Upper Deschutes Watershed Council

Technical Report

Middle Deschutes River Instream Flow Restoration and Temperature Responses 2001-2013

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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 Middle Deschutes and 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, 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 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 2013 to address the following key questions:

1) <u>Temperature status</u>: What was the status of Middle Deschutes River water temperature relative to the State of Oregon 18°C (64°F) standard as of 2013?

   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 102 days between May 6 and September 16, and were above the 24°C lethal threshold for ten days. Temperatures exceeded 18°C along 31 miles of the Middle Deschutes River, between North Canal Dam and Lower Bridge Road, for 29 days in 2013. These data represent 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, 2013 flows were rarely higher than the instream water rights protected through stream flow restoration, and were the lowest recorded since 2007, with the smallest proportion of cooler Tumalo Creek flow.

2) <u>Restoration effectiveness</u>: Have cumulative increases in stream flow resulted in reduced water temperatures at key locations along the Middle Deschutes?

   Comparison of flows protected to flows observed and regression of the mean 7DMAX temperatures for all associated observed flows provide support for increased stream flow secured through stream flow restoration reducing temperatures in the Middle Deschutes. July median flows in the Deschutes closely track median protected flows; July median protected

flows in Tumalo Creek have been inconsistently met, but observed July median flows rarely fall below levels observed during early years of restoration efforts. Temperatures describe an inverse relationship, decreasing from highest at the lowest flows to lowest at the highest flows. Comparison of mean temperatures at three different sites at the lowest and highest flows recorded from 2001 to 2013 show that increased July flows produced substantially lower temperatures. Together, these data provide support for higher protected flows guaranteeing higher baseflows and lower stream temperature.

3) Target stream flow: What flow scenarios for the Deschutes River and Tumalo Creek will achieve the 18°C temperature standard between North Canal Dam and Lower Bridge Road?

   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 the 18°C state standard temperature in the Deschutes below the confluence with Tumalo Creek. Mass balance equation results suggest 24 cfs are required from Tumalo Creek to achieve 18°C in the Deschutes immediately downstream of the confluence with Tumalo Creek at the Deschutes River flow target of 250 cfs. Increasing Tumalo flow by only 13 cfs, to 37 cfs, results in a temperature reduction equivalent to increasing Deschutes River flows by 90 cfs, achieving 18°C at a Deschutes flow of 160 cfs. It is worth noting that this Tumalo Creek flow is only five cfs above the 32 cfs state water right. Especially in light of the current status of protected flows, 124 cfs in the Deschutes and 20 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 greater temperature benefits at an equivalent cost.

Temperatures thus remain elevated in the middle Deschutes River, exceeding the state standard and likely compromising rearing and migration habitat for resident native trout. Temperatures showed substantial improvement with higher combined flows from the Deschutes and from Tumalo Creek in July 2011 and 2012, but 2013 flows that barely met the instream water rights protected through stream flow restoration resulted in the worst temperature conditions observed since 2007. The 2013 status of flow and corresponding temperature in the Middle Deschutes emphasizes the critical importance of stream flow restoration in maintaining elevated baseflows. Mass balance results suggest strategically increasing flows in Tumalo Creek will maximize temperature reductions in the Deschutes downstream of the confluence. Particularly at the low flow currently protected in Tumalo Creek, increasing flows in the Deschutes is also expected to achieve some temperature benefit.

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 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 have not been well described. Data on fish response to increased flows and use of habitat including cold-water refuges, to be collected by ODFW through 2016, will greatly improve our knowledge of how stream flow affects habitat quality 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

Deschutes River Conservancy provided funding in support of research and analyses that form the basis for this report. Water quality monitoring conducted by Upper Deschutes Watershed Council is funded in large part by the Oregon Watershed Enhancement Board and the Oregon Department of Environmental Quality (ODEQ) 319 Grant Program; their generous support has been instrumental in the data collection and analysis informing this report. Monitoring by the City of Bend, ODEQ, Oregon State University (OSU), Oregon Water Resources Department (OWRD), and DRC has contributed invaluable data to this long-term effort. Many thanks to members of the 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 emerged. 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 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
CI	Confidence interval
cfs	Cubic feet per second
Ln	Natural logarithm
QA/QC	Quality assurance / quality control
QD	Average daily flow
S	Standard distance from regression line

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 12 cfs in 2013, and July median average daily flow in the Deschutes River at North Canal Dam has increased from 48 cfs in 2001 to 129 cfs in 2013. 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 2013 amounted to 90 cfs, from 53 cfs in 2001 to 143 cfs in 2013. 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.

Prior analyses of water temperature in the Middle Deschutes and Tumalo Creek (UDWC, 2013) 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 (UDWC, 2006) (ODEQ, 2004) (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 flows that are already at or around 18°C at North Canal Dam will not create an active cooling effect, restoration that increases flows at 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, 2004) (ODEQ, 2007) (UDWC, 2003) (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 2013 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 as of 2013; 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 2013 temperature results and discuss implications for stream flow restoration.

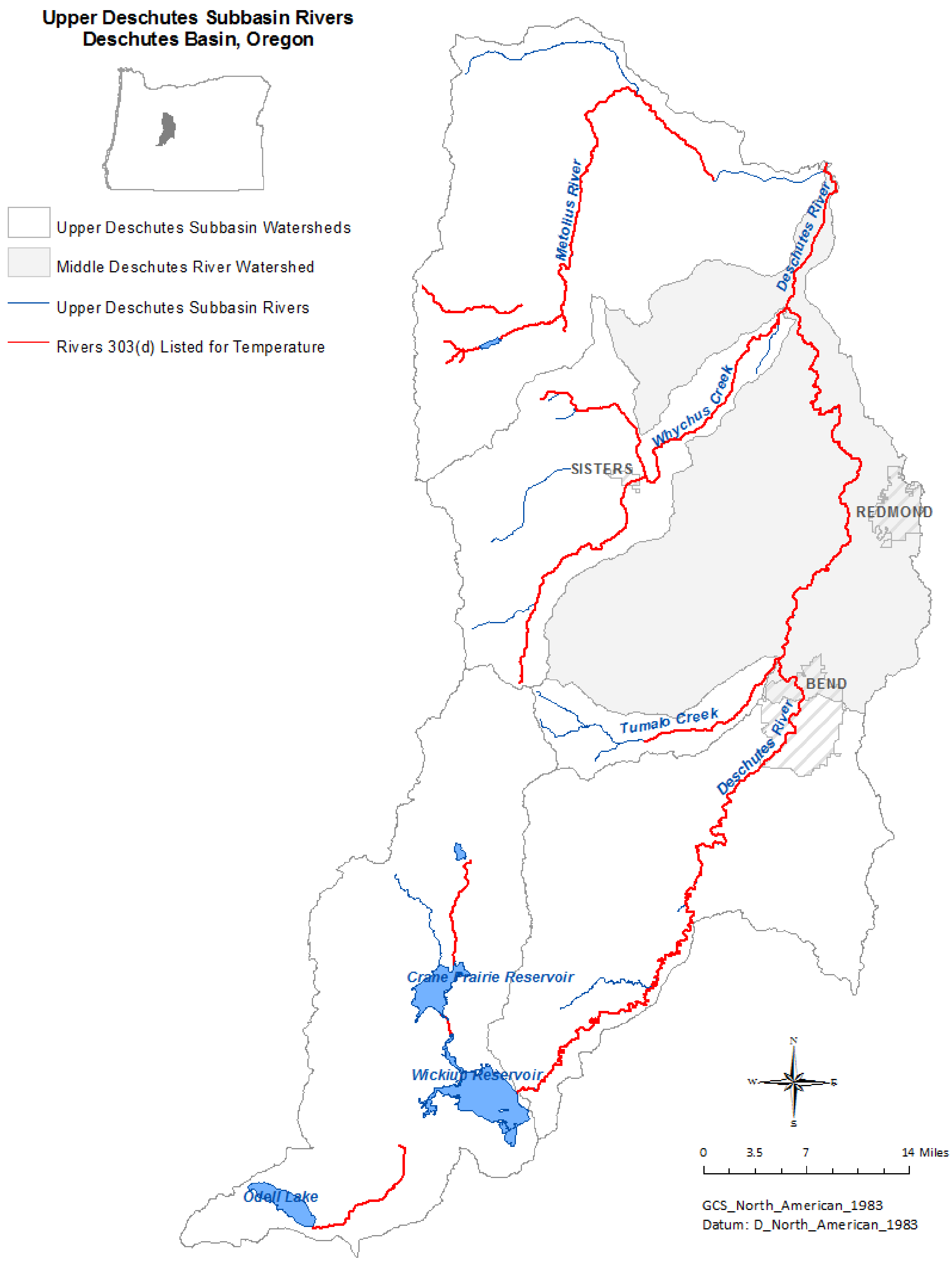


Figure 1. The Upper Deschutes Subbasin and Middle Deschutes River Watershed.
Extensive reaches of most Upper Deschutes Subbasin rivers are 303(d) listed as exceeding state temperature standards for salmon and trout rearing and migration (ODEQ 2010).

2 Methods

2.1 Data Collection

2.1.1 Water Temperature

UDWC collected and compiled continuous water temperature data for 2001-2013 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, 2008) under a State of Oregon approved Quality Assurance Project Plan (UDWC, 2008).

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 2001-2013.

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
DR 217.25	Deschutes River	Pringle Falls		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
DR 164.75	Deschutes River	u/s Riverhouse Hotel				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
DR 160.00	Deschutes River	d/s Tumalo Boulder Field					X	X	X	X	X	X	X	X	-
DR 133.50	Deschutes River	Lower Bridge	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	Data available for analysis														
-	Limited data available for analyses														

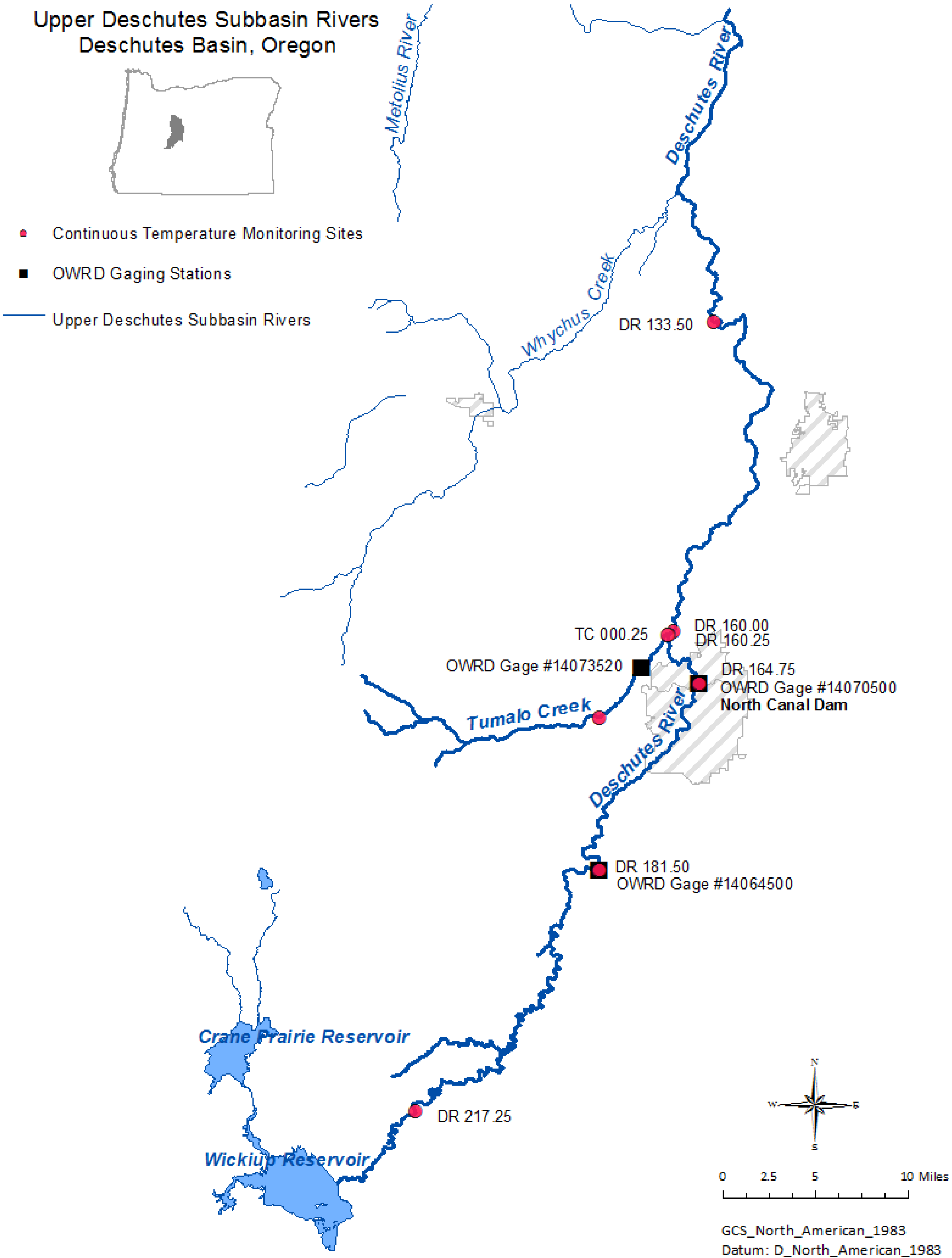


Figure 2. UDWC continuous temperature monitoring sites and OWRD stream flow gages on the Middle and Upper Deschutes.

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) (ODEQ, 2012). We evaluated July 7DMAX temperatures from 2001-2013 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 and because the range of stream temperatures in July and August differ substantially. 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 in reducing stream temperature, and 2) to develop flow scenarios for the Deschutes River and Tumalo Creek that would achieve the 18°C state standard temperature in the Deschutes below the confluence with Tumalo Creek. To quantify reductions in temperature with increasing flows 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 sites of stream flow restoration on each waterway and are anticipated to demonstrate reductions in temperature resulting from increased flows; due to their respective locations immediately upstream of the confluence they also most accurately represent the temperature-flow relationships that directly affect stream temperature downstream of the confluence. Because no tributaries or known 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 used temperature data from Lower Bridge Road, DR 133.50, with the combined average daily flow values from the two OWRD gages to show the longitudinal temperature effects of increasing flows 26.5 miles upstream at the confluence of the Deschutes River and Tumalo Creek.

We restricted data included in the analysis to one month of the year to reduce the effect of inter-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, 2003) (UDWC, 2006). 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 2002-2013, 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 2004-2013 with the exception of 2008, for which temperature data were also not available. For DR 133.50 at Lower Bridge Road, we analyzed July temperature and flow data for 2001-2002 and 2005-2011. Temperature data were not available for this site for 2003 and 2004, and limited data were available for 2009, 2010 and 2011.

To evaluate the relationship between stream flow and temperature and to estimate temperatures at corresponding flows we performed a regression of temperature and flow data. The resulting equations accurately represent the relationship between flow and temperature, and can be used to calculate temperature values for the specified locations, within the evaluated time period, and within the range of flows observed. We paired 7DMAX temperature records with the natural log of the corresponding average daily flow (LnQD) for each July day included in the analysis, then ranked flow values and assigned all July temperature records to their corresponding flow value. 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. Although this approach does not reflect the flow corresponding to maximum daily temperatures on the fifth, sixth, or seventh days included in the 7DMAX, the flow corresponding to the 7DMAX for the same date is related to the flow three days before and three days after. On this premise we selected the flow for the same date as the 7DMAX to represent flow conditions corresponding to that temperature statistic.

For our 2012 analysis we had plotted flow versus temperature and fitted the linear and polynomial regression trendlines for six permutations of the data to evaluate which approach best represented the observed temperature and flow data and would result in estimated temperatures that would as closely as possible approximate those we might anticipate occurring (UDWC 2013). We plotted the following permutations of temperature data: 1) all temperature-flow pairs; 2) all temperature-flow pairs excluding flows for which there were fewer than two temperature records; 3) all temperature-flow pairs excluding flows for which there were fewer than five temperature records; 4) all mean 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; 5) mean temperature-flow pairs excluding flows for which there were fewer than two temperature records; and 6) mean temperature-flow pairs excluding flows for which there were fewer than five temperature records. We evaluated the resulting regression trendlines visually, and evaluated regression equations for a given regression model quantitatively by comparing adjusted R^2 values. The R^2 value represents the proportion of the variation in mean 7DMAX temperatures that is explained by stream flow (Ln QD). As the fit of the regression to the data improves, the R^2 value increases toward a maximum 100%.

We used the regression of all mean temperature-flow pairs, selected on the basis of adjusted R^2 values as the most representative of conditions observed and accordingly as the most useful for describing temperatures observed at a given flow and predicting the temperature anticipated to occur at a given flow (UDWC 2013). Because including temperature-flow pairs for which only one temperature record existed in regression of DR 133.50 temperature and flow data resulted in a standard error value >1, we performed the regression for this site including only temperature-flow pairs for which at least two temperature records were available.

For the resulting datasets we used an ANOVA in R open source statistical software to determine the highest polynomial term that statistically improved the model on the basis of the R^2 value associated with each model. For DR 160.25 data, the quadratic model was statistically better than the linear model, but the cubic model was not better than the quadratic model. For Tumalo data, the quadratic, cubic, and quartic models were each statistically better than the lower-order model. For DR 133.50 data, the quadratic model was no better than the linear model.

Using the resulting regression equation for DR 160.25 and for TC 000.25, we calculated the estimated temperature and 95% confidence interval for all flows within the observed range (Appendix A). We calculated the 95% confidence interval (CI) as:

$$Y \pm Y^{(Z_{1-\alpha/2}\, S(x) / \sqrt{N})}$$

$$\text{where } Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.475} = 1.9 \text{ (NIST 2011)}$$

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 flows between 10 and 100 cfs at Deschutes River flows of 160, 180, 200, 220, 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. 160 cfs is the median flow protected instream in the Deschutes River during July; 250 is the instream water right and DRC stream flow restoration target.

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 (ODEQ, 2007). 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 2012 by up to 6.3°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 2013 and in every other year for which data are available for analysis.

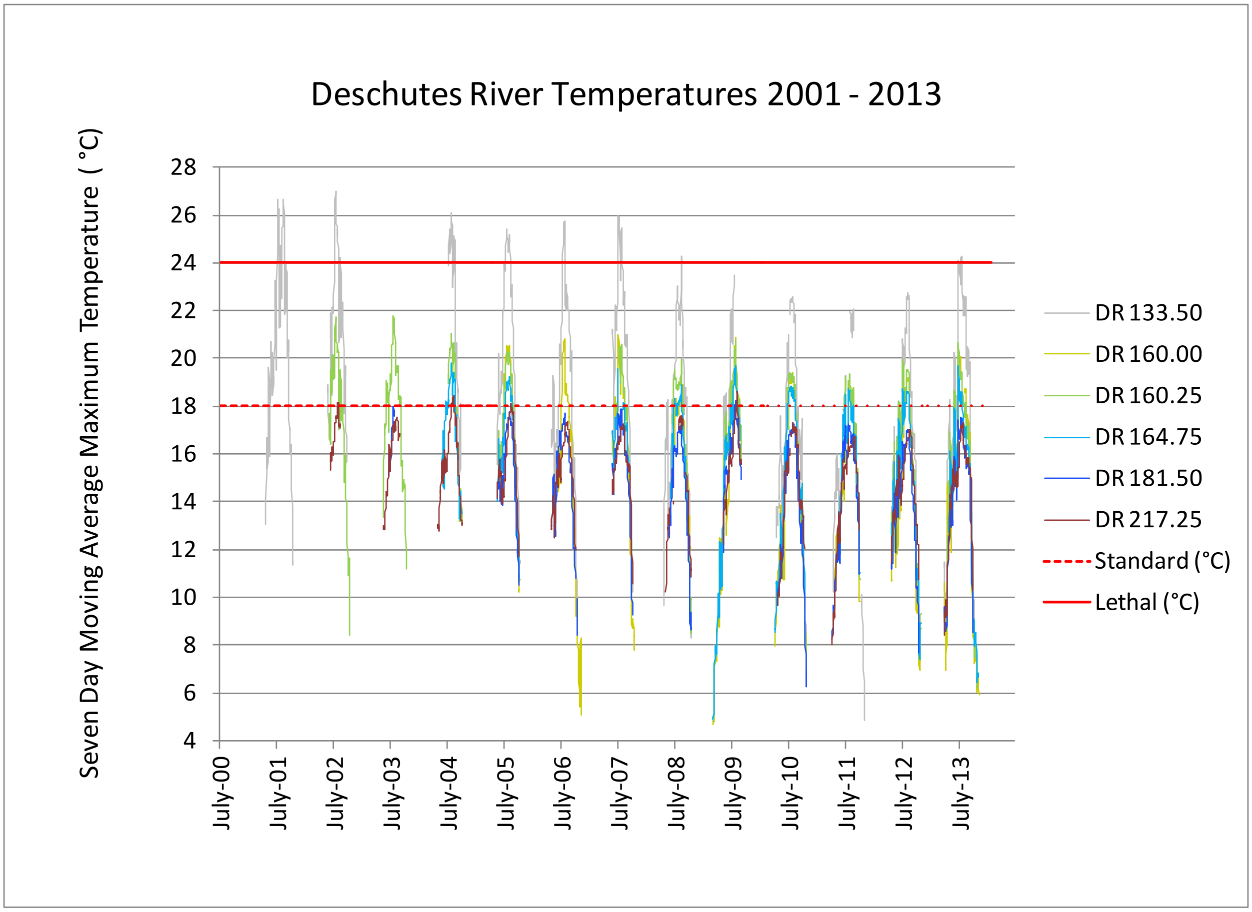


Figure 3. Deschutes River Temperatures 2001-2013

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 2013 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 (dashed black line) for ten days in 2013.

Temperatures at DR 160.00, downstream of the confluence with Tumalo Creek, exceeded 18°C for 29 days in 2013, from June 29 to July 21 and August 15 to 20, at flows of 128-293 cfs (116-220 cfs from the Deschutes and 11-73 cfs from Tumalo Creek) (Figure 4). Data are missing for the 24 days between July 21 and August 15; during these dates temperatures exceeded 18°C at DR 160.25, upstream of the confluence with Tumalo Creek, for 17 of the 24 days; although Tumalo Creek flows sometimes cool the Deschutes, temperatures at the downstream site (DR 160.00) were higher than at DR 160.25 for two weeks prior to, and over a month subsequent to, the interim for which data were missing, suggesting that temperatures at DR 160.00, downstream of Tumalo Creek, likely also exceeded 18°C for at least the additional 17 days observed at DR 160.25, if not the entire 24 days, for a total of 46 to 53 days. Temperatures above 18°C for more than 29 days at DR 160.00 would represent an increase over 2011 and 2012.

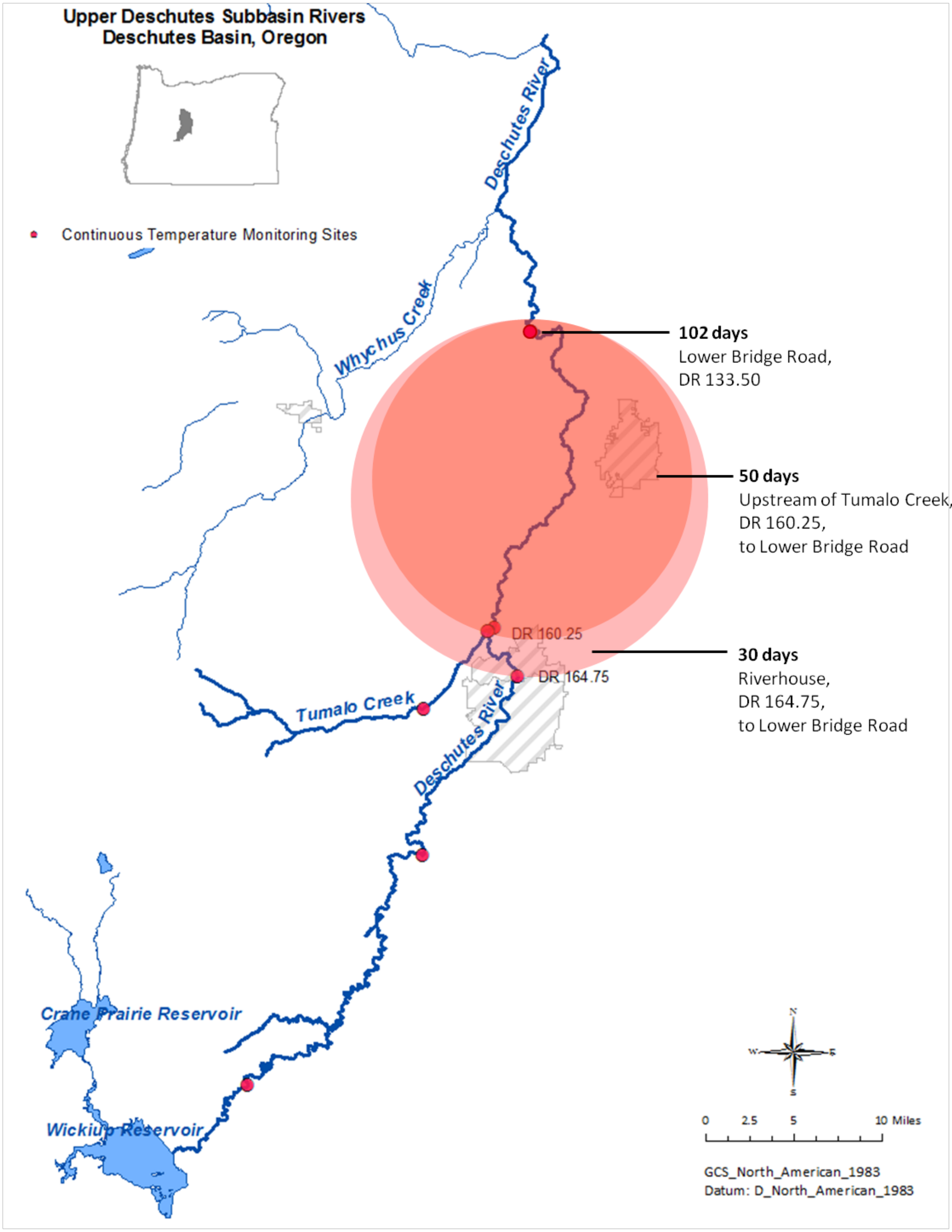
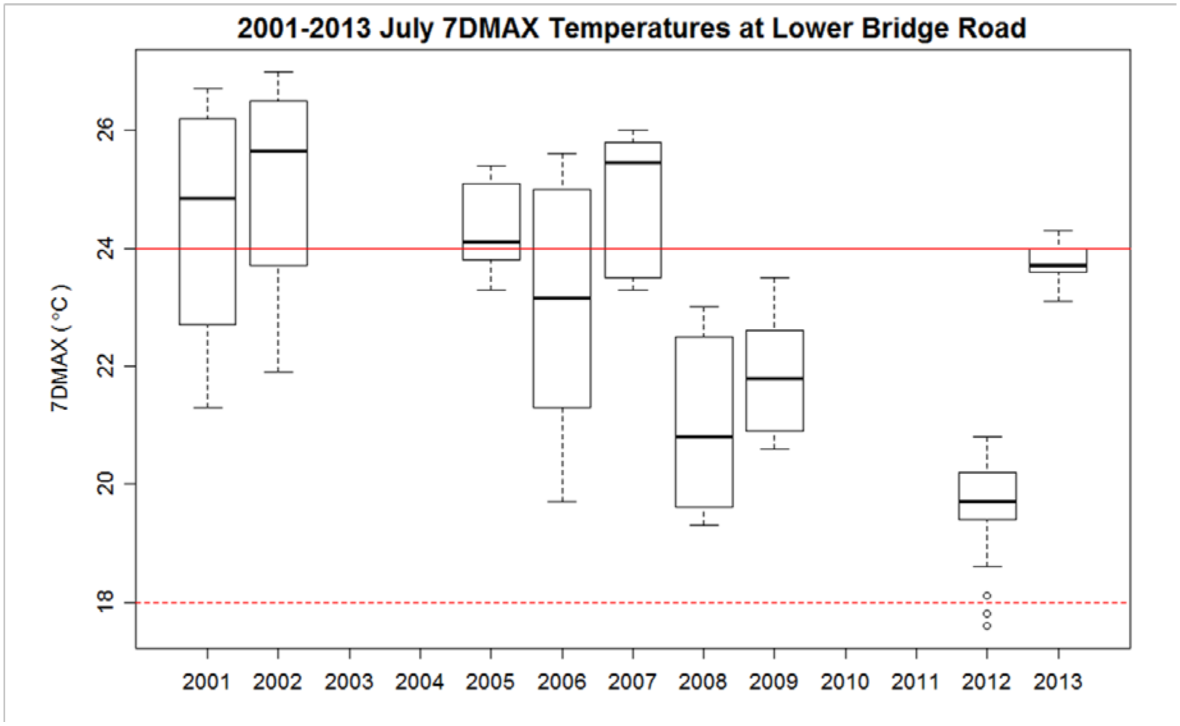


Figure 4. 2013 Middle Deschutes stream temperatures > 18°C. 7DMAX temperatures exceeded 18°C from 30 days at DR 164.75 below North Canal Dam to 102 days at Lower Bridge Road, approximately 31 miles downstream.

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 2013 (Figure 5), exceeding this criterion for 102 days between May 6 and September 16 at flows between 122 and 364 cfs (108-353 cfs from the Deschutes and 8.4-126 cfs in Tumalo Creek). Temperatures at Lower Bridge Road were above the 24°C lethal threshold for fish for ten days, at total flows of 128-171 cfs.

a



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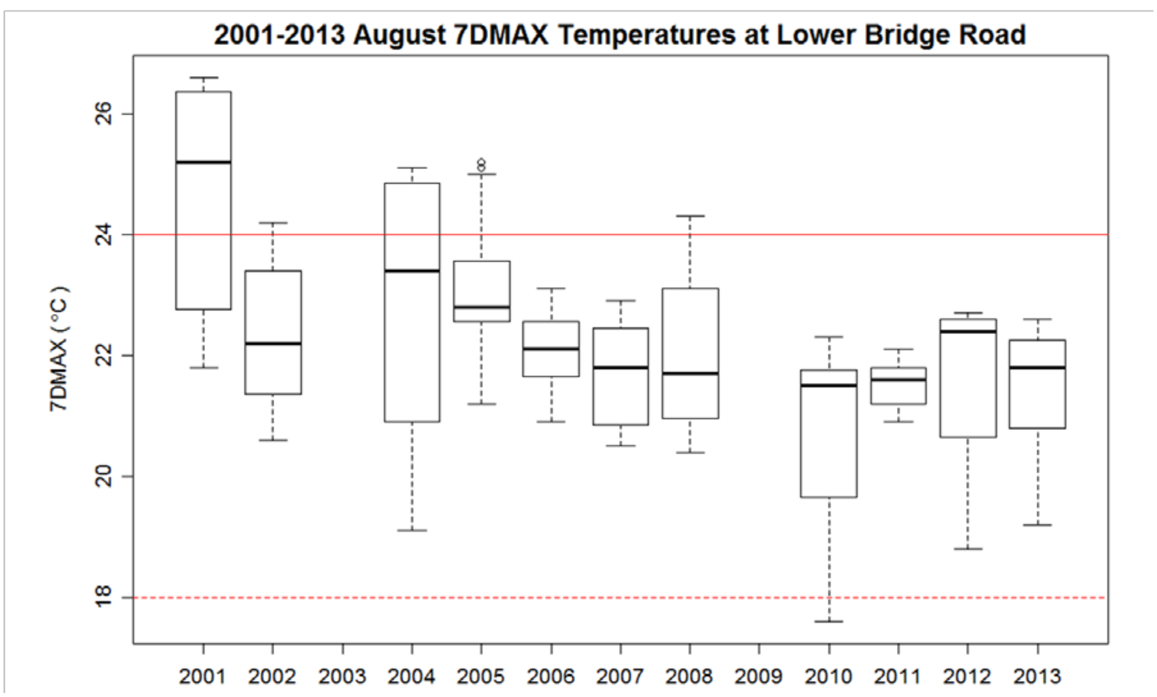
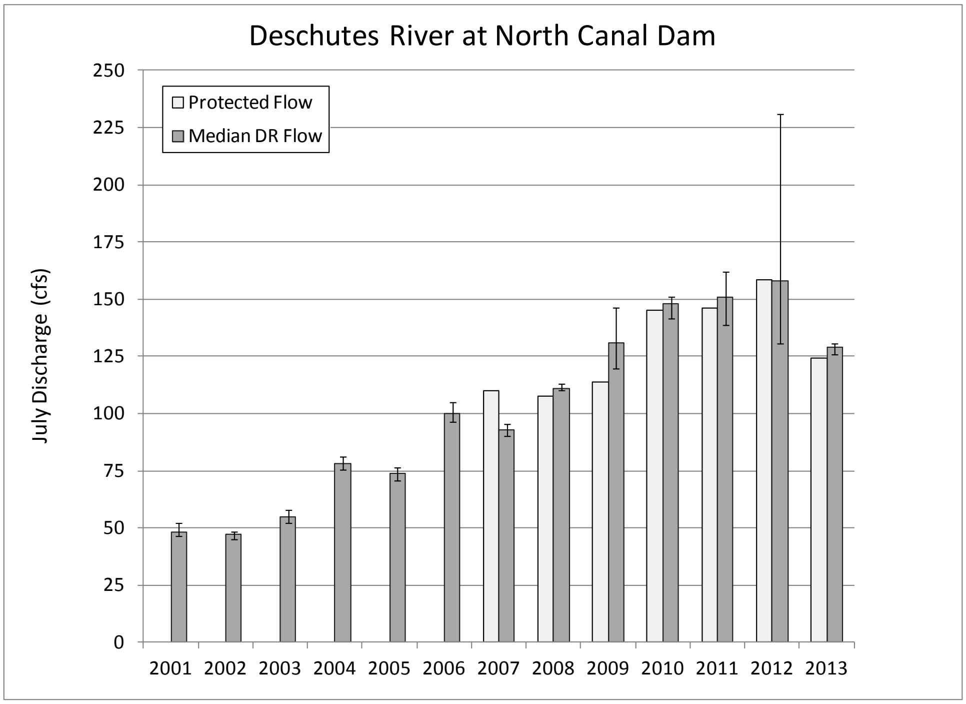


Figure 5. 2001-2013 July and August 7DMAX Temperatures at Lower Bridge Road
A) July 1-22 and b) August 6-28 mean 7DMAX temperatures at Lower Bridge Rd (DR 133.50), the most impaired site for which temperature data are available, chart a declining trend since 2001. Data for this location is missing for July 2003, 2004, 2010 and 2011 and for August 2003 and 2009. Despite reductions of approximately 3°C between 2001 and 2013, 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 2013.

3.2 Stream flow Restoration Effectiveness

July median flow tracks July median protected flow, and mean temperatures chart a declining trend from the lowest to highest flows for which temperature data are available, 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 2013. 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 2013, flows protected in the Deschutes at the same location increased from 110 to 124 cfs while flows protected in Tumalo Creek increased from 17 to 20.1 cfs. Increases in median protected flow from 2007 to 2013 correspond to increased July flows in both waterways (Figure 6). July median flows in the Deschutes closely track median protected flows; July median protected flows in Tumalo Creek have been inconsistently met, but observed July median flows rarely fall below levels observed during early years of restoration efforts.

Regressions of mean July 7DMAX temperatures and corresponding flow values from 2001-2013 at two Deschutes River and one Tumalo Creek site 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. Annual flow ranges for which temperature data are available and which are included in regressions increased from 41-51 cfs in 2002 to 100-327 cfs in 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), modest reductions in 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 7DMAX temperature of 19.2°C at DR 160.25, approximately five miles downstream; flows between 290 and 313 cfs resulted in a mean temperature only 1°C lower, of 18.2°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: 3.5 cfs (1.3 LnQD) resulted in a mean temperature of 21.2°C, with flows between 145 and 156 cfs (5 LnQD) resulting in a mean temperature of 11.7°C, a temperature reduction of almost 10°C. At Lower Bridge Road (DR 133.50), combined Deschutes River and Tumalo Creek flows between 47 and 52 cfs (3.9 LnQD) resulted in a mean temperature of 24.9°C; the highest flows for which temperature data are available, 355-362 cfs (5.9 LnQD) resulted in a mean temperature 5.3°C lower at 19.6°C.



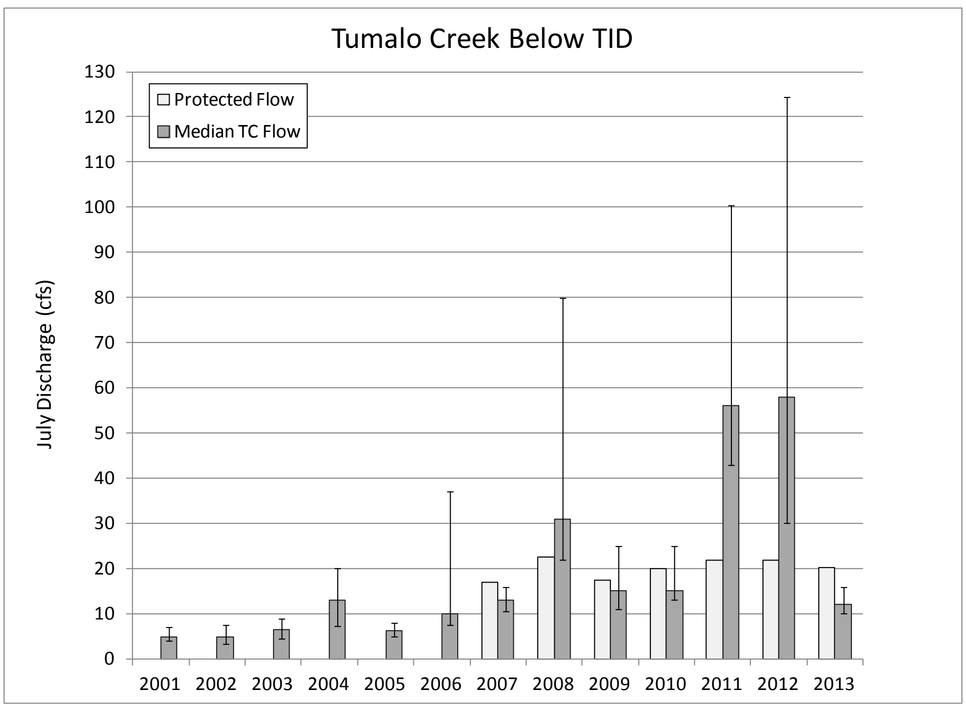
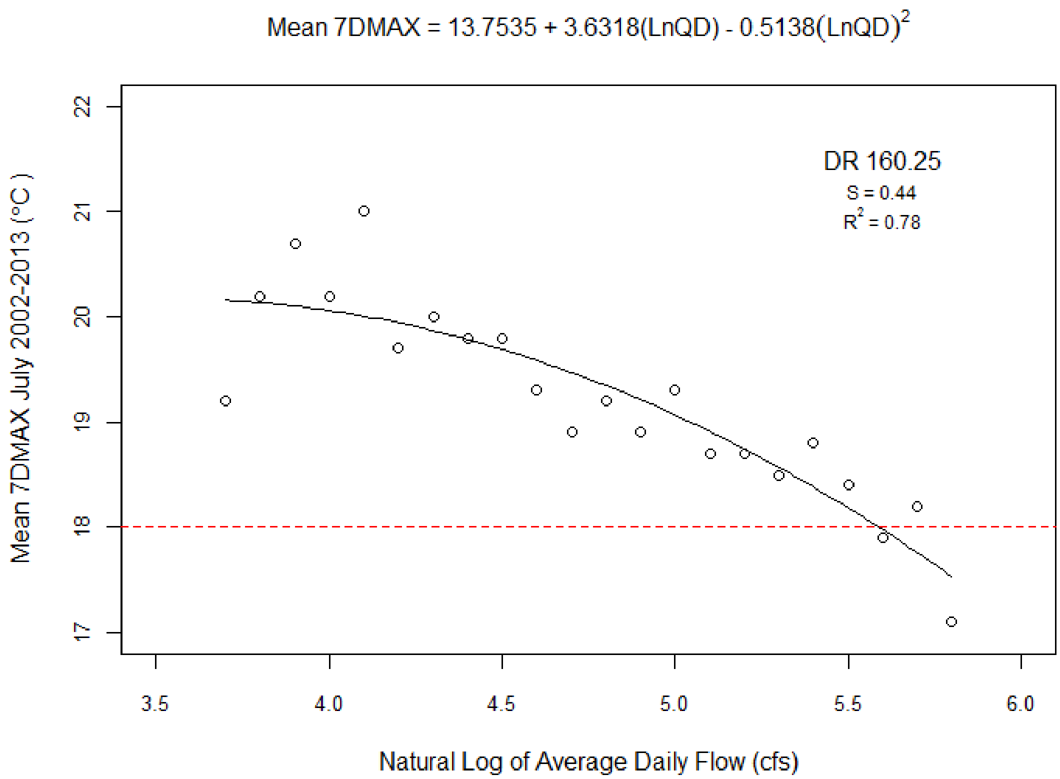
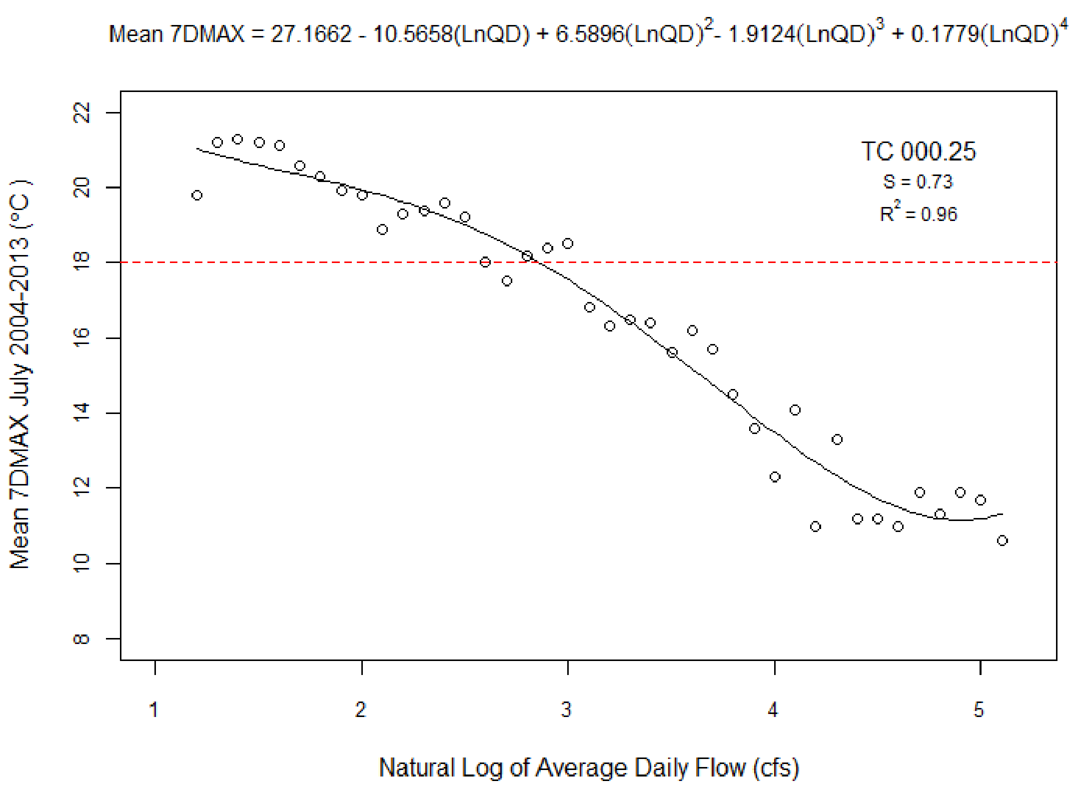


Figure 6. Deschutes River and Tumalo Creek Protected Flow and July Median Flow, 2001-2013.
July median flows steadily increased from 2001 to 2012, corresponding to increases in flow protected instream. 2013 marked a drop in July median flow from 2012 levels. Data for flows protected instream are not available prior to 2007.

a


Mean 7DMAX = 13.7535 + 3.6318(LnQD) - 0.5138(LnQD)^2
DR 160.25
S = 0.44
R^2 = 0.78
Mean 7DMAX July 2002-2013 (°C)
Natural Log of Average Daily Flow (cfs)
17
18
19
20
21
22
3.5
4.0
4.5
5.0
5.5
6.0

b


Mean 7DMAX = 27.1662 - 10.5658(LnQD) + 6.5896(LnQD)^2- 1.9124(LnQD)^3 + 0.1779(LnQD)^4
TC 000.25
S = 0.73
R^2 = 0.96
Mean 7DMAX July 2004-2013 (°C)
Natural Log of Average Daily Flow (cfs)
8
10
12
14
16
18
20
22
1
2
3
4
5

c

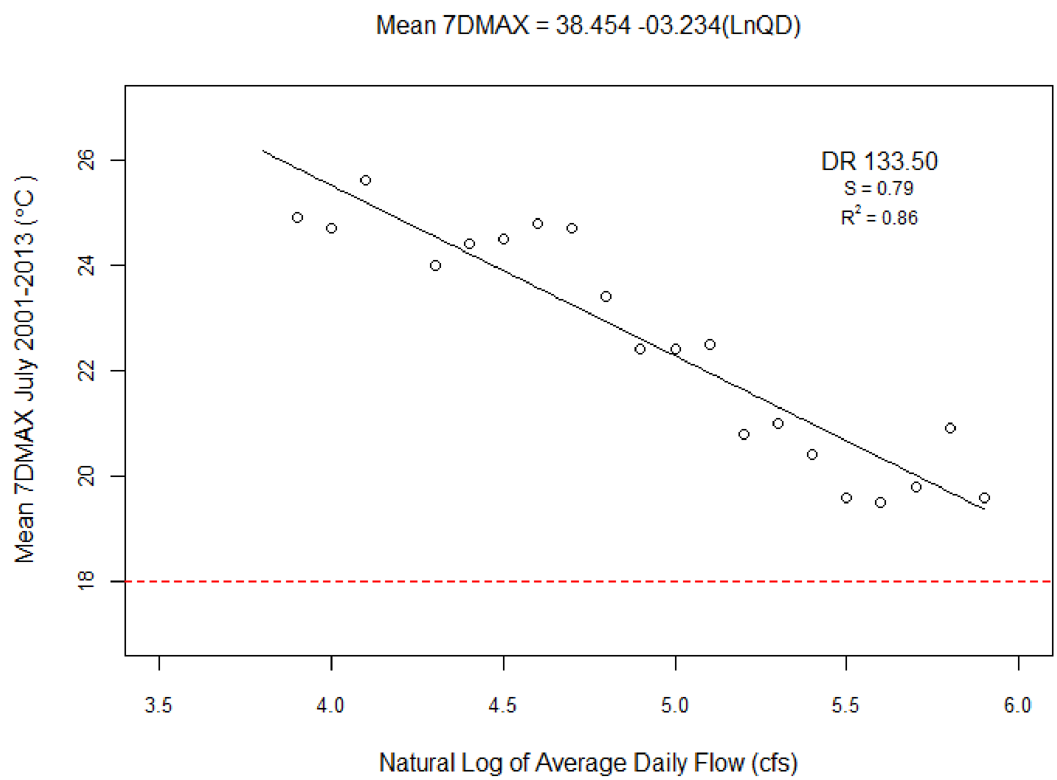


Figure 7. Temperature-Flow Regression Models
Regression models fitted to temperature-flow data demonstrate reduced temperatures at higher flows and describe the relationship between temperature and flow observed a) during July 2002-2013 at DR 160.25, the Deschutes River upstream of the confluence with Tumalo Creek, b) during July 2004-2013 at TC 000.25, Tumalo Creek upstream of the mouth, and c) during July 2001-2013 at DR 133.50, the Deschutes River at Lower Bridge Road.

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 7). Temperature records were available from DR 160.25 for Deschutes River flows between 41 and 327cfs (3.7-5.8 LnQD), and from TC 000.25 for Tumalo Creek flows between 3.3 and 158 cfs (1.2-5.1 LnQD). A quadratic regression trendline and equation provided the best fit to DR 160.25 temperature and flow data; a quartic (4th order polynomial) regression trendline and equation best described TC 000.25 data. We used the resulting equations to calculate temperatures for Deschutes flows between 43 and 250 cfs, and for Tumalo flows between three and 158 cfs (Appendix A).

Temperature estimates calculated for five Deschutes River flow scenarios illustrated dramatic gains in 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, 24 cfs from Tumalo Creek resulted in 18°C at DR

160.00. At 160 cfs in the Deschutes below North Canal Dam, the flow currently protected instream, 18°C was estimated to occur at DR 160.00 when Tumalo flows were 42 cfs; an 18 cfs difference in Tumalo flow achieved the same temperature outcome, meeting the 18°C standard, as did a 90 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 250 cfs.

Estimated temperature gains were magnified as Tumalo flows increased to approximately 78 cfs. Tumalo flows of 46 cfs at Deschutes River flows of 250 cfs resulted in 17.5°C at DR 160.00; the same temperature was achieved at 160 cfs of Deschutes flow by adding nine cfs in Tumalo Creek, at a Tumalo flow of 55 cfs. Above 78 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 81 cfs in Tumalo, Deschutes flows of 160 cfs resulted in an estimated temperature of 16.5°C; to obtain the same temperature at 250 cfs in the Deschutes required 86 cfs in Tumalo.

Heat Source model estimates are available for instream water right (ODFW) flows for the Deschutes and for Tumalo Creek. The Heat Source average seven day average daily maximum (7DADM) temperature estimate for Deschutes flows of 250 cfs at the Tumalo instream water right of 32 cfs at approximately DR 160.00 is 17.0°C, almost a full degree lower than the mass balance temperature estimate of 17.9°C for the same flow at the same site. Similarly, the Heat Source average 7DADM for the Deschutes at 250 cfs at approximately DR 160.25, above the confluence with Tumalo, was 17.2°C, a full degree lower than the 18.1°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 2013, 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 102 days between May 6 and September 16, and were above the 24°C lethal threshold for ten days. Temperatures exceeded the 18°C standard for 30 days at all four Deschutes River monitoring sites downstream of North Canal Dam; although we only have data for four sites along the approximately 31 miles between Lower Bridge Road and North Canal Dam, we can infer that temperatures along the entire 31 mile reach were above 18°C throughout those 30 days. This includes the only site where there is potential for cooling below North Canal Dam, at DR 160.00, below the confluence with Tumalo Creek. These data represent 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, 2013 Deschutes flows at North Canal Dam were barely higher than the instream water rights protected through stream flow restoration and flows in Tumalo Creek never met the instream water right in 2013. Flows recorded in 2013 were the lowest recorded since 2007, with the smallest proportion of cooler Tumalo Creek flow (data not shown).

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. 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 flow protected instream and July median flow suggests that flows protected instream have resulted in higher July median and minimum flows. Comparison of mean temperatures at three different sites at the lowest and highest flows recorded from 2001 to 2013 show that increased July flows produced substantially lower temperatures. Together, these data provide support for higher protected flows guaranteeing higher baseflows and lower stream temperature.

4.3 Target Stream flow

Mass balance equation results suggest that the Deschutes River flow target of 250 cfs will achieve the 18°C standard immediately downstream of the confluence with Tumalo Creek at 26 cfs in Tumalo Creek. Alternatively, the Tumalo Creek flow target of 32 cfs will achieve the 18°C standard in the Deschutes downstream of the confluence at Deschutes River flows of 220 cfs. At the currently protected Deschutes flow of 160 cfs, 38 cfs will be required in Tumalo Creek to meet the 18°C state standard.

Temperature estimates indicate that as flows in Tumalo Creek increase, temperature benefits of additional flow in the Deschutes diminish and ultimately are lost altogether, such that increasing flows in the Deschutes requires commensurate increases in Tumalo flows to achieve the same temperature benefits obtained at lower Deschutes and Tumalo Creek flows. The 13 cfs increase between 24 and 37 cfs in Tumalo Creek results in temperature gains equivalent to increasing Deschutes flows by 90 cfs, from 160 cfs to 250 cfs, to produce a 7DMAX temperature of 18°C below the confluence of the Deschutes and Tumalo. At lower Tumalo Creek flows, increases in Deschutes flows result in comparatively greater temperature reductions. Temperature reductions associated with increasing Deschutes flows are greatly diminished once Tumalo flows increase above 50 cfs; above approximately 60 cfs in Tumalo, temperatures *increase* with increases in Deschutes flows. Especially in light of the current status of protected flows, 124 cfs in the Deschutes and 20.1 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 greater temperature benefits at an equivalent 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 maximizing Tumalo flows and increasing Deschutes flows to 250 cfs, temperatures at DR 160.00 will still be high enough to necessitate a low rate of temperature change between DR 160.00 and DR 133.50 to obtain 18°C at Lower Bridge (DR 133.50). 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.

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, increases in flow that approach the instream water right and DRC flow targets in both the Deschutes and 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 fish response to increased flows and use of habitat including cold-water refugia, to be collected by ODFW in the Middle Deschutes and in Tumalo Creek through 2016, will contribute to the ability of restoration partners to discern how flow and temperature affect habitat availability and use, and 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)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)
41	20.2	1.7	**94**	19.6	1.7	**147**	19.1	1.7	**200**	18.6	1.7
42	20.2	1.7	**95**	19.6	1.7	**148**	19.1	1.7	**201**	18.6	1.7
43	20.1	1.7	**96**	19.6	1.7	**149**	19.1	1.7	**202**	18.6	1.7
44	20.1	1.7	**97**	19.6	1.7	**150**	19.1	1.7	**203**	18.5	1.7
45	20.1	1.7	**98**	19.6	1.7	**151**	19.0	1.7	**204**	18.5	1.7
46	20.1	1.7	**99**	19.6	1.7	**152**	19.0	1.7	**205**	18.5	1.7
47	20.1	1.7	**100**	19.6	1.7	**153**	19.0	1.7	**206**	18.5	1.7
48	20.1	1.7	**101**	19.6	1.7	**154**	19.0	1.7	**207**	18.5	1.7
49	20.1	1.7	**102**	19.6	1.7	**155**	19.0	1.7	**208**	18.5	1.7
50	20.1	1.7	**103**	19.5	1.7	**156**	19.0	1.7	**209**	18.5	1.7
51	20.1	1.7	**104**	19.5	1.7	**157**	19.0	1.7	**210**	18.5	1.7
52	20.1	1.7	**105**	19.5	1.7	**158**	19.0	1.7	**211**	18.5	1.7
53	20.1	1.7	**106**	19.5	1.7	**159**	19.0	1.7	**212**	18.5	1.7
54	20.1	1.7	**107**	19.5	1.7	**160**	19.0	1.7	**213**	18.5	1.7
55	20.1	1.7	**108**	19.5	1.7	**161**	18.9	1.7	**214**	18.4	1.7
56	20.0	1.7	**109**	19.5	1.7	**162**	18.9	1.7	**215**	18.4	1.7
57	20.0	1.7	**110**	19.5	1.7	**163**	18.9	1.7	**216**	18.4	1.7
58	20.0	1.7	**111**	19.5	1.7	**164**	18.9	1.7	**217**	18.4	1.7
59	20.0	1.7	**112**	19.5	1.7	**165**	18.9	1.7	**218**	18.4	1.7
60	20.0	1.7	**113**	19.4	1.7	**166**	18.9	1.7	**219**	18.4	1.7
61	20.0	1.7	**114**	19.4	1.7	**167**	18.9	1.7	**220**	18.4	1.7
62	20.0	1.7	**115**	19.4	1.7	**168**	18.9	1.7	**221**	18.4	1.7
63	20.0	1.7	**116**	19.4	1.7	**169**	18.9	1.7	**222**	18.4	1.7
64	20.0	1.7	**117**	19.4	1.7	**170**	18.9	1.7	**223**	18.4	1.7
65	20.0	1.7	**118**	19.4	1.7	**171**	18.8	1.7	**224**	18.4	1.7
66	20.0	1.7	**119**	19.4	1.7	**172**	18.8	1.7	**225**	18.4	1.7
67	19.9	1.7	**120**	19.4	1.7	**173**	18.8	1.7	**226**	18.3	1.7
68	19.9	1.7	**121**	19.4	1.7	**174**	18.8	1.7	**227**	18.3	1.7
69	19.9	1.7	**122**	19.3	1.7	**175**	18.8	1.7	**228**	18.3	1.7
70	19.9	1.7	**123**	19.3	1.7	**176**	18.8	1.7	**229**	18.3	1.7
71	19.9	1.7	**124**	19.3	1.7	**177**	18.8	1.7	**230**	18.3	1.7
72	19.9	1.7	**125**	19.3	1.7	**178**	18.8	1.7	**231**	18.3	1.7
73	19.9	1.7	**126**	19.3	1.7	**179**	18.8	1.7	**232**	18.3	1.7
74	19.9	1.7	**127**	19.3	1.7	**180**	18.8	1.7	**233**	18.3	1.7
75	19.9	1.7	**128**	19.3	1.7	**181**	18.7	1.7	**234**	18.3	1.7
76	19.8	1.7	**129**	19.3	1.7	**182**	18.7	1.7	**235**	18.3	1.7
77	19.8	1.7	**130**	19.3	1.7	**183**	18.7	1.7	**236**	18.3	1.7
78	19.8	1.7	**131**	19.2	1.7	**184**	18.7	1.7	**237**	18.2	1.7
79	19.8	1.7	**132**	19.2	1.7	**185**	18.7	1.7	**238**	18.2	1.7
80	19.8	1.7	**133**	19.2	1.7	**186**	18.7	1.7	**239**	18.2	1.7
81	19.8	1.7	**134**	19.2	1.7	**187**	18.7	1.7	**240**	18.2	1.7
82	19.8	1.7	**135**	19.2	1.7	**188**	18.7	1.7	**241**	18.2	1.7
83	19.8	1.7	**136**	19.2	1.7	**189**	18.7	1.7	**242**	18.2	1.7
84	19.8	1.7	**137**	19.2	1.7	**190**	18.7	1.7	**243**	18.2	1.7
85	19.7	1.7	**138**	19.2	1.7	**191**	18.7	1.7	**244**	18.2	1.7
86	19.7	1.7	**139**	19.2	1.7	**192**	18.6	1.7	**245**	18.2	1.7
87	19.7	1.7	**140**	19.2	1.7	**193**	18.6	1.7	**246**	18.2	1.7
88	19.7	1.7	**141**	19.1	1.7	**194**	18.6	1.7	**247**	18.2	1.7
89	19.7	1.7	**142**	19.1	1.7	**195**	18.6	1.7	**248**	18.2	1.7
90	19.7	1.7	**143**	19.1	1.7	**196**	18.6	1.7	**249**	18.2	1.7
91	19.7	1.7	**144**	19.1	1.7	**197**	18.6	1.7	**250**	18.1	1.7
92	19.7	1.7	**145**	19.1	1.7	**198**	18.6	1.7			
93	19.7	1.7	**146**	19.1	1.7	**199**	18.6	1.7			

Tumalo Creek upstream of the mouth (TC 000.25)

Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)
3	21.2	2.0	**56**	13.4	1.8	**109**	11.3	1.7			
4	20.7	2.0	**57**	13.3	1.8	**110**	11.3	1.7			
5	20.5	2.0	**58**	13.2	1.8	**111**	11.3	1.7			
6	20.2	2.0	**59**	13.2	1.8	**112**	11.3	1.7			
7	20.0	2.0	**60**	13.1	1.8	**113**	11.3	1.7			
8	19.8	2.0	**61**	13.0	1.8	**114**	11.3	1.7			
9	19.6	2.0	**62**	13.0	1.8	**115**	11.2	1.7			
10	19.4	2.0	**63**	12.9	1.8	**116**	11.2	1.7			
11	19.2	2.0	**64**	12.8	1.8	**117**	11.2	1.7			
12	19.0	1.9	**65**	12.8	1.8	**118**	11.2	1.7			
13	18.8	1.9	**66**	12.7	1.8	**119**	11.2	1.7			
14	18.7	1.9	**67**	12.7	1.8	**120**	11.2	1.7			
15	18.5	1.9	**68**	12.6	1.8	**121**	11.2	1.7			
16	18.3	1.9	**69**	12.6	1.8	**122**	11.2	1.7			
17	18.1	1.9	**70**	12.5	1.8	**123**	11.2	1.7			
18	17.9	1.9	**71**	12.5	1.8	**124**	11.2	1.7			
19	17.7	1.9	**72**	12.4	1.8	**125**	11.2	1.7			
20	17.6	1.9	**73**	12.4	1.8	**126**	11.2	1.7			
21	17.4	1.9	**74**	12.3	1.8	**127**	11.2	1.7			
22	17.2	1.9	**75**	12.3	1.8	**128**	11.2	1.7			
23	17.1	1.9	**76**	12.2	1.8	**129**	11.2	1.7			
24	16.9	1.9	**77**	12.2	1.8	**130**	11.2	1.7			
25	16.7	1.9	**78**	12.1	1.8	**131**	11.2	1.7			
26	16.6	1.9	**79**	12.1	1.8	**132**	11.1	1.7			
27	16.4	1.9	**80**	12.1	1.8	**133**	11.1	1.7			
28	16.3	1.9	**81**	12.0	1.8	**134**	11.1	1.7			
29	16.2	1.9	**82**	12.0	1.8	**135**	11.1	1.7			
30	16.0	1.9	**83**	11.9	1.8	**136**	11.1	1.7			
31	15.9	1.9	**84**	11.9	1.8	**137**	11.1	1.7			
32	15.7	1.9	**85**	11.9	1.8	**138**	11.1	1.7			
33	15.6	1.9	**86**	11.8	1.7	**139**	11.2	1.7			
34	15.5	1.9	**87**	11.8	1.7	**140**	11.2	1.7			
35	15.4	1.9	**88**	11.8	1.7	**141**	11.2	1.7			
36	15.2	1.9	**89**	11.8	1.7	**142**	11.2	1.7			
37	15.1	1.8	**90**	11.7	1.7	**143**	11.2	1.7			
38	15.0	1.8	**91**	11.7	1.7	**144**	11.2	1.7			
39	14.9	1.8	**92**	11.7	1.7	**145**	11.2	1.7			
40	14.8	1.8	**93**	11.6	1.7	**146**	11.2	1.7			
41	14.7	1.8	**94**	11.6	1.7	**147**	11.2	1.7			
42	14.6	1.8	**95**	11.6	1.7	**148**	11.2	1.7			
43	14.5	1.8	**96**	11.6	1.7	**149**	11.2	1.7			
44	14.4	1.8	**97**	11.5	1.7	**150**	11.2	1.7			
45	14.3	1.8	**98**	11.5	1.7	**151**	11.2	1.7			
46	14.2	1.8	**99**	11.5	1.7	**152**	11.2	1.7			
47	14.1	1.8	**100**	11.5	1.7	**153**	11.2	1.7			
48	14.0	1.8	**101**	11.5	1.7	**154**	11.2	1.7			
49	13.9	1.8	**102**	11.4	1.7	**155**	11.2	1.7			
50	13.8	1.8	**103**	11.4	1.7	**156**	11.2	1.7			
51	13.8	1.8	**104**	11.4	1.7	**157**	11.2	1.7			
52	13.7	1.8	**105**	11.4	1.7	**158**	11.3	1.7			
53	13.6	1.8	**106**	11.4	1.7						
54	13.5	1.8	**107**	11.3	1.7						
55	13.4	1.8	**108**	11.3	1.7						

APPENDIX B Estimated temperatures at five 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)	**140**	**160**	**180**	**200**	**220**	**250**	**Flow (cfs)**	**140**	**160**	**180**	**200**	**220**	**250**
10	19.2	19.0	18.8	18.6	18.4	18.2	**56**	17.5	17.5	17.5	17.4	17.4	17.3
11	19.2	19.0	18.8	18.6	18.4	18.2	**57**	17.5	17.5	17.4	17.4	17.3	17.2
12	19.1	19.0	18.8	18.6	18.4	18.2	**58**	17.4	17.4	17.4	17.4	17.3	17.2
13	19.1	18.9	18.8	18.6	18.4	18.2	**59**	17.4	17.4	17.4	17.3	17.3	17.2
14	19.1	18.9	18.8	18.6	18.4	18.2	**60**	17.3	17.4	17.3	17.3	17.3	17.2
15	19.1	18.9	18.7	18.6	18.4	18.2	**61**	17.3	17.3	17.3	17.3	17.2	17.1
16	19.1	18.9	18.7	18.6	18.4	18.2	**62**	17.3	17.3	17.3	17.2	17.2	17.1
17	19.0	18.9	18.7	18.5	18.4	18.1	**63**	17.2	17.2	17.2	17.2	17.2	17.1
18	19.0	18.8	18.7	18.5	18.4	18.1	**64**	17.2	17.2	17.2	17.2	17.1	17.1
19	19.0	18.8	18.7	18.5	18.3	18.1	**65**	17.1	17.2	17.2	17.2	17.1	17.0
20	19.0	18.8	18.6	18.5	18.3	18.1	**66**	17.1	17.1	17.1	17.1	17.1	17.0
21	18.9	18.8	18.6	18.5	18.3	18.1	**67**	17.1	17.1	17.1	17.1	17.1	17.0
22	18.9	18.7	18.6	18.4	18.3	18.1	**68**	17.0	17.1	17.1	17.1	17.0	17.0
23	18.9	18.7	18.6	18.4	18.3	18.1	**69**	17.0	17.0	17.0	17.0	17.0	16.9
24	18.8	18.7	18.5	18.4	18.2	18.0	**70**	16.9	17.0	17.0	17.0	17.0	16.9
25	18.8	18.7	18.5	18.4	18.2	18.0	**71**	16.9	17.0	17.0	17.0	16.9	16.9
26	18.8	18.6	18.5	18.3	18.2	18.0	**72**	16.9	16.9	16.9	16.9	16.9	16.9
27	18.7	18.6	18.5	18.3	18.2	18.0	**73**	16.8	16.9	16.9	16.9	16.9	16.8
28	18.7	18.6	18.4	18.3	18.2	18.0	**74**	16.8	16.9	16.9	16.9	16.9	16.8
29	18.6	18.5	18.4	18.3	18.1	17.9	**75**	16.8	16.8	16.8	16.9	16.8	16.8
30	18.6	18.5	18.4	18.2	18.1	17.9	**76**	16.7	16.8	16.8	16.8	16.8	16.8
31	18.6	18.5	18.3	18.2	18.1	17.9	**77**	16.7	16.8	16.8	16.8	16.8	16.7
32	18.5	18.4	18.3	18.2	18.1	17.9	**78**	16.6	16.7	16.8	16.8	16.8	16.7
33	18.5	18.4	18.3	18.2	18.0	17.8	**79**	16.6	16.7	16.7	16.7	16.7	16.7
34	18.4	18.3	18.2	18.1	18.0	17.8	**80**	16.6	16.7	16.7	16.7	16.7	16.7
35	18.4	18.3	18.2	18.1	18.0	17.8	**81**	16.5	16.6	16.7	16.7	16.7	16.6
36	18.4	18.3	18.2	18.1	18.0	17.8	**82**	16.5	16.6	16.6	16.7	16.7	16.6
37	18.3	18.2	18.1	18.0	17.9	17.8	**83**	16.5	16.6	16.6	16.6	16.6	16.6
38	18.3	18.2	18.1	18.0	17.9	17.7	**84**	16.4	16.5	16.6	16.6	16.6	16.6
39	18.2	18.2	18.1	18.0	17.9	17.7	**85**	16.4	16.5	16.6	16.6	16.6	16.6
40	18.2	18.1	18.0	17.9	17.8	17.7	**86**	16.4	16.5	16.5	16.5	16.6	16.5
41	18.1	18.1	18.0	17.9	17.8	17.7	**87**	16.3	16.4	16.5	16.5	16.5	16.5
42	18.1	18.0	18.0	17.9	17.8	17.6	**88**	16.3	16.4	16.5	16.5	16.5	16.5
43	18.1	18.0	17.9	17.8	17.8	17.6	**89**	16.3	16.4	16.4	16.5	16.5	16.5
44	18.0	18.0	17.9	17.8	17.7	17.6	**90**	16.2	16.3	16.4	16.4	16.5	16.4
45	18.0	17.9	17.9	17.8	17.7	17.6	**91**	16.2	16.3	16.4	16.4	16.4	16.4
46	17.9	17.9	17.8	17.8	17.7	17.5	**92**	16.2	16.3	16.4	16.4	16.4	16.4
47	17.9	17.9	17.8	17.7	17.6	17.5	**93**	16.2	16.3	16.3	16.4	16.4	16.4
48	17.8	17.8	17.8	17.7	17.6	17.5	**94**	16.1	16.2	16.3	16.3	16.4	16.4
49	17.8	17.8	17.7	17.7	17.6	17.5	**95**	16.1	16.2	16.3	16.3	16.3	16.3
50	17.8	17.7	17.7	17.6	17.6	17.4	**96**	16.1	16.2	16.3	16.3	16.3	16.3
51	17.7	17.7	17.7	17.6	17.5	17.4	**97**	16.0	16.2	16.2	16.3	16.3	16.3
52	17.7	17.7	17.6	17.6	17.5	17.4	**98**	16.0	16.1	16.2	16.3	16.3	16.3
53	17.6	17.6	17.6	17.5	17.5	17.3	**99**	16.0	16.1	16.2	16.2	16.3	16.3
54	17.6	17.6	17.5	17.5	17.4	17.3	**100**	16.0	16.1	16.2	16.2	16.2	16.2
55	17.5	17.5	17.5	17.5	17.4	17.3							