Upper Deschutes Watershed Council

Technical Report

Middle Deschutes River Instream Flow Restoration and Temperature Responses 2001-2021

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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 (TID's) diversion (lower Tumalo Creek) as a priority because very low summer flows in these two reaches consistently result in summer water temperatures that exceed the Oregon Department of Environmental Quality (ODEQ) standard established to protect salmon and trout rearing and migration.

To evaluate the effectiveness and potential of stream flow restoration efforts in reducing temperature in the middle Deschutes River, the DRC, its funders, and other partners have been interested in understanding: 1) how stream flow has changed with cumulative stream flow restoration actions; 2) how stream temperature has changed with cumulative stream flow restoration actions; 3) how stream flow affects stream temperature; and 4) how stream flow restoration in the Deschutes River and Tumalo Creek can achieve the greatest reduction in stream temperature. Since 2008 the DRC has partnered with the Upper Deschutes Watershed Council (UDWC) to conduct temperature monitoring to investigate observed and potential temperature changes associated with stream flow restoration projects. This ongoing monitoring effort incorporates data collected from 2001 to 2021 and builds off analyses developed for the Upper Deschutes Basin Study to address the following key questions:

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

   Key findings:

   - July median stream flow in the middle Deschutes at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs to 158 cfs.
   - July median flows in the middle Deschutes from 2013 to 2021 (129-136 cfs) represent a marked decrease from 2010 to 2012 flows (148 to 158 cfs), and were similar to that observed in 2009 (131 cfs).
   - July median flows in the middle Deschutes at North Canal Dam in the last three years (2019-2021) and August median flows in the last two years (2020-2021) were lower than any median for these months recorded since 2008.
   - August 2021 median flow in the middle Deschutes at North Canal Dam was lower than any median for this month recorded since 2007.
   - Stream flow restoration in Tumalo Creek has increased July and August median flows to new highs of 25 cfs and 24 cfs respectively (17.9 cfs protected in both months) in 2020; 2021 July and August median flows were slightly lower but approximated the 17.5 cfs protected in both months.

July median stream flow in the middle Deschutes at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs to 158 cfs. July median streamflow in the middle Deschutes dropped in 2013 to 129 cfs and from 2013 to 2018 approximated the 2009 July median flow of 131 cfs, fluctuating between 129 and 136 cfs, commensurate with reductions in flow leased instream and in flow left instream by irrigation districts under a voluntary agreement. In 2019 July median flow in the middle Deschutes dropped to 122 cfs, the lowest median observed since 2008; 2020 and 2021 July medians at 123 and 127 cfs remained below the 2009, 131 cfs July median. Deschutes River flows have historically closely tracked or exceeded flow protected instream, which increased from 107 cfs in 2008 to 158 cfs in 2012, dropped to 124 cfs in 2013, and has since fluctuated between 126 and 134 cfs; since 2019 July median flow has averaged 6 cfs lower than the July median flow protected. July median stream flow and median protected flow in the middle Deschutes from 2013 to 2021 represent a marked decrease from 2010-2012 flows. Notably, moderate to exceptional drought characterized five of the eight years between 2013 and 2021 while 2010-2012 were characterized by milder drought or normal precipitation. The median July flow protected instream was 128 cfs in 2020 and 134 cfs in 2021; the median recorded average daily flow in July of each year was 123 cfs and 127 cfs, respectively.

Stream flow in Tumalo Creek exceeded flow protected instream in most years, including in July and August 2020 and in July 2021. July and August 2020 median flows were 25 and 24 cfs respectively with 17.9 cfs protected instream in both months; July 2021 median flow was 19 cfs with 17.9 cfs protected instream, while the August 2021 median flow fell just shy of the 17.9 cfs protected, at 16 cfs. July median flow in Tumalo increased from 5 cfs in 2001 to a high of 58 cfs in 2012, in most years hovering between 12 and 15 cfs. Flows protected instream with pre-1961 priority dates range from 7.8 cfs in 2009 to 17.9 cfs in 2020.

2) Temperature status and trend: What was the status of middle Deschutes River and Tumalo Creek Seven-Day Average Daily Maximum (7DADM) stream temperature in 2020 and 2021 relative to the State of Oregon 18°C (64°F) standard protecting salmon and trout rearing and migration, and in relation to previous years?

Key findings:

- Stream temperature at Lower Bridge on the middle Deschutes River (DR 133.50) exceeded the state temperature standard for just over three months between April and September 2020 and for almost four months (110 days) between April and September 2021. The number and percent of days exceeding the state temperature standard between April and September 2021 is higher than in any year except 2001.
- Conversely, stream temperature at Lower Bridge on the middle Deschutes River (DR 133.50) met the state temperature standard for almost two months between April and September 2020 and for just over a month between April and September 2021. The number and percent of days meeting the state temperature standard between April and September 2021 is lower than in any year except 2001.

- Stream temperature at four sites spanning 32 miles downstream of Bend exceeded the 18°C state standard for for 48-63% of days between April 30 and September 21 in 2020 and for 44-76% of days between April 30 and September 21 in 2021.
- July stream temperatures at Lower Bridge (DR 133.50) downstream of Bend from 2013 to 2020 were lower than from 2001 to 2007, but were on average almost 2.5°C warmer than from 2008 to 2012.
- July stream temperatures at Lower Bridge (DR 133.50) were lower and exceeded 24°C less frequently from 2013 to 2020 than from 2001 to 2007.
- July stream temperatures at Lower Bridge in 2021 mark a return to pre-2008 temperatures, with all 7DADM records between July 1 and 22, 2021 exceeding 24°C, despite July median flows at North Canal Dam (127 cfs) and below the Tumalo Irrigation District diversion (19.3 cfs) similar to or higher than in years prior to 2008.
- Although the increase in stream temperature and in days exceeding 24°C from 2013 to 2021 coincides with the 2013 drop in flows protected in the middle Deschutes, the magnitude of the change in stream temperature (degrees rather than the tenths of degrees estimated using mass balance) and the weak relationship between Deschutes River flow and temperature above the confluence with Tumalo Creek ($R^2 = 0.22$) point to factors other than reduced Deschutes River streamflow to explain increasing stream temperatures from 2013 to 2021, including air temperature ($R^2 = 0.45$).
- Stream temperatures exceeding 24°C for 28% of days (40 days) in 2021 represent the highest percentage and number of days above the lethal threshold in any year for which data are available since 2001.
- Stream temperature at the mouth of Tumalo Creek (TC 000.25) met the 18°C state temperature standard for only 37% of days, the lowest percent on record for this site, and exceeded the standard for 63% of days between April 30 and September 21 in 2021. Stream temperature at the mouth of Tumalo Creek met the 18°C standard for 81-100% of days between April 30 and September 21 from 2006 to 2020.
- Stream flow restoration actions targeted at reducing stream temperatures specifically during the July 2nd to August 5th period when temperatures most often exceed 24°C, and continuing to invest in stream flow restoration in Tumalo Creek, will attenuate the worst effects of low flows on stream conditions for fish.

Stream temperature in the middle Deschutes River exceeded the 18°C state standard protecting salmon and trout rearing and migration for 48-63% of days between April 30 and September 21 in 2020 and for 44-76% of days between April 30 and September 21 in 2021, at all four Deschutes River monitoring locations downstream of Bend.

Temperatures recorded at Lower Bridge (DR 133.50) in 2020 and 2021 continued to exceed the state standard for more days than in most years since the earliest days of stream flow restoration in 2001. In 2021 7DADM temperatures exceeded the 24°C lethal threshold for more days than in any other year, and for more days than the percent and number that met the 18°C state standard. From 2013 to 2019 stream temperatures exceeded 24°C as early as July 2 and as late as August 5. In 2021 the 7DADM at Lower Bridge first exceeded 24°C on June 24 and last exceeded 24°C on August 15. Stream flow restoration actions targeted at reducing stream temperatures specifically during the period when temperatures most often exceed 24°C will attenuate the worst effects of low flows on stream conditions for fish.

Although stream temperatures continue to exceed 24°C at Lower Bridge, the number and percent of days for which temperatures at Lower Bridge were above 24°C were lower from 2013 to 2020 than prior to 2008, signaling a reduction in the amount time each year during which fish are exposed to potentially lethal stream conditions. This reduction coincides with increases in protected flow and observed stream flow in the Deschutes River at North Canal Dam and in Tumalo Creek compared to 2008 and earlier years. However, the number and percent of days for which temperatures at Lower Bridge were above 24°C were higher from 2013 to 2020 than from 2008 to 2012. It remains to be seen whether the high percentage of days exceeding 24°C in 2021 was an anomaly or a harbinger of a new normal.

Despite worse stream temperature conditions since 2018 than in most earlier years for which data are available, stream flow in the Deschutes downstream of North Canal Dam, in Tumalo Creek downstream of the TID diversion, and in the Deschutes downstream of the confluence with Tumalo Creek was roughly equivalent to or higher than in years with fewer days exceeding 18°C and 24°C, pointing to other factors influencing stream temperature. Increases in stream temperatures observed between North Canal Dam and the confluence of the Deschutes River and Tumalo Creek, and a decreasing R^2 value for the relationship between temperature and flow at DR 160.25 upstream of the confluence, also indicate less variation in stream temperature at DR 160.25 is being explained by stream flow and could signal the effects of a warmer climate on Deschutes River flow stored in Wickiup and Crane Prairie reservoirs. Additionally, changes to Wickiup Reservoir operations resulting in lower summer reservoir levels beginning in 2018 could be affecting stream temperature. Preliminary review of drought data from Deschutes County from 2001-2021 suggest drought as another possible driver of stream temperature.

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

Key findings:

- July and August stream temperatures at Lower Bridge and three other temperature monitoring sites downstream of Bend decreased as July and August median flows increased from 2000-2012
- Stream temperatures in Tumalo Creek were substantially lower at the highest flow than at the lowest flow recorded in Tumalo Creek; temperatures in the middle Deschutes

were moderately lower at the highest flow than at the lowest flow recorded in the Deschutes River below North Canal Dam.

- Regressions of stream flow and temperature data show lower stream temperatures at higher stream flows, but the strength of the relationship varies with site and flow source.
- These results suggest higher stream flows in Tumalo Creek and in the middle Deschutes River contribute to lower stream temperatures.
- The observed success of increased stream flow resulting in lower stream temperatures in Tumalo Creek suggests that the single most important thing we can do to reduce stream temperatures in Tumalo Creek and the middle Deschutes River is to continue to boldly invest in stream flow restoration in Tumalo Creek.

Multiple lines of evidence show reduced stream temperatures at the higher stream flows achieved through stream flow restoration in the middle Deschutes River and Tumalo Creek. July and August stream temperatures at DR 133.50 decreased alongside increasing July median flows in the middle Deschutes and in Tumalo Creek from 2001-2012. Comparison of seven-day average daily maximum (7DADM) temperatures at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded from 2002 to 2015 show that moderately (in the Deschutes River) to substantially (in Tumalo Creek) lower stream temperatures occurred at higher flows. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2021 at DR 160.25, DR 160.00, and TC 000.25 show temperatures decreasing as flows increase. Stream flow from the Deschutes River or from Tumalo Creek explained 22%, 50%, and 70% of variation in stream temperature in the middle Deschutes at DR 160.25, at DR 160.00, and at the mouth of Tumalo Creek, respectively, providing statistical support for the role of higher stream flows in reducing stream temperature.

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

   Key findings:

   - Air temperature, not stream flow, explained the greatest proportion of variation in stream temperature at DR 160.25, at 45%; stream flow explained only 22% of the variation and the two together explained 53% of the variation. This relationship highlights the need for reservoir and upstream management that reduce the temperature of river water at and above North Canal Dam.
   - Restoring as much flow as possible in Tumalo Creek in July will achieve the maximum reduction possible in stream temperature in the middle Deschutes downstream of Tumalo Creek.
   - Based on the regression of DR 160.00 stream temperature and Tumalo Creek stream flow, increasing the 2021 July median protected flow of 17.5 cfs by 20 cfs, to 38 cfs,

would achieve a 0.9°C± 2.0°C (prediction interval) temperature reduction at DR 160.00, from 19.4°C to 18.5°C. These numbers do not change much (by tenths of a degree) as Deschutes River flows increase up to 175 cfs.

- Forty-nine (49) cfs in Tumalo Creek and 134 cfs in the Deschutes River below North Canal Dam in July is estimated to achieve, on average, 18°C ± 2.1°C (prediction interval) in the Deschutes River immediately downstream of the confluence
- Because the Deschutes River is on average 3°C warmer at Lower Bridge Road than immediately below the confluence of Tumalo Creek and the Deschutes River, often resulting in July temperatures that are lethal to redband trout, it is critically important to achieve the greatest possible reduction in stream temperature below this confluence.

Flow scenarios developed from regression and mass balance equations indicate that allocating the maximum possible Tumalo Creek flow to instream use during July will achieve the greatest reduction in stream temperature in the middle Deschutes. At the 134 cfs protected instream in the Deschutes River at North Canal Dam as of 2021, 49 cfs from Tumalo Creek is estimated to produce an average 7DADM temperature of 18°C ± 2.1°C in the Deschutes immediately downstream of the confluence with Tumalo Creek. While this scenario would significantly improve temperatures in the Deschutes River, the approximately 3°C warming that typically occurs at these flows between the confluence of the Deschutes and Tumalo Creek and DR 133.50 means that some reaches along approximately 26 miles of the middle Deschutes River would continue to exceed the state temperature standard by up to seven degrees (at 49 cfs in Tumalo Creek), with potential peak temperatures of 23.1°C or higher.

Because stream flow explains only 22% of the variation in stream temperature at DR 160.25, in the Deschutes River upstream of Tumalo Creek, increasing flow at North Canal Dam be ineffective to cool stream temperature. Rather, managing reservoirs in ways that reduce the temperature of river water coming into Bend should be explored as an alternative approach to achieving reductions in stream temperature in the middle Deschutes.

Acknowledgments

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Abbreviations

Organizations

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

Terminology

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

1 Introduction

The middle Deschutes River watershed (formally designated as the McKenzie Canyon – Deschutes River watershed) is located in the Deschutes Basin, Oregon, and is bordered by the Metolius River, Whychus Creek, Tumalo Creek, and Upper Deschutes River watersheds (Figure 1). The middle Deschutes River from the North Canal Diversion Dam to Whychus Creek has been listed since 2004 as a temperature impaired waterway under Clean Water Act Section 303(d) for not meeting State of Oregon water temperature standards for salmon and trout rearing and migration (ODEQ 2020).

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

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

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

Tumalo Creek stream temperature and flow data from 2001 through 2021 to address the following questions: 1) How have flows in the middle Deschutes River and Tumalo Creek changed with cumulative stream flow restoration actions? 2) What was the status of middle Deschutes River water temperature in 2016 relative to the State of Oregon 18°C (64°F) standard and in relation to previous years?; 3) Have cumulative increases in stream flow resulted in reduced water temperatures at key locations along the middle Deschutes River; and 4) What flow scenarios for the Deschutes River and Tumalo Creek will achieve the 18°C temperature standard in the Deschutes River immediately below the confluence with Tumalo Creek? We present 2020 and 2021 temperature results and discuss implications for stream flow restoration.

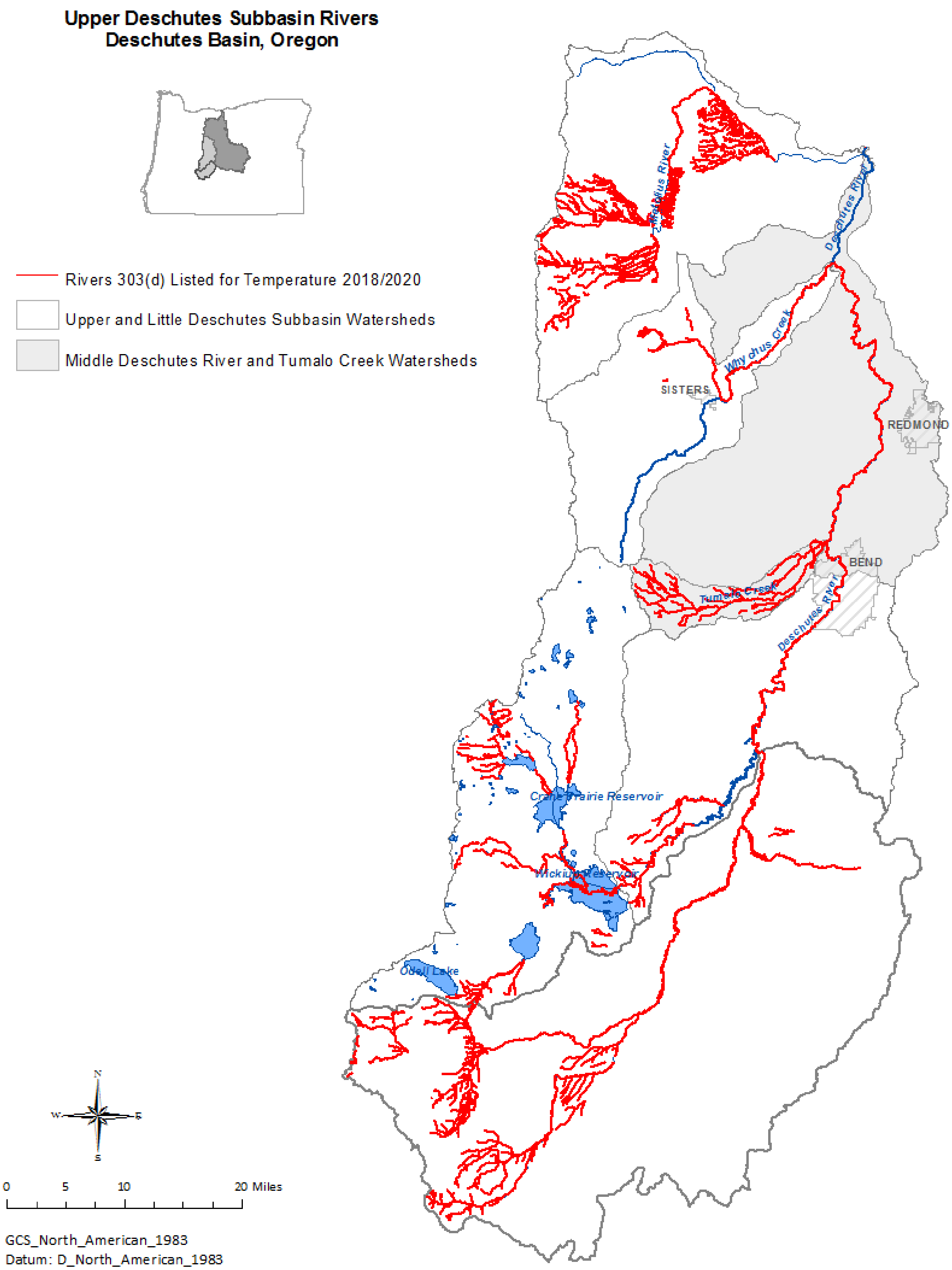


Figure 1. Upper Deschutes and Little Deschutes subbasin watersheds 303(d) listed as exceeding state temperature standards for fish and aquatic life. Applicable fish and aquatic life temperature criteria differ by designated use (species and life history) and water body and DEQ spatial data do not differentiate among those criteria.

2 Methods

2.1 Data Collection

2.1.1 Stream Temperature

UDWC collected and compiled continuous water temperature data for 2001-2021 from six stream temperature monitoring stations on the Deschutes River and one monitoring station on Tumalo Creek (Table 1; Figure 2), using Vemco and HOBO dataloggers rated to an accuracy of 0.5°C and 0.2°C, respectively. Tumalo Creek (TC 000.25) continuous temperature data for 2004-2018 were obtained from the City of Bend; UDWC began collecting continuous temperature data at this site in 2019. Data are not available for all years due to equipment failure or no monitoring (Table 2). UDWC operates per its *Water Quality Monitoring Program Standard Operating Procedures* (UDWC 2008a) under a Quality Assurance Project Plan approved by DEQ in 2008 and an addendum to this plan approved in 2015 (UDWC 2008b, UDWC 2015).

2.1.2 Stream Flow

We obtained July median daily instream water rights data for the Deschutes River and for Tumalo Creek from DRC. We refer to July median daily instream water rights as median protected flow to differentiate from the state instream water right. July median daily instream water right data are available from 2007-2021 for the Deschutes River, and from 2006-2021 for Tumalo Creek. Tumalo Creek July median daily instream water rights exclude water rights with a priority date junior to 1961, which as a result of their late priority date are never delivered.

UDWC obtained average daily stream flow (QD) data for the Deschutes River and Tumalo Creek from the Oregon Water Resources Department (OWRD 2021) (Table 1; Figure 2). All Deschutes River flow data through September 2018 and Tumalo Creek flow data through September 2008 and from October 2009 through September 2011 are considered published; Deschutes River flow data from October 1, 2018 through 2021 and Tumalo Creek flow data from October 2008 through September 2009 and from October 2011 through 2021 included in this report are considered provisional, preliminary or raw and subject to change.

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

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

Table 2. Summary of available July temperature data 2001-2021

Station ID	Description	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
DR 217.25	Pringle Falls	-	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x
DR 181.50	Benham Falls	-	-	x	-	x	x	x	x	x	x	x	x	x	x	x	-	x	-	-	x	x
DR 164.75	u/s Riverhouse Hotel	-	-		x	x	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
DR 160.25	u/s Tumalo Creek	-	x	x	x	x	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
DR 160.00	d/s Tumalo Boulder Field	-	-	-	-	x	x	x	x	x	x	x	x	-	x	x	-	x	x	x	x	x
DR 133.50	Lower Bridge	x	x	-	x	x	x	x	x	-	x	x	x	x	x	-	x	x	-	x	x	x
TC 000.25	u/s of Tumalo Creek mouth	-	-	-	x	x	-	x	-	x	x	x	x	x	x	x	-	x	-	x	x	x

x *Data available for analysis*

\- *Limited or no data available for analyses*

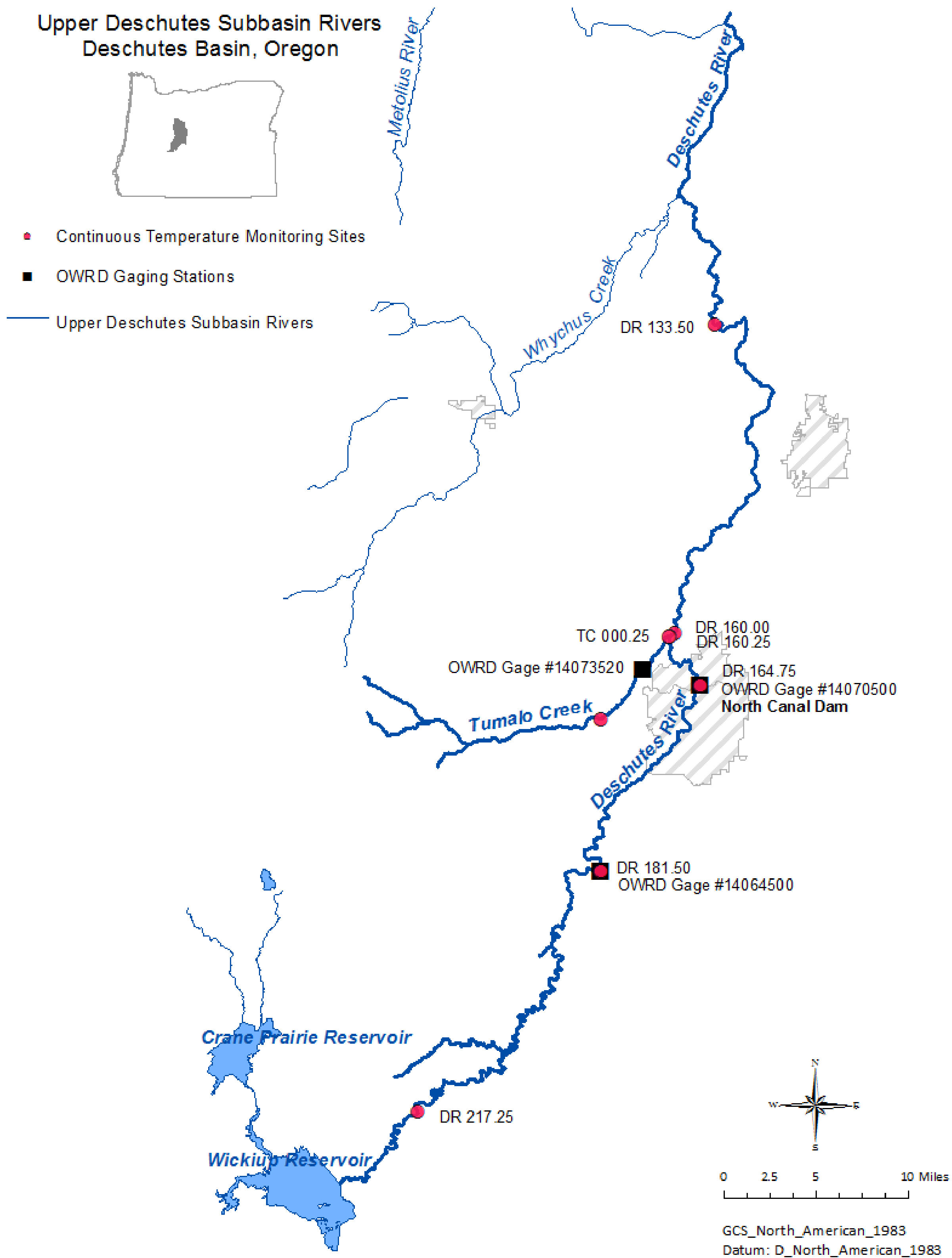


Figure 2. UDWC continuous temperature monitoring sites and OWRD stream flow gages on the middle and upper Deschutes River and on Tumalo Creek.

2.2 Data Analysis

2.2.1 Stream Flow Status and Trend

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

2.2.2 Stream Temperature Status and Trend

We used the Oregon Department of Environmental Quality (ODEQ) Hydrostat Simple spreadsheet (ODEQ, 2010) to calculate the seven-day moving average daily maximum (7DADM) temperature, the statistic used by the State of Oregon to evaluate stream temperatures. The State of Oregon water temperature standard for salmon and trout rearing and migration identifies a 7DADM threshold of 18°C/64°F (OAR 340-041-0028). We evaluated 7DADM temperatures from 2001-2021 in relation to the state standard of 18°C to describe changes in temperature in the middle Deschutes River since 2001 and to assess progress toward the 18°C state standard for salmonid rearing and migration.

To describe the proportion of the irrigation season when stream temperatures exceeded the 18°C state standard between 2001 and 2021, we calculated the number and percent of days in each year between April 30 and September 21 when the 7DADM stream temperature met the 18°C standard, exceeded the 18°C standard, or exceeded the 24°C lethal threshold. We selected April 30 and September 21 as the earliest and latest calendar dates when stream temperatures have exceeded 18°C. 7DADM datasets for some sites and years are incomplete because of data loss due to datalogger stranding, damage or loss. We reviewed data for years for which fewer than the 145 days between April 30 and September 21 were available. For some data gaps it was possible to extrapolate with high confidence whether 7DADM temperatures met or exceeded 18°C at a given site from temperature trends at upstream or downstream dataloggers. Where possible to do so with high confidence, we extrapolated temperatures to be above or below 18°C. Where temperature data were missing and adjacent data available (dates and sites) did not suggest stream temperatures exceeding 24°C it was not possible to extrapolate whether stream temperatures exceeded 24°C. Accordingly, all percentages for days exceeding 24°C represent recorded (not extrapolated) data values.

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

2.2.3 Effect of Stream Flow on Stream Temperature

To evaluate the effectiveness of increasing flows through stream flow restoration to reduce stream temperature in the middle Deschutes River and in Tumalo Creek, we 1) compared 2001-2021 July 7DADM stream temperatures at DR 133.50 to July median stream flow at the Tumalo Creek (OWRD gage #14073520) and Deschutes Below Bend (OWRD gage #14070500) stream gages, and 2) used regressions of 2001-2021 July stream temperature at DR 160.25, DR 160.00, and at TC 000.25, and flow data from the same two gages to illustrate the relationships between temperature and flow at the three sites. Methods for regressions, which were also used for stream flow target analyses, are described below.

2.2.4 Stream Flow Targets

We used regressions of 2001-2021 temperature and stream flow data and a mass balance approach to develop flow scenarios for the middle Deschutes River and Tumalo Creek that will achieve the greatest temperature reduction in the Deschutes below the confluence with Tumalo Creek. Because the objective of our regression analysis is to develop flow scenarios, we have not historically incorporated air temperature, which, although known to influence stream temperature, is beyond the scope restoration partners are able to address through stream flow restoration. However, as previous regressions of stream temperature and Deschutes River stream flow have explained relatively low proportions (< 56%) of the variation in stream temperature at DR 160.25, the Deschutes River above Tumalo Creek, and at DR 160.00, the Deschutes River below Tumalo Creek, for our 2020-2021 analysis we incorporated air temperature data as well as Tumalo Creek minimum daily flow to investigate the effect of these two factors on stream temperature in the Deschutes River at two sites on the Deschutes and one site on Tumalo Creek.

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

Because regression analysis has shown stream flow in the Deschutes River below North Canal Dam to explain only a small proportion of the variation in stream temperature at DR 160.25 upstream of the confluence with Tumalo Creek, we include a third regression, of stream temperature data from DR 160.00 on the Deschutes downstream of Tumalo Creek and stream flow from OWRD gage #14073520, Tumalo Creek Below Tumalo Feed Canal, to evaluate the relationship between stream flow in Tumalo Creek downstream of the diversion and in the Deschutes River immediately downstream of the confluence, and as an alternative approach to estimate stream temperature at DR 160.00 below the confluence. In addition to the average daily flow from Tumalo Creek downstream of the diversion we used the minimum daily flow, as we expect high stream temperatures to occur in part in response to the lowest flows, and average daily flow can often mask the lowest flows experienced on a given day.

We used air temperature data from the Tumalo Ridge Oregon RAWS (Regional Automated Weather Stations) station (WRCC 2022). Where Tumalo Ridge air temperature data were incomplete we used air temperature data from the nearby Lava Butte station to create a dataset with the maximum possible number of values corresponding to 7DADM stream temperature values. We calculated the 3-day moving average daily maximum air temperature (Tair3) as the average of the daily maximum temperature for a given date and the two days prior.

We restricted data included in the analysis to one month of the year to reduce the effect of intra-annual seasonal variation in the analysis (Helsel & Hirsch, 1991) and selected July as the historically hottest month for water temperatures in the Deschutes River, and the month during which stream flow restoration will most improve stream conditions (UDWC unpublished data). For each site, we included all July dates for which stream temperature, stream flow, and air temperature data were available. We used R open-source statistical software (R Core Team, 2020) to perform linear, quadratic, and cubic regressions for each site, using the 7DADM stream temperature with each of two flow metrics (average daily flow and the natural logarithm of average daily flow) and each of two air temperature metrics (daily maximum air temperature and 3-day moving average daily maximum air temperature; Table 3). For regressions using Tumalo Creek flow data, we included two additional flow metrics (minimum daily flow and the natural logarithm of minimum daily flow). In previous years we had also evaluated the daily maximum stream temperature with each flow metric but because regression models using the 7DADM stream temperature consistently performed better than models using the daily maximum stream temperature, we did not evaluate the latter models in this analysis.

The best regression model for DR 160.25 explained only 45% of the variation in stream temperature, and the best stream flow regression model for this site explained only 22% of the variation in stream temperature. For this site we additionally performed a multiple linear regression of 7DADM on average daily flow and 3-day moving average air temperature (7DADM ~ QD + Tair3) to evaluate whether this model provided a better fit than the other regression models.

Table 3. Nineteen possible regression models evaluated for the Deschutes River at DR 160.25, Tumalo Creek at TC 000.25, and for the Deschutes River at DR 160.00 with flow from Tumalo Creek below the diversion. Minimum daily flow models were evaluated for TC 000.25 and DR 160.00 but not for DR 160.25.

	Regression Model
1.	7DADM ~ QD
2.	7DADM ~ QD + $(QD)^2$
3.	7DADM ~ QD + $(QD)^2$ + $(QD)^3$
4.	7DADM ~ LnQD
5.	7DADM ~ LnQD + $(LnQD)^2$
6.	7DADM ~ LnQD + $(LnQD)^2$ + $(LnQD)^3$

7. 7DADM ~ MIN
8. 7DADM ~ MIN + $(MIN)^2$
9. 7DADM ~ MIN + $(MIN)^2$ + $(MIN)^3$
10. 7DADM ~ LnMIN
11. 7DADM ~ LnMIN + $(LnMIN)^2$
12. 7DADM ~ LnMIN + $(LnMIN)^2$ + $(LnMIN)^3$
13. 7DADM ~ Tair
14. 7DADM ~ Tair + $(Tair)^2$
15. 7DADM ~ Tair + $(Tair)^2$ + $(Tair)^3$
16. 7DADM ~ Tair3
17. 7DADM ~ Tair3 + $(Tair3)^2$
18. 7DADM ~ Tair3 + $(Tair3)^2$ + $(Tair3)^3$
19. 7DADM ~ QD + Tair3

We used the extractAIC function in R to generate Akaike Information Criterion (AIC) values for each regression model. AIC values rank models relative to each other on the basis of goodness of fit and number of parameters, with values decreasing as models improve; the lowest value indicates the best model. A difference of two or more between AIC values for two models denotes a statistically better model. For each site we evaluated R-squared (R^2), residual standard error (S), and AIC values to select the model that resulted in the best fit to the observed data; for the best model we evaluated residuals plots and normal probability plots to assess normality of residuals and verify the data meet model assumptions, and plotted regression data with the selected model and prediction intervals for each of the three sites evaluated.

For each site, we reported the regression equations for the three top models. In R, we used the best regression model for stream flow for each site to calculate the estimated temperature and 95% prediction interval for all flows within the observed range (**Appendix A**). The 95% prediction interval (PI) is calculated as:

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

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

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

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

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

Where:

Q = average daily flow
T = 7DADM temperature
$_T$ = Tumulo Creek (TC 000.25)

$_D$ = Deschutes River (DR 160.25)
$_{D2}$ = Deschutes River (DR 160.00)

We calculated stream temperatures for all Tumalo Creek flows between 10 and 100 cfs at Deschutes River flows of 127, 134, 150, 175, and 200 cfs. Ten cfs approximates minimum July flows in Tumalo Creek; 100 cfs exceeds average natural July flows and is well above the ODFW instream water right of 32 cfs. One hundred and thirty-four cfs approximates the median flow protected instream in the middle Deschutes in July 2021, and 127 cfs approximates the median of average daily flows recorded in the middle Deschutes in July 2021.

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

3 Results

3.1 Stream Flow Status and Trend

July and August median average daily flow in Tumalo Creek and the Deschutes River has increased with median protected flow (Figure 3). Efforts to restore stream flow in the Deschutes River downstream of Bend began in 2001; data documenting flows protected instream are available for the middle Deschutes River for July from 2003 to 2019 and for August from 2002 to 2019, and for Tumalo Creek for July from 2006 to 2019 and for August from 2005 to 2019.

July and August median stream flow in the Deschutes River at North Canal Dam more than tripled from 2002 to 2012, from 47 cfs in both months to 158 cfs in July and 151 cfs in August, alongside increases in protected flow (Table 4, Figure 3). Protected flow dropped sharply from 2012 to 2013, from 160 cfs to 126 cfs in July and from 163 cfs to 134 cfs in August, with an accompanying decrease in observed flow, reflecting reductions in flow leased instream and less flow left instream by irrigation districts under a voluntary agreement. Since 2013 protected flows have fluctuated between 125 and 134 in July (in 2013 and 2021, respectively) and between 127 and 136 in August (in 2019 and 2015, respectively); observed flows have typically closely tracked protected flows. In 2020, 128 cfs were protected in July and 130 cfs were protected in August; in 2021, 134 cfs were protected in both July and in August. Median flows in July and August 2020 were 123 cfs and 119 cfs, respectively. The 2020 July median was lower than in any year since 2010 except 2019; the 2020 August median was lower than in any year since 2008. In 2021, the July median flow recovered to 127 cfs, while the August median flow fell even farther from the 2020, post-2008 low of 119 cfs, to 99 cfs, 35 cfs below the median flow protected instream for this month. Whereas from 2013 to 2016 July and August median streamflow in the middle Deschutes approximated 2009 levels, in four of the last five years (2017-2021) median July and August flows have been lower than any median for these months recorded since 2009.

July and August median average daily stream flow in Tumalo Creek has been equivalent to or exceeded flow rates protected instream in most years. July median average daily flow in the creek increased from 5 cfs in 2001 to a high of 58 cfs in 2012, hovering between 12 and 15 cfs in most years; August median average daily flow increased from 6 cfs in 2001 to a new high of 24 cfs in 2020, exceeding flow protected instream (Table 4, Figure 3). July and August senior water rights protected instream with pre-1961 priority dates that are reliably served ranged from 7 cfs in 2005 to a new high of 17.9 cfs in 2020. Up to an additional 7.8 cfs in July and 6.3 cfs in August of protected 1961 water rights may be left instream in years when the amount of flow above the TID diversion is greater than the sum of all rights senior to 1961. In 2020 July and August median flows were 25 cfs and 24 cfs, 7 cfs and 6 cfs higher than flow protected instream, respectively. In 2021, July and August median flows were 19 and 16 cfs, higher in July and lower in August than the 17.5 cfs protected instream.

Table 4. Deschutes River and Tumalo Creek median stream flow protected and measured at OWRD gage 14070500, Deschutes River Below Bend, and 14073520, Tumalo Creek Below Tumalo Feed Canal, respectively, from 2001 to 2021.

	Deschutes River				Tumalo Creek			
	July		August		July		August	
	Flow Protected	Median Flow	Flow Protected	Median Flow	Flow Protected	Median Flow	Flow Protected	Median Flow
2001	--	48	--	47	--	5	--	6
2002	31	47	31	47	--	5	--	8
2003	39	55	40	55	--	6	--	10
2004	59	78	61	85	--	13	--	13
2005	68	74	81	77	7	6	7	6
2006	89	100	95	93	7	10	11	10
2007	111	93	113	98	11	13	11	15
2008	109	111	109	111	15	31	15	15
2009	114	131	116	123	10	15	14	13
2010	146	148	147	150	12	15	12	13
2011	147	151	155	157	13	56	13	18
2012	159	158	163	151	14	58	14	15
2013	125	129	132	133	12	12	12	10
2014	129	134	130	130	12	19	12	18
2015	134	136	136	134	16	14	16	16
2016	128	136	133	133	13	15	13	12
2017	131	128	132	123	14	15	14	18
2018	132	135	132	133	15	16	15	15
2019	127	122	127	123	17	24	17	21
2020	128	123	130	119	18	25	18	24
2021	134	127	134	99	17	19	17	16

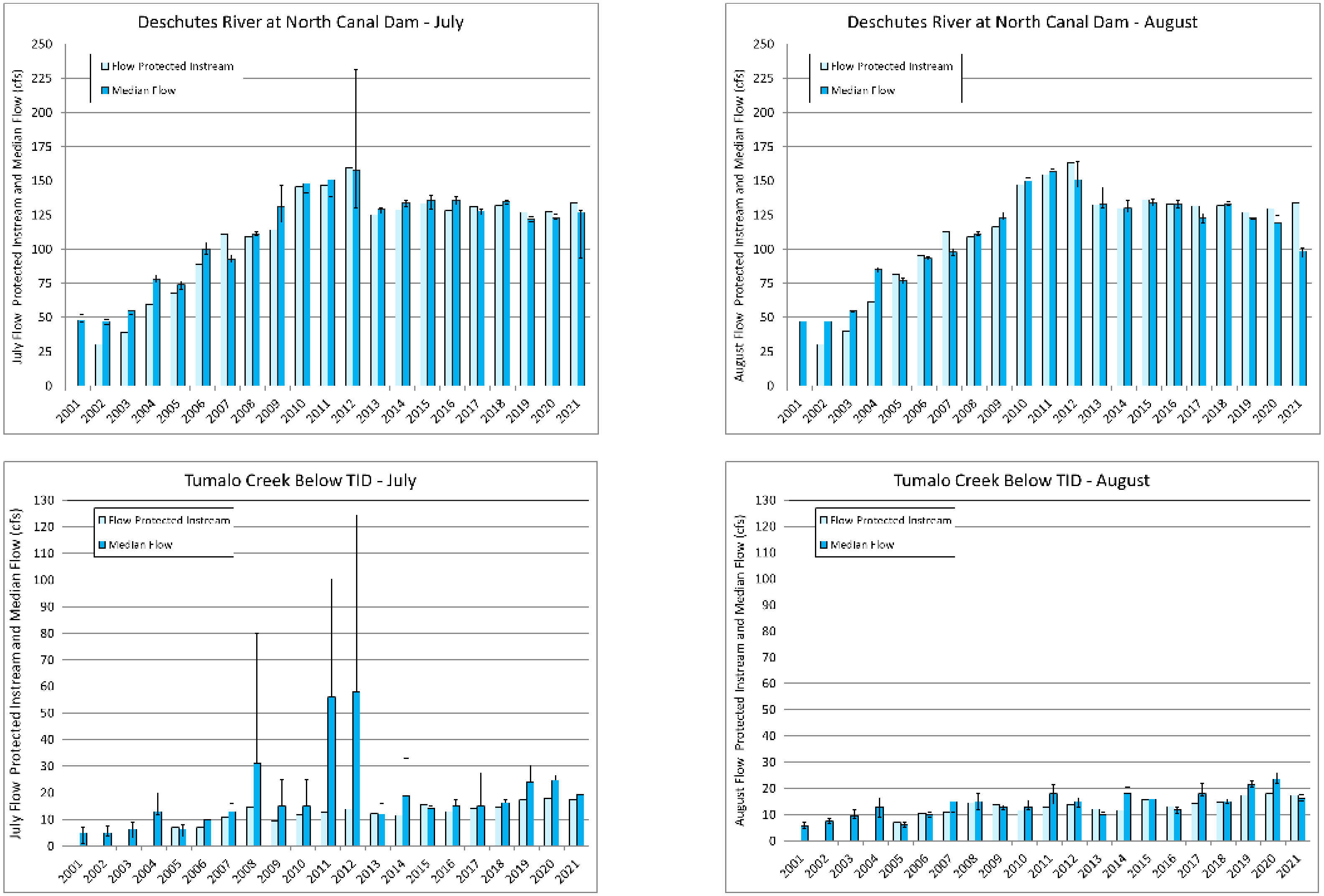


Figure 3. Deschutes River and Tumalo Creek July median protected and recorded flow in July and August, 2001-2021.
July and August median Deschutes River flows steadily increased from 2001 to 2012, corresponding to increases in flow protected instream. July and August median Deschutes River flows fell in 2013, reflecting reductions in both flow leased instream and flow left instream by irrigation districts under a voluntary agreement. 2020 marked a new high in July and August median protected flow in Tumalo Creek, at 17.9 cfs.

3.2 Stream Temperature

3.2.1 Data Quality

Field audits of dataloggers prescribed by UDWC's QAPP and SOP provide quality control data to evaluate the precision of temperatures recorded by dataloggers. UDWC uses a NIST thermometer certified annually by DEQ to measure stream temperature at each datalogger location and records the date and time of the NIST stream temperature measurement. Following download of continuous temperature data from the datalogger, the resulting field audit temperature is compared to the temperature recorded by the datalogger on the same date and at the time closest to the time of the audit. Data for which the field audit measurement is within half a degree (0.5°C) of the datalogger temperature record receives an "A" grade; data for which the field audit measurement is within 2 degrees (2.0°C) of the datalogger temperature record receives a "B" grade; and data for which there is a difference of more than two degrees between the field audit measurement and the datalogger record receives a "C" grade. The "C" grade is applicable to the data from the date of the audit until a subsequent audit provides a "B" or "A" grade.

Audit temperatures resulting in a "C" grade introduce uncertainty regarding the quality of the stream temperature data recorded by the datalogger. Discrepancies between the audit temperature and the datalogger temperature can result from not allowing sufficient time for the datalogger to cool to stream temperature before recording an audit temperature during deployment; from the timing of the audit measurement relative to the hour, on which the datalogger records temperature; from the datalogger being out of the water during the audit (to visually confirm that it is logging) on the hour when it records the temperature; or from incorrectly recording the date and/or time of the audit. Additionally, launching dataloggers prior to Daylight Savings Time (beginning the second Sunday in March) would result in the audit time being recorded as an hour later than the time logged by the datalogger.

Stream temperatures recorded during multiple field audits of dataloggers deployed at Deschutes River temperature monitoring sites in 2019 resulted in a "C" grade for the audit (Table 5). For DR 133.50 and DR 160.25, where two dataloggers were deployed, we compared stream temperatures recorded by the two dataloggers at, before, and after the time of the audit. For all four sites for which field audits received "C" grades, we reviewed pre- and post-deployment accuracy datalogger audit values and grades. Temperatures recorded by the two dataloggers at DR 133.50 and at DR 160.25 were within 0.3°C of each other over seven days including three days before and three days after audits receiving a "C". All dataloggers for which a field audit resulted in a "C" grade received "A" grades in pre- and post-deployment accuracy audits, with the exception of one datalogger deployed at DR 133.50 which received "B" grades for the post-deployment audit. Based on these data, it seems highly likely that in most or all cases audit measurements resulting in a "C" grade reflect operator error during the audit rather than a true lack of precision in temperatures recorded by dataloggers. Data receiving a "C" grade in 2019 were used to evaluate stream temperature status and trend (Figure 4, Figure 5), but they were not used to evaluate July and August temperatures at Lower Bridge Road (Figure 6) nor in regression analyses (Figure 7).

In 2021, all dataloggers deployed at Deschutes River monitoring stations were initialized and launched before Daylight Savings Time began on March 14th. As a result, the time recorded during field audits was an hour later than the time recorded by the logger. To account for the discrepancy, the datalogger temperature from an hour prior to the time recorded for the field audit was used to grade temperature data.

All dataloggers deployed at Deschutes River monitoring stations in 2020 and 2021 received “A” or “B” grades in field audits and in pre and post-deployment audits except the retrieval field audit for one datalogger at DR 133.50, which received a “C” grade. Because the field audit resulting in a “C” grade was the retrieval audit, this grade does not affect the continuous temperature data from the datalogger as no subsequent water temperatures were recorded following this audit.

Table 5. Deschutes River temperature monitoring sites and dates for which field audit “C” grades are applicable

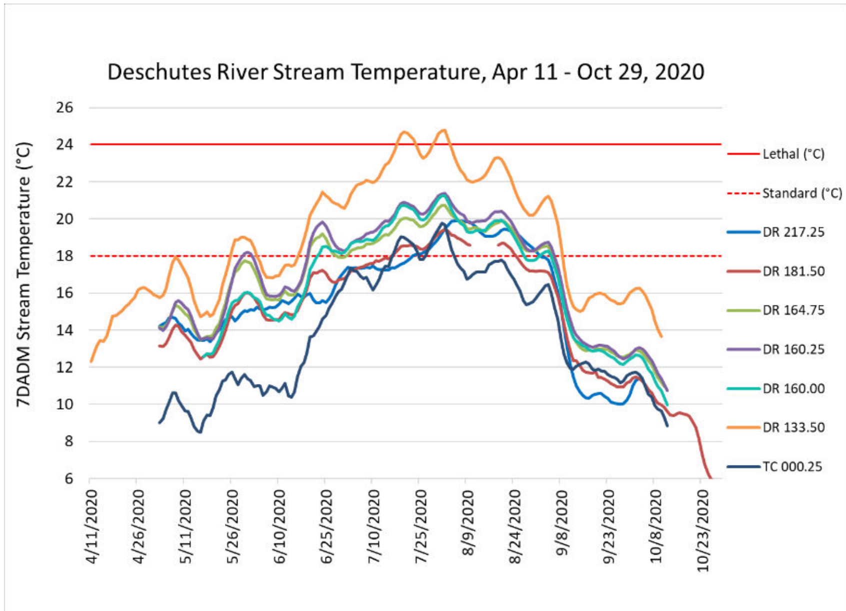
Site	Dates for which a field audit "C" grade are applicable
DR 133.50	5/23/2019 - 6/16/2019
	9/25/2019 - 10/2/2019
DR 160.25*	8/26/2019 - 10/14/2019
DR 181.50	5/9/2019 - 5/22/2019
DR 217.25	5/9/2019 - 5/22/2019
	7/12/2019 - 8/26/2019

* One of two loggers

3.2.2 Status and Trend

Seven-day moving average maximum (7DADM) temperatures in 2020 and 2021 exceeded the 18°C state standard for trout and salmon rearing and migration on the middle Deschutes River and Tumalo Creek in 2020 at both monitoring locations on the upper Deschutes River between Wickiup Reservoir and Bend, at the four Deschutes River monitoring locations downstream of North Canal Dam, and on Tumalo Creek at the mouth, supporting the existing State of Oregon Section 303(d) listing of the upper and middle Deschutes River for temperature impairment. In 2021 the 7DADM exceeded the 18°C state standard at all seven sites, spanning 83.8 miles of the middle and Upper Deschutes River and 0.25 miles of Tumalo Creek, for between 53 and 100 days between May and September. Temperatures at Lower Bridge Road exceeded the state standard by over 8°C in 2021 and by over 6°C in 2020 (Figure 4). Temperatures at the four Deschutes River sites downstream of Bend have exceeded the state standard in every year for which data are available for analysis and exceeded the state standard on Tumalo Creek at the mouth in all but two years for which data are available for analysis. Stream temperature at DR 217.25 exceeded 18°C by almost 4°C in 2021 and by 2°C in 2020; at DR 181.50 stream temperature exceeded 18°C by almost 3°C in 2021 and by not quite 2°C in 2020 (Figure 5). Data are not available from DR 181.50 in 2018 and 2019 to evaluate whether stream temperature in these years exceeded 18°C, in 2018 due to the datalogger going missing and in 2019 due to the datalogger failing while deployed. Prior to 2018, the

7DADM stream temperature had not exceeded 18°C at either DR 217.25 or DR 181.50 since 2009, except during three days in 2015 at DR 181.50.



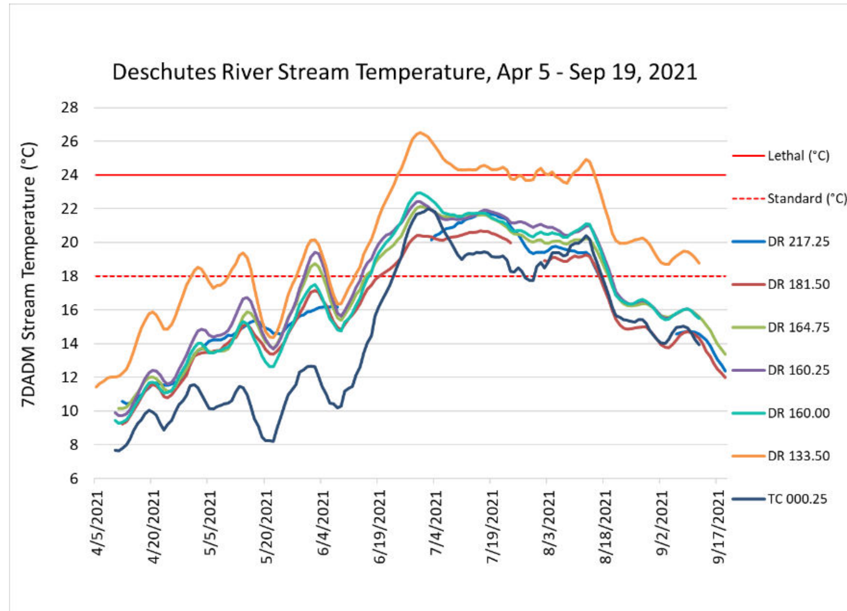
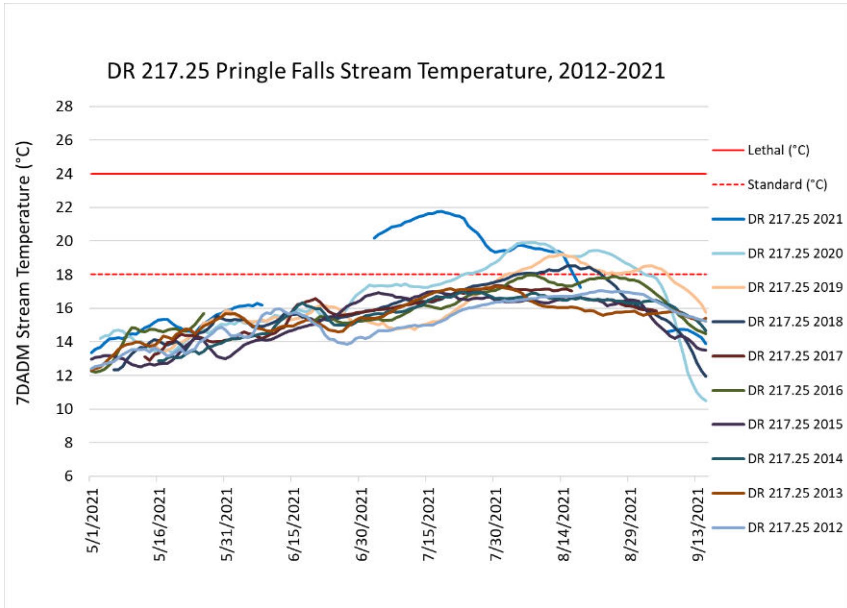


Figure 4. Deschutes River and Tumalo Creek temperatures April 11 - October 29, 2020, and April 5- September 19, 2021. Temperatures exceeded the 18°C State of Oregon temperature standard (dashed red line) at all six monitoring sites spanning 83.8 miles on the Deschutes River and one site on Tumalo Creek just upstream of the mouth in 2020 and 2021. Temperatures exceeded 20°C at four sites downstream of North Canal Dam in 2020 and exceeded 22°C at the same four sites in 2021. Temperatures exceeded 24°C in 2020 and exceeded 26°C in 2021 at DR 133.50.



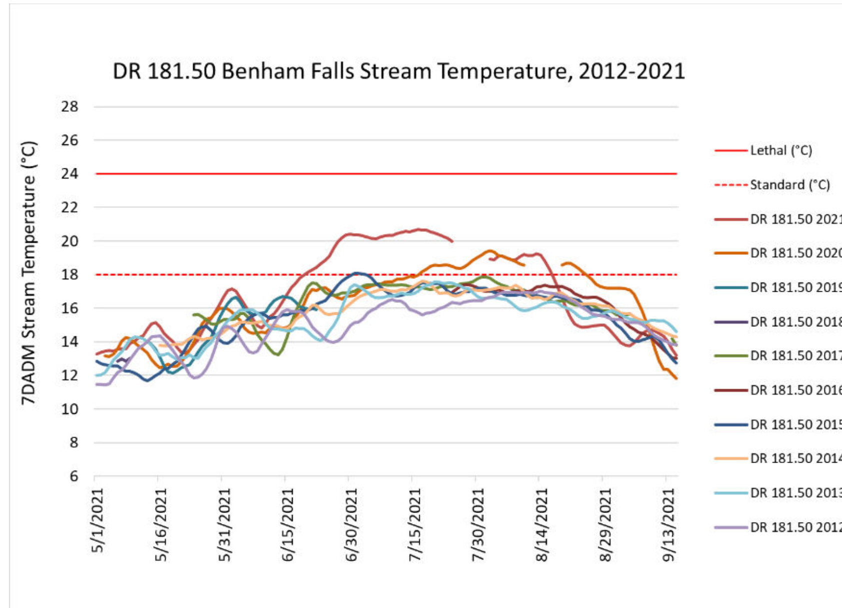


Figure 5. DR 217.25 Pringle Falls and DR 181.50 Benham Falls 7DADM stream temperature, 2012-2021. 7DADM stream temperature at DR 217.25, Pringle Falls, and DR 181.50, Benham Falls, very rarely exceeded 18°C prior to 2018. From 2018 to 2021 the 7DADM exceeded 18°C at Pringle Falls for 19 (2018) to 45 (2021) days. 7DADM stream temperature at DR 181.50 exceeded 18°C for 39 days in 2020 and 58 days in 2021. Incomplete 2021 data for Pringle Falls underrepresent the true number of days exceeding 18°C at this location.

Percent of data days exceeding 18°C between April 30 and September 21, the dates during which stream temperatures have historically exceeded 18°C in the middle Deschutes River downstream of Bend, represents the amount of time during which stream conditions are likely limiting for rearing trout in this reach; conversely, the percent of days meeting 18°C represents the amount of time during which stream conditions are optimal to support rearing fish. Temperatures downstream of Bend exceeded 18°C for 48-63% of days between April 30 and September 21 in 2020 and for 44-76% of days between April 30 and September 21 in 2021 (Table 6, Figure 6) and conversely met the 18°C standard for 37-52% of those days in 2020 and 24-56% of those days in 2021.

At DR 133.50, temperatures were 18°C or below for 37% (53 days) of data days in 2020, higher than in eight years, and lower than in eight other years, between 2001 and 2019 for which data are available[1]. Temperatures at this site in 2021 were 18°C or below for 24% (35 days) of data days, lower than in any year but 2001. While the percent of days in 2020 exceeding 24°C (the lethal threshold for trout rearing; ODEQ 1995) was similar to recent years, at 8% (11 days), an astonishing 28% (40 days) exceeded the lethal threshold in 2021, the highest percent of any year for which data are available, almost a third of all data days and 4% more than the number of days meeting the state temperature standard in that year. This record corresponds to the lowest August flows in the middle Deschutes River at North Canal Dam observed since 2006. Temperatures exceeded 24°C in 2020 from July 18-23 and from July 30-August 3 at flows of 141 to 154 cfs (118-127 cfs from the Deschutes and 23-27 cfs from Tumalo Creek); temperatures exceeded 24°C in 2021 from June 25-July 23, July 31-August 4, and August 10-15 at flows of 109 to 175 cfs (93-147 cfs from the Deschutes and 16-28 cfs from Tumalo Creek). Stream temperatures exceeding 24°C in almost every year since 2013 are coincident with the 2013 drop in flows protected in the middle Deschutes and with more than five years of moderate to exceptional drought experienced since 2013.[2]

Temperatures at DR 160.00, downstream of the confluence with Tumalo Creek, exceeded 18°C for 48% (69 days) and 44% (64 days) of data days in 2020 and 2021 respectively, an equivalent or higher number than in all but one year (2015) since 2005. Temperatures met the temperature standard at this site for 52% (76 days) and 56% (81 days) of data days in these two years. Stream temperature at DR 160.00 exceeded 18°C from June 23 to August 27 and from September 2-4 in 2020, at flows of 129 to 190 cfs (115-119 cfs from the Deschutes and 10-75 cfs from Tumalo Creek). In 2021 stream temperature at DR 160.00 exceeded 18°C from July 7 to September 5, at flows of 92 to 171 cfs (79-130 cfs from the Deschutes and 13-41 cfs from Tumalo Creek).

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[1] These data reference 2018 and 2019 values for percent and number of days exceeding 18°C at DR 133.50 that have been corrected from the 2018-2019 report, which stated that the percent of days exceeding 18°C at DR 133.50 was 21% and 25% in 2018 and 2019 respectively. The actual percent of days exceeding 18°C at DR 133.50 was 27% in both 2018 and in 2019.

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

Temperatures at DR 160.25 met the standard for 44% (64) of data days in 2020, lower than in any year for which data are available except 2003. Temperatures at this site met the standard for 50% (73) of data days in 2021, lower than in all but four of the 18 years for which data are available between 2002 and 2020. Temperatures at DR 164.75, immediately downstream of North Canal Dam, met the standard for 48% (75) of data days in 2021, fewer days than in any other year for which data are available, and met the standard for 52% (69) of data days in 2021, fewer than in any year except 2020. This result is consistent with the highest stream temperatures on record observed in each successive year since 2018 at Pringle Falls (DR 217.25) and since 2020 at Benham Falls (DR 181.50), where data for 2018 and 2019 are very limited.

Stream temperature at the mouth of Tumalo Creek (TC 000.25) exceeded the 18°C state temperature standard for 12% of days and met the standard for 88% of days between April 30 and September 21 in 2020. Temperatures at the mouth of Tumalo exceeded 18°C for 37% of days and met the 18°C standard for only 63% of days in 2021, the lowest percent on record for this site, marking a return to conditions not observed since 2005. Temperatures in Tumalo Creek exceeded 18°C for between 0 and 19% of days April 30 through September 21 from 2006 to 2020, meeting the criteria for 81-100% of days April 30 through September 21 during these years[3].

[3] These data correct the 2017 report, where we stated that temperatures in Tumalo Creek had exceeded 18°C for between 0 and 19% of days April 30 through September 21 since 2005.

Table 6. Percent of days between April 21 and September 30 meeting the state temperature standard for salmon and steelhead rearing and migration (≤ 18°C) and exceeding the standard (> 18°C) from 2001 to 2021 at four Deschutes River sites and one Tumalo Creek site downstream of the City of Bend.

	DR 164.75		DR 160.25		DR 160.00		DR 133.50		TC 000.25	
	% Days ≤ 18°C	% Days > 18°C	% Days ≤ 18°C	% Days > 18°C	% Days ≤ 18°C	% Days > 18°C	% Days ≤ 18°C	% Days > 18°C	% Days ≤ 18°C	% Days > 18°C
2001	--	--	--	--	--	--	12%	88%	--	--
2002	--	--	55%	45%	--	--	30%	70%	--	--
2003	--	--	39%	61%	--	--	--	--	--	--
2004	65%	35%	62%	38%	--	--	57%	43%	73%	27%
2005	72%	28%	61%	39%	60%	40%	29%	71%	65%	35%
2006	--	--	--	--	68%	32%	37%	63%	86%	14%
2007	70%	30%	65%	26%	62%	38%	29%	71%	81%	19%
2008	76%	24%	61%	39%	76%	24%	39%	61%	--	--
2009	76%	24%	64%	36%	64%	36%	39%	61%	87%	13%
2010	70%	30%	65%	35%	70%	30%	53%	47%	88%	12%
2011	83%	17%	69%	31%	80%	20%	60%	40%	100%	0%
2012	77%	23%	62%	38%	80%	20%	52%	48%	100%	0%
2013	79%	21%	66%	34%	68%	32%	30%	70%	82%	18%
2014	77%	23%	65%	35%	70%	30%	38%	62%	91%	9%
2015	78%	22%	50%	50%	49%	51%	29%	71%	90%	10%
2016	72%	28%	54%	46%	59%	41%	48%	52%	85%	15%
2017	61%	39%	55%	45%	68%	32%	41%	59%	87%	13%
2018	69%	31%	58%	42%	59%	41%	27%	73%	94%	6%
2019	62%	38%	47%	53%	57%	43%	27%	73%	90%	10%
2020	48%	52%	44%	56%	52%	48%	37%	63%	88%	12%
2021	52%	48%	50%	50%	56%	44%	24%	76%	63%	37%

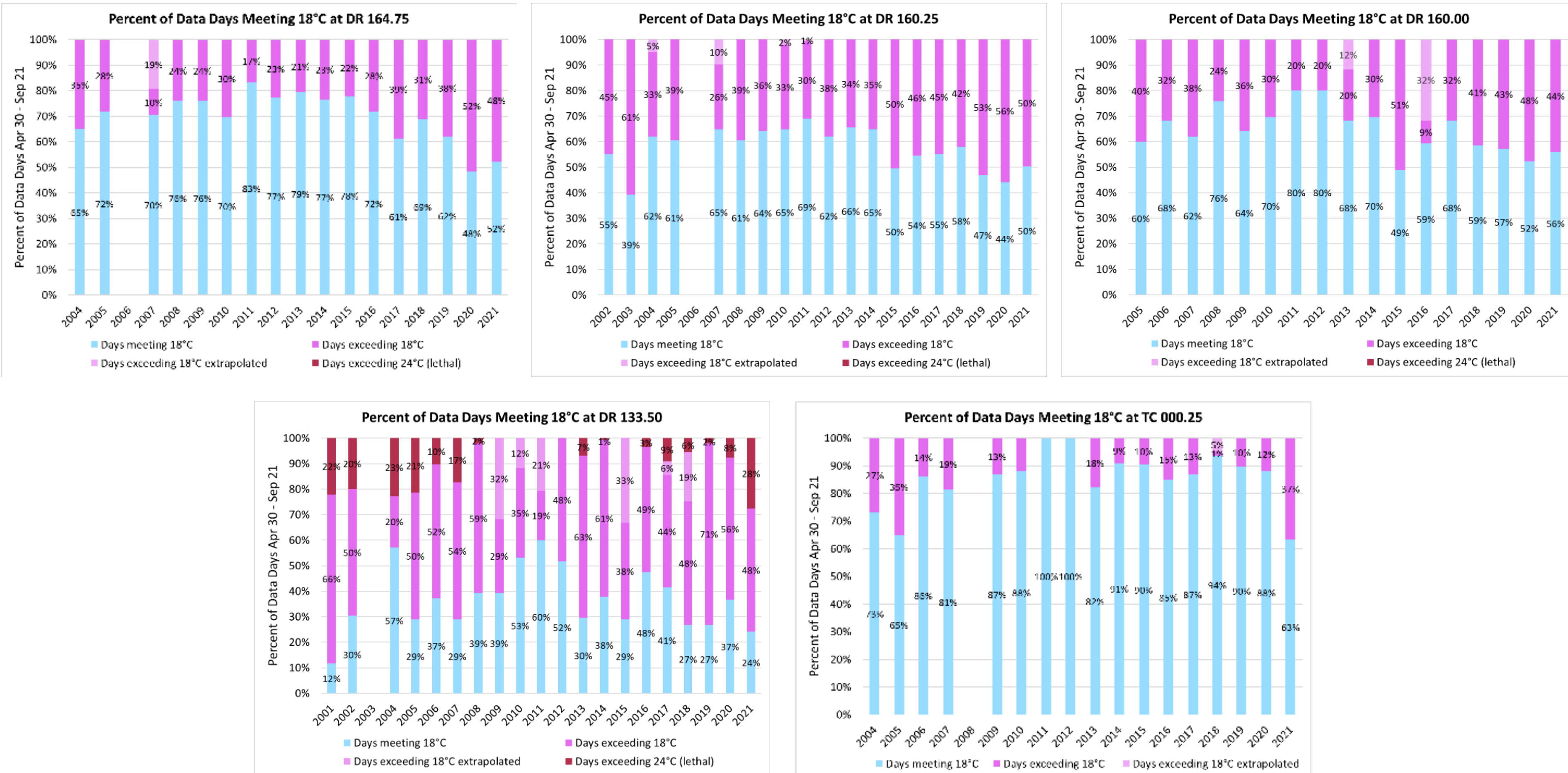

Figure 6. Percent of data days meeting and exceeding 18°C, 2001-2021.

Stream temperature in the Deschutes River downstream of Bend exceeded 18°C for 48-64% of days between April 30 and September 21 in 2020 and for 48-76% of days between April 30 and September 21 in 2021. The percent of days meeting the stream temperature standard in 2020 and 2021 at all four sites downstream of Bend approach the lowest on record. Stream temperature in Tumalo Creek at the mouth met the 18°C standard for 88% of days in 2020 and for 63% of days in 2021.

July stream temperatures at Lower Bridge Road (DR 133.50) from 2013 to 2020 are far lower and exceed 24°C far less frequently than from 2001 to 2007 (Figure 6). But, median July temperatures from 2013 to 2020 are on average almost 2.5°C warmer than from 2008 to 2012, and in some years since 2013, July and August temperatures have exceeded 24°C, which they did not from 2008 to 2012. July stream temperatures at Lower Bridge in 2021 mark a return to pre-2008 temperatures, with all 7DADM records between July 1 and 22, 2021 exceeding 24°C, despite July median flows at North Canal Dam (127 cfs) and below the Tumalo Irrigation District diversion (19.3 cfs) similar to or higher than previous years. Thus, although some sustained progress has been made in reducing stream temperatures, since 2013 stream temperature conditions have deteriorated from the significant gains made between 2008 and 2012.

The 7DADM stream temperature exceeded the lethal 24°C threshold in both July and August 2020; temperatures exceeding 24°C in August 2020 occurred outside of the dates included in Figure 6 and therefore are not shown. The median temperature for August 2020 was higher than in any year since 2012, surpassed only by the 2021 August median temperature.

The 7DADM stream temperature exceeded 24°C in both July and August 2021. The July median 7DADM temperature was higher than in any other year since 2007, while the August median 7DADM temperature was higher than in any other year since 2005. Whereas July 2021 temperatures remain lower than the highest temperature observed from 2001-2007, 2021 marks the first year in which all 7DADM temperature between July 1 and 22, the days included in Figure 6, exceeded 24°C. August median temperatures chart a decreasing trend through 2014 which has attenuated since, with the August 6-28 median climbing by a degree and a half from 2014 to 2021.

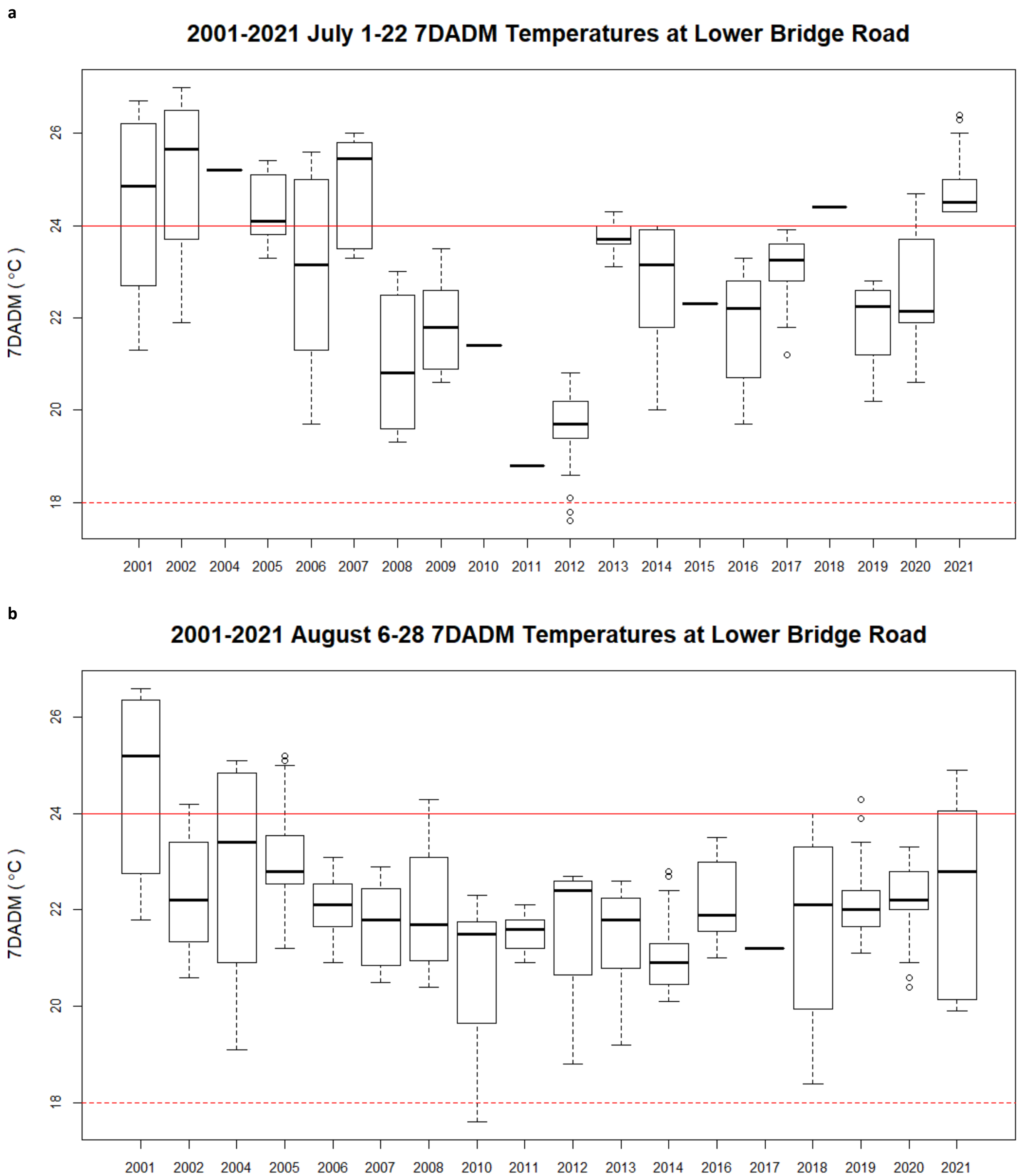

Figure 7. 2001-2021 July and August 7DADM temperatures at Lower Bridge

a) July 1-22 and b) August 6-28 7DADM temperatures at Lower Bridge (DR 133.50) chart a declining trend since 2001. Years for which data are not available are not represented; for years for which some data are available, the median of available values is shown. Despite reductions of approximately 2-4°C between 2001 and 2020, temperatures at Lower Bridge remain well above the 18°C standard (dashed red line) throughout July and August. July 2021 temperatures approximate 2001 values; August 2021 temperatures were also higher than in most years since 2001.

3.3 Effect of Stream Flow on Stream Temperature

Multiple lines of evidence show lower stream temperatures at higher stream flows achieved in part through stream flow restoration in Tumalo Creek and to a lesser degree in the middle Deschutes River. This relationship is strongest in July but is also evident in August. As July median flows in Tumalo Creek and the middle Deschutes increased from 2001-2012, July and August stream temperatures decreased (Figure 3, Figure 7). July stream temperatures spiked with the 2013 drop in middle Deschutes River stream flow and came down somewhat through 2020 as flows crept up from 2013 levels, but spiked again in 2021 despite July flows in the middle Deschutes similar to the last eight years and higher than average Tumalo Creek flows. August stream temperatures also dropped through 2010 and fluctuated through 2014 but have climbed steadily since. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2021 at DR 160.25, DR 160.00, and at TC 000.25 show temperatures decreasing as flows increase, with flow explaining different proportions of the variation in stream temperature at different sites (Figure 8).

The regression for each site represents a range of flows for each year that reflect July flows resulting in part from stream flow restoration. The range of flows annually for which temperature data are available between 2002 and 2021 increased from a low of 41 cfs and a high of 51 cfs in 2002 to a low of 100 cfs and high of 327 cfs in 2011 in the Deschutes at North Canal Dam; in Tumalo Creek, flows included in regressions increased from a low of 3.3 cfs and high of 37 cfs in 2004 to a low of 11 and high of 177 cfs in 2008.[4] With 2020 and 2021 data included, stream flow explained only 22% of the variation in stream temperature at DR 160.25 ($R^2 = 0.22$), 70% of the variation in stream temperature at TC 000.25 ($R^2 = 0.70$), and 50% of the variation in stream temperature at DR 160.00 ($R^2 = 0.50$) in July, providing support for increases in July stream flow contributing to reduced July stream temperatures in Tumalo Creek but more limited support for increases in July stream flow from the Deschutes at North Canal Dam contributing to reduced stream temperatures at DR 160.25 upstream of the confluence with Tumalo Creek and for increases in July stream flow from Tumalo Creek contributing to reduced stream temperatures at DR 160.00 in the Deschutes downstream of the confluence with Tumalo.

Increasing flows in the Deschutes River versus in Tumalo Creek resulted in dramatically different estimated reductions in stream temperature. At DR 160.25, where increased flows reduce warming rather than actively cooling stream temperature, and the distance over which to reduce warming is relatively short (< 5 mi from North Canal Dam), modest reductions in predicted temperature were observed as flows increased. A flow rate of 43 cfs from the Deschutes River at North Canal Dam (the lowest flow included in the analysis) resulted in a predicted 7DADM temperature of 20.6°C ± 1.8°C (upper interval = 22.4°C) at DR 160.25, approximately five miles downstream; flows between 201 and 211 cfs resulted in a mean temperature *only 2.0°C lower*, at 18.6°C ± 1.8°C (upper interval = 20.4°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

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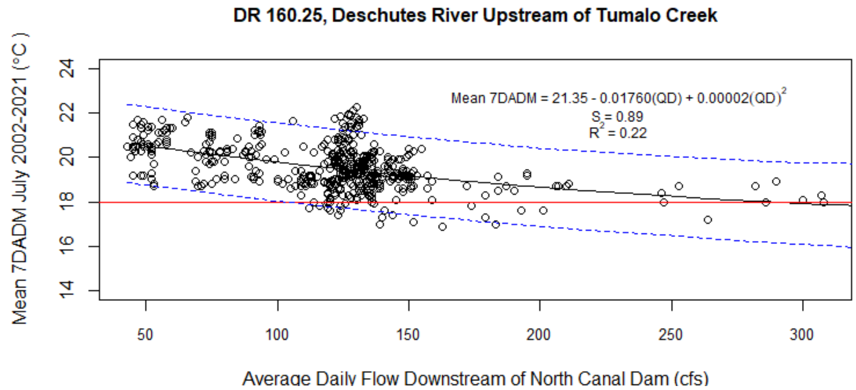
[4] Temperature data were not available for the dates on which 177 cfs was recorded on Tumalo Creek below the TID diversion (July 1, 2008) and accordingly this flow value is not included in the regression.

temperature: for the purpose of illustration, the lowest flow included in the analysis, 3.3 cfs, resulted in a mean temperature of 20.4°C ± 2.9°C (upper interval = 23.3°C), with flows between 110 and 126 cfs resulting in the lowest mean temperature of 11.1 ± 2.9°C (upper interval=14.0°C), a temperature reduction of more than 9°C. Increasing flows in Tumalo Creek also reduced stream temperature in the Deschutes below the confluence with Tumalo, at DR 160.00, more dramatically than the effect of flow at North Canal Dam observed at DR 160.25 but less so than the effect of flow below the TID diversion in Tumalo Creek on temperatures at the mouth. At 3.3 cfs in Tumalo Creek the 7DADM temperature at DR 160.00 is predicted to be 20.1 ± 2.0°C (upper interval = 22.1°C); flows in Tumalo Creek between 119 and 139 are predicted to result in a 7DADM temperature at DR 160.00 that is 4.1°C lower at 16.0 ± 2.0°C (upper interval = 18°C).

a



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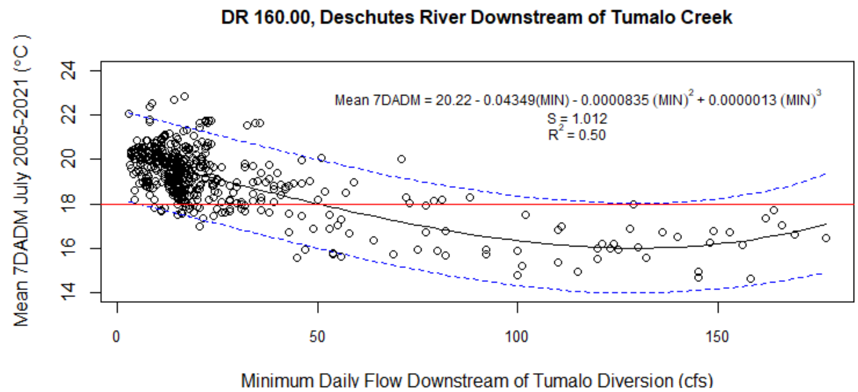

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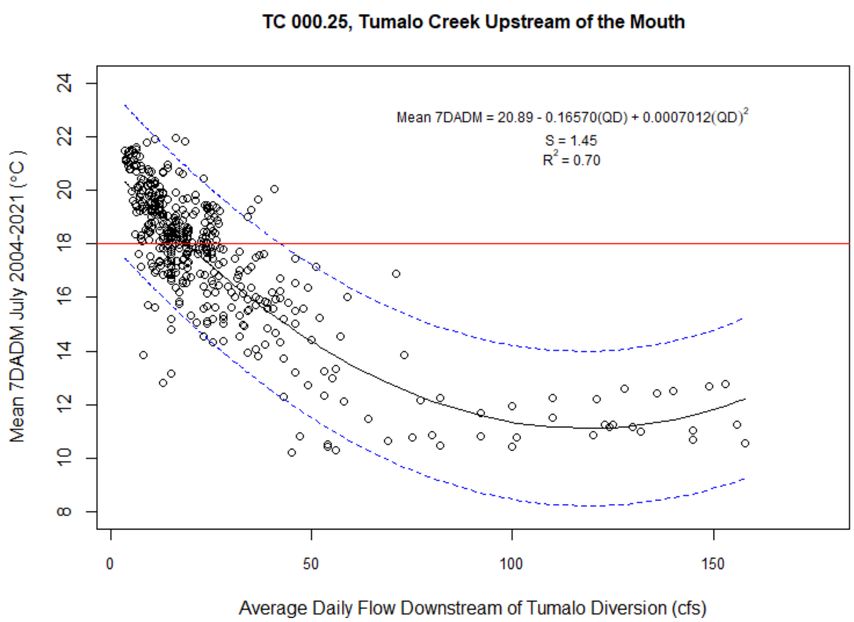

Figure 8. Temperature-flow regression models.

Regression models fitted to temperature-flow data demonstrate modestly to substantially lower temperatures at higher flows and describe the relationship between temperature at a) DR 160.25 upstream of the confluence with Tumalo Creek and flow at North Canal Dam from July 2002-2021, b) DR 160.00 downstream of the confluence with Tumalo Creek and flow in Tumalo Creek downstream of the diversion from July 2005-2021, and c) TC 000.25, Tumalo Creek upstream of the mouth and flow in Tumalo Creek downstream of the diversion from July 2004-2021.

3.4 Target Stream Flow

Temperature records were available from DR 160.25 for July dates from 2002-2021 at Deschutes River flows between 43 and 327 cfs, from TC 000.25 for July dates from 2004-2021 at Tumalo Creek flows between 3.5 and 158 cfs, and from DR 160.00 from 2005-2021 at Tumalo Creek flows between 3.5 and 158 cfs. The mixed linear regression of the 7DADM stream temperature on the 3-day moving average maximum daily air temperature and the average daily flow performed best of 13 regression models for DR 160.25; even this model, which incorporates both air temperature and stream flow, explains only 53% of the variation in stream temperature at this location (Table 7). The quadratic regression of the 7DADM stream temperature on the average daily flow (7DADM ~ Flow + $(Flow)^2$) performed best of six stream flow models for this site and still explained only 22% of the variation in stream temperature (R^2 = 0.22; Table 4, Figure 8). This model demonstrates the relatively small influence of the amount of Deschutes River flow on stream temperature at this site in July. The linear regression of the 3-day moving average maximum daily air temperature performed best of six air temperature models for the site and explained 45% of the variation in stream temperature (R^2 = 0.45). For DR 160.00 July stream temperature and flow from OWRD gage #14073520 on Tumalo Creek below the diversion, the cubic regression of the 7DADM stream temperature on the minimum daily flow (7DADM ~ Min + $(Min)^2$ + $(Min)^3$) performed best of 18 models for this site and explained 50% of the variation in stream temperature (R^2 = 0.50). For TC 000.25 stream temperature and flow data, the quadratic regression of the 7DADM stream temperature on average daily flow (7DADM ~ Flow + $(Flow)^2$) performed best of the 18 models. Stream flow explained 70% of the variation in stream temperature at the mouth of Tumalo Creek in July (R^2 = 0.70). Residuals for the best performing stream flow model for each site were approximately normally distributed. We used the best stream flow equation for each site to calculate predicted temperatures for the range of flows on which regressions were trained for the three sites (Appendix A).

Table 7. The best three regression models for predicting stream temperature for July at DR 160.25, DR 160.00, and TC 000.25**.**

Regression Model	Intercept	Coefficient 1	Coefficient 2	Coefficient 3	n	df	R^2	S	AIC value
DR 160.25									
7DADM ~ Tair3 + QD	**15.264263**	**-0.0076881**	**0.1780359**	--	**523**	**520**	**0.53**	**0.69**	**-384.6**
7DADM ~ Tair3	13.603508	0.203	--	--	523	521	0.45	0.75	-298.4
7DADM ~ Tair3 + $(\text{Tair3})^2$	15.666703	0.057834	0.002519	--	523	520	0.45	0.75	-297.9
DR 160.00									
7DADM ~ MIN + $(\text{MIN})^2$ + $(\text{MIN})^3$	**20.22**	**-0.04349**	**-0.0000835**	**0.0000013**	**484**	**480**	**0.50**	**1.01**	**15.9**
7DADM ~ MIN + $(\text{MIN})^2$	20.39000000	-0.05958000	0.00021060	--	484	481	0.50	1.02	17.0
7DADM ~ LnMIN + $(\text{LnMIN})^2$	19.43727	0.90235	-0.32061	--	484	481	0.49	1.03	26.7
TC 000.25									
7DADM ~ QD + $(\text{QD})^2$	**20.8900000**	**-0.1657000**	**0.0007012**	--	**431**	**428**	**0.70**	**1.45**	**322.4**
7DADM ~ QD + $(\text{QD})^2$ + $(\text{QD})^3$	20.91	-0.1679	0.0007483	-0.0000002317	431	427	0.70	1.45	324.4
7DADM ~ LnQD + $(\text{LnQD})^2$	21.688354	0.004098	-0.4508	--	431	428	0.69	1.48	338.5

Predicted temperatures calculated for six Deschutes River flow scenarios illustrate marked reductions in stream temperature in the Deschutes River below the confluence with Tumalo Creek (DR 160.00) as flows in Tumalo increased (Appendix B). At the July 2021 median protected flow of 134 cfs, 49 cfs in Tumalo Creek was estimated to achieve the state temperature standard of 18°C ± 2.1°C on average in the Deschutes River immediately downstream of the confluence with Tumalo Creek; at the observed July 2021 median middle Deschutes River flow of 127 cfs (as well as for the July 2021 median protected flow of 134 cfs) the same temperature and prediction interval were predicted for 50 cfs in Tumalo Creek. Increasing Deschutes River flows from the 2021 protected flow of 134 cfs to the instream flow target of 250 cfs was estimated to achieve an additional 1.0°C reduction in stream temperature at the 2021 protected Tumalo Creek flow of 17 cfs, a 0.8°C reduction in stream temperature at 32 cfs in Tumalo Creek and a 0.2°C reduction in stream temperature at 49 cfs in Tumalo Creek. At 60 cfs in Tumalo Creek stream temperature in the Deschutes downstream of the confluence was estimated to be approximately equivalent (within 0.1°C) at 127 or at 250 cfs in the Deschutes (Table 8), highlighting the significant reductions in stream temperature that can be achieved in the middle Deschutes River by prioritizing stream flow restoration in Tumalo Creek over stream flow restoration at North Canal Dam.

Table 8. Estimated Deschutes River stream temperatures at four Tumalo Creek flows and two Deschutes River flows. Seventeen (17) and 134 cfs in Tumalo Creek and the Deschutes River, respectively, represent flows protected instream in 2021. Forty-nine cfs represents the flow needed in Tumalo to meet 18**°**C downstream of the confluence with the Deschutes at the 134 cfs currently protected in the Deschutes.

Tumalo Creek Flow Scenario	Tumalo Creek Stream Flow (cfs)	Deschutes River Stream Flow (cfs)	Estimated 7DADM Stream Temperature (°C)	Deschutes River Stream Flow (cfs)	Estimated 7DADM Stream Temperature (°C)
2021 protected flow	17	134	19.2°C ± 1.9°C	250	18.2°C ± 1.9°C
State instream water right	32	134	18.8°C ± 2.0°C	250	18.0°C ± 1.9°C
Flow meeting 18.0°C	49	134	18.0°C ± 2.1°C	250	17.8°C ± 2.0°C
Flow meeting 17.5°C	58	134	17.5°C ± 2.1°C	250	17.3°C ± 2.0°C

Whereas increasing stream flow in Tumalo Creek from the July 2021 protected flow of 17 cfs to 60 cfs was estimated to achieve substantial reductions in stream temperature, simultaneously increasing Deschutes River stream flow conferred small additional reductions in stream temperature that diminished as Tumalo Creek flows approached 60 cfs. From 67 to 70 cfs in Tumalo Creek, increasing Deschutes River flow from 127 to 250 cfs had no effect on temperature. Above 70 cfs in Tumalo Creek, adding stream flow in the Deschutes River was predicted to result in higher stream temperatures in the Deschutes than at the lower Deschutes River flow.

At benchmark, achievable Tumalo Creek flows, 7DADM stream temperatures calculated using the DR 160.00 ~ Tumalo Creek flow regression model were slightly higher than, and within 0.3°C of, those calculated using the mass balance equation (Table 9, Appendix C). At the lowest flows and at higher flows the difference in 7DADM calculated using the two approaches increases.

Table 9. Comparison of stream temperatures at DR 160.00 below the confluence of Tumalo Creek and the Deschutes River calculated using a mass balance equation and a regression equation**.**

Tumalo Creek Stream Flow (cfs)	Deschutes River Stream Flow (cfs)	Mass Balance Estimated Stream Temperature (°C)	DR 160.00 Regression Estimated Stream Temperature (°C)
17	134	19.2°C ± 1.9°C	19.5°C ± 2.0°C
32	134	18.8°C ± 2.0°C	18.8°C ± 2.0°C
49	134	18.0°C ± 2.1°C	18.0°C ± 2.0°C
58	134	17.5°C ± 2.1°C	17.7°C ± 2.0°C

The Heat Source model developed by Watershed Sciences and MaxDepth Aquatics under contract with ODEQ (Watershed Sciences and MaxDepth Aquatics 2008) simulated stream temperature from historical stream flow and temperature measurements for the Deschutes River and Tumalo Creek, and provides estimated stream temperatures against which we can compare those calculated from our regression equations. Heat Source model estimates are available for state instream water right (ODFW) flows in July for the Deschutes River (250 cfs) and for Tumalo Creek (32 cfs). The Heat Source average seven day average daily maximum (7DADM) temperature estimate for Deschutes flows of 250 cfs and Tumalo flows of 32 cfs at approximately DR 160.00 (Heat Source rkm 72.4) is 17.4°C, over half a degree lower than the mass balance estimate of 18.0°C for the same flow at the same site based on our analysis. The Heat Source average 7DADM for the Deschutes at 250 cfs at approximately DR 160.25 (Heat Source rkm 72.8), above the confluence with Tumalo, was 17.2°C, 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, over half a degree lower than the 16.3°C calculated from the regression equation for that flow and site.

Stream temperatures at DR 160.00 in 2021 that exceeded 18°C at flows between 92 and 171 cfs, representing 79-130 cfs from the Deschutes and 13-41 cfs from Tumalo Creek, are consistent with mass balance and regression results estimating 18.4°C ± 2.0°C at 41 cfs in Tumalo Creek and at flows in the Deschutes up to 134 cfs (Appendix A, Appendix B). Stream temperatures at this site in 2020 that exceeded 18°C at flows between 129 and 190 cfs representing 115-119 cfs from the Deschutes and 10-75 cfs from Tumalo Creek are higher than calculated from the regression model, which results in estimated temperatures falling below 18°C ± 2.0°C at 52 cfs in Tumalo Creek. Although we did not calculate mass balance estimated temperatures for Deschutes River flows below 127 cfs and thus cannot directly compare temperatures observed at 2020 flows with temperatures estimated from mass balance, 52 cfs from Tumalo Creek at 127 cfs from the Deschutes is also estimated to result in stream temperatures below 18°C ± 2.0°C at this site. Temperatures exceeding 18°C at observed flows might still be within the mass balance and regression prediction intervals for these flows.

4 Discussion

4.1 Stream Flow Status and Trend

Stream flow in the middle Deschutes River steadily increased alongside protected flows through 2012. Since 2012 protection of additional flow in stream has stalled, returning the amount of flow protected, as well as flow recorded in stream, to pre-2010 levels. Median flow protected in the middle Deschutes River in July and August 2021 was higher than in any year since 2015. Observed flows in both July and August 2021 fell short of protected flows, and were lower than most other years since 2013, with an August median that was 35 cfs less than the protected flow for this month.

Sustained drought over multiple years in combination with new reservoir management to provide adequate winter flows for Oregon Spotted Frog has contributed to a summer stream flow deficit. In summer 2021, this deficit resulted in insufficient flow in the upper Deschutes River downstream of Wickiup reservoir to serve senior water rights, with those rights being regulated accordingly.

The marked increase in 2019 to 17.3 cfs protected in Tumalo Creek, up from the previous high of 15.7 in 2015, was sustained in 2020 and 2021, with 17.5 cfs protected as of 2021. July median flow in both years exceeded the protected flow, at 25 cfs in 2020 and 19 cfs in 2021.

4.2 Temperature Status and Trend

Stream temperature at four locations on the middle Deschutes River downstream of Bend that met the 18°C state standard for 37-52% of days between April 30 and September 21, 2020 and for 24-56% of days between April 30 and September 21, 2021 represent optimal temperature conditions for rearing salmon and trout. Conversely, temperatures exceeding the 18°C standard for 48-63% of days between April 30 and September 21, 2020 and 44-76% of days between April 30 and September 21, 2021 represent temperature conditions that cause physiological stress for salmon and trout at those locations and might create a competitive advantage for non-native brown trout. At Lower Bridge (DR 133.50), stream temperature met the state temperature standard for close to two months between April and September 2020, and for just over a month between April and September in 2021. The percentage of days meeting the state temperature standard at this site has fluctuated between 24% and 48% in most years since 2002, with only four years meeting the state temperature standard for more than half of days between April 30 and September 21.

Given July median flows of 127 cfs in the Deschutes River and 19 cfs in Tumalo Creek, temperatures above 18°C at DR 160.00 for 48% of days in 2021, including every day in July, are consistent with mass balance results which predict 50 cfs required in Tumalo Creek at 127 cfs in the Deschutes to achieve 18°C at this site, and with DR 160.00 regression results which predict 49 cfs required in Tumalo Creek to achieve 18°C at the same site.

From 2009 to 2012 no 7DADM stream temperatures 24°C or higher were recorded at Lower Bridge, coincident with higher flows during these years achieved in part through stream flow restoration. Since 2013 stream temperatures 24°C and above have been recorded at Lower Bridge in every year except

2015, when data were unavailable from June 20th to July 15th. The return to summer stream temperatures exceeding the lethal 24°C threshold corresponds to the 2013 drop in flows protected in the middle Deschutes. While the percent of days exceeding 24°C at Lower Bridge in 2020 was similar to percentages observed in other years since 2013, the percent of days exceeding 24°C at Lower Bridge in 2021 was the highest by 7% more than the percentage observed in any other year for which data are available since 2001.

Regression analysis of stream flow, stream temperature, and air temperature data for the Deschutes (DR 160.25) and Tumalo Creek (TC 000.25) developed for the Upper Deschutes Basin Study resulted in models that incorporated both stream flow and air temperature explaining the greatest proportion of variation in stream temperature of the models run (UDWC 2016). This result indicates that air temperature, in addition to stream flow, influences stream temperature in the middle Deschutes and in Tumalo Creek. Despite similar July stream flow medians and ranges in 2009 and from 2013-2021, the proportion of days exceeding the 18°C state standard at DR 133.50 has fluctuated by up to 24%, between 52% and 76%, over those years. Differences in air temperature between years, as well as other factors such as variation in flow in earlier months or effects of solar radiation and reservoir level on the temperature of flow released from Wickiup and Crane Prairie reservoirs, might contribute to the wide variation in percent and number of days exceeding the 18°C state standard at similar July flows.

Small reductions in Tumalo Creek flow during the July 2nd to August 5th period when temperatures most often exceed 24°C will meaningfully reduce lethal and chronic sub-lethal stream temperatures for redband in both Tumalo Creek and in the Deschutes River. A strategy is needed to partner with the City of Bend and Tumalo Irrigation District to increase surface water in Tumalo Creek during this timeframe.

4.3 Restoration Effectiveness

Higher stream flows resulting from stream flow restoration (water rights transferred or leased and delivered instream) result in lower stream temperatures in Tumalo Creek and in the middle Deschutes River. July and August stream temperatures at DR 133.50 decreased with increases in July median flows in the middle Deschutes and in Tumalo Creek between 2001 and 2012. Comparison of 7DADM temperatures at DR 160.25 and TC 000.25 at the lowest and highest July flows recorded show lower stream temperatures have historically occurred at higher flows. Regressions of mean July 7DADM temperatures and corresponding flow values from 2001-2021 at DR 160.25, DR 160.00, and TC 000.25 also show lower temperatures occurring at higher flows.

Tumalo Creek stream flow explained 70% of the variation in stream temperature in Tumalo Creek (R^2 = 0.70) and 50% of the variation in stream temperature in the Deschutes River downstream of the confluence (DR 160.00, R^2 = 0.50), providing support for higher protected flows in Tumalo Creek guaranteeing higher baseflows and lower stream temperatures in Tumalo Creek and in the Deschutes downstream of Tumalo Creek. But, for the Deschutes immediately upstream of the confluence with Tumalo Creek, stream flow explained only 22% of the variation in stream temperature (R^2 = 0.22), indicating factors other than stream flow contribute substantially to stream temperature at this site; and, whereas observed and calculated stream temperatures at DR 160.25 decrease as flows increase, stream temperature is only estimated to be 2.3°C lower at 250 cfs than it is at 50 cfs. Additionally, the R^2 value for the DR 160.25 regression equation has decreased over time with addition of more recent stream flow and temperature data, suggesting the influence of stream flow at NCD on temperature is decreasing, possibly in relation to hotter air temperatures and a changing climate. While these data suggest stream flow restoration in the middle Deschutes will have a relatively small effect on stream temperature at DR 160.25, increasing flows at North Canal Dam remains important to reduce the rate of warming downstream of Tumalo Creek and for the greater amount of aquatic habitat provided by higher flows.

4.4 Target Stream Flow

Mass balance equation results suggest that restoring 50 cfs in Tumalo Creek will achieve the 18°C standard in the Deschutes downstream of the confluence at a Deschutes River flow of 134 cfs below North Canal Dam, the median flow protected as of July 2021; DR 160.00 regression results indicate 49 cfs in Tumalo Creek will result in 18°C in the Deschutes downstream of the confluence with Tumalo Creek. Increasing Tumalo Creek flows to 58 cfs is estimated to reduce stream temperature in the Deschutes below the confluence to 17.5°C ± 2.1°C (or 17.7 ± 2.0°C calculated from the DR 160.00 regression equation) and allow in part for downstream warming between the confluence and Lower Bridge (DR 133.50). Achieving the 18°C standard in the Deschutes downstream of the confluence at the Tumalo Creek state instream water right of 32 cfs would require 250 cfs (the pending state instream water right) in the Deschutes. In light of the 2021 status of protected flows, 134 cfs in the Deschutes and 17.5 cfs in Tumalo Creek, these results suggest that achieving the desired reductions in stream temperature in the middle Deschutes River may be significantly accelerated by strategically prioritizing Tumalo Creek water transactions; preferentially increasing flows in Tumalo Creek over restoring stream flow in the Deschutes may achieve the greatest temperature benefits at the lowest cost.

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

Higher flows achieved through stream flow restoration scenarios described above will reduce stream temperatures meaningfully. However, mass balance and Heat Source model results suggest that it is not possible to meet the state temperature standard in all reaches of the middle Deschutes River between Tumalo Creek and Whychus Creek given diversion of Tumalo Creek flows for municipal and agricultural use, and while Deschutes River water is subject to heating in Wickiup and Crane Prairie reservoirs prior to being released downstream. Preliminary analysis of stream temperature from Pringle Falls at DR 217.25, approximately ten miles below Wickiup Reservoir, and stream temperature from DR 164.75, immediately below North Canal Dam, suggest stream temperature at North Canal Dam increases as a function of increasing stream temperature at DR 217.25 ($R^2 = 0.35$), which in turn we hypothesize increases as a function of reservoir level. Further evidence for reservoir storage resulting in increased stream temperature in the Deschutes River is found in historic accounts of abundant bull trout, which require cooler (10°C) stream temperatures than other salmonids, in the Deschutes River at Pringle Falls (DR 217.25; Fies et al 1996). Allocating the maximum amount of streamflow possible from Tumalo Creek and the Deschutes River during the month of July will reduce the frequency and duration of lethal stream temperatures in the middle Deschutes and improve rearing habitat for juvenile redband.

4.5 Implications for Native Redband Populations

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

Whether or not it is possible to meet the state temperature standard along every mile of the middle Deschutes River between North Canal Dam and Lower Bridge Road given current reservoir operations and irrigation infrastructure and management, increases in flow that approach or exceed the instream water right and DRC flow targets in the Deschutes River and Tumalo Creek may nonetheless confer substantial ecological benefits beyond improving temperature conditions. Although elevated stream temperature is an important consequence of modified flows in the Deschutes River and in Tumalo Creek, altered flows affect other stream functions and habitat parameters, notably stream width and depth which contribute to habitat availability and diversity. And, while temperature requirements for salmon and trout are well-documented and encoded in state water quality standards, specific requirements for the habitat functions of the hydrograph in the middle Deschutes River are less well understood. Starcevich and Bailey (2017) found channel width between North Canal Dam and Steelhead Falls was on average eight meters narrower during irrigation season than during water storage season, demonstrating the dramatic reduction in the sheer amount of fish habitat that results from irrigation withdrawals at North Canal Dam. Allocating resources to stream flow restoration in Tumalo Creek will optimize reductions in temperature in Tumalo Creek and in the Deschutes River downstream of Tumalo Creek, as well as habitat benefits associated with increased habitat quantity (stream width and depth) in the reach of Tumalo Creek where stream flow is restored. Restoring stream flow in the Deschutes River will provide important habitat benefits associated with increased habitat quantity, while providing an additional cooling effect when Tumalo Creek flows are 67 cfs or below. This report provides information that will allow Deschutes River Conservancy, fisheries managers, and basin partners to identify flow scenarios for Tumalo Creek and the middle Deschutes River that balance the habitat benefits of lower stream temperatures and increased habitat quantity to provide the greatest habitat benefit for resident redband trout.

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APPENDIX A Estimated temperatures at given flows calculated from regression equations

Deschutes River upstream of Tumalo Creek (DR 160.25; R^2 = 0.22)

Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)
43	20.6	1.8	**96**	19.8	1.8	**149**	19.2	1.8	**202**	18.6	1.8
44	20.6	1.8	**97**	19.8	1.8	**150**	19.2	1.8	**203**	18.6	1.8
45	20.6	1.8	**98**	19.8	1.8	**151**	19.2	1.8	**204**	18.6	1.8
46	20.6	1.8	**99**	19.8	1.8	**152**	19.1	1.8	**205**	18.6	1.8
47	20.6	1.8	**100**	19.8	1.8	**153**	19.1	1.8	**206**	18.6	1.8
48	20.5	1.8	**101**	19.8	1.8	**154**	19.1	1.8	**207**	18.6	1.8
49	20.5	1.8	**102**	19.8	1.8	**155**	19.1	1.8	**208**	18.6	1.8
50	20.5	1.8	**103**	19.8	1.8	**156**	19.1	1.8	**209**	18.6	1.8
51	20.5	1.8	**104**	19.7	1.8	**157**	19.1	1.8	**210**	18.6	1.8
52	20.5	1.8	**105**	19.7	1.8	**158**	19.1	1.8	**211**	18.6	1.8
53	20.5	1.8	**106**	19.7	1.8	**159**	19.1	1.8	**212**	18.5	1.8
54	20.5	1.8	**107**	19.7	1.8	**160**	19.1	1.8	**213**	18.5	1.8
55	20.4	1.8	**108**	19.7	1.8	**161**	19.0	1.8	**214**	18.5	1.8
56	20.4	1.8	**109**	19.7	1.8	**162**	19.0	1.8	**215**	18.5	1.8
57	20.4	1.8	**110**	19.7	1.8	**163**	19.0	1.8	**216**	18.5	1.8
58	20.4	1.8	**111**	19.6	1.8	**164**	19.0	1.8	**217**	18.5	1.8
59	20.4	1.8	**112**	19.6	1.8	**165**	19.0	1.8	**218**	18.5	1.8
60	20.4	1.8	**113**	19.6	1.8	**166**	19.0	1.8	**219**	18.5	1.8
61	20.3	1.8	**114**	19.6	1.8	**167**	19.0	1.8	**220**	18.5	1.8
62	20.3	1.8	**115**	19.6	1.8	**168**	19.0	1.8	**221**	18.5	1.8
63	20.3	1.8	**116**	19.6	1.8	**169**	19.0	1.8	**222**	18.5	1.8
64	20.3	1.8	**117**	19.6	1.8	**170**	19.0	1.8	**223**	18.5	1.8
65	20.3	1.8	**118**	19.6	1.8	**171**	18.9	1.8	**224**	18.4	1.8
66	20.3	1.8	**119**	19.5	1.8	**172**	18.9	1.8	**225**	18.4	1.8
67	20.3	1.8	**120**	19.5	1.8	**173**	18.9	1.8	**226**	18.4	1.8
68	20.2	1.8	**121**	19.5	1.8	**174**	18.9	1.8	**227**	18.4	1.8
69	20.2	1.8	**122**	19.5	1.8	**175**	18.9	1.8	**228**	18.4	1.8
70	20.2	1.8	**123**	19.5	1.8	**176**	18.9	1.8	**229**	18.4	1.8
71	20.2	1.8	**124**	19.5	1.8	**177**	18.9	1.8	**230**	18.4	1.8
72	20.2	1.8	**125**	19.5	1.8	**178**	18.9	1.8	**231**	18.4	1.8
73	20.2	1.8	**126**	19.5	1.8	**179**	18.9	1.8	**232**	18.4	1.8
74	20.2	1.8	**127**	19.4	1.8	**180**	18.8	1.8	**233**	18.4	1.8
75	20.1	1.8	**128**	19.4	1.8	**181**	18.8	1.8	**234**	18.4	1.8
76	20.1	1.8	**129**	19.4	1.8	**182**	18.8	1.8	**235**	18.4	1.8
77	20.1	1.8	**130**	19.4	1.8	**183**	18.8	1.8	**236**	18.3	1.8
78	20.1	1.8	**131**	19.4	1.8	**184**	18.8	1.8	**237**	18.3	1.8
79	20.1	1.8	**132**	19.4	1.8	**185**	18.8	1.8	**238**	18.3	1.8
80	20.1	1.8	**133**	19.4	1.8	**186**	18.8	1.8	**239**	18.3	1.8
81	20.1	1.8	**134**	19.4	1.8	**187**	18.8	1.8	**240**	18.3	1.8
82	20.0	1.8	**135**	19.3	1.8	**188**	18.8	1.8	**241**	18.3	1.8
83	20.0	1.8	**136**	19.3	1.8	**189**	18.8	1.8	**242**	18.3	1.8
84	20.0	1.8	**137**	19.3	1.8	**190**	18.8	1.8	**243**	18.3	1.8
85	20.0	1.8	**138**	19.3	1.8	**191**	18.7	1.8	**244**	18.3	1.8
86	20.0	1.8	**139**	19.3	1.8	**192**	18.7	1.8	**245**	18.3	1.8
87	20.0	1.8	**140**	19.3	1.8	**193**	18.7	1.8	**246**	18.3	1.8
88	20.0	1.8	**141**	19.3	1.8	**194**	18.7	1.8	**247**	18.3	1.8
89	19.9	1.8	**142**	19.3	1.8	**195**	18.7	1.8	**248**	18.3	1.8
90	19.9	1.8	**143**	19.3	1.8	**196**	18.7	1.8	**249**	18.2	1.8
91	19.9	1.8	**144**	19.2	1.8	**197**	18.7	1.8	**250**	18.2	1.8
92	19.9	1.8	**145**	19.2	1.8	**198**	18.7	1.8			
93	19.9	1.8	**146**	19.2	1.8	**199**	18.7	1.8			
94	19.9	1.8	**147**	19.2	1.8	**200**	18.7	1.8			
95	19.9	1.8	**148**	19.2	1.8	**201**	18.6	1.8			

Deschutes River downstream of Tumalo Creek (DR 160.00; R^2 = 0.50) at Tumalo Creek flows

Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)
10	19.8	2.0	**63**	17.5	2.0	**116**	16.1	2.0
11	19.7	2.0	**64**	17.4	2.0	**117**	16.1	2.0
12	19.7	2.0	**65**	17.4	2.0	**118**	16.1	2.0
13	19.6	2.0	**66**	17.4	2.0	**119**	16.0	2.0
14	19.6	2.0	**67**	17.3	2.0	**120**	16.0	2.0
15	19.6	2.0	**68**	17.3	2.0	**121**	16.0	2.0
16	19.5	2.0	**69**	17.2	2.0	**122**	16.0	2.0
17	19.5	2.0	**70**	17.2	2.0	**123**	16.0	2.0
18	19.4	2.0	**71**	17.2	2.0	**124**	16.0	2.0
19	19.4	2.0	**72**	17.1	2.0	**125**	16.0	2.0
20	19.3	2.0	**73**	17.1	2.0	**126**	16.0	2.0
21	19.3	2.0	**74**	17.1	2.0	**127**	16.0	2.0
22	19.2	2.0	**75**	17.0	2.0	**128**	16.0	2.0
23	19.2	2.0	**76**	17.0	2.0	**129**	16.0	2.0
24	19.1	2.0	**77**	17.0	2.0	**130**	16.0	2.0
25	19.1	2.0	**78**	16.9	2.0	**131**	16.0	2.0
26	19.1	2.0	**79**	16.9	2.0	**132**	16.0	2.0
27	19.0	2.0	**80**	16.9	2.0	**133**	16.0	2.0
28	19.0	2.0	**81**	16.8	2.0	**134**	16.0	2.0
29	18.9	2.0	**82**	16.8	2.0	**135**	16.0	2.0
30	18.9	2.0	**83**	16.8	2.0	**136**	16.0	2.0
31	18.8	2.0	**84**	16.7	2.0	**137**	16.0	2.0
32	18.8	2.0	**85**	16.7	2.0	**138**	16.0	2.0
33	18.7	2.0	**86**	16.7	2.0	**139**	16.0	2.0
34	18.7	2.0	**87**	16.7	2.0	**140**	16.1	2.0
35	18.7	2.0	**88**	16.6	2.0	**141**	16.1	2.0
36	18.6	2.0	**89**	16.6	2.0	**142**	16.1	2.0
37	18.6	2.0	**90**	16.6	2.0	**143**	16.1	2.0
38	18.5	2.0	**91**	16.5	2.0	**144**	16.1	2.0
39	18.5	2.0	**92**	16.5	2.0	**145**	16.1	2.0
40	18.4	2.0	**93**	16.5	2.0	**146**	16.1	2.0
41	18.4	2.0	**94**	16.5	2.0	**147**	16.1	2.0
42	18.3	2.0	**95**	16.4	2.0	**148**	16.2	2.0
43	18.3	2.0	**96**	16.4	2.0	**149**	16.2	2.0
44	18.3	2.0	**97**	16.4	2.0	**150**	16.2	2.0
45	18.2	2.0	**98**	16.4	2.0	**151**	16.2	2.0
46	18.2	2.0	**99**	16.4	2.0	**152**	16.2	2.0
47	18.1	2.0	**100**	16.3	2.0	**153**	16.3	2.0
48	18.1	2.0	**101**	16.3	2.0	**154**	16.3	2.0
49	18.0	2.0	**102**	16.3	2.0	**155**	16.3	2.0
50	18.0	2.0	**103**	16.3	2.0	**156**	16.3	2.0
51	18.0	2.0	**104**	16.3	2.0	**157**	16.4	2.1
52	17.9	2.0	**105**	16.2	2.0	**158**	16.4	2.1
53	17.9	2.0	**106**	16.2	2.0			
54	17.8	2.0	**107**	16.2	2.0			
55	17.8	2.0	**108**	16.2	2.0			
56	17.8	2.0	**109**	16.2	2.0			
57	17.7	2.0	**110**	16.2	2.0			
58	17.7	2.0	**111**	16.1	2.0			
59	17.6	2.0	**112**	16.1	2.0			
60	17.6	2.0	**113**	16.1	2.0			
61	17.6	2.0	**114**	16.1	2.0			
62	17.5	2.0	**115**	16.1	2.0			

Tumalo Creek upstream of the mouth (TC 000.25; R^2 = 0.70)

Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)	Flow (cfs)	Mean Temp (7DADM)	PI (±)
10	19.3	2.9	**63**	13.2	2.9	**116**	11.1	2.9
11	19.1	2.9	**64**	13.2	2.9	**117**	11.1	2.9
12	19.0	2.9	**65**	13.1	2.9	**118**	11.1	2.9
13	18.9	2.9	**66**	13.0	2.9	**119**	11.1	2.9
14	18.7	2.9	**67**	12.9	2.9	**120**	11.1	2.9
15	18.6	2.9	**68**	12.9	2.9	**121**	11.1	2.9
16	18.4	2.9	**69**	12.8	2.9	**122**	11.1	2.9
17	18.3	2.9	**70**	12.7	2.9	**123**	11.1	2.9
18	18.1	2.9	**71**	12.7	2.9	**124**	11.1	2.9
19	18.0	2.9	**72**	12.6	2.9	**125**	11.1	2.9
20	17.9	2.9	**73**	12.5	2.9	**126**	11.1	2.9
21	17.7	2.9	**74**	12.5	2.9	**127**	11.2	2.9
22	17.6	2.9	**75**	12.4	2.9	**128**	11.2	2.9
23	17.4	2.9	**76**	12.3	2.9	**129**	11.2	2.9
24	17.3	2.9	**77**	12.3	2.9	**130**	11.2	2.9
25	17.2	2.9	**78**	12.2	2.9	**131**	11.2	2.9
26	17.1	2.9	**79**	12.2	2.9	**132**	11.2	2.9
27	16.9	2.9	**80**	12.1	2.9	**133**	11.3	2.9
28	16.8	2.9	**81**	12.1	2.9	**134**	11.3	2.9
29	16.7	2.9	**82**	12.0	2.9	**135**	11.3	2.9
30	16.5	2.9	**83**	12.0	2.9	**136**	11.3	2.9
31	16.4	2.9	**84**	11.9	2.9	**137**	11.4	2.9
32	16.3	2.9	**85**	11.9	2.9	**138**	11.4	2.9
33	16.2	2.9	**86**	11.8	2.9	**139**	11.4	2.9
34	16.1	2.9	**87**	11.8	2.9	**140**	11.4	2.9
35	15.9	2.9	**88**	11.7	2.9	**141**	11.5	2.9
36	15.8	2.9	**89**	11.7	2.9	**142**	11.5	2.9
37	15.7	2.9	**90**	11.7	2.9	**143**	11.5	2.9
38	15.6	2.9	**91**	11.6	2.9	**144**	11.6	2.9
39	15.5	2.9	**92**	11.6	2.9	**145**	11.6	2.9
40	15.4	2.9	**93**	11.5	2.9	**146**	11.6	3.0
41	15.3	2.9	**94**	11.5	2.9	**147**	11.7	3.0
42	15.2	2.9	**95**	11.5	2.9	**148**	11.7	3.0
43	15.1	2.9	**96**	11.4	2.9	**149**	11.8	3.0
44	15.0	2.9	**97**	11.4	2.9	**150**	11.8	3.0
45	14.9	2.9	**98**	11.4	2.9	**151**	11.9	3.0
46	14.8	2.9	**99**	11.4	2.9	**152**	11.9	3.0
47	14.7	2.9	**100**	11.3	2.9	**153**	12.0	3.0
48	14.6	2.9	**101**	11.3	2.9	**154**	12.0	3.0
49	14.5	2.9	**102**	11.3	2.9	**155**	12.1	3.0
50	14.4	2.9	**103**	11.3	2.9	**156**	12.1	3.0
51	14.3	2.9	**104**	11.2	2.9	**157**	12.2	3.0
52	14.2	2.9	**105**	11.2	2.9	**158**	12.2	3.0
53	14.1	2.9	**106**	11.2	2.9			
54	14.0	2.9	**107**	11.2	2.9			
55	13.9	2.9	**108**	11.2	2.9			
56	13.8	2.9	**109**	11.2	2.9			
57	13.7	2.9	**110**	11.1	2.9			
58	13.6	2.9	**111**	11.1	2.9			
59	13.6	2.9	**112**	11.1	2.9			
60	13.5	2.9	**113**	11.1	2.9			
61	13.4	2.9	**114**	11.1	2.9			
62	13.3	2.9	**115**	11.1	2.9			

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)	**127**	**134**	**150**	**175**	**200**	**250**	**Flow (cfs)**	**127**	**134**	**150**	**175**	**200**	**250**
10	19.4	19.4	19.2	18.9	18.7	18.3	**56**	17.6	17.6	17.6	17.6	17.5	17.4
11	19.4	19.3	19.2	18.9	18.7	18.3	**57**	17.6	17.6	17.6	17.6	17.5	17.3
12	19.4	19.3	19.2	18.9	18.7	18.3	**58**	17.5	17.5	17.5	17.5	17.5	17.3
13	19.4	19.3	19.1	18.9	18.7	18.3	**59**	17.5	17.5	17.5	17.5	17.4	17.3
14	19.4	19.3	19.1	18.9	18.7	18.3	**60**	17.4	17.4	17.5	17.4	17.4	17.3
15	19.4	19.3	19.1	18.9	18.6	18.3	**61**	17.4	17.4	17.4	17.4	17.4	17.2
16	19.3	19.3	19.1	18.9	18.6	18.3	**62**	17.3	17.4	17.4	17.4	17.3	17.2
17	19.3	19.2	19.1	18.8	18.6	18.2	**63**	17.3	17.3	17.3	17.3	17.3	17.2
18	19.3	19.2	19.1	18.8	18.6	18.2	**64**	17.2	17.3	17.3	17.3	17.3	17.1
19	19.3	19.2	19.0	18.8	18.6	18.2	**65**	17.2	17.2	17.2	17.2	17.2	17.1
20	19.2	19.2	19.0	18.8	18.6	18.2	**66**	17.2	17.2	17.2	17.2	17.2	17.1
21	19.2	19.1	19.0	18.8	18.6	18.2	**67**	17.1	17.1	17.2	17.2	17.2	17.1
22	19.2	19.1	19.0	18.8	18.5	18.2	**68**	17.1	17.1	17.1	17.1	17.1	17.0
23	19.1	19.1	18.9	18.7	18.5	18.2	**69**	17.0	17.0	17.1	17.1	17.1	17.0
24	19.1	19.0	18.9	18.7	18.5	18.2	**70**	17.0	17.0	17.0	17.1	17.1	17.0
25	19.1	19.0	18.9	18.7	18.5	18.1	**71**	16.9	17.0	17.0	17.0	17.0	17.0
26	19.0	19.0	18.9	18.7	18.5	18.1	**72**	16.9	16.9	17.0	17.0	17.0	16.9
27	19.0	19.0	18.8	18.6	18.4	18.1	**73**	16.8	16.9	16.9	17.0	17.0	16.9
28	19.0	18.9	18.8	18.6	18.4	18.1	**74**	16.8	16.8	16.9	16.9	16.9	16.9
29	18.9	18.9	18.8	18.6	18.4	18.1	**75**	16.7	16.8	16.8	16.9	16.9	16.8
30	18.9	18.8	18.7	18.6	18.4	18.1	**76**	16.7	16.7	16.8	16.8	16.9	16.8
31	18.9	18.8	18.7	18.5	18.4	18.0	**77**	16.7	16.7	16.8	16.8	16.8	16.8
32	18.8	18.8	18.7	18.5	18.3	18.0	**78**	16.6	16.7	16.7	16.8	16.8	16.8
33	18.8	18.7	18.6	18.5	18.3	18.0	**79**	16.6	16.6	16.7	16.7	16.8	16.7
34	18.7	18.7	18.6	18.4	18.3	18.0	**80**	16.5	16.6	16.6	16.7	16.7	16.7
35	18.7	18.7	18.6	18.4	18.3	18.0	**81**	16.5	16.5	16.6	16.7	16.7	16.7
36	18.6	18.6	18.5	18.4	18.2	17.9	**82**	16.4	16.5	16.6	16.6	16.7	16.7
37	18.6	18.6	18.5	18.3	18.2	17.9	**83**	16.4	16.5	16.5	16.6	16.6	16.6
38	18.6	18.5	18.5	18.3	18.2	17.9	**84**	16.4	16.4	16.5	16.6	16.6	16.6
39	18.5	18.5	18.4	18.3	18.1	17.9	**85**	16.3	16.4	16.5	16.5	16.6	16.6
40	18.5	18.4	18.4	18.2	18.1	17.8	**86**	16.3	16.3	16.4	16.5	16.5	16.5
41	18.4	18.4	18.3	18.2	18.1	17.8	**87**	16.3	16.3	16.4	16.5	16.5	16.5
42	18.4	18.4	18.3	18.2	18.0	17.8	**88**	16.2	16.3	16.4	16.4	16.5	16.5
43	18.3	18.3	18.3	18.1	18.0	17.8	**89**	16.2	16.2	16.3	16.4	16.5	16.5
44	18.3	18.3	18.2	18.1	18.0	17.7	**90**	16.1	16.2	16.3	16.4	16.4	16.4
45	18.2	18.2	18.2	18.1	18.0	17.7	**91**	16.1	16.2	16.3	16.3	16.4	16.4
46	18.2	18.2	18.1	18.0	17.9	17.7	**92**	16.1	16.1	16.2	16.3	16.4	16.4
47	18.1	18.1	18.1	18.0	17.9	17.7	**93**	16.0	16.1	16.2	16.3	16.3	16.4
48	18.1	18.1	18.1	18.0	17.9	17.6	**94**	16.0	16.1	16.2	16.3	16.3	16.4
49	18.1	18.0	18.0	17.9	17.8	17.6	**95**	16.0	16.0	16.1	16.2	16.3	16.3
50	18.0	18.0	18.0	17.9	17.8	17.6	**96**	15.9	16.0	16.1	16.2	16.3	16.3
51	18.0	18.0	17.9	17.9	17.8	17.6	**97**	15.9	16.0	16.1	16.2	16.2	16.3
52	17.9	17.9	17.9	17.8	17.7	17.5	**98**	15.9	15.9	16.0	16.1	16.2	16.3
53	17.9	17.9	17.8	17.8	17.7	17.5	**99**	15.8	15.9	16.0	16.1	16.2	16.2
54	17.8	17.8	17.8	17.7	17.7	17.5	**100**	15.8	15.9	16.0	16.1	16.2	16.2
55	17.8	17.8	17.8	17.7	17.6	17.5							

APPENDIX C 7DADM temperatures and prediction intervals estimated for DR 160.00 from regression and mass balance equations

Tumalo Creek Flow (cfs)	Mass Balance Mean Temp (7DADM)	Mass Balance PI (±)	Regression Mean Temp (7DADM)	Regression PI (±)	Flow (cfs)	Mass Balance Mean Temp (7DADM)	Mass Balance PI (±)	Regression Mean Temp (7DADM)	Regression PI (±)
10	19.4	1.8	19.8	2.0	**56**	17.6	2.1	17.8	2.0
11	19.3	1.8	19.7	2.0	**57**	17.6	2.1	17.7	2.0
12	19.3	1.8	19.7	2.0	**58**	17.5	2.1	17.7	2.0
13	19.3	1.9	19.6	2.0	**59**	17.5	2.1	17.6	2.0
14	19.3	1.9	19.6	2.0	**60**	17.4	2.1	17.6	2.0
15	19.3	1.9	19.6	2.0	**61**	17.4	2.1	17.6	2.0
16	19.3	1.9	19.5	2.0	**62**	17.4	2.1	17.5	2.0
17	19.2	1.9	19.5	2.0	**63**	17.3	2.1	17.5	2.0
18	19.2	1.9	19.4	2.0	**64**	17.3	2.1	17.4	2.0
19	19.2	1.9	19.4	2.0	**65**	17.2	2.1	17.4	2.0
20	19.2	1.9	19.3	2.0	**66**	17.2	2.1	17.4	2.0
21	19.1	1.9	19.3	2.0	**67**	17.1	2.1	17.3	2.0
22	19.1	1.9	19.2	2.0	**68**	17.1	2.1	17.3	2.0
23	19.1	1.9	19.2	2.0	**69**	17.0	2.1	17.2	2.0
24	19.0	1.9	19.1	2.0	**70**	17.0	2.1	17.2	2.0
25	19.0	1.9	19.1	2.0	**71**	17.0	2.1	17.2	2.0
26	19.0	1.9	19.1	2.0	**72**	16.9	2.1	17.1	2.0
27	19.0	1.9	19.0	2.0	**73**	16.9	2.1	17.1	2.0
28	18.9	1.9	19.0	2.0	**74**	16.8	2.2	17.1	2.0
29	18.9	2.0	18.9	2.0	**75**	16.8	2.2	17.0	2.0
30	18.8	2.0	18.9	2.0	**76**	16.7	2.2	17.0	2.0
31	18.8	2.0	18.8	2.0	**77**	16.7	2.2	17.0	2.0
32	18.8	2.0	18.8	2.0	**78**	16.7	2.2	16.9	2.0
33	18.7	2.0	18.7	2.0	**79**	16.6	2.2	16.9	2.0
34	18.7	2.0	18.7	2.0	**80**	16.6	2.2	16.9	2.0
35	18.7	2.0	18.7	2.0	**81**	16.5	2.2	16.8	2.0
36	18.6	2.0	18.6	2.0	**82**	16.5	2.2	16.8	2.0
37	18.6	2.0	18.6	2.0	**83**	16.5	2.2	16.8	2.0
38	18.5	2.0	18.5	2.0	**84**	16.4	2.2	16.7	2.0
39	18.5	2.0	18.5	2.0	**85**	16.4	2.2	16.7	2.0
40	18.4	2.0	18.4	2.0	**86**	16.3	2.2	16.7	2.0
41	18.4	2.0	18.4	2.0	**87**	16.3	2.2	16.7	2.0
42	18.4	2.0	18.3	2.0	**88**	16.3	2.2	16.6	2.0
43	18.3	2.0	18.3	2.0	**89**	16.2	2.2	16.6	2.0
44	18.3	2.0	18.3	2.0	**90**	16.2	2.2	16.6	2.0
45	18.2	2.0	18.2	2.0	**91**	16.2	2.2	16.5	2.0
46	18.2	2.0	18.2	2.0	**92**	16.1	2.2	16.5	2.0
47	18.1	2.0	18.1	2.0	**93**	16.1	2.2	16.5	2.0
48	18.1	2.0	18.1	2.0	**94**	16.1	2.2	16.5	2.0
49	18.0	2.1	18.0	2.0	**95**	16.0	2.2	16.4	2.0
50	18.0	2.1	18.0	2.0	**96**	16.0	2.2	16.4	2.0
51	18.0	2.1	18.0	2.0	**97**	16.0	2.2	16.4	2.0
52	17.9	2.1	17.9	2.0	**98**	15.9	2.2	16.4	2.0
53	17.9	2.1	17.9	2.0	**99**	15.9	2.2	16.4	2.0
54	17.8	2.1	17.8	2.0	**100**	15.9	2.2	16.3	2.0
55	17.8	2.1	17.8	2.0					