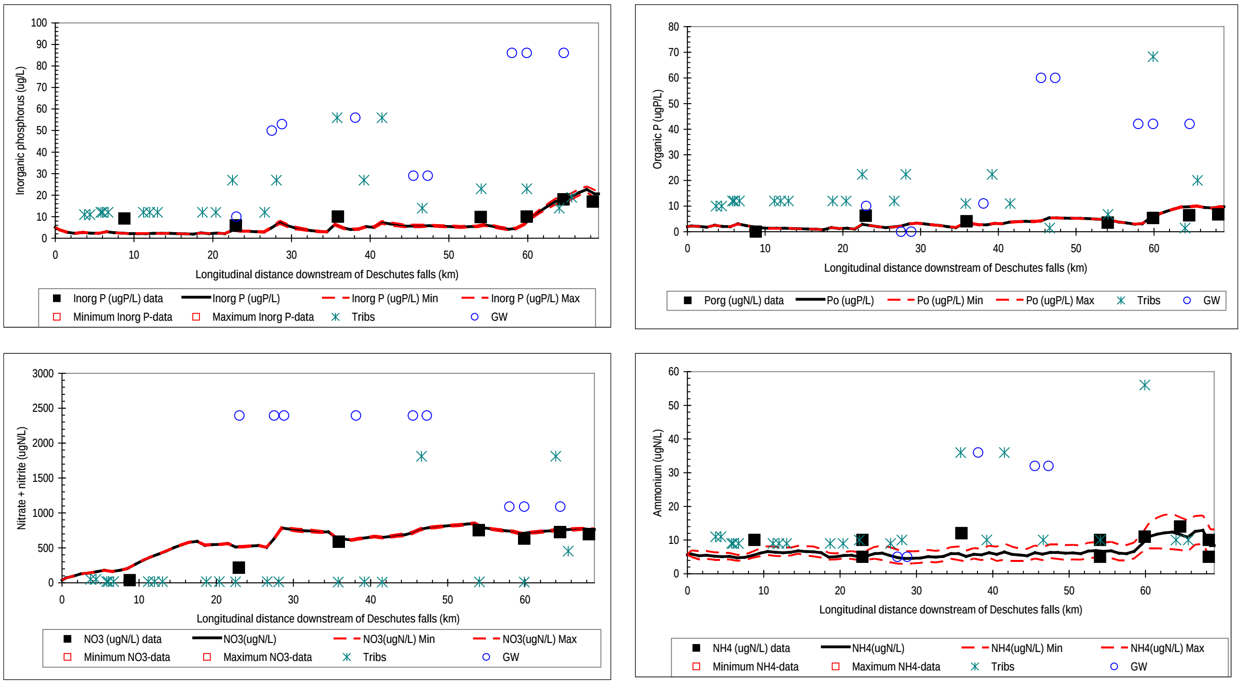


Figure 68. Predicted nutrient levels in the Deschutes River for the August 11-15, 2003 stream walk survey.

Measured nutrient concentrations are from August 2004.

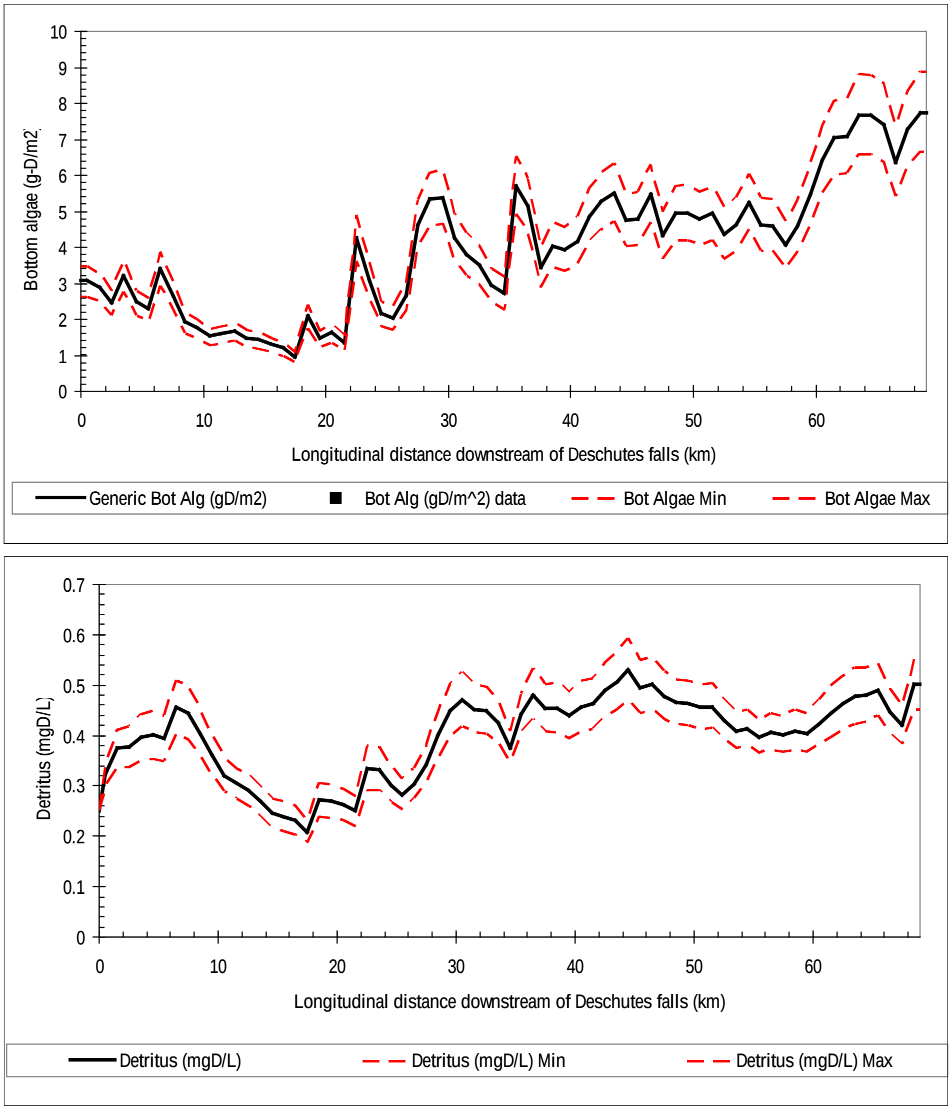


Figure 69. Predicted bottom algae and detritus levels in the Deschutes River for the August 11-15, 2003 stream walk survey.

QUAL2Kw DO and pH Model Sensitivity Analyses

Several sensitivity analyses were performed to evaluate various rate parameters and to test assumptions used in the calibration.

The effect of varying tributary nutrient concentrations on mainstem Deschutes River DO and pH was evaluated. The nutrient concentrations of the tributaries were categorized by geologic unit, based on Plate 1 of Sinclair and Bilhimer (2007):

- Bedrock (RK 0 through RK 20.4).
- Vashon recessional outwash gravel and sand (RK 22.5 through RK 46.6).
- Vashon recessional outwash sand and silt (RK 54.1 through RK 65.6).

Table 28 summarizes the lowest 10th percentile concentrations from the 2003-2004 monitoring for tributary sites within each of the three geology types. Only summer results were included.

Table 28. Lowest 10th percentile summer tributary concentrations by geology type for the 2003-2004 monitoring period.

River kilometer (RK)	Geology type	Ammonium	Nitrate + nitrite	Organic nitrogen	Ortho-phosphate	Organic phosphorus
0 – 20.4	Bedrock	0.010	0.042	0.111	0.008	0.001
22.5 – 46.6	Outwash (gravel and sand)	0.010	0.117	0.256	0.007	0.004
54.1 – 65.6	Outwash (sand and silt)	0.010	0.017	0.113	0.010	0.003

Tributary concentrations were set to the 10th percentile of the 2003-2004 monitoring or lower if the measured values were less than these values. Concentrations for the two springs were not changed because they are primarily groundwater sources. Headwater concentrations were not changed because they were less than the 10th percentile concentrations. Minimum DO levels increased as much as 0.16 mg/L and 0.04 mg/L on average, while maximum pH values decreased 0.05 SU, on average, and up to 0.29 SU (Figure 70).

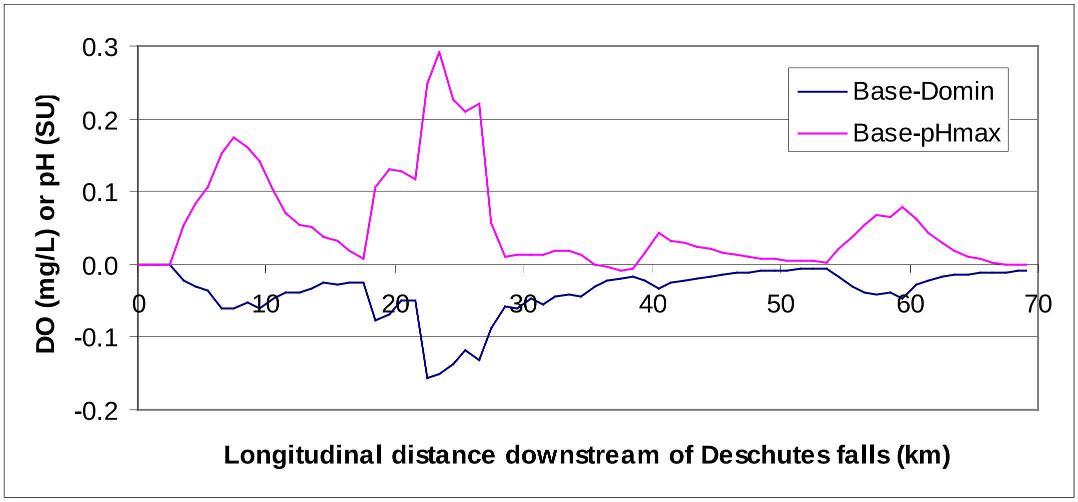


Figure 70. Differences in predicted minimum DO and maximum pH for tributaries set to ≤10th percentile concentrations for the DO calibration time period.

Loading Capacity

Deschutes River Watershed Loading Capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards (40CFR §130.2(f))." Loading capacities for DO and pH in the Deschutes River watershed are expressed as solar radiation heat loads based on system potential vegetation, channel conditions, DO and pH in tributaries and the headwater, and nutrient inputs.

Solar radiation, primary productivity, reaeration, and other processes influence DO and pH levels in the Deschutes River and its tributaries. Solar radiation strongly influences water temperature, which also affects DO since DO saturation is a function of temperature. Cooler water holds more DO than warmer water. Solar radiation, along with nutrient concentrations, also influences primary productivity, which governs DO and pH. Therefore, decreasing light and nutrient levels can improve minimum DO, maximum pH, and pH ranges that result from too much primary productivity. In most freshwater systems, phosphorus is limiting when nutrients limit primary productivity, although some waters are nitrogen limited. While biochemical oxygen demand (BOD) also is a source of oxygen demand that can be controlled, BOD is very low throughout the Deschutes River system and is not included in the loading capacity or subsequent reduction targets.

This interim loading capacity is based on meeting water quality standards and system potential conditions within the Deschutes River system. The Capitol Lake and Budd Inlet DO TMDL may require a lower nutrient load to achieve water quality standards in those water bodies than would be needed in the Deschutes River alone. The Deschutes River DO and pH TMDL will be revisited when the downstream load and wasteload allocations are determined; see the Capitol Lake and Budd Inlet DO TMDL section of this report for further information.

The system potential DO and pH are estimates of the levels that would occur under natural conditions during critical 7Q10 and 90th percentile meteorological conditions. In this study, the system potential DO and pH are based in part on the system potential temperature described in the Temperature TMDL section. In addition, tributary and groundwater nutrient inputs were based on potential natural concentrations stratified by geologic type. The system potential DO and pH values do not replace the numeric criteria. The values also do not invalidate the need to meet the numeric criteria at other times of the year and at other less extreme low flows.

Scenarios to establish system potential conditions

The system potential DO and pH were evaluated in two steps. First, human activities that affect the current temperatures also influence DO and pH in the Deschutes River. These temperature scenarios evaluated as part of the Deschutes River Temperature TMDL were analyzed to quantify the effect on DO and pH. Second, other human activities have altered tributary and groundwater quality, and these were explored in a second set of scenarios.

The following temperature-related scenarios were evaluated under 7Q10 flow and critical meteorological conditions:

- **Current – Current shade and nutrient inputs**. Effective shade was set to the current riparian vegetation and nutrient inputs were based on the same current 7Q10 flows and 90th percentile air temperatures as used for the water temperature current conditions.
- **Scenario DO1 – Maximum potential shade**. Effective shade was set to the system potential mature riparian vegetation that would naturally occur in the Deschutes River watershed, as described in the temperature model section. Current nutrient levels were used for the headwater, tributaries, and diffuse sources.
- **Scenario DO2 – Decrease widest sections of the Deschutes River**. Channel banks are expected to stabilize and become more resistant to erosion as the riparian vegetation along the river matures and as fine sediment is controlled (see Temperature and Fine Sediment TMDL sections of this report). Portions of the Deschutes River floodplain have a very wide NSDZ, including areas more than 30 m wide. The NSDZ and wetted width were set to a maximum of 20 m each, with full mature riparian vegetation beyond the NSDZ.
- **Scenario DO3 – Reduce channel width**. Both the wetted width and bottom width were decreased 10% throughout the system to calculate shade and to modify the reach hydraulics.
- **Scenario DO4 – Microclimate improvements**. Increases in vegetation height, density, and riparian zone width are expected to result in localized decreases in air temperature. To evaluate the effect of this potential change in microclimate on water temperature, and subsequent effects on DO and pH, the hourly air temperatures were decreased by 2°C (Bartholow, 2000).
- **Scenario DO5 – Reduced headwater and tributary water temperatures**. The headwater and tributary temperatures were set to the water quality criteria (16°C upstream of Offutt Lake and 17.5°C downstream of Offutt Lake) to quantify the benefit to Deschutes River DO and pH.

Three additional DO, pH, and nutrient reduction scenarios were evaluated:

- **Scenario DO6 – Increase headwater and tributary DO levels**. The effect of low DO levels in the headwaters and tributaries on mainstem DO was evaluated by setting all tributaries and the headwaters to at least the numeric water quality criteria. Where DO concentrations currently are better than the minimum levels in the water quality criteria, the higher values were maintained. Tributaries upstream of Offutt Lake were set to 9.5 mg/L or higher, while tributaries downstream were set to 8.0 mg/L or higher. The two springs were left at current conditions.
- **Scenario DO7 – Decrease nutrient levels in tributaries**. The headwaters and all tributaries except Chambers Creek and the assumed conditions for the Tempo Lake tributary and the unnamed creek at RK 65.6 were nitrogen limited (DIN:OP<7.2), but the mainstem of the Deschutes River at 1000 Road and downstream was phosphorus limited (DIN:OP>7.2). Therefore, both nitrogen and phosphorus species were set to values no greater than the 10th percentile of the 2003-2004 monitoring results by geology type. The two springs were left at current conditions.

- **Scenario DO8 – Decrease nutrient levels in groundwater**. Groundwater nitrate concentrations were calibrated. Other parameter concentrations were based on the hydrogeology study. The effect of decreasing groundwater nutrient concentrations throughout the system was evaluated by setting concentrations equal to the medians from the hydrogeology study. Nitrate was back-calculated from the groundwater value for the area identified in Pitz (1999) and the median ammonium data in Sinclair and Bilhimer (2007) because so many of the nitrate values in the piezometers were below the reporting limit. Groundwater concentrations were capped at 0.054 mg/L for organic phosphorus, 0.052 mg/L for inorganic phosphorus, 0.616 mg/L for nitrate, 0.034 mg/L for ammonia, and 0.007 mg/L for organic nitrogen.

Scenario DO8 represents the system potential condition for DO and pH in the Deschutes River. Scenario DO8 eliminates disturbances to riparian vegetation and channel characteristics, includes headwaters meeting DO standards, and has tributary and groundwater nutrients set to estimated natural conditions. Where minimum DO falls below the numeric criteria, humans cannot cause more than a 0.2 mg/L decrease. Humans also cannot cause the pH to rise above 8.5 SU and natural pH range to change by more than 0.2 SU upstream of Offutt Lake and 0.5 SU downstream of Offutt Lake. Figure 71 summarizes the current dissolved inorganic nitrogen (DIN) and orthophosphate (OP) nutrient loads compared with system potential loads. Nonpoint sources add 119 kg/d of DIN and 1.8 kg/d of orthophosphate to the Deschutes River system under low flows.

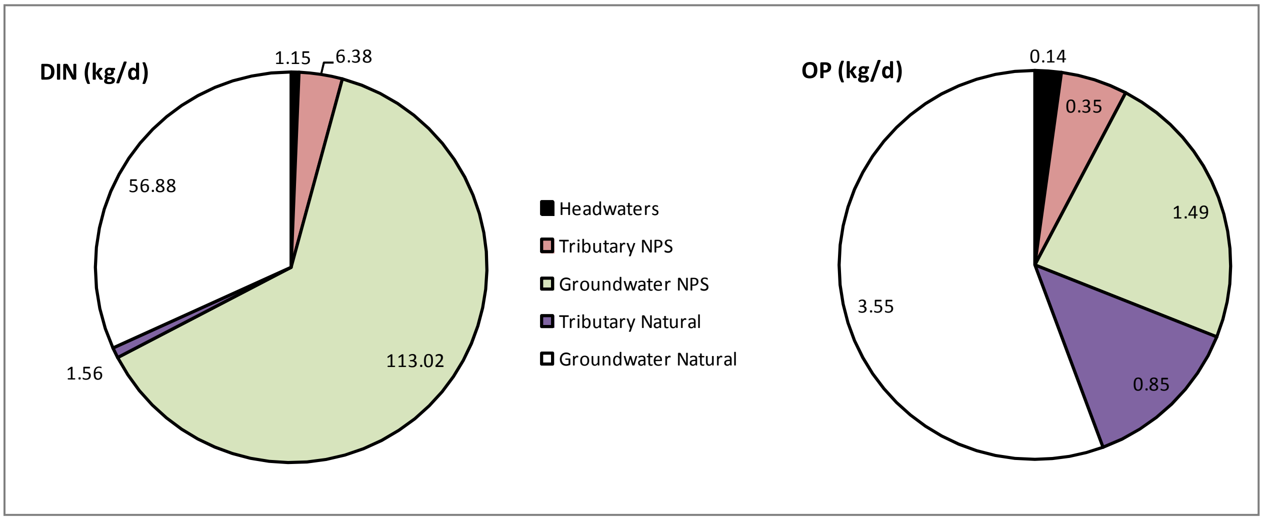


Figure 71. Nutrient load targets (DIN and orthophosphate) under critical conditions for the Deschutes River. NPS = nonpoint sources.

Dissolved Oxygen

Figure 72 and Table 29 summarize minimum DO under current vegetation and the effects of reducing human influences. Improving temperature by restoring vegetation and channel characteristics along the Deschutes River and tributaries would substantially improve minimum DO by 0.98 mg/L on average and as much as 1.18 mg/L. Reducing nutrient inputs in tributaries and groundwater also would improve minimum DO.

Upstream of Offutt Lake, eliminating human influences would not achieve a minimum DO of 9.5 mg/L. The system potential minimum DO varies between 9.0 and 9.5 mg/L. Human activities currently cause more than a 0.2 mg/L decrease throughout this portion of the river. Downstream of Offutt Lake, the Deschutes River meets the DO standard between RK 46 and 58 and downstream of RK 68. Between RK 58 and 68, the Deschutes River can achieve the minimum DO standard through a variety of management actions.

The DO-based loading capacity of the Deschutes River is presented in Figure 73. Upstream of Offutt Lake, minimum DO must be improved to within 0.2 mg/L of the system potential condition. The loading capacity is the system potential minimum DO minus 0.2 mg/L. Downstream of Offutt Lake, the current condition is the loading capacity between RK 46 and 58 and also downstream of RK 68. Between RK 58 and 68, the loading capacity is 8.0 mg/L. The loading capacity will be expressed as loads of solar radiation, DO, and nutrients in the subsequent Water Quality Improvement Report.

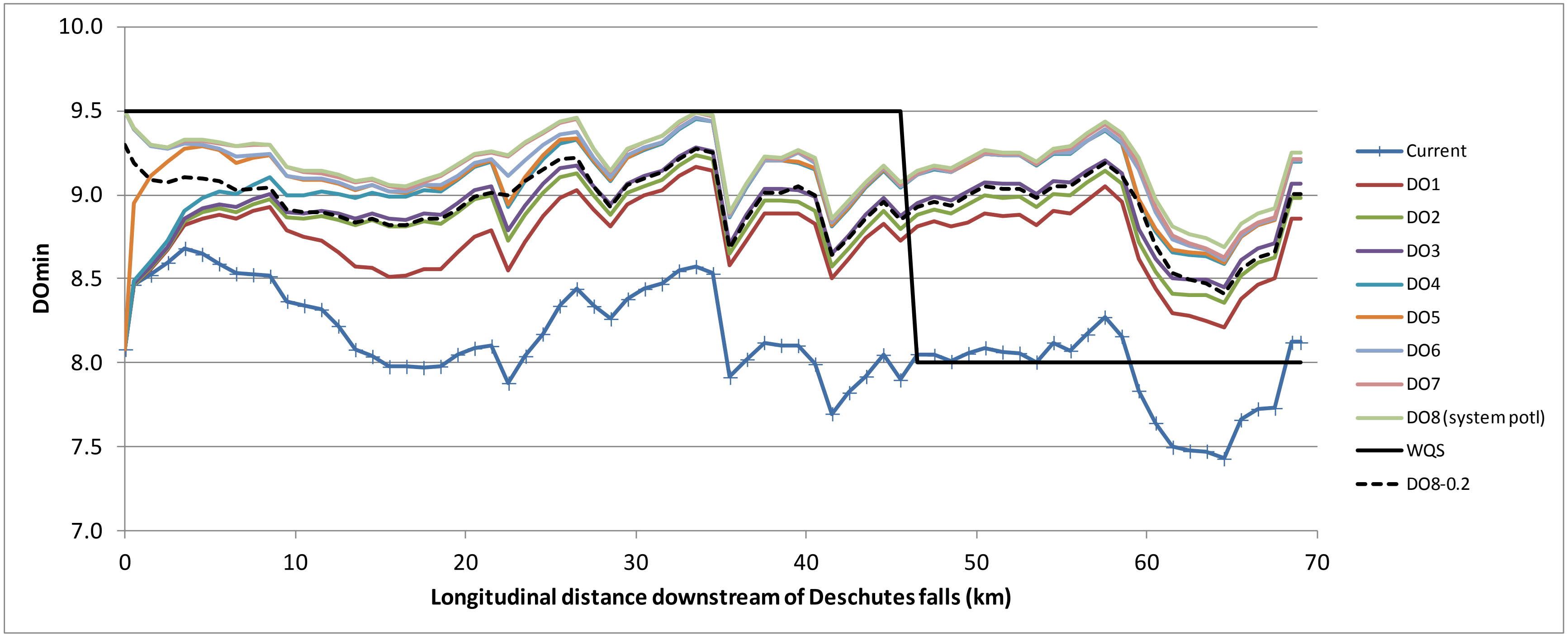


Figure 72. Predicted daily minimum DO in the Deschutes River for critical conditions under current conditions and various temperature scenarios.

Table 29. Predicted changes in Deschutes River daily minimum DO (mg/L) under current conditions and various temperature and nutrient scenarios.

DO_{min} is expressed as the minimum in any one reach and averaged over the entire river.

ΔDO_{min} is expressed as the maximum improvement in any one reach and as the system-wide average.

Scenario	Lowest DO_{min}	Mean DO_{min}	Maximum improvement in DO_{min}	Average improvement in DO_{min}
Current (current vegetation, temperature, and channel widths under recent 7Q10 flows)	7.43	8.12	NA	NA
Scenario DO1 (mature riparian vegetation)	8.08	8.74	0.84	0.62
Scenario DO2 (Scenario DO1 with NSDZ, WW <20m)	8.08	8.85	0.30	0.11
Scenario DO3 (Scenario DO2 with WW, bottom width -10%)	8.08	8.91	0.09	0.06
Scenario DO4 (Scenario DO3 with air temp – 2ºC)	8.08	9.05	0.18	0.14
Scenario DO5 (Scenario with HW, tribs < 16/17.5ºC)	8.08	9.10	0.51	0.05
Scenario DO5 compared with current conditions	*NA*	*NA*	*1.18*	*0.98*
Scenario DO6 (Scenario DO5 with HW, tribs <9.5/8.0 mg/L DO)	8.61	9.15	1.42	0.05
Scenario DO7 (Scenario DO6 with tributaries set to no more than the 10th percentile current nutrient concentrations)	8.62	9.17	0.12	0.03
Scenario DO8 (Scenario DO7 with groundwater nutrients reduced)	8.69	9.19	0.06	0.02
Scenario DO8 compared with current conditions	*NA*	*NA*	*1.42*	*1.07*

Abbreviations are defined in Appendix B.

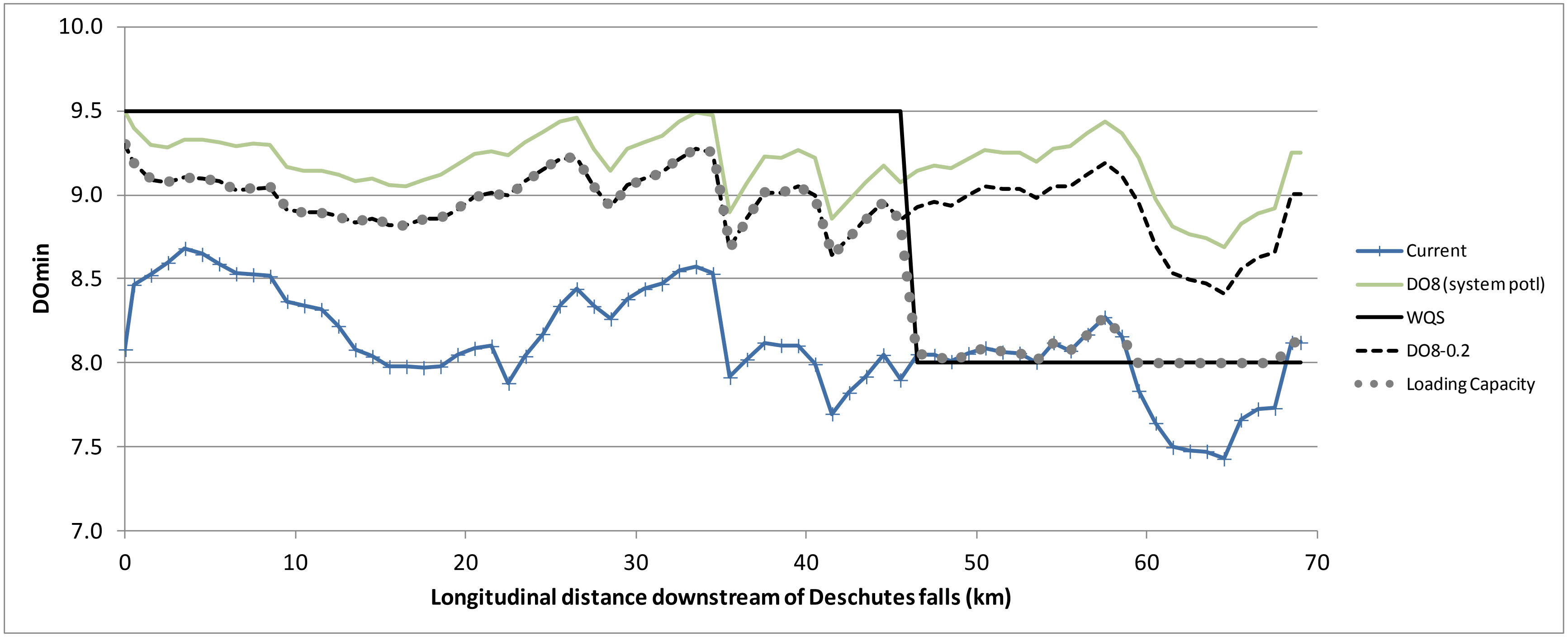


Figure 73. DO-based loading capacity for the Deschutes River, expressed as minimum DO (mg/L).

pH

Figures 74 and 75 and Table 30 summarize the influences of human activities on maximum pH and the pH range (pHmax – pHmin). Several sections do not meet the water quality standards for maximum pH, pH range, or both. Upstream of Offutt Lake, three regions do not meet the water quality standards. Between RK 5.5 and 8.5 and between RK 21.5 and 27, human influences are causing >0.2 SU increase in the pH range, even though maximum pH meets the standard. Between RK 37.5 and Offutt Lake, human influences cause >0.2 SU increase in the pH range, and the maximum pH violates standards. Downstream of Offutt Lake, two regions do not meet water quality standards. Between RK 55 and 59 and between RK 60 and the mouth, the maximum pH violates the standard. Humans also increase the pH range by >0.5 SU between RK 62 and 68.

The pH-based loading capacity for the Deschutes River is presented in Figure 76 for maximum pH and Figure 77 for pH range. The loading capacity for maximum pH is the current condition between RK 0 and 40, between RK 46 and 55, and between RK 59 and 60. The loading capacity is 8.5 SU for RK 40 to 46, RK 55 to 59, and downstream of RK 60. For the pH range, the loading capacity is the current condition between RK 0 and 5.5, between RK 8.5 and 21.5, between RK 27 and 37.5, between RK 46 and 62, and downstream of RK 68. The pH range loading capacity is the system potential pH range plus 0.2 SU for RK 5.5 to 8.5, RK 21.5 to 27, and RK 37.5 to 46. The pH range loading capacity between RK 62 and 68 is the system potential pH range plus 0.5 SU.

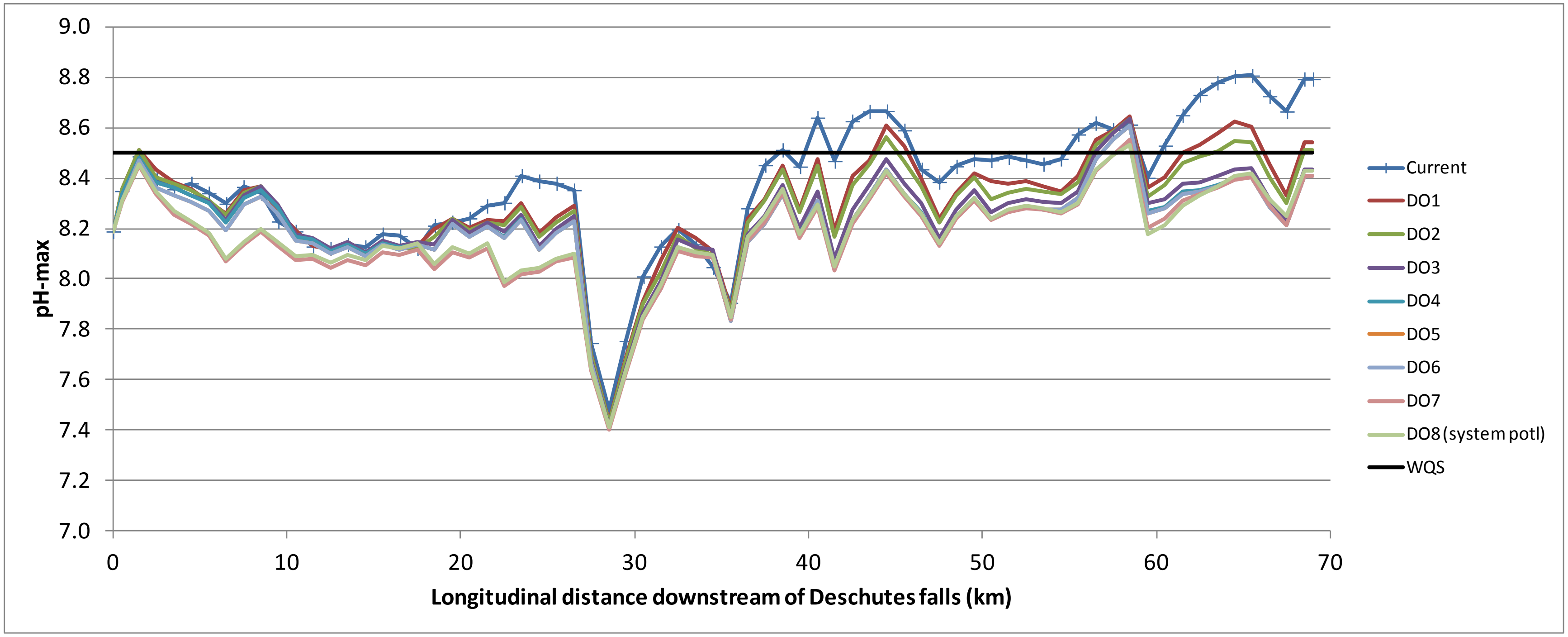


Figure 74. Predicted daily maximum pH in the Deschutes River for critical conditions under current conditions and various temperature and nutrient scenarios.

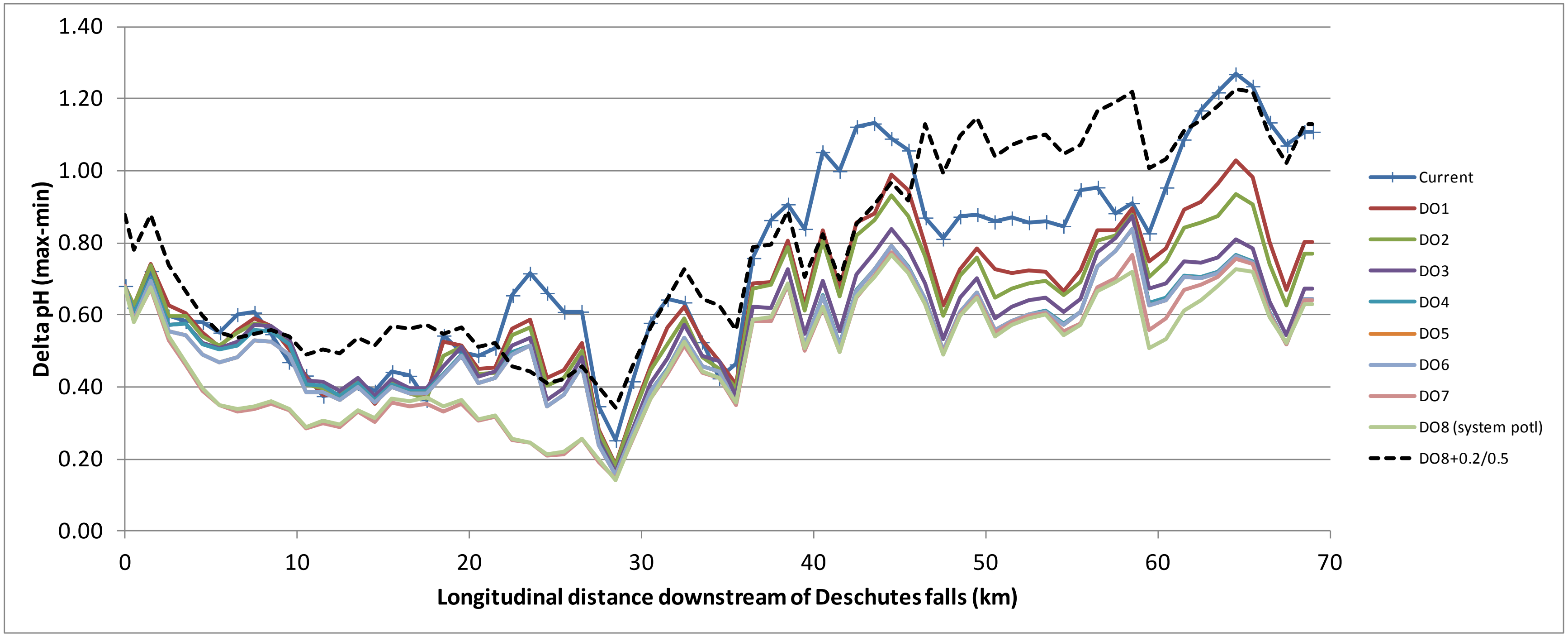


Figure 75. Predicted differences in the pH range (pHmax – pHmin) for critical conditions under current conditions and various temperature and nutrient scenarios.

Table 30. Predicted changes in daily maximum pH (SU) under the current condition and various temperature and nutrient scenarios.
pH_{max} is expressed as the maximum in any one reach and averaged over the entire river.
ΔpH_{max} is expressed as the maximum improvement in any one reach and as the system-wide average.

Scenario	Maximum pH					pH range (pHmax – pHmin)			
	Highest pH_{max}	Mean pH_{max}	Mean improvement in pH_{max}	Max improvement in pH_{max} (upstream of Offutt Lake)	Max improvement in pH_{max} (downstream of Offutt Lake)	Highest range	Mean range	Maximum improvement in range (upstream of Offutt Lake)	Maximum improvement in range (downstream of Offutt Lake)
Current (current vegetation, temperature, and channel widths under recent 7Q10 flows)	8.81	8.37	NA	NA	NA	1.27	0.74		
Scenario DO1 (mature riparian vegetation)	8.64	8.30	-0.08	-0.28	-0.33	1.03	0.64	-0.33	-0.40
Scenario DO2 (Scenario DO1 with NSDZ, WW <20m)	8.64	8.28	-0.02	-0.06	-0.08	0.94	0.61	-0.07	-0.09
Scenario DO3 (Scenario DO2 with WW, bottom width -10%)	8.64	8.24	-0.04	-0.10	-0.11	0.87	0.57	-0.11	-0.13
Scenario DO4 (Scenario DO3 with air temp – 2ºC)	8.61	8.22	-0.02	-0.04	-0.04	0.84	0.55	-0.05	-0.04
Scenario DO5 (Scenario with HW, tribs < 16/17.5ºC)	8.61	8.21	-0.01	-0.01	-0.01	0.84	0.54	-0.03	-0.01
Scenario DO5 compared with current conditions	*NA*	*NA*	*-0.16*	*-0.42*	*-0.45*				
Scenario DO6 (Scenario DO5 with HW, tribs <9.5/8.0 mg/L DO)	8.61	8.21	0.00	0.00	0.00	0.84	0.54	0.00	0.00
Scenario DO7 (Scenario DO6 with tribs set to no more than the 10th percentile nutrient concentrations)	8.55	8.17	-0.04	-0.22	-0.06	0.77	0.49	-0.27	-0.07
Scenario DO8 (Scenario DO7 with groundwater nutrients reduced)	8.53	8.18	-0.01	-0.03	-0.04	0.77	0.48	-0.01	-0.06
Scenario DO8 compared with current conditions	*NA*	*NA*	*-0.19*	*-0.42*	*-0.41*				

Abbreviations are defined in Appendix B.

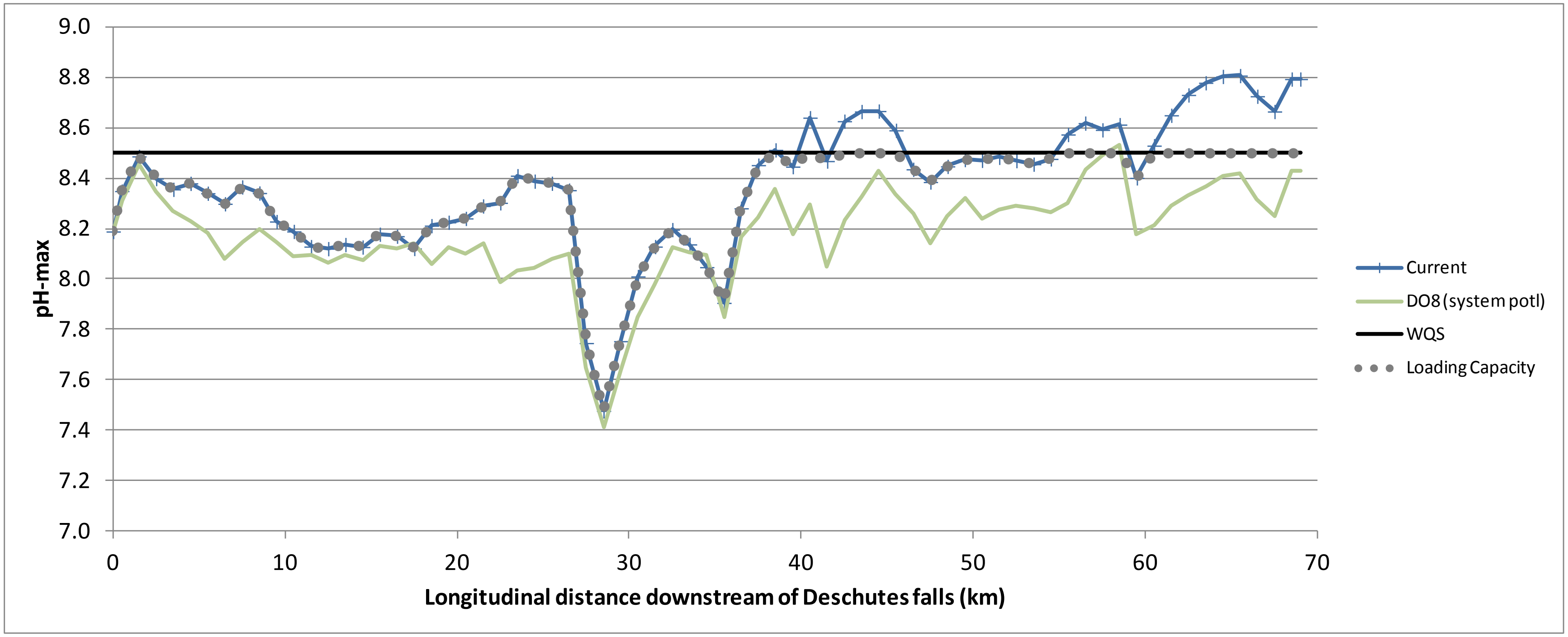


Figure 76. pH-based loading capacity for the Deschutes River expressed as maximum pH (SU).

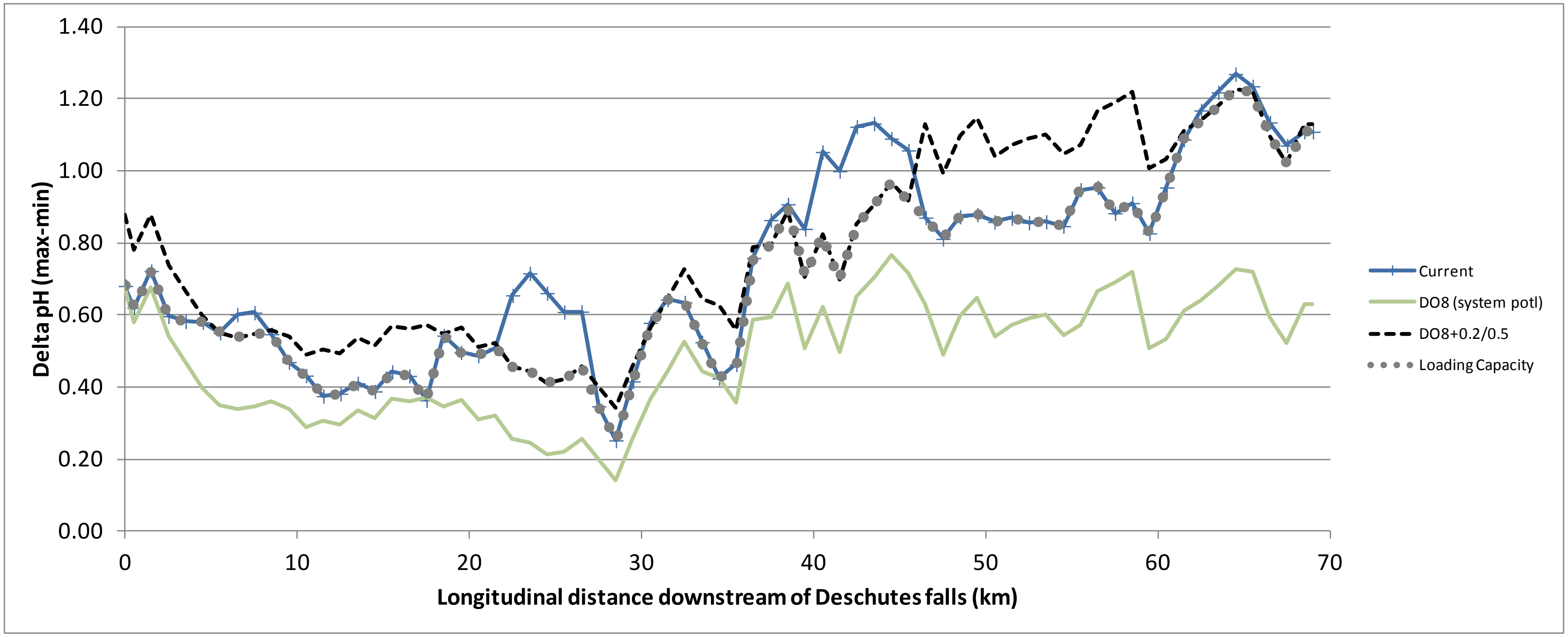


Figure 77. pH-based loading capacity for the Deschutes River expressed as pH range (pHmax – pHmin, SU).

Percival Creek and Black Lake Ditch Loading Capacity

The QUAL2Kw model was not applied to determine the system potential temperature, DO, or pH within the Percival Creek/Black Lake Ditch watershed. Instead, the interim loading capacity for DO and pH in the Percival Creek watershed is expressed as the solar radiation heat loads based on system potential vegetation. The decreased temperatures that would result from mature riparian vegetation would improve the DO due to saturation effects alone, and both DO and pH due to decreased primary productivity.

The temperature, DO, and pH regimes are highly influenced by Black Lake and wetlands at the headwaters in both branches, and natural conditions may not meet the numeric criteria. Figure 59 in the Temperature TMDL of this report presents the temperature pattern of decreasing temperature in a downstream direction, which coincides with gaining reaches from groundwater. Figure 78 presents the DO and pH profiles.

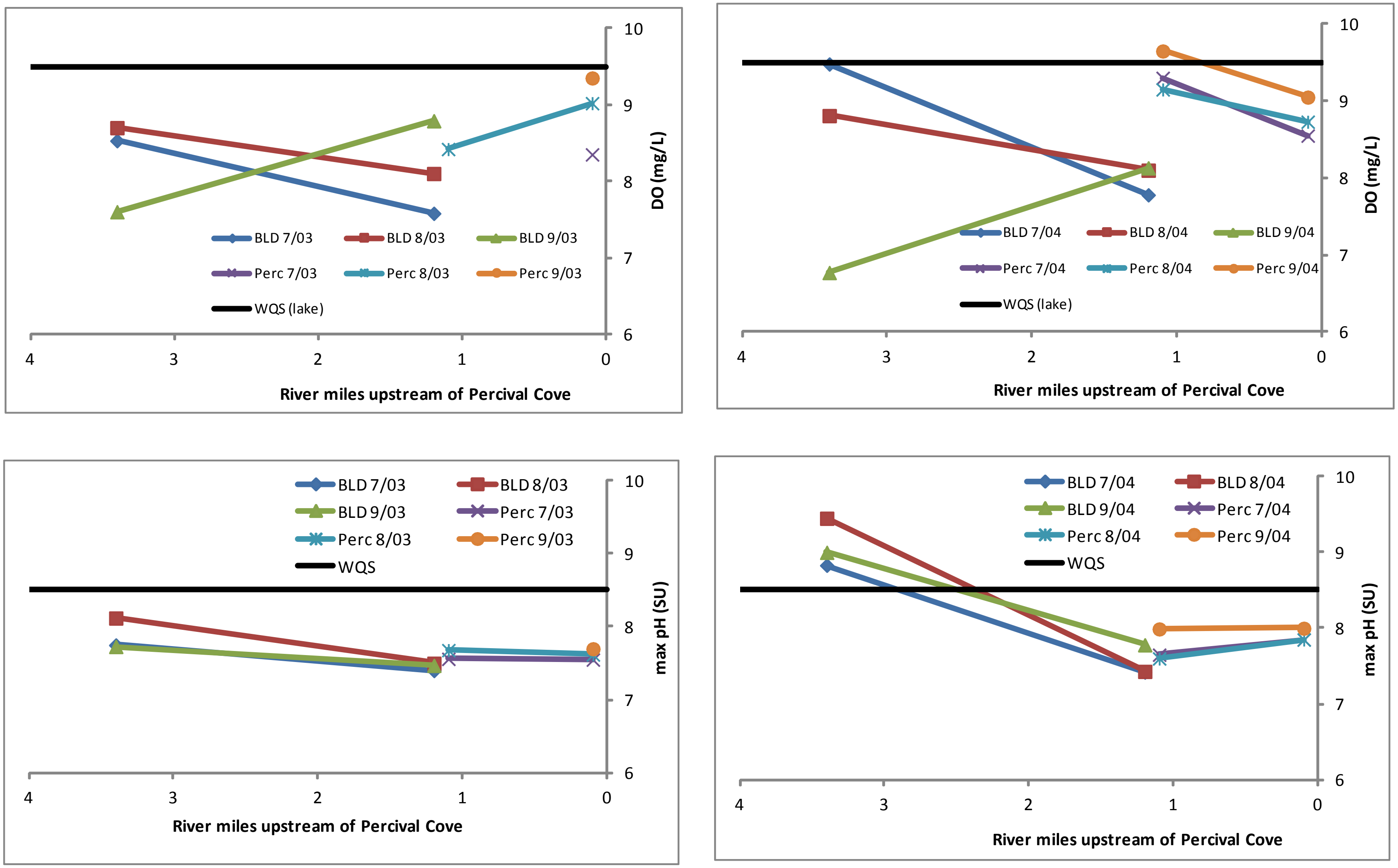


Figure 78. Discharge, temperature, DO, and pH profiles in Percival Creek and Black Lake Ditch from 2003 (left) and 2004 (right).

Load and Wasteload Targets

Deschutes River Watershed Load Targets

The subsequent Water Quality Improvement Report (WQIR) will establish load reduction targets and load allocations based on specific management activities applied to specific river reaches. These activities could include the shade that would result from full mature riparian vegetation with microclimate effects; channel improvements that would reduce the near-stream disturbance zone (NSDZ) and wetted width to <20 m; and improvements to headwater, tributary, and groundwater quality.

The Temperature TMDL section of this report summarizes the effective shade deficit, and solar heat load targets for potential vegetation are detailed in Appendix E for critical conditions. Temperature improvements alone would substantially improve minimum DO, but additional improvements in headwater, tributary, and groundwater quality will be needed in some locations. Figures 72, 74, and 75 can be used to identify which management activities are most influential by river reach, based on the differences between scenario lines. For minimum DO upstream of Offutt Lake, the most influential activity between RK 0 and 5 would be restoring headwater DO to meet the numeric standard. Between RK 5 and 46 (Offutt Lake), restoring full mature riparian shade would have the greatest benefit to DO. Between RK 10 and 20, decreasing the NSDZ and wetted width would have the next highest impact. Achieving microclimate benefits would have the third highest benefit to the section between RK 10 and 46. Downstream of Offutt Lake, partially restoring riparian shade downstream of RK 58 would meet water quality standards, although other activities also may succeed in achieving standards.

For maximum pH, management activities are needed to reduce pH between RK 40 and 46, between RK 55 and 59, and between RK 60 and 68. Restoring full mature riparian shade would have the greatest impact in all three sections. Additional actions would be needed between RK 43 and 46 and near RK 58 to meet the maximum pH standard. For the pH range, management activities are needed to reduce the pH range between RK 5.5 and 8.5, between RK 21.5 and 27, between RK 37.5 and 46, and between RK 62 and 68. Reducing tributary nutrients would strongly influence the reaches between RK 5.5 and 8.5 and between RK 21.5 and 27.5. Shade also strongly influences the section between RK 21.5 and 27.5, as well as the reaches between RK 37.5 and 46 and between RK 62 and 68.

The subsequent WQIR also will establish load reduction targets and load allocations for several tributaries to the Deschutes River that do not meet the water quality standards for DO. As required in the Temperature TMDL, full mature riparian vegetation is needed along the creeks listed in Table 26. Table 31 summarizes tributaries that need increased DO to meet the standards, within the tributaries themselves and possibly within the Deschutes River.

Historical wetland complexes and current wetland soils likely influence minimum DO in Ayer and Reichel Creeks, and the creeks may not meet the numeric criteria. However, substantial increases are likely with improved water temperatures. During the winter months, Ayer Creek achieves a minimum DO of 6.7 mg/L and Reichel achieves 10.3 mg/L, when biological activity is low. Lake Lawrence influences the outlet stream DO and nutrients and should be evaluated further as part of a total phosphorus TMDL. Load targets for Ayer Creek, Reichel Creek, and the Lake Lawrence tributary should include reductions in solar radiation that would result from mature riparian vegetation to limit primary productivity to the maximum extent possible.

Table 31. Recommended targets for streams that do not meet the water quality standards for DO.

Tributary		Recommended Target
	DO min (mg/L)	DO min (mg/L)
Ayer (Elwanger)	1.05	8.0
Reichel	4.30	8.0
Lake Lawrence tributary	1.60	8.0

Additional nutrient load reductions may be needed within the Deschutes River watershed in order to meet water quality standards in Capitol Lake or Budd Inlet. The WQIR will address these.

Antidegradation provisions also apply. Tributaries and river reaches that meet standards should not worsen.

In addition to the numeric load targets to be established in the WQIR for the Deschutes River watershed and narratives established in the Temperature TMDL, the following DO, pH, and nutrient narratives and management activities are recommended:

- Because phosphorus tends to be bound to particles, activities that control fine sediment would decrease phosphorus generation and transport from tributaries and the upper watershed. The fine sediment load and wasteload targets would benefit nutrients, DO, and pH.
- As required for temperature, tributaries should achieve full mature riparian vegetation. Benefits include cooler water within the tributaries and decreased heat loads to the Deschutes River, which have a dual benefit to DO and pH. Establishing mature riparian vegetation along tributaries is important to meeting the DO and pH standards at the mouths of the tributaries.
- Tributaries with high nutrient concentrations such as Ayer (Elwanger) Creek and Reichel Creek should be evaluated for nutrient reduction opportunities to parallel shade increases. Activities that reduce nutrient loads to natural levels should be considered. Future developments should evaluate management activities that reduce nutrient inputs from current conditions.

Deschutes River Watershed Wasteload Targets

This technical report does not recommend facility-specific numeric wasteload targets for locations covered by the stormwater general permits. Instead, wasteload allocations should consider the load reduction targets by subbasin. Facilities covered by general permits should receive wasteload allocations comparable to the load allocations for the subbasin in which the facility is located. Nutrient levels will be revisited in the subsequent WQIR that establishes load and wasteload allocations for Capitol Lake and Budd Inlet.

Ecology regulates municipal, industrial, and construction stormwater facilities as point sources under various general permits. The conditions established in those permits, particularly activities promoting infiltration, may reduce the likelihood of future increases in nutrient loads from areas covered by the permits. While nutrient loads from existing development may be contributing to low DO levels in the summer in the Deschutes River and its tributaries, nutrients are not covered under general permits.

The Construction Stormwater General Permit requires that facilities that discharge to water bodies impaired for high pH conduct pH sampling. Construction sites that affect the Deschutes River in the area currently not meeting standards for maximum pH (RK 38 to RK 45 and downstream of RK 55) should monitor pH in offsite runoff during summer storms. More importantly, these sites must eliminate offsite transport of particulates, particularly during the summer season. Phosphorus generally is associated with particulates. Because it is the limiting nutrient in this part of the Deschutes River, increasing phosphorus loads could increase primary productivity and exacerbate maximum pH and pH range.

The Construction Stormwater General Permit also requires that facilities discharging to water bodies listed as impaired for phosphorus conduct water quality sampling for turbidity. Construction sites surrounding Capitol Lake, including Percival Creek and downstream portions of the Deschutes River, should eliminate the offsite transport of particulates because Capitol Lake is listed for total phosphorus.

Any new permitted facilities in the Deschutes River watershed should not increase nutrient inputs to the Deschutes River or its tributaries beyond existing conditions. Any increase must be offset such that DO and pH improve and do not worsen. The facilities should not produce offsite transport of nutrients.

Percival Creek Watershed Load Targets

The Percival Creek watershed load targets will be established in the subsequent WQIR as the levels required to meet the loading capacity of Capitol Lake and Budd Inlet. Interim load targets are recommended in this DO and pH TMDL, based on effective shade needed to reduce direct solar radiation to free-flowing reaches of Percival Creek and Black Lake Ditch. The load targets described in the Temperature TMDL section of this report apply to DO and pH as well. Given that natural conditions may be warmer than the numeric criteria because of the headwater lake and wetland complexes, full mature riparian vegetation is necessary to mitigate anthropogenic effects.

Figure 62 in the Temperature TMDL section of this report presents current and potential future shade, and load targets are detailed in Appendix F.

In addition to the numeric load targets for effective shade in the Percival Creek watershed, the following narratives and management activities apply:

- The watershed should be evaluated for nutrient load reductions to parallel shade increases.
- Activities that decrease loads and concentrations to natural levels should be considered.

Percival Creek Watershed Wasteload Targets

This technical report does not recommend facility-specific numeric wasteload targets. Instead, wasteload allocations should consider the load reduction targets by subbasin. Facilities covered by general permits should receive wasteload allocations comparable to the load allocations for the subbasin in which the facility is located. Nutrient levels will be revisited in the subsequent WQIR that establishes load and wasteload allocations for Capitol Lake and Budd Inlet. As described for the Deschutes River wasteload targets, management activities required by existing permits will benefit DO, pH, and nutrients by maximizing infiltration.

Any new permitted facilities in the Percival Creek watershed should not increase nutrient inputs beyond existing conditions. The facilities should not produce offsite transport of nutrients.

Conclusions and Recommendations

Anthropogenic sources of heat should be reduced to improve DO and pH in the Deschutes River and its tributaries to protect the beneficial use of salmonid spawning. The QUAL2Kw model calibrated to the temperature conditions in the Deschutes River was further calibrated to DO and pH in the mainstem. Minimum DO levels were reproduced with a RMSE of 0.64 mg/L, and maximum pH with a RMSE of 0.58 SU. The calibration used a genetic algorithm to optimize the fit of rate parameters to in-situ measurements. The stream walk survey was used to confirm model performance.

Based on modeling critical conditions in the Deschutes River, defined by recent 7Q10 flow and 90th percentile air temperatures, portions of the Deschutes River would not meet the water quality standards for DO and pH under current vegetation and current nutrient loads. The lowest DO and highest pH occur downstream of RK 60 (13-DES-5.8). Maximum pH meets the water quality standards upstream of RK 38 (Military Road). Several river sections do not meet the pH range in the water quality standards.

Establishing full mature riparian shade, as included in the Temperature TMDL load targets, would benefit significantly both DO and pH. Portions of the Deschutes River would still not meet water quality standards, and additional management activities are needed. The subsequent WQIR will establish load and wasteload allocations and will quantify reduction targets based on specific actions applied to specific reaches.

Upstream of Offutt Lake, the combined effects of shade, microclimate, channel improvements, and headwater and tributaries temperature improvements would reduce human influences to within 0.2 mg/L of system potential conditions in all but two sections. Headwater and tributary DO improvements would be needed to improve DO from RK 0 to 2 and near RK 22. For pH upstream of Offutt Lake, the combined effects of shade, microclimate, channel improvements, and headwater and tributary temperature improvements would reduce human influences to within 0.2 SU of system potential conditions in all but three sections. Additional activities, such as reducing tributary nutrients, would be needed between RK 5.5 and 8.5 and also between RK 21.5 to 27.5.

Downstream of Offutt Lake, the river meets the DO standards through RK 58. Below that, shade improvements alone would allow that portion of the river to meet DO standards. Improvements to shade, microclimate, channel conditions, and headwater and tributary temperature will also meet the maximum pH and pH range standards except in one section. Additional activities are needed near RK 58.

The heat load reductions and recommended management activities necessary to meet the temperature water quality standards also are necessary to meet the DO and pH water quality standards throughout the system.

Mature riparian vegetation would have several secondary benefits to temperature, DO, pH, and fine sediment (see separate Fine Sediment and Temperature TMDL sections in this report). Cooler water holds more oxygen, and decreased solar radiation decreases periphyton growth and primary productivity. A mature riparian forest also would provide large woody debris (LWD) that protect banks from enhanced erosion, which could improve fine sediment and phosphorus loads. LWD also increases channel complexity, enhances hyporheic exchanges, and reduces transport of fine sediment. Increased channel complexity provides more zones where biogeochemical processes decrease nutrient transport downstream (Roberts et al., 2007). Controlling anthropogenic sediment sources (see Fine Sediment TMDL section) would benefit temperature and decrease phosphorus. Because most of the Deschutes River is phosphorus limited, decreasing phosphorus would decrease primary productivity and improve DO and pH.

Urbanization and climate change both have the potential to worsen DO and pH conditions in the Deschutes River and tributaries. In addition to the processes described in the Temperature TMDL section, urbanization may lead to higher nitrogen and phosphorus levels in the watersheds from increased wastewater sources, land cover type, land management practices (Brett et al., 2005), and activities that enhance erosion, if development continues using previous management strategies and practices. Residential land cover produces much higher nutrient loads than do natural forest lands (Herrera Environmental Consultants, 2011). Because the Deschutes River and tributaries already violate the water quality standards and because development will continue, both new development and redevelopment must not worsen conditions and must improve DO and pH in the system.

Recommendations to benefit temperature apply to DO and pH as well. In addition, the following management activities are recommended to mitigate the low DO and high pH in the Deschutes River watershed:

- Low impact development (LID) should be instituted for future development in appropriate areas in the watershed, with particular attention to decreasing nutrient contributions below current levels. Future development should not worsen DO or pH.
- Septic systems, particularly those near a water body, could be contributing excess nutrient loads. Existing management programs by Thurston County should continue and intensify. In addition, future efforts should examine and implement options to reduce nutrient loading from onsite sewage systems. These could include state-of-the-art onsite systems that should be considered in sensitive areas, such as upstream of Offutt Lake, Chambers Lake and its outlet creek, Tempo Lake and its outlet creek, and the Ayer Creek watershed.
- Future groundwater infiltration facilities should quantify the potential increases in nutrient loads to the Deschutes River and tributaries and offset any inputs by reducing other local sources such that DO and pH do not worsen. The issue will be part of future discussions during the development of the WQIR.
- Agricultural operations, including dairies, should eliminate offsite transport of sediments and nutrients. The two operations in the Deschutes watershed should be further evaluated for facility management and manure applications; water quality monitoring should be considered.
- Current tributary nutrient loads contribute to violations of the DO and pH standards in the mainstem Deschutes River. Nitrogen and phosphorus hot spots exist and should be evaluated for future nutrient reduction strategies. Tributaries with elevated nitrogen include Ayer/Elwanger Creek, Tempo Lake, Chambers Creek, and the unnamed creek at RK 64. Tributaries with elevated phosphorus include the Lake Lawrence outlet and Reichel, Spurgeon, and Ayer/Elwanger Creeks. Upstream nutrient sources in these areas should be quantified. Lake Lawrence is on the 303(d) list for total phosphorus, and a TMDL should be conducted and implemented soon so that management activities may be coordinated.
- In addition to identifying contributors to elevated nitrogen and phosphorus in the Ayer (Elwanger) Creek and Reichel Creek watersheds, future efforts should mitigate existing low DO and low pH to the extent possible. Initial management should focus on establishing mature riparian shade, and restoration plans should evaluate naturalizing the channel to increase complexity.
- Ecology staff noted cows on the banks and fecal material in the river and on gravel bars between Old Camp Lane and the Lake Lawrence Tributary (RK 18 - 20). This site should be evaluated for nutrient management.

Long-term monitoring for DO, pH, and nutrients should continue at the mouth of the Deschutes River, possibly expanding to continuous DO and pH monitoring for several days in late July or early August. One element missing from the data collection program was the amount of periphyton coating gravels. In the future, periphyton levels in the mainstem of the Deschutes Rivers should be quantified.

Anthropogenic sources of heat in the Percival Creek watershed also must be reduced to improve DO and pH in the system. The headwater lake and wetland complexes naturally warm the water, but restoring appropriate riparian vegetation would increase effective shade substantially, leading to lower peak temperatures. The outlet from Black Lake should be evaluated to determine whether subsurface hydraulic connections are possible. The recommendations for the Deschutes River watershed also apply to the Percival Creek watershed.

In keeping with the antidegradation policy in the Washington State's water quality standards, areas where the current water quality is better than the water quality criteria should be considered during development of the Implementation Strategy. Specific actions and/or institutional safeguards may be necessary to prevent a loss in current water quality conditions in these areas as further development or other changes occur in the watershed.

Recommendation for Future Growth

This DO and pH TMDL does not include a specific reserve capacity for future growth for the Deschutes River watershed. Future development should not increase nutrient loads or enhance periphyton growth in the Deschutes River or its tributaries, particularly in the sensitive areas upstream of Offutt Lake and near Henderson Blvd.

Future growth within the Percival and Deschutes River watersheds, including Ayer (Elwanger) and Reichel Creeks, should maintain intact riparian vegetation and restore degraded areas, as recommended under the Temperature TMDL, and should not increase nutrient loads or enhance periphyton growth in those water bodies.

Margin of Safety

The margin of safety accounts for uncertainty in pollutant loading or water body response, and may be either explicit or implicit. For the DO and pH TMDL, the margin of safety is both implicit through the use of conservative assumptions and explicit. Conservative assumptions include the coincident use of the 7-day average flows occurring on average once every ten years and the 90th percentile of the highest 7-day averages of daily maximum air temperatures to simulate water temperatures in the Deschutes River.

The Deschutes River pH model overestimated values, especially in the lower Deschutes, in both calibration and confirmation. Using the model without adjustment adds to the margin of safety that standards will be met for maximum pH and pH range.

Fine Sediment

Analytical Framework

Fine sediments occur naturally in river systems. However, fine sediments should be common in pool features and should constitute only a small fraction of the sediments within riffles. Fine sediments within the heads (upstream extent) of riffles are particularly important because these represent optimal spawning sites.

Fine sediment levels in river substrates reflect both inputs of sediment to the system and redistribution within the system. Redistribution includes both short-term and long-term storage in channel features, gravel bars, and river banks as well as transport by high river flows and high velocities. The analytical framework is to use in-situ characteristics to quantify current conditions and target reductions, linked to specific sources with the sediment budget.

Fine sediment load reduction targets are based on data collected in 2004 (Konovsky and Puhn, 2005), as well as a sediment budget developed in 2007 (Raines, 2007). Targets are based on the anthropogenic contributions to reaches with elevated fine sediment levels. Numeric limits are not specified by the water quality standards. As described above, fine sediment levels must not produce deleterious effects on aquatic life uses that include both *Salmonid Spawning, Rearing, and Migration* and *Core Summer Salmonid Habitat*. Both the original impairment and existing loading capacity for fine sediment are based on good habitat quality metrics defined in the Timber Fish and Wildlife Watershed Analysis Manual (Washington Forest Practices Board, 1997).

Sediment inputs are episodic and are associated with seasonal high-discharge events (Raines, 2007). However, in-situ fine sediment levels on which the loading capacity and load reduction targets are based do not necessarily vary seasonally. In-situ fine sediment levels are characteristic of year-round conditions but implementation should focus on winter, wet-weather conditions because precipitation events are the trigger and mechanism for sediment inputs.

Load reductions ($FS_{reduction}$) are calculated from the current fine sediment levels:

$$FS_{reduction} = 1 - \frac{FS_{target}}{FS_{data}}$$

where FS_{data} is the current fine sediment concentration and FS_{target} is the target fine sediment level.

Loading Capacity

The loading capacity is the maximum load received by a water body such that the water body still meets the water quality standards. In the case of fine sediment, the loading capacity is determined by in-situ values compared against habitat quality criteria defined by suitability for salmonid aquatic life uses.

The Timber Fish and Wildlife Watershed Analysis Manual (Washington Forest Practices Board, 1997) Appendix F summarizes fish habitat surveys and metrics that characterize habitat quality. Table F-2 of the Watershed Analysis Manual presents various indices of habitat quality and establishes numerical thresholds for fines in gravel, as summarized in Table 32.

Table 32. Habitat quality associated with various levels of fine sediments (<0.85 mm).

Source: Washington Forest Practices Board (1997), Table F-2.

Percent fine sediments in gravels	Habitat quality
>17%	Poor
12 to 17%	Fair
<12%	Good

The aquatic life uses to be protected in the Deschutes River include: *Core Summer Salmonid Habitat* upstream of Offutt Lake and *Salmonid Spawning, Rearing, and Migration* downstream of the lake. Because spawning is the beneficial use to be protected throughout the system, the entire Deschutes River must provide healthy spawning habitat, including appropriate levels of fine sediment. The loading capacity for fine sediment in Deschutes River gravels is <12% to meet the good habitat quality definitions established by the Washington Forest Practices Board (1997).

Load and Wasteload Targets

Target reductions may be either in terms of concentration or load or both. This TMDL is expressed in terms of in-situ concentrations of fine sediment within the gravels of the Deschutes River as allowed under 40 CFR 130.2(I) as "other appropriate measures." Fine sediment concentration is appropriate because in-situ concentrations and not loads define suitability for spawning, which is the beneficial use to be protected.

Percent reduction targets are based on the combined contributions of point sources and nonpoint sources. Wasteload targets are recommended for all permitted point-source discharges, including stormwater, while load targets are recommended for all other nonpoint sources. While the data collection conducted for the present study did not include monitoring of fine sediment levels from permitted sources, non-zero permitted source contributions are assumed to be part of the unaccounted sources in the Deschutes River watershed sediment budget.

Load Targets

Load targets are the nonpoint-source reductions needed in the system, and the targets are expressed as percent reduction from current conditions. Future compliance with these targets will be based on comparison of measured data with the healthy habitat levels established in the Timber Fish and Wildlife Watershed Analysis Manual (Washington Forest Practices Board, 1997. Table 33 and Figure 79 present the load targets for the Deschutes River watershed based on the river reaches in Figure 28 assessed by Konovsky and Puhn (2005). The target will be to reduce fine sediments to no more than 12% of the substrate.

Table 33. Fine sediment load targets by reach for the Deschutes River watershed.

Segment	Name	River mile	1995	2004	Target	% reduction
19	Weyerhaeuser	31.4-35.4	15.5%	17.7%	12%	32%
22	Lake Lawrence	28.8-30.4	22.5%	17.1%	12%	30%
28	State Route 507	20.8-24.4	19.4%	20.5%	12%	41%
31	Waldrick	14.5-17.2	19.9%	20.1%	12%	40%
36	Pioneer	0.5-2.7	22.0%	22.1%	12%	46%

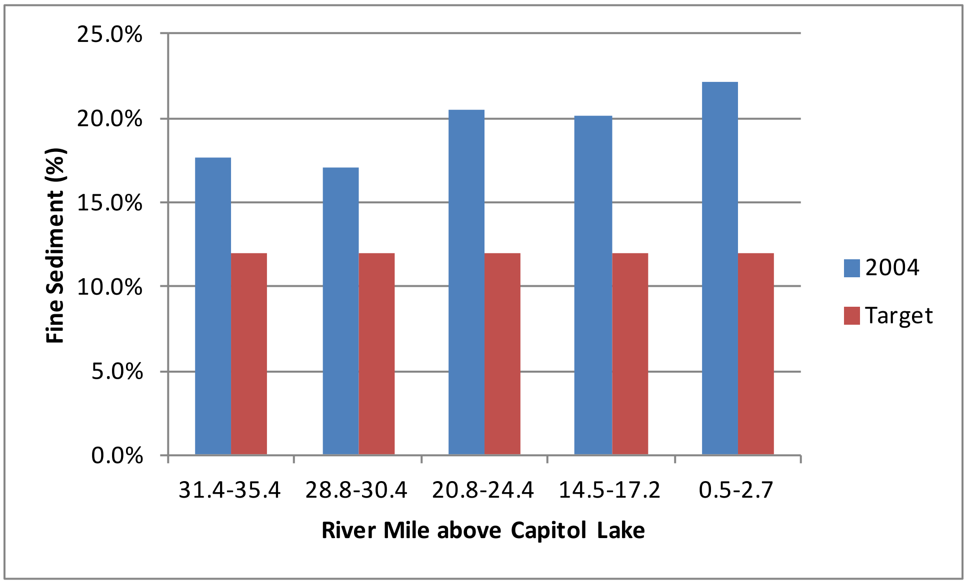


Figure 79. Fine sediment load targets for the Deschutes River watershed.

Of the sediment inputs accounted for by Raines (2007), human sources represent 26 to 32%. However, Raines (2007) also found that unidentified sources account for approximately 29% of the total sediment inputs to Capitol Lake beyond the sources specifically identified. Including unaccounted sources, human sources comprise 18 to 23% of the fine or total sediment inputs to Capitol Lake (Figure 80). Human and unaccounted sources represent 47 to 52% of the sediment inputs to Capitol Lake.

The size threshold to define fine sediments varies between the two studies on which the reductions are based. Konovsky and Puhn (2005) used 0.85 mm, defined as detrimental to fish, while Raines (2007) used 2 mm to be consistent with road-erosion modeling tools; both thresholds were also consistent with previous studies in those disciplines. Both 0.85 and 2 mm fall within the sand category of major soil classification systems, which define fine sediments using even smaller thresholds. Size fractions up to 2 mm can fill the interstitial spaces of spawning gravels and decrease the amount of aeration in the gravels.

The load targets are based on the 0.85-mm threshold used to analyze field samples. The sediment budget (1) confirms that both humans and natural sources contribute coarse and fine sediments and (2) provides insight as to the relative contributions. Raines (2007) found similar patterns overall for both coarse and fine sediments. The 2-mm threshold in the sediment budget represents a conservative approach. The predominant human source is landslides associated with roads, which contribute all sediment size fractions represented in the native soil in the region.

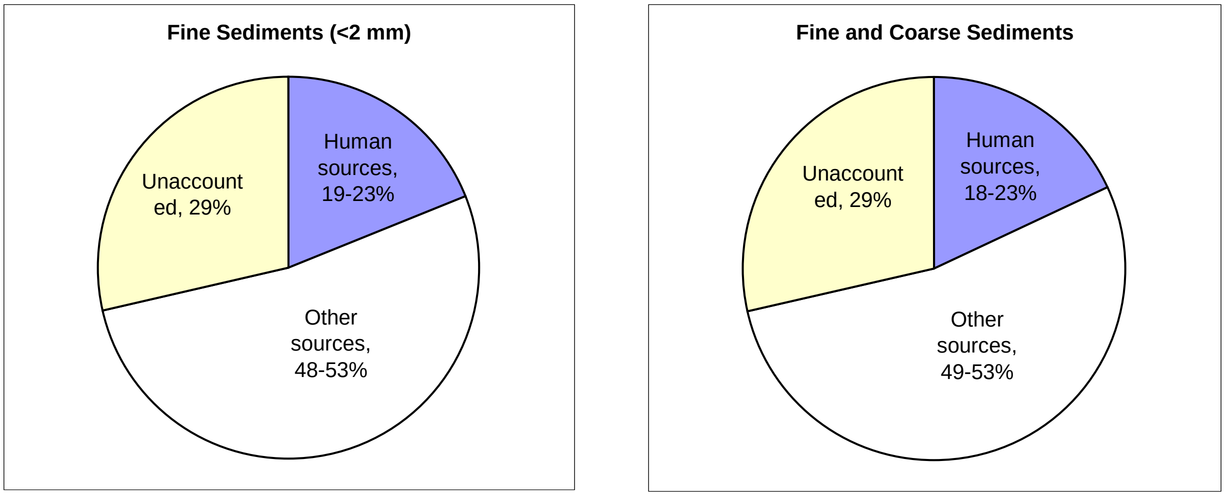


Figure 80. Fine sediments (<2 mm) and all sediments by source from Raines (2007).

Unaccounted sources represent the difference between loads to Capitol Lake determined from historical dredging and recent bathymetry and sediment inputs identified by Raines (2007).

The Deschutes River watershed is a mixed-use watershed, with non-forested land, private forests, and public forests. Load targets are included in this TMDL for non-federal forest lands. In accordance with Clean Water Act Assurances established under Schedule M-2 of the Forests and Fish Report (USFWS et al., 1999), Ecology will not require more stringent measures except through adaptive management-based changes established under the Forests and Fish Adaptive Management Program and subject to reopeners (Hicks, 2009). If achievement of the TMDL load allocation cannot be met through the forest practices regulations, the adjustment of those management practices will be through the process of adaptive management established under the state's forest practices laws and regulations. Over the long term, failure of adaptive management to meet the-TMDL's load allocations would be a potential cause to withdraw these assurances.

Under Schedule M-2, forest landowners are encouraged to participate in watershed planning, including providing watershed assessment data and modeling information related to expected improvements due to implementation of management practices. For the purposes of this TMDL, the Weyerhaeuser Company has provided data to Ecology and to Raines (2007) for the technical assessments.

Wasteload Targets

Several facilities and geographic areas covered by general permits have the potential to contribute fine sediment to the system. Table 34 summarizes the wasteload targets for NPDES-permitted entities within the Deschutes River watershed. The targets are expressed in both numeric and narrative form.

Table 34. Wasteload targets for fine sediment loads in the Deschutes River watershed.

Water Body	Facility Name	Permit No.	Wasteload target (allowable load)	Notes
Western Washington Phase II Municipal Stormwater Permit				
Deschutes River	City of Olympia	WAR045015A	0	A
Deschutes River	City of Lacey	WAR045011A	0	A
Deschutes River	City of Tumwater	WAR045020A	0	A
Deschutes River and tributaries	Thurston County	WAR045025A	0	A
Washington State Department of Transportation (WSDOT) Municipal Stormwater Permit				
Deschutes River and tributaries	WSDOT	WAR043000	0	B
Industrial Stormwater General Permit				
Deschutes River	O'Neill and Sons	SO3001404	0	B
Deschutes River	Tumwater Lumber Company	SO3004272	0	B
Construction Stormwater General Permit				
Deschutes River and tributaries	(varies)	(varies)	0	B
Sand and Gravel General Permit				
Deschutes River	Waldrick Road Pit	WAG501231	0	C

A: No increase over natural conditions.
B: No visible accumulation of fine sediment in the Deschutes River or its tributaries downstream of the facilities.
C: No offsite transport via runoff of any materials. No visible accumulation of fine sediment in the Deschutes River or its tributaries downstream.

The Construction Stormwater General Permit requires that facilities discharging to water bodies listed as impaired for fine sediment must conduct water quality sampling for turbidity. More importantly, sites covered by the Construction Stormwater General Permit must control the offsite transport of fine sediment along the entire length of the Deschutes River.

The Sand and Gravel General Permit requires that facilities discharging to a 303(d)-listed water body cannot increase the loading of the listed pollutant, such as turbidity or fine sediment.

Any new permitted facilities in the Deschutes River watershed must not enhance fine sediment inputs to streams or the Deschutes River beyond natural conditions. The facilities cannot produce any offsite transport of fine sediment or any visible accumulation of fine sediment downstream of the facilities.

Conclusions and Recommendations

Anthropogenic sources of fine sediment must be reduced to protect the beneficial use of salmonid spawning throughout the Deschutes River. Improved fine sediment levels would produce the greatest increase in coho production of the various restoration components evaluated in the Deschutes system (Anchor Environmental, 2008). The dominant anthropogenic sources identified in Raines (2007) are landslides associated with roads and inputs from unpaved roads. Raines (2007) also states that other potential anthropogenic sources exist but were not quantified.

Some areas require greater reductions than currently identified as stemming from human sources. However, implementation measures should be maximized to manage all controllable sources.

Extensive road rehabilitation and other sediment control strategies have been implemented within the area covered by the Forests and Fish Agreement. Long-term turbidity has declined (Reiter et al., 2009). This likely reflects source control measures, but fine sediment levels within the upstream reaches remain poor and have increased. Intensive management should continue, given that instream responses often are not evident for many years after a management program begins (Sullivan et al., 1987). Implementation is via the terms of the Forests and Fish Agreement.

Enhanced enforcement should verify that facilities covered by the general permits are in compliance with the permits and with the wasteload targets and narrative criteria in this report.

In addition, other potential anthropogenic sources may contribute fine sediment inputs. Konovsky and Puhn (2005) report extensive all-terrain vehicle (ATV) use near 1000 Road and suggest that the activity has accelerated soil erosion rates. Domestic animals were noted on the banks and in the river between Old Camp Lane and the Lake Lawrence tributary during surveys conducted by Ecology staff and may be enhancing localized bank erosion over natural levels. These human-induced sources of sediment should be controlled to the maximum extent. Fencing to remove access should be considered.

Finally, river restoration strategies that include control of instream fine sediment should be evaluated. Channel and riparian restoration, particularly between RK 12 and RK 20, will have multiple benefits in addition to mitigating fine sediment levels, including temperature improvements from increased channel complexity. Channel restoration should include large woody debris (LWD) to enhance pool formation and decrease the transport of fines in the system as sources are controlled. River restoration strategies will benefit coho and other fisheries resources (Anchor Environmental, 2008).

Any new land cover changes in the Deschutes River watershed must not enhance fine sediment inputs to streams or to the Deschutes River beyond natural conditions. Projects should be designed so that they do not produce any offsite transport of fine sediment or any visible accumulation of fine sediment downstream of the sites.

In keeping with the antidegradation policy in the state’s water quality standards, areas where the current water quality is better than the water quality criteria should be considered during development of the Implementation Strategy for this TMDL. Specific actions and/or institutional safeguards may be necessary to prevent a loss in current water quality conditions in these areas as further development or other changes occur in the watershed.

Recommendation for Future Growth

This fine sediment TMDL does not include a specific reserve capacity for future growth. Because the fine sediment source area is primarily the headwaters for both human and other sources, any future development in this area must eliminate existing human sources of fine sediment and cannot produce any accumulation of fine sediments outside of the range defined as good habitat by the Washington Forest Practices Board (1997).

Future monitoring programs should quantify both the effect of growth since the study was conducted as well as the beneficial effect of ongoing management practices. Sites surveyed by Konovsky and Puhn (2005) should be reoccupied and data collected according to the protocols in Konovsky (2004). Effectiveness monitoring could be conducted at 5-year intervals.

Margin of Safety

A margin of safety to account for scientific uncertainty must be considered in all TMDLs to ensure that the targets will protect water quality in cases when the data and other factors in the analysis are naturally variable or unknown. The margin of safety for this fine sediment TMDL analysis is implicit through the use of conservative assumptions and targets.

More stringent target reductions were based on meeting good habitat quality conditions for fine sediment in gravels (<12% fines) instead of fair (12 to 17% fines). In addition, load reduction targets were based on the high estimate of sediment budget inputs from Raines (2007) using the 2-mm threshold.

Capitol Lake and Budd Inlet Dissolved Oxygen

Analytical Framework

Background

Initial Modeling for the 1998 LOTT Study

J. E. Edinger Associates, Inc. (JEEAI) applied the three-dimensional hydrodynamic and water quality model GLLVHT (Generalized, Longitudinal-Lateral-Vertical Hydrodynamics and Transport model) to Budd Inlet during studies conducted from 1996-1998 (Aura Nova Consultants et al., 1998), with follow-up work in 1999 and 2000 (Aura Nova Consultants and J.E. Edinger Associates, 1999). JEEAI was subsequently acquired by ERM Group Inc. (ERM). The GLLVHT modeling framework was updated by JEEAI and ERM and is currently called the Generalized Environmental Modeling System for Surfacewaters (GEMSS).

GEMSS is a dynamic model that simulates continuous changes in hydrodynamics and water quality with a time step that varied between 10 seconds and 6 minutes in our applications. The three-dimensional model grid for this project has 19 layers below a horizontal datum starting at 6 meters (m) above mean lower low water (MLLW). The top 10 layers each have a thickness of 1 m, while the rest of the layers are 2 m graduating to 3 m thick in the deepest layers. The conditions in Budd Inlet and Capitol Lake are dynamically calculated and updated every time step in response to dynamic changes in boundary conditions such as tides, meteorology, river flows and loads, and wastewater flows and loads.

The original JEEAI model application was performed for Lacey, Olympia, Tumwater, and Thurston County (LOTT) Wastewater Partnership (name since changed to LOTT Clean Water Alliance) to support National Pollutant Discharge and Elimination System (NPDES) permitting activities (Aura Nova et al., 1999). The model consisted of hydrodynamic and carbon-based water quality computations and was calibrated for the 1997 field data.

According to the naming convention used at the time of the LOTT Budd Inlet Scientific Study (BISS), the model was called the “combined model” (for example, combined hydrodynamics and water quality computations) and relied on observed sediment oxygen demand values to compute oxygen uptake at the bottom. During the study, the sediment diagenesis model Ocean Margin Exchange Nutrient Diagenesis (OMEXDIA) was linked to the combined model (the “linked model”), but the combined model without sediment diagenesis was chosen for the final calibration and permitting simulations. For the purposes of the present TMDL project, the combined model calibrated to the 1997 data is referred to as the “LOTT model.”

Model Changes for This Report

Ecology conducted a very thorough review of the Fortran code for the water quality modules in GEMSS. Model code errors were corrected for the 2008 draft version of this report. Additional improvements were made following the draft report. The model was completely re-calibrated following the 2008 draft report as described in Appendices G and H. The following GEMSS water quality modules are used in this study for Budd Inlet and Capitol Lake:

- **Water Quality Carbon Based Model (WQCBM)** can simulate up to two saltwater phytoplankton groups (diatoms and dinoflagellates), DO, ammonia, nitrate, inorganic phosphorus (P), dissolved organic nitrogen (N), particulate organic N, dissolved organic P, particulate organic P, and dissolved organic carbon (C) (CBOD).
- **General Algae Model (GAM)** can simulate a user-specified number of additional phytoplankton groups for saltwater or freshwater environments.
- **Water Quality Additional Model (WQADD)** can simulate the combined bottom plant community of macrophytes, epiphytes, and attached algae as a lumped variable.

As part of this study, Ecology conducted very rigorous review and testing of the GEMSS modeling framework. The level of rigor used for review and testing is comparable to the review and testing used by EPA for their Water Quality Analysis Simulation Program (WASP) modeling framework, and was conducted by the same expert that developed WASP (Robert Ambrose). Model review identified and completed biogeochemical process improvements to align the model code with the state of the science (Appendix J).

In addition to reviewing and correcting the coding errors, Ecology also specified tests to determine quality assurance (QA) of the model (Appendix K). ERM conducted the QA tests (Appendix L) for rigorous checking of the corrected model to demonstrate that the model equations for various kinetic processes were performing correctly, and that the model calculations conserved mass for the water quality variables. The final corrected source code for the WQCBM, GAM, and WQADD modules is presented in Appendix M.

Modeling Approach

The hydrodynamic module and three water quality modules of GEMSS were used to simulate hydrodynamics and water quality variables in Budd Inlet and Capitol Lake in this study:

- **Transport** module was used to simulate hydrodynamic variables including water levels, current velocities, temperature, and salinity.
- **WQCBM** module was used to simulate one saltwater phytoplankton group in Budd Inlet (dinoflagellates), DO, ammonia, nitrate, inorganic P, dissolved organic N, particulate organic N, dissolved organic P, particulate organic P, and dissolved organic C (CBOD).
- **GAM** module was used to simulate two additional saltwater phytoplankton groups in Budd Inlet and two freshwater phytoplankton groups in Capitol Lake. The influence of the GAM phytoplankton groups on variables in the WQCBM module was accounted for in the WQCBM module.

- **WQADD** module was used to simulate the combined bottom plant community of macrophytes, epiphytes, and attached algae as a lumped variable that is referred to hereafter as macrophytes. The influence of macrophytes on variables in the WQCBM module was accounted for in the WQCBM module.

The model simulated how macrophytes and phytoplankton transform carbon, nitrogen, and phosphorus and subsequently influence DO within Capitol Lake. The mass transfer of transformed nutrient forms between Capitol Lake and Budd Inlet also was simulated, including accounting for the oxygen demand and organic carbon, nitrogen, and phosphorus in the biomass of freshwater phytoplankton subject to salinity-induced die-off in Budd Inlet.

The key water quality constituents include the various forms of carbon, nitrogen, and phosphorus (dissolved organic carbon, particulate organic carbon, nitrate, ammonia, organic nitrogen, inorganic phosphorus, and organic phosphorus), as well as phytoplankton biomass (chlorophyll-a), macrophyte biomass, DO, temperature, and sediment fluxes of oxygen, nitrate, ammonia, and inorganic phosphorus.

Calibration of the GEMSS Water Quality Model

Budd Inlet

The results of model calibration for Budd Inlet are presented in detail in Appendix G. The following presents selected results from the calibration of Budd Inlet.

Figures 81, 82, and 83 show model-predicted time series of bottom layer DO, surface layer total chlorophyll-a, and surface layer dissolved inorganic nitrogen (DIN) in relation to observed data. The root mean squared error (RMSE) statistic presented on each plot indicates the goodness-of-fit of the predictions to the field data for the specified layer at that specific location.

The seasonal pattern of DO in the bottom layer shows a gradual increase in DO into May, peaking with the spring phytoplankton bloom and then decreasing through summer and into autumn. The re-calibrated model was able to reproduce the long-term temporal trends quite well throughout Budd Inlet (Figure 81) with reasonably low RMSE values at all stations (average RMSE of 1.2 mg/L), indicating good agreement between model predictions and field observations.

The RMSE at some locations would have been significantly lower were it not for a few anomalous field measurements that clearly increased the RMSE statistic. For example, the bottom layer DO of 13.53 mg/L measured at BI-1 on 9/10/97 was higher than any other DO record from that station (from any depth) during 1996-97. If this outlier value was excluded, the RMSE at this location would drop from 2.4 mg/L to 1.45 mg/L. If real, those data appear to represent an abrupt event; while the model did not predict such extreme short-term variability, it nonetheless proved capable of capturing the long-term trends in bottom DO.

The model skill for reproducing the observed conditions was quantified using an unbiased statistic (RMSE) as well as a measure of mean bias (average of the differences between predicted and observed concentrations). The model skill for predicting bottom DO is presented in Figure 84. The mean bias at all stations is much lower than the RMSE, which indicates that the model is not significantly biased overall. The model has a slight but insignificant tendency to over-predict the bottom DO in West Bay (stations BI-5 and BI-6) and under-predict the bottom DO in East Bay (stations BI-1 and BI-2). The RMSE is comparable to similar model calibration studies in South Puget Sound (Pelletier et al., 2011).

Overall, the model is considered to be suitable for the main purpose of this project to predict the response of critical bottom DO concentrations in inner Budd Inlet to variations in nutrient loading and concentration.

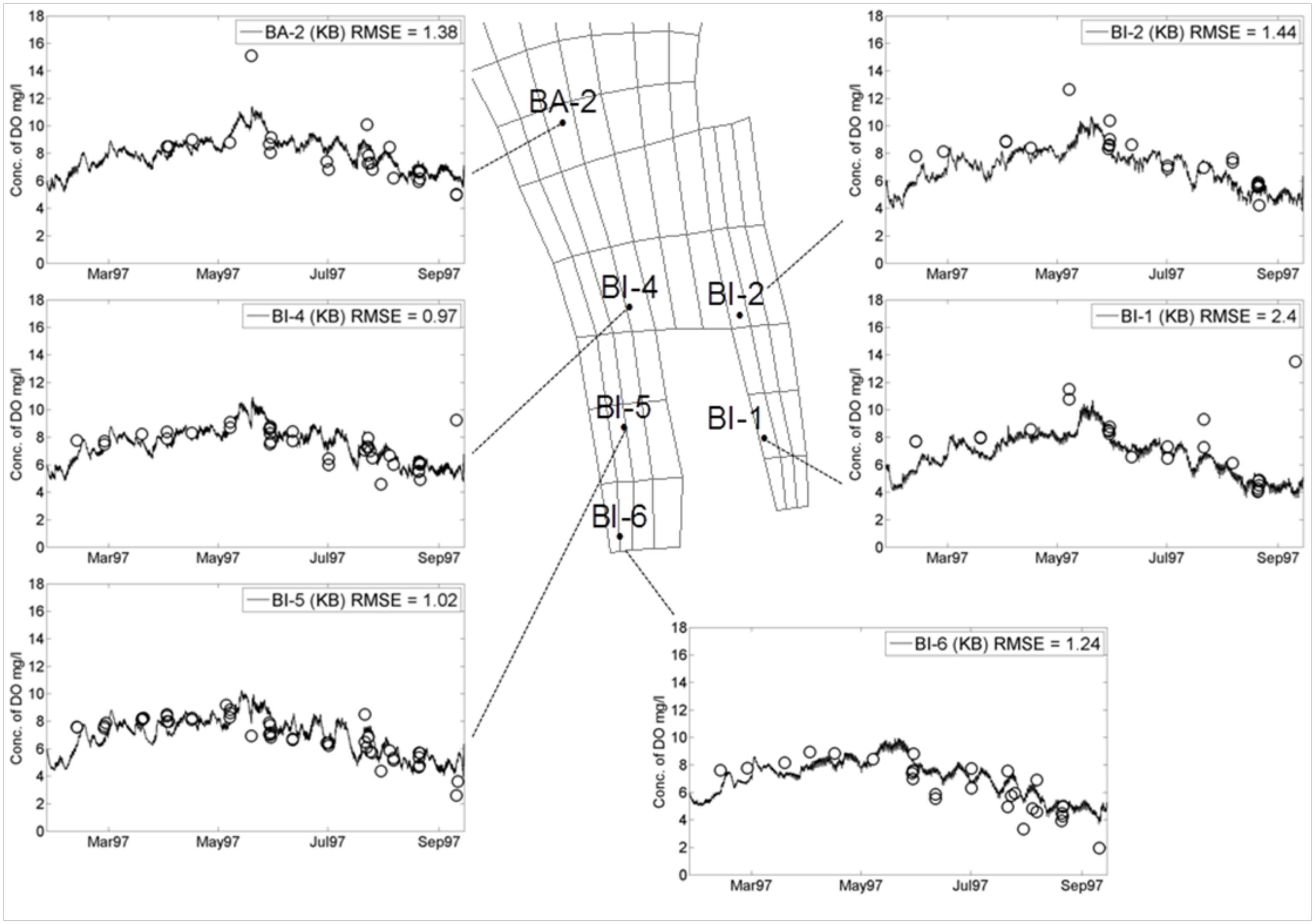


Figure 81. Measured and predicted concentrations of DO in the bottom layer (KB) in inner Budd Inlet during the model calibration period (1997).

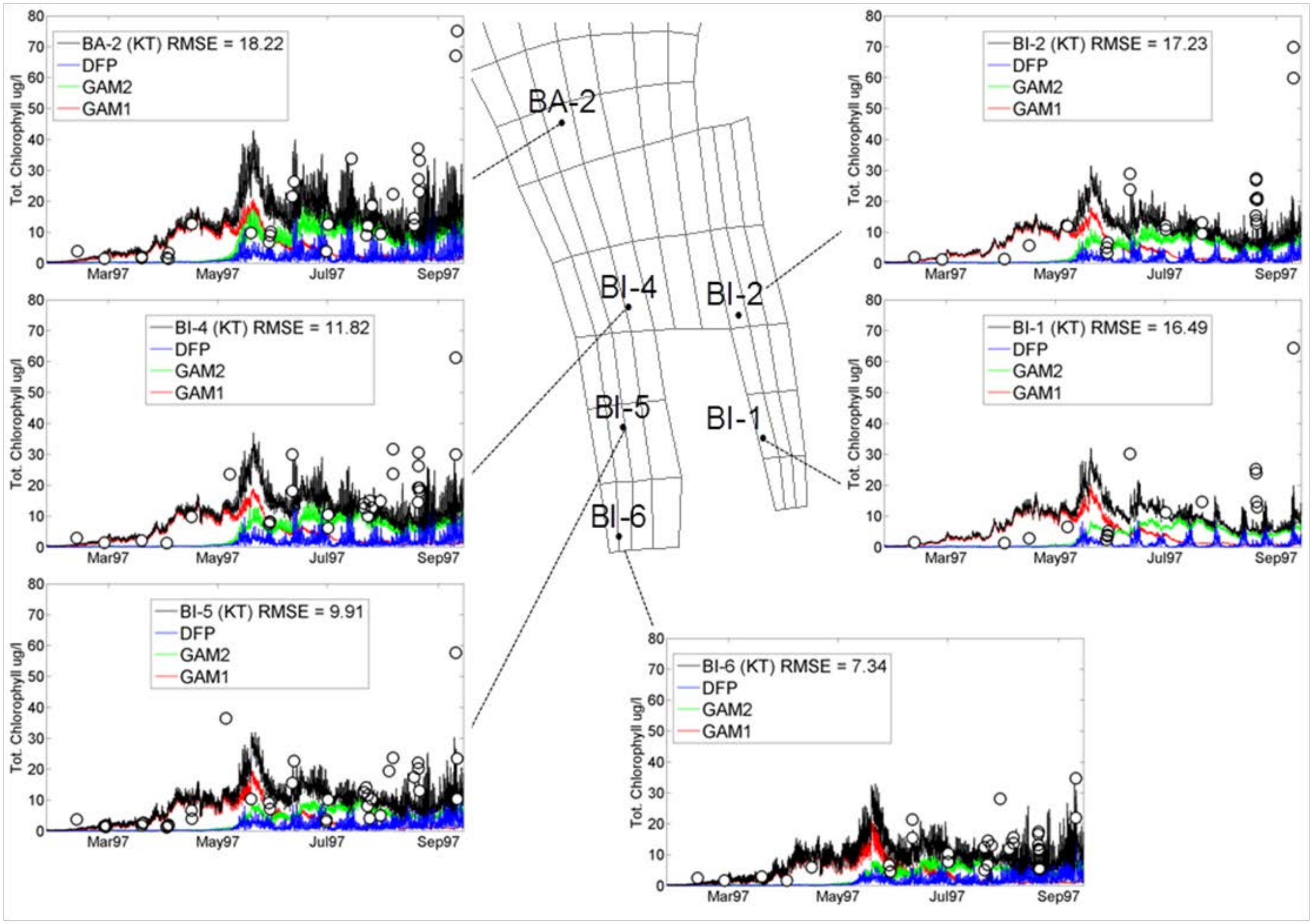


Figure 82. Measured and predicted concentrations of chlorophyll-a in the surface layer (KT) in inner Budd Inlet, including WQCBM dinoflagellates (DFP) and the two GAM phytoplankton groups (GAM1 and GAM2).

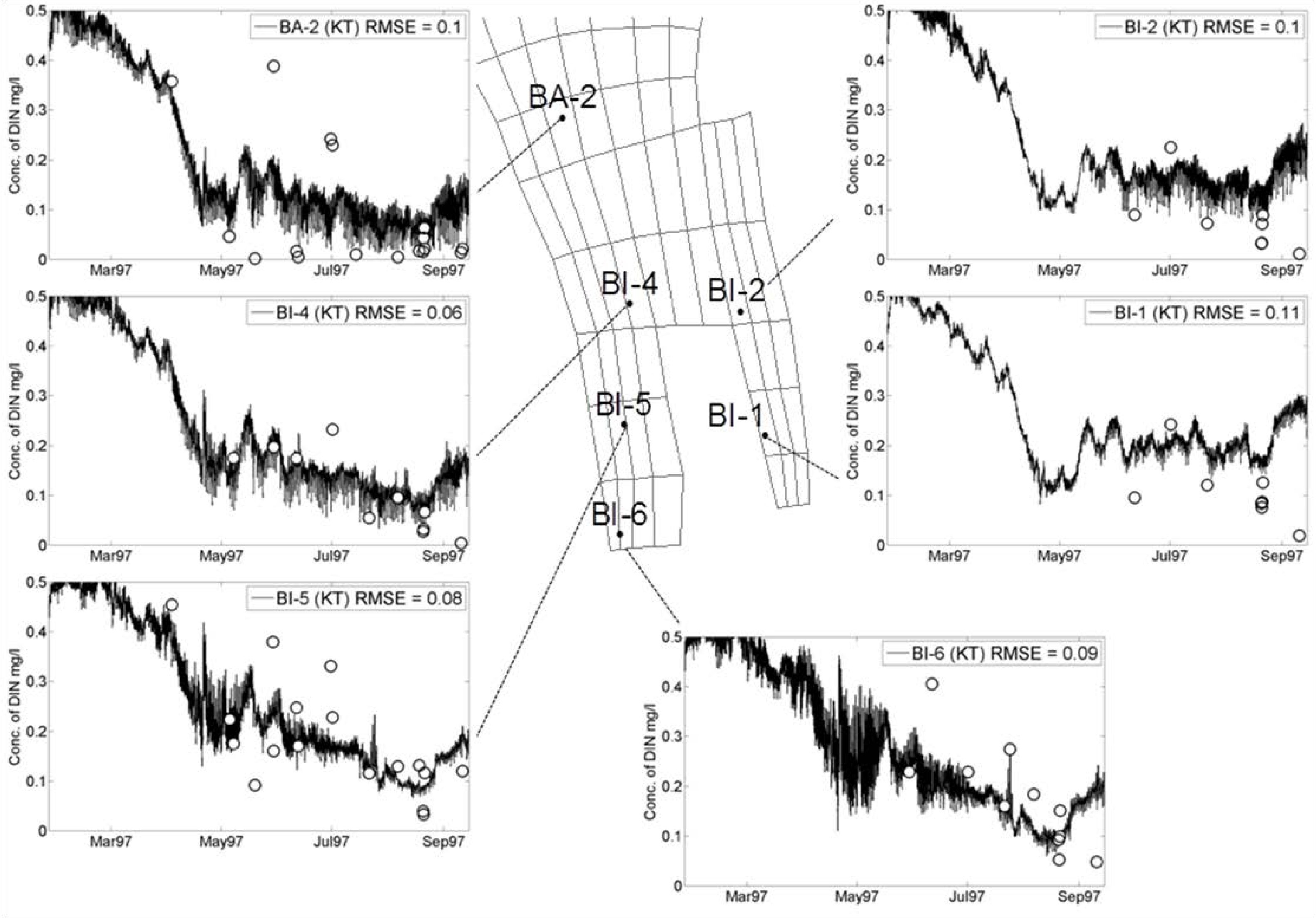


Figure 83. Measured and predicted concentrations of DIN in the surface layer (KT) in inner Budd Inlet during the model calibration period (1997).

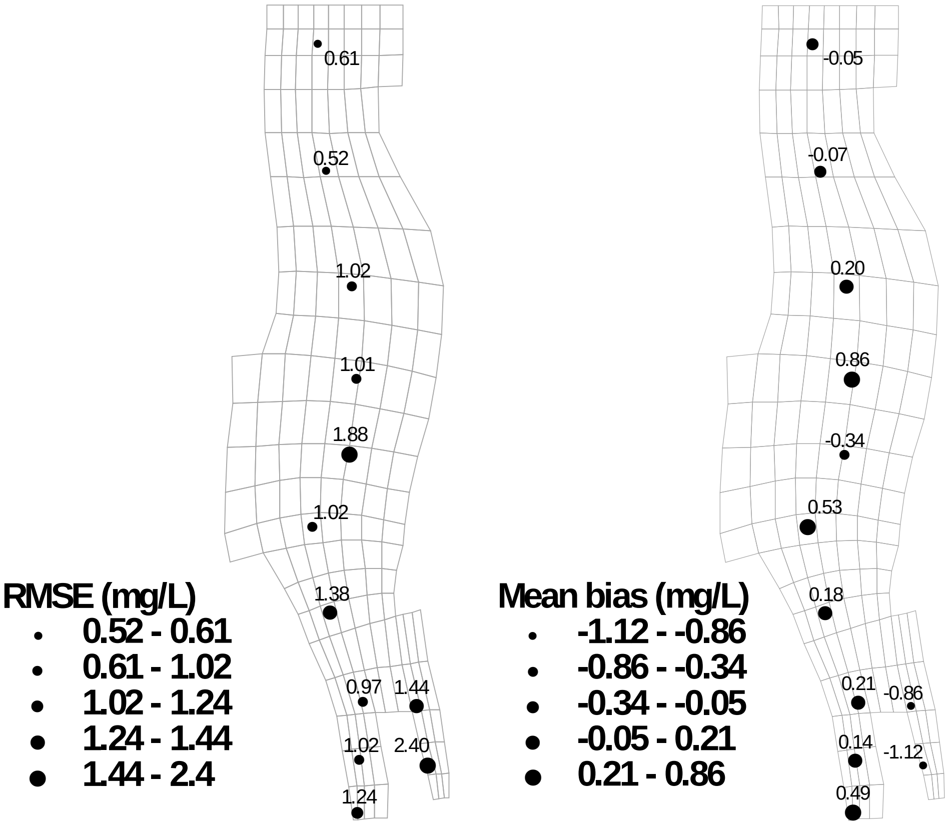


Figure 84. Model skill for prediction of bottom layer DO as represented by RMSE and mean bias statistics for the model calibration period (1997).

Capitol Lake

The results of model calibration and verification for Capitol Lake are presented in detail in Appendix H. The following presents selected results from the calibration and verification of Capitol Lake.

Calibration

The calibration period adopted for the study was May 18 to September 30, 2004, based on the availability of boundary condition and calibration data. While not anticipated in the original study design (Roberts et al., 2004), during this period, herbicide was introduced into Capitol Lake to control invasive milfoil, the dominant macrophyte (see Appendix C for pre- and post-application plant biomass). The sudden die-off of the invasive milfoil released nutrients into the lake that contributed to excessive algal growth.

The application of herbicide was carried out in two steps. Herbicide was first introduced in the middle and south basin on July 19, 2004, and then in the north basin on July 29, 2004, during which the outlet from the lake remained closed. To replicate this behavior, two sets of kinetic rates were adopted. One set represented the pre-herbicide period, and the second set represented the post-herbicide period.

During the calibration process, the lake was divided into four distinct basins for the purpose of considering regional specification of model parameters:

- North Basin (NB) is at the outlet of the lake and is deeper compared to other sections of the lake.
- Middle Basin (MB) is wide and shallow.
- South Basin (SB) is at the mouth of the Deschutes River.
- Percival Cove (PC) is at the mouth of Percival Creek.

Macrophyte measurements in July 2004 showed that no invasive milfoil were present in Percival Cove in the pre-herbicide period. Time-varying die-off rates were used in NB, MB, and SB to simulate die-off of invasive macrophytes during herbicide application. Macrophyte measurements in September 2004 showed populations of macrophyte at pre-herbicide levels, and no milfoil were present.

Two freshwater phytoplankton variables were simulated using the GAM module with growth kinetics varying over the four regions (NB, MB, SB, and PC) to depict the seasonal and spatial chlorophyll variation observed in the lake.

Figure 85 shows the DO concentrations (predicted and observed) at four stations in Capitol Lake. Appendix H contains calibration plots for temperature, macrophyte, chlorophyll, DO, organic and inorganic phosphorus and nitrogen, as well as particulate organic carbon and BOD. The model successfully captured the long-term system trend for nutrients and the response to the herbicide application.

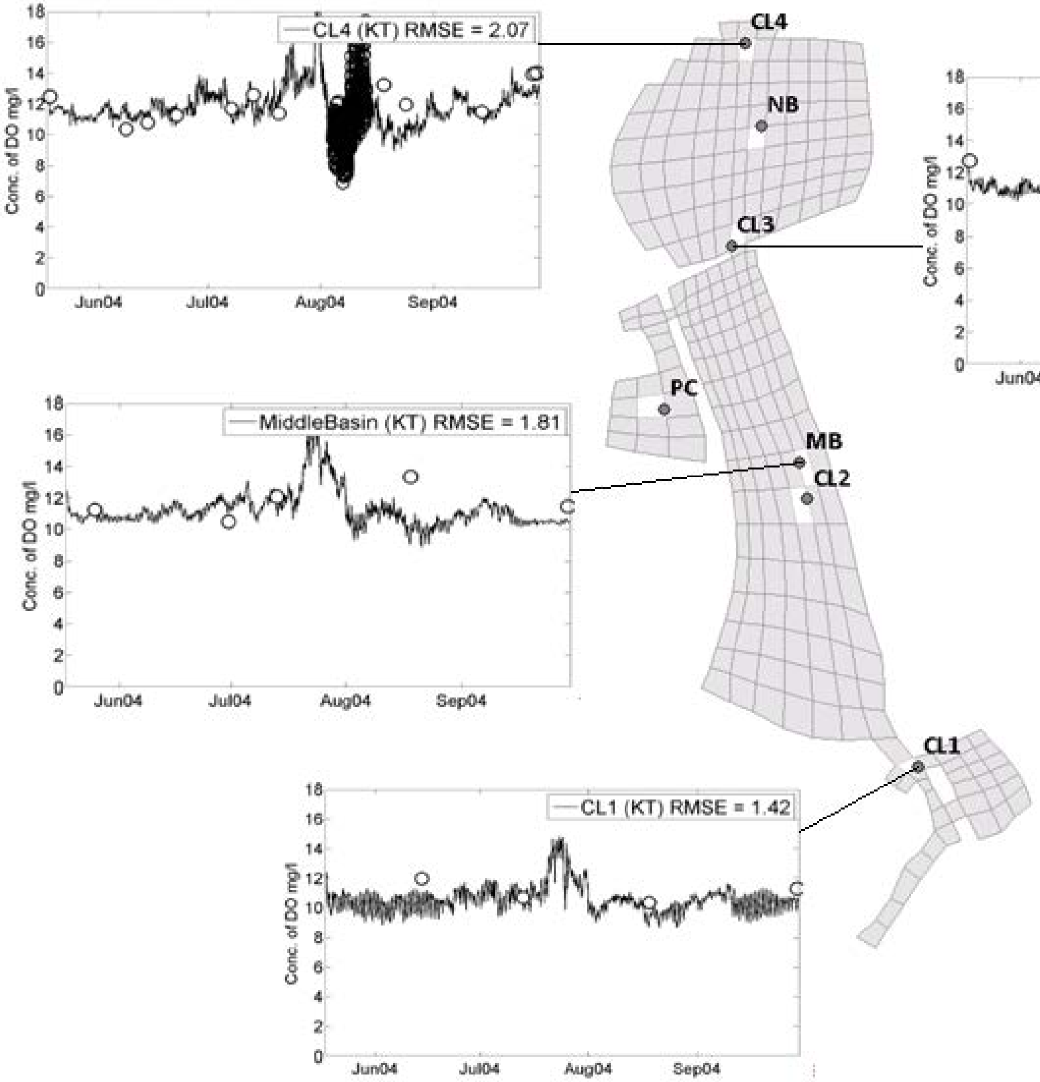


Figure 85. Measured and predicted concentrations of DO in the surface layer (KT) at stations CL4, CL3, MB, and CL1 during the model calibration (2004).

Verification

The verification period adopted for the study was April 25 to June 13, 2001, based on the availability of boundary condition and verification data (CH2M Hill, 2001). During this period the pre-herbicide kinetic rates from the calibration period were used to model the nutrients and phytoplankton growth in the lake.

Appendix H contains verification plots for temperature, chlorophyll, DO, organic and inorganic phosphorus and nitrogen, as well as particulate organic carbon and BOD. The model successfully captured the long-term system trend for these water quality variables.

Loading Capacity and Comparison of Alternative Loading Management Scenarios

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards (40CFR §130.2(f))." The absolute loading capacity of Budd Inlet and Capitol Lake will be developed in the Water Quality Improvement Report. The present report establishes whether the results predicted for scenarios of current and potential nonpoint and point pollutant loads meet the loading capacity (based on comparing model predictions to the numeric water quality criteria).

A total of ten alternative scenarios were evaluated using the calibrated GEMSS model. Five scenarios include the Capitol Lake outlet dam (lake scenarios), and five scenarios assume that the dam is not present and that Capitol Lake functions as an estuary (estuary scenarios) with a simple 500-ft (150-m) opening. For each Capitol Lake option (lake scenarios with the dam and estuary scenarios without the dam), the following were run for the entire combined Capitol Lake/Budd Inlet model domain:

- **Scenario 1: Baseline estimated natural conditions**. Wastewater treatment plants (WWTPs) are assumed to be at zero flow; the Deschutes River and other tributaries were estimated to be at natural conditions based on the low end of nutrient levels measured historically. Details are described in Appendix I.
- **Scenario 2a: Current nonpoint sources without point sources**. All tributaries and nonpoint sources discharge at existing conditions, and point sources/WWTPs are set to zero.
- **Scenario 2b: Current point sources with natural nonpoint sources**. All WWTPs and tributary nonpoint sources were set to existing conditions. Nonpoint sources were estimated to be at natural conditions (same as Scenario 1).
- **Scenario 3: Current point and nonpoint sources**. All WWTPs and tributary nonpoint sources were set to existing conditions.
- **Scenario 4: Permitted point sources and current nonpoint sources**. WWTPs were set to permit limits; nonpoint sources were set to existing conditions.

For the estuary scenarios assuming the dam is not present, the GEMSS grid was modified to include a channel of grid cells between the Deschutes River and the location of the existing dam. The revised bathymetry approximates changes expected based on independent hydraulic and sediment transport modeling to support the Deschutes Estuary Feasibility Study (George et al., 2006); however, detailed bathymetric changes quantified in George et al. (2006) and ongoing efforts were not simulated.

All scenarios used the period January 15 through September 15, 1997 for comparing results. Appendix I details the development of boundary condition inputs for the scenarios.

Scenarios 2a, 2b, 3, and 4 were compared to estimated natural conditions (Scenario 1) to isolate the DO depletion caused by nonpoint sources and point sources as follows, separately for the lake alternative and the estuary alternative:

- Scenario 1 vs. 2a evaluates the DO depletion caused by current nonpoint sources relative to the estimated natural conditions baseline.
- Scenario 1 vs. 2b evaluates the DO depletion caused by current point sources relative to the estimated natural conditions baseline.
- Scenario 1 vs. 3 evaluates the DO depletion caused by current nonpoint and point sources relative to the estimated natural conditions baseline.
- Scenario 1 vs. 4 evaluates the DO depletion caused by current nonpoint sources combined with maximum permitted point sources relative to the estimated natural conditions baseline.

Comparison of Predicted Daily Minimum DO between Lake and Estuary Management Alternatives for the Existing Condition of Nutrient Loading (Scenario 3)

The DO concentrations in Budd Inlet under lake scenarios are predicted to be significantly lower than DO concentrations under estuary scenarios for the current levels of nutrient loading (Scenario 3). Figure 86 shows the predicted hourly DO during July-September at selected locations in inner Budd Inlet for the lake and estuary management alternatives. The selected locations correspond to the sampling stations during the 1997 study. The hourly DO predictions at each location shown in Figure 86 were selected from the layer that was found to have the largest difference in daily minimum DO for each station.

The DO differences between lake and estuary scenarios increase progressively during the late summer, with greatest differences tending to be in the later summer when the DO concentrations are lowest. The maximum predicted difference in daily minimum DO between lake and estuary scenarios at each grid cell in Budd Inlet is shown in Figure 87. Negative values indicate that DO under the lake scenario is less than DO under the estuary scenario, and increasing absolute values indicate increasing magnitude of differences. Absolute values of differences in daily minimum DO greater than 1 mg/L are common throughout inner Budd Inlet. Highest absolute values of maximum DO differences greater than 2 mg/L occur in East Bay.

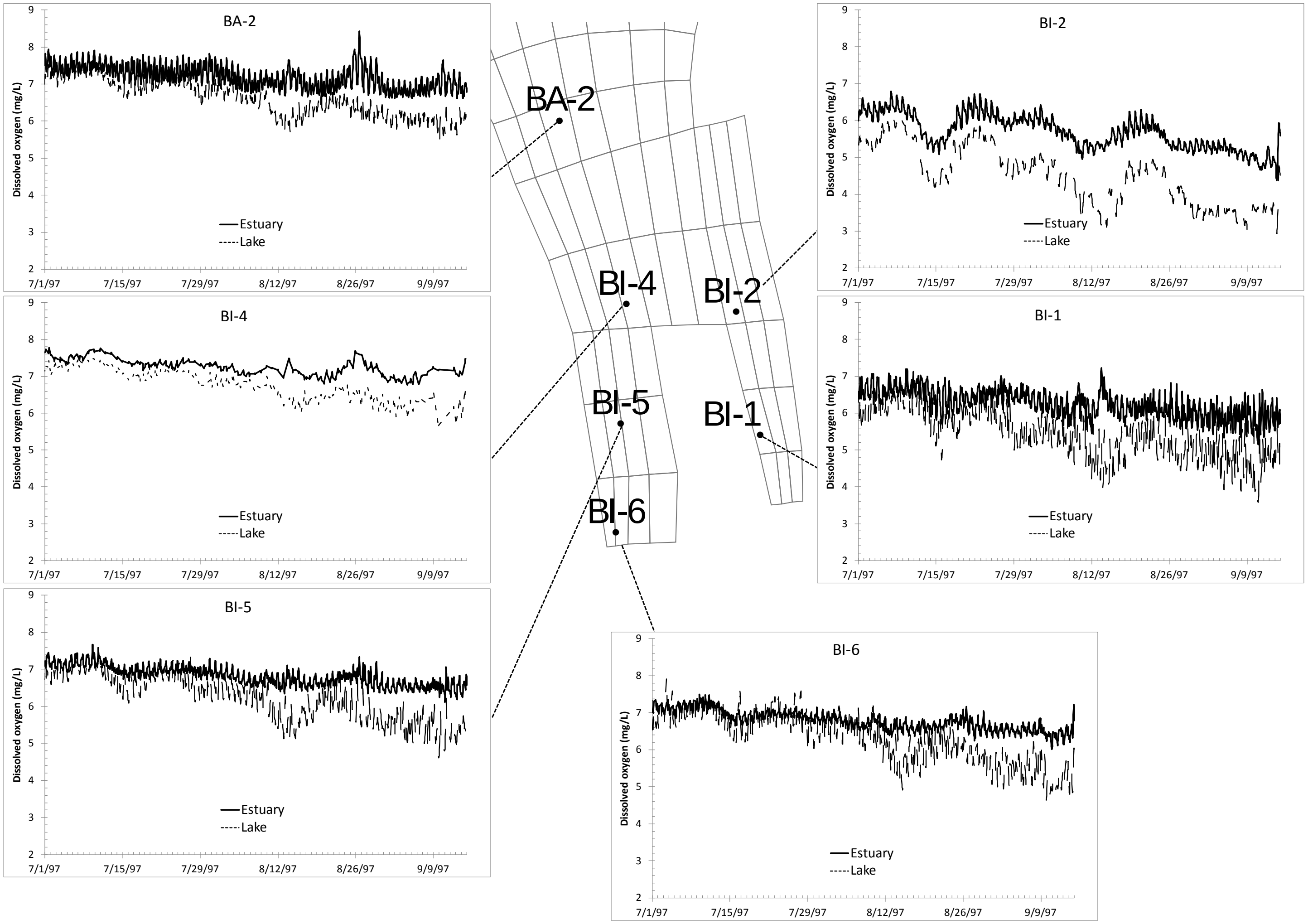


Figure 86. Predicted DO at selected sampling stations under lake scenarios and estuary scenarios for the current levels of nutrient loading (Scenario 3).

The layer with the maximum difference is plotted for each grid cell.

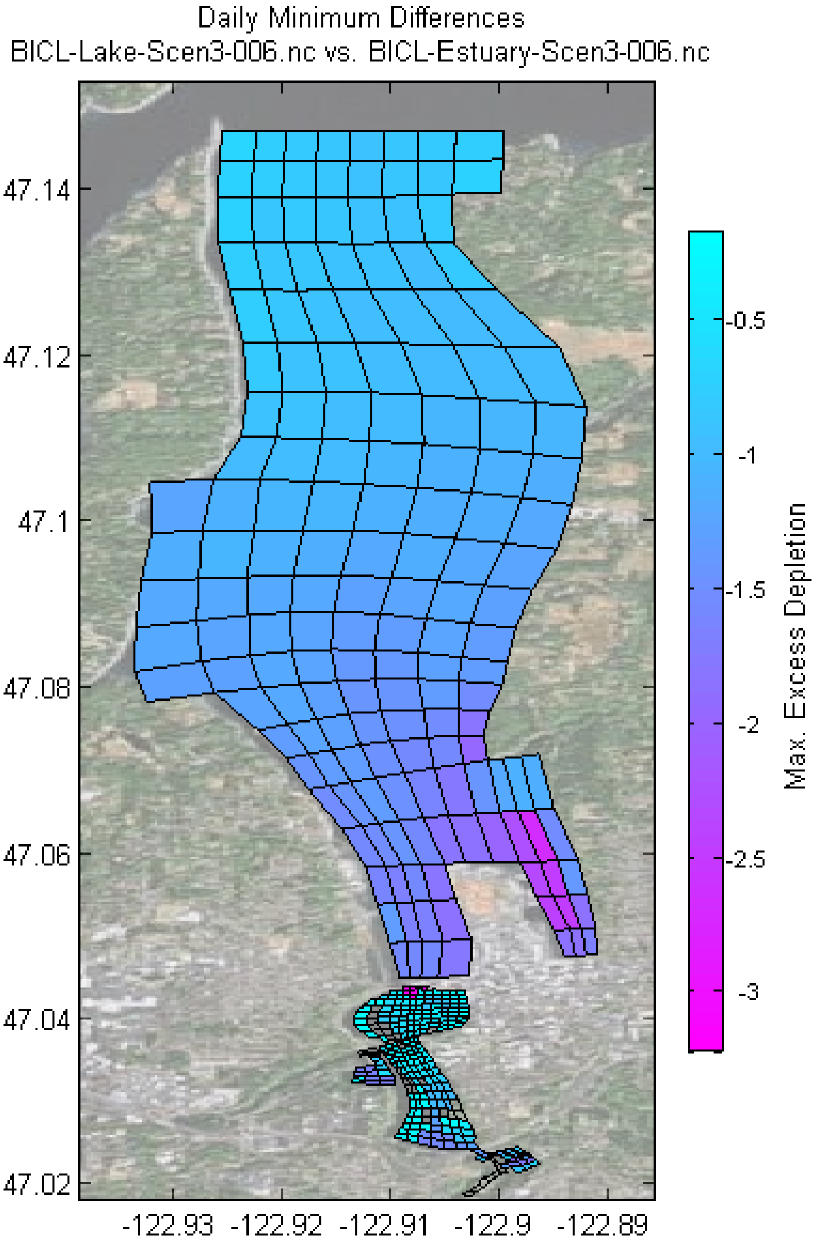


Figure 87. Predicted maximum difference in DO between lake and estuary scenarios for the current levels of nutrient loading (Scenario 3).

Negative values indicate that DO under the lake scenario is lower than DO under the estuary scenario. Cells with no color indicate greater than -0.2 mg/L or positive differences. The layer with the maximum difference is plotted for each grid cell.

Comparison of Nutrient Loads and Sediment Flux Adjustment for Each Scenario

The DIN loading for each scenario during the growing season of April-September is presented in Figure 88 and Table 35. Since nitrogen (N) is the nutrient that is limiting the growth of phytoplankton in Budd Inlet, increases in DIN loading are expected to increase the growth of phytoplankton. The increased growth of phytoplankton is expected to result in decreased minimum DO concentrations due to the increased respiration and decomposition of phytoplankton and detritus biomass.

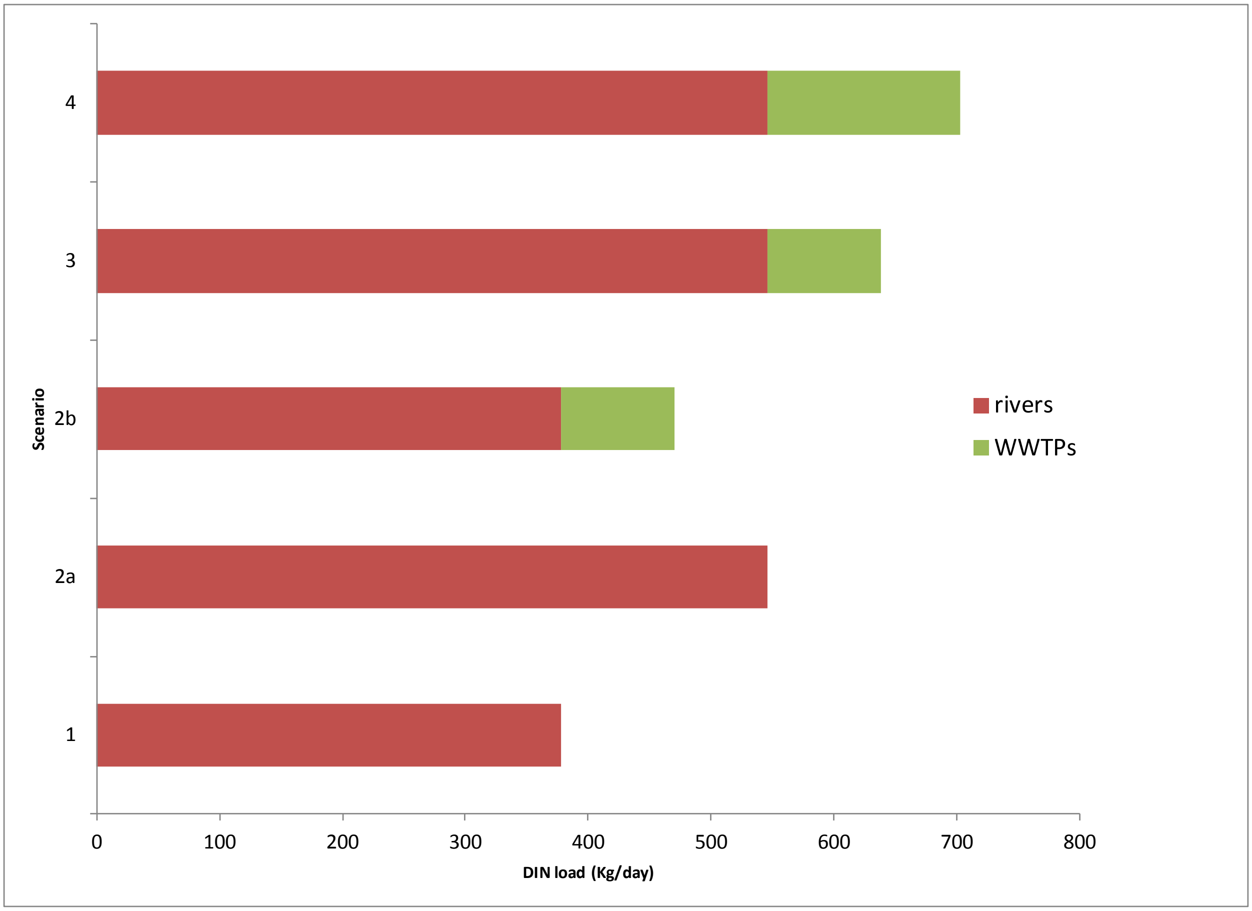


Figure 88. Comparison of DIN loads from rivers and WWTPs for each scenario.

Table 35. Summary of DIN loads and sediment flux adjustment factors for each scenario for Budd Inlet.

	Scenario 1	Scenario 2a	Scenario 2b	Scenario 3	Scenario 4
April-September DIN loads (KgN/day)					
Open boundary	8348	8348	8348	8348	8348
Rivers	378	545	378	545	545
WWTPs	0	0	92	92	157
Total	8726	8893	8818	8985	9050
Sediment oxygen demand and ammonia flux adjustment relative to current conditions					
	97.11%	98.97%	98.13%	100.00%	100.72%

The sediment flux of DO (sediment oxygen demand) and ammonia were estimated for the current condition (Scenario 3) as part of the model calibration process (Appendices G and H). Sediment fluxes are influenced by the rate of deposition of organic carbon and nitrogen, and these depositional fluxes will likely be different for different nutrient loading scenarios.

For Budd Inlet, simple adjustment factors relative to the current condition for sediment flux for each scenario were estimated by assuming proportionality between sediment oxygen demand (SOD) and ammonia flux relative to total DIN loading, where the total DIN loading includes all sources including the open boundary. The DIN loading from the open boundary was estimated as the product of the subtidal residual inflow and DIN concentrations below the depth of no motion across the mouth of Budd Inlet (Table 36). These adjustment factors were considered to be reasonable because they probably represent the maximum potential changes in sediment flux due to changes in DIN loading. Over the long-term, sediment flux to the water cannot exceed the rate of deposition, and the factors are relatively minor adjustments that vary between the range of about 97% to 101% of the current sediment flux across all scenarios.

For Capitol Lake under the lake scenarios, the limiting nutrient is phosphorus, and the phosphorus load to the lake is mainly from the Deschutes River and Percival Creek. The sediment fluxes for Capitol Lake for Scenarios 2a and 4 were assumed to equal the current condition (Scenario 3) that was determined during model calibration (Appendix G). For Scenarios 1 and 2b, sediment SOD and soluble reactive phosphorus (SRP) fluxes were assumed to be proportional to the relative load compared with the current condition (Scenario 3) of SRP from the Deschutes River and Percival Creek, and the ammonia flux would be proportional to the relative load of DIN (Table 36).

Table 36. Summary of SRP and DIN loads and sediment flux adjustment factors for each Capitol Lake scenario.

	Scenario 1	Scenario 2a	Scenario 2b	Scenario 3	Scenario 4
April-September SRP loads (KgP/d)					
Deschutes R	6.51	8.49	6.51	8.49	8.49
Percival Cr	1.76	2.39	1.76	2.39	2.39
Total	8.27	10.89	8.27	10.89	10.89
Sediment oxygen demand and SRP flux adjustment relative to current conditions					
	75.94%	100.00%	75.94%	100.00%	100.00%
April-September DIN loads (KgP/d)					
Deschutes R	299	440	299	440	440
Percival Cr	27.8	40.2	27.8	40.2	40.2
Total	327	480	327	480	480
Sediment ammonia flux adjustment relative to current conditions					
	68.14%	100.00%	68.14%	100.00%	100.00%

Method of Evaluation of Predicted Violations of the DO Criteria

DO differences for each scenario relative to Scenario 1 were compared for each grid cell in each layer. The water quality standards establish both an absolute numeric threshold criterion and a relative difference criterion when the natural DO level is below the numeric criterion. Budd Inlet results were compared two ways:

1. Where natural DO levels are higher than the numeric criterion, additional pollutant loading cannot cause DO levels to fall below the numeric criterion at any time.
2. Where natural DO levels are below the numeric criterion, additional pollutant loading cannot depress DO levels more than 0.2 mg/L below natural conditions at any time.

The absolute DO criteria are different for inner and outer Budd Inlet (5.0 and 6.0 mg/L, respectively) (Figure 89).

For Capitol Lake, water quality standards are based on a maximum of 0.2 mg/L DO change from natural conditions, regardless of the magnitude of the DO under natural conditions.

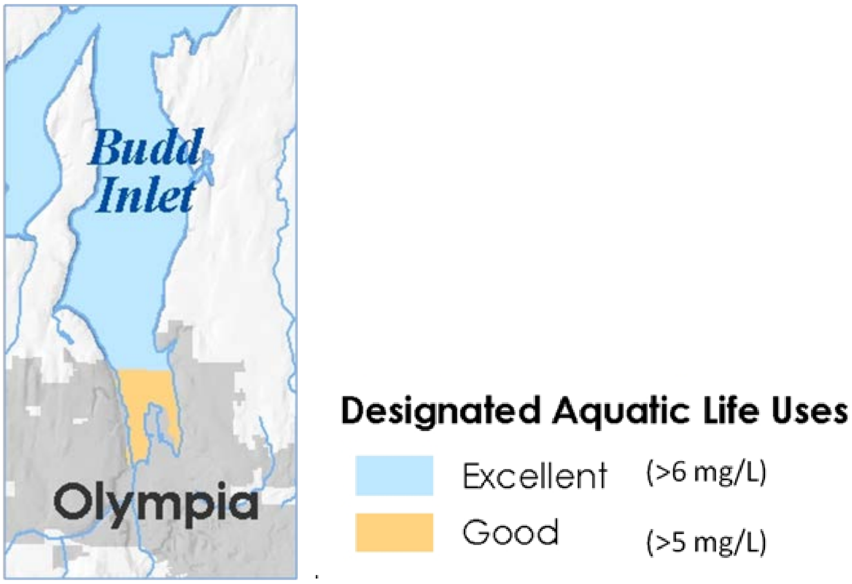


Figure 89. Water quality standards in Budd Inlet and Capitol Lake.

Comparison of the water quality standards to model predictions in tidal water bodies requires additional interpretation. The following method was used to determine whether the predicted depletion of DO for each scenario relative to natural conditions indicated a violation of the water quality standard:

- For each cell and each layer in the model, calculate the minimum DO for each day from the model output. Compare the minimum DO for each day between the natural condition (Scenario 1) and the comparison scenario (2a, 2b, 3, and 4).
- When the natural condition daily minimum is below the absolute criterion, a violation of the water quality standard occurs if the difference in DO compared with natural conditions is greater than 0.2 mg/L at any time of year. When the natural condition is above the threshold, a violation of the water quality standard occurs if the scenario causes the predicted DO to fall below the criterion threshold.

Predicted Violation of the DO Water Quality Standard for Nutrient Loading Scenarios

Lake Scenarios

The predicted maximum violations of the DO water quality standard for the nutrient loading scenarios under the lake scenarios are presented in Figure 90, and the duration of violations are presented in Figure 91. The following patterns of maximum violations and duration of violations are apparent for the lake scenarios:

- Current nonpoint sources (Scenario 2a) are predicted to cause violations throughout Capitol Lake for several months, and in East Bay in inner Budd Inlet for a few days.
- Current point sources (Scenario 2b) are predicted to cause violations in several locations in inner Budd Inlet and in the northern areas of Capitol Lake for a few days.
- The combined effect of current nonpoint and point sources (Scenario 3) is predicted to cause violations throughout Capitol Lake similar to Scenario 2a, and in several locations in inner Budd Inlet similar to Scenario 2b but with greater magnitude and duration up to months of violation in East Bay.
- The combined effect of current nonpoint and permitted point sources (Scenario 4) is predicted to cause violations in more locations in inner Budd Inlet similar to Scenario 3, and with greater magnitude and duration.

The magnitude of predicted maximum violations in Capitol Lake is presented in greater detail in Figure 92. The greatest violations are predicted to occur in the deep hole near the outlet of the lake in the north basin.

Estuary Scenarios

The predicted maximum violations of the DO water quality standard for nutrient loading under the estuary scenarios are presented in Figure 93, and the durations of violations are presented in Figure 94. The following patterns of maximum violations and duration of violations are apparent for the estuary scenarios:

- None of the nutrient loading alternatives are predicted to cause violations in the Capitol Lake grid cells under estuary scenarios.
- Current nonpoint sources (Scenario 2a) are predicted to cause violations in East Bay in inner Budd Inlet for a few days.
- Current point sources (Scenario 2b) are not predicted to cause any violations.
- The combined effect of current nonpoint and point sources (Scenario 3) is predicted to cause violations in East Bay similar to Scenario 2a, and with greater magnitude with duration on the order of days.
- The combined effect of current nonpoint and permitted point sources (Scenario 4) is predicted to cause violations in more locations in East Bay and other locations in inner Budd Inlet, and with greater magnitude and duration up to months.

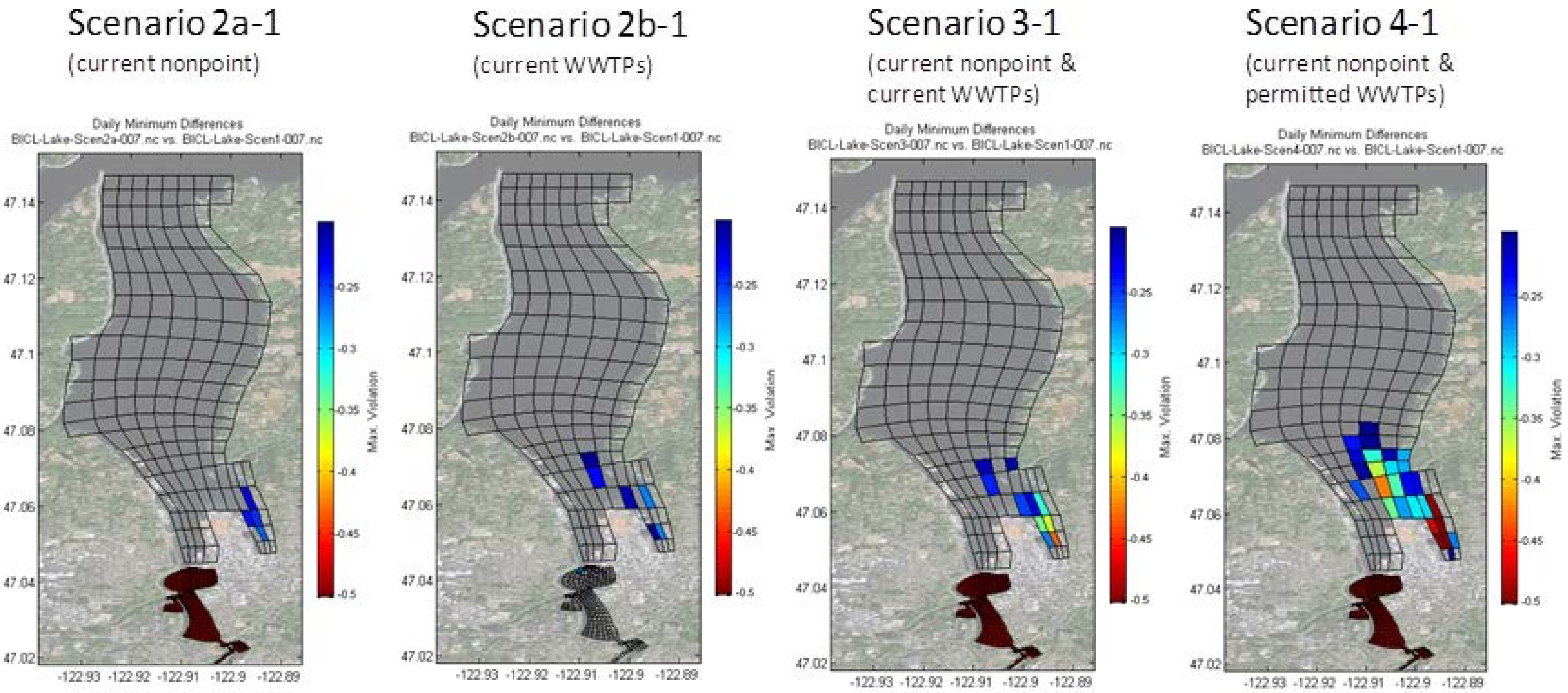


Figure 90. Predicted maximum violation of the DO water quality standard under the lake scenarios.

The layer with the maximum violation is plotted for each grid cell.

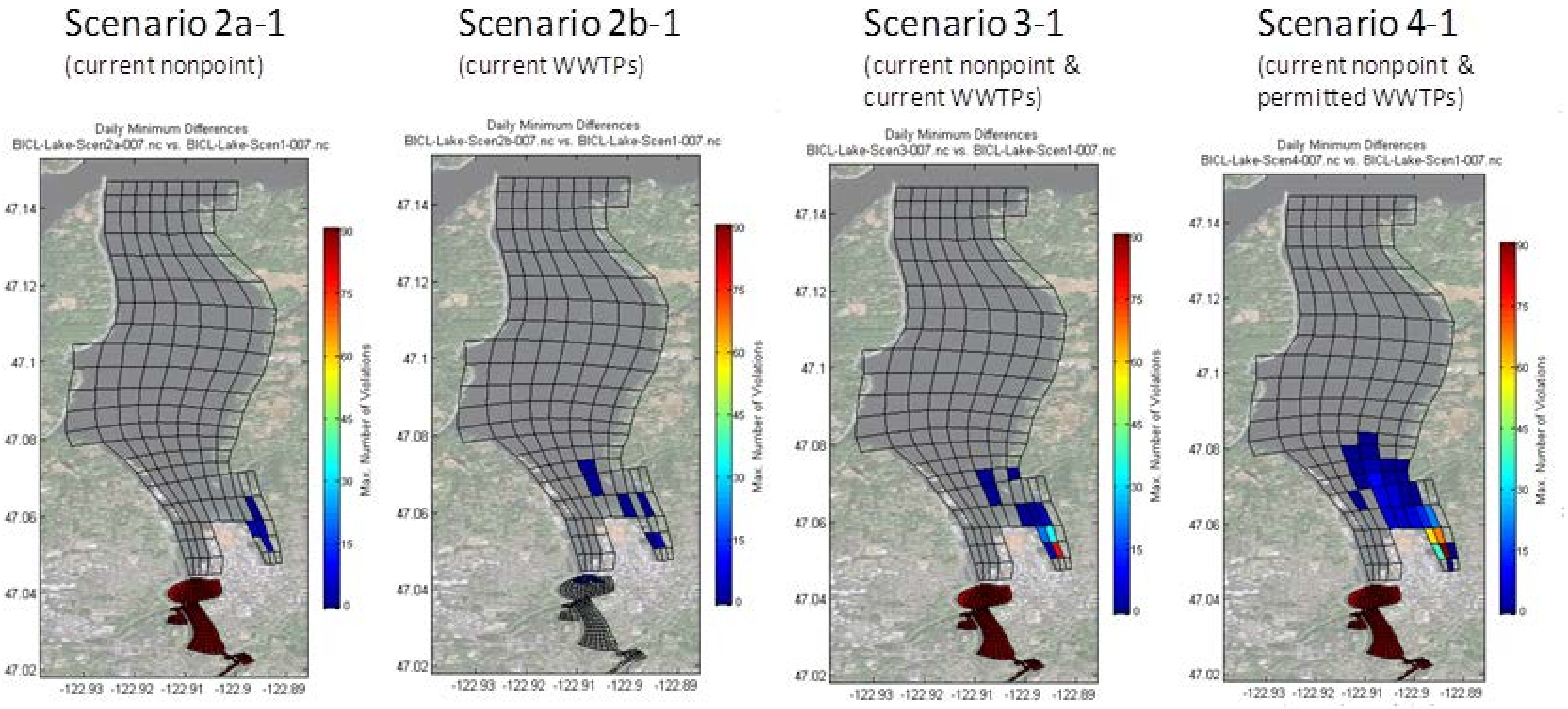


Figure 91. Predicted number of days/layers with violation of the DO water quality standard under the lake scenarios.

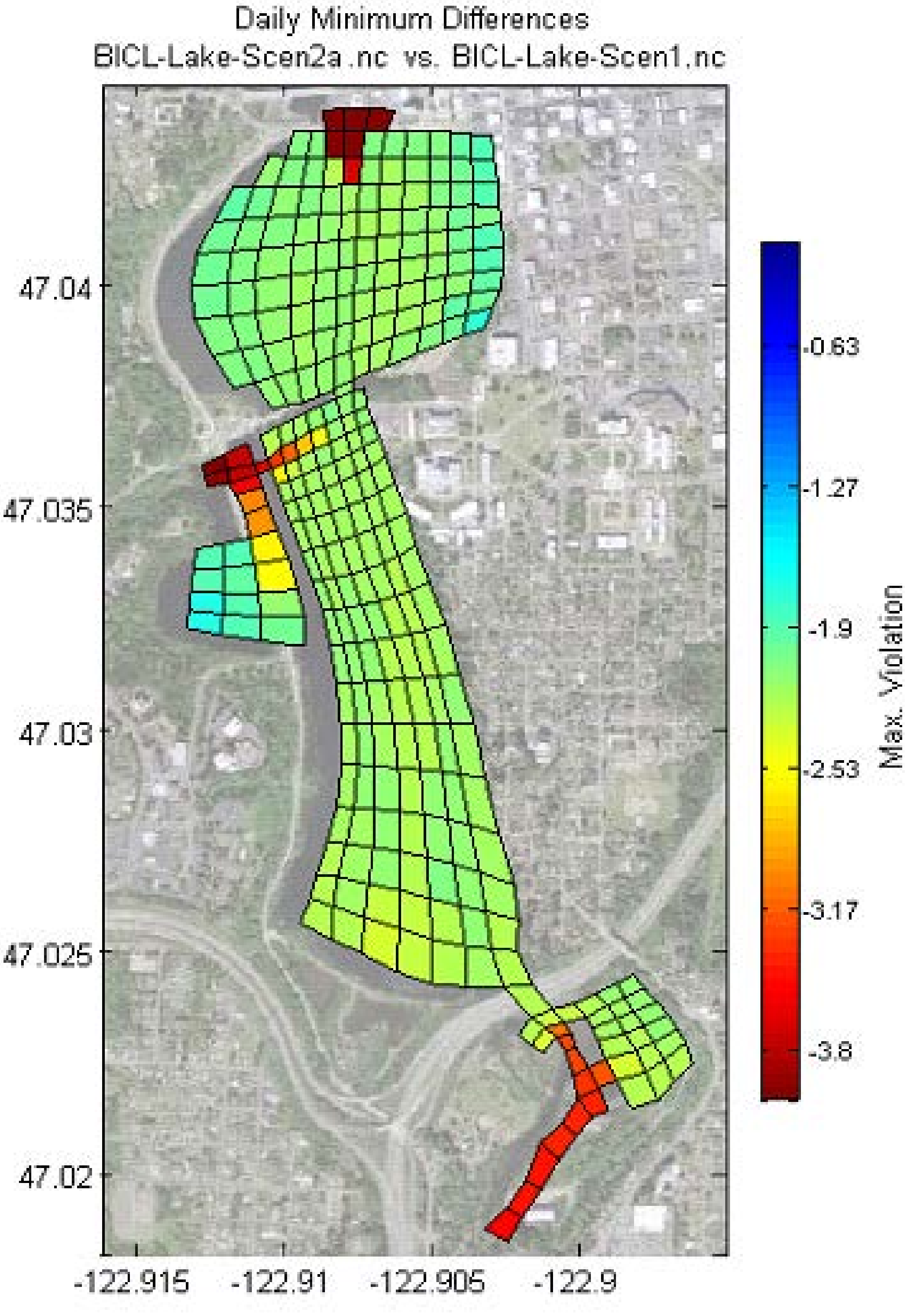


Figure 92. Predicted maximum violation of the DO water quality standard in Capitol Lake from nonpoint sources (Scenario 2a-1).

The layer with the maximum violation is plotted for each grid cell.

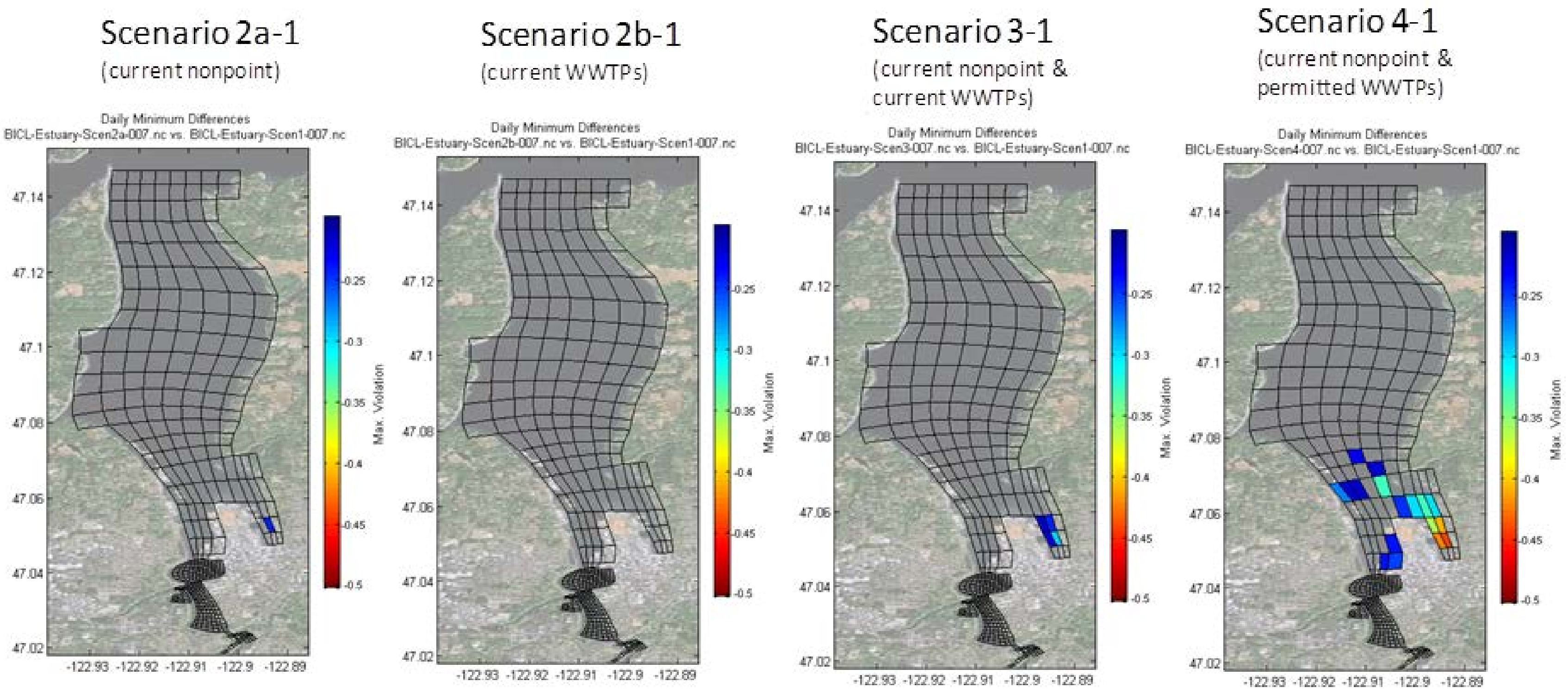
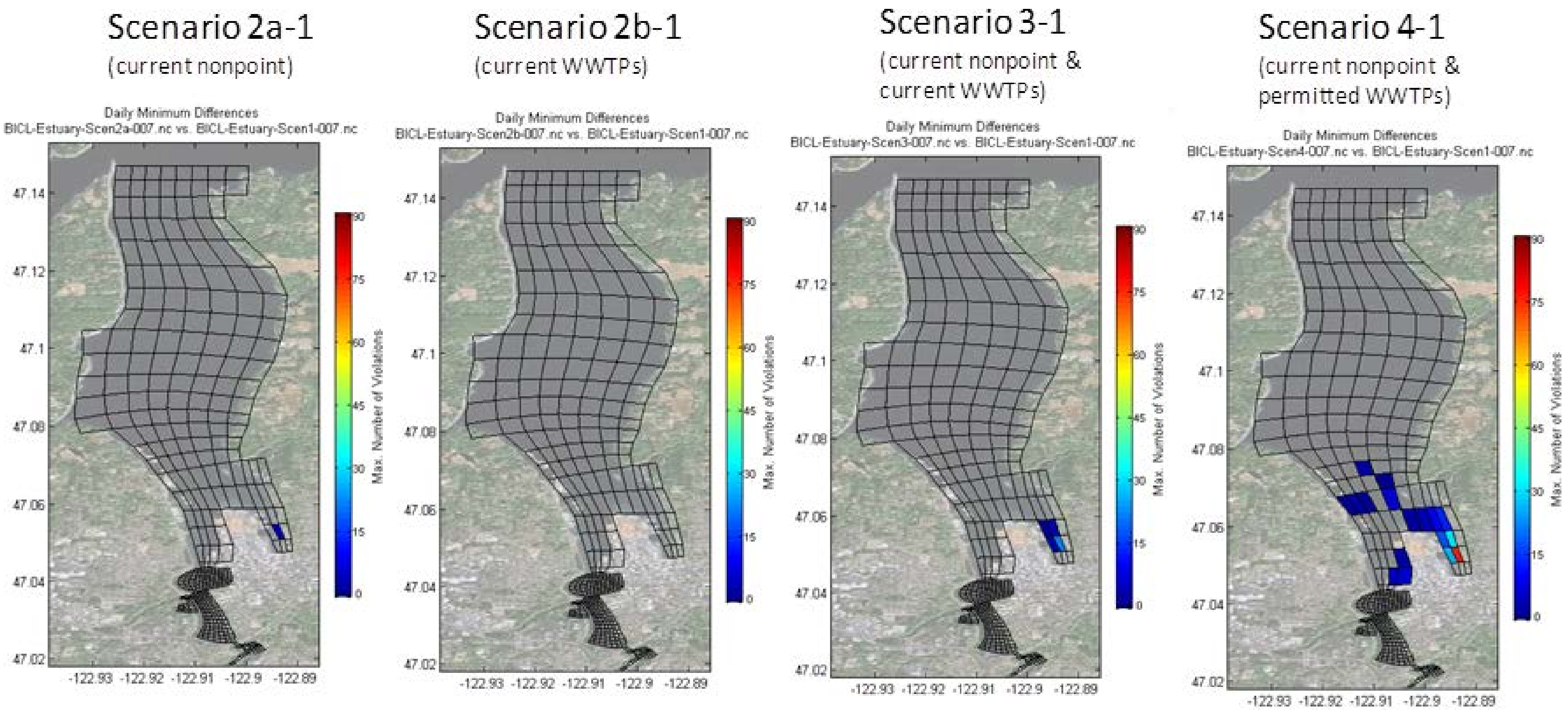


Figure 93. Predicted maximum violation of the DO water quality standard under the estuary scenarios.

The layer with the maximum violation is plotted for each grid cell.


Scenario 2a-1
(current nonpoint)

Scenario 2b-1
(current WWTPs)

Scenario 3-1
(current nonpoint & current WWTPs)

Scenario 4-1
(current nonpoint & permitted WWTPs)

Figure 94. Predicted number of days/layers with violation of the DO water quality standard under the estuary scenarios.

Critical Conditions

The lowest DO concentrations tend to occur when the tides are transitioning from a strong neap to a strong spring condition. Spring and neap tides result from the interaction of the sun and moon. Spring tides occur twice within a 28-day period and refer to periods when the biggest changes in water surface elevation between high and low tides occur. Neap tides also occur twice within a 28-day period and are periods when the smallest changes occur. Within a 28-day period, one spring and one neap tide produce much higher or much lower water surface elevation differences than the other. For this report, a strong spring tide refers to the greatest water surface elevation difference, and strong neap tide refers to the smallest difference within a 28-day period.

The greatest stagnation of water occurs just following a strong neap tide. Low DO levels coincide with the most stagnant water condition (Figure 95). During the simulation period, strong neap conditions representing lowest flushing occur around July 14, August 10, and September 9, and strong spring conditions occur around July 20, August 18, and September 15. Low DO levels progressively worsen from July through September, likely due to increased algal growth superimposed on the circulation patterns. Therefore, critical conditions generally occur following strong neap tides in September.

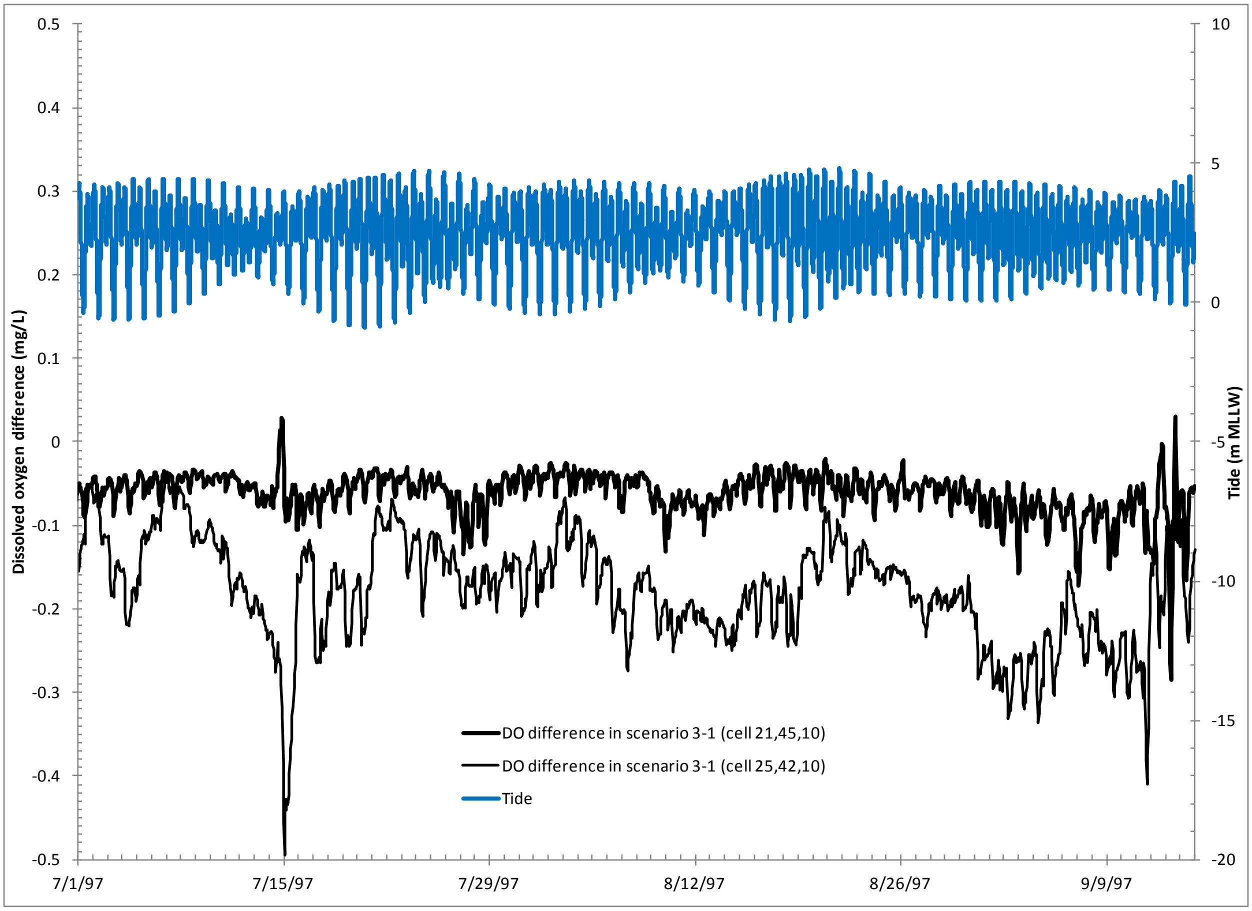


Figure 95. Predicted hourly differences in DO between Scenario 3 and Scenario 1 with Capitol Lake compared with tides at two locations: (1) a grid cell about 1 Km north of the LOTT outfall (layer 10 in cell 21,45), and (2) a grid cell in East Bay (layer 10 in cell 25,42).

Summary of Loading Capacity

The combined effects of current nonpoint and point sources exceed the loading capacity of Budd Inlet, either with Capitol Lake in place or as an estuary, and nutrient load reductions are necessary. With Capitol Lake in place, the current nonpoint sources exceed the loading capacity of the freshwater Capitol Lake, and nutrient load reductions are necessary. If the lake were to revert to an estuary, the region that is currently Capitol Lake would meet marine water quality standards for DO. All of the nutrient loading scenarios evaluated with the model (current nonpoint sources, current point sources, and permitted point sources) would meet the loading capacity of the Deschutes estuary portion of southern Budd Inlet; only the loading capacity of East Bay would be exceeded.

Conclusions and Recommendations

Current point and nonpoint sources exceed the loading capacity of Capitol Lake and Budd Inlet. The combined effects cause portions of inner Budd Inlet to fall below the numeric criteria and contribute >0.2 mg/L decrease in DO concentrations under both the existing Capitol Lake configuration and an estuary scenario. Nutrient load reductions are necessary; however, load and wasteload allocations will be addressed in the Water Quality Improvement Report.

Next Steps

This part of the project determined that the combined effects of nonpoint sources and point sources exceed the loading capacity of Budd Inlet and Capitol Lake. During the next phase, several model runs will be developed in conjunction with the Deschutes Advisory Group. Load and wasteload allocations will be determined such that Budd Inlet and Capitol Lake meet water quality standards. The Water Quality Improvement Report also will establish allocations for future growth and a margin of safety.

Conclusions and Recommendations

Portions of the Deschutes River, Capitol Lake, and Budd Inlet do not meet the water quality standards for one or more of the following parameters: fecal coliform bacteria, temperature, dissolved oxygen (DO), pH, or fine sediment. This study involved data collection to characterize the sources and processes relevant to the impairments as well as analytical tool development, including computer models, to simulate the potential benefits of various management strategies.

Fecal Coliform Bacteria

Fecal coliform levels do not meet the water quality standards during the summer and winter seasons in various areas, and reductions are necessary. More locations violate the water quality standards in summer than in winter. The small tributaries to Budd Inlet require the highest reductions in either season. In subwatersheds where multiple locations were monitored, concentrations trend up in a downstream direction, indicating that multiple bacteria sources affect water quality.

Fecal coliform management activities should build from past and ongoing efforts by the City of Olympia and Thurston County. Urban areas include a variety of potential sources, including cross-connected infrastructure, failing septic systems, domestic animals, recreational users, and homeless populations. Stormwater should receive particular attention given the high winter concentrations. Additional summer source identification and reduction is recommended for tributaries to Budd Inlet, Reichel Creek, and the Percival Creek watershed. Specific management activities could include fencing and waste management for the Deschutes River between Rainier and Old Camp Lane where cows and fecal material were noted on the banks and gravel bars. Winter source identification and stormwater controls should be evaluated for tributaries to Budd Inlet, the Percival Creek watershed, and Capitol Lake at the railroad trestle.

Fecal coliform reduction targets were calculated geographically by subwatershed. The load and wasteload targets, expressed as percent reductions from current conditions, are uniform throughout a given subwatershed. Any facilities covered by a general permit receive the load and wasteload reduction targets listed for the subwatershed in which they operate.

Temperature, Dissolved Oxygen, and pH

Riparian Shade and Channel Restoration

Current vegetation produces effective shade levels below that for mature vegetation. The decreased shade increases maximum water temperatures by 4.5°C, depresses minimum oxygen levels by 0.7 mg/L, and causes maximum pH to increase by 0.2 SU. Restoring effective shade and channel conditions would not meet numeric temperature or DO criteria upstream of Offutt Lake. However, these management actions would cool peak temperatures by as much as 6.9°C, reduce the number of reaches above the lethality limit of 22°C from 63 km (91%) under current conditions to 5 km (7%), increase minimum DO concentrations, and decrease maximum pH.

Downstream of Offutt Lake, riparian vegetation and channel improvements also would benefit temperature, DO, and pH.

Establishing mature riparian vegetation would produce direct benefits to water temperature through decreased solar radiation. Mature vegetation also would produce many secondary benefits to temperature, DO, pH, and fine sediment. Greater canopy cover establishes a continuous riparian microclimate that reduces air temperatures near the water surface and reduces water temperature. Cooler water holds more oxygen, and shade reduces the periphyton growth that influences oxygen and pH levels. A mature riparian corridor also provides large woody debris that protects river banks from enhanced erosion, increases the channel complexity, enhances hyporheic exchanges, and reduces transport of fine sediment and phosphorus. Restoring riparian vegetation would significantly improve temperature even under future climate changes.

In addition to restoring riparian vegetation, management activities should enhance channel complexity. Enhanced restoration should include large woody debris within the bankfull channel to promote bank stabilization and pool formation and within riparian zones to provide self-armoring elements as banks are eroded. Key locations include the areas around Henderson Boulevard, Waldrick Road, State Route 507, and Old Camp Lane.

Wide near-stream disturbance zones result from an accumulation of sediment from upstream natural and anthropogenic sources. Bank erosion also contributes and may be enhanced by the lack of channel complexity and by the young or absent riparian vegetation that no longer protects the banks. These wide gravel areas may contribute >1°C warming due to the lack of vegetation. Warm headwaters and tributaries cause a 0.4°C increase. Current summer baseflows (7Q10) increase maximum water temperatures an additional 0.3°C compared with higher historical baseflows.

Cool-water sources identified in the thermal infrared (TIR) imagery should be protected from flow depletion or temperature increases. Future fisheries surveys may characterize these sites further as thermal refugia.

Future Growth

The Deschutes River downstream of 1000 Road through Vail Cutoff Road SE is the warmest part of the river and highly sensitive to disturbance. Future development and management should be conditioned to prevent degradation from loss of riparian vegetation, groundwater withdrawals, or decreased groundwater recharge. Protecting those areas currently meeting standards and preventing further degradation of those areas already not meeting standards are required by the antidegradation portions of the water quality standards.

The Deschutes River watershed, similar to other areas in the Puget Lowland, is subject to intense development pressure, both near and away from existing urban growth areas. With no change in development from previous practices, future growth is expected to reduce riparian vegetation further, increase impervious surfaces, and increase the demand for groundwater. All of these factors will worsen existing temperature, DO, and pH impairments in the Deschutes River watershed.

Increased residential development and urbanization may lead to higher nitrogen and phosphorus levels in the watersheds from increased wastewater sources, land cover type, land management practices (Brett et al., 2005), and activities that enhance erosion if development continues using previous management strategies and practices. Residential land cover produces much higher nutrient loads than do natural forest lands (Herrera Environmental Consultants, 2011).

Management activities should investigate opportunities to enhance (1) groundwater recharge through low impact development (LID) practices for new development and redevelopment and (2) infiltration of existing stormwater wherever possible. Because the Deschutes River and tributaries already violate the water quality standards, and because development will continue, both new development and redevelopment must not worsen conditions and must improve DO and pH in the system. Stormwater management should also control nutrients and should decrease nutrient contributions below current levels.

Septic Systems

Septic systems, particularly those near a water body, could be contributing excess nutrient loads in addition to fecal coliform bacteria. Existing management programs by Thurston County should continue and intensify. In addition, future efforts should examine and implement options to reduce nutrient loading from onsite sewage systems in areas with high surface or groundwater nutrient concentrations, such as upstream of Offutt Lake, Chambers Lake and its outlet creek, Tempo Lake and its outlet creek, and the Ayer Creek watershed. These could include state-of-the-art onsite systems.

River Flows

Summer baseflows have declined in the Deschutes River since historical gaging began in the 1950s. Instream flow influences stream temperature and subsequently DO and pH, and flow reductions may increase peak temperatures. However, separate regulatory programs manage instream flows and surface water/groundwater withdrawals, and TMDLs do not establish minimum instream flows. The Deschutes River watershed is closed to any further consumptive uses of water. This TMDL does not affect any entity’s existing legal water rights.

Local governments should consider a water management strategy that recognizes the benefits of maintaining summer baseflows while meeting the community’s need for water. Strategies should consider projected future growth and increases in water demand. Water conservation will be a key element and should be encouraged throughout the watershed, particularly for those served by exempt wells. Water conservation programs should be strengthened to reach urban, suburban, and rural water users from residential, industrial, commercial, agricultural, and forestry sectors. Successful methods of reaching and assisting exempt well users should be evaluated. Water withdrawals should be quantified for all watershed users. Illegal withdrawals should be identified, and agencies should work with landowners. If needed, enforcement actions should be taken to eliminate them.

Opportunities exist to mitigate the effects of current and potential future withdrawals. Reclaimed water facilities are currently in operation, and others are planned for the region. Use of reclaimed water with appropriate management practices would reduce the need for potable water or groundwater but should not lead to increased nutrient loads to surface water. Future groundwater infiltration facilities should quantify the potential increases in nutrient loads to the Deschutes River and tributaries and offset any inputs by reducing other local sources such that DO and pH do not worsen. The issue will be part of future discussions during the development of the Water Quality Improvement Report.

Deschutes River Tributaries

In addition to restoring riparian vegetation along the mainstem Deschutes River, full mature riparian vegetation should be established along tributaries to the Deschutes River. The hottest conditions are in the Tempo Lake outflow, due in part to solar heating of the lake surface. The Lake Lawrence tributary also has high water temperatures, due in part to the solar radiation received by the surface of the lake.

Future management plans should restore and protect natural wetlands in areas such as Ayer, Reichel, and Spurgeon Creeks. Ayer Creek also should be targeted for enhanced riparian restoration appropriate to the soils. Creek temperatures would benefit from restoration of riparian zones with plantings appropriate to the soils present. Even wetland shrubby vegetation would reduce solar heating of these streams.

Current tributary nutrient loads contribute to violations of the DO and pH standards in the mainstem Deschutes River. Nitrogen and phosphorus hot spots exist and should be evaluated for future nutrient reduction strategies. Tributaries with elevated nitrogen include Ayer/Elwanger Creek, Tempo Lake, Chambers Creek, and the unnamed creek at river kilometer (RK) 64. Tributaries with elevated phosphorus include the Lake Lawrence outlet, as well as Reichel, Spurgeon, and Ayer/Elwanger Creeks. Upstream nutrient sources in these areas should be quantified. Lake Lawrence is on the 303(d) list for total phosphorus, and a TMDL should be conducted and implemented soon so that management activities may be coordinated.

In addition to identifying contributors to elevated nitrogen and phosphorus in the Ayer Creek and Reichel Creek watersheds, future efforts should mitigate existing low DO and low pH to the extent possible. Initial management should focus on establishing mature riparian shade, and restoration plans should evaluate naturalizing the channels to increase complexity.

Agricultural Sources

Agricultural operations and dairies should eliminate offsite transport of sediments and nutrients. Ecology staff noted cows on the banks and fecal material in the river and on gravel bars between Old Camp Lane and the Lake Lawrence tributary (RK 18 – RK 20). This site should be evaluated for nutrient management.

NPDES Permits

No numeric targets were developed for heat (temperature), nutrients, DO, or pH from areas covered by municipal, industrial, construction, transportation stormwater, or sand and gravel facilities. Strict adherence to the general permit conditions is necessary and sufficient. Once mature riparian vegetation is established, runoff from sites covered by general permits should be evaluated for the potential to contribute heat or nutrient loads that result in violations of the temperature, DO, or pH water quality standards.

Percival Creek Watershed

In the Percival Creek system, establishing full mature riparian vegetation, with heights governed by soil type, would increase effective shade from 47% to 84% on average in Black Lake Ditch and from 84% to 98% in Percival Creek. While numeric water quality criteria may not be met even with full shade, due in part to the headwater lake and wetland complexes, mature shade should reduce stream temperatures significantly. Hydraulic modifications may be made at the outlet from Black Lake to enhance subsurface water connections and minimize the surface water connectivity. The lake outlet should be evaluated further. Anthropogenic sources of heat in the Percival Creek watershed also must be reduced to improve DO and pH in the system. The general recommendations for the Deschutes River watershed also apply to the Percival Creek watershed.

Fine Sediment

Anthropogenic activities contribute up to 32% of the known sediment sources, or 23% of the total sediment inputs to the Deschutes River. Anthropogenic sources include unpaved roads and landslides associated with roads. These must be reduced to achieve healthy levels of fine sediments in the gravels of the Deschutes River for salmonid spawning. Improved fine sediment levels would produce the greatest increase in coho production of the various restoration components evaluated in the Deschutes system (Anchor Environmental, 2008).

Extensive road rehabilitation and other sediment control strategies have been implemented within the area covered by the Forests and Fish Agreement. Long-term turbidity has declined (Reiter et al., 2009). This likely reflects source control measures, but fine sediment levels within the upstream reaches remain poor and have increased. Intensive management should continue, given that instream responses often are not evident for many years after a management program begins (Sullivan et al., 1987). Implementation is via the terms of the Forests and Fish Agreement.

Other activities that may be contributing to fine sediment inputs include off-road vehicle use, bank erosion from domestic animals, and fine sediment from entities covered under general permits. Konovsky and Puhn (2005) report extensive all-terrain vehicle (ATV) use along and across the Deschutes River near 1000 Road and suggest that the activity has accelerated soil erosion rates. Domestic animals were noted on the banks and in the river between Old Camp Lane and the Lake Lawrence tributary during surveys conducted by Ecology staff and may be enhancing localized bank erosion over natural levels. These human-induced sources of sediment should be controlled to the maximum extent. Fencing to remove access should be considered.

Sand and gravel facilities should strictly adhere to the conditions in the general permit. Enhanced enforcement should verify that facilities covered by the general permits are in compliance with the permits and with applicable wasteload targets and narrative criteria in this report. Facilities covered by general permits must not produce loads above natural conditions, and no visual accumulation of fine sediments downstream of the facilities should occur. Other facilities covered by general permits should be reevaluated for their potential to contribute fine sediments.

Channel and riparian restoration would mitigate fine sediment, in addition to improving temperature, DO, and pH. Restoration should include channel complexity elements, including large woody debris, to enhance pool formation and decrease the transport of fine sediment and phosphorus in the system.

Future land cover changes in the Deschutes River watershed must not enhance fine sediment inputs to streams or to the Deschutes River beyond natural conditions. Projects should be designed so that they do not produce any offsite transport of fine sediment or any visible accumulation of fine sediment downstream of the sites.

Measures to protect high quality areas in the Deschutes watershed should be considered during preparation of the Implementation Strategy for this TMDL. While the primary focus of this TMDL is to address waters not meeting water quality criteria, Washington State’s water quality standards also call for protection of waters of a higher quality than the criteria. Continued development in the watershed may result in a loss of current water quality in these high quality areas unless additional safeguards are instituted.

Capitol Lake Total Phosphorus and DO and Budd Inlet DO

The combined effects of current nonpoint and point-source nutrient loads exceed the loading capacity of Capitol Lake and Budd Inlet for DO. Load reductions are needed. With Capitol Lake in place, more of Budd Inlet would not meet water quality standards under critical conditions compared with the estuary alternative. In addition, existing nonpoint sources exceed the loading capacity of Capitol Lake, and load reductions are needed.

Load and wasteload targets are recommended for many parameters and areas within the watershed that could benefit Capitol Lake and Budd Inlet. Tributary and nutrient load reductions are needed for the Deschutes River to meet the water quality standards for DO and pH. The subsequent Water Quality Improvement Report will reevaluate Deschutes watershed nutrients and will determine the nutrient load reductions needed in the Deschutes watershed so that Capitol Lake and Budd Inlet meet water quality standards. That report will recommend load and wasteload allocations to address total phosphorus and DO in Capitol Lake and DO in Budd Inlet.

Next Steps

Ecology has convened the Deschutes Advisory Group to develop the next steps. The information contained in this technical report will be the basis for committee discussions on wasteload and load allocations. Once allocations have been determined, a strategy for implementation also will be developed. Information on this approach will be compiled with this technical report and load and wasteload allocations into a Water Quality Improvement Report. The Water Quality Improvement Report will be submitted to EPA for approval. Ecology also will work with the advisory group to establish specific details for implementation actions, and this information will be compiled into a Water Quality Implementation Plan.

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Appendices

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Appendix A. Glossary

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

Anthropogenic: Human-caused.

Baseflow: Groundwater discharge to a surface stream or river. The component of total streamflow that originates from direct groundwater discharges to a stream.

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

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

Diel: Involving a 24-hour period that usually includes a day and the adjoining night.

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

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

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

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

Geometric Mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from ten to 10,000 fold over a given period. The calculation is performed by either: (1) taking the n^{th} root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

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

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

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

Macrophytes: Aquatic plants growing in or near water that may be rooted in shallow water or floating.

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

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

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

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

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

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

Periphyton: Benthic (attached) algae that grow in freshwater systems attached to surfaces like rocks or other plants.

Phase I Municipal Stormwater Permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites that disturb a land area 1 acre or greater, including projects less than one acre that are part of a larger common plan of development.

Phase II Municipal Stormwater Permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites that disturb a land area 1 acre or greater, including projects less than one acre that are part of a larger common plan of development.

Phytoplankton: Microscopic aquatic plants (algae) that grow in freshwater or marine water systems.

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

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state as will or is likely to create a nuisance or render such waters harmful, detrimental, or injurious to the public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish, or other aquatic life.

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

Riparian: Transitional zone between aquatic and upland areas. The riparian area has vegetation or other physical features reflecting permanent influence on surface water or subsurface water.

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

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

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

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

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

Appendix B. Acronyms and Abbreviations

30Q10	Lowest 30-day running average discharge in a river that occurs on average once every 10 years
7-DADMax	7-day average of daily maximum temperatures
7Q10	Lowest 7-day running average discharge in a river that occurs on average once every 10 years
ALK	Alkalinity
ATV	All-terrain vehicle
BOD	Biochemical oxygen demand
BOD5	5-day biochemical oxygen demand
BODULT	Ultimate BOD, determined from a 35-day test
CHL	Chlorophyll-a
CLAMP	Capitol Lake Adaptive Management Plan committee
CSO	Combined sewer overflow
DEM	Digital elevation model
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DTP	Dissolved total phosphorus
DTPN	Dissolved total (persulfate) nitrogen
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
EPA	United States Environmental Protection Agency
ERM	ERM Inc.
FC	Fecal coliform bacteria
GAM	General Algae Model
GEMSS	Generalized Environmental Model System for Surfacewaters
Geomean	Geometric mean
GIS	Geographic Information Systems
GLLVHT	Generalized, Longitudinal-Lateral-Vertical Hydrodynamics and Transport
GWT	Groundwater temperature
HW	Headwaters
LCS	Laboratory control sample
LID	Low impact development
LiDAR	Light imaging detection and ranging
LOTT	LOTT Clean Water Alliance, the wastewater utility partnership of Lacey, Olympia, Tumwater, and Thurston County
LWD	Large woody debris
MEL	Manchester Environmental Laboratory

MQO	Measurement quality objective
n	Number
N	Nitrogen
NH4N	Ammonium
NIST	National Institute of Standards and Technology
NO23N	Nitrate plus nitrite
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
NSDZ	Near-stream disturbance zone
ODEQ	Oregon Department of Environmental Quality
OP	Orthophosphate
OMEXDIA	Ocean Margin Exchange Nutrient Diagenesis Model
PCB	Polychlorinated biphenyls
Q	Discharge
QA	Quality assurance
RK	River kilometer
RM	River mile
RMSE	Root mean square error
RSD	Relative standard deviation
SD	Standard deviation
SIT	Squaxin Island Tribe
SOD	Sediment oxygen demand
SRP	Soluble reactive phosphorus
TIR	Thermal infrared
TKN	Total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TOC	Total organic carbon
TP	Total phosphorus
TPLL	Total phosphorus (low detection limit method)
TPN	Total (persulfate) nitrogen
TSS	Total suspended solids
USFS	United States Forest Service
USGS	United States Geological Survey
WARSEM	Washington Road Surface Erosion Model
WDFW	Washington Department of Fish and Wildlife
WPU	Watershed Planning Unit
WQCBM	Water Quality Carbon-Based Module
WQIR	Water Quality Improvement Report
WQS	Water Quality Standard
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

WW	Wetted width
WWTP	Wastewater treatment plant

Units of measurement

Ac-ft	acre-foot, the amount of water that would cover one acre one foot deep
°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second
ft	feet
g	gram, a unit of mass
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
mm	millimeters
mole	an International System of Units (IS) unit of matter
SU	standard units

Appendices C - M

Appendices C through M are available only on the internet, linked to this report at www.ecy.wa.gov/biblio/1203008.html

Appendix C. Aquatic Plant Surveys
Appendix D. Station Identifiers
Appendix E. Effective Shade Targets for the Deschutes River Watershed
Appendix F. Effective Shade Targets for the Percival Creek Watershed
Appendix G. Budd Inlet Recalibration Report
Appendix H. Capitol Lake Water Quality Model Calibration and Verification
Appendix I. Development of Loading Scenarios for the Capitol Lake and Budd Inlet Models
Appendix J. GEMSS Code Review
Appendix K. Verification Tests for GEMSS
Appendix L. GEMSS Code Testing
Appendix M. Fortran Source Code for GEMSS Modules