Upper Deschutes Watershed Council

Technical Report

Middle Deschutes River Instream Flow Restoration and Temperature Responses 2001-2014

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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 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 of stream flow restoration efforts in reducing temperature in the middle Deschutes River, the DRC, its funders, and other partners have been interested in tracking 1) whether cumulative stream flow restoration actions have reduced water temperatures in downstream reaches of the river, 2) whether reductions in temperature, if observed, can be attributed to stream flow restoration projects, and 3) how stream flow restoration in the middle Deschutes River and in Tumalo Creek may differentially affect stream temperature. Since 2008 the DRC has partnered with the Upper Deschutes Watershed Council (UDWC) to conduct temperature monitoring to investigate potential temperature changes associated with stream flow restoration projects. This ongoing monitoring effort incorporates data collected from 2001 to 2014 to address the following key questions:

1) Temperature status: What was the status of Middle Deschutes River water temperature relative to the State of Oregon 18°C (64°F) standard as of 2014?

   July temperatures downstream of Bend exceeded the 18°C state standard set to protect salmon and trout rearing and migration at all four monitoring locations downstream of North Canal Dam, confirming the temperature impaired status of the middle Deschutes River under Clean Water Act Section 303(d). Temperatures at the most impaired site, Lower Bridge Road, exceeded 18°C for 90 days between June and September 21, and were above the 24°C lethal threshold for four days. Temperatures exceeded 18°C along 31 miles of the middle Deschutes River, between North Canal Dam and Lower Bridge Road, for 34 days in 2014. These data represent an improvement over 2013 conditions but remain some of the most extreme temperatures, and worst flow conditions, observed since 2007. Although stream flow restoration has resulted in far better flow conditions in the middle Deschutes River than occurred previously, 2014 middle Deschutes River protected flows were lower than from 2010-2012 and the July median flow at North Canal Dam was barely higher than protected flows; July flows in Tumalo Creek surpassed the protected flow although the July median flow was below what is protected.

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

Comparison of flows protected to flows observed and regression of July 7DMAX temperatures for all associated observed flows provide support for increased stream flow secured through stream flow restoration reducing temperatures in the middle Deschutes River. July median flows in the Deschutes River have increased alongside median protected flows; although Tumalo Creek July median observed flows have inconsistently met July median protected flows, observed flows have been consistently higher than during early years of restoration efforts. July 7DMAX temperatures in both the Deschutes River and in Tumalo Creek above the confluence describe an inverse relationship, decreasing from highest at the lowest flows to lowest at the highest flows. Comparison of 7DMAX temperatures at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded from 2002 to 2014 show that increased flows produced moderately (in the Deschutes River) to substantially (in Tumalo Creek) lower temperatures. Together, these data provide support for higher protected flows guaranteeing higher baseflows and lower stream temperatures.

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

   We used temperature estimates calculated from regression of temperature-flow data in a mass balance equation to develop flow scenarios for the Deschutes River and Tumalo Creek that would achieve an average 7DMAX temperature of 18°C in the Deschutes below the confluence with Tumalo Creek. Mass balance equation results suggest 23 cfs are required from Tumalo Creek to achieve an average 7DMAX temperature of 18°C in the Deschutes River immediately downstream of the confluence with Tumalo Creek at the Deschutes River flow target of 250 cfs. At the July 2014 median Deschutes River flow of 134 cfs, 116 cfs lower than 250 cfs, an increase of only 20 more cfs of Tumalo Creek flow, to 43 cfs, results in the same temperature reduction. It is worth noting that this Tumalo Creek flow is only eleven cfs above the 32 cfs state water right. Increasing Tumalo Creek flow to 62 cfs, approximately the 80% exceedence surface water availability during July[1], is predicted to reduce the average 7DMAX temperature in the Deschutes River below the confluence with Tumalo Creek by an additional 0.7°C, to 17.3°C, at Deschutes River flows between 130 and 239 cfs. Especially in light of the current status of protected flows, 128 cfs in the Deschutes and 21.7 cfs in Tumalo, these results suggest that achieving the desired reductions in stream temperature in the middle Deschutes River may be accelerated by strategically prioritizing Tumalo Creek water transactions; preferentially increasing flows in Tumalo Creek over restoring stream flow in the Deschutes River may achieve the greatest temperature benefit at the lowest cost.

Increasing stream flow to approach the state water right and instream flow targets in the Deschutes River and in Tumalo Creek will confer habitat benefits beyond improving temperature conditions, by increasing stream width and depth and thereby habitat availability and diversity. Whereas temperature

[1] calculated as the 80% exceedence surface water availability during July (72 cfs) minus the average City of Bend net water withdrawal (10 cfs; DRC, unpublished data)

requirements for native trout are well-documented and encoded in state water quality standards, specific requirements for habitat functions of the hydrograph in the middle Deschutes River have not been well described. Data on trout distribution and use of habitat including margin and edge habitats, to be collected by the Oregon Department of Fish and Wildlife (ODFW) through 2016, will improve our understanding of habitat functions of flow beyond temperature and contribute to the ability of restoration partners to refine stream flow targets accordingly to maximize ecological benefits. Restoration approaches that prioritize increasing Tumalo Creek flows to achieve temperature reductions should take into account potential strategic long-term trade-offs of deferring greater gains in stream flow volume, and corresponding habitat benefits, in favor of achieving lower temperatures at lower flows.

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 and the Oregon Department of Environmental Quality (ODEQ) 319 Grant Program. 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 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
7DMAX	Seven Day Moving Average 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 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 is listed 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.

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 successfully protected approximately 124 cubic feet per second (cfs) of stream flow instream in the Middle Deschutes River and more than 17 cfs in Tumalo Creek. Bolstered by higher base flows resulting from stream flow restoration, July median average daily stream flow entering the Deschutes River from Tumalo Creek has increased from 5 cfs in 2001 to 19 cfs in 2014, and July median average daily flow in the Deschutes River at North Canal Dam has increased from 48 cfs in 2001 to 134 cfs in 2014. Combined, stream flow restoration efforts at each of these locations have contributed to an increase in middle Deschutes River July median average daily flows that in 2014 amounted to almost 100 cfs, from 53 cfs in 2001 to 152 cfs in 2014. Because flows downstream of North Canal Dam have historically resulted 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 because downstream temperatures are driven by stream flow and temperature in these two reaches, DRC has prioritized stream flow restoration in these reaches. DRC stream flow restoration efforts aim to meet the State of Oregon instream flow targets of 250 cfs in the Middle Deschutes from North Canal Dam (RM 165) to Round Butte Reservoir (RM 119), and 32 cfs in Tumalo Creek from the South Fork of Tumalo Creek 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, the DRC increasingly aims to restore streamflow preferentially in Tumalo Creek to maximize temperature reductions in the Middle Deschutes.

Prior analyses of water temperature in the Middle Deschutes and Tumalo Creek (UDWC 2014) have suggested that the relative contribution of flows from the two waterways substantially influences the effects of increased flow on temperature downstream of the confluence. Middle Deschutes water flowing over North Canal Dam is consistently at or above 18°C in July (ODEQ, 2004; UDWC 2006; UDWC unpublished data). Tumalo Creek, approximately five miles downstream of the dam, is the only tributary and source of additional flow between North Canal Dam and Lower Bridge Road, approximately 31 miles downstream, where temperatures are historically highest and conditions worst for fish. Increasing the total volume of flow between North Canal Dam and Lower Bridge Road is anticipated to lower the rate of warming in this reach, making some contribution to reducing temperatures downstream. However, because increasing flow that is already at or around 18°C at North Canal Dam will not create an active cooling effect, restoration that increases flow downstream from North Canal Dam is likely to be minimally effective in achieving the necessary temperature reductions to result in that same 18°C temperature 31 miles downstream. While the temperature of flows entering the Deschutes from Tumalo Creek varies with volume, Tumalo Creek flows are typically substantially cooler than flows in the Deschutes above the confluence (UDWC 2006). Increasing flows in Tumalo Creek may therefore represent an opportunity to achieve the greatest cooling effect in the Middle Deschutes 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 projects. 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 temperature and flow data from 2001 through 2014 to address the following questions: 1) What was the status of Middle Deschutes River water temperatures relative to the State of Oregon 18°C/64°F standard in 2014; 2) Have cumulative increases in stream flow resulted in reduced water temperatures at key locations along the Middle Deschutes; and 3) 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 2014 temperature results and discuss implications for stream flow restoration.

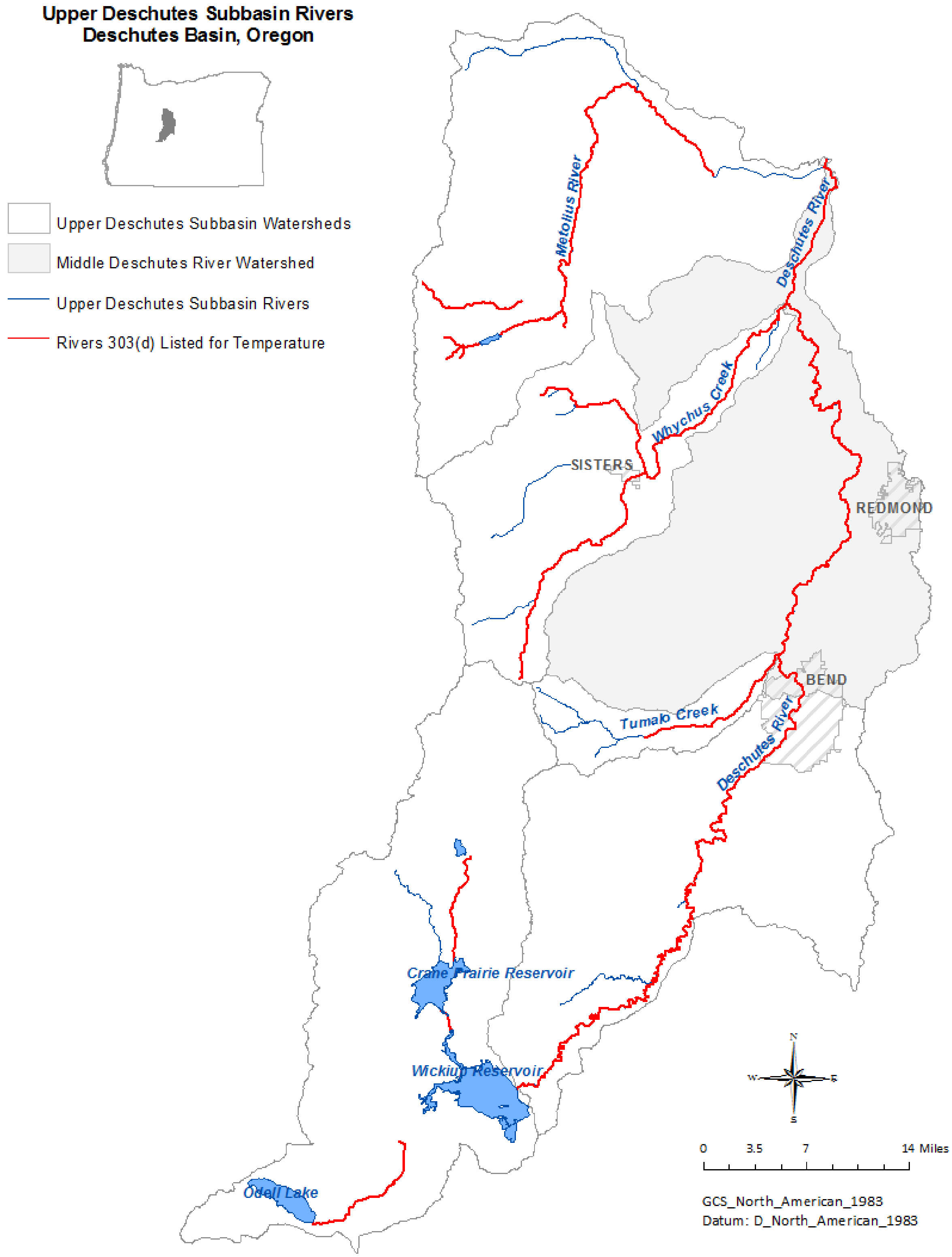


Figure 1. The Upper Deschutes Subbasin and Middle Deschutes River Watershed.
Extensive reaches of most Upper Deschutes Subbasin rivers are 303(d) listed as exceeding state temperature standards for salmon and trout rearing and migration (ODEQ 2012).

2 Methods

2.1 Data Collection

2.1.1 Water Temperature

UDWC collected and compiled continuous water temperature data for 2001-2014 from six water temperature monitoring stations on the Deschutes River and one monitoring station on Tumalo Creek (Table 1; Figure 2). 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). All temperature data used in analyses were collected by ODEQ, the City of Bend, and UDWC. UDWC operates per the *Water Quality Monitoring Program Standard Operating Procedures* (UDWC 2008a) under a State of Oregon approved Quality Assurance Project Plan (UDWC 2008b).

2.1.2 Average Daily Flow

UDWC obtained average daily stream flow (QD) data for the Deschutes River and Tumalo Creek from the Oregon Water Resources Department (OWRD 2014) (Table 1; Figure 2). In the absence of an active gage station on the Deschutes River downstream of Tumalo Creek, stream flows recorded at OWRD gage #14070500, Deschutes River below Bend, and at OWRD gage #14073520, Tumalo Irrigation District Feed Canal, are combined to approximate the stream flow below the confluence of the Deschutes River and Tumalo Creek. 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 flow data from October 1, 2012 to the present, and Tumalo flow data from October 2008 through September 2009 and from October 2011 to the present are considered provisional and subject to change.

2.1.3 Median Protected Flow

We obtained July median daily instream water rights data for the Deschutes River and for Tumalo Creek from Deschutes River Conservancy. Reductions in July median daily instream water rights between years reflect water leases in previous years which were not renewed in subsequent years. 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 2001-2014.

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

Station ID	Waterway	Description	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
DR 217.25	Deschutes River	Pringle Falls		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
DR 164.75	Deschutes River	u/s Riverhouse Hotel				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
DR 160.00	Deschutes River	d/s Tumalo Boulder Field					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
TC 000.25	Tumalo Creek	u/s of Tumalo Creek mouth				X	X	-	X		X	X	X	X	X	X
X	Data available for analysis															
-	Limited data available for analyses															

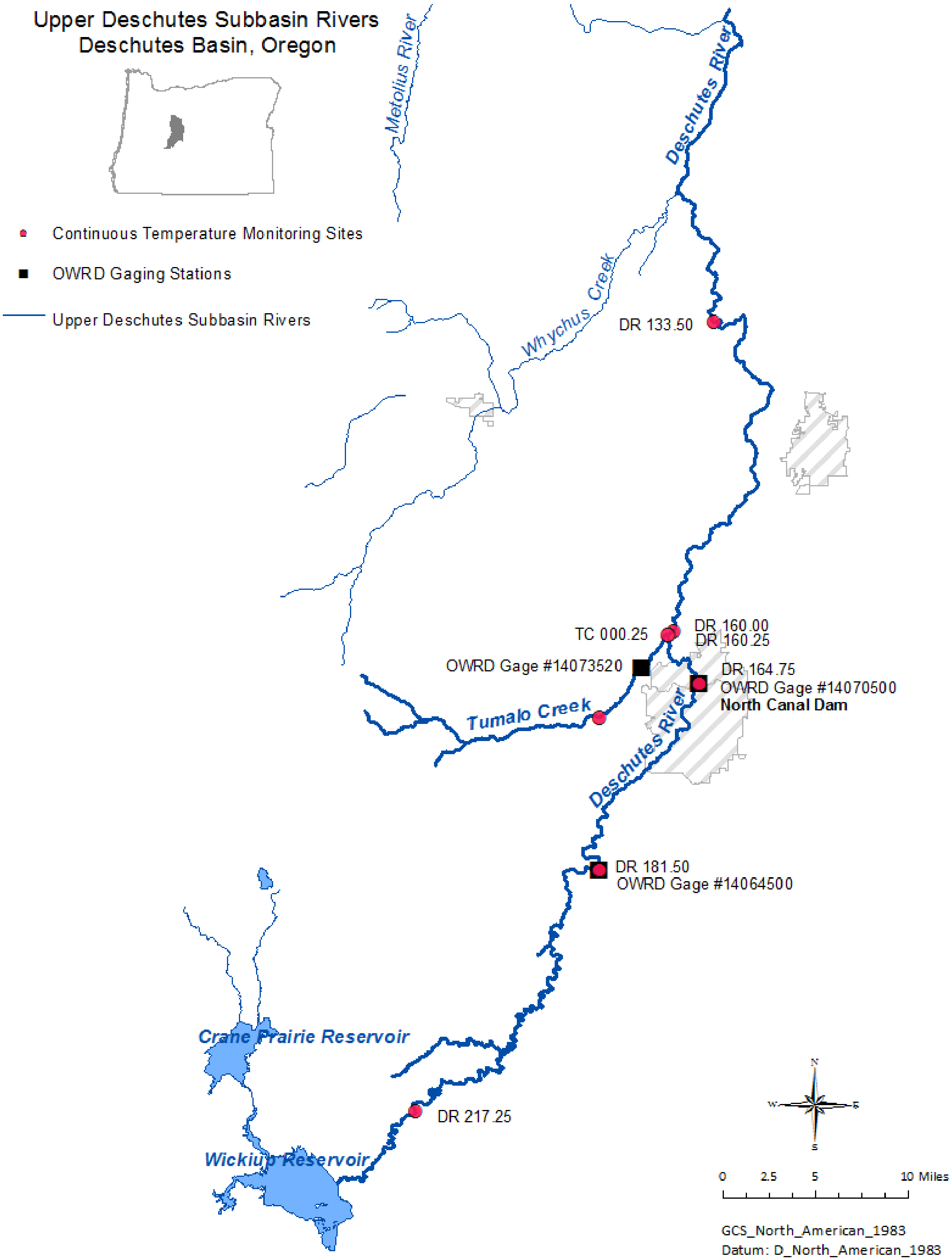


Figure 2. UDWC continuous temperature monitoring sites and OWRD stream flow gages on the Middle and Upper Deschutes.

2.2 Data Analysis

2.2.1 Temperature Status

We used the Oregon Department of Environmental Quality (ODEQ) Hydrostat Simple spreadsheet (ODEQ, 2010) to calculate the seven day moving average maximum (7DMAX) temperature, the same statistic used by the State of Oregon to evaluate stream temperatures. The current State of Oregon water temperature standard for salmon and trout rearing and migration identifies a 7DMAX threshold of 18°C/64°F (OAR 340-041-0028). We evaluated July 7DMAX temperatures from 2001-2014 in relation to the state standard of 18°C to describe changes in temperature in the Middle Deschutes since 2001 and to assess progress toward the 18°C state standard for salmonid rearing and migration. We evaluated July temperature data from DR 160.00, downstream of the confluence of the Deschutes and Tumalo Creek, in relation to the July median average daily flow in the Deschutes below North Canal Dam, Tumalo Creek below the Tumalo Feed Canal, and the July median of combined flows from these two sources. To illustrate temperature status at Lower Bridge Road (DR 133.50) we present data for August in addition to July because more data are available for August for the years of interest. Both July and August data represent summer conditions characterized by high temperatures and low flows.

2.2.2 Restoration Effectiveness and Target Stream flow

We compared July median daily protected flow to July median average daily flow to evaluate the relationship between observed and protected stream flow. We used regressions of temperature and stream flow data to 1) evaluate the effectiveness of increasing flows through stream flow restoration to reduce stream temperature in the Middle Deschutes River and in Tumalo Creek, and 2) to develop flow scenarios for the Middle Deschutes and Tumalo that will achieve the 18°C state standard temperature in the Deschutes below the confluence with Tumalo Creek. To show reductions in temperature at increasing flow rates and to estimate corresponding temperature and flow values we used temperature data from the Deschutes River above Tumalo Creek (DR 160.25) and corresponding flow data from OWRD gage #14070500, Deschutes River Below Bend, and temperature data from the mouth of Tumalo Creek (TC 000.25) with flow data from OWRD gage #14073520, Tumalo Creek Below Tumalo Feed Canal. The two 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 they also most accurately represent the temperature-flow relationships that directly affect stream temperature downstream of the confluence. Because no tributaries or springs enter the Deschutes between Tumalo Creek and Lower Bridge Road, the relative flow contributions of the Deschutes and Tumalo Creek at the two upstream sites directly influence stream temperature 26.5 miles downstream at Lower Bridge Road (DR 133.50), where temperature conditions are historically the worst on the Middle Deschutes.

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 therefore the month during which stream temperature requires the greatest mitigation and when increased stream flow will most improve stream conditions (UDWC unpublished data). We used the seven day moving average maximum temperature (7DMAX), the statistic used by DEQ to determine the status of a waterway in relation to the state water quality standard. For DR 160.25 upstream of Tumalo Creek, we analyzed July 7DMAX temperature and average daily flow data from 2002-2014, with the exception of 2006 for which temperature data were unavailable; for TC 000.25 at the mouth of Tumalo Creek we analyzed July temperature and flow data for 2004-2014 with the exception of 2008, for which temperature data were also not available.

We paired 7DMAX temperature with the corresponding natural logarithm of the average daily flow (LnQD) for each day included in the analysis. The seven day moving average maximum temperature for a given day is the average of the maximum temperature for that day, the three days prior, and the three days following; we paired the 7DMAX for a given day with the flow for the same day to best match the 7DMAX temperature to flow conditions on both the first and seventh days represented by the 7DMAX temperature. While this approach does not reflect flows corresponding to maximum daily temperatures on the fifth, sixth, or seventh days included in the 7DMAX temperature, we selected the flow corresponding to the 7DMAX for the same date as potentially more representative of the flow on both the first and seventh days included in the 7DMAX than if we used the flow from the seventh day to correspond to the 7DMAX temperature and thereby to represent the flow corresponding to the temperature from the first day of the 7DMAX. We calculated the natural log to hundredths to retain the precision of average daily flow data.

We regressed 7DMAX temperature on the natural log of the average daily flow for two permutations of the data and compared regression models to select the analysis that provided the most accurate fit to the data for the purpose of identifying at what flow stream temperature will meet or be below 18°C. We compared temperatures, prediction intervals, standard error (S) and R^2 values calculated from: 1) all 7DMAX temperature-flow pairs; and 2) all mean 7DMAX temperature-flow pairs representing the average of all temperatures observed at a given flow for all flows for which there was at least one temperature record. Using all 7DMAX temperature-flow pairs resulted in calculated temperatures within half a degree of temperatures calculated from the regression of all mean 7DMAX temperature-flow pairs (for relevant flows), with prediction intervals at most 0.3°C different than those calculated from all mean 7DMAX temperature-flow pairs. Because differences between regression models and calculated temperatures and prediction intervals for the two datasets were within the accuracy of the temperature data (0.5°C), we used all 7DMAX temperature-flow pairs for analysis.

We used ANOVA and Akaike Information Criterion (AIC) values in R open source statistical software to determine the highest polynomial term that statistically improved the regression model (linear, quadratic, or cubic) on the basis of the p-value (ANOVA) associated with, and numeric difference between (AIC), each model. We used a normal distribution plot to evaluate the normality of the residuals of the selected model. Using the resulting regression equation for each location, 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 $1\text{-}\alpha/2^{th}$ percentile of a T distribution with n-2 degrees of freedom.

For DR 160.25 data, no polynomial model was statistically better than the linear model. For TC 000.25 data, the quadratic and cubic models were each statistically better than the lower-order model.

To calculate Deschutes River temperatures downstream of the confluence with Tumalo Creek under a variety of flow scenarios we used the temperatures and given flows from the Deschutes River (DR 160.25) and Tumalo Creek (TC 000.25) temperature-flow regression equations in a mass balance equation. We used the following mass balance equation solved for T_{D2}:

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

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

Where:

Q = average daily flow
T = 7DMAX temperature
$_T$ = Tumulo Creek (TC 000.25)
$_D$ = Deschutes River (DR 160.25)
$_{D2}$ = Deschutes River (DR 160.00)

We calculated temperatures for all Tumalo Creek flows between 10 and 100 cfs at Deschutes River flows of 134, 160, 180, 200, 232, and 250. Ten cfs approximates the median flow currently protected instream in Tumalo Creek during July; 100 cfs exceeds average natural July flows and is well above the ODFW instream water right of 32 cfs. 134 cfs was the July median instream flow at North Canal Dam in 2014; 232 is the maximum flow needed at North Canal Dam to meet the combined State of Oregon instream water rights from the Deschutes River and Tumalo Creek if Tumalo Creek flows were restored to meet 50 cfs.

We compared temperatures calculated from temperature-flow regressions 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 Temperature Status

Seven-day moving average maximum (7DMAX) temperatures exceeded the 18˚C state standard for steelhead and salmon rearing and migration at four monitoring locations in 2014 by up to 6°C (Figure 3), supporting the existing State of Oregon Section 303(d) listing of the middle Deschutes River for temperature impairment. Temperatures upstream of Bend and all major irrigation diversions, at DR 217.25 and DR 181.50, remained below 18°C during July, the month during which the hottest water temperatures have historically been recorded. Temperatures at these sites have exceeded 18°C in some years (2002, 2004, 2005, 2009) but typically remain below 18°C. Temperatures at all four monitoring sites downstream of North Canal Dam and below major irrigation diversions exceeded the state standard in 2014 and in every other year for which data are available for analysis.

Temperatures at DR 160.00, downstream of the confluence with Tumalo Creek, exceeded 18°C for 44 days in 2014, from July 2 to August 11 and August 18 to 20, at flows of 140-250 cfs (123-227 cfs from the Deschutes and 12-73 cfs from Tumalo Creek).

Despite substantial reductions in temperature observed since 2001, mean 7DMAX temperatures at Lower Bridge Road (DR 133.50) remained well above the 18°C standard in 2014 (Figure 4), exceeding this criterion for 90 days between June 1 and September 21 at flows between 117 and 262 cfs (100-227 cfs from the Deschutes and 11-136 cfs in Tumalo Creek). Temperatures at Lower Bridge Road were above the 24°C lethal threshold for fish for four days in 2014 at total flows of 145-154 cfs.

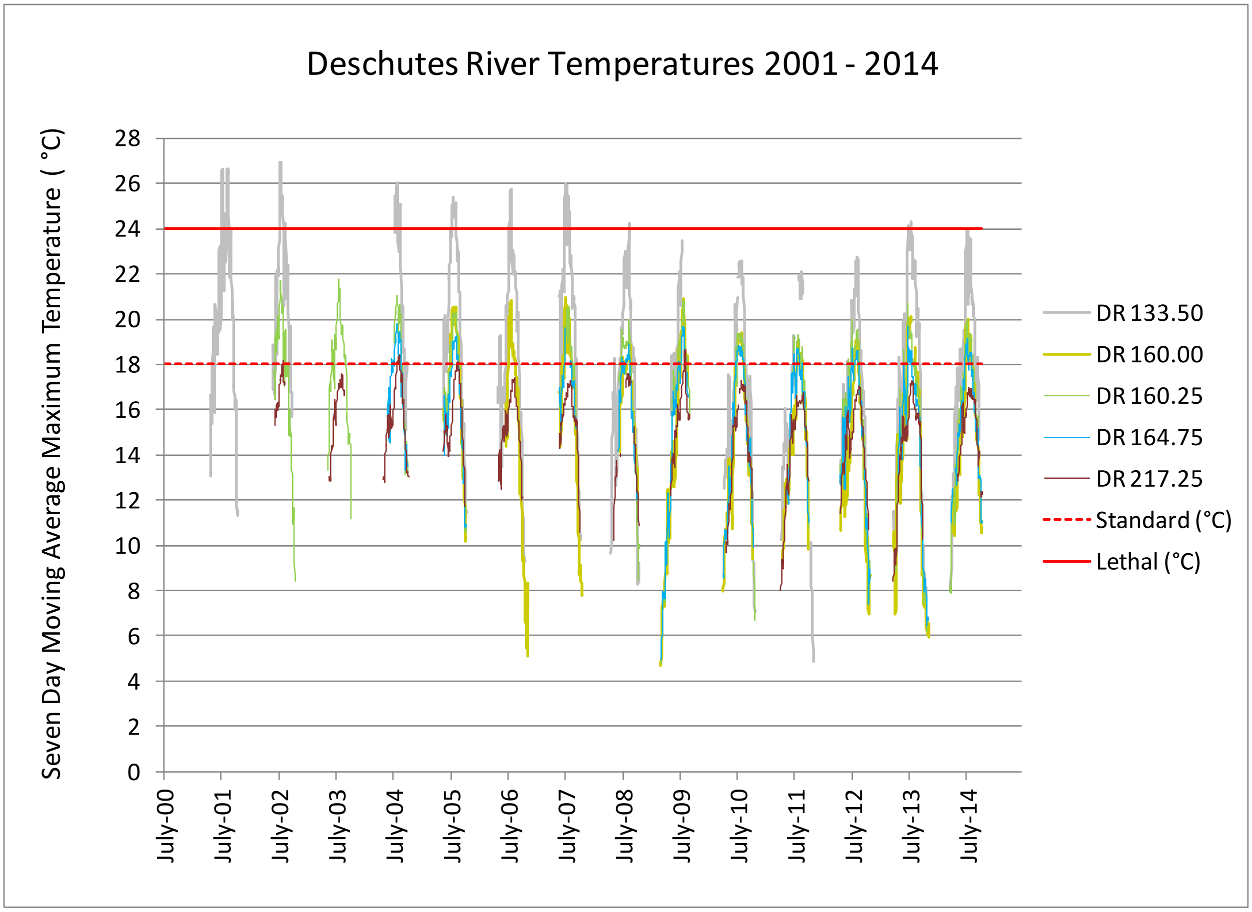
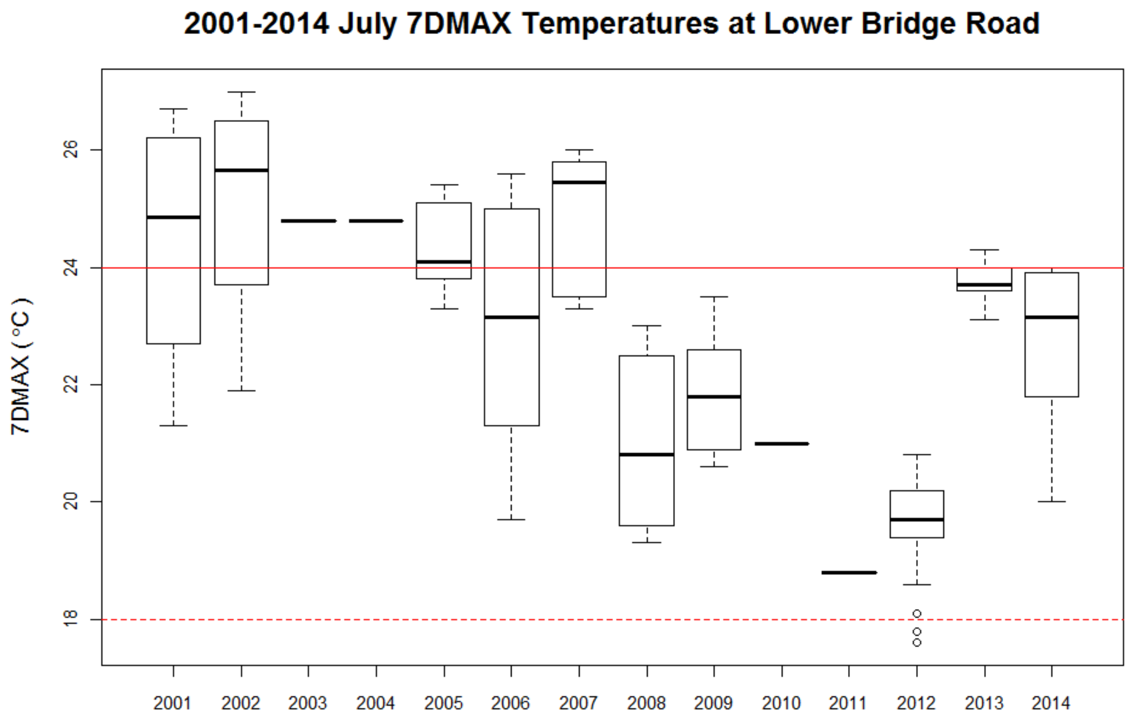


Figure 3. Deschutes River Temperatures 2001-2014

Temperatures regularly exceeded the State of Oregon temperature standard (dashed red line) at four monitoring locations along the Deschutes River from DR 133.50 to DR 164.75 between 2001 and 2014 and exceeded the temperature standard in two additional upstream locations, DR 181.50 and DR 217.25 in some years. Temperatures at DR 133.50 exceeded the lethal limit (solid red line) for four days in 2014.

a



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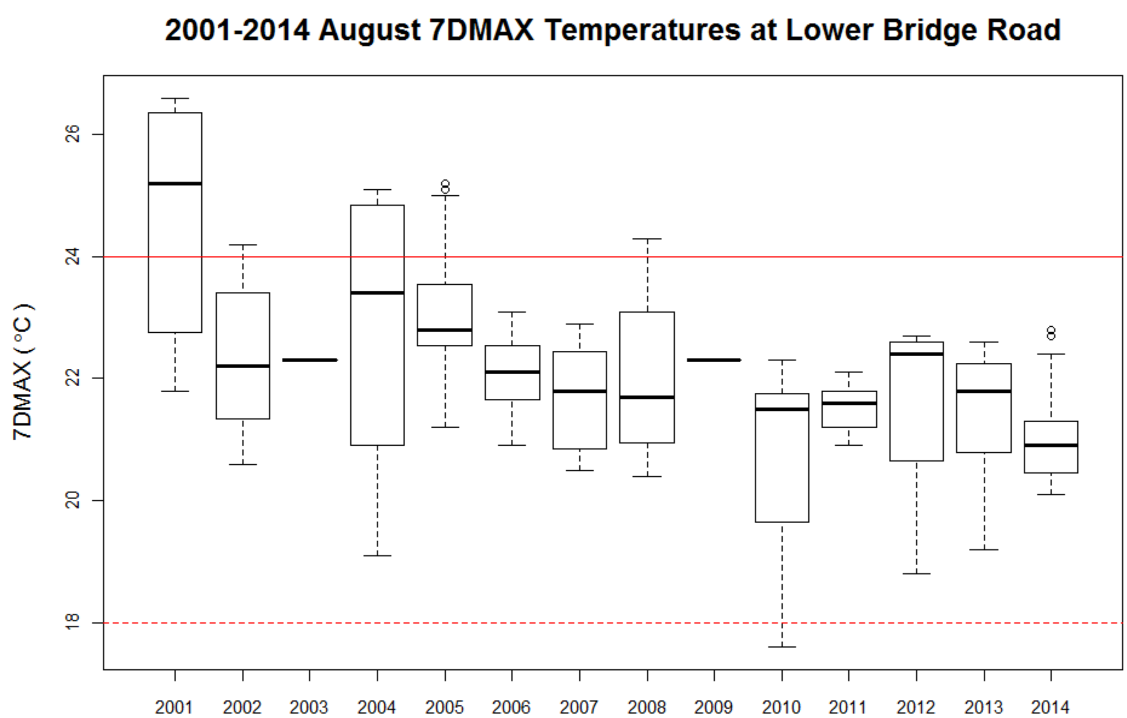
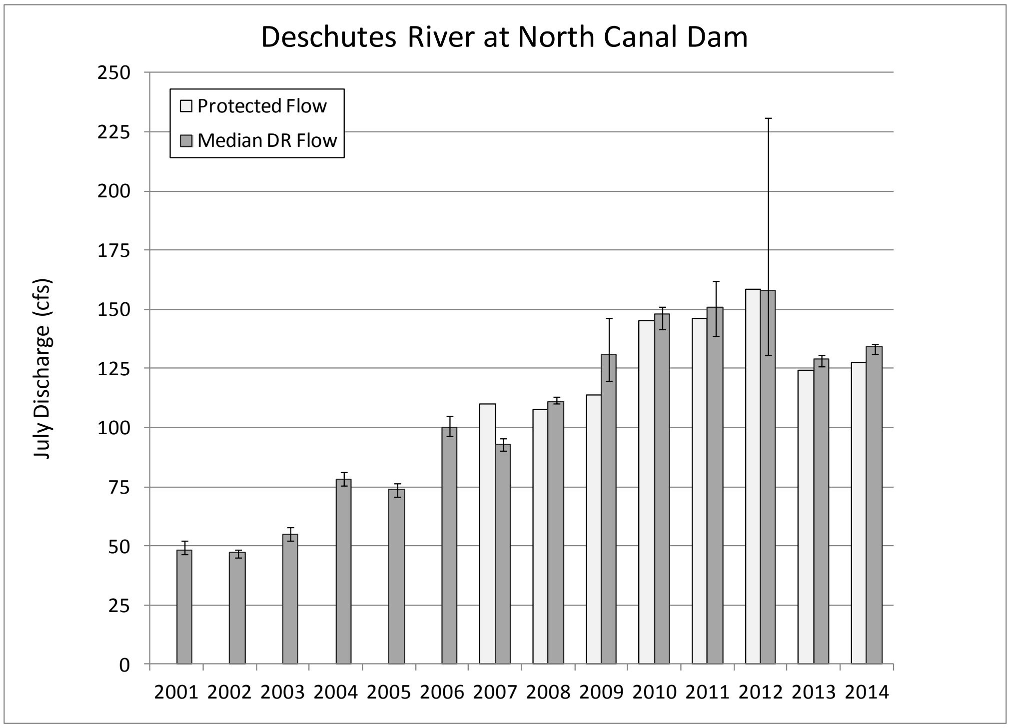


Figure 4. 2001-2014 July and August 7DMAX Temperatures at Lower Bridge Road
A) July 1-22 and b) August 6-28 mean 7DMAX temperatures at Lower Bridge Rd (DR 133.50), the most impaired site for which temperature data are available, chart a declining trend since 2001. Data for this location is missing for July 2003, 2004, 2010 and 2011 and for August 2003 and 2009. Despite reductions of approximately 3-4°C between 2001 and 2014, temperatures at Lower Bridge Road remain well above the 18°C standard (dashed red line) throughout July and August. July temperatures exceeded the lethal limit (solid red line) in 2014.

3.2 Stream flow Restoration Effectiveness

2001-2014 July median flow track July median protected flow (Figure 6), and mean temperatures chart a declining trend from the lowest to highest flows for which temperature data are available (Figure 7), substantiating the role of increasing stream flow through stream flow restoration in reducing temperatures in the Middle Deschutes River and in Tumalo Creek. Streamflow restoration efforts in the Middle Deschutes began in 2001; data documenting flows protected instream for the Middle Deschutes and Tumalo Creek are available from 2007 to 2014. Although stream flow restoration data (flows protected instream) are not available from 2001-2006, July median flow in the Deschutes at North Canal Dam increased steadily over this interval, from 48 to 100 cfs. From 2007 to 2012, flows protected in the Deschutes at the same location increased from 110 to 158, dropping off in 2013 (124 cfs) and creeping up in 2014 (128 cfs), while flows protected in Tumalo Creek increased from 17 to 22 cfs. Increases in median protected flow from 2007 to 2014 correspond to increased July flows in both waterways (Figure 5). July median flows in the Deschutes closely track median protected flows; July median protected flows in Tumalo Creek have been inconsistently met in some years and in others median flows far exceed protected flows.

Regressions of mean July 7DMAX temperatures and corresponding flow values from 2001-2014 at DR 160.25 and at TC 000.25 show temperatures decreasing as flows increase (Figure 6). 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. Annual flow ranges for which temperature data are available and which are included in regressions increased from a low of 41-51 cfs over the course of 2002 to a high of 100-327 cfs over the course of 2011 in the Deschutes at North Canal Dam, from 3.3-37 cfs in 2004 to 11-177 cfs in 2008 in Tumalo Creek, and from 46.4-62 cfs in 2002 to 134-447 cfs in 2011 downstream of the confluence. 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 at increasing flows. A flow rate of 41 (3.7 LnQD) from the Deschutes River at North Canal Dam resulted in a predicted 7DMAX temperature of 20.8°C ±1.4°C (upper interval = 22.3°C) at DR 160.25, approximately five miles downstream; flows between 308 and 327 cfs resulted in a mean temperature 3°C lower, at 17.8°C±1.4°C (upper interval = 19.3°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: 3.3 cfs (1.3 LnQD) resulted in a mean temperature of 20.8°C±2.9°C (upper interval = 23.7°C), with flows of 157 and 158 cfs (5 LnQD) resulting in a mean temperature of 10.8°C±2.9°C (upper interval=13.7°C), a temperature reduction of 10°C.



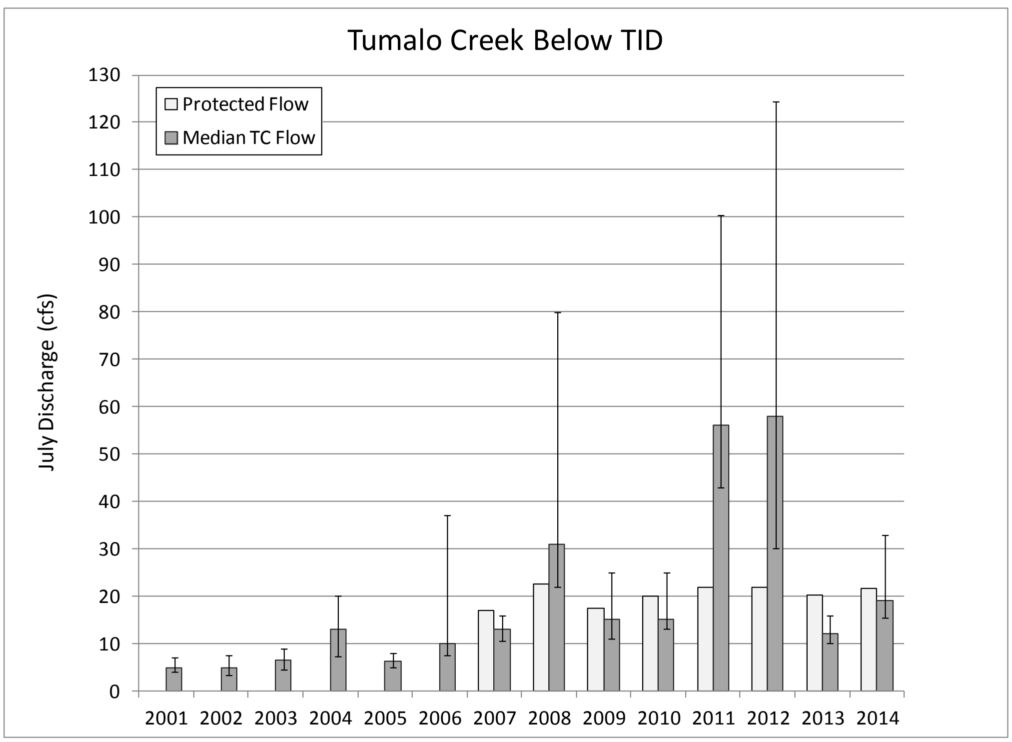
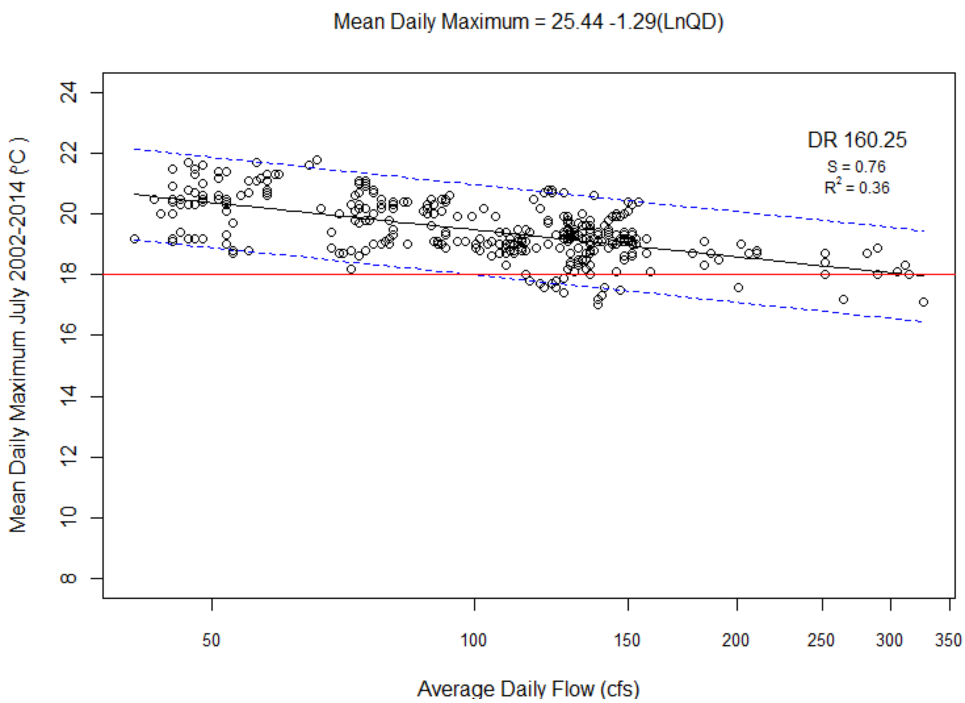


Figure 5. Deschutes River and Tumalo Creek Protected Flow and July Median Flow, 2001-2014.
July median flows steadily increased from 2001 to 2012, corresponding to increases in flow protected instream. 2013 marked a drop in July median flow from 2012 levels. Flows protected instream also fell from 2012 to 2013, reflecting reductions in flow leased instream and flow left instream according to a gentlemen's agreement with the districts. Data for flows protected instream are not available prior to 2007.

a



b

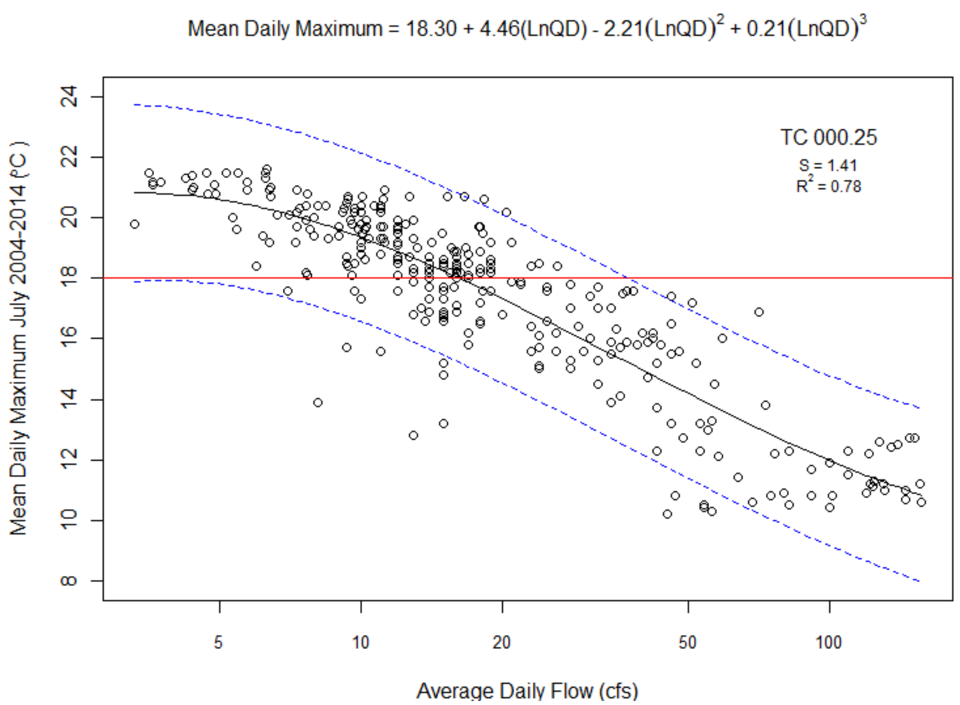


Figure 6. Temperature-Flow Regression Models
Regression models fitted to temperature-flow data demonstrate reduced temperatures at higher flows and describe the relationship between temperature and flow observed a) during July 2002-2014 at DR 160.25, the Deschutes River upstream of the confluence with Tumalo Creek, and b) during July 2004-2014 at TC 000.25, Tumalo Creek upstream of the mouth.

3.3 Target Stream flow

Regression equations for trendlines fitted to July temperature and stream flow data from the middle Deschutes River upstream of the confluence with Tumalo Creek (DR 160.25) and from Tumalo Creek at the mouth (TC 000.25) describe the relationship between flow levels and the average 7DMAX temperature observed at each level (Figure 6). Temperature records were available from DR 160.25 for Deschutes River flows between 41 and 327cfs, and from TC 000.25 for Tumalo Creek flows between 3.3 and 158 cfs. A linear regression trendline and equation provided the best fit to DR 160.25 temperature and flow data; a cubic (3rd order polynomial) regression trendline and equation best described TC 000.25 data. We used the resulting equations to calculate predicted temperatures for these flow ranges (Appendix A).

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 250 cfs in the Deschutes below North Canal Dam, the ODFW instream water right for the Deschutes below Bend, 23 cfs from Tumalo Creek resulted in 18°C at DR 160.00. At 134 cfs in the Deschutes below North Canal Dam, the July 2014 median flow, 18°C was estimated to occur at DR 160.00 when Tumalo flows were 43 cfs; a 20 cfs difference in Tumalo flow achieved the same temperature outcome, meeting the 18°C standard, as did a 116 cfs difference in Deschutes flow from North Canal Dam. The Tumalo Creek ODFW instream water right of 32 cfs resulted in an estimated 18°C at Deschutes River flows between 220 and 234 cfs.

Estimated temperature gains were magnified as Tumalo flows increased to approximately 70 cfs. Above 70 cfs in Tumalo, increases in Deschutes flows resulted in equivalent or increased temperatures, such that increasing flows in the Deschutes required commensurate increases in Tumalo flows. For example, at 70 cfs in Tumalo, Deschutes flows of 134 cfs or 250 cfs resulted in an estimated temperature of 17.0°C; at 80 cfs in Tumalo, Deschutes flows of 134 cfs resulted in 16.7 degrees, while obtaining the same temperature at 250 cfs in the Deschutes required 84 cfs in Tumalo.

Heat Source model estimates are available for 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 (HeatSource rkm 72.4) is 17.4°C, a half degree lower than the mass balance temperature estimate of 17.9°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 (HeatSource rkm 72.8), above the confluence with Tumalo, was 17.2°C, a full degree lower than the 18.2°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, identical to the temperature calculated from the regression equation for that flow and site.

4 Discussion

4.1 Temperature Status

Temperatures exceeded the state temperature standard of 18°C at four monitoring locations between DR 164.75 and DR 133.50 in 2014, confirming the temperature impaired status of the middle Deschutes River under Clean Water Act Section 303(d). Temperatures at the most impaired site, Lower Bridge Road, exceeded 18°C for 90 days between June 1 and September 21, and were above the 24°C lethal threshold for four days. Temperatures exceeded the 18°C standard for 34 days at all four Deschutes River monitoring sites between North Canal Dam and Lower Bridge Road, including the only site where there is potential for cooling, at DR 160.00, below the confluence with Tumalo Creek. The absence of any other cold water inputs in the reach suggests that temperatures along the entire 31 mile reach were above 18°C throughout those 34 days. These data represent an improvement over 2013 conditions but remain some of the most extreme temperatures, and worst flow conditions, observed since 2007. Although stream flow restoration has resulted in far better flow conditions in the Deschutes than occurred previously, 2014 Deschutes protected flows were lower than from 2010-2012 and the July median flow at North Canal Dam was barely higher than protected flows; July flows in Tumalo Creek surpassed the protected flow although the July median flow was below what is protected.

4.2 Restoration Effectiveness

Regression of mean 7DMAX temperatures for all associated observed flows provides empirical evidence for increased stream flow secured through stream flow restoration reducing temperatures in the Middle Deschutes River. In years for which data are available documenting flows protected instream, July median flows correspond to protected flows, particularly in the Deschutes. Temperatures describe an inverse relationship, decreasing from highest at the lowest flows to lowest at the highest flows. Comparison of July median flow protected instream and recorded July median flow suggests that flows protected instream have resulted in higher July median and minimum flows. Comparison of 7DMAX temperatures at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded from 2002 to 2014 show that increased flows produced substantially lower temperatures. Together, these data provide support for higher protected flows guaranteeing higher baseflows and lower stream temperatures.

4.3 Target Stream flow

Mass balance equation results suggest that the Deschutes River state instream water right of 250 cfs will achieve the 18°C standard immediately downstream of the confluence with Tumalo Creek at 23 cfs in Tumalo Creek. Alternatively, the Tumalo Creek state instream water right of 32 cfs will achieve the 18°C standard in the Deschutes downstream of the confluence at Deschutes River flows of 223-239 cfs. At the July median Deschutes flow of 134 cfs, as little as 43 cfs are predicted to be required in Tumalo Creek to meet the 18°C state standard. Increasing Tumalo Creek flows to 62 cfs, the 80% exceedance surface water availability in July given current City of Bend diversions, is estimated to reduce stream temperature in the Deschutes below the confluence to 17.3°C and allow in part for downstream warming between the confluence and Lower Bridge (DR 133.50). In light of the current status of protected flows, 128 cfs in the Deschutes and 21.7 cfs in Tumalo, these results suggest that achieving the desired reductions in stream temperature in the Middle Deschutes may be 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.

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 and Deschutes flows to achieve the greatest possible temperature reduction, the lowest temperatures achievable at DR 160.00 will likely 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). While direct comparison is difficult because of how river miles/kilometers are measured in the two analyses, the Heat Source model for the Deschutes suggests that at instream water right (ODFW) flows for both the Deschutes and for Tumalo, 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). Although higher flows will have some effect in reducing the rate of warming, mass balance equation and Heat Source model results suggest that current instream water right flows for the Middle Deschutes and for Tumalo may be insufficient to meet the state temperature standard in some reaches of the Middle Deschutes between Tumalo Creek and Whychus Creek while Deschutes River water continues to be heated in Wickiup and Crane Prairie reservoirs prior to being released downstream.

Whether or not it is possible to meet the state temperature standard along every mile of the Middle Deschutes between North Canal Dam and Lower Bridge Road given current reservoir operations, increases in flow that approach or exceed the instream water right in the Deschutes River, and increases that approach or meet the DRC flow target in Tumalo Creek, may nonetheless confer substantial ecological benefits. 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 are less well understood. Data on trout distribution and use of habitat including margin and edge habitats, to be collected by ODFW through 2016, will improve our understanding of habitat functions of flow beyond temperature and contribute to the ability of restoration partners to refine stream flow targets accordingly to maximize ecological benefits. Restoration approaches that prioritize increasing Tumalo Creek flows to achieve temperature reductions should take into account potential long-term trade-offs of deferring greater gains in stream flow volume, and corresponding habitat benefits, in favor of achieving lower temperatures at lower flows.

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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	20.6	1.5	**94**	19.6	1.5	**147**	19.0	1.5	**200**	18.6	1.5
42	20.6	1.5	**95**	19.5	1.5	**148**	19.0	1.5	**201**	18.6	1.5
43	20.6	1.5	**96**	19.5	1.5	**149**	19.0	1.5	**202**	18.6	1.5
44	20.5	1.5	**97**	19.5	1.5	**150**	19.0	1.5	**203**	18.6	1.5
45	20.5	1.5	**98**	19.5	1.5	**151**	18.9	1.5	**204**	18.6	1.5
46	20.5	1.5	**99**	19.5	1.5	**152**	18.9	1.5	**205**	18.6	1.5
47	20.5	1.5	**100**	19.5	1.5	**153**	18.9	1.5	**206**	18.5	1.5
48	20.4	1.5	**101**	19.5	1.5	**154**	18.9	1.5	**207**	18.5	1.5
49	20.4	1.5	**102**	19.5	1.5	**155**	18.9	1.5	**208**	18.5	1.5
50	20.4	1.5	**103**	19.4	1.5	**156**	18.9	1.5	**209**	18.5	1.5
51	20.4	1.5	**104**	19.4	1.5	**157**	18.9	1.5	**210**	18.5	1.5
52	20.3	1.5	**105**	19.4	1.5	**158**	18.9	1.5	**211**	18.5	1.5
53	20.3	1.5	**106**	19.4	1.5	**159**	18.9	1.5	**212**	18.5	1.5
54	20.3	1.5	**107**	19.4	1.5	**160**	18.9	1.5	**213**	18.5	1.5
55	20.3	1.5	**108**	19.4	1.5	**161**	18.9	1.5	**214**	18.5	1.5
56	20.2	1.5	**109**	19.4	1.5	**162**	18.9	1.5	**215**	18.5	1.5
57	20.2	1.5	**110**	19.4	1.5	**163**	18.9	1.5	**216**	18.5	1.5
58	20.2	1.5	**111**	19.3	1.5	**164**	18.8	1.5	**217**	18.5	1.5
59	20.2	1.5	**112**	19.3	1.5	**165**	18.8	1.5	**218**	18.5	1.5
60	20.1	1.5	**113**	19.3	1.5	**166**	18.8	1.5	**219**	18.5	1.5
61	20.1	1.5	**114**	19.3	1.5	**167**	18.8	1.5	**220**	18.5	1.5
62	20.1	1.5	**115**	19.3	1.5	**168**	18.8	1.5	**221**	18.5	1.5
63	20.1	1.5	**116**	19.3	1.5	**169**	18.8	1.5	**222**	18.5	1.5
64	20.1	1.5	**117**	19.3	1.5	**170**	18.8	1.5	**223**	18.4	1.5
65	20.0	1.5	**118**	19.3	1.5	**171**	18.8	1.5	**224**	18.4	1.5
66	20.0	1.5	**119**	19.3	1.5	**172**	18.8	1.5	**225**	18.4	1.5
67	20.0	1.5	**120**	19.2	1.5	**173**	18.8	1.5	**226**	18.4	1.5
68	20.0	1.5	**121**	19.2	1.5	**174**	18.8	1.5	**227**	18.4	1.5
69	20.0	1.5	**122**	19.2	1.5	**175**	18.8	1.5	**228**	18.4	1.5
70	19.9	1.5	**123**	19.2	1.5	**176**	18.8	1.5	**229**	18.4	1.5
71	19.9	1.5	**124**	19.2	1.5	**177**	18.7	1.5	**230**	18.4	1.5
72	19.9	1.5	**125**	19.2	1.5	**178**	18.7	1.5	**231**	18.4	1.5
73	19.9	1.5	**126**	19.2	1.5	**179**	18.7	1.5	**232**	18.4	1.5
74	19.9	1.5	**127**	19.2	1.5	**180**	18.7	1.5	**233**	18.4	1.5
75	19.9	1.5	**128**	19.2	1.5	**181**	18.7	1.5	**234**	18.4	1.5
76	19.8	1.5	**129**	19.2	1.5	**182**	18.7	1.5	**235**	18.4	1.5
77	19.8	1.5	**130**	19.1	1.5	**183**	18.7	1.5	**236**	18.4	1.5
78	19.8	1.5	**131**	19.1	1.5	**184**	18.7	1.5	**237**	18.4	1.5
79	19.8	1.5	**132**	19.1	1.5	**185**	18.7	1.5	**238**	18.4	1.5
80	19.8	1.5	**133**	19.1	1.5	**186**	18.7	1.5	**239**	18.4	1.5
81	19.8	1.5	**134**	19.1	1.5	**187**	18.7	1.5	**240**	18.3	1.5
82	19.7	1.5	**135**	19.1	1.5	**188**	18.7	1.5	**241**	18.3	1.5
83	19.7	1.5	**136**	19.1	1.5	**189**	18.7	1.5	**242**	18.3	1.5
84	19.7	1.5	**137**	19.1	1.5	**190**	18.7	1.5	**243**	18.3	1.5
85	19.7	1.5	**138**	19.1	1.5	**191**	18.6	1.5	**244**	18.3	1.5
86	19.7	1.5	**139**	19.1	1.5	**192**	18.6	1.5	**245**	18.3	1.5
87	19.7	1.5	**140**	19.0	1.5	**193**	18.6	1.5	**246**	18.3	1.5
88	19.6	1.5	**141**	19.0	1.5	**194**	18.6	1.5	**247**	18.3	1.5
89	19.6	1.5	**142**	19.0	1.5	**195**	18.6	1.5	**248**	18.3	1.5
90	19.6	1.5	**143**	19.0	1.5	**196**	18.6	1.5	**249**	18.3	1.5
91	19.6	1.5	**144**	19.0	1.5	**197**	18.6	1.5	**250**	18.3	1.5
92	19.6	1.5	**145**	19.0	1.5	**198**	18.6	1.5			
93	19.6	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	20.8	2.9	**56**	13.8	2.8	**109**	11.7	2.8			
4	20.8	2.8	**57**	13.7	2.8	**110**	11.7	2.8			
5	20.6	2.8	**58**	13.7	2.8	**111**	11.7	2.8			
6	20.4	2.8	**59**	13.6	2.8	**112**	11.7	2.8			
7	20.1	2.8	**60**	13.6	2.8	**113**	11.6	2.8			
8	19.9	2.8	**61**	13.5	2.8	**114**	11.6	2.8			
9	19.6	2.8	**62**	13.5	2.8	**115**	11.6	2.8			
10	19.4	2.8	**63**	13.4	2.8	**116**	11.6	2.8			
11	19.1	2.8	**64**	13.4	2.8	**117**	11.5	2.8			
12	18.9	2.8	**65**	13.3	2.8	**118**	11.5	2.8			
13	18.7	2.8	**66**	13.3	2.8	**119**	11.5	2.8			
14	18.4	2.8	**67**	13.2	2.8	**120**	11.5	2.8			
15	18.2	2.8	**68**	13.2	2.8	**121**	11.5	2.8			
16	18.0	2.8	**69**	13.1	2.8	**122**	11.4	2.8			
17	17.9	2.8	**70**	13.1	2.8	**123**	11.4	2.8			
18	17.7	2.8	**71**	13.0	2.8	**124**	11.4	2.8			
19	17.5	2.8	**72**	13.0	2.8	**125**	11.4	2.8			
20	17.3	2.8	**73**	12.9	2.8	**126**	11.4	2.8			
21	17.2	2.8	**74**	12.9	2.8	**127**	11.3	2.8			
22	17.0	2.8	**75**	12.8	2.8	**128**	11.3	2.8			
23	16.9	2.8	**76**	12.8	2.8	**129**	11.3	2.8			
24	16.7	2.8	**77**	12.8	2.8	**130**	11.3	2.8			
25	16.6	2.8	**78**	12.7	2.8	**131**	11.3	2.8			
26	16.5	2.8	**79**	12.7	2.8	**132**	11.2	2.8			
27	16.3	2.8	**80**	12.6	2.8	**133**	11.2	2.8			
28	16.2	2.8	**81**	12.6	2.8	**134**	11.2	2.8			
29	16.1	2.8	**82**	12.6	2.8	**135**	11.2	2.8			
30	16.0	2.8	**83**	12.5	2.8	**136**	11.2	2.8			
31	15.9	2.8	**84**	12.5	2.8	**137**	11.1	2.8			
32	15.7	2.8	**85**	12.5	2.8	**138**	11.1	2.8			
33	15.6	2.8	**86**	12.4	2.8	**139**	11.1	2.8			
34	15.5	2.8	**87**	12.4	2.8	**140**	11.1	2.9			
35	15.4	2.8	**88**	12.4	2.8	**141**	11.1	2.9			
36	15.3	2.8	**89**	12.3	2.8	**142**	11.1	2.9			
37	15.2	2.8	**90**	12.3	2.8	**143**	11.0	2.9			
38	15.1	2.8	**91**	12.3	2.8	**144**	11.0	2.9			
39	15.1	2.8	**92**	12.2	2.8	**145**	11.0	2.9			
40	15.0	2.8	**93**	12.2	2.8	**146**	11.0	2.9			
41	14.9	2.8	**94**	12.2	2.8	**147**	11.0	2.9			
42	14.8	2.8	**95**	12.1	2.8	**148**	11.0	2.9			
43	14.7	2.8	**96**	12.1	2.8	**149**	11.0	2.9			
44	14.6	2.8	**97**	12.1	2.8	**150**	10.9	2.9			
45	14.6	2.8	**98**	12.0	2.8	**151**	10.9	2.9			
46	14.5	2.8	**99**	12.0	2.8	**152**	10.9	2.9			
47	14.4	2.8	**100**	12.0	2.8	**153**	10.9	2.9			
48	14.3	2.8	**101**	12.0	2.8	**154**	10.9	2.9			
49	14.3	2.8	**102**	11.9	2.8	**155**	10.9	2.9			
50	14.2	2.8	**103**	11.9	2.8	**156**	10.9	2.9			
51	14.1	2.8	**104**	11.9	2.8	**157**	10.8	2.9			
52	14.1	2.8	**105**	11.8	2.8	**158**	10.8	2.9			
53	14.0	2.8	**106**	11.8	2.8						
54	13.9	2.8	**107**	11.8	2.8						
55	13.9	2.8	**108**	11.8	2.8						

APPENDIX B Estimated temperatures at six Deschutes River flow scenarios

	Estimated temperature at TC+DR flow							Estimated temperature at TC+DR flow					
TC 000.25	**DR QD (cfs)**						**TC 000.25**	**DR QD (cfs)**					
Flow (cfs)	**134**	**160**	**180**	**200**	**232**	**250**	**Flow (cfs)**	**134**	**160**	**180**	**200**	**232**	**250**
10	19.1	18.8	18.7	18.5	18.4	18.2	**56**	17.5	17.5	17.5	17.5	17.5	17.4
11	19.1	18.8	18.7	18.5	18.4	18.2	**57**	17.5	17.5	17.5	17.4	17.4	17.3
12	19.1	18.8	18.7	18.5	18.4	18.2	**58**	17.4	17.5	17.4	17.4	17.4	17.3
13	19.0	18.8	18.6	18.5	18.4	18.2	**59**	17.4	17.4	17.4	17.4	17.4	17.3
14	19.0	18.8	18.6	18.5	18.3	18.2	**60**	17.4	17.4	17.4	17.4	17.4	17.3
15	19.0	18.8	18.6	18.5	18.3	18.2	**61**	17.3	17.4	17.3	17.3	17.3	17.2
16	19.0	18.7	18.6	18.5	18.3	18.1	**62**	17.3	17.3	17.3	17.3	17.3	17.2
17	18.9	18.7	18.6	18.4	18.3	18.1	**63**	17.3	17.3	17.3	17.3	17.3	17.2
18	18.9	18.7	18.6	18.4	18.3	18.1	**64**	17.2	17.3	17.3	17.2	17.3	17.2
19	18.9	18.7	18.5	18.4	18.3	18.1	**65**	17.2	17.2	17.2	17.2	17.2	17.2
20	18.8	18.6	18.5	18.4	18.3	18.1	**66**	17.2	17.2	17.2	17.2	17.2	17.1
21	18.8	18.6	18.5	18.4	18.2	18.1	**67**	17.1	17.2	17.2	17.2	17.2	17.1
22	18.8	18.6	18.5	18.3	18.2	18.1	**68**	17.1	17.1	17.1	17.1	17.2	17.1
23	18.8	18.6	18.4	18.3	18.2	18.0	**69**	17.0	17.1	17.1	17.1	17.1	17.1
24	18.7	18.5	18.4	18.3	18.2	18.0	**70**	17.0	17.1	17.1	17.1	17.1	17.0
25	18.7	18.5	18.4	18.3	18.2	18.0	**71**	17.0	17.0	17.1	17.1	17.1	17.0
26	18.6	18.5	18.4	18.3	18.2	18.0	**72**	16.9	17.0	17.0	17.0	17.1	17.0
27	18.6	18.5	18.3	18.2	18.1	18.0	**73**	16.9	17.0	17.0	17.0	17.0	17.0
28	18.6	18.4	18.3	18.2	18.1	18.0	**74**	16.9	16.9	17.0	17.0	17.0	17.0
29	18.5	18.4	18.3	18.2	18.1	17.9	**75**	16.8	16.9	16.9	16.9	17.0	16.9
30	18.5	18.4	18.3	18.2	18.1	17.9	**76**	16.8	16.9	16.9	16.9	17.0	16.9
31	18.5	18.3	18.2	18.1	18.0	17.9	**77**	16.8	16.8	16.9	16.9	17.0	16.9
32	18.4	18.3	18.2	18.1	18.0	17.9	**78**	16.7	16.8	16.9	16.9	16.9	16.9
33	18.4	18.3	18.2	18.1	18.0	17.9	**79**	16.7	16.8	16.8	16.8	16.9	16.8
34	18.4	18.2	18.1	18.1	18.0	17.8	**80**	16.7	16.8	16.8	16.8	16.9	16.8
35	18.3	18.2	18.1	18.0	18.0	17.8	**81**	16.6	16.7	16.8	16.8	16.9	16.8
36	18.3	18.2	18.1	18.0	17.9	17.8	**82**	16.6	16.7	16.7	16.8	16.8	16.8
37	18.2	18.1	18.1	18.0	17.9	17.8	**83**	16.6	16.7	16.7	16.7	16.8	16.8
38	18.2	18.1	18.0	18.0	17.9	17.8	**84**	16.5	16.6	16.7	16.7	16.8	16.7
39	18.2	18.1	18.0	17.9	17.9	17.7	**85**	16.5	16.6	16.7	16.7	16.8	16.7
40	18.1	18.0	18.0	17.9	17.8	17.7	**86**	16.5	16.6	16.6	16.7	16.7	16.7
41	18.1	18.0	17.9	17.9	17.8	17.7	**87**	16.4	16.6	16.6	16.6	16.7	16.7
42	18.1	18.0	17.9	17.8	17.8	17.7	**88**	16.4	16.5	16.6	16.6	16.7	16.6
43	18.0	17.9	17.9	17.8	17.8	17.6	**89**	16.4	16.5	16.5	16.6	16.7	16.6
44	18.0	17.9	17.9	17.8	17.8	17.6	**90**	16.3	16.5	16.5	16.6	16.7	16.6
45	17.9	17.9	17.8	17.8	17.7	17.6	**91**	16.3	16.4	16.5	16.5	16.6	16.6
46	17.9	17.8	17.8	17.7	17.7	17.6	**92**	16.3	16.4	16.5	16.5	16.6	16.6
47	17.9	17.8	17.8	17.7	17.7	17.6	**93**	16.3	16.4	16.4	16.5	16.6	16.5
48	17.8	17.8	17.7	17.7	17.7	17.5	**94**	16.2	16.4	16.4	16.5	16.6	16.5
49	17.8	17.7	17.7	17.7	17.6	17.5	**95**	16.2	16.3	16.4	16.4	16.5	16.5
50	17.7	17.7	17.7	17.6	17.6	17.5	**96**	16.2	16.3	16.4	16.4	16.5	16.5
51	17.7	17.7	17.6	17.6	17.6	17.5	**97**	16.1	16.3	16.3	16.4	16.5	16.5
52	17.7	17.6	17.6	17.6	17.6	17.4	**98**	16.1	16.2	16.3	16.4	16.5	16.4
53	17.6	17.6	17.6	17.5	17.5	17.4	**99**	16.1	16.2	16.3	16.3	16.4	16.4
54	17.6	17.6	17.6	17.5	17.5	17.4	**100**	16.0	16.2	16.3	16.3	16.4	16.4
55	17.6	17.5	17.5	17.5	17.5	17.4							