Upper Deschutes Watershed Council

Water Quality Monitoring Program

Technical Report

Instream Flow Restoration and Temperature Responses
Middle Deschutes River, Deschutes Basin, Oregon

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EXECUTIVE SUMMARY

Since 1996, the Deschutes River Conservancy (DRC) has engaged in efforts to restore summer streamflow in the middle Deschutes River and lower Tumalo Creek through a variety of techniques, including conservation, leasing, and acquisition. The DRC has identified streamflow restoration in the Deschutes River and Tumalo Creek as a priority because summer flows have historically been very low, resulting in summer water temperatures that exceed the Oregon Department of Environmental Quality (ODEQ) standard established to protect salmon and trout rearing and migration.

To evaluate the effectiveness of streamflow restoration efforts, the DRC, its funders, and other partners have been interested in tracking 1) whether specific streamflow restoration actions have reduced water temperatures in downstream reaches of the river and 2) whether reductions in temperature, if observed, can be attributed to streamflow restoration projects. In 2008 the DRC contracted with the Upper Deschutes Watershed Council (UDWC) to conduct temperature monitoring to investigate potential temperature changes associated with streamflow restoration projects. This ongoing monitoring effort addresses the following key questions:

1) Temperature status: What is the status of water temperatures in the middle Deschutes River relative to the state of Oregon standard?

   We found temperatures to regularly rise above the state standard of 18°C / 64°F set to protect salmon and trout rearing and migration, consistent with existing Clean Water Act Section 303(d) listing for temperature impairment along the Deschutes River. Until there are more significant changes to streamflow and/or other factors that affect water temperature, these results suggest that the middle Deschutes River will continue to exceed the state temperature standard during the summer months.

2) Restoration effectiveness: Have increases in streamflow effectively reduced water temperatures?

   Restoration effectiveness analysis indicates that temperatures changed in restoration reaches of the middle Deschutes River in response to local and longitudinal effects of streamflow restoration. Streamflow restoration efforts initiated in 2005 have incrementally increased flows in the middle Deschutes River. Data from 2005 to 2007 indicate no initial temperature response to increased flows. However, from 2007 to 2008 temperatures in middle Deschutes restoration reaches increased; in 2009 this warming trend was reversed, with middle Deschutes temperatures cooling. In 2010, middle Deschutes temperatures again increased. Thus, increased flows in the middle Deschutes River resulting from streamflow restoration at North Canal Dam and in Tumalo Creek produced either a net warming or a net cooling in July temperatures along the middle Deschutes River from one year to the next between 2007 and 2010. Results suggest that the direction of the change in temperature (warming or cooling) may depend in part on the relative streamflow contribution of the Deschutes at North Canal Dam and Tumalo Creek at the confluence with the Deschutes, with relatively greater flows at North Canal Dam increasing downstream temperatures, and a relatively greater flow contribution from Tumalo Creek reducing downstream temperatures.

3) Target streamflow: What is the estimated streamflow needed to meet the 18°C/64°F State of Oregon temperature standard for salmon and trout rearing and migration?

   We used data from 2001 to 2010 to evaluate this question for two locations on the middle Deschutes River: a) downstream of Tumalo Creek near the site of instream flow restoration, and b) at Lower Bridge Road 30 miles downstream of flow restoration.

   a) *Deschutes River downstream of Tumalo Creek: How much instream flow do we need in the Deschutes River downstream of Tumalo Creek to reduce water temperatures to meet state standards?* Based on temperature and flow analysis, flows of 130 cfs are needed to reduce temperatures to the 18°C state standard in July. However, at 149 cfs the cooling trend is reversed as temperatures begin to increase, and at flows greater than 157 cfs, July temperatures again exceed the state standard.

   b) *Deschutes River at Lower Bridge Road: How much instream flow do we need at Lower Bridge Road to reduce water temperatures to meet state standards?* Results of the 2010 analysis suggest that the current target of 250 cfs for the middle Deschutes River is sufficient to achieve state temperature standards at Lower Bridge Road, 30 miles downstream from the point of instream flow restoration.

Temperatures thus remain elevated in the middle Deschutes River, exceeding the state standard and potentially compromising rearing and migration habitat for salmon and trout. In addition, restoration effectiveness analysis suggests that increasing flows to meet the instream flow target of 250 cfs is likely to further increase July temperature above the 18°C state standard in the middle Deschutes River from North Canal Dam to immediately downstream of Tumalo Creek. The streamflow target analysis suggests that one instream flow target of 250 cfs applied to the longitudinal extent of the middle Deschutes from the confluence with Tumalo Creek downstream to Lower Bridge Road will meet the state temperature standard in some reaches but not in others. Flows from 130 to 157 cfs result in temperatures along the

Deschutes River downstream of Tumalo Creek that meet or are less than the 18°C state standard, creating potential benefits for fish such as temperature refugia and increased access to pools and cover. At flows above 157 cfs, as temperatures rise above 18°C and any temperature refuge which may have existed at this site is lost, other potential benefits to fish from restored streamflow remain. Downstream at Lower Bridge Road the temperature standard is only met when flows meet or exceed 250 cfs. Implementing studies that evaluate relationships between increased streamflow, temperature, fish population response and fish habitat use will contribute substantially to the ability of restoration partners to identify a flow target that maximizes the ecological benefits of streamflow restoration for fish and the middle Deschutes River ecosystem.

ACKNOWLEDGMENTS

The Upper Deschutes Watershed Council would like to thank the Deschutes River Conservancy (DRC) for sponsoring the middle Deschutes River streamflow and temperature study summarized in this technical report. Water quality monitoring conducted by Upper Deschutes Watershed Council is funded in large part by the Oregon Department of Environmental Quality (ODEQ) 319 Grant Program and the Oregon Watershed Enhancement Board; their generous support has been instrumental in the data collection and analysis informing this report. We thank our many partners including the City of Bend, ODEQ, Oregon State University (OSU), and Oregon Water Resources Department (OWRD) whose regional water quality monitoring efforts contributed to the long-term dataset analyzed in this Technical Report. We also thank the many individuals who have contributed their time, knowledge and insights to the development of the strategies, analyses, and findings in this report, including the members of the Water Quality Committee who oversaw the work presented here, contributing partners, and our Water Quality Monitoring Program staff and interns.

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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
OSU	Oregon State University
OWRD	Oregon Water Resources Department
TID	Tumalo Irrigation District

Terminology

°C	Degree Celsius
°F	Degree Fahrenheit
7DMAX	Seven Day Moving Average Maximum
BACI	Before After Control Impact
df	Degrees of freedom
CI	Confidence interval
CL	Confidence level
cfs	Cubic feet per second
Ln	Natural logarithm
OAR	Oregon Administrative Rules
PBACI	Paired Before After Control Impact
QA/QC	Quality assurance / quality control
QD	Average daily flow
S	Standard distance from regression line
StDev	Standard deviation from mean
TMDL	Total Maximum Daily Load

1. Introduction

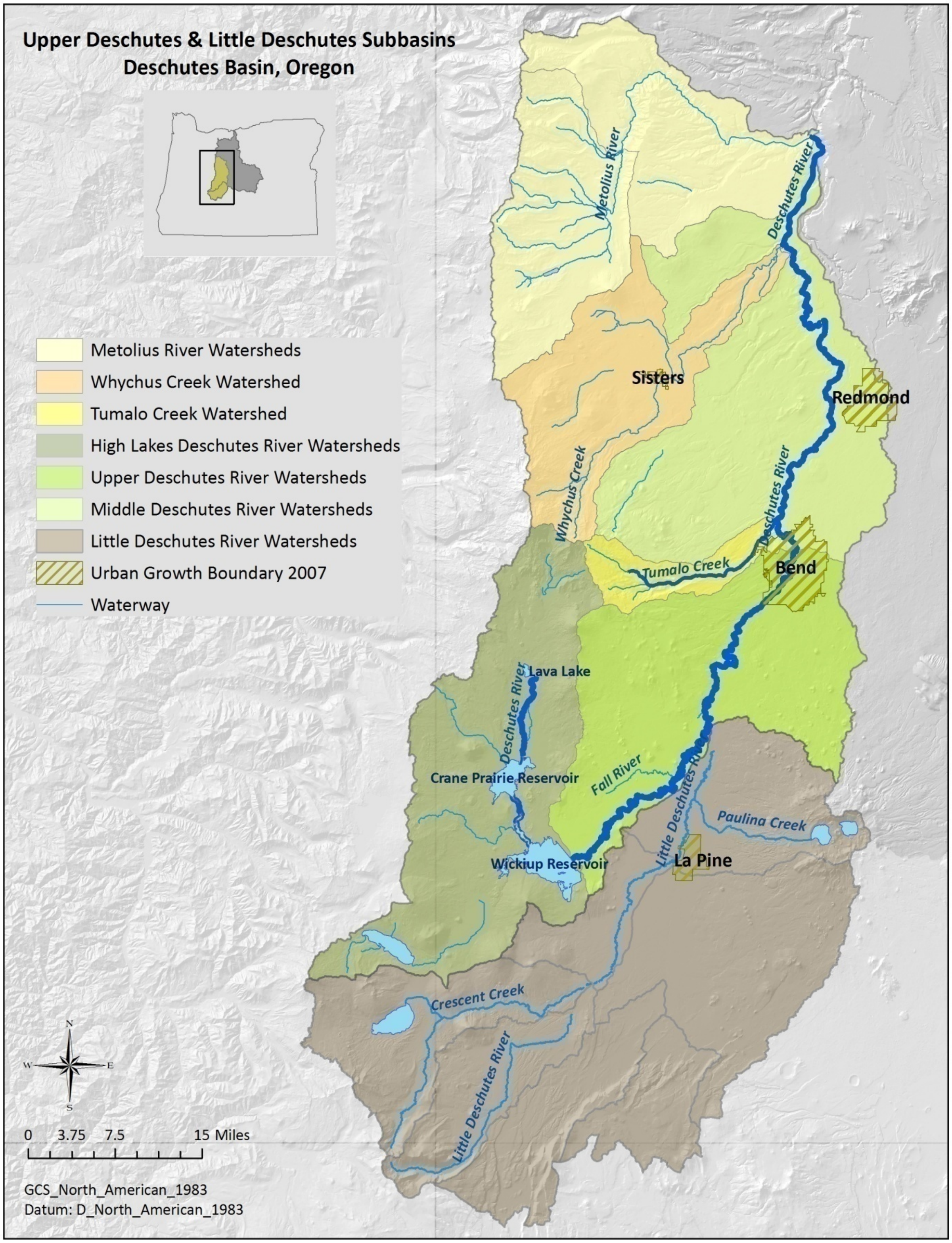
The middle Deschutes River Watershed is located within the Deschutes Basin, Oregon, and is bordered by the Metolius River, Whychus Creek, Tumalo Creek, and Upper Deschutes River watersheds (Map 1). The middle Deschutes River is listed as a temperature impaired waterway under Clean Water Act Section 303(d) for not meeting State of Oregon water temperature standards for salmon and trout rearing and migration (Map 2).

Since 1996, the Deschutes River Conservancy (DRC) has engaged in efforts to restore summer streamflow in the middle Deschutes River and lower Tumalo Creek. Through a variety of techniques, including conservation, leasing, and acquisition, the DRC has successfully negotiated more than 150 cubic feet per second (cfs) of streamflow for the middle Deschutes River and more than 10 cfs for Tumalo Creek. As a result, July median average daily streamflow has increased from 5 cfs in 2001 to 15 cfs in 2010 at the mouth of Tumalo Creek, and from 48 cfs in 2001 to 148 cfs in 2010 in the Deschutes River at North Canal Dam below Bend, OR (Figure 1). Combined, streamflow restoration efforts at each of these locations have contributed to a 111 cfs increase in middle Deschutes River July median average daily flows, from 53 cfs in 2001 to 164 cfs in 2010[1]. DRC has prioritized streamflow restoration in these reaches because historically low summer flows have resulted in summer water temperatures that exceed the Oregon Department of Environmental Quality standard of 18°C / 64°F established to protect salmon and trout rearing and migration.

Although model predictions and substantial empirical evidence indicate that reductions in summer streamflow lead to increased water temperatures in central Oregon (ODEQ, 2004) (ODEQ, 2007) (UDWC, 2003) (UDWC, 2006), the DRC and restoration partners are interested in showing how increased flows resulting from specific restoration actions affect water temperatures in downstream reaches. Although collecting water temperature and streamflow data is straightforward, the ability to establish a correlation between small changes in temperature and small increases in streamflow that result from specific restoration actions requires accounting for inter-annual climatic variation and seasonality, which can substantially alter the relationship between streamflow and water temperature. An approach that incorporates multiple years of data and uses statistical analyses that can accommodate inter-annual environmental variability allows restoration partners to understand how streamflow restoration projects affect long-term trends in water temperature and, accordingly, to prioritize restoration actions that will most effectively reduce temperatures in the middle Deschutes River.

[1] There is not an active gage station on the Deschutes River downstream of Tumalo Creek to collect middle Deschutes River flow data. To estimate flows for the middle Deschutes River, the streamflow data collected by the Oregon Water Resources Department (OWRD) gage located on the Deschutes River below Bend (OWRD gage #14070500) is combined with the streamflow data collected by the OWRD gage located on Tumalo Creek downstream the Tumalo Irrigation District Feed Canal (OWRD gage #14073520). Therefore, middle Deschutes River streamflow data used in this Technical Report is estimated.

Map 1 Middle Deschutes River Study Area



Map 2 Salmon and Trout Rearing and Migration Section 303(d) Impaired Waterways

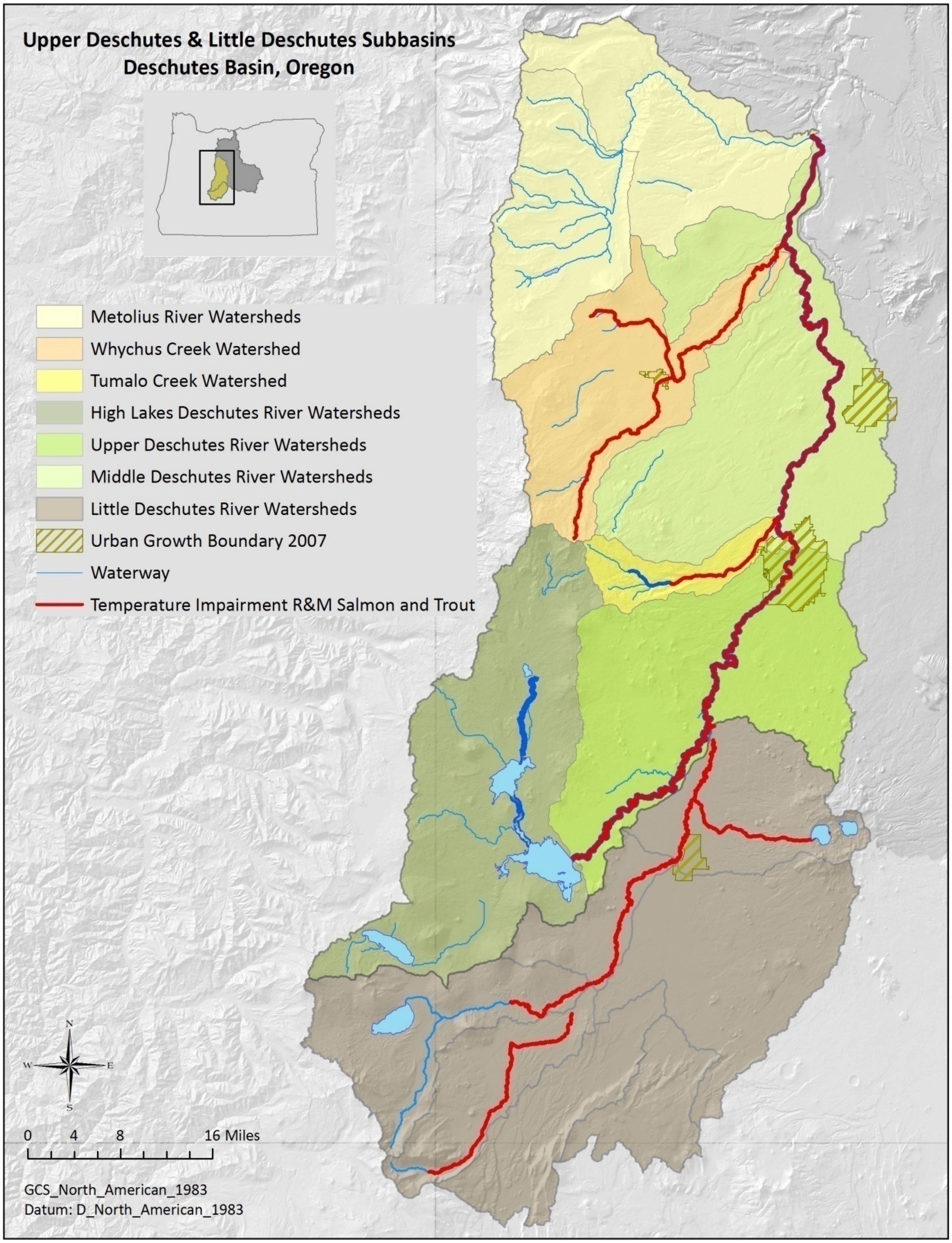
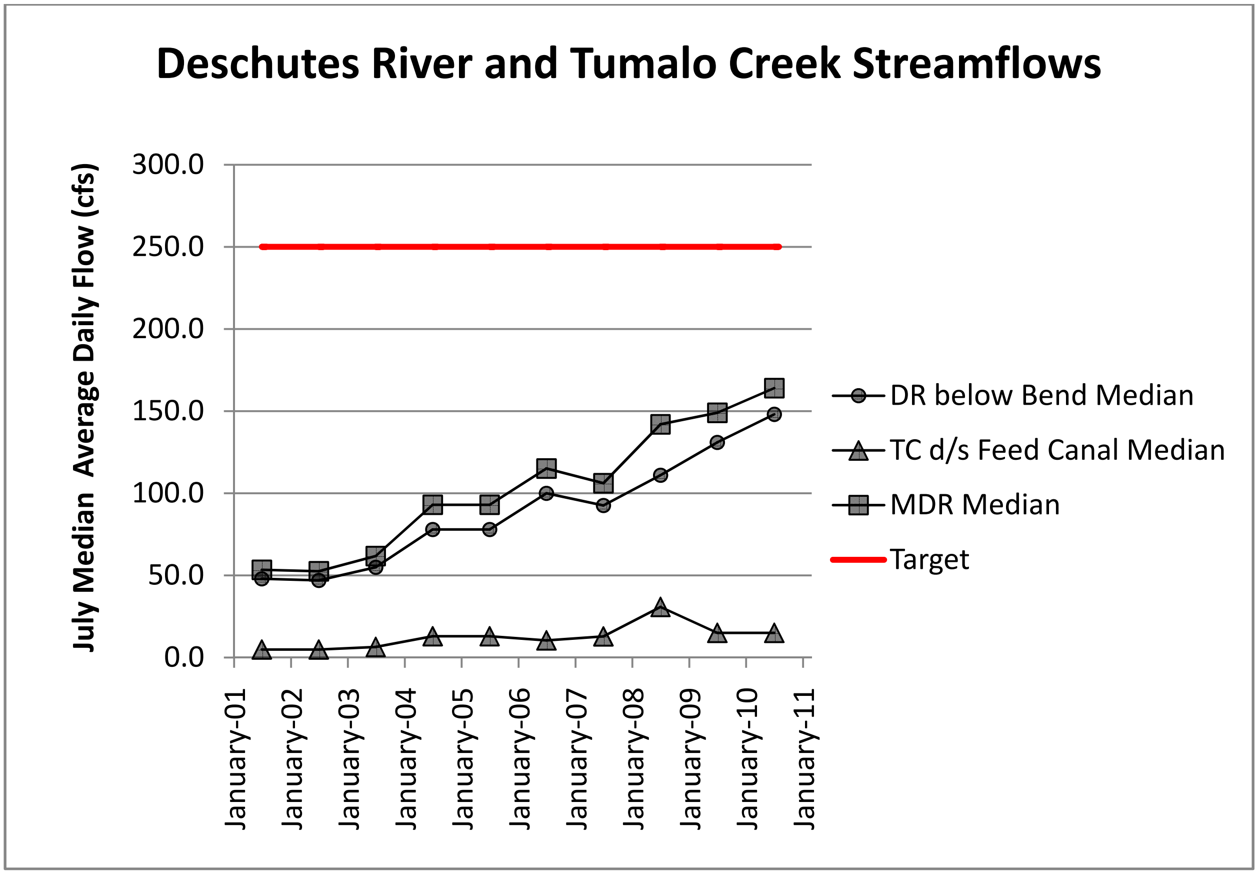


Figure 1 Middle Deschutes River and Tumalo Creek Streamflows July 2001 – 2010

July median average daily streamflows have increased as a result of DRC instream flow restoration, from 5 cfs in 2001 to 15 cfs in 2010 at the mouth of Tumalo Creek, and from 48 cfs in 2001 to 148 cfs in 2010 in the Deschutes River at North Canal Dam below Bend, OR. Combined, streamflow restoration efforts at each of these locations have contributed to a 111 cfs increase in middle Deschutes River July median average daily flows, from 53 cfs in 2001 to 164 cfs in 2010[2].



[2] There is not an active gage station on the Deschutes River downstream of Tumalo Creek to collect middle Deschutes River flow data. To estimate flows for the middle Deschutes River, the streamflow data collected by the Oregon Water Resources Department (OWRD) gage located on the Deschutes River below Bend (OWRD gage #14070500) is combined with the streamflow data collected by the OWRD gage located on Tumalo Creek downstream the Tumalo Irrigation District Feed Canal (OWRD gage #14073520). Therefore, middle Deschutes River streamflow data used in this Technical Report is estimated.

1.1. Key Questions

In 2008 the DRC contracted with the Upper Deschutes Watershed Council (UDWC) to conduct temperature monitoring to investigate potential temperature changes associated with streamflow restoration projects. UDWC and monitoring partners have monitored water temperature throughout the Upper Deschutes River subbasin since 2001 and have developed relevant statistical approaches to describe relationships between streamflow and temperature. UDWC and partners conducted temperature monitoring and data analysis to address the following questions:

1) Temperature status: What is the status of middle Deschutes River water temperatures relative to the State of Oregon 18°C / 64°F standard?

2) Restoration effectiveness: Has the increase in streamflow reduced water temperatures?

3) Target streamflow: What is the estimated streamflow needed to meet the State of Oregon temperature standard?

2. Methods

2.1. Data Collection

2.1.1. Water Temperature

UDWC compiled continuous water temperature data from six water temperature monitoring stations on the Deschutes River (Table 1; Map 3). Data for 2001 through 2010 were obtained from the UDWC's online water quality database (UDWC, 2010). Data is not available for all years due to equipment failure or no monitoring (Table 2). All temperature data used in analyses were collected by ODEQ, the City of Bend, and UDWC. UDWC operates per the *Water Quality Monitoring Program Standard Operating Procedures* (UDWC, 2008) under a State of Oregon approved Quality Assurance Project Plan (UDWC, 2008).

2.1.2. Average Daily Flow

UDWC obtained average daily streamflow (QD) data for the Deschutes River and Tumalo Creek from the Oregon Water Resources Department (OWRD) (OWRD, 2010) (Table 1; Map 4). Streamflows recorded at the two gage stations are combined to approximate the streamflow below the confluence of the Deschutes River and Tumalo Creek.[3] Some of the streamflow data used for analysis is considered provisional by OWRD. Of the 2008-2010 flow data, Tumalo Creek data is considered provisional and subject to change; Deschutes River data is considered published with a few exceptions on several dates (Golden, 2010). Although some data is provisional, the 2001-2010 datasets are large enough that provisional data is not expected to affect the results of analyses; we further minimized possible effects of outliers by using statistical metrics that are robust to outliers.

[3] There is not an active gage station on the Deschutes River downstream of Tumalo Creek to collect middle Deschutes River flow data. To estimate flows for the middle Deschutes River, the streamflow data collected by the Oregon Water Resources Department (OWRD) gage located on the Deschutes River below Bend (OWRD gage #14070500) is combined with the streamflow data collected by the OWRD gage located on Tumalo Creek downstream the Tumalo Irrigation District Feed Canal (OWRD gage #14073520). Therefore, middle Deschutes River streamflow data used in this Technical Report is estimated.

Table 1 Monitoring Stations

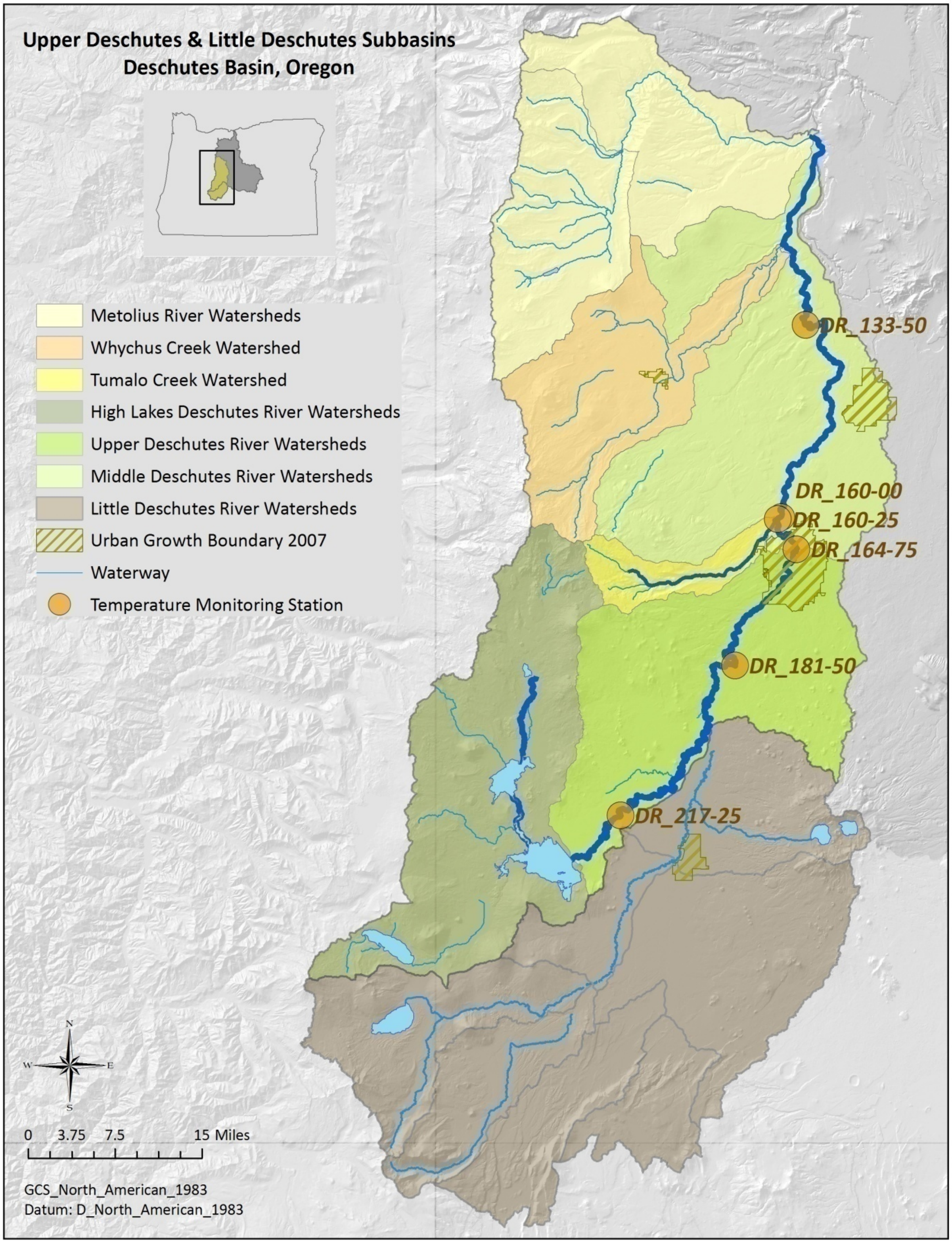
Station ID	Waterway	Description	Latitude	Longitude	Elev. (ft)
OWRD gage #14073520	Tumalo Creek	d/s of Tumalo Feed Canal	44.08944	-121.36667	3550
OWRD gage #14070500	Deschutes River	d/s of North Canal Dam, Bend	44.08280	-121.30690	3495
DR 217.25	Deschutes River	Pringle Falls	43.74075	-121.60672	4250
DR 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

Table 2 Summary of Available July Temperature Data

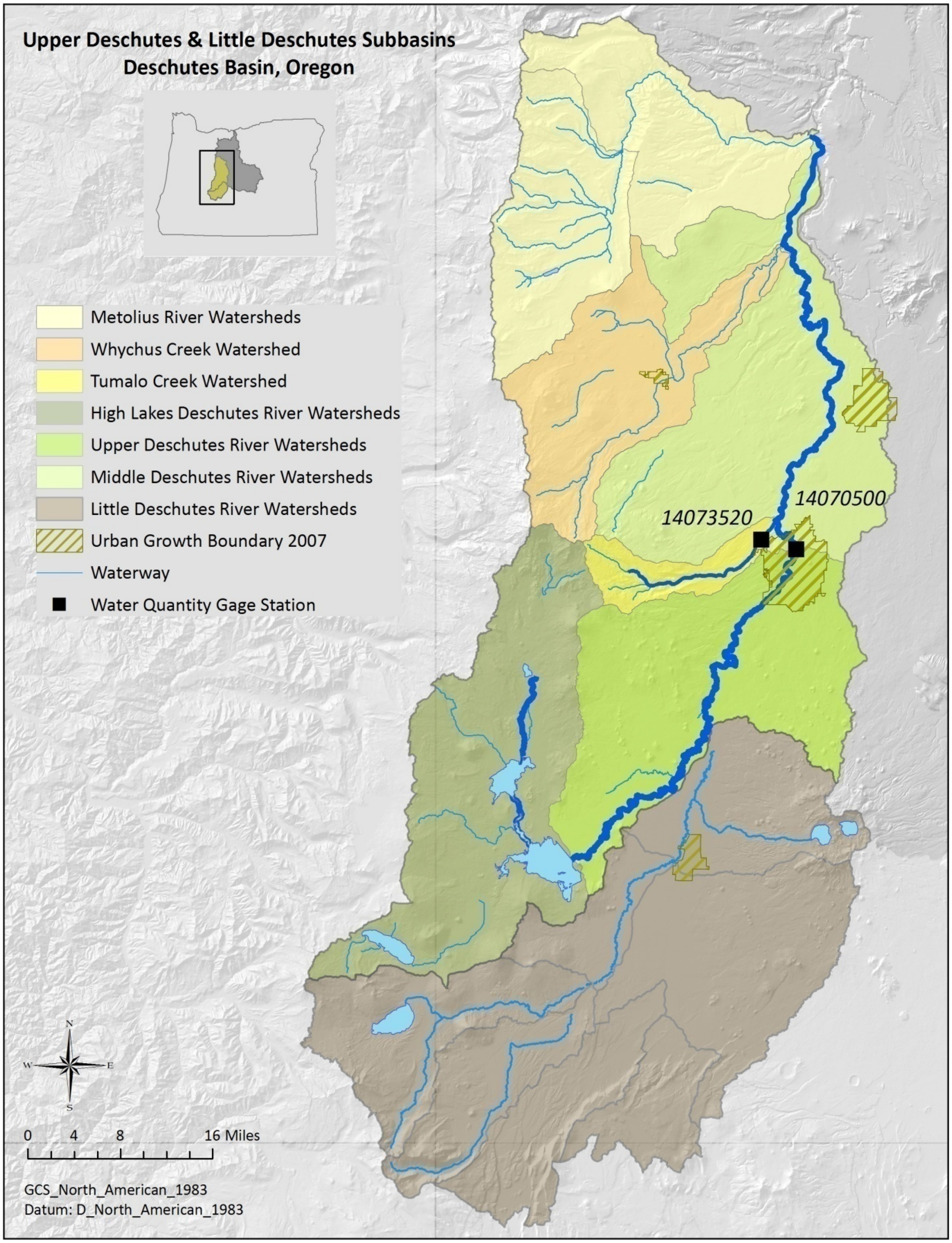
Station ID	Waterway	Description	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DR 217.25	Deschutes River	Pringle Falls		X	X	X	X	X	X	-	X	X
DR 181.50	Deschutes River	Benham Falls			X		X	X	X	X	X	X
DR 164.75	Deschutes River	u/s of Riverhouse Hotel				X	X		-	X	X	X
DR 160.25	Deschutes River	u/s of Tumalo Creek		X	X	X	X		-	X	X	X
DR 160.00	Deschutes River	d/s of Tumalo Creek					X	X	X	X	X	X
DR 133.50	Deschutes River	Lower Bridge	X	X		X	X	X	X	X	X	X

X	Data available for analyses
-	Limited data available for analyses

Map 3 Temperature Monitoring Stations used in Analyses



Map 4 Streamflow Gaging Stations used in Analyses



2.2. Data Analysis

2.2.1. Temperature Status

The seven day moving average maximum (7DMAX) temperature is the statistic used by the State of Oregon to evaluate stream temperatures and is calculated using the Hydrostat Simple spreadsheet available online from ODEQ (ODEQ, 2010). The current State of Oregon water temperature standard that applies to the Deschutes River above the Pelton Round Butte Dam complex specifies that the 7DMAX shall not exceed 18°C / 64°F to protect salmon and trout rearing and migration (OAR 340-041-0028) (ODEQ, 2010). We compared July 7DMAX temperatures for 2001-2010 to the state standard of 18°C / 64°F to evaluate whether temperatures in the middle Deschutes River meet the state standard for salmonid rearing and migration.

2.2.2. Restoration Effectiveness

We monitored a total of five stations to establish trends in temperature associated with ongoing streamflow restoration: two upstream stations provided data for a reference reach where no streamflow restoration has occurred; we used data from three downstream stations to evaluate streamflow restoration impacts on downstream temperatures in two restoration reaches where streamflow restoration has increased flows (Map 5). Future monitoring should be conducted at the same five stations. The reaches are defined as follows (Map6):

Reference Reach
DR 217.25 to DR 181.50 This reach serves as an experimental control because flows are regulated and therefore are consistent year to year; temperatures are not affected by local non-flow-related influences, but are expected to be affected by climate and regional variations.

Deschutes Reach
DR 164.75 to DR 160.25 This reach captures the effect of restored streamflow at North Canal Dam (NCD) by examining changes in temperature in the Deschutes River downstream of the NCD diversion and upstream of Tumalo Creek. This reach is *not* expected to be influenced by restored streamflow in Tumalo Creek.

Tumalo Reach
DR 160.25 to DR 160.00 This reach captures the combined effects of restored streamflow at North Canal Dam and in Tumalo Creek by examining changes in temperature in the Deschutes River immediately downstream of Tumalo Creek.

To control for natural variability in streamflow, climate (e.g. precipitation, solar radiation, air temperature, etc.) and other environmental factors that influence inter-annual differences in temperature we used a paired Before After Control Impact (BACI) analysis that compares pre- (Before; B) and post- (After; A) restoration changes between years within a reference (Control; C) reach to changes between years within a restoration (Impact; I) reach. By accounting for inter-annual environmental variability we are able to attribute differences we observe in temperature between restoration and reference reaches to the effects of streamflow restoration. Because additional streamflow was restored in each year of the analysis, for each pair of consecutive years for which data are available the preceding year represents the BACI "Before" year and the subsequent year represents the BACI "After" year. We compared the Before-After (B-A) difference of changes between years in upstream temperatures and changes between years in downstream temperatures in the reference reach (C) to the difference of changes between years in upstream temperatures and changes between years in downstream temperatures (B-A) in the two restoration reaches (I - Tumalo and I - Deschutes) for all years for which enough July data was available for analysis, including 2005/2007 and 2007/2008 for the Tumalo restoration reach, and 2008/2009 and 2009/2010 for the Tumalo and Deschutes restoration reaches. We restricted data included in the analysis to one month of the year, July, and included temperature data from at least seven of the same July calendar dates for each year, to reduce the effect of inter-annual seasonal variation in the analysis (Helsel & Hirsch, 1991). July data were used because July represents the hottest month for water temperatures in the Deschutes River (UDWC, 2003) (UDWC, 2006). For each year included in the analysis, Before-After differences were calculated from the means of July daily median temperatures, a statistic which reflects small changes in temperature more precisely than the daily mean or daily maximum temperature, and at a finer time scale than the seven day moving average maximum temperature.

We used a Student's t-test to identify 1) whether temperature changes observed between years in restoration reaches were significantly different than changes observed between years in reference reaches, and 2) in which direction these changes occurred (warming or cooling) relative to the reference reach. The Student's t-test indicates whether two population means are significantly different (Helsel & Hirsch, 1991) (NIST, 2010). The p-value calculated in the t-test is compared to the α-value corresponding to a specified confidence level; if the p-value is greater than the α-value the null hypothesis (Null) cannot be rejected; if the p-value is less than the α-value we can reject the null hypothesis and support the alternative hypothesis (Alt1) (Table 3). For this analysis we selected a Confidence Level of 90% and a corresponding α-value of 0.10.

To verify the direction of change in temperature in restoration reaches relative to the reference reach we compared the T-value calculated from degrees of freedom (df) in the Student's t-test to the Tα value corresponding to the 90% confidence level value in a t distribution table (NIST, 2010). A T-value greater than the Tα value supported alternative hypothesis two (Alt2) and led us to reject alternative hypothesis three (Alt3); a T-value less than the Tα value supported alternative hypothesis three (Alt3) and conversely led us to reject alternative hypothesis two.

Steps one through seven below provide a simplified description of the analysis. For a more detailed description of the paired BACI analysis reference the *Encyclopedia of Environmetrics* (NIST, 2010). For a more detailed description of the Student's t-test reference *Statistical Methods in Water Resources* (Helsel & Hirsch, 1991).

<u>Steps in BACI Analysis and Student's t-test of Hypotheses</u>

1. Establish upstream and downstream stations for the reference reach and both restoration reaches.

2. For each reach, calculate the Before-After difference:

a) Calculate the between-years difference (e.g. 2005-2007) of the mean July daily median temperature for the upstream station and for the downstream station.

b) For the same reach, calculate the difference between upstream and downstream stations from the upstream and downstream differences between years from step a).

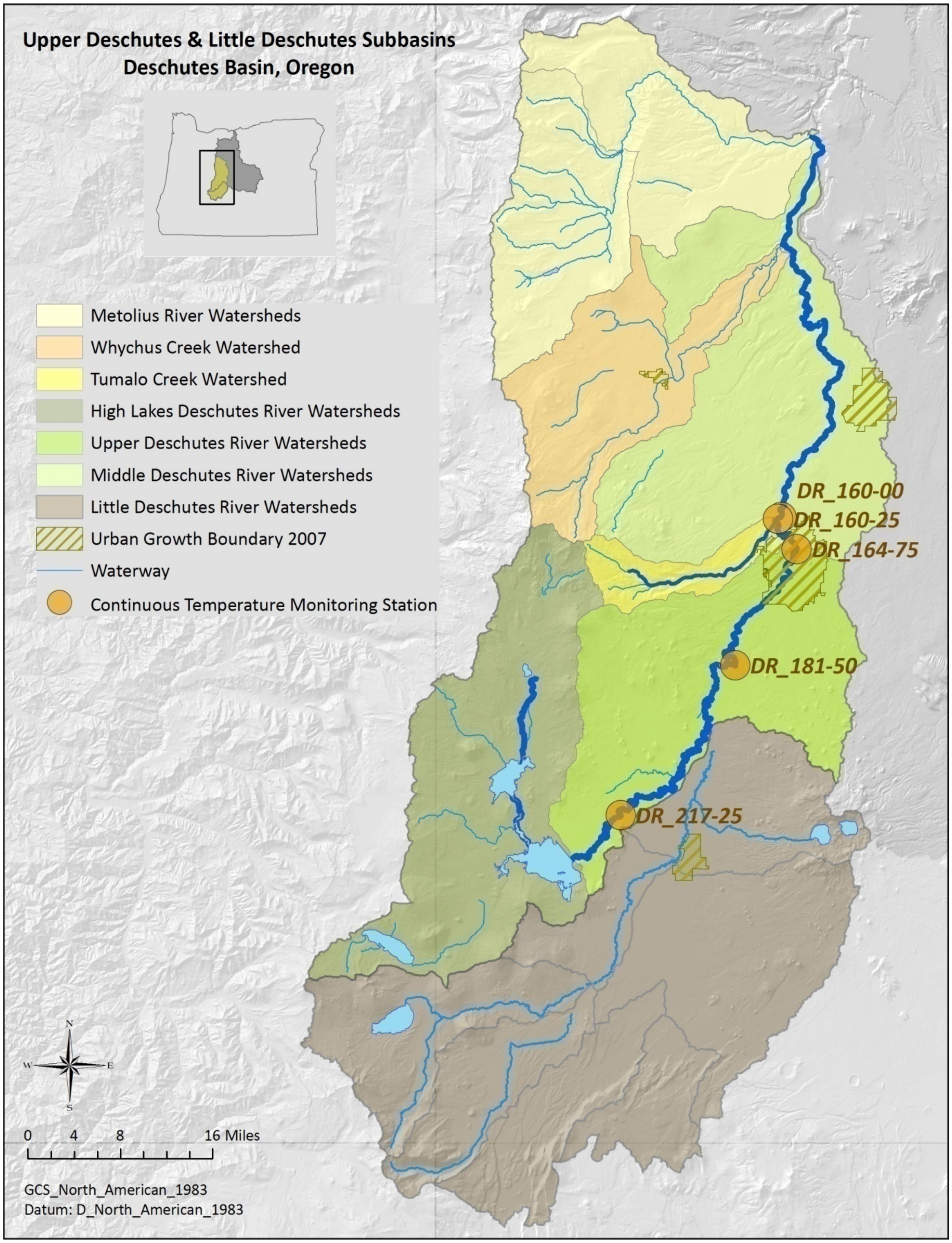
3. Use a probability plot to test the normal distribution of the Before-After differences and remove outliers as necessary.

4. Create a paired Before-After-Control-Impact (PBACI) interval plot to visually compare the paired, Control (reference reach)-Impact (restoration reach) difference of Before-After differences for each pair of reaches and years.

6. Perform a Student's t-test to statistically evaluate PBACI differences for each pair of reaches for each consecutive set of years, and direction of changes in temperature, if any.

7. Evaluate hypotheses (Table 3).

Map 5 Continuous Temperature Monitoring Stations used in Restoration Effectiveness Analysis



Map 6 Deschutes and Tumalo Restoration Reaches used in Restoration Effectiveness Analysis

Table 3 Hypotheses for Restoration Effectiveness Analysis

Null:	The Before-After difference for the restoration (Impact) reach and the Before-After difference for the reference (Control) reach are equal
Alt1:	The Before-After difference for the restoration reach and the Before-After difference for the reference reach are different.
Alt2:	The Before-After difference for the restoration reach is significantly less than the Before-After difference for the reference reach; the restoration reach is relatively cooler.
Alt3:	The Before-After difference for the restoration reach is significantly more than the Before-After difference for the reference reach; the restoration reach is relatively warmer.

2.2.3. Target Streamflow

The DRC streamflow restoration efforts aim to meet the State of Oregon instream flow target in order to improve water temperatures to support sustainable anadromous and resident fish populations. The State of Oregon streamflow target is based on Oregon Department of Fish and Wildlife (ODFW) *minimum* streamflow required to support fish populations. In 1990, ODFW applied to the OWRD for certified instream water rights for the Deschutes River, Deschutes Basin, Oregon (OWRD, 2010). The pending application for an instream water right for the Deschutes River describes the following target:

Streamflow Restoration Target

250 cfs target: North Canal Dam (river mile 165) to Round Butte Reservoir (river mile 119) (Application #IS 70695)

To determine the volume of streamflow required to reduce water temperatures in the middle Deschutes River to meet the 18°C/64°F state standard, we analyzed the relationship between flow and temperature for two locations on the middle Deschutes: a) downstream of Tumalo Creek near the site of streamflow restoration (DR 160.00), and b) at Lower Bridge Road 30 miles downstream of flow restoration (DR 133.50) (Map 7). For DR 160.00 downstream of Tumalo Creek, we analyzed July 7DMAX temperature and average daily flow data for 2005-2010; for DR 133.50 at Lower Bridge Road we analyzed July temperature and flow data for 2001-2010.

Steps in Target Streamflow Regression Analysis

1. Establish locations where instream flow and temperature relationships are of interest.

2. Compile 7DMAX temperature and natural logarithm average daily flow (LnQD) data for each location (from this point forward referred to as temperature and flow data).

3. From temperature and flow data, isolate July data for all years of interest.

4. Match the daily temperature and flow data into temperature, flow pairs.

5. Rank flows and assign associated temperatures to each flow (For example, at 4.1 LnQD there may be 20 temperatures). Exclude flow levels where temperature data sample size n < 10.

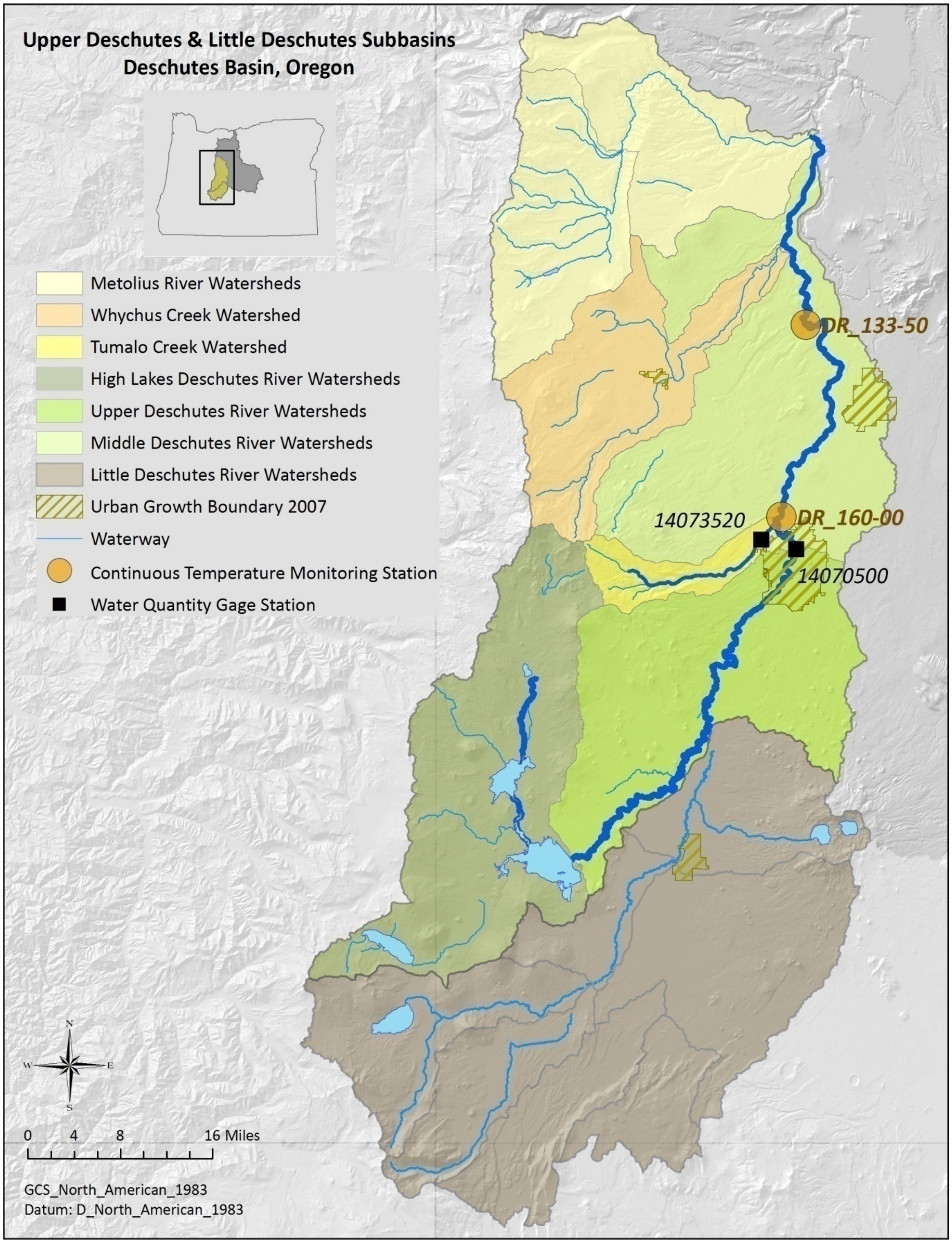
6. Establish the mean temperature at each flow level.

7. Plot the flow level LnQD versus the mean temperature, add a regression trendline and associated regression equation, and evaluate R^2 and S values. Assign a confidence level and calculate a confidence interval.

8. The derived regression equation describes the relationship between flow and temperature at the selected location.

Note: this equation describes the relationship between flow and temperature a) at the selected location, b) within the evaluated time period, and c) within the range of flow levels. If all apply, then the results of the regression equation demonstrate the relationship between flow and temperature to the specified level of confidence. If not all of these conditions are met, then the derived regression equation and the regression results are considered predictive and a greater confidence interval (known as a predictive interval) should be calculated.

Map 7 Temperature Monitoring and Streamflow Gaging Stations used in Target Streamflow Analysis



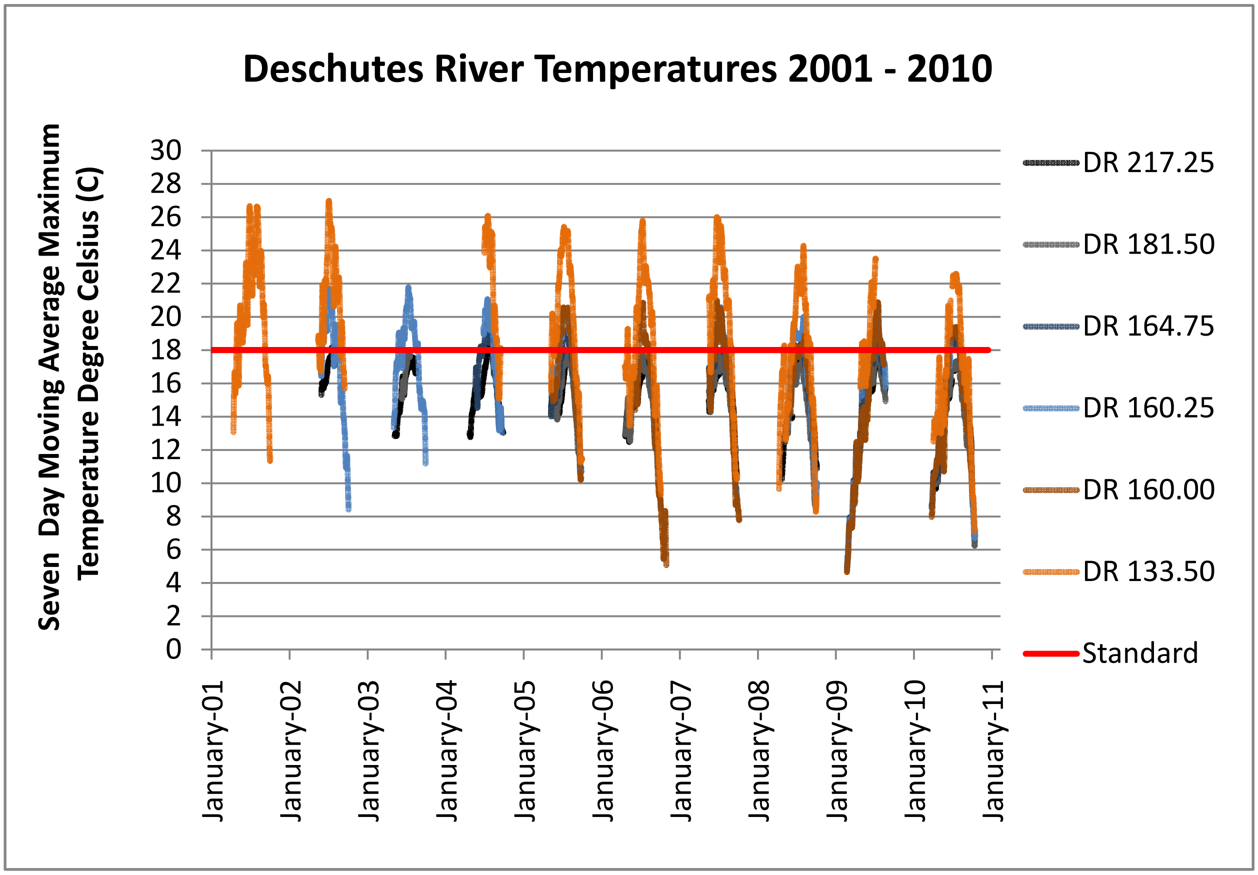
3. Results

3.1. Temperature Status

Observed 7DMAX temperatures exceed the State of Oregon 18°C / 64°F standard for salmonid spawning and rearing, supporting the existing State of Oregon Section 303(d) listing of the middle Deschutes River for temperature impairment (Figure 2). Temperatures in the reference reach (DR 217.25 to DR 181.50) exceeded the state standard in 2002, 2004, 2005, and 2009, and consistently hovered near 18°C / 64°F throughout July, the hottest month for water temperatures, for all other years evaluated. Temperatures in the Deschutes restoration reach (DR 164.65 to DR 160.25), the Tumalo restoration reach (DR 160.25 – DR 160.00), and at Lower Bridge Road (DR 133.50) exceeded the state standard in every year for which data is available for analysis.

Figure 2 Deschutes River Temperatures 2001 – 2010

Temperatures at 6 stations along the Deschutes River between 2001 and 2010 exceeded the State of Oregon temperature standard established to protect salmon and trout rearing and migration (solid red line) at all sites and in most years.



3.2. Restoration Effectiveness

Temperatures recorded at the two upstream reference reach stations and the three downstream restoration reach stations from 2005 to 2010 varied between stations, between reaches, and between years (Figure 3). The probability plot generated from Before-After differences in mean July daily median temperatures for the reference (Control) reach and for both the Deschutes and Tumalo (Impact) restoration reaches established that these data for all three reaches are normally distributed at the 95% confidence level (Figure 4). The normal distribution illustrated by the probability plot was supported by a hypothesis test. Since the Before-After difference data are normally distributed, the Student's t-test provides an appropriate statistical comparison of differences in temperature between reaches.

Figure 3 Temperature Data used in Restoration Effectiveness Analysis

Deschutes River water temperatures vary between stations, between reaches, and between years. A paired BACI analysis using only July data allows for the identification of trends in temperature that are associated with instream flow restoration and controls for the effects of seasonal and inter-annual environmental variability.

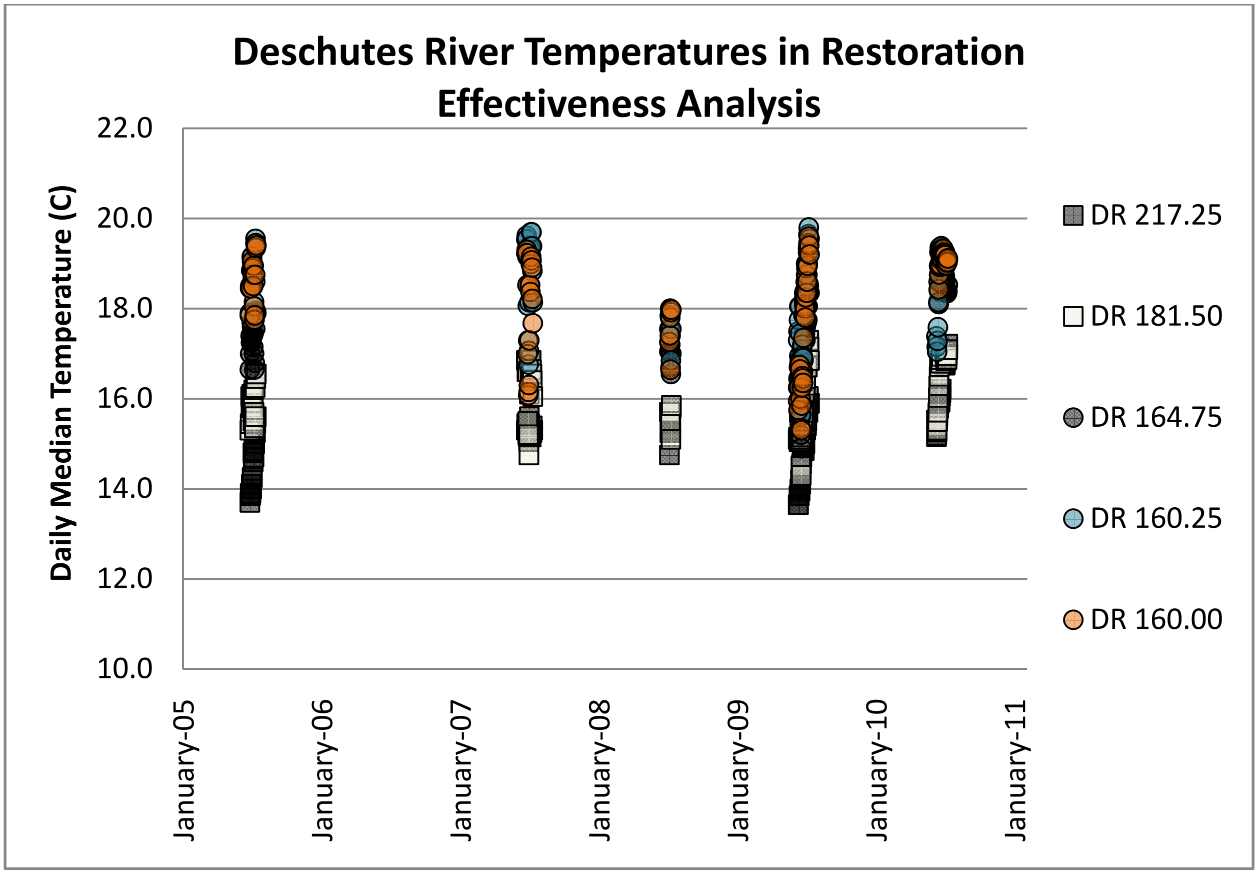
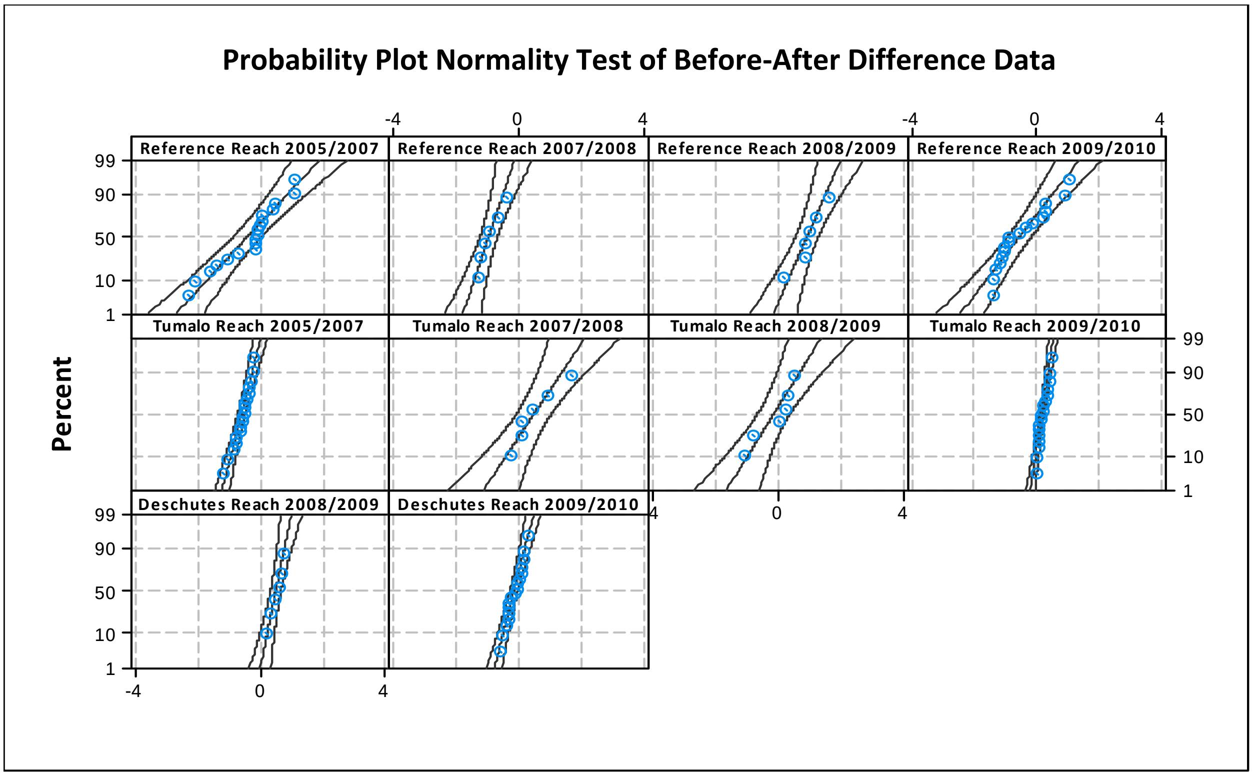


Figure 4 Normality Test of Before-After Difference Data

The reference reach, Deschutes reach, and Tumalo reach Before-After differences of mean July daily median temperatures have a normal distribution at the 95% confidence level. A 95% confidence interval (black lines) is displayed around the Before-After difference values (circles). Since the Before-After difference data are normally distributed the Student's t-test is an appropriate analysis to evaluate differences in temperature between reaches. Hypothesis test results below confirm the normal distribution of Before-After difference data.



Before-After Difference	N	Mean	StDev	p-value	α-value	Result	Distribution
Reference Reach 2005/2007	18	-0.39	0.99	0.08	0.05	p > α	Normal
Reference Reach 2007/2008	6	-0.97	0.36	0.62	0.05	p > α	Normal
Reference Reach 2008/2009	6	0.96	0.46	0.54	0.05	p > α	Normal
Reference Reach 2009/2010	17	-0.55	0.81	0.07	0.05	p > α	Normal
Tumalo Reach 2005/2007	18	-0.60	0.27	0.43	0.05	p > α	Normal
Tumalo Reach 2007/2008	6	0.49	0.71	0.43	0.05	p > α	Normal
Tumalo Reach 2008/2009	6	-0.12	0.65	0.27	0.05	p > α	Normal
Tumalo Reach 2009/2010	17	0.15	0.16	0.12	0.05	p > α	Normal
Deschutes Reach 2008/2009	6	0.49	0.21	0.76	0.05	p > α	Normal
Deschutes Reach 2009/2010	17	-0.17	0.27	0.63	0.05	p > α	Normal

p-value > α-value indicates a normal distribution at a 95% confidence level (α-value = 0.05)

The interval plot pairing the 2005/2007 reference reach Before-After difference of mean July daily median temperatures with the 2005/2007 Tumalo restoration reach Before-After difference shows the comparative difference between the two reaches between years approximating zero with a 90% confidence interval overlapping zero, indicating that changes in temperature in the reference reach were not significantly different from changes in the Tumalo reach from 2005 to 2007 (Figure 5); this result is supported by a Student's t-test p-value > 0.10, which fails to reject the null hypothesis (Table 4) and indicates relatively similar temperature responses in the reference reach and in the Tumalo restoration reach from 2005 to 2007. Paired BACI differences between the reference reach and the Deschutes and Tumalo restoration reaches for all other years for which data are available (Deschutes: 2008/2009, 2009/2010; Tumalo: 2007/2008, 2008/2009, 2009/2010) do not approximate zero nor do associated 90% confidence intervals overlap zero, indicating that changes in mean July daily median temperatures between years from 2007 to 2010 in the two restoration reaches are significantly different than changes in mean July daily median temperature between years in the reference reach over the same time frame; mean July daily median temperatures in the restoration reaches for the specified years are thus changing differently relative to temperatures in the reference reach. T-test results provide statistical support for this conclusion (Table 4). Together these results suggest that changes in temperature observed in restoration reaches from 2007 to 2010 are driven by increased flows resulting from restoration actions.

T-test t-values indicated the direction of changes in temperature in restoration reaches (Table 5). The Before-After difference of mean July daily median temperature in the Tumalo restoration reach from 2007/2008 was significantly greater than this difference for the reference reach; the Tumalo Reach was thus significantly warmer than the reference reach, and this difference can be directly attributed to the local and longitudinal effects of instream flow restoration (Figure 5; Table 5). Conversely, the Before-After difference of mean July daily median temperature in the Tumalo reach as well as in the Deschutes reach for 2008/2009 was significantly less than this difference for the reference reach, indicating that July temperatures in both restoration reaches cooled from 2008 to 2009 relative to July temperatures in the reference reach, again in response to local and longitudinal effects of instream flow restoration. From 2009 to 2010 the trend was again reversed, with Before-After differences for both restoration reaches significantly greater than this difference for the reference reach, indicating a warming trend from 2009 to 2010 in response to increases in streamflow in restoration reaches.

Figure 5 Interval Plot of PBACI Differences in Mean July Daily Median Temperatures

An Interval Plot shows the PBACI difference of Before-After differences resulting from pairing the reference reach Before-After difference to the Deschutes reach and Tumalo reach Before-After differences of July daily median temperatures in ° C (y-axis). PBACI values equal to zero indicate no temperature response to streamflow restoration; PBACI values greater than zero represent a cooling temperature response to streamflow restoration, while values less than zero demonstrate a warming response. The paired reference reach and Tumalo reach BACI value for 2005/2007 (furthest left on x-axis) approximates zero and the 90% confidence interval overlaps zero, indicating that changes in temperature in these reaches are relatively similar. The other five PBACI values (five to the right on x-axis) do not approximate zero and the 90% confidence intervals do not overlap zero, indicating that changes in temperature in the Deschutes and Tumalo restoration reaches were significantly different than changes in temperature in the reference reach from 2007 to 2010.

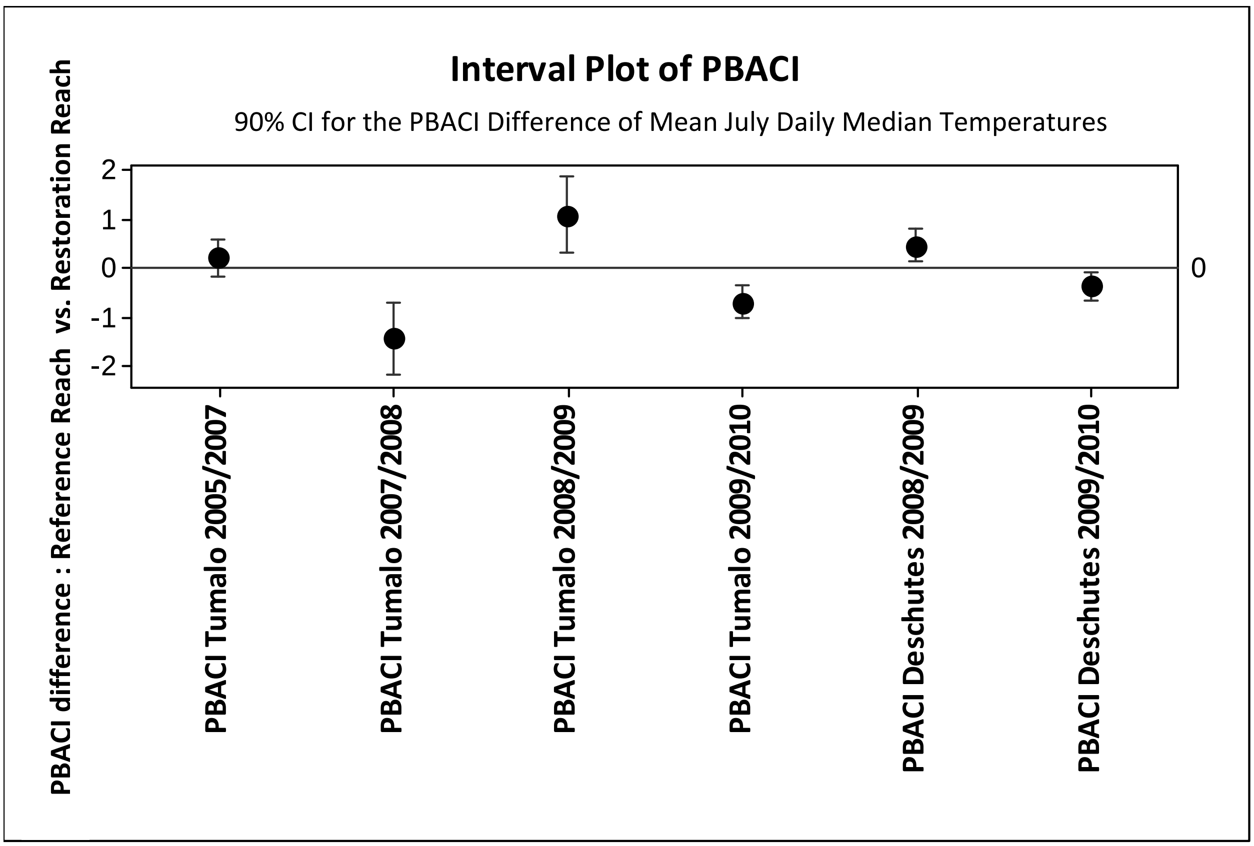


Table 4 Student's t-test of Null Hypothesis

PBACI	P-value	α-value	Test	Result	90% CI 5%	90% CI PBACI Difference	90% CI 95%
Reference Reach & Tumalo Reach 2005/2007	0.40	0.10	P>α	Accept null	-0.21	0.21	0.63
Reference Reach & Tumalo Reach 2007/2008	0.00	0.10	P<α	Reject null, accept Alt1	-2.08	-1.46	-0.84
Reference Reach & Tumalo Reach 2008/2009	0.01	0.10	P<α	Reject null, accept Alt1	0.48	1.08	1.68
Reference Reach & Tumalo Reach 2009/2010	0.00	0.10	P<α	Reject null, accept Alt1	-1.04	-0.70	-0.36
Reference Reach & Deschutes Reach 2008/2009	0.06	0.10	P<α	Reject null, accept Alt1	0.07	0.47	0.90
Reference Reach & Deschutes Reach 2009/2010	0.08	0.10	P<α	Reject null, accept Alt1	-0.73	-0.38	-0.03

P-value > α-value = > accept null Ho

At 90% Confidence Level α-value = 0.10

Null:	The Before-After difference for the restoration (Impact) reach and the Before-After difference for the reference (Control) reach are equal
Alt1:	The Before-After difference for the restoration reach and the Before-After difference for the reference reach are different.

Table 5 T-test Results for Direction of Change in Temperature

PBACI	df	T-value	Tα	Test	Result
Reference Reach & Tumalo Reach 2007/2008	7	-4.49	1.90	T<Tα	Accept Alt 3
Reference Reach & Tumalo Reach 2008/2009	9	3.29	1.83	T>Tα	Accept Alt 2
Reference Reach & Tumalo Reach 2009/2010	17	-3.50	1.74	T<Tα	Accept Alt 3
Reference Reach & Deschutes Reach 2008/2009	6	2.28	1.94	T>Tα	Accept Alt 2
Reference Reach & Deschutes Reach 2009/2010	19	-1.84	1.73	T<Tα	Accept Alt 3

T-value > Tα = > Accept Alt2
Tα is obtained from df (degrees of freedom) and a t distribution table at 90% Confidence Level (NIST, 2010)

Alt2:	The Before-After difference for the restoration reach is significantly less than the Before-After difference for the reference reach; the restoration reach is relatively cooler.
Alt3:	The Before-After difference for the restoration reach is significantly more than the Before-After difference for the reference reach; the restoration reach is relatively warmer.

Streamflow volume and temperature in the middle Deschutes River are influenced by flows from two sources: upper Deschutes streamflow passing over North Canal Dam, and flows from Tumalo Creek (Figure 6). These two locations are also the source of instream flow restoration. Streamflow passing over North Canal Dam is consistently above the state temperature standard of 18°C/64°F in July (UDWC, 2006) (ODEQ, 2004). Streamflow originating in Tumalo Creek has been recorded at temperatures both above and below the state standard depending on the volume of flow in Tumalo Creek (UDWC, 2006). The Deschutes restoration reach (DR 164.00 – 160.25) is above the confluence of Tumalo Creek and the Deschutes River, thus we do not expect increases in Tumalo Creek flows to influence temperature trends in this reach. The Tumalo restoration reach (DR 160.25 – DR 160.00) extends from immediately above the confluence with the Deschutes to just below the confluence, therefore we expect temperatures in this reach to be affected by increases in streamflow from both the upper Deschutes at North Canal Dam and from Tumalo Creek.

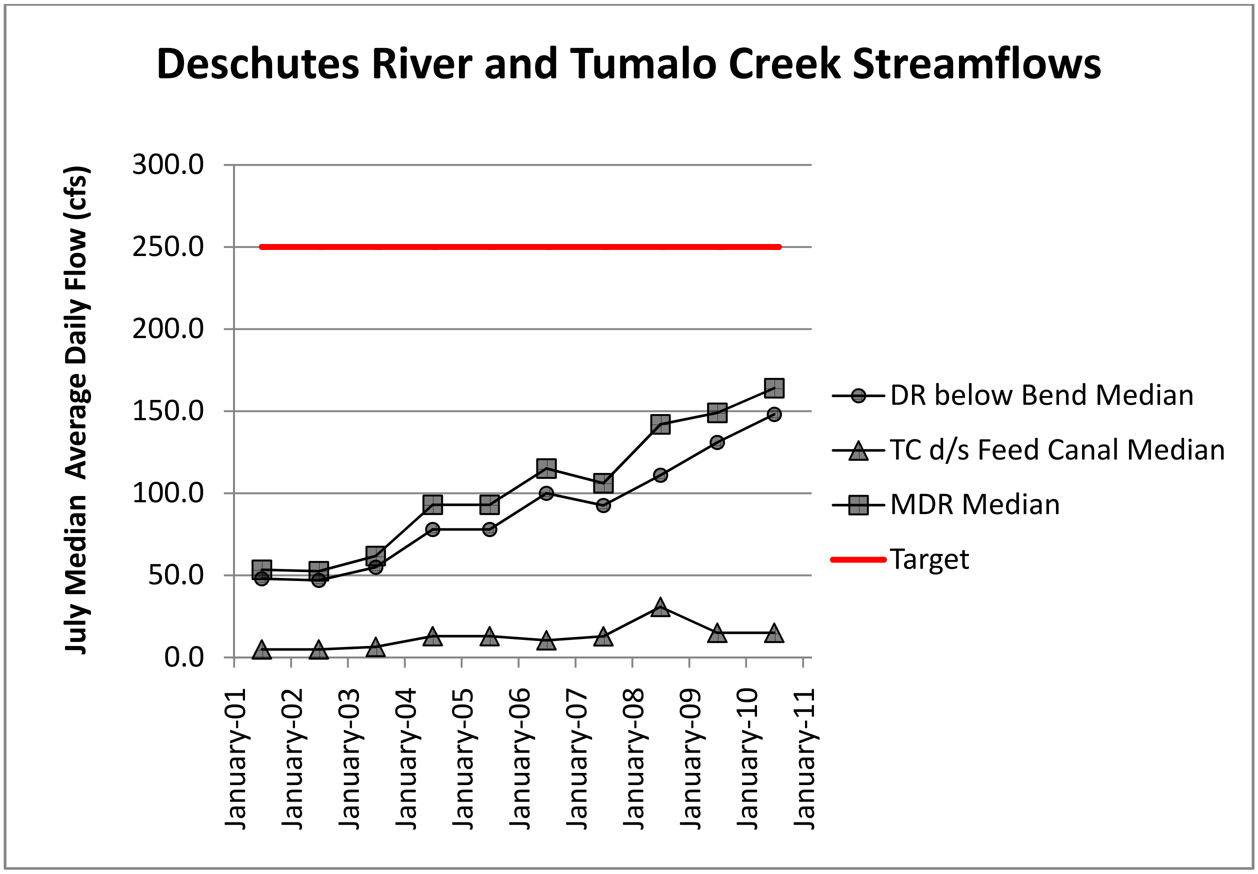
Temperature responses in the middle Deschutes to ongoing streamflow restoration from these two sources varied from 2007-2008, 2008-2009, and 2009-2010. Streamflow in the middle Deschutes increased each year from 2007 to 2010, resulting in warming (2007-2008, 2009-2010) or cooling (2008-2009) trends in the Deschutes and Tumalo restoration reaches. Although we are unable to identify a temperature trend for the Deschutes restoration reach for 2007-2008 due to insufficient data, the Deschutes and Tumalo restoration reaches otherwise show the same trends, both cooling in 2008-2009 and warming in 2009-2010. Warming trends in both the Tumalo (2007-2008, 2009-2010) and Deschutes (2009-2010) restoration reaches may result from the increasing contribution of warm upper Deschutes River flows to the middle Deschutes River since 2007.

The variable cooling and warming trends observed in the Tumalo restoration reach may be driven by the relative flow contributions of the Deschutes River at North Canal Dam and Tumalo Creek. Specifically, in years when the increase in streamflow from the upper Deschutes River at North Canal Dam was greater relative to increases in streamflow from Tumalo Creek, Tumalo restoration reach temperatures warmed relative to the reference reach, whereas in years when the flow contributions from North Canal Dam and from Tumalo were relatively more similar we observed a cooling trend in the Tumalo restoration reach as compared to the reference reach (Figure5; Figure 6).

The 2008-2009 cooling trend in the Deschutes restoration reach in relation to the upstream reference reach is not explained either by the increasing contribution of warm flows from the upper Deschutes at North Canal Dam nor by the higher relative contribution of cool flows from Tumalo Creek since Tumalo Creek flows enter the middle Deschutes River downstream of the Deschutes restoration reach. Calculating temperature-flow relationships specific to this reach may help to elucidate the cooling response observed from 2008-2009; examining the role of external hydrologic dynamics such as groundwater inputs to the middle Deschutes in the Deschutes restoration reach may also provide some insight into this trend.

Figure 6 Deschutes River and Tumalo Creek Streamflow in July 2001 – 2010

Middle Deschutes River streamflow represents a combination of flows passing over North Canal Dam and flows from Tumalo Creek. These are also the locations of instream flow restoration. Although combined flows from the upper Deschutes at North Canal Dam and from Tumalo Creek increased middle Deschutes River flows between 2007 and 2008, the flow contributions from these two sources resulted in a net warming of temperature along the middle Deschutes River. Conversely, between 2008 and 2009 increases in middle Deschutes flows contributed by the upper Deschutes River at North Canal Dam and by Tumalo Creek resulted in a net cooling along the middle Deschutes; from 2009 to 2010 this trend was again reversed as middle Deschutes temperatures warmed in response to further increases in streamflow from North Canal Dam and Tumalo Creek. See Figure 5 and Table 5.



3.3. Target Streamflow

A regression of July temperature and streamflow data from the middle Deschutes River downstream of Tumalo Creek and at Lower Bridge Road from 2001 – 2010 describes temperature-flow relationships for observed flows and estimates target flows needed to achieve the 18°C/64°F state temperature standard at these sites. There are gaps in temperature data for July 2003 and 2004 for both locations of interest; consequently these years are not included in streamflow target analysis. July 7DMAX temperatures for the middle Deschutes River downstream of Tumalo Creek (DR 160.00) ranged from 15.0°C to 21.0°C (Figure 7). July 7DMAX temperatures for the middle Deschutes at Lower Bridge Road (DR 133.50) ranged from 18.9°C to 27.0 °C. Streamflows available for target analysis ranged from 46.4 to 317.3 cfs in July between 2001 and 2010 (Figure 8)[4]. The regression equation derived from temperature-flow data is specific to the range of flows and corresponding temperatures observed, and therefore can only accurately describe temperature-flow relationships with the assigned confidence level for the given range of flows.

[4] There is not an active gage station on the Deschutes River downstream of Tumalo Creek to collect middle Deschutes River flow data. To estimate flows for the middle Deschutes River, the streamflow data collected by the Oregon Water Resources Department (OWRD) gage located on the Deschutes River below Bend (OWRD gage #14070500) is combined with the streamflow data collected by the OWRD gage located on Tumalo Creek downstream the Tumalo Irrigation District Feed Canal (OWRD gage #14073520). Therefore, middle Deschutes River streamflow data used in this Technical Report is estimated.

Figure 7 July Temperature Data used in Target Streamflow Analysis

Middle Deschutes River July 7DMAX temperatures used in streamflow target analysis range from 15.0 ℃ to 21.0 ℃ downstream of Tumalo Creek (DR 160.00; dark squares) and from 18.9 ℃ to 27.0 ℃ at Lower Bridge Road (DR 133.50; light circles).

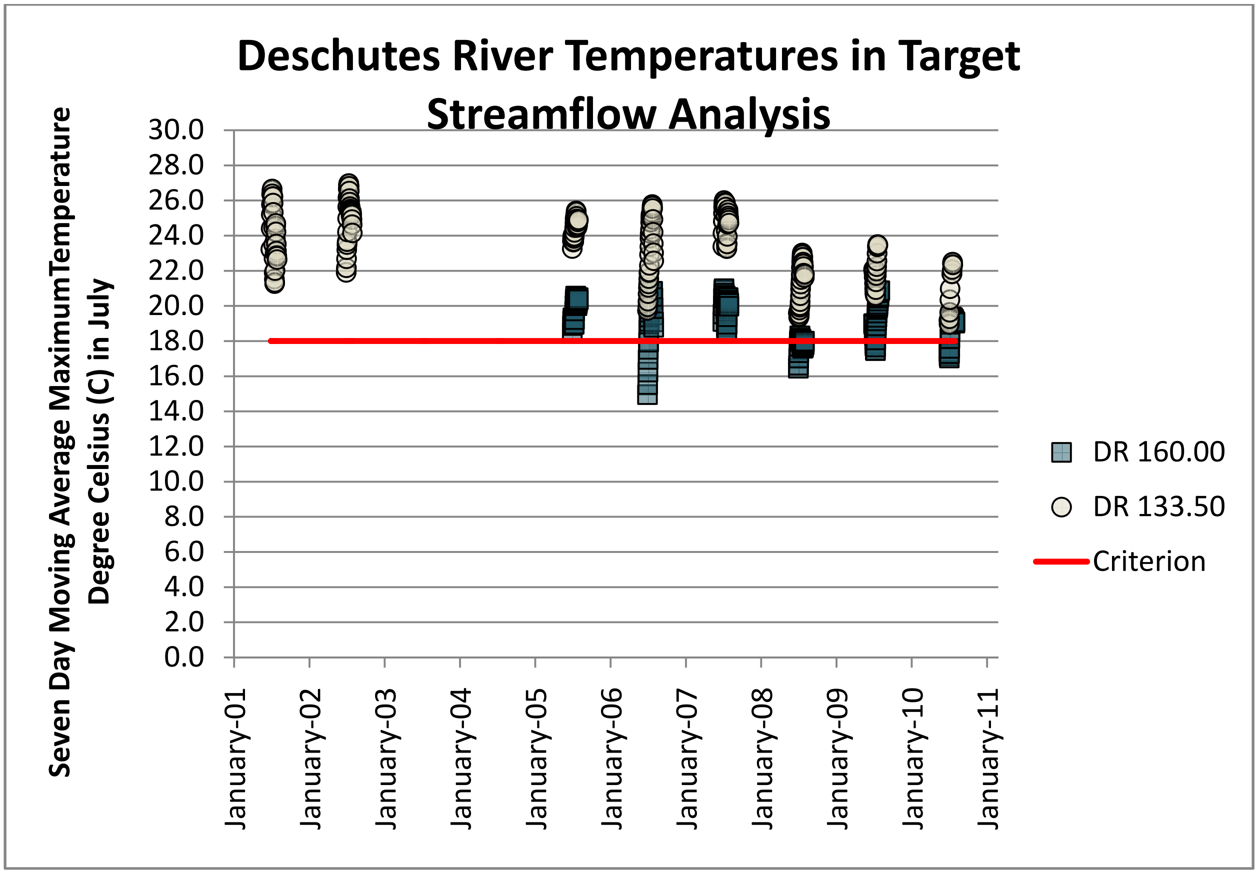
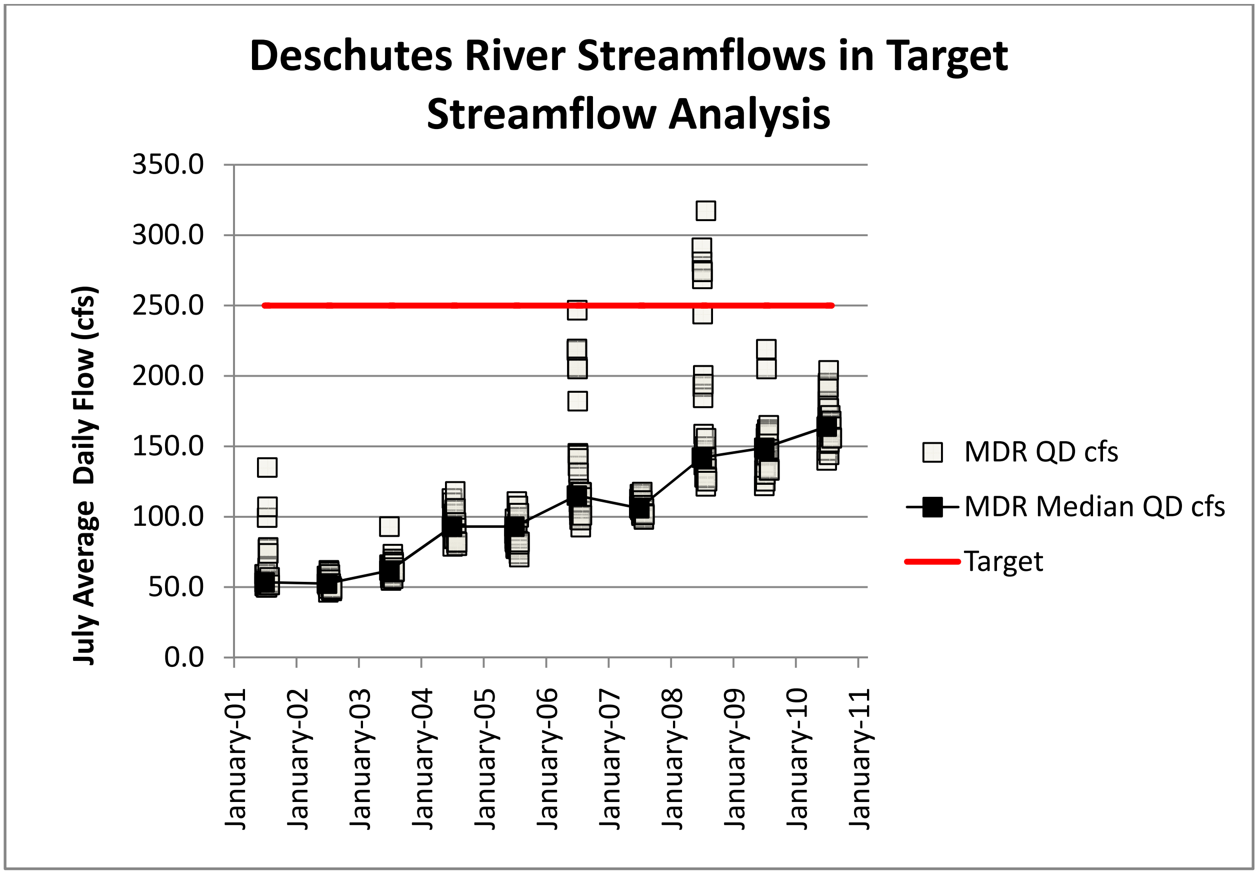


Figure 8 July Streamflow Data used in Target Streamflow Analysis

Streamflows used in target analysis range from 46.4 to 317.3 cfs in July (x-axis)[5].



[5] There is not an active gage station on the Deschutes River downstream of Tumalo Creek to collect middle Deschutes River flow data. To estimate flows for the middle Deschutes River, the streamflow data collected by the Oregon Water Resources Department (OWRD) gage located on the Deschutes River below Bend (OWRD gage #14070500) is combined with the streamflow data collected by the OWRD gage located on Tumalo Creek downstream the Tumalo Irrigation District Feed Canal (OWRD gage #14073520). Therefore, middle Deschutes River streamflow data used in this Technical Report is estimated.

The relationships between 7DMAX temperature and average daily flow on the Deschutes River downstream of Tumalo Creek (DR 160.00) and at Lower Bridge Road (DR 133.50) in July 2001-2010 for the specified range of flows are described by the following equations (Figures 9 & 10):

DR 160.00 Mean 7DMAX = $-6225.40 + 3960.43 \text{ LnQD} - 835.51 \text{ LnQD}^2 + 58.63 \text{ LnQD}^3$

DR 133.50 Mean 7DMAX = $- 192.31 + 131.16 \text{ LnQD} -25.44 \text{ LnQD}^2+1.56 \text{ LnQD}^3$

95% Confidence Level (NIST, 2010) = $Y \pm Y^{(Z_{1-\alpha/2}\, s(x) / \sqrt{N})}$ Where $Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.475} = 1.9$

The S and R values reported are measures of how well the regression model fits the temperature-flow data. S represents the standard distance in degrees Celsius that mean 7DMAX temperature values fall from the regression line. A better fit between the regression line and the data results in a lower S value. R-Sq represents the proportion of the variation in mean 7DMAX temperatures that is explained by streamflow (Ln QD). The better the regression fits the data, the closer to 100% the R-Sq value will be. Sample size N is the number of values that are included in regression analysis. For the Deschutes River downstream of Tumalo Creek (DR 160.00), N = 7. For the Deschutes River at Lower Bridge Road (DR 133.50), N = 9.

Regression results indicated at a 95% confidence level that 130 cfs (4.87 Ln QD) is the minimum streamflow necessary during July 2001-2010 to achieve mean 7DMAX temperatures of 18.0°C ± 2.0°C in the Deschutes River downstream of Tumalo Creek (DR 160.00) (Figure 9). Whereas the Heat Source model predicts temperatures continuing to cool as flows increase with a 250 cfs model input resulting in an estimated 17 °C 7DMAX in the Deschutes River downstream of Tumalo Creek during the hottest time of year (Watershed Sciences; MaxDepth Aquatics, Inc., 2007), July temperatures observed in the middle Deschutes downstream of Tumalo Creek began to *increase* at 149 cfs from a low of 17.7, and at flows above 157 cfs exceeded the 18.0°C state standard ± 2.0°C.[6] Because no temperature-flow data currently exist for flows above 171 cfs in the middle Deschutes River downstream of Tumalo Creek we are unable to resolve the discrepancy between the cooling temperatures predicted by the HeatSource model for flows of 250 cfs and the increase in temperature observed at 149 cfs for the same location. However, this discrepancy may result from a number of differences in the temperature data used in each approach, including the longitudinal frequency, location, and depth at which data were collected, over what time frame, and what statistics were used to summarize the data.[6]

The regression model for temperature-flow relationships at Lower Bridge Road (DR 133.50) derived from temperature and flow data for July 2001-2010 predicts at a 95% confidence level

[6] Note: The Heat Source model uses seven day moving average maximum temperatures (a daily statistic) while the regression model in this Technical Report uses the mean seven day moving average maximum temperature for July (a monthly statistic), hence direct comparison of results is difficult.

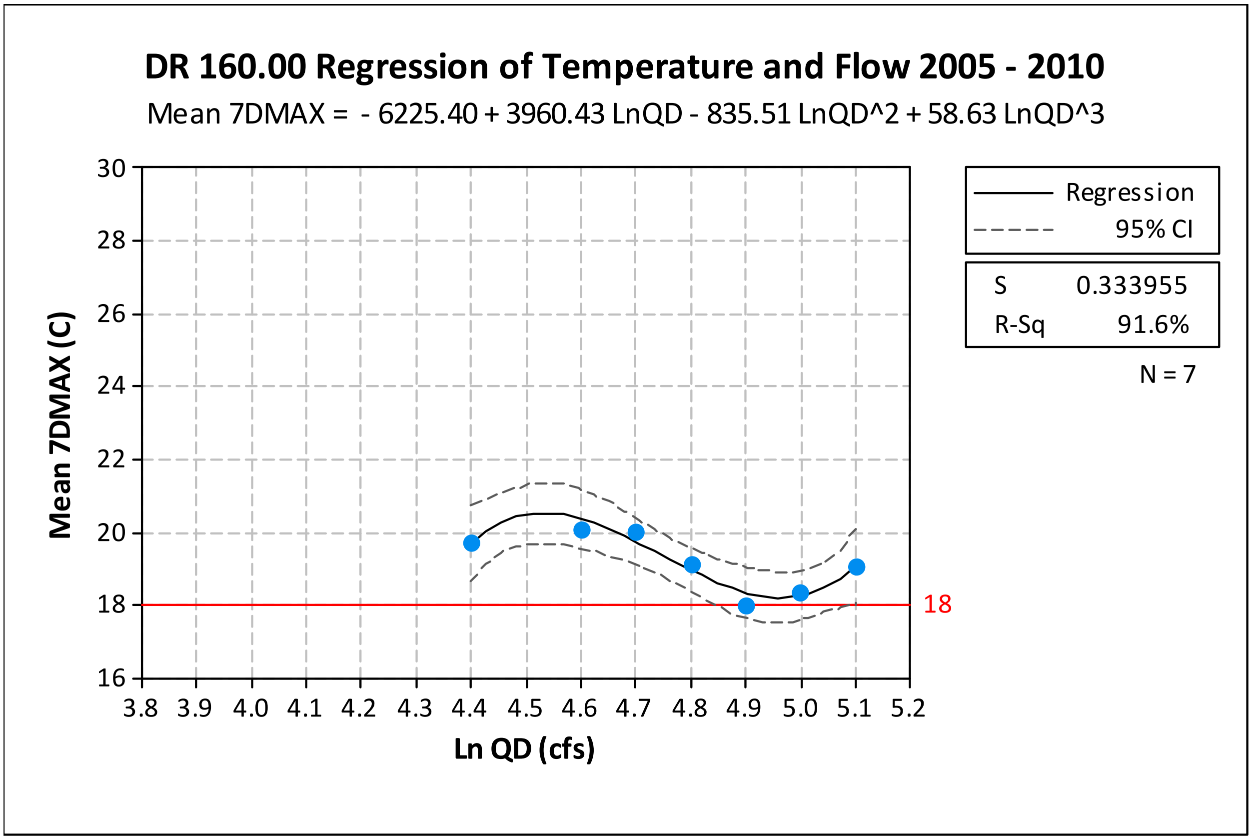
that flows of 283 cfs (5.65 Ln QD) will result in a mean 7DMAX temperature of 18.0 ± 4.2°C.[7] (Figure 10), with flows of 250 cfs (5.5 Ln QD) achieving a projected mean 7DMAX temperature of 18.9 ± 4.3°C. This result is supported by Heat Source model predictions which estimate a 7DMAX temperature of approximately 19 °C at flows of 250 cfs for the middle Deschutes River at Lower Bridge Road (Watershed Sciences; MaxDepth Aquatics, Inc., 2007).[8] Observed and predicted temperature-flow relationships in the middle Deschutes at Lower Bridge Road thus suggest that the 250 cfs streamflow target will restore July 7DMAX temperatures that meet or are within 5.2 degrees of the state standard and therefore may be sufficient to meet state temperature standards as well as salmonid rearing and migration requirements, even if intermittently. For more detail regarding flow and associated temperatures see Appendix A.

[7] Note: the equation is applicable to describing the relationship between flow and temperature at (a) the selected location, (b) within the evaluated time period, and (c) within the original range of flow and temperatures. If all apply, then the results of the regression equation demonstrate to a degree of confidence the relationship between flow and temperature. If not all apply, then the results of the regression equation are predictive and a greater range of error is expected.

[8] Note: Heat Source model uses seven day moving average maximum temperatures (a daily statistic) while the regression model in this Technical Report uses the mean seven day moving average maximum temperature for July (a monthly statistic), hence direct comparison of results is difficult.

Figure 9 Deschutes River downstream of Tumalo Creek Estimated Streamflow Target

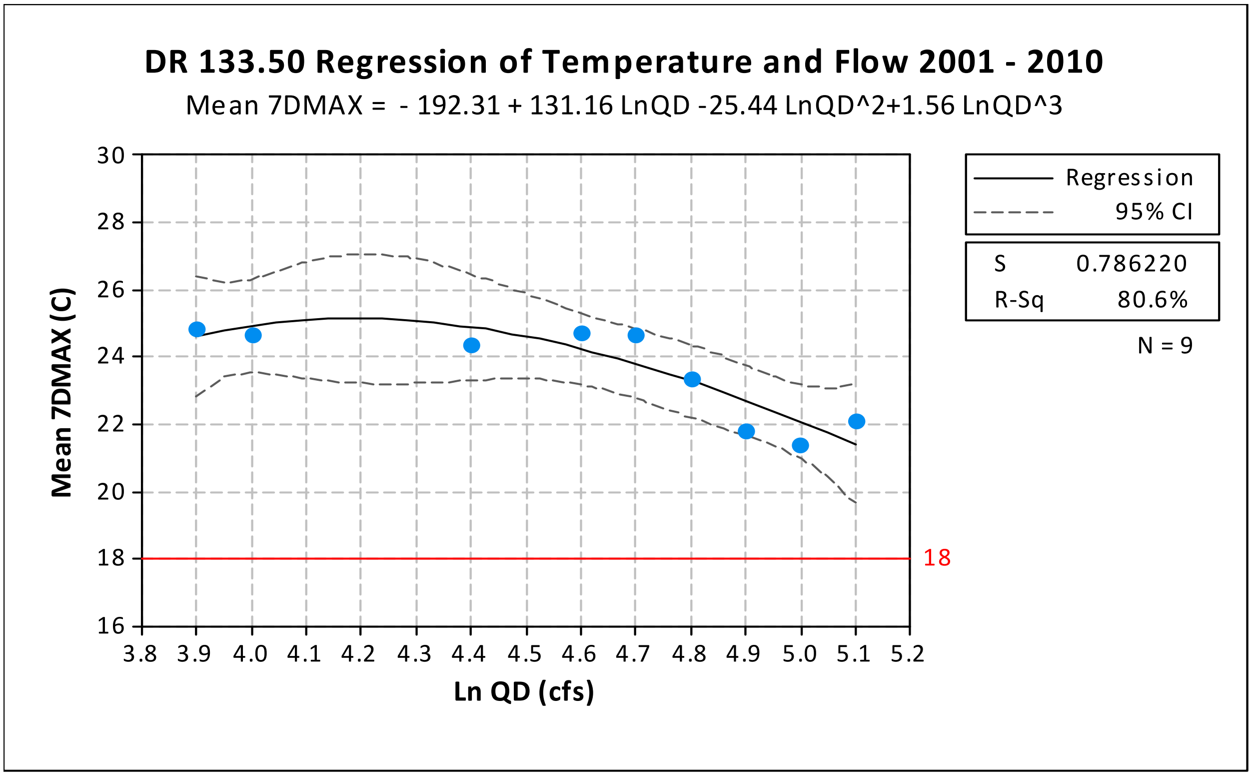
A regression streamflow target analysis of July temperature and streamflow data from the middle Deschutes River downstream of Tumalo Creek from 2001 – 2010 describes temperature-flow relationships for observed flows and predicts the flows needed to achieve the state temperature standard at this site. The equation derived from observed temperature-flow relationships can be used to identify temperatures associated with observed flows with the assigned level of confidence; while the regression equation may also be used to estimate temperatures at flows outside of the observed range, the given confidence level is only accurate for flows within the observed range. Also see Appendix A.



Note: Flow range = 4.36 – 5.14 LnQD (78.3 – 170.7 cfs)

Figure 10 Deschutes River at Lower Bridge Road Estimated Streamflow Target

A regression streamflow target analysis of July temperature and streamflow data from the middle Deschutes River at Lower Bridge Road (DR 133.50) from 2001 – 2010 describes temperature-flow relationships for observed flows and predicts the flows needed to achieve the state temperature standard at this site. The equation derived from observed temperature-flow relationships can be used to identify temperatures associated with observed flows with the assigned level of confidence; while the regression equation may also be used to estimate temperatures at flows outside of the observed range, the given confidence level is only accurate for flows within the observed range. Also see Appendix A.



Note: Flow range = 3.86 – 5.14 LnQD (78.3 – 170.7 cfs)

4. Discussion

4.1. Temperature Status

What is the status of water temperatures in the middle Deschutes River relative to the State of Oregon 18℃ / 64℉ standard?

Temperatures observed for all monitoring locations exceed the state temperature standard of 18°C / 64°F, confirming the temperature impaired status of the middle Deschutes River under Clean Water Act Section 303(d). Until there are more significant changes to streamflow and/or other factors that affect water temperature, these results suggest that the middle Deschutes River will continue to exceed the state temperature standard during the summer months.

4.2. Restoration Effectiveness

Has the increase in streamflow reduced water temperatures?

Significantly different changes in temperature in the two restoration reaches of the middle Deschutes River relative to the reference reach indicate that downstream temperatures are directly influenced by increased flows from streamflow restoration. However, the 2008 and 2010 warming trends observed in both Deschutes and Tumalo restoration reaches suggest that increasing flows from the upper Deschutes at North Canal Dam is likely to increase temperatures above Tumalo Creek. Downstream of Tumalo Creek, higher flows may reduce temperatures only when the flow contribution of Tumalo Creek increases relative to the flow contribution of the upper Deschutes at North Canal Dam, representing a relatively greater proportion of the total increase in middle Deschutes streamflow. Therefore, streamflow restoration projects that strategically increase flows in Tumalo Creek in proportion to the flow contribution of the upper Deschutes at North Canal Dam may be an effective approach to reducing temperatures in the middle Deschutes downstream of Tumalo Creek.

4.3. Target Streamflow

What is the estimated streamflow needed to meet the State of Oregon temperature standard?

Given observed temperature-flow relationships, the current streamflow target of 250 cfs is projected to achieve the 18°C state temperature standard in the middle Deschutes River at Lower Bridge Road; however, immediately downstream of Tumalo Creek temperatures meet the state standard at flows between 130 and 157 cfs, exceed the 18°C standard at flows above 157 cfs, and continue to increase as flows increase to the highest observed flow of 171 cfs (See Appendix A). Although the temperature-flow relationships presented were developed for locations downstream of both restoration reaches and temperature-flow relationships have yet to be established for these reaches, warming trends observed at flows of approximately 90~~ cfs~~-110 cfs and at 130-150 cfs in the Deschutes and Tumalo restoration reaches (Figure 6) also suggest that flows of 250 cfs are likely to increase temperatures in the Deschutes and Tumalo restoration reaches. Thus, an instream flow target of 250 cfs applied to the entire longitudinal extent of the Middle Deschutes River is predicted to meet the state temperature standard in some reaches but not in others (Table 6).

Because the temperature-flow relationships we observed are a direct reflection of flow regimes in the upper Deschutes at North Canal Dam and in Tumalo Creek and the ratio of flows from each source over the ten-year period during which data were collected, restoration of streamflow that results in long-term changes to the ratio of flows from each source may also alter downstream temperature-flow relationships. Under a scenario in which the relative contribution of Tumalo Creek was much higher relative to that of the upper Deschutes at North Canal Dam, lower downstream temperatures may be achieved at relatively higher flows than what we have observed; for the middle Deschutes immediately downstream of Tumalo Creek, flows above 157 cfs might achieve temperatures approaching or meeting the 18°C state standard.

While it does not appear to be possible to increase flows to meet the 250 cfs streamflow target and simultaneously reduce temperatures to meet the 18°C state standard in the Deschutes and Tumalo restoration reaches given the present flow regimes for the upper Deschutes at North Canal Dam and Tumalo Creek, both increased flows and reduced temperatures will provide associated ecological benefits. Flows of 130 to 157 cfs at DR 160.00 immediately downstream of Tumalo Creek may provide increased access to pools and cover while resulting in temperatures at or below 18°C that may create a cold-water refuge for fish. Although this temperature refuge is lost at flows above 157 cfs, the other ecological benefits of increased flows remain. Improved information on fish response to increased flows and fish habitat use will contribute substantially to the ability of restoration partners to discern which habitat attributes are most limiting in which locations and develop streamflow targets accordingly to maximize ecological benefits. Developing temperature-flow relationships for reaches where temperature responses to streamflow restoration remain poorly understood, and conducting studies to expand the present understanding of external hydrologic inputs that may influence temperature, will be helpful in refining streamflow restoration targets for the middle Deschutes River.

Table 6 Summary of Flow Scenarios and Temperature Status for the Middle Deschutes River: Deschutes Reach, Tumalo Reach, and Lower Bridge Road.

QD (cfs)	Deschutes Reach	Tumalo Reach	Lower Bridge Road
<130	standard not met	standard not met	standard not met
130-157		standard met	standard not met
158 - 250	standard not met	standard not met	standard not met
>250			standard met
	No data.		

1. References

Golden, B. (2010). Program Manager, Deschutes River Conservancy. (L. Jones, Interviewer)

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

NIST. (2010). *NIST/SEMATECH e-Handbook of Statistical Methods*. Retrieved from http://www.itl.nist.gov/div898/handbook/index.htm.

ODEQ. (2007). *Deschutes River, Whychus Creek, and Tumalo Creek Temperautre Modeling.* Bend, Oregon: Prepared by Watershed Sciences and Max Depth Aquatics Inc., Oregon Department of Environmental Quality.

ODEQ. (2010). *Laboratory and Environmental Assessment, Oregon Department of Environmental Quality*. Retrieved from http://www.deq.state.or.us/lab/wqm/volmonresources.htm.

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

ODEQ. (2010). *Water Quality Standards: Beneficial Uses, Policies, and Criteria for Oregon. Oregon Administrative Rules, Chapter 340, Division 041*. Retrieved from http://www.deq.state.or.us/regulations/rules.htm.

OWRD. (2010). Instream Flow Application IS #70695. Retrieved from: http://apps2.wrd.state.or.us/apps/wr/wrinfo/.

OWRD. (2010, February). *Oregon Water Resource Department*. Retrieved from Oregon Surface Water Resources: http://www.wrd.state.or.us/OWRD/SW/index.shtml

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

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

UDWC. (2003). *Temperatures of the Upper Deschutes and Little Deschtues Subbasins.* Bend, Oregon: Prepared by: Breuner, N., Upper Deschutes Watershed Council.

UDWC. (2003). *Temperatures of the Upper Deschutes and Little Deschtues Subbasins.* Bend, Oregon: Prepared by: Breuner, N., Upper Deschutes Watershed Council.

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

UDWC. (2010). *Water Quality Regional Database, Upper Deschutes Watershed Council*. Retrieved from http://www.restorethedeschutes.org/What_We_Do/Monitoring/Water_Quality/WaterQualityRegionalDatabase/default.aspx.

Watershed Sciences; MaxDepth Aquatics, Inc. (2007). *Deschutes River, Whychus Creek, and Tumalo Creek Temperature Modeling.* Portland, Oregon: Oregon Department of Environmental Quality.

Appendix A Deschutes River Streamflows and Associated Temperatures

	DR 160.00		DR 133.50	
Flow (cfs)	**Mean 7DMAX (°C)**	**95% CI (±)**	**Mean 7DMAX (°C)**	**95% CI (±)**
48	-	-	24.7	4.9
49	-	-	24.8	4.9
50	-	-	24.9	5.0
51	-	-	24.9	5.0
52	-	-	25.0	5.0
53	-	-	25.0	5.0
54	-	-	25.1	5.0
55	-	-	25.1	5.0
56	-	-	25.2	5.0
57	-	-	25.2	5.0
58	-	-	25.3	5.0
59	-	-	25.3	5.0
60	-	-	25.3	5.0
61	-	-	25.3	5.0
62	-	-	25.3	5.0
63	-	-	25.4	5.0
64	-	-	25.4	5.0
65	-	-	25.4	5.0
66	-	-	25.4	5.0
67	-	-	25.4	5.0
68	-	-	25.4	5.0
69	-	-	25.4	5.0
70	-	-	25.4	5.0
71	-	-	25.4	5.0
72	-	-	25.3	5.0
73	-	-	25.3	5.0
74	-	-	25.3	5.0
75	-	-	25.3	5.0
76	-	-	25.3	5.0
77	-	-	25.3	5.0
78	18.7	2.0	25.2	5.0
79	18.9	2.0	25.2	5.0
80	19.1	2.0	25.2	5.0
81	19.3	2.0	25.2	5.0

	DR 160.00		DR 133.50	
Flow (cfs)	**Mean 7DMAX (°C)**	**95% CI (±)**	**Mean 7DMAX (°C)**	**95% CI (±)**
82	19.4	2.0	25.1	5.0
83	19.6	2.0	25.1	5.0
84	19.7	2.0	25.1	5.0
85	19.8	2.0	25.1	5.0
86	19.9	2.0	25.0	5.0
87	20.0	2.1	25.0	5.0
88	20.0	2.1	25.0	5.0
89	20.1	2.1	24.9	5.0
90	20.1	2.1	24.9	5.0
91	20.1	2.1	24.9	5.0
92	20.2	2.1	24.8	4.9
93	20.2	2.1	24.8	4.9
94	20.2	2.1	24.8	4.9
95	20.1	2.1	24.7	4.9
96	20.1	2.1	24.7	4.9
97	20.1	2.1	24.7	4.9
98	20.1	2.1	24.6	4.9
99	20.0	2.1	24.6	4.9
100	20.0	2.1	24.5	4.9
101	19.9	2.0	24.5	4.9
102	19.9	2.0	24.5	4.9
103	19.8	2.0	24.4	4.9
104	19.8	2.0	24.4	4.9
105	19.7	2.0	24.3	4.9
106	19.6	2.0	24.3	4.9
107	19.6	2.0	24.3	4.9
108	19.5	2.0	24.2	4.9
109	19.4	2.0	24.2	4.9
110	19.3	2.0	24.1	4.9
111	19.3	2.0	24.1	4.9
112	19.2	2.0	24.1	4.9
113	19.1	2.0	24.0	4.9
114	19.1	2.0	24.0	4.9
115	19.0	2.0	23.9	4.9
116	18.9	2.0	23.9	4.9
117	18.8	2.0	23.8	4.8

	DR 160.00		DR 133.50	
Flow (cfs)	**Mean 7DMAX (°C)**	**95% CI (±)**	**Mean 7DMAX (°C)**	**95% CI (±)**
118	18.8	2.0	23.8	4.8
119	18.7	2.0	23.8	4.8
120	18.6	2.0	23.7	4.8
121	18.6	2.0	23.7	4.8
122	18.5	2.0	23.6	4.8
123	18.4	2.0	23.6	4.8
124	18.4	2.0	23.5	4.8
125	18.3	2.0	23.5	4.8
126	18.2	2.0	23.5	4.8
127	18.2	2.0	23.4	4.8
128	18.1	2.0	23.4	4.8
129	18.1	2.0	23.3	4.8
130	18.0	2.0	23.3	4.8
131	18.0	2.0	23.2	4.8
132	18.0	2.0	23.2	4.8
133	17.9	2.0	23.1	4.8
134	17.9	2.0	23.1	4.8
135	17.9	2.0	23.1	4.8
136	17.8	2.0	23.0	4.8
137	17.8	2.0	23.0	4.8
138	17.8	2.0	22.9	4.8
139	17.8	2.0	22.9	4.8
140	17.7	2.0	22.8	4.7
141	17.7	2.0	22.8	4.7
142	17.7	2.0	22.8	4.7
143	17.7	2.0	22.7	4.7
144	17.7	2.0	22.7	4.7
145	17.7	2.0	22.6	4.7
146	17.7	2.0	22.6	4.7
147	17.7	2.0	22.5	4.7
148	17.7	2.0	22.5	4.7
149	17.8	2.0	22.5	4.7
150	17.8	2.0	22.4	4.7
151	17.8	2.0	22.4	4.7
152	17.8	2.0	22.3	4.7
153	17.9	2.0	22.3	4.7

	DR 160.00		DR 133.50	
Flow (cfs)	**Mean 7DMAX (°C)**	**95% CI (±)**	**Mean 7DMAX (°C)**	**95% CI (±)**
154	17.9	2.0	22.3	4.7
155	17.9	2.0	22.2	4.7
156	18.0	2.0	22.2	4.7
157	18.0	2.0	22.1	4.7
158	18.1	2.0	22.1	4.7
159	18.2	2.0	22.1	4.7
160	18.2	2.0	22.0	4.7
161	18.3	2.0	22.0	4.7
162	18.4	2.0	21.9	4.7
163	18.4	2.0	21.9	4.6
164	18.5	2.0	21.8	4.6
165	18.6	2.0	21.8	4.6
166	18.7	2.0	21.8	4.6
167	18.8	2.0	21.7	4.6
168	18.9	2.0	21.7	4.6
169	19.0	2.0	21.6	4.6
170	19.1	2.0	21.6	4.6
171	19.2	2.0	21.6	4.6