TMDL Technical Report – External Review Draft – October 2008

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

Water Quality Study Findings

DRAFT - October 2008

Publication No. 09-03-0xx

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Publication and Contact Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/09030xx.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search User Study ID, MROB0001.

Ecology's Study Tracker Code for this study is 03-077-01.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600
Olympia, WA 98504-7600

E-mail: jlet461@ecy.wa.gov
Phone: 360-407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

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

If you need this publication in an alternate format, call Joan LeTourneau at 360-407-6764. Persons with hearing loss can call 711 for Washington Relay Service. Persons with a speech disability can call 877-833-6341.

Cover photo: Shoreline Aerial Photo THU0154 (May 13, 1992), Department of Ecology

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

Water Quality Study Findings

by

Mindy Roberts, Anise Ahmed, and Greg Pelletier

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

Waterbody ID:
WA-13-1010, WA-13-1020, WA-13-1380, WA-13-1015, WA-13-1300,
WA-13-1022, WA-13-9020, WA-13-1350, WA-13-0030, WA-13-1024
(see Tables 1 and 2 for complete list of waterbodies addressed)

This page is purposely left blank

Table of Contents

Page

List of Figures 7

List of Tables 12

Abstract 14

Acknowledgements 15

Executive Summary 17
- Introduction 17
- Budd Inlet, Capitol Lake, and Deschutes River Watershed 17
- Water Quality Standards 19
- Technical Approach 19
- Load Reduction Targets 20
- Conclusions and Recommendations 21
- Next Steps 22

What is a Total Maximum Daily Load (TMDL)? 23
- Federal Clean Water Act requirements 23
- TMDL Process Overview 23
- Elements Required in a TMDL 25
- Total Maximum Daily Load Analyses: Loading capacity 25

Why is Ecology Conducting a TMDL Study in this Watershed? 26
- Overview 26
- Study Area 26
- Pollutants Addressed by this TMDL 27
- Impaired Beneficial Uses and Waterbodies on Ecology's 303(d) List of Impaired Waters 28
- Why are We Doing this TMDL Now? 34

Water Quality Standards 35
- Designated Uses 35
- Criteria to Protect Designated Uses 37
- Antidegradation 44

Watershed Description 45
- Watershed Characteristics 45
- Land Cover 45
- Regulatory Activities 46
- Fisheries 51
- Potential Pollutant Sources 52

Goals and Objectives 57
- Project Goals 57
- Study Objectives 57

Study Methods 59

Data Collection Activities 59
Data Analytical Methods 66

Study Quality Assurance Evaluation 69
Field and Laboratory Data 69
Model Calibration and Confirmation 75

Results and Discussion 79
Meteorology and Hydrology 79
Fecal Coliform Bacteria Results 84
Temperature Results 87
Nutrients, Dissolved Oxygen, and pH Results 90
Fine Sediment Results 101

TMDL Analyses 108
Fecal Coliform Bacteria 108
Temperature 119
Freshwater Dissolved Oxygen and pH 162
Fine Sediment 191
Capitol Lake and Budd Inlet Dissolved Oxygen 200

Conclusions and Recommendations 220

Next Steps 223

References 224

Appendices 233
Appendix A. Glossary and Acronyms 234
Appendix B. Acronyms 237
Appendix C. Aquatic Plant Surveys 239
Appendix D. Thermal Infrared Survey Images 239
Appendix E. Effective Shade Targets for the Deschutes River 239
Appendix F. Effective Shade Targets for the Percival Creek Watershed 239
Appendix G. Budd Inlet Recalibration Report 239
Appendix H. Capitol Lake Water Quality Model Calibration and Verification 239
Appendix I. Development of Loading Scenarios for the Capitol Lake and Budd Inlet Models 239
Appendix J. Station Identifiers 239

List of Figures

Page

Figure 1. Five steps in TMDL development. 24

Figure 2. Deschutes River, Capitol Lake, and Budd Inlet TMDL study area. 27

Figure 3. Temperature monitoring stations (solid dots) within the Deschutes River and Percival Creek watersheds. 60

Figure 4. Continuous discharge monitoring (red cross hatch) and synoptic flow (black dots) stations within the Deschutes River and Percival Creek watersheds. 62

Figure 5. Bacteria monitoring stations (filled triangles) within the Deschutes River and Percival Creek watersheds. 63

Figure 6. Capitol Lake monitoring stations for 2003 (small dots) and 2004 (open circles). Benthic flux stations are indicated with a + symbol. 64

Figure 7. Stations evaluated for fecal coliform during intense dry- and wet-weather monitoring. 65

Figure 8. Mean monthly 7-day average of daily maximum air temperature and monthly precipitation at the Olympia Airport. 79

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. 80

Figure 10. Dewpoint temperatures in the Deschutes River watershed for July 21-27, 2004 by station and averaged across both stations. 80

Figure 11. Cloud cover at the Olympia Airport for 2003-2004. 81

Figure 12. Historical minimum, mean, and maximum average monthly flows at the USGS station 12080010 (E Street bridge) compared with 2003 and 2004 conditions. 82

Figure 13. Longitudinal profile of flows in the Deschutes River recorded August 2-4, 2004. 83

Figure 14. Peak instantaneous temperature (mean ± 1 SD) by month for Ecology ambient monitoring station 13A060 (1988 through 2007). 87

Figure 15. Peak 7-day average of daily maximum temperatures (ºC) in 2003 and 2004 in the study area. 88

Figure 16. Profile of peak annual 7-day average of daily maximum temperatures in 2003 and 2004 along the Deschutes River from the Deschutes Falls (RM42.3) to the E Street bridge (RM00.5). 88

Figure 17. Example thermal infrared (left) and visible band (right) paired images from the TIR survey. Source: Watershed Sciences (2004). 89

Figure 18. Detailed longitudinal profile from TIR survey for the mainstem Deschutes River as well as measured and estimated tributary and spring temperatures. Distance is miles from

Capitol Lake. Source: Watershed Sciences (2004). Arrows added to identify areas with warming or cooling of 1.0ºC (small arrows) to >2ºC (large arrows). 90

Figure 19. Long-term trends in nitrogen concentrations at Ecology's ambient monitoring station 13A060 at the E Street bridge. 91

Figure 20. Long-term trends in phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge. 92

Figure 21. 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). 93

Figure 22. Monthly values for nitrogen and phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge. 93

Figure 23. Continuous DO (top) and pH (bottom) results from Hydrolab measurements at five stations. Solid lines represent stations upstream of Offut Lake, while dashed lines represent sites downstream of Offut Lake. 95

Figure 24. Longitudinal variation in 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. 97

Figure 25. Longitudinal variation in phosphorus concentrations from the 1000 Road to the E Street bridge. See Figure 24 for legend. 98

Figure 26. Temperature, DO, pH, and conductivity longitudinal profiles recorded August 11-15, 2003 99

Figure 27. Capitol Lake phytoplankton density (#/mL) and volume (um^3/mL) in 2004.100

Figure 28. Fine sediment study reaches sampled in 2004. Source: Konovsky and Puhn (2005). River kms are downstream of Deschutes Falls. 102

Figure 29. Fine sediment levels by study reach. Source: Konovsky and Puhn (2005)..103

Figure 30. Sediment budgets for both fine sediments and the combination of fine and coarse sediments 107

Figure 31. Fecal coliform concentrations and loading capacities for the growing season (May through September). Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use 110

Figure 32. Fecal coliform concentrations and loading capacities for the non-growing season (October through April). Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use. 111

Figure 33. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the growing season (May through September). 115

Figure 34. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the non-growing season (October through April). 116

Figure 35. Long-term monitoring of surface water temperature in the Deschutes River watershed. 122

Figure 36. 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.124

Figure 37. Effective shade based on current vegetation and July 24, 2004, solar characteristics. 127

Figure 38. Relationships between 2003 and 2004 7-day average of daily maximum and minimum surface water temperatures in the mainstem of the Deschutes River.....128

Figure 39. Predicted and observed water temperature in the Deschutes River for the calibration time period (July 21-27, 2004).....130

Figure 40. QUAL2Kw model run results for the validation period July 27 through August 2, 2003 (peak daily maximum surface water temperatures). 132

Figure 41. QUAL2Kw model run results for the validation period August 20, 2003 (TIR survey).....133

Figure 42. Smoothed TIR results scaled to the river kilometer length scale used in the model. Data were smoothed 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.....134

Figure 43. QUAL2Kw model run results for the validation period August 5-11, 2003 (low daily maximum surface water temperatures during non-storm conditions). 135

Figure 44. Effect of varying headwater temperature (HWT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 136

Figure 45. Effect of varying tributary temperature (tribT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 137

Figure 46. Effect of varying groundwater temperature (GWT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 137

Figure 47. Effect of varying air temperature on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 138

Figure 48. Effect of varying channel bottom width (BW) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 138

Figure 49. Effect of varying vegetation characteristics (height [Ht] and density [Dns]) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. ...139

Figure 50. Effect of varying Manning's n on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. 140

Figure 51. Effect of varying hyporheic zone thickness (shz) and exchange flow (hxq) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period. ...141

Figure 52. Predicted daily maximum water temperature in the Deschutes River for critical conditions under current conditions and various scenarios. 144

Figure 53. Decreases in peak temperature under various critical conditions scenarios by river reach. 145

Figure 54. NSDZ and wetted width under current conditions and several scenarios. 146

Figure 55. Temperature improvements (system-wide average Tmax ºC) associated with various management strategies. 148

Figure 56. Temperature profiles in Percival Creek and Black Lake Ditch. 149

Figure 57. Effective shade targets for the Deschutes River with full mature riparian shade and with supplemental channel modifications. 150

Figure 58. Shade deficit (%) between current and potential vegetation and supplemental channel modifications along the Deschutes River. 151

Figure 59. Percival Creek watershed effective shade targets. 155

Figure 60. Shade deficit (%) between current and potential vegetation along Percival Creek and Black Lake Ditch. 156

Figure 61. Predicted and observed DO and pH in the Deschutes River for the calibration time period (August 10-12, 2004). 165

Figure 62. Predicted and observed nitrogen and phosphorus concentrations along the Deschutes River for the calibration time period (August 10-12, 2004). 166

Figure 63. Predicted bottom algae and detritus concentrations along the Deschutes River for the calibration time period (August 10-12, 2004). 167

Figure 64. Predicted and observed DO and pH in the Deschutes River for the stream walk survey (August 11-15, 2003). 168

Figure 65. Predicted nutrient levels in the Deschutes River for the stream walk survey (August 11-15, 2003). Measured nutrient concentrations are from August 2004. 169

Figure 66. Predicted bottom algae and detritus levels in the Deschutes River for the stream walk survey (August 11-15, 2003). 170

Figure 67. Differences in predicted minimum DO and maximum pH for tributaries set to ≤10th percentile concentrations for the DO calibration time period. 171

Figure 68. Predicted daily minimum DO in the Deschutes River for critical conditions under current conditions and various temperature scenarios. 174

Figure 69. Predicted daily maximum pH in the Deschutes River for critical conditions under current conditions and various temperature scenarios. 174

Figure 70. Predicted daily minimum DO in the Deschutes River for critical conditions under current conditions and various DO and nutrient scenarios. 177

Figure 71. Predicted daily maximum pH in the Deschutes River for critical conditions under current conditions and various DO and nutrient scenarios. 178

Figure 72. Decrease in minimum DO and increase in maximum pH compared with natural conditions due to anthropogenic nutrient loads in the tributaries (Scenario DO7) and in all but the Lake Lawrence tributary (Scenario DO8). 179

Figure 73. Discharge, temperature, DO, and pH profiles in Percival Creek and Black Lake Ditch.....182

Figure 74. DO and pH improvements in the Deschutes River (system-wide average DOmin (left) and pHmax (right) associated with various management strategies.....184

Figure 75. Nutrient load allocations (DIN and orthophosphate) under critical conditions for the Deschutes River. 184

Figure 76. Fine sediment load targets for the Deschutes River watershed. RK refers to river kilometer from the upstream Deschutes Falls.....194

Figure 77. Fine sediments (<2mm) 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). 195

Figure 78. Measured and predicted concentrations of macrophytes, algae and nutrients at station CL4 (Capitol Lake outlet) during model calibration. 204

Figure 79. Measured and predicted concentrations of algae and nutrients comparison at station CL4 (Capitol Lake outlet) during model verification. 205

Figure 80. Water quality standards in Budd Inlet and Capitol Lake. 207

Figure 81. Number of days violating the water quality standards by scenario for the July 15 through September 15 simulation period.....209

Figure 82. Maximum (mg/L) decrease in DO for cells violating the water quality standards by scenario for the July 15 through September 15 simulation period based on the direct comparison of results.....210

Figure 83. Predicted dissolved oxygen concentrations for layer 7 of model grid cell (22,45), near the Olympia Peninsula. 212

Figure 84. Maximum (mg/L) decrease in DO for cells violating the water quality standards by scenario for the worst-case 7-day conditions (September 7-14), based on the cumulative frequency distribution of results 215

Figure 85. Number of days violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the July 15 through September 15 simulation period, based on the direct comparison of results.....217

Figure 86. Maximum (mg/L) decrease in DO for cells violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the July 15 through September 15 simulation period, based on the direct comparison of results. 218

Figure 87. Maximum (mg/L) decrease in DO for cells violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the worst-case 7-day conditions (September 7-14). Based on the cumulative frequency distribution of results. 218

List of Tables

Page

Table 1. Study area waterbodies on the 303(d) list established in 2004 by parameter.....28

Table 2. Study area waterbodies on the 303(d) list submitted in 2008 by parameter.....30

Table 3. Additional 303(d) listings not addressed by this report.....33

Table 4. Designated uses for freshwater and marine waterbodies in the study. 36

Table 5. Individual and general permits issued with the study area. 47

Table 6. Manchester Environmental Laboratory quality control results. 72

Table 7. Discharge measurement field replicates. 74

Table 8. Field replicates analyzed by the MEL. 75

Table 9. Time periods used for Deschutes River model calibration and confirmation and related surveys. 76

Table 10. Historical 7Q10 discharge estimates for the two USGS gages (D. Kresch, personal communication). 82

Table 11. 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. 83

Table 12. Fecal coliform bacteria results for the Deschutes River, Capitol Lake, and tributaries. 85

Table 13. Fecal coliform monitoring results for the Percival Creek watershed. 85

Table 14. Fecal coliform monitoring results for tributaries to Budd Inlet.....86

Table 15. Reaeration coefficients, average daily production, and average daily respiration derived from the Hydrolab measurements.....96

Table 16. Capitol Lake benthic fluxes (g/m^2-d) quantified in September 2004. Italicized values are means over the light and dark chambers.....101

Table 17. Sediment budget summary for the Deschutes River from all sources, including a low and high range for some parameters. Source: Raines (2007). 105

Table 18. Sediment budget summary for the Deschutes River from anthropogenic sources. Source: Raines (2007). Low and high estimates are based on assuming only road-associated landslides or all landslides are anthropogenic in origin.....106

Table 19. Target reductions necessary to achieve water quality standards within the Deschutes River, Capitol Lake, and Budd Inlet watersheds during the growing season (May through September. 112

Table 20. Target reductions necessary to achieve water quality standards within the Deschutes River, Capitol Lake, and Budd Inlet watersheds during the non-growing season (October through April).....114

Table 21. Riparian vegetation codes and characteristics used for the Deschutes River watershed. 120

Table 22. Peak summer temperatures at two stations since 2003. 122

Table 23. 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. 147

Table 24. Conditions in tributaries to the Deschutes River, including temperature load allocations for streams that do not meet the water quality standards. 152

Table 25. Rate constants with high variability between applications of the genetic algorithm to Deschutes River DO and pH. 164

Table 26. Lowest 10th percentile summer concentrations by geology type for the 2003-2004 monitoring period.....171

Table 27. Predicted increases in 7-day average of daily minimum DO and daily maximum pH under the current condition base case and various temperature-related scenarios. DO_{min} and pH_{max} refer to the minimum and maximum levels throughout the entire river downstream of the falls, while the mean DO_{min} and mean pH_{max} are the average over the entire river. ΔDO_{min} and ΔpH_{max} are the incremental benefits as the system-wide average for each scenario. 175

Table 28. Predicted increases in 7-day average of daily minimum DO and decreases in maximum pH under the current condition base case and various DO and nutrient scenarios. 180

Table 29. Conditions in tributaries to the Deschutes River, including DO, pH, and nutrient load allocations for streams that do not meet the water quality standards for DO or pH. 183

Table 30. Habitat quality associated with various levels of fine sediments (<0.85 mm). Source: Washington Forest Practices Board (1997), Table F-2. 192

Table 31. Fine sediment load targets by reach for the Deschutes River watershed.....193

Table 32. Wasteload targets for fine sediment loads in the Deschutes River watershed.196

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, pH, or fine sediment. A water cleanup plan, or Total Maximum Daily Load study, was conducted to determine the targets that enable waterbodies 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, 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 meet 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 SU under critical conditions.

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

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

Acknowledgements

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

- The Technical Advisory Group has met for several years and was an invaluable source of information. The group included Sue Davis, Barbara Wood, and Jim Bachmeier (Thurston County Environmental Health); John Konovsky (Squaxin Island Tribe); Andy Haub, Vince McGowan, Liz Hoenig, and Roy Iwai (City of Olympia); Karla Fowler and Ken Butti (LOTT); Don Bache (Port of Olympia); Ann Mills (Thurston Conservation District and South Sound GREEN); Kathy Whalen (Thurston Conservation District); Rich Eltrich and Hal Michael (Department of Fish and Wildlife); Jim Erskine and Nathaniel Jones (General Administration); Steve Morrison (Thurston Regional Planning Council); Dave Ragsdale (EPA); Sue Danver (Black Hills Audubon Society), Julie Rector (City of Lacey), Bob Bilby (Weyerhaeuser Company); Bob Simmons (Washington State University); Kim Zabel (Department of Health); Mike Stephens (Department of Transportation); and Dave Dougherty, Betsy Dickes, Chris Hempleman, Chuck Hoffman, Andrew Kolosseus, Azizullah Mahar, Kim McKee, Derek Rockett, Jason Shira, and Lydia Wagner (Department of Ecology). The Technical Advisory Group provided peer review.
- Mary Raines (Raines Terra) conducted a geomorphologic assessment to quantify sources of fine sediment to the Deschutes River in cooperation with John Konovsky (Squaxin Island Tribe) and funded by a grant from EPA. John Konovsky also provided results of the 2004 gravel survey. Ted Turner (Weyerhaeuser Company) provided landslide inventories for this work and access to conduct sampling.
- Rich Eltrich (Department of Fish and Wildlife) consulted with Ecology on a sampling plan to quantify nutrient processes within the Deschutes Hatchery. Steve Eberl, Lydia Wagner, and Greg Cloud (Ecology) have consulted on the facility and permit requirements.
- Julie Keough (Weyerhaeuser Forest Land Use Manager) granted permission to access Weyerhaeuser's Vail Tree Farm to sample. John Heffner and Bob Bilby (Weyerhaeuser) provided flow, temperature, and water quality information for the upper Deschutes watershed.
- Steve Morrison (Thurston Regional Planning Council), Nathaniel Jones (General Administration), Dave Schilperoort (General Administration), and Perry Lund (Ecology) exchanged information with the parallel Capitol Lake Adaptive Management Plan (CLAMP) committee process.
- 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.
- Doug George and Guy Gelfenbaum (USGS) exchanged information regarding the sediment transport modeling conducted under the Deschutes Estuary Feasibility Study.
- David Kresch (USGS) provided historical and recent low-flow statistics for the Deschutes River gaging stations.

- Watershed Sciences, LLC, conducted the thermal infrared (TIR) survey to characterize water temperature in the mainstem Deschutes River, under a grant from EPA.
- Kathy Hamel (Ecology) provided information on the Capitol Lake milfoil treatment, Jenifer Parsons (Ecology) conducted pre-application biomass monitoring, and Sue Davis (Thurston County) conducted post-application biomass monitoring.
- Mark Hicks, Susan Braley, Helen Bresler, and Melissa Gildersleeve (Ecology) reviewed water quality standards and policy. Steve Bernath (Ecology) provided examples of water quality trading. Todd Bolster reviewed anti-degradation language.
- Kim McKee, Garin Schrieve, Sally Toteff, and Chris Hempleman (Ecology) provided overall project direction.
- Kirk Sinclair, Dustin Bilhimer, Mike LeMoine, and Brian Zalewsky (Ecology) conducted groundwater studies that greatly informed the hydrologic and nutrient processes of the Deschutes River watershed.
- Trevor Swanson and Lawrence Sullivan (Ecology) performed field sampling throughout the Deschutes River watershed and Capitol Lake.
- Teizeen Mohamedali (Ecology) provided current and potential shade levels in the Percival Creek watershed.
- Anise Ahmed and Greg Pelletier (Ecology) and Venkat Kolluru and Shwet Prakash (ERM) developed the Budd Inlet and linked Budd Inlet/Capitol Lake hydrodynamic and water quality models based on the Budd Inlet Scientific 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.
- Peter Ruggiero (USGS) completed the updated bathymetric survey of Capitol Lake in cooperation with Ecology.
- Thurston County provided digital aerial orthophotos.
- The Puget Sound LiDAR Consortium provided LiDAR data via Jerry Franklin of Ecology's SEA Program.
- Pat Paulsen and Larry Kessel (General Administration) clarified Capitol Lake dam outlet operations.

Executive Summary

Introduction

Ecology, in cooperation with the Squaxin Island Tribe, Thurston County, City of Olympia, and others, conducted this Total Maximum Daily Load (TMDL) study, also called a Water Cleanup Plan, because several waterbodies do not meet the 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, 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.

The federal Clean Water Act requires that a TMDL be developed for each waterbody 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 will work 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 waterbody under critical conditions and still meet water quality standards, allocating loads among the various contributors. Point sources, discrete sources covered by a permit, receive wasteload allocations, and nonpoint 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 develop the loading capacity for fecal coliform bacteria, temperature, dissolved oxygen, pH, and fine sediment in portions of the watershed and to recommend loading reductions targets to meet water quality standards. The Water Quality Improvement Report will develop load and wasteload allocations for Capitol Lake and Budd Inlet and may re-evaluate nutrient reductions for the Deschutes River.

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, entirely within Water Resource Inventory Area 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.

The Lacey, Olympia, Tumwater, and Thurston County (LOTT) Alliance provides secondary wastewater treatment before discharging to Budd Inlet, as well as denitrification (nitrogen

removal) from April through October. Other domestic wastewater treatment plant discharges include Boston Harbor, Seashore Villa, and Tamoshan, and all operate under individual National Pollutant Discharge Elimination System (NPDES) permits managed by Ecology. In addition, Ecology regulates Washington State Department of Transportation (WSDOT) stormwater through a NPDES Phase 1 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 under 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, recreational users, road building, and natural phenomena contribute to water quality impairments.

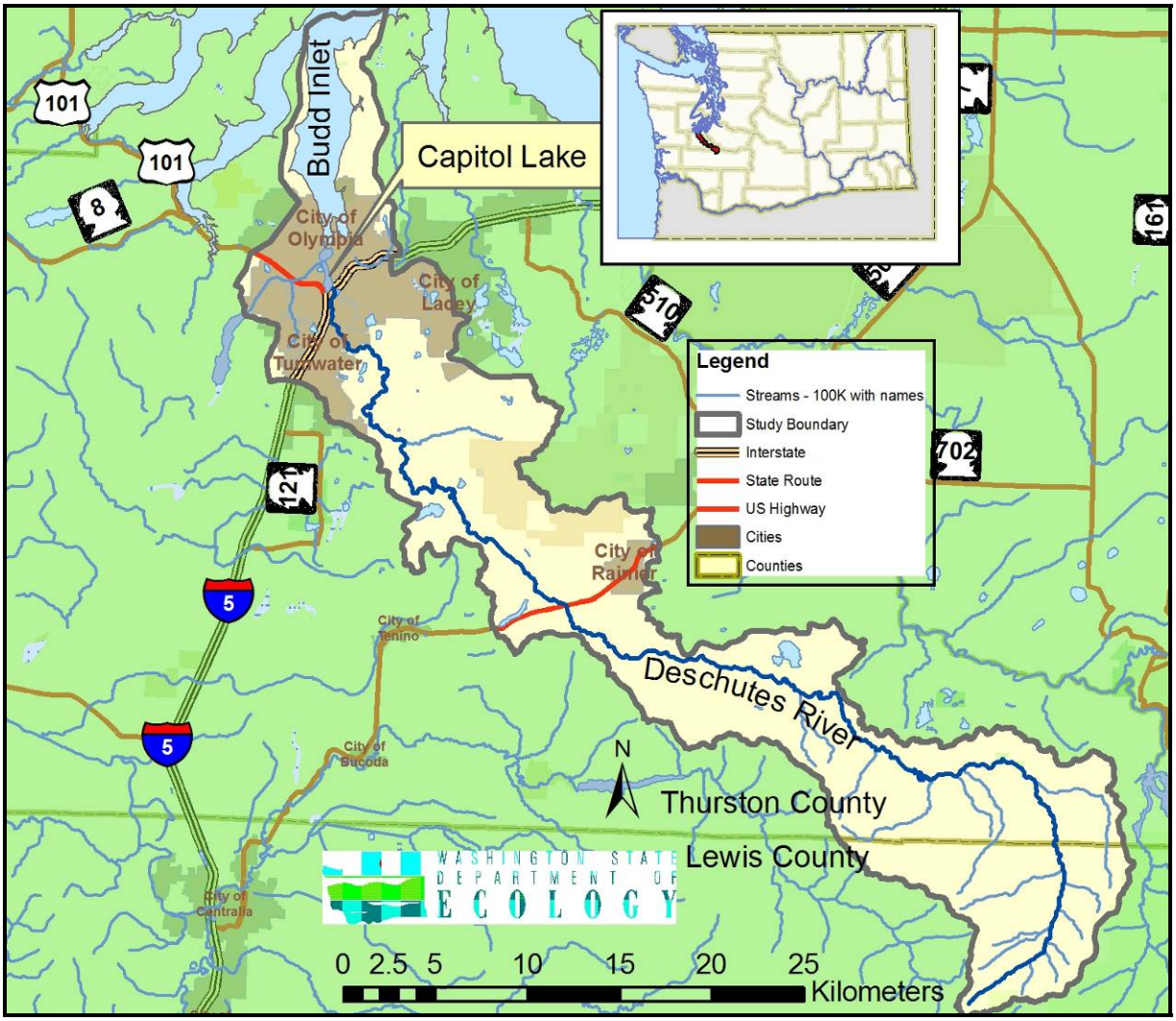


Figure ES-1. Deschutes River, Capitol Lake, and Budd Inlet TMDL study area.

Water Quality Standards

Water quality standards define the goals for a waterbody by designating beneficial uses, setting criteria to protect those uses, and establishing provisions to protect waterbodies 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 uses. An independent, parallel process convened by the Washington State Department of General Administration (GA) is evaluating 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 TMDL 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 in 2004 for fecal coliform bacteria. 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 established for facilities covered by the industrial and construction stormwater or sand and gravel general permits or dairy operations 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 Offut 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 and pH would not meet the numeric criteria in portions of the Deschutes River under critical conditions, but the combined effect of human activities on tributary nutrient levels would not change DO or pH by more than 0.2 mg/L or 0.2 SU in areas

where the numeric criteria are not met. Therefore, no nutrient load reductions were recommended, since current loads are within the loading capacity for the river to meet water quality standards. However, nutrient loads cannot increase and reductions may be needed in the Deschutes system to meet standards in Capitol Lake and Budd Inlet.

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.

A future 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.

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, either with the lake in place or under a potential future Estuary alternative. Under the Lake alternative, more of Budd Inlet would not meet standards for DO under critical conditions than under the Estuary alternative. Load reductions are needed under either alternative and will be developed in the Water Quality Improvement Report.

Next Steps

Ecology will convene an advisory committee in early 2009 and 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 allocations into a Water Quality Improvement Report. The Water Quality Improvement Report will be submitted to the U.S. Environmental Protection Agency for approval. Once approval has been received, Ecology again will work with the advisory committee 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 (CWA) established a process to identify and clean up polluted waters. Under the CWA, 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 waterbodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list. To develop the list, Ecology compiles its own water quality data along with data 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. This list divides waterbodies into one of five categories:

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

Category 2 – Waters of concern.

Category 3 – Waters with no data available.

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

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

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

TMDL Process Overview

The Clean Water Act requires that a Total Maximum Daily Load (TMDL), also referred to as a water cleanup plan, be developed for each of the waterbodies 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). First, existing data are reviewed and data gaps are identified. Second, a Quality Assurance Project Plan is prepared and additional field data collection is performed to fill data gaps and collect additional environmental

information. Third, data are evaluated to establish water quality relationships and computer modeling is performed to identify pollutant reduction needs. The fourth step is a stakeholder process to explore options and assignment of wasteload and load allocations. In addition, an implementation strategy is developed (who needs to do what) that identifies 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 for approval. The fifth and final step is to develop a Water Quality Implementation Plan (when, where, and how implementation will occur), which acknowledges detailed information for necessary actions and includes a schedule for when implementation actions will take place.

This report documents the results from the first three steps.

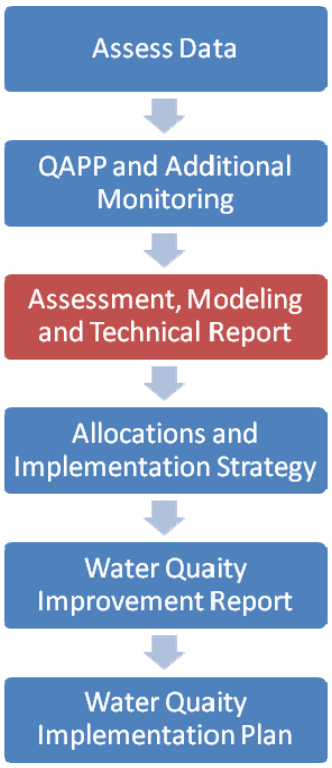


Figure 1. Five steps in TMDL development.

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

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 this 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, dissolved oxygen, 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), is the state agency that manages the facilities of the Capitol Campus, and operates the dam. A concurrent process is evaluating the scientific, technical, economic, and cultural significance of maintaining the lake as is or reverting 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: Capitol Lake as it now exists and 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.

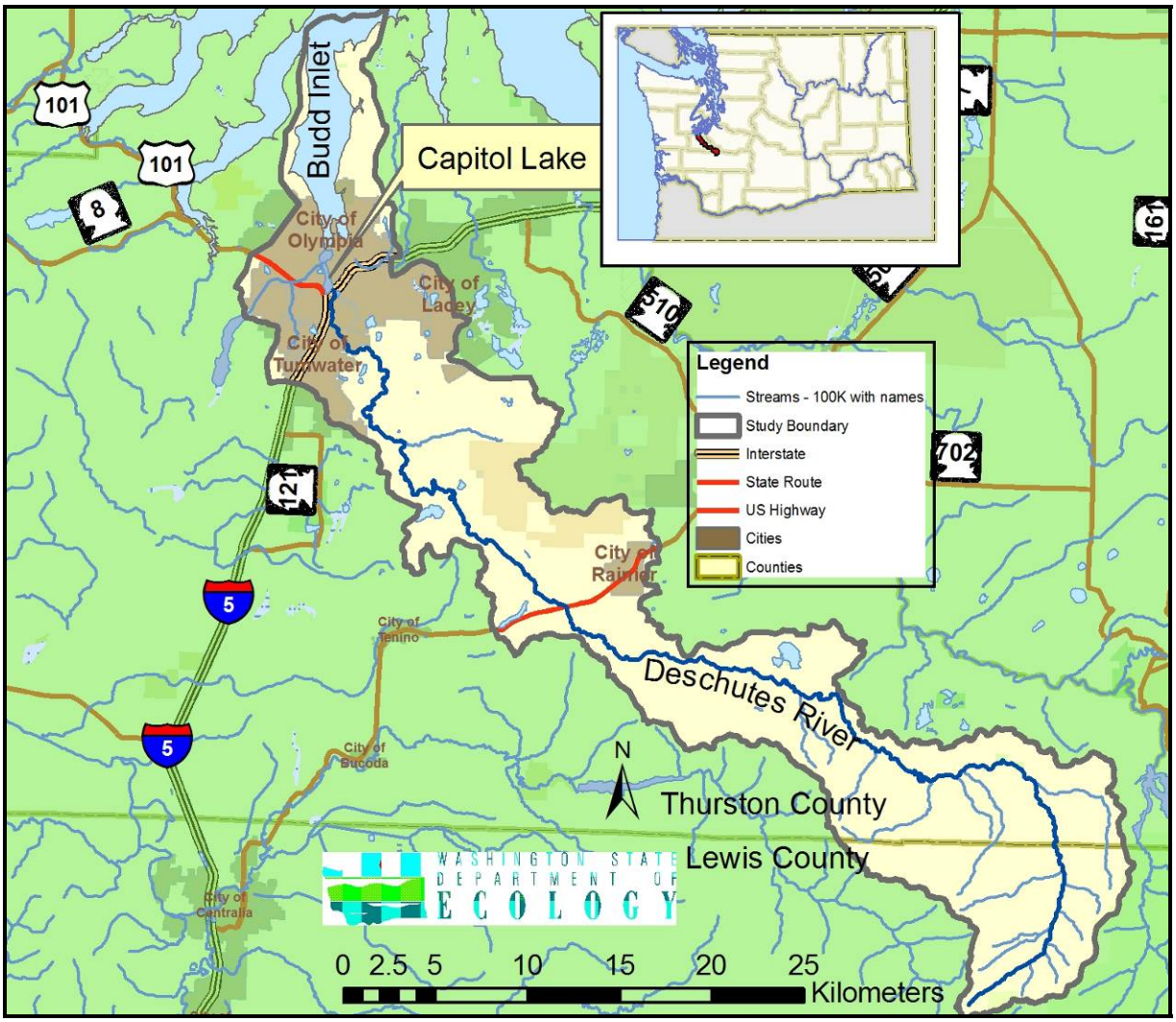


Figure 2. Deschutes River, Capitol Lake, and Budd Inlet TMDL study area.

Pollutants Addressed by this TMDL

This TMDL addresses temperature, dissolved oxygen, pH, and fine sediment in the mainstem of the Deschutes River; fecal coliform bacteria, temperature, dissolved oxygen, 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 waterbodies are compared with the water quality standards.

Impaired Beneficial Uses and Waterbodies 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 waterbodies 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 waterbodies on the 303(d) list established in 2004 by parameter.

Marine Waterbodies	Parameter	Listing ID	Grid cell	WASWIS
Budd Inlet (Outer)	Dissolved Oxygen	7583		
Budd Inlet (Outer)	Dissolved Oxygen	7586		
Budd Inlet (Inner)	Dissolved Oxygen	5862		
Budd Inlet (Inner)	Dissolved Oxygen	5864		
Budd Inlet (Inner)	Dissolved Oxygen	5852		
Budd Inlet (Inner)	Dissolved Oxygen	40581[1]		
Budd Inlet (Inner)	Dissolved Oxygen	5863		
Budd Inlet (Inner)	Dissolved Oxygen	5853		
Budd Inlet (Outer)	Dissolved Oxygen	7587	47122A9H1	390KRD
Budd Inlet (Outer)	Dissolved Oxygen	7585	47122A9I1	
Budd Inlet (Outer)	Dissolved Oxygen	7582	47122A9IO	390KRD
Budd Inlet (Outer)	Dissolved Oxygen	10188	47122A9J1	390KRD
Budd Inlet (Outer)	Dissolved Oxygen	7584	47122A8J9	390KRD
Budd Inlet (Outer)	Dissolved Oxygen	3769	47122B9E2	390KRD
Fresh Waterbodies	**Parameter**	**Listing ID**	**Township**	**Range** / **Section**
Capitol Lake (North Arm)	Total Phosphorus	22718		
Capitol Lake (North Arm)	Fecal Coliform	40588		
Indian Creek	Fecal Coliform	3758	18N	01W / 18

[1] Same location as listing ID 5852.

Indian/Moxlie Creek	Fecal Coliform	3759	18N	02W	41
Black River Ditch	Temperature	42337	18N	02W	29
Deschutes River	Fecal Coliform	16722[2]	18N	02W	60
Deschutes River	Temperature	6576	18N	02W	60
Deschutes River	Temperature	7590	17N	01W	33
Deschutes River	Temperature	7591[3]	16N	01E	18
Reichel Creek	Fecal Coliform	3763	16N	01E	27
Deschutes River	Temperature	7592	16N	02E	30
Deschutes River	Fine Sediment	6232	16N	02E	30
Deschutes River	Temperature	7593	16N	02E	34
Deschutes River	Temperature	7588	15N	03E	07
Ayer (Elwanger) Creek	Dissolved Oxygen	5851	17N	01E	07
Ayer (Elwanger) Creek	pH	5850	17N	01E	07
Ayer (Elwanger) Creek	Fecal Coliform	5849	17N	01E	07
Moxlie Creek	Fecal Coliform	3761	18N	02W	27
Huckleberry Creek	Temperature	3757	15N	04E	17
Percival Cove Lake	Total Phosphorus	22725[4]	18N	02W	22

[2] Was Category 5 in 303(d) list in 2004 but is Category 1 in the 303(d) list submitted in 2008.
[3] In the 303(d) list submitted in 2008, the waterbody name has been updated to an unnamed tributary to the Deschutes River.
[4] Listing not included in the 303(d) list submitted in 2008, but part of the overall total phosphorus listing for Capitol Lake (listing ID 22718).

Table 2. Study area waterbodies on the 303(d) list submitted in 2008 by parameter.

Fresh Waterbodies	Parameter	Listing ID	Township	Range	Section
Deschutes River	Temperature	48726	15N	03E	10
Deschutes River	Temperature	48724	16N	02E	29
Deschutes River	Dissolved Oxygen	47756	16N	02E	30
Deschutes River	Fecal Coliform	46210	16N	02E	30
Deschutes River	Temperature	7595	16N	01E	26
Reichel Creek	Dissolved Oxygen	47714	16N	01E	26
Reichel Creek	Fecal Coliform	45566	16N	01E	26
Reichel Creek	Temperature	48666	16N	01E	26
Deschutes River	Temperature	48721	16N	01E	22
Deschutes River	Temperature	48720	16N	01E	20
Deschutes River	Fecal Coliform	9881	16N	01E	18
Deschutes River	Temperature	9439	16N	01E	18
Unnamed tributary to Deschutes River	Temperature	7591	16N	01E	18
Deschutes River	Temperature	48718	16N	01W	40
Deschutes River	Temperature	48717	16N	01W	02
Deschutes River	Temperature	48715	17N	01W	28
Tempo Lake Outlet	Temperature	48696	17N	01W	28
Deschutes River	Temperature	48714	17N	01W	29
Deschutes River	Fecal Coliform	46500	17N	01W	19
Deschutes River	Dissolved Oxygen	47754	17N	01W	19
Deschutes River	Temperature	48713	17N	01W	19
Spurgeon Creek	Fecal Coliform	46061	17N	01W	19
Deschutes River	Temperature	48712	17N	01W	13
Deschutes River	Fecal Coliform	46499	17N	01W	07
Deschutes River	Dissolved Oxygen	47753	17N	01W	07
Deschutes River	Temperature	48711	17N	01W	07
Deschutes River	Temperature	48710	17N	02W	07
Chambers Creek	Fecal Coliform	45560	18N	02W	36
Deschutes River	Dissolved Oxygen	10894	18N	02W	60
Percival Creek	Temperature	48727	18N	02W	55
Percival Creek	Dissolved Oxygen	48085	18N	02W	55
Percival Creek	Fecal Coliform	46103	18N	02W	55
Percival Creek	Temperature	42321	18N	02W	21
Black Lake Ditch	Dissolved Oxygen	47761	18N	02W	21
Black Lake Ditch	Temperature	48733	18N	02W	21
Percival Creek	Dissolved Oxygen	48086	18N	02W	21
Percival Creek	Fecal Coliform	46108	18N	02W	21
Percival Creek	Temperature	48249	18N	02W	28
Percival Creek	Temperature	48729	18N	02W	34
Black Lake Ditch	Temperature	48734	18N	02W	29

Black Lake Ditch	Dissolved Oxygen	47762	18N	02W	32
Black Lake Ditch	Temperature	48735	18N	02W	32
Black Lake Ditch	pH	50990	18N	02W	32
Indian Creek	Fecal Coliform	45213	18N	02W	24
Indian Creek	Fecal Coliform	46410	18N	02W	52
Moxlie Creek	Fecal Coliform	45252	18N	02W	41
Moxlie Creek	Fecal Coliform	46432	18N	02W	56
Mission Creek	Fecal Coliform	46102	18N	02W	53
Mission Creek	Fecal Coliform	45212	18N	02W	64
Ellis Creek	Fecal Coliform	45480	18N	02W	53
Adams Creek	Fecal Coliform	45695	19N	02W	26
Adams Creek	Fecal Coliform	45462	19N	02W	25
Adams Creek	pH	50965	19N	02W	25
Butler Creek, SW Fork	Fecal Coliform	45342	18N	02W	66
Butler Creek	Fecal Coliform	45471	18N	02W	66
Schneider Creek	Fecal Coliform	45559	18N	02W	59

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.

Budd Inlet toxics listings are associated with the Cascade Pole site and are addressed by the remediation efforts of the Department of Ecology, Toxics Cleanup Program. 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.

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

Waterbody	Parameter	Medium	Listing ID	Township	Range	Section
Budd Inlet (Inner)	Benzo(a)anthracene	Tissue	8688			
Budd Inlet (Inner)	Benzo(b)fluorine	Tissue	8685			
Budd Inlet (Inner)	Benzo(k)fluorine	Tissue	8686			
Budd Inlet (Inner)	Chrysene	Tissue	8689			
Budd Inlet (Inner)	Total PCBs	Tissue	8690			
Budd Inlet (Outer)	Fecal Coliform	Water	45317	47122B8A9		
Budd Inlet (Outer)	Fecal Coliform	Water	45829	47122A8J9		
Deschutes River	Instream Flow*	Habitat	6194	16N	01E	22
Deschutes River	Instream Flow*	Habitat	6195	18N	02W	35
Deschutes River	Large woody debris*	Habitat	6225	15N	03E	08
Deschutes River	Large woody debris*	Habitat	6224	15N	03E	07
Lawrence Lake	Total Phosphorus	Water	6348	16N	02E	29
Ward Lake	Total PCBs	Tissue	7022			

* Category 4C listings addressed through processes other than TMDLs

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 (CWA) 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, (SIT) 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, dissolved oxygen, 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 waterbodies in 1998 was reviewed to identify waterbodies in Ecology's Southwest Region that were not meeting 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.

Water Quality Standards

Water Quality Standards define the goals for a waterbody 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 waterbody (for example, aquatic life or recreation),
2. water quality criteria to protect designated uses (numeric pollutant concentrations and narrative requirements), and
3. antidegradation policy to maintain and protect existing uses and high quality waters.

Designated Uses

Water quality standards are established by the State of Washington to protect the designated uses within waterbodies. Table 602, established in WAC 173-201A-602, lists use designations for fresh waterbodies, while Table 612, established in WAC 173-201A-612, lists use designations for marine waterbodies. 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 waterbodies not specifically named in Table 602 are assigned uses in WAC-173-201A-600(1). Table 4 summarizes designated uses for the waterbodies included in this study.

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

Fresh Waterbodies	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 Offut Lake		X		X	X	X
Deschutes River and tributaries, upstream from Offut 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 Offut 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 Waterbodies	**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

Under the water quality standards, the current configuration of Capitol Lake is considered Lake Class. Lakes are distinguished from riverine systems in WAC 173-201-020 as waterbodies, including reservoirs, with a mean detention time of greater than fifteen days. 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 United States 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 CH2MHill (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 defined as 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 waterbody to a tributary to Budd Inlet, shifting the designated uses to those associated with other waters not specifically listed.

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, like oxygen, or physical conditions, like water temperature. A typical numeric criterion for aquatic life protection usually contains a concentration (for example, 5 mg/L) and an averaging period. 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

Fresh waters

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 of 1998 or 2004, 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 waterbody 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 waterbody. 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 the United States Environmental Protection Agency (EPA) in February 2008. The Deschutes River and its tributaries from the mouth to and including the tributary from Offut 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 Offut 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 online at Ecology's website http://www.ecy.wa.gov/programs/wq/swqs.

Fresh waters

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

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

In the 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 waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a waterbody is naturally warmer than the above-described criteria, 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 the department determines the temperature criteria established for a waterbody 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 ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global 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 stream banks, 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 not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global 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 in a waterbody.

Freshwaters

In the 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 Offut 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 Offut 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 "Salmon and Trout Spawning, Core Rearing, and Migration" 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 and Noncore Rearing" 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 waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully

protective DO criteria. When a waterbody 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 waterbody, 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 waterbodies, 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 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 criteria described above are used to ensure that where a waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a waterbody 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 Offut 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 Offut 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 and 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 0.2 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 Aquatic Life 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) and Thurston County (1995) 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 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 mi (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 Highway 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). Historically the inlet was used for shellfish harvesting, but the Washington Department of Health (DOH) has closed the beds due to contamination and the discharge of treated wastewater.

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 ft (7.6 m) to 50 ft (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 U.S. Geological Survey (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 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, 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. Highway 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).

The Lacey, Olympia, Tumwater, and Thurston County (LOTT) Alliance provides secondary wastewater treatment before discharging to Budd Inlet, as well as denitrification between the months of April and October. A portion of Olympia is served by combined sewer systems, usually routed through the treatment plant. When stormwater discharges exceed the hydraulic capacity of the plant, the combined stormwater and wastewater is discharged through the Fiddlehead outfall. A discharge from the Fiddlehead Outfall has occurred once in the last 16 years (Dougherty, personal communication, 2007). 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 in the downtown Olympia area from manholes or pump stations have occurred during major storm events (Dougherty, personal communication, 2007). Separate storm sewers serve the remaining developed areas. Other domestic wastewater treatment plant discharges include Boston Harbor, Seashore Villa, and Tamoshan.

Regulatory Activities

The United States Environmental Protection Agency (EPA) is responsible for implementing the federal Clean Water Act (CWA). The EPA has designated the Washington State Department of Ecology (Ecology) to administer the CWA, including writing permits, developing water quality standards, and conducting water cleanup studies. The 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. Portions of this watershed are within the Squaxin Island Tribe's treaty "usual and accustomed" fishing area and within the Tribe's aboriginal hunting grounds.

Load allocations are included in this TMDL for non-federal forest lands in accordance with Section M-2 of the Forests and Fish Report (USFWS et al., 1999). Discussion about expectations for TMDL implementation on non-federal forest lands will be discussed in the development of the 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 (until June 30, 2009). This was believed to provide adequate time to determine if the rules and their associated programs are effective in protecting water quality. Ecology is now in the process of assessing if 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 (CWA). The results of the review will be used by Ecology and the United States Environmental Protection Agency (EPA) to determine if Clean Water Act assurances should be continued beyond June 30, 2009.

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 individual permits for marine net pens and is in the process of developing a general permit for freshwater net pens. General permits apply to a group of dischargers as a whole and implement both the federal CWA and state Water Pollution Control Act. The Washington State Department of Agriculture (WSDA) permits dairies under a Memorandum of Understanding with Ecology. Table 5 summarizes individual and general permit status for facilities within the study area.

Table 5. Individual and general permits issued with the study area.

Waterbody	Facility Name	Permit No.	Parameter Limits	Reporting Parameters
Individual Wastewater Permits				
Budd Inlet	LOTT	WA0037061	BOD5 and TIN, with seasonal variation, FC, pH, TSS	Q, BOD5, TSS, pH, FC, Temp, NH3, NO23N, TKN
Budd Inlet	Boston Harbor	WA0040291	BOD5, TSS, FC, pH	Q, BOD5, TSS, FC, NH3, 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
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
(county wide)	Thurston County	WAR04-5025	(not required)	Annual report with Stormwater Management Program

Waterbody	Facility Name	Permit No.	Parameter Limits	Reporting Parameters
Capitol Lake	General Administration[5]			
WSDOT Municipal Stormwater Permit				
(multiple)	WSDOT**	(draft only)	Not applicable	TSS, FC, TP, OP, temperature and others
General Industrial Stormwater				
Deschutes River	O'Neill and Sons	SO3001404		
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[6]				
(study area)	(varies)	(varies)		
General Sand and Gravel Operations				
Deschutes River	Waldrick Road Pit	WAG501231		
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		
Dairies				
Deschutes River	Mahan Ranch LLC	Dairy license no. 2079		
Deschutes River	Plowman Dairy	Dairy license no. 5949		
Other facilities				
Deschutes River	WDFW net pens and rearing	*		

* The WDFW has applied for an individual marine net pen but was not granted a permit pending the outcome of the present study.
** The current WSDOT permit covers discharges within existing Phase I municipal stormwater areas, but there are no Phase 1 coverage areas within this TMDL study . However, the new permit would cover

[5] General Administration is a secondary permittee under the Phase II permit for the Capitol Campus
[6] Facilities covered under the Construction Stormwater General Permit change monthly, but projects often include residential and commercial development.

WSDOT discharges in Phase I and Phase II areas and applicable TMDL areas statewide, including within the area covered by this study. The permit is scheduled to be issued in fall/winter 2008.

Four domestic wastewater facilities discharge to Budd Inlet. The LOTT wastewater treatment plant facility includes activated sludge and seasonal advanced treatment. 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. A small facility at Beverly Beach previously discharged to Budd Inlet, but the wastewater has since been routed to an upgraded facility at Tamoshan.

Ecology issued the 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). The permit stipulates that permittees have in place, the 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, and;
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, and
2. Evaluation and assessment of program compliance.

Stormwater permittees must implement actions necessary to achieve pollutant reductions in TMDLs that are approved by the 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) is required by state and federal regulations to have a NPDES stormwater permit. This general permit will cover stormwater runoff from state highways, rest areas, weigh stations, scenic view points, park and ride lots, ferry terminals, and maintenance facilities in Phase I, Phase II, and TMDL areas. Currently the WSDOT is operating under the 1995 Phase I Municipal Stormwater General Permit which will expire upon issuance of the new stormwater permit. The target date is late 2008. When issued, the WSDOT will be required to implement their Stormwater Management Program and their Highway Runoff Manual consistent with federal and state requirements.

The Industrial Stormwater General Permit is currently being redeveloped. Ecology expects to re-issue the updated general permit in late spring of 2009. To cover the time until the updated permit is issued, Ecology will re-issue the expired general permit, without changes, with an expiration of April 30, 2009. Under permit section S3, Discharge Limitations, subsection E, discharges to 303(d)-listed waters must not cause a violation of the water quality standards.

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 Construction Stormwater General Permit was issued in November 2005 with an effective date of December 16, 2005. Facilities covered under the permit must not cause or contribute to a violation of surface water quality standards. Those that discharge to waterbodies listed as impaired for high pH must conduct pH sampling under section S8 of the permit, and those that discharge to waterbodies listed as impaired for turbidity, fine sediment, or phosphorus must conduct water quality sampling for turbidity under section S8 of the permit. Further, any discharges to waterbodies subject to TMDLs for those parameters must comply with any specific wasteload allocations. Where an applicable 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 this TMDL study 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. Several facilities discharging to the Deschutes River or Budd Inlet currently operate under the Construction Stormwater General Permit.

The current Sand and Gravel General Permit was issued in 2005, with the latest modifications June 17, 2006. 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. Under section S3(A) subsections 3, 4, and 5, existing facilities that discharge to an impaired waterbody on the 303(d) list shall not increase the loading of the listed pollutant (turbidity, fine sediment, pH, or temperature). 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 waterbody without a completed TMDL shall not discharge the listed pollutant at a concentration or volume that will cause or contribute to a violation of the applicable water quality standard. TMDLs completed after the issuance date of the permit apply to existing permittees only if they are imposed through an administrative order issued by Ecology or through a modification of permit coverage. Five facilities operating under the Sand and Gravel General Permit discharge to waterbodies in the Deschutes River watershed. Two facilities discharge to Black Lake Ditch near the outlet from Black Lake. Three other facilities discharge to the Deschutes River, one near Waldrick Road, one near Rixie Road, and one near the Olympia Regional Airport.

There are no permitted agricultural operations within the Deschutes River watershed. Two dairies continue within the watershed, but currently are not required to obtain a Confined Area

Feeding Operation permit. The Washington State Department of Agriculture (WSDA) has regulatory authority for dairies as part of its Livestock Nutrient Management Program. The WSDA conducts routine inspections, receives and responds to complaints, and is responsible for regulatory enforcement. 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. Any complaints received by Ecology are referred to the Southwest Regional Office nonpoint source inspectors for follow up. Regulatory authority is through general nonpoint source pollution responsibilities.

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 a general permit. The WDFW has proposed a future Deschutes Watershed Center that includes both rearing facilities and public education opportunities.

Fisheries

The Deschutes River and Budd Inlet watershed support important shellfish and anadromous fish populations. Five salmonid species use the study area for spawning and rearing: steelhead trout, searun 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 searun 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 important to recreational and commercial harvesters are 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 shellfish harvest (DOH, 2008).

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, sand and gravel operations, and dairies. 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, failing or improperly maintained septic 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 stream bank 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 width and depth 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 either natural or 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 waterbodies. 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, Dissolved Oxygen, Nutrients, and pH

Fecal Coliform Bacteria

Potential sources of fecal coliform bacteria and nutrients include humans, domestic animals, agricultural activities, and wildlife. Low DO and high pH levels may result from increased sunlight or nutrient loads that stimulate algae growth, referred to as biological productivity, above natural levels. The diel cycle of algae 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. Enhanced algae growth increases the daily variation resulting in lower DO and higher pH levels than would have resulted under natural conditions. Thus, productivity generally produces the highest pH in the late afternoon and the lowest DO levels in the early morning hours. Productivity may be limited by a specific nutrient, generally phosphorus in streams and nitrogen in marine waterbodies, by sunlight to fuel photosynthesis, or by retention time in a waterbody.

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.

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.

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. Domestic animals such as horses, cows, and sheep may contribute via overland flow during storms, unmanaged animal access, or from improper manure storage and disposal. Domestic animals are considered nonpoint sources unless the effluent reaches stormwater infrastructure covered by a general permit.

Birds and other wildlife may contribute bacteria and nutrients directly to waterbodies 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.

pH

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.

Dissolved Oxygen

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 productivity, as occurs in the freshwater systems described above. A small portion of the area served by the LOTT wastewater treatment plant also directs stormwater to the facility. Hydraulic relief points in the system can discharge mixed stormwater and wastewater when the capacity of the system is exceeded, resulting in combined sewer overflows (CSOs). Stormwater can also decrease treatment efficiency at the facility. 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 long residence times, 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.

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 natural sources, such as landslides and bank erosion; or anthropogenic sources from land disturbances, such as, road building, timber harvest, agricultural activities, residential development, and increases in stormwater runoff resulting in down cutting.

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 down cutting. 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 down cut 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 stream banks 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.

Goals and Objectives

Project Goals

The project goals were to determine the loading capacity for fecal coliform bacteria, temperature, dissolved oxygen, 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 and Percival Creek.

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 determine load allocations 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 dissolved oxygen, nutrients, pH, and parameters related to productivity in Capitol Lake.
- Model productivity in Capitol Lake. Load reduction targets for all inflows to the lake will be evaluated in a future 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. While the original QA Project Plan (Roberts et al., 2004) called for establishing point source wasteload allocations and nonpoint source load allocations for DO and related parameters, this will be deferred to a future report.

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, the 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 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.

Figure 3. Temperature monitoring stations (solid dots) within the Deschutes River and Percival Creek watersheds.

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).

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.

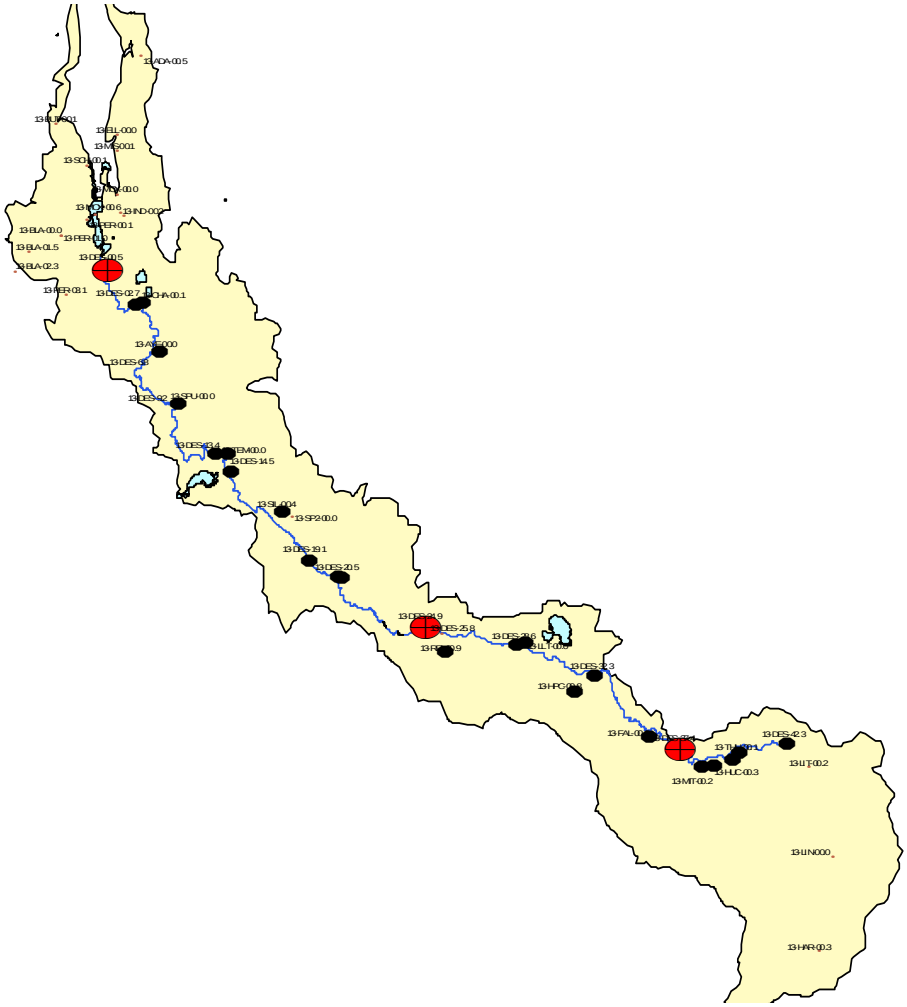


Figure 4. Continuous discharge monitoring (red cross hatch) and synoptic flow (black dots) stations within the Deschutes River and Percival Creek watersheds.

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.

Fecal Coliform Bacteria, Dissolved Oxygen, Nutrients, and pH

To characterize bacteria, nutrient levels, and productivity within the Deschutes River, monthly or twice-monthly grab samples were collected from nine locations along the mainstem and eight tributaries from July 2003 through December 2004. Similarly, monthly or twice-monthly samples were collected from four locations within the Percival Creek watershed and at two locations within Capitol Lake. Bacteria levels were characterized in seven tributaries to Budd Inlet. Figure 5 shows the station locations. Total (persulfate) nitrogen, nitrate plus nitrite, ammonium, total phosphorus, and 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, dissolved oxygen, and pH were recorded with a Hydrolab ® multi-probe instrument.

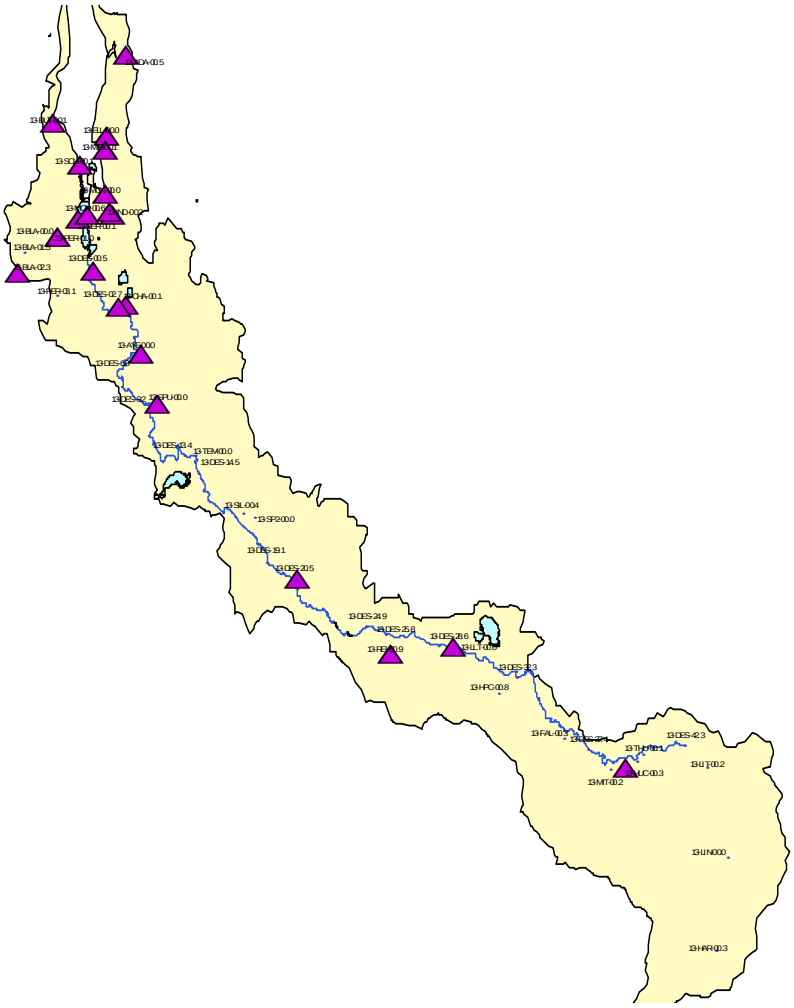


Figure 5. Bacteria monitoring stations (filled triangles) within the Deschutes River and Percival Creek watersheds.

Continuous DO, pH, temperature, and conductivity levels were recorded at five locations along the mainstem of the Deschutes River during the period 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.

In addition, water column profiles were recorded from eight locations within Capitol Lake in 2003 and a subset of four in 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 if the Washington Department of General Administration (GA) did not, but no monitor was installed during the project.

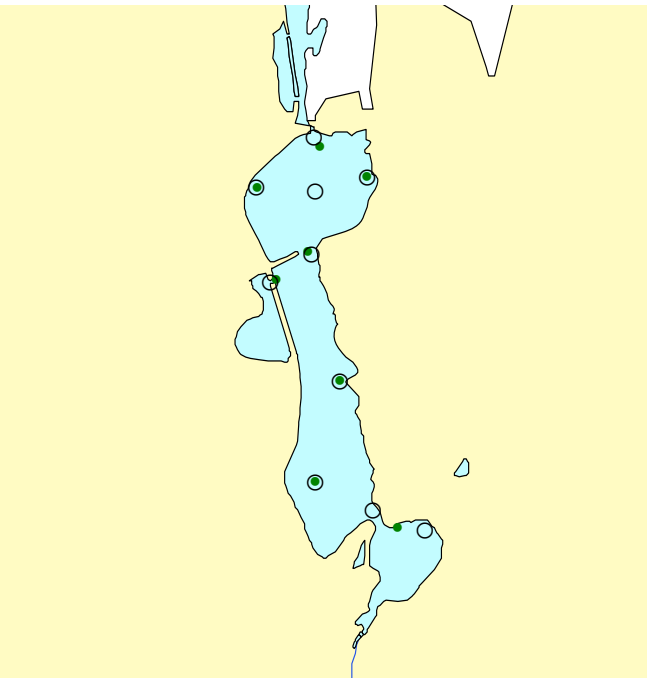


Figure 6. Capitol Lake monitoring stations for 2003 (small dots) and 2004 (open circles). Benthic flux stations are indicated with a + symbol.

The QA Project Plan included a bathymetric survey of Capitol Lake to provide the current lake volume. Ecology contracted with the 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.

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. As part of the surveys required by the GA under Ecology's Aquatic Weeds Management Fund grant agreement to verify no adverse effect to non-target plants, a second survey was conducted by Thurston County in 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 storm, in winter 2004. However, due to unusually dry conditions during the winter of 2004-2005, only one storm event and one dry-weather monitoring round was 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.

Thurston County will conduct follow-up source identification surveys, as outlined in the QA Project Plan, but these were deferred until after the publication of the present study.

Fine Sediment

As described in the QA Project Plan, the Squaxin Island Tribe (SIT) received a grant from the EPA to conduct field investigations and develop a sediment source inventory. Field work was conducted by the SIT, as described in Konovsky (2004). RainesTerra, LLC summarized historical sediment yields for the periods 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 Stream Hydrology Unit at fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp?region=1.

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 bacteria 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 biological 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 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 applications to Budd Inlet 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 Raines Terra (Raines, 2007) were used to develop fine sediment load and wasteload 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 the period 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 an empirical road sediment model (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.

Study Quality Assurance Evaluation

All environmental studies conducted by the Department of 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 dissolved oxygen (DO), pH, conductivity, and temperature were recorded using Hydrolabs.

All field meters were calibrated according to the manufacturer's 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 TFW stream temperature survey protocols (Schuett-Hames et al., 1999), which includes both pre-calibration and post-checking against an 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 0.2ºC or i-buttons that differed by more than 0.4ºC from the National Institute of Standards and Technology (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 Environmental Information Management (EIM).

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 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 the Manchester Environmental Laboratory (MEL) using standard protocols (MEL, 2005). All samples were received and processed by the 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 6 summarizes laboratory quality control samples, including blanks, laboratory spiked samples, standards, and laboratory replicates. Measurement quality objectives 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.

The MEL split 386 samples received and analyzed 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 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.

Table 6. 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
NH3	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
NO2NO3	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				

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
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			

Notes:
(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 NH3 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 the glossary (Appendix A).

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 7 summarizes the results. The within-team mean relative standard deviation (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 7. 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 8. Field replicates met the project target RSD for all parameters except 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 8. Field replicates analyzed by the MEL.

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
BODULT	3			
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
NH3	44	1.7%	10%	0.0 - 12.9
NO2NO3	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%[7]	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%[8]	50%	
Total	**493**			

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).

[7] Only one pair was beyond five times the detection limit (RSD = 0.0%).
[8] 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 headwater, 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 seven-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 9. 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 9. 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	7/21-27/04	Hottest 7-day average temperature in 2004	31.1	78.9
	VAL1	7/27/03-8/2/03	Hottest 7-day average temperature in 2003	22.6	72.0
	VAL2	8/20/03	Thermal infrared survey	24.0	65.0
	VAL3	8/5-11/03	Cool, non-storm conditions	23.9	69.4
DO and pH	DOCAL	8/10-12/04	Productivity surveys in Deschutes River	27.7	74.3
	Stream walk	8/11-15/03	Stream walk	28.4	476.4
Hydrology	Synoptic survey	8/5-6/03	Detailed flow distribution	22.5	70.0
	Tracer study	8/2-4/04	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 Capital 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 study (Aura Nova et al., 1999). Data collected from June-September 1997 was used for calibration, and data collected from January-September 1997 was used for confirmation. 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 between May-September 2004. Confirmation of the model for the Capitol Lake region was based on data collected by Miller Brewing Co. (CH2MHill, 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 the period of 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 reproduce as closely as possible the previous Aurora Nova Consultants et al. (1998) calibration by making minimum changes to rate constants but based on the code changes that necessitated the recalibration. Rate constants and sediment fluxes were compared with and kept within the literature values during the re-evaluation process.

First, the original control file without any changes was run using the corrected model provided by ERM. A relative error of mean (REME) of observed versus predicted value at each station was estimated for both time-series plots as well as vertical profiles. The REME is defined as follows:

$$REME = \frac{1}{N}\sum\frac{(X_M - X_F)}{X_F}$$

Where: X_M = model predicted value
X_F = field observed value
N = number of paired model and field data

The REMEs for all plots for each model run were then aggregated to an average REME value. Changes in rate constants and sediment fluxes were then made and an average REME value estimated for each run. This was compared with the REME of the original model run. A set of five model runs with lowest REME were further evaluated visually to ensure no abnormalities were present, for example if predicted DO was much below or above observed data. Additional model runs were made by incorporating changes in variables within the short list in different combinations.

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, 2004 to September 30, 2004. This period was adopted based on the availability of boundary condition and calibration data. The REME was 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.

Results and Discussion

Meteorology and Hydrology

During the data collection period, 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 conditions were wetter than average and summer 2003 was drier.

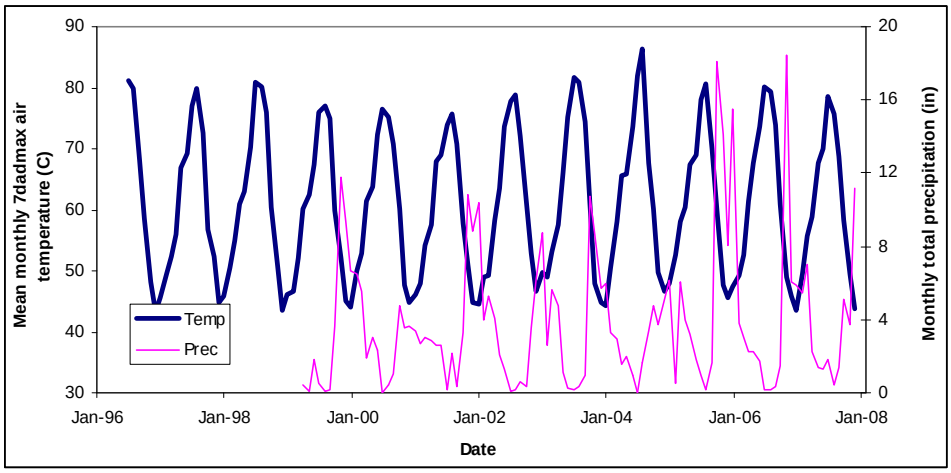


Figure 8. Mean monthly 7-day average of daily maximum air temperature and monthly precipitation at the Olympia Airport.

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 RM 5.6, 12.1, and 37.4 while warmest time series are for RM 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.

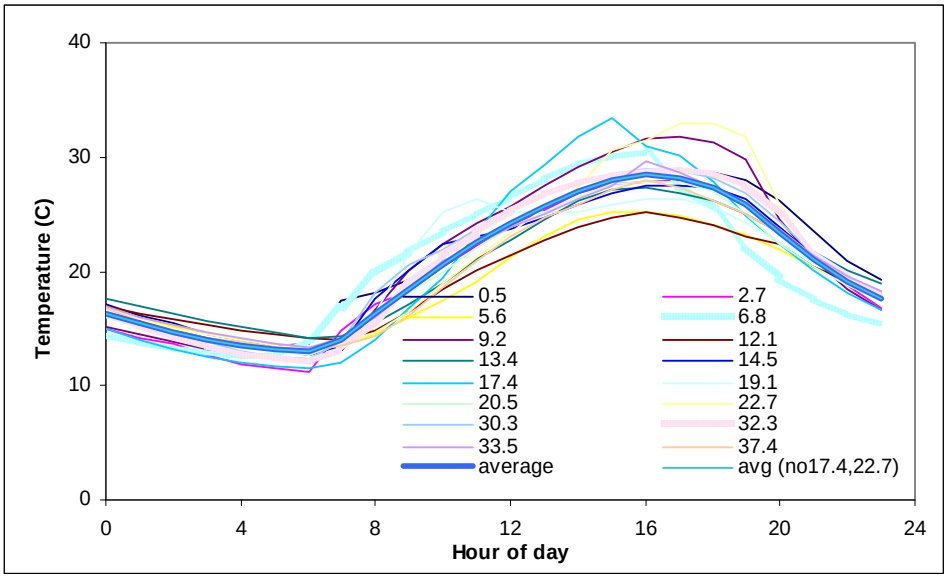


Figure 9. Air temperature monitoring in the Deschutes River watershed in July 21-27, 2004 by station identified by river mile and averaged across stations.

Dewpoint temperatures for the temperature model were developed from one station (RM42.3) in 2003 and two stations (RM0.5 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.

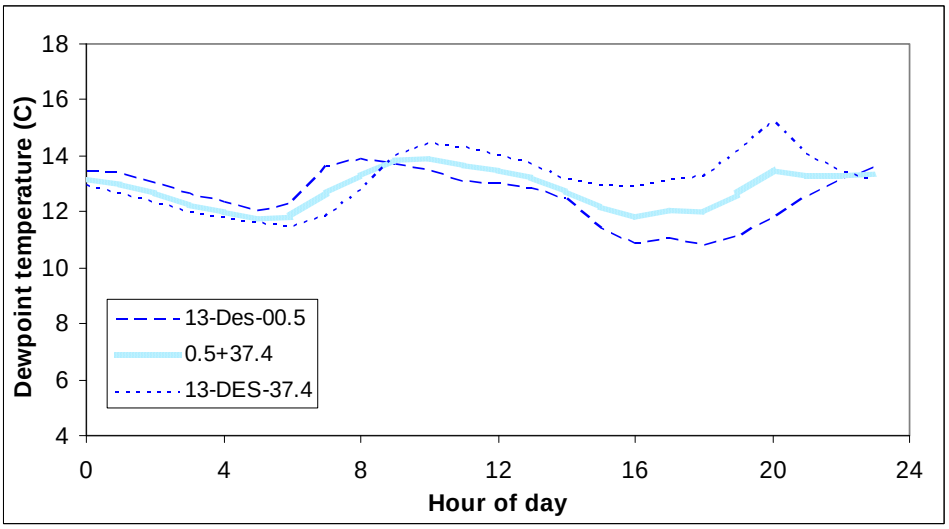


Figure 10. Dewpoint temperatures in the Deschutes River watershed for July 21-27, 2004 by station and averaged across both stations.

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

time periods except the VAL3 runs, which characterized cool, non-storm conditions. 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 seven-day calibration or validation time period was used. Overall cloud cover during warm periods was low but was not necessarily zero.

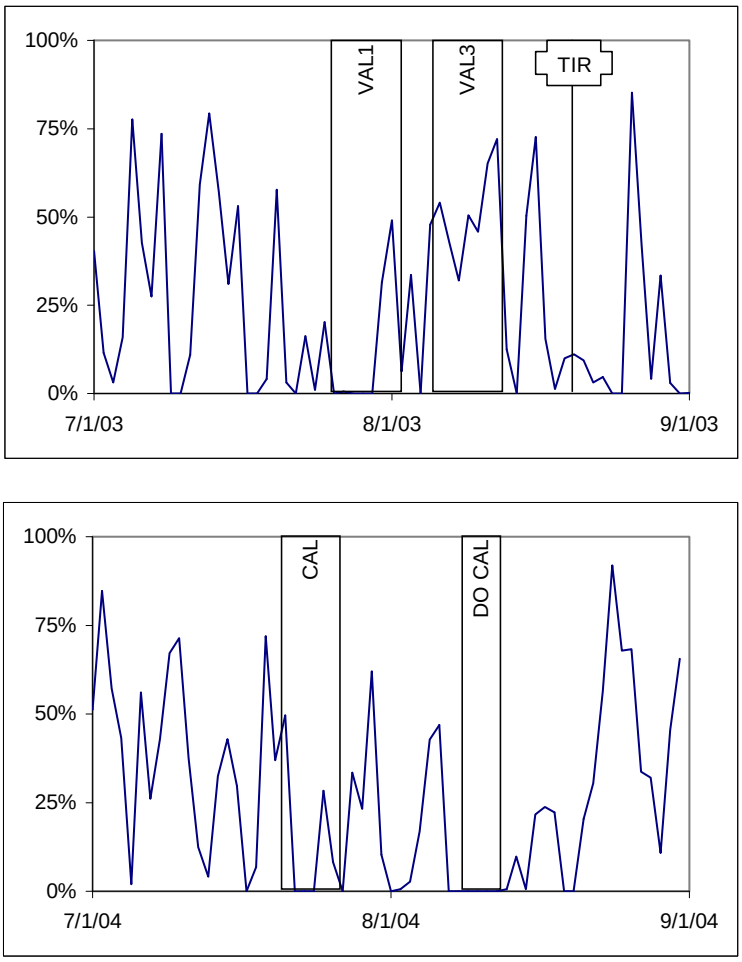


Figure 11. Cloud cover at the Olympia Airport for 2003-2004.

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 the 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.

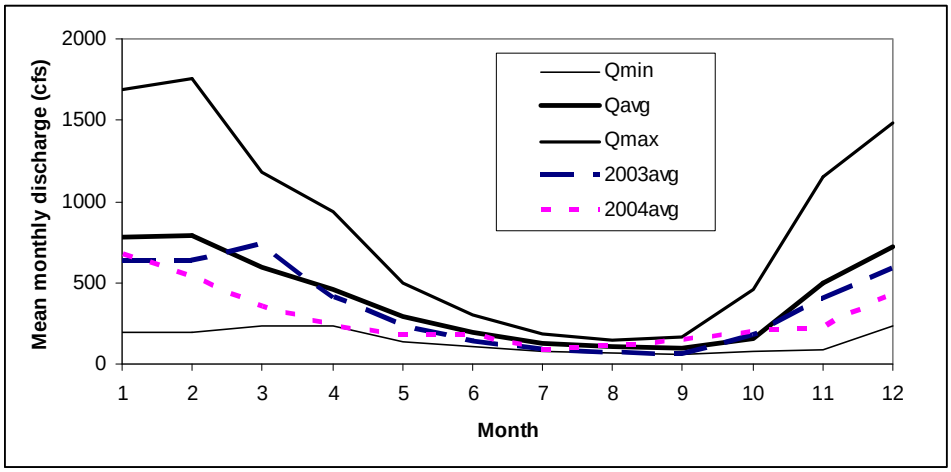


Figure 12. Historical minimum, mean, and maximum average monthly flows at the USGS station 12080010 (E Street bridge) compared with 2003 and 2004 conditions.

The USGS estimated the seven-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 10 summarizes the discharges. 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 10. 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 from tributaries. Groundwater inputs were calculated by difference. Figure 13 presents the longitudinal variation in flows from the upper falls to the E Street bridge. Discharge remained nearly constant with some losing reaches for 20 km downstream of the falls. Small increases in flow occurred between RK20 and RK60. Large groundwater discharges in the Tumwater area downstream of RK60 significantly increased the flow in the Deschutes River.

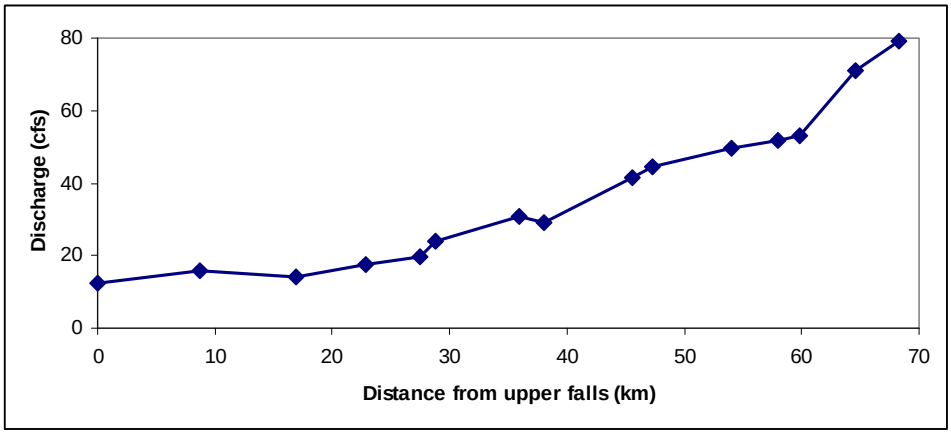


Figure 13. Longitudinal profile of flows in the Deschutes River recorded August 2-4, 2004.

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. Sinclair and Bilhimer (2007) and Quarterly Report #6 summarize the results. Moving from downstream to upstream in approximately 5-km reaches, rhodamine dye was released at three locations, and fluorometers recorded dye concentrations at multiple locations downstream. A storm event on August 5, 2004, prevented the final reach from being characterized. Table 11 presents the incremental and cumulative travel time in the Deschutes River during summer baseflow conditions. Velocity is uniform downstream of the Deschutes Falls.

Table 11. 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	0.07	0.0022	14.6	0.35	0.35
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

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. 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).

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 bacteria concentrations. The geometric mean concentration for the period October 1999 through August 2007 was 22.6 colonies/100 mL. During the period 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 12 through Table 14 summarize 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 growing season (May through September) and non-growing season (October through April). Non-growing season results include targeted stormwater sampling conducted at multiple locations within each watershed (Figure 7). 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.

Table 12. Fecal coliform bacteria results for the Deschutes River, Capitol Lake, and tributaries.

Station	Growing Season (July through September 2003; May through September 2004)			Non-Growing Season (October 2003 through April 2004; October through December 2004; March 2005)		
	Count	Geomean	% > Pt. 2	Count	Geomean	% > Pt. 2
Deschutes River						
13-DES-37.4	1		0.0%	0		NS
13-DES-32.3	2		0.0%	0		NS
13-DES-30.2	2		0.0%	2		0.0%
13-DES-28.6	12	56.1	8.3%	18	8.1	0.0%
13-DES-20.5	10	89.2	20.0%	14	6.5	0.0%
13-DES-09.2	10	81.5	10.0%	14	13.3	0.0%
13-DES-05.5	10	65.8	10.0%	14	13.2	0.0%
13-DES-02.7	16	16.9	0.0%	18	6.5	0.0%
13-DES-00.5	16	21.1	0.0%	18	9.1	0.0%
Tributaries to Deschutes River						
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-EQUU	0		NS	4	18.8	0.0%
13-SPU-LATI	0		NS	4	17.8	0.0%
13-SPU-MOOD	0		NS	4	17.1	0.0%
13-SPU-00.0	16	81.2	12.5%	22	11.2	0.0%
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%
Capitol Lake						
13-CAP-08	1		0.0%	0		NS
13-CAP-07	1		0.0%	0		NS
13-CAP-06	1		0.0%	0		NS
13-CAP-05	1		0.0%	0		NS
13-CAP-04	5	1.8	0.0%	0		NS
13-CAP-03	5	3.4	0.0%	0		NS
13-CAP-02	1		0.0%	0		NS
13-CAP-01	5	18.8	0.0%	0		NS
13-LAK-00.0	2		0.0%	2		0.0%
13-CAP-00.4	16	3.9	6.3%	18	15.9	11.1%

NS Not sampled

Table 13. Fecal coliform monitoring results for the Percival Creek watershed.

Station	Growing Season (July through September 2003; May through September 2004)			Non-Growing Season (October 2003 through April 2004; October through December 2004; March 2005)		
	Count	Geomean	% > Pt. 2	Count	Geomean	% > Pt. 2
Percival Creek watershed						
13-BLA-02.3	16	5.6	0.0%	22	7.0	4.5%
13-BLA-00.0	15	21.3	0.0%	22	10.4	9.1%
13-PER-54TH	0	NS	NS	4	48.5	25.0%
13-PER-01.0	16	93.5	43.8%	21	27.8	14.3%
13-PER-00.1	16	44.0	12.5%	22	13.4	4.5%

Table 14. Fecal coliform monitoring results for tributaries to Budd Inlet.

Station	Growing Season (July through September 2003; May through September 2004)			Non-Growing Season (October 2003 through April 2004; October through December 2004; March 2005)		
	Count	Geomean	% > Pt. 2	Count	Geomean	% > Pt. 2
Budd Inlet tributaries (east side)						
13-ADA-UNK	10	2667.7	90.0%	11	351.5	72.7%
13-ADA-00.5	16	22.1	6.3%	21	53.5	23.8%
13-ELL-33RD	0	NS	NS	4	81.8	0.0%
13-ELL-00.0	16	132.5	25.0%	21	33.3	19.0%
13-MIS-ETHR	0	NS	NS	4	180.8	25.0%
13-MIS-BETH	0	NS	NS	4	306.4	75.0%
13-MIS-00.1	16	173.5	50.0%	22	66.1	27.3%
13-MOX-PARK	0	NS	NS	4	39.7	25.0%
13-MOX-PLUM	0	NS	NS	4	74.1	0.0%
13-MOX-00.6	15	177.5	46.7%	22	62.8	22.7%
13-MOX-8TH	0	NS	NS	5	190.2	60.0%
13-MOX-5TH	0	NS	NS	6	253.5	50.0%
13-MOX-00.0	15	438.3	93.3%	22	330.6	68.2%
13-IND-12TH	0	NS	NS	3	25.7	0.0%
13-IND-SBAY	0	NS	NS	4	455.0	75.0%
13-IND-MART	0	NS	NS	4	1169.8	75.0%
13-IND-BOUL	0	NS	NS	4	342.3	75.0%
13-IND-FRED	0	NS	NS	4	297.0	75.0%
13-IND-WHEE	0	NS	NS	4	368.7	75.0%
13-IND-00.2	16	540.8	81.3%	22	104.7	31.8%
Budd Inlet tributaries (west side)						
13-BUT-NW	0	NS	NS	4	29.4	0.0%
13-BUT-SW	0	NS	NS	4	143.4	25.0%
13-BUT-SE	0	NS	NS	4	76.3	0.0%
13-BUT-00.1	16	60.7	6.3%	22	33.4	9.1%
13-SCH-00.1	13	23.6	0.0%	17	15.2	11.8%

Bacteria levels were relatively low along the mainstem of the Deschutes River, with the exception of the flood event of October 20, 2003. Among tributaries to the Deschutes River, concentrations were lowest for the uninhabited Huckleberry Creek watershed and highest for Reichel Creek. Concentrations were similar in the Percival Creek watershed but much higher within tributaries to Budd Inlet. Of 24 locations monitored in both the growing season (May through September) and non-growing season (October through April), only two sites had higher geometric mean concentrations in the non-growing season. Concentrations were on average 4.3 times higher during the summer growing season than in the winter non-growing season.

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).

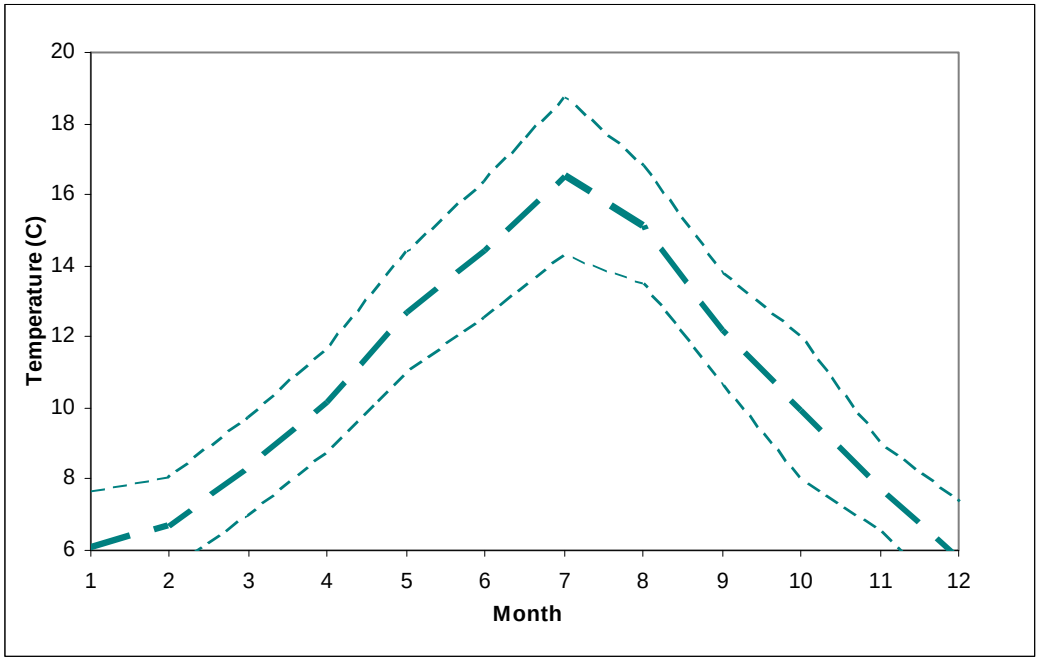


Figure 14. Peak instantaneous temperature (mean ± 1 SD) by month for Ecology ambient monitoring station 13A060 (1988 through 2007).

In 2003-2004, temperature probes were installed along the Deschutes River mainstem and tributaries in 2003. Figure 15 and Figure 16 present the peak 7-day average of daily maximum temperatures by site. Temperatures in the mainstem of the Deschutes River increased about 5ºC within 10 mi of the Deschutes Falls. Peak temperatures declined about 4ºC over the next 10 mi (16 km) downstream. Temperatures rose somewhat before a secondary peak in temperatures around RM5.

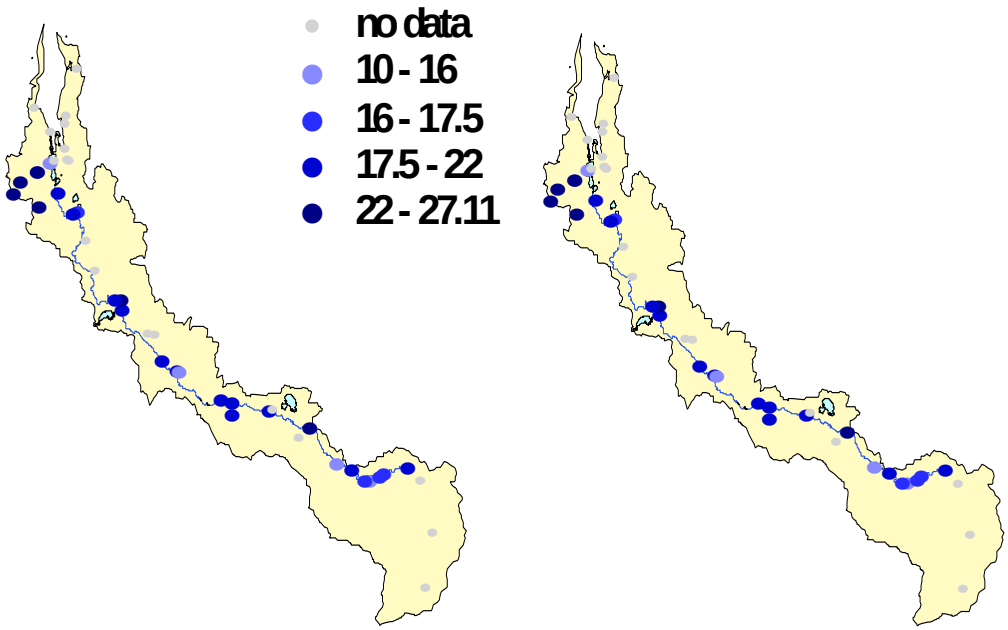


Figure 15. Peak 7-day average of daily maximum temperatures (ºC) in 2003 and 2004 in the study area.

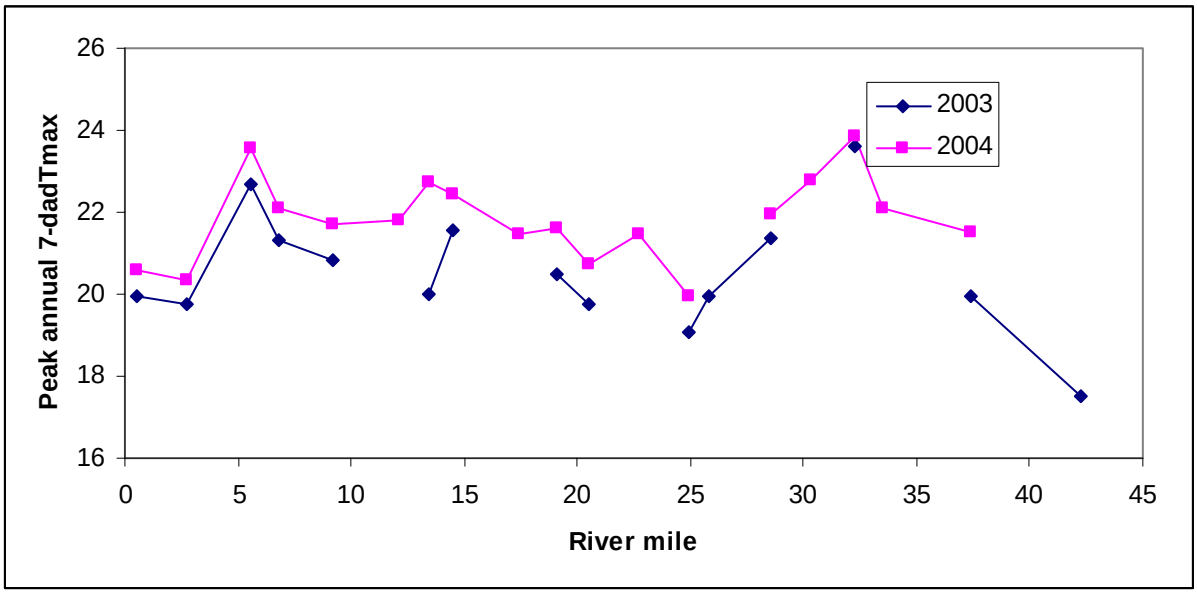


Figure 16. Profile of peak annual 7-day average of daily maximum temperatures in 2003 and 2004 along the Deschutes River from the Deschutes Falls (RM42.3) to the E Street bridge (RM00.5).

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. Appendix D presents both the TIR and visible band images. Thermal infrared 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 17 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.

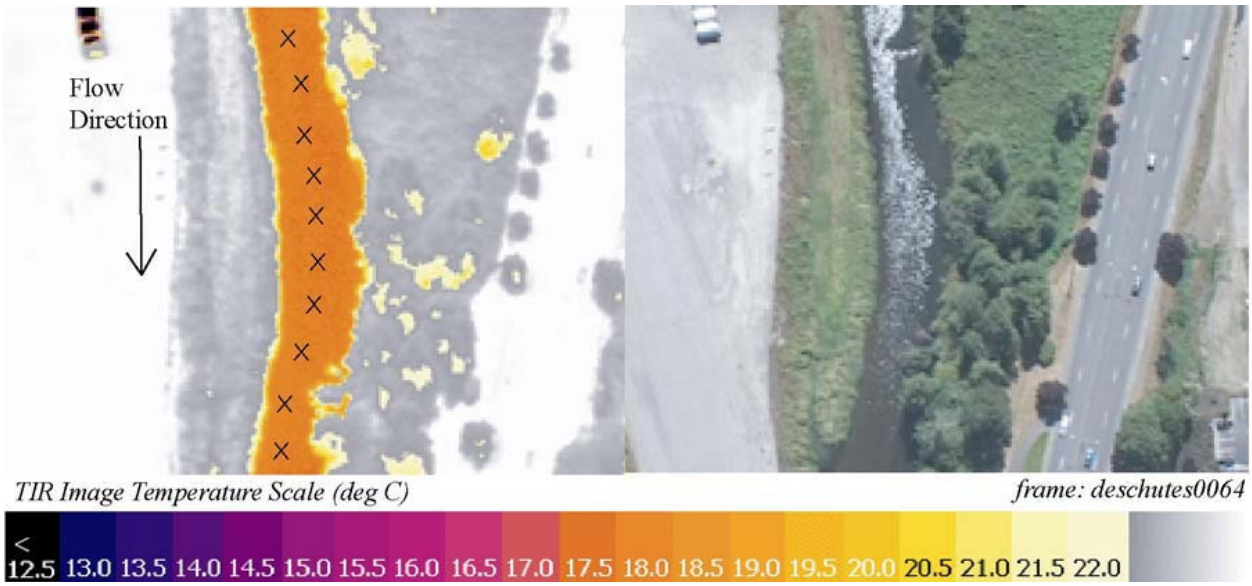


Figure 17. Example thermal infrared (left) and visible band (right) paired images from the TIR survey. Source: Watershed Sciences (2004).

Figure 18 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 RM40 (5 km 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.

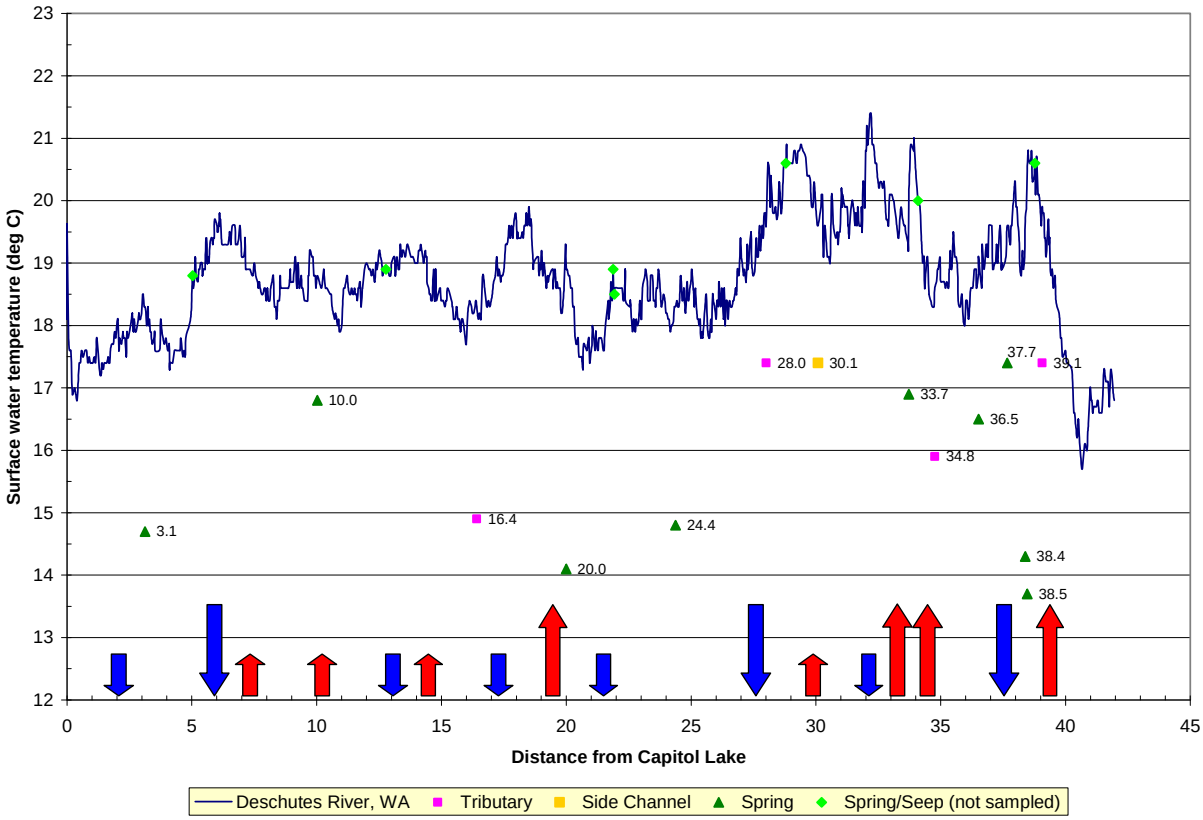


Figure 18. Detailed longitudinal profile from TIR survey for the mainstem Deschutes River as well as measured and estimated tributary and spring temperatures. Distance is miles from Capitol Lake. Source: Watershed Sciences (2004). Arrows added to identify areas with warming or cooling of 1.0ºC (small arrows) to >2ºC (large arrows).

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 in the report (Watershed Sciences, 2004) and are identified in images in Appendix D and on the web page. Watershed Sciences (2004) noted a water temperature decrease of 1.0ºC through a logjam near RM5.3.

Nutrients, Dissolved Oxygen, and pH Results

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, particularly dissolved inorganic nitrogen, have increased ($p=0.016$ and $p<0.001$), as shown in Figure 19. Ammonium concentrations have decreased ($p=0.007$) during the same time, in part due to the decrease in high-concentration spikes in recent years, but the decrease is more than offset by the increase in nitrate plus nitrite.

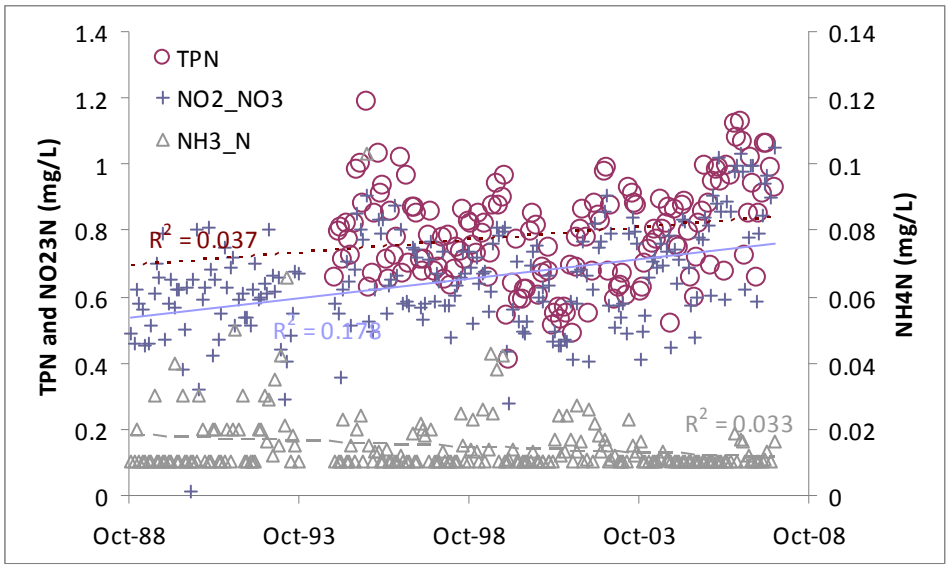


Figure 19. Long-term trends in nitrogen concentrations at Ecology's ambient monitoring station 13A060 at the E Street bridge.

Total phosphorus concentrations have declined over the past 20 years ($p<0.001$), although it is unclear whether changes in analytical methods in 1999 and 2003 influence the results (Figure 20). Conversely, orthophosphorus concentrations have increased ($p<0.001$), even with a decrease in the reported detection limit from 0.01 mg/L through 1993 to 0.005 mg/L since that time.

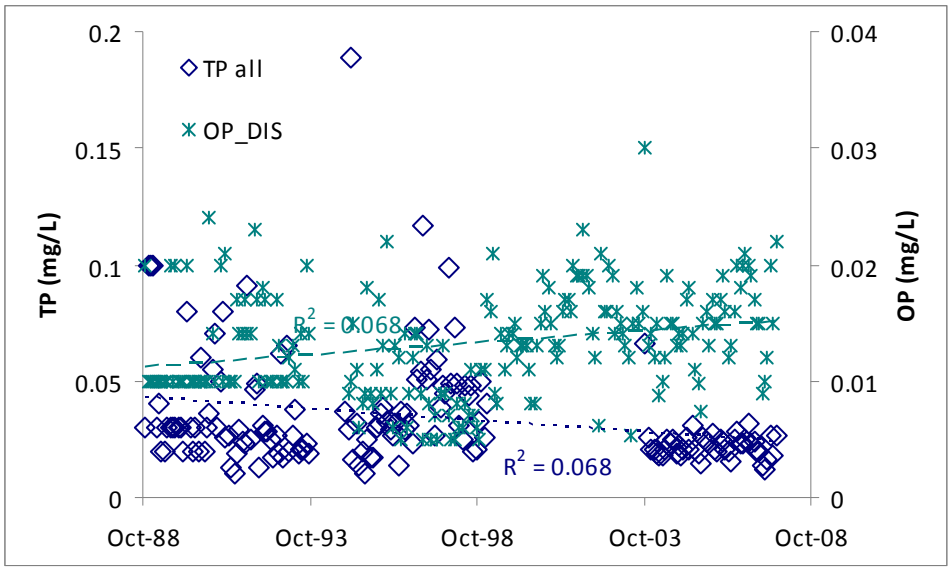


Figure 20. Long-term trends in phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge.

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 21). Nutrient patterns are more complex but also show seasonal patterns (Figure 22). 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 follows a more variable pattern, 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.

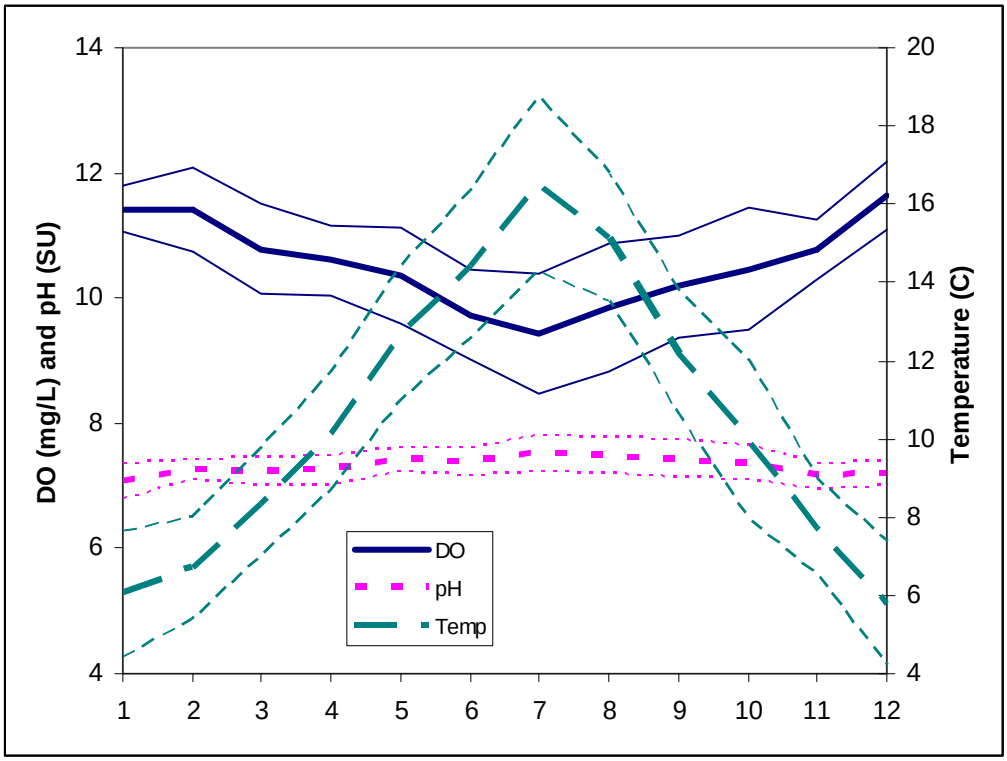


Figure 21. Monthly values (mean ± 1 SD) for DO, pH, and temperature at Ecology's ambient monitoring station 13A060 at the E Street bridge (1988 through 2007).

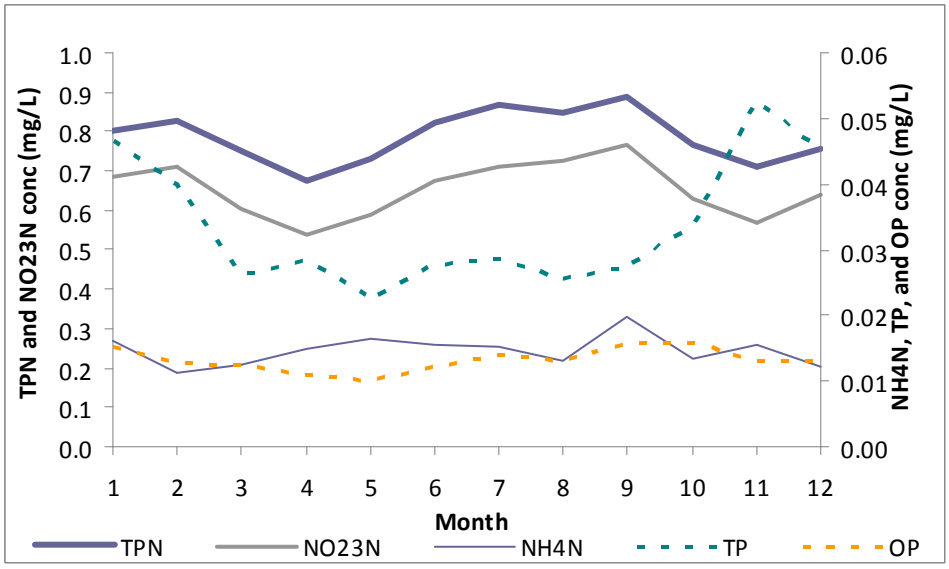


Figure 22. Monthly values for nitrogen and phosphorus at Ecology's ambient monitoring station 13A060 at the E Street bridge.

The detailed monitoring program conducted in 2003-2004 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 23 presents both DO 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.

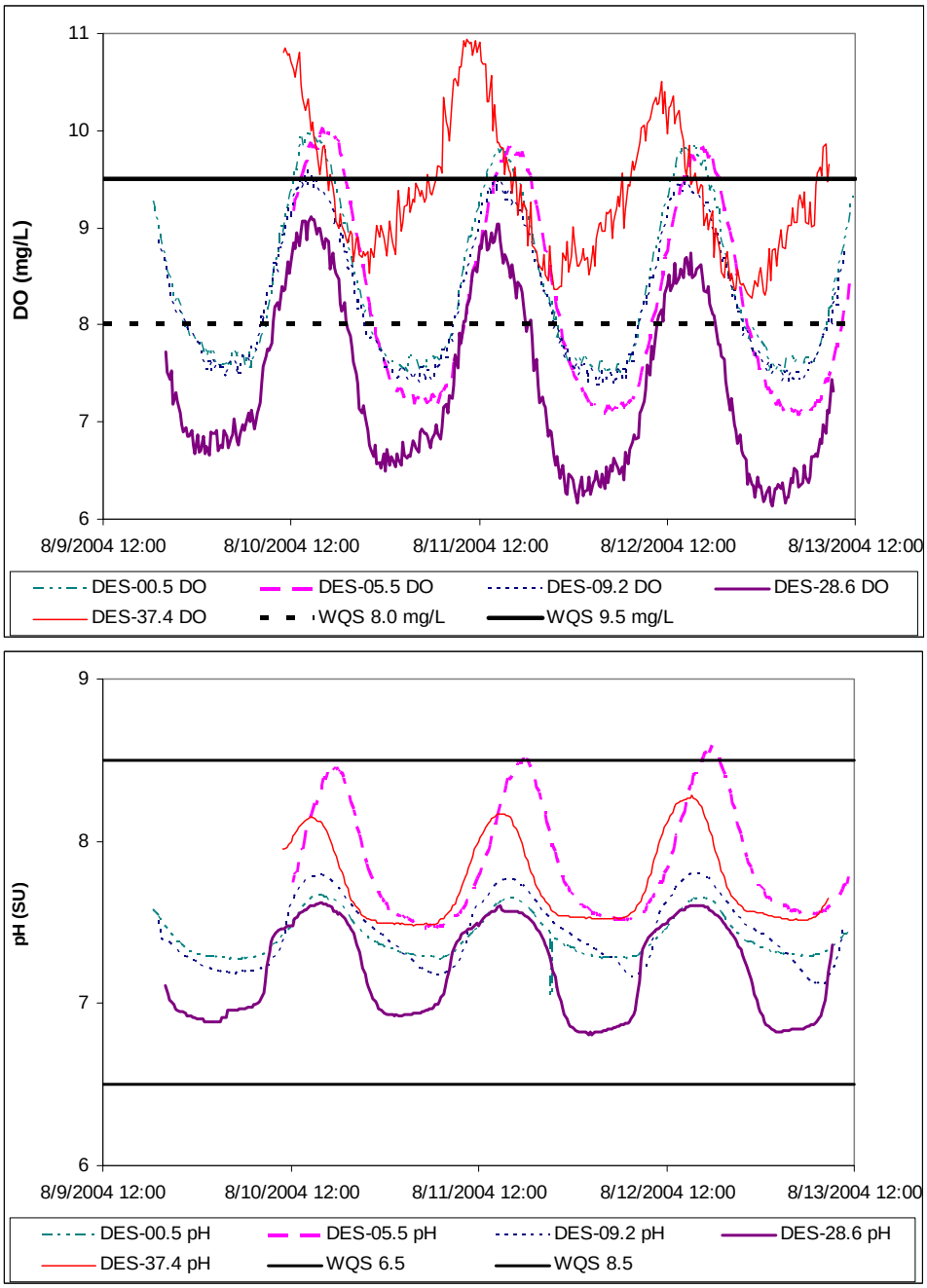


Figure 23. Continuous DO (top) and pH (bottom) results from Hydrolab measurements at five stations. Solid lines represent stations upstream of Offut Lake, while dashed lines represent sites downstream of Offut Lake.

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 15.

Table 15. 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 24 presents the profile of 2004 nitrogen concentrations from the upper falls through Capitol Lake. Total nitrogen and nitrate plus 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 25), 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.

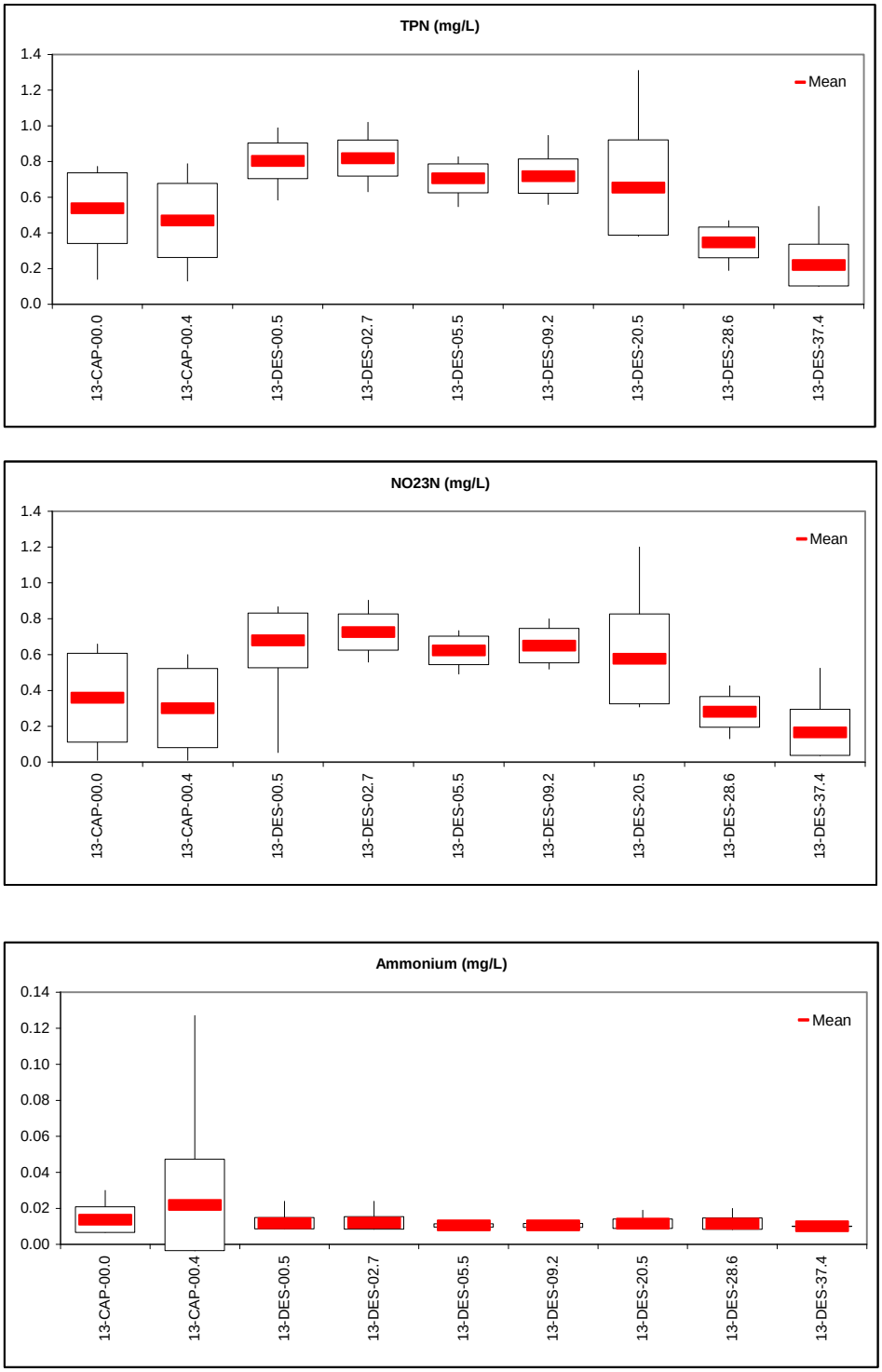
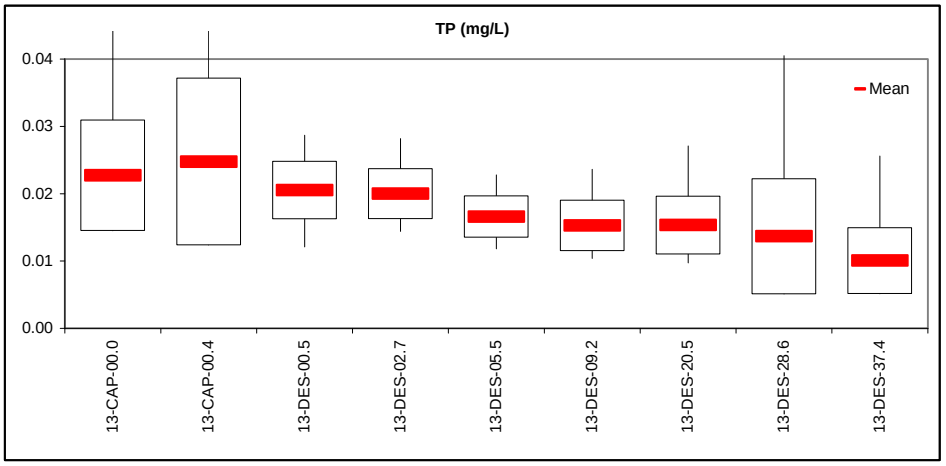


Figure 24. Longitudinal variation in nitrogen concentrations from the 1000 Road to the E Street bridge, from right to left. Boxes indicate 25th and 75th percentiles, while whiskers extend to the minimum and maximum values.



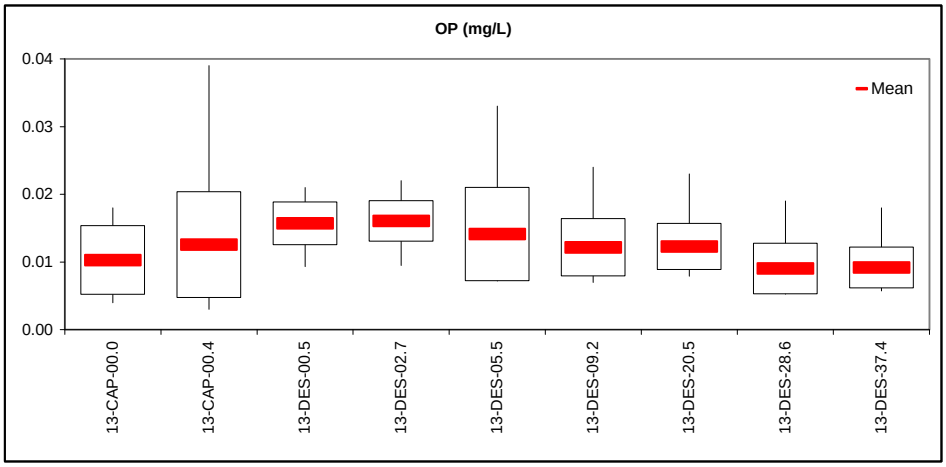


Figure 25. Longitudinal variation in phosphorus concentrations from the 1000 Road to the E Street bridge. See Figure 24 for legend.

In addition, a stream survey was conducted August 11-15, 2003 moving from upstream to downstream. Discharge at the E Street bridge was 76.4 cfs. Temperature, DO, conductivity, and pH were recorded along 30 river miles over five days. 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.

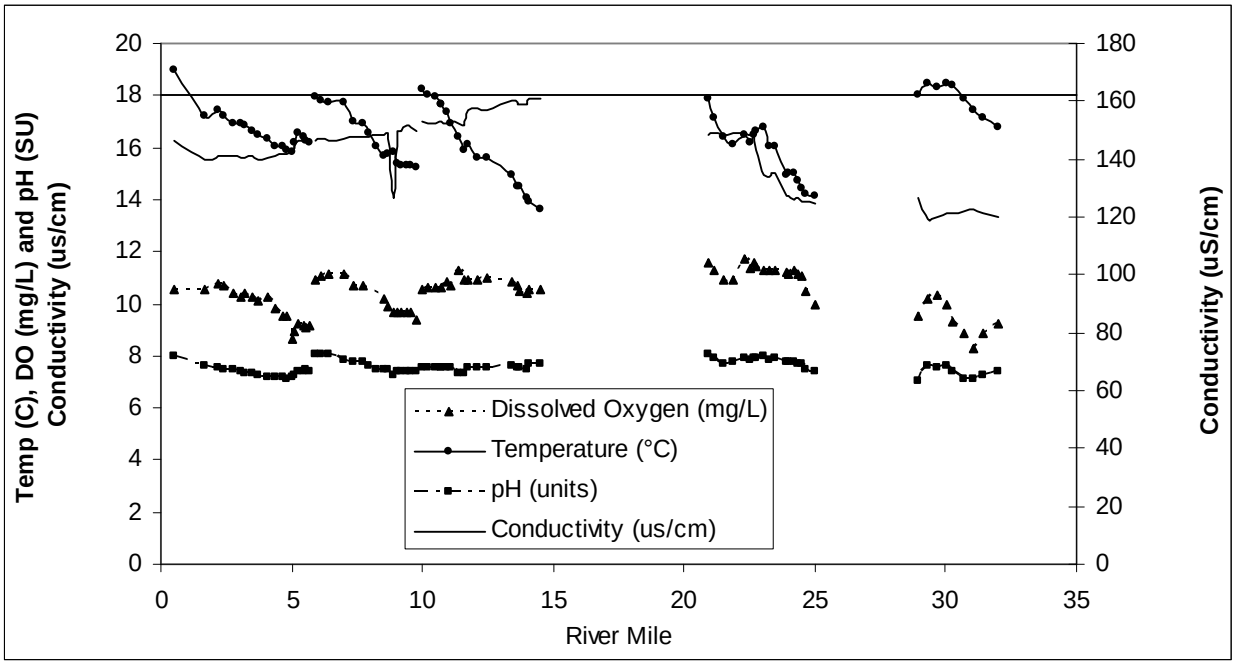


Figure 26. Temperature, DO, pH, and conductivity longitudinal profiles recorded August 11-15, 2003.

Surface water samples collected from the south basin (CL1), railroad trestle (CL3), and outlet of Capitol Lake (CL4) 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.

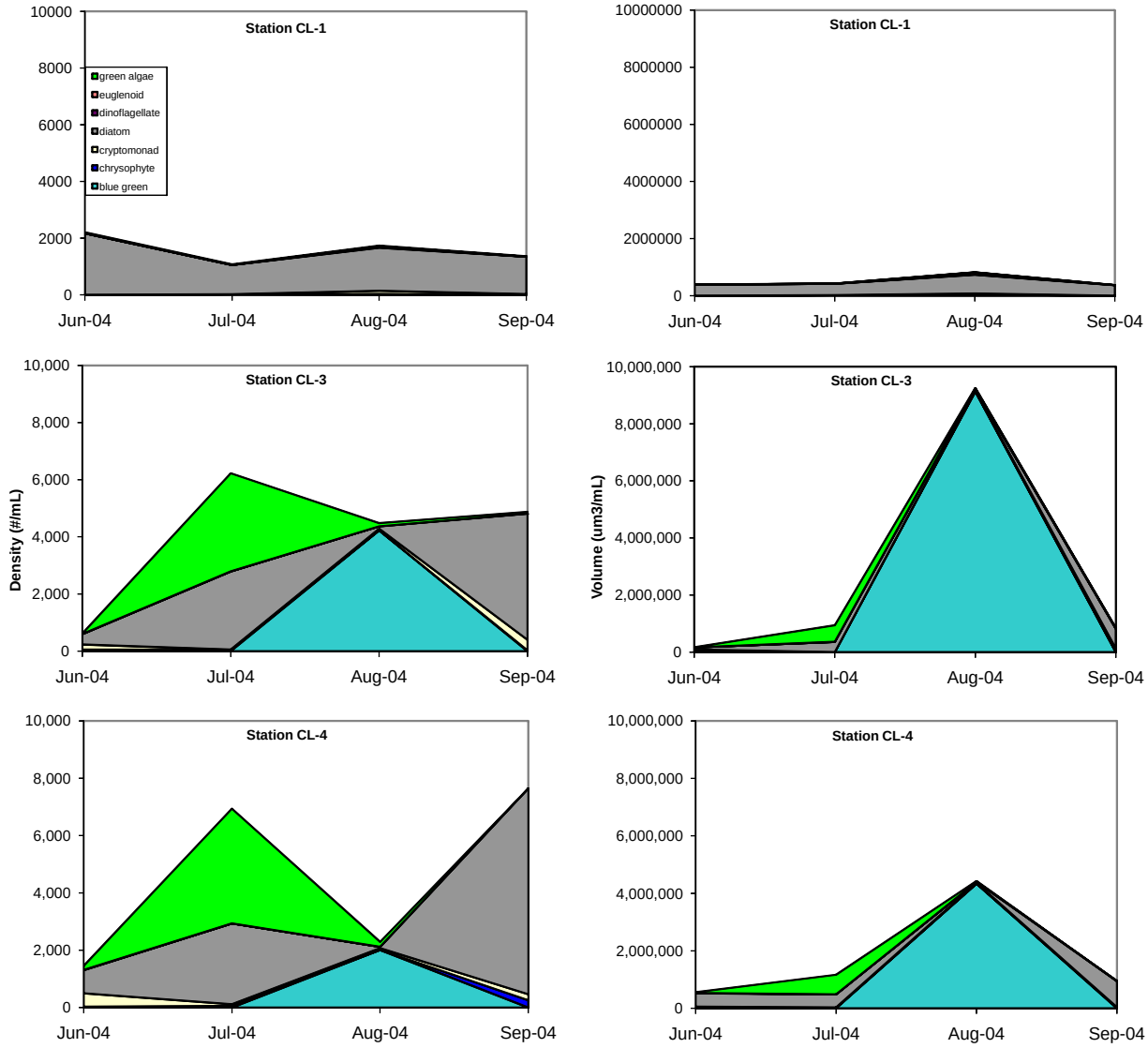


Figure 27. Capitol Lake phytoplankton density (#/mL) and volume (um^3/mL) in 2004.

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 16 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 16. Capitol Lake benthic fluxes (g/m^2-d) quantified in September 2004. Italicized values are means over the light and dark chambers.

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

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 28 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).

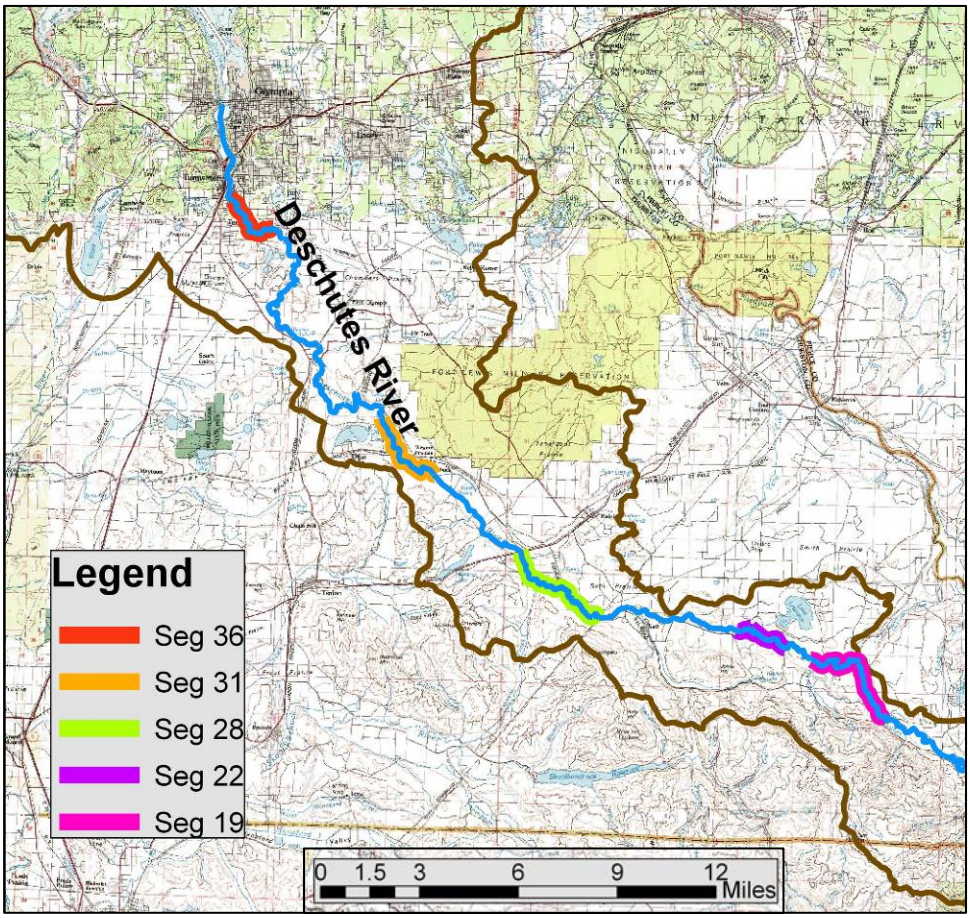


Figure 28. Fine sediment study reaches sampled in 2004. Source: Konovsky and Puhn (2005). River kms are downstream of Deschutes Falls.

Figure 29 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 a combination of the January 1990 storm event or recreational offroad vehicle use, which is common in the area (Konovsky and Puhn, 2005).

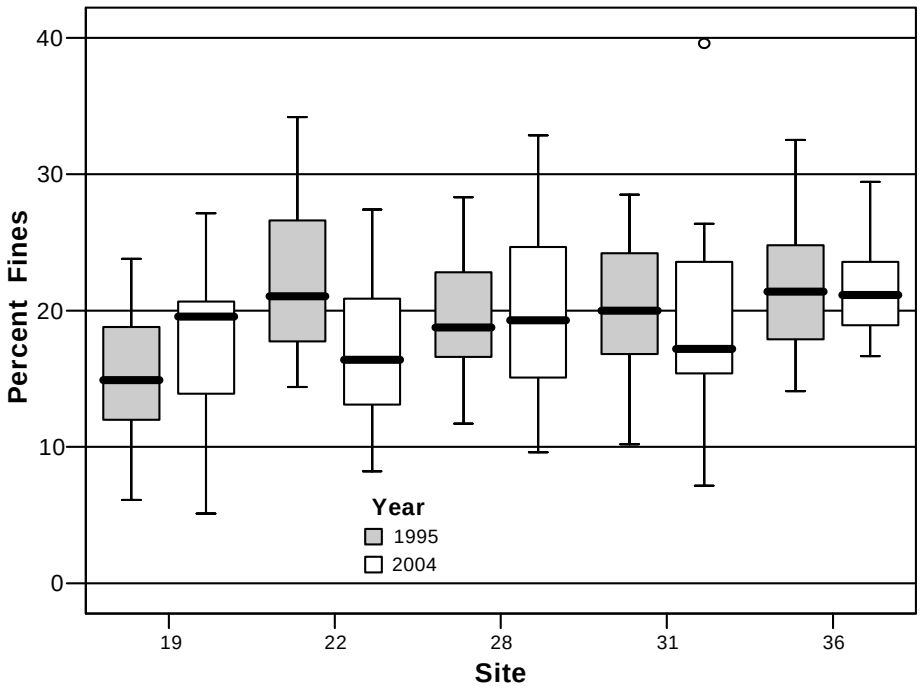


Figure 29. Fine sediment levels by study reach. Source: Konovsky and Puhn (2005).

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 RM31 and RM41 as the most critical segments for restoration.

The study 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 RM31 and RM41 meet the restoration target, while 0 to 2% of the mainstem meets the restoration target.

Partial restoration of LWD (70% in tributaries between RM31 and RM41 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 17 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. Raines (2007) used a fine sediment size fraction of <2 mm, which differs from the definition used by Konovsky and Puhn (2005).

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 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 was geology, soils, and terrain. Road-associated landslides constituted 73% of the sediment inputs, and 79% of the 100 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, and 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).

Table 17. Sediment budget summary for the Deschutes River from all sources, including a low and high range for some parameters. Source: Raines (2007).

Bank erosion from all sources	1972-81	1981-91	1991-2003	1972 - 2003
	low	low	low	low
Fine (yd^3)	79,600	271,000	59,000	409,600
Coarse (yd^3)	28,800	61,000	42,000	131,800
Total (yd^3)	108,400	332,000	101,000	541,400
Fine (yd^3/yr)	*8,800*	*27,100*	*4,900*	*13,200*
Coarse (yd^3/yr)	*3,200*	*6,100*	*3,500*	*4,300*
Total (yd^3/yr)	*12,000*	*33,200*	*8,400*	*17,500*
Landslides from all sources	1970-78	1978-90	1990-2001	1970 - 2001
	low	low	low	low
Fine (yd^3)	42,600	67,300	28,800	138,700
Coarse (yd^3)	18,300	28,800	12,400	59,500
Total (yd^3)	60,900	96,100	41,200	198,200
Fine (yd^3/yr)	*5,300*	*5,600*	*2,600*	*4,500*
Coarse (yd^3/yr)	*2,300*	*2,400*	*1,100*	*1,900*
Total (yd^3/yr)	*7,600*	*8,000*	*3,700*	*6,400*
Unpaved roads from all sources	1972-81	1981-91	1991-2003	1972 - 2003
	low	low	low	low
Fine (yd^3)	11,400	9,000	36,000	56,400
Coarse (yd^3)	0	0	0	0
Total (yd^3)	11,400	9,000	36,000	56,400
Fine (yd^3/yr)	*1,300*	*900*	*3,000*	*1,800*
Coarse (yd^3/yr)	*0*	*0*	*0*	*0*
Total (yd^3/yr)	*1,300*	*900*	*3,000*	*1,800*
Total identified sources (yd^3/yr)	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	1974-1983	1983-1990	1990-1998	1972-2003
Capitol Lake load (yd^3/yr)	*55,000*	*35,000*	*29,000*	*33,000-38,000*

Notes:
(a) Collins (1994).
(b) Landslide data from 1966-1970 not included in total; annual average used in sediment source annual average as analysis periods were not the same.
(c) Sullivan et al. (1987).
(d) Average of annual range extrapolated to 12-year period of 1991-2003 bank erosion analysis.
(e) Annual average for each source used in total sediment source average for each analysis period as not all are the same; totals and averages for 31 year total use both totals and average totals.
(f) George et al. (2006). Low estimate from 25,200 m^3 rating curve estimate. High estimate from averaging sediment accumulation data: 1952-1974 rate used for 1972-1974 and 1990-1998 rate used for 1998-2003.

Raines (2007) quantified anthropogenic contributions to the sediment inputs (Table 18). 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 sediment inputs to the Deschutes River system. Most of these sources are fine sediment, and anthropogenic contributions of fine sediment (<2 mm) constitute 20 to 25% of the sediment inputs to the system.

Table 18. Sediment budget summary for the Deschutes River from anthropogenic sources. 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	
	low	high	low	high	low	high	low	high
Fine (yd^3)	0	0	0	0	0	0	0	0
Coarse (yd^3)	0	0	0	0	0	0	0	0
Total (yd^3)	0	0	0	0	0	0	0	0
Fine (yd^3/yr)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Coarse (yd^3/yr)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Total (yd^3/yr)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Landslides from anthropogenic sources	1970-78		1978-90		1990-2001		1970 - 2001	
	low	high	low	high	low	high	low	high
Fine (yd^3)	35,500	42,600	47,800	67,300	19,300	28,800	102,600	138,700
Coarse (yd^3)	15,200	18,300	20,500	28,800	8,300	12,400	44,000	59,500
Total (yd^3)	50,700	60,900	68,300	96,100	27,600	41,200	146,600	198,200
Fine (yd^3/yr)	*4,400*	*5,300*	*4,000*	*5,600*	*1,800*	*2,600*	*3,300*	*4,500*
Coarse (yd^3/yr)	*1,900*	*2,300*	*1,700*	*2,400*	*800*	*1,100*	*1,400*	*1,900*
Total (yd^3/yr)	*6,300*	*7,600*	*5700*	*8,000*	*2,500*	*3,700*	*4,700*	*6,400*
Unpaved roads from anthropogenic sources	1972-81		1981-91		1991-2003		1972 - 2003	
	low	high	low	high	low	high	low	high
Fine (yd^3)	11,400	11,400	9,000	9,000	36,000	36,000	56,400	56,400
Coarse (yd^3)	0	0	0	0	0	0	0	0
Total (yd^3)	11,400	11,400	9,000	9,000	36,000	36,000	56,400	56,400
Fine (yd^3/yr)	*1,300*	*1,300*	*900*	*900*	*3,000*	*3,000*	*1,800*	*1,800*
Coarse (yd^3/yr)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Total (yd^3/yr)	*1,300*	*1,300*	*900*	*900*	*3,000*	*3,000*	*1,800*	*1,800*
TOTAL ANNUAL AVERAGES (yd^3/yr)								
FINE	*5,700*	*6,600*	*4,900*	*6,500*	*4,800*	*5,600*	*5,100*	*6300*
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*
Proportions								
Anthro Fine/Anthro Total	75%	74%	74%	73%	86%	83%	78%	77%
Anthro Total/All Total	36%	42%	16%	21%	36%	44%	26%	32%
Anthro Fine/All Total	27%	32%	12%	15%	31%	37%	20%	25%
Anthro Fine/All Fine	37%	43%	15%	19%	45%	53%	26%	32%

Figure 30 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.

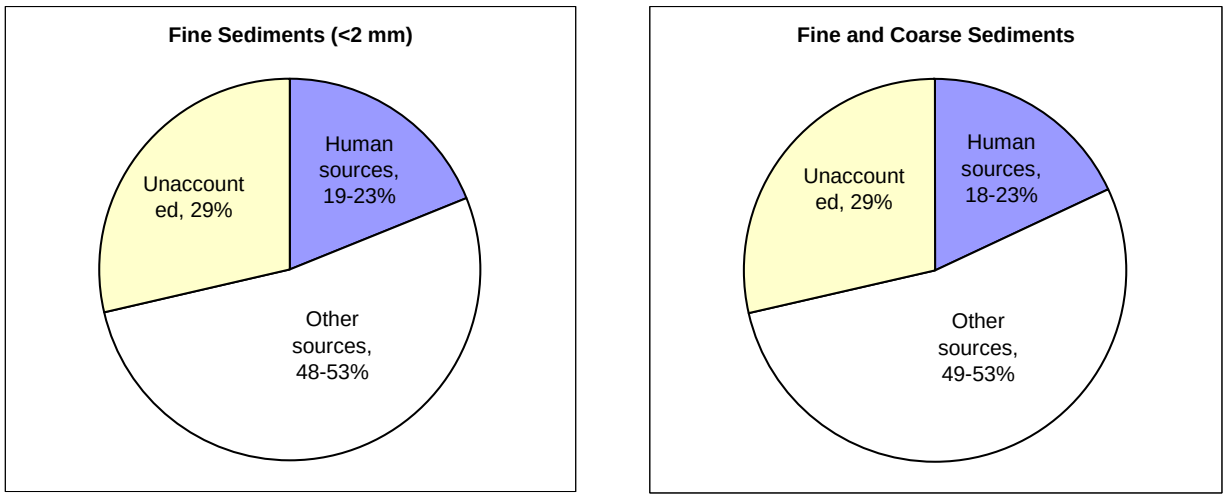


Figure 30. Sediment budgets for both fine sediments and the combination of fine and coarse sediments.

TMDL Analyses

Fecal Coliform Bacteria

Analytical framework

Fecal coliform bacteria load reduction targets are based on data collected from July 2003 through March 2005 in both routine monitoring and targeted stormwater sampling. 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 the geometric mean or the percent samples greater than some threshold. 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; and Pelletier and Seiders, 2000).

Fecal coliform bacteria 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 waterbody 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 set is compared with the value in the standards (std):

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

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

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 waterbody such that the waterbody 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 31 presents the geometric mean and 90th percentile of data collected for all stations with at least 10 samples for the growing season and Figure 32 presents the results for the non-growing season. The loading capacity is indicated by numeric values for Part 1 and Part 2 of the water quality standards. Of the 25 stations, eight did not meet Part 1 of the water quality standards and 12[9] did not meet Part 2 of the water quality standards for the growing season. However, for the non-growing season, three stations did not meet Part 1 of the water quality standards and 10 did not meet Part 2. 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)).

[9] A few stations with <10% of samples above the Part 2 threshold do meet the standard even though the estimated 90th percentile is above the threshold. In this case, 13-DES-28.6 and 13-BUT-00.1 meet Part 2 of the standards because <10% of samples were <200/100 mL; however, their estimated 90th percentiles are >200/100 mL.

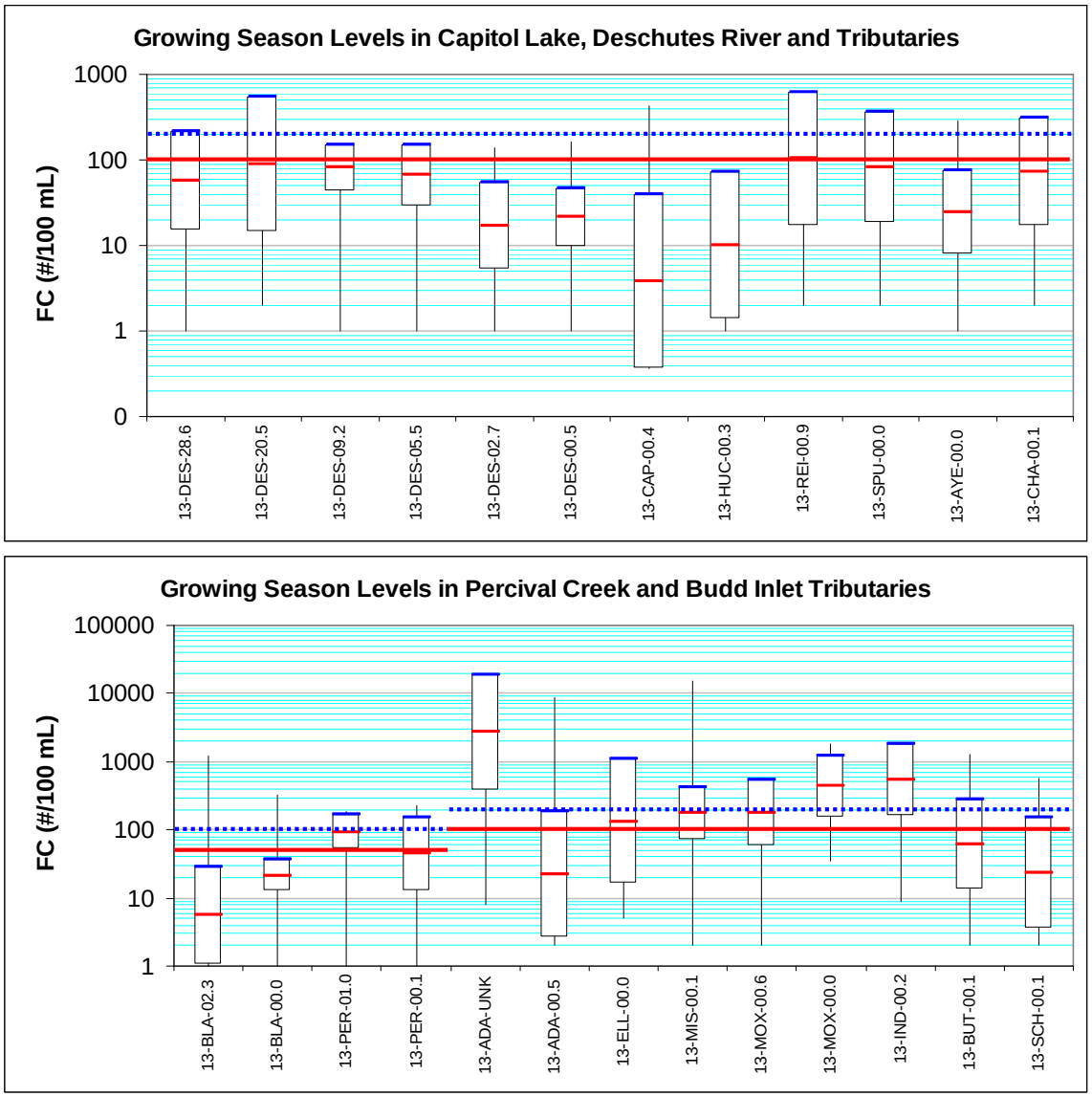


Figure 31. Fecal coliform concentrations and loading capacities for the growing season (May through September). Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use.

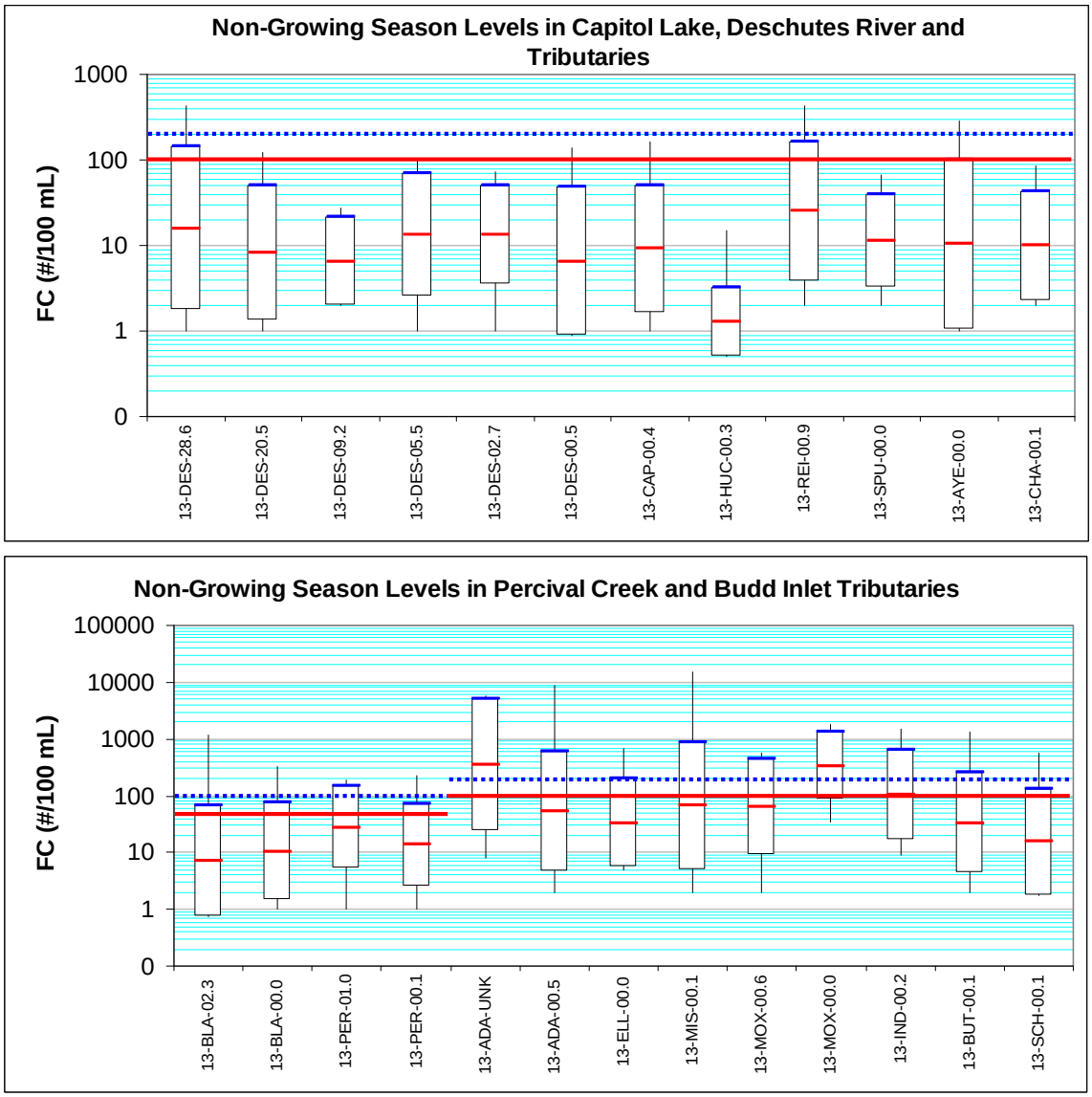


Figure 32. Fecal coliform concentrations and loading capacities for the non-growing season (October through April). Solid red lines indicate the geometric mean and dashed blue lines indicate the 90th percentile concentration by designated use.

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 systems.

Load Targets

Load targets are the nonpoint source reductions recommended at each location. 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 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 19 summarizes the load reduction targets necessary to meet the water quality standards during the growing season, and Table 20 presents the targets for the non-growing season. Figure 33 and Figure 34 present the same information spatially.

Table 19. Target reductions necessary to achieve water quality standards within the Deschutes River, Capitol Lake, and Budd Inlet watersheds during the growing season (May through September.

Station	Count	Water Quality Standards Part 1				Water Quality Standards Part 2					Overall	
		Geomean	WQS Part 1	Meets?	% Reduction	% > WQS Part 2	WQS Part 2	Meets?	90%ile	% Reduction	Meets?	% Reduction
Deschutes River												
13-DES-28.6	12	56.1	100	meets		8.3%	200	meets	213		meets	
13-DES-20.5	10	89.2	100	meets		20.0%	200	**fails**	544	63%	**fails Part 2**	63%
13-DES-09.2	10	81.5	100	meets		10.0%	200	meets	153		meets	
13-DES-05.5	10	65.8	100	meets		10.0%	200	meets	150		meets	
13-DES-02.7	16	16.9	100	meets		0.0%	200	meets	54		meets	
13-DES-00.5	16	21.1	100	meets		0.0%	200	meets	46		meets	
Tributaries to Deschutes River												
13-HUC-00.3	10	10.0	100	meets		0.0%	200	meets	73		meets	
13-REI-00.9	16	102.4	100	**fails**	2%	18.8%	200	**fails**	620	68%	**fails both**	68%
13-SPU-00.0	16	81.2	100	meets		12.5%	200	**fails**	357	44%	**fails Part 2**	44%
13-AYE-00.0	16	24.2	100	meets		0.0%	200	meets	74		meets	
13-CHA-00.1	16	71.5	100	meets		18.8%	200	**fails**	306	35%	**fails Part 2**	35%
Capitol Lake												
13-CAP-00.4	16	3.9	50	meets		6.3%	100	meets	40		meets	
Percival Creek watershed												
13-BLA-02.3	16	5.6	50	meets		0.0%	100	meets	29		meets	
13-BLA-00.0	15	21.3	50	meets		0.0%	100	meets	36		meets	
13-PER-01.0	16	93.5	50	**fails**	47%	43.8%	100	**fails**	171	41%	**fails both**	47%

13-PER-00.1	16	44.0	50	meets		12.5%	100	**fails**	152	34%	**fails Part 2**	34%
Budd Inlet tributaries (east side)												
13-ADA-UNK	10	2667.7	100	**fails**	96%	90.0%	200	**fails**	18736	99%	**fails both**	99%
13-ADA-00.5	16	22.1	100	meets		6.3%	200	meets	189		meets	
13-ELL-00.0	16	132.5	100	**fails**	25%	25.0%	200	**fails**	1082	82%	**fails both**	82%
13-MIS-00.1	16	173.5	100	**fails**	42%	50.0%	200	**fails**	425	53%	**fails both**	53%
13-MOX-00.6	15	177.5	100	**fails**	44%	46.7%	200	**fails**	538	63%	**fails both**	63%
13-MOX-00.0	15	438.3	100	**fails**	77%	93.3%	200	**fails**	1239	84%	**fails both**	84%
13-IND-00.2	16	540.8	100	**fails**	82%	81.3%	200	**fails**	1841	89%	**fails both**	89%
Budd Inlet tributaries (west side)												
13-BUT-00.1	16	60.7	100	meets		6.3%	200	meets	277		meets	
13-SCH-00.1	13	23.6	100	meets		0.0%	200	meets	154		meets	

Table 20. Target reductions necessary to achieve water quality standards within the Deschutes River, Capitol Lake, and Budd Inlet watersheds during the non-growing season (October through April).

Station	Count	Water Quality Standards Part 1				Water Quality Standards Part 2					Overall	
		Geomean	WQS Part 1	Meets?	% Reduction	% > WQS Part 2	WQS Part 2	Meets?	90%ile	% Reduction	Meets?	% Reduction
Deschutes River												
13-DES-28.6	18	8.1	100	meets		0.0%	200	meets	50		meets	
13-DES-20.5	14	6.5	100	meets		0.0%	200	meets	22		meets	
13-DES-09.2	14	13.3	100	meets		0.0%	200	meets	70		meets	
13-DES-05.5	14	13.2	100	meets		0.0%	200	meets	49		meets	
13-DES-02.7	18	6.5	100	meets		0.0%	200	meets	49		meets	
13-DES-00.5	18	9.1	100	meets		0.0%	200	meets	51		meets	
Tributaries to Deschutes River												
13-HUC-00.3	14	1.3	100	meets		0.0%	200	meets	3		meets	
13-REI-00.9	18	24.8	100	meets		5.6%	200	meets	160		meets	
13-SPU-00.0	22	11.2	100	meets		0.0%	200	meets	39		meets	
13-AYE-00.0	21	10.3	100	meets		9.5%	200	meets	99		meets	
13-CHA-00.1	18	9.9	100	meets		0.0%	200	meets	43		meets	
Capitol Lake												
13-CAP-00.4	18	15.9	50	meets		11.1%	100	**fails**	144	30%	**fails Part 2**	30%
Percival Creek watershed												
13-BLA-02.3	22	7.0	50	meets		4.5%	100	meets	66		meets	
13-BLA-00.0	22	10.4	50	meets		9.1%	100	meets	74		meets	
13-PER-01.0	21	27.8	50	meets		14.3%	100	**fails**	152	34%	**fails Part 2**	34%
13-PER-00.1	22	13.4	50	meets		4.5%	100	meets	72		meets	
Budd Inlet tributaries (east side)												
13-ADA-UNK	11	351.5	100	**fails**	72%	72.7%	200	**fails**	5069	96%	**fails both**	96%
13-ADA-00.5	21	53.5	100	meets		23.8%	200	**fails**	617	68%	**fails Part 2**	68%
13-ELL-00.0	21	33.3	100	meets		19.0%	200	**fails**	203	2%	**fails Part 2**	2%
13-MIS-00.1	22	66.1	100	meets		27.3%	200	**fails**	880	77%	**fails Part 2**	77%
13-MOX-00.6	22	62.8	100	meets		22.7%	200	**fails**	433	54%	**fails Part 2**	54%
13-MOX-00.0	22	330.6	100	**fails**	70%	68.2%	200	**fails**	1295	85%	**fails both**	85%
13-IND-00.2	22	104.7	100	**fails**	5%	31.8%	200	**fails**	646	69%	**fails both**	69%
Budd Inlet tributaries (west side)												
13-BUT-00.1	22	33.4	100	meets		9.1%	200	meets	262		meets	
13-SCH-00.1	17	15.2	100	meets		11.8%	200	**fails**	130	nom 10%	**fails Part 2**	nom 10%

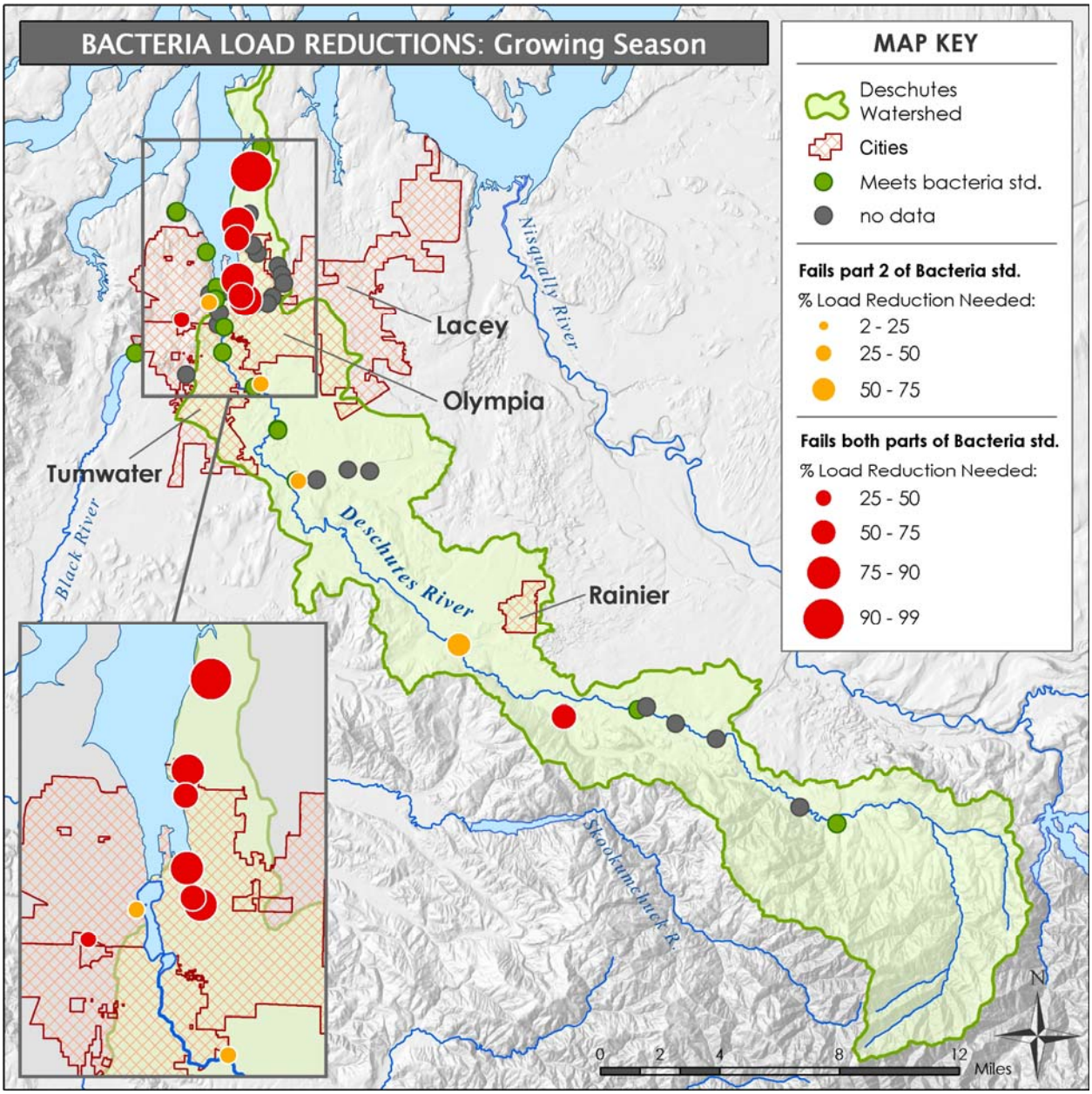


Figure 33. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the growing season (May through September).

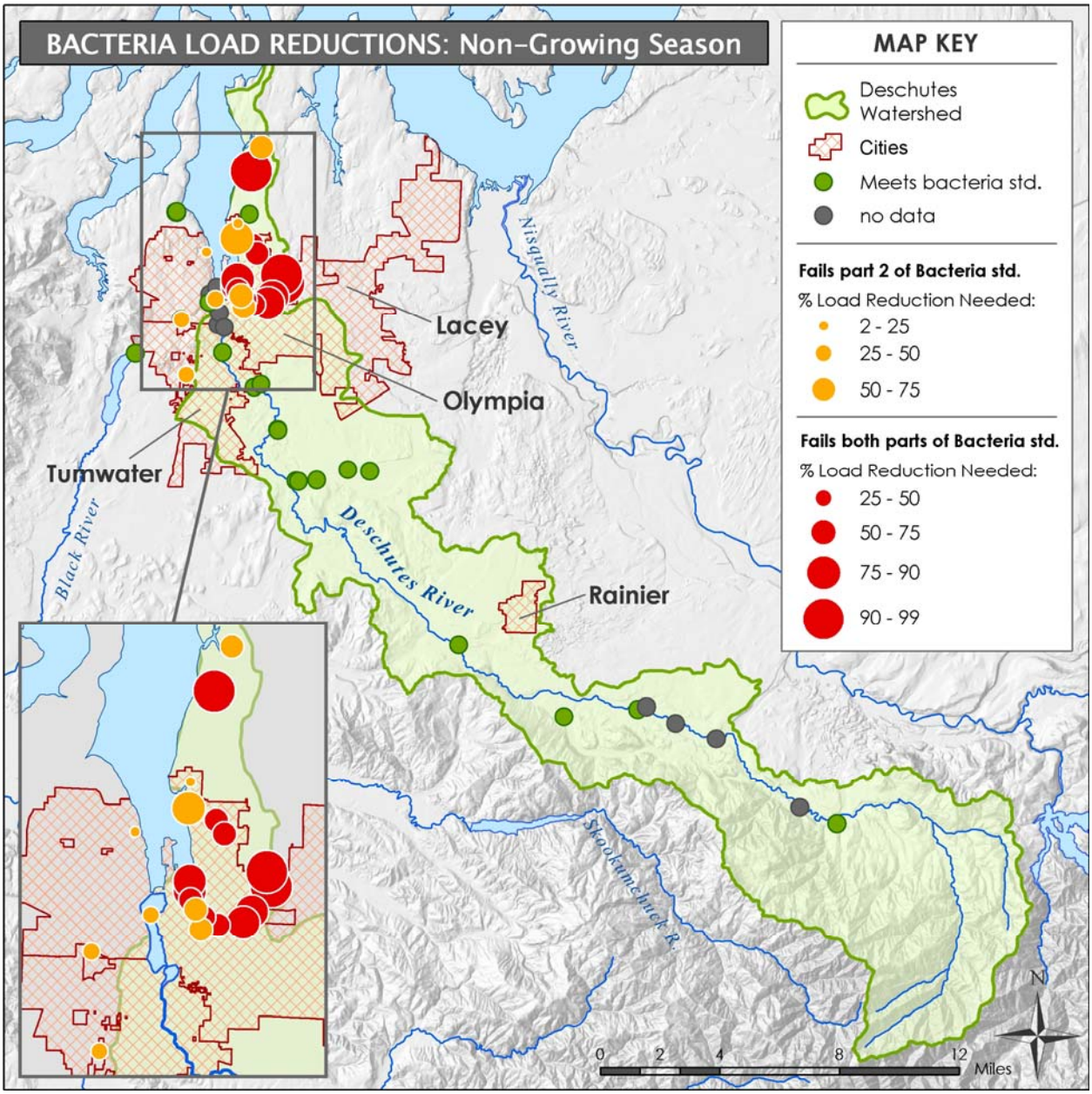


Figure 34. Target reductions (%) needed to meet the water quality standards in the Deschutes River, Capitol Lake, and Budd Inlet watershed during the non-growing season (October through April).

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 in 1998 or 2004 for fecal coliform bacteria. 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.

Figure 33 and Figure 34 include the areas covered by the Phase II municipal stormwater NPDES permits and expected WSDOT statewide operations stormwater permit. 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 bacteria 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.

Facilities covered under the dairy general permit do have the potential to contribute fecal coliform bacteria to the Deschutes River. Although they do not appear to cause fecal coliform violations in the mainstem of the Deschutes River, dairy nutrient management plans should be adhered to strictly by the facilities.

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 system, 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.

One location in the Deschutes River (13-DES-20.5) did not meet Part 2 of the water quality standards, and further source identification is recommended.

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.

If future microbial source tracking or similar survey in the watershed identifies 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 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 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 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 simulation 69 km (43 mi) of the Deschutes River from the upper falls through the lower falls.

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 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 21 summarizes riparian vegetation characteristics by code.

Table 21. 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

Vegetation type was sampled at nine 4.5-m (15-ft) intervals from the stream bank 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 55 m to match in situ values more closely. Stream reach (100 m) aspect was calculated using TTools, and Shade 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 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[10] based on flow gaging values. 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 35. 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 22, along with characteristics recorded at 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.

[10] 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.

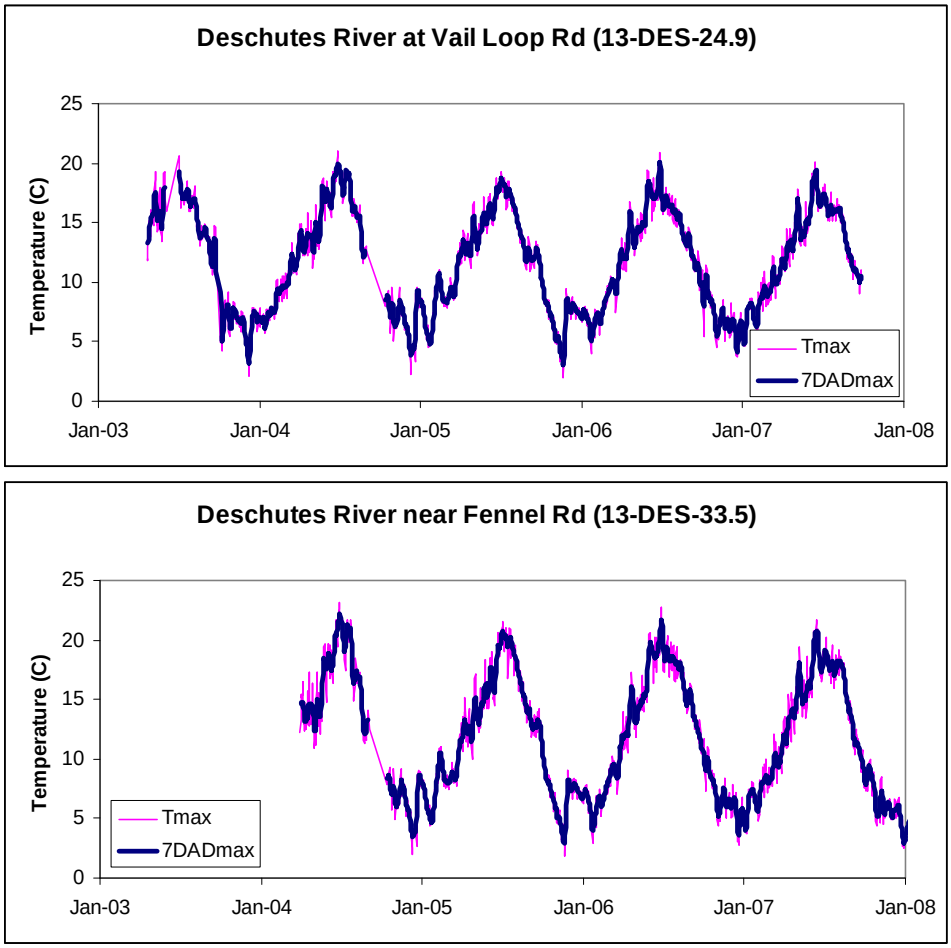


Figure 35. Long-term monitoring of surface water temperature in the Deschutes River watershed.

Table 22. Peak summer temperatures at two stations 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 rearing designation. 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 seven-day average of daily maximum temperatures in 2004 and 2003. Cool validation periods were selected to avoid storm events. Table 9 in the previous report section summarized the various calibration and validation time periods and conditions. Figure 36 illustrates the discharge patterns, survey timing, and the context for the calibration and validation time period selection.

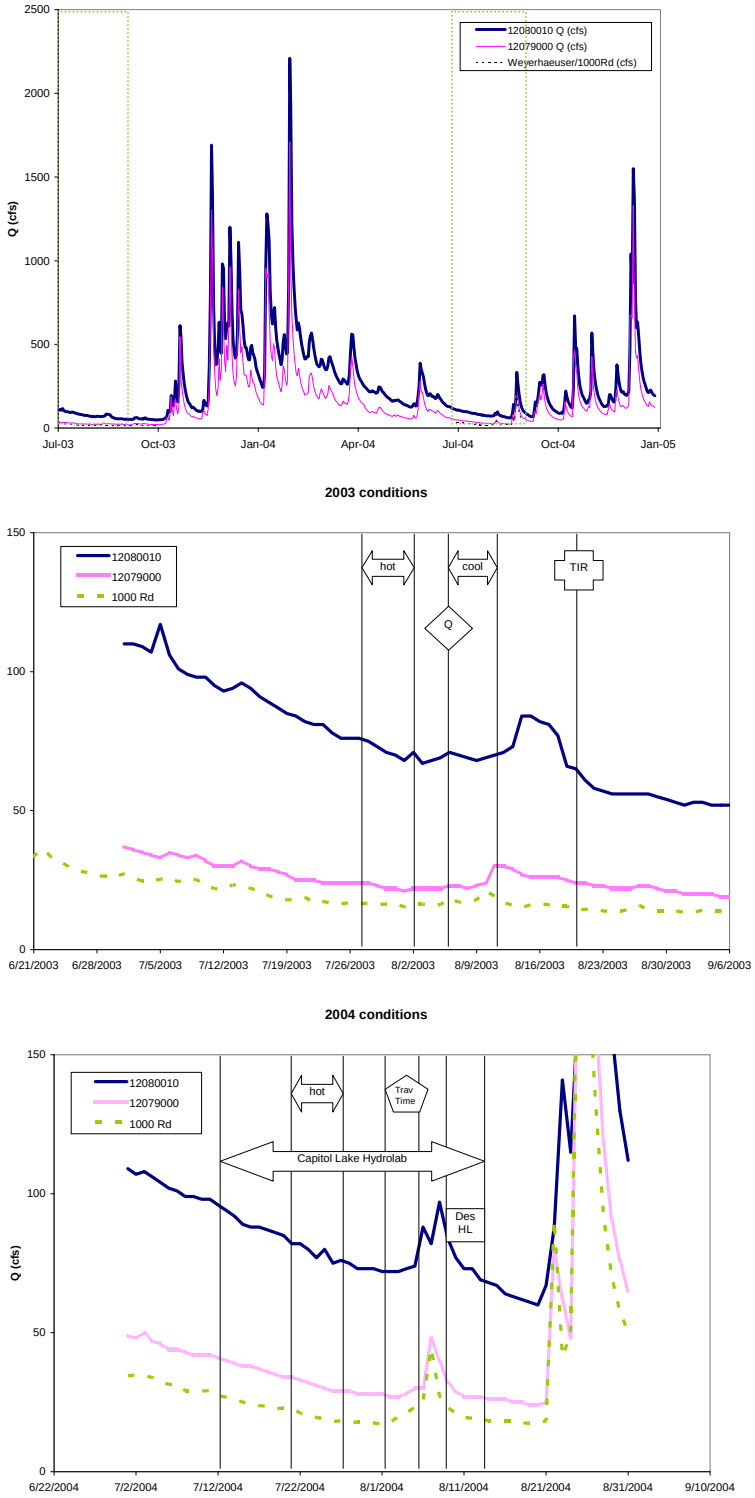


Figure 36. Discharge at the USGS and Weyerhaeuser long-term gaging sites for the 2003-04 study period, including the dates selected for calibration and validation of the QUAL2Kw model. Dashed boxes in the top chart highlight the time periods plotted in the two lower charts.

The discharge at Rainier was 31 to 39% of the discharge at the E Street bridge for calibration and validation time periods, averaging 36%. Because the geology and hydrogeology of the Deschutes River watershed changes near the Rainier gage, the two gages were used to scale the flows in the upper (above Rainier) and lower (between Rainier and E Street) watersheds to simulate the various time periods. The 1000 Road gage was used to scale flows at the headwater near the Deschutes Falls. In all cases, the synoptic survey flows were used to establish the distribution of discharge throughout the watershed, where differences in upstream and downstream discharge were attributed to groundwater sources and sinks. 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 the other low-flow time periods.

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 ten 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 ten river segments from the tracer study were presented in Table 11. 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 0.35 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 in the upper watershed. Discharge during the calibration

time period also was slightly higher than during the synoptic flow study, and the synoptic flows were scaled accordingly.

Reach Thermal Properties

QUAL2K guidance was used to select values for sediment thermal properties. Sediment thermal conductivity was set to 1.82 W/m-ºC 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 percent as a value typical of cobble, sand, silt systems.

Meteorology

For the calibration time period, 16 riparian air temperature records were available. The hourly data show a typical 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 RM 5.6, 12.1 and 37.4, while the warmest occurred at RM 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 (RM00.5 and RM37.4) was used throughout the model domain.

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

Shade

Shade.xls 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%.

Shade.xls 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 37). The average current effective shade is 47% over the Deschutes River.

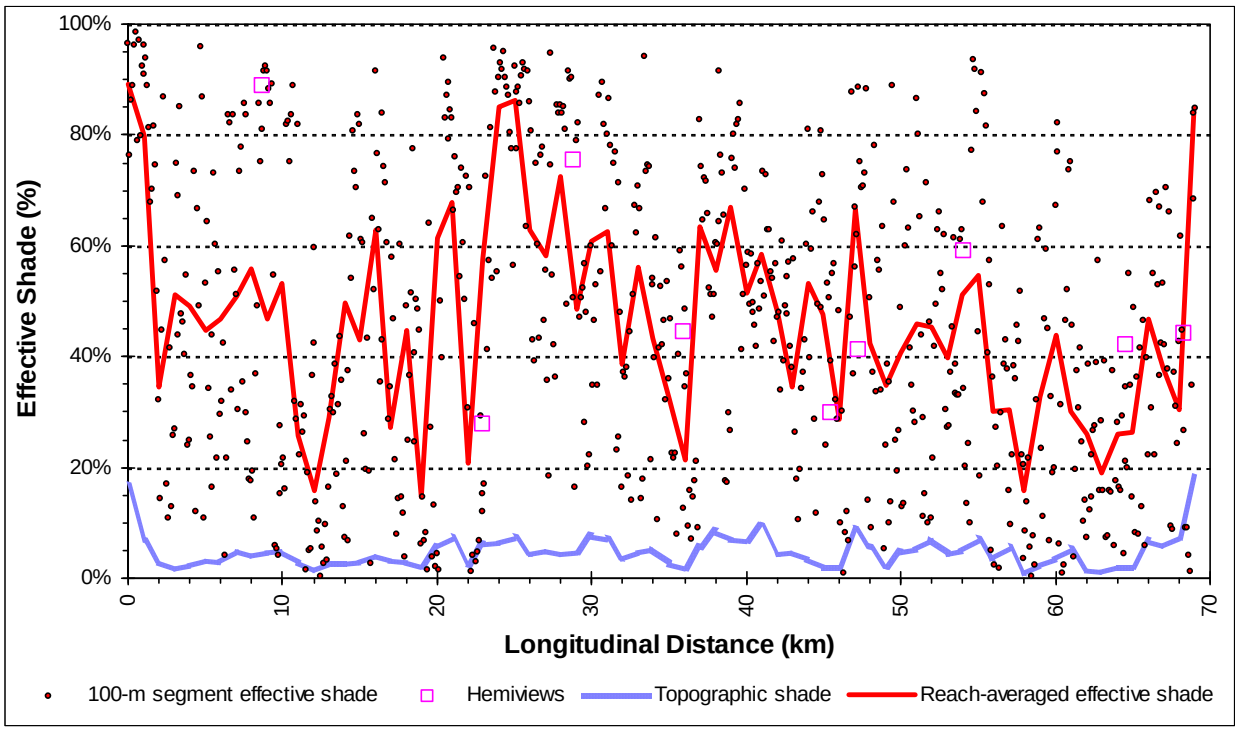


Figure 37. Effective shade based on current vegetation and July 24, 2004, solar characteristics.

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 38), 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.

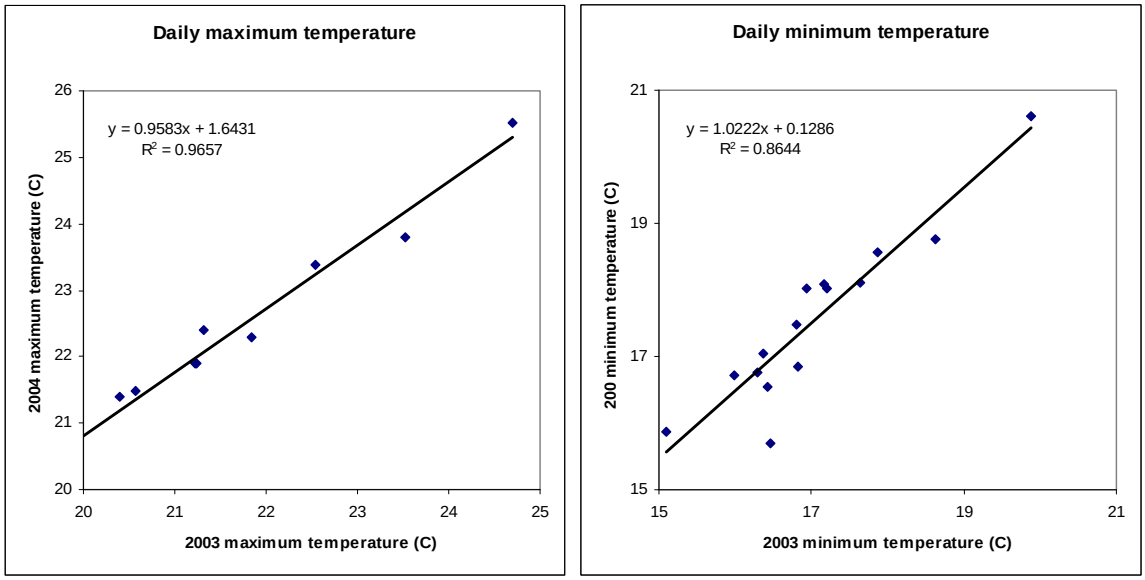


Figure 38. Relationships between 2003 and 2004 7-day average of daily maximum and minimum surface water temperatures in the mainstem of the Deschutes River.

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 39 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.

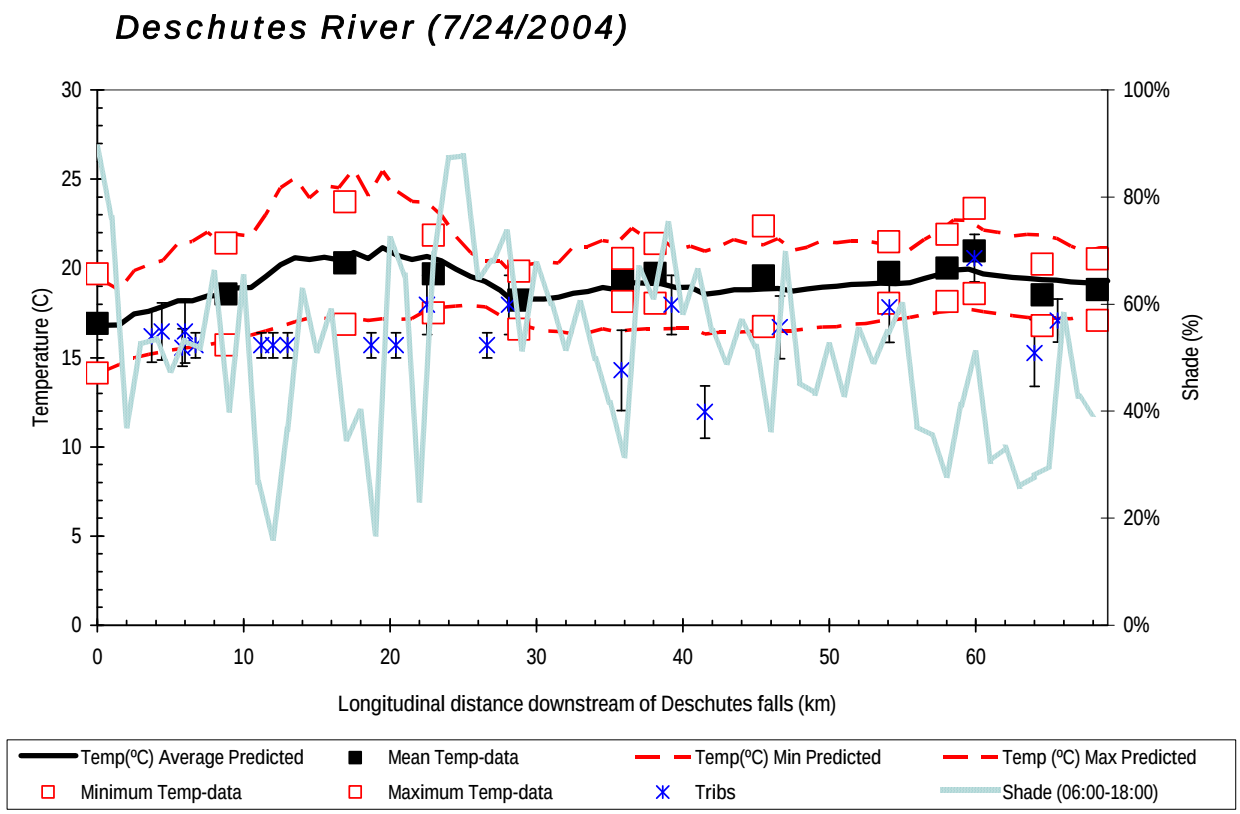


Figure 39. Predicted and observed water temperature in the Deschutes River for the calibration time period (July 21-27, 2004).

From the headwaters at the Deschutes Falls, maximum temperatures increased to a peak between RK13 and RK20 (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 RK20 and RK28, coinciding with increases in shade, groundwater inputs, and flow. Peak temperature remained somewhat constant downstream, but a secondary peak in maximum temperatures near RK60 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 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 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 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.

Diffuse 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 40 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 underpredicted. 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.

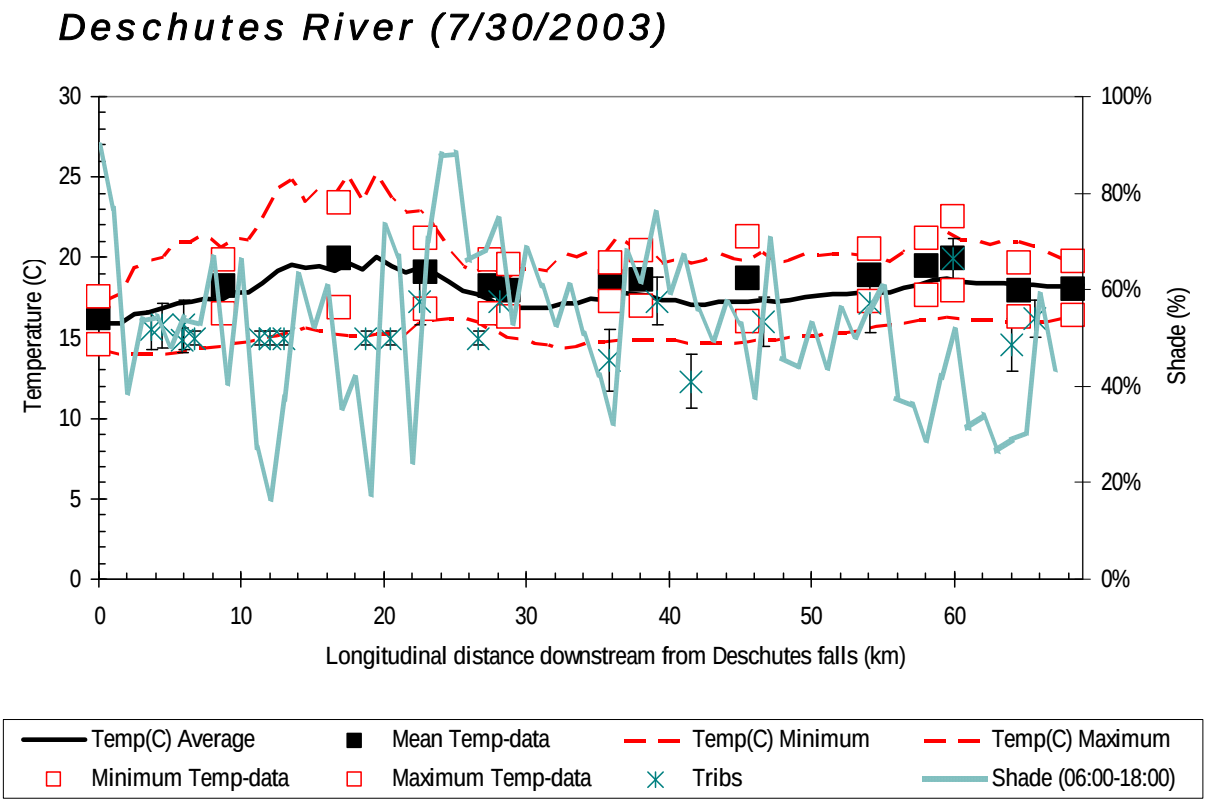


Figure 40. QUAL2Kw model run results for the validation period July 27 through August 2, 2003 (peak daily maximum surface water temperatures).

The TIR survey was conducted after an unusual summer storm had increased flow and cloudy conditions had decreased temperatures along the Deschutes River (Figure 36). 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 41 illustrates that while maximum temperatures were similar between observed data and predicted values, the application consistently underpredicted both the minimum and maximum temperatures in much of the system. Model RMSE was 1.51ºC for maximum values and 2.19 ºC for the combined minimum and maximum values. Conditions were cooler throughout the system in both the observed data and model predictions.

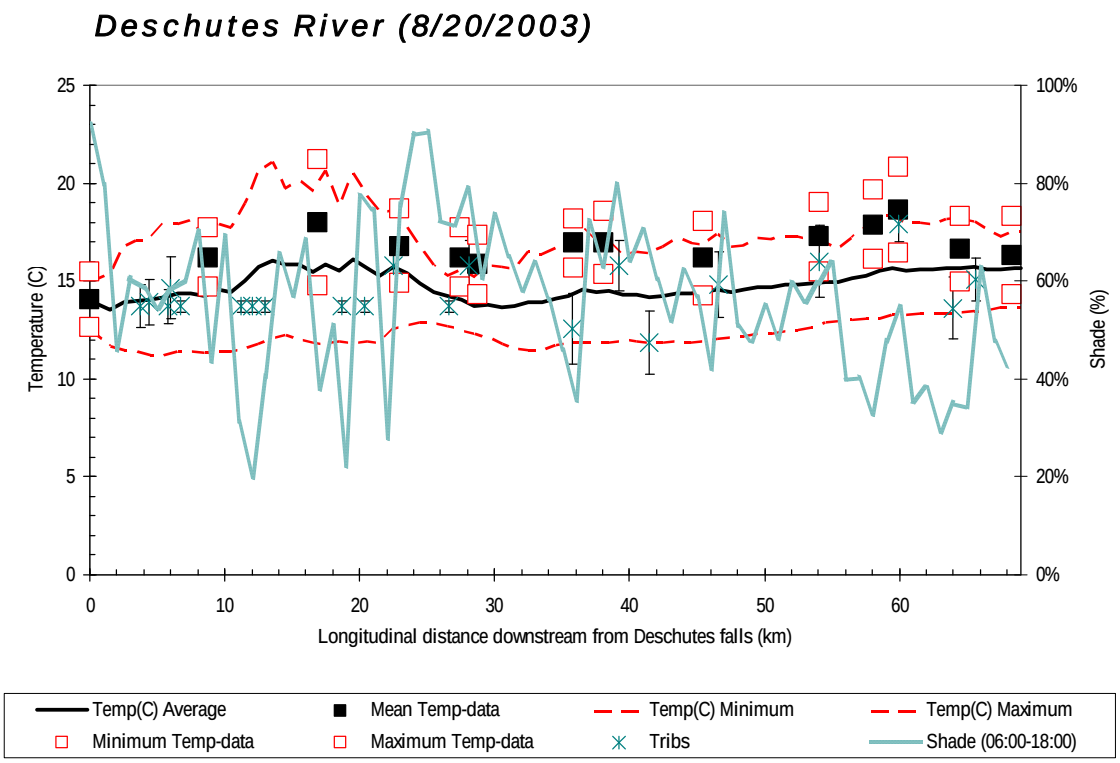


Figure 41. QUAL2Kw model run results for the validation period August 20, 2003 (TIR survey).

The detailed TIR data were smoothed and scaled to the 1-km reaches used in the model. Figure 42 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 the peak temperatures, the survey found temperatures similar to those recorded by the Ecology Tidbits (0.1ºC 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 in situ heterogeneity. The detailed TIR profile also confirms many of the details predicted by the temperature model, including location and magnitude of heating and cooling.

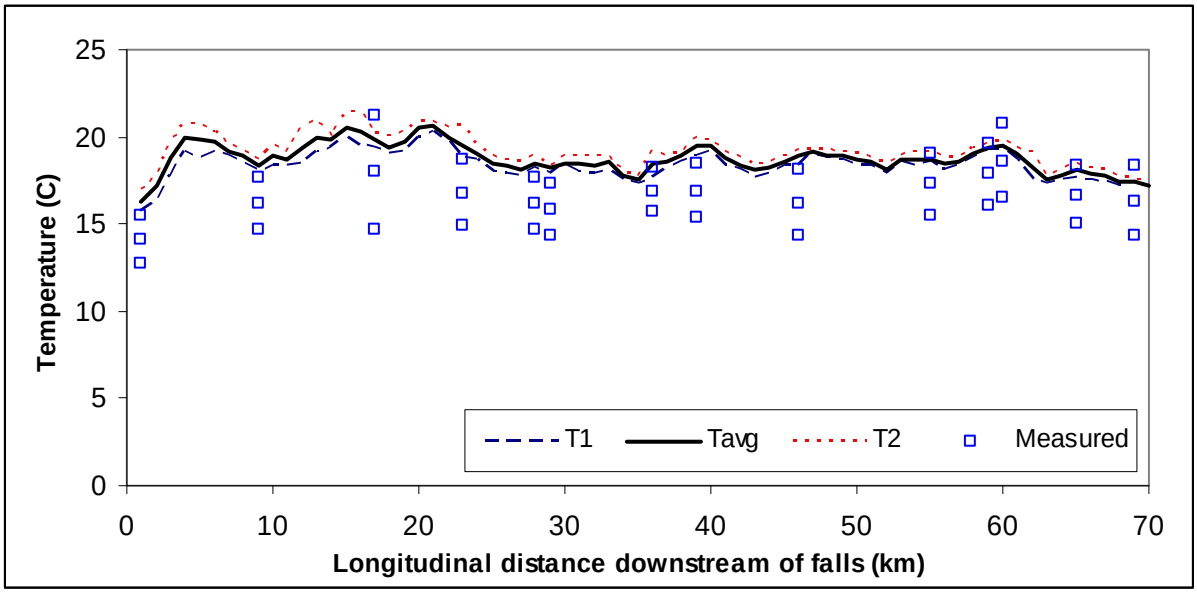


Figure 42. Smoothed TIR results scaled to the river kilometer length scale used in the model. Data were smoothed each river kilometer (Tavg) but the lowest (T1) and highest (T2) instantaneous values within each reach are identified. Measured data include the daily minimum, maximum, and average temperatures 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 RK4 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. 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 43). 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.

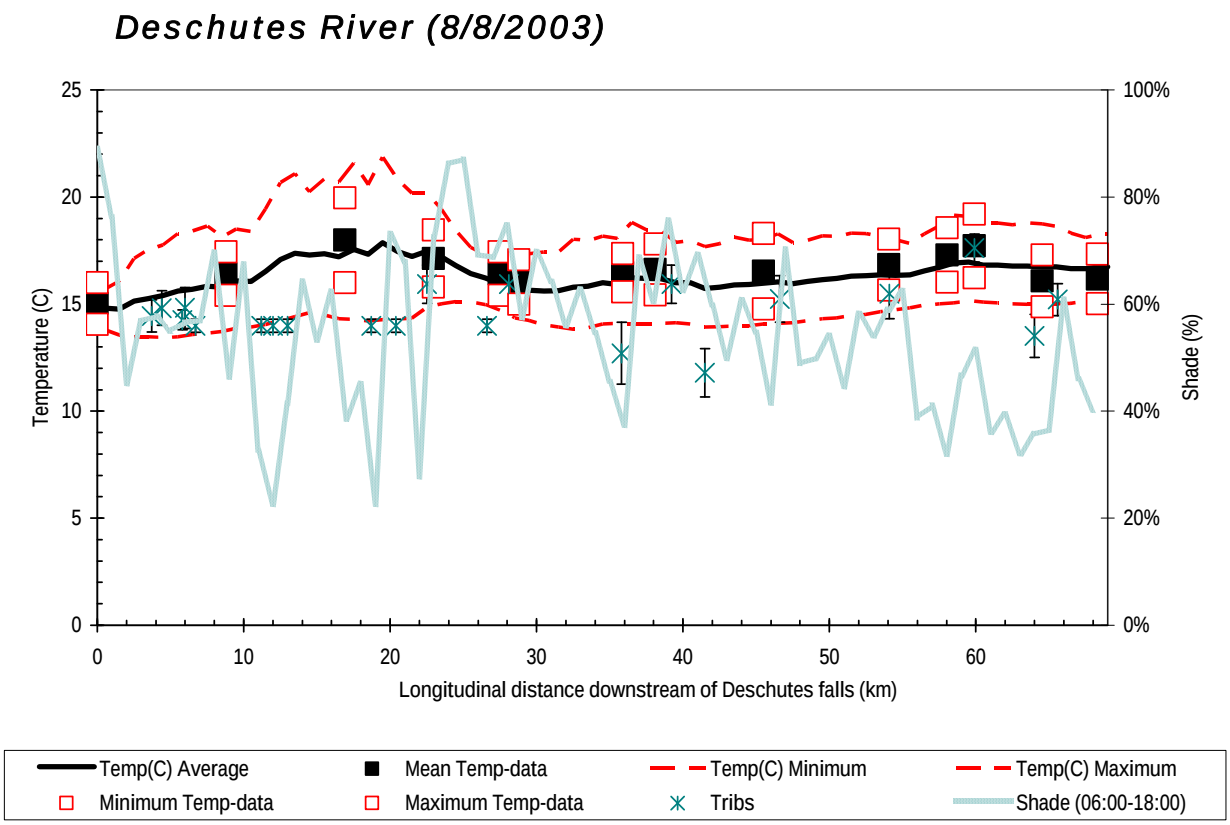


Figure 43. QUAL2Kw model run results for the validation period August 5-11, 2003 (low daily maximum surface water temperatures during non-storm conditions).

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.

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 44). 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 overprediction because the headwater was based on the measured temperature at 13-DES-37.4. Within the peak temperatures between RK12 and RK20 the effect is 0.3ºC. Therefore, while the predicted daily maximum temperatures in the critical stretches of the Deschutes River may be as much as 0.3ºC, basing the temperature on the next downstream station mitigates this influence, and the peak temperatures are not heavily influenced by the assumed relationship between the headwaters and 13-DES-37.4. Values used for the calibration and validation model runs are appropriate.

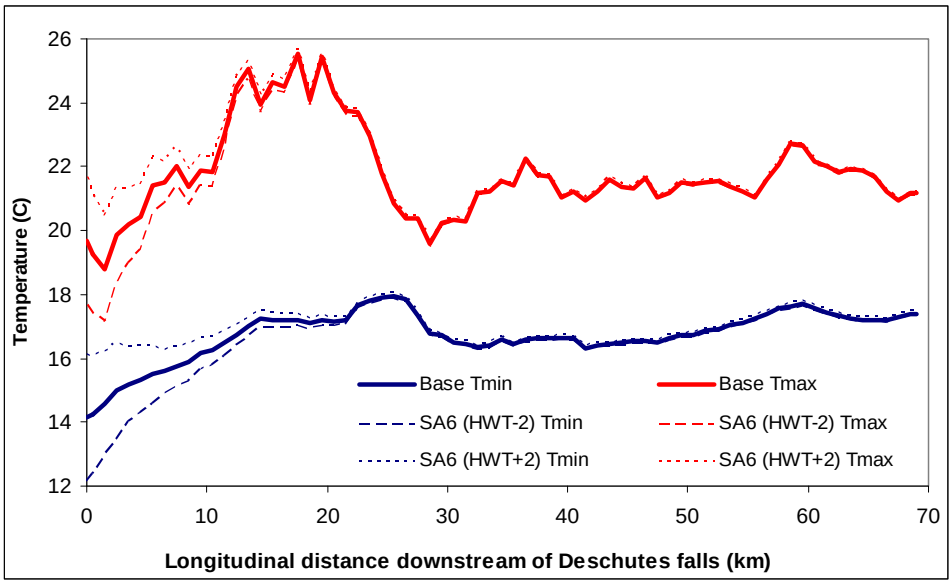


Figure 44. Effect of varying headwater temperature (HWT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

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 45, 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 of their higher flow rates than the other tributaries reaching the Deschutes River below the falls, Mitchell Creek and Thurston Creek have the greatest influence. Between RK12 and RK20, varying the tributary temperatures by up to 2ºC produces a change in predicted maximum temperatures of up to 0.3ºC.

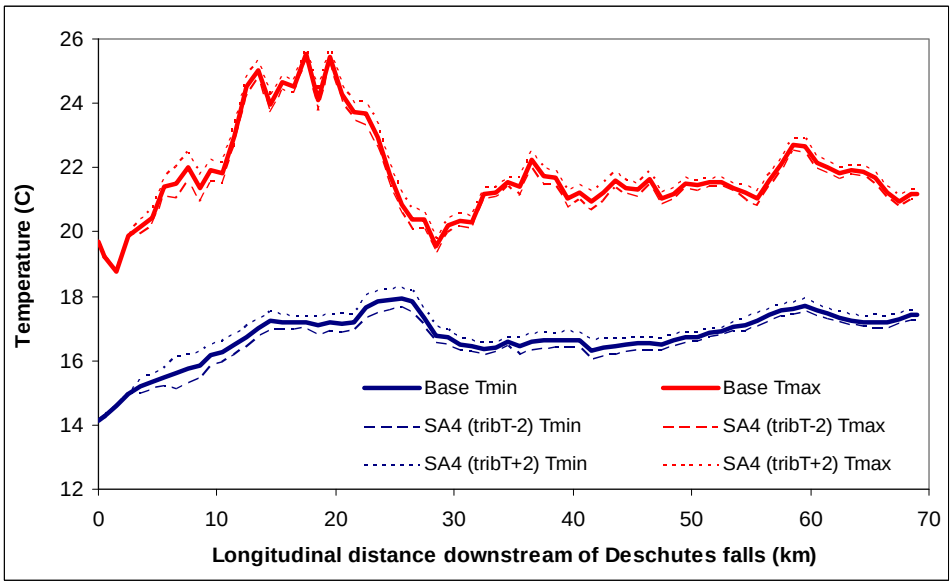


Figure 45. Effect of varying tributary temperature (tribT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

Groundwater temperature was increased and decreased by 2ºC throughout the system (Figure 46). 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 RK23. Upstream of RK23, groundwater is a net loss from the system, so the assumed groundwater temperature does not influence the peak system temperatures between RK12 and RK20. The biggest influence is downstream of RK65 where very high groundwater inflows occurred. Groundwater temperature was used as a calibration parameter.

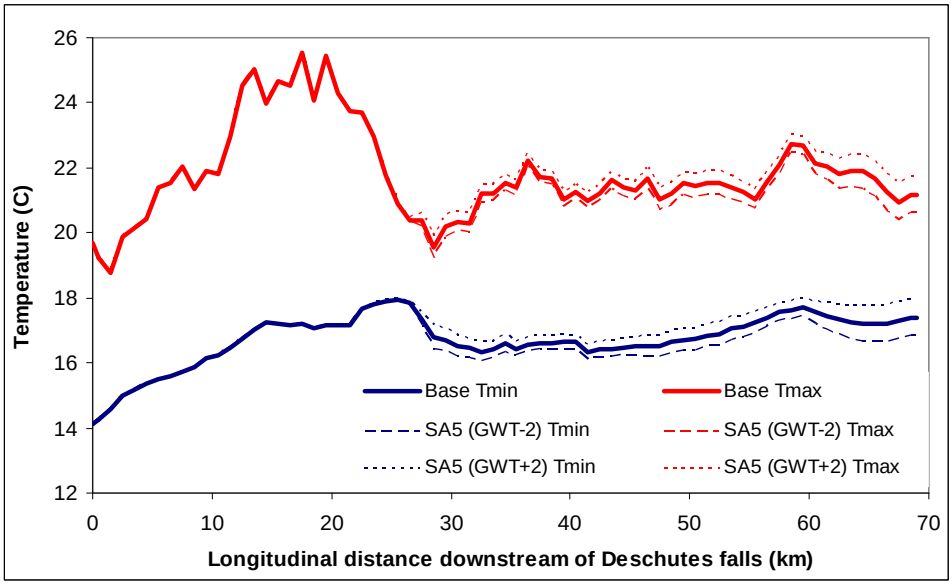


Figure 46. Effect of varying groundwater temperature (GWT) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

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 47, 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 underpredicting peak temperatures between RK12 and RK20 in the calibration run, since these are sensitive to moderate changes in air temperature.

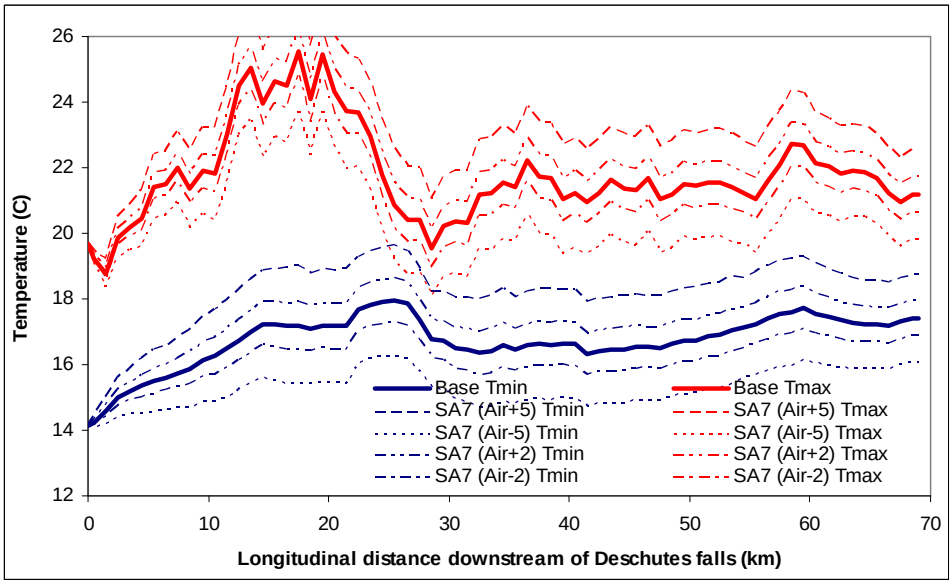


Figure 47. Effect of varying air temperature on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

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 RK12 and RK20, 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 48. Minimum temperature is not sensitive to bottom width.

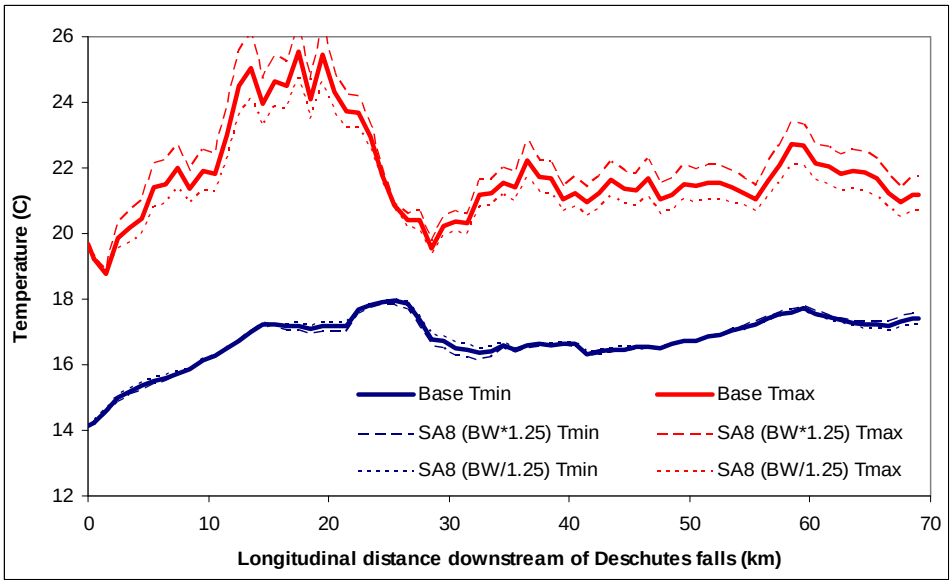


Figure 48. Effect of varying channel bottom width (BW) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

Figure 49 presents the effect of changing vegetation characteristics on shade predicted using the Shade 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 RK12 and RK20. Decreasing the density for all forested categories to 90% and 80% increases 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.

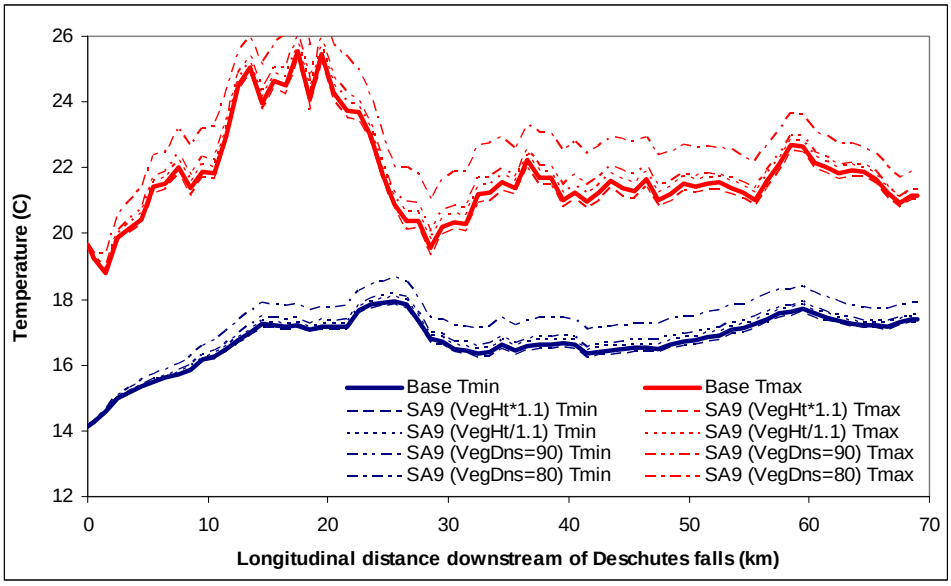


Figure 49. Effect of varying vegetation characteristics (height [Ht] and density [Dns]) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

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. While the faster transport time would decrease exposure time to solar radiation, it also reduces 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 increases the interaction with the hyporheic zone, producing lower maximum temperatures.

In the sensitivity analysis, Manning's n was changed to 0.11 and 0.35 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 RK12 and RK20 (Figure 50). Increasing Manning's n to 0.35 slows down the flow in the system, increasing the travel time to

8.3 days, increasing the interaction with the hyporheic zone, and decreasing peak temperatures by an average of 0.8ºC and as much as 1.7ºC between RK12 and RK20.

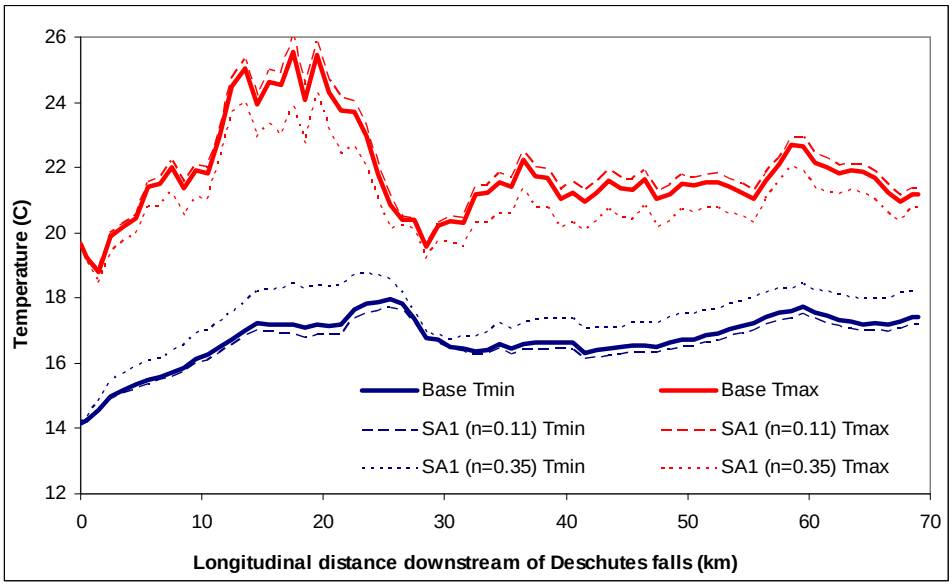


Figure 50. Effect of varying Manning's n on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

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 50 cm value used in the calibration, which changed predicted maximum temperatures by as much as 0.5ºC within the critical area between RK12 and RK20 (Figure 51). 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 RK12 and RK20, while doubling it would decrease peak temperatures by 0.9ºC.

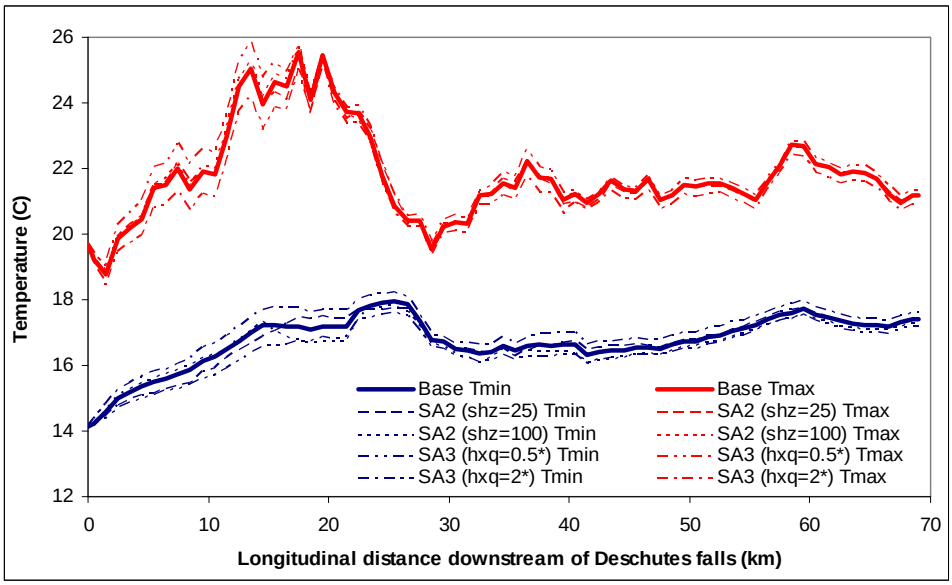


Figure 51. Effect of varying hyporheic zone thickness (shz) and exchange flow (hxq) on mainstem Deschutes River temperatures for the July 20-27, 2004 calibration period.

In summary, the Deschutes River temperature calibration, while sensitive to some parameters, is robust. Within the critical area of peak temperatures between RK12 and RK20, peak temperatures are most sensitive to air temperature, channel width, hyporheic zone exchange flow, and Manning's n and less sensitive or not sensitive at all to headwater temperature, tributary temperatures, groundwater temperature, current vegetation characteristics, and hyporheic zone active depth. The system 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 RK12 and RK20 produced maximum values within 0.6ºC of the assumed system value. Therefore, while the area between RK12 and RK20 is sensitive to air temperatures, the region is not expected to produce air temperatures more than 2ºC or 5ºC above the assumed value.

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. The EPA's current regulation defines loading capacity as "the greatest amount of loading that a waterbody 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 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 seven-day average flow that occurs 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 at the Deschutes riparian Tidbits and at the airport for the calibration and validation time periods. For the period 1996-2007, the annual maximum 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 the period 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 headwater 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). Portions of the Deschutes River floodplain have very wide near-stream disturbance zones, including areas more than 30 m wide. 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 also the bottom within 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 Offut Lake and 17.5ºC downstream of Offut Lake) to quantify the effect on the mainstem of the Deschutes River. [SCEN4A without channel changes and SCEN4B with SCEN3C channel changes]
- **Increased baseflows**. The historical 7Q10 conditions provided by Kresch (2003) were evaluated. [SCEN5A includes historical 7Q10 flows in addition to SCEN4B channel, headwater, and tributary characteristics]

Figure 52 summarizes daily maximum water temperatures under current vegetation and the changes possible under various scenarios, while Figure 53 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 16 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."

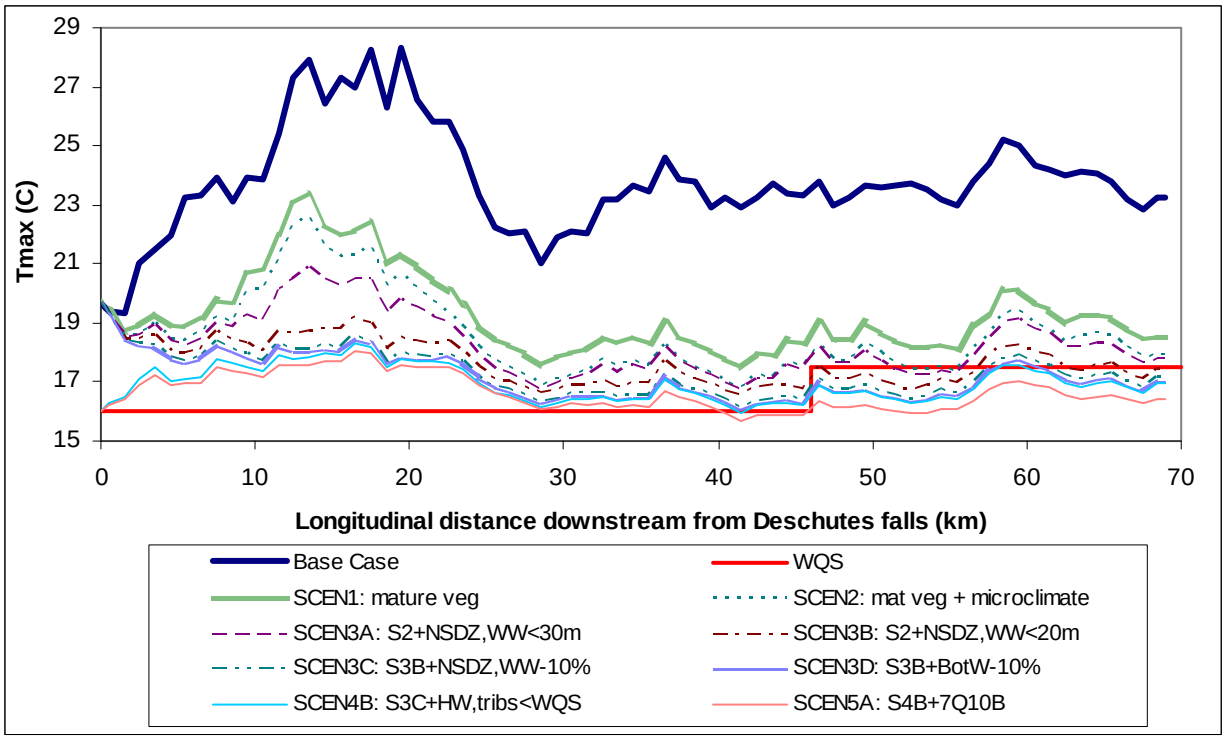


Figure 52. Predicted daily maximum water temperature in the Deschutes River for critical conditions under current conditions and various scenarios.

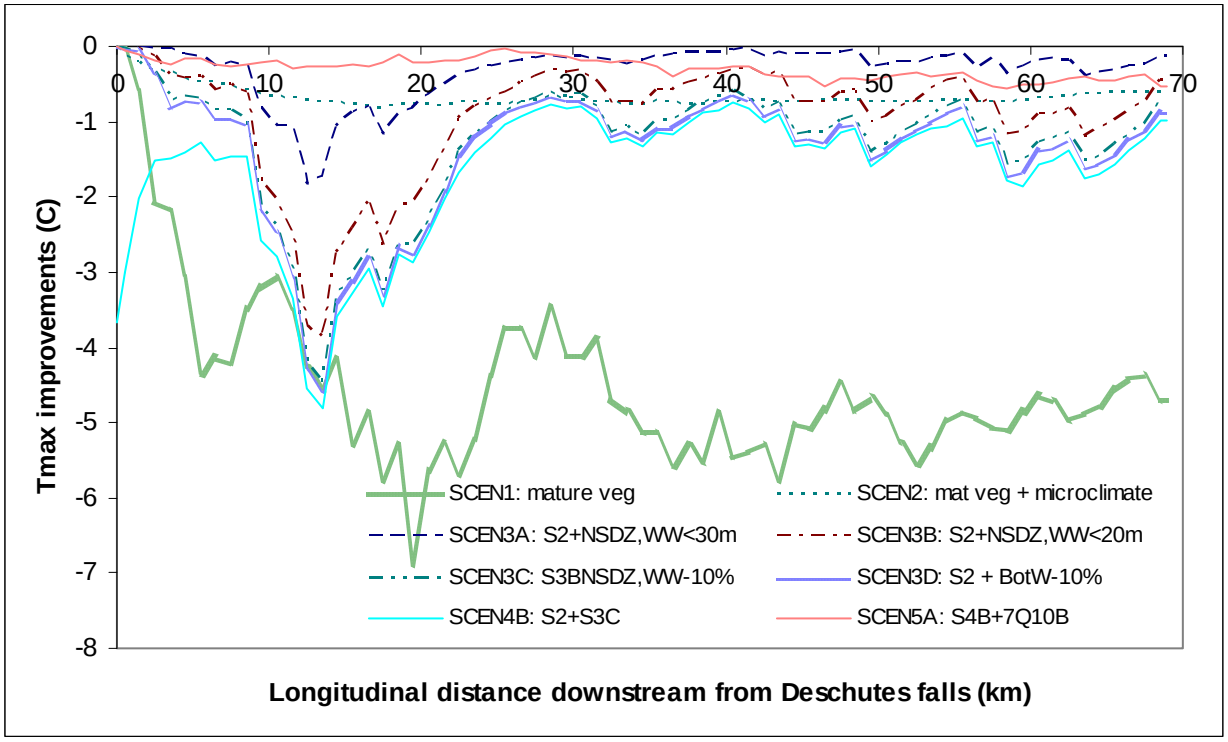


Figure 53. Decreases in peak temperature under various critical conditions scenarios by river reach.

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).

Several scenarios related to channel characteristics were evaluated. The near-stream disturbance zone (NSDZ) is as wide as 35 m in 1000-m average reaches and over 50 m in 100-m segments where extensive gravel bars are visible on the aerial photos. Scenario 3A evaluated conditions if neither the NSDZ nor the wetted width were 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 54 presents the wetted width and NSDZ for each scenario.

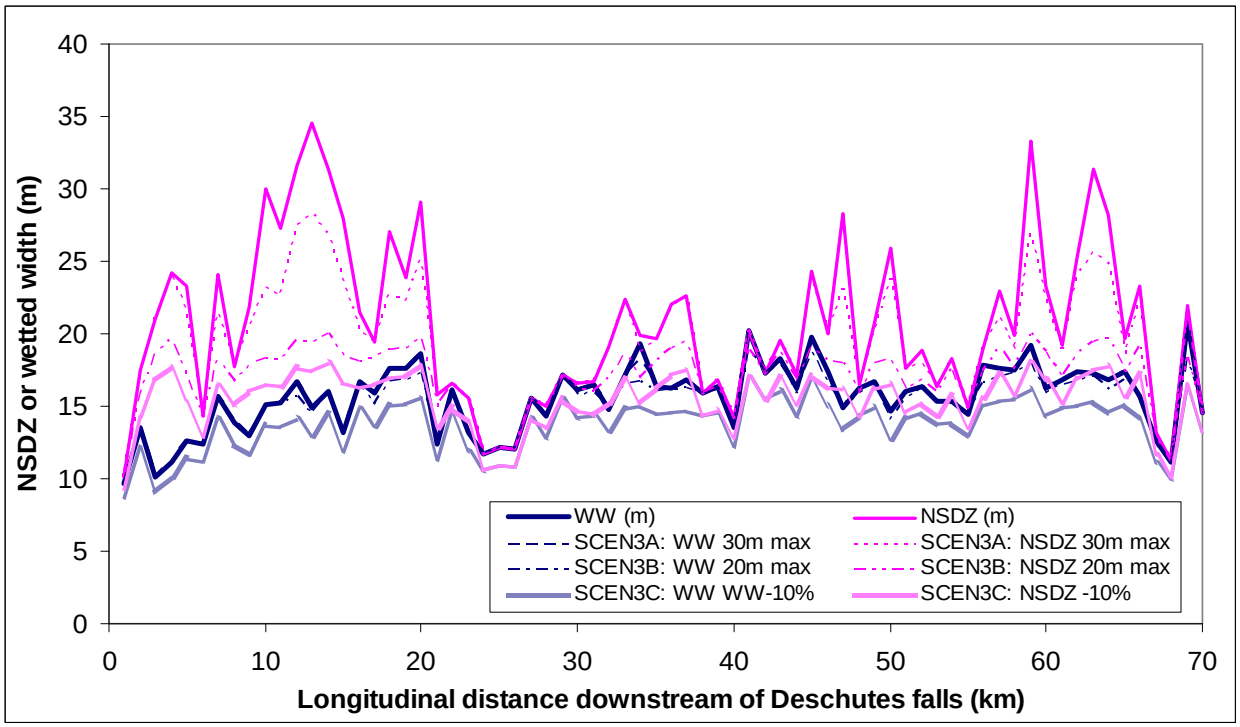


Figure 54. NSDZ and wetted width under current conditions and several scenarios.

The headwaters and tributaries have temperatures above the water quality standards. Scenario 4 evaluated mainstem Deschutes River temperatures when the headwaters and tributaries had peak temperatures no greater than the 16ºC water quality standard upstream of Offut 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 23 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 23. 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 Offut Lake (16ºC)		Downstream of Offut 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 4A (Scenario 2 with HW and tributaries = WQS)	22.09	18.19	-0.41	0 km	0%	5 km	7%	1 km (1%)
Scenario 4B (Scenario 4A + Scenario 3C)	18.34	16.93	-1.67	1 km	1%	22 km	32%	0 km (0%)
Scenario 5A (Scenario 4B + historical 7Q10)	18.07	16.64	-0.29	6 km	9%	24 km	35%	0 km (0%)

* Compared with Scenario 2

Figure 55 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.

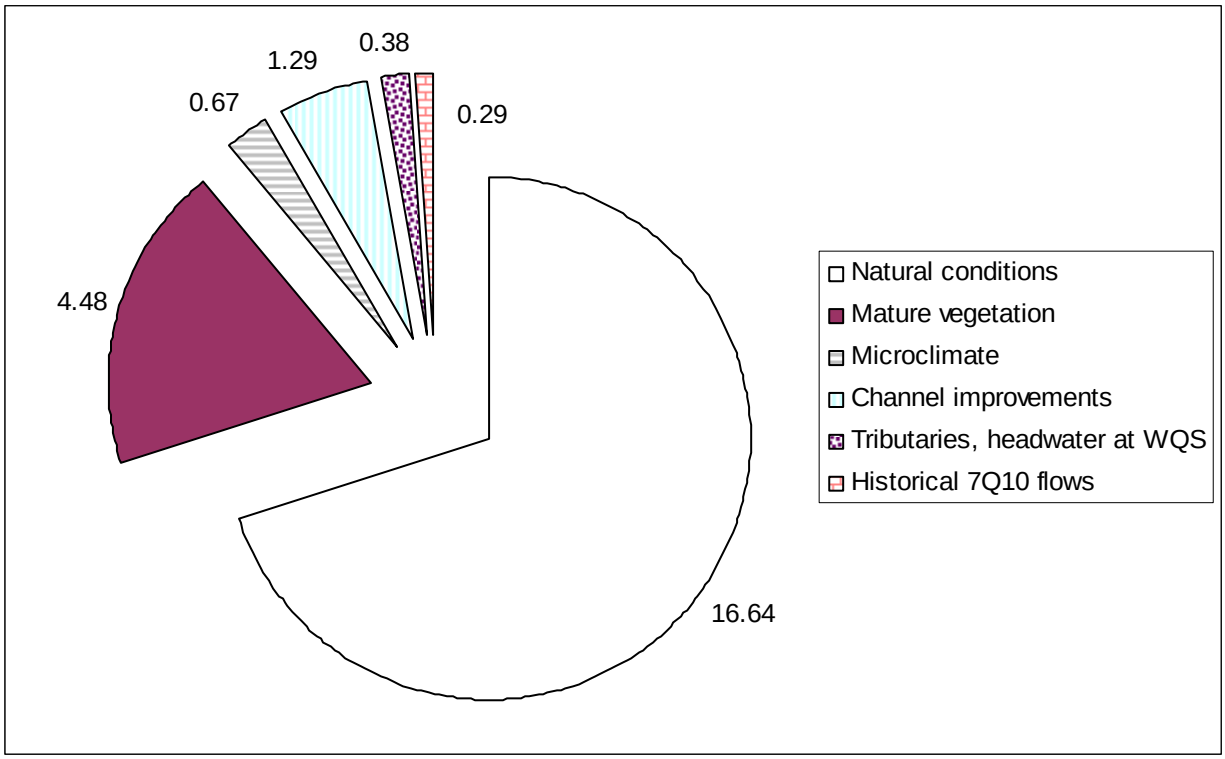


Figure 55. Temperature improvements (system-wide average Tmax ºC) associated with various management strategies.

Percival Creek and Black Lake Ditch Loading Capacity

Loading capacity for the 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 the QUAL2Kw model. 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 56).

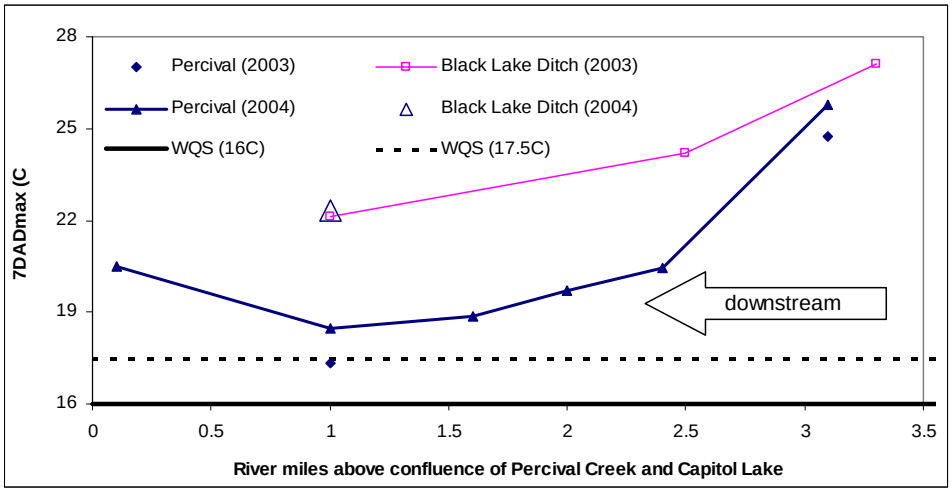


Figure 56. Temperature profiles in Percival Creek and Black Lake Ditch.

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). Figure 57 and Figure 58 summarize the effective shade deficit, and solar heat load allocations 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.

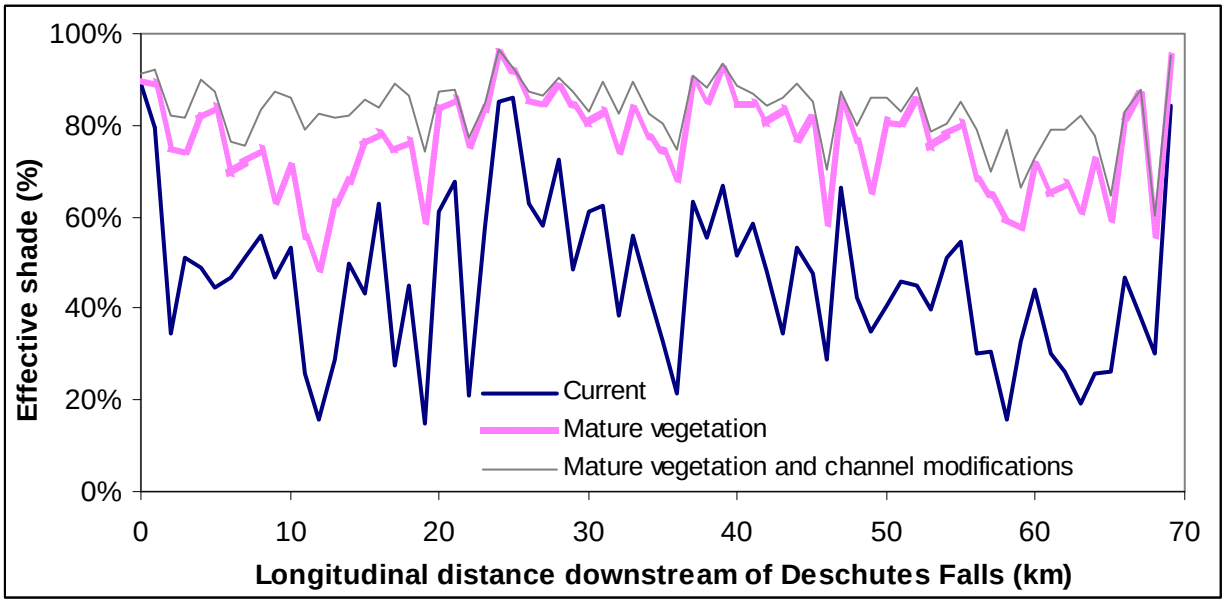


Figure 57. Effective shade targets for the Deschutes River with full mature riparian shade and with supplemental channel modifications.

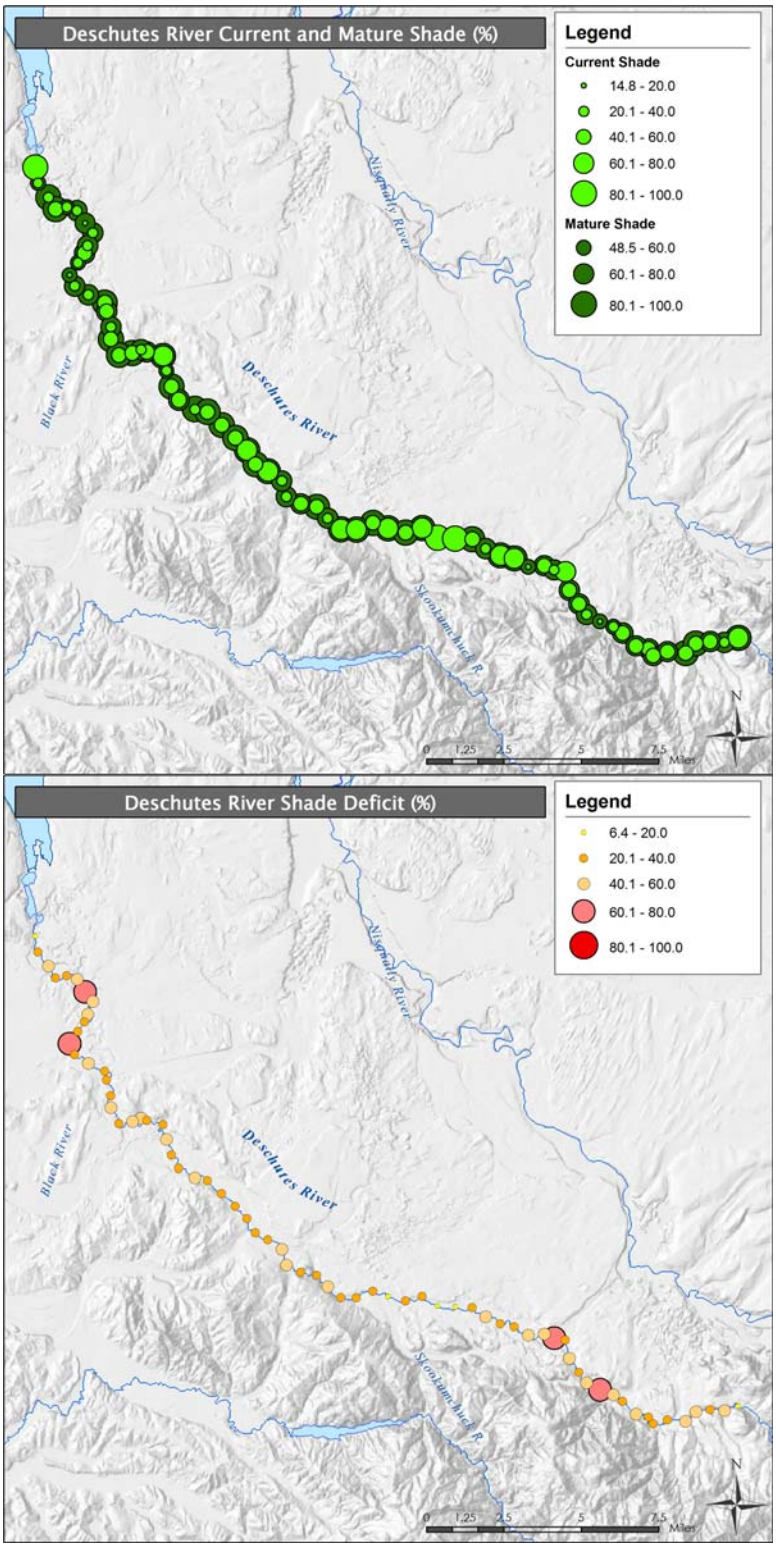


Figure 58. Shade from current and mature vegetation (top) and shade deficit (bottom) along the Deschutes River.

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 24. 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*.

Table 24. Conditions in tributaries to the Deschutes River, including temperature load allocations for streams that do not meet the water quality standards.

Deschutes River km	Station	Description	7DADmax		WQS	Meets WQS?	Target (ºC)	Load target
			2003 (ºC)	2004 (ºC)				
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		*
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 Highway 507	15.65		16.0	yes		
41.5	13-SIL-00.4	Silver Spring near mouth	14.00		16.0	yes		
46.5	13-DES-13.4spr	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		

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 Section M-2 of the Forests and Fish Report (USFWS et al., 1999). 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 United States 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 RK12 and RK20 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 eventual improvement in channel characteristics. See the Fine Sediment TMDL 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 modeling demonstrated would improve peak temperatures by enhancing hyporheic interactions even though higher residence time would increase time exposed to solar radiation.
- 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 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 for additional recommendations.

Deschutes River Wasteload Targets

No numeric wasteload targets for heat were recommended for the 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 the Department of Ecology to date, the highest temperatures used for critical conditions assessments 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. Dairies are not expected to contribute heat loads, except from reduced riparian shading, and no additional permit requirements are recommended.

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 from heating of Black Lake and wetland complexes. While temperatures decrease downstream because of increased cool groundwater inputs, no part of either branch meets the water quality standards, 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 human 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 59 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 60 presents the current and mature vegetation and effective shade deficits throughout the Percival Creek system.

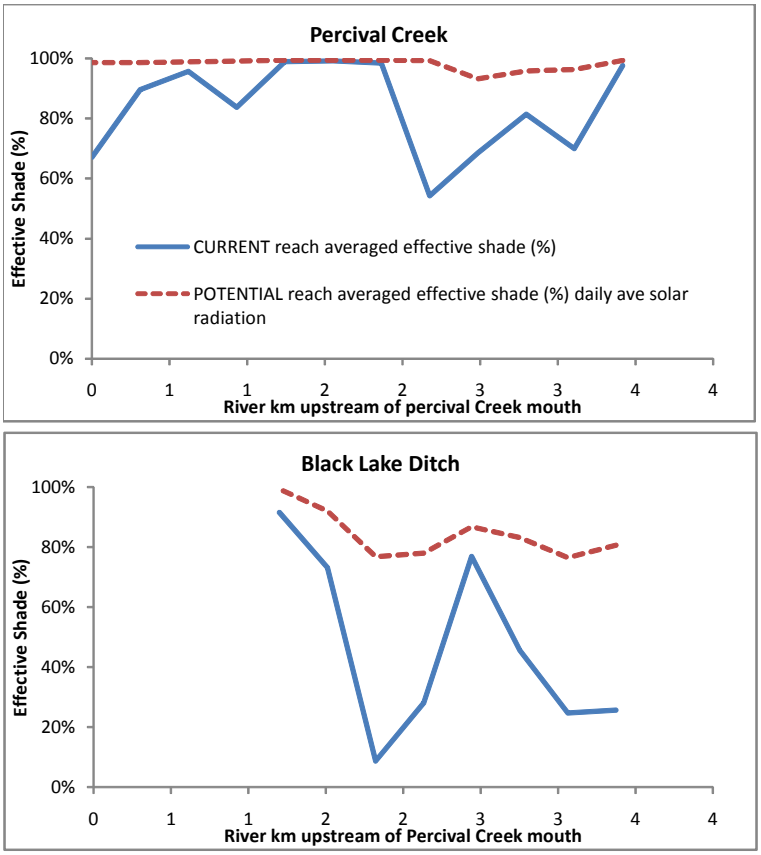
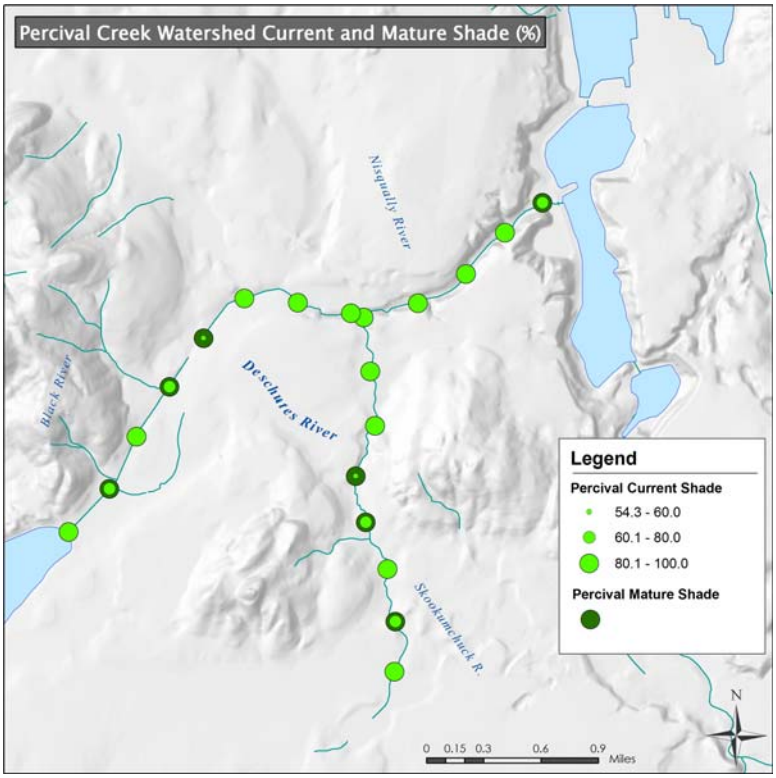


Figure 59. Percival Creek watershed effective shade targets.



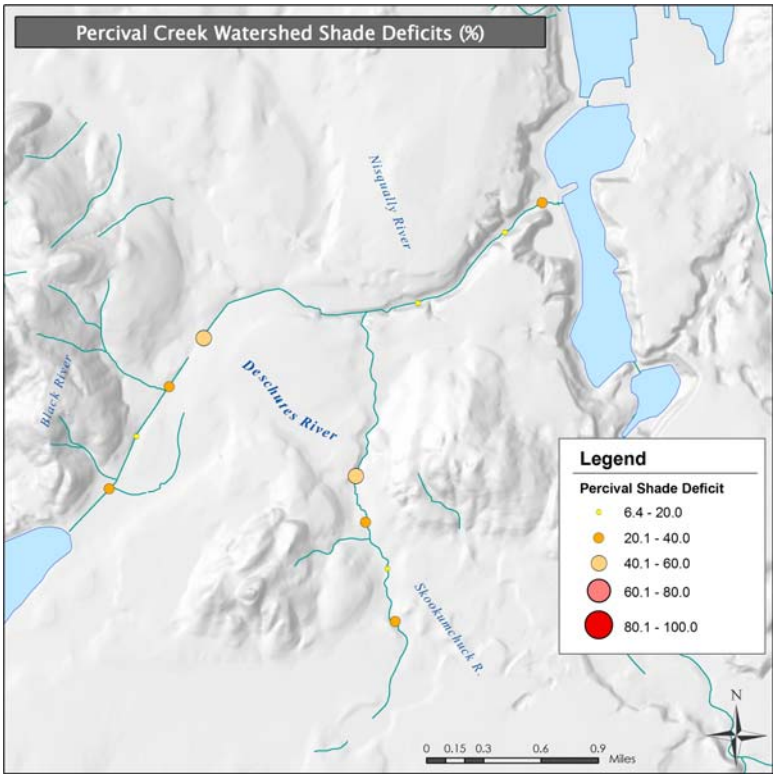


Figure 60. Shade from current and mature vegetation (top) and shade deficit (bottom) along Percival Creek and Black Lake Ditch.

In addition to the numeric load allocations 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 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 waterbodies downstream of the facilities.

Conclusions and recommendations

QUAL2Kw models simulated the heat budget and water temperatures of the Deschutes River and its tributaries under varying conditions. The models reproduced monitoring data under a variety of solar radiation conditions, with square root of the mean square error (RMSE) of 0.85ºC for daily maximum temperatures for the calibration period and 0.8 to 0.9ºC for 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, the significant decrease 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). 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 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 Allocations. 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. Modeling confirmed that increasing channel complexity, as represented by higher Manning's roughness coefficient, would decrease peak temperatures due to enhanced hyporheic exchanges, even with greater exposure to solar radiation.

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. Establishing instream flows and regulating groundwater withdrawals are managed through separate regulatory authorities, and TMDLs do not establish flows. Drinking water is a use to be protected under WAC 173-201(A) 600. This TMDL does not regulate 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 store stormwater in groundwater to 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.
- 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.
- 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 subwatershed should be evaluated for existing hydraulic modifications that could be altered to decrease downstream temperatures.
- The Deschutes River downstream of 1000 Road through Vail Cutoff Road SE is the most sensitive part of the river. Future development and management should be conditioned to prevent impacting the riparian area, withdrawing groundwater or decreasing groundwater recharge to prevent further degradation of those areas already not meeting standards and to 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 result in the receiving water temperatures to rise 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 13-DES-37.4 and 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 improvements temperature could occur at intervals of 5 to 10 years, given the need to establish riparian vegetation and the relatively slow growth.

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 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 13-DES-37.4 and 13-DES-28.6, located between 1000 Road and Vail Cutoff Road SE.

Future growth within the Percival Creek watershed should maintain intact riparian vegetation and restore degraded areas.

Margin of safety

The margin of safety accounts for uncertainty in pollutant loading or waterbody 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 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. 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. 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 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. The pattern was confirmed by detailed monitoring, which also found critical conditions 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 the lowest DO levels in a single day generally occur near sunrise and highest pH in late afternoon. Therefore, critical conditions for the Deschutes River are morning DO and afternoon pH in early August.

Critical conditions were evaluated as 7Q10 streamflow and 90th percentile air temperature.

Calibration and Confirmation of Deschutes River QUAL2Kw model

The calibration time period uses the available in situ continuous DO and pH data in the mainstem of the Deschutes River collected when the mouth of the Deschutes River historically had the lowest annual DO and peak pH levels. Flows were similar for this time period as for 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 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. The values and process are described above for the temperature model. All were updated for the mean conditions during the DO calibration time period of August 10-12, 2004. 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 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 most measured nutrient or DO parameters. The weighting factors were used to normalize the RMSE, and the fitness function is the inverse of the weighted-average RMSE.

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 25 lists rate constants with high variability (>50% between successive model runs). Other rate constants exhibited low or moderate variability between successive runs. If a rate constant was near the upper or lower limit or varied by >50% from the previous model run, an initial value was selected near the middle of the range for the next application of the genetic algorithm.

Table 25. 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 gross groundwater inputs to the system. Groundwater nutrient concentrations were higher than surface water values. Therefore, upstream of RK23, approximately 50% of the net groundwater inflow was recirculated within the reach, with nutrient inputs representative of groundwater. Groundwater nitrate concentrations were calibrated using the genetic algorithm.

Figure 61 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 underpredicted 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 overpredict minimum DO concentrations. The pH model characterized the highest maximum pH in the system but consistently overpredicted peak pH values at other locations and did not reflect the decline in peak pH at RK23. The subsequent confirmation, described below, confirmed the predicted decline in pH near RK28, and the difference in the predicted value and calibration data at RK23 was not merely an offset longitudinally,

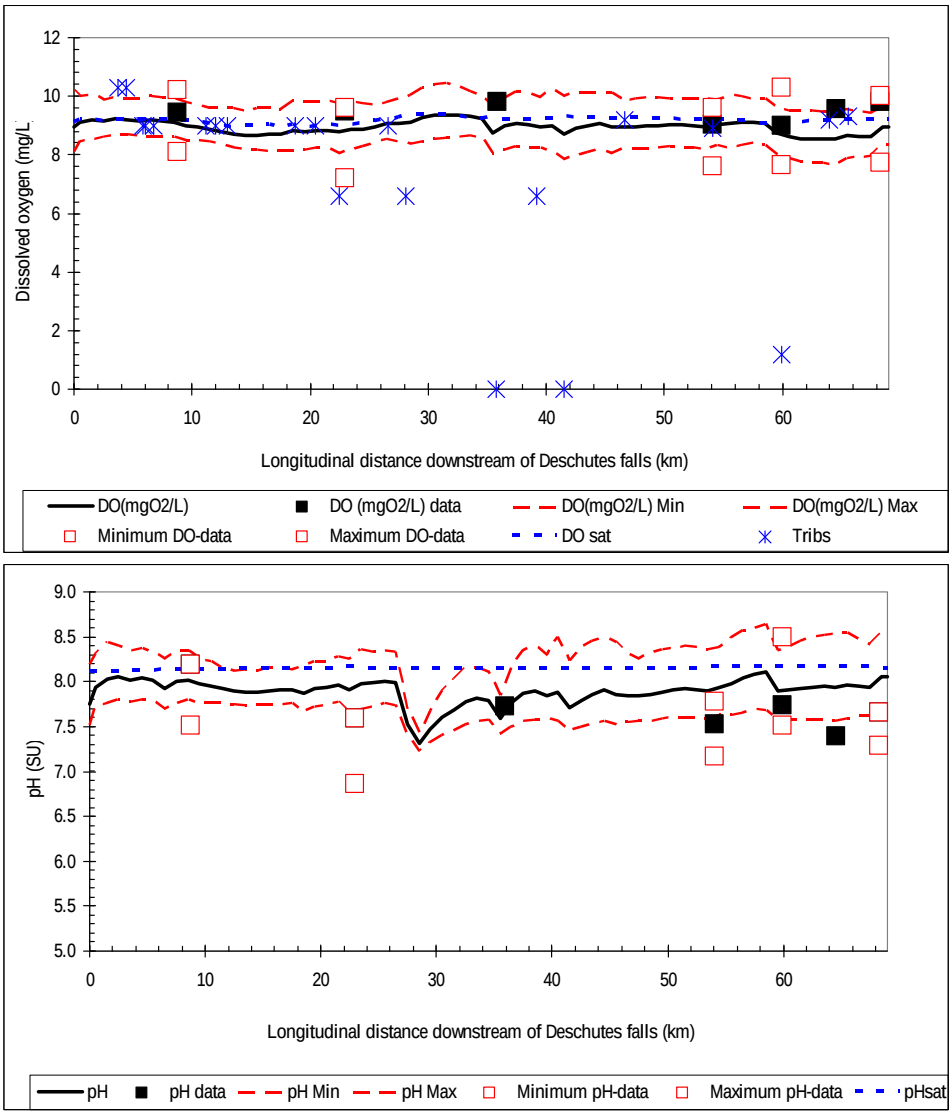


Figure 61. Predicted and observed DO and pH in the Deschutes River for the calibration time period (August 10-12, 2004).

Figure 62 presents the longitudinal profile of nitrogen and phosphorus species in the mainstem, tributaries, and groundwater. Nitrate plus nitrite increased in a downstream direction, consistent with the data, and the 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. Predicted periphyton concentrations were close to values measured in other western Washington streams (Mohamedali and Lee, 2008; Appendix D indicates periphyton values of 2 to 10 g-algae/m^2 with one site up to 23 g-algae/m^2), but no data were collected during the 2003-2004 monitoring period (Figure 63). Detritus concentrations also were low and close to the estimated values, which were well below the total organic carbon (TOC) detection limit of 1.0 mg/L. Overall, the model describes the DO, pH, and nutrient variations in the Deschutes River.

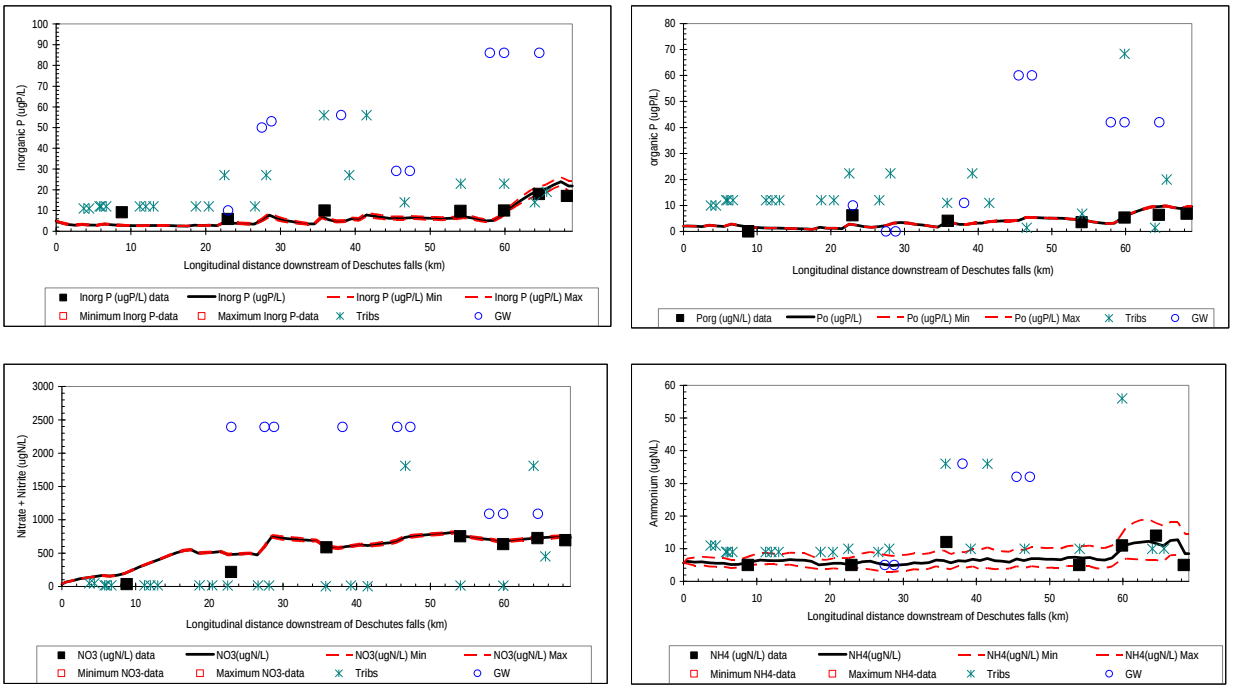


Figure 62. Predicted and observed nitrogen and phosphorus concentrations along the Deschutes River for the calibration time period (August 10-12, 2004).

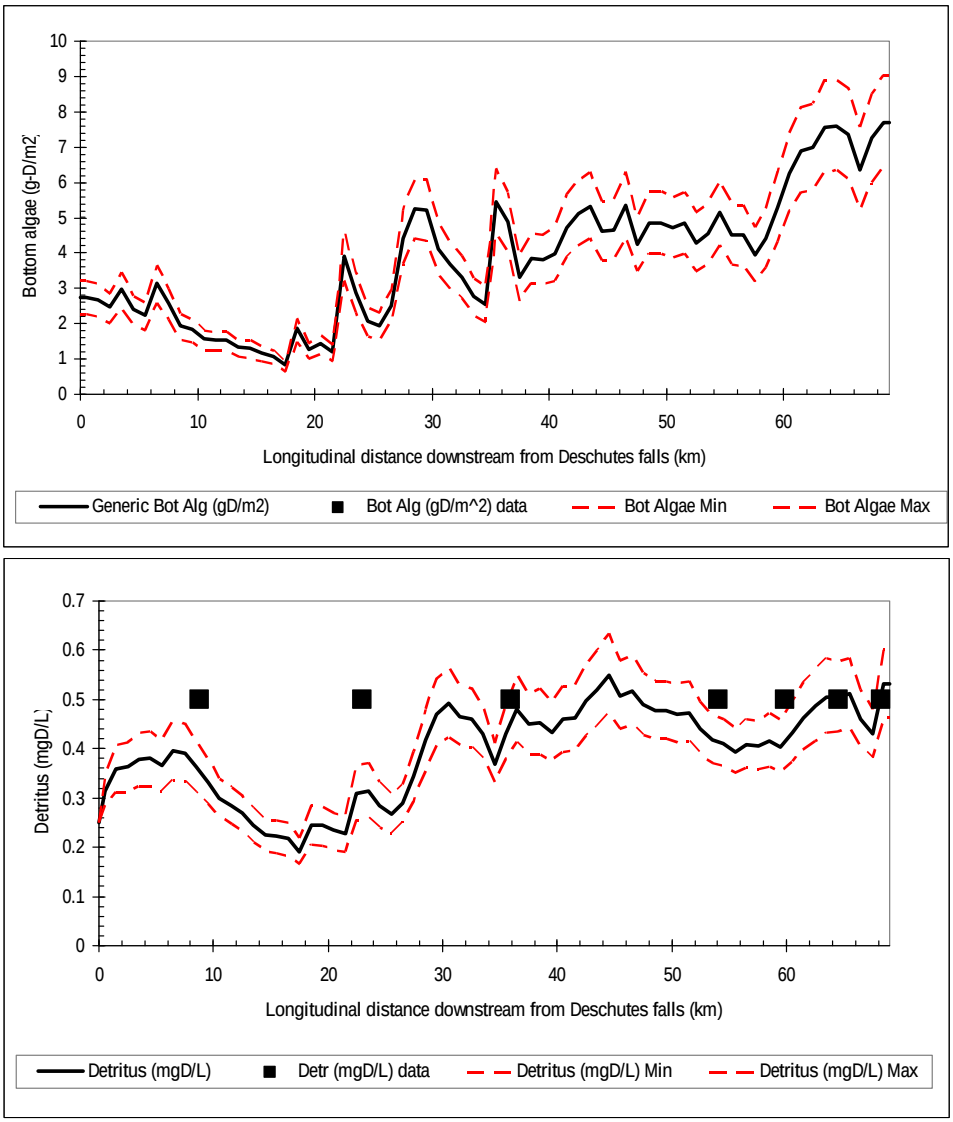


Figure 63. Predicted bottom algae and detritus concentrations along the Deschutes River for the calibration time period (August 10-12, 2004).

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 data 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, however, the daily minimum values were not captured and the model likely overestimated the minimum DO concentrations (Figure 64). The model generally overestimated the peak pH values. While the model characterized pH

fluctuations very well near RK30, the model overestimated maximum pH at RK20 and downstream of RK50.

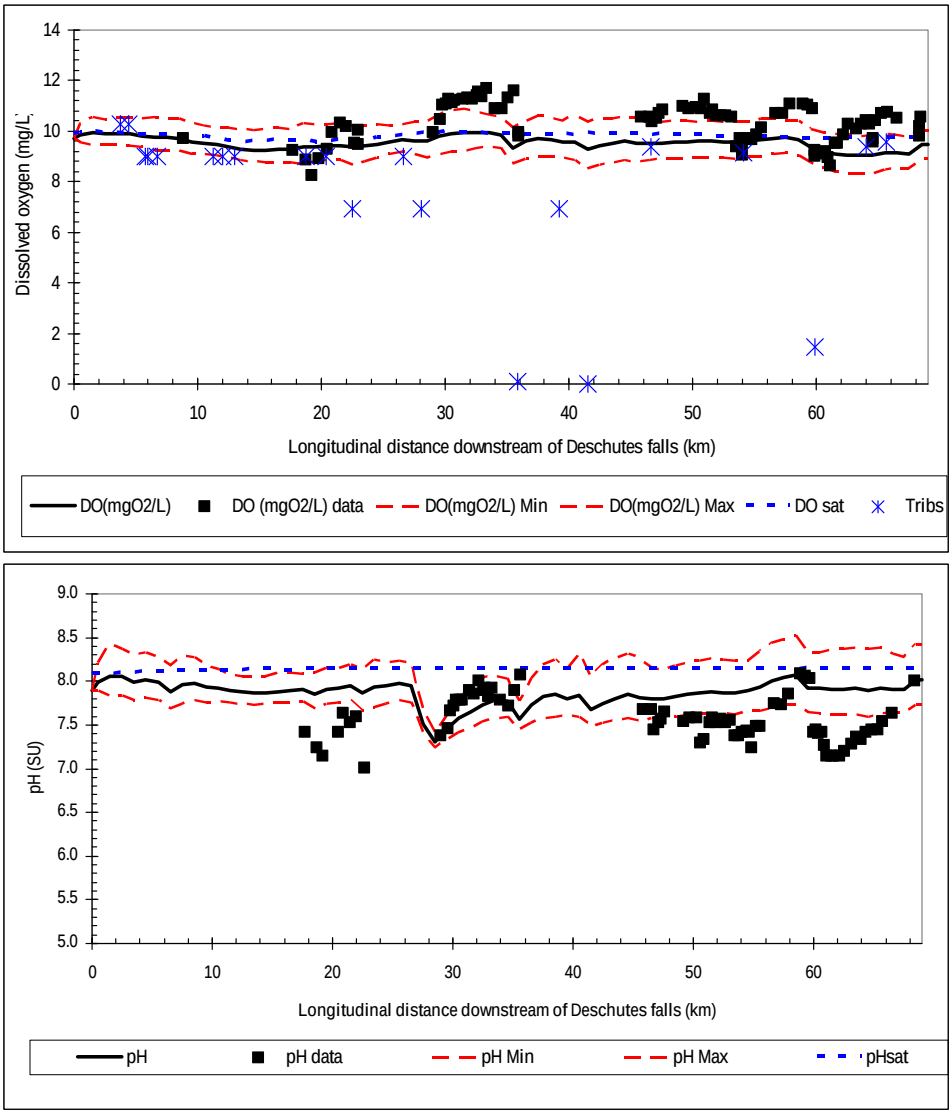


Figure 64. Predicted and observed DO and pH in the Deschutes River for the stream walk survey (August 11-15, 2003).

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 65), as were bottom algae and detritus (Figure 66).

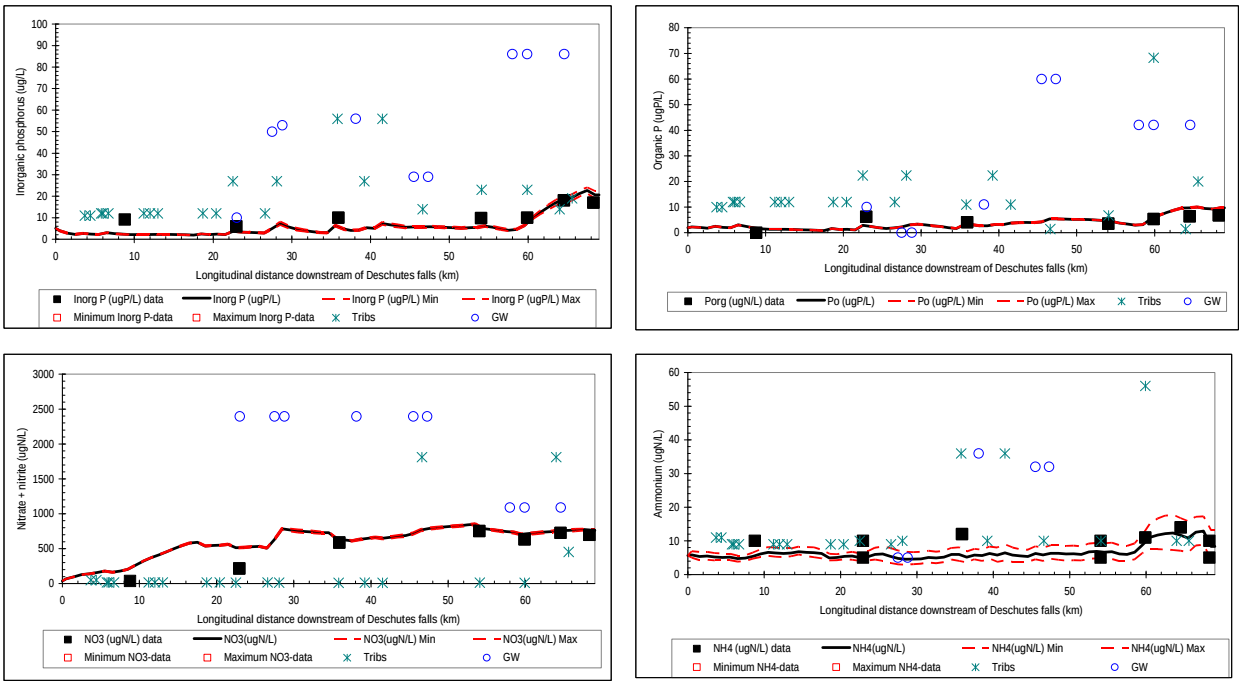


Figure 65. Predicted nutrient levels in the Deschutes River for the stream walk survey (August 11-15, 2003). Measured nutrient concentrations are from August 2004.

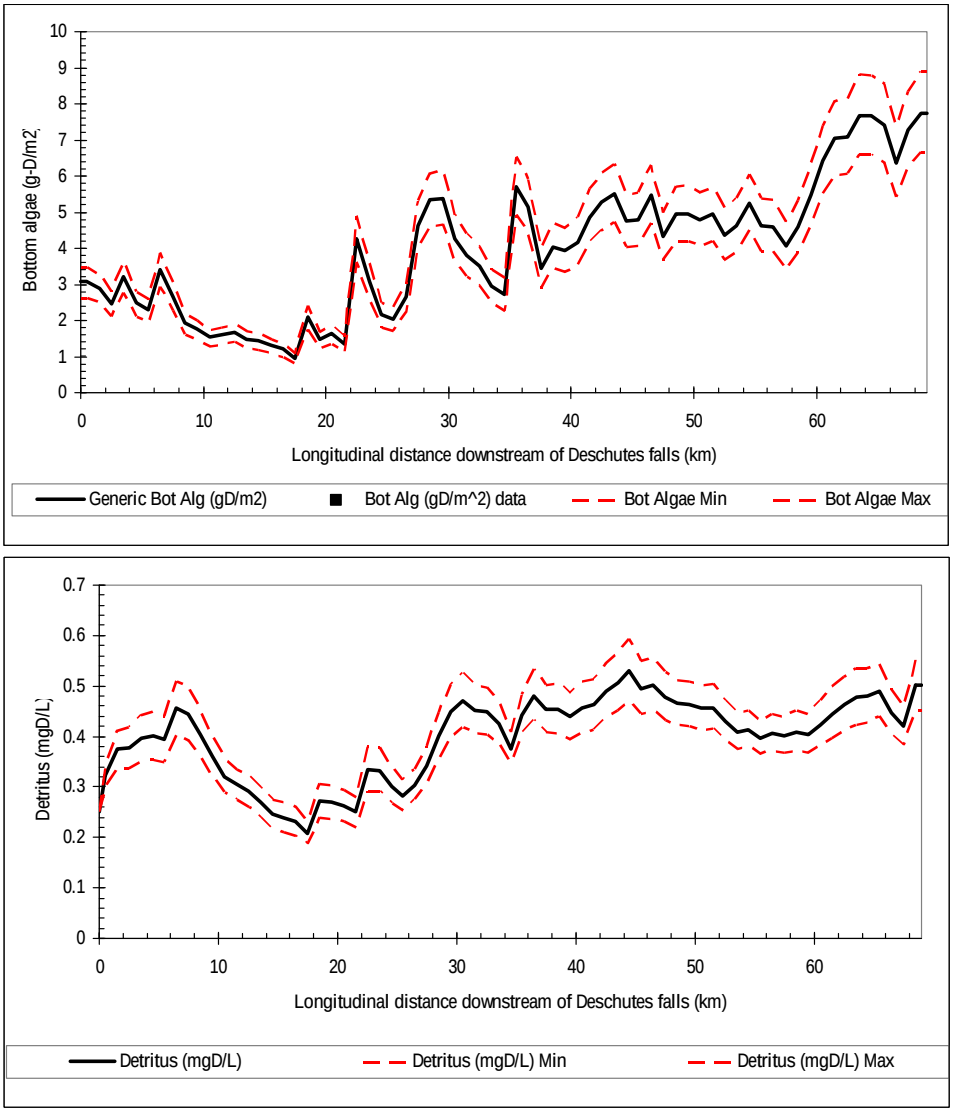


Figure 66. Predicted bottom algae and detritus levels in the Deschutes River for the stream walk survey (August 11-15, 2003).

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

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. Because background nutrient concentrations were related to geologic unit, the tributaries were categorized by bedrock (RK0 through RK20.4), Vashon recessional outwash

gravel and sand (RK22.5 through RK46.6), and Vashon recessional outwash sand and silt (RK54.1 through RK65.6), based on Plate 1 of Sinclair and Bilhimer (2007). Table 26 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 26. Lowest 10th percentile summer concentrations by geology type for the 2003-2004 monitoring period.

River km	Geology type	Ammonium	Nitrate + nitrite	Organic nitrogen	Orthophosphate	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 67).

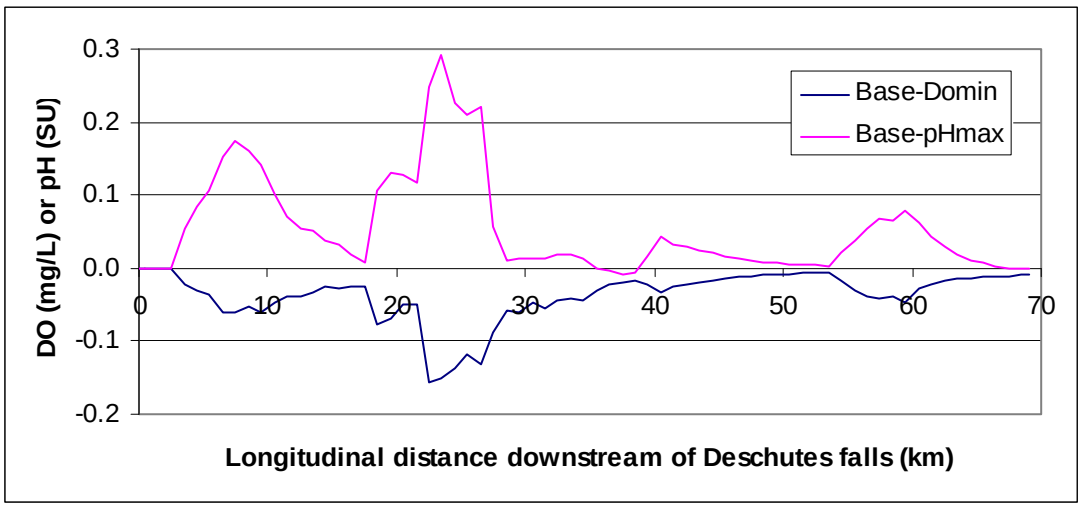


Figure 67. Differences in predicted minimum DO and maximum pH for tributaries set to ≤10th percentile concentrations for the DO calibration time period.

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. The EPA's current regulation defines loading capacity as "the greatest amount of loading that a waterbody 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, in situ DO and pH in tributaries and the headwater, and nutrient inputs.

Primary productivity, reaeration, and other processes influence DO and pH levels in the Deschutes River. DO saturation is a function of water temperature, and cooler water holds more DO than warmer water. In DO TMDLs, often nutrient loads are adjusted to determine the loading capacity and nutrient reductions needed for compliance with water quality standards, since primary productivity from periphyton often dominates over other influences. In most freshwater systems, phosphorus controls the amount of primary productivity. In systems where nutrient levels govern DO and pH, loading capacity is expressed as phosphorus loads. However, light also controls primary productivity, and increasing effective shade also would benefit DO levels, in terms of both DO saturation and decreasing algal growth. Finally, biochemical oxygen demand (BOD) also is a source of oxygen demand that could be controlled in DO TMDLs.

For the purposes of the Deschutes River DO and pH TMDLs, the loading capacity is expressed in terms of the effective shade, in situ DO and pH, and nutrient levels within the Deschutes River system. However, the related Capitol Lake and Budd Inlet DO TMDL may require a lower loading capacity than would be needed in the freshwater alone. The Deschutes River DO and pH TMDL will be revisited when the marine load and wasteload allocations are determined; see the Marine DO section for further information.

The system potential DO and pH are estimates of the levels that would occur under natural conditions. In this study, the system potential DO and pH were based in part on the system potential temperature described in the Temperature TMDL, including the 7Q10 flow and 90th percentile air temperature. In addition, nutrient inputs under natural conditions were based on the lowest 10th percentile 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.

The calibrated QUAL2Kw DO and pH model was used to determine the loading capacity for the combined effective shade and nutrient inputs for the mainstem of the Deschutes River. Loading capacity was determined based on natural conditions for temperature and the combined effects of natural and current nutrient inputs from tributaries.

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

- **Base case – Current shade and nutrient inputs**. The effective shade produced by the current riparian vegetation and nutrient inputs based on the same current 7Q10 flows and 90th percentile air temperatures as used for the water temperature base case.
- **Scenario DO1 – Maximum potential shade**. Effective shade from the system potential maximum mature riparian vegetation that would naturally occur in the Deschutes River watershed, as described in the Temperature model section. Mature vegetation was represented by maximum height and densities within 100 meters to either side of the near-stream disturbance zone (NSDZ). 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 stream matures and as fine sediment is controlled (see Temperature and Fine Sediment sections). Portions of the Deschutes River floodplain have very wide NSDZ, including areas more than 30 m wide. As was done for temperature, 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 2ºC (Bartholow, 2000).
- **Scenario DO5** – Reduced headwater and tributary water temperatures. Because DO saturation is a function of temperature, and cooler water holds more dissolved oxygen, as temperatures decrease in the system, minimum DO concentrations should increase. The headwater and tributary temperatures were set to the water quality criteria (16ºC upstream of Offut Lake and 17.5ºC downstream of Offut Lake) to quantify the benefit to Deschutes River DO.

Figure 68 summarizes minimum DO and Figure 69 summarizes maximum pH under current vegetation (Base) and the changes possible under various scenarios. Under current vegetation and critical conditions, the entire Deschutes River would have daily minimum DO concentrations below the numeric criteria in the water quality standards for 56 km (79% of the river downstream of Deschutes Falls). In addition, while no part of the river falls below a pH of 6.5, 20 reaches, or 28% of the length of the river downstream of the Deschutes Falls, would have a maximum pH above 8.5 under critical conditions. Highest maximum pH values occur near RK45 (Waldrick Road) and RK65 (Henderson Boulevard).

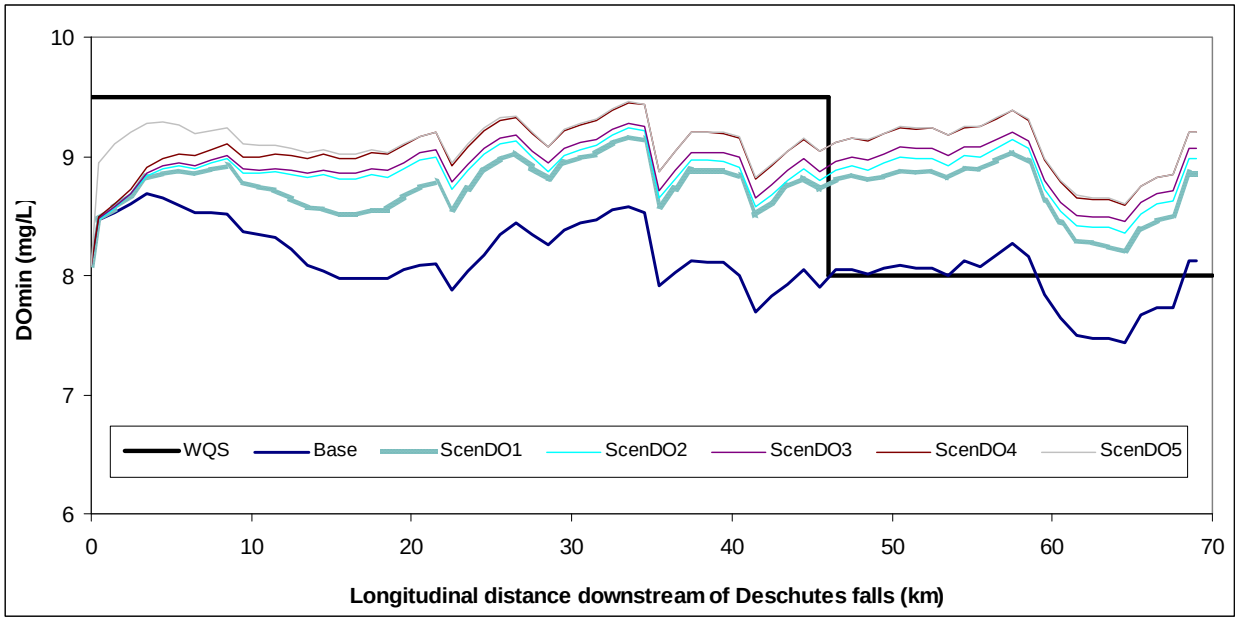


Figure 68. Predicted daily minimum DO in the Deschutes River for critical conditions under current conditions and various temperature scenarios.

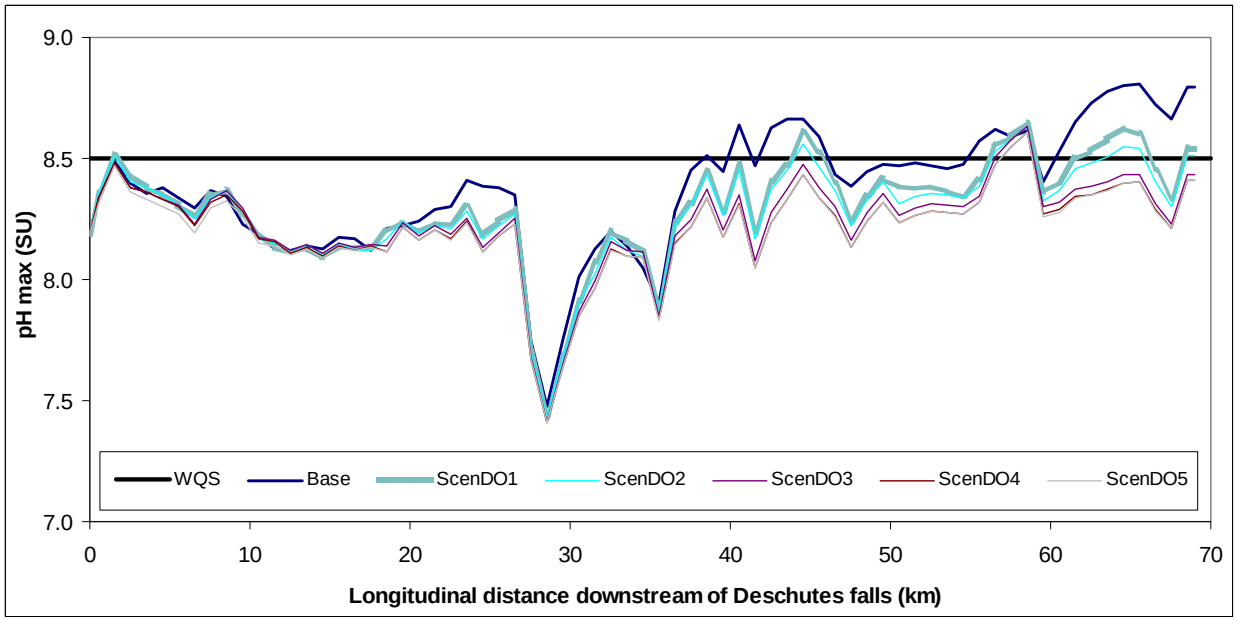


Figure 69. Predicted daily maximum pH in the Deschutes River for critical conditions under current conditions and various temperature scenarios.

Of the scenarios evaluated, developing full mature riparian shade would have the greatest benefit to minimum DO and maximum pH levels throughout the system. Increasing riparian shade would have the dual benefit of increasing DO saturation with cooler waters and reducing periphyton mass by 10% from decreased solar radiation.

Table 27 summarizes predicted increases in daily minimum DO concentrations and decreases in maximum pH with the implementation of mature riparian vegetation, riparian microclimate, and channel improvements under 7Q10 conditions. With mature riparian shade (Scenario DO1), the lowest DO level would be at the headwaters, and the minimum DO would increase by as much as 0.84 mg/L, but no part of the river upstream of Offut Lake would meet the water quality criteria. Maximum pH would decrease by 0.33 SU over the system and 82% of the river length downstream of Deschutes Falls would meet the standards. Reducing the NSDZ and channel width (Scenarios DO2 and DO3) would increase minimum DO throughout the system by 0.1 mg/L and decrease maximum pH by up to 0.1 SU. Decreasing air temperatures due to microclimate (Scenario DO4) would benefit DO levels another 0.1 mg/L but the effect on pH would be very small. Decreasing headwater and tributary temperatures (Scenario DO5) would increase minimum DO another 0.1 mg/L but would not substantially affect pH.

Table 27. Predicted increases in 7-day average of daily minimum DO and daily maximum pH under the current condition base case and various temperature-related scenarios. DO_{min} and pH_{max} refer to the minimum and maximum levels throughout the entire river downstream of the falls, while the mean DO_{min} and mean pH_{max} are the average over the entire river. ΔDO_{min} and ΔpH_{max} are the incremental benefits as the system-wide average for each scenario.

Scenario	DO_{min}	Mean DO_{min}	ΔDO_{min}	pH_{max}	Mean pH_{max}	ΔpH_{max}	Length of river in compliance with numeric criteria			
							Upstream of Offut Lake (9.5 mg/L and 6.5 to 8.5 SU)		Downstream of Offut Lake (8.0 mg/L and 6.5 to 8.5 SU)	
	(mg/L)	(mg/L)	(mg/L)	(SU)	(SU)	(SU)	DO	pH	DO	pH
Base case (current vegetation, temperature, and channel widths under recent 7Q10 flows)	7.43	8.12	0.0	8.81	8.37	0.0	0 km (0%)	41 km (58%)	15 km (21%)	10 km (14%)
Scenario DO1 (mature riparian vegetation)	8.08	8.74	+0.84	8.64	8.30	-0.08	0 km (0%)	44 km (62%)	24 km (34%)	14 km (20%)
Scenario DO2 (Scenario DO1 with NSDZ, WW <20m)	8.08	8.85	+0.11	8.64	8.28	-0.02	0 km (0%)	45 km (63%)	24 km (34%)	16 km (23%)
Scenario DO3 (Scenario DO2 with WW, bottom width -10%)	8.08	8.91	+0.06	8.64	8.24	-0.04	0 km (0%)	47 km (66%)	24 km (34%)	21 km (30%)
Scenario DO4 (Scenario DO3 with air temp – 2ºC)	8.08	9.05	+0.14	8.61	8.22	-0.02	0 km (0%)	47 km (66%)	24 km (34%)	22 km (31%)
Scenario DO5 (Scenario with HW, tribs < 16/17.5ºC)	8.08	9.10	+0.05	8.61	8.21	-0.01	0 km (0%)	47 km (66%)	24 km (34%)	22 km (31%)

Instituting the management activities described to benefit temperature would lead to substantial improvements in DO and pH. Under full implementation of the temperature management activities, 24 km (34%) of the Deschutes River would meet the DO criteria and 69 km (97%) would meet the pH criteria.

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 water quality criteria. Where DO concentrations were greater than the minimum levels in the water quality criteria, the higher values were maintained.
- **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.

Figure 70 and Figure 71 present the base case and the effect of nutrient and DO scenarios on minimum DO and maximum pH, respectively. The Deschutes River upstream of Offut Lake would not meet the numeric water quality criteria for minimum DO but would meet the criteria for maximum pH with the tributaries set to current (Scenario DO6) or natural (Scenario DO7) conditions. Conversely, the Deschutes River downstream of Offut Lake would meet the DO criteria, but one reach would not meet the pH criteria.

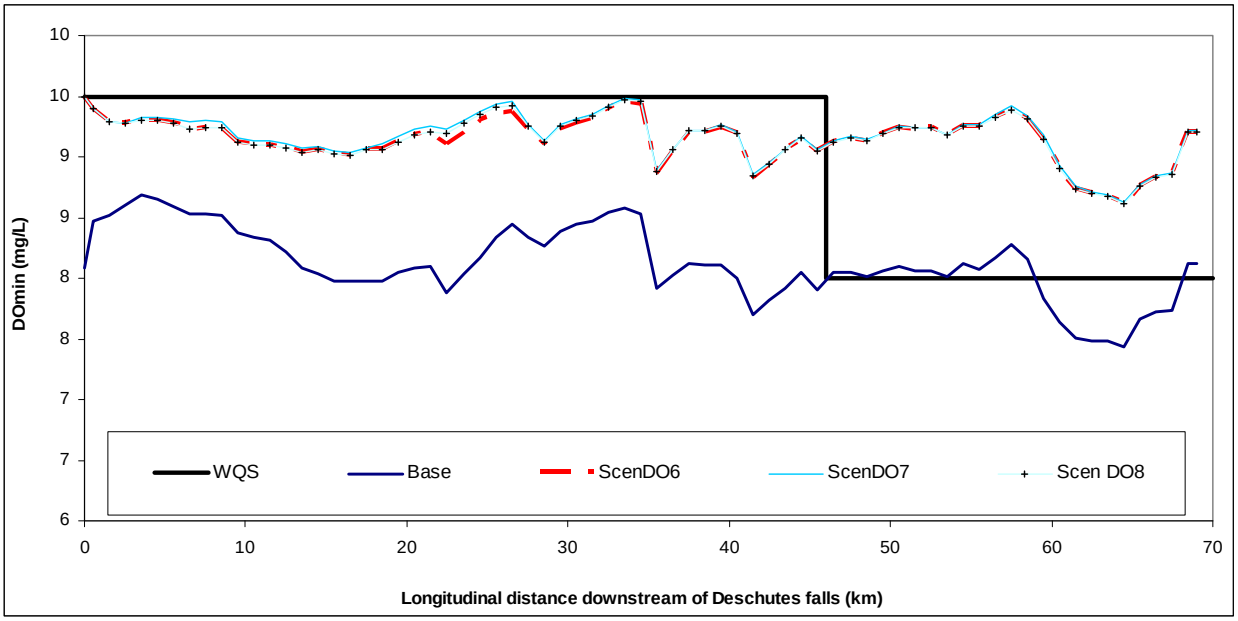


Figure 70. Predicted daily minimum DO in the Deschutes River for critical conditions under current conditions and various DO and nutrient scenarios.

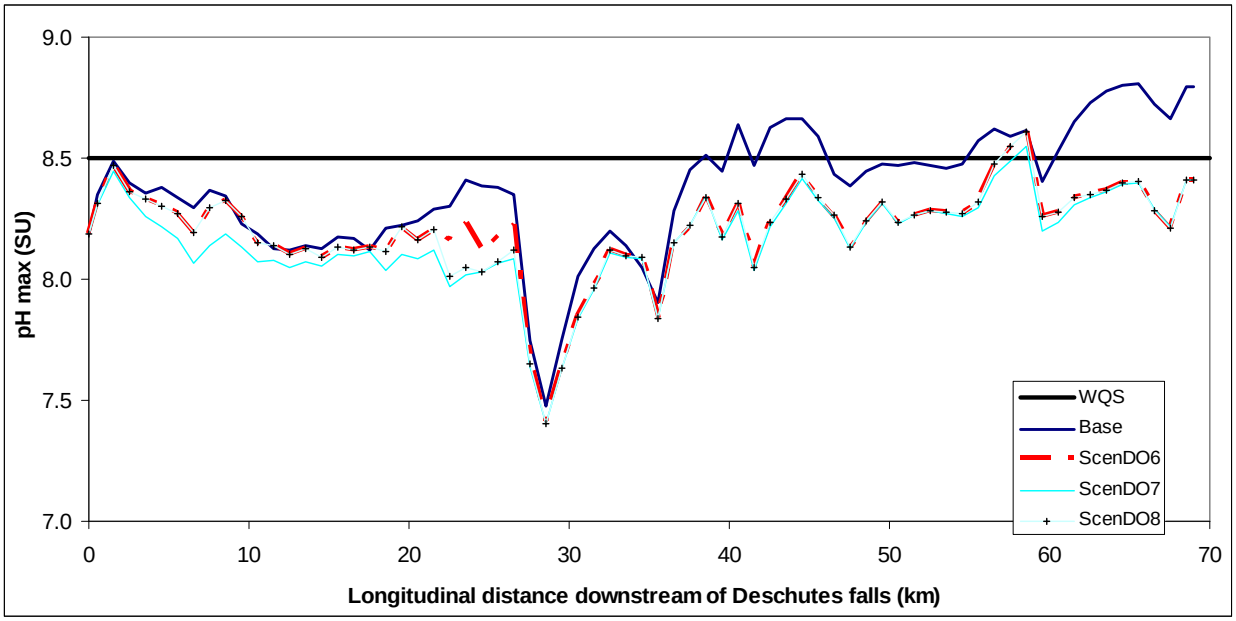


Figure 71. Predicted daily maximum pH in the Deschutes River for critical conditions under current conditions and various DO and nutrient scenarios.

Increasing DO in the headwaters and tributaries (Scenario DO6) would slightly increase the number of reaches meeting minimum standards (25 km = 35%), and 69 km (97%) would also meet the maximum pH limits. Comparing Scenarios DO6 and DO7, the current nutrient loads cause a 0.12 mg/L decrease in DO concentrations below natural conditions. For pH, the maximum pH would decrease slightly, and the current nutrient loads would increase maximum pH by up to 0.22 SU. Figure 72 presents the differential DO and pH predicted under current and natural conditions. Scenario 6 represents the loading capacity.

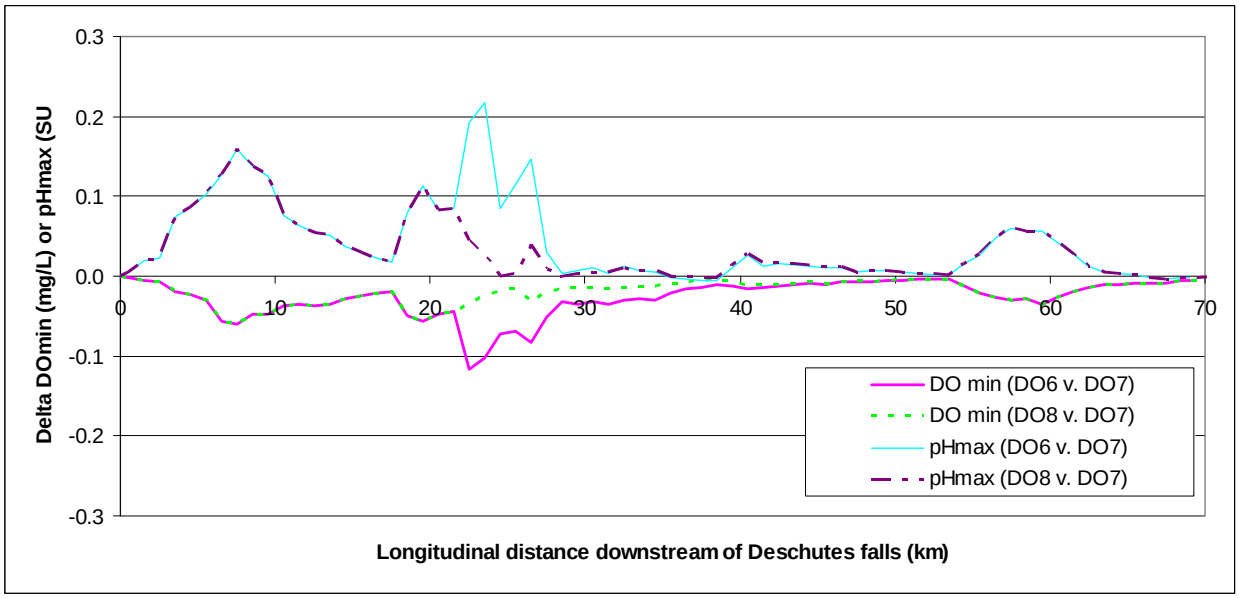


Figure 72. Decrease in minimum DO and increase in maximum pH compared with natural conditions due to anthropogenic nutrient loads in the tributaries (Scenario DO7) and in all but the Lake Lawrence tributary (Scenario DO8).

Scenario DO7 represents the system potential natural conditions for DO, pH, and nutrients. Because minimum DO concentrations would be below the numeric criteria throughout the system, the combined effects of all human activities must not cause more than a 0.2 mg/L decrease below natural conditions. With the tributaries set to the current nutrient concentrations, the differential minimum DO is <0.2 mg/L compared with natural conditions throughout the mainstem. For pH in Scenario DO6 (current nutrient loads with mature riparian vegetation, microclimate, and channel improvements), only one reach would violate the numeric criteria for maximum pH. Comparing Scenarios DO6 and DO7, the human sources of nutrients in the tributaries contribute to <0.2 SU increase in maximum pH where maximum pH is >8.5 SU. The only area where human sources contribute >0.2 SU is a reach where the maximum pH is <8.5 SU. The Lake Lawrence tributary causes the incremental increase in pH at reach 24 (Scenario 8), but the tributary does not cause a violation of the water quality standards.

Table 28 summarizes the incremental benefits of several DO and nutrient scenarios.

Table 28. Predicted increases in 7-day average of daily minimum DO and decreases in maximum pH under the current condition base case and various DO and nutrient scenarios.

Scenario	DO_{min}	Mean DO_{min}	ΔDO_{min}	pH_{mx}	Mean pH_{max}	ΔpH_{max}	Length of river in compliance with water quality standards			
							Upstream of Offut Lake (9.5 mg/L and 6.5 to 8.5 SU)		Downstream of Offut Lake (8.0 mg/L and 6.5 to 8.5 SU)	
	(mg/L)	(mg/L)	(mg/L)	(SU)	(SU)	(SU)	DO	pH	DO	pH
Base case (current vegetation, temperature, and channel widths under recent 7Q10 flows)	7.43	8.12	0.0	8.81	8.37	0.0	0 km (0%)	41 km (58%)	15 km (21%)	10 km (14%)
Scenario DO6 (Scenario DO5 with HW, tribs <9.5/8.0 mg/L DO)	8.61	9.15	0.05	8.61	8.21	0.00	1 km (1%)	47 km (66%)	24 km (34%)	22 km (31%)
Scenario DO7 (Scenario DO6 with tribs set to no more than the 10th percentile nutrient concentrations)	8.62	9.17	0.03 (0.12 max)	8.55	8.17	-0.04	1 km (1%)	47 km (66%)	24 km (34%)	23 km (32%)
Scenario DO8 (Scenario DO6 with Lake Lawrence tributary reduced to 10th percentile phosphorus concentrations)	8.61	9.15	-0.02 (+0.01*)	8.61	8.20	0.03 (-0.01*)	1 km (1%)	47 km (66%)	24 km (34%)	22 km (31%)

* Compared with Scenario DO7 values

Percival Creek and Black Lake Ditch Loading Capacity

Loading capacity for DO and pH in the Percival Creek watershed is expressed as solar radiation heat loads based on system potential vegetation. The QUAL2Kw model was not applied to determine the system potential temperature, DO, or pH within the watershed. However, the decreased temperatures that would result from mature riparian vegetation would improve the DO and pH due to saturation effects alone. The temperature, DO, and pH regimes are highly influenced by Black Lake and wetlands at the headwaters in both branches, and natural conditions likely would not meet the numeric criteria. Figure 56 in the Temperature TMDL

presents the current longitudinal temperature pattern, and Figure 73 presents the DO and pH profiles.

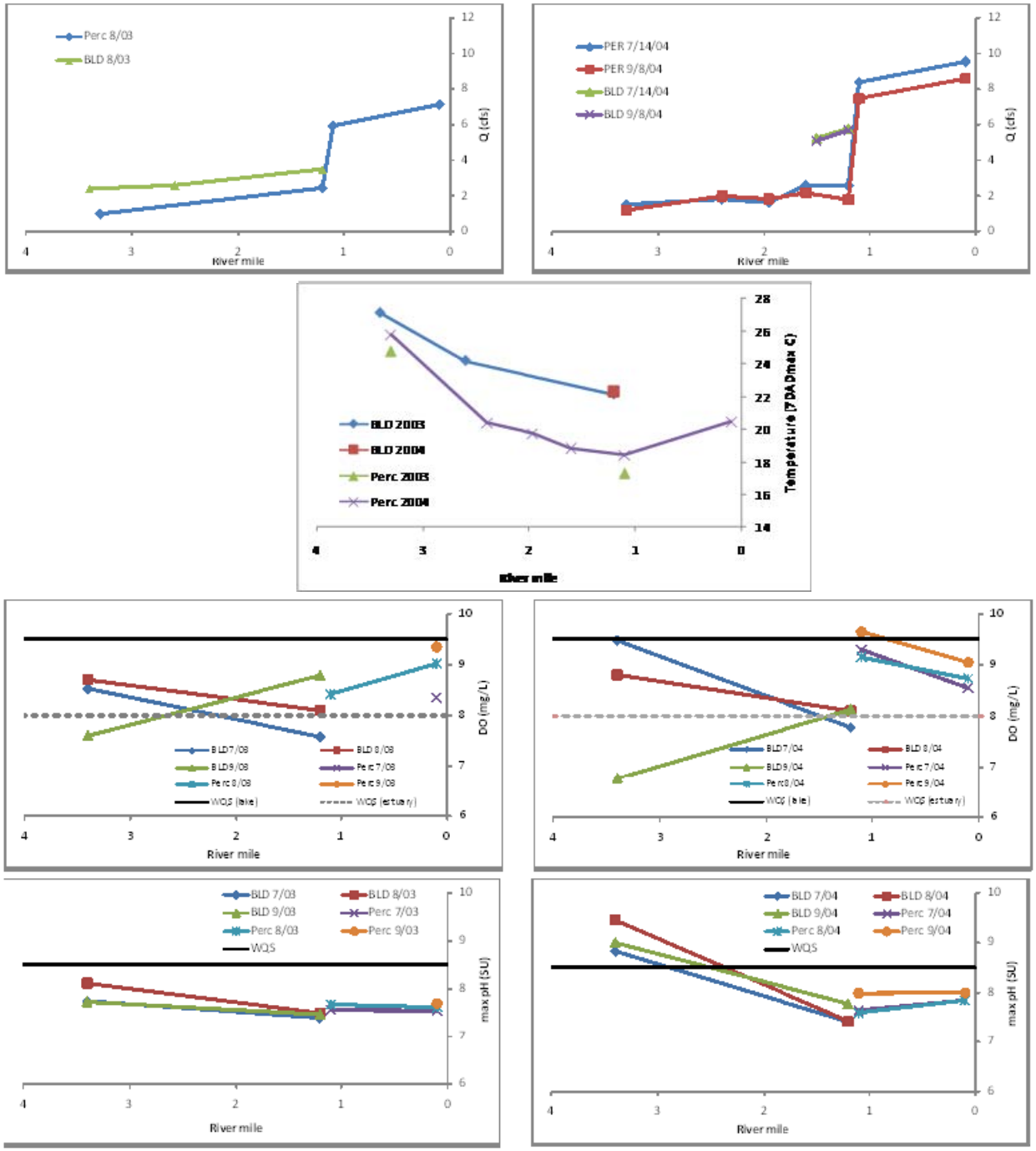


Figure 73. Discharge, temperature, DO, and pH profiles in Percival Creek and Black Lake Ditch.

Load and wasteload targets

Deschutes River Watershed Load Targets

Load targets are established in this TMDL to meet both the numeric threshold criteria and the allowances for human influences under conditions that are naturally lower in DO and higher in pH than those criteria. Minimum DO and maximum pH levels were evaluated under natural conditions. For this TMDL, natural conditions for the Deschutes River are defined as full mature riparian shade with channel improvements and microclimate effects, all tributaries meet the temperature and DO water quality standards, and all tributaries have concentrations no more than the 10th percentile of measured summer concentrations for inorganic phosphorus, organic phosphorus, ammonium, nitrate + nitrite, and organic nitrogen.

Minimum DO and maximum pH under natural conditions would not meet the numeric water quality criteria upstream of Offut Lake and in reach 59, respectively. However, where those criteria would not be met, the combined effects of human influences on tributary nutrient levels is <0.2 mg/L for DO and <0.2 SU for pH. Therefore, the load allocation is the shade that would result from full mature riparian vegetation with microclimate effects and channel improvements that would reduce the near-stream disturbance zone (NSDZ) and wetted width to <20 m. Figure 57 and Figure 58 in the Temperature TMDL summarize the effective shade deficit, and solar heat load allocations for potential vegetation are detailed in Appendix E for critical conditions.

Several tributaries to the Deschutes River do not meet the water quality standards for temperature, DO, or pH. As required in the Temperature TMDL, full mature riparian vegetation is needed along the creeks listed in Table 24. Table 29 summarizes tributaries that need increased DO or pH to meet the standards, both within the tributaries themselves and within the Deschutes River. Historical wetland complexes and current wetland soils likely influence both minimum DO and pH, and neither creek may meet the numeric criteria; however, substantial increases are likely with decreased water temperatures. During the winter months Ayer Creek achieves a minimum DO of 6.7 mg/L and Reichel achieves 10.3 mg/L.

Table 29. Conditions in tributaries to the Deschutes River, including DO, pH, and nutrient load allocations for streams that do not meet the water quality standards for DO or pH.

Tributary	Measured		Target	
	DO min (mg/L)	pH min (SU)	DO min (mg/L)	pH min (SU)
Ayer (Elwanger)	1.05	6.18	8.0	6.5
Reichel	4.30	6.37	8.0	6.5

Because the combined effect of human activities on tributary concentrations is <0.2 mg/L for DO and <0.2 SU for pH, no further tributary nutrient load reductions are needed to meet DO and pH water quality standards in the Deschutes River. However, if nutrient load reductions are needed at the mouth of the Deschutes River to meet water quality standards in Capitol Lake or Budd Inlet, to be addressed in a separate future report, then tributary nutrient reduction targets may be reevaluated. At a minimum, tributary nutrient concentrations and loads cannot worsen from current summer conditions. Upstream of Offut Lake, human influences on nutrient

concentrations during critical conditions with full mature riparian vegetation decrease mainstem DO by as much as 0.12 mg/L.

The remaining 0.08 mg/L allowed in the water quality standards is reserved as a margin of safety, particularly given the time necessary to establish mature riparian vegetation in the system and uncertainty in tributary and groundwater inputs. Antidegradation provisions also apply. Figure 74 summarizes the DO and pH improvements and Figure 75 presents the nutrient load allocations to achieve standards for Deschutes River DO and pH. Scenario DO7 was used to establish the loading capacity for nutrients; nutrient reduction targets are identified as the difference in tributary nutrient levels between current conditions and the loading capacity.

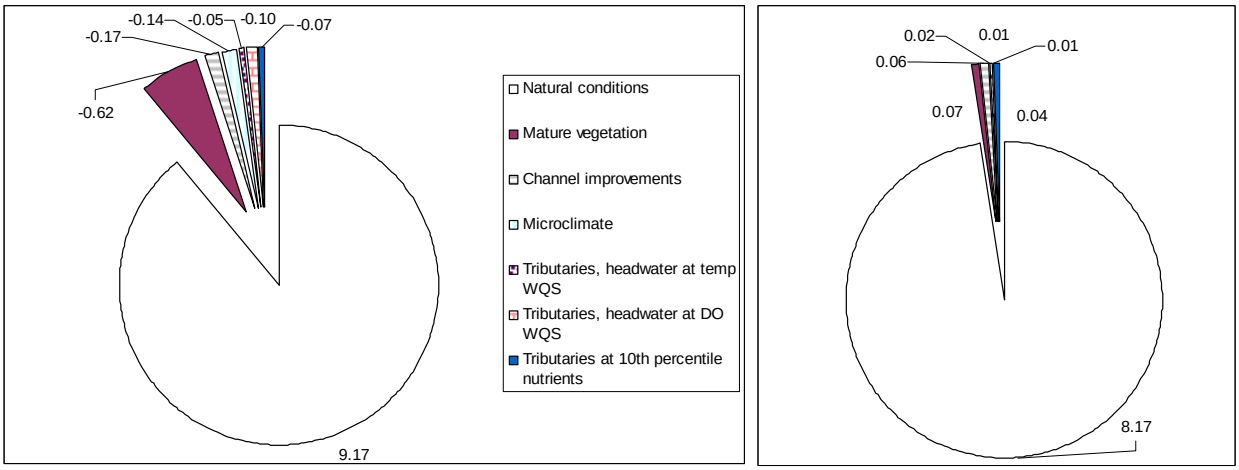


Figure 74. DO and pH improvements in the Deschutes River (system-wide average DOmin (left) and pHmax (right) associated with various management strategies.

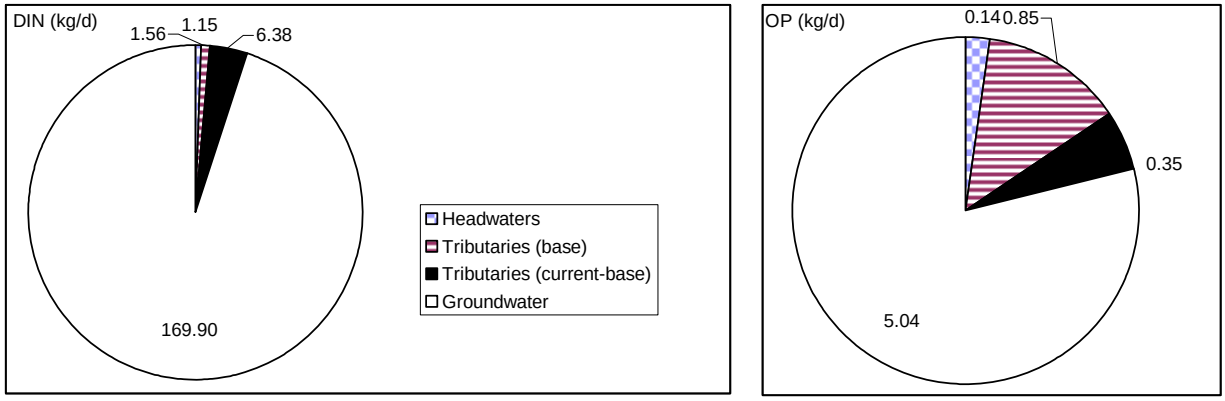


Figure 75. Nutrient load allocations (DIN and orthophosphate) under critical conditions for the Deschutes River.

The table and figure include load targets for Ayer (Elwanger) and Reichel Creek to meet the Deschutes River water quality standards. While no additional nutrient load targets were established for Ayer or Reichel Creek such that the creeks meet the water quality criteria for DO and pH, establishing mature riparian vegetation appropriate for the wetland soils adjacent to the

creeks would improve DO and pH conditions within the creeks, given that cooler water holds more DO and reducing solar radiation would reduce primary productivity in the creeks. The historically prominent wetland complexes may establish natural conditions for DO and pH that do not meet the numeric standards. Therefore, the load targets for Ayer Creek and Reichel Creek are the reductions in solar radiation that would result from mature riparian vegetation to limit primary productivity to the maximum extent possible.

In addition to the numeric load targets for shade and nutrients in the Deschutes River watershed, and in addition to the narratives established in the Temperature TMDL, the following DO, pH, and nutrient narratives and management activities apply:

- 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. Cooler water temperatures hold more DO and decreased solar radiation reduces primary productivity. At sea level and pressure, the saturation DO would be 9.87 mg/L at 16.0ºC and would be 9.57 mg/L at 17.5ºC. Therefore, establishing mature riparian vegetation along tributaries is important to meeting the DO and pH standards at the mouths of the tributaries.
- Nutrient loads in the Ayer (Elwanger) Creek watershed should not increase over current conditions. Future developments should evaluate management activities that reduce nutrient inputs from current conditions.
- Nutrient loads in the Reichel Creek watershed should not increase over current conditions. Future developments should evaluate management activities that reduce nutrient inputs from current conditions.

Deschutes River Watershed Wasteload Targets

No numeric wasteload targets for nutrients were recommended for the Deschutes River DO and pH TMDLs for facilities covered by the stormwater general permits. However, nutrient levels will be revisited in a subsequent report 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, they are not covered under general permits.

The Construction Stormwater General Permit requires that facilities that discharge to waterbodies impaired for high pH conduct pH sampling. However, the two Deschutes River

tributaries are listed for low pH, and no additional pH monitoring is required. Constructions sites that affect the Deschutes River in the area currently not meeting standards for maximum pH (RK38 to RK45 and downstream of RK55) should monitor pH in offsite runoff during summer storms. More importantly, these sites must eliminate any 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 peak pH.

The Construction Stormwater General Permit also requires that facilities discharging to waterbodies 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, must eliminate the offsite transport of particulates, because Capitol Lake is listed for total phosphorus.

Of the facilities covered by general permits, dairies have the greatest potential to contribute nutrients to the Deschutes River or its tributaries. No site-specific numeric wasteload allocations were established in this TMDL, and strict adherence to each facility's Nutrient Management Plan is required.

Any new permitted facilities in the Deschutes River watershed must 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 cannot produce any off-site transport of nutrients.

Percival Creek Watershed Load Targets

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 wasteload targets described in the Temperature TMDL 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 59 in the Temperature TMDL presents current and potential future shade and load allocations are detailed in Appendix F.

The numeric load allocations for effective shade in the Percival Creek watershed and the narratives and management activities listed in the Temperature TMDL apply for nutrients, DO, and pH.

Percival Creek Watershed Wasteload Targets

No numeric wasteload targets for nutrients were recommended for this DO and pH TMDL. However, nutrient levels will be revisited in a subsequent report that establishes load and wasteload allocations for Capitol Lake and Budd Inlet.

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 nutrient 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 nutrients above natural conditions. While nutrient loads from existing development may be contributing to low DO levels in the summer in the Deschutes River and its tributaries, they are not covered under general permits.

Any new permitted facilities in the Percival Creek watershed must not increase nutrient inputs beyond existing conditions. The facilities cannot produce any off-site transport of nutrients.

Conclusions and recommendations

Anthropogenic sources of heat must 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 dozens 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 RK60 (13-DES-5.8). The highest DO occurs near the upper falls. Maximum pH would meet the water quality standards upstream of RK38 (Military Road).

Establishing full mature riparian shade, as included in the Temperature TMDL load targets, would benefit significantly both DO and pH, although the river upstream of Offut Lake would not meet the numeric criteria for minimum DO and the river near RK59 would not meet the numeric criteria for maximum pH. With the effects of microclimate, channel improvements, and if the headwater and tributaries met the temperature criteria, 24 km (34%) of the Deschutes River would meet the numeric standards for DO and 69 km (97%) would meet the numeric standards for pH. If the headwater and tributaries meet the DO and pH water quality standards and nutrient concentrations do not worsen, 25 km (35%) of the river would meet the numeric standards for DO and 69 km (97%) would meet the numeric standards for pH. Compared with natural conditions, current tributary nutrient loads do not cause >0.2 mg/L decrease in minimum DO or >0.2 SU increase in maximum pH where the numeric criteria are not met. Therefore, no tributary nutrient reductions are needed beyond the need to establish mature riparian vegetation and to meet the water quality standards for temperature, DO, and pH. 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.

As described in the Temperature TMDL, mature riparian vegetation would have several secondary benefits to temperature, DO, pH, and fine sediment (see separate Fine Sediment and Temperature TMDL sections). 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 protects 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 develops 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, 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. 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 the watershed, with particular attention to decreasing nutrient contributions below current levels and not worsening DO or pH.
- Failing septic systems, particularly those near a waterbody, could be contributing excess nutrient loads. Existing management programs by Thurston County should continue and intensify. In addition, state-of-the-art onsite systems should be considered in sensitive areas, such as upstream of Offut Lake.
- 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.
- Agricultural operations, including those covered under the dairy program, should eliminate off-site transport of sediments and nutrients.
- Although current tributary nutrient loads do not cause >0.2 mg/L or <0.2 SU changes in minimum DO and maximum pH, nitrogen and phosphorus hot spots exist and should be evaluated for future nutrient reduction strategies. Tributaries with elevated nitrogen include Ayer/Elwanger, Tempo Lake, and Chambers Creek, and the unnamed creek at RK64. Tributaries with elevated phosphorus include the Lake Lawrence outlet, Reichel Creek,

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 watershed, 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.
- For Reichel Creek, future efforts should mitigate existing low DO 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 (RK18 – RK20). 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 two to three 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 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 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 the sensitive areas upstream of Offut Lake and near Henderson Blvd.

Future growth within the Percival, Ayer (Elwanger), and Reichel Creek watersheds 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 waterbodies.

Margin of safety

The margin of safety accounts for uncertainty in pollutant loading or waterbody 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. In addition, current tributary loads decrease minimum DO concentrations by up to 0.12 mg/L. Although allowed under the water quality standards, the additional 0.08 mg/L differential DO was set aside as a margin of safety, given the time necessary to establish riparian vegetation in the system and uncertainty in tributary and groundwater inputs. For the Percival Creek watershed, no numeric margin of safety was calculated. Established mature riparian vegetation should decrease temperatures substantially, and no allowance was assigned to specific human influences.

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 river flows. 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 and rearing and core summer 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:

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

where $FS_{current}$ 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 waterbody such that the waterbody 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 30.

Table 30. 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 Offut Lake and salmonid spawning outside the summer season, 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 levels 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 31 and Figure 76 present the load targets for the Deschutes River watershed. The ultimate target will be to reduce fine sediments to no more than 12% of the substrate, with an interim target of 17% (see below under Recommendations).

Table 31. Fine sediment load targets by reach for the Deschutes River watershed.

Reach (River Kilometer)	Reach (Konovsky and Puhn, 2005)	1995 Levels	Current Levels	12% Target % Reduction	17% Target % Reduction
RK 12.2 to 18.7	19/WeyCo	15.4%	17.3%	-44%	-2%
RK 20.3 to 23.0	22/Lake Lawrence	22.5%	17.0%	-42%	0%
RK 30.0 to 35.9	28/Hwy508	19.4%	20.2%	-68%	-19%
RK 41.6 to 46.0	31/Waldrick	19.9%	19.5%	-63%	-15%
RK 64.6 to 68.3	36/Pioneer	22.0%	22.0%	-83%	-29%

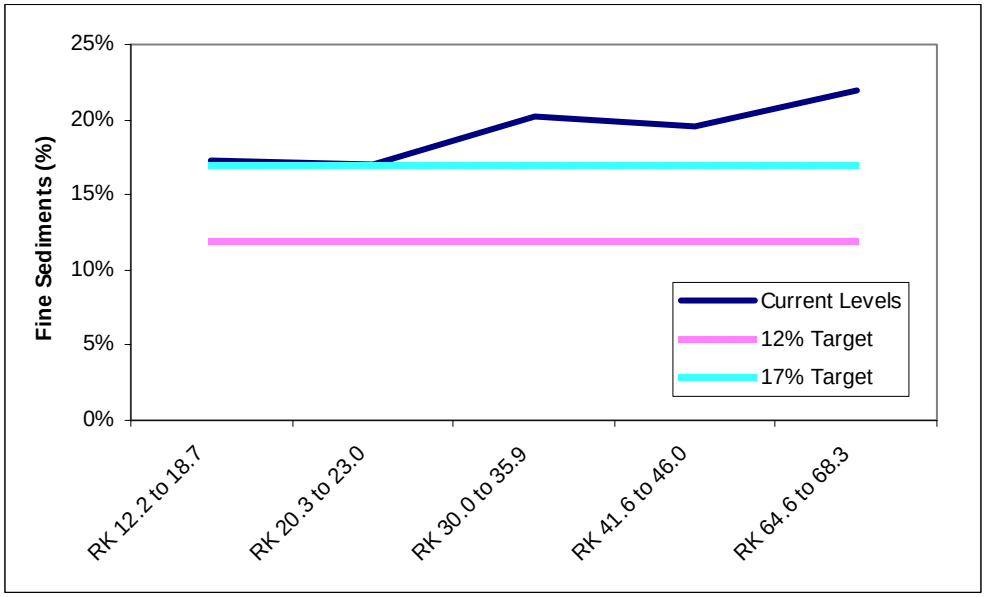


Figure 76. Fine sediment load targets for the Deschutes River watershed. RK refers to river kilometer from the upstream Deschutes Falls.

Of the sediment inputs quantified 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 77). Human and unaccounted sources represent 47 to 52% of the sediment inputs to Capitol Lake.

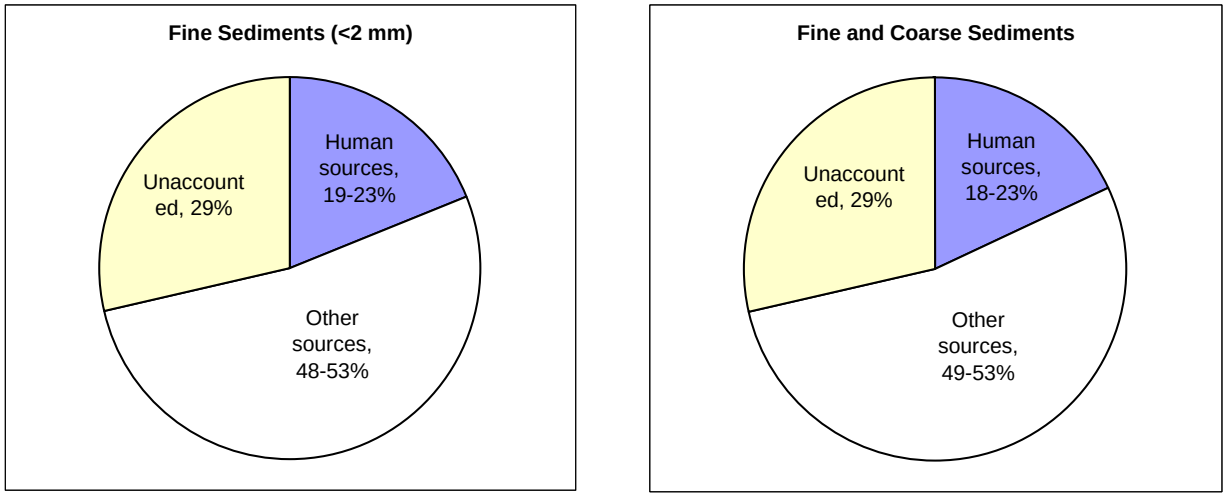


Figure 77. Fine sediments (<2mm) and all sediments by source from Raines (2007). Unaccounted sources represent the difference between loads to Capitol Lake determined from historical dredging and recent bathymetry and sediment inputs identified by Raines (2007).

The Deschutes River watershed is a mixed-use watershed, with non-forested land, private forests, and public forests. Load allocations are included in this TMDL for non-federal forest lands in accordance with Schedule M-2 of the Forests and Fish Report (USFWS et al., 1999) for TMDLs developed prior to July 1, 2009. Under the Timber, Fish, and Wildlife Agreement, Ecology will not require more stringent measures except through adaptive management and subject to reopeners for a 10-year period from publication of the Forests and Fish Report. Implementation of load allocations is via the Timber Fish and Wildlife Agreement.

According to Schedule M-2, Clean Water Act Section 303 Assurances, Assurance and Contingencies, EPA and Ecology Assurances, Part 5, Section (b), "if achievement of the TMDL load allocations cannot be met through the forest practices regulations, the adjustment of those management practices will be through adaptive management…." 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 32 summarizes the wasteload allocations for NPDES-permitted entities within the Deschutes River watershed.

Table 32. Wasteload targets for fine sediment loads in the Deschutes River watershed.

Waterbody	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	(draft only)	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	Suncrest at Somerset Hill	WAR007078	0	B
Sand and Gravel General Permit				
Deschutes River	Waldrick Road Pit	WAG501231	0	C
Dairies				
Deschutes River	Mahan Ranch LLC	License No. 2079	0	B
Deschutes River	Plowman Dairy	License No. 5949	0	B

Notes:
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 waterbodies 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 waterbody 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 off-site 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. The dominant anthropogenic sources identified in Raines (2007) are inputs from unpaved roads and landslides associated with roads, although Raines (2007) 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, and long-term turbidity has declined (Reiter et al., 2006). 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 allocations 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. Extensive tracks are visible in aerial photos (Appendix D). 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 RK12 and RK20, 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).

Based on the Anchor Environmental (2008 analysis of Deschutes River salmonid habitat, 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 flows, temperature, or LWD. Full restoration of LWD to meet the 25th percentile for intermediate-sized rivers in western Washington (29 pieces per 100 m; Fox and Bolton, 2007) would produce the biggest coho increase of any habitat parameter in the Deschutes system.

Any new land uses in the Deschutes River watershed must not enhance fine sediment inputs to streams or to the Deschutes River beyond natural conditions. Sites should be designed so that they do not produce any off-site 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).

Capitol Lake and Budd Inlet Dissolved Oxygen

Analytical framework

Background

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 (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).

The original JEEAI model application was performed for Lacey, Olympia, Tumwater and Thurston County (LOTT) Partnership 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 study, 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 model (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."

From 2003 through 2007, Ecology contracted with ERM to perform the following tasks:

- Conversion of the 1997 LOTT model to the latest version of GEMSS.
- Verification of goodness-of-fit relative to the 1997 calibration.
- Capitol Lake setup in GEMSS, linkage with Budd Inlet, and testing.
- Incorporation of a more recent data set (2000-2001 Miller Brewing Company study of Capitol Lake).
- Conduct a workshop on the GEMSS application for Ecology staff.
- Calibration assistance and technical support.

The following additional tasks were performed by ERM:

1. Updated the existing Budd Inlet model setup to include the combined Budd Inlet and Capitol Lake grid connected by the outlet structure at the dam.

2. Calibrated the flow exchange of the combined Capitol Lake/Budd Inlet GEMSS model application to recent data collected during 2003-2004 by Ecology and Thurston County. The simulation period was May 18, 2004 – September 30, 2004.
3. Calibrated temperature, DO, and other water quality constituents of the combined Capitol Lake/Budd Inlet GEMSS model application to recent data collected during 2003-2004 by Ecology and Thurston County. The simulation period was May 18, 2004 – September 30, 2004.
4. Confirmed flow exchange, temperature, DO, and other water quality constituents of the combined Capitol Lake/Budd Inlet model application with recent data collected during 2000-2001 by CH2MHill (2001) and Thurston County. The simulation period was April 25, 2001 – June 13, 2001.
5. Performed model scenario runs and comparisons for a total of eight scenarios. Four scenarios included the dam and four scenarios assumed that dam was not present and that Capitol Lake functioned as an estuary.
6. Documented and delivered of the work products of bullets 1 through 5. A memo report was provided by ERM.

The project was scoped originally to utilize the calibrated and accepted model of Budd Inlet from the Budd Inlet Scientific Study, given the significant resources invested in this model calibration and extensive review by multiple entities. Because that model considered Capitol Lake as a boundary condition, the model domain was extended south to encompass Capitol Lake. However, no recalibration of Budd Inlet was planned.

In 2006, ERM provided the latest calibrated model of Budd Inlet to Ecology along with a comparison to the previous model outputs (Kolluru, 2006). ERM also provided a combined calibrated model of Budd Inlet/Capitol Lake in January 2008.

In the course of review of the calibrated Budd Inlet/Capitol Lake model, the source codes for the Water Quality Carbon-Based Module (WQCBM) were reviewed. The following issues with WQCBM were noted and later corrected by ERM:

1. The increase in zooplankton biomass due to grazing was not included in any of the mass balance equations for particulate organic phosphorus, nitrogen, and carbon. This inclusion was necessary for mass balance to be correct.
2. The particulate organic carbon was expressed in units of oxygen rather than carbon.
3. Grazing of diatoms was incorrectly included twice where the grazing of dinoflagellates was included only once. Correcting this resulted in an increase in the diatom population and a decrease in dinoflagellates.

With the model code errors corrected, the parameters calibrated in the Budd Inlet Scientific Study were re-evaluated by Ecology to determine if calibration to the 1996-1997 data was still acceptable. Because some differences were noted, Ecology re-calibrated the Budd Inlet region of the model.

Modeling Approach

The GEMSS general algae module, macrophyte module incorporated from QUAL2Kw, and the WQCBM were applied to represent the growth of macrophytes and freshwater algae in Capitol Lake and saltwater phytoplankton in Budd Inlet (diatoms and dinoflagellates). The transformation of nutrient forms of carbon, nitrogen, and phosphorus, and the influence on DO within Capitol Lake by macrophytes and phytoplankton were simulated. 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, dissolved oxygen, temperature, and sediment fluxes of oxygen, nitrate, ammonia, and inorganic phosphorus. Capitol Lake stratifies and it was necessary to reproduce the vertical profiles of temperature and DO as well as the nutrient forms. Capitol Lake also exhibits large diel ranges of DO due to productivity of macrophytes and phytoplankton and it was necessary to represent the diel variability. Continuous DO monitoring data at station CL4 (near the Capitol Lake outlet; Figure 6) for August 5-13, 2004, were used to confirm the ability of the model to reproduce diel variability.

Calibration and verification of the of GEMSS water quality model

Budd Inlet

Appendix G details the re-calibration of the Budd Inlet region of the model from that originally described in Aura Nova Consultants et al. (1998). Once the grid was extended to encompass Capitol Lake and the model code errors were corrected, the previously calibrated rates and constants produced some differences in predicted results compared with the original calibration. A complete review of rates and constants was conducted, and several values were outside the range reported in the literature or measured in Budd Inlet and were not documented in the previous efforts. During re-calibration, rates and constants were varied as little as possible from the original calibration but were maintained within documented ranges. Details on the parameters changed are presented in Appendix G. Following is a summary of the corrections made to the original calibration.

1. Some rates and constants were varied in the original calibration with time but no justification was provided in the subsequent report (Aura Nova Consultants et al., 1998). During re-calibration, these rate constants were kept constant throughout the model simulation.
2. Sediment fluxes for sediment oxygen demand (SOD), ammonia, nitrate and phosphorus were increased during the previous calibration without comparing the resultant values with those in the literature. During re-calibration, only SOD was selectively varied but kept within reported values in literature.

3. Originally a multiplier was used to adjust measured chlorophyll-a at the open boundary, based on a field measurement error. The documented value of this multiplier was 12. However, in the calibrated model factors of 36 and 24 were used as time-varying multipliers. During re-calibration, the documented multiplier of 12 was maintained.

Results predicted based on the re-calibrated rates and constants provided a closer fit to observed data than the original calibration values with the corrected code. The combined relative error of the mean (REME), a measure of the differences between observed and predicted values, of all plots including time-series and profiles was better for re-calibration (0.25) compared to the previous calibration (0.3). In particular, time series for the important parameters DO and ammonia better represented observed data. Also, surface time-series from re-calibration reflected the observed data better compared to the old calibration. The re-calibration was conducted for the original verification period (January through September 1997). This period included the calibration period (June through September 1997) as well.

Capitol Lake

The results of model calibration and verification by ERM and Ecology are presented in detail in Appendix H. The following presents selected results from the calibration and verification.

Calibration

The calibration period adopted for the study was May 18, 2004 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 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. The lake was also divided into two regions (north basin and south basin) with different dates for herbicide application. Significant macrophyte regrowth occurred beginning approximately two weeks (residence time of Capitol Lake) following the herbicide application.

Figure 78 shows the model results compared with the discrete measurements at Ecology station CL4 in the north basin. The model performed well in reproducing the macrophytes and algae growth. Both the predicted surface (red) and bottom (green) algae concentrations decreased in September whereas the data show continued high chlorophyll concentrations; however, the other constituents represent September conditions well. The model also successfully captured the long-term system trend for nutrients and the response to the herbicide application.

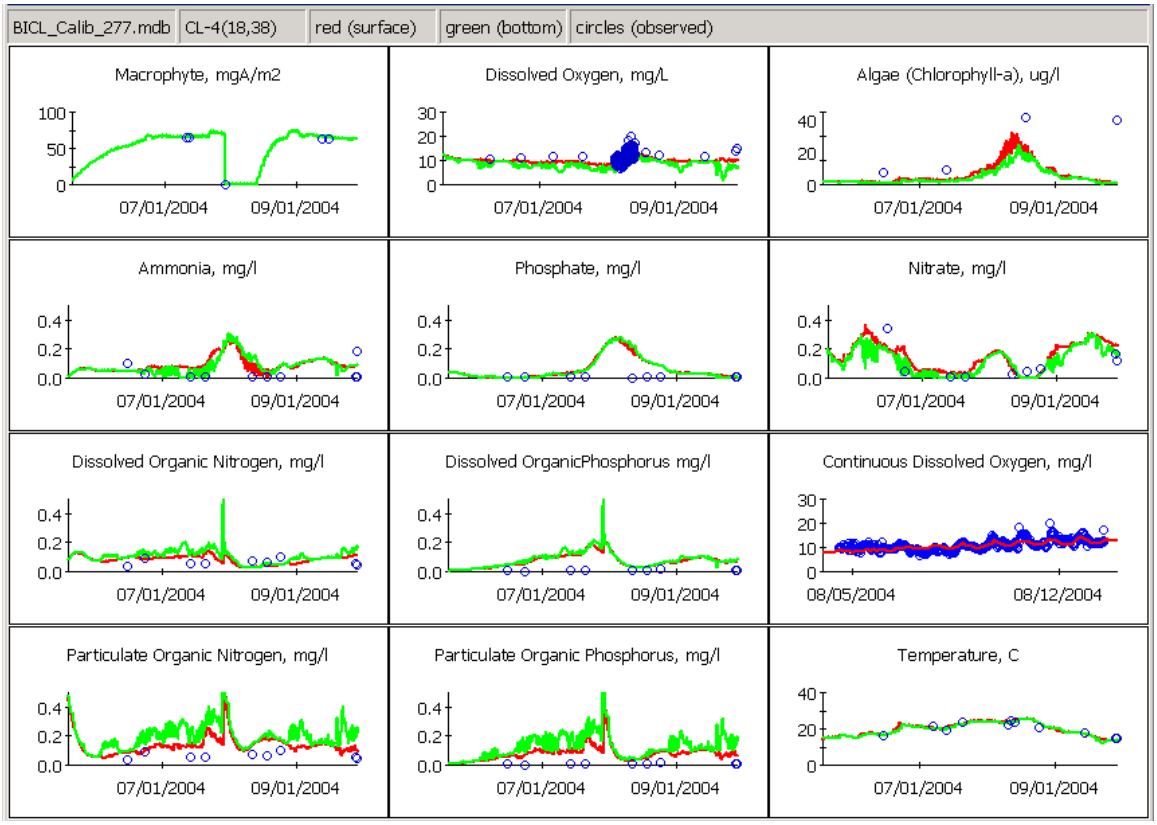


Figure 78. Measured and predicted concentrations of macrophytes, algae and nutrients at station CL4 (Capitol Lake outlet) during model calibration.

Verification

The verification period adopted for the study was April 25, 2001 to June 13, 2001, based on the availability of boundary condition and verification data (CH2MHill, 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.

Figure 79. presents the model results compared with the discrete measurements during the verification period. The model performed well in reproducing the nutrients and algae growth using the pre-herbicide settings. The model also successfully captured the long-term system trend for nutrients. DO levels tended to be overpredicted compared with the instantaneous values, but few data were available.

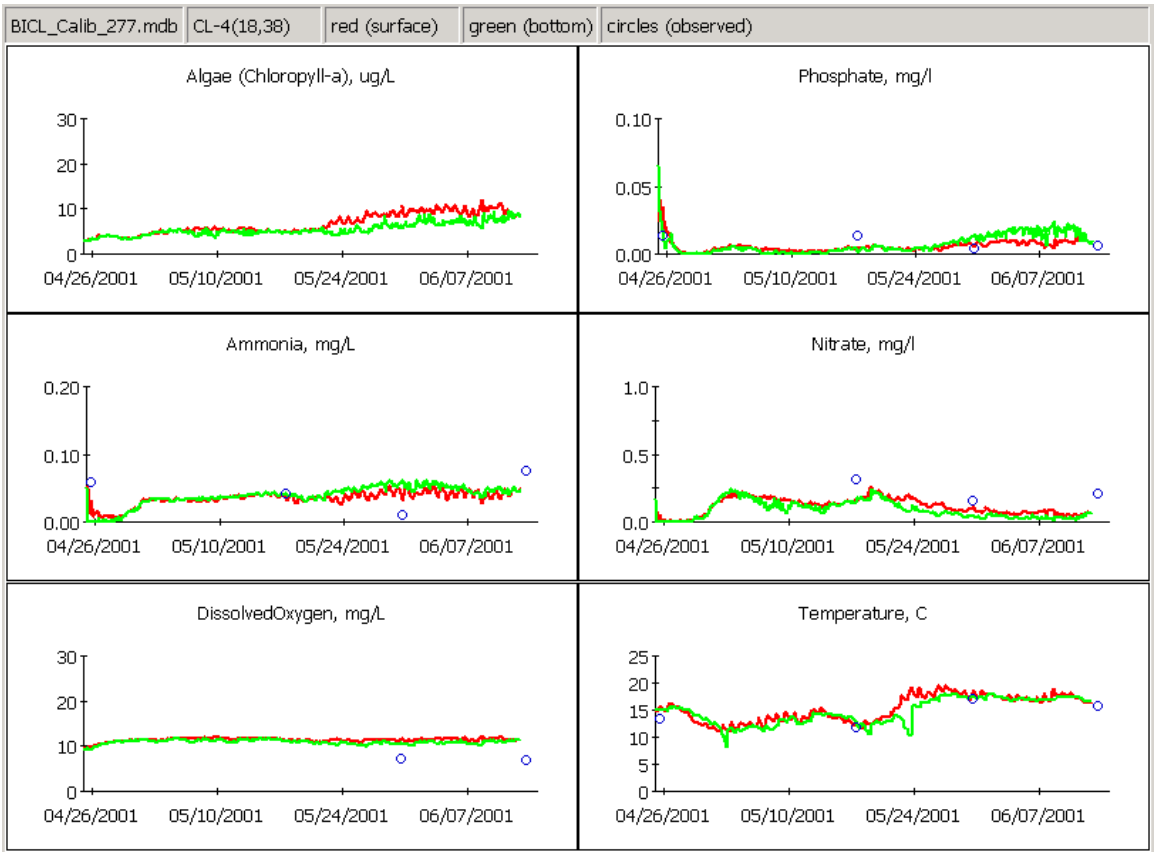


Figure 79. Measured and predicted concentrations of algae and nutrients comparison at station CL4 (Capitol Lake outlet) during model verification.

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. The EPA's current regulation defines loading capacity as "the greatest amount of loading that a waterbody 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 a subsequent future 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 eight alternative scenarios were evaluated using the calibrated GEMSS model. Four scenarios include the Capitol Lake outlet dam (Lake alternative) and four scenarios assume that the dam is not present and that Capitol Lake functions as an estuary (Estuary alternative) with a simple 500-ft (150-m) opening. For each Capitol Lake management option (Lake alternative with the dam and Estuary alternative without the dam), the following four scenarios were run for the entire combined Capitol Lake/Budd Inlet model domain:

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 lowest nutrient levels measured historically. Details are described in Appendix I.
2. **Current nonpoint sources**. All tributaries and nonpoint sources discharge at existing conditions, and point sources/WWTPs are set to zero.
3. **Current point and nonpoint sources**. All WWTPs and tributary nonpoint sources were set to existing conditions.
4. **Permitted point sources and current nonpoint sources**. WWTPs were set to permit limits; nonpoint sources were set to existing conditions.

For the scenarios assuming the dam is not present (Estuary alternative), 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 July 15, 1997 through September 15, 1997 for comparing results. Appendix I details the development of the scenarios.

Scenarios 2, 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. 2 evaluates the DO depletion caused by current nonpoint sources relative to the estimated natural conditions baseline.
- Scenario 1 vs. 3 evaluates the DO depletion cased by current nonpoint sources combined with current point sources relative to the estimated natural conditions baseline.
- Scenario 1 vs. 4 evaluates the DO depletion cased by current nonpoint sources combined with maximum permitted point sources relative to the estimated natural conditions baseline.

DO differences were compared for each grid cell in each layer. The water quality standards establish both absolute numeric threshold criteria and relative difference criteria when the natural DO levels are below the numeric criteria. 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); therefore, results are presented for each region (Figure 80).

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.

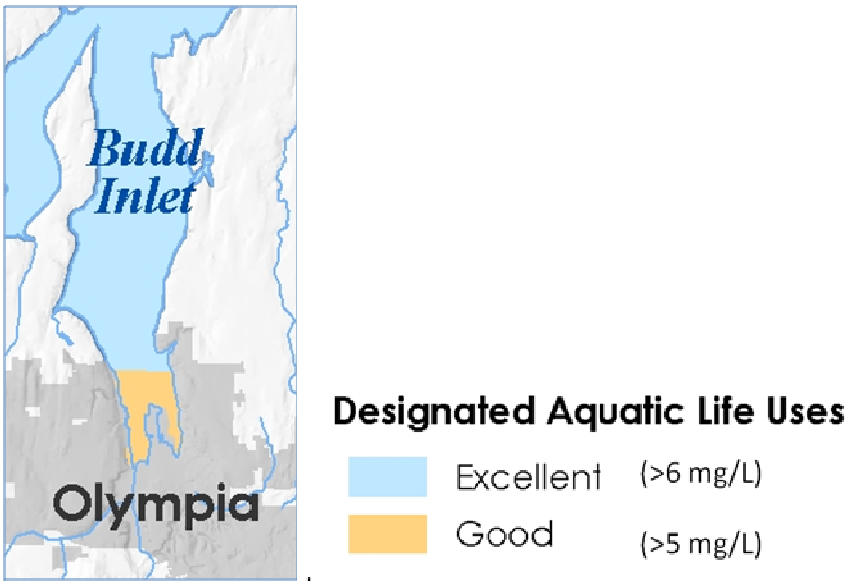


Figure 80. Water quality standards in Budd Inlet and Capitol Lake.

Application of the water quality standards to tidal waterbodies requires additional interpretation. For example, if a scenario changes the timing of predicted dissolved oxygen but not the overall magnitude, calculating the absolute difference between two scenarios may identify a violation where the overall DO reduction may not exceed the threshold that defines a violation. Therefore, scenario results are compared two ways:

- Does increased loading over natural conditions cause an absolute decrease in DO that would violate the water quality standards at any grid cell or any vertical layer at any time? If so, how long would the violations persist?
- Does increased loading over natural conditions cause a net decrease in dissolved oxygen that would violate the water quality standards for any grid cell or any vertical layer during the critical period?

To determine whether the absolute decrease in DO would cause violations at any time, scenario results are directly compared. To determine whether the net decrease would cause violations during the critical period, scenario results are compared using a cumulative frequency distribution. Both are described below.

Evaluation of Model Output for Budd Inlet by Direct Comparison with Dissolved Oxygen Criteria

Natural conditions (Scenario 1) were compared with current nonpoint sources (Scenario 2), the combined effect of current nonpoint sources and current point sources (Scenario 3), and the combined effect of current nonpoint sources and maximum permitted point sources (Scenario 4) by directly subtracting the predicted DO time series. Figure 81 identifies any cell that would

violate the water quality standard for at least one hour between July 15 and September 15 under the three comparisons for both the Lake alternative and Estuary alternative. The calculations are completed for each grid cell horizontally and each vertical layer. The maximum depletion of any layer is calculated for each horizontal grid cell. The total time violating the water quality standards within the worst layer of each cell is shown using a color ramp. If no color is shown, all layers in the grid cell meet the water quality standards at all times.

Current nonpoint sources would not cause violations of the water quality standards in any layer of any cell within Budd Inlet under either the Lake or the Estuary alternatives (Scenario 1 – Scenario 2). Predicted DO levels are slightly lower with the nonpoint sources compared with natural conditions, but maximum differences are no more than 0.2 mg/L when the natural condition is below the numeric criteria.

The combined effect of current nonpoint sources and current point sources would violate the water quality standards within some portions of Budd Inlet (Scenario 1 – Scenario 3). DO violations would persist longest in the areas close to the Olympia Peninsula under the Lake alternative. DO violations would occur in outer Budd Inlet but would not persist more than one day for the conditions and time period simulated. Under the Estuary alternative, fewer areas of Budd Inlet would violate the water quality standards, but violations would still occur and persist longest near the Olympia Peninsula. All of West Bay and much of the west side of inner Budd Inlet would meet the water quality standards, due to improved circulation and possibly changes in algae growth associated with the circulation changes.

If all point sources discharged at their maximum permitted levels for 24 hours a day and 365 days a year, more areas of Budd Inlet would violate the water quality standards under the Lake alternative (Scenario 1 – Scenario 4) compared with current discharge levels. DO violations would persist longer than compared with current discharge levels, and areas near the Olympia Peninsula would persist longest. DO violations would occur under the Estuary alternative as well, with somewhat more persistent violations near Priest Point Park. Under either the Lake or the Estuary alternative, if all point sources discharged at maximum levels, the assimilative capacity of Budd Inlet would be overwhelmed.

Figure 82 presents the maximum DO decrease in the cells that would violate the water quality standards. Depletions over 1 mg/L would occur under the Lake alternative from the combined effect of current nonpoint sources and current point sources, but maximum depletions would be less intense under an Estuary alternative.

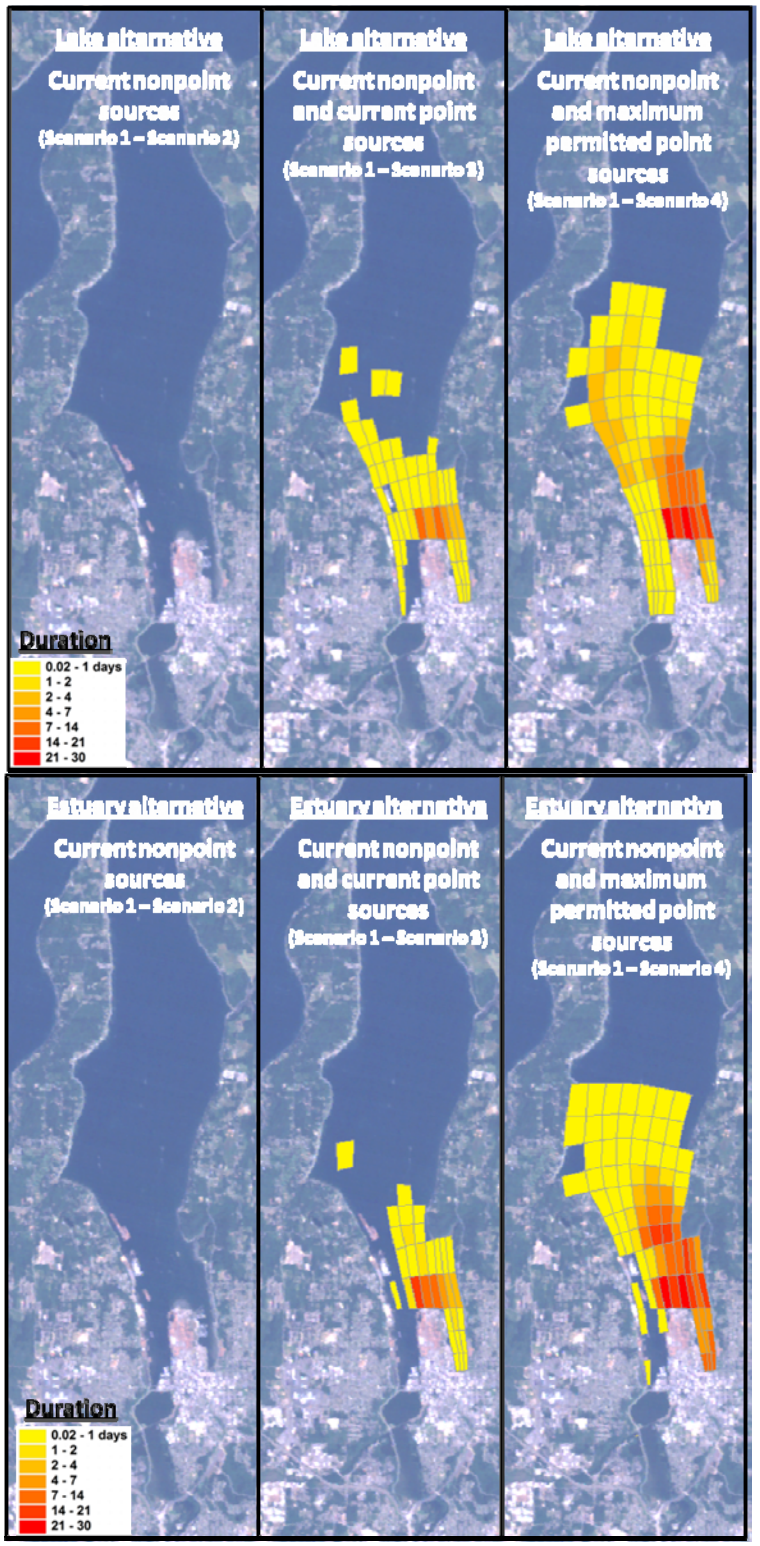


Figure 81. Number of days violating the water quality standards by scenario for the July 15 through September 15 simulation period.

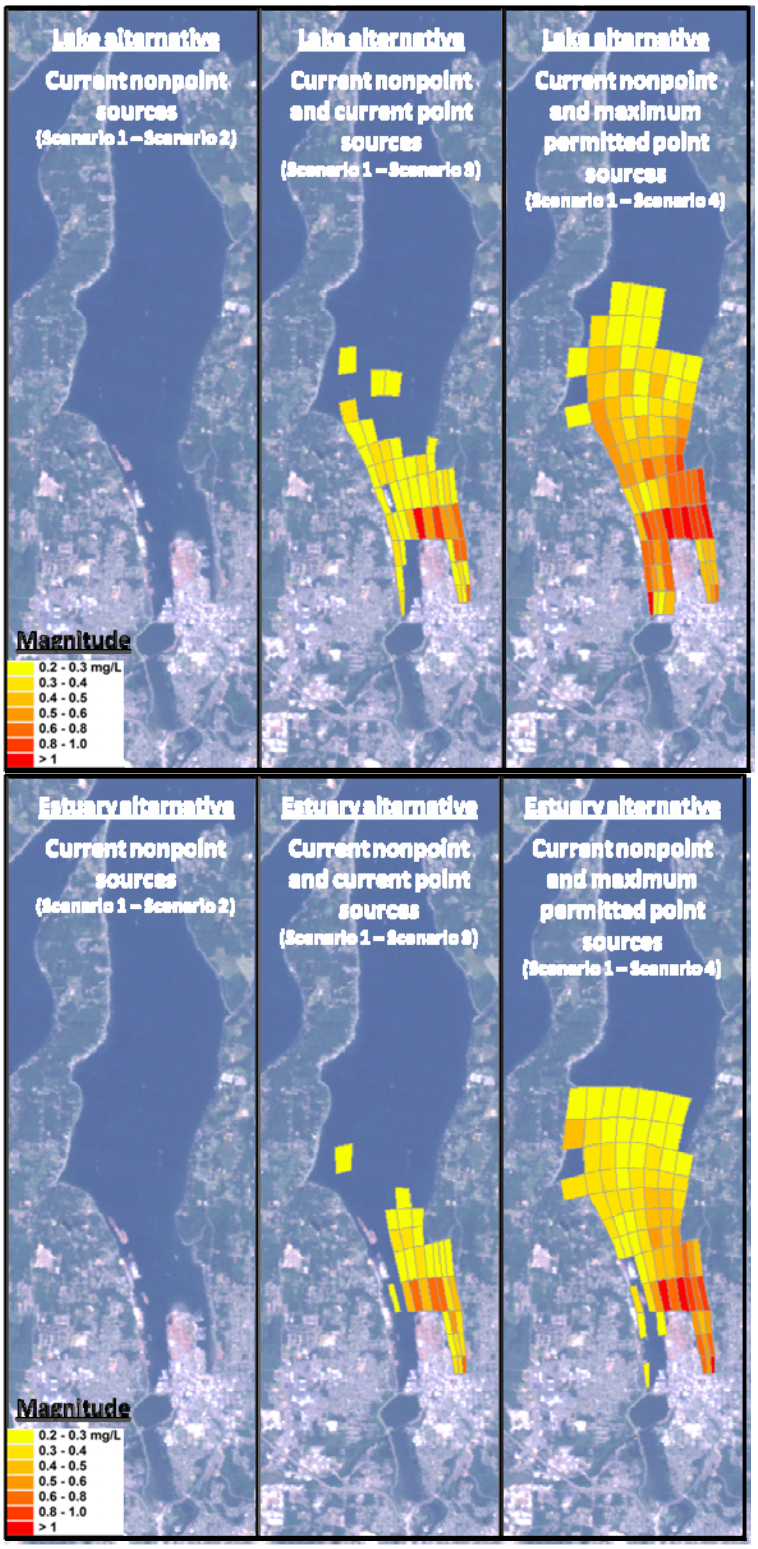


Figure 82. Maximum (mg/L) decrease in DO for cells violating the water quality standards by scenario for the July 15 through September 15 simulation period based on the direct comparison of results.

Evaluation of Model Output for Budd Inlet using Cumulative Frequency Distributions

Model output also may be examined using cumulative frequency distributions (CFDs) of predicted dissolved oxygen conditions in each cell. This method looks at overall shifts in water quality during a specified time period within each cell rather than direct hour-by-hour comparisons of model predictions with water quality criteria.

Cumulative frequency distributions provide a means to compare the net effect of increased loading between two scenarios. Figure 83 illustrates how model results were used to calculate a CFD for a single grid cell off the Olympia Peninsula from a layer near the bottom under the Lake alternative.

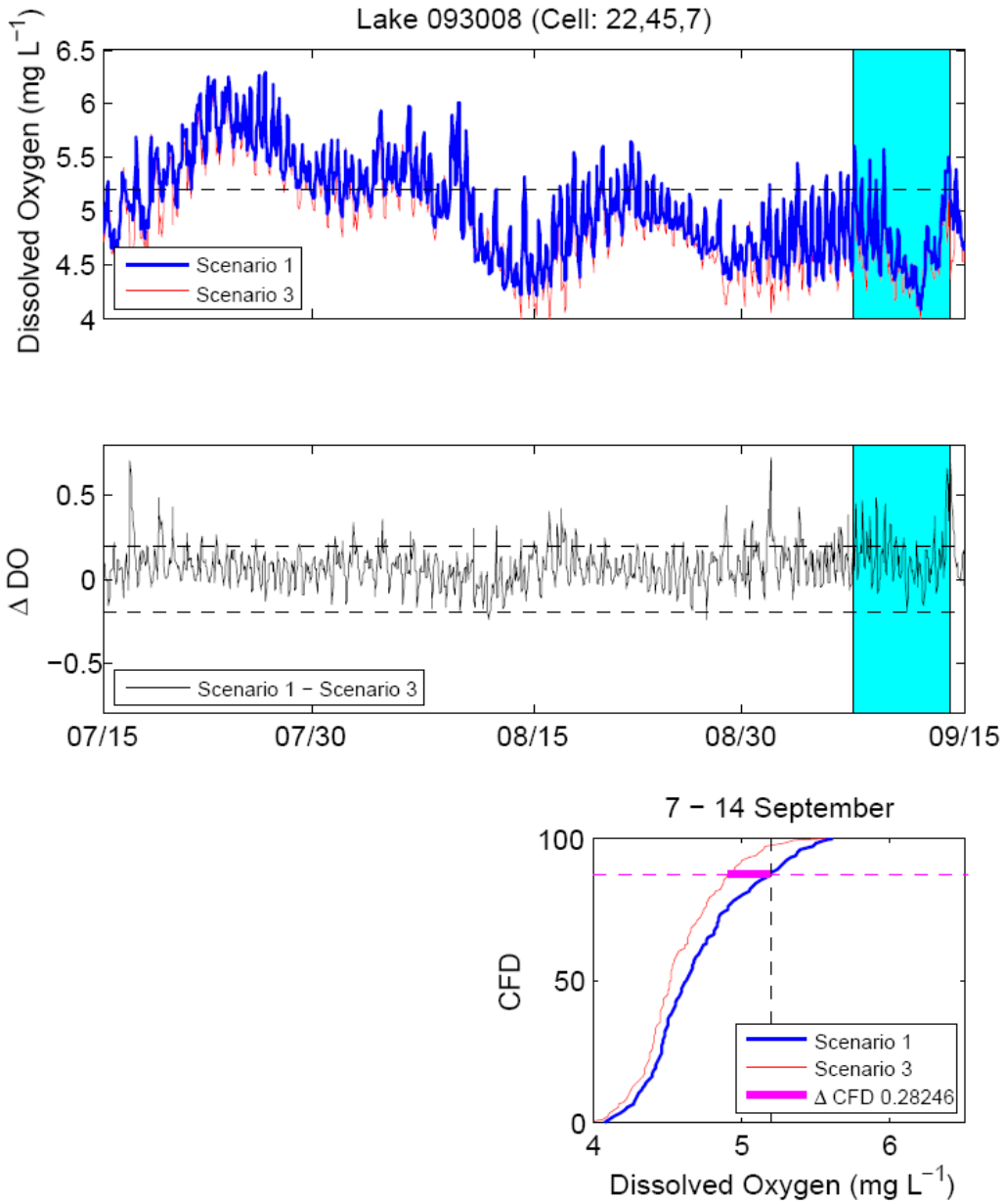


Figure 83. Predicted dissolved oxygen concentrations for layer 7 of model grid cell (22,45), near the Olympia Peninsula. "Lake" refers to scenarios run with Capitol Lake in place. (a) presents the predicted DO for natural conditions (Scenario 1) and the combined effects of current nonpoint and point sources (Scenario 3) as both the hourly output and the daily minimum. (b) presents the difference in predicted DO between the two scenarios for both hourly and daily minimum values. (c) presents the cumulative frequency distributions of the predicted hourly DO for Scenarios 1 and 3.

From Figure 83(a), the predicted DO in this cell with the additional sources (Scenario 3) generally is lower than DO associated with natural conditions (Scenario 1), although during some time periods DO is higher. The hourly predicted DO values shown in the figure as thin

lines illustrate periodic fluctuations over the two-month period under both scenarios, discussed below under Critical Conditions.

Figure 83(b) results from subtracting the two time series of hourly predicted DO. The difference in DO also exhibits a periodic nature. The highest depletions occur when DO concentrations are the lowest within the 2-month period, also coinciding with low water exchanges. In this example, because the DO depletion is more than 0.2 mg/L at least once, the cell would show as a violation in Figure 81. The total amount of time the differential DO is above 0.2 mg/L between July 15 and September 15 is the duration. In Figure 83(b), however, the differential DO is sometimes negative, indicating that predicted DO is higher than for natural conditions with the additional loading. Direct differences in DO also could reflect changes to the timing of the predicted DO concentrations, such as if DO patterns were no different in magnitude but simply offset slightly in time between two scenarios.

During the highlighted 7-day period in Figure 83(b), large positive values (DO decreases) often are followed by large negative values (DO increases). The net effect could be slightly positive or slightly negative or could indicate no change in magnitude at all. In this CFD, the hourly predicted DO concentrations over the 7-day period are pooled and ranked from lowest to highest. The percent of time (or the percent of values within the pooling period) that DO concentrations are below a particular value is calculated for each scenario (Figure 83(c)). For example, from September 7 through September 14, DO concentrations are at or below 4.6 mg/L 50%[11] of the time under Scenario 1 (natural conditions). In the same plot but for Scenario 3, 50% of the time DO concentrations are at or below 4.5 mg/L due to the combined effects of current point and nonpoint sources. The horizontal difference between the two distributions is 0.1 mg/L at 50% on the y-axis, but greater for other percentiles.

DO concentrations in this cell are below 5.2 mg/L (dashed vertical line) about 90%[11] of the time (dashed horizontal line). With the combined effects of nonpoint and point sources (Scenario 3), 90% of the time DO concentrations are below 4.9 mg/L. Therefore, the additional loading caused more frequent low DO concentrations compared with natural conditions, and a decrease in DO experienced 90% of the time from 5.2 mg/L to 4.9 mg/L. Because this is greater than 0.2 mg/L, a violation of the water quality standards would occur, based on the CFD.

The water quality standards state that when natural conditions are below the numeric standard, no more than 0.2 mg/L depletion can occur. Therefore, the difference between the CFDs for Scenario 1 and Scenario 3 can be no more than 0.2 mg/L. For this example, the maximum difference between the CFDs is 0.28 mg/L, and it results when the DO concentration decreases from 5.2 to 4.9 mg/L. If the maximum difference between CFDs for the two scenarios was less than 0.2 mg/L for all percentiles below 5.2 mg/L (horizontal distance between CFDs), the cell would meet the water quality standards.

The time period selected for examination (pooling period) is an essential part of CFDs. If the entire July 15 through September 15 period were pooled, the lower differences found at some times would partially offset the higher differences at other times, and the results could mask

[11] CFDs are compared for all percentiles between 1 and 100, and the 50th or 90th percentile values are used only as examples of how to read the figure.

problem periods. A 7-day pooling period allows for both daily and tidal variations. Additional tests with a 4-day pooling period did not change the overall results, so a finer pooling period was not justified. To find the most critical 7-day period, results were analyzed using a rolling 7-day period over the two-month simulation period. The worst case occurred between September 7 and September 14 and represents the critical condition for the simulation period.

Figure 84 presents a corollary to Figure 82 using a comparison of CFD results instead of direct hour-by-hour comparisons of model output to water quality criteria. Using a CFD to represent each scenario, portions of inner Budd Inlet would violate the water quality standards due to the combined effects of current nonpoint sources and current point sources in both the Lake and Estuary alternatives. The magnitude of the maximum depletion is slightly lower in the critical cell under an Estuary alternative. If all point sources discharged at their maximum permitted levels at all times, additional parts of inner Budd Inlet and portions of outer Budd Inlet would not meet the water quality standards. Under an Estuary alternative and maximum point source discharges, all of East Bay would violate the water quality standards, likely due to overall changes in circulation compared with a Lake alternative. The current nonpoint sources alone would not violate the water quality standards on the basis of CFDs.

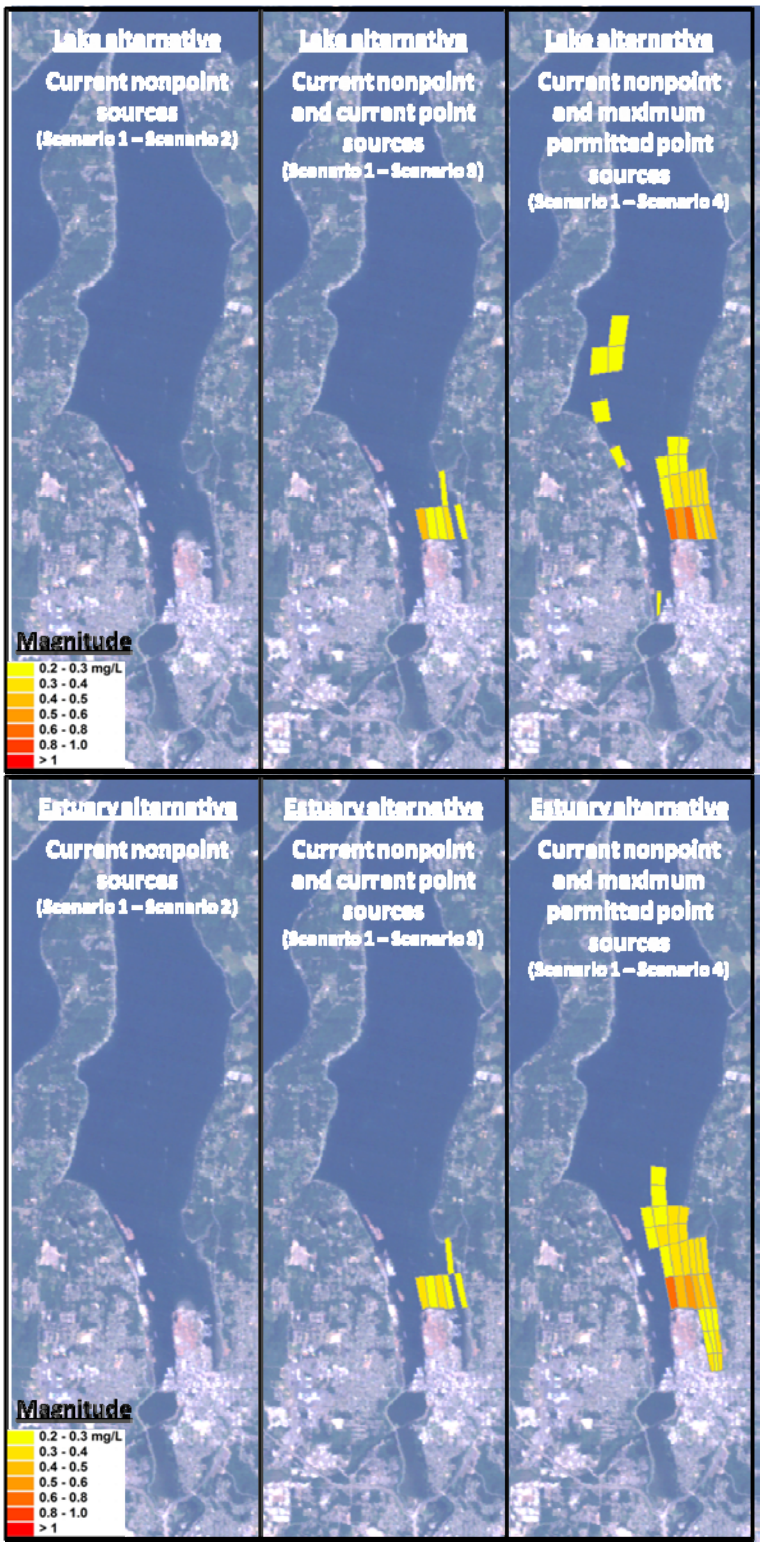


Figure 84. Maximum (mg/L) decrease in DO for cells violating the water quality standards by scenario for the worst-case 7-day conditions (September 7-14), based on the cumulative frequency distribution of results

Critical Conditions

A frequency analysis using Fourier transformation confirmed that both predicted DO and differential DO between scenarios shows variation with a subdaily tidal cycle (~12.2 hours), daily processes (24 hours), and the spring-neap tidal cycle (~14 and 28 days). 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.

In the example grid cell near the Olympia Peninsula shown in Figure 83, the lowest DO levels and the highest DO depletions occur as a strong neap tide transitions to a strong spring tide. During a strong spring tide, large water exchanges flush water out of inner Budd Inlet. However, as the next neap, spring, and strong neap cycle occur, less and less water is flushed out of inner Budd Inlet. The greatest stagnation of water occurs just following a strong neap tide. Low DO levels coincide with the most stagnant water condition.

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. Based on the rolling 7-day CFDs, but also apparent from the direct comparison of scenario time series, the worst-case conditions within the simulation period occur between September 7 and September 14, which coincides with the most stagnant water condition just after a strong neap condition. These low DO levels progressively worsen from July through September, likely due to increased algal growth superimposed on the circulation patterns.

Maximum DO Differences in Capitol Lake

The effects of nonpoint sources from the Deschutes River and Percival Creek on Capitol Lake also were evaluated, both with direct comparisons and using CFDs. Current nonpoint sources cause portions of Capitol Lake to violate the water quality standards, expressed as a change of no more than 0.2 mg/L from natural conditions. Figure 85 identifies areas of Capitol Lake violating the standards as well as the duration based on direct comparison of results. Figure 86 identifies the maximum magnitude of the depletion. Only Percival Cove would meet the water quality standards, and the rest of Capitol Lake would violate the water quality standards for DO.

Because some high depletions are followed by increases in DO when comparing nonpoint sources with natural conditions, the net effect of nonpoint sources was evaluated using a CFD (Figure 87). Portions of Capitol Lake would not meet the water quality standards based on a

CFD. Violations would occur throughout the simulation period of July through September. However, rolling-7-day pooling periods for the CFDs indicate that the critical condition for Capitol Lake occurs August 14-21. Nonpoint loads from the Deschutes River and Percival violate water quality standards, and nonpoint source nutrient reductions are necessary for Capitol Lake to meet the water quality standards.

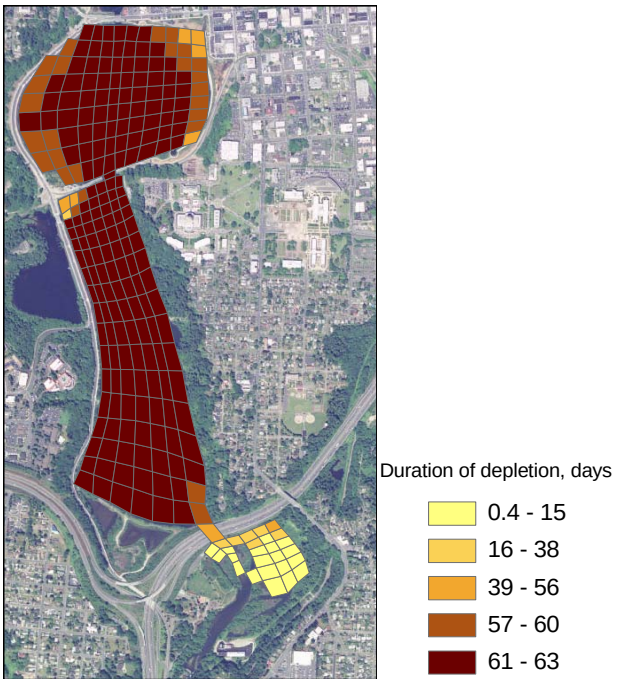


Figure 85. Number of days violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the July 15 through September 15 simulation period, based on the direct comparison of results.

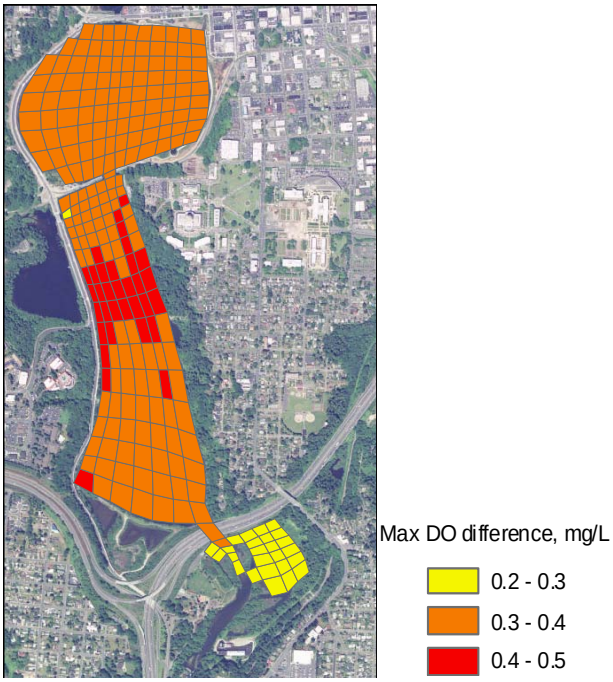


Figure 86. Maximum (mg/L) decrease in DO for cells violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the July 15 through September 15 simulation period, based on the direct comparison of results.

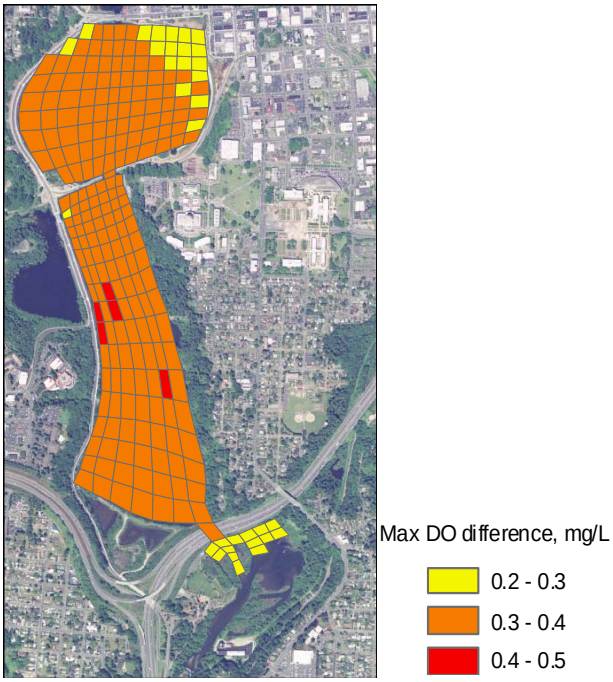


Figure 87. Maximum (mg/L) decrease in DO for cells violating the water quality standards within Capitol Lake from nonpoint sources compared with natural conditions for the worst-case 7-day conditions (September 7-14). Based on the cumulative frequency distribution of results.

Summary of Loading Capacity

The combined effects of current nonpoint and point sources exceeds 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 Capitol Lake, and nutrient load reductions are necessary. As an estuary, the current nonpoint sources meet the loading capacity of the Deschutes estuary portions of southern Budd Inlet (the geographic area that is currently Capitol Lake).

Conclusions and recommendations

Current point and nonpoint sources exceed the loading capacity of Budd Inlet. The combined effects cause portions of inner and outer 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. Nutrient load reductions are necessary; however, load and wasteload allocations will be addressed in a separate future 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 nonpoint sources exceed the loading capacity of Capitol Lake. During the next phase, several model runs will be developed in conjunction with the advisory committee. Load and wasteload allocations will be determined such that Budd Inlet and Capitol Lake meet the water quality standards. The Water Quality Improvement Report also will establish allocations for future growth and the 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, pH, and 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 levels do not meet the water quality standards during both the summer growing season and winter non-growing season in various areas, and reductions are necessary based on data collected for this project. More locations violate the water quality standards in summer than in winter, and the small tributaries to Budd Inlet require the highest reductions. In subwatersheds where multiple locations were monitored, concentrations trend up in a downstream direction, indicating that multiple bacteria sources affect water quality. Immediate efforts should build from past efforts by the City of Olympia and Thurston County, possibly intensifying the source identification and cleanup programs.

Current vegetation produces effective shade levels below that for mature vegetation, and the decreased shade increases maximum water temperatures by 4.5°C and depresses minimum oxygen levels by 0.8 mg/L. 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. Restoring effective shade and channel conditions would not meet numeric temperature or DO criteria upstream of Offut 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 dissolved oxygen concentrations by 1.2 mg/L, and decrease maximum pH by 0.5 SU.

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, dissolved oxygen, pH, and fine sediment as well. 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.

Summer baseflows have declined in the Deschutes River since historical gaging began in the 1950s and 1960s. Instream flow influences stream temperature and subsequently DO and pH, and flow reductions may increase peak temperatures. However, instream flows and surface

water/groundwater withdrawals are managed through separate regulatory programs, 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.

Anthropogenic sources 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. 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. Channel and riparian restoration would mitigate fine sediment in addition to improving temperature, dissolved oxygen, 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.

The combined effects of current nonpoint and point source nutrient loads exceeds the loading capacity of Budd Inlet for DO, and load reductions are needed under both the Lake or Estuary alternative. 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. The Water Quality Improvement Report will develop detailed load and wasteload allocations for Budd Inlet and Capitol Lake, including the Deschutes River and Percival Creek.

Load and wasteload targets were recommended for many parameters and areas within the watershed. Fecal coliform reduction targets were calculated geographically by subwatershed. The load and wasteload targets, expressed as percent reductions from current conditions, are identical within a given subwatershed. For temperature, dissolved oxygen, and pH in the Deschutes River and its tributaries, load targets were based on the solar radiation reductions provided by mature riparian shade along the mainstem and tributaries, including the benefits of channel restoration. No numeric targets were developed for heat (temperature) from areas covered by municipal, industrial, construction, or transportation stormwater, sand and gravel facilities, or dairies; adherence to the general permit conditions is necessary and sufficient. For DO and pH, no numeric targets were developed for areas covered by stormwater or sand and gravel general permits, and adherence to the general permit conditions is sufficient. For dairies, adherence to the nutrient management plans is required, and no numeric targets were established. For fine sediment, 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.

Load and wasteload allocations to address total phosphorus and DO in Capitol Lake and DO in Budd Inlet will be determined in the Water Quality Improvement Report. No nutrient load reductions are needed from tributaries to the Deschutes River for the Deschutes River to meet the water quality standards for DO and pH. The Water Quality Improvement Report will determine the nutrient load reductions needed in the Deschutes watershed so that Capitol Lake and Budd Inlet meet water quality standards.

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, the 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.

Next Steps

Ecology will convene an advisory committee in early 2009 and 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 allocations into a Water Quality Improvement Report. The Water Quality Improvement Report will be submitted to the U.S. Environmental Protection Agency for approval. Once approval has been received, Ecology again will work with the advisory committee to establish specific details for implementation actions, and this information will be compiled into a Water Quality Implementation Plan.

References

Adams, T.N. and K. Sullivan. 1989. The Physics of Forest Stream Heating: A Simple Model. Timber, Fish, and Wildlife Report Number TFW-WQ3-90-007. Washington Department of Natural Resources, Olympia, WA.

Ahmed, A., 2004a. Upper Chehalis River Fecal Coliform Bacteria Total Maximum Daily Load Recommendations. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-004. www.ecy.wa.gov/pubs/0403004.pdf.

Ahmed, A., 2004b. North Fork Palouse River Fecal Coliform Bacteria Total Maximum Daily Load Recommendations. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-022. www.ecy.wa.gov/pubs/0403022.pdf.

Ahmed, A. and C. Hempleman. 2006. Tributaries to Totten, Eld, and Little Skookum Inlets: Fecal Coliform Bacteria and Temperature Total Maximum Daily Load Water Quality Improvement Report. Washington State Department of Ecology Publication No. 06-03-007.

Ahmed, A. and D. Rountry. 2007. Willapa River Fecal Coliform Bacteria Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology Publication No. 07-03-021.

Anchor Environmental, LLC. 2008. Final Deschutes River Watershed Recovery Plan: Effects of Watershed Habitat Conditions on Coho Salmon Production. Prepared for Squaxin Island Tribe Natural Resources Department. (A copy can be found at www.ecy.wa.gov/_____)

Aura Nova Consultants, Inc., Brown and Caldwell, Evans-Hamilton, J.E. Edinger and Associates, Ecology, and the University of Washington Department of Oceanography. 1998. Budd Inlet Scientific Study Final Report. Prepared for the LOTT Partnership, Olympia, Washington.

Aura Nova Consultants and J.E. Edinger Associates, Inc. 1999. LOTT NPDES permit modifications modeling revised interim report. November 19, 1999.

Baranski, ___. 1996.

Bartholow, J.M. 2000. Estimating cumulative effects of clearcutting on stream temperatures. Rivers 7(4):284-297.

Bilby, R.E., K. Sullivan, and S.H. Duncan. 1989. The generation and fate of road-surface sediment in forested watersheds in Southwestern Washington. Forest Science 35(2):453-468.

Bisson, P.A., J.L. Nielsen, J.W. Ward, R.E. Bilby, and J.T. Heffner. 1985. Salmon Enhancement in Streams. Progress Report Number 3. Technical Report 348. Weyerhaeuser Company, Tacoma, WA.

Brett, M.T., G.B. Arhonditsis, S.E. Mueller, D.M. Hartley, J.D. Frodge, and D.E. Funke. 2005. Non-point-source impacts on stream nutrient concentrations along a forest to urban gradient. Environmental Management 35(3):330-342.

Brown, G.W. and J.T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resources Research 6(4):1133-1139.

Brown, G.W., G.W. Swank, and J. Rothacher. 1971. Water Temperature in the Steamboat Drainage. USDA Forest Service Research paper PNW-119, Portland, OR. 17 p.

Bull, W.B. 1979. Threshold of critical power in streams. Geological Society of America 90:453-464.

Casola, J.H., J.E. Kay, A.K. Snover, R.A. Norheim, L.C. Whitely Binder, and the Climate Impacts Group. 2005. Climate Impacts on Washington's Hydropower, Water Supply, Forests, Fish, and Agriculture. A report prepared for King County (Washington) by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle).

CH2MHill. 2001. Technical Evaluation Report for the Discharge of Treated Wastewater from the Tumwater Brewery. Prepared for Miller Brewing Company Tumwater Brewery.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117(1):1-21.

Chapra, S. C. 1997. Surface Water Quality Modeling. McGraw-Hill Companies, Inc. New York.

Chapra, S.C. and D.M. DiToro. 1991. The Delta Method for estimating community production, respiration, and reaeration in streams. Journal of Environmental Engineering 117(5):640-655.

Chen, Y.D. 1996. Hydrologic and Water Quality Modeling for Aquatic Ecosystem Protection and Restoration in Forest Watersheds: A Case Study of Stream Temperature in the Upper Grande Ronde River, Oregon. Ph.D. dissertation. University of Georgia, Athens, Georgia.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter. 1998a. Stream temperature simulation of forested riparian areas: I. Watershed-scale model development. Journal of Environmental Engineering 124(4):304-315.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter. 1998b. Stream temperature simulation of forested riparian areas: II. Model application. Journal of Environmental Engineering 124(4):316-328.

Collins, B. 1994. A study of rates and factors influencing channel erosion along the Deschutes River, Washington, with application to watershed management planning. Report prepared for Squaxin Island Tribe Natural Resources Department, Shelton, WA. 103 p. + appendices.

Department of Health. 2008. Shellfish Safety Information, Marine Closure Zones. www.doh.wa.gov/ehp/sf/default.htm.

Dickison, J. 1996. Data submitted to Department of Ecology for Clean Water Act Section 303(d) listing. Squaxin Island Tribe.

Dinicola, R.S. 1979. Relationship of Fish Habitat and Geomorphology and Sediment in the Upper Deschutes River Basin. Technical Report. Weyerhaeuser Company, Centralia, WA.

Dubé, , K., W. Megahan, and M. McCalmon. 2004. Washington Road Surface Erosion Model. Prepared for Washington Department of Natural Resources. www.dnr.wa.gov/Publications/fp_data_warsem_manual.pdf.

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

Ecology. 2003. A Tool for Estimating Shade from Riparian Vegetation. Washington State Department of Ecology. www.ecy.wa.gov/programs/eap/models.html.

Edinger, J.E. and E.M. Buchak. 1980. Numerical Hydrodynamics of Estuaries in Estuarine and Wetland Processes with Emphasis on Modeling. P. Hamilton and K.B. MacDonald (eds.). Plenum Press, New York. Pp. 115-146.

Edinger, J.E. and E.M. Buchak. 1985. Numerical waterbody dynamics and small computers. Proceedings of the ASCE 1985 Hydraulic Division Specialty Conference on Hydraulics and Hydrology in the Small Computer Age. American Society of Civil Engineers, Lake Buena Vista, Florida. pp. 1316.

Edinger, J.E. and E.M. Buchak. 1995. Numerical intermediate and far field dilution modeling. Journal of Water, Air, and Soil Pollution 83:147-160. Kluwer Academic Publishers, The Netherlands.

Edinger, J.E., E.M. Buchak, and M.D. McGurk. 1994. Analyzing larval distributions using hydrodynamic and transport modeling. Estuarine and Coastal Modeling III. American Society of Civil Engineers, New York.

Edinger, J.E., J. Wu, and E.M. Buchak. 1997. Hydrodynamic and Hydrothermal Analyses of the Oncethrough Cooling Water System at Hudson Generating Station. Prepared for Public Service Electric and Gas by J.E. Edinger Associates, Inc.

EPA. 2001. Overview of Current Total Maximum Daily Load - TMDL - Program and Regulations. U.S. Environmental Protection Agency. www.epa.gov/owow/tmdl/overviewfs.html

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cedarholm. 1985. Fine sediment and salmonid production: a paradox. In: E.O. Salo and T.W. Cundy (eds.), Streamside Management: Forestry and Fishery Interactions 57:98-142. College of Forest Resources, University of Washington, Seattle.

Fox, M. and S. Bolton. 2007. A regional and geomorphic reference for quantities and volumes of instream wood in unmanaged forested basins of Washington State. North American Journal of Fisheries Management 27:342-359.

General Administration. 2002. Capitol Lake, A Vision for the Next Ten Years.

George, D.A., G. Gelfenbaum, G. Lesser, and A.W. Stevens. 2006. Deschutes estuary feasibility study: hydrodynamics and sediment transport modeling. U.S. Geological Survey Open-File Report 2006-1318, 222p.

Hamlet A.F. and D.P. Lettenmaier, 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. Journal of the American Water Resources Association, 35(6):1597- 1623.

Hamlet, A.F., P.W. Mote, M. Clark, and D.P. Lettenmaier, 2005. Effects of temperature and precipitation variability on snowpack trends in the western U.S. Journal of Climate, 18 (21): 4545-4561.

Haring, D. and J. Konovsky. 1999. Salmonid habitat limiting factors: Water Resources Inventory Area 13. Final Report. Washington State Conservation Commission, Olympia, WA.

Hicks, M. 2002. Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards – Temperature Criteria – Draft Discussion paper and Literature Summary. Washington State Department of Ecology Publication No. 00-10-070, Olympia, Washington. www.ecy.wa.gov/biblio/0010070.html.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, B.C., and associated impacts on the coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Hsieh, P.A., W. Wingle, and R.W. Healy. 2000. VS2DI—A Graphical Software Package for Simulating Fluid Flow and Solute or Energy Transport in Variably Saturated Porous Media: U.S. Geological Survey Water-Resources Investigations Report 99-4130, 16 p.

Iwamoto, R.N., E.O. Salo, M.A. Madej, and R.L. McComas. 1978. Sediment and Water Quality: A Review of the Literature Including a Suggested Approach for the Water Quality Criteria. EPA 910/9-78-048. USEPA. Seattle, WA.

Johnson, R.A. 1980. Oxygen transport in salmon spawning gravels. Canadian Journal of Fisheries and Aquatic Sciences 37:155-162.

Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources research 32(4):959-974.

Joy, J., 2000. Lower Nooksack River Basin Bacteria Total Daily Maximum Load Evaluation. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-006. www.ecy.wa.gov/biblio/0003006.html.

Kavanaugh, Robert. 1980. Deschutes River Basin Instream Resources Protection Program, including proposed Administrative Rules (Water Resource Inventory Area 13). Washington State Department of Ecology Publication, WWIRPP Series No. 8. aww.ecology/programs/wr/bmp-irpp/drb-irpp.pdf and aww.ecology/programs/wr/irpp_wrp/Deschutes_for_review.pdf.

Kolluru, Venkat. 2006. Personal communication (email, dated January 18, 2006). Appendix A: Comparison of GEMSS results and field data. Appendix B: Results from previous Modeling Results. ERM Consultants.

Konovsky, J. 2004. Squaxin Island Tribe Spawning Gravel Composition Survey QAPP. Squaxin Island Tribe Natural Resources Department Publication submitted to USEPA.

Konovsky, J. and J. Puhn. 2005. Trends in Spawning Gravel Fine Sediment Levels—Deschutes River, Washington. Squaxin Island Tribe, Shelton, Washington.

Koski, K.V. 1966. The Survival and Fitness of Coho Salmon (*Oncorhynchus kisutch*) from Egg Deposition to Emergence in Three Oregon Coastal Streams. Masters Thesis, Oregon State University, Corvallis.

Levno, A. and J. Rothacher. 1967. Increases in Maximum Stream Temperatures after Logging in Old Growth Douglas-Fir Watersheds. USDA Forest Service Research Paper PNW-65, Portland, OR. 12 p.

Lombard, S. and C. Kirchmer. 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. www.ecy.wa.gov/biblio/0403030.html.

Lynch, J.A., G.B. Rishel, and E.S. Corbett. 1984. Thermal alterations of streams draining clearcut watersheds: quantification and biological implications. Hydrobiologia 111:161-169.

MEL. 2005. Manchester Environmental Laboratory Lab Users Manual, Eight Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Mathieu, N. 2006. Replicate Precision for 12 TMDL Studies and Recommendations for Precision Measurement Quality Objectives for Water Quality Parameters. Washington State Department of Ecology Publication No. 06-03-044, Olympia, Washington.

Miller, J.F. et al. 1973. Precipitation-Frequency Atlas of the Western United States, Volume IX, Washington. U.S. Department of Commerce, NOAA.

Mohamedali, T. and S. Lee. 2008. Bear-Evans Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load Water Quality Improvement Report. Washington State Department of Ecology Publication No. 08-10-058. www.ecy.wa.gov/biblio/0810058.html.

Mote, P.W., E. Salathé, and C. Peacock, 2005. Scenarios of future climate for the Pacific Northwest, Climate Impacts Group, University of Washington, Seattle, WA. 13 pp.

Naiman, R.J. and R.E. Bilby (eds.). 1998. River Ecology and Management. Springer-Verlag, New York.

National Atmospheric Deposition Program (NRSP-3)/National Trends Network. 2004. NADP Program Office, Illinois State Water Survey, Champaign, Illinois. nadp.sws.uiuc.edu/isopleths/annualmaps.asp.

National Research Council. 2002. Riparian Areas: Functions and Strategies for Management. Committee on Riparian Zone Function and Strategies for Management, Water Science and Technology Board. 444 p. ISBN 978-0-309-08295-2. www.nap.edu/openbook.php?isbn-0309082951.

Oregon Department of Environmental Quality. 2001. TTools 3.0 user Manual. Portland, Oregon. www.deq.state.or.us/wq/TMDLs/tools.htm.

Parsons, J. 2004. Preliminary Summary of Aquatic Plant Data, Capitol Lake, Thurston County from Summer 2004. (Appendix B of this report)

Parsons, J. 2005. Preliminary Summary of Aquatic Plant Data, Capitol Lake, Thurston County Fall 2005. (Appendix B of this report)

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. Journal of Environmental Quality 9(1):73-79.

Pelletier, G. and S. Chapra. 2006 (draft). QUAL2Kw: Theory and Documentation for A Modeling Framework to Simulate River and Stream Water Quality. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models.html.

Pelletier, G.J., S.C. Chapra, and H. Tao. 2006. QUAL2Kw—A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environmental Modeling & Software 21:419-425.

Pelletier, G. and K. Seiders. 2000. Grays Harbor Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-020. www.ecy.wa.gov/biblio/0003020.html.

Pitt, R., A. Maestre, and R. Morquecho. 2004. National Stormwater Quality Database (NSQD, Version 1.1). Department of Civil and Environmental Engineering, University of Alabama, Tuscaloosa, AL. http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/recentpaper.htm

Raines, M. 2007. Deschutes River Bank Erosion: 1991 to 2003. Report submitted to the Squaxin Island Tribe Natural Resources Department and Washington Department of Ecology.

Reiter, et al., 2006.

Rishel, G.B., J.A. Lynch, and E.S. Corbett. 1982. Seasonal stream temperature changes following forest harvesting. Journal of Environmental Quality 11(1):112-116.

Roberts, B. J., Mulholland P. J. and Houser, J. N. 2007. Effects of upland disturbance and instream restoration on hydrodynamics and ammonium uptake in headwater streams. Journal of the North American Benthological Society 26: 38–53.

Roberts, M., 2003. South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-021. www.ecy.wa.gov/biblio/0303021.html.

Roberts, M. 2004. Lower Deschutes and Budd Inlet tributaries wet weather monitoring plan. April 15 memorandum to Sue Davis (Thurston County) and Roy Iwai (Olympia). www.ecy.wa.gov/programs/wq/tmdl/deschutes/technical_reports/stormwaterplan_final_nofigs.pdf.

Roberts, M., B. Zalewsky, T. Swanson, L. Sullivan, K. Sinclair, and M. LeMoine. 2004. Quality Assurance Project Plan, Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Study. Washington State Department of Ecology Publication No. 04-03-103.

Robinson, D.A., C.M.K. Gardner, and J.D. Cooper. 1999. Measurement of relative permittivity in sand soils using TDR, capacitance, and theta probes: comparison, including the effects of bulk soil electrical conductivity. Journal of Hydrology 223:198-211.

Schuett-Hames, D. and I. Child. 1996. An Assessment of Stream Temperature, Large Woody Debris Abundance and Spawning Gravel Fine Sediment Levels in the Mainstem Deschutes River. Squaxin Island Tribe, Shelton, Washington.

Schuett-Hames, D and H. Flores. 1994. Final Report: The Squaxin Island Tribe/Thurston County Streambed Characterization Contract, 1992-93. Prepared for the Squaxin Island Tribe, Shelton, WA, 9 pages.

Schuett-Hames, D., A. Pleus, E. Rashin, and J. Matthews. 1999. TFW Monitoring Program Method Manual for the Stream Temperatures Survey. Prepared for the Washington State Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-005. DNR #107.

Sargeant, D., M. Roberts, and B. Carey, 2005. Nisqually River Basin Fecal Coliform Bacteria and Dissolved Oxygen Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-002. www.ecy.wa.gov/biblio/0503002.html.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. TR-4501-96-6057. ManTech Environmental Research Services Corporation, Corvallis, Oregon.

Sullivan, K.O. and S.H. Duncan. 1980. Sediment yield from road surfaces in response to truck traffic and rainfall. Weyerhaeuser Technical Report 042-4402.80. Weyerhaeuser Company, Technical Center.

Sullivan, K., S. Duncan,. P. Bisson, J. Heffner, J. Ward, R. Bilby, and J. Nielsen. 1987. A Summary Report of the Deschutes River Basin: Sediment Flow, Temperature, and Fish Habitat. Weyerhaeuser Company Research Report. 129 pp.

Swanson, F.J., S.L. Johnson, S.V. Gregory, and S.A. Acker. 1998. Flood disturbance in a forested mountain landscapes: interactions of land use and floods. Bioscience 48(9):681-689.

Swanson, T. 2007. Standard Operating Procedure (SOP) for Hydrolab® DataSonde® and MiniSonde® Multiprobes. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Hydrolab_v1_0.pdf

Swift, L.W. and J.B. Messer. 1971. Forest cuttings raise water temperatures of a small stream in the southern Appalachians. Journal of Soil and Water Conservation 26:11-15.

Thurston County. 1995.

Thurston County Public Health and Social Services Department. 2004. Septic System Program. www.co.thurston.wa.us/health/ehoss/index.html.

Toth, S. 1991. A Road Damage Inventory for the Upper Deschutes River Basin. Washington State Timber-Fish-Wildlife Program Report. TFW-SH-14-91-007.

U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Association, National Marine Fisheries Service, Environmental Protection Agency, Office of the Governor of the State of Washington, Washington State Department of Natural Resources, Washington State Department of Fish and Wildlife, Washington State Department of Ecology, Colville Confederated Tribes, Washington State Association of Counties, Washington Forest Protection Association, and the

Washington Farm Forestry Association. 1999. Forests and Fish Report. www.dnr.wa.gov/Publications/fp_rules_forestsandfish.pdf

Washington Forest Practices Board. 1997. Standard Methodology for Conducting Watershed Analysis. Washington State Department of Natural Resources. www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesRules/Pages/fp_board_manual.aspx.

Watershed Sciences, LLC. 2004. Aerial Survey of the Deschutes River, Washington Thermal Infrared and Color Videography. (www.ecy.wa.gov/_____).

White, M. 2005. 2005 NPDES Progress Report for the Cedar-Green, Island-Snohomish, and South Puget Sound Water Quality Management Areas. Washington State Department of Transportation.

Williams, R.W., R.M. Laramie, and J.J. Ames. 1975. A Catalogue of Washington Streams and Salmon Utilization. Volume 1—Puget Sound Region. Washington Department of Fisheries.

Zulauf, A., T. Nelson, L. Tamayo, J. Perkins, and B. McIntosh. 1990. Deschutes/Budd Inlet Watershed—Thurston County, Washington. Prepared for the Deschutes/Budd Inlet Watershed Management Committee.

Appendices

Appendix A. Glossary and Acronyms

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.

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

Clean Water Act (CWA): Federal Act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the CWA 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 waterbody or segment, regardless of whether or not the uses are currently attained.

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

Enterococci: A subgroup of the fecal streptococci that includes S. *faecalis*, *S. faecium* , *S. gallinarum* and *S. avium*. The enterococci are differentiated from other streptococci by their ability to grow in 6.5% sodium chloride, at pH 9.6, and at 10 degrees C and 45 degrees C.

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 nth root of a product of n factors, or 2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

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

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

Macrophytes: Aquatic plants growing in or near water that may be rooted in shallow water or floating.

Margin of Safety (MOS): Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving waterbody.

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.

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: Such 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.

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 waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: 1) individual wasteload allocations (WLAs) 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 (WLA): The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. WLAs 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

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
Ac-ft	Acre-foot, the amount of water that would cover one acre one foot deep
ALK	Alkalinity
ATV	All-terrain vehicle
BOD	Biochemical oxygen demand
BOD5	5-day biochemical oxygen demand
Cfs	Cubic feet per second
CHL	Chlorophyll a
CLAMP	Capitol Lake Adaptive Management Plan committee
Cms	Cubic meters per second
CSO	Combined sewer overflow
CWA	Clean Water Act
DEM	Digital elevation model
Diel	Involving a 24-hour period that usually includes a day and the adjoining night
DIN	Dissolved inorganic nitrogen
DOC	Dissolved organic carbon
DTP	Dissolved total phosphorus
DTPN	Dissolved total (persulfate) nitrogen
EIM	Environmental Information Management
EPA	Environmental Protection Agency
FC	Fecal coliform bacteria
GEMSS	Generalized Environmental Model System for Surface Waters
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	Lacey, Olympia, Tumwater, and Thurston County Water Alliance
LWD	Large woody debris
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NH3	Ammonium
NIST	National Institute of Standards and Technology
NO2NO3	Nitrite plus nitrate
NPDES	National Pollutant Discharge Elimination System

NSDZ	Near-stream disturbance zone
ODEQ	Oregon Department of Environmental Quality
OP	Orthophosphate
OMEXDIA	Ocean Margin Exchange Nutrient Diagenesis Model
PCB	Polychlorinated biphenyls
QAPP	Quality Assurance Project Plan
RK	River kilometer
RM	River mile
RMSE	Root mean square error
RSD	Relative standard deviation
SIT	Squaxin Island Tribe
SOD	Sediment oxygen demand
TIR	Thermal infrared
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
ULTBOD	Ultimate BOD
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
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WW	Wetted width
WWTP	Wastewater treatment plant

NOTE TO REVIEWERS: See separate document for the following appendices.

Appendix C. Aquatic Plant Surveys

Appendix D. Thermal Infrared Survey Images

Appendix E. Effective Shade Targets for the Deschutes River

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. Station Identifiers