

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 2018 and 2019 data to 1) evaluate the 2019 status of stream temperature in Whychus Creek relative to state standards for salmonid spawning, rearing and migration; 2) quantify 2000-2019 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 2019, supporting the ODEQ 2012 and 2018 303(d) Category 5 listings of Whychus Creek as water quality limited (ODEQ 2020). 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 at every site below the TSID diversion from river mile 1.5 (WC 001.50) to approximately river mile 26 (WC 026.00) in 2019. Seven day average daily maximum temperatures above 13°C for up to 52% of data days April 21-May 15 and at all seven monitoring sites between approximately river miles 0.25 and 19.50 (WC 000.25 and WC 019.50), as well as for the majority of September data days downstream of Camp Polk, also indicate marginal spawning conditions for steelhead and Chinook salmon. Temperatures from up to six monitoring sites below the TSID diversion exceeding the spawning standard for 13-71% of data days from April 1 to May 15 since adult steelhead first returned to Whychus Creek in 2012, and for 70-100% of September days since adult spring Chinook salmon first returned in 2011, flag a consistent temperature problem for spawning steelhead and Chinook salmon. Stream temperature exceeded the 24°C lethal threshold for two to eight days at two sites (WC 006.00 and WC 008.50) in 2019. Despite stream temperatures continuing to exceed the 18 °C standard for 50% of days between May 6 and September 21 in 2019 at monitoring station WC 006.00, stream temperatures meeting the state standard for more days in 2019 than in eight years (from 2000 to 2002, in 2005, 2007, 2009, 2013, 2015, and 2018) at this site show sustained improvement over early years of stream flow restoration (data from WC 006.00 are not available for 2003 and 2004). Regression of 2000-2019

temperature and flow data, as well as Heat Source model results, show 66 cfs would be required to meet 18°C on average in lower reaches of Whychus Creek in July; a maximum stream temperature of 21°C is predicted to occur at 66 cfs, emphasizing the critical need for 60 cfs as a minimum average daily flow during July to reduce stream temperatures below the 20°C threshold at which trout experience chronic effects that result in mortality. These results show the 33 cfs state water right, resulting in sub-lethal July stream temperatures of 20.8°C on average and up to 23.8°C, 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, demonstrating an ongoing need for flow restoration solutions to increase flows and reduce summer stream temperatures in the lower reaches of Whychus Creek. While no solution currently exists to leave 60 cfs in Whychus Creek in July given current water rights and use in the Three Sisters Irrigation District, alternatives such as pulse flows during key periods could meaningfully reduce temperatures for fish. Continued development of creative solutions to allocate flow instream in Whychus Creek in July particularly in low water years is needed to provide 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 creates conditions that contribute to elevated stream temperatures with likely commensurate adverse impacts to dissolved oxygen and other water quality parameters. Whychus Creek has been listed by ODEQ under Clean Water Act Section 303(d) as water quality limited for flow modification (Category 4C) since 2002 and water quality limited with TMDLs needed for temperature (Category 5) since 2004 (Table 1, Figure 1). 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 spawning was no longer considered a designated fish use in Whychus Creek prior to reintroduction of salmon and steelhead. However, this habitat use is anticipated to resume, and the spawning temperature standard to become relevant, as returning adult steelhead and salmon resume spawning in 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.

ODEQ assessed dissolved oxygen and pH in Whychus Creek in 2018 (ODEQ 2020). Dissolved oxygen attained the state water quality standard in all reaches of Whychus Creek, except in the headwaters of Whychus Creek (River Mile (RM) 40.25 to 31.5), where insufficient data was available to assess dissolved oxygen for spawning. PH attained the state standard from Indian Ford Creek to the confluence with the Deschutes River but was 303(d) listed as impaired (not attaining the state standard) and needing a TMDL from the headwaters of Whychus Creek to the confluence with Indian Ford Creek. 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. Low pH values in Whychus Creek have been attributed to the influence of volcanic soils and are not expected either to limit ecological function or to be affected by increases in summer stream flow associated with stream flow restoration. Accordingly UDWC 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. However, these rights are the most junior rights on the creek and because Whychus Creek is overallocated not enough water is available at most times during the irrigation season to leave the state water right in the 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. The USFWS and NMFS Habitat Conservation Plan anticipated to be completed in late 2020 will establish a flow or temperature threshold that will provide the basis for a new flow or temperature restoration target on Whychus Creek.

This report presents analyses of 2000-2019 temperature and flow data that: 1) evaluate the 2019 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 2000-2019 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. 2018/2020 Oregon Clean Water Act Section 303(d) status of Whychus Creek.

	Parameter	Temperature		Dissolved Oxygen		pH
	Designated or Beneficial Use	Salmon & Trout Rearing & Migration	Steelhead Spawning	Salmon & Trout Non-Spawning	Salmon & Trout Spawning	Fish and Aquatic Life
	Season	Year Round	January 1 - May 15	Year Round	January 1 - May 15	Year Round
	Standard	18° C	13° C	8.0 mg / L @ 90% Sat	11.0 mg / L @ 90% Sat	6.5-8.5 SU
ODEQ Assessment Unit (River Mile)	Indian Ford Creek to confluence with Deschutes RM 0 – 19.55	Category 5: Impaired, TMDL needed	Use not designated for Deschutes Basin	Category 2: Attaining standard	Category 2: Attaining standard	Category 2: Attaining Standard
	Upper and Headwaters Whychus 1 st through 4 th order streams RM 19.55 – 40.25	Category 2: Attaining standard	Use not designated for Deschutes Basin	Category 2: Attaining standard	Category 2: Attaining standard	Category 5: Impaired, TMDL needed

Source: ODEQ 2020

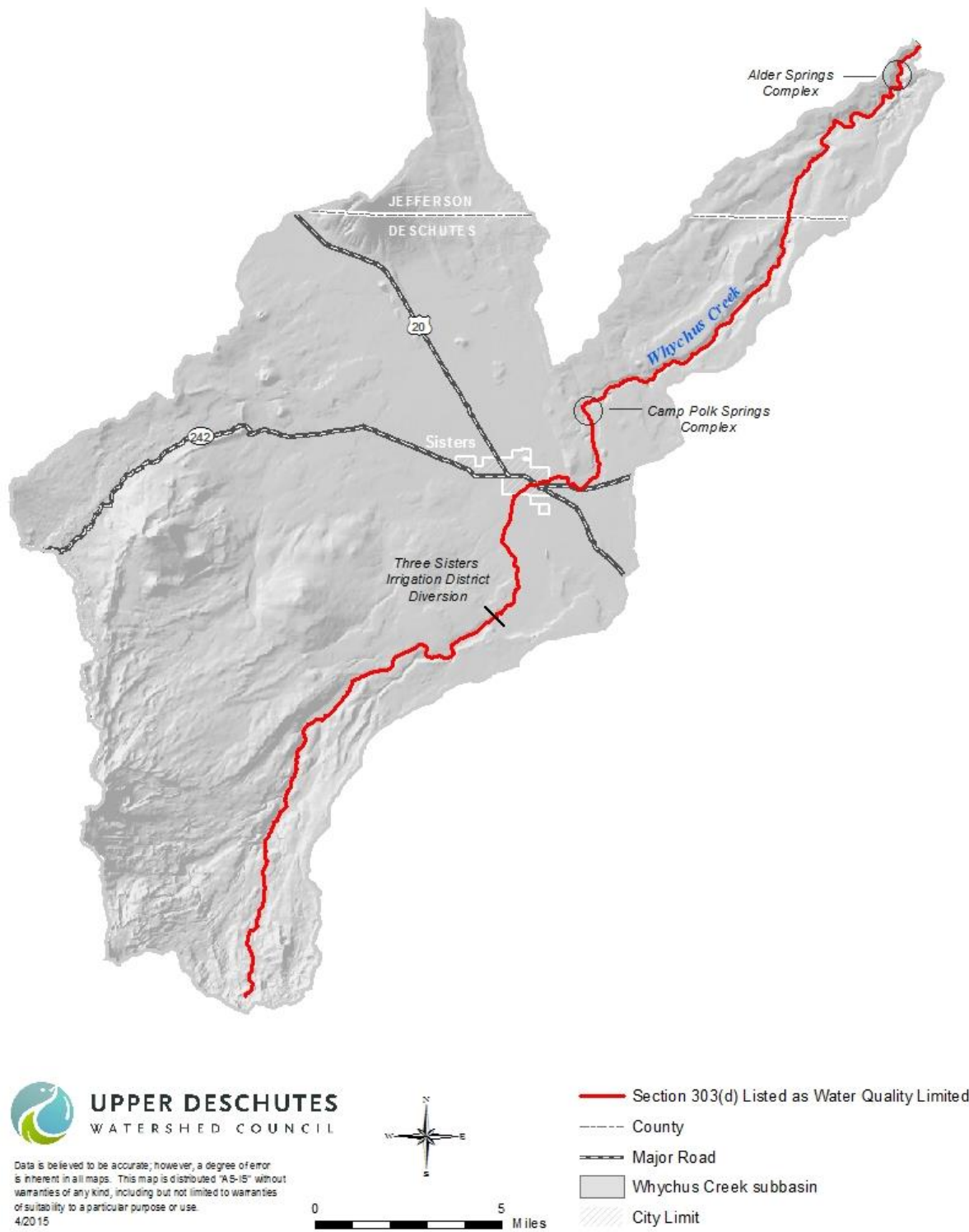


Figure 1. Whychus Creek is listed as Water Quality Limited from river mile (RM) 0.0 to RM 40.25 under ODEQ’s 2018/2020 303(d) list. (ODEQ 2020)

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 2020). 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 2019 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 2020) 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 2001-2019 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 instantaneous flows in Whychus Creek continue to drop to less than ten cfs and stream temperatures exceed 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 report the number of days for which data are available at WC 006.00 from April 1 to 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.

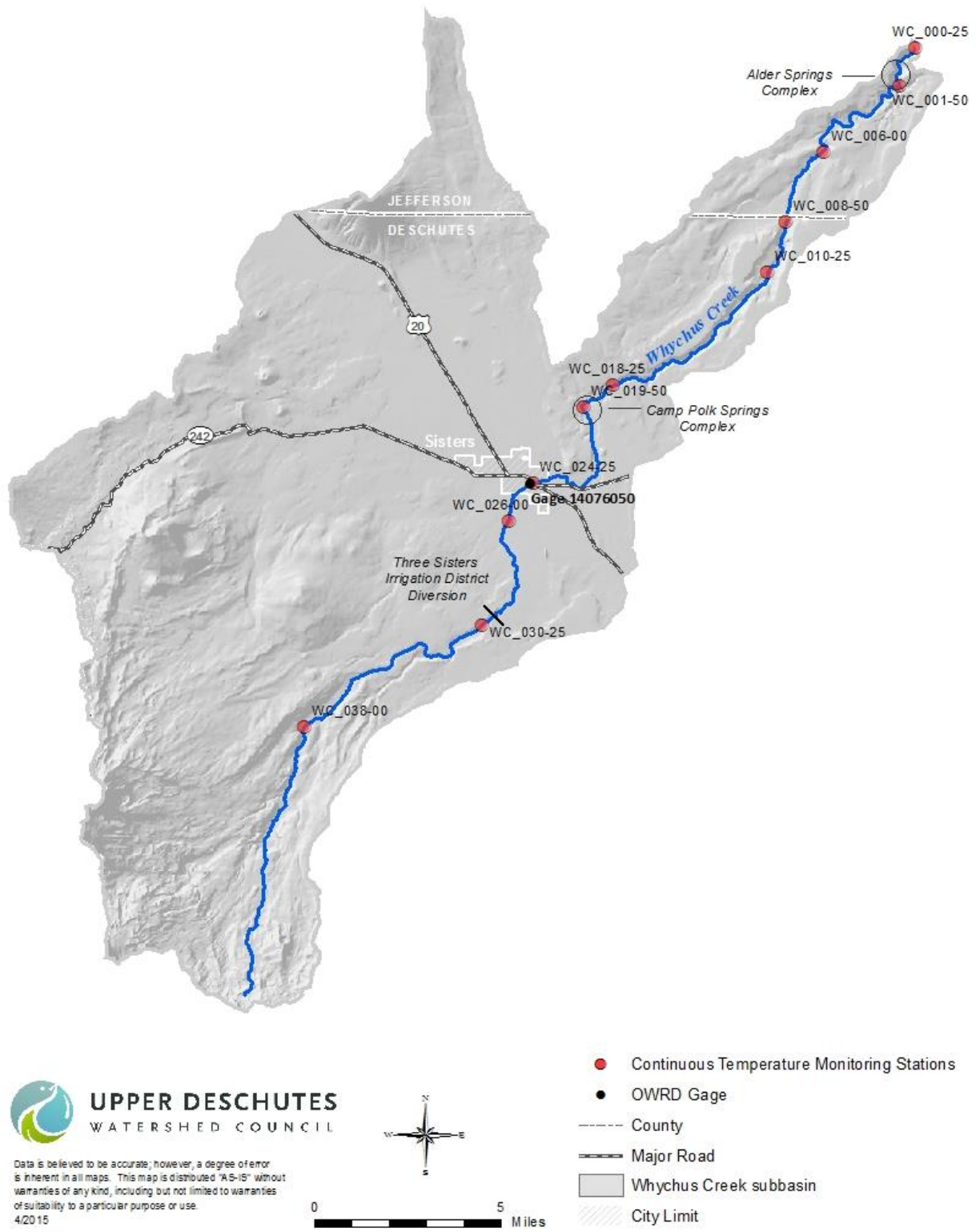


Figure 2. Continuous temperature monitoring stations monitored in 2019, and OWRD Gage 14076050 at Sisters City Park, on Whychus Creek.

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 2020). 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 006.00 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. Based on regressions of 2000-2015 September data (Mork 2016) resulting in poor fits between the models and the data as indicated by low R^2 values, we included two multiple regression models for September: regression of 7DADM stream temperature on the natural log of average daily flow and the three-day moving average maximum daily air temperature ($7DADM \sim \ln QD + 3DAir$), and regression of 7DADM stream temperature on the average daily flow and the three-day moving average maximum daily air temperature ($7DADM \sim QD + 3DAir$). The resulting equations represent the relationship between flow

and temperature and can be used to estimate stream temperature values for the specified locations, within the evaluated time period, and within the range of flows observed. We used the 2010-2019 September median maximum daily temperature in combination with selected flows to estimate stream temperature in September.

Table 2. Fourteen 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 + (Ln QD) ²
6.	7DADM ~ Ln QD + (Ln QD) ² + (Ln QD) ³
7.	7DADM ~ Air
8.	7DADM ~ Air + (Air) ²
9.	7DADM ~ Air + (Air) ² + (Air) ³
10.	7DADM ~ 3DAir
11.	7DADM ~ 3DAir + (3DAir) ²
12.	7DADM ~ 3DAir + (3DAir) ² + (3DAir) ³
13.	7DADM ~ LnQD + 3DAir (<i>September only</i>)
14.	7DADM ~ QD + 3DAir (<i>September only</i>)

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 (R²), 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, April, and September, we used R to calculate the predicted temperature and 95% prediction interval for all flows within the observed range (Appendix A). The 95% prediction interval (PI) is calculated as:

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

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

For July data, we compared the resulting 2000-2019 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 2000-2019 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 every site below the TSID diversion from river mile 1.5 (WC 001.50) to approximately river mile 26 (WC 026.00) in 2019 (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 as early as May 3, at seven sites between rm 0.25 and rm 19.50, in 2019.

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 50% of days (69 days) between May 6 and September 21 in 2019 (Figure 4), higher than in eight of the seventeen years for which data are available and lower than in the remaining eight years for which data are available (data for 2003, 2004, and 2008 are unavailable). Temperatures at this site met the applicable standard, providing suitable conditions for rearing trout, for 50% of days May 6 – September 21 (70 days) in 2019. Temperatures exceeded 24°C at WC 006.00 for 6% of days May 6 – September 21 (8 days) in 2019. Stream temperature exceeded 18°C between July 1 and September 7, 2019, at Sisters City Park average daily flows of 11 to 54 cfs.

Data were available for 21 days between April 1 and May 15 at WC 006.00 in 2019, from April 21 to May 15. Stream temperature at WC 006.00 exceeded 13°C for 52% (12) of these days, higher than in six of the fifteen years for which data are available (Table 3). 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 13 to 71 percent of data days from April 1 to May 15 since adult steelhead first returned to Whychus Creek in October 2011 flag a consistent temperature problem for spawning steelhead. Stream temperature exceeded 13°C between April 21 and May 15, 2019 at Sisters City Park flows of 63 to 97 cfs.

Stream temperature at WC 006.00 exceeded 13°C for 26 days in September 2019 (86%). Temperatures exceeded 13°C for 70-100% of September data days since September 2011, the first September when adult Chinook had been passed upstream of the Pelton Round Butte hydroelectric facility. September stream flow at Sisters City Park from 2011-2019 ranged from 9.6 to 65 cfs, with a median flow of 21 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 eleven years (2009 – 2019) July stream temperatures at WC 006.00 (Road 6360) have exceeded state standards less frequently than in early years of stream flow restoration (2000-2002, 2005, 2007) (Figure 5).

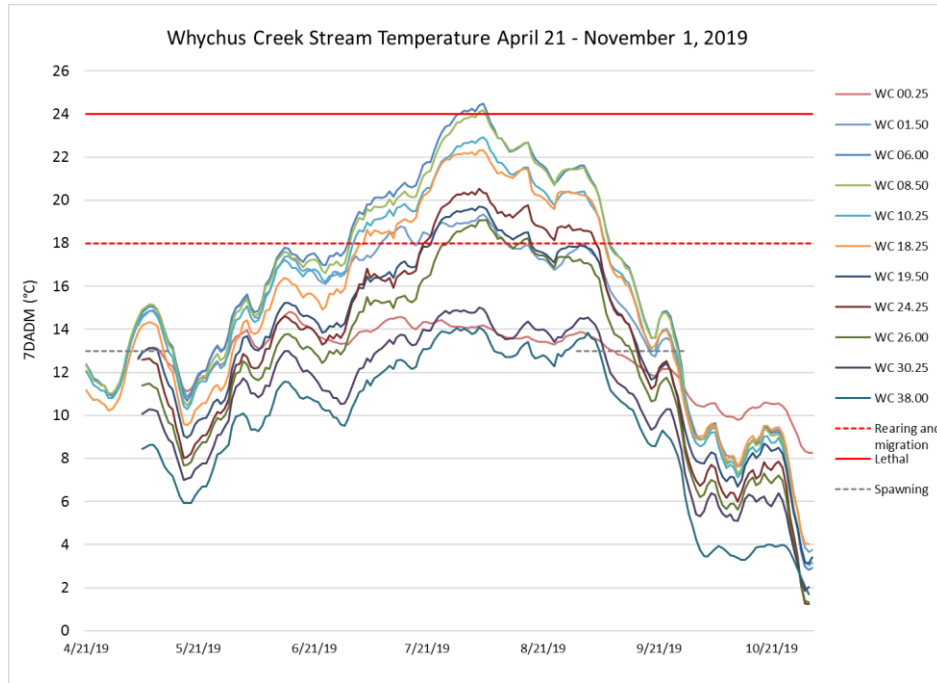


Figure 3. 2019 7DADM temperatures at eleven Whychus Creek monitoring sites. Stream temperature exceeded the 18°C rearing standard at eight sites in 2019, from rm 1.5 (WC 01.50) to rm 24.25 (WC 24.25), exceeded the 24°C lethal threshold at two sites between rm 6.0 (WC 06.00) and rm 8.5 (WC 08.50), and exceeded the January 1-May 15 13°C steelhead spawning standard at seven sites from rm 0.25 (WC 00.25) to rm 19.50 (WC 19.50).

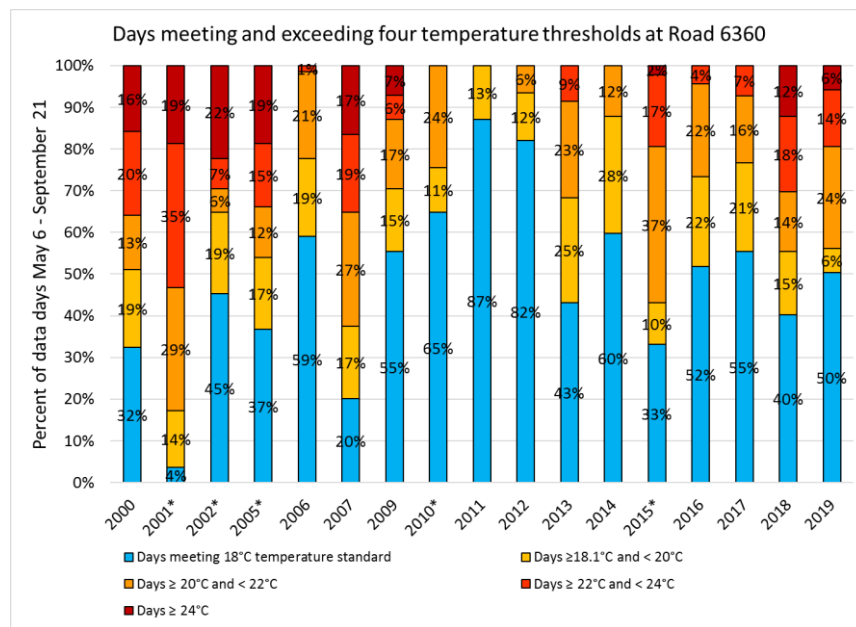
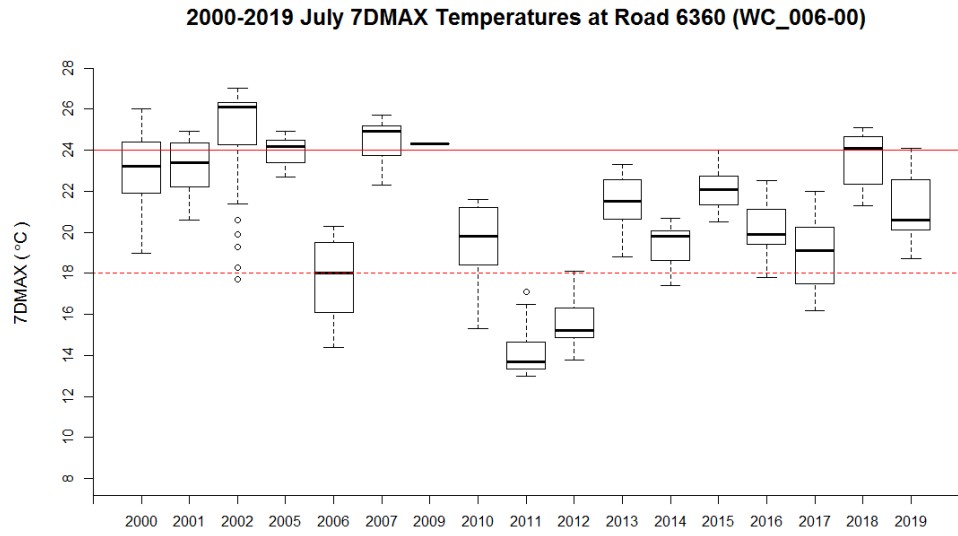


Figure 4. Percent of data days meeting and exceeding four critical temperature thresholds for rearing native trout and salmon at Road 6360 (WC_006-00). Seven-day average daily maximum (7DADM) stream temperatures exceeded the 18°C rearing and migration state standard for 50% of days between May 6 and September 21 in 2019 and exceeded the lethal 24°C threshold for 6% of days in 2019. Asterisks indicated Governor-declared drought years in Deschutes County (Figure 5b).

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	53%
2002	20	4/26	15	75%
2005	37	4/19	24	65%
2007	13	5/3	9	69%
2009	25	4/21	8	32%
2010	36	4/30	15	42%
2011	14	5/7	9	64%
2012	19	5/8	8	42%
2013	38	4/24	19	50%
2014	31	4/30	12	39%
2015	35	4/17	25	71%
2016	38	4/8	20	53%
2017	8	5/8	1	13%
2018	38	4/22	22	58%
2019	25	5/3	13	52%

a



b

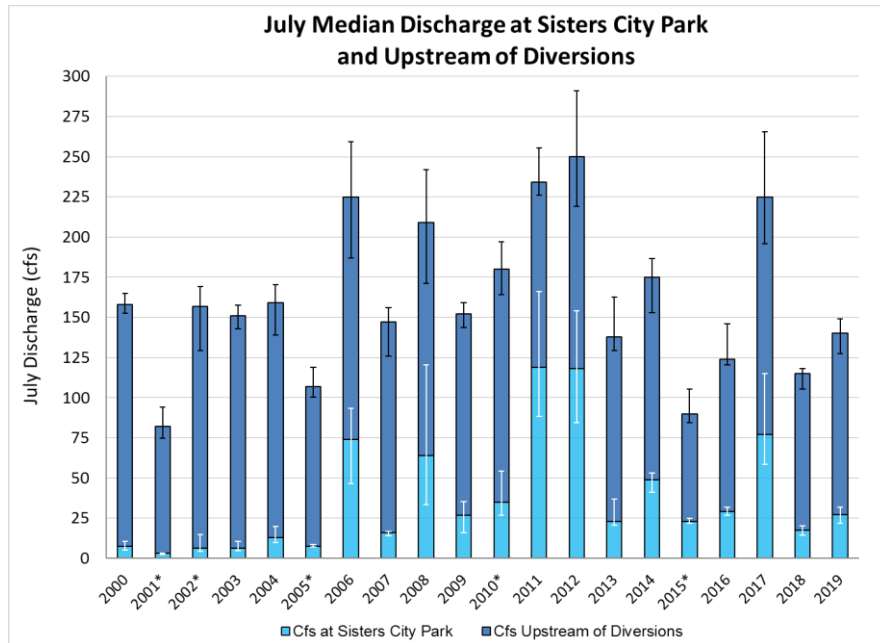


Figure 5. 2001-2019 July Median 7DADM Stream Temperature and Stream Flow

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; asterisks indicate Governor-declared drought years in Deschutes County. July stream temperature 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 2019 (Table 4), at Sisters City Park flows from 2 to 201 cfs. The cubic regression of 7DADM stream temperature on the natural log of average daily flow ($7DADM \sim \ln QD + (\ln QD)^2 + (\ln QD)^3$) performed best of the twelve regression models for both sites (Table 5). Using this model, stream flow explained 77% and 80% of the variation in stream temperature in July at WC 024.25 and at WC 006.00, respectively ($R^2 = 0.77$; $R^2 = 0.80$). Of the air temperature models 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 ($R^2 = 0.18$). Of the air temperature models 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 23 cfs was the minimum stream flow resulting in a mean 7DADM temperature at or below $18^\circ\text{C} (\pm 2.9^\circ\text{C})$ given temperatures observed from July 2000-2019 at Sisters City Park (Appendix A); allowing for the 2.9°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 33 cfs state instream water right predicts a mean 7DADM temperature of $16.8^\circ\text{C} \pm 2.9^\circ\text{C}$ 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 2000-2019 temperature estimate for Sisters City Park is substantially (1.8°C) higher than the 2008 Heat Source model estimate of $15^\circ\text{C} \pm 1^\circ\text{C}$ at 33 cfs at the OWRD gage at Sisters City Park (Watershed Sciences and MaxDepth Aquatics 2008).

The cubic regression of 2000-2019 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 $18.0^\circ\text{C} \pm 3.0^\circ\text{C}$. According to this model the state instream water right of 33 cfs below Indian Ford Creek is projected to produce a mean 7DADM temperature of $20.8^\circ\text{C} \pm 3.0^\circ\text{C}$ at Road 6360, exceeding the chronic sub-lethal temperature threshold of 20°C . The 2000-2019 cubic regression model estimate of $18.3^\circ\text{C} \pm 3.0^\circ\text{C}$ at 62 cfs is slightly lower than the Heat Source model estimate of $18.5^\circ\text{C} \pm 1^\circ\text{C}$ at 62 cfs at Road 6360.

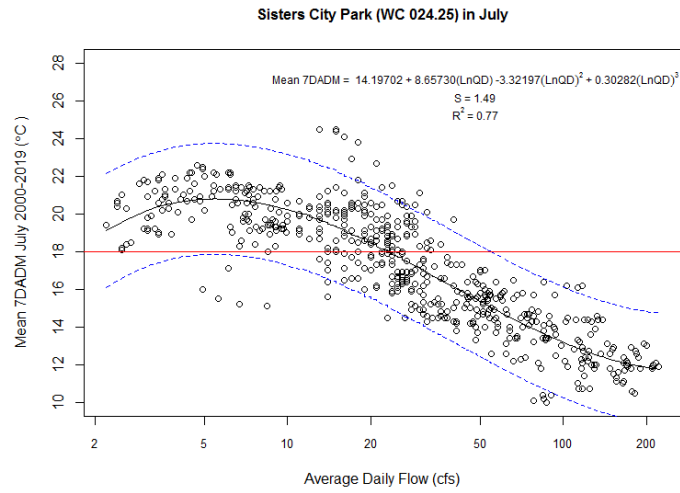
Steelhead and salmon spawning standard

Temperature records were available from WC 006.00 for April dates from 2001 through 2016 and from 2018 and 2019 corresponding to Sisters City Park flows from 2 to 128 cfs (Table 4); April data from 2017 are not available. The quadratic regression of 7DADM stream temperature on the natural log of average daily flow ($7DADM \sim \ln QD + (\ln QD)^2$) performed slightly better than the cubic and linear regressions ($7DADM \sim \ln QD + (\ln QD)^2 + (\ln QD)^3$; $7DADM \sim \ln QD$), explaining slightly more of the variation in stream temperature with a slightly higher R^2 value and a slightly lower standard error (Table 5). Stream flow explained only 39% of the variation in stream temperature in April ($R^2 = 0.385$). The quadratic regression of stream temperature on three-day moving average air temperature performed best of the six air temperature models, explaining 30% of the variation in stream temperature ($R^2 = 0.297$).

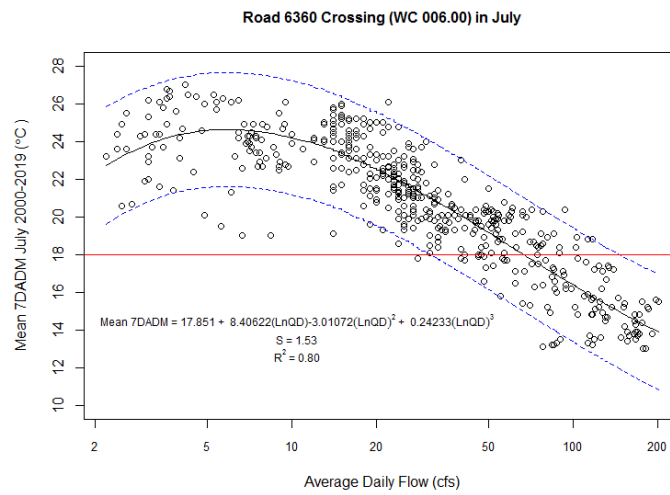
Table 5. A cubic regression model provided the best fit to July 2000-2019 temperature-flow data for both WC 024.25 and WC 006.00 data; the quadratic regression model provided the best fit to April 2000-2019 data for WC 006.00. A multiple regression model provided the best fit to September 2000-2019 air temperature, flow, and WC 006.00 stream temperature data. 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	14.19702	8.65730	-3.32197	0.30282	581	577	0.77	1.494	470
7DADM ~ QD + (QD) ² + (QD) ³	21.430	-0.1675	0.001054	-0.0000023	581	577	0.77	1.506	480
7DADM ~ QD + (QD) ²	20.9337631	-0.1256031	0.0004278	--	581	578	0.76	1.543	507
July - WC 006.00									
7DADM ~ LnQD + (LnQD)² + (LnQD)³	17.851	8.40622	-3.01072	0.24233	492	488	0.7967	1.53	423
7DADM ~ QD + (QD) ² + (QD) ³	25.17	-0.1511	0.0007531	-0.000001362	492	488	0.7876	1.564	444
7DADM ~ QD + (QD) ²	24.91	-0.1292	0.000404	--	492	489	0.7859	1.57	447
April - WC 006.00									
7DADM ~ LnQD + (LnQD)²	19.9576	-3.1122	0.2373	--	192	189	0.385	1.627	190
7DADM ~ LnQD	17.615	-1.568	--	--	192	190	0.377	1.637	191
7DADM ~ QD + (QD) ² + (QD) ³	20.155816	-3.345	0.319127	-0.008886	192	188	0.382	1.631	192
September - WC 006.00									
7DADM ~ LnQD + 3DAir	12.74236	-1.21198	0.26550	--	421	418	0.511	1.635	417
7DADM ~ QD + 3DAir	9.997962	-0.024561	0.262258	--	421	418	0.429	1.767	482
7DADM ~ 3DAir + (3DAir) ²	7.060806	0.464519	-0.003971	--	421	418	0.376	1.846	519

a



b



c

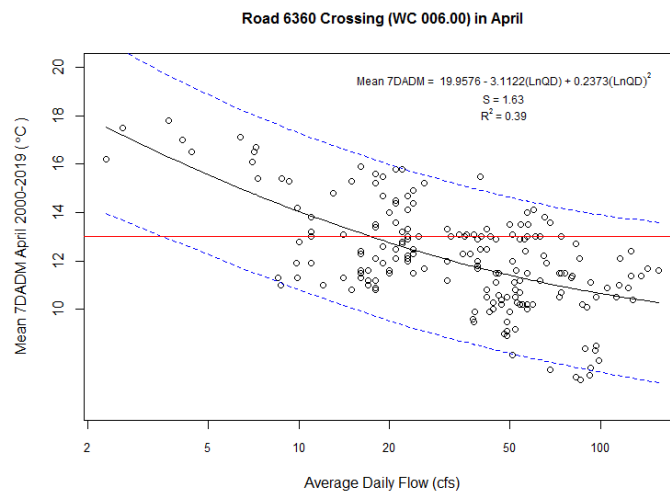


Figure 8. Temperature-Flow Regression Models

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 2000-2019 at WC 024.25, b) during July 2000-2019 at WC 006.00, and c) during April 2001-2019 at WC 006.00.

Discussion

Temperature status and trend

7DADM stream temperature exceeded the state standard for trout rearing and migration in 2019, supporting the ODEQ 2012 303(d) Category 5 listing of Whychus Creek as water quality limited for temperature (ODEQ 2020). Stream temperatures exceeding the 18°C standard at every monitoring station downstream of the TSID diversion, from rm 1.5 (WC 001.50) to Road 4606 (WC 026.00) over a prolonged duration suggest temperature conditions compromised habitat suitability for rearing and migrating trout and salmon in Whychus Creek in 2019. Seven day average daily maximum temperatures above 13°C for 52% of data days April 1-May 15 at WC 006.00, 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 temperatures exceeded the 24°C lethal threshold for eight days in 2019. Stream temperatures at Road 6360 (WC 006.00) meeting the state standard for only 50% of days in 2019, and remaining below the 20°C chronic sub-lethal threshold for only 56% of days, demonstrate an ongoing need for stream flow restoration solutions that reduce summer stream temperatures in the lower reaches of Whychus Creek. Simultaneously, stream temperatures meeting the state standard for more days in 2019 than in eight years (from 2000 to 2002, in 2005, 2007, 2009, 2013, 2015, and 2018) at this site show sustained improvement over early years of stream flow restoration (data from WC 006.00 are not available for 2003 and 2004).

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) 2000-2019 temperature and flow data indicate a minimum flow of 66 cfs is necessary to achieve stream temperatures of 18°C ± 3.0°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 ± 3.0°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, 23.8°C, just misses the lethal temperature threshold of 24°C. The mean 2000-2019 July median stream flow in Whychus Creek measured at OWRD gauge 14075000, upstream of all irrigation diversions, was 155 cfs, suggesting that in many years flow available above irrigation diversions is well above the 66 cfs needed to meet 18°C on average at Road 6360.

Regression of April stream temperature and flow data suggests the 33 cfs DRC stream flow restoration target will result in stream temperatures between 8.8 and 15.2°C at WC 006.00, encompassing and exceeding the 13°C spawning threshold (predicted mean 7DADM = 12.0°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 30% 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 17 cfs is predicted to result in a mean 7DADM $13^{\circ}\text{C} \pm 3.2$ stream temperature, observed 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 12.1°C and 18.5°C (predicted mean 7DADM = $15.3^{\circ}\text{C} \pm 3.2^{\circ}\text{C}$) at the September median maximum daily air temperature of 25.6°C (78.1°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. Although only a few September flow records correspond with 7DADM temperatures less than 13°C , the lowest of these is 46 cfs, suggesting this may be the minimum flow needed to meet 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 52 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 38 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 ten years (2010-2019) 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, steelhead and salmon 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; a maximum stream temperatures of 21°C is predicted to occur at Road 6360 at 66 cfs in July, emphasizing the imperative need for 60 cfs as a minimum flow during July to reduce stream temperatures below the 20 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.

References

Carlson, K. M., L. M. Curran, A. G. Ponette-González, D. Ratnasari, Ruspita, N. Lisnawati, Y. Purwanto, K. A. Brauman, and P. A. Raymond (2015) Influence of watershed-climate interactions on stream temperature, sediment yield, and metabolism along a land use intensity gradient in Indonesian Borneo, *J. Geophys. Res. Biogeosci.*, 119, doi: 10.1002/2013JG002516.

Jones L. 2010. Whychus Creek water quality status, temperature trends, and stream flow restoration targets p. 18-55 in Golden B, Houston R, Editors. 2009 Whychus Creek Monitoring Report. Upper Deschutes Watershed Council, Bend, Oregon. 134 p.

Helsel DR and Hirsch RM. 2002. Hydrologic Analysis and Interpretation, Chapter A3 *in* Statistical Methods in Water Resources, Techniques of Water Resources Investigations of the United States Geological Survey, Book 4. United States Geological Survey. <http://water.usgs.gov/pubs/twri/twri4a3/>

Mohseni O, Stefan HG (1999) Stream temperature/air temperature relationship: a physical interpretation. *J Hydrol* 218:128–141

Mohseni O, Stefan HG, Eaton JG (2003) Global warming and potential changes in fish habitat in U.S. streams. *Clim Change* 59:389–409

Mork L 2016. "Whychus Creek Water Quality Status, Temperature Trends, and Stream Flow Restoration Targets." Pages 22-47 in Mork L., Houston R, Editors. 2016. 2015 Whychus Creek Monitoring Report. Upper Deschutes Watershed Council. Bend, Oregon. 144 p.

Morrill JC, Bales RC, Conklin MH. 2005. Estimating stream temperature from air temperature: implications for future water quality. *J Env Engineering*. Jan; 131(1):139-46.

Myrick CA, Cech JJ. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum. Technical Publication 01-1. 57 p.

Nielsen JL, Lisle TE, Ozaki V. 1994. Thermally stratified pools and their use by steelhead in Northern California streams. *Transactions of the American Fisheries Society*, 123:613-626

ODEQ (Oregon Department of Environmental Quality). 1995. State of Oregon 1992-1994 Water Quality Standards Review. Oregon Department of Environmental Quality. Portland, Oregon.

ODEQ (Oregon Department of Environmental Quality). 2009. Water Quality Standards: Beneficial Uses, Policies, and Criteria for Oregon. Oregon Administrative Rules, Chapter 340, Division 041. Oregon Department of Environmental Quality. Portland, Oregon.

ODEQ (Oregon Department of Environmental Quality). 2020. Oregon's 2018/2020 integrated report. Oregon Department of Environmental Quality. Portland, Oregon.
<https://www.oregon.gov/deq/wq/Pages/2018-Integrated-Report.aspx> Accessed online August 26, 2020.

OWRD (Oregon Water Resources Department). 2020. Near real time hydrographic data.
http://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/display_hydro_graph.aspx?station_nbr=14076050. Accessed online May 26, 2020.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
Runge JP, Peterson JT, Martin CR. 2008. Survival and dispersal of hatchery-raised rainbow trout in a river basin undergoing urbanization. *N Am J Fish Manage* 28:745-757.

Spatheholts B. PGE Fisheries Biologist. Personal communication, February 15, 2015.

Thompson K. 1972. Determining stream flows for fish life. Presentation at Pacific Northwest River Basins Commission Stream Flow Workshop. March 15-16, 1972.

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

UDWC (Upper Deschutes Watershed Council). 2008b. Water Quality Monitoring Program Standard Operating Procedures - Field. Upper Deschutes Watershed Council. Bend, Oregon.

UDWC (Upper Deschutes Watershed Council). 2016a. Whychus Creek and Middle Deschutes River Temperature Assessments. Technical memo to the Upper Deschutes Basin Study Work Group. Upper Deschutes Watershed Council. Bend, Oregon. 9 p.

US EPA (U.S Environmental Protection Agency). 1999. A review and synthesis of effects of alteration to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Region 10, Seattle, WA. EPA 910-R-99-010. 279 p. Available online at:
<http://www.critfc.org/tech/EPA/report.htm>

US EPA (U.S. Environmental Protection Agency) 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Water Quality Standards. Region 10, Seattle, WA. EPA 910-B-03-002. 49 p. Available online at: <http://www.epa.gov/r10earth/temperature.htm>

Watershed Sciences and MaxDepth Aquatics. 2008. Whychus Creek Stream Temperature Modeling: Various Flow Scenarios. *Addendum to* Deschutes River, Whychus Creek and Tumalo Creek Temperature Modeling. Deschutes River Conservancy. Bend, Oregon.

Webb BW, Clack PD, Walling DE (2003) Water-air temperature relationships in a Devon river system and the role of flow. *Hydrol Proc* 17:3069–3084

Webb BW, Zhang Y (1997) Spatial and seasonal variability in the components of the river heat budget. *Hydrol Proc* 11:79–101

WRCC (2020) RAWS USA climate archive. <http://www.raws.dri.edu/index.html> . Accessed online May 19, 2020.

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	18.7	3.0	57	14.9	2.9	112	12.9	2.9	167	12.1	3.0
3	20.1	3.0	58	14.9	2.9	113	12.9	2.9	168	12.1	3.0
4	20.6	2.9	59	14.8	2.9	114	12.9	2.9	169	12.1	3.0
5	20.8	2.9	60	14.7	2.9	115	12.8	2.9	170	12.1	3.0
6	20.8	2.9	61	14.7	2.9	116	12.8	2.9	171	12.0	3.0
7	20.7	2.9	62	14.6	2.9	117	12.8	2.9	172	12.0	3.0
8	20.6	2.9	63	14.6	2.9	118	12.8	2.9	173	12.0	3.0
9	20.4	2.9	64	14.5	2.9	119	12.8	2.9	174	12.0	3.0
10	20.2	2.9	65	14.5	2.9	120	12.7	2.9	175	12.0	3.0
11	20.0	2.9	66	14.4	2.9	121	12.7	2.9	176	12.0	3.0
12	19.8	2.9	67	14.4	2.9	122	12.7	2.9	177	12.0	3.0
13	19.7	2.9	68	14.3	2.9	123	12.7	2.9	178	12.0	3.0
14	19.5	2.9	69	14.3	2.9	124	12.7	2.9	179	12.0	3.0
15	19.3	2.9	70	14.2	2.9	125	12.6	2.9	180	12.0	3.0
16	19.1	2.9	71	14.2	2.9	126	12.6	2.9	181	12.0	3.0
17	18.9	2.9	72	14.1	2.9	127	12.6	2.9	182	12.0	3.0
18	18.8	2.9	73	14.1	2.9	128	12.6	2.9	183	12.0	3.0
19	18.6	2.9	74	14.1	2.9	129	12.6	2.9	184	11.9	3.0
20	18.5	2.9	75	14.0	2.9	130	12.6	2.9	185	11.9	3.0
21	18.3	2.9	76	14.0	2.9	131	12.5	2.9	186	11.9	3.0
22	18.2	2.9	77	13.9	2.9	132	12.5	2.9	187	11.9	3.0
23	18.0	2.9	78	13.9	2.9	133	12.5	2.9	188	11.9	3.0
24	17.9	2.9	79	13.9	2.9	134	12.5	2.9	189	11.9	3.0
25	17.7	2.9	80	13.8	2.9	135	12.5	2.9	190	11.9	3.0
26	17.6	2.9	81	13.8	2.9	136	12.5	2.9	191	11.9	3.0
27	17.5	2.9	82	13.8	2.9	137	12.4	2.9	192	11.9	3.0
28	17.4	2.9	83	13.7	2.9	138	12.4	2.9	193	11.9	3.0
29	17.2	2.9	84	13.7	2.9	139	12.4	2.9	194	11.9	3.0
30	17.1	2.9	85	13.6	2.9	140	12.4	2.9	195	11.9	3.0
31	17.0	2.9	86	13.6	2.9	141	12.4	2.9	196	11.9	3.0
32	16.9	2.9	87	13.6	2.9	142	12.4	2.9	197	11.9	3.0
33	16.8	2.9	88	13.5	2.9	143	12.4	2.9	198	11.9	3.0
34	16.7	2.9	89	13.5	2.9	144	12.3	3.0	199	11.9	3.0
35	16.6	2.9	90	13.5	2.9	145	12.3	3.0	200	11.9	3.0
36	16.5	2.9	91	13.4	2.9	146	12.3	3.0			
37	16.4	2.9	92	13.4	2.9	147	12.3	3.0			
38	16.3	2.9	93	13.4	2.9	148	12.3	3.0			
39	16.2	2.9	94	13.4	2.9	149	12.3	3.0			
40	16.1	2.9	95	13.3	2.9	150	12.3	3.0			
41	16.0	2.9	96	13.3	2.9	151	12.3	3.0			
42	16.0	2.9	97	13.3	2.9	152	12.2	3.0			
43	15.9	2.9	98	13.2	2.9	153	12.2	3.0			
44	15.8	2.9	99	13.2	2.9	154	12.2	3.0			
45	15.7	2.9	100	13.2	2.9	155	12.2	3.0			
46	15.6	2.9	101	13.2	2.9	156	12.2	3.0			
47	15.6	2.9	102	13.1	2.9	157	12.2	3.0			
48	15.5	2.9	103	13.1	2.9	158	12.2	3.0			
49	15.4	2.9	104	13.1	2.9	159	12.2	3.0			
50	15.4	2.9	105	13.1	2.9	160	12.2	3.0			
51	15.3	2.9	106	13.0	2.9	161	12.1	3.0			
52	15.2	2.9	107	13.0	2.9	162	12.1	3.0			
53	15.2	2.9	108	13.0	2.9	163	12.1	3.0			
54	15.1	2.9	109	13.0	2.9	164	12.1	3.0			
55	15.0	2.9	110	12.9	2.9	165	12.1	3.0			
56	15.0	2.9	111	12.9	2.9	166	12.1	3.0			

Whychus Creek at Road 6360 (WC 006.00) 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	22.3	3.1	57	18.6	3.0	112	15.9	3.0	167	14.5	3.0
3	23.8	3.0	58	18.6	3.0	113	15.9	3.0	168	14.5	3.0
4	24.4	3.0	59	18.5	3.0	114	15.9	3.0	169	14.5	3.0
5	24.6	3.0	60	18.4	3.0	115	15.8	3.0	170	14.4	3.0
6	24.6	3.0	61	18.4	3.0	116	15.8	3.0	171	14.4	3.0
7	24.6	3.0	62	18.3	3.0	117	15.8	3.0	172	14.4	3.0
8	24.5	3.0	63	18.2	3.0	118	15.7	3.0	173	14.4	3.0
9	24.4	3.0	64	18.2	3.0	119	15.7	3.0	174	14.4	3.0
10	24.2	3.0	65	18.1	3.0	120	15.7	3.0	175	14.3	3.0
11	24.0	3.0	66	18.0	3.0	121	15.6	3.0	176	14.3	3.0
12	23.9	3.0	67	18.0	3.0	122	15.6	3.0	177	14.3	3.0
13	23.7	3.0	68	17.9	3.0	123	15.6	3.0	178	14.3	3.1
14	23.5	3.0	69	17.9	3.0	124	15.6	3.0	179	14.3	3.1
15	23.3	3.0	70	17.8	3.0	125	15.5	3.0	180	14.3	3.1
16	23.2	3.0	71	17.7	3.0	126	15.5	3.0	181	14.2	3.1
17	23.0	3.0	72	17.7	3.0	127	15.5	3.0	182	14.2	3.1
18	22.8	3.0	73	17.6	3.0	128	15.4	3.0	183	14.2	3.1
19	22.7	3.0	74	17.6	3.0	129	15.4	3.0	184	14.2	3.1
20	22.5	3.0	75	17.5	3.0	130	15.4	3.0	185	14.2	3.1
21	22.4	3.0	76	17.5	3.0	131	15.4	3.0	186	14.1	3.1
22	22.2	3.0	77	17.4	3.0	132	15.3	3.0	187	14.1	3.1
23	22.1	3.0	78	17.4	3.0	133	15.3	3.0	188	14.1	3.1
24	21.9	3.0	79	17.3	3.0	134	15.3	3.0	189	14.1	3.1
25	21.8	3.0	80	17.3	3.0	135	15.2	3.0	190	14.1	3.1
26	21.7	3.0	81	17.2	3.0	136	15.2	3.0	191	14.1	3.1
27	21.5	3.0	82	17.2	3.0	137	15.2	3.0	192	14.0	3.1
28	21.4	3.0	83	17.1	3.0	138	15.2	3.0	193	14.0	3.1
29	21.3	3.0	84	17.1	3.0	139	15.1	3.0	194	14.0	3.1
30	21.1	3.0	85	17.0	3.0	140	15.1	3.0	195	14.0	3.1
31	21.0	3.0	86	17.0	3.0	141	15.1	3.0	196	14.0	3.1
32	20.9	3.0	87	16.9	3.0	142	15.1	3.0	197	14.0	3.1
33	20.8	3.0	88	16.9	3.0	143	15.0	3.0	198	13.9	3.1
34	20.7	3.0	89	16.8	3.0	144	15.0	3.0	199	13.9	3.1
35	20.6	3.0	90	16.8	3.0	145	15.0	3.0	200	13.9	3.1
36	20.5	3.0	91	16.8	3.0	146	15.0	3.0			
37	20.4	3.0	92	16.7	3.0	147	14.9	3.0			
38	20.3	3.0	93	16.7	3.0	148	14.9	3.0			
39	20.2	3.0	94	16.6	3.0	149	14.9	3.0			
40	20.1	3.0	95	16.6	3.0	150	14.9	3.0			
41	20.0	3.0	96	16.5	3.0	151	14.8	3.0			
42	19.9	3.0	97	16.5	3.0	152	14.8	3.0			
43	19.8	3.0	98	16.5	3.0	153	14.8	3.0			
44	19.7	3.0	99	16.4	3.0	154	14.8	3.0			
45	19.6	3.0	100	16.4	3.0	155	14.8	3.0			
46	19.5	3.0	101	16.3	3.0	156	14.7	3.0			
47	19.4	3.0	102	16.3	3.0	157	14.7	3.0			
48	19.3	3.0	103	16.3	3.0	158	14.7	3.0			
49	19.3	3.0	104	16.2	3.0	159	14.7	3.0			
50	19.2	3.0	105	16.2	3.0	160	14.6	3.0			
51	19.1	3.0	106	16.2	3.0	161	14.6	3.0			
52	19.0	3.0	107	16.1	3.0	162	14.6	3.0			
53	18.9	3.0	108	16.1	3.0	163	14.6	3.0			
54	18.9	3.0	109	16.0	3.0	164	14.6	3.0			
55	18.8	3.0	110	16.0	3.0	165	14.5	3.0			
56	18.7	3.0	111	16.0	3.0	166	14.5	3.0			

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	17.9	3.6	57	11.3	3.2	112	10.6	3.3
3	16.8	3.4	58	11.2	3.2	113	10.5	3.3
4	16.1	3.3	59	11.2	3.2	114	10.5	3.3
5	15.6	3.3	60	11.2	3.2	115	10.5	3.3
6	15.1	3.3	61	11.2	3.2	116	10.5	3.3
7	14.8	3.3	62	11.2	3.2	117	10.5	3.3
8	14.5	3.2	63	11.1	3.2	118	10.5	3.3
9	14.3	3.2	64	11.1	3.2	119	10.5	3.3
10	14.0	3.2	65	11.1	3.2	120	10.5	3.3
11	13.9	3.2	66	11.1	3.2	121	10.5	3.3
12	13.7	3.2	67	11.1	3.2	122	10.5	3.3
13	13.5	3.2	68	11.1	3.2	123	10.5	3.3
14	13.4	3.2	69	11.0	3.2	124	10.5	3.3
15	13.3	3.2	70	11.0	3.2	125	10.5	3.3
16	13.2	3.2	71	11.0	3.2	126	10.5	3.3
17	13.0	3.2	72	11.0	3.2	127	10.5	3.3
18	12.9	3.2	73	11.0	3.2	128	10.4	3.3
19	12.9	3.2	74	11.0	3.2	129		
20	12.8	3.2	75	10.9	3.2	130		
21	12.7	3.2	76	10.9	3.2	131		
22	12.6	3.2	77	10.9	3.2	132		
23	12.5	3.2	78	10.9	3.2	133		
24	12.5	3.2	79	10.9	3.2	134		
25	12.4	3.2	80	10.9	3.2	135		
26	12.3	3.2	81	10.9	3.2	136		
27	12.3	3.2	82	10.9	3.2	137		
28	12.2	3.2	83	10.8	3.2	138		
29	12.2	3.2	84	10.8	3.2	139		
30	12.1	3.2	85	10.8	3.2	140		
31	12.1	3.2	86	10.8	3.2	141		
32	12.0	3.2	87	10.8	3.2	142		
33	12.0	3.2	88	10.8	3.2	143		
34	11.9	3.2	89	10.8	3.2	144		
35	11.9	3.2	90	10.8	3.2	145		
36	11.9	3.2	91	10.7	3.2	146		
37	11.8	3.2	92	10.7	3.2	147		
38	11.8	3.2	93	10.7	3.2	148		
39	11.7	3.2	94	10.7	3.2	149		
40	11.7	3.2	95	10.7	3.2	150		
41	11.7	3.2	96	10.7	3.2	151		
42	11.6	3.2	97	10.7	3.2	152		
43	11.6	3.2	98	10.7	3.2	153		
44	11.6	3.2	99	10.7	3.2	154		
45	11.5	3.2	100	10.7	3.2	155		
46	11.5	3.2	101	10.6	3.2	156		
47	11.5	3.2	102	10.6	3.2	157		
48	11.5	3.2	103	10.6	3.2	158		
49	11.4	3.2	104	10.6	3.2	159		
50	11.4	3.2	105	10.6	3.3	160		
51	11.4	3.2	106	10.6	3.3	161		
52	11.4	3.2	107	10.6	3.3	162		
53	11.3	3.2	108	10.6	3.3	163		
54	11.3	3.2	109	10.6	3.3	164		
55	11.3	3.2	110	10.6	3.3	165		
56	11.3	3.2	111	10.6	3.3	166		