Whychus Creek Water Quality Status, Temperature Trends, and Stream Flow Restoration Targets

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Abstract

Diversion of almost 90% of summer stream flow and channelization of over 50% of the length of Whychus Creek have degraded water quality, resulting in Whychus Creek running dry two out of three years from 1960 until 1998, and an ODEQ listing of water quality limited since 1998. Deschutes River Conservancy (DRC) and partners have been implementing stream flow restoration actions to ameliorate low flows and high stream temperatures in Whychus Creek since 1997. To evaluate how stream flow restoration is changing stream temperature, the Upper Deschutes Watershed Council has monitored temperature annually since 2000 at eleven sites representing diverse flow conditions in Whychus Creek. This report incorporates 2017 data to 1) evaluate the 2017 status of stream temperature in Whychus Creek relative to state standards for salmonid spawning, rearing and migration; 2) quantify 2000-2017 temperature trends in relation to stream flow; 3) describe the effects of stream flow and air temperature on stream temperature in Whychus Creek, and 4) update temperatures predicted to occur at the observed range of Whychus Creek stream flows. 7DADM stream temperature exceeded the state standard for trout rearing and migration in 2017, supporting the ODEQ 2012 303(d) Category 5 listing of Whychus Creek as water quality limited (ODEQ 2018). Stream temperatures exceeding the 18˚C standard over a prolonged duration suggest temperature conditions compromised habitat suitability for rearing and migrating trout and salmon in Whychus Creek from rm 1.5 (WC 001.50) to below Camp Polk Meadow Preserve (WC 018.25) in 2017. Seven day average daily maximum temperatures above 13 ˚C for 13-35% of data days April 1-May 15 (at WC 006.00 and WC 008.50), as well as for the majority of September data days downstream of Camp Polk, also indicate marginal spawning conditions for steelhead and Chinook salmon. Stream temperature never reached the 24˚C lethal threshold in 2017. Stream temperatures meeting the state standard for more days in 2017 than in eight years (from 2000 to 2002, in 2005, 2007, 2009, 2013, 2015, and 2016) show a sustained improvement over early years of stream flow restoration (data from WC 006.00 are not available for 2003 and 2004). Regression of 2000-2017 temperature and flow data and Heat Source model results show 66 cfs is required to meet 18°C on average in lower reaches of Whychus Creek in July; stream temperatures as high as 21.1°C are predicted to occur at 66 cfs, emphasizing the critical need for 60 cfs as a minimum flow during July to reduce stream temperatures below the threshold at which trout experience chronic effects that result in mortality. These results show the 33 cfs state water right, resulting in sub-lethal stream temperatures of 20°C and above in July, to be far short of the flows needed to meet the state temperature standard or provide suitable conditions for fish in downstream reaches of Whychus Creek throughout the irrigation season. Continued

development of creative solutions to allocate flow instream in Whychus Creek in low water years is needed to guarantee conditions that will support the recovery of native fish populations.

Introduction

Restoration partners have identified the Whychus Creek watershed as a priority watershed for conservation and restoration within the upper Deschutes Basin (NWPPC 2004, UDWC 2006). Diversion of almost 90% of average summer flows and historic channelization of nearly 50% of the creek length have created conditions that contribute to elevated stream temperatures and may compromise other water quality parameters. Whychus Creek has been listed by ODEQ under Clean Water Act Section 303(d) as water quality limited with TMDLs needed for temperature (Category 5) and categorized as having insufficient data for assessment for dissolved oxygen and pH (Category 3)(Table 1, Figure 1) since 1998. Development of a TMDL for the Deschutes Basin has been suspended since 2012 as a result of litigation of DEQ's natural condition temperature criterion and is pending resolution of the litigation.

UDWC began monitoring temperature on Whychus Creek in 1995. In 1999 DRC stream flow restoration efforts first returned continuous summer flows to Whychus Creek, and the volume of flows protected instream has incrementally increased since. Restoration partners expect that increasing stream flow will reduce temperatures in Whychus Creek to more frequently and consistently meet spawning and rearing and migration habitat requirements for native fish including anadromous steelhead trout and Chinook salmon re-introduced to the creek in 2007 and 2009, respectively.

Water temperature affects the growth and survival of aquatic organisms. Temperature naturally fluctuates on a daily and seasonal basis, with daily fluctuations resulting from continuous changes in solar radiation and air temperature, and seasonal fluctuations in response to changes in climate, solar aspect, and variable amounts of stream flow from snowmelt and precipitation. Water temperature naturally increases as water flows downstream, and temperature can decrease as a result of groundwater inflows (springs) or the inflow of cooler tributaries. Anthropogenic changes that alter the natural hydrograph, such as diversions for irrigation, groundwater pumping, and climate change, also influence temperature.

ODEQ state temperature standards were developed to protect fish and other aquatic life in Oregon waterways (ODEQ 2009). The year-round temperature standard applied to Whychus Creek for salmon and trout rearing and migration specifies that seven-day moving average maximum (7DADM) temperatures are not to exceed 18˚C. The 2002 303(d) list also identified Whychus Creek as not meeting the 13˚C state temperature standard for salmon and steelhead spawning. No subsequent 303(d) list has applied this criterion to Whychus Creek because anadromous fish were not spawning in Whychus Creek when data for these lists were collected. However, this habitat use is anticipated to resume, and the spawning temperature standard to become relevant, as steelhead and salmon reintroduced in 2007 and 2009 begin to return to the creek. The State of Oregon 1992-1994 Water Quality Standards Review (ODEQ 1995) identified 24˚C as the lethal temperature threshold for salmon and trout. Runge et al (2008) showed stream temperatures as low as 20˚C to have chronic sub-lethal effects on rainbow trout, with trout survival inversely related to the amount of time stream temperatures were 20˚C. Twenty-two degrees Celsius (22˚C) is generally agreed to have severe consequences for trout, including decreased foraging and increased aggressive behavior (Nielsen 1994), elimination of salmonids from a location (Nielsen 1994, US EPA 1999), and broad mortality (US EPA 2003). For steelhead and Chinook salmon spawning conditions, egg mortality is high at 15˚C compared to lower temperatures (Myrick and Cech 2001).

In addition to temperature, dissolved oxygen and pH levels also directly affect aquatic organisms. Waterways naturally produce oxygen through photosynthesis and aeration. Dissolved oxygen is consumed through respiration and degradation of organic plant compounds. The amount of dissolved oxygen available (percent saturation) is also affected by altitude and temperature: water at higher altitudes holds less dissolved oxygen than water at lower altitudes (because the degree of atmospheric pressure is less at higher altitudes), and cold water holds more dissolved oxygen than warm water. When oxygen is consumed at a faster rate than it is produced, dissolved oxygen concentrations fall, negatively affecting aquatic organisms. Salmon and trout, especially in their early life stages, are very susceptible to low dissolved oxygen concentrations.

Water pH levels (alkalinity) are primarily affected by plant photosynthesis, but can also be influenced by the chemistry of the local substrate. The volcanic soils of the Upper Deschutes Basin may increase the acidity (and decrease pH) of basin waterways. Water pH directly influences aquatic insect populations as well as salmon and trout egg development, egg hatching, and embryo development. Extreme pH levels can negatively impact fish by increasing the availability and toxicity of pollutants such as heavy metals and ammonia.

Whychus Creek is categorized as having insufficient data for assessment for dissolved oxygen and pH. UDWC analyses of dissolved oxygen data collected from 2006 to 2008 indicated that Whychus Creek met state dissolved oxygen standards for salmon and trout rearing and migration, although dissolved oxygen levels did not consistently meet state criteria for salmon and trout spawning (Jones 2010). Because dissolved oxygen saturation is directly affected by temperature, we expect dissolved oxygen levels to track temperature trends. While observed trends in stream temperature continue to demonstrate cooling, and in the absence of other novel environmental conditions, we expect dissolved oxygen levels to improve or remain constant. Under these circumstances, temperature data are a suitable proxy for dissolved oxygen data, and indicate dissolved oxygen levels that will continue to meet the state standard for salmon and trout rearing and migration. UDWC discontinued monitoring dissolved oxygen on Whychus Creek in 2009 on this premise. A consistent warming trend in temperature would flag potentially deteriorating dissolved oxygen conditions and warrant resuming monitoring of dissolved oxygen. Although 2006-2008 data indicated pH standards were not consistently met in the summer, low pH values were attributed to the influence of volcanic soils and were not expected either to limit ecological function or to be affected by increased flows with stream flow restoration. Accordingly we also discontinued monitoring pH subsequent to 2009. While this report does not present dissolved oxygen or pH data, we consider the observed trends in temperature to provide a surrogate measure of water quality in Whychus Creek. For further discussion of temperature, dissolved oxygen, pH, and state standards for each parameter, refer to *Whychus Creek Water Quality Status, Temperature Trends, and Stream flow Restoration Targets* (Jones 2010).

The stream flow and habitat restoration efforts of Deschutes River Conservancy (DRC), UDWC, and restoration partners aim to improve water temperatures to meet the 18˚C state standard and support sustainable anadromous and resident native fish populations by reducing warming rates, improving water quality, and reconnecting the creek to floodplains and groundwater. DRC and restoration partners adopted a stream flow target for Whychus Creek consistent with state instream water rights. State of Oregon March, April and May instream water rights protect 20 cfs upstream and 50 cfs downstream of Indian Ford Creek (RM 18); state water rights for June, July, August and September when flows are historically low, specify 20 cfs upstream and 33 cfs downstream of Indian Ford Creek. State instream water rights correspond to recommended minimum flows identified through the Oregon Method, which relates stream flow to fish habitat availability (Thompson 1972). UDWC analyses and the HeatSource model (Watershed Sciences and MaxDepth Aquatics 2008) have shown these flows to be insufficient to create suitable conditions for fish or meet state temperature standards. The DRC stream flow restoration target aims to protect 33 cfs of consistent and measurable water instream at Sisters City Park. Because no substantial flows enter Whychus Creek between this location and Alder Springs just below WC 001.50, the DRC target will effectively also protect 33 cfs downstream of Indian Ford Creek.

This report presents analyses of 2000-2017 temperature and flow data that: 1) evaluate the 2017 status of stream temperature in Whychus Creek relative to state standards and anticipated timing for salmonid spawning, rearing and migration and 2) quantify temperature trends in relation to stream flow. We also present 2000-2017 regression analyses to describe the effects of stream flow and air temperature on stream temperature in Whychus Creek, as well as temperatures predicted to occur at the observed range of Whychus Creek stream flows.

Table 1. 2012 Oregon Clean Water Act Section 303(d) status of Whychus Creek.

	Parameter	**Temperature**		**Dissolved Oxygen**		**pH**	
	Beneficial Use	Salmon & Trout Rearing & Migration	Steelhead Spawning	Salmon & Steelhead Non-Spawning	Salmon & Trout Spawning	Multiple Uses	Multiple Uses
	Season	Year Round	January 1 - May 15	Year Round	January 1 - May 15	Fall/ Winter/ Spring	Summer
	Standard	18° C	13° C	8.0 mg / L @ 90% Sat	11.0 mg / L @ 90% Sat	6.5-8.5 SU	6.5-8.5 SU
ODEQ Reach (River Mile)	0 - 40.3	TMDL Needed	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Insufficient Data for Section 303(d) Assessment	Insufficient Data for Section 303(d) Assessment
	1 - 13.3	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Not Applicable	Not Applicable	Not Applicable
	13.3 - 40.3	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Not Applicable	Not Applicable	Not Applicable

Source: ODEQ 2014

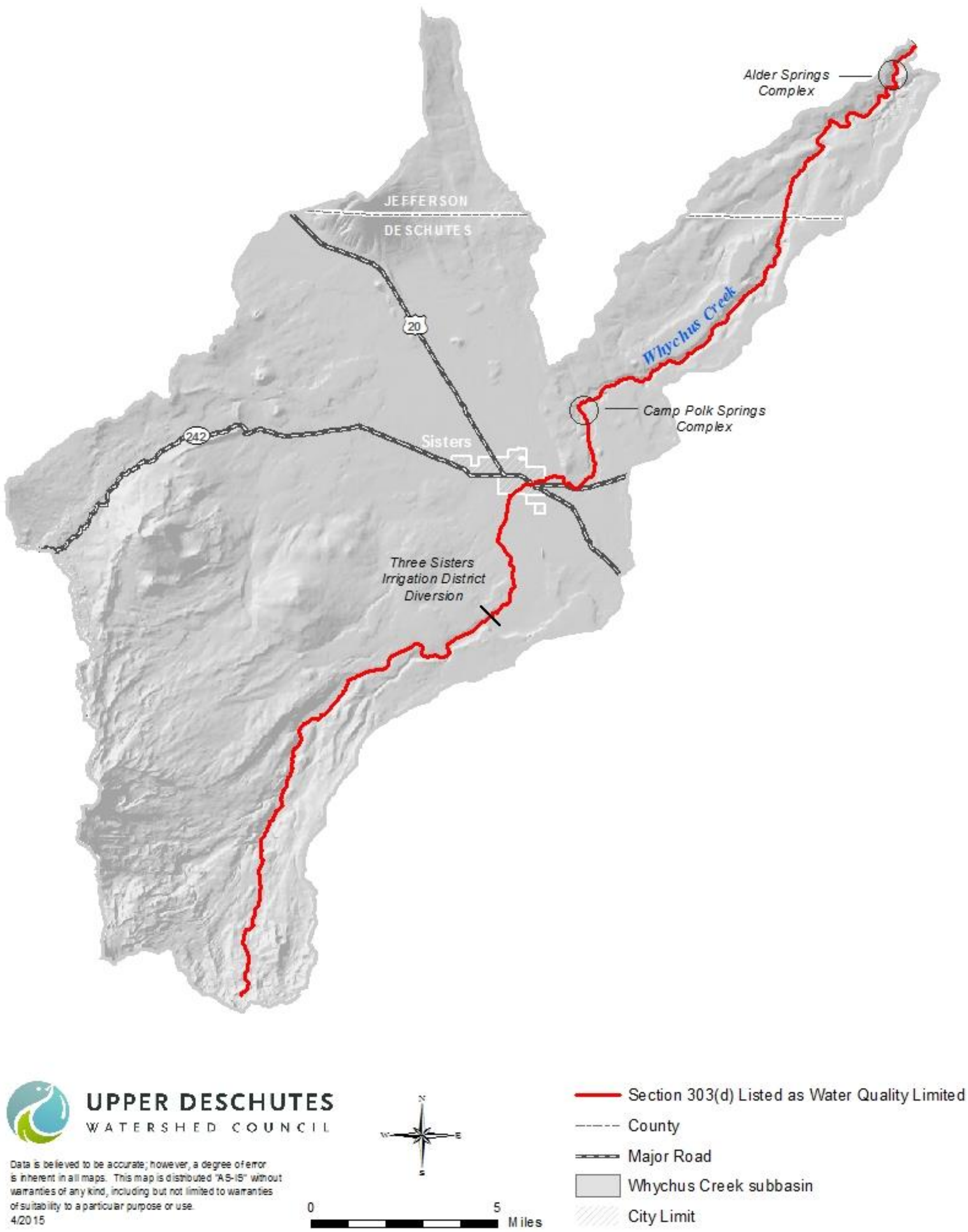


Figure 1.
Whychus Creek is listed as Water Quality Limited from river mile (RM) 0.0 to RM 40.3 under ODEQ's 2012 303(d) list. (ODEQ 2016)

Methods

Data collection

Stream Temperature Data

Beginning in 1995, UDWC and partners collected continuous temperature data annually at a subset of thirteen locations on Whychus Creek between river mile (RM) 38 and RM 0.25 (Figure 2, Appendix A). All temperature data used in analyses were collected by USFS, BLM, ODEQ, and UDWC. Coordinated monitoring efforts were conducted according to standard methods and protocols outlined in the ODEQ-approved UDWC Quality Assurance Project Plan (UDWC 2008a) and summarized in UDWC Water Quality Monitoring Program Standard Operating Procedures (UDWC 2008b).

In 2009 UDWC, Deschutes Land Trust (DLT), private landowners and other restoration partners reached an agreement to restore 1.9 miles of the historic meadow channel of Whychus Creek at Rimrock Ranch. The planned restoration will divert the creek from the existing channel into the meadow, and the UDWC monitoring station historically located on the existing channel will no longer be on the stream. To replace this monitoring location and generate pre-restoration data above and below the restoration project site UDWC established two new temperature monitoring stations, one upstream and one downstream of the planned restoration. As of 2009 UDWC discontinued temperature monitoring at the old Rimrock temperature monitoring station at WC 009.00 and began monitoring temperatures at the two new locations. Site names assigned to the two new sites are based on distance from the original WC 009.00 site. Although the downstream site is 0.7 mi from WC 009.00, another site had already been designated as WC 008.25. We accordingly designated the downstream Rimrock site as WC 008.50, the next closest quarter-mile increment.

Stream Flow Data

We obtained average daily stream flow (QD) data for Whychus Creek from Oregon Water Resources Department (OWRD) gage 14076050 at the City of Sisters (OWRD 2015). This gage is located downstream from the Three Sisters Irrigation District diversion and other major irrigation diversions. We use data collected at this gage from 2000 to 2017 in this report, including some data considered by OWRD to be provisional and subject to change.

Air Temperature Data

We obtained daily maximum air temperature data from the Colgate, Oregon Western Regional Climate Center (WRCC 2015) RAWS station (44° 18’ 57”, 121° 36’ 20”), the closest RAWS station to Whychus Creek.

Data analysis

Stream Temperature Status

We used the Oregon Department of Environmental Quality (ODEQ) Hydrostat Simple spreadsheet (ODEQ, 2010) to calculate the seven day average daily maximum (7DADM) temperature, the statistic used by the State of Oregon to evaluate stream temperature. 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). Because steelhead spawning season has yet to be identified for Whychus Creek, we reference the January 1 – May 15 spawning season identified for the Lower Deschutes sub-basin for evaluation of temperature relative to the 13˚C state standard for steelhead and salmon spawning.

Chinook salmon spawning in Whychus Creek is anticipated to occur from late August through early October with incubation occurring through March or April (personal communication, B. Spateholts, February 15, 2015), earlier than the October 15 – May 15 spawning and October 15 – June 15 incubation dates designated for the lower Deschutes.

We evaluated 7DADM stream temperatures from 2001-2017 in relation to the state standard of 18°C and the 13˚C state standard for steelhead and salmon spawning to describe changes in temperature in Whychus Creek since 2001 and to assess progress toward the 18°C state standard for salmonid rearing and migration. To determine the percent of days when 7DADM stream temperatures exceeded the 18°C rearing and migration standard on Whychus Creek, we identified the earliest and latest dates on which stream temperatures have exceeded 18°C and used the number of days between and including these dates as our total number of days. For four years (2000, 2002, 2006, and 2009) data were missing between the earliest and latest dates exceeding 18°C. For these years, we were able to extrapolate 7DADM stream temperatures to be greater or less than 18°C based on temperatures at upstream and downstream sites, allowing percent of days exceeding 18°C to be calculated from the same dates and number of days for each year.

UDWC stream temperature monitoring in Whychus Creek has been focused on summer stream temperatures, when flows in Whychus Creek historically dropped to less than ten cfs and stream temperatures exceeded the lethal threshold for native redband trout and steelhead. As a result, datasets between April 1 and May 15, when steelhead are anticipated to spawn in Whychus Creek and diversions for irrigation have resumed but it is not yet warm enough for snow to melt and contribute additional flow, are incomplete. To evaluate stream temperature conditions for spawning steelhead in Whychus Creek between April 1 and May 15, we reported the number of days for which data are available April 1- May 15, the earliest of those dates when stream temperature exceeded 13˚C, and the number and percent of days exceeding 13˚C. For Chinook, we report the number of days in September when stream temperature at WC 006.00 exceeded the 13˚C spawning criteria.

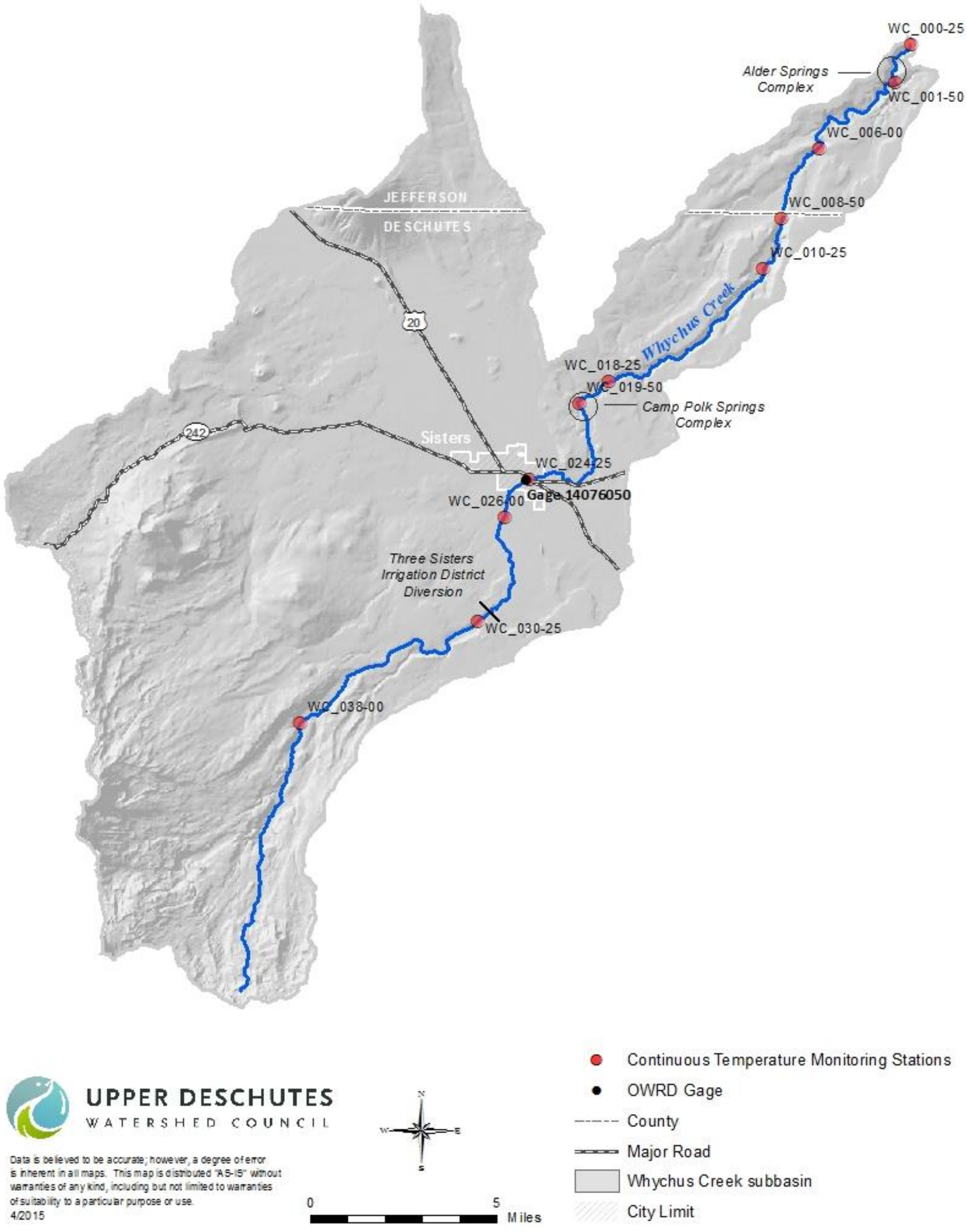


Figure 2.
Continuous temperature monitoring stations monitored in 2016, and OWRD Gage 14076050 at Sisters City Park, on Whychus Creek.

Target Stream Flow

We used regressions of stream temperature, stream flow, and air temperature data to 1) quantify the effects of stream flow and air temperature on stream temperature, and 2) to calculate stream flows predicted to produce the 18°C rearing temperature standard and 13°C steelhead spawning temperature standard at key monitoring sites.

While the use of air temperature to predict stream temperature has been the subject of debate within the scientific community, we included air temperature in regressions on the basis of an extensive body of scientific literature supporting its application for this purpose. Air temperature has been shown to be a useful proxy for heat energy transfer from the atmosphere to water by long-wave radiation and sensible heat transfer (Webb and Zhang 1997; Mohseni and Stefan 1999), and multiple studies have used air temperature to accurately predict stream temperature variation (e.g. Webb et al. 2003; Mohseni et al. 2003; Morrill et al. 2005; Carlson et al. 2015).

We used 7DADM temperature data for each year and site included in the analysis with corresponding stream flow data from the OWRD gage at Sisters City Park and air temperature data from the Colgate, OR Western Regional Climate Center RAWS station (WRCC 2015). We restricted data included in each regression to a one-month (30-day) interval to reduce the effect of intra-annual seasonal variation in the analysis (Helsel and Hirsch 2002). To calculate stream flows required to produce 18°C we evaluated July stream temperature data from WC 024.25 and WC 006.00. We selected July as the historically hottest month for stream temperature in Whychus Creek (UDWC unpublished data). Temperature data from WC 024.25 represent stream conditions immediately below major irrigation diversions; data from WC 0006.00 represent the historically worst temperature conditions on the creek, and thus the location that is both most critically in need of and also stands to benefit the most from stream flow restoration. To calculate stream flows required to produce 13°C during the January 1 – May 15 spawning season we evaluated April stream temperature data from WC 006.00. We selected April as the month during which stream temperature most often begins to exceed the 13°C steelhead spawning standard, and evaluated the relationship between stream temperature and stream flow at WC 006.00 as the site which typically represents the highest stream temperatures. To calculate stream flows required to produce 13°C during the late August to early October period during which Chinook salmon spawning is anticipated to occur in Whychus Creek we evaluated September stream temperature data from WC 006.00. We selected September as the month encompassing the majority of dates during which Chinook salmon are anticipated to spawn. For data for each month we evaluated the effect of air temperature on stream temperature to account for variation in stream temperature not explained by stream flow.

For each site and month we included all dates for which stream temperature, stream flow, and air temperature data were available. We used R open source statistical software (R Core Team, 2017) to perform linear, quadratic, and cubic regressions for each site: 1) with each of two flow metrics (average daily flow and the natural logarithm of average daily flow); and 2) with each of two air temperature metrics (daily maximum and three-day moving average maximum; 3DAir) for a total of twelve models (Table 2), to evaluate which metrics and models best described the data. The resulting equations represent the relationship between flow and temperature and can be used to estimate temperature values for the specified locations, within the evaluated time period, and within the range of flows observed.

Table 2. Twelve regression models evaluated for Whychus Creek at WC 024.25 and WC 006.00.

Regression Model	
1.	7DADM ~ QD
2.	7DADM ~ QD + $(QD)^2$
3.	7DADM ~ QD + $(QD)^2$ + $(QD)^3$
4.	7DADM ~ Ln QD
5.	7DADM ~ Ln QD + $(\text{Ln QD})^2$
6.	7DADM ~ Ln QD + $(\text{Ln QD})^2$ + $(\text{Ln QD})^3$
7.	7DADM ~ Air
8.	7DADM ~ Air + $(\text{Air})^2$
9.	7DADM ~ Air + $(\text{Air})^2$ + $(\text{Air})^3$
10.	7DADM ~ 3DAir
11.	7DADM ~ 3DAir + $(\text{3DAir})^2$
12.	7DADM ~ 3DAir + $(\text{3DAir})^2$ + $(\text{3DAir})^3$

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

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

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

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

For July data, we compared the resulting 2000-2017 temperature-flow regressions and predicted temperatures at given flows for each site to Heat Source model scenarios for the same locations on Whychus Creek (Watershed Sciences and MaxDepth Aquatics 2008). Because available Heat Source scenarios assume 33 cfs at WC 024.25 and 62 cfs at WC 006.00, we compared 2000-2017 predicted temperatures to Heat Source estimates for these flows.

Results

Temperature status

Seven-day moving average maximum (7DADM) temperatures exceeded the 18°C state standard for trout and salmon rearing and migration at five locations between rm 1.5 and rm 18.25 in 2017, (Figure 3), supporting the existing State of Oregon Section 303(d) listing of Whychus Creek as water quality limited. Seven-day moving average maximum temperatures exceeded the January 1 – May 15 13°C state standard for steelhead spawning at two sites, between rm 6.0 and rm 8.50, in 2017.

Percent of data days exceeding 18°C between May 6 and September 21 represent the maximum amount of time annually during which stream conditions are unsuitable for rearing trout in Whychus Creek; conversely, the percent of days meeting 18°C represents the amount of time during which stream conditions are suitable to support rearing fish. Similarly the percent of data days exceeding or meeting 13°C between April 1 and May 15, and during the month of September, represent the amount of time during which stream conditions are unsuitable or suitable for spawning summer steelhead and Chinook salmon, respectively.

Stream temperature at WC 006.00 exceeded 18°C for 45% of days (62 days) between May 6 and September 21 in 2017 (Figure 4), higher than in six of the fifteen years for which data are available and lower than in the remaining eight years for which data are available (data for 2008 are unavailable). Temperatures at this site met the applicable standard, providing suitable conditions for rearing trout, for 55% of days May 6 – September 21 (77 days) in 2017. Temperatures did not exceed 24°C in Whychus Creek in 2017. Stream temperature exceeded 18°C between July 11 and September 10, 2017, at Sisters City Park average daily flows of 18 to 93 cfs.

Data were available for eight days between April 1 and May 15 at WC 006.00 in 2017, from May 8 to May 15. Stream temperature at WC 006.00 exceeded 13°C for one of these days, 13% of the eight days for which temperature data were available (Table 3). At WC 008.50 temperature data were available for 17 days between April 1 and May 15; stream temperature exceeded 13°C for six of these days (35%). Incomplete data make a comparison to previous years uninformative. However, temperatures exceeding the spawning standard for 32 to 75 percent of data days over the years for which data are available flag a consistent temperature problem for spawning steelhead. Stream temperature exceeded 13°C between April 1 and May 15 at Sisters City Park flows of 31 to 111 cfs.

Stream temperature at WC 006.00 exceeded 13°C for 53% of days (20 out of of 38) between April 1 and May 15 in 2016 (Table 3), also higher than in six of the fourteen years for which data are available. Temperatures at this site were suitable for steelhead spawning for 47% of days for which data were available April 1 – May 15. Because temperature data are available for different numbers of days and different dates from April 1 – May 15 between years, direct comparison of trends in the number and percent of days exceeding the spawning standard will not be accurate. However, temperatures exceeding the spawning standard for 32 to 75 percent of data days over the years for which data are available flag a consistent temperature problem for spawning steelhead. Stream temperature exceeded 13°C between April 1 and May 15, 2017 at a median Sisters City Park average daily flow of 86 cfs (range: 43 to 117 cfs).

Stream temperature at WC 006.00 exceeded 13°C for 22 days in September 2017 (73%). Temperatures exceeded 13°C for all September days for which data were available in eight of fourteen years; in the remaining six years temperatures exceeded 13°C for 70-97% of data days. September stream flow at Sisters City Park over thirteen years from 2000-2017 ranged from 1 to 43 cfs, with a median flow of 15 cfs. Anomalously high flows between 105 cfs and 400 cfs occurred from September 28-30, 2013.

Despite stream temperatures continuing to exceed rearing and migration and spawning temperature standards, over the last nine years (2009 – 2017) July stream temperatures at WC 006.00 (Road 6360) have exceeded state standards less frequently than in early years of stream flow restoration (2000-2005; 2007)(Figure 5).

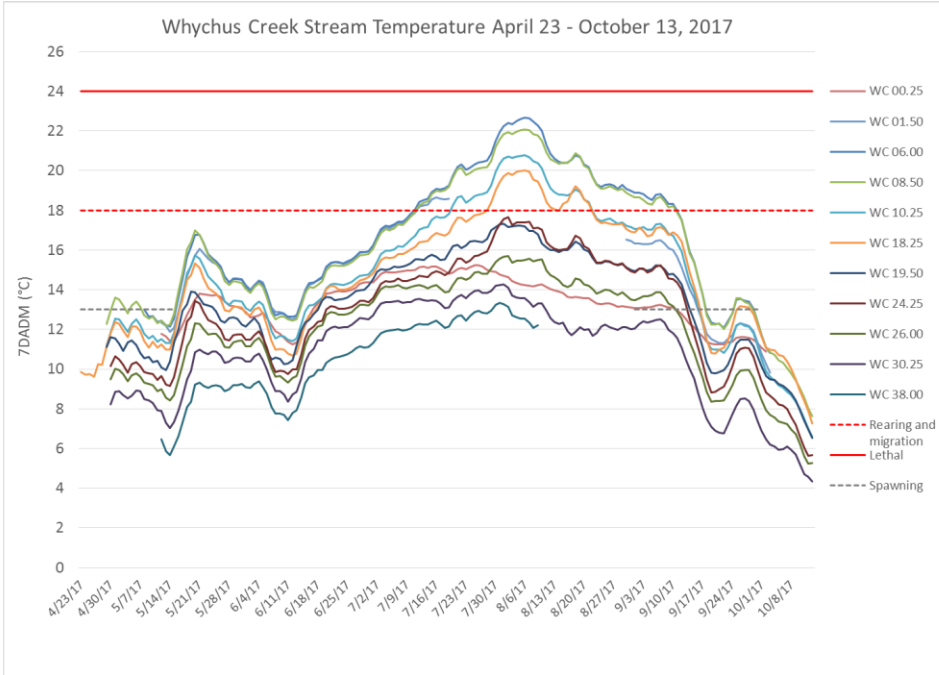


Figure 3. 2016 7DADM temperatures at eleven Whychus Creek monitoring sites. Stream temperature exceeded the 18˚C rearing standard at eight sites in 2016, from rm 1.5 (WC 001.50) to rm 24.25 (WC 024.25), and exceeded the January 1-May 15 13˚C steelhead spawning standard at seven sites from rm 0.25 (WC 000.25) to rm 19.50 (WC 019.50).

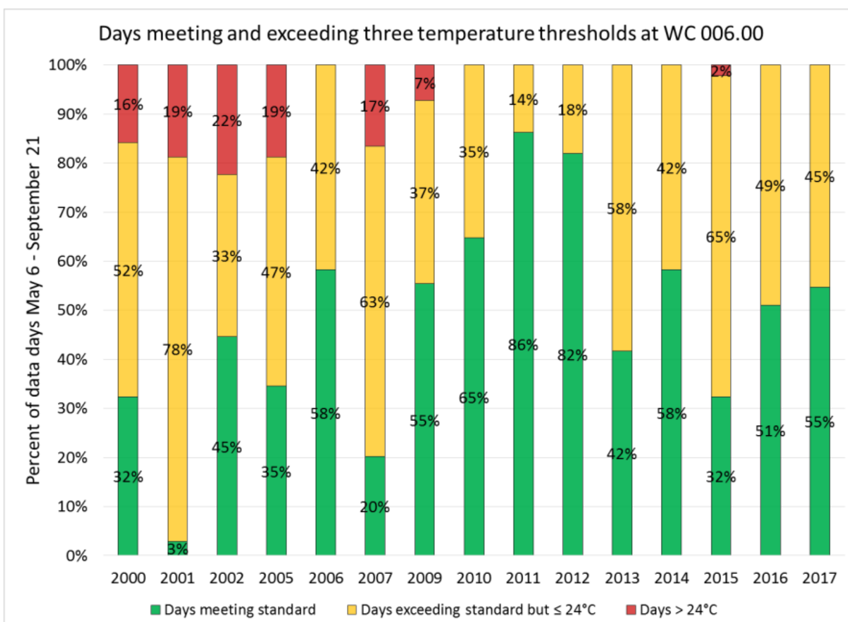


Figure 4. Percent of data days meeting and exceeding three temperature thresholds at WC 006.00. Seven day average daily maximum stream temperatures exceeded the 18˚C rearing and migration state standard for 45% of days in 2017; 7DADM temperatures never exceeded the lethal 24 ˚C threshold in 2017. 2001, 2005, and 2015 were dry years (Figure 5).

Table 3. Number of data days and earliest date, number, and percent of days exceeding 13°C between April 8 and May 15.

	Data days 4/1-5/15	Earliest date exceeding 13°C	Number of days exceeding 13°C	Percent of days exceeding 13°C
2001	30	4/22	16	0.53
2002	20	4/26	15	0.75
2005	37	4/19	24	0.65
2007	13	5/3	9	0.69
2009	25	4/21	8	0.32
2010	36	4/30	15	0.42
2011	14	5/7	9	0.64
2012	19	5/8	8	0.42
2013	38	4/24	19	0.50
2014	31	4/30	12	0.39
2015	35	4/17	25	0.71
2016	38	4/8	20	0.53
2017	8	5/8	1	0.13

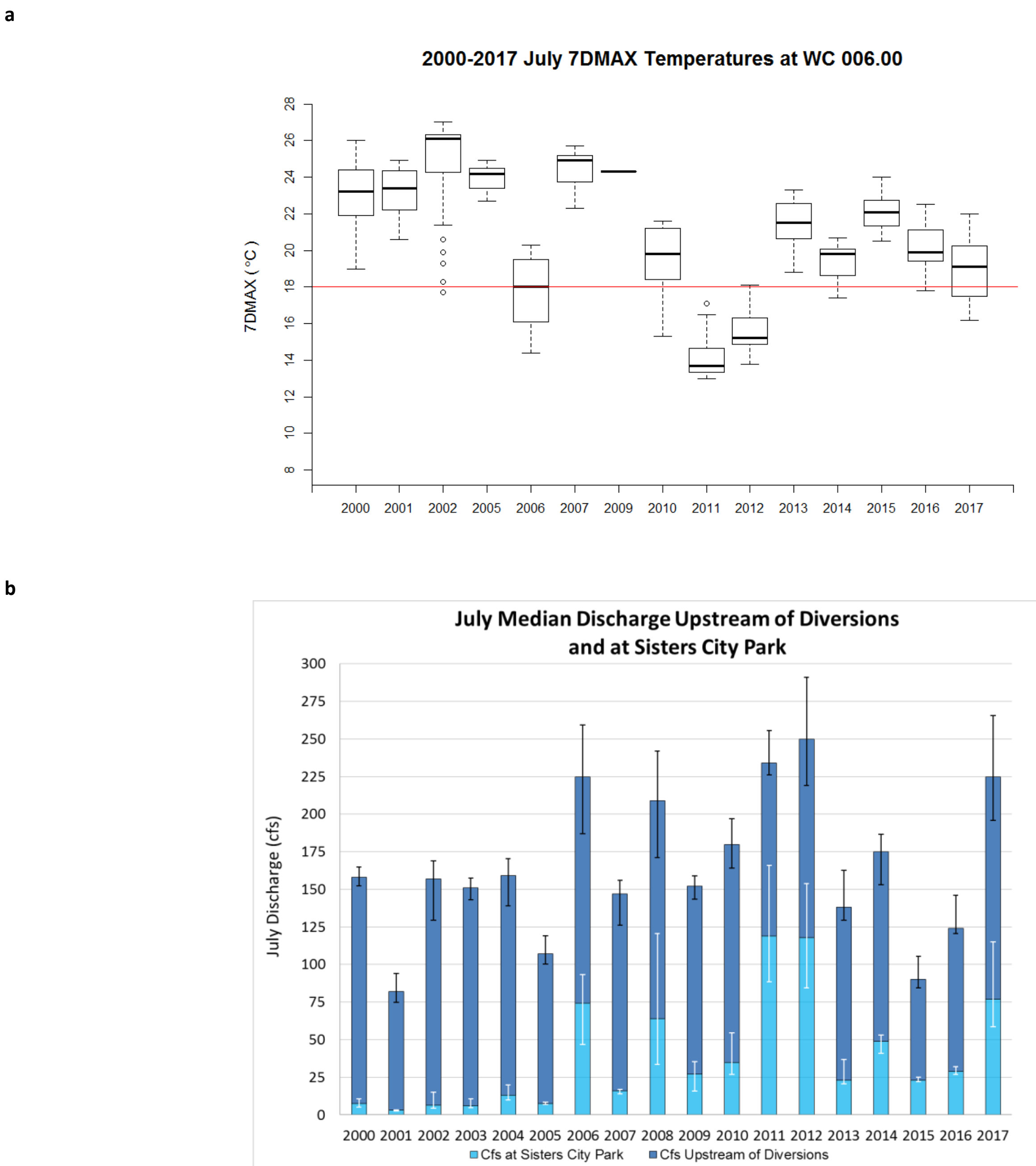


Figure 5. 2001-2017 July Median 7DADM Stream Temperature and Stream Flow

a) July stream temperatures at WC 006.00 (Road 6360) correspond closely to b) stream flow at Sisters City Park. Dark blue bars show July median stream flow upstream of all mainstem diversions on Whychus Creek. July data were incomplete in 2009 thus the median of available data is shown.

Target stream flow

Rearing and migration temperature standard

Temperature records were available from WC 024.25 and from WC 006.00 for July dates from 2000 through 2017 at Sisters City Park flows from 2 to 201 cfs (Table 4). The cubic regression of 7DADM stream temperature on the natural log of average daily flow (7DADM ~ LnQD + $(LnQD)^2$ + $(LnQD)^3$) performed best of the twelve regression models for both sites (Table 5). Using this model, stream flow explained 78% and 80% of the variation in stream temperature in July at WC 024.25 and at WC 006.00, respectively ($R^2 = 0.78$; $R^2 = 0.80$). For WC 024.25, the linear and quadratic regressions of stream temperature on the three day moving average maximum daily air temperature and the cubic regression of stream temperature on maximum daily air temperature performed equally and were better than the remaining three air temperature models, explaining 18% of the variation in stream temperature ($R^2 = 0.18$). For WC 006.00 the linear regression of stream temperature on the three day moving average maximum daily air temperature was the best of the six air temperature models, explaining 20% of the variation in stream temperature ($R^2 = 0.20$).

Temperatures calculated from the July WC 024.25 cubic regression model suggest that 22 cfs was the minimum stream flow resulting in a mean 7DADM temperature at or below 18°C (± 3°C) given temperatures observed from July 2000-2017 at Sisters City Park (Appendix A); allowing for the 3°C prediction interval, 54 cfs is the lowest flow predicted to result in an upper limit stream temperature of 18°C at Sisters City Park. The existing 33 cfs restoration target predicts a mean 7DADM temperature of 16.7°C ± 3°C at this site. Although direct comparison to Heat Source model predictions is not possible because Heat Source uses the seven day average daily maximum temperature, a daily statistic, and we use the mean seven day average daily maximum temperature for July, a monthly statistic, our 2000-2017 estimate for Sisters City Park is substantially (1.7°C) higher than the 2008 Heat Source model estimate of 15°C ± 1°C at 33 cfs at the ODFW gage at Sisters City Park (Watershed Sciences and MaxDepth Aquatics 2008).

The cubic regression of 2000-2017 7DADM stream temperature on the natural logarithm of flow at Road 6360 (WC 006.00) estimates 66 cfs to be the minimum stream flow that will achieve a mean 7DADM temperature of 18.0°C ± 3.1°C. According to this model the target stream flow of 33 cfs below Indian Ford Creek is projected to produce a mean 7DADM temperature of 20.8°C ± 3.1°C at Road 6360. The 2000-2017 cubic regression model estimate of 18.3°C ± 3.1°C at 62 cfs is slightly lower than the Heat Source model estimate of 18.5°C ± 1°C at 62 cfs at Road 6360.

Steelhead and salmon spawning standard

Temperature records were available from WC 006.00 for April dates from 2001 through 2016 corresponding to Sisters City Park flows from 2 to 128 cfs (Table 4); April data from 2017 are not available. The cubic and linear regressions of 7DADM stream temperature on the natural log of average daily flow (7DADM ~ LnQD + $(LnQD)^2$ + $(LnQD)^3$; 7DADM ~ LnQD) performed equally well and the cubic regression explained slightly more of the variation in stream temperature with a slightly higher R2 value and a slightly lower standard error (Table 5). Stream flow explained only 46% of the variation in stream temperature in April ($R^2 = 0.46$). The quadratic regression of stream temperature on three-day moving average air temperature performed best of the six air temperature models, explaining 29% of the variation in stream temperature ($R^2 = 0.29$).

Because the April regression models explained relatively little of the variation in stream temperature, in 2016 we used the same methods to evaluate the same relationships for May stream temperature, stream flow, and air temperature data from 2000-2015. May regressions explained less of the variation in stream temperature than April regressions. The cubic regression of 7DADM stream temperature on average daily flow (7DADM ~ QD + $(QD)^2$ + $(QD)^3$) performed best of the twelve models for May and explained 26% (R^2 = 0.26) of the variation in stream temperature; the best model for air temperature, the quadratic regression of stream temperature on three day moving average air temperature (7DADM ~ 3DAir + $(3DAir)^2$), explained 20% of the variation in stream temperature (R^2 = 0.26). Because the April regression provides better information about the relationship between stream flow and stream temperature during the April 1- May 15 anticipated steelhead spawning season, we did not update the May analysis for 2017.

We used the April cubic regression of 7DADM stream temperature on the natural log of average daily flow (7DADM ~ LnQD + $(LnQD)^2$ + $(LnQD)^3$), which explained the greatest proportion of variation in stream temperature of the April regression model, to calculate temperatures at the range of April flows. This model predicts a mean 7DADM stream temperature of 13°C±3.2°C (a range encompassing 9.8°C – 16.2°C) at 18 cfs at Sisters City Park. The state instream water right and DRC stream flow target of 33 cfs resulted in 12.1°C±3.2°C (8.9°C – 15.3°C). Ninety-one cfs were required at the Sisters City Park gauge (WC 024.25) to produce 13.0°C (mean 7DADM 9.8°C) as the upper limit of the prediction interval at WC 006.00 in April. This number corresponds to the highest average daily flows at which temperatures of 13°C have been recorded (Figure 8).

Temperature records were available from WC 006.00 for September dates from 2000 through 2017 at Sisters City Park flows from 1 to 400 cfs. Based on regressions of 2000-2015 data (Mork 2016) we included two multiple regression models: regression of 7DADM stream temperature on the natural log of average daily flow and the three-day moving average maximum daily air temperature (7DADM ~ LnQD + 3DAir), and regression of 7DADM stream temperature on the average daily flow and the three-day moving average maximum daily air temperature (7DADM ~ QD + 3DAir). The former model performed the best of the fourteen models, explaining 52% (R^2 = 0.52) of the variation in stream temperature. This model predicted a mean 7DADM temperature of 14.9°C±3.3°C (11.6°C–18.2°C) at the natural log of 33 cfs (3.4965 LnQD) and the September median maximum daily air temperature of 25.53°C (78°F). The best-performing stream flow and air temperature models explained 20% and 34% of the variation in stream temperature, respectively.

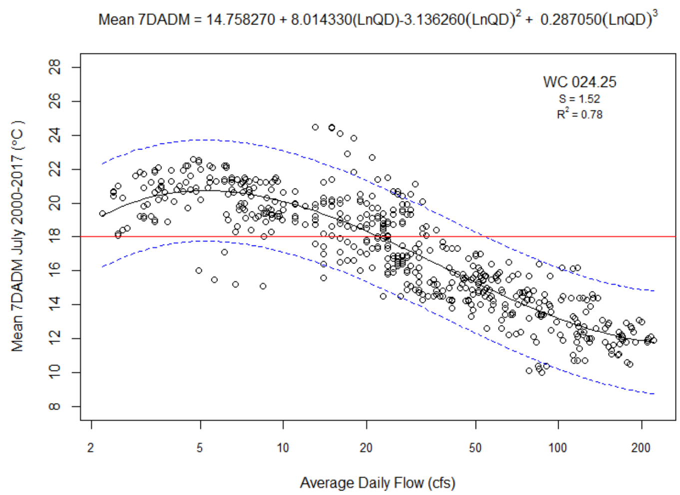
Table 4. Years for which data are available and which are represented in regression analyses. The number of days for which data are available for any given month varies.

Site and Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
WC 024.00																		
July	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
WC 006.00																		
April		x	x			x				x	x		x	x	x	x	x	
July	x	x	x			x	x	x		x	x	x	x	x	x	x	x	x
September	x	x				x	x	x		x	x	x	x	x	x	x	x	x

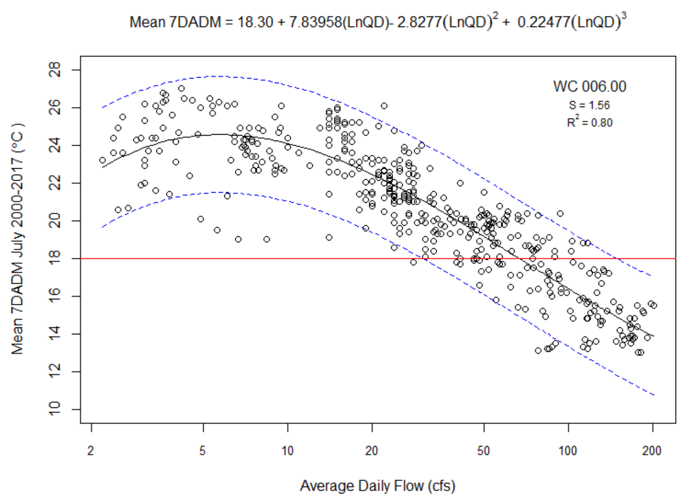
Table 5. A cubic regression model provided the best fit to July 2000-2017 temperature-flow data for both WC 024.25 and WC 006.00 data, and for April 2000-2017 data for WC 006.00. Temperatures calculated using the corresponding regression equations are expected to be the most accurate of the regression models evaluated.

Regression Model	Intercept	Coefficient 1	Coefficient 2	Coefficient 3	n	df	R^2	S	AIC value
July - WC 024.25									
7DADM ~ LnQD + (LnQD)^2 + (LnQD)^3	14.75827	8.01433	-3.13626	0.28705	**519**	**515**	**0.78**	**1.515**	**435**
7DADM ~ QD + (QD)^2 + (QD)^3	21.340	-0.1676	0.001072	-0.0000023	519	515	0.777	1.525	442
7DADM ~ QD + (QD)^2	20.8392465	-0.1239742	0.0004217	--	519	516	0.765	1.567	469
July - WC 006.00									
7DADM ~ LnQD + (LnQD)^2 + (LnQD)^3	**18.30**	**7.8396**	**-2.82770**	**0.22477**	**430**	**426**	**0.802**	**1.558**	**385**
7DADM ~ QD + (QD)^2 + (QD)^3	25.06	-0.1487	0.0007385	-0.000001338	430	426	0.794	1.587	401
7DADM ~ QD + (QD)^2	24.81	-0.127	0.0003946	--	430	427	0.793	1.593	404
April - WC 006.00									
7DADM ~ QD + (QD)^2 + (QD)^3	**23.221**	**-7.759**	**2.175**	**-0.247**	**159**	**155**	**0.460**	**1.602**	**154**
7DADM ~ LnQD	18.4399	-1.8532	--	--	159	157	0.456	1.608	153
7DADM ~ QD + (QD)^2	18.465257	-1.870614	0.002774	--	159	156	0.453	1.613	155
September - WC 006.00									
7DADM ~ LnQD + 3DAir	**13.19164**	**-1.27615**	**0.25134**	**--**	**361**	**358**	**0.518**	**1.576**	**331**
7DADM ~ QD + 3DAir	10.47544	-0.02525	0.242562	--	361	358	0.409	1.745	405
7DADM ~ 3DAir + (3DAir)^2	7.176809	0.469469	-0.004379	--	361	258	0.341	1.84	444

a



b



c

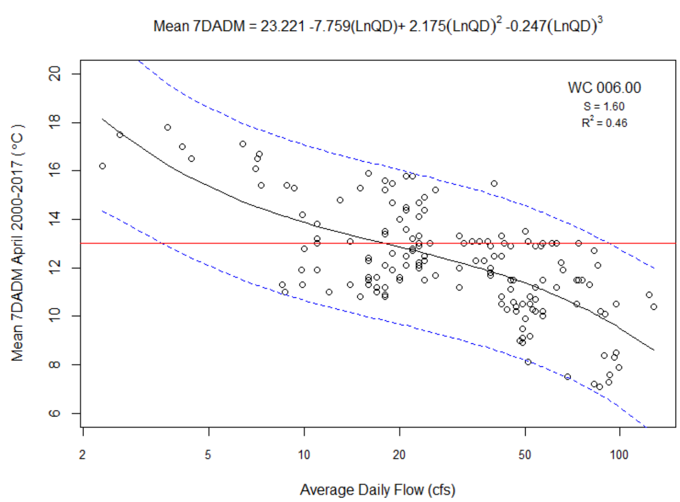


Figure 8. Temperature-Flow Regression Models

Regression models fitted to temperature-flow data demonstrate reduced temperatures at higher flows and describe the relationship between temperature and flow observed a) during July 2000-2017 at WC 024.25, b) during July 2000-2017 at WC 006.00, and c) during April 2001-2017 at WC 006.00.

Discussion

Temperature status and trend

7DADM stream temperature exceeded the state standard for trout rearing and migration in 2017, supporting the ODEQ 2012 303(d) Category 5 listing of Whychus Creek as water quality limited (ODEQ 2018). Stream temperatures exceeding the 18˚C standard over a prolonged duration suggest temperature conditions compromised habitat suitability for rearing and migrating trout and salmon in Whychus Creek from rm 1.5 (WC 001.50) to below Camp Polk Meadow Preserve (WC 018.25) in 2017. Seven day average daily maximum temperatures above 13˚C for 13-35% of data days April 1-May 15 (at WC 006.00 and WC 008.50), as well as for the majority of September data days downstream of Camp Polk, also indicate marginal spawning conditions for steelhead and Chinook salmon. Stream temperature never reached the 24˚C lethal threshold in 2017. Stream temperatures meeting the state standard for more days in 2017 than in eight years (from 2000 to 2002, in 2005, 2007, 2009, 2013, 2015, and 2016) show a sustained improvement over early years of stream flow restoration (data from WC 006.00 are not available for 2003 and 2004). It is worth noting that the 2017 water year (November 1, 2016 – October 31, 2017) was characterized by one of the biggest snowpacks on record.

Regression of temperature and flow data as well as comparison of median monthly temperature and stream flow data and mean 7DADM temperatures for given flow levels show stream temperatures decreasing in Whychus Creek as flows increase. Stream flow restoration has increased the minimum flow delivered instream, resulting in higher July median flows that reflect consistently higher average daily flows, which in turn correspond to lower observed temperatures.

Target stream flow

The state water right for Whychus Creek protects 20 cfs instream above Indian Ford Creek, between RM 20 and RM 21, and 33 cfs downstream of Indian Ford Creek. Because no additional flows enter Whychus Creek between the headwaters and Indian Ford Creek, DRC established a stream flow restoration target of 33 cfs for the entire length of the creek from headwaters to mouth. July regression results from Road 6360 (WC 006.00) 2000-2017 temperature and flow data indicate a minimum flow of 66 cfs is necessary to achieve stream temperatures of 18°C±3.1°C at this site. According to this model the target stream flow of 33 cfs below Indian Ford Creek is projected to produce a mean 7DADM temperature of 20.8°C ± 3.1°C at Road 6360, above the 18°C state standard and the 20°C threshold shown to increase mortality in trout (Runge *et al* 2008); the highest temperature predicted at this flow, 23.9°C, just misses the lethal temperature threshold for trout of 24°C. The mean 2000-2017 July median stream flow in Whychus Creek measured at OWRD gauge 14075000, upstream of all irrigation diversions, was 164 cfs.

Regression of April stream temperature and flow data suggests the 33 cfs DRC stream flow restoration target will result in stream temperatures between 8.9 and 15.3°C at WC 006.00, encompassing and exceeding the 13°C spawning threshold (predicted mean 7DADM = 12.1°C±3.2°C). This result suggests 33 cfs will support suitable steelhead spawning temperatures some of the time; the influence of air temperature on stream temperature in April, explaining 33% of the variability in stream temperature during this month, suggests air temperature will determine whether stream temperature meets or exceeds the spawning criteria at 33 cfs. Although 18 cfs is predicted to result in a mean 7DADM 13°C±3.2 stream temperature, temperatures exceeding that criteria at flows of 20 cfs and higher support the need for 33 cfs or higher in April and May.

Regression of September stream temperature, stream flow, and air temperature data suggests 33 cfs will result in stream temperatures between 11.6°C and 18.2°C (predicted mean 7DADM = 14.9°C±3.3°C) at the median September air temperature of 25.53°C (78°F), also encompassing, and exceeding by a greater amount than in April, the 13°C spawning threshold during anticipated Chinook salmon spawning. This result suggests 33 cfs will inconsistently support suitable Chinook salmon spawning temperatures, depending in large part on air temperature. The lack of September flow records above 43 cfs at Sisters City Park limits our ability to make predictions about what September flows are likely to provide conditions that support the 13°C spawning criteria for Chinook salmon.

These results clearly demonstrate the current state water right of 33 cfs is well below the stream flow necessary to meet state standards and provide suitable conditions for rearing and migrating native trout and salmon, and support the conclusion of previous regression models and Heat Source model results (Watershed Sciences and MaxDepth Aquatics 2008). In addition, minimum flows that on average have resulted in 18°C may not be sufficient to meet that threshold in hotter years given the influence of air temperature on stream temperature. Flows above 53 cfs are predicted to maintain July temperatures below the 22°C threshold at which trout have been shown to suffer severe effects of chronic sub-lethal temperatures; flows above 39 cfs are predicted to maintain April temperatures below the 15°C threshold at which egg morality increases.

This report evaluates stream temperature status and trends relative to state temperature standards and stream flow. Given competing needs for a limited amount of stream flow, further analyses by stream flow restoration partners and fish biologists that prioritize when and where it is most important to meet the applicable state standard will be useful to inform restoration planning. Questions to be addressed might include: Are there critical reaches in which to prioritize meeting the state temperature standard and at what times during the irrigation season, based on life cycle and movement of native fish species? Could strategic pulse flows during specific periods help fish migrate into areas that represent better habitat quality, e.g. reaches where springs cool stream flows or cooler upstream reaches?

Conclusions

Stream flow restoration and TSID management practices have achieved some sustained improvements in reducing the magnitude and duration of high stream temperatures in Whychus Creek. In particular, July stream temperatures at WC 006.00 (Road 6360) have been consistently lower in the last eight years (2010-2017) than in early years of stream flow restoration (2000-2005; 2007), as has the percent of days exceeding the 18°C state standard. These results suggest some improvement in the suitability of stream conditions in Whychus Creek for rearing trout during the irrigation season.

Regression analyses of empirical stream temperature and stream flow data substantiate Heat Source model results showing more than 60 cfs is required to meet 18°C on average in lower reaches of Whychus Creek in July; stream temperatures as high as 21.1°C are predicted to occur at 66 cfs, emphasizing the imperative need for 60 cfs as a minimum flow during July to reduce stream temperatures below the threshold at which trout experience chronic effects that result in mortality.

Although 60 cfs may not be a feasible restoration target given current land and water use in the Three Sisters Irrigation District, these data provide a benchmark for stream flow restoration and, importantly, show the 33 cfs state water right to be far short of the flows needed to meet the state temperature standard or provide suitable conditions for fish. Small gains in stream flow restoration that result in similarly small reductions in temperature are nonetheless likely to improve habitat conditions for some fish in some locations, for example by providing adequate flow for steelhead outmigration, increasing channel margin habitat by increasing channel width, and creating pools and cover for resident redband trout.

Our results show that higher stream flow achieved in part through stream flow restoration results in lower temperatures and better stream conditions for reintroduced salmon and steelhead trout, highlight the significant need for higher flows to achieve suitable conditions for salmon and trout in Whychus Creek, and contribute to an improved understanding of temperature and flow that that we hope will support restoration partners in planning more ambitious stream flow restoration efforts on Whychus Creek.

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APPENDIX A Temperatures at given flows.

Whychus Creek at Sisters City Park (WC 024.25) predicted temperatures for July at flows from 2 to 200 cfs

Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)
2	18.9	3.1	57	14.9	3.0	112	12.9	3.0	167	12.1	3.0
3	20.2	3.0	58	14.8	3.0	113	12.9	3.0	168	12.1	3.0
4	20.6	3.0	59	14.8	3.0	114	12.9	3.0	169	12.1	3.0
5	20.7	3.0	60	14.7	3.0	115	12.8	3.0	170	12.1	3.0
6	20.7	3.0	61	14.6	3.0	116	12.8	3.0	171	12.1	3.0
7	20.6	3.0	62	14.6	3.0	117	12.8	3.0	172	12.1	3.0
8	20.4	3.0	63	14.5	3.0	118	12.8	3.0	173	12.1	3.0
9	20.3	3.0	64	14.5	3.0	119	12.8	3.0	174	12.0	3.0
10	20.1	3.0	65	14.4	3.0	120	12.7	3.0	175	12.0	3.0
11	19.9	3.0	66	14.4	3.0	121	12.7	3.0	176	12.0	3.0
12	19.7	3.0	67	14.3	3.0	122	12.7	3.0	177	12.0	3.0
13	19.5	3.0	68	14.3	3.0	123	12.7	3.0	178	12.0	3.0
14	19.3	3.0	69	14.3	3.0	124	12.7	3.0	179	12.0	3.0
15	19.2	3.0	70	14.2	3.0	125	12.6	3.0	180	12.0	3.0
16	19.0	3.0	71	14.2	3.0	126	12.6	3.0	181	12.0	3.0
17	18.8	3.0	72	14.1	3.0	127	12.6	3.0	182	12.0	3.0
18	18.7	3.0	73	14.1	3.0	128	12.6	3.0	183	12.0	3.0
19	18.5	3.0	74	14.0	3.0	129	12.6	3.0	184	12.0	3.0
20	18.3	3.0	75	14.0	3.0	130	12.6	3.0	185	12.0	3.0
21	18.2	3.0	76	14.0	3.0	131	12.5	3.0	186	12.0	3.0
22	18.0	3.0	77	13.9	3.0	132	12.5	3.0	187	11.9	3.0
23	17.9	3.0	78	13.9	3.0	133	12.5	3.0	188	11.9	3.0
24	17.8	3.0	79	13.8	3.0	134	12.5	3.0	189	11.9	3.0
25	17.6	3.0	80	13.8	3.0	135	12.5	3.0	190	11.9	3.0
26	17.5	3.0	81	13.8	3.0	136	12.5	3.0	191	11.9	3.0
27	17.4	3.0	82	13.7	3.0	137	12.5	3.0	192	11.9	3.0
28	17.3	3.0	83	13.7	3.0	138	12.4	3.0	193	11.9	3.0
29	17.1	3.0	84	13.7	3.0	139	12.4	3.0	194	11.9	3.0
30	17.0	3.0	85	13.6	3.0	140	12.4	3.0	195	11.9	3.0
31	16.9	3.0	86	13.6	3.0	141	12.4	3.0	196	11.9	3.0
32	16.8	3.0	87	13.6	3.0	142	12.4	3.0	197	11.9	3.0
33	16.7	3.0	88	13.5	3.0	143	12.4	3.0	198	11.9	3.0
34	16.6	3.0	89	13.5	3.0	144	12.4	3.0	199	11.9	3.0
35	16.5	3.0	90	13.5	3.0	145	12.3	3.0	200	11.9	3.0
36	16.4	3.0	91	13.4	3.0	146	12.3	3.0			
37	16.3	3.0	92	13.4	3.0	147	12.3	3.0			
38	16.2	3.0	93	13.4	3.0	148	12.3	3.0			
39	16.1	3.0	94	13.4	3.0	149	12.3	3.0			
40	16.1	3.0	95	13.3	3.0	150	12.3	3.0			
41	16.0	3.0	96	13.3	3.0	151	12.3	3.0			
42	15.9	3.0	97	13.3	3.0	152	12.3	3.0			
43	15.8	3.0	98	13.2	3.0	153	12.2	3.0			
44	15.7	3.0	99	13.2	3.0	154	12.2	3.0			
45	15.7	3.0	100	13.2	3.0	155	12.2	3.0			
46	15.6	3.0	101	13.2	3.0	156	12.2	3.0			
47	15.5	3.0	102	13.1	3.0	157	12.2	3.0			
48	15.4	3.0	103	13.1	3.0	158	12.2	3.0			
49	15.4	3.0	104	13.1	3.0	159	12.2	3.0			
50	15.3	3.0	105	13.1	3.0	160	12.2	3.0			
51	15.2	3.0	106	13.0	3.0	161	12.2	3.0			
52	15.2	3.0	107	13.0	3.0	162	12.2	3.0			
53	15.1	3.0	108	13.0	3.0	163	12.1	3.0			
54	15.0	3.0	109	13.0	3.0	164	12.1	3.0			
55	15.0	3.0	110	12.9	3.0	165	12.1	3.0			
56	14.9	3.0	111	12.9	3.0	166	12.1	3.0			

Whychus Creek at Road 6360 (WC 006.00) predicted temperatures for July at flows from 2 to 201 cfs

Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)
2	22.5	3.2	57	18.6	3.1	112	16.0	3.1	167	14.5	3.1
3	23.8	3.1	58	18.6	3.1	113	15.9	3.1	168	14.5	3.1
4	24.3	3.1	59	18.5	3.1	114	15.9	3.1	169	14.5	3.1
5	24.5	3.1	60	18.4	3.1	115	15.9	3.1	170	14.4	3.1
6	24.6	3.1	61	18.4	3.1	116	15.8	3.1	171	14.4	3.1
7	24.5	3.1	62	18.3	3.1	117	15.8	3.1	172	14.4	3.1
8	24.4	3.1	63	18.2	3.1	118	15.8	3.1	173	14.4	3.1
9	24.3	3.1	64	18.2	3.1	119	15.7	3.1	174	14.4	3.1
10	24.1	3.1	65	18.1	3.1	120	15.7	3.1	175	14.3	3.1
11	23.9	3.1	66	18.0	3.1	121	15.7	3.1	176	14.3	3.1
12	23.8	3.1	67	18.0	3.1	122	15.6	3.1	177	14.3	3.1
13	23.6	3.1	68	17.9	3.1	123	15.6	3.1	178	14.3	3.1
14	23.4	3.1	69	17.9	3.1	124	15.6	3.1	179	14.3	3.1
15	23.3	3.1	70	17.8	3.1	125	15.5	3.1	180	14.2	3.1
16	23.1	3.1	71	17.8	3.1	126	15.5	3.1	181	14.2	3.1
17	22.9	3.1	72	17.7	3.1	127	15.5	3.1	182	14.2	3.1
18	22.8	3.1	73	17.6	3.1	128	15.4	3.1	183	14.2	3.1
19	22.6	3.1	74	17.6	3.1	129	15.4	3.1	184	14.2	3.1
20	22.5	3.1	75	17.5	3.1	130	15.4	3.1	185	14.1	3.1
21	22.3	3.1	76	17.5	3.1	131	15.4	3.1	186	14.1	3.1
22	22.2	3.1	77	17.4	3.1	132	15.3	3.1	187	14.1	3.1
23	22.0	3.1	78	17.4	3.1	133	15.3	3.1	188	14.1	3.1
24	21.9	3.1	79	17.3	3.1	134	15.3	3.1	189	14.1	3.1
25	21.7	3.1	80	17.3	3.1	135	15.2	3.1	190	14.1	3.1
26	21.6	3.1	81	17.2	3.1	136	15.2	3.1	191	14.0	3.1
27	21.5	3.1	82	17.2	3.1	137	15.2	3.1	192	14.0	3.1
28	21.3	3.1	83	17.1	3.1	138	15.2	3.1	193	14.0	3.1
29	21.2	3.1	84	17.1	3.1	139	15.1	3.1	194	14.0	3.1
30	21.1	3.1	85	17.0	3.1	140	15.1	3.1	195	14.0	3.1
31	21.0	3.1	86	17.0	3.1	141	15.1	3.1	196	14.0	3.1
32	20.9	3.1	87	16.9	3.1	142	15.1	3.1	197	13.9	3.1
33	20.8	3.1	88	16.9	3.1	143	15.0	3.1	198	13.9	3.1
34	20.6	3.1	89	16.8	3.1	144	15.0	3.1	199	13.9	3.1
35	20.5	3.1	90	16.8	3.1	145	15.0	3.1	200	13.9	3.1
36	20.4	3.1	91	16.8	3.1	146	15.0	3.1	201	13.5	3.1
37	20.3	3.1	92	16.7	3.1	147	14.9	3.1			
38	20.2	3.1	93	16.7	3.1	148	14.9	3.1			
39	20.1	3.1	94	16.6	3.1	149	14.9	3.1			
40	20.0	3.1	95	16.6	3.1	150	14.9	3.1			
41	19.9	3.1	96	16.6	3.1	151	14.8	3.1			
42	19.8	3.1	97	16.5	3.1	152	14.8	3.1			
43	19.7	3.1	98	16.5	3.1	153	14.8	3.1			
44	19.7	3.1	99	16.4	3.1	154	14.8	3.1			
45	19.6	3.1	100	16.4	3.1	155	14.8	3.1			
46	19.5	3.1	101	16.4	3.1	156	14.7	3.1			
47	19.4	3.1	102	16.3	3.1	157	14.7	3.1			
48	19.3	3.1	103	16.3	3.1	158	14.7	3.1			
49	19.2	3.1	104	16.2	3.1	159	14.7	3.1			
50	19.2	3.1	105	16.2	3.1	160	14.6	3.1			
51	19.1	3.1	106	16.2	3.1	161	14.6	3.1			
52	19.0	3.1	107	16.1	3.1	162	14.6	3.1			
53	18.9	3.1	108	16.1	3.1	163	14.6	3.1			
54	18.8	3.1	109	16.1	3.1	164	14.6	3.1			
55	18.8	3.1	110	16.0	3.1	165	14.5	3.1			
56	18.7	3.1	111	16.0	3.1	166	14.5	3.1			

Whychus Creek at Road 6360 (WC 006.00) predicted temperatures for April at flows from 2 to 128 cfs

Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)	Flow (cfs)	Mean Temp (7DMAX)	PI (±)
2	18.8	4.0	57	11.1	3.2	112	9.1	3.3
3	17.0	3.5	58	11.1	3.2	113	9.1	3.3
4	16.0	3.3	59	11.0	3.2	114	9.0	3.3
5	15.3	3.3	60	11.0	3.2	115	9.0	3.3
6	14.9	3.2	61	10.9	3.2	116	9.0	3.3
7	14.5	3.2	62	10.9	3.2	117	8.9	3.3
8	14.3	3.2	63	10.9	3.2	118	8.9	3.3
9	14.1	3.2	64	10.8	3.2	119	8.9	3.4
10	13.9	3.2	65	10.8	3.2	120	8.8	3.4
11	13.7	3.2	66	10.7	3.2	121	8.8	3.4
12	13.6	3.2	67	10.7	3.2	122	8.8	3.4
13	13.5	3.2	68	10.7	3.2	123	8.8	3.4
14	13.4	3.2	69	10.6	3.2	124	8.7	3.4
15	13.3	3.2	70	10.6	3.2	125	8.7	3.4
16	13.2	3.2	71	10.6	3.2	126	8.7	3.4
17	13.1	3.2	72	10.5	3.2	127	8.6	3.4
18	13.0	3.2	73	10.5	3.2	128	8.6	3.4
19	12.9	3.2	74	10.4	3.2	129		
20	12.9	3.2	75	10.4	3.2	130		
21	12.8	3.2	76	10.4	3.2	131		
22	12.7	3.2	77	10.3	3.2	132		
23	12.7	3.2	78	10.3	3.2	133		
24	12.6	3.2	79	10.3	3.2	134		
25	12.5	3.2	80	10.2	3.2	135		
26	12.5	3.2	81	10.2	3.2	136		
27	12.4	3.2	82	10.1	3.2	137		
28	12.4	3.2	83	10.1	3.2	138		
29	12.3	3.2	84	10.1	3.2	139		
30	12.3	3.2	85	10.0	3.2	140		
31	12.2	3.2	86	10.0	3.2	141		
32	12.2	3.2	87	10.0	3.2	142		
33	12.1	3.2	88	9.9	3.2	143		
34	12.1	3.2	89	9.9	3.2	144		
35	12.0	3.2	90	9.9	3.2	145		
36	12.0	3.2	91	9.8	3.2	146		
37	11.9	3.2	92	9.8	3.2	147		
38	11.9	3.2	93	9.8	3.2	148		
39	11.9	3.2	94	9.7	3.2	149		
40	11.8	3.2	95	9.7	3.2	150		
41	11.8	3.2	96	9.7	3.2	151		
42	11.7	3.2	97	9.6	3.2	152		
43	11.7	3.2	98	9.6	3.2	153		
44	11.6	3.2	99	9.5	3.3	154		
45	11.6	3.2	100	9.5	3.3	155		
46	11.5	3.2	101	9.5	3.3	156		
47	11.5	3.2	102	9.4	3.3	157		
48	11.5	3.2	103	9.4	3.3	158		
49	11.4	3.2	104	9.4	3.3	159		
50	11.4	3.2	105	9.3	3.3	160		
51	11.3	3.2	106	9.3	3.3	161		
52	11.3	3.2	107	9.3	3.3	162		
53	11.3	3.2	108	9.2	3.3	163		
54	11.2	3.2	109	9.2	3.3	164		
55	11.2	3.2	110	9.2	3.3	165		
56	11.1	3.2	111	9.1	3.3	166		