

**Upper Deschutes Watershed Council
Technical Report**

Middle Deschutes River Instream Flow Restoration and Temperature Responses 2001-2017

Prepared by

Lauren Mork
Upper Deschutes Watershed Council
www.upperdeschuteswatershedcouncil.org

April 2020

Table of Contents

Executive Summary..... iii

Acknowledgments..... viii

Abbreviations ix

1 Introduction 1

2 Methods..... 4

 2.1 Data Collection..... 4

 2.1.1 *Stream Temperature* 4

 2.1.2 *Stream Flow* 4

 2.2 Data Analysis..... 7

 2.2.1 *Stream Flow Status and Trend* 7

 2.2.2 *Stream Temperature Status and Trend*..... 7

 2.2.3 *Effect of Stream Flow on Stream Temperature*..... 8

 2.2.4 *Stream Flow Targets* 8

3 Results..... 10

 3.1 Stream Flow Status and Trend 10

 3.2 Stream Temperature Status and Trend 13

 3.3 Effect of Stream Flow on Stream Temperature 17

 3.4 Target Stream flow..... 19

4 Discussion..... 21

 4.1 Stream Flow Status and Trend 21

 4.2 Temperature Status and Trend 21

 4.3 Restoration Effectiveness 22

 4.4 Target Stream flow 23

5 References 21

APPENDIX A Estimated temperatures at given flows calculated from regression equations I

APPENDIX B Estimated temperatures at six Deschutes River flow scenarios III

List of Figures

Figure 1. The Upper Deschutes subbasin and middle Deschutes River watershed..... 3
Figure 2. UDWC continuous temperature monitoring sites and OWRD stream flow gages on the middle and upper Deschutes River. 6
Figure 3. Deschutes River and Tumalo Creek July median protected and recorded flow, 2001-2015..... 12
Figure 4. Deschutes River temperature April-November 2016 13
Figure 5. Percent of data days meeting and exceeding 18°C, 2001-2016. 15
Figure 6. 2001-2016 July and August 7DADM temperatures at Lower Bridge Road..... 16
Figure 7. 2001-2015 Stream temperature-flow regression models. 18

List of Tables

Table 1. Middle Deschutes River flow gages and temperature monitoring stations 5
Table 2. Summary of available July temperature data 2001-2015 5
Table 3. Twelve regression models evaluated for the Deschutes River at DR 160.25 and for Tumalo Creek at TC 000.25. 8
Table 4. The top three regression models for predicting stream temperature for July at DR 160.25 and at TC 000.25. 19
Table 5. Estimated Deschutes River stream temperatures at three Tumalo Creek flows and two Deschutes River flows. 20

Executive Summary

Since 1996, the Deschutes River Conservancy (DRC) has engaged in efforts to restore summer stream flow in the middle Deschutes River and lower Tumalo Creek through a variety of techniques, including conservation, leasing, and acquisition. The DRC has identified stream flow restoration in the Deschutes River between the City of Bend and Lake Billy Chinook (middle Deschutes River) and Tumalo Creek downstream from Tumalo Irrigation District's diversion (lower Tumalo Creek) as a priority because very low summer flows in these two reaches consistently result in summer water temperatures that exceed the Oregon Department of Environmental Quality (ODEQ) standard established to protect salmon and trout rearing and migration.

To evaluate the effectiveness and potential of stream flow restoration efforts in reducing temperature in the middle Deschutes River, the DRC, its funders, and other partners have been interested in understanding: 1) how stream flow has changed with cumulative stream flow restoration actions; 2) how stream temperature has changed with cumulative stream flow restoration actions; 3) how stream flow affects stream temperature; and 4) how stream flow restoration in the Deschutes River and Tumalo Creek can achieve the greatest reduction in stream temperature. Since 2008 the DRC has partnered with the Upper Deschutes Watershed Council (UDWC) to conduct temperature monitoring to investigate observed and potential temperature changes associated with stream flow restoration projects. This ongoing monitoring effort incorporates data collected from 2001 to 2017 and builds off analyses developed for the Upper Deschutes Basin Study to address the following key questions:

- 1) Stream flow status and trend: How have flows in the middle Deschutes River changed with cumulative stream flow restoration actions?

Key findings:

- July median stream flow in the middle Deschutes at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs to 158 cfs
- July median flows in the middle Deschutes from 2013 to 2017 (129-136 cfs) represent a marked decrease from 2010 to 2012 flows (x to x cfs), and were similar to that observed in 2009 (131 cfs)
- Stream flow restoration in Tumalo Creek has increased July median flow to 15 cfs in 2017.

July median stream flow in the middle Deschutes at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs to 158 cfs. July median streamflow in the middle Deschutes dropped in 2013 to 129 cfs and from 2013 to 2017 approximated the 2009 July median flow of 131 cfs, fluctuating between 129 and 136 cfs, commensurate with reductions in flow leased instream and less flow left instream by irrigation districts under a voluntary agreement. Deschutes River flows closely track flow protected instream, which increased from 107 cfs in 2008 to 158 cfs in 2012, dropped to 124 cfs in 2013, and has since fluctuated between 126 and 134 cfs. July

median stream flow and median protected flow in the middle Deschutes from 2013 to 2017 represents a marked decrease from 2010-2012 flows. The median July flow protected instream in 2017 was 132 cfs; the median recorded average daily flow was 128 cfs.

Stream flow in Tumalo Creek exceeds flow protected instream in most years, including in 2017, when July median flow was 15 cfs to 14.2 cfs July median protected flow. July median flow in Tumalo increased from 5 cfs in 2001 to a high of 58 cfs in 2012, in most years hovering between 12 and 15 cfs. Flows protected instream with pre-1961 priority dates range from 7.8 cfs in 2009 to 15.6 cfs in 2015.

- 2) Temperature status and trend: What was the status of middle Deschutes River stream temperature in 2017 relative to the State of Oregon 18°C (64°F) standard protecting salmon and trout rearing and migration, and in relation to previous years?

Key findings:

- Stream temperature in the middle Deschutes River exceeded the 18°C state standard for 32 to 59% of days April 30 to September 21, 2017, along 32 miles downstream of Bend
- July stream temperatures downstream of Bend from 2013 to 2017 were far lower and exceeded 24°C far less frequently than from 2001 to 2007 but were on average over two degrees warmer than from 2008 to 2012.
- The increase in stream temperature and in days exceeding 24°C from 2013 to 2017 coincides with the 2013 drop in flows protected in the middle Deschutes.
- In 2017 stream temperatures exceeded 24°C for more days than in any year since 2007.
- Stream flow restoration actions targeted at reducing stream temperatures specifically during the July 2nd to August 5th period when temperatures most often exceed 24°C will attenuate the worst effects of low flows on stream conditions for fish

Stream temperature in the middle Deschutes River exceeded the 18°C state standard protecting salmon and trout rearing and migration for 32-59% of days between April 30 and September 21, 2017, at all four Deschutes River monitoring locations downstream of Bend:

- Stream temperatures at the site characterized by the highest temperatures, DR 133.50, exceeded the standard for fewer days (59% or 85 days) and met the standard for more days (41% or 60 days) in 2017 than in ten of sixteen years between 2001 and 2017;
- Downstream of the confluence with Tumalo Creek, at DR 160.00, temperatures exceeded the standard for fewer days (32% or 46 days) and met the standard for more days (68% or 99 days) in 2017 than in five of thirteen years between 2005 and 2017;
- Temperatures at DR 160.25 met the 18°C temperature standard for fewer days (55% or 80 days), and exceeded the temperature standard for more days (45% or 65 days) than in all but three years between 2002 and 2017;

- Temperatures at DR 164.75, immediately downstream of North Canal Dam, exceeded the standard for the most days (39% or 57 days) and met the standard for the fewest days (61% or 88 days) of the thirteen years for which data are available since 2004;
- Stream temperatures at Lower Bridge (DR 133.5) exceeded 24°C (the lethal threshold for trout rearing; ODEQ 1995) for more days in 2017 than in any year since 2007 (9% or 13 days). The increasing trend in days exceeding the 24°C lethal threshold is consistent with other years including and since 2013, coincident with the 2013 drop in flows protected in the middle Deschutes.

Temperatures recorded at Lower Bridge (DR 133.50) in 2017 show sustained improvement in the percent of days meeting stream temperatures and representing suitable rearing conditions for trout, but simultaneously exceeded the lethal threshold more consistently from 2013 to 2017 than in earlier years of stream flow restoration. From 2013 to 2017 stream temperatures exceeded 24°C as early as July 2nd and as late as August 5th. Stream flow restoration actions targeted at reducing stream temperatures specifically during the period when temperatures most often exceed 24°C will attenuate the worst effects of low flows on stream conditions for fish.

Although stream temperatures continue to exceed 24°C at Lower Bridge, the number and percent of days for which temperatures at Lower Bridge were above 24°C were lower from 2013 to 2017 than prior to 2008, signaling a reduction in the amount time each year during which fish are exposed to potentially lethal stream conditions. This reduction coincides with increases in protected flow and observed stream flow in the Deschutes River at North Canal Dam and in Tumalo Creek compared to 2008 and earlier years. However, the number and percent of days for which temperatures at Lower Bridge were above 24°C were higher from 2013 to 2017 than from 2008 to 2013, again coincident with the 2013 drop in flows protected in the middle Deschutes.

Increases in stream temperatures observed between North Canal Dam and the confluence of the Deschutes River and Tumalo Creek, and a decreasing R² value for the relationship between temperature and flow at DR 160.25 upstream of the confluence, indicate less variation in stream temperature at DR 160.25 is being explained by stream flow and could signal the effects of a warmer climate on Deschutes River flow stored in Wickiup and Crane Prairie reservoirs.

- 3) Restoration effectiveness: Have cumulative increases in stream flow resulted in reduced water temperatures at key locations along the middle Deschutes River?

Key findings:

- July and August stream temperatures at Lower Bridge and three other temperature monitoring sites downstream of Bend decreased as July median flows increased from 2000-2012

- Stream temperatures in Tumalo Creek were substantially lower, and temperatures in the middle Deschutes were moderately lower, at the highest recorded stream flow than at the lowest recorded flow.
- Regressions of stream flow and temperature data show lower stream temperatures at higher stream flows.

Multiple lines of evidence show reduced stream temperatures at the higher stream flows achieved through stream flow restoration in the middle Deschutes River and Tumalo Creek. July and August stream temperatures at DR 133.50 decreased alongside increasing July median flows in the middle Deschutes and in Tumalo Creek from 2001-2012. Comparison of seven-day average daily maximum temperatures (7DADM) at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded from 2002 to 2015 show that moderately (in the Deschutes River) to substantially (in Tumalo Creek) lower stream temperatures occurred at higher flows. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2017 at DR 160.25 and at TC 000.25 show temperatures decreasing as flows increase. Stream flow explained 33% and 78% of variation in stream temperature in the middle Deschutes and in Tumalo Creek, respectively, providing statistical support for the role of higher stream flows in reducing stream temperature.

- 4) Target stream flow: What flow scenarios for the Deschutes River and Tumalo Creek will most efficiently achieve the 18°C temperature standard immediately below the confluence of the Deschutes River and Tumalo Creek?

Key findings:

- Restoring as much flow as possible in Tumalo Creek in July, without increasing flow at North Canal Dam on the Deschutes, will achieve the maximum reduction possible in stream temperature in the Middle Deschutes downstream of Tumalo Creek, given storage in Wickiup and Crane Prairie reservoirs
- Forty-four cfs in Tumalo Creek and 132 cfs in the Deschutes River below North Canal Dam in July is estimated to achieve, on average, 18°C ± 1.8°C in the Deschutes River immediately downstream of the confluence
- Increasing flow in Tumalo Creek to 54 cfs is estimated to achieve 17.6°C ± 1.9°C in the Deschutes at the same location
- Because the Deschutes River is 3°C warmer at Lower Bridge Road than immediately below the confluence of Tumalo Creek and the Deschutes River, often resulting in July temperatures that are lethal to redband trout, it is important to achieve the greatest possible reduction in stream temperature below this confluence.

Flow scenarios developed from regression and mass balance equations indicate that allocating the maximum possible Tumalo Creek flow to instream use during July while holding constant Deschutes River flow downstream of North Canal Dam at the 132 cfs July median protected

instream as of 2017 will achieve the greatest reduction in stream temperature in the middle Deschutes. At the 2017 July median protected flow of 132 cfs, 44 cfs from Tumalo Creek will produce an average 7DADM temperature of $18^{\circ}\text{C} \pm 1.8^{\circ}\text{C}$ in the Deschutes River immediately downstream of the confluence. Increasing Tumalo Creek flows to 54 cfs (*i.e.*, approximately the 72 cfs 80% exceedence surface water availability during July, less the 18 cfs City of Bend diversion) is predicted to reduce the average 7DADM temperature in the Deschutes River below the confluence to $17.6^{\circ}\text{C} \pm 1.9^{\circ}\text{C}$. While these scenarios would significantly improve temperatures in the Deschutes River, the approximately 3°C warming that typically occurs at these flows between the confluence of the Deschutes and Tumalo Creek and DR 133.50 means that some reaches along approximately 26 miles of the middle Deschutes River would continue to exceed the state temperature standard by up to seven degrees (at 44 cfs in Tumalo Creek), with potential peak temperatures of 22.8°C or higher.

Acknowledgments

Thanks to Deschutes River Conservancy for ongoing funding support for the monitoring and analyses that form the basis for this report. Water quality monitoring conducted by Upper Deschutes Watershed Council is also funded in large part by the Oregon Watershed Enhancement Board. Monitoring by the City of Bend, ODEQ, Oregon State University (OSU), Oregon Water Resources Department (OWRD), and DRC has contributed invaluable data to UDWC's long-term monitoring effort. Many thanks to members of the founding Water Quality Committee and contributing partners who provided expertise, insight, and time in support of the development of the UDWC Regional Water Quality Monitoring Program from which the data and analyses included here originated. Special thanks to Lesley Jones, who spearheaded and grew the UDWC Regional Water Quality Monitoring Program to produce rigorous statistical analyses of the effects of stream flow restoration on temperature, and to Lisa Ganio at OSU and Mike Cole of Cole Ecological Inc., who have provided excellent insight into and thoughtful review of the analyses presented.

Abbreviations

Organizations

DRC	Deschutes River Conservancy
UDWC	Upper Deschutes Watershed Council
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OWRD	Oregon Water Resources Department

Terminology

°C	Degree Celsius
°F	Degree Fahrenheit
7DADM	Seven Day Moving Average Daily Maximum
df	Degrees of freedom
PI	Prediction interval
cfs	Cubic feet per second
Ln	Natural logarithm
QA/QC	Quality assurance / quality control
QD	Average daily flow
S	Standard error

1 Introduction

The middle Deschutes River watershed (formally designated as the McKenzie Canyon – Deschutes River watershed) is located in the Deschutes Basin, Oregon, and is bordered by the Metolius River, Whychus Creek, Tumalo Creek, and Upper Deschutes River watersheds (Figure 1). The middle Deschutes River has been listed since 2004 as a temperature impaired waterway under Clean Water Act Section 303(d) for not meeting State of Oregon water temperature standards for salmon and trout rearing and migration (ODEQ 2019).

Since 1996, the Deschutes River Conservancy (DRC) has engaged in efforts to restore summer stream flow in the middle Deschutes River and lower Tumalo Creek. DRC has prioritized stream flow restoration in these two reaches, where irrigation season low flows result in temperatures that exceed the Oregon Department of Environmental Quality standard of 18°C/64°F established to protect salmon and trout rearing and migration, and where stream flow restoration can have the greatest impact on stream temperature both in those reaches and in reaches downstream. DRC stream flow restoration efforts aim to meet the State of Oregon instream flow targets of 250 cfs in the Deschutes River from North Canal Dam (RM 165) to Lake Billy Chinook (RM 119), and 32 cfs in Tumalo Creek from the Tumalo Irrigation District's diversion to the mouth, in order to, among other objectives, improve water temperature to support sustainable anadromous and resident fish populations.

Based on recent analyses of temperature and flow in Tumalo Creek and the Deschutes River suggesting the relative contribution of flow from each stream substantially influences downstream temperature, the DRC increasingly aims to restore streamflow preferentially in Tumalo Creek to maximize temperature reductions in the middle Deschutes River. Because Deschutes River water is consistently at or above 18°C at North Canal Dam in July, restoring stream flow in the Deschutes River at North Canal Dam can only decrease downstream temperatures by decreasing the rate of warming through increasing the amount of flow. Restoring stream flow in Tumalo Creek reduces warming downstream of the TID diversion, delivering cooler flows to the Deschutes River and actively cooling Deschutes River water. Tumalo Creek, approximately five miles downstream of North Canal Dam, is the only tributary and source of additional flow between the dam and Lower Bridge Road approximately 31 miles downstream, where temperatures are historically highest and conditions worst for fish. Increasing flows in Tumalo Creek therefore represents an opportunity to achieve the greatest cooling effect in the Deschutes River between Tumalo Creek and Lower Bridge Road by contributing a greater volume of colder water at the confluence, both reducing warming and actively cooling Deschutes River flows.

The DRC has partnered with the Upper Deschutes Watershed Council (UDWC) since 2008 to monitor water temperature in the middle Deschutes River and quantify temperature changes associated with stream flow restoration. Although model results and substantial empirical evidence indicate that reductions in summer stream flow lead to increased water temperatures in central Oregon (ODEQ 2010; ODEQ 2004; UDWC 2006), the DRC and restoration partners are interested in evaluating how increasing flows in the middle Deschutes River and Tumalo Creek through stream flow restoration transactions affects water temperatures in downstream reaches. We evaluated available Deschutes River and

Tumalo Creek stream temperature and flow data from 2001 through 2017 to address the following questions: 1) How have flows in the middle Deschutes River and Tumalo Creek changed with cumulative stream flow restoration actions? 2) What was the status of middle Deschutes River water temperature in 2016 relative to the State of Oregon 18°C (64°F) standard and in relation to previous years?; 3) Have cumulative increases in stream flow resulted in reduced water temperatures at key locations along the middle Deschutes River; and 4) What flow scenarios for the Deschutes River and Tumalo Creek will achieve the 18°C temperature standard in the Deschutes River immediately below the confluence with Tumalo Creek? We present 2017 temperature results and discuss implications for stream flow restoration.

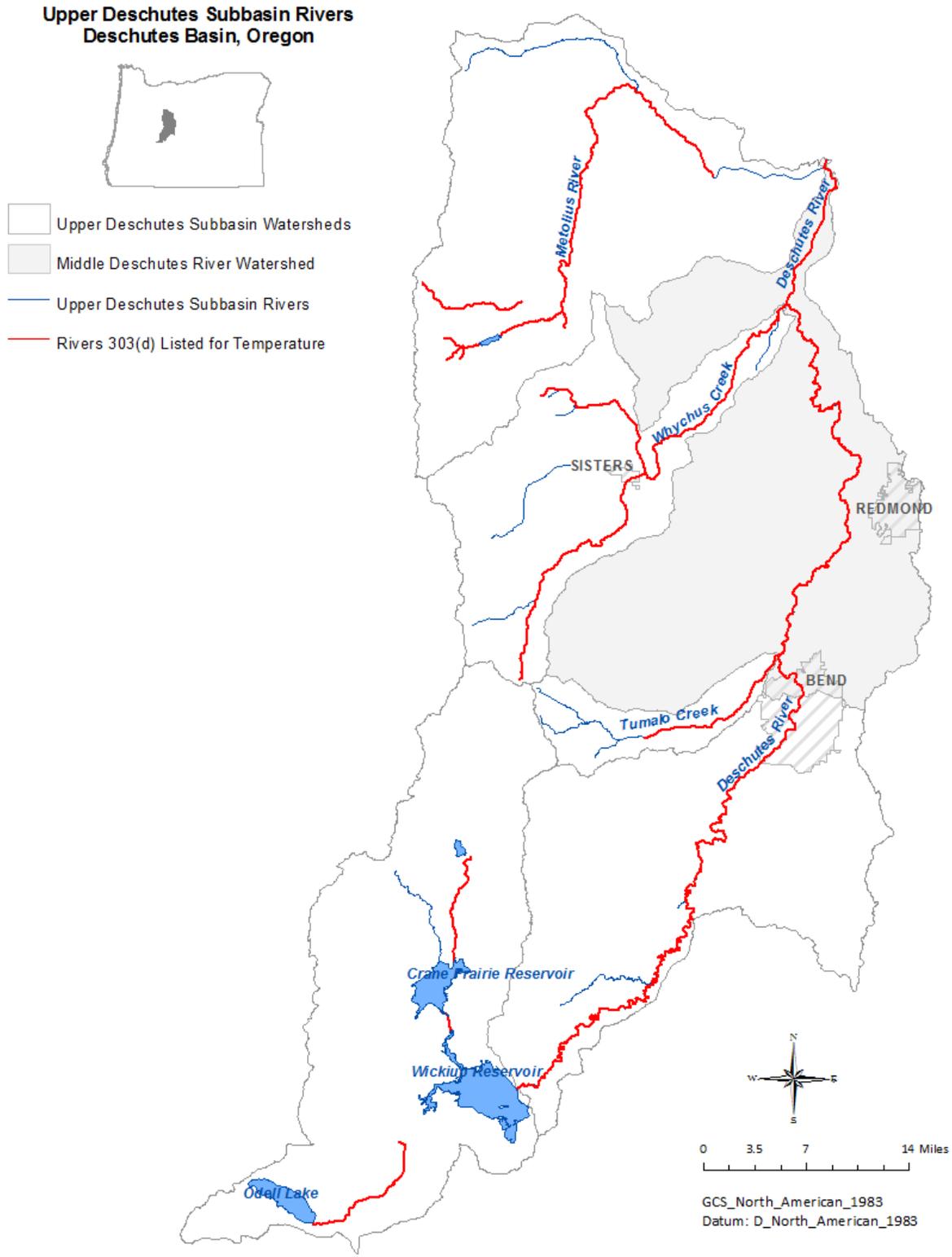


Figure 1. The Upper Deschutes subbasin and middle Deschutes River watershed. Extensive reaches of most Upper Deschutes Subbasin rivers are 303(d) listed as exceeding state temperature standards for salmon and trout rearing and migration (ODEQ 2019).

2 Methods

2.1 Data Collection

2.1.1 *Stream Temperature*

UDWC collected and compiled continuous water temperature data for 2001-2017 from six stream temperature monitoring stations on the Deschutes River and one monitoring station on Tumalo Creek (Table 1; Figure 2), using Vemco and HOBO dataloggers rated to an accuracy of 0.5°C and 0.2°C, respectively. Data for Tumalo Creek since 2009 were obtained from the City of Bend. Data is not available for all years due to equipment failure or no monitoring (Table 2). UDWC operates per its *Water Quality Monitoring Program Standard Operating Procedures* (UDWC 2008a) under a State of Oregon approved Quality Assurance Project Plan (UDWC 2008b).

2.1.2 *Stream Flow*

We obtained July median daily instream water rights data for the Deschutes River and for Tumalo Creek from DRC. Reductions in July median daily instream water rights between years reflect a reduction in the amount of flow allocated instream by irrigation districts under a long-standing gentleman's agreement, as well as a decline in the volume of water leased instream through the DRC's Annual Water Leasing Program. We refer to July median daily instream water rights as median protected flow to differentiate from the state instream water right. July median daily instream water right data are available from 2007-2017 for the Deschutes River, and from 2006-2017 for Tumalo Creek. Tumalo Creek July median daily instream water rights exclude water rights with a priority date junior to 1961, which as a result of their late priority date are never delivered.

UDWC obtained average daily stream flow (QD) data for the Deschutes River and Tumalo Creek from the Oregon Water Resources Department (OWRD 2017) (Table 1; Figure 2). All Deschutes River flow data through September 2012 and Tumalo Creek flow data through September 2008 and from October 2009 through September 2011, are considered published; Deschutes River flow data from October 1, 2012 through 2017 and Tumalo Creek flow data from October 2008 through September 2009 and from October 2011 through 2017 and included in this report are considered provisional and subject to change.

Table 1. Middle Deschutes River flow gages and temperature monitoring stations

Station ID	Waterway	Description	Latitude	Longitude	Elev. (ft)
OWRD gage #14073520	Tumalo Creek	d/s of Tumalo Feed Canal	44.08944	-121.36667	3550
OWRD gage #14070500	Deschutes River	d/s of North Canal Dam, Bend	44.08280	-121.30690	3495
DR 217.25	Deschutes River	Pringle Falls	43.74075	-121.60672	4250
DR 181.50	Deschutes River	Benham Falls	43.93080	-121.41107	4140
DR 164.75	Deschutes River	u/s of Riverhouse Hotel	44.07733	-121.30592	3540
DR 160.25	Deschutes River	u/s of Tumalo Creek	44.11501	-121.33904	3240
DR 160.00	Deschutes River	d/s of Tumalo Creek	44.11767	-121.33326	3210
DR 133.50	Deschutes River	Lower Bridge	44.35970	-121.29378	2520
TC 000.25	Tumalo Creek	u/s of Tumalo Creek mouth	44.11567	-121.34031	3250

Table 2. Summary of available July temperature data 2001-2017

Station ID	Waterway	Description	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
DR 217.25	Deschutes River	Pringle Falls		x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x
DR 181.50	Deschutes River	Benham Falls			x		x	x	x	x	x	x	x	x	x	x	x	-	x
DR 164.75	Deschutes River	u/s Riverhouse Hotel				x	x		-	x	x	x	x	x	x	x	x	x	x
DR 160.25	Deschutes River	u/s Tumalo Creek		x	x	x	x		-	x	x	x	x	x	x	x	x	x	x
DR 160.00	Deschutes River	d/s Tumalo Boulder Field					x	x	x	x	x	x	x	x	-	x	x	-	x
DR 133.50	Deschutes River	Lower Bridge	x	x		x	x	x	x	x	-	x	x	x	x	x	-	x	x
TC 000.25	Tumalo Creek	u/s of Tumalo Creek mouth				x	x	-	x		x	x	x	x	x	x	x	-	x
X	<i>Data available for analysis</i>																		
-	<i>Limited data available for analyses</i>																		

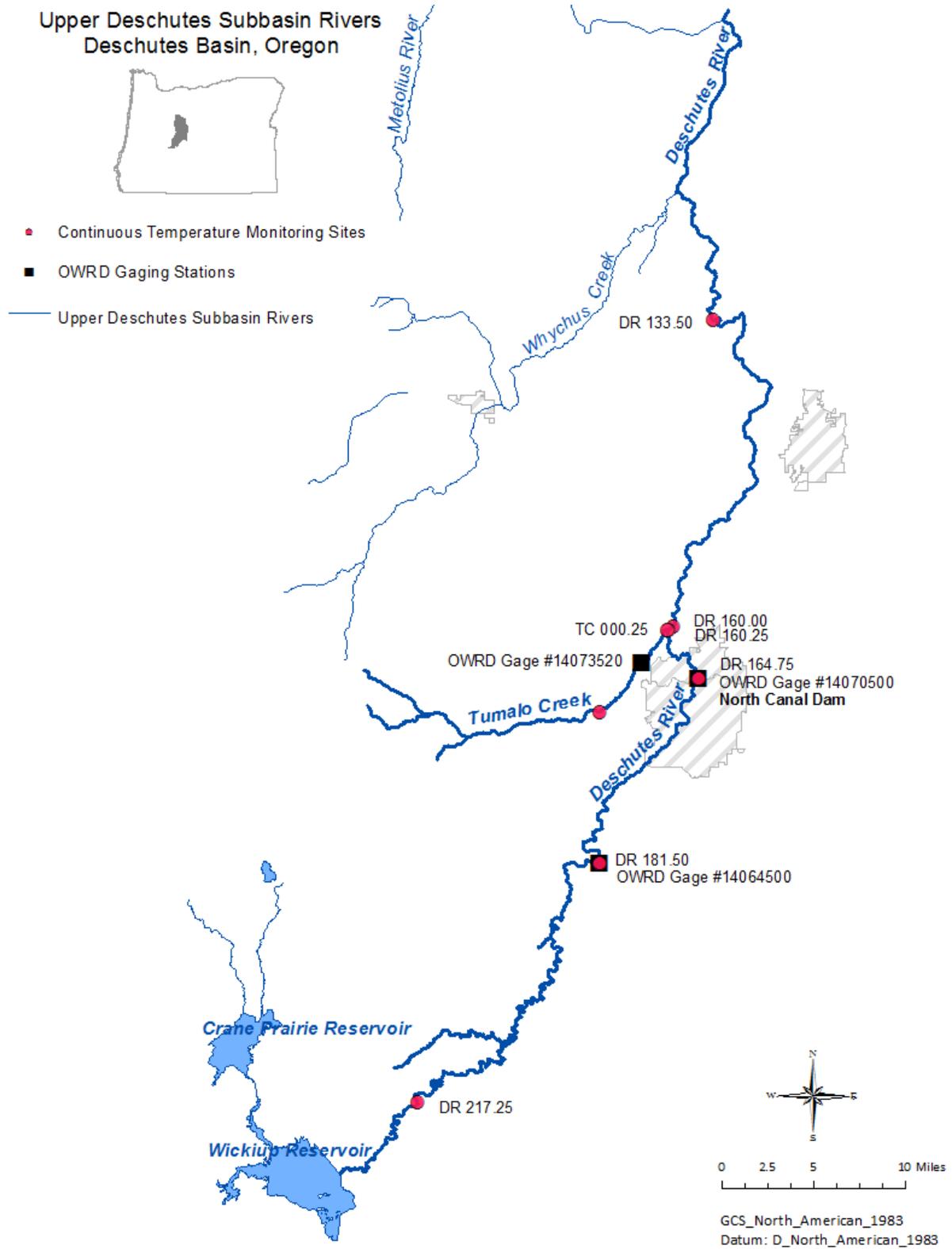


Figure 2. UDWC continuous temperature monitoring sites and OWRD stream flow gages on the middle and upper Deschutes River.

2.2 Data Analysis

2.2.1 Stream Flow Status and Trend

We evaluated July and August median daily protected flow and median average daily flow to understand how stream flow has increased in response to stream flow restoration. Both the daily protected stream flow and average daily flow change within and across years. July median flow was selected as an indicator as it represents the central tendency of flow rates during one of the hottest summer months. We included August median flow as a measure of base flow resulting from stream flow restoration.

2.2.2 Stream Temperature Status and Trend

We used the Oregon Department of Environmental Quality (ODEQ) Hydrostat Simple spreadsheet (ODEQ, 2010) to calculate the seven day moving average daily maximum (7DADM) temperature, the statistic used by the State of Oregon to evaluate stream temperatures. The State of Oregon water temperature standard for salmon and trout rearing and migration identifies a 7DADM threshold of 18°C/64°F (OAR 340-041-0028). We evaluated 7DADM temperatures from 2001-2017 in relation to the state standard of 18°C to describe changes in temperature in the middle Deschutes River since 2001 and to assess progress toward the 18°C state standard for salmonid rearing and migration.

To describe the proportion of the irrigation season when stream temperatures exceeded the 18°C state standard between 2001 and 2017, we calculated the number and percent of days in each year between April 30 and September 21 when the 7DADM stream temperature met the 18°C standard, exceeded the 18°C standard, or exceeded the 24°C lethal threshold. We selected April 30 and September 21 as the earliest and latest calendar dates when stream temperatures have exceeded 18°C. 7DADM datasets for some sites and years are incomplete because of data loss due to datalogger stranding, damage or loss. We reviewed data for years for which fewer than the 145 days between April 30 and September 21 were available. For some data gaps it was possible to extrapolate with high confidence whether 7DADM temperatures met or exceeded 18°C at a given site from temperature trends at upstream or downstream dataloggers. Where possible to do so with high confidence, we extrapolated temperatures to be above or below 18°C. Where temperature data were missing, adjacent data available (dates and sites) did not suggest stream temperatures exceeding 24°C; it is not known whether stream temperatures exceeded 24°C in the years and at the sites for which data were extrapolated. Accordingly, all percentages for days exceeding 24°C represent recorded (not extrapolated) data values.

We evaluated July temperature data from DR 160.00, downstream of the confluence of the Deschutes River and Tumalo Creek, in relation to the July median average daily flow in the Deschutes below North Canal Dam and in Tumalo Creek below the Tumalo Feed Canal. To evaluate temperature status at DR 133.50 (Lower Bridge Road) we present data for August in addition to July because more data are available for August for years of interest. Both July and August data represent summer conditions characterized by high temperatures and low flows.

2.2.3 *Effect of Stream Flow on Stream Temperature*

To evaluate the effectiveness of increasing flows through stream flow restoration in reducing stream temperature in the middle Deschutes River and in Tumalo Creek, we 1) compared 2001-2017 July 7DADM stream temperatures at DR 133.50 to July median stream flow at the Tumalo Creek (OWRD gage #14073520) and Deschutes Below Bend (OWRD gage #14070500) stream gauges, and 2) used regressions of 2001-2017 July stream temperature and flow data at DR 160.25 and at TC 000.25 to illustrate the relationship between temperature and flow. Methods for regressions, which were also used for stream flow target analyses, are described below.

2.2.4 *Stream Flow Targets*

We used regressions of 2001-2017 temperature and stream flow data with a mass balance approach to develop flow scenarios for the middle Deschutes River and Tumalo that will achieve the greatest temperature reduction in the Deschutes below the confluence with Tumalo Creek. Because the objective of these regressions is to develop flow scenarios, we do not incorporate air temperature, which, although known to influence stream temperature, is beyond the scope restoration partners are able to address through stream flow restoration.

We used stream temperature data from the Deschutes River above Tumalo Creek (DR 160.25) and from the mouth of Tumalo Creek (TC 000.25) with corresponding flow data from OWRD gage #14070500, Deschutes River Below Bend, and from OWRD gage #14073520, Tumalo Creek Below Tumalo Feed Canal. The two temperature monitoring sites are short distances downstream of major points of stream flow restoration on each waterway, and temperatures are anticipated to decrease in response to increased flows; due to the respective locations of the two sites immediately upstream of the confluence of Tumalo Creek and the Deschutes River, these sites most accurately represent the temperature-flow relationships that directly affect stream temperature downstream of the confluence. Because no tributaries or springs enter the Deschutes River between Tumalo Creek and Lower Bridge Road, the relative flow contributions of the Deschutes River and Tumalo Creek at the two upstream sites directly influence stream temperature 26.5 miles downstream at DR 133.50.

We restricted data included in the analysis to one month of the year to reduce the effect of intra-annual seasonal variation in the analysis (Helsel & Hirsch, 1991) and selected July as the historically hottest month for water temperatures in the Deschutes River, and the month during which stream flow restoration will most improve stream conditions (UDWC unpublished data). For each site, we included all July dates for which stream temperature and stream flow data were available. We used R open source statistical software (R Core Team, 2017) to perform linear, quadratic, and cubic regressions for each site: 1) with each of two stream temperature metrics (7DADM and daily maximum); and 2) with each of two flow metrics (average daily flow and the natural logarithm of average daily flow), for a total of twelve models (Table 3), to evaluate which metrics and models provided the best model fit.

Table 3. Twelve regression models evaluated for the Deschutes River at DR 160.25 and for Tumalo Creek at TC 000.25.

Regression Model	
1.	7DADM ~ Flow
2.	7DADM ~ Flow + (Flow) ²
3.	7DADM ~ Flow + (Flow) ² + (Flow) ³
4.	7DADM ~ LnFlow
5.	7DADM ~ LnFlow + (LnFlow) ²
6.	7DADM ~ LnFlow + (LnFlow) ² + (LnFlow) ³
7.	Daily Max ~ Flow
8.	Daily Max ~ Flow + (Flow) ²
9.	Daily Max ~ Flow + (Flow) ² + (Flow) ³
10.	Daily Max ~ LnFlow
11.	Daily Max ~ LnFlow + (LnFlow) ²
12.	Daily Max ~ LnFlow + (LnFlow) ² + (LnFlow) ³

We used the extractAIC function in R to generate Akaike Information Criterion (AIC) values for each regression model. AIC values rank models relative to each other on the basis of goodness of fit and number of parameters, with values decreasing as models improve; the lowest value indicates the best model. A difference of two or more between AIC values for two models denotes a statistically better model. For each site we evaluated R-squared (R²), residual standard error (S), and AIC values to select the model that resulted in the best fit to the observed data; we evaluated residuals plots and normal probability plots for normality of residuals for the best model, and plotted predicted v. observed values for the top three models.

Using the best regression model for each site, we used R to calculate the predicted temperature and 95% prediction interval for all flows within the observed range (**Appendix A**). The 95% prediction interval (PI) is calculated as:

$$\hat{y}_i^* \pm T_{df=n-2, \alpha/2} * SE(\hat{y}_i^* | x_o)$$

where T is the 1- $\alpha/2$ th percentile of a T distribution with n-2 degrees of freedom.

To calculate Deschutes River temperatures downstream of the confluence with Tumalo Creek under a variety of flow scenarios we used predicted temperatures for each flow for the two sites in a mass balance equation. We used the following mass balance equation solved for T_{D2}:

$$(Q_T * T_T) + (Q_D * T_D) = (Q_T + Q_D) * (T_{D2})$$

$$(T_{D2}) = ((Q_T * T_T) + (Q_D * T_D)) / (Q_T + Q_D)$$

Where:

Q = average daily flow

T = 7DADM temperature

T = Tumulo Creek (TC 000.25)

D = Deschutes River (DR 160.25)

D₂ = Deschutes River (DR 160.00)

We calculated stream temperatures for all Tumalo Creek flows between 10 and 100 cfs at Deschutes River flows of 130, 160, 180, 200, and 250. Ten cfs approximates minimum July flows in Tumalo Creek; 100 cfs exceeds average natural July flows and is well above the ODFW instream water right of 32 cfs. One hundred and thirty cfs approximates both the median flow protected instream and the median of average daily flows recorded in the middle Deschutes in July 2017.

We compared temperatures calculated from the best regression model and from the mass balance equation to Heat Source model scenarios for the same locations on the Deschutes River and Tumalo Creek (Watershed Sciences 2008). Heat Source results report the peak seven day average daily maximum temperature; we compared mass balance equation results to the mean seven day average daily maximum temperature, calculated from Heat Source temperature data. Heat Source temperature data for the Deschutes and for Tumalo Creek included daily maximum temperatures from July 19 to August 7, 2001.

3 Results

3.1 Stream Flow Status and Trend

July and August median average daily flow in Tumalo Creek and the Deschutes River has increased with median protected flow (Figure 3). Stream flow restoration efforts in the middle Deschutes River began in 2001; data documenting flows protected instream are available for the middle Deschutes River for July from 2003 to 2017 and for August from 2002 to 2017, and for Tumalo Creek for July from 2006 to 2017 and for August from 2005 to 2017.

July and August median stream flow in the Deschutes River at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs in both months to 158 cfs in July and 151 cfs in August, alongside increases in protected flow (Figure 3). Protected flow dropped sharply from 2012 to 2013, from 160 cfs to 126 cfs in July and from 163 cfs to 134 cfs in August, with an accompanying decrease in observed flow, reflecting reductions in flow leased instream and less flow left instream by irrigation districts under a voluntary agreement. Since 2013 protected flows have fluctuated between 126 and 134 in July and between 129 and 136 in August; observed flows closely track protected flows. In 2017 132 cfs were protected in July and in August; median flows in July and August were 128 cfs and 123 cfs, respectively, slightly lower than the 134-136 cfs July and 130-134 cfs August medians from 2014-2016. July and August median stream flow in the middle Deschutes has approximated 2009 levels since 2013.

July and August median average daily stream flow in Tumalo Creek is equivalent to or exceeds flow rates protected instream in most years. July median average daily flow in the creek increased from 5 cfs in 2001 to a high of 58 cfs in 2012, hovering between 12 and 15 cfs in most years; August median average daily flow increased from 6 cfs in 2001 to a high of 18 cfs in 2011, 2014, and most recently in 2017, more closely tracking flow protected instream (Figure 3). July and August senior water rights protected instream with pre-1961 priority dates that are reliably served ranged from 7 cfs in 2005 to 15.7 cfs in

2015. In 2017 July and August median flows were 15 cfs and 18 cfs, respectively, in both months higher than the 14 cfs protected in stream.

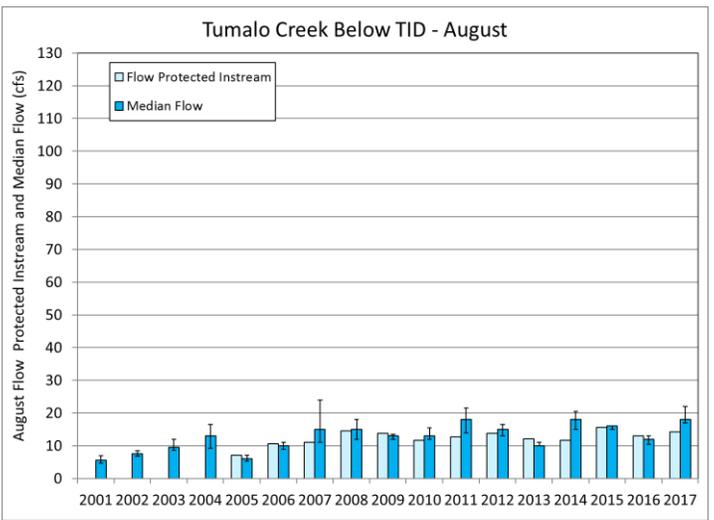
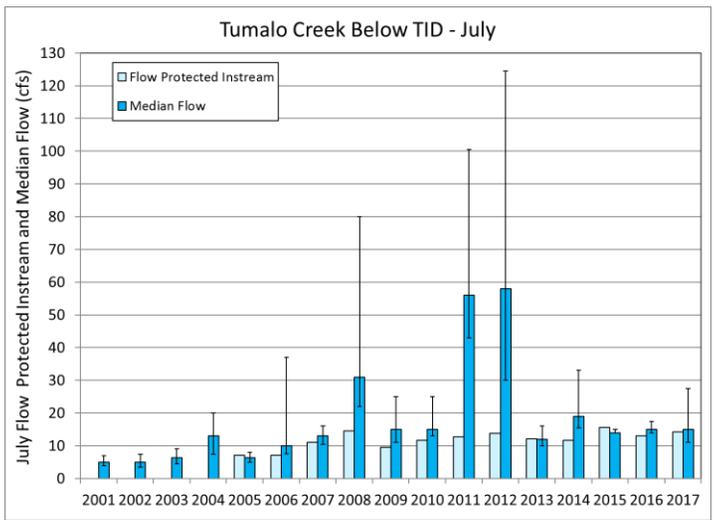
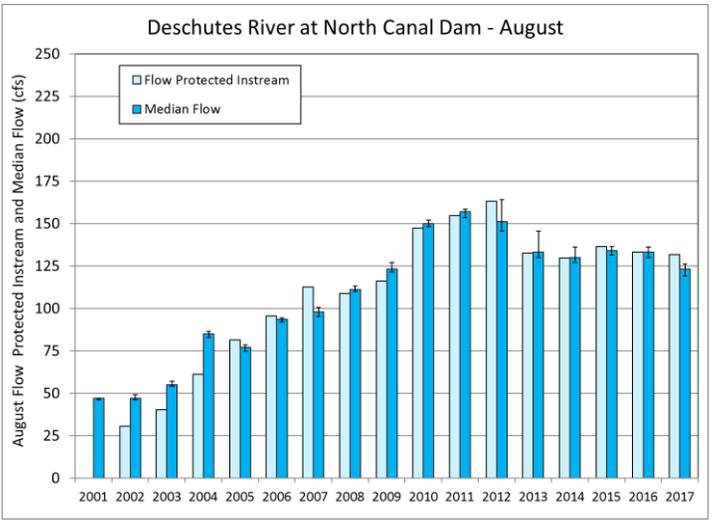
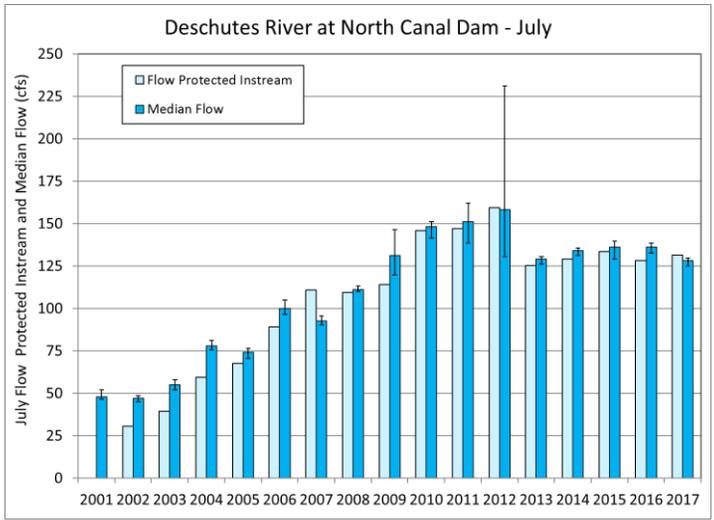


Figure 3. Deschutes River and Tumalo Creek July median protected and recorded flow in July and August, 2001-2017.

July and August median Deschutes River flows steadily increased from 2001 to 2012, corresponding to increases in flow protected instream. July and August median Deschutes River flows fell in 2013, reflecting reductions in both flow leased instream and flow left instream by irrigation districts under a voluntary agreement. July and August median flows protected in Tumalo Creek have fluctuated between 10 and 15 cfs since 2007, with July flows recorded instream varying widely.

3.2 Stream Temperature Status and Trend

Seven-day moving average maximum (7DADM) temperatures exceeded the 18°C state standard for trout and salmon rearing and migration on the middle Deschutes River and Tumalo Creek in 2017 below major irrigation diversions, at the four Deschutes River monitoring locations downstream of North Canal Dam and on Tumalo Creek at the mouth, by up to 7°C (Figure 4), supporting the existing State of Oregon Section 303(d) listing of the middle Deschutes River for temperature impairment. Temperatures at the four Deschutes River sites have exceeded the state standard in every year for which data are available for analysis, and exceeded the state standard on Tumalo Creek at the mouth in all but two years for which data are available for analysis. Stream temperature remained below 18°C in 2017 at the two monitoring locations upstream of Bend, DR 181.50 and DR 217.25; temperatures have exceeded 18°C at DR 181.50 in some years (2002, 2004, 2005, 2009, 2015) but in most years remain below 18°C.

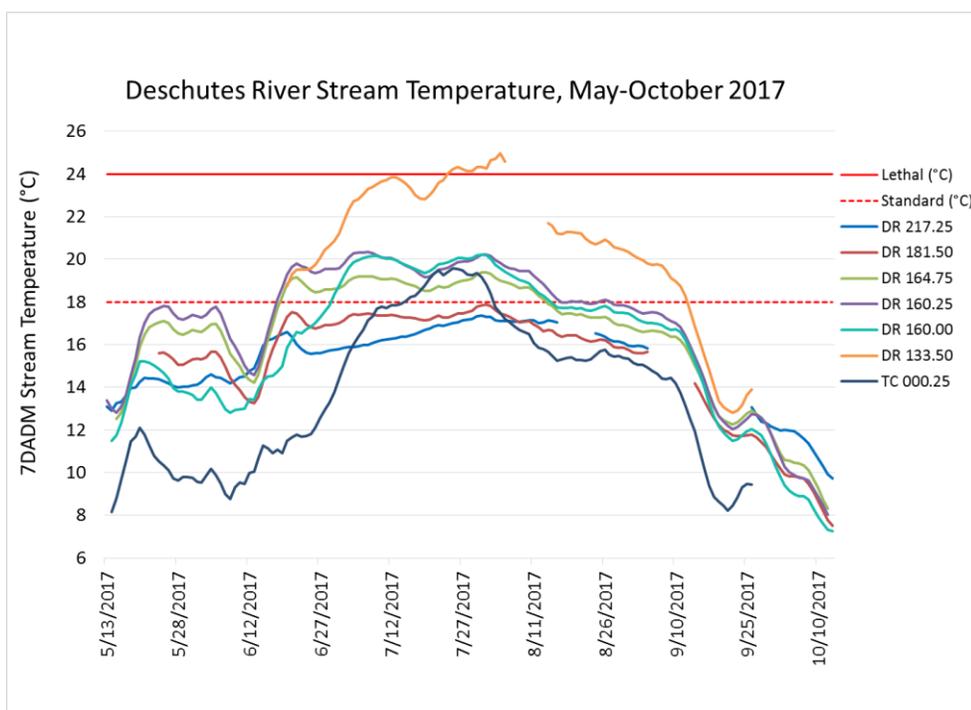


Figure 4. Deschutes River and Tumalo Creek temperatures May-October 2017

Temperatures exceeded the 18°C State of Oregon temperature standard (dashed red line) at four of six monitoring sites on the Deschutes River in 2017, from DR 133.50 to DR 164.75, and in Tumalo Creek just upstream of the mouth, at TC 000.25.

Percent of data days exceeding 18°C between April 30 and September 21, the dates during which stream temperatures have historically exceeded 18°C in the middle Deschutes River downstream of Bend, represents the amount of time during which stream conditions are likely limiting for rearing trout in this reach; conversely, the percent of days meeting 18°C represents the amount of time during which stream conditions are optimal to support rearing fish. Temperatures downstream of Bend exceeded 18°C for 32-59% of days between April 30 and September 21, 2017 (Figure 5) and conversely met the

18°C standard for 41-68% of those days. At DR 133.50, temperatures were 18°C or below for 41% of data days (60 days), a higher percentage than in all but five of the sixteen years for which data are available since 2001. Temperatures exceeded 24°C (the lethal threshold for trout rearing; ODEQ 1995) for 9% (13) of those days, from July 24 to August 5, more days than in any year since 2007 and consistent with other years including and since 2013, coincident with the 2013 drop in flows protected in the middle Deschutes.¹ Temperatures at DR 160.00, downstream of the confluence with Tumalo Creek, exceeded 18°C for 32% of data days (46 days), meeting the 18°C standard for 68% of data days (99 days) in 2017, more days than in five previous years since 2005. Stream temperature at DR 160.00 exceeded 18°C from June 30 to August 14, at flows of 131 to 204 cfs (123-195 cfs from the Deschutes and 6.1-50 cfs from Tumalo Creek). Temperatures at DR 160.25 met the standard for 55% of data days (80 days) in 2017, a lower percentage and fewer days than in all but three years; temperatures at DR 164.75, immediately downstream of North Canal Dam, met the standard for 61% of data days (88 days), fewer days than in any other year for which data are available.

Stream temperatures at TC 000.25, at the mouth of Tumalo Creek, exceeded the 18°C state temperature standard for 13% of days and met the standard for 87% of days between April 30 and September 21 in 2017. Temperatures in Tumalo Creek have exceeded 18°C for between 0 and 19% of days April 30 through September 21 since 2005, meeting the criteria for 81-100% of days April 30 through September 21 during these years; in 2004, the earliest year for which data are available for this site, stream temperatures exceeded 18°C for 35% of days April 30 through September 21 and met the standard for only 65% of days during this date range (data not shown).

July stream temperatures in the middle Deschutes River downstream of Bend from 2013 to 2017 are far lower and exceed 24°C far less frequently than from 2001 to 2007. But, median July temperatures from 2013 to 2017 are on average over two degrees warmer than from 2008 to 2012, and since 2013, July temperatures have exceeded 24°C, which they did not from 2008 to 2012. Thus, although some sustained improvements have been made in reducing stream temperatures, since 2013 stream temperature conditions have deteriorated from the significant gains made between 2008 and 2012.

July 2017 data from DR 133.50 remained below the lethal 24°C threshold by the narrowest of margins, maintaining the trend of sub-24°C temperatures observed from 2008-2012, but marked an increase from temperatures observed in 2016 (Figure 6). Stream temperature data were incomplete for August 2017. July and August data from DR 133.50 show a consistent decreasing trend in medians and ranges of 7DADM stream temperatures from 2001 to 2017.

¹ Although no recorded stream temperatures exceeded 24°C in 2015, data for DR 133.50 in 2015 were missing and extrapolated for 48 days between June 20 and August 21. Insufficient data were available to extrapolate with confidence if or for how many days stream temperatures exceeded 24°C during that period, although based on stream temperatures at DR 160.00, temperatures at DR 133.50 almost certainly exceeded the 24°C lethal threshold in 2015.

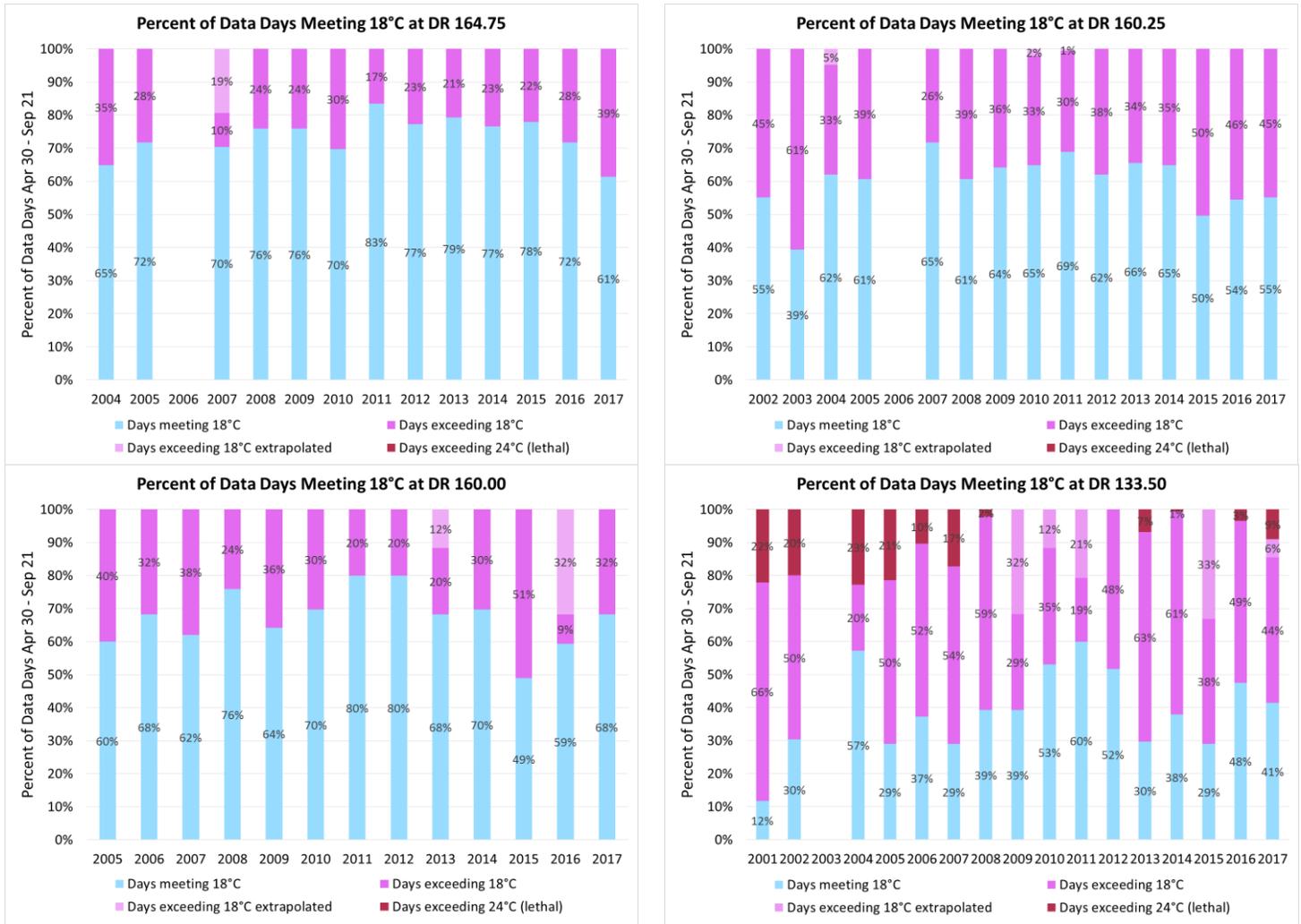
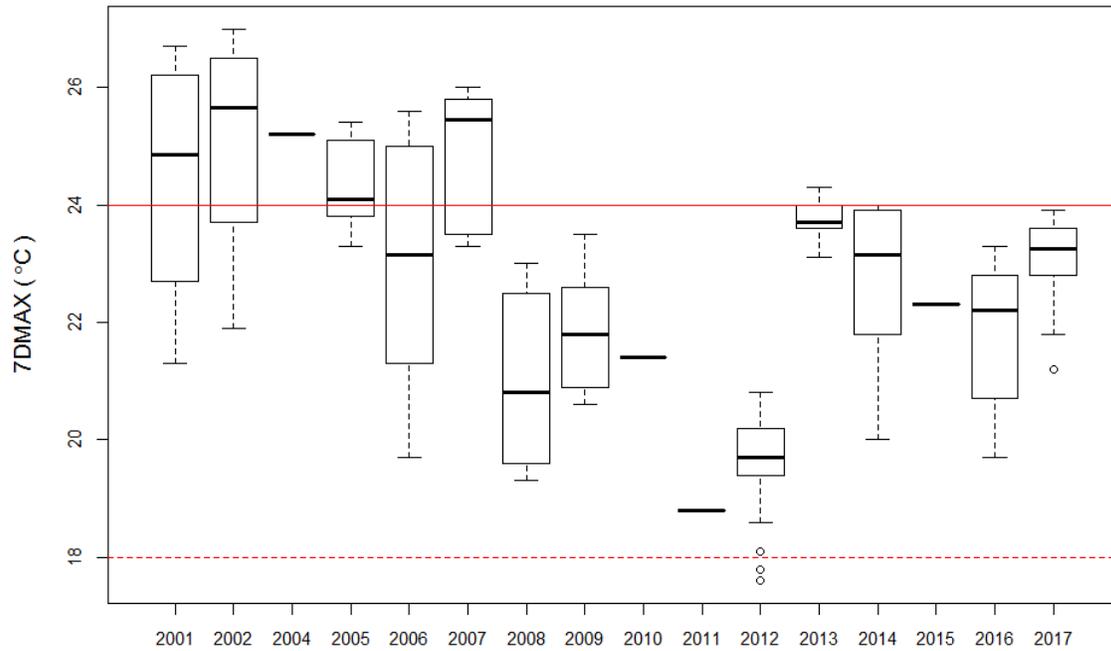


Figure 5. Percent of data days meeting and exceeding 18°C, 2001-2017. Stream temperature downstream of Bend exceeded 18°C for 32-59% of days between April 30 and September 21, 2017. The most dramatic improvements in the percent of days meeting stream temperature have occurred at Lower Bridge, DR 133.50.

a

2001-2017 July 7DADM Temperatures at Lower Bridge Road



b

2001-2017 August 7DADM Temperatures at Lower Bridge Road

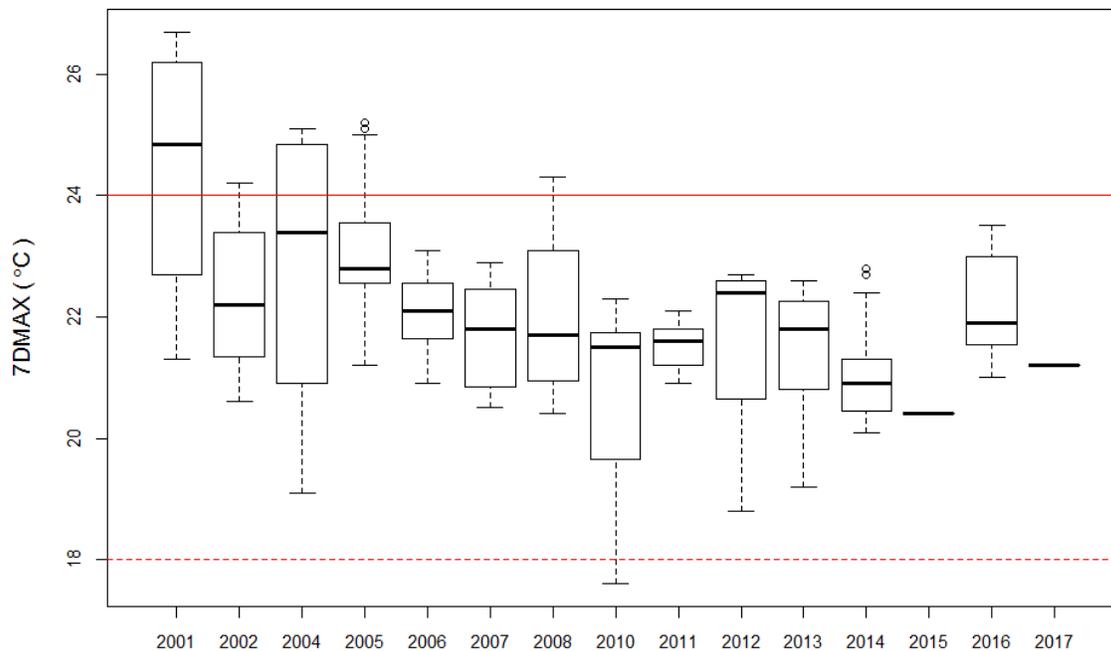


Figure 6. 2001-2017 July and August 7DADM temperatures at Lower Bridge

a) July 1-22 and b) August 6-28 7DADM temperatures at Lower Bridge (DR 133.50) chart a declining trend since 2001. Years for which data are not available are not represented; for years for which some data are available, the median of available values is shown. Despite reductions of approximately 2-4°C between 2001 and 2017, temperatures at Lower Bridge remain well above the 18°C standard (dashed red line) throughout July and August.

3.3 Effect of Stream Flow on Stream Temperature

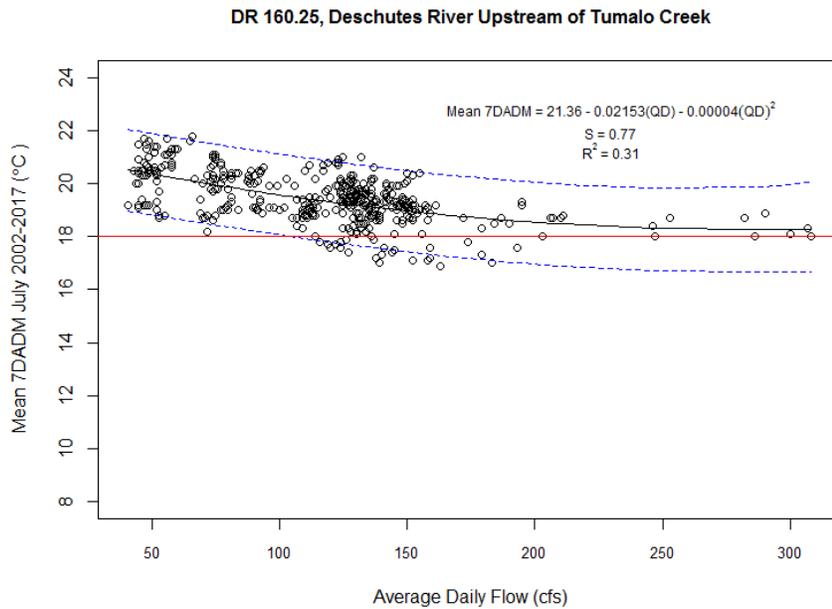
Multiple lines of evidence show reduced stream temperatures at higher stream flows achieved through stream flow restoration in the middle Deschutes River and Tumalo Creek. This relationship is strongest in July but is also evident in August. As July median flows in the middle Deschutes and in Tumalo Creek increased from 2001-2012, July and August stream temperatures decreased (Figure 3, Figure 6). July stream temperatures spiked with the 2013 drop in middle Deschutes River stream flow, and have come down slightly as flows have crept up from 2013 levels. August stream temperatures also dropped through 2010, and have fluctuated since. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2017 at DR 160.25 and at TC 000.25 show temperatures decreasing as flows increase (Figure 7).

The regression for each site represents a range of flows for each year that reflect increased July flows resulting in part from stream flow restoration. The range of flows annually for which temperature data are available between 2002 and 2017 increased from a low of 41 cfs and a high of 51 cfs in 2002 to a low of 100 cfs and high of 327 cfs in 2011 in the Deschutes at North Canal Dam; in Tumalo Creek, flows included in regressions increased from a low of 3.3 cfs and high of 37 cfs in 2004 to a low of 11 and high of 177 cfs in 2008.² Stream flow explained 31% of the variation in stream temperature at DR 160.25 ($R^2 = 0.31$), and 76% of the variation in stream temperature at TC 000.25 ($R^2 = 0.76$) in July, providing further support for increases in July stream flow contributing to reduced stream temperatures.

Increasing flows in the Deschutes River versus Tumalo Creek resulted in dramatically different estimated reductions in stream temperature. At DR 160.25, where increased flows reduce warming rather than actively cooling stream temperature, and the distance over which to reduce warming is relatively short (< 5 mi from North Canal Dam), modest reductions in predicted temperature were observed as flows increased. A flow rate of 41 cfs from the Deschutes River at North Canal Dam (the lowest flow included in the analysis) resulted in a predicted 7DADM temperature of $20.5^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$ (upper interval = 22.0°C) at DR 160.25, approximately five miles downstream; flows between 222 and 308 cfs resulted in a mean temperature *only 2°C lower*, at $18.4^{\circ}\text{C} \pm 1.5\text{-}1.6^{\circ}\text{C}$ (upper interval = $19.9\text{-}20^{\circ}\text{C}$). In Tumalo Creek, a smaller-volume system which flows directly from its headwaters with no impoundment or associated warming, proportionally greater increases in colder stream flow have a greater effect on temperature: for the purpose of illustration, the lowest flow included in the analysis, 3.3 cfs, resulted in a mean temperature of $20.7^{\circ}\text{C} \pm 2.8^{\circ}\text{C}$ (upper interval = 23.5°C), with flows between 106 and 129 cfs resulting in the lowest mean temperature of $11.4 \pm 2.9^{\circ}\text{C}$ (upper interval= 14.3°C), a temperature reduction of more than 9°C .

² Temperature data were not available for the dates on which 327 cfs and 177 cfs were recorded on Whychus Creek at Sisters (July 19, 2011) and on Tumalo Creek below the TID diversion (July 1, 2008), respectively, and accordingly these flow values are not included in regressions.

a



b

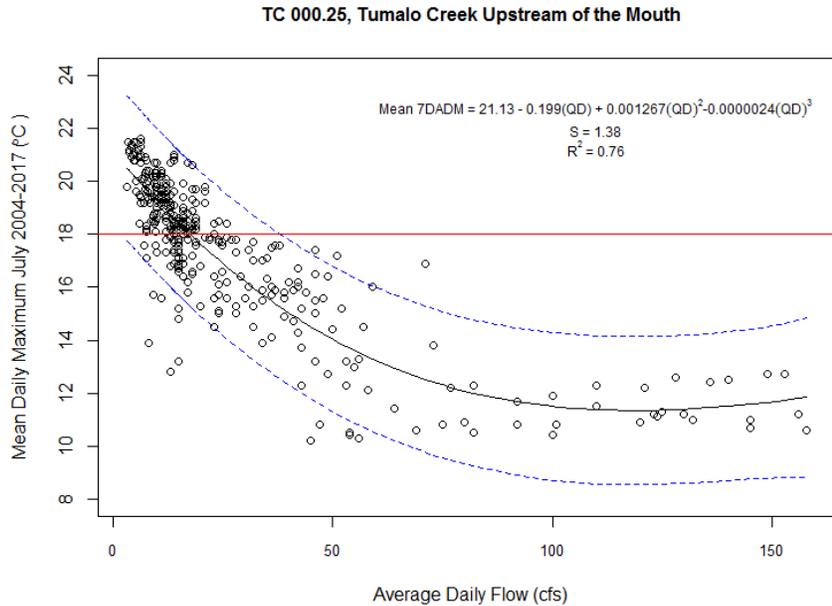


Figure 7. Temperature-flow regression models.

Regression models fitted to temperature-flow data demonstrate lower temperatures at higher flows and describe the relationship between temperature and flow observed a) during July 2002-2017 at DR 160.25, the Deschutes River upstream of the confluence with Tumalo Creek, and b) during July 2004-2017 at TC 000.25, Tumalo Creek upstream of the mouth.

3.4 Target Stream Flow

Temperature records were available from TC 000.25 for July dates from 2004 through 2017 at Tumalo Creek flows between 3.5 and 158 cfs, and for DR 160.25 for July dates from 2002-2017 at Deschutes River flows between 41 and 308 cfs. The quadratic regression of the 7DADM stream temperature on average daily flow ($7DADM \sim Flow + (Flow)^2$) performed best of the twelve regression models for DR 160.25; this model demonstrates the relatively small influence of Deschutes River flow on stream temperature in July, explaining only 31% of the variation in stream temperature ($R^2 = 0.31$). For TC 000.25 stream temperature and flow data, the cubic regression of the 7DADM stream temperature on average daily flow ($7DADM \sim Flow + (Flow)^2 + (Flow)^3$) performed best of the twelve models (Table 4). Stream flow explained 76% of the variation in stream temperature at the mouth of Tumalo Creek in July ($R^2 = 0.76$). Residuals for the best performing model for each site were approximately normally distributed. We used the resulting equations to calculate predicted temperatures for the range of flows on which regressions were trained for both sites (Appendix A).

Table 4. The best three regression models for predicting stream temperature for July at DR 160.25 and at TC 000.25.

Regression Model	Intercept	Coefficient 1	Coefficient 2	Coefficient 3	n	df	R ²	S	AIC value
DR 160.25									
7DADM ~ Flow + (Flow)²	21.36	-0.02153	0.00004	--	438	435	0.31	0.77	-220
7DADM ~ Flow + (Flow) ² + (Flow) ³	21.22	-0.02	0.00001	0.0000001	438	434	0.33	0.76	-218
7DADM ~ LnFlow	25.4116	-1.27715	--	--	438	436	0.32	0.76	-216
TC 000.25									
7DADM ~ Flow + (Flow)² + (Flow)³	21.13	-0.199	0.001267	-0.0000024	337	333	0.76	1.38	223
7DADM ~ Flow + (Flow) ²	20.89	-0.175	0.00077	--	337	334	0.76	1.39	224
7DADM ~ LnFlow + (LnFlow) ² + (LnFlow) ³	18.88058	3.33737	-1.69141	0.14	337	333	0.75	1.44	249

Predicted temperatures calculated for six Deschutes River flow scenarios illustrated dramatic temperature reductions in the Deschutes River below the confluence with Tumalo Creek (DR 160.00) as flows in Tumalo increased (Appendix B).

At both the July 2017 median protected flow of 132 cfs and the observed median middle Deschutes River flow of 128 cfs, 44 cfs in Tumalo Creek was estimated to achieve the state temperature standard of $18^{\circ}\text{C} \pm 1.8^{\circ}\text{C}$ on average in the Deschutes River immediately downstream of the confluence with Tumalo Creek. If Tumalo Creek flows were further increased to 54 cfs (*i.e.*, approximately the 80% exceedance surface water availability during July, less an 18 cfs City of Bend diversion³) at the same Deschutes River flow, the average 7DADM temperature in the Deschutes River below the confluence with Tumalo Creek would be reduced to $17.5^{\circ}\text{C} \pm 1.9^{\circ}\text{C}$ at both the July 2017 median protected and observed Deschutes River flows of 132 and 128 cfs, respectively. Increasing Deschutes River flows from the 2017 protected flow of 132 cfs to the instream flow target of 250 cfs was estimated to achieve an additional 0.8°C reduction in stream temperature at the 2017 protected Tumalo Creek flow of 14 cfs, a 0.5°C reduction in stream temperature at 32 cfs in Tumalo Creek and a 0.2°C reduction in stream temperature at 44 cfs in Tumalo Creek. At 54 cfs in Tumalo Creek stream temperature in the Deschutes downstream of the confluence was estimated to be approximately equivalent (within 0.1°C) at 132 or at 250 cfs in the Deschutes (Table 5), highlighting the significant reductions in stream temperature that can be achieved in the middle Deschutes River by prioritizing stream flow restoration in Tumalo Creek over at North Canal Dam.

Table 5. Estimated Deschutes River stream temperatures at four Tumalo Creek flows and two Deschutes River flows. Fourteen (14) and 132 cfs in Tumalo Creek and the Deschutes River, respectively, represent flows protected instream in 2017. Forty-four cfs represents the flow needed in Tumalo to meet 18°C downstream of the confluence with the Deschutes at the 132 cfs currently protected in the Deschutes; 54 cfs represents the 80% exceedance surface water availability in Tumalo Creek during July.

Tumalo Creek Stream Flow (cfs)	Deschutes River Stream Flow (cfs)	Estimated 7DADM Stream Temperature ($^{\circ}\text{C}$)	Deschutes River Stream Flow (cfs)	Estimated 7DADM Stream Temperature ($^{\circ}\text{C}$)
14	132	$19.1^{\circ}\text{C} \pm 1.6^{\circ}\text{C}$	250	$18.3^{\circ}\text{C} \pm 1.6^{\circ}\text{C}$
32	132	$18.5^{\circ}\text{C} \pm 1.8^{\circ}\text{C}$	250	$18.0^{\circ}\text{C} \pm 1.7^{\circ}\text{C}$
44	132	$18.0^{\circ}\text{C} \pm 1.8^{\circ}\text{C}$	250	$17.8^{\circ}\text{C} \pm 1.7^{\circ}\text{C}$
54	132	$17.6^{\circ}\text{C} \pm 1.9^{\circ}\text{C}$	250	$17.5^{\circ}\text{C} \pm 1.8^{\circ}\text{C}$

Whereas increasing stream flow in Tumalo Creek from the July 2017 protected flow of 14 cfs to 54 cfs was estimated to achieve large reductions in stream temperature, simultaneously increasing Deschutes River stream flow conferred small additional reductions in stream temperature that diminished as Tumalo Creek flows approached 50 cfs. At 55, 57, and 58 cfs in Tumalo Creek, increasing Deschutes River flow from 132 to 250 cfs had no effect on temperature. Above 58 cfs in Tumalo Creek, adding stream flow in the Deschutes River required commensurate increases in Tumalo Creek flow to achieve the same temperature met at lower flows in both Tumalo Creek and in the Deschutes. For example, flows of 67 cfs

³ calculated as the 80% exceedance surface water availability during July (72 cfs) minus the average City of Bend net water withdrawal (18 cfs; DRC, unpublished data)

in Tumalo Creek and 132 cfs in the Deschutes, or 71 cfs in Tumalo Creek and 250 cfs in the Deschutes, both resulted in an estimated stream temperature of 17°C in the Deschutes downstream of the confluence.

The Heat Source model developed by Watershed Sciences and MaxDepth Aquatics under contract with ODEQ (Watershed Sciences and MaxDepth Aquatics 2008) simulated stream temperature from historical stream flow and temperature measurements for the Deschutes River and Tumalo Creek, and provides estimated stream temperatures against which we can compare those calculated from our regression equations. Heat Source model estimates are available for state instream water right (ODFW) flows in July for the Deschutes River (250 cfs) and for Tumalo Creek (32 cfs). The Heat Source average seven day average daily maximum (7DADM) temperature estimate for Deschutes flows of 250 cfs and Tumalo flows of 32 cfs at approximately DR 160.00 (Heat Source rkm 72.4) is 17.4°C, over half a degree lower than the mass balance temperature estimate of 18.0°C for the same flow at the same site. The Heat Source average 7DADM for the Deschutes at 250 cfs at approximately DR 160.25 (Heat Source rkm 72.8), above the confluence with Tumalo, was 17.2°C, over a degree lower than the 18.3°C calculated from the regression equation. The Heat Source estimate for Tumalo Creek flows of 32 cfs at approximately TC 000.25 was 15.7°C, 0.3°C lower than the 16.0°C calculated from the regression equation for that flow and site.

4 Discussion

4.1 Stream Flow Status and Trend

Stream flow in the middle Deschutes River steadily increased alongside protected flows through 2012. Since 2012 protection of additional flow in stream has stalled, returning the amount of flow protected, as well as flow recorded in stream, to pre-2010 levels. Stream flow protected in Tumalo Creek has fluctuated between 12.2 and 15.6 cfs since 2010. Actual Tumalo Creek July median instream flow in 2017 was slightly higher than the July 2017 median protected flow.

4.2 Temperature Status and Trend

Stream temperature in the middle Deschutes River exceeded the 18°C state standard protecting salmon and trout rearing and migration for 32-59% of days between April 30 and September 21, 2017. Conversely, stream temperature was 18°C or lower, representing optimal rearing conditions for trout, for 41-68% of days in 2017. These data represent some recovery, varying among sites, since 2015, after a decline in conditions from 2011 to 2015.

Given July median flows of 128 cfs in the Deschutes River and 15 cfs in Tumalo Creek, temperatures above 18°C at DR 160.00 for 32% of days in 2017, including every day in July, are consistent with mass balance results which predict 44 cfs required in Tumalo Creek at 132 cfs in the Deschutes to achieve 18°C at this site.

From 2008 to 2012 no 7DADM stream temperatures 24°C or higher were recorded at Lower Bridge, coincident with higher flows during these years achieved in part through stream flow restoration. Since 2013 stream temperatures 24°C and above have been recorded at Lower Bridge in every year except 2015, when data were unavailable from June 20th to July 15th. The return to summer stream temperatures exceeding the lethal 24°C threshold corresponds to the 2013 drop in flows protected in the middle Deschutes. The percent of days in 2017 exceeding 24°C at Lower Bridge was the highest observed since 2007.

Regression analysis of stream flow, stream temperature, and air temperature data for the Deschutes (DR 160.25) and Tumalo Creek (TC 000.25) developed for the Upper Deschutes Basin Study resulted in models that incorporated both stream flow and air temperature explaining the greatest proportion of variation in stream temperature of the models run (UDWC 2016). This result indicates that air temperature, in addition to stream flow, influences stream temperature in the middle Deschutes and in Tumalo Creek. Despite similar July stream flow medians and ranges in 2009 and from 2013-2017, the proportion of days exceeding the 18°C state standard at DR 133.50 has fluctuated by around 20%, between 52% and 71%, over those years. Differences in air temperature between years, as well as other factors such as variation in flow in earlier months or effects of solar radiation and reservoir level on the temperature of flow released from reservoirs, could explain the wide variation in number of days exceeding the 18°C state standard at similar July flows.

4.3 Restoration Effectiveness

Higher stream flows resulting from stream flow restoration (water rights transferred and delivered instream) have resulted in lower stream temperatures in Tumalo Creek and in the middle Deschutes River. July and August stream temperatures at DR 133.50 decreased with increases in July median flows in the middle Deschutes and in Tumalo Creek between 2001 and 2012. Comparison of 7DADM temperatures at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded from 2002 to 2015 show lower stream temperatures have historically occurred at higher flows. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2017 at DR 160.25 and at TC 000.25 also show lower temperatures occurring at higher flows.

Stream flow explained 76% of the variation in stream temperature in Tumalo Creek ($R^2 = 0.76$), providing support for the role of higher protected flows in Tumalo Creek guaranteeing higher baseflows and lower stream temperatures. But, for the Deschutes upstream of the confluence with Tumalo Creek, stream flow explained only 31% of the variation in stream temperature ($R^2 = 0.13$), indicating factors other than stream flow contribute substantially to stream temperature at this site; and, whereas observed and calculated stream temperatures at DR 160.25 decrease as flows increase, stream temperature is only 2°C lower at 250 cfs than it is at 50 cfs. Additionally, the R^2 value for the DR 160.25 regression equation has decreased over time with addition of more recent stream flow and temperature data, suggesting the influence of stream flow at NCD on temperature is decreasing, possibly in relation to hotter air temperatures and a changing climate. While these data suggest stream flow restoration in the middle Deschutes will have a relatively small effect on stream temperature at DR 160.25, increasing flows at

North Canal Dam remains important both to reduce the rate of warming downstream of Tumalo Creek and for the greater amount of aquatic habitat provided by higher flows.

4.4 Target Stream Flow

Mass balance equation results suggest that restoring 44 cfs in Tumalo Creek will achieve the 18°C standard in the Deschutes downstream of the confluence at a Deschutes River flow of 132 cfs below North Canal Dam, the median flow observed in July 2017. Increasing Tumalo Creek flows to 54 cfs, the 80% exceedance surface water availability during July assuming a City of Bend diversion of 18 cfs, is estimated to reduce stream temperature in the Deschutes below the confluence to 17.6°C ± 1.9°C and allow in part for downstream warming between the confluence and Lower Bridge (DR 133.50). Achieving the 18°C standard in the Deschutes downstream of the confluence at the Tumalo Creek state instream water right of 32 cfs would require 250 cfs (the pending state instream water right) in the Deschutes. In light of the 2017 status of protected flows, 132 cfs in the Deschutes and 14 cfs in Tumalo Creek, these results suggest that achieving the desired reductions in stream temperature in the middle Deschutes River may be significantly accelerated by strategically prioritizing Tumalo Creek water transactions; preferentially increasing flows in Tumalo Creek over restoring stream flow in the Deschutes may achieve the greatest temperature benefits at the lowest cost. Water conservation activities slated for implementation in Tumalo Irrigation District are anticipated to result in an estimated 50 cfs instream below the diversion in July, which would achieve 17.8°C ± 1.9°C downstream of the confluence at the current protected Deschutes River flow of 132 cfs, or 17.6°C ± 1.8°C at the pending instream water right flow of 250 cfs in the Middle Deschutes.

Mass balance results for Tumalo Creek and Deschutes River flows immediately below the confluence of Tumalo Creek and the Deschutes suggest that, even by optimizing Tumalo Creek and Deschutes River flows to achieve the greatest possible temperature reduction, the lowest temperatures achievable at DR 160.00 given total flow potentially available for stream flow restoration in Tumalo Creek will likely still be too high to achieve 18°C at Lower Bridge (DR 133.50) given observed rates of temperature increase between DR 160.00 and DR 133.50 (~ 3°C in July). While direct comparison is difficult because of how river miles/kilometers are measured in the two analyses, the Heat Source model for the Deschutes River suggests that, at instream water right (ODFW) flows for both the river and for Tumalo Creek, temperatures in the Deschutes exceed 18°C in reaches totaling approximately 9 miles between the confluence with Tumalo Creek and the confluence with Whychus Creek at RM 123 (Watershed Sciences 2008). Mass balance results that are higher than Heat Source stream temperatures for the Deschutes likely reflect the influence of air temperature and changing climate conditions on middle Deschutes River stream temperature since 2001, the year for which Heat Source temperatures were calculated.

Higher flows achieved through stream flow restoration scenarios described above will reduce stream temperatures meaningfully. However, mass balance and Heat Source model results suggest that it is not possible to meet the state temperature standard in all reaches of the middle Deschutes River between Tumalo Creek and Whychus Creek given diversion of Tumalo Creek flows for municipal and agricultural use and while Deschutes River water is subject to heating in Wickiup and Crane Prairie reservoirs prior to being released downstream. Preliminary analysis of stream temperature from Pringle Falls at DR

217.25, approximately ten miles below Wickiup Reservoir, and stream temperature from DR 164.75, immediately below North Canal Dam, suggest stream temperature at North Canal Dam increases as a function of increasing stream temperature at DR 217.25 ($R^2 = 0.35$), which in turn we hypothesize increases as a function of reservoir depth and solar radiation. Further evidence for reservoir storage resulting in increased stream temperature in the Deschutes River is found in historic accounts of abundant bull trout, which require cooler (10°C) stream temperatures than other salmonids, in the Deschutes River at Pringle Falls (DR 217.25; Fies et al 1996). Allocating the maximum amount of streamflow possible from Tumalo Creek and the Deschutes River during the month of July (up to 63 cfs in Tumalo Creek) will reduce the frequency and duration of lethal stream temperatures in the middle Deschutes and improve rearing habitat for juvenile redband.

4.5 Implications for Native Redband Populations

7DADM stream temperature was not a significant explanatory variable for young of year redband trout or brown trout occupancy probabilities in the middle Deschutes River in a 2015 study (Starcevich and Bailey 2017) despite 7DADM temperatures exceeding 18°C . While the thermal range and temperature tolerance of redband may exceed the state standard, the authors cited the substantial body of literature documenting adverse effects of temperatures above 18°C on redband trout physiology, growth and survival, and identifying optimal temperature preferences of redband trout as below the 18°C state standard. Starcevich and Bailey further note that exceeding the 18°C standard may preferentially benefit nonnative brown trout, which have a higher occurrence probability than redband in warmer stream temperatures.

Whether or not it is possible to meet the state temperature standard along every mile of the middle Deschutes River between North Canal Dam and Lower Bridge Road given current reservoir operations and irrigation infrastructure and management, increases in flow that approach or exceed the instream water right and DRC flow targets in the Deschutes River and Tumalo Creek may nonetheless confer substantial ecological benefits beyond improving temperature conditions. Although elevated stream temperature is an important consequence of modified flows in the Deschutes and in Tumalo Creek, altered flows affect other stream functions and habitat parameters, notably stream width and depth which contribute to habitat availability and diversity. And, while temperature requirements for salmon and trout are well-documented and encoded in state water quality standards, specific requirements for the habitat functions of the hydrograph in the middle Deschutes River are less well understood. Starcevich and Bailey (2017) found channel width between North Canal Dam and Steelhead Falls was on average 7.9 m narrower during irrigation season than during water storage season, demonstrating the large reduction in habitat quantity that results from irrigation withdrawals at North Canal Dam. Allocating resources to stream flow restoration in Tumalo Creek will optimize reductions in temperature in Tumalo Creek and in the Deschutes River downstream of Tumalo Creek, as well as habitat benefits associated with increased habitat quantity (stream width and depth) in the reach of Tumalo Creek where stream flow is restored. Restoring stream flow in the Deschutes River will provide important habitat benefits associated with increased habitat quantity, while providing an additional cooling effect (up to 55 cfs in Tumalo Creek). This report provides information that will allow fisheries managers to identify flow scenarios for Tumalo Creek and the middle Deschutes River that balance the habitat

benefits of lower stream temperatures and increased habitat quantity to provide the greatest habitat benefit for resident redband trout.

5 References

Fies, T., Fortune, J., Lewis, B., Manion, M. & Marx, S. 1996. Upper Deschutes River Subbasin Fish Management Plan. Oregon Department of Fish and Wildlife, Upper Deschutes Fish District, Bend, Oregon. 373 p.

Helsel, D. R., & Hirsch, R. M. 1991. Statistical Methods in Water Resources, Techniques of Water Resources Investigations of the United States Geological Survey, Book 4, Hydrologic Analysis and Interpretation Chapter A3. United States Geological Survey.

NASA. 2017. Global Climate Change Vital Signs of the Planet. <https://climate.nasa.gov/vital-signs/global-temperature/> Accessed online 6/29/2017.

ODEQ. 1995. State of Oregon 1992-1994 Water Quality Standards Review. Portland, Oregon: Oregon Department of Environmental Quality.

ODEQ. 2004. *Oregon's 2004 Water Quality Assessment*. Water Quality Division. Portland, Oregon: Oregon Department of Environmental Quality.

ODEQ. 2019. Oregon's 2018/2020 Draft Integrated Report. Accessed online 12/16/2019. Available online at https://travispritchard.shinyapps.io/2018-2020_IR_Database/

ODEQ. 2010. *Laboratory and Environmental Assessment, Oregon Department of Environmental Quality*. From <http://www.deq.state.or.us/lab/wqm/volmonresources.htm>.

OWRD. 2017. OWRD Near Real Time Hydrographic Data. Retrieved from http://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/Default.aspx. Accessed online 7/3/2018.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

Starcevich, S. J. and Bailey, B. 2017. 2015 Deschutes River Fisheries Monitoring Report: Assessing Redband Trout status in the middle and upper Deschutes River basin using young-of-the-year occupancy surveys in lateral habitats. Native Fish Investigations Program, Oregon Department of Fish and Wildlife. Corvallis, OR.

UDWC. 2006. Deschutes River Temperature Summary 2004-2006. Bend, Oregon. Prepared by Jones, L., Upper Deschutes Watershed Council.

UDWC. 2008a. *Water Quality Monitoring Program Standard Operating Procedures*. Bend, Oregon: Prepared by: Jones, L. and M. Logan, Upper Deschutes Watershed Council.

UDWC. 2008b. *Quality Assurance Project Plan; Water Quality Monitoring Program*. Bend, Oregon: Prepared by Jones, L., Upper Deschutes Watershed Council.

UDWC. 2014. *Instream Flow Restoration and Temperature Responses, middle Deschutes River, Deschutes Basin, Oregon*. Bend, Oregon. Prepared by: Mork, L., Upper Deschutes Watershed Council.

UDWC. 2016. *Whychus Creek and Middle Deschutes River Temperature Assessments*. Bend, Oregon. Prepared by: Mork, L., Upper Deschutes Watershed Council.

Watershed Sciences. 2008. *Deschutes River, Whychus Creek, and Tumalo Creek Temperature Modeling*. Bend, Oregon: Prepared by Watershed Sciences and Max Depth Aquatics Inc. Bend, Oregon. 83 p.

APPENDIX A Estimated temperatures at given flows calculated from regression equations

Deschutes River upstream of Tumalo Creek (DR 160.25)

Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)
41	20.5	1.5	94	19.7	1.5	147	19.0	1.5	200	18.5	1.5
42	20.5	1.5	95	19.7	1.5	148	19.0	1.5	201	18.5	1.5
43	20.5	1.5	96	19.6	1.5	149	19.0	1.5	202	18.5	1.5
44	20.5	1.5	97	19.6	1.5	150	19.0	1.5	203	18.5	1.5
45	20.5	1.5	98	19.6	1.5	151	19.0	1.5	204	18.5	1.5
46	20.4	1.5	99	19.6	1.5	152	18.9	1.5	205	18.5	1.5
47	20.4	1.5	100	19.6	1.5	153	18.9	1.5	206	18.5	1.5
48	20.4	1.5	101	19.6	1.5	154	18.9	1.5	207	18.5	1.5
49	20.4	1.5	102	19.6	1.5	155	18.9	1.5	208	18.5	1.5
50	20.4	1.5	103	19.5	1.5	156	18.9	1.5	209	18.5	1.5
51	20.4	1.5	104	19.5	1.5	157	18.9	1.5	210	18.5	1.5
52	20.3	1.5	105	19.5	1.5	158	18.9	1.5	211	18.5	1.5
53	20.3	1.5	106	19.5	1.5	159	18.9	1.5	212	18.5	1.5
54	20.3	1.5	107	19.5	1.5	160	18.9	1.5	213	18.5	1.5
55	20.3	1.5	108	19.5	1.5	161	18.9	1.5	214	18.5	1.5
56	20.3	1.5	109	19.5	1.5	162	18.9	1.5	215	18.5	1.5
57	20.3	1.5	110	19.4	1.5	163	18.8	1.5	216	18.4	1.5
58	20.2	1.5	111	19.4	1.5	164	18.8	1.5	217	18.4	1.5
59	20.2	1.5	112	19.4	1.5	165	18.8	1.5	218	18.4	1.5
60	20.2	1.5	113	19.4	1.5	166	18.8	1.5	219	18.4	1.5
61	20.2	1.5	114	19.4	1.5	167	18.8	1.5	220	18.4	1.5
62	20.2	1.5	115	19.4	1.5	168	18.8	1.5	221	18.4	1.5
63	20.2	1.5	116	19.4	1.5	169	18.8	1.5	222	18.4	1.5
64	20.1	1.5	117	19.4	1.5	170	18.8	1.5	223	18.4	1.5
65	20.1	1.5	118	19.3	1.5	171	18.8	1.5	224	18.4	1.5
66	20.1	1.5	119	19.3	1.5	172	18.8	1.5	225	18.4	1.5
67	20.1	1.5	120	19.3	1.5	173	18.8	1.5	226	18.4	1.5
68	20.1	1.5	121	19.3	1.5	174	18.7	1.5	227	18.4	1.5
69	20.1	1.5	122	19.3	1.5	175	18.7	1.5	228	18.4	1.5
70	20.0	1.5	123	19.3	1.5	176	18.7	1.5	229	18.4	1.5
71	20.0	1.5	124	19.3	1.5	177	18.7	1.5	230	18.4	1.5
72	20.0	1.5	125	19.3	1.5	178	18.7	1.5	231	18.4	1.5
73	20.0	1.5	126	19.2	1.5	179	18.7	1.5	232	18.4	1.5
74	20.0	1.5	127	19.2	1.5	180	18.7	1.5	233	18.4	1.5
75	20.0	1.5	128	19.2	1.5	181	18.7	1.5	234	18.4	1.5
76	19.9	1.5	129	19.2	1.5	182	18.7	1.5	235	18.4	1.5
77	19.9	1.5	130	19.2	1.5	183	18.7	1.5	236	18.4	1.5
78	19.9	1.5	131	19.2	1.5	184	18.7	1.5	237	18.4	1.5
79	19.9	1.5	132	19.2	1.5	185	18.7	1.5	238	18.3	1.5
80	19.9	1.5	133	19.2	1.5	186	18.6	1.5	239	18.3	1.5
81	19.9	1.5	134	19.1	1.5	187	18.6	1.5	240	18.3	1.5
82	19.8	1.5	135	19.1	1.5	188	18.6	1.5	241	18.3	1.5
83	19.8	1.5	136	19.1	1.5	189	18.6	1.5	242	18.3	1.5
84	19.8	1.5	137	19.1	1.5	190	18.6	1.5	243	18.3	1.6
85	19.8	1.5	138	19.1	1.5	191	18.6	1.5	244	18.3	1.6
86	19.8	1.5	139	19.1	1.5	192	18.6	1.5	245	18.3	1.6
87	19.8	1.5	140	19.1	1.5	193	18.6	1.5	246	18.3	1.6
88	19.8	1.5	141	19.1	1.5	194	18.6	1.5	247	18.3	1.6
89	19.7	1.5	142	19.1	1.5	195	18.6	1.5	248	18.3	1.6
90	19.7	1.5	143	19.0	1.5	196	18.6	1.5	249	18.3	1.6
91	19.7	1.5	144	19.0	1.5	197	18.6	1.5	250	18.3	1.6
92	19.7	1.5	145	19.0	1.5	198	18.6	1.5			
93	19.7	1.5	146	19.0	1.5	199	18.6	1.5			

Tumalo Creek upstream of the mouth (TC 000.25)

Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)
3	20.5	2.7	56	13.5	2.7	109	11.4	2.8			
4	20.4	2.7	57	13.5	2.7	110	11.4	2.8			
5	20.2	2.7	58	13.4	2.7	111	11.4	2.8			
6	20.0	2.7	59	13.3	2.7	112	11.4	2.8			
7	19.8	2.7	60	13.2	2.7	113	11.4	2.8			
8	19.6	2.7	61	13.2	2.7	114	11.3	2.8			
9	19.4	2.7	62	13.1	2.7	115	11.3	2.8			
10	19.3	2.7	63	13.0	2.7	116	11.3	2.8			
11	19.1	2.7	64	13.0	2.7	117	11.3	2.8			
12	18.9	2.7	65	12.9	2.7	118	11.3	2.8			
13	18.7	2.7	66	12.8	2.8	119	11.3	2.8			
14	18.6	2.7	67	12.8	2.8	120	11.3	2.8			
15	18.4	2.7	68	12.7	2.8	121	11.3	2.8			
16	18.3	2.7	69	12.6	2.8	122	11.3	2.8			
17	18.1	2.7	70	12.6	2.8	123	11.3	2.8			
18	17.9	2.7	71	12.5	2.8	124	11.3	2.8			
19	17.8	2.7	72	12.5	2.8	125	11.4	2.8			
20	17.6	2.7	73	12.4	2.8	126	11.4	2.8			
21	17.5	2.7	74	12.4	2.8	127	11.4	2.8			
22	17.3	2.7	75	12.3	2.8	128	11.4	2.8			
23	17.2	2.7	76	12.3	2.8	129	11.4	2.8			
24	17.0	2.7	77	12.2	2.8	130	11.4	2.8			
25	16.9	2.7	78	12.2	2.8	131	11.4	2.8			
26	16.8	2.7	79	12.1	2.8	132	11.4	2.8			
27	16.6	2.7	80	12.1	2.8	133	11.4	2.8			
28	16.5	2.7	81	12.0	2.8	134	11.4	2.8			
29	16.4	2.7	82	12.0	2.8	135	11.4	2.8			
30	16.2	2.7	83	12.0	2.8	136	11.5	2.8			
31	16.1	2.7	84	11.9	2.8	137	11.5	2.8			
32	16.0	2.7	85	11.9	2.8	138	11.5	2.8			
33	15.9	2.7	86	11.9	2.8	139	11.5	2.8			
34	15.7	2.7	87	11.8	2.8	140	11.5	2.8			
35	15.6	2.7	88	11.8	2.8	141	11.5	2.8			
36	15.5	2.7	89	11.8	2.8	142	11.5	2.8			
37	15.4	2.7	90	11.7	2.8	143	11.6	2.8			
38	15.3	2.7	91	11.7	2.8	144	11.6	2.8			
39	15.2	2.7	92	11.7	2.8	145	11.6	2.8			
40	15.0	2.7	93	11.6	2.8	146	11.6	2.8			
41	14.9	2.7	94	11.6	2.8	147	11.6	2.8			
42	14.8	2.7	95	11.6	2.8	148	11.6	2.9			
43	14.7	2.7	96	11.6	2.8	149	11.7	2.9			
44	14.6	2.7	97	11.6	2.8	150	11.7	2.9			
45	14.5	2.7	98	11.5	2.8	151	11.7	2.9			
46	14.4	2.7	99	11.5	2.8	152	11.7	2.9			
47	14.3	2.7	100	11.5	2.8	153	11.7	2.9			
48	14.2	2.7	101	11.5	2.8	154	11.8	2.9			
49	14.1	2.7	102	11.5	2.8	155	11.8	3.0			
50	14.0	2.7	103	11.4	2.8	156	11.8	3.0			
51	14.0	2.7	104	11.4	2.8	157	11.8	3.0			
52	13.9	2.7	105	11.4	2.8	158	11.8	3.0			
53	13.8	2.7	106	11.4	2.8						
54	13.7	2.7	107	11.4	2.8						
55	13.6	2.7	108	11.4	2.8						

APPENDIX B Estimated temperatures at six Deschutes River flow scenarios

TC 000.25	Estimated temperature at TC+DR flow						TC 000.25	Estimated temperature at TC+DR flow					
	DR QD (cfs)							DR QD (cfs)					
Flow (cfs)	128	132	160	180	200	250	Flow (cfs)	128	132	160	180	200	250
10	19.2	19.2	18.9	18.7	18.6	18.3	56	17.5	17.5	17.5	17.5	17.4	17.4
11	19.2	19.2	18.9	18.7	18.6	18.3	57	17.4	17.4	17.4	17.4	17.4	17.4
12	19.2	19.1	18.9	18.7	18.6	18.3	58	17.4	17.4	17.4	17.4	17.4	17.4
13	19.2	19.1	18.9	18.7	18.6	18.3	59	17.3	17.4	17.4	17.4	17.4	17.4
14	19.2	19.1	18.8	18.7	18.5	18.3	60	17.3	17.3	17.3	17.3	17.3	17.3
15	19.1	19.1	18.8	18.7	18.5	18.3	61	17.3	17.3	17.3	17.3	17.3	17.3
16	19.1	19.1	18.8	18.7	18.5	18.3	62	17.2	17.2	17.3	17.3	17.3	17.3
17	19.1	19.0	18.8	18.6	18.5	18.3	63	17.2	17.2	17.2	17.2	17.2	17.2
18	19.1	19.0	18.8	18.6	18.5	18.3	64	17.1	17.1	17.2	17.2	17.2	17.2
19	19.0	19.0	18.8	18.6	18.5	18.3	65	17.1	17.1	17.1	17.2	17.2	17.2
20	19.0	19.0	18.7	18.6	18.5	18.3	66	17.0	17.1	17.1	17.1	17.1	17.2
21	19.0	18.9	18.7	18.6	18.4	18.2	67	17.0	17.0	17.1	17.1	17.1	17.1
22	18.9	18.9	18.7	18.5	18.4	18.2	68	17.0	17.0	17.0	17.0	17.1	17.1
23	18.9	18.9	18.7	18.5	18.4	18.2	69	16.9	16.9	17.0	17.0	17.0	17.1
24	18.9	18.8	18.6	18.5	18.4	18.2	70	16.9	16.9	17.0	17.0	17.0	17.1
25	18.8	18.8	18.6	18.5	18.4	18.2	71	16.8	16.8	16.9	16.9	17.0	17.0
26	18.8	18.8	18.6	18.4	18.3	18.2	72	16.8	16.8	16.9	16.9	16.9	17.0
27	18.8	18.7	18.5	18.4	18.3	18.1	73	16.7	16.8	16.8	16.9	16.9	17.0
28	18.7	18.7	18.5	18.4	18.3	18.1	74	16.7	16.7	16.8	16.8	16.9	17.0
29	18.7	18.7	18.5	18.4	18.3	18.1	75	16.7	16.7	16.8	16.8	16.8	16.9
30	18.6	18.6	18.5	18.3	18.2	18.1	76	16.6	16.6	16.7	16.8	16.8	16.9
31	18.6	18.6	18.4	18.3	18.2	18.1	77	16.6	16.6	16.7	16.8	16.8	16.9
32	18.6	18.5	18.4	18.3	18.2	18.0	78	16.5	16.6	16.7	16.7	16.8	16.8
33	18.5	18.5	18.4	18.3	18.2	18.0	79	16.5	16.5	16.6	16.7	16.7	16.8
34	18.5	18.5	18.3	18.2	18.1	18.0	80	16.5	16.5	16.6	16.7	16.7	16.8
35	18.4	18.4	18.3	18.2	18.1	18.0	81	16.4	16.5	16.6	16.6	16.7	16.8
36	18.4	18.4	18.2	18.2	18.1	18.0	82	16.4	16.4	16.5	16.6	16.6	16.8
37	18.4	18.3	18.2	18.1	18.1	17.9	83	16.4	16.4	16.5	16.6	16.6	16.7
38	18.3	18.3	18.2	18.1	18.0	17.9	84	16.3	16.4	16.5	16.5	16.6	16.7
39	18.3	18.3	18.1	18.1	18.0	17.9	85	16.3	16.3	16.4	16.5	16.6	16.7
40	18.2	18.2	18.1	18.0	18.0	17.9	86	16.3	16.3	16.4	16.5	16.5	16.7
41	18.2	18.2	18.1	18.0	17.9	17.8	87	16.2	16.2	16.4	16.5	16.5	16.6
42	18.1	18.1	18.0	18.0	17.9	17.8	88	16.2	16.2	16.4	16.4	16.5	16.6
43	18.1	18.1	18.0	17.9	17.9	17.8	89	16.2	16.2	16.3	16.4	16.5	16.6
44	18.0	18.0	18.0	17.9	17.8	17.8	90	16.1	16.2	16.3	16.4	16.4	16.6
45	18.0	18.0	17.9	17.9	17.8	17.7	91	16.1	16.1	16.3	16.3	16.4	16.5
46	17.9	17.9	17.9	17.8	17.8	17.7	92	16.1	16.1	16.2	16.3	16.4	16.5
47	17.9	17.9	17.8	17.8	17.7	17.7	93	16.0	16.1	16.2	16.3	16.4	16.5
48	17.9	17.9	17.8	17.8	17.7	17.7	94	16.0	16.0	16.2	16.3	16.3	16.5
49	17.8	17.8	17.8	17.7	17.7	17.6	95	16.0	16.0	16.2	16.2	16.3	16.5
50	17.8	17.8	17.7	17.7	17.6	17.6	96	15.9	16.0	16.1	16.2	16.3	16.4
51	17.7	17.7	17.7	17.6	17.6	17.6	97	15.9	15.9	16.1	16.2	16.3	16.4
52	17.7	17.7	17.6	17.6	17.6	17.5	98	15.9	15.9	16.1	16.2	16.2	16.4
53	17.6	17.6	17.6	17.6	17.5	17.5	99	15.9	15.9	15.9	16.1	16.1	16.3
54	17.6	17.6	17.6	17.5	17.5	17.5	100	15.8	15.8	15.9	16.0	16.1	16.3
55	17.5	17.5	17.5	17.5	17.5	17.5							