Upper Deschutes and Little Deschutes Subbasins TMDLs

Context for Reviewing Watershed Sciences Temperature Modeling Reports

The Oregon Department of Environmental Quality (DEQ) contracted with Watershed Sciences, Inc. to conduct some of the preliminary temperature modeling analyses in the Upper Deschutes, Little Deschutes and Crooked River Subbasins. This work was done under two different contracts (2007-2008 and 2008-2011) and was designed to support TMDL development by DEQ at a later date. This work was funded by the U.S. Environmental Protection Agency.

Heat Source is the computer model DEQ uses to simulate stream thermodynamics and hydrology. Under the first contract, Watershed Sciences calibrated Heat Source temperature models for Tumalo Creek, Whychus Creek, and Deschutes River between Wickiup Reservoir and Lake Billy Chinook. Under the second contract, Watershed Sciences did additional modeling on Metolius River, Little Deschutes River, Crescent Creek, Deschutes River above Wickiup Reservoir and a number of streams in the Crooked River Subbasins. Under these contracts, Watershed Sciences wrote a series of reports providing background material on the data used in the Heat Source models and on model calibration.

DEQ began work on TMDL development in the Upper Deschutes and Little Deschutes Subbasins in 2011, with the expectation of completing these TMDLs by the end of 2012. During TMDL development, it is possible that some of the calibration and modeling results presented in the Watershed Sciences reports may be modified. The existing models may be revised to incorporate more site-specific input gathered from local stakeholders during the advisory committee process and/or public review. DEQ is not working on TMDLs in the Crooked River subbasins at this time so the information provided in the Watershed Sciences reports for the streams in this area are very preliminary in nature at this time.

The attached report describes the modeling done under the first contract. Until completion of TMDLs, this document provides useful information about data used in the models, preliminary calibration of the Heat Source models, and preliminary flow scenario simulation results. See pages 1-3 of this report for additional information on the scope and limitations of this modeling effort.

DEQ

State of Oregon
Department of Environmental Quality

Water Quality
Eastern Region
Bend Office
475 NE Bellevue, Suite 110
Bend, OR 97701
Phone: (541) 388-6146
(866) 863-6668
Fax: (541) 388-8283
Contact: Bonnie Lamb

www.oregon.gov/DEQ

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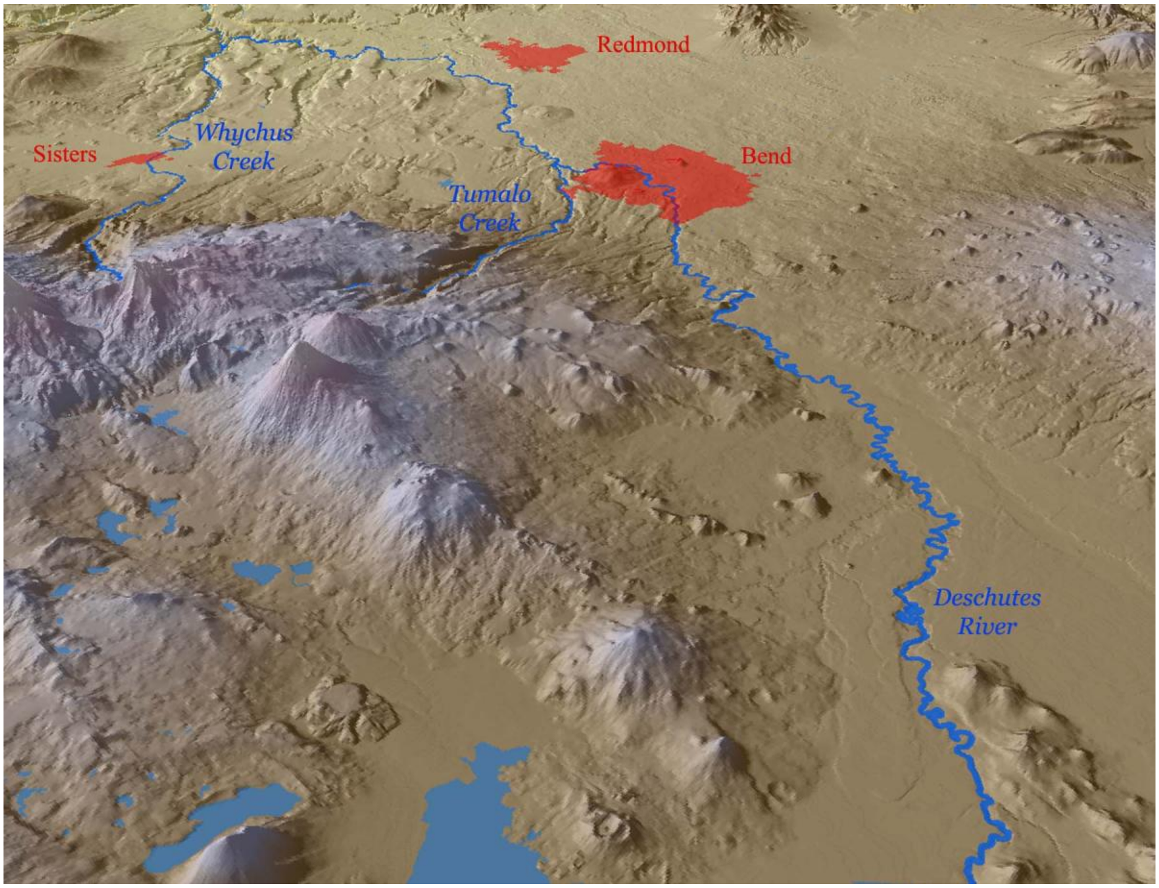
By: Bonnie lamb

Deschutes River, Whychus Creek, and Tumalo Creek Temperature Modeling



Prepared for,

State of Oregon
Department of Environmental Quality

Prepared by,

Watershed Sciences
Applied Remote Sensing & Analysis

with

MaxDepth Aquatics, Inc.

Bend, Oregon

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Overview and Scope

Tumalo Creek, Whychus Creek, and the upper Deschutes River currently exceed Oregon State water quality standards for temperature during critical summertime periods. The standards are set to protect fish and aquatic life. During the summer, the numeric standard that applies along most of these three streams to protect salmonid rearing and migration is 64.4°F (18.0°C). Tumalo Creek has the least severe exceedances, reaching nearly 68°F near the mouth. Whychus Creek and the upper Deschutes River between Bend and Lake Billy Chinook often approach 80°F during late July and early August. Such extreme temperatures can be lethal to aquatic life.

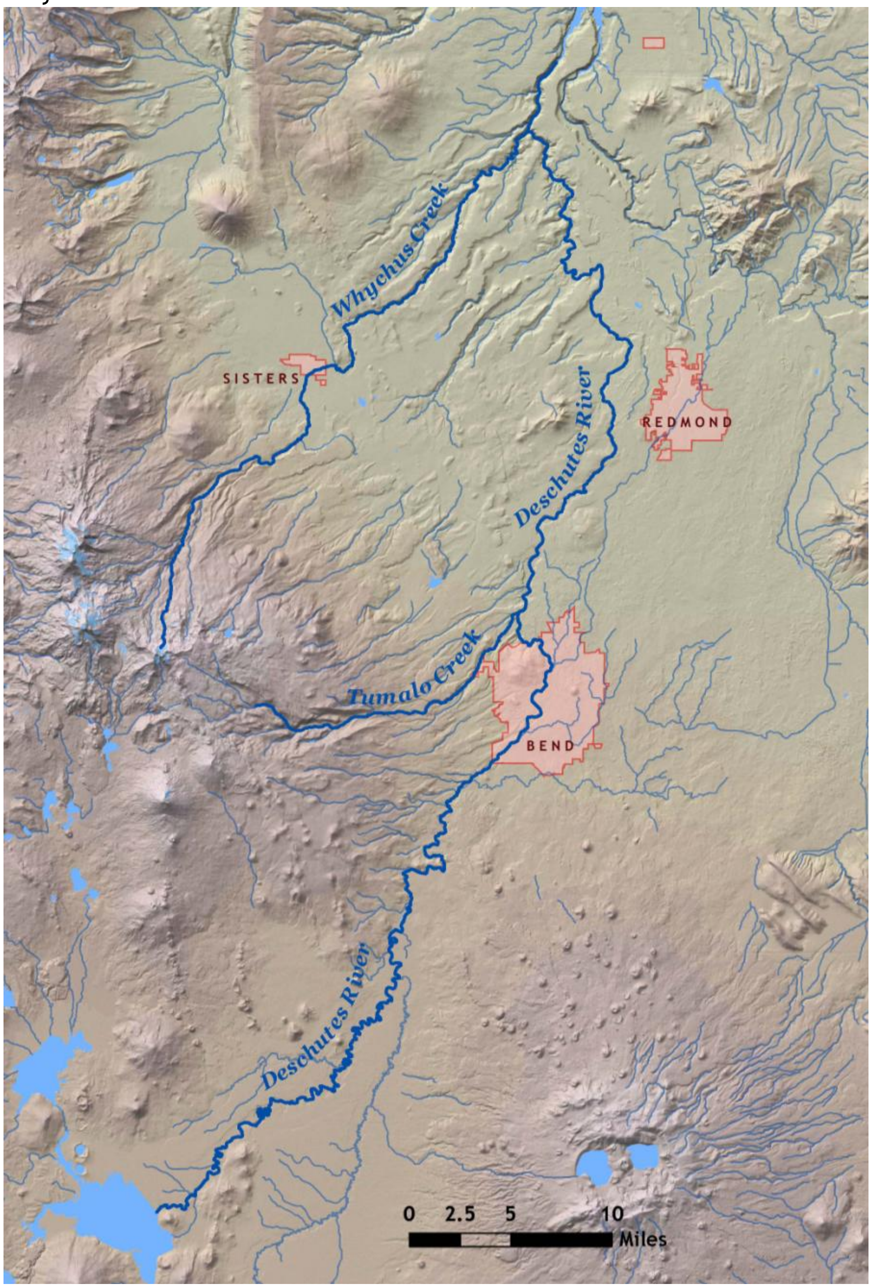
The federal Clean Water Act requires the establishment of a total maximum daily load (TMDL) for pollutants when water quality standards are not met. A TMDL determines how much pollutant a waterbody may receive without exceeding water quality standards. The TMDL identifies where the pollution comes from and divides or allocates the pollutant load among difference sources. The Oregon Department of Environmental Quality (DEQ) needs to develop TMDLs for temperature for a number of streams in the Deschutes Basin, including the Deschutes River, Tumalo Creek and Whychus Creek.

Stream temperatures are influenced by stream-side vegetation, hydrology (flow), climate, geographic location and many other factors. While factors such as climate and geographic location are outside of human control, near-stream vegetation disturbance/removal and reduction of summertime stream flows are human-induced changes that can cause streams to heat up. The loss of riparian vegetation reduces stream shading, thus allowing more solar energy to reach the water's surface. Reduction of summertime flows decreases the thermal assimilative capacity of streams, causing larger temperature increases in stream segments where flows are reduced. In TMDL modeling, DEQ typically will assess the thermal effects of both stream-side vegetation and flow on stream temperatures.

To get started on TMDL development in the Upper Deschutes Subbasin, the DEQ began by modeling stream temperatures in the upper Deschutes River, Tumalo Creek, and Whychus Creek (Figure 1). The DEQ contracted with MaxDepth Aquatics, Inc. and Watershed Sciences, Inc. to simulate stream temperatures under several different flow scenarios. This work was prioritized in order to help provide water quality information for the on-going flow restoration efforts in the Upper Deschutes Subbasin. DEQ will model the affects of improving stream-side vegetation at some point in the future and use this information to complete the TMDL modeling at a later date.

ODEQ and other stakeholders have collected a significant amount of ground level and remotely sensed data. Models for each of the three streams were calibrated using data collected in 2000 for Whychus Creek and 2001 for the Deschutes River and Tumalo Creek. This report summarizes the existing data (Section One), describes the temperature model calibrations (Section Two), and presents the results of different stream flow simulations (Section Three).

Figure 1 – Study area and streams of interest.



Model Limitations

The temperature modeling effort undertaken in the Upper Deschutes provides some very interesting and meaningful results. However, it is worth identifying up-front some of the specific limitations of the models and the appropriate scale in which to interpret the results. Stream temperature dynamics are complex and analytical methods have limitations.

- Heat Source simulations are only valid for the simulation time period (which corresponds to the time period that ground level data was collected). Watershed Sciences calibrated the Heat Source model based on conditions in summer 2000 and summer 2001. It would not be appropriate to use these models to simulate stream temperature in another year without re-calibrating the model with input data from that other year.

  Simulating other seasons or years introduces un-measurable uncertainty via a combination of climate, flow, and boundary condition assumptions. In addition, the existing flows in portions of Tumalo Creek and Whychus Creek were quite small (i.e. less than 10 cfs). Small flows equate to temperatures that are extra sensitive to climate and effective shade. Certain features such as vegetation growth or changes in flow can be simulated for the same time period, assuming that all other calibration inputs remain unchanged.

- Heat Source is not a groundwater model. The model has simulation inputs for groundwater and hyporheic exchange and attempts to include them in the heat flux, but Heat Source does not model far-field groundwater processes. Complex and wide-scale water table processes are not accounted for.

  Heat Source only includes groundwater contributions to surface water that were measured during the simulation time period. Alder Springs was the only spring where flows were measured during field data collection. Other springs were identified in the thermal infrared imagery and a flow mass balance was derived for those areas. The models developed for the Deschutes River, Whychus Creek and Tumalo Creek contain estimated flows and temperatures of springs that were observed in the TIR data. The uncertainty associated with such inputs is not directly quantifiable and therefore should not be used for simulating different spring flow scenarios.

- Heat Source results are only as good as the field data. Measured temperatures, flows, velocities, widths, effective shade, substrate, and other data are used as model validation. When these data types are sparse or absent, the user is required to make assumptions regarding channel morphology and hydrology. These assumptions introduce uncertainty and increase the model error. For some reaches along the Deschutes River, Whychus Creek and Tumalo Creek there was limited field data due to lack of access. Verifying model accuracy in these reaches is difficult and is a source of uncertainty.

Section One - Data Summary

Introduction

Stream temperature, flow, and habitat data have been collected in the upper Deschutes River watershed by the following stakeholders:

- Oregon Department of Environmental Quality (DEQ)
- United States Forest Service (USFS)
- Oregon Department of Fish and Wildlife (ODFW)
- Oregon Water Resources Department (OWRD)
- Deschutes Basin Land Trust
- Portland General Electric (PGE)
- City of Bend
- United States Bureau of Land Management (BLM)
- Various irrigation districts

The data collection methods include both ground level measurements and remote sensing. Most of the data was collected during the summers of 2000 and 2001. This section summarizes the existing data for Tumalo Creek (2001), Whychus Creek (2000), and the upper Deschutes River (2001) and describes the methodology used to assemble and analyze the data for stream temperature modeling.

Flow Data

Flow Measurement Locations and Values

Flow measurements were made by DEQ at several locations on the stream of interest and within selected tributary mouths and diversions during 2000 and 2001 (Figure 2). The flow measurements were intended to correspond with the thermal infrared (TIR) stream temperature data collection on each stream.

Figure 2 – Flow measurement locations in 2000 and 2001.

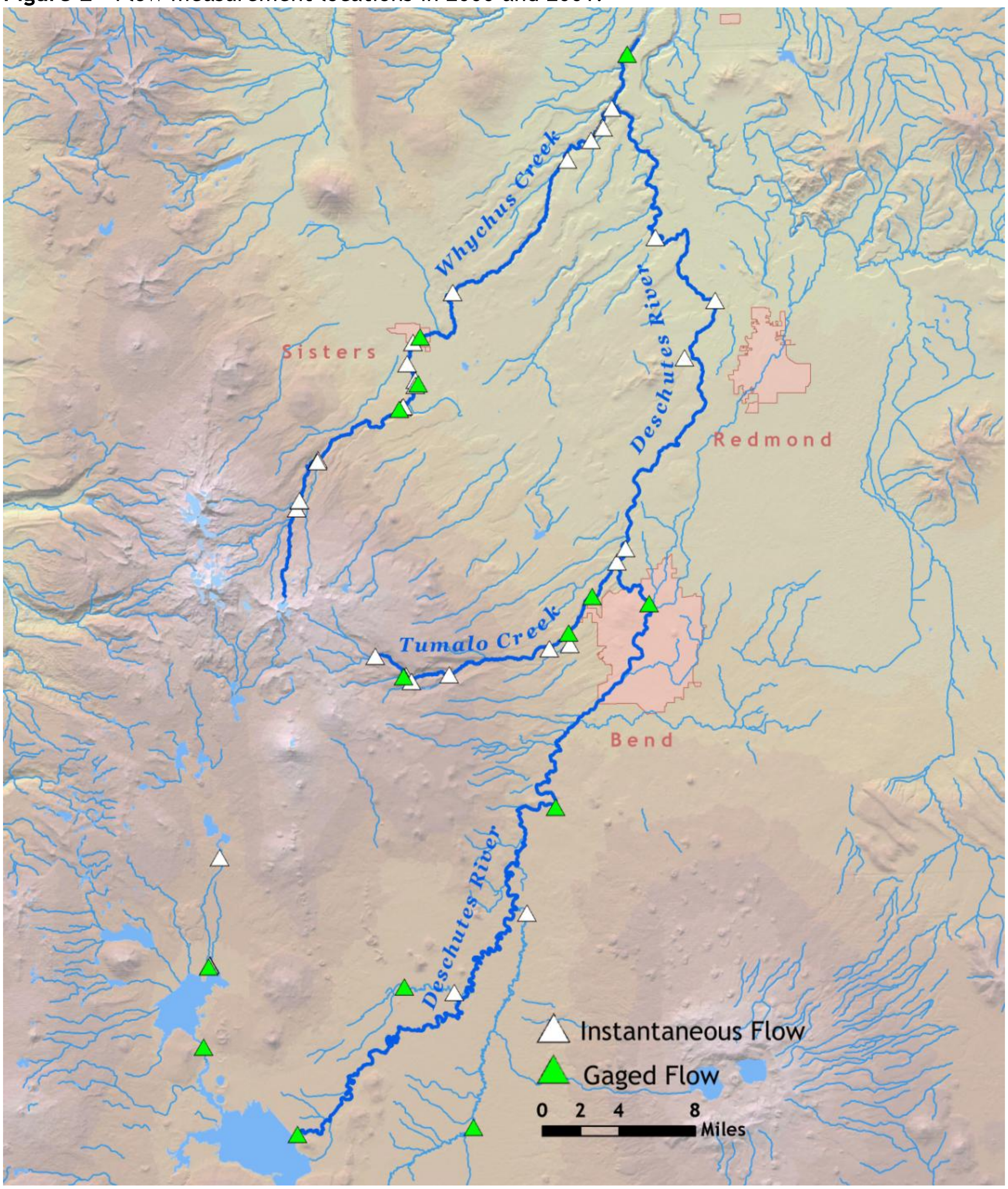


Table 1 summarizes the locations, dates, and values of the flow measurements. The instantaneous flow measurement sites also have wetted width, depth, and velocity data which were used as validation for simulated stream hydraulics. The flow gage data records include stream flow values which range from daily to quarter-hourly, depending upon the location. The time was not recorded at some of the instantaneous flow measurement locations; therefore there is a blank in the time column for some sites.

The longitudinal flow profiles for each simulated stream were based upon the available measured data. The thermal infrared (TIR) data was used as a supplemental source of information. Tributaries and springs may appear in the TIR data that were not measured in the field. If upstream flows were known, the TIR temperature of upstream, of the source, and of downstream were used within a mass balance equation to estimate the flow volume of the tributary or spring.

Table 1 – Flow data locations, dates and values.

Location	Date	Time	Flow (cfs)	Type
Whychus Creek at Trailhead	7/25/2000	19:45	145.83	Instant
Whychus Creek upstream North Fork	7/25/2000	10:45	140.32	Instant
North Fork Whychus Creek at Mouth	7/25/2000	10:10	25.73	Instant
Whychus Creek upstream Snow Creek	7/25/2000	12:47	144.51	Instant
Snow Creek at Mouth	7/25/2000	12:07	11.61	Instant
Whychus Creek at Gage above Diversions	7/25/2000	14:05	152.49	Instant
Plainview Diversion	7/25/2000	13:50	<1	Instant
McAllister Diversion	7/25/2000	13:50	0.97	Instant
TSID Canal	7/25/2000	16:55	114.11	Instant
Return to Whychus Creek from TSID Canal	7/25/2000	-	2.74	Instant
Whychus Creek downstream TSID Canal	7/25/2000	16:00	14.76	Instant
Whychus Creek upstream Sokol Diversion	7/25/2000	18:30	9.89	Instant
Sokol Diversion (in pipe)	7/25/2000	18:45	3.17	Instant
Sokol Diversion (d/s pipe)	7/25/2000	18:45	3.98	Instant
Diversion in Sisters	7/25/2000	18:00	0.74	Instant
Whychus Creek at Park in Sisters	7/25/2000	17:27	3.15	Instant
Whychus Creek downstream Camp Polk Road	7/27/2000	9:35	11.11	Instant
Whychus Creek at 6360 Road	7/26/2000	11:30	9.01	Instant
Whychus Creek at End of 6370 Road	7/26/2000	13:00	8	Instant
Whychus Creek upstream Alder Springs	7/26/2000	14:56	10.85	Instant
Alder Springs at Mouth	7/26/2000	14:25	8.7	Instant
Tumalo downstream Middle/North Fork Confluence	7/23/2001	14:10	18.74	Instant
Tumalo upstream Bridge Creek	7/23/2001	-	26.75	Instant
Bridge Creek at Mouth	7/23/2001	16:30	12.48	Instant
South Fork Tumalo Creek at Mouth	7/25/2001	14:10	4.03	Instant
Tumalo downstream Skyliner	7/25/2001	15:30	41.84	Instant
Tumalo at Road 4606	7/26/2001	15:15	40.14	Instant

Table 1 (continued) - Flow data locations, dates and values.

Location	Date	Time	Flow (cfs)	Type
Tumalo at Mouth	7/25/2001	17:05	7.03	Instant
Deschutes River downstream Little Lava Lake and Blue Pool	7/24/2001	-	12.62	Instant
Deschutes River upstream Snow Creek	7/24/2001	-	45.11	Instant
Snow Creek at Mouth	7/24/2001	-	20.24	Instant
Fall River ~1.5 miles upstream Mouth	7/23/2001	16:00	101.40	Instant
Little Deschutes River at Crosswater Bridge	7/24/2001	9:15	131.38	Instant
Deschutes River at Tumalo State Park	7/26/2001	8:45	42.53	Instant
Deschutes River at Cline Falls State Park	7/26/2001	-	35.11	Instant
Deschutes River upstream Tetherow Crossing	7/26/2001	12:15	50.63	Instant
Deschutes River at Lower Bridge	7/26/2001	13:13	53.64	Instant
Deschutes River at Lower Bridge	8/17/2001	11:44	41.78	Instant
Creek at Mouth	7/26/2001	10:40	109.70	Instant
Whychus Creek near Sisters 14075000	2000	-	-	Gage
TSID Canal near Sisters 14076000	2000	-	-	Gage
Whychus Creek near Sisters 14076050	2000	-	-	Gage
City of Bend diversion from Bridge Creek[1]	2001	-	-	Gage
Return from City of Bend Diversion[2]	2001	-	-	Gage
Tumalo Creek near Bend	2001	-	-	Gage
Deschutes River downstream Snow Creek 14050000	2001	-	-	Gage
Deschutes River downstream Crane Prairie Reservoir 14054000	2001	-	-	Gage
Deschutes River downstream Wickiup Reservoir 14056500	2001	-	-	Gage
Fall River 14063000	2001	-	-	Gage
Little Deschutes River near La Pine 14063000	2001	-	-	Gage
Deschutes River at Benham Falls 14064500	2001	-	-	Gage
Deschutes River downstream Bend 14070500	2001	-	-	Gage
Deschutes River at Culver 14076500	2001	-	-	Gage

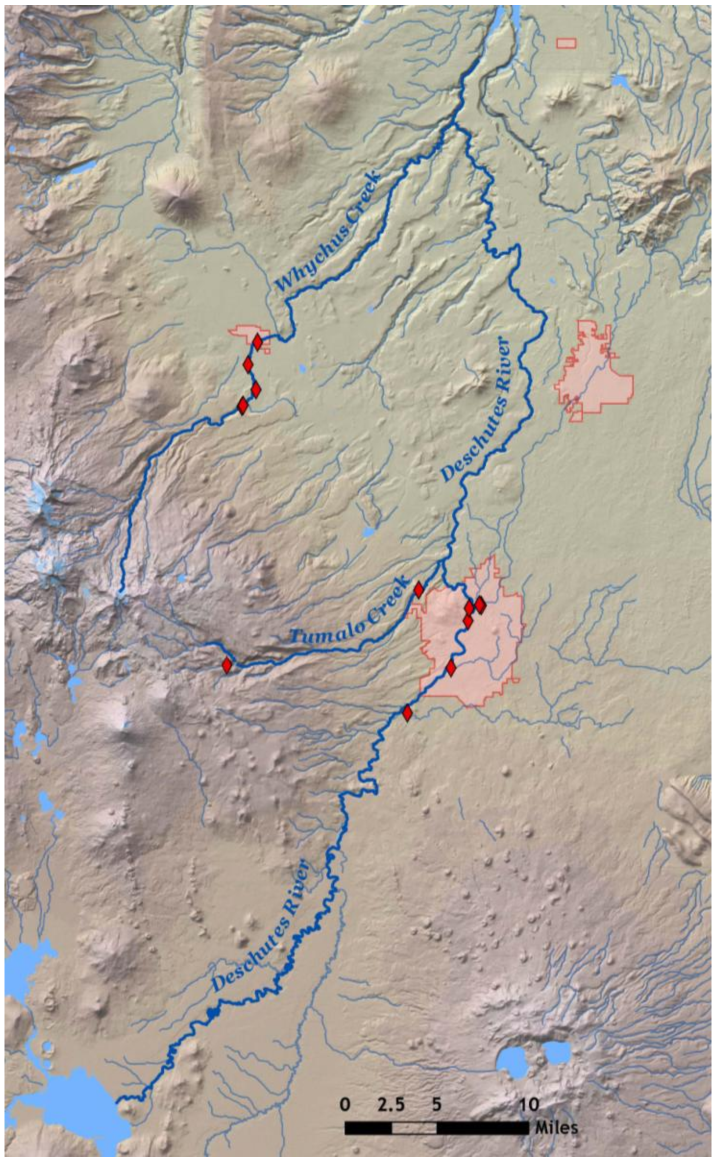
[1] A portion of Bridge Creek is diverted for use by the City of Bend.
[2] Diversion water that is not used by the City of Bend is returned to Tumalo Creek.

Diversions

Substantial flow volumes are diverted from each stream for irrigation purposes. Figure 3 shows the locations of monitored irrigation canal diversions within the study area. The flow volumes of each canal were monitored by the irrigation districts, and in most cases hourly data is available. This information was incorporated into the temperature model where appropriate.

The OWRD points of diversion (POD) database indicates multiple smaller diversions or water rights throughout the area of interest. However, those small private diversions were typically not monitored and were not included in the stream temperature simulation analysis.

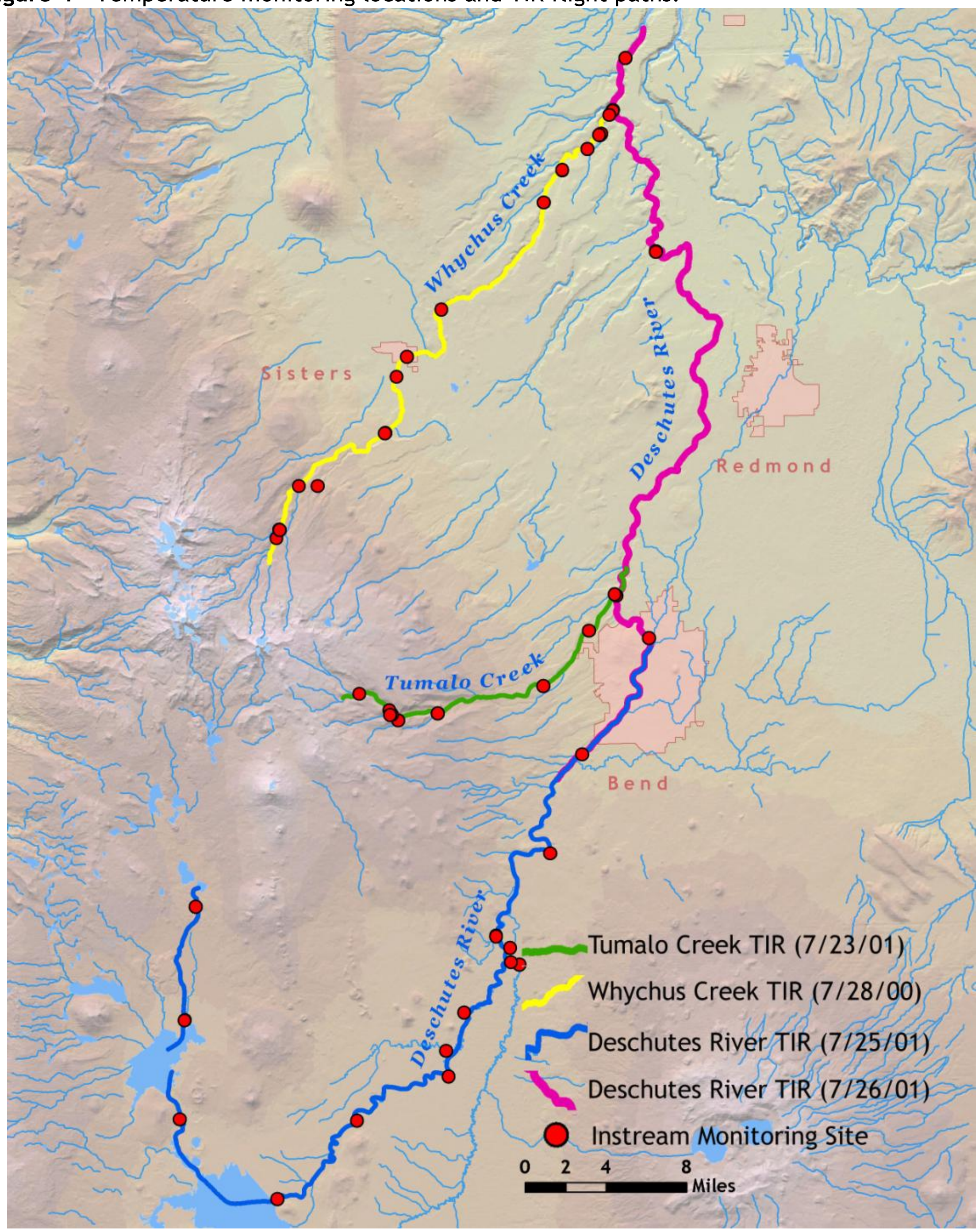
Figure 3 – Irrigation canal locations.



Stream Temperature Data

Two types of stream temperature data were collected on the streams of interest and their tributaries (Figure 4). Temperature monitoring instruments were deployed within the streams and recorded half-hourly or hourly stream temperature data. Thermal infrared (TIR) stream temperature data was collected via helicopter in 2000 and 2001 during the critical summertime period (Watershed Sciences, 2001 & 2002). The Deschutes River TIR data had to be collected over a 2-day period due to its length.

Figure 4 – Temperature monitoring locations and TIR flight paths.



Deschutes River TIR Data

Thermal infrared (TIR) stream temperature data was collected on the Deschutes River from Lake Billy Chinook on July 25 and 26, 2001. Figure 5 shows the TIR temperature profile between Lake Billy Chinook and Wickiup Reservoir. Temperature simulations were performed from Wickiup Reservoir to Lake Billy Chinook, and the TIR data was used as inputs and for model calibration.

Figure 5 – Thermal infrared (TIR) temperature profile of Deschutes River.

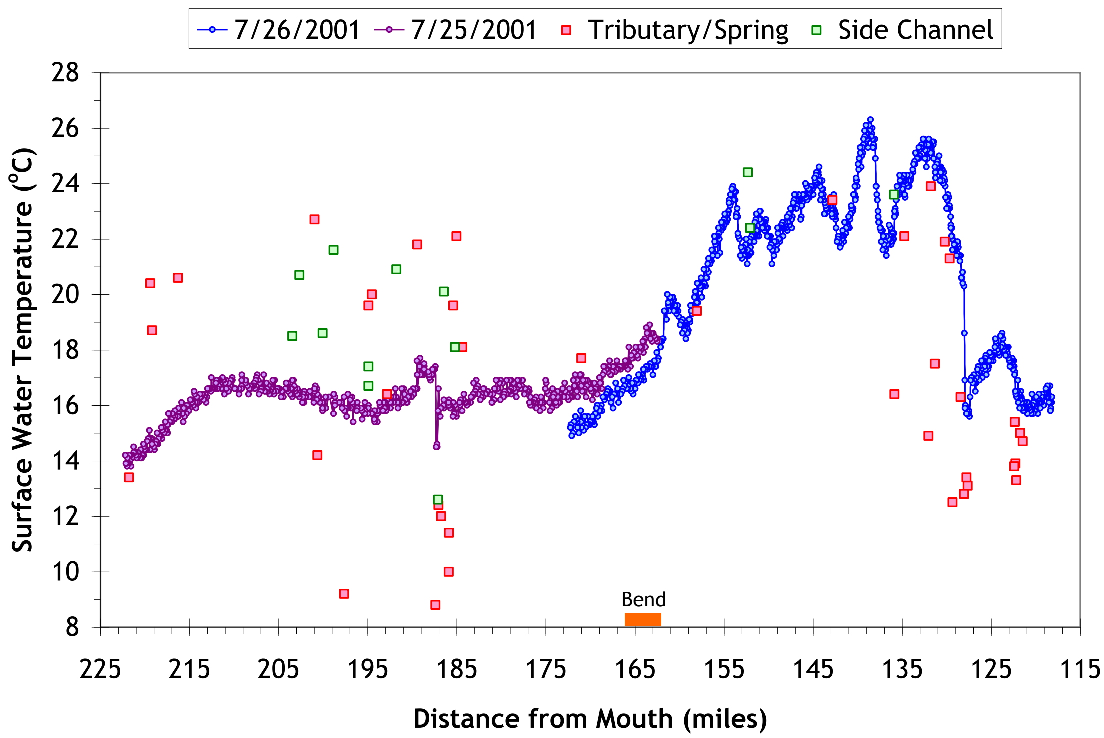
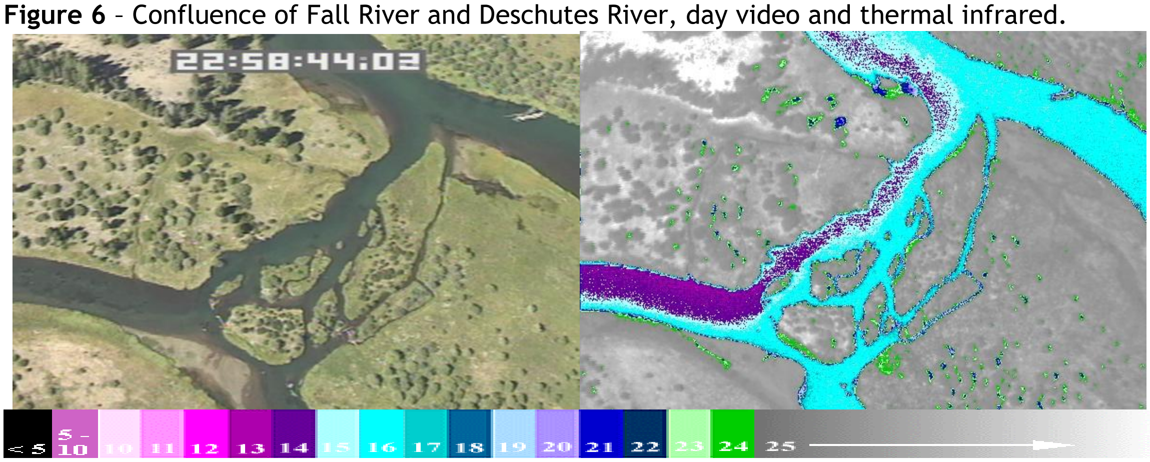


Figure 6 is an example of thermal imagery near at the confluence of Fall River and Deschutes River (near mile 201). Fall River is cooler than the Deschutes River and its plume is visible.

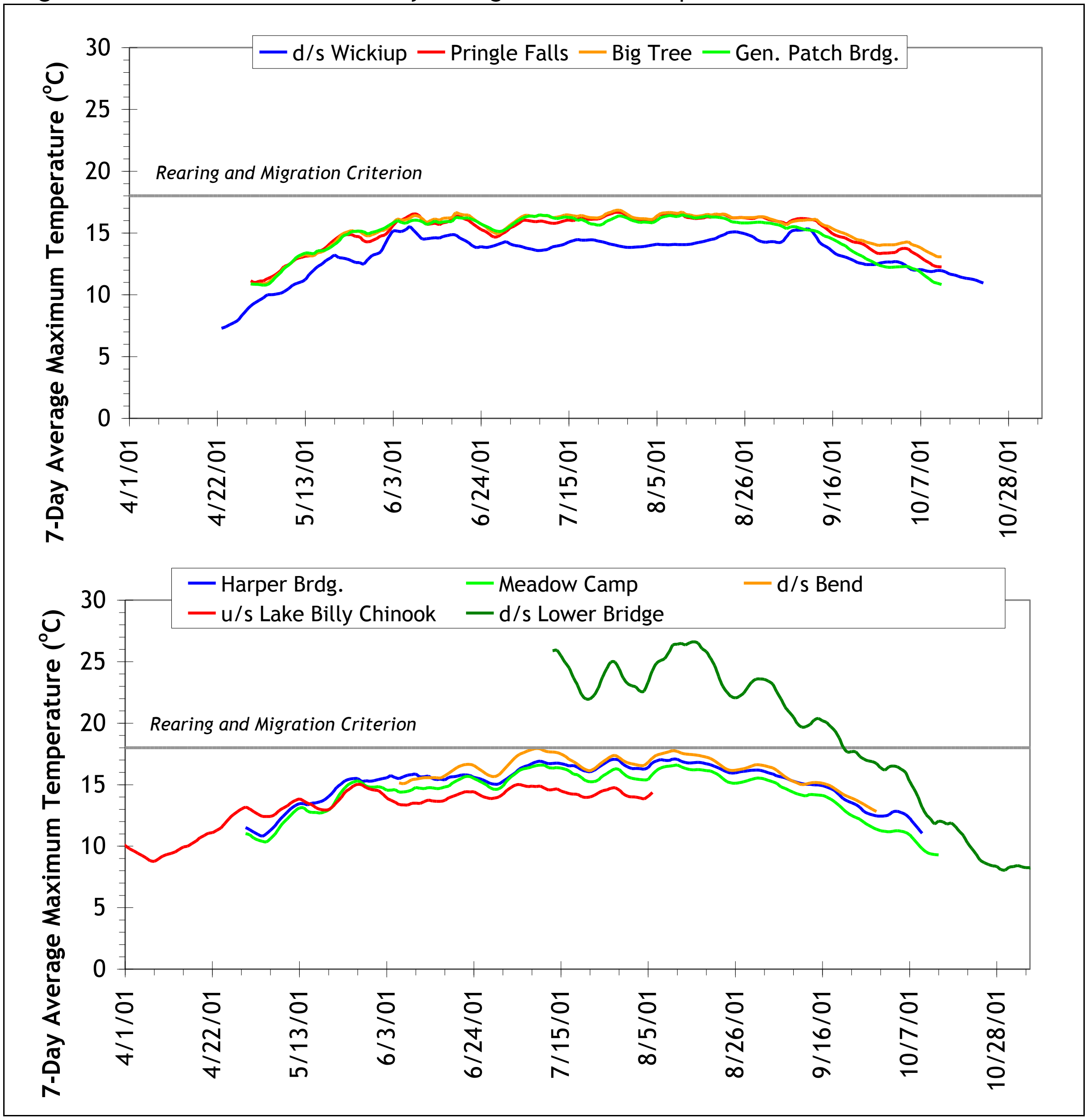
Figure 6 – Confluence of Fall River and Deschutes River, day video and thermal infrared.



Deschutes River Instream Temperature Data

Various agencies deployed temperature monitoring instruments within the Deschutes River during 2001. The seven day average maximum temperatures were calculated from the continuous data and are plotted in Figure 7 below. The plots have been divided into upper and lower reaches for simplified viewing. The rearing and migration criterion (18˚C) applies all year. According to the Oregon DEQ fish periodicity charts, there is no anadromous fish spawning within the upper Deschutes River below Wickiup Reservoir, Tumalo Creek, or Whychus Creek; however, there is residential fish spawning use. Additionally, there is bull trout spawning and rearing (numeric criterion of 12˚C) that occurs in the upper reaches of the Deschutes River and Tumalo Creek watersheds.

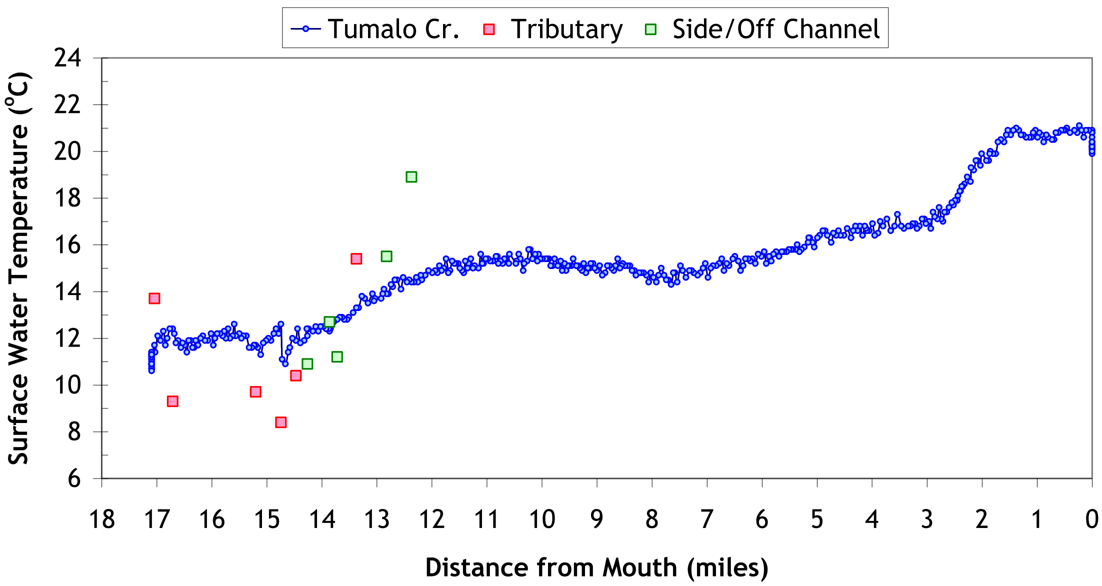
Figure 7 – Deschutes River seven day average maximum temperatures.



Tumalo Creek TIR Data

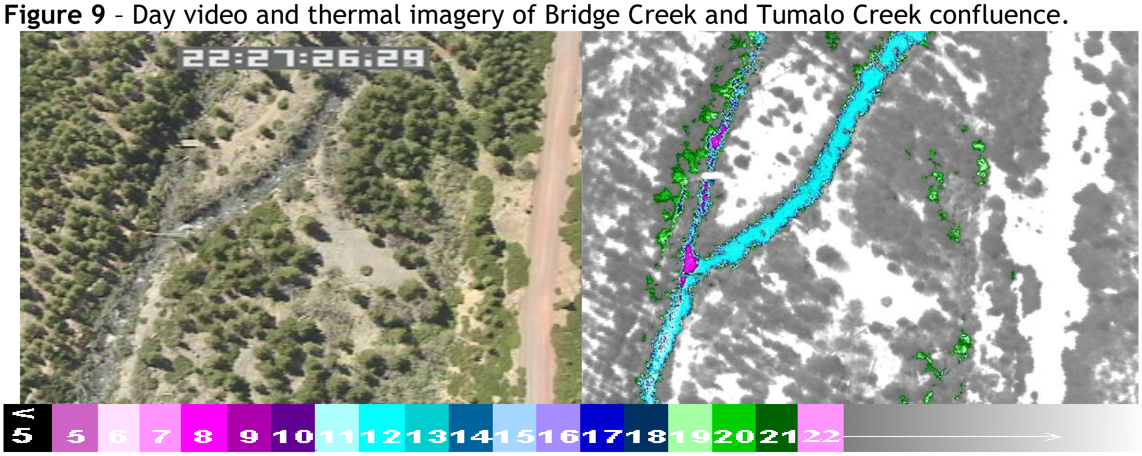
Thermal infrared (TIR) stream temperature data was collected on Tumalo Creek on July 23, 2001 from 2:37 to 3:34 PM. The TIR flight began at the mouth and continued upstream to the confluence of the north and middle forks. Figure 8 shows the TIR stream temperature profile and measured tributaries and side channels. This data was used as input and for calibration of the stream temperature model.

Figure 8 – Tumalo Creek thermal infrared (TIR) stream temperature profile.



An example of the thermal imagery is presented in Figure 9. Bridge Creek enters Tumalo Creek near mile 14.7 and is much cooler. Notice how Bridge Creek reduces the temperature of Tumalo Creek in the thermal profile above.

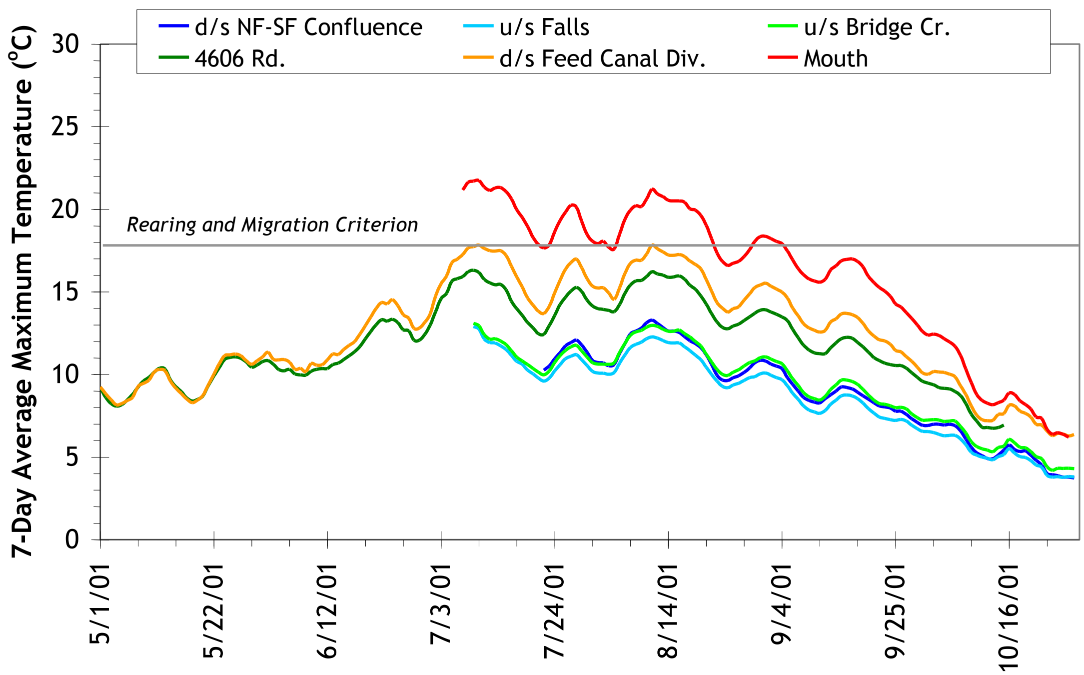
Figure 9 – Day video and thermal imagery of Bridge Creek and Tumalo Creek confluence.



Tumalo Creek Instream Temperature Data

Oregon DEQ and the USFS deployed temperature monitoring instruments in Tumalo Creek during 2001. Stream temperatures generally increased in the downstream direction, with the highest measured temperatures near the mouth (Figure 10). The rearing and migration criterion (18°C) was exceeded at the mouth. The highest stream temperatures occurred in July and August, which corresponds to the stream's critical summertime period.

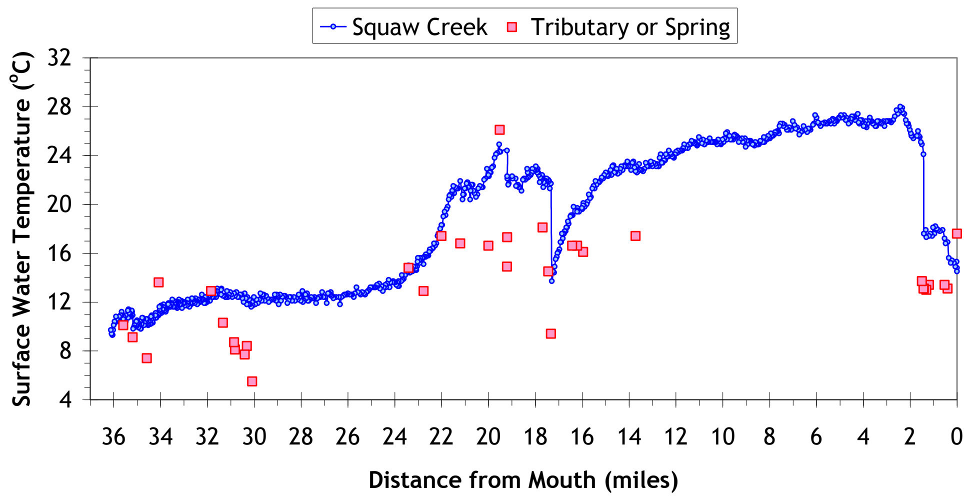
Figure 10 – Tumalo Creek seven day average maximum temperatures.



Whychus Creek TIR Data

Thermal infrared (TIR) stream temperature data was collected on Whychus Creek on July 28, 2000 from 4:06 to 5:00 pm (Figure 11). The flight began at the mouth and proceeded to just upstream Park Creek. The stream temperatures gradually heated in the downstream direction, until just upstream of Sisters (approximately mile 22) where much more rapid heating took place. Downstream of Sisters, near mile 17, spring water inflow dramatically reduces the stream temperature. Alder Springs near the mouth also has a dramatic cooling effect.

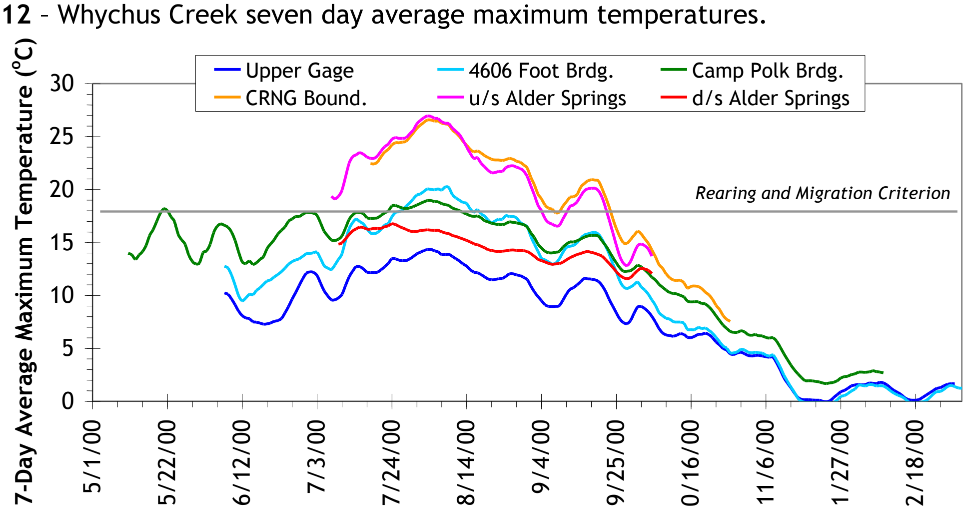
Figure 11 – Whychus Creek thermal infrared (TIR) stream temperature profile.



Whychus Creek Instream Temperature Data

Temperature monitoring instruments were deployed in Whychus Creek during 2000. The seasonal maximum temperatures were observed in July and August (Figure 12). The warmest stream reaches were in the lower portions of Whychus Creek, upstream of Alder Springs. Alder Springs contributed a significant volume of cold water to Whychus Creek, which dramatically decreased stream temperatures to the mouth. The only sites in Whychus Creek that did not violate the numeric criterion (18°C) were at the upper gage and downstream of Alder Springs.

Figure 12 – Whychus Creek seven day average maximum temperatures.



Seven-Day Average of the Daily Maximum

Table 2 summarizes the temperature monitoring locations, the recorded data time period, and the calculated peak seven day average maximum stream temperatures. The agency responsible for collecting the data is indicated in parentheses within each of the site descriptions. Sites where the rearing and migration criterion (18°C) was violated are denoted in bold. This data was used as input and for calibration of the stream temperature models.

Table 2 – Temperature monitoring sites and peak seven day average maximums.

Site Name	Start Date	Stop Date	Peak 7-Day Average Maximum	
			Date	Value
Deschutes River downstream Little Lava Lake (DEQ)	7/4/01	11/1/01	7/4/01	15.8
Deschutes River downstream Little Lava Lake (QA) (DEQ)	7/4/01	9/19/01	7/4/01	16
Deschutes River upstream Snow Creek (USFS)	**5/10/01**	**10/12/01**	**7/3/01**	**19**
Snow Creek at Mouth (Tributary to Deschutes R) (USFS)	5/10/01	10/12/01	5/21/01	13.7
Deschutes River at Brown's Crossing (USFS)	**5/10/01**	**10/15/01**	**8/11/01**	**24**
Deschutes River at Wickiup Gage (OWRD)	6/1/01	9/29/01	9/3/01	15.7
Deschutes River downstream Wickiup (DEQ)	4/17/01	10/22/01	6/1/01	15.5
Deschutes River upstream Pringle Falls (USFS)	4/24/01	10/12/01	7/20/01	16.7
Deschutes River upstream Big Tree (USFS)	4/24/01	10/12/01	7/21/01	16.8
Fall River near Mouth (DEQ)	4/17/01	10/27/01	7/2/01	13.5
Deschutes River upstream General Patch Bridge (USFS)	4/24/01	10/12/01	8/5/01	16.4
Little Deschutes River at Crosswater Bridge near Mouth (DEQ)	**4/18/01**	**11/6/01**	**7/4/01**	**24.4**
Little Deschutes River at Mouth (ODFW)	**5/17/01**	**11/8/01**	**7/4/01**	**24.2**
Deschutes River at Harper Bridge (USFS)	4/24/01	10/10/01	8/5/01	17.1
Spring River 500 yards upstream Mouth (DEQ)	4/17/01	11/1/01	5/19/01	8.8
Spring River 500 yards upstream Mouth (QA) (DEQ)	7/6/01	11/1/01	7/9/01	8.4
Spring River 700 yards upstream Mouth (DEQ)	7/19/01	10/11/01	8/11/01	7.8
Deschutes River at Benham Falls Gage (OWRD)	6/1/01	9/29/01	8/13/01	14
Deschutes River at Meadow Camp (USFS)	4/24/01	10/14/01	8/6/01	16.6
Deschutes River at Gage below Bend (OWRD)	6/1/01	9/29/01	7/3/01	17.9
Deschutes River at Lower Bridge (DEQ)	**7/7/01**	**11/6/01**	**8/10/01**	**26.6**
Deschutes River at Pump House upstream Lower Bridge (ODFW)	**4/19/01**	**10/14/01**	**7/4/01**	**26.7**
Deschutes River near USGS Gage above LBC (PGE)	3/13/01	8/6/01	5/21/01	15
Tumalo Creek downstream NF-MF Confluence (DEQ)	7/16/01	10/28/01	8/5/01	13.4
Tumalo Creek downstream NF-MF Confluence (QA) (DEQ)	7/16/01	10/28/01	8/5/01	13.3
Tumalo Creek upstream Falls (DEQ)	7/3/01	10/28/01	7/3/01	12.9

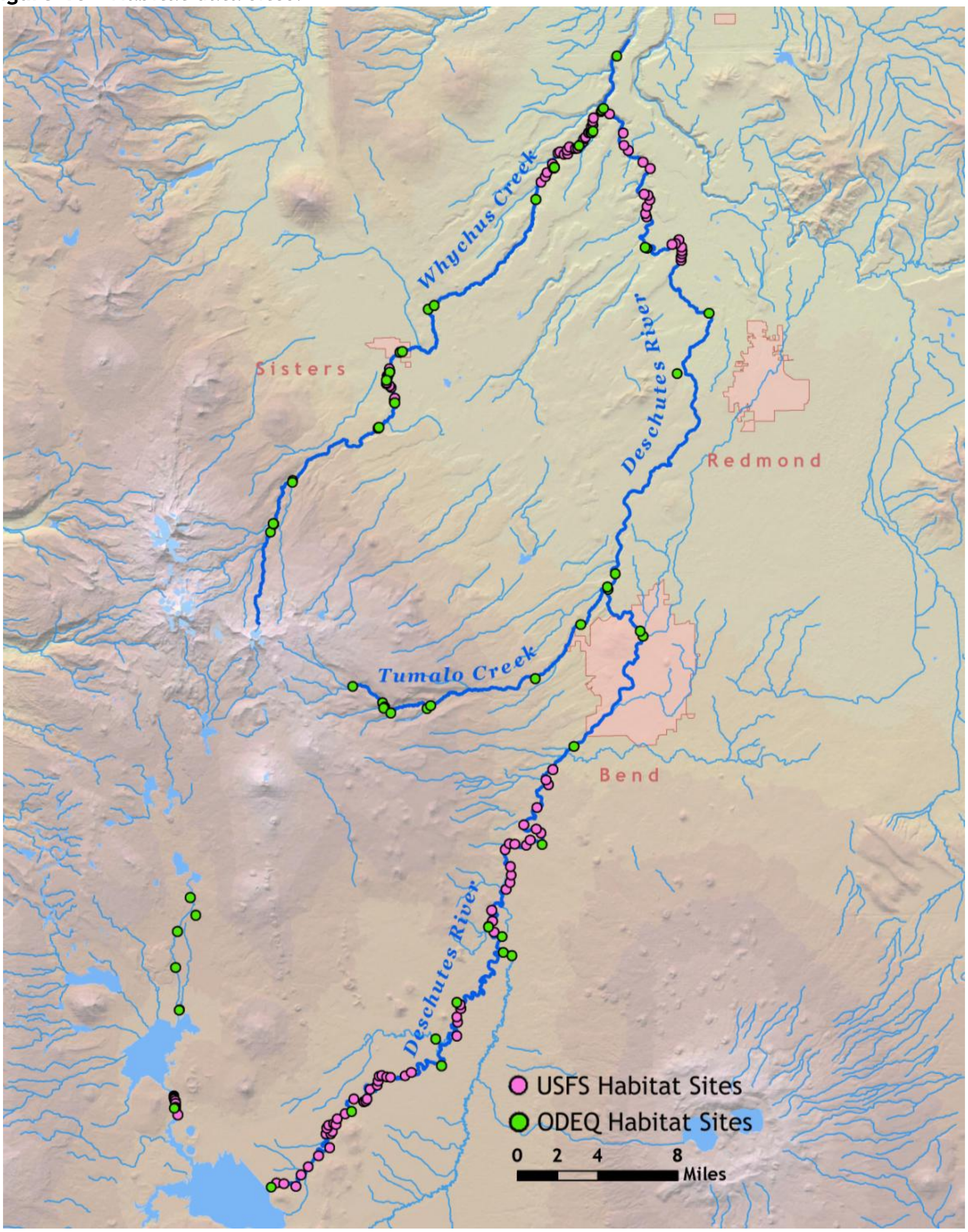
Table 2 (continued) - Temperature monitoring sites and peak seven day average maximums.

Site Name	Start Date	Stop Date	Peak 7-Day Average Maximum	
			Date	Value
Tumalo Creek upstream Bridge Creek (DEQ)	7/3/01	10/28/01	7/3/01	13.1
Bridge Creek at Mouth (USFS)	6/2/01	10/28/01	6/29/01	7.1
South Fork Tumalo Creek near Mouth (DEQ)	7/3/01	10/28/01	7/3/01	9.7
Tumalo Lake Creek near Skyliner Lodge (USFS)	5/6/01	10/28/01	7/2/01	13.3
Tumalo Creek upstream Road 4606 (USFS)	4/25/01	10/15/01	7/3/01	16.3
Tumalo Creek downstream Feed Canal Diversion (USFS)	4/25/01	10/28/01	7/4/01	17.8
Whychus Creek at Trailhead (DEQ)	7/25/00	8/15/00	7/28/00	12.1
Whychus Creek at Trailhead (QA) (DEQ)	7/25/00	8/15/00	7/28/00	12.2
Whychus Creek upstream North Fork (DEQ)	7/26/00	8/15/00	7/28/00	12.3
North Fork Whychus Creek at Mouth (DEQ)	7/26/00	8/15/00	7/28/00	15.5
Snow Creek (Whychus Trib) at Mouth (DEQ)	7/26/00	8/15/00	7/29/00	11.5
Whychus Creek upstream Snow Creek (DEQ)	7/26/00	8/15/00	7/28/00	13.5
Whychus Creek at Gage above Diversions (DEQ)	7/26/00	8/15/00	7/29/00	14.3
Whychus Creek at Upper Gage (USFS)	6/1/00	12/29/00	7/29/00	14.3
Whychus Creek at 4606 Foot Bridge (USFS)	**6/1/00**	**1/4/01**	**8/2/00**	**20.2**
Whychus Creek at Park in Sisters (DEQ)	**7/26/00**	**8/15/00**	**7/28/00**	**21.6**
Whychus Creek at Sisters Park Gage (USFS)	**5/5/00**	**12/9/00**	**7/28/00**	**22.4**
Whychus Creek downstream Camp Polk Bridge (USFS)	5/5/00	12/9/00	7/29/00	18.9
Whychus Creek downstream Camp Polk Road (DEQ)	**7/27/00**	**8/15/00**	**7/28/00**	**21.5**
Whychus Creek at CRNG (USFS)	**7/12/00**	**10/27/00**	**7/29/00**	**26.6**
Whychus Creek at Road 6360 (DEQ)	**7/27/00**	**8/15/00**	**7/29/00**	**27.7**
Whychus Creek at End of Road 6370 (DEQ)	**7/27/00**	**8/15/00**	**7/28/00**	**27.1**
Whychus Creek upstream Alder Springs (DEQ)	**7/27/00**	**8/15/00**	**7/28/00**	**23**
Whychus Creek upstream Alder Springs (USFS)	**7/1/00**	**10/5/00**	**7/28/00**	**27**
Alder Springs at Mouth (DEQ)	7/27/00	8/15/00	8/6/00	11.4
Whychus Creek downstream Alder Springs (USFS)	7/3/00	10/5/00	7/18/00	16.8
Whychus Creek at Mouth (DEQ)	7/7/01	11/6/01	7/8/01	13.2

Habitat Data

Habitat data has been collected by ODEQ and the USFS at many locations in the study area (Figure 13). Vegetation descriptions, effective shade measurements, channel, and substrate information were collected at these sites. This data was used for stream shade simulation validation and temperature model inputs.

Figure 13 – Habitat data sites.



Effective shade measurements are summarized in Table 3. At some sites, multiple measurements were collected, approximately 100 feet apart. The data is listed according to the month it represents. The July and August data were used for stream shade simulation validation.

Table 3 – Effective shade measurement data.

Site ID	Location	Latitude	Longitude	Effective Shade Measurement (%)			
				July	Aug	Sept	Oct
1	Whychus Creek Upstream of Sisters	44.25200	-121.55060	27	26		
2	Whychus Creek Upstream of Sisters	44.25360	-121.55080	44	48		
3	Whychus Creek Upstream of Sisters	44.25470	-121.55040	65	69		
4	Whychus Creek Upstream of Sisters	44.26230	-121.55340	56	54		
5	Whychus Creek Upstream of Sisters	44.26370	-121.55520	28	47		
6	Whychus Creek Upstream of Sisters	44.26540	-121.55830	39	40		
7	Whychus Creek Upstream of Sisters	44.26620	-121.55850	23	31		
8	Whychus Creek Upstream of Sisters	44.26960	-121.55760	9	14		
9	Whychus Creek Upstream of Sisters	44.27080	-121.55740	56	60		
10	Whychus Creek Upstream of Sisters	44.27230	-121.55610	2	16		
11	Whychus Creek Upstream of Sisters	44.27330	-121.55500	65	67		
12	Whychus Creek Upstream of Sisters	44.27410	-121.55440	5	6		
13	Whychus Creek Upstream of Sisters	44.27620	-121.55500	34	39		
14	Whychus Creek in the Lower 6 miles	44.40910	-121.39900	27	31		
15	Whychus Creek in the Lower 6 miles	44.41260	-121.39470	43	50		
16	Whychus Creek in the Lower 6 miles	44.41570	-121.39260	37	42		
17	Whychus Creek in the Lower 6 miles	44.41880	-121.38610	42	51		
18	Whychus Creek in the Lower 6 miles	44.42180	-121.38700	5	7		
19	Whychus Creek in the Lower 6 miles	44.42980	-121.38130	2	3		
20	Whychus Creek in the Lower 6 miles	44.43060	-121.37930	1	2		
21	Whychus Creek in the Lower 6 miles	44.42850	-121.37510	0	14		
22	Whychus Creek in the Lower 6 miles	44.42890	-121.37190	1	1		
23	Whychus Creek in the Lower 6 miles	44.43170	-121.37210	26	25		
24	Whychus Creek in the Lower 6 miles	44.43400	-121.36950	7	8		
25	Whychus Creek in the Lower 6 miles	44.43270	-121.36360	22	24		
26	Whychus Creek in the Lower 6 miles	44.43300	-121.36120	26	30		
27	Whychus Creek in the Lower 6 miles	44.43560	-121.35830	55	69		

Site ID	Location	Latitude	Longitude	Effective Shade Measurement (%)			
				July	Aug	Sept	Oct
28	Whychus Creek in the Lower 6 miles	44.43720	-121.35570	38	39		
29	Whychus Creek in the Lower 6 miles	44.43930	-121.35490	44	58		
30	Whychus Creek in the Lower 6 miles	44.44070	-121.35310	40	44		
31	Whychus Creek in the Lower 6 miles	44.44400	-121.35010	29	34		
32	Whychus Creek in the Lower 6 miles	44.44420	-121.34820	8	10		
33	Whychus Creek in the Lower 6 miles	44.44560	-121.34590	11	12		
34	Whychus Creek in the Lower 6 miles	44.44800	-121.34720	33	37		
35	Whychus Creek in the Lower 6 miles	44.44950	-121.34530	19	19		
36	Whychus Creek in the Lower 6 miles	44.45210	-121.34570	2	5		
37	Whychus Creek in the Lower 6 miles	44.45460	-121.34470	20	27		
38	Whychus Creek in the Lower 6 miles	44.45890	-121.33690	40	55		
1	Deschutes River Between Crane Prairie Res and Wickiup Res	43.75328	-121.78259				37
2	Deschutes River Between Crane Prairie Res and Wickiup Res	43.75225	-121.78257				48
3	Deschutes River Between Crane Prairie Res and Wickiup Res	43.75116	-121.78212				47
4	Deschutes River Between Crane Prairie Res and Wickiup Res	43.74979	-121.78132				58
5	Deschutes River Between Crane Prairie Res and Wickiup Res	43.74771	-121.78109				65
6	Deschutes River Between Crane Prairie Res and Wickiup Res	43.74509	-121.78130				32
7	Deschutes River Between Crane Prairie Res and Wickiup Res	43.74420	-121.78125				29
8	Deschutes River Between Crane Prairie Res and Wickiup Res	43.73961	-121.77901				2
9	Deschutes River Between Wickiup Res and Little Deschutes R	43.68905	-121.68150				54
10	Deschutes River Between Wickiup Res and Little Deschutes R	43.68838	-121.67462				40
11	Deschutes River Between Wickiup Res and Little Deschutes R	43.68633	-121.66267				21
12	Deschutes River Between Wickiup Res and Little Deschutes R	43.69490	-121.65721				38
13	Deschutes River Between Wickiup Res and Little Deschutes R	43.70037	-121.64999				30
14	Deschutes River Between Wickiup Res and Little Deschutes R	43.70836	-121.63943				34
15	Deschutes River Between Wickiup Res and Little Deschutes R	43.71400	-121.62790				32
16	Deschutes River Between Wickiup Res and Little Deschutes R	43.72408	-121.63178				21
17	Deschutes River Between Wickiup Res and Little Deschutes R	43.72427	-121.62676				24
18	Deschutes River Between Wickiup Res and Little Deschutes R	43.72595	-121.62530				25
19	Deschutes River Between Wickiup Res and Little Deschutes R	43.72833	-121.63087				6

Site ID	Location	Latitude	Longitude	Effective Shade Measurement (%)			
				July	Aug	Sept	Oct
20	Deschutes River Between Wickiup Res and Little Deschutes R	43.73011	-121.62895				6
21	Deschutes River Between Wickiup Res and Little Deschutes R	43.73130	-121.62396				7
22	Deschutes River Between Wickiup Res and Little Deschutes R	43.73064	-121.62164				11
23	Deschutes River Between Wickiup Res and Little Deschutes R	43.73467	-121.62018				4
24	Deschutes River Between Wickiup Res and Little Deschutes R	43.73839	-121.61199				4
25	Deschutes River Between Wickiup Res and Little Deschutes R	43.74904	-121.60329				49
26	Deschutes River Between Wickiup Res and Little Deschutes R	43.74707	-121.59349				22
27	Deschutes River Between Wickiup Res and Little Deschutes R	43.74755	-121.59162				42
28	Deschutes River Between Wickiup Res and Little Deschutes R	43.74884	-121.59009				56
29	Deschutes River Between Wickiup Res and Little Deschutes R	43.75564	-121.58672				25
30	Deschutes River Between Wickiup Res and Little Deschutes R	43.75872	-121.57951				22
31	Deschutes River Between Wickiup Res and Little Deschutes R	43.76189	-121.57870				13
31b	Deschutes River Between Wickiup Res and Little Deschutes R	43.76496	-121.57769				31
32	Deschutes River Between Wickiup Res and Little Deschutes R	43.76551	-121.57509				13
33	Deschutes River Between Wickiup Res and Little Deschutes R	43.76444	-121.56994				35
34	Deschutes River Between Wickiup Res and Little Deschutes R	43.76416	-121.56616				22
35	Deschutes River Between Wickiup Res and Little Deschutes R	43.76488	-121.55150				34
36	Deschutes River Between Wickiup Res and Little Deschutes R	43.76749	-121.54569				36
37	Deschutes River Between Wickiup Res and Little Deschutes R	43.79335	-121.49954				11
38	Deschutes River Between Wickiup Res and Little Deschutes R	43.80322	-121.49853				50
39	Deschutes River Between Wickiup Res and Little Deschutes R	43.80690	-121.49909				2
40	Deschutes River Between Wickiup Res and Little Deschutes R	43.81301	-121.49512				7
41	Deschutes River Between Wickiup Res and Little Deschutes R	43.81594	-121.49553				5.5
42	Deschutes River Between Little Deschutes R and Bend	43.86777	-121.46054				3
43	Deschutes River Between Little Deschutes R and Bend	43.87569	-121.46201				2
44	Deschutes River Between Little Deschutes R and Bend	43.88363	-121.46261				14
45	Deschutes River Between Little Deschutes R and Bend	43.89822	-121.44767				8
46	Deschutes River Between Little Deschutes R and Bend	43.90335	-121.44335				7
47	Deschutes River Between Little Deschutes R and Bend	43.90864	-121.44235				0.5
48	Deschutes River Between Little Deschutes R and Bend	43.91501	-121.44273				7

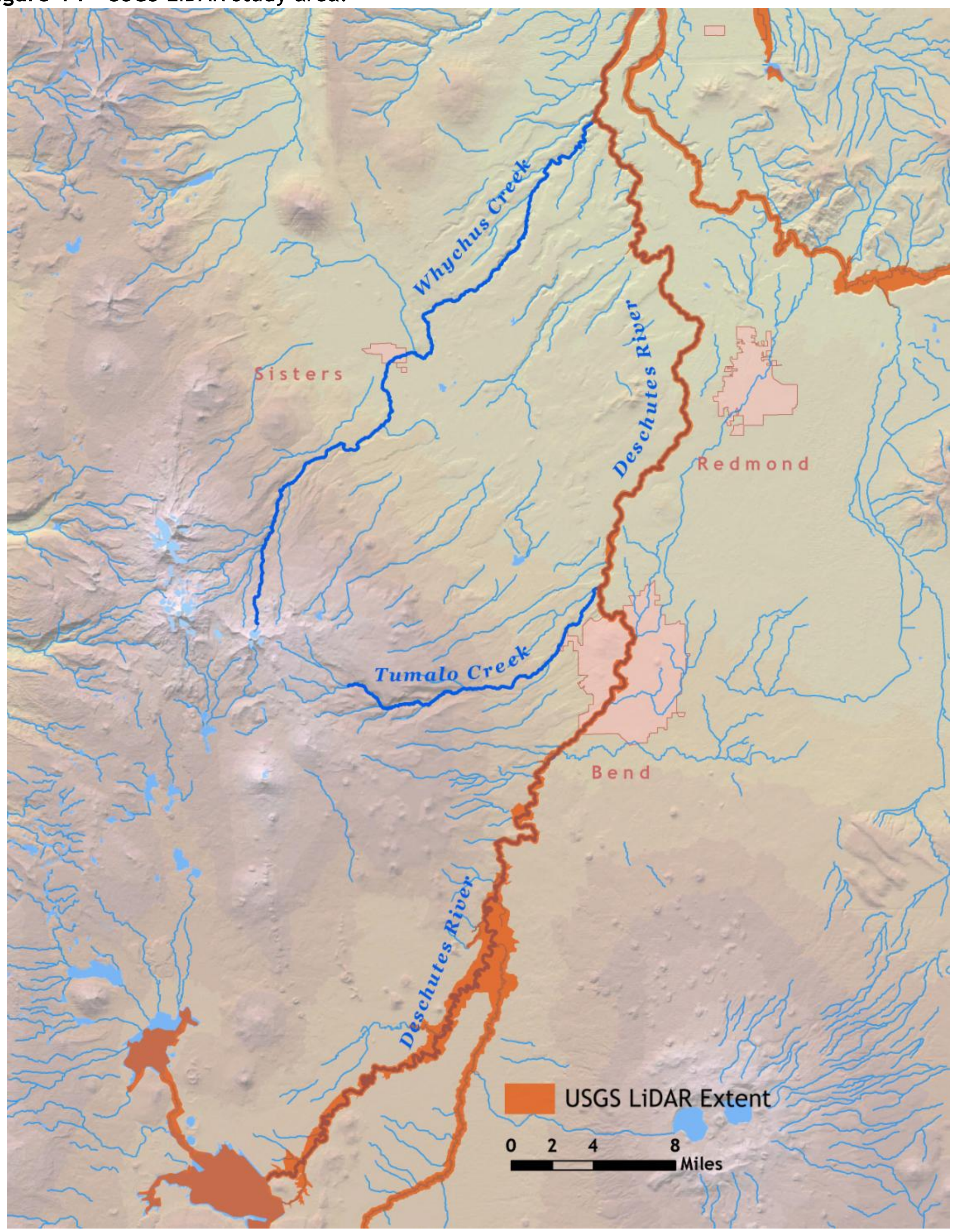
Site ID	Location	Latitude	Longitude	Effective Shade Measurement (%)			
				July	Aug	Sept	Oct
49	Deschutes River Between Little Deschutes R and Bend	43.92734	-121.44791				32
50	Deschutes River Between Little Deschutes R and Bend	43.93130	-121.44330				22
51	Deschutes River Between Little Deschutes R and Bend	43.93083	-121.43821				16
52	Deschutes River Between Little Deschutes R and Bend	43.93010	-121.42643				16
53	Deschutes River Between Little Deschutes R and Bend	43.93369	-121.42251				12
54	Deschutes River Between Little Deschutes R and Bend	43.93873	-121.41154				40
55	Deschutes River Between Little Deschutes R and Bend	43.94162	-121.41626				58
56	Deschutes River Between Little Deschutes R and Bend	43.94482	-121.42880				5
57	Deschutes River Between Little Deschutes R and Bend	43.95702	-121.41511				18
58	Deschutes River Between Little Deschutes R and Bend	43.97360	-121.40302				0
59	Deschutes River Between Little Deschutes R and Bend	43.97698	-121.40567				0
60	Deschutes River Between Little Deschutes R and Bend	43.98440	-121.39871				4
61	Deschutes River Upstream of Lake Billy Chinook	44.35043	-121.25954			1	
62	Deschutes River Upstream of Lake Billy Chinook	44.35275	-121.25953			26	
63	Deschutes River Upstream of Lake Billy Chinook	44.35489	-121.25867			15	
64	Deschutes River Upstream of Lake Billy Chinook	44.35707	-121.25836			6	
65	Deschutes River Upstream of Lake Billy Chinook	44.36015	-121.25870			22	
66	Deschutes River Upstream of Lake Billy Chinook	44.36514	-121.26148			20	
67	Deschutes River Upstream of Lake Billy Chinook	44.36247	-121.26437			6	
68	Deschutes River Upstream of Lake Billy Chinook	44.36204	-121.26823			5.5	
69	Deschutes River Upstream of Lake Billy Chinook	44.38222	-121.29323			2	
70	Deschutes River Upstream of Lake Billy Chinook	44.38491	-121.29437			20	
71	Deschutes River Upstream of Lake Billy Chinook	44.38970	-121.29246			6	
72	Deschutes River Upstream of Lake Billy Chinook	44.39470	-121.28994			20	
73	Deschutes River Upstream of Lake Billy Chinook	44.39796	-121.29137			29	
74	Deschutes River Upstream of Lake Billy Chinook	44.39877	-121.29538			29	
75	Deschutes River Upstream of Lake Billy Chinook	44.41707	-121.28867			29	
76	Deschutes River Upstream of Lake Billy Chinook	44.42186	-121.29575			22	
77	Deschutes River Upstream of Lake Billy Chinook	44.43067	-121.31047			19	
78	Deschutes River Upstream of Lake Billy Chinook	44.43410	-121.31465			18	

Site ID	Location	Latitude	Longitude	Effective Shade Measurement (%)			
				July	Aug	Sept	Oct
79	Deschutes River Upstream of Lake Billy Chinook	44.44309	-121.31506			76	
81	Deschutes River Upstream of Lake Billy Chinook	44.45695	-121.32812			41	
	Whychus Creek @ Trail Head	44.15962	-121.67707		96		
	Whychus Creek u/s Snow Creek	44.19664	-121.65409		67,78,81		
	Snow Creek @ mouth	44.19510	-121.65440		94,77,73		
	Whychus Creek @ Gaging Station above Diversions	44.23351	-121.56737		13,28,65,61		
	Whychus Creek d/s Camp Polk Road	44.32117	-121.50892		59,75,41		
	Whychus Creek @ 6360 Road (the ford)	44.41979	-121.38515		53,21,42		
	Whychus Creek @ end of 6370 Road	44.43446	-121.35991		26,46,42		
	Whychus Creek u/s Alder Springs	44.44435	-121.34760		22,42,24		
	Tumalo d/s Middle/North Fork confluence	44.04709	-121.59718		72,100,97		
	Tumalo u/s Tumalo Falls	44.03499	-121.56788		12,10,7		
	Tumalo u/s Bridge Creek	44.03191	-121.56549		17,23,34		
	Tumalo d/s Skyliner	44.03202	-121.51997		100,100,94		
	Tumalo u/s Rd 4606	44.05040	-121.41421		37,21,21		
	Tumalo @ mouth	44.11567	-121.34031		68.37,51		
	Deschutes d/s Little Lava Lake & Blue Pool	43.89645	-121.76353		33,29		
	Deschutes d/s Little Lava Lake & Blue Pool - AIR	43.89645	-121.76353		8		
	Deschutes @ Mile Campground (Day Use)	43.88370	-121.75790		15		
	Deschutes off Rd 46	43.84600	-121.77930		50		
	Deschutes u/s Snow Creek	43.81540	-121.77580		54,13		
	Deschutes @ Brown's Crossing	43.74424	-121.78240		13,24		
	Deschutes @ Tumalo State Park	44.12500	-121.33220		31,30,28		
	Deschutes @ Cline Falls State Park	44.26840	-121.26590		5		
	Deschutes u/s Tetherow Crossing	44.31150	-121.23240		0,0,0		
	Deschutes d/s Lower Bridge	44.36020	-121.29520		1		

Light Detection and Ranging - LiDAR

The USGS has collected LiDAR data on the entire Deschutes River and some of its tributaries (Figure 14) (USGS 2003). Whychus and Tumalo Creeks were not part of the survey. The LiDAR data was used for assessing land cover heights for Deschutes River temperature simulation input.

Figure 14 – USGS LiDAR study area.



DEQ provided the LiDAR data that was collected by USGS. Watershed Sciences imported the ASCII (xyz) files into Microstation and exported 2-meter rasters of the bare ground and the highest hit data. A raster calculation was performed in which the bare ground elevations were subtracted from the highest hit elevations which resulted in a land cover height raster. The land cover heights were then filtered to remove all values less than one meter and all values greater than 50 meters.

Figure 15 is an example of the highest hit LiDAR data along the upper Deschutes River. Each 2-meter cell of the LiDAR DEM has an elevation value reported to the nearest centimeter. Vegetation height ranges have been artificially colored for display purposes.

Figure 15 – LiDAR highest hit model.

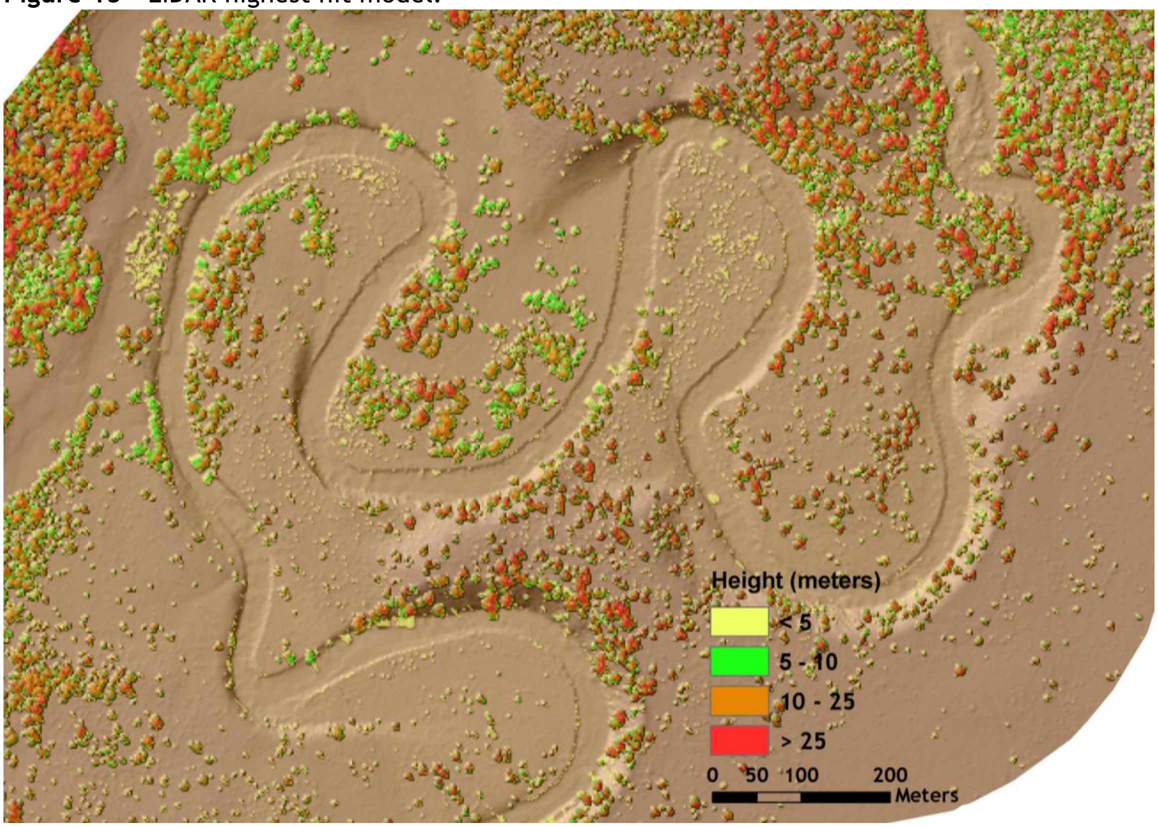


Figure 16 on the following page is an example of the highest hit LiDAR data with simple black and white hill shading. Figure 17 is the bare earth LiDAR at the same location. The digitized stream thalweg, channel edges, and 50-meter TTools segments are displayed within the figures. The stream thalweg and channel edges were originally digitized from the NAIP orthophotos and then overlaid on the LiDAR to verify the spatial accuracy. The NAIP orthophotos and the LiDAR data correspond well with one another.

Figure 16 – LiDAR highest hit model.

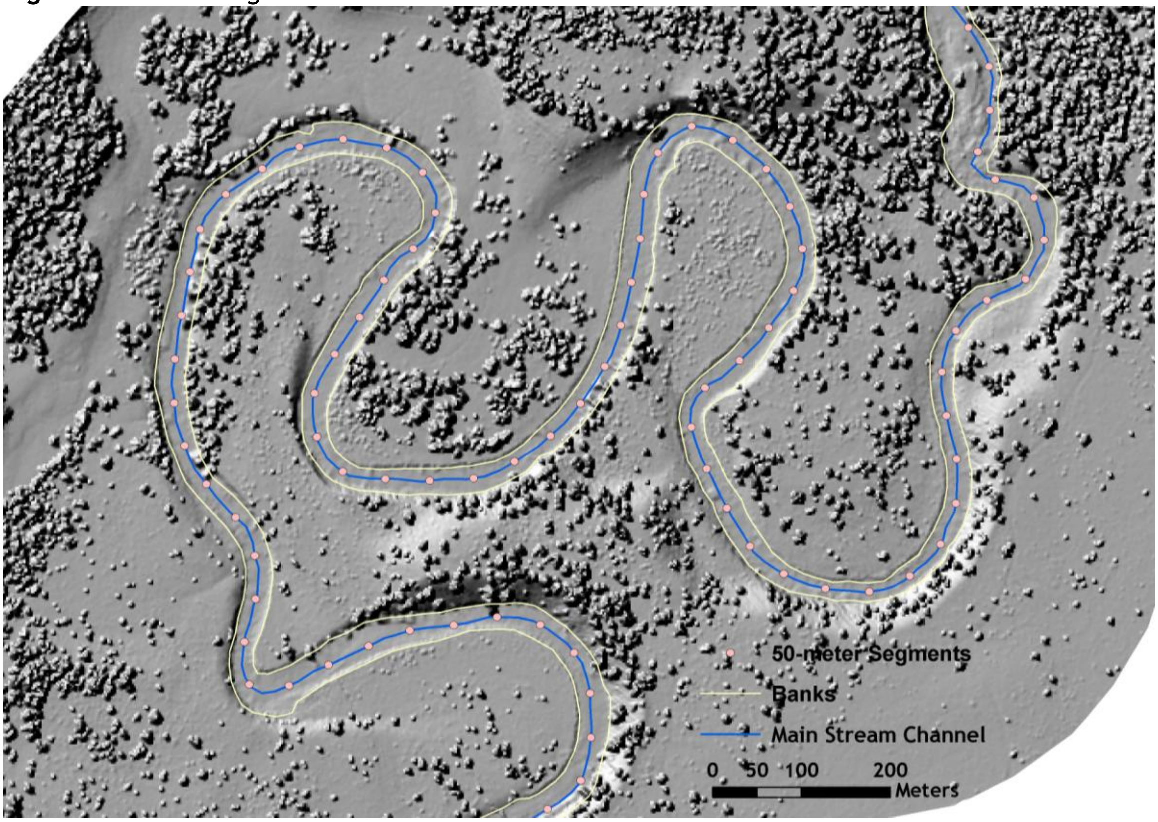


Figure 17 - Bare earth LiDAR digital elevation model.

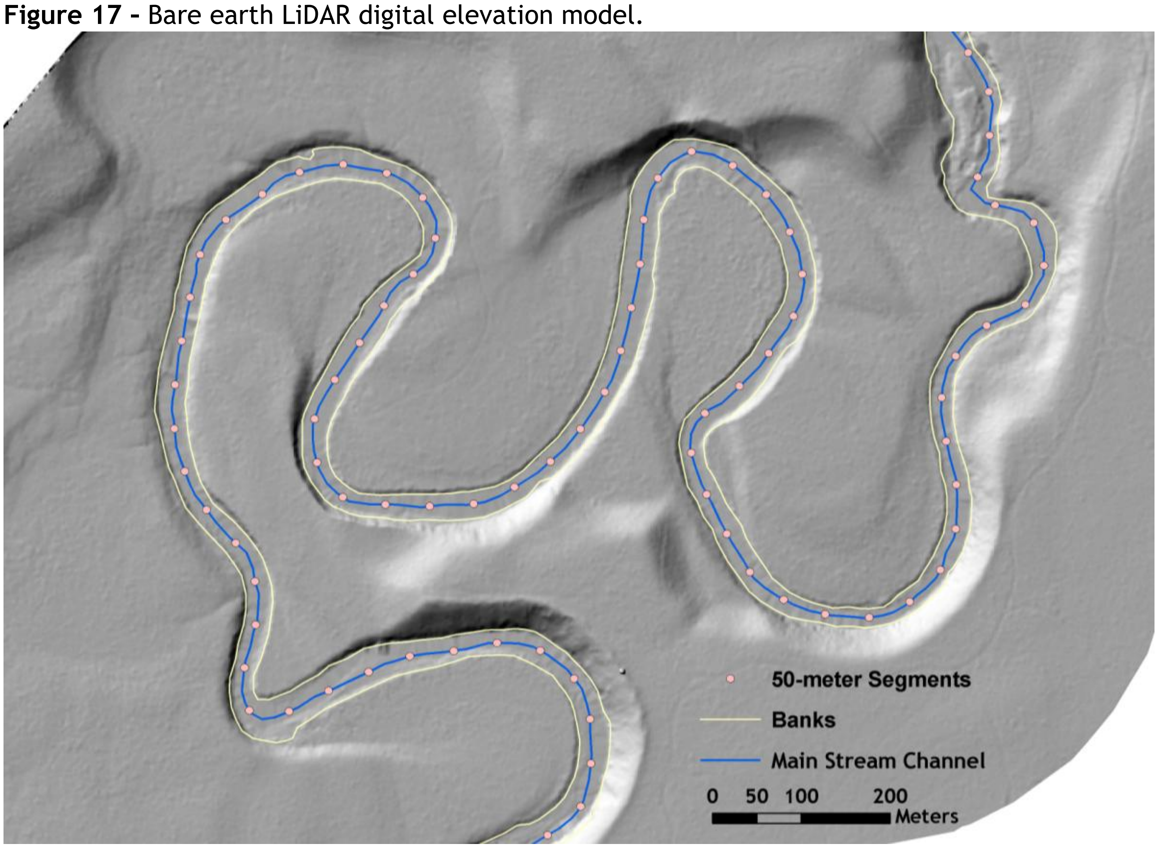
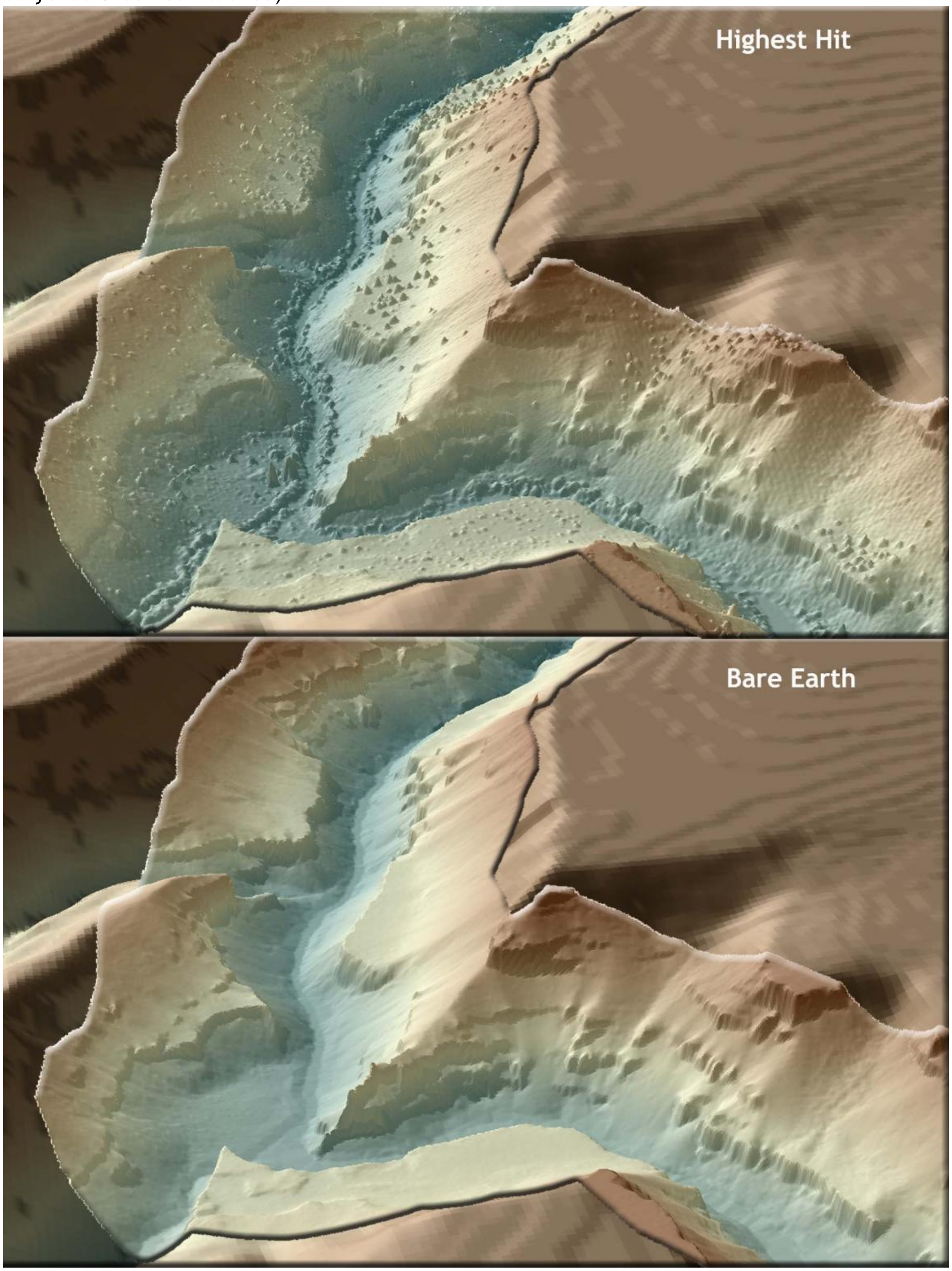


Figure 18 contains the highest hit and bare earth LiDAR DEMs of the Deschutes River near the Whychus Creek confluence. For comparison purposes, the 10-meter DEM of the surrounding area is also shown. LiDAR data provides high-resolution land surface and land cover elevation data.

Figure 18 – Highest hit and bare earth LiDAR DEM overlaid on 10-meter DEM (Deschutes River at Whychus Creek confluence).



Derived Data

Color digital orthoimagery of the study area was acquired in 2005 (NAIP 2005). The imagery was published with a 1-meter pixel resolution, mosaiced according to county, and MrSid compressed. The NAIP orthophotos have a horizontal accuracy of ±5 meters and are referenced to digital ortho quarter quads (DOQQs) from the National Digital Ortho Program (NDOP). The NAIP orthophotos are formatted to the UTM NAD83 coordinate system.

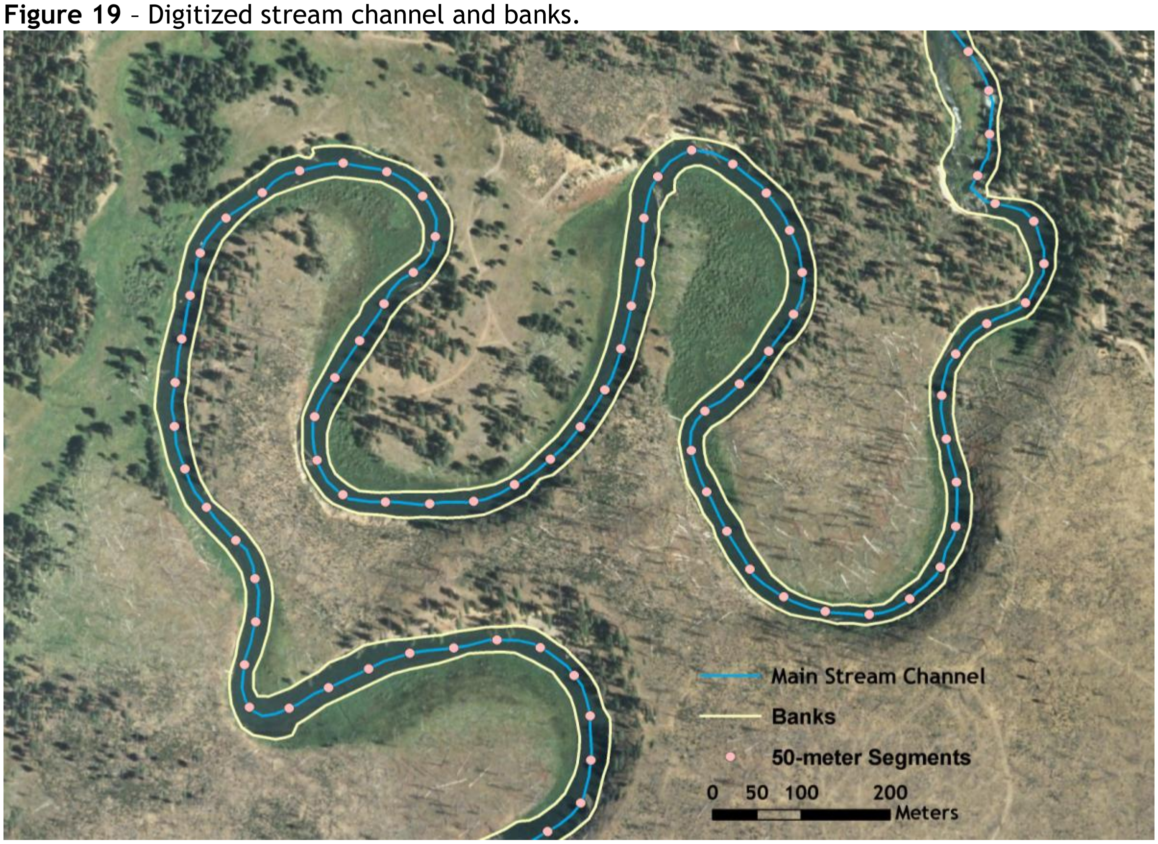
Digitized Stream and Channel Edges

Stream channels were digitized at a 1:5,000 or smaller map scale from the NAIP orthophotos for all three streams. In reaches where the stream channel split, the larger channel was digitized.

The right and left banks (looking in the downstream direction) were also digitized from the NAIP orthophotos at a 1:5,000 or smaller map scale. The Deschutes River was the only stream large enough to clearly distinguish the banks in the along its entire length. Many reaches of Whychus and Tumalo Creeks were either too narrow or too vegetated to digitize the channel edges. In such cases, the channel widths were estimated based on field data or upstream and downstream comparison.

Figure 19 shows the digitized stream and channel edges on the upper Deschutes River. The digitized stream channel was used to determine the location and course of the stream for modeling input, and is the basis for creating 50-meter stream segments. The digitized banks were used for measuring the stream channel width at each of the 50-meter segments.

Figure 19 – Digitized stream channel and banks.



Digitized Near Stream Land Cover

The streams were buffered by 100 meters from each channel edge. The buffer was then overlaid on the digital ortho images and polygons were created according to unique land cover types at a 1:5,000 map scale or less (Figure 20). Each polygon contains a unique species or land cover composition, height class, and density class.

The land cover polygons were delineated based upon NAIP orthophoto interpretation. Each land cover polygon was assigned a generalized height class of “small” or “large”. Density was characterized as greater than 50% or less than 50%. Land cover types were classified as deciduous, conifer, mixed, shrub, grass, building, and other general descriptions.

The digitized near stream land cover is most accurate according to the date that the NAIP orthophotos were collected, which was in 2005.

Figure 20 – Digitized land cover.

Table 4 summarizes the numeric codes and descriptions used to uniquely identify each of the digitized land cover polygons. Within the Whychus Creek and Tumalo Creek Heat Source models, height values and densities were estimated for each land cover code based on field measurements and LiDAR height values for equivalent stand types. In the Deschutes River model, the height values were sampled from the LiDAR data.

Table 4 – Digitized land cover polygon codes and descriptions.

Code	Description
500	Mixed Forest, Large, Higher Density
501	Mixed Forest, Small, Higher Density
550	Mixed Forest, Large, Lower Density
551	Mixed Forest, Small, Lower Density
700	Conifer Forest, Large, Higher Density
701	Conifer Forest, Small, Higher Density
750	Conifer Forest, Large, Lower Density
751	Conifer Forest, Small, Lower Density
850	Shrubs
499	Juniper, Sage
477	Recently Disturbed Forest
315	Clearcut with >50% Regeneration Saplings
302	Pasture, Cultivated or Lawn
900	Dry Grasses
901	Wet Grasses
902	Golf Course
304	Rock
305	Embankment
306	Campground or Park
307	Gravel Pit
308	Clearcut
309	Clearcut with <50% Regeneration Saplings
400	Road (paved)
401	Road (unpaved forest)
403	Road (unpaved agricultural)
310	Barren
311	Recently Burned Forest, <50% Regeneration
3248	Residential Structure
3249	Commercial Structure
3011	River Bottom, Flood Plain
301	Water
849	Riparian Shrubs, Large
899	Riparian Shrubs, Small
3252	Dam
3253	Pipeline

TTools Sampling Methods and Results

TTools is a set of ArcView GIS tools that are designed to automatically sample spatial data sets and assemble an input database for Heat Source modeling (Watershed Sciences, 2003). This section describes the various TTools sampling routines that were performed on the Deschutes River, Whychus Creek, and Tumalo Creek in preparation for stream temperature modeling.

<u>Deschutes River</u>

Segmentation – The digitized stream polylines was segmented into 50-meter reaches.

Channel Widths – The distance between each of the digitized banks (perpendicular to the stream aspect) was measured at each of the 50-meter segments.

Stream Elevation and Gradient – The stream elevation at each of the 50-meter segments was measured from the 10-meter DEM, using a radial 25-cell sampling routine.

Topographic Shade Angles – The maximum topographic shade angles to the north, south, and west were measured at each 50-meter segment from the 10-meter DEM. The sampling routine extended 20 kilometers in each direction.

Land Cover – The land cover height raster (derived from the original USGS LiDAR data) was sampled in a radial pattern, using a 15-meter outward step, up to 60 meters from the stream centerline.

<u>Whychus and Tumalo Creeks</u>

Segmentation – The digitized stream polylines were segmented into 50-meter reaches.

Channel Widths – In many reaches, the banks were not visible within the NAIP orthophotos because of the small stream size or vegetation cover, and therefore channel widths were not measurable. In such reaches, the channel widths were estimated based upon field data and upstream/downstream observations.

Stream Elevation and Gradient – The stream elevation at each of the 50-meter segments was measured from the 10-meter DEM, using a radial 25-cell sampling routine.

Topographic Shade Angles – The maximum topographic shade angles to the north, south, and west were measured at each of the 50-meter segments from the 10-meter DEM. The sampling routine extended 20 kilometers in each direction.

Land Cover – The land cover polygons that were digitized from the digital ortho images were sampled in a radial pattern, using a 15-meter outward step, up to 60 meters from the stream centerline.

The Deschutes River right and left banks were digitized from the NAIP orthophotos. TTools was used to measure the channel width (perpendicular to the stream aspect) every 50 meters along the stream from Wickiup Reservoir to Lake Billy Chinook. Figure 21 shows the TTools-sampled channel widths. The city of Bend is located from around kilometers 85 through 101 in Figure 21. Downstream of Bend, the Deschutes River flows through a more constricted canyon and the channel widths are narrower than upstream of Bend.

Figure 21 - Deschutes River channel widths.

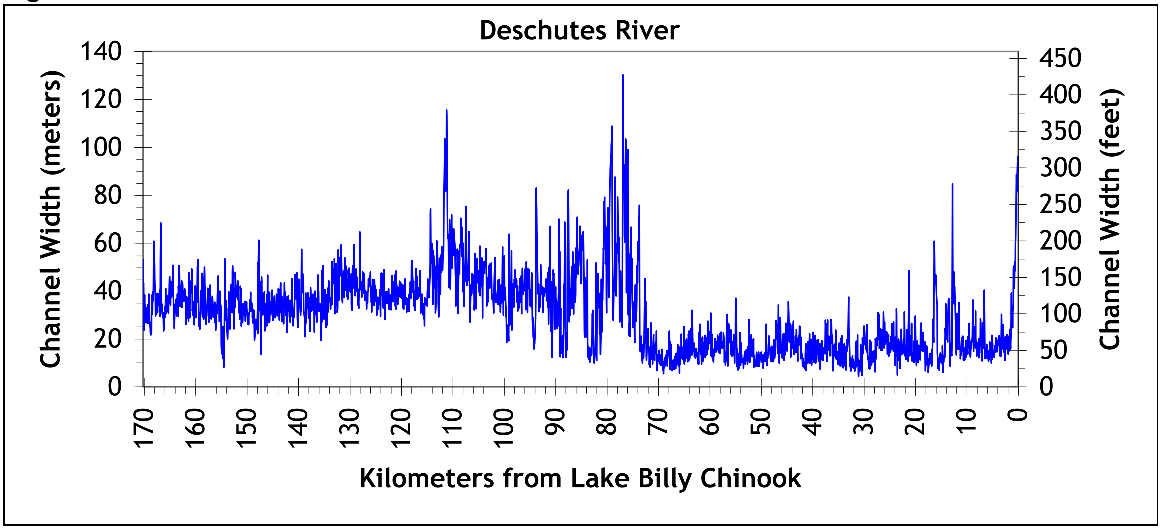


Figure 22 on the following page contains the TTools-sampled stream elevations and calculated gradients for each 50-meter stream segment. Upstream of Bend, the Deschutes River gradient is well below 1%, while downstream of Bend the gradients increase to around 0.5-3.0%. The gradient of Tumalo Creek is typically 1-2%, with a steeper reach near the middle. Whychus Creek has its steepest gradients in the upper elevations.

Figure 23 summarizes the stream aspects (direction of flow) for each of the 50-meter segments. The Deschutes River generally flows from the south to the north. Tumalo Creek flows east to north east. Whychus Creek flows toward the northeast. Stream aspect is an important model input parameter because it used for calculating the amount of solar radiation that reaches the stream surface at each 50-meter segment.

Figure 24 displays the TTools-sampled topographic shade angles. For simplified display purposes, the 1-kilometer moving averages are shown. East, south and west topographic shade angles were sampled at each 50-meter segment and are used within the temperature model for determining the timing and amount of solar radiation loading at the stream surface.

Figure 22 – Stream elevations and gradients.

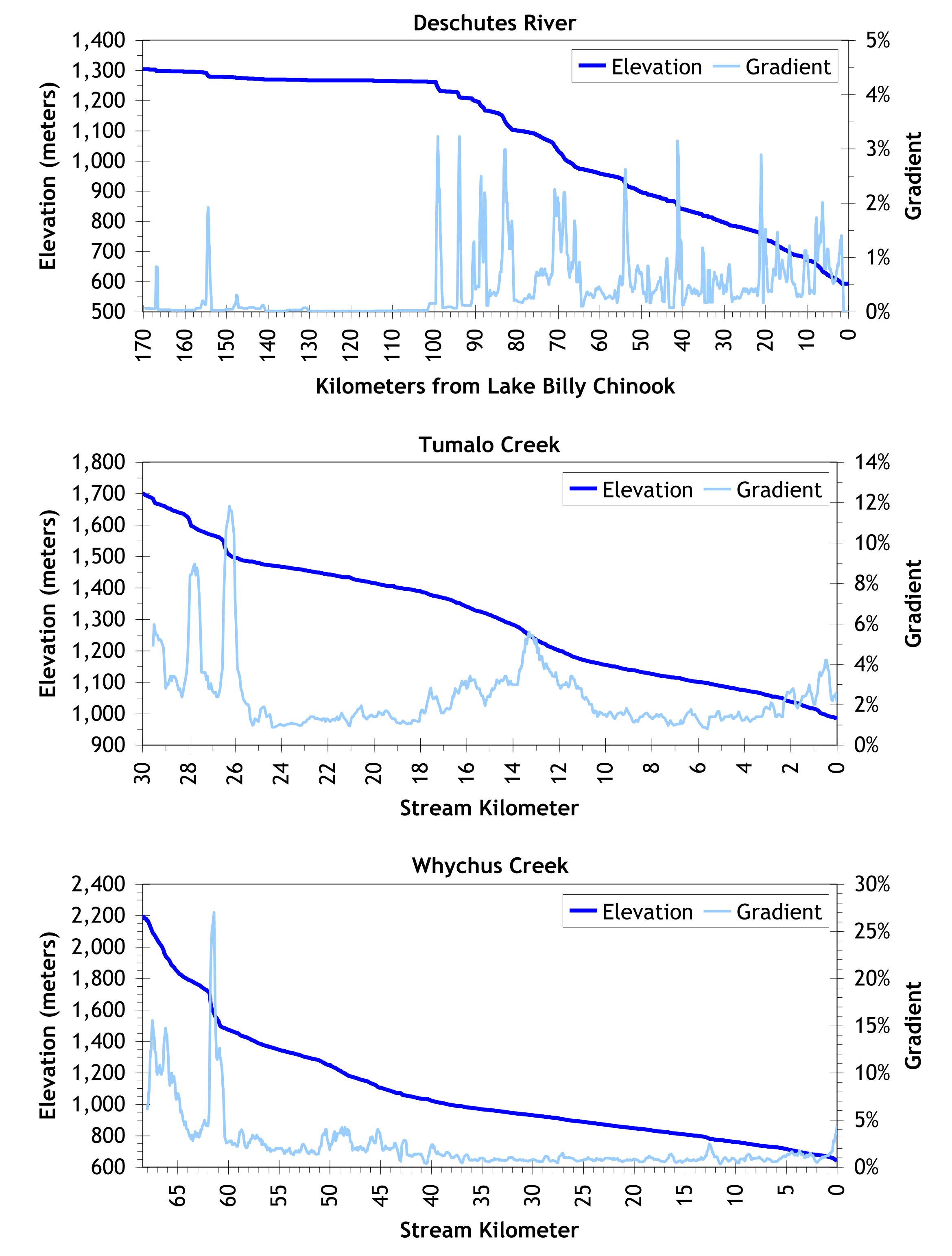


Figure 23 – Stream aspects (direction of flow).

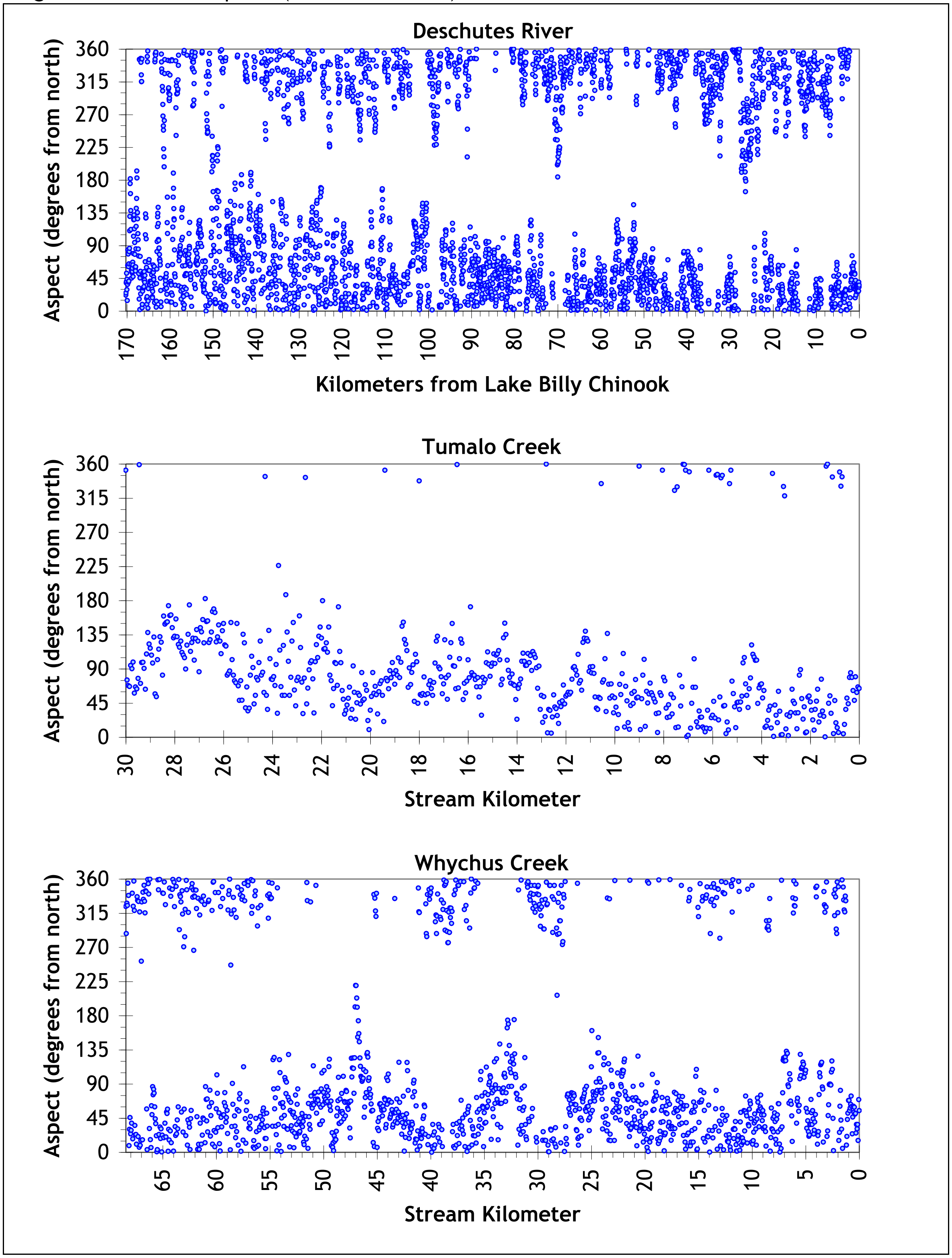
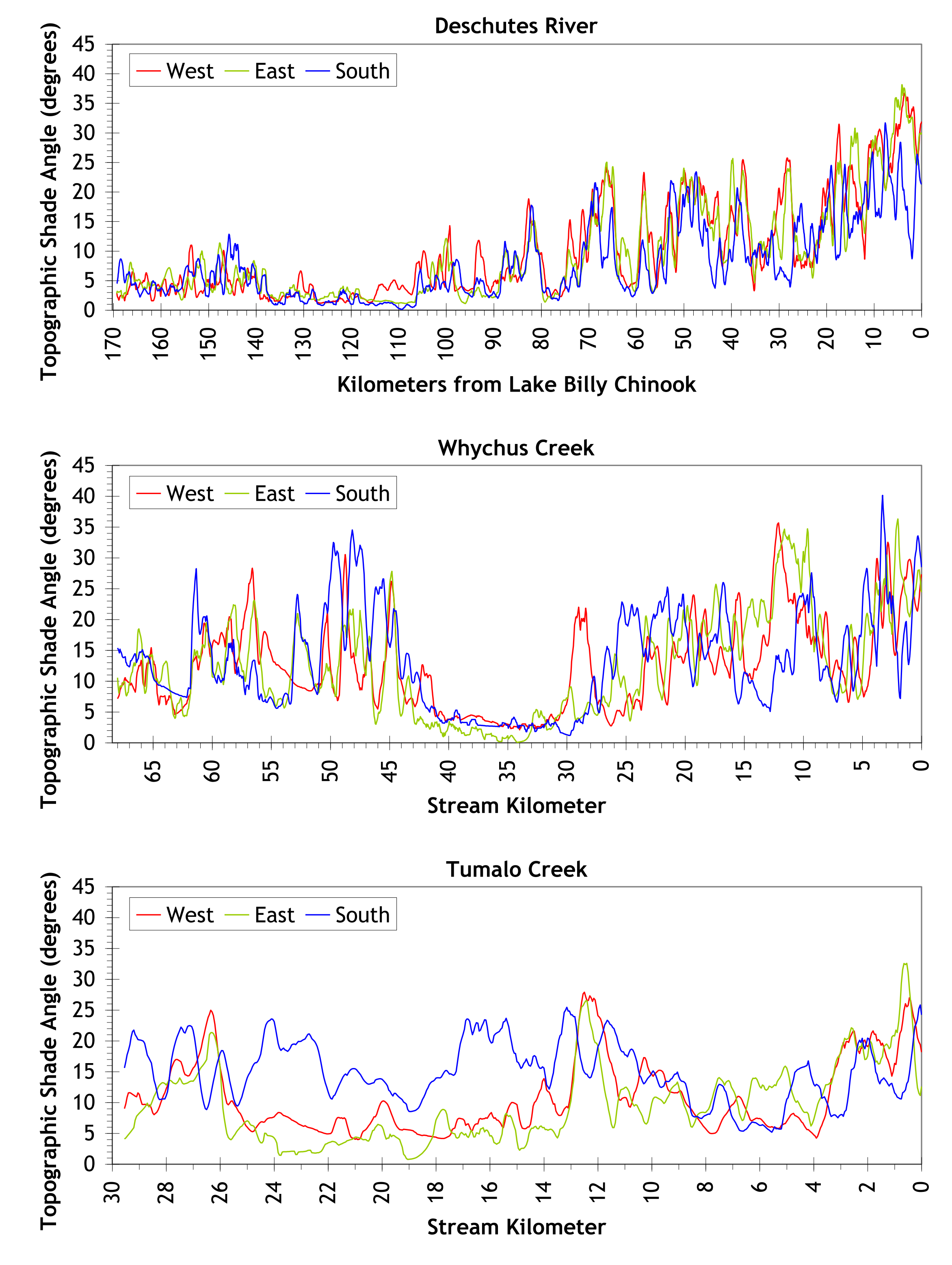


Figure 24 – Topographic shade angles.



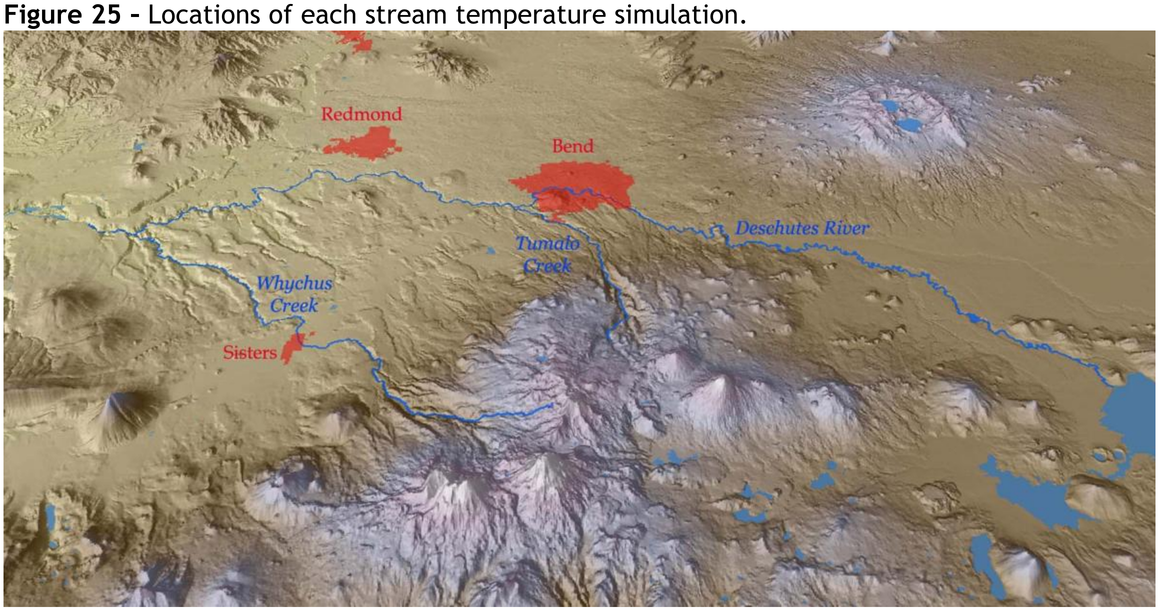
Section Two – Stream Temperature Model Calibration

Introduction

The data sources described in the previous section were used to set up individual Heat Source models for the Deschutes River, Tumalo Creek, and Whychus Creek (study area shown in Figure 25). Each model was calibrated to the hourly instream temperature data, the TIR temperature profiles, and measured stream flow parameters.

This section describes each model's resolution, extent, time period, data sources, and assumptions. The simulated current condition temperatures were compared to the measured hourly instream and TIR data and the root mean square error (RMSE) statistics were calculated. Typically, a calibrated Heat Source model is accurate within ±1.0°C on average. Simulated effective shade and hydraulic parameters were also compared to ground level measured values.

Figure 25 – Locations of each stream temperature simulation.

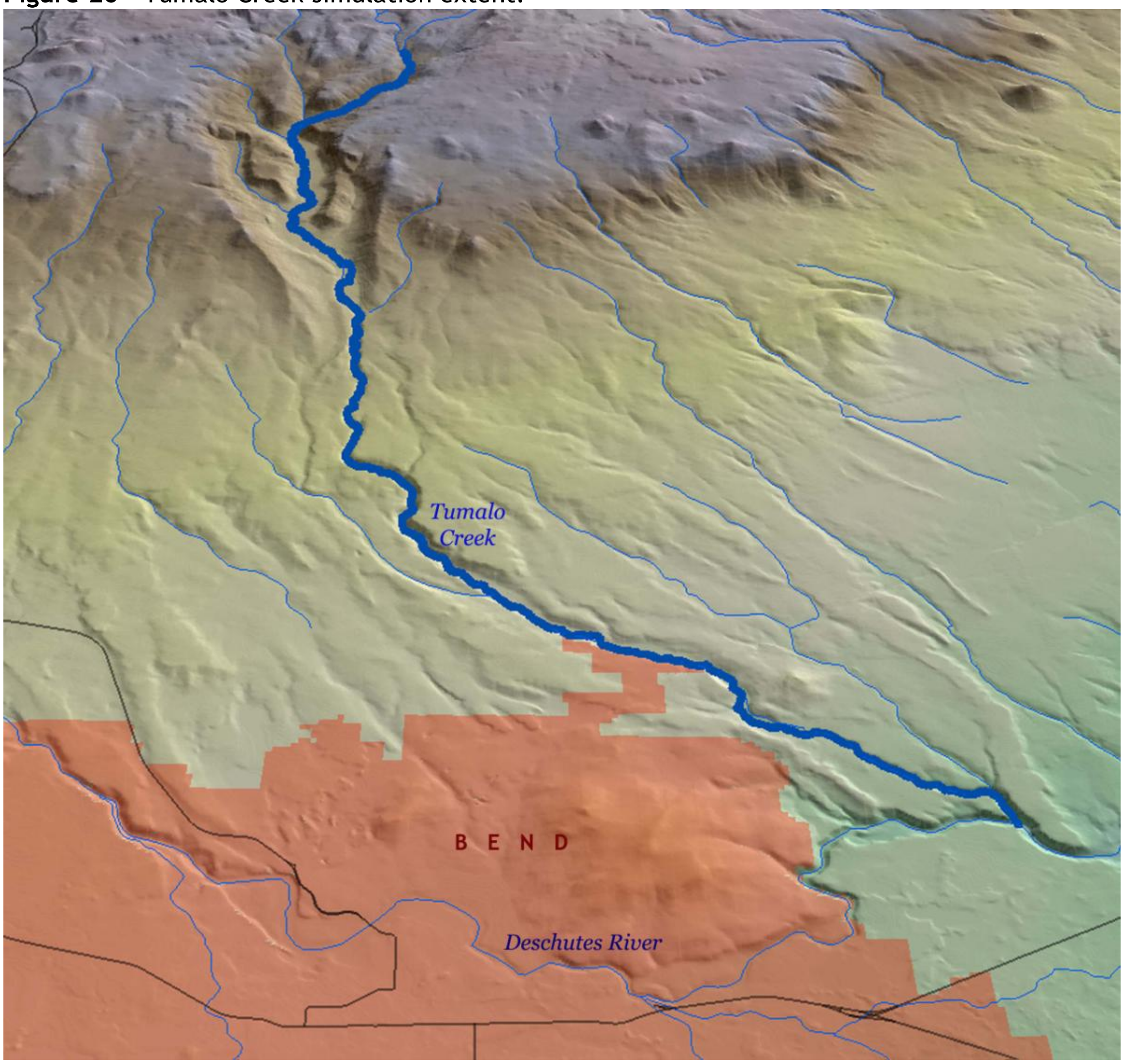


Tumalo Creek Stream Temperature Simulation

Overview:

Tumalo Creek was simulated from the confluence of its forks to the mouth for a three week period beginning July 19, 2001 (Figure 26). The existing flow regime is influenced by diversions that occur within Tumalo Creek and its tributaries. For example, the City of Bend diverts water from Bridge Creek for municipal use, and whatever the city does not use is returned to Tumalo Creek many miles downstream of Bridge Creek. In addition, there is a large irrigation canal (Tumalo Irrigation District – TID) approximately 4 kilometers from the mouth which diverts most of Tumalo Creek. Flow alterations, combined with channel modification and near stream vegetation disturbance influences Tumalo Creek temperatures.

Figure 26 - Tumalo Creek simulation extent.



Simulation Extent:

- Confluence of the Middle Fork and North Fork to the mouth.
- 30 stream kilometers (18.6 stream miles).

Simulation Resolution:

- Time step: one minute.
- Input distance step: 50 meters.
- Output distance step: 100 meters.

Simulation Period:

- July 19, 2001 through August 7, 2001

Data Sources:

- Thermal infrared (TIR) stream temperature data was collected on July 23, 2001 from 14:57 to 15:32, beginning at the mouth and progressing upstream.
- Hourly instream temperature data was collected at five locations within Tumalo Creek and at the mouths of Bridge Creek and the South Fork Tumalo Creek during the simulation period.
- Flow data consisted of hourly gage data and instantaneous flow measurements collected during the simulation period.
- The City of Bend was diverting a constant rate from Bridge Creek. Hourly usage amounts were recorded.
- Near stream land cover, active channel edges, and the stream thalweg were delineated from the 2005 NAIP orthophotos.
- Stream elevations, gradients, and topographic shade angles were sampled from the USGS 10-meter digital elevation model (DEM).
- Hourly climate data collected by the Redmond airport during the simulation period were used.

Calibration Notes and Assumptions:

- Vegetation height values were estimated based upon the field data ranges and sampled values of the Deschutes River LiDAR in similar tree-type stands.
- Elevation and gradient sampling from the DEM produced many artificially steep reaches or “stair steps”. The 500-meter moving average of the TTools-calculated gradients was used within the model.
- The stream channels were too small to digitize from the NAIP orthophotos in many reaches, especially below the TID canal. Those reaches had to be estimated by taking several manual measurements of the NAIP orthophotos wherever the stream was visible. Estimated channel widths were applied within the model on a one-kilometer reach basis.
- Stream temperature data collected at the mouth did not pass quality assurance protocols and was not used for model validation.
- Hourly climate data is from the Redmond airport (the most comprehensive climate record available in the basin). Raw values were used for air temperature and humidity. The wind speeds were reduced by 75%.
- Tributary and spring inflows were identified within the TIR imagery and a flow/temperature mass balance was performed in the downstream direction in order to derive the input flow volumes. The derived flow profile of Tumalo Creek was validated using instream flow measurements and gage data.

- The City of Bend collected hourly data on the amount of diversion water used. That amount was subtracted from the diversion rate at Bridge Creek in order to estimate the amount returning to Tumalo Creek downstream.
- Return from Bridgewater Creek diversion was monitored by City of Bend and those records were used to account for the water returning to Tumalo Creek.
- Hourly diversion data is available for the TID canal and was used to simulate the diversion.
- Downstream of the diversion canal, the drastically reduced flow volume made model calibration more challenging. The channel was too small and/or too vegetated to view in the NAIP orthophotos; therefore, the widths could not be digitized. That, combined with the small flow volume makes simulated stream temperatures more variable or sensitive to a variety of parameters.
- The OWRD point of diversion database was assessed to identify potential significant diversions, other than the Tumalo Canal. The number and quantity of diversions in the POD database were insignificant relative to the stream flow, and not included within the model (there is no data for actual diversion rates at those PODs during the simulation period).
- Stream kilometers 26-21.5 flow through a recently disturbed area (Figure 27). The near stream vegetation in this reach is immature and provides little effective shade. Additionally, this reach is low-gradient and the channel is wider than it is upstream or downstream. The TIR data was collected in 2001, and there have been restoration efforts in that area since then. Comparison of the 2001 TIR day video images with the 2005 NAIP orthophotos reveals no major differences in channel or vegetation that would significantly impact the simulation results; therefore it is assumed that the vegetation and stream channel digitized from the 2005 NAIP orthophotos is representative of the 2001 conditions.

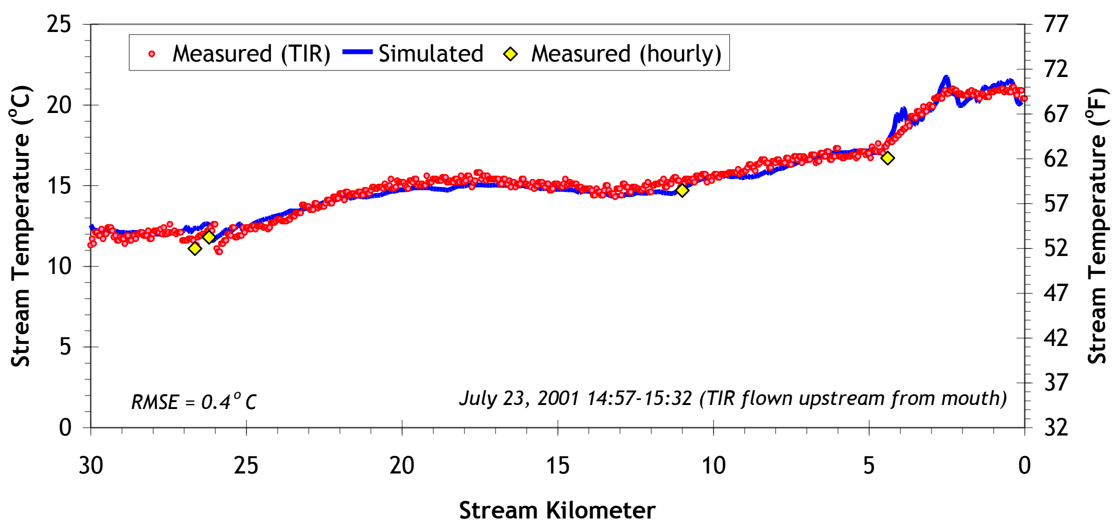
Figure 27 – Tumalo Creek, looking upstream through recently disturbed area (stream kilometers 22-26).

Tumalo Creek Calibration Results:

The simulated stream temperature was calibrated to both instantaneous TIR and hourly instream data. Hydraulic parameters such as flow volume, velocity, depth, and wetted width were validated against field measurements and gage data. Simulated effective shade was validated against Solar Pathfinder measurements collected at various locations along the stream.

Figure 28 shows the simulated and measured stream temperatures for the date and time that the TIR data was collected. The RMSE is 0.4°C for the instantaneous longitudinal temperature data. (Hourly RMSE statistics are presented on the following page.) There is increased variability in the simulated stream temperatures of the lower 4 kilometers due to the significantly reduced flow volumes.

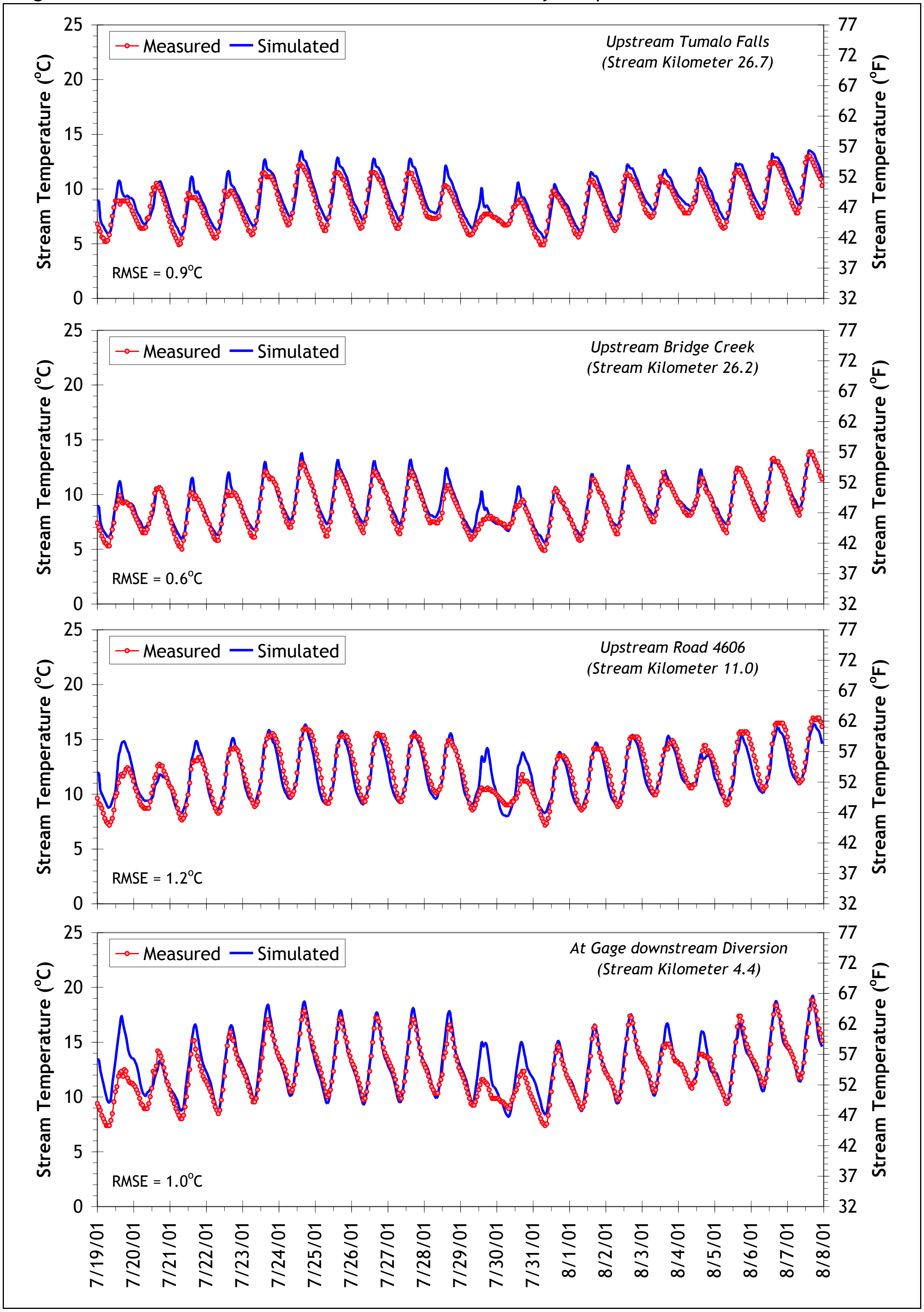
Figure 28 - Tumalo Creek measured and simulated stream temperature data.



The simulated and measured hourly stream temperatures are presented in Figure 29 on the following page. The RMSE for the hourly data was ranged from 0.6 to 1.2°C. There was a monitoring site at the mouth of Tumalo Creek; however, the temperature data did not pass quality assurance inspection.

On July 30 and 31, the measured temperatures were cooler than the rest of the simulation time period. The model failed to simulate those markedly cooler stream temperatures, especially at the lower monitoring sites. The anomaly is likely the result of meteorological conditions that were poorly represented by the Redmond airport climate data (e.g., there could have been isolated thunder showers in the upper watershed which impacted stream temperatures).

Figure 29 - Tumalo Creek measured and simulated hourly temperature data.



The simulated and measured effective shade values are shown in Figure 30. The dots are individual outputs for each 100 meters, while the solid lines are the ½-kilometer moving averages.

Figure 30 - Tumalo Creek simulated and measured effective shade and solar flux (August 1).

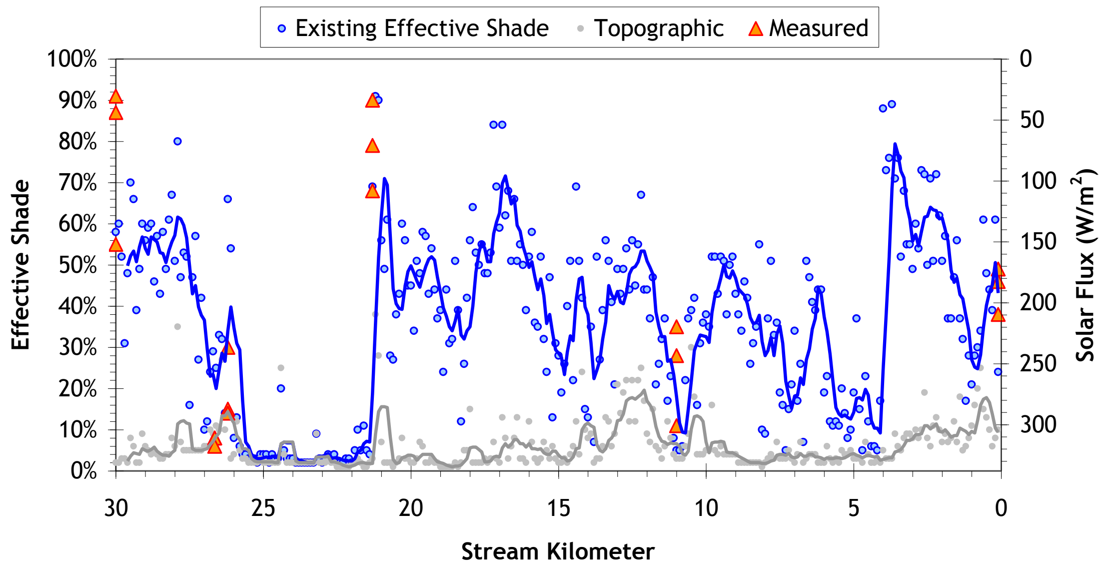


Figure 31 through Figure 33 show the simulated and measured hydraulic parameters for Tumalo Creek on the day of the TIR flight. Most of the stream flow is diverted at approximately stream kilometer 4.

Figure 31 - Tumalo Creek simulated and measured stream flow velocities (7/23/2001).

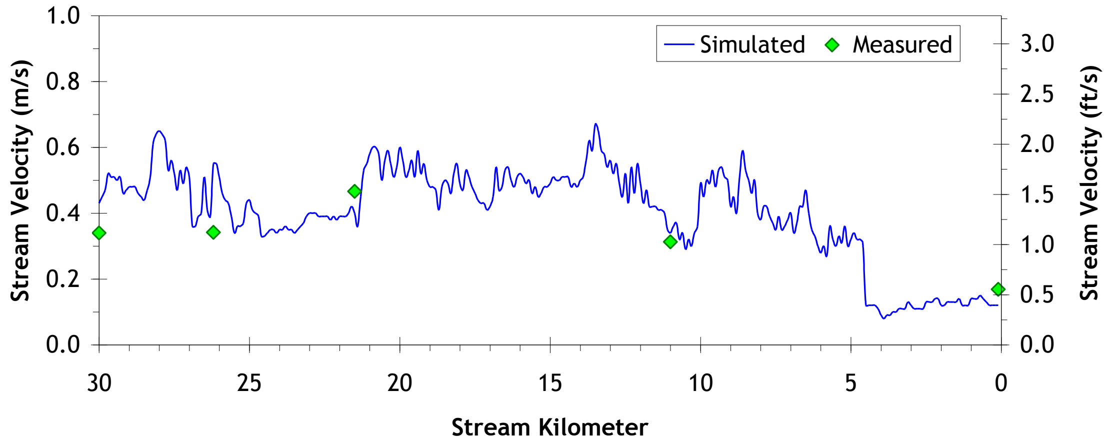


Figure 32 - Tumalo Creek simulated and measured wetted widths (7/23/2001).

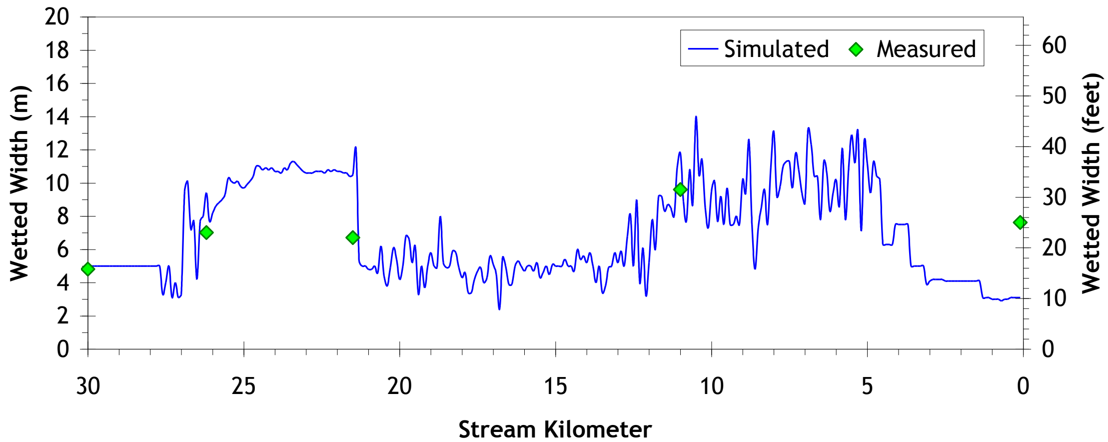
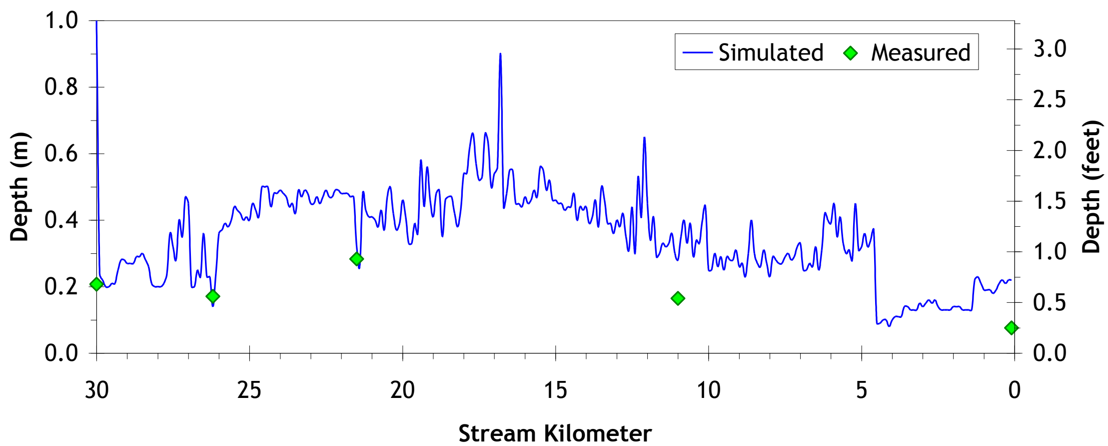


Figure 33 - Tumalo Creek simulated and measured stream depths (7/23/2001).



Tumalo Creek Flow Profile

The measured and simulated flows are shown in Figure 34. Flow measurements were collected over three different days. The large reduction in flow near stream kilometer 4 is caused by the TID Canal diversion. Figure 35 shows the measured diversion rates that occurred during the simulation period.

Figure 34 - Tumalo Creek simulated and measured flow volumes.

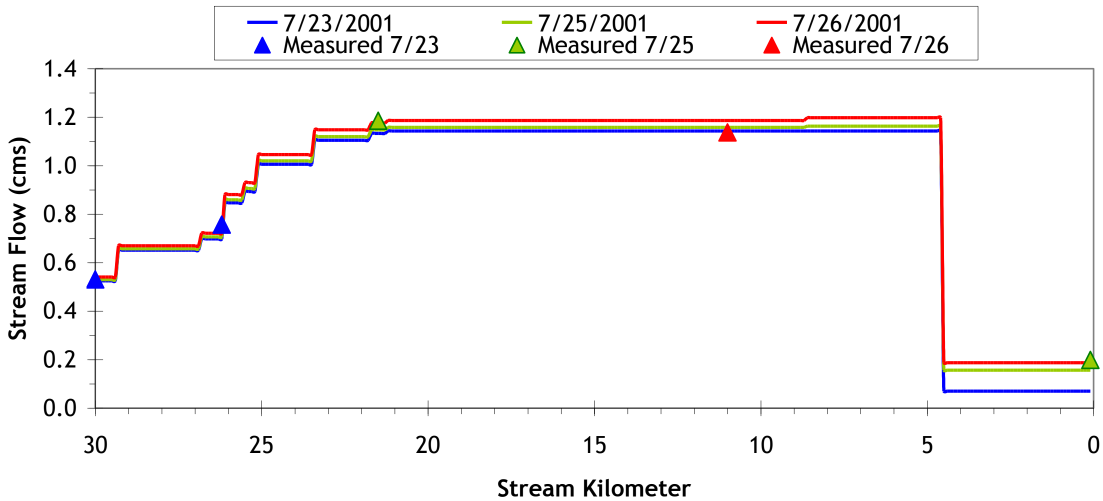


Figure 35 - Tumalo Creek daily average irrigation canal diversion rates.

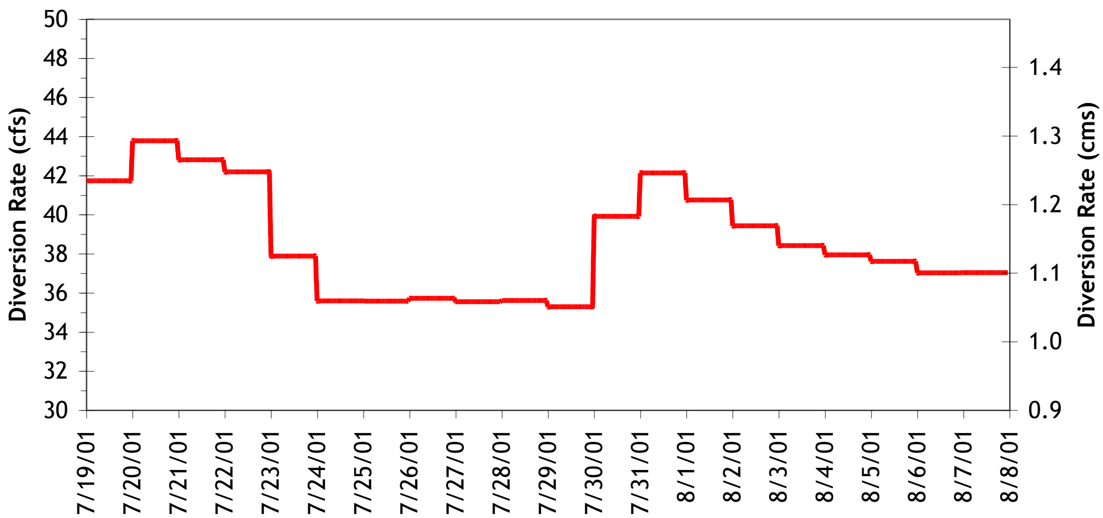
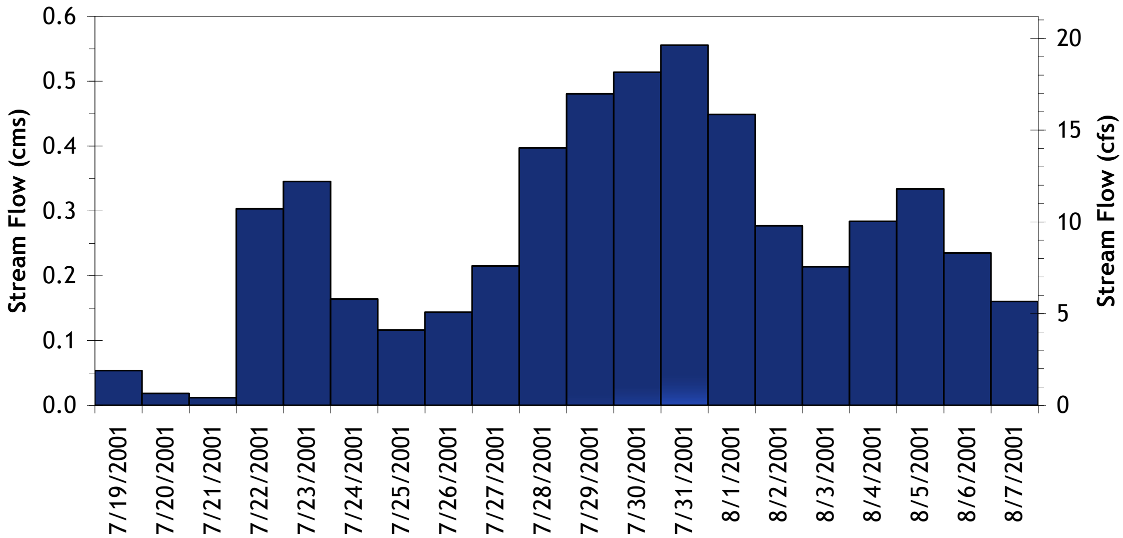


Figure 36 shows the daily average flow volumes recorded at the OWRD gage (14076000) near Bend. This gage is located downstream of the TID diversion canal and is therefore not representative of the upstream flows. During the simulation period, the flows of the lower 4 kilometers of Tumalo Creek ranged from near zero cfs to almost 20 cfs.

Figure 36 – Gaged stream flows on Tumalo Creek near Bend (Gage 14076000).

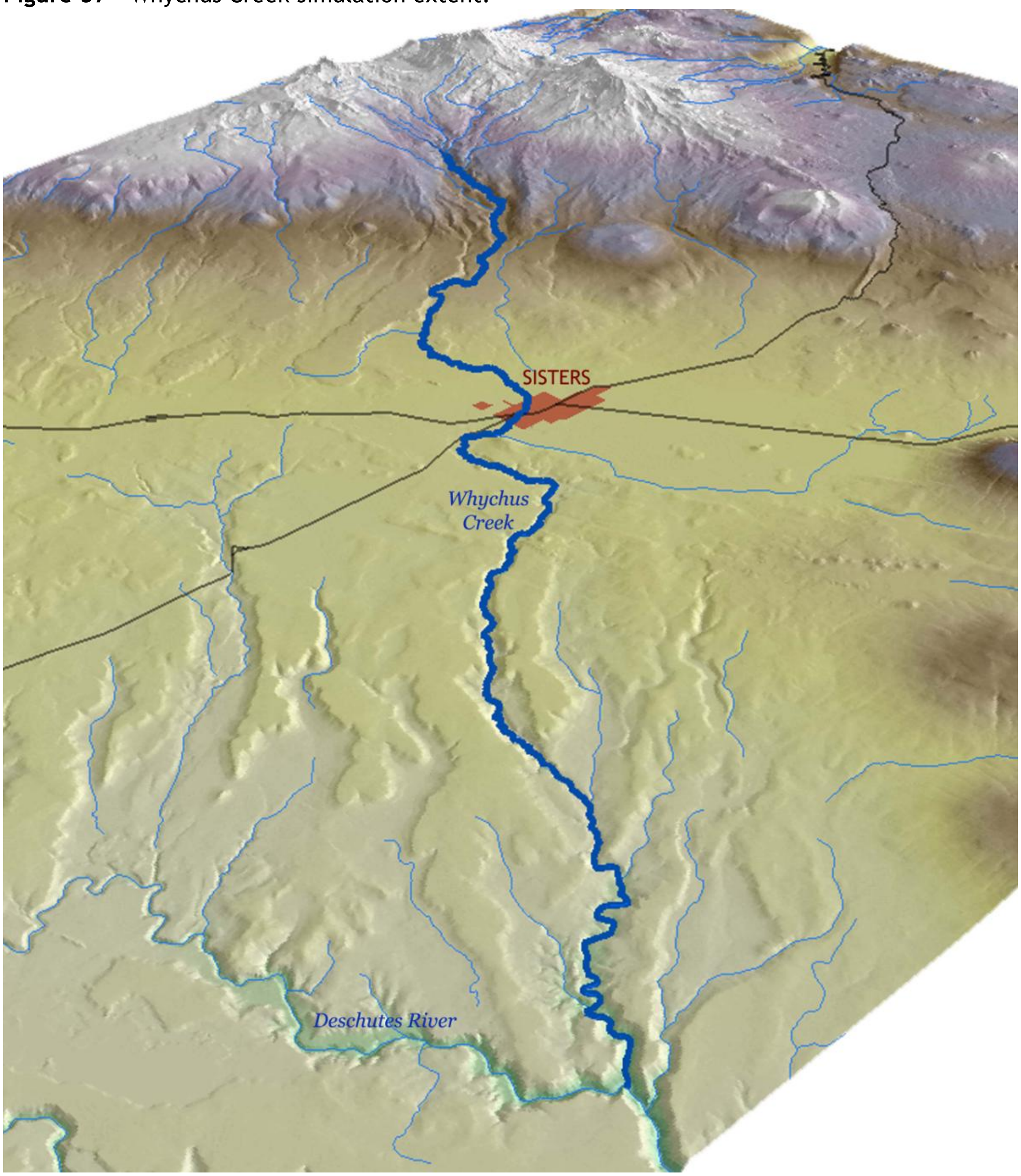


Whychus Creek Stream Temperature Simulation

Overview:

Whychus Creek was simulated from upstream of the North Fork to the mouth (Figure 37). A series of irrigation canals between Snow Creek and the city of Sisters diverts most of the water out of Whychus Creek. Summer stream flows are relatively low (less than 10 cfs) downstream of Sisters, until Alder Springs, near the mouth of Whychus Creek. Above the diversions, the stream flow has a 20-30 cfs diurnal fluctuation due to daily glacial melting patterns.

Figure 37 - Whychus Creek simulation extent.



Simulation Extent:

- One kilometer upstream of the North Fork to the mouth.
- 59.4 stream kilometers (36.9 stream miles).

Simulation Resolution:

- Time step: one minute.
- Input distance step: 50 meters.
- Output distance step: 100 meters.

Simulation Period:

- July 25, 2000 through August 15, 2000

Data Sources:

- Thermal infrared (TIR) stream temperature data was collected on July 28, 2000 from 16:06 to 17:00.
- Hourly instream temperature data was collected at 12 locations in Whychus Creek and in the mouths of North Fork Whychus Creek, Snow Creek and Alder Springs during the simulation period.
- Flow data consisted of hourly gage data and instantaneous flow measurements collected during the simulation period.
- Near stream land cover, active channel edges, and the stream thalweg were delineated from the 2005 NAIP orthophotos and verified with the existing field measurements.
- Stream elevations, gradients, and topographic shade angles were sampled from the USGS 10-meter digital elevation model (DEM).
- Hourly climate data collected by the Redmond airport during the simulation period were used.

Calibration Notes and Assumptions:

- There is a discrepancy in the flow volumes of the upper reaches. The measured Whychus Creek flows summed with the North Fork and Snow Creek tributaries do not add up to what was measured downstream. There are no known significant withdrawals in those upper reaches. It is possible that the reaches are naturally losing reaches or the stream flow measurements contained errors. It has been assumed that the flow measurements are correct and the differences are accounted for within the model as “losing reaches”.
- Above the diversions, there is approximately a 20-30 cfs diurnal fluctuation due to daily glacier melting patterns.
- The stream channels were too small to digitize from the NAIP orthophotos in many reaches, especially below Sisters. Those reaches had to be estimated by taking several manual measurements of the NAIP orthophotos wherever the stream was visible. Estimated channel widths were applied within the model on a one-kilometer reach basis.
- Spring flows were not measured, except for Alder Springs (Figure 38). The significantly sized springs were identified in the TIR and a flow mass balance was derived in the downstream direction.
- In some reaches there are several smaller springs and/or cooler hyporheic areas. Those have been “clustered” within the model and represented as a single source input.
- There are several springs located within a kilometer of Alder Springs. Those are grouped as a single input within Heat Source and called “Alder Springs”. There are also

several small springs downstream of Alder Springs, one of which is larger and has a significant thermal impact – the mass balance reveals that the spring actually has more volume input than Alder Springs. There was no flow measurement taken at the mouth in 2000, so there is no validation data.

- Assumption: The instantaneous and gaged instream flow measurements are valid. If this is true, then the upper reaches are losing flow, especially between North Fork and Snow Creek confluences. In order to match the 7/25 measured flows above Sisters; water was removed evenly from each node between flow measurement sites in order to match the measured data.
- There is approximately a 6 cfs gain between Indian Ford and Camp Polk Road. In the TIR, there are several areas of hyporheic flow and a few springs. The location of the larger spring was identified and the entire volume input at that point in the simulation in order to represent the whole reach. It is an area of significant immediate cooling in the TIR profile.
- The Oregon Water Resources Department (OWRD) provided seepage run surveys for various years and months, focused mainly on reaches downstream of the diversions in Sisters. The seepage runs do not contain precise values that can be used as model inputs because they were measured at different months and years; however, the seepage run information confirms some of the reaches that were modeled as “losing” or “gaining” reaches. Additional support for simulating the gaining reaches comes from examination of the TIR imagery, where several springs and hyporheic areas were identified.
- The OWRD point of diversion database was assessed to identify potential significant diversions, other than the canals. The number and quantity of diversions in the POD database were insignificant relative to the stream flow, and not directly included within the model (there is no data for actual diversion rates at those PODs during the simulation period). Specific withdrawals downstream of Sisters were not measured and therefore not included as explicit withdrawals in Heat Source. They are indirectly accounted for within the losing reaches where flows were reduced at regular intervals in order for the simulated flow profile to meet the measured values.
- The TIR data does not match the instream measurements very well in the upper 5-10 stream kilometers. The TIR is about a degree Celsius lower than the instream data. Since this occurred at more than one site, the model was calibrated to the hourly instream data.

Figure 38 - Whychus Creek at Alder Springs (Alder Springs is the draw near top center of image).

Calibration Results:

The simulated stream temperature was calibrated to both instantaneous TIR and hourly instream data. Hydraulic parameters such as flow volume, velocity, depth, and wetted width were validated against field measurements and gage data. Simulated effective shade was validated against Solar Pathfinder measurements collected at various locations along the stream.

Figure 39 below shows the measured and simulated stream temperatures for Whychus Creek. The root mean square error of the longitudinal temperature calibration is 0.7°C. There is some uncertainty in the upper 7 kilometers of the simulation where the TIR temperatures indicate cooler temperatures than were simulated. The hourly instream temperature monitoring instruments recorded warmer stream temperatures than the TIR recorded. It is assumed that the hourly instream monitoring data is correct. The instream temperature monitoring equipment passed its audits, indicating that it was recording correct temperatures.

Figure 39 - Whychus Creek measured and simulated stream temperature data.

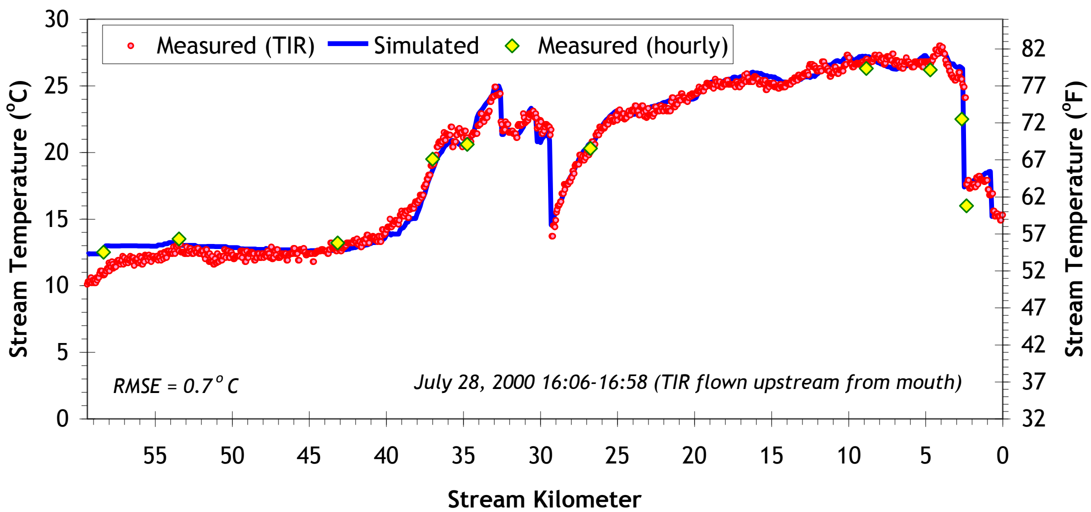


Figure 40 on the following pages shows the simulated and measured hourly stream temperature data. The hourly stream temperature calibration results are generally good. The sites upstream and downstream of Alder Springs had measured hourly temperatures that were slightly cooler than the simulated surface temperatures. Within this region, the model was calibrated to match the TIR data, which is most representative of mixed water column temperatures. Temperature monitoring instruments are generally anchored close to the stream bed, which may help explain the hourly temperature discrepancy at the lower two sites. There is significant ground water upwelling through the substrate in Whychus Creek around Alder Springs, which may make the stream bottom cooler than the fully mixed surface layer.

Figure 40 - Whychus Creek measured and simulated hourly stream temperatures.

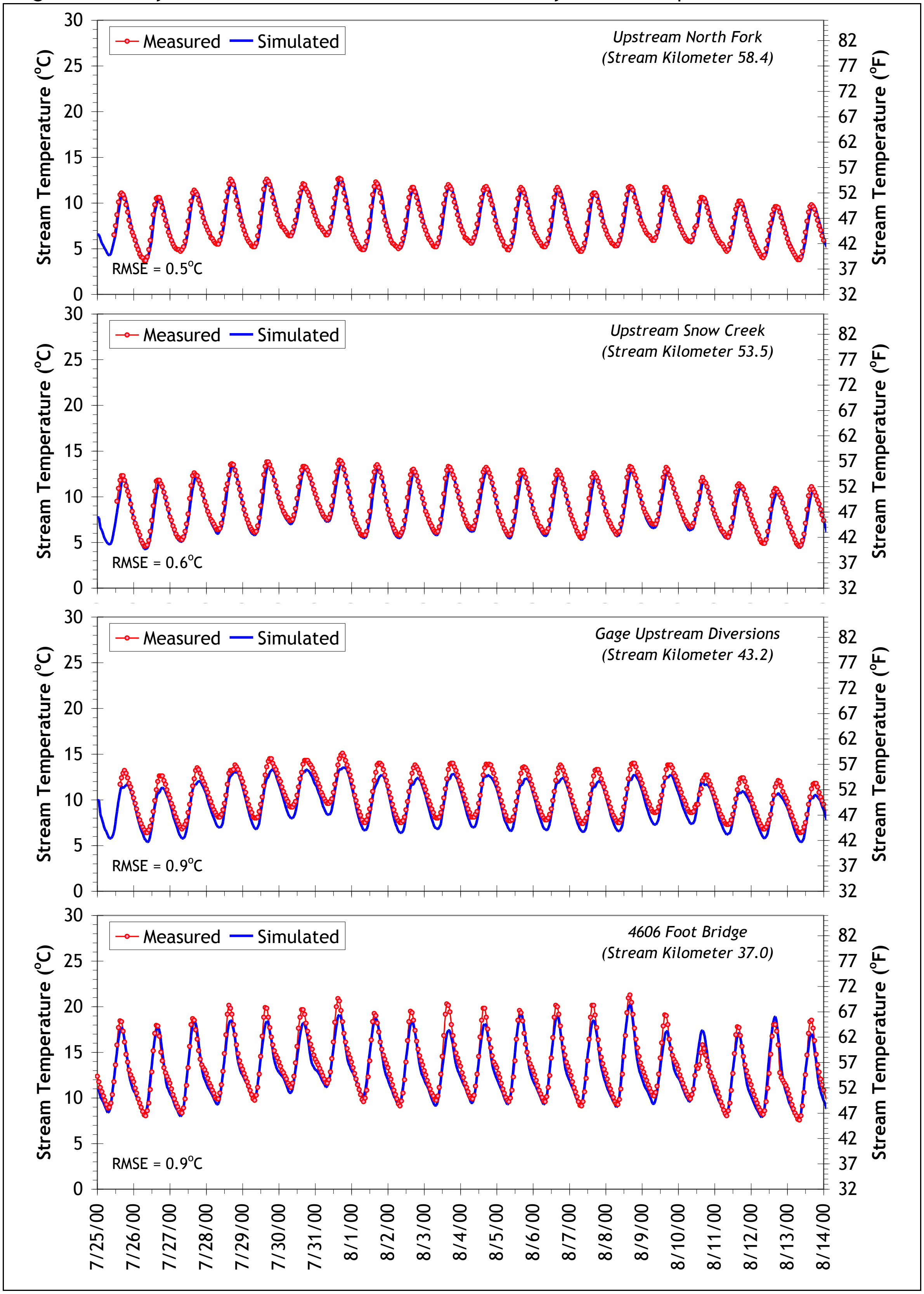


Figure 39 (continued) - Whychus Creek measured and simulated hourly stream temperatures.

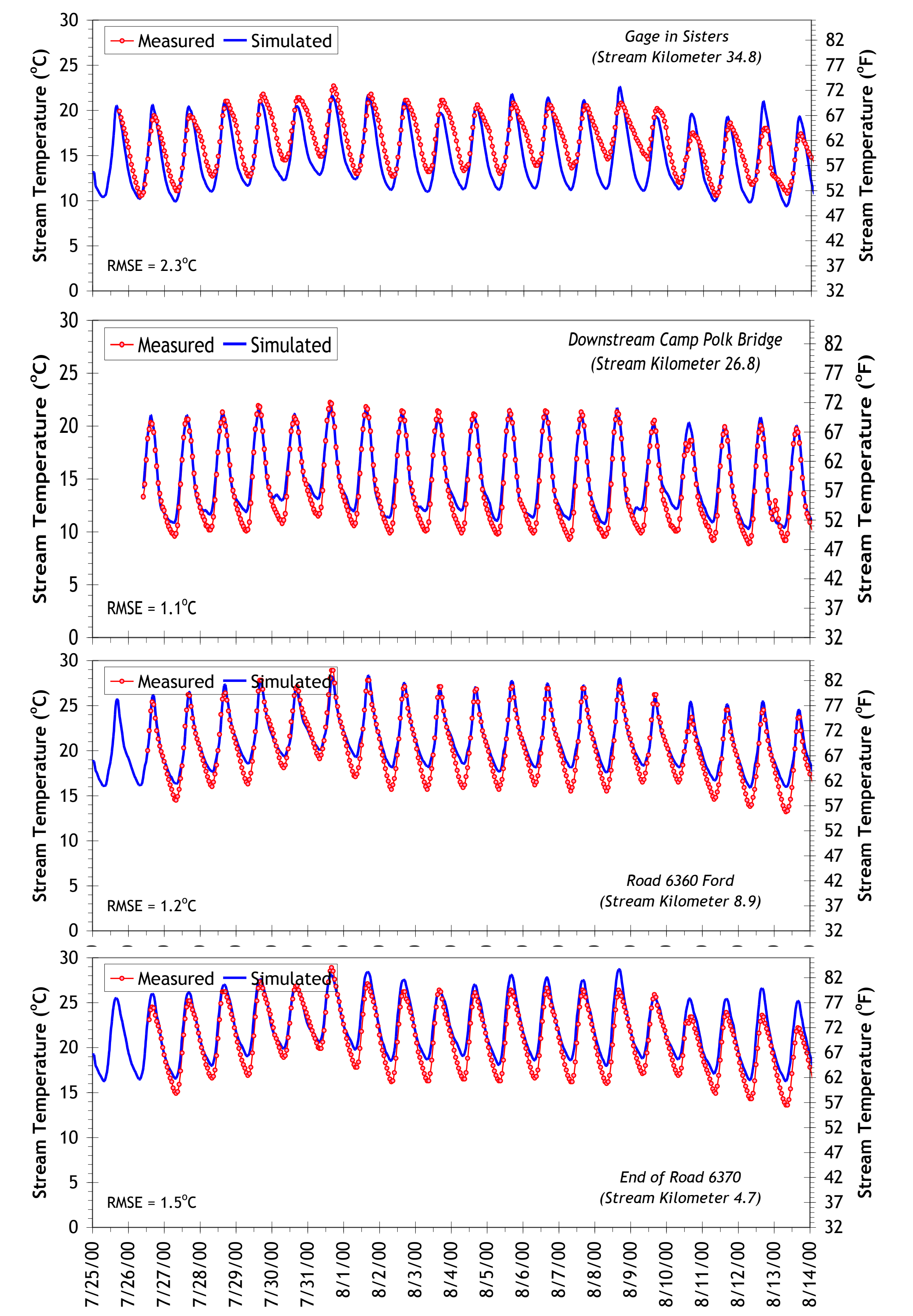


Figure 39 (continued) - Whychus Creek measured and simulated hourly stream temperatures.

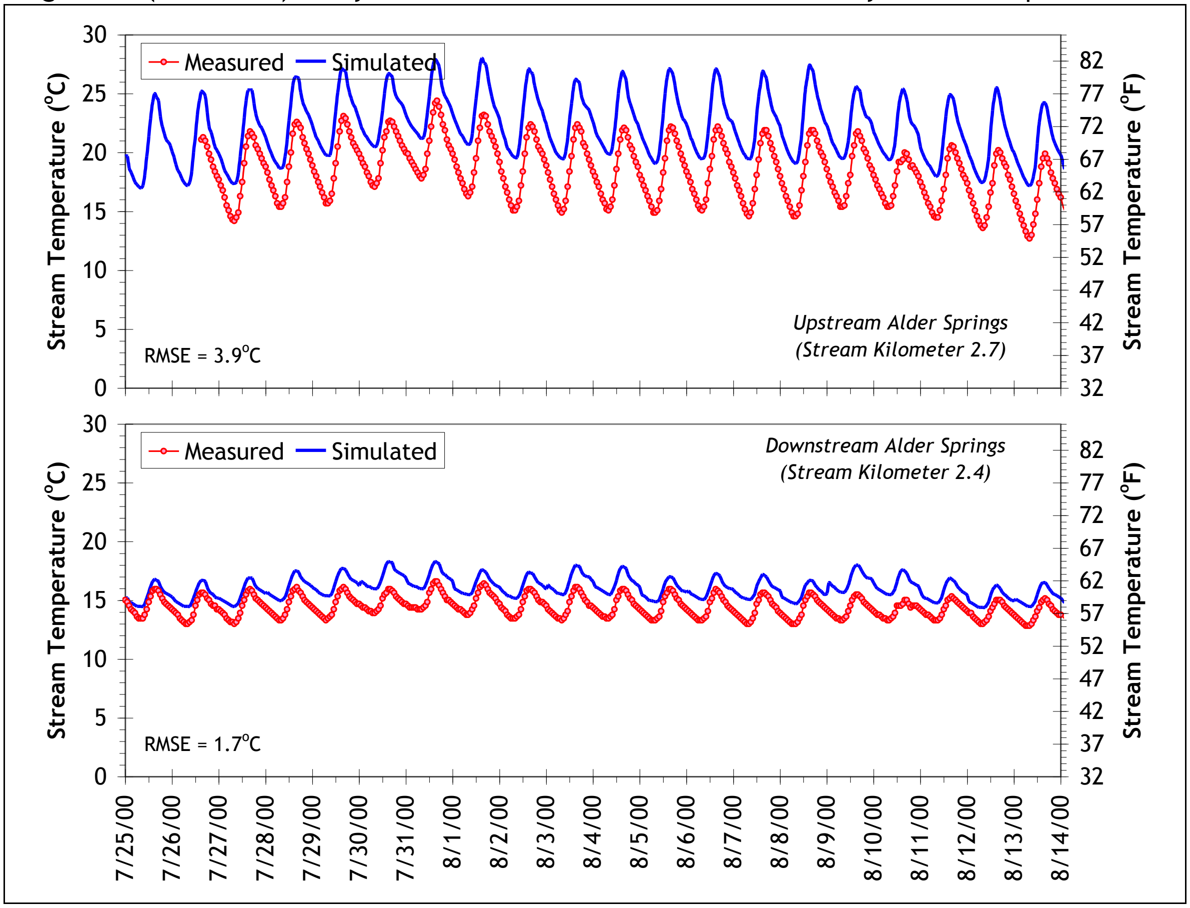
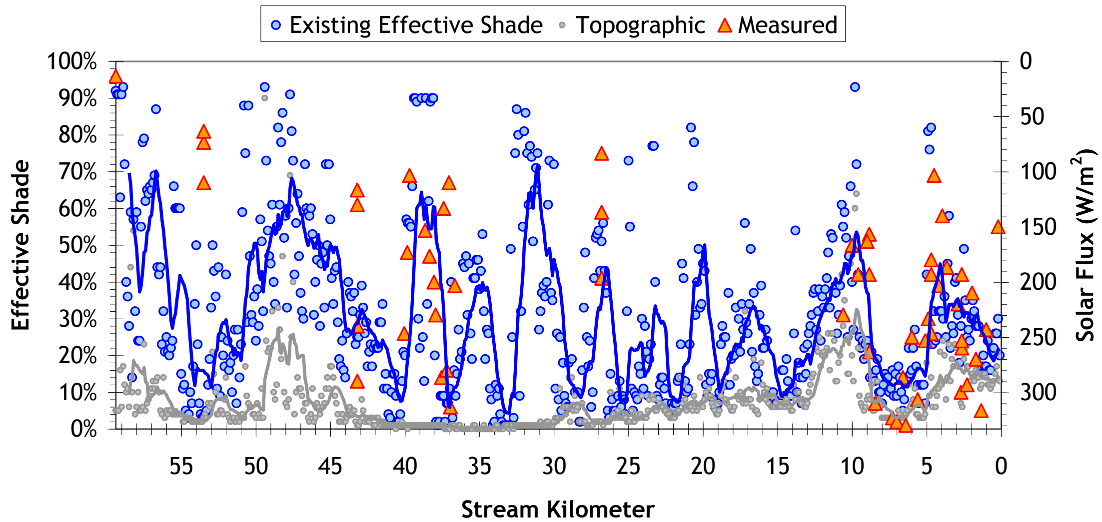


Figure 41 shows the measured and simulated effective shade on Whychus Creek. The dots represent values output every 100 meters, while the solid lines are 1-kilometer moving averages. In the lower 10 stream kilometers, much of the effective shade is produced by topographic features, as opposed to vegetation.

Figure 41 - Whychus Creek simulated and measured effective shade and solar flux (August 1).



Whychus Creek Flow Profiles

Figure 42 below shows the simulated and measured stream flows for Whychus Creek. Flow measurements were taken on July 26th and 27th, 2001. The majority of water is diverted upstream of Sisters for irrigation (Figure 43 and Figure 44). The largest diversion is at the TSID Canal (Figure 44). Hourly diversion rates were gaged at some canals and daily average values were calculated for modeling purposes.

Figure 42 - Whychus Creek simulated and measured flow profile.

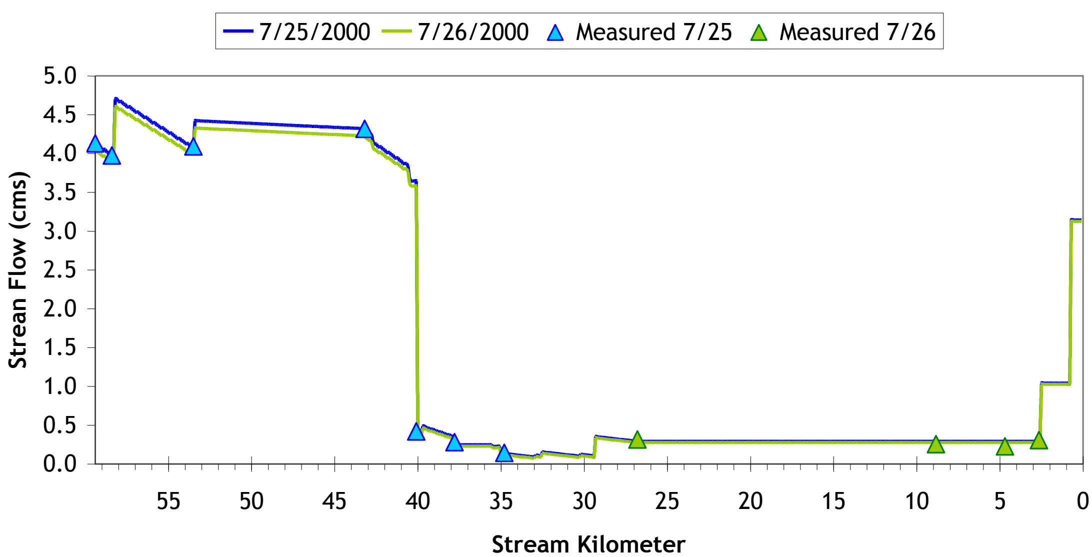


Figure 43 – Daily average diversion rates of the smaller canals on Whychus Creek.

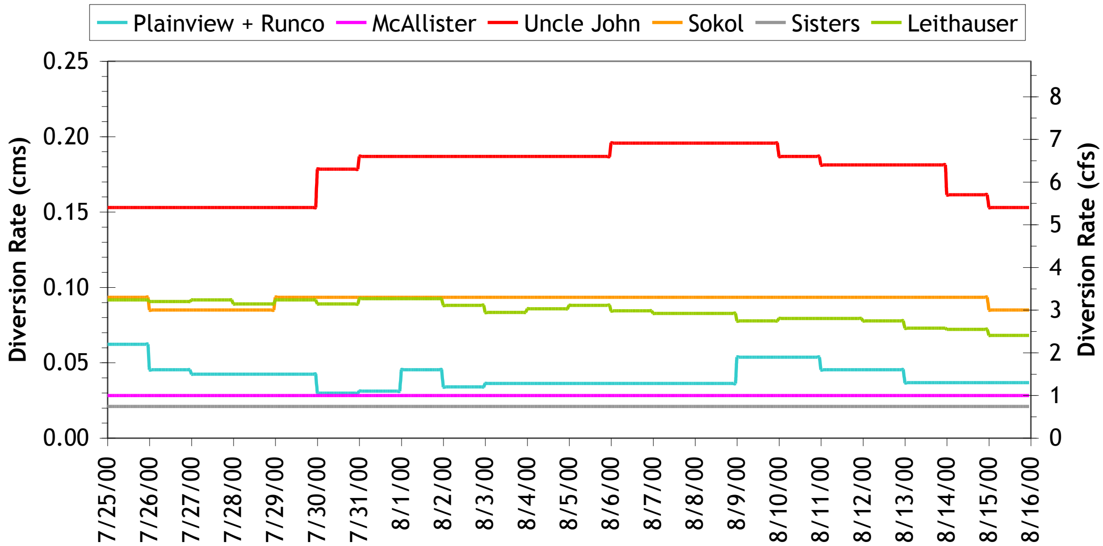


Figure 44 – Daily average diversion rates at the TSID Canal on Whychus Creek.

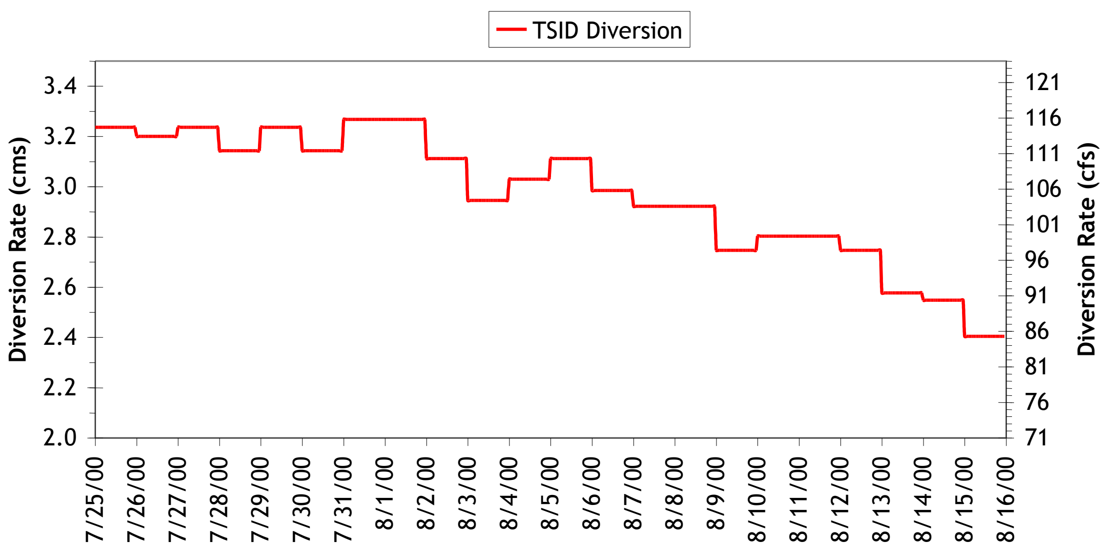


Figure 45 shows the daily average stream flows recorded upstream of the diversions and in Sisters. Generally, the flows were between 110 and 150 cfs during the simulation period upstream of the diversions. Downstream of the diversions, the flow was less than 5 cfs.

Figure 45 – Daily Average stream flows at OWRD gages on Whychus Creek.

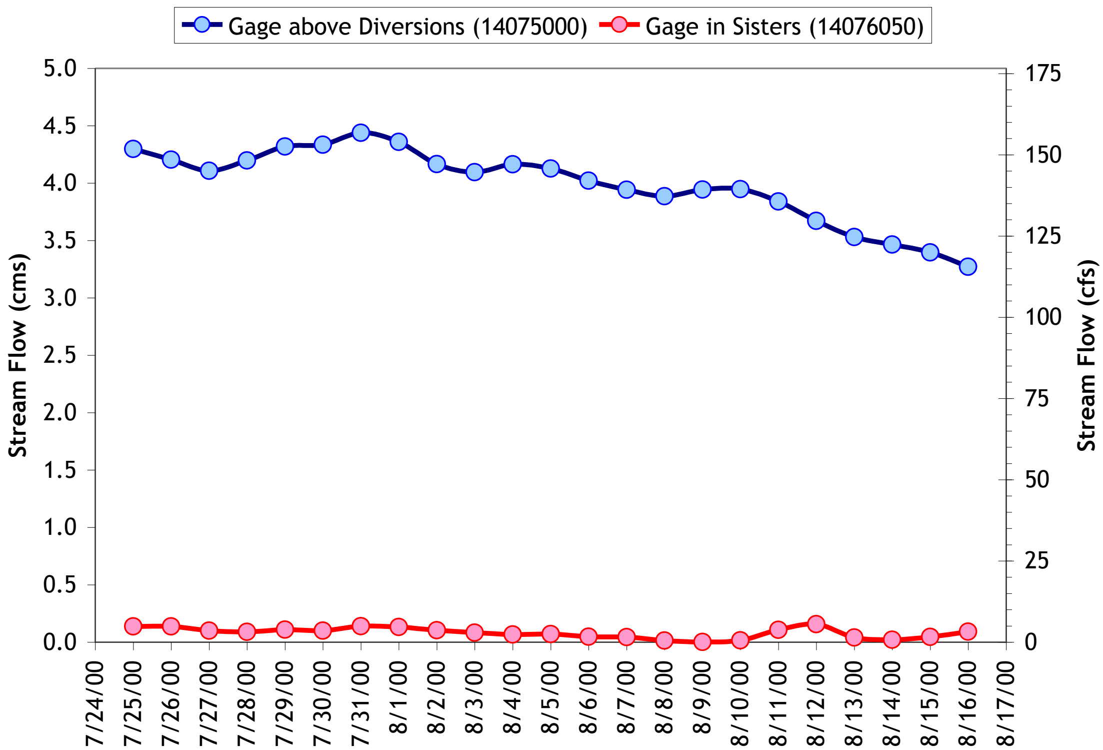


Figure 46 through Figure 48 show the simulated and measured stream hydraulic parameters for Whychus Creek. Near stream kilometer 40, most of the water is diverted for irrigation.

Figure 46 - Whychus Creek simulated and measured stream flow velocities (7/25/2000).

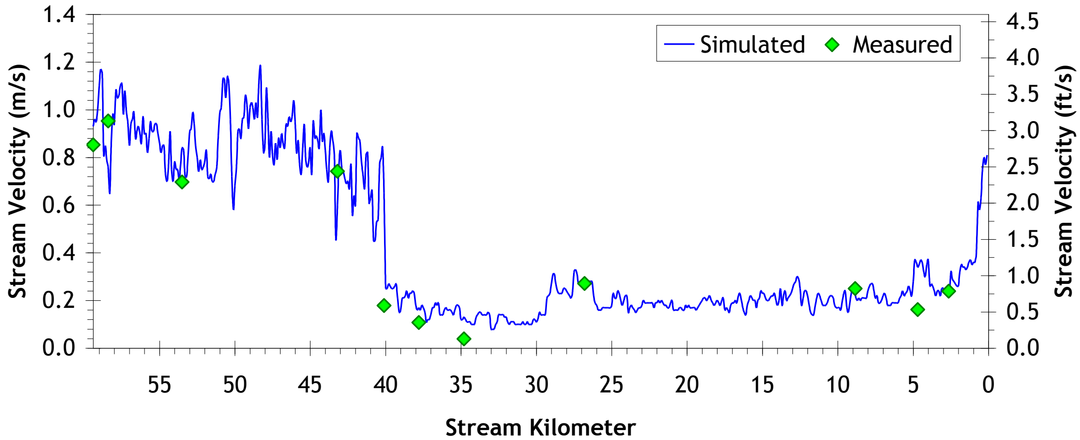


Figure 47 - Whychus Creek simulated and measured wetted widths (7/25/2000).

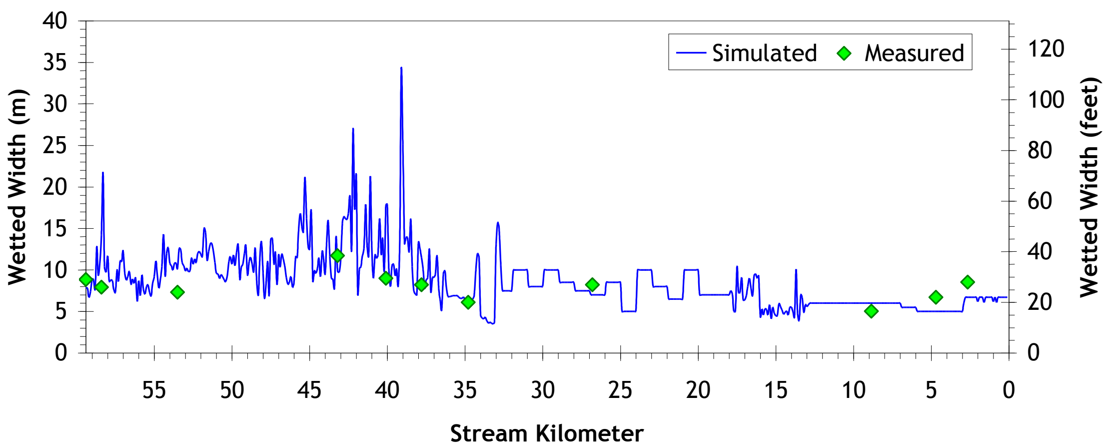
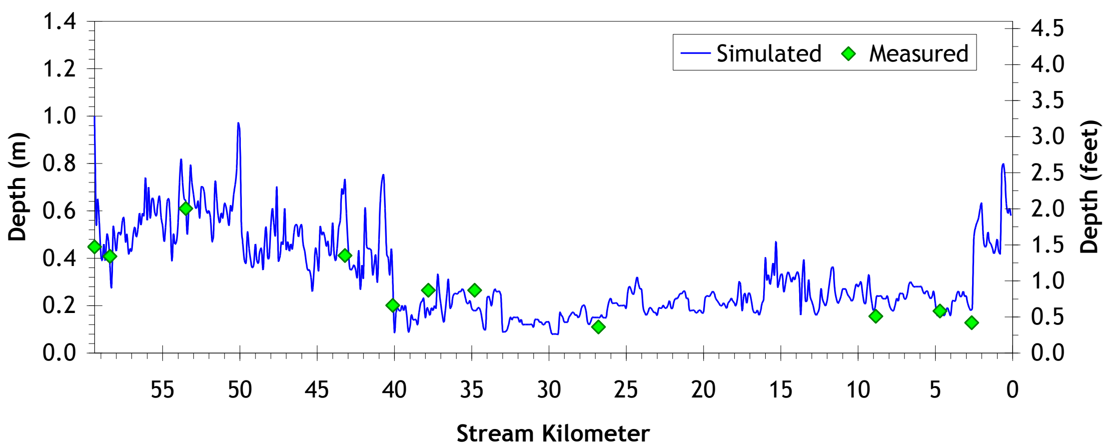


Figure 48 - Whychus Creek simulated and measured stream depths (7/25/2000).

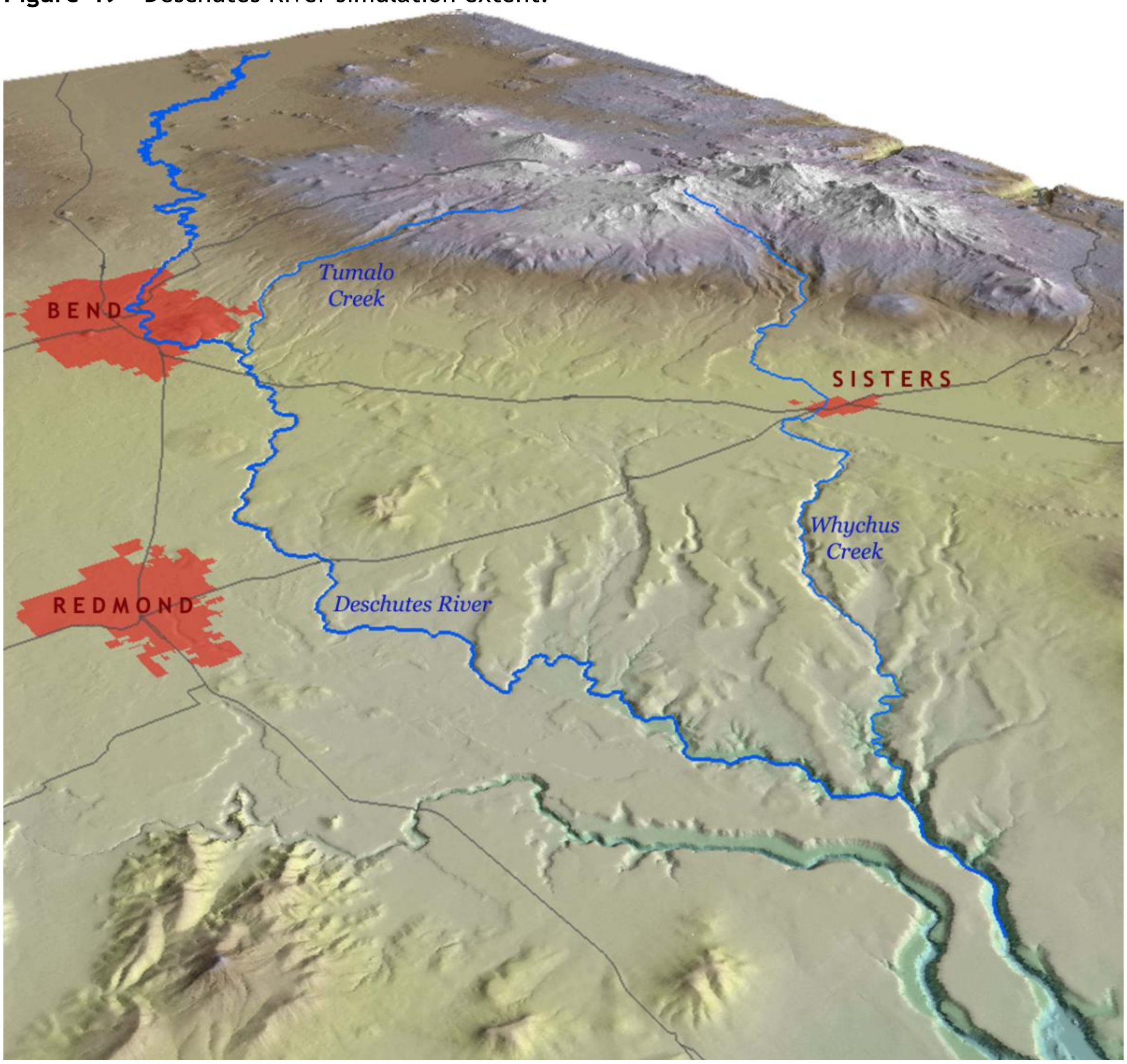


Deschutes River Temperature Simulation

Overview:

The Deschutes River was simulated from Wickiup Reservoir to Lake Billy Chinook (Figure 49). Diversion data was incorporated to account for the irrigation canals in and around Bend. There were relatively few instantaneous flow measurements collected due to the large flow volume upstream of Bend and limited accessibility below Bend. LiDAR data was available for this simulation and the vegetation heights were sampled from it.

Figure 49 - Deschutes River simulation extent.



Simulation Extent:

- Wickiup Reservoir to Lake Billy Chinook.
- 170.25 stream kilometers (105.8 stream miles).

Simulation Resolution:

- Time step: 30 seconds.
- Input distance step: 50 meters.
- Output distance step: 100 meters.

(The time step used for this simulation was smaller than the standard one minute time step in order to accommodate the large flow volumes and high velocities upstream of Bend.)

Simulation Period:

- July 19, 2001 through August 7, 2001

Data Sources:

- Thermal infrared (TIR) stream temperature data was collected on July 25 and 26, 2001.
- Hourly instream temperature data was collected at various locations in the Deschutes River and tributary mouths (Fall River, Little Deschutes River, Spring River, Whychus Creek) during the simulation period.
- Flow data consisted of hourly gage data and instantaneous flow measurements collected during the simulation period.
- Active channel edges and the stream thalweg were delineated from the 2005 NAIP orthophotos.
- Stream elevations, gradients, and topographic shade angles were sampled from the USGS 10-meter digital elevation model (DEM).
- Hourly climate data collected by the Redmond airport during the simulation period were used.

Calibration Notes and Assumptions:

- Spring River discharge was not measured; however, hourly temperature data is available. A mass balance was derived based on the TIR data which estimates approximately 300 cfs from Spring River. The mass balance corresponds well with the OWRD estimates of 278 cfs for July and 302 cfs for August.
- Downstream of the diversions, there are many reaches where the stream temperature declines. Examination of the TIR imagery within those reaches does not reveal any springs, shade, or other obvious sources of cooling. Those reaches have been assigned higher hyporheic flow values in order to account for the cooling. Since the river is wide and un-shaded in those cooling reaches and the substrate is cobble and boulder, hyporheic flow is likely contributing to the cooler temperatures.
- The vegetation heights were sampled directly from the LiDAR data.
- Due to the length of the river, TIR was flown in two consecutive days; the top half and the lower half. The model is calibrated to each of those days.
- It is assumed that the gaged and manual flow measurements are correct. The hydraulics were calibrated to those values.
- The OWRD point of diversion database was assessed to identify potential significant diversions, other than the canals. The number and quantity of diversions in the POD database were insignificant relative to the stream flow, and not included within the

model (there is no data for actual diversion rates at those PODs during the simulation period).

- The OWRD collected stream flow data in July and August 2005 in order to quantify seepage and identify gaining/losing reaches. The data was not directly used for this modeling analysis; however, the TIR derived stream flows were visually compared to the seepage run data in order to confirm overall longitudinal patterns.There is a long reach above Bend (stream kilometer 135-100) that is very low gradient (e.g., <0.03%). This reach also has some of the highest flow volumes. There is no instream flow volume, velocity, depth data for calibration purposes. In order to simulate hydraulic conditions that met the TIR temperatures within that reach, a low Manning's n value was used.
- There is a losing reach between Benham falls and Bend (Figure 50). During the simulation period, there was approximately a 100 cfs loss. (The OWRD estimated the reach to be losing 90 cfs in their July/August 2005 seepage run.) In the model, this loss was distributed evenly across the reach.

Figure 50 - Deschutes River near Benham Falls and lava flows (flow direction from top to bottom of image).

Calibration Results:

The simulated stream temperature was calibrated to both instantaneous TIR and hourly instream data. Hydraulic parameters such as flow volume, velocity, depth, and wetted width were validated against field measurements and gage data. Simulated effective shade was validated against Solar Pathfinder measurements collected at various locations along the stream.

The simulated and measured stream temperatures for the Deschutes River are shown in Figure 51. The RMSE for the upper reaches was 0.4°C and the RMSE for the lower reaches was 0.6°C. Stream temperatures were relatively stable upstream of Bend where the flow volumes were significantly large.

Downstream of Bend (approximately stream kilometer 80), most of the water has been diverted for irrigation and the reduced flow volumes results in a more variable temperature profile. Smaller volumes of water are more susceptible to solar heating, therefore the stream temperature increase more rapidly over shorter distances. In addition, smaller stream flow volumes are more sensitive to cool water inputs such as hyporheic flow, which often causes reaches to cool down.

Figure 51 - Deschutes River TIR and Simulated Stream Temperature Data.

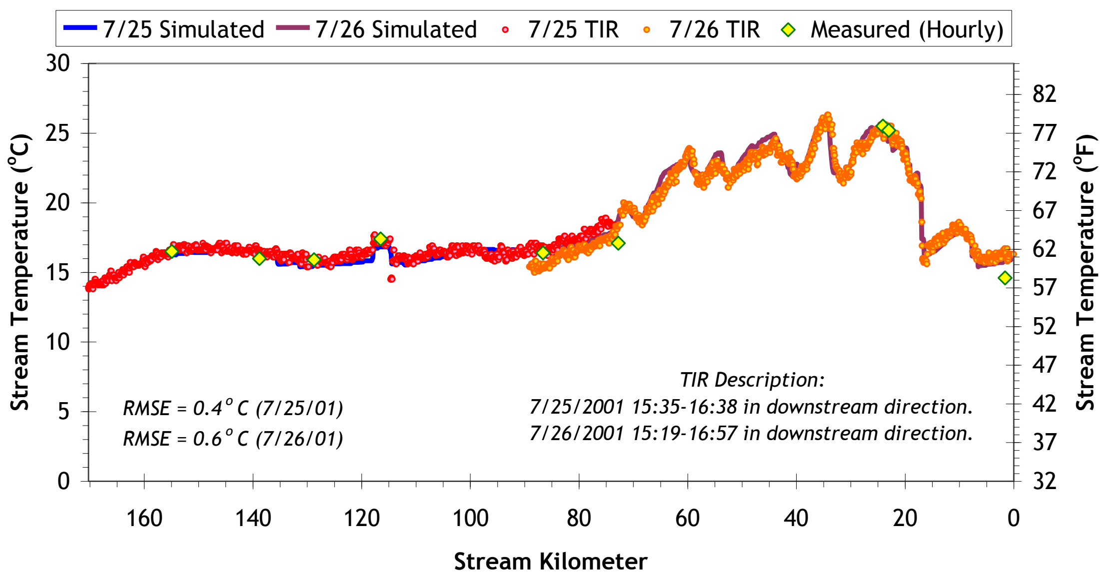


Figure 52 presents the simulated and measured hourly stream temperatures. The RMSE for the hourly temperature calibration ranged from 0.4-2.2°C.

The sites at Meadow Camp and the gage downstream of Bend had relatively small measured diel fluctuations. Calibration to those hourly data was difficult, and it is possible that the temperature monitoring instruments were deployed in a cooler region near the stream bed (i.e., hyporheic interactions often cause the stream to be slightly cooler at the water column/stream bed interface).

On July 30 and 31, the measured temperatures were cooler than the rest of the simulation time period. The model failed to simulate those markedly cooler stream temperatures, especially at the lower monitoring sites. The anomaly is likely the result of meteorological conditions that were poorly represented by the Redmond airport climate data (e.g., there could have been isolated thunder showers in the upper watershed which impacted stream temperatures).

Figure 52 - Measured and simulated hourly temperatures in the Deschutes River.

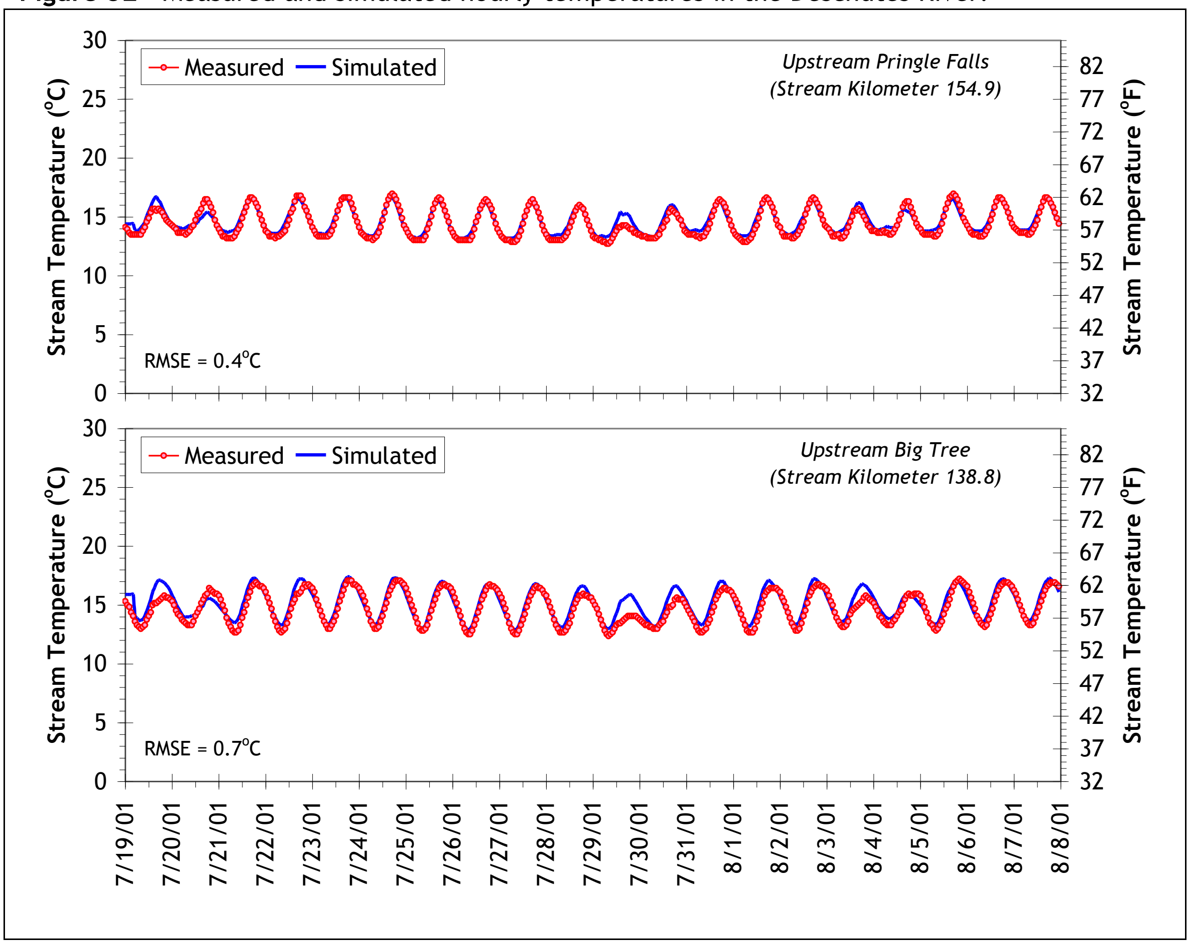


Figure 50 (continued) - Measured and simulated hourly temperatures in the Deschutes River.

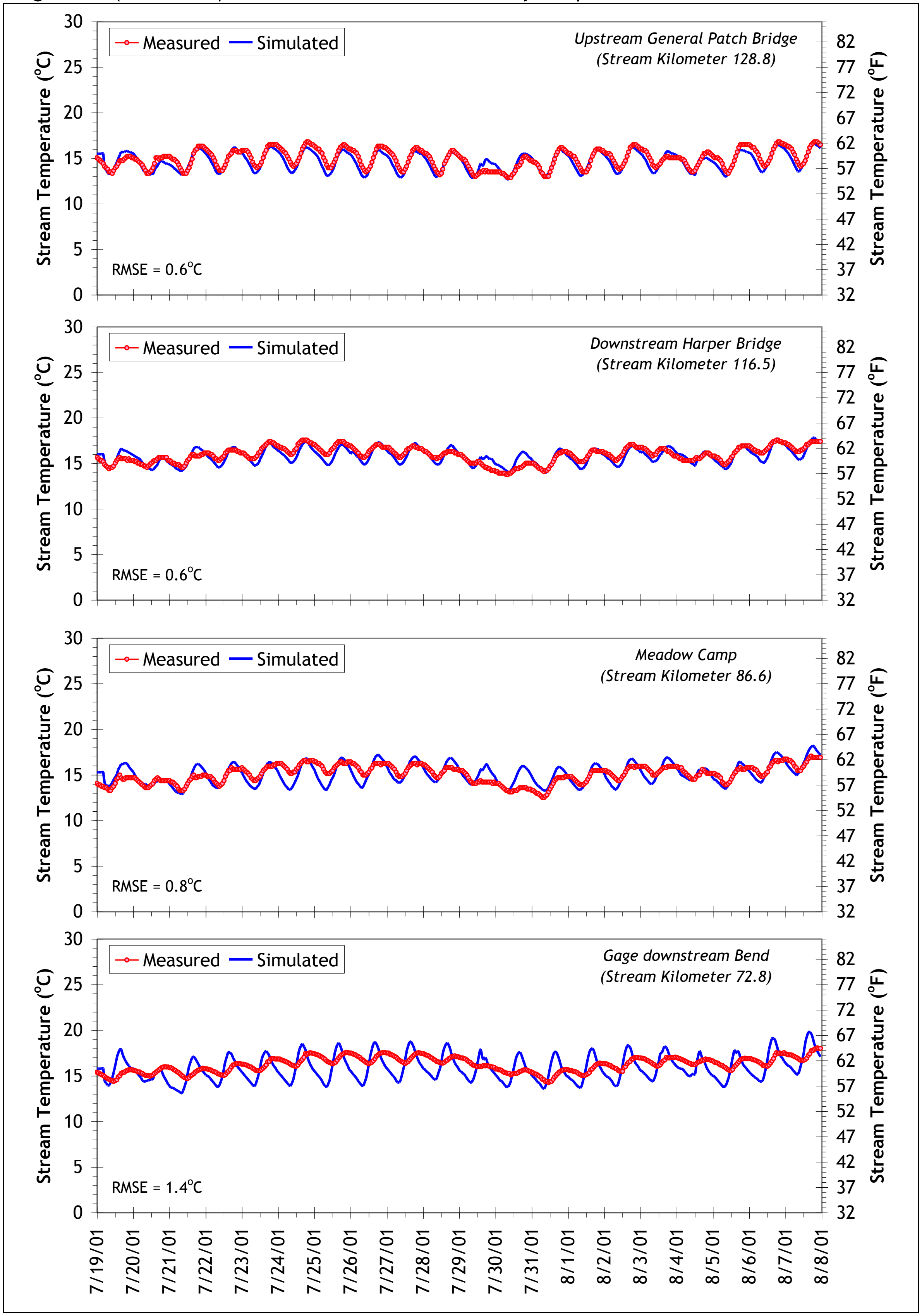


Figure 50 (continued) - Measured and simulated hourly temperatures in the Deschutes River.

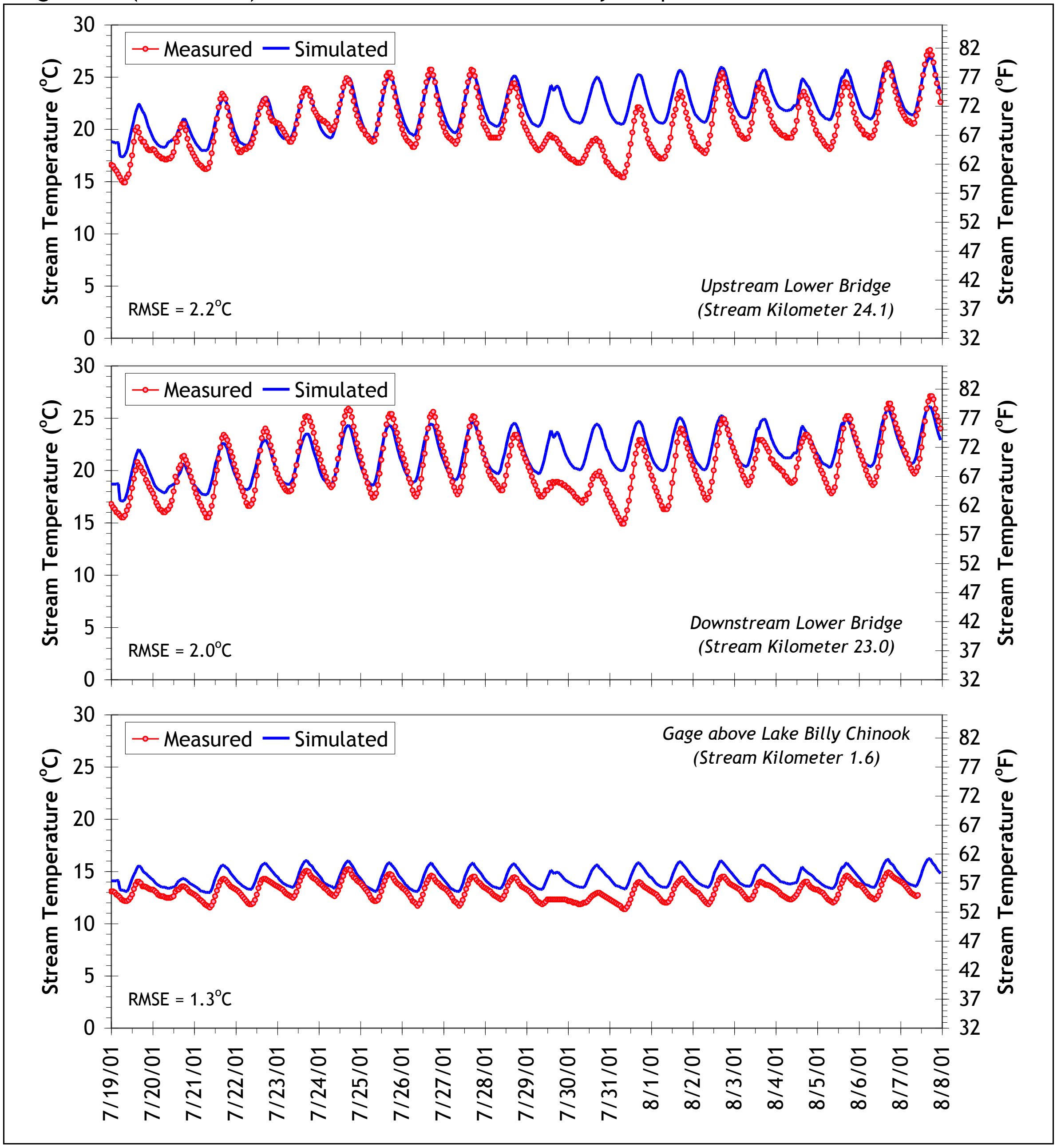


Figure 53 and Figure 54 show the simulated and measured effective shade and solar flux for the Deschutes River. The light blue dots are the simulated effective shade for every 100 meters, while the solid blue lines are one-kilometer moving averages. The upper reaches (Figure 53) flow through a more broad and flat valley with little topographic shade. Vegetation does not produce very much effective shade because the river is naturally very wide. The lower reaches (Figure 54) flow through a more confined box canyon where topographic features produce the majority of effective shade. For reference purposes, the city limits of Bend are located between stream kilometers 85 and 69. Solar Pathfinder measurements were not collected in the upper reaches because the river is too wide and deep.

Figure 53 - Deschutes River (above Bend) simulated and measured effective shade (August 1).

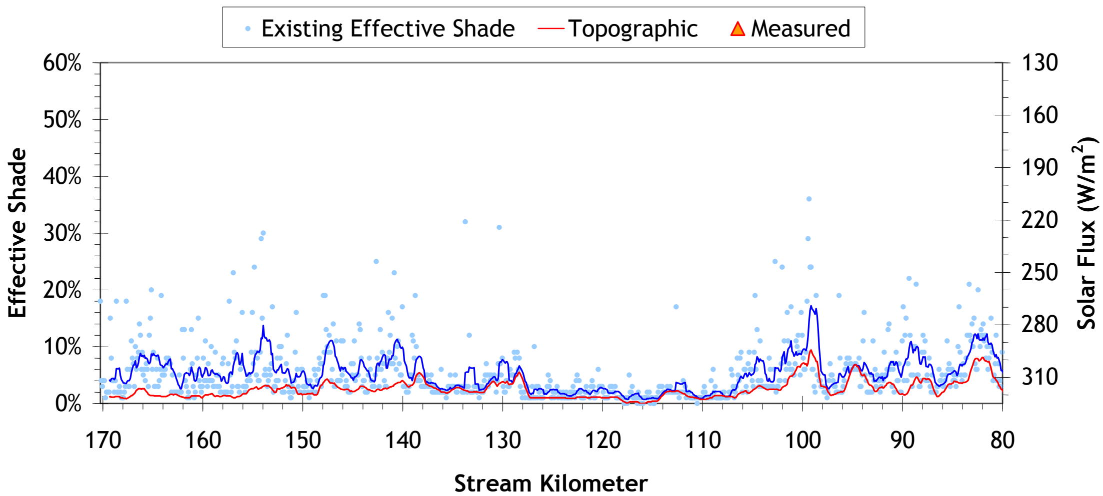


Figure 54 - Deschutes River (below Bend) simulated and measured effective shade (August 1).

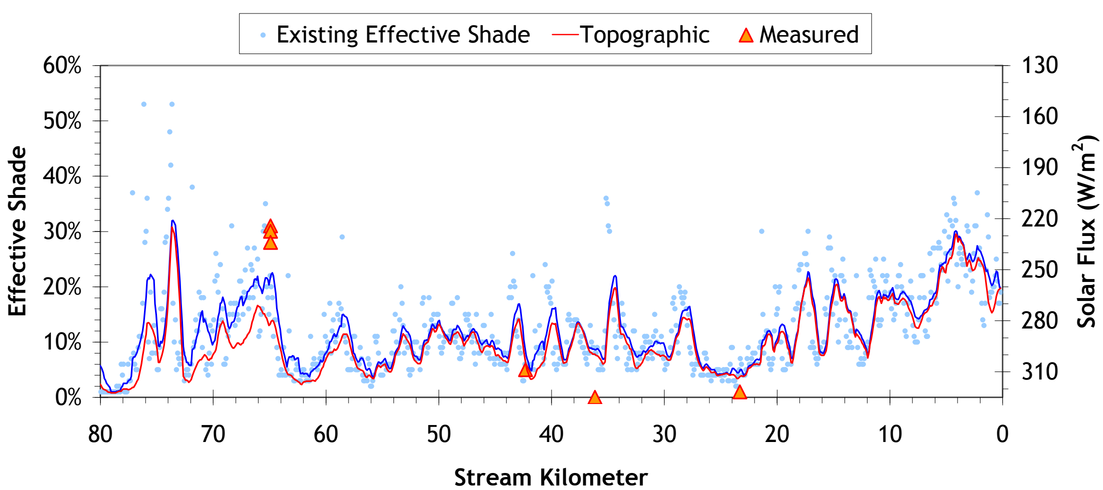


Figure 55 through Figure 57 show the simulated and measured hydraulic parameters for the Deschutes River. Near stream kilometer 78, the majority of water is diverted from the river and velocities, widths, and depths are smaller in the lower reaches.

Figure 55 - Deschutes River simulated and measured stream flow velocities (7/26/2001).

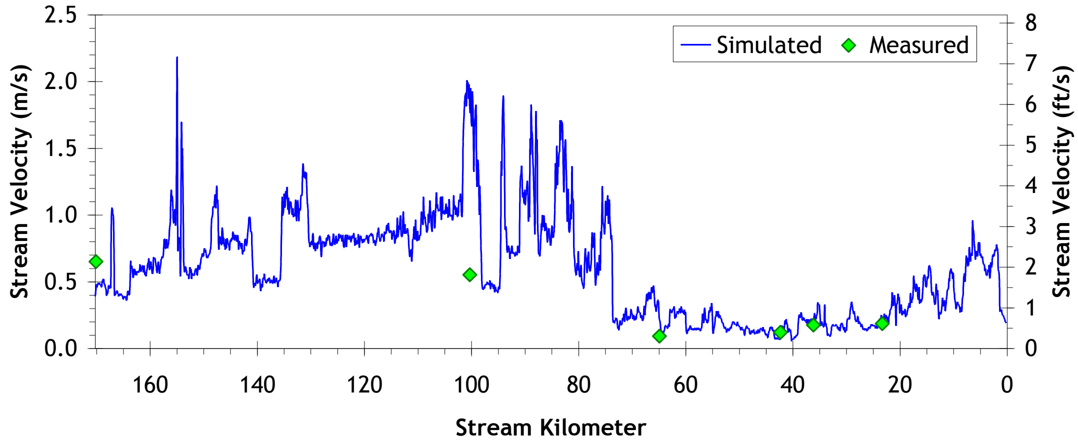


Figure 56 - Deschutes River simulated and measured wetted widths (7/26/2001).

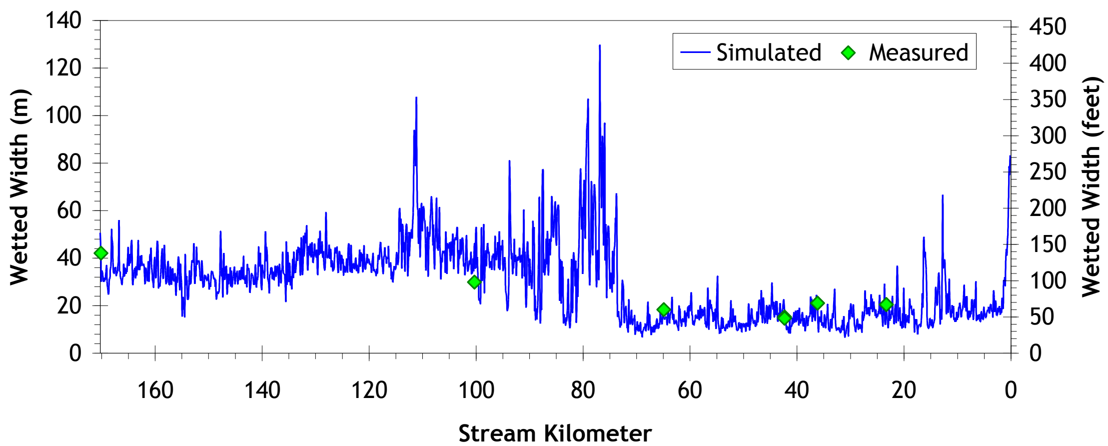
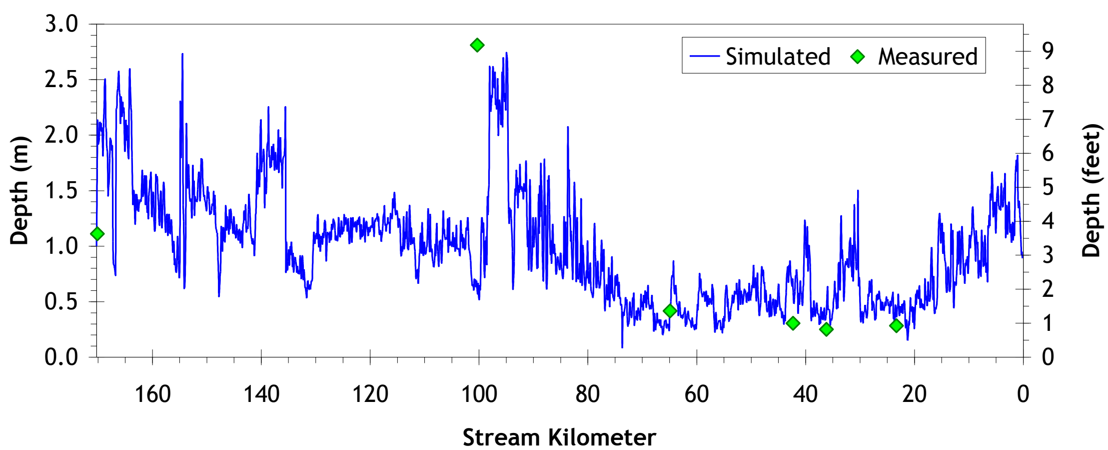


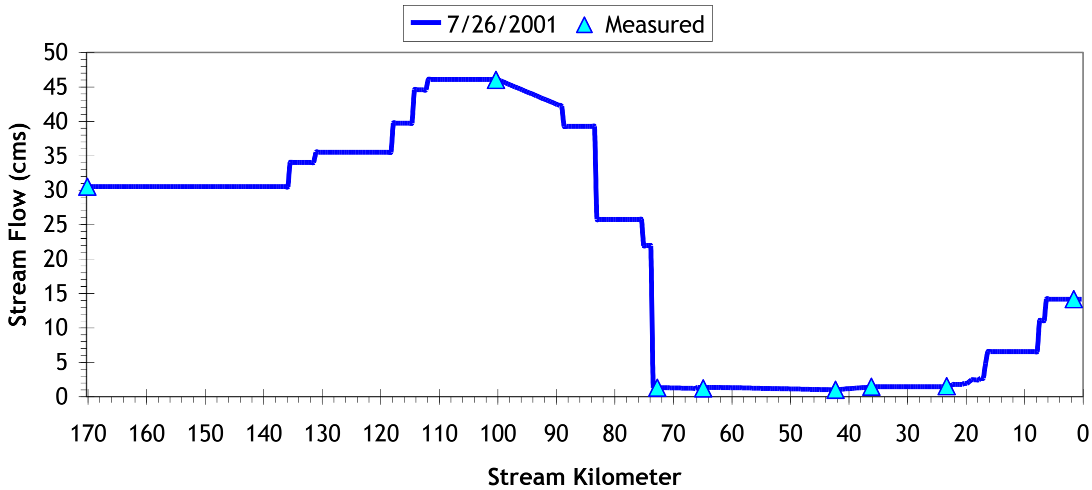
Figure 57 - Deschutes River simulated and measured stream depths (7/26/2001).



Deschutes River Flow Profile

Flow measurements were collected on July 26, 2001 on the Deschutes River. The simulated and measured flows are shown in Figure 58. Tributary and spring flow volumes were either measured or derived through mass balance analysis. Most of the Deschutes River is diverted above and within the city of Bend.

Figure 58 - Deschutes River flow profile from Wickiup Reservoir to Lake Billy Chinook.



The diversion rates for the major canals are shown in Figure 59. Since the North, North Main, and Swalley Canal diversions occur at the same location, they are presented as a summed value. Hourly rates were gaged at the canals and daily average values were calculated for modeling purposes.

Figure 59 - Diversion rates along the Deschutes River.

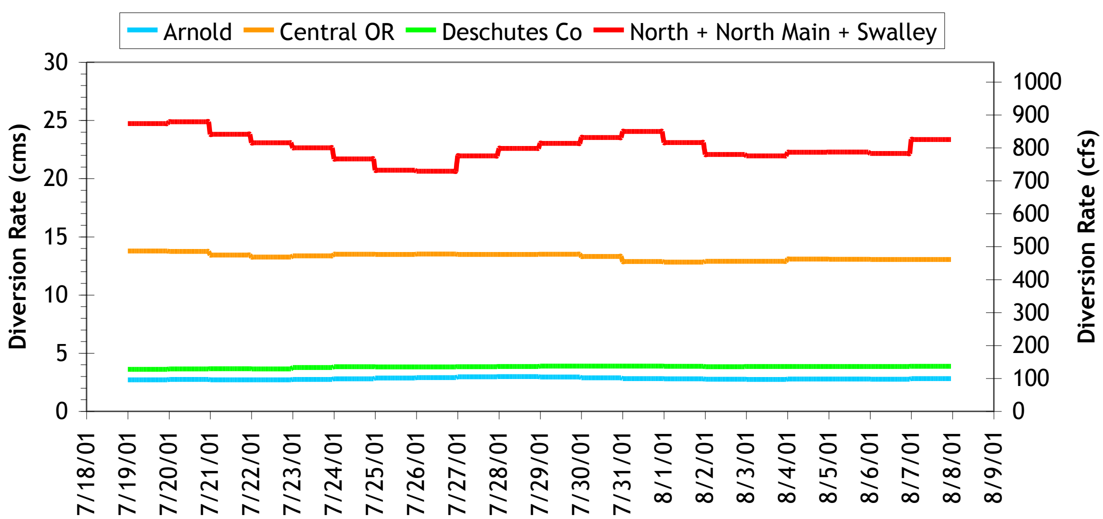
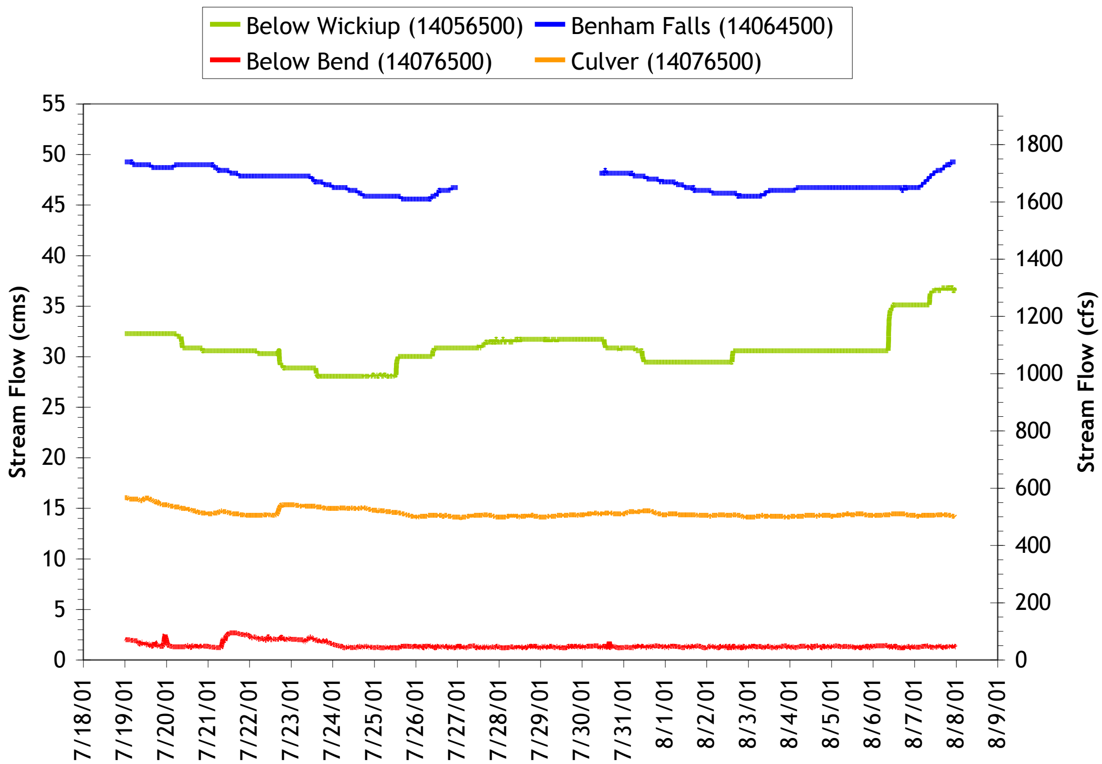


Figure 60 summarizes the measured stream flows at four gages along the Deschutes River during the simulation period. The smallest stream flows were occurring just downstream of Bend, after much of the river had been diverted for irrigation. Approximately 450 cfs was gained between Bend and Lake Billy Chinook during this time period.

Figure 60 – Stream flows at gages on the Deschutes River.



Section Three – Flow Scenario Simulation Results

Introduction

The calibrated Heat Source models were used to simulate two different stream flow scenarios. The natural stream flow was simulated for each stream, assuming that there were no active diversions or augmentations. Note that the estimated natural flows are specific to the simulation time period. If natural flows were calculated for an “average year”, the values may differ slighty. The ODFW instream water rights targets were also simulated.

In all three streams, the natural flow scenario resulted in much cooler stream temperatures than the current condition. The ODFW scenario also resulted in cooler stream temperatures, but was generally warmer than the natural flow scenario.

Tumalo Creek

Tumalo Creek Natural Flow Scenario Description

- In the current condition, water is diverted from Crater Ditch into the upper reaches of Tumalo Creek. This flow augmentation was removed in the natural flow scenario by subtracting 7 cfs from the upstream boundary flow volume (OWRD estimation).
- The City of Bend was diverting water from Bridge Creek in the current condition. That water was left in Bridge Creek (a tributary to Tumalo Creek) in the natural flow scenario. In addition, the return flow from this diversion which occurs at Shevlin Park was removed in the natural flow scenario.
- No water was diverted into the TID canal in the natural flow scenario.
- All other tributary and spring flows and temperatures remained unchanged from the current condition.
- Since other small PODs were not simulated in the current condition, they were not accounted for in the natural flow scenario.

Tumalo Creek ODFW Flow Scenario Description

- In order to meet the ODFW instream water right of 32 cfs downstream of Bridge Creek, the City of Bend diversion was reduced when necessary.
- The City of Bend return flow at Shevlin Park was reduced by the same amount.
- The TID canal diversion was reduced in order for Tumalo Creek to meet 32 cfs at all times.
- All other tributaries, springs, and hydraulic parameters were unchanged.

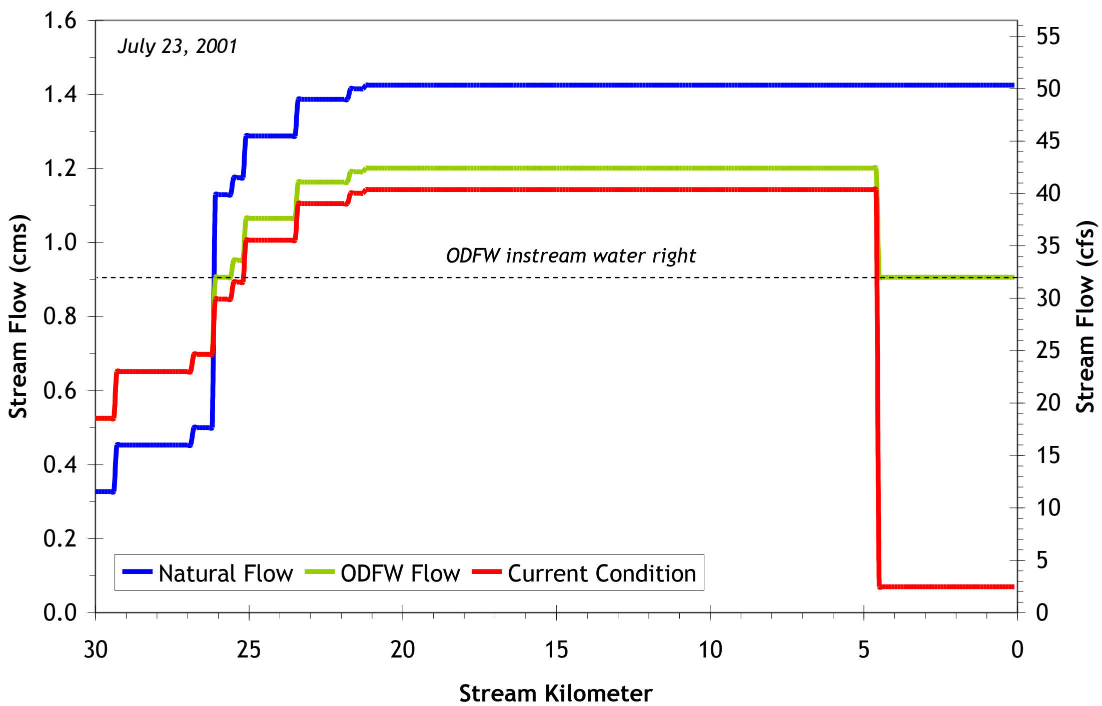
Tumalo Creek Stream Flow Results

The current, natural, and ODFW flows for Tumalo Creek are shown in Figure 61. The flow profiles are shown for July 23, 2001, which corresponds to the date that TIR data was collected. Note that the natural and ODFW flow scenarios were applied to the entire simulation period; however, one day is plotted in Figure 61 in order to simplify the presentation.

The natural flow in the upper 4 stream kilometers is less than the current flow because of flow augmentation from Crater Ditch. Crater Ditch water does not naturally contribute to Tumalo Creek. Near stream kilometer 26, Bridge Creek contributes increased flow volumes because the City of Bend diversion was removed from the simulation. The TID canal near kilometer 4 was not diverting water in the natural flow scenario, so the flow volumes to the mouth are much larger than in the current condition.

The ODFW stream flow in the upper 4 stream kilometers is the same as the current condition. Stream flows are naturally less than 32 cfs upstream of Bridge Creek. Slightly less water was diverted by the City of Bend (from Bridge Creek) in order to ensure that downstream reaches of Tumalo Creek had a minimum of 32 cfs. The TID canal diversion rates were also reduced in order to maintain 32 cfs in the stream (on the July 23, 2001 simulation date the TID diversion was reduced by 29.5 cfs).

Figure 61 - Tumalo Creek current, natural, and ODFW flows.



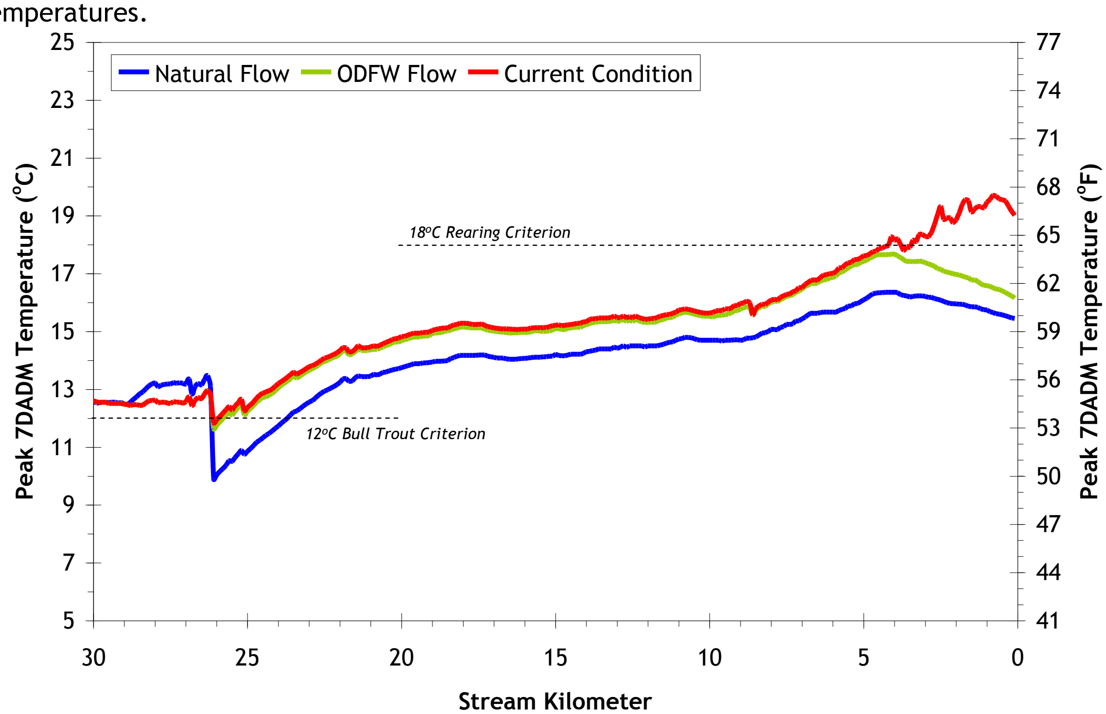
Tumalo Creek Stream Temperature Results

Figure 62 shows the simulated stream temperatures for the current condition, the natural flow scenario, and the ODFW flow scenario. The moving seven-day average of the daily maximums (7DADM) was calculated for the 3-week simulation period. Then the maximum 7DADM value for each 100-meter segment were selected and plotted in Figure 62. The results are intended to represent the critical summertime period when stream temperatures reach their yearly maximums and aquatic life is at the greatest risk of thermal impairment. For reference purposes, the applicable Oregon state water quality criteria are included on the chart.

In the natural flow scenario, the simulated stream temperatures were warmer than the current condition upstream of Bridge Creek (kilometer 26) because of reduced flow volumes that occur without augmentation from Crater Ditch. The simulated stream temperatures below Bridge Creek were approximately one degree Celsius cooler than the current condition, until stream kilometer 4. Below stream kilometer 4, the flow volume was around 50 cfs greater than the current condition due to the removal of the TID canal from the simulation. This resulted in much cooler temperatures than in the current condition. The 18˚C rearing criterion is met throughout Tumalo Creek in the natural flow scenario. The 12˚C Bull trout criterion was met only for a short distance downstream of Bridge Creek.

In the ODFW flow scenario, the simulated stream temperatures upstream of Bridge Creek were the same as the current condition. The City of Bend withdrawals from Bridge Creek were lowered slightly on some days in order to meet the 32 cfs instream water right in Tumalo Creek. This resulted in stream temperatures that were approximately 0.1˚C cooler than the current condition between Bridge Creek and the TID canal. (Note that 0.1˚C is smaller than the model's accuracy range of ±1˚C.) More statistically significant stream temperature differences were observed downstream of kilometer 4, where 32 cfs was left in the stream (compared to the current condition). The Bull trout criterion was not met in the ODFW flow scenario; however, the rearing criterion was met throughout the simulated stream length.

Figure 62 - Tumalo Creek simulated current, natural flow, and ODFW flow scenario temperatures.



Whychus Creek

Whychus Creek Natural Flow Scenario Description

- The diversion canals included in the calibrated Heat Source model were "turned off" so that no water was diverted in the natural flow scenario.
- In the current condition, no Pole Creek water reaches Whychus Creek because it is diverted. In the natural flow scenario, Pole Creek enters Whychus Creek at stream kilometer 47.9. The flow volumes (7-10 cfs) are based upon the Patterson diversion data and Snow Creek temperatures were used.
- All other tributaries, springs, and losing or gaining reaches were unchanged in the natural flow scenario.
- Since other small PODs were not simulated in the current condition, they were not accounted for in the natural flow scenario.

Whychus Creek ODFW Flow Scenario Description

- The ODFW instream water right above Indian Ford Creek is 20 cfs.
- The ODFW instream water right below Indian Ford Creek is 33 cfs.
- In order to meet 33 cfs downstream of Indian Ford, the TSID diversion was reduced accordingly.All other tributaries, springs, and losing or gaining reaches were unchanged.

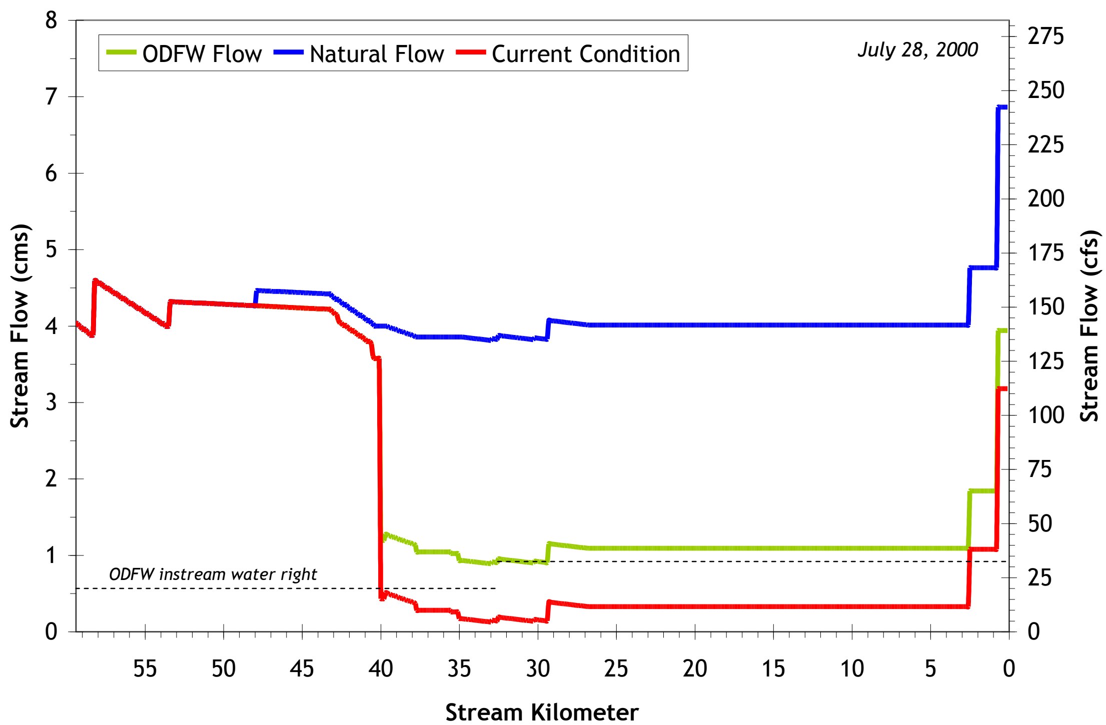
Whychus Creek Stream Flow Results

Figure 63 shows the simulated current, natural, and ODFW stream flows. The data plotted is for July 28, 2000 which corresponds to the TIR data collection date. Upstream of Indian Ford Creek, the ODFW instream water right is 20 cfs. Downstream of Indian Ford Creek, the ODFW instream water right is 33 cfs.

The natural flow volume upstream of Pole Creek (kilometer 48) is the same as the current condition. Currently, Pole Creek water never reaches Whychus Creek because it is diverted elsewhere. In the natural flow scenario, Pole Creek contributes to Whychus Creek. Without irrigation canals, the natural flow was nearly 150 cfs throughout most of the stream (approximately 130 cfs greater than the current condition on July 28, 2000).

Upstream of the TSID diversion (kilometer 40), the flow in the ODFW scenario is the same as the current condition. The diversion rates at the TSID diversion were reduced by approximately 27 cfs (on July 28, 2000) in order for Whychus Creek to attain the instream water right of 33 cfs in all downstream reaches. The ODFW instream water rights are significantly less than the natural flow volume.

Figure 63 – Whychus Creek current, natural, and ODFW flows.



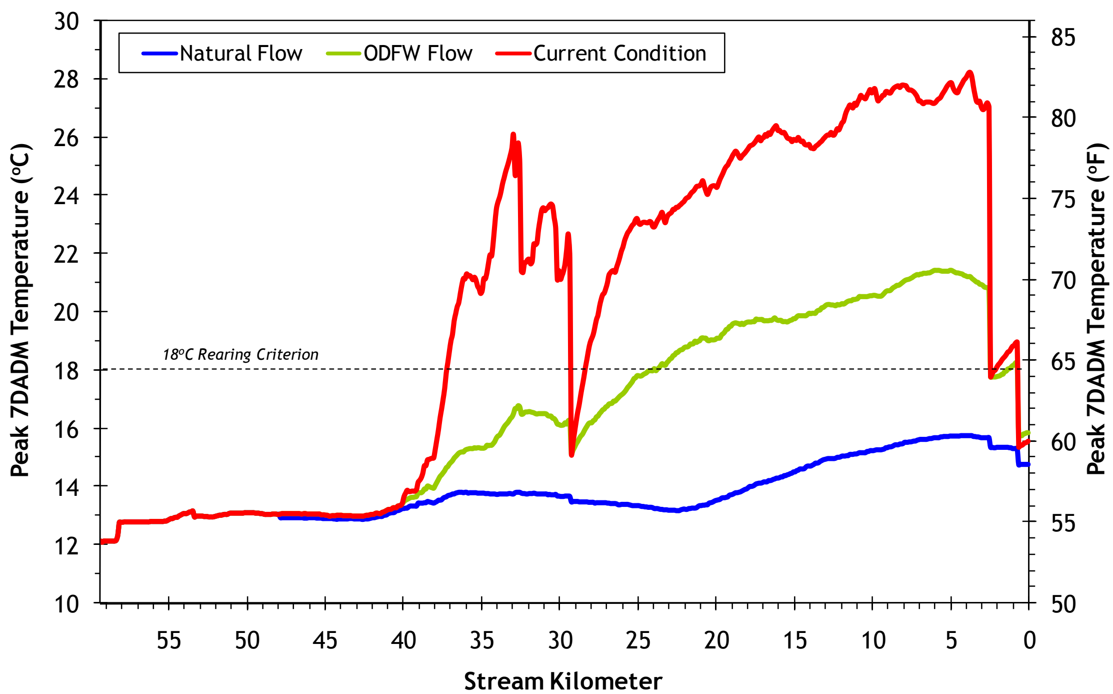
Whychus Creek Stream Temperature Results

Figure 64 shows the simulated current, natural, and ODFW scenario temperatures for Whychus Creek. The moving seven-day average of the daily maximums (7DADM) was calculated. The peak values of the 7DADM were then selected for the simulation period and plotted in Figure 64. The results are intended to represent the critical summertime period when stream temperatures reach their yearly maximums and aquatic life is at the greatest risk of thermal impairment. For reference purposes, the applicable Oregon state water quality criteria are included on the chart. The applicable Oregon water quality criterion is 18°C for the entire stream. Currently, the criterion is exceeded in most reaches downstream of Sisters.

In the natural flow scenario, the stream temperatures were the same as the current condition upstream of Pole Creek (kilometer 48). Allowing Pole Creek to reach Whychus Creek resulted in slightly cooler temperatures downstream. Leaving all of the water instream resulted in peak 7DADM temperatures less than 60°F throughout the stream. Springs and tributaries have less thermal impact on Whychus Creek in the natural flow scenario due to the relatively large stream flow volume. Likewise, Whychus Creek is less susceptible to solar heating when the flow volumes are nearly 15 times greater than the current condition.

The simulated stream temperatures under the ODFW flow scenario were the same as the current condition upstream of kilometer 40. Meeting the 33 cfs instream water right resulted in much cooler stream temperatures, compared to the current condition. In particular, the stream heated much less rapidly downstream of the diversions. The 18°C rearing criterion was exceeded in the lower 24 kilometers; however, temperatures were approximately 12°F cooler than the current condition.

Figure 64 - Whychus Creek current and natural flow scenario stream temperatures.



Deschutes River

Deschutes River Natural Flow Scenario Description

- The “natural flow” volumes were calculated and used as the boundary condition which assumes there are no reservoirs. The OWRD had calculated the natural flow upstream of Wickiup dam by estimating the total contribution from all tributaries in the presumed absence of reservoirs. The estimated natural flow volume downstream of Wickiup was smaller than the actual flow volumes in 2001.

- Little Deschutes River natural stream flows were estimated to be 21 cfs for the simulation period, which is significantly smaller than the actual 2001 flows of 140-160 cfs. (Crescent Lake storage influences the current condition). The Little Deschutes River stream temperatures were not changed.

- Temperature and flow volume output from the Tumalo Creek natural flow simulation was used as input to the Deschutes River natural flow simulation.

- Temperature and flow volume output from the Whychus Creek natural flow scenario was used as input to the Deschutes River natural flow simulation. Note that Whychus Creek’s simulation period was for the year 2000, while the Deschutes River simulation was for 2001. All simulations (2000 and 2001) captured the summertime critical period when stream temperatures were at their peak. It is assumed that similar conditions would have been achieved in the 2001 simulation time period for Whychus Creek.

- All diversions were removed from the simulation and the water was left in stream.

- The naturally losing reach between Benham Falls and Bend remained unchanged.

- Other losing reaches, spring inflows, and tributaries were unchanged.

- Downstream of Bend, the Manning’s n coefficient was reduced by 50% in order to accommodate the much greater natural flow volumes

Since other small PODs were not simulated in the current condition, they were not accounted for in the natural flow scenario.

Deschutes River ODFW Stream Flow Scenario

- Wickiup to Little Deschutes River instream water right is 300 cfs.

- Little Deschutes River to Spring River instream water right is 400 cfs.

- Spring River to North Canal Dam instream water right is 660 cfs.

- North Canal Dam to Lake Billy Chinook instream water right is 250 cfs.

- The instream water rights were being met during the simulation period upstream of the North Canal dam, therefore no changes were made in that reach.

- The diversion rates at North Canal Dam were reduced in order to meet the 250 cfs downstream minimum at all times.

- Simulated temperature and flows from the Tumalo Creek and Whychus Creek ODFW scenarios were used as input to the Deschutes River simulation.

- All other model inputs remained unchanged.

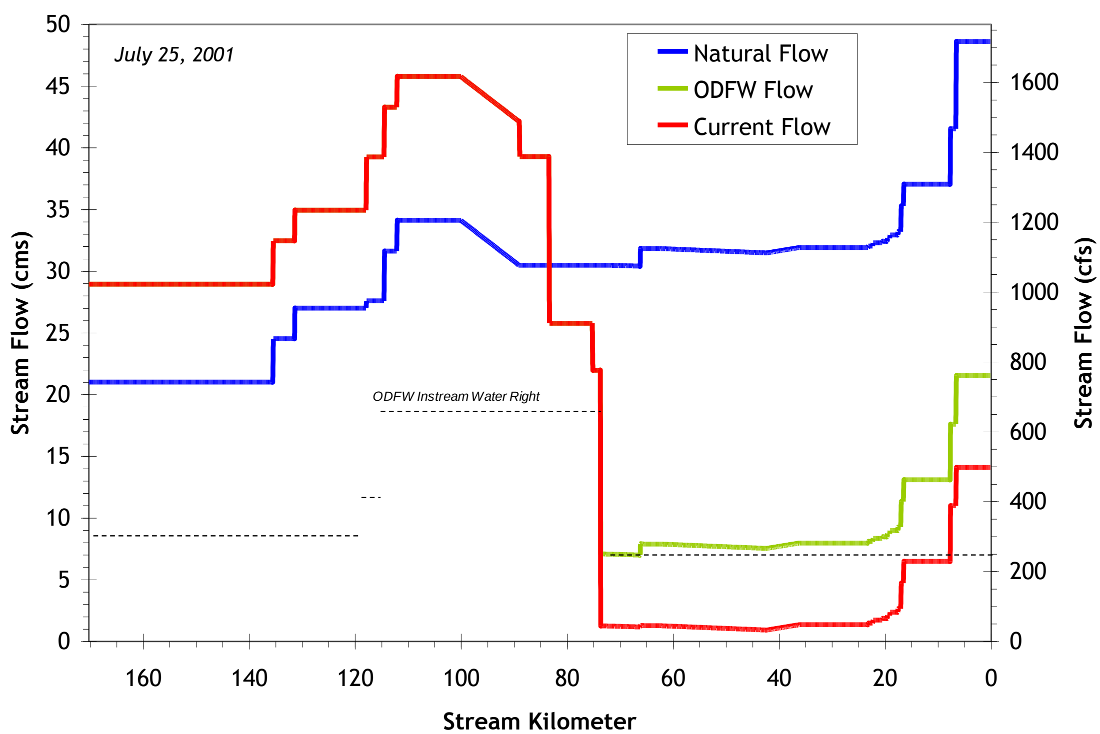
Deschutes River Stream Flow Results

The simulated current, natural, and ODFW flows are shown in Figure 65. The data was plotted for July 25, 2001 which corresponds to the TIR data collection date. The ODFW instream water rights are indicated by the dashed lines.

Upstream of Bend (approximately kilometer 80), the current flow volumes are augmented by storage releases from Wickiup reservoir, making them greater than natural. Most of the Deschutes River is diverted for irrigation by the time it leaves the City of Bend. In the natural flow scenario, no water is diverted at the irrigation canals, resulting in much greater flow volumes between Bend and Lake Billy Chinook. The natural flow downstream of Bend was approximately 1,080 cfs greater than the current condition on July 25, 2001. Note that the reach downstream of Benham Falls (kilometer 100) is a naturally losing reach.

In the ODFW flow scenario, the flow upstream of Bend is the same as in the current condition. The diversion rates at the North Canal Dam in Bend were reduced in order to meet the 250 cfs instream target downstream. On the July 25, 2001 simulation date, the North Canal Dam diversions were reduced 205 cfs from the current rate. Throughout the simulation period, the current condition flows upstream of Bend were above the ODFW instream targets.

Figure 65 - Deschutes River current, natural, and ODFW scenario flows.



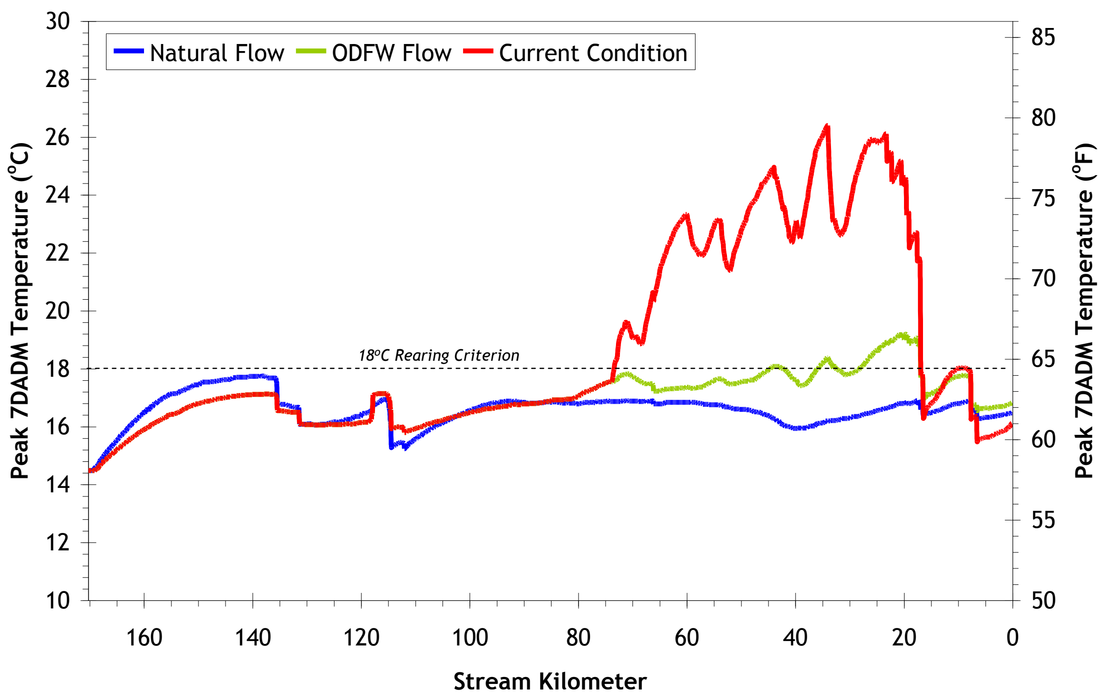
Deschutes River Stream Temperature Results

Figure 66 shows the simulated current, natural and ODFW flow scenario temperatures for the Deschutes River. The moving seven-day average of the daily maximums (7DADM) was calculated. The peak values of the 7DADM were then selected for the simulation period and plotted in Figure 66. The results are intended to represent the critical summertime period when stream temperatures reach their yearly maximums and aquatic life is at the greatest risk of thermal impairment. For reference purposes, the applicable Oregon state water quality criterion is included on the chart. Currently, the peak 7DADM temperatures downstream of Bend reach nearly 80˚F.

Since the natural flow volumes between Wickiup Reservoir and Bend are less than the current condition, the simulated natural flow stream temperatures were warmer in many of those reaches. Leaving all of the water instream also resulted in much cooler stream temperatures between Bend and Lake Billy Chinook. In the natural flow scenario, the 18˚C rearing criterion was not exceeded.

In the ODFW flow scenario, the stream temperatures were the same as the current condition everywhere upstream of the North Canal Dam. Diversions were reduced at the North Canal Dam in order to maintain the 250 cfs target between there and Lake Billy Chinook. The resulting stream temperatures downstream of Bend were much cooler than the current condition and exceeded the numeric criterion in only a few reaches.

Figure 66 - Deschutes River current, natural, and ODFW flow scenario stream temperatures.



Conclusion

Tumalo Creek, Whychus Creek, and the upper Deschutes River currently exceed Oregon State water quality standards during the critical summertime periods. Tumalo Creek has the least severe exceedances, reaching nearly 68°F near the mouth. Whychus Creek and the upper Deschutes River between Bend and Lake Billy Chinook often approach 80°F during late July and early August. Such extreme temperatures can be lethal to aquatic life.

Irrigation diversions are one of the major sources of anthropogenic stream heating. The majority of flow volume is diverted from each of the three streams during the critical summertime period. Less water in the streams equates to reduced bulk volume and shallower water columns. These two factors make the stream much more susceptible to solar heating. Longitudinal heating rates increase greatly and the daily maximum stream temperatures rise.

Other anthropogenic factors such as channel modification, near stream vegetation disturbance, and reservoir operations may also impact stream temperatures. Those parameters were not examined as part of this project. It is anticipated that Oregon DEQ will examine the impact of these additional anthropogenic heat sources through its Total Maximum Daily Load (TMDL) program.

The stream temperature simulations performed for this project demonstrate the impacts of flow modification. The natural flow scenarios revealed that each of the three simulated streams may meet the State rearing and migration criterion of 18°C in the absence of irrigation diversions. Targeting the ODFW instream water rights of each stream also resulted in temperatures cooler than the current condition; however, the numeric criteria were still exceeded in Whychus Creek and the Deschutes River.

It should be noted that the simulation results are valid for the specific time period for which the models were set up. Results may vary for different seasons and different years due to changes in flow volume and climatic conditions.

Citations

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