# *Aerial Surveys in the Deschutes River Basin*
## Thermal Infrared and Color Videography

**February 11, 2002**

*Report to*:

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**Final Report**

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## Introduction

Thermal infrared remote sensing has been demonstrated as a reliable, cost-effective, and accessible technology for monitoring and evaluating stream temperatures from the scale of watersheds to individual habitats (Karalus et. al., 1996; Torgersen et. al. 1999; Torgersen et. al. 2001). In 2001, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC (WS, LLC) to map and assess stream temperatures in the Deschutes River basin using thermal infrared (TIR) remote sensing.

This report presents longitudinal temperature profiles for each survey stream as well as a discussion of the thermal features observed in the basin. TIR and associated color video images are included in the report in order to illustrate significant thermal features. An associated ArcView GIS[1] database includes all of the images collected during the survey and is structured to allow analysis at finer scales. Appendix A presents a collection of selected TIR and visible band images from the surveys.

## Methods

*Data Collection*

Data were collected using a TIR sensor and a visible band color video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally along the stream channel with the sensors in a vertical (or near vertical) position. Figure 1 illustrates the extent of the TIR surveys and Table 1 summarizes the dates and times of each survey. The flights were coordinated with field crews from the ODEQ who measured stream flow levels.

TIR images were collected digitally and recorded directly from the sensor to an on-board computer. The TIR sensor detects emitted radiation at wavelengths from 8-12 microns and records the level of emitted radiation in the form of an image. Each image pixel contains a measured value that can be directly converted to a temperature. The raw TIR images represent the full 12 bit dynamic range of the instrument and were tagged with time and position data provided by a Global Positioning System (GPS). Visible band color images were recorded to an on-board digital videocassette recorder at a rate of 30 frames/second. GPS time and position were encoded on the recorded video. The color video camera was aligned to present the same ground area as the TIR sensor.

Surveys were conducted at altitudes between 1400 ft and 2000 ft above ground level (AGL) depending on channel width and sinuosity. At 1400 ft, the image presents 150-meter wide footprint with a pixel size of 0.25 meters. At 2000 ft, the footprint width is 214 meters with a 0.36-meter pixel. The flight direction (upstream versus downstream) depended on the stream layout as well as operational variables. In general, the long surveys (> 40 miles) were surveyed in the downstream direction and tributaries were

[1] Geographic Information System

surveyed in the upstream direction. The Deschutes River was surveyed in the downstream direction through most of its length. However, the stream segment between Crane Prairie Reservoir and Little Lava Lake was surveyed upstream due to wind conditions. The image orientations are in the direction of flight.

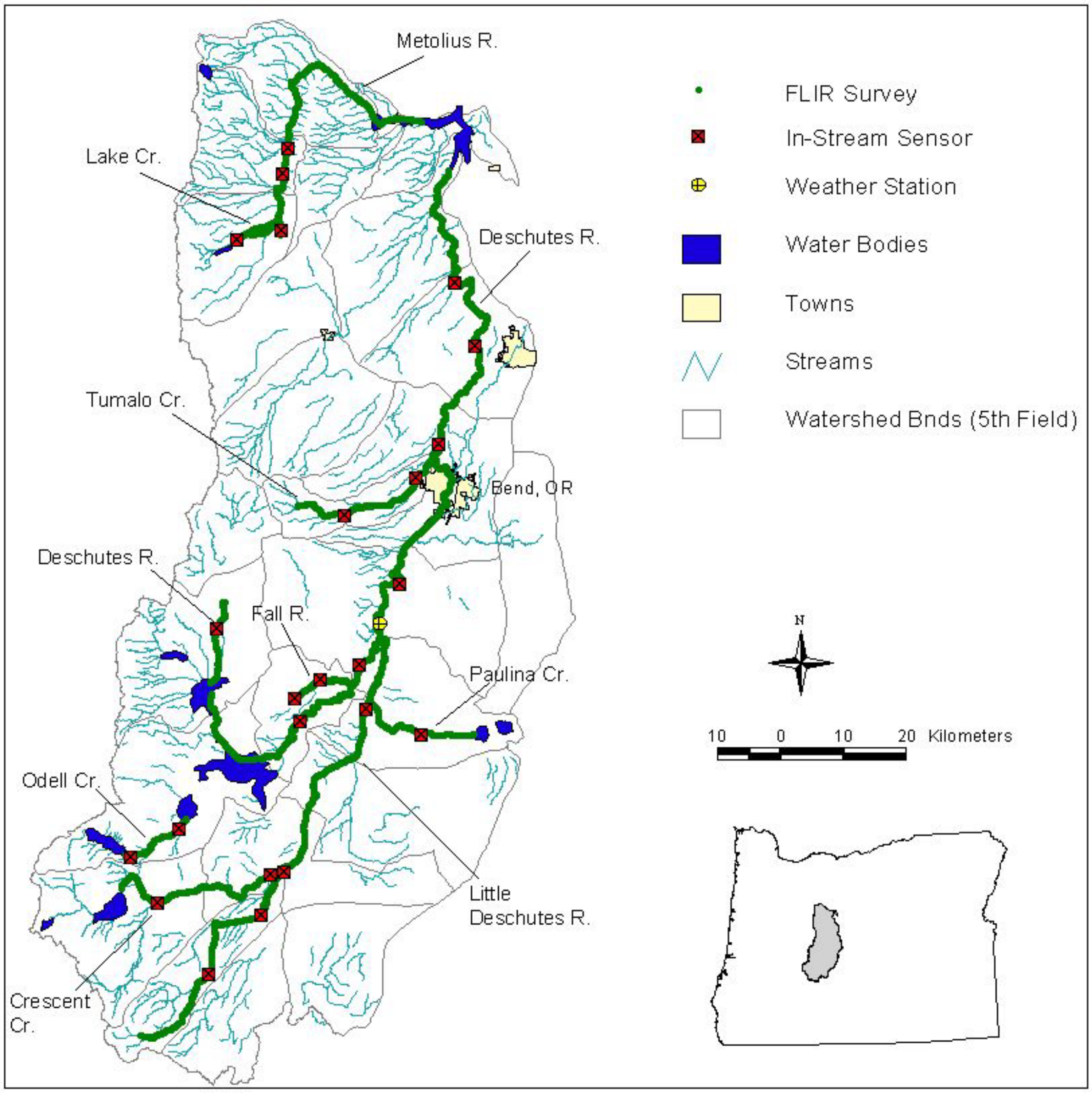



Figure 1 – Map of the Deschutes River basin showing streams surveyed using TIR and visible band color video. The map also shows the location of in-stream sensors used to verify the accuracy of the radiant temperatures.

WS, LLC distributed in-stream temperature data loggers (Onset Stowaways) at 24 locations in the basin prior to the surveys (Figure 1). The in-stream sensors were used to ground truth (i.e. verify the accuracy of) the radiant temperatures measured by the TIR sensor. The advertised accuracy of the Onset Stowaway's is ±0.2°C. These locations were supplemented by data provided by ODEQ from ten additional in-stream temperature loggers. Meteorological conditions for July 23 to 25 were recorded using a field station located at the Sunriver Airport. For July 26th and 27th, meteorological conditions were recorded from the Agrimet Station located in Madras, OR.

Table 1 - Time, date and distance for the Deschutes River Surveys.

| Stream | Date | Time (PM) | Survey Direct. | Survey Extent |
|---|---|---|---|---|
| Tumalo Cr. | 23-Jul | 2:57 – 3:34 | us | Mouth to MF/NF Confluence |
| Fall Cr. | 23-Jul | 3:45 – 4:03 | us | Mouth to headwaters |
| Paulina Cr. | 23-Jul | 4:09 – 4:47 | us | Mouth to Paulina Lake |
| Little Deschutes R. | 24-Jul | 2:09 – 3:57 | ds | Clover Cr. to mouth |
| Little Deschutes R. | 25-Jul | 1:49 – 1:58 | us | Cresent Cr. to Gilchrist, OR |
| Crescent Cr. | 25-Jul | 2:02 –2:36 | us | Mouth to Crescent Lake |
| Odell Cr. | 25-Jul | 2:40 – 2:58 | ds | Odell Lake to Davis Lake |
| Deschutes R. | 25-Jul | 3:06 – 4:38 | us/ds | Lava Lake to Bend, OR |
| Deschutes R. | 26-Jul | 3:19 – 4:37 | ds | Bend, OR to Lake Billy Chinook |
| Lake Cr. | 27-Jul | 2:29 – 3:03 | us | Mouth to Suttle Lake |
| Metolius R. | 27-Jul | 3:06 – 3:56 | us | Headwater to Lake Billy Chinook |

*us = upstream; ds = downstream*

Table 2 – Meteorological conditions recorded in the Deschutes River basin for the dates and times of the TIR surveys.

| *Date* | *Time* | *Temp °C* | *Temp °F* | *RH %* |
|---|---|---|---|---|
| 23-Jul | 15:00 | 27.5 | 81.5 | 21.7 |
| 23-Jul | 16:00 | 27.1 | 80.8 | 20.4 |
| 23-Jul | 17:00 | 27.9 | 82.2 | 20.4 |
| 24-Jul | 14:00 | 27.1 | 80.8 | 29.4 |
| 24-Jul | 15:00 | 28.3 | 82.9 | 27.5 |
| 24-Jul | 16:00 | 28.7 | 83.7 | 23.4 |
| 25-Jul | 14:30 | 28.7 | 83.7 | 15.8 |
| 25-Jul | 15:00 | 29.5 | 85.1 | 13.8 |
| 25-Jul | 16:00 | 29.5 | 85.1 | 15.8 |
| 25-Jul | 17:00 | 28.3 | 83.0 | 17.4 |
| 26-Jul | 14:00 | 28.4 | 83.2 | 13.0 |
| 26-Jul | 15:00 | 29.2 | 84.6 | 12.8 |
| 26-Jul | 16:00 | 30.3 | 86.6 | 12.8 |
| 26-Jul | 17:00 | 29.9 | 85.9 | 13.0 |
| 27-Jul | 13:00 | 26.8 | 80.2 | 16.8 |
| 27-Jul | 14:00 | 27.4 | 81.4 | 15.3 |
| 27-Jul | 15:00 | 27.6 | 81.7 | 20.4 |
| 27-Jul | 16:00 | 27.7 | 81.9 | 20.4 |
| 27-Jul | 17:00 | 26.9 | 80.4 | 23.8 |
| 27-Jul | 17:15 | 26.6 | 79.8 | 24.3 |
| 27-Jul | 17:30 | 26.0 | 78.8 | 25.1 |

*Data Processing*

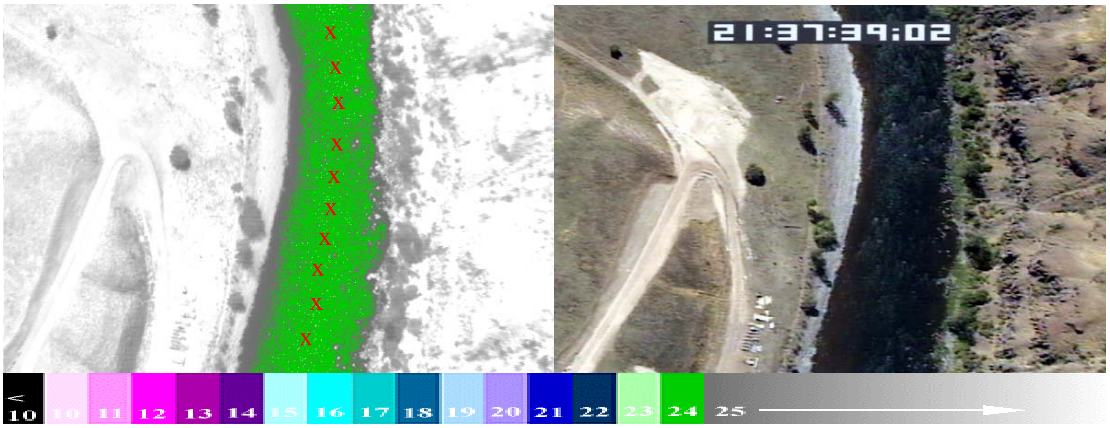
A computer program was used to create an ArcView GIS point coverage containing the image name, time, and location it was acquired. The coverage provided the basis for assessing the extent of the survey and for integrating with other spatially explicit data layers in the GIS. This allowed WS, LLC to identify the images associated with the ground truth locations. The data collection software was used to extract temperature values from these images at the location of the in-stream recorder. The radiant temperatures were then compared to the kinetic temperatures from the in-stream data loggers.

The image points were associated with a river kilometer within the GIS environment. The river kilometers were derived from 1:100K "routed" stream covers from the Environmental Protection Agency (EPA). The route measures provide a spatial context for developing longitudinal temperature profiles of stream temperature.

In the laboratory, a computer algorithm was used to convert the raw thermal images (radiance values) to ARC/INFO GRIDS where each GRID cell contained a temperature value. A GIS program was used to display the GRID associated with an image location selected in the point coverage. The GRID was color-coded to visually enhance temperature differences, enabling the user to extract temperature data.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, a computer program was used to sample the GRID cell (temperature) values in the stream channel. Ten sample points were taken longitudinally in the center of the stream channel. Figure 2 provides an example of how temperatures are sampled. The red "x"s on the psuedo-color TIR image show typical sample locations. Samples were taken to provide complete coverage without sampling the same water twice. Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled. For each sampled image, the sample minimum, maximum, median, and standard deviation was recorded directly to the point coverage attribute file. The median value is the most useful measure of stream temperatures because it minimizes the effect of extreme values. The temperature of tributaries and other detectable surface inflows were also sampled from images. These inflows were sampled at their mouth using the same techniques described for sampling the main channel. If possible, the surface inflows were identified on the USGS 24K base maps. The inflow name and median temperature were then entered into the point coverage attribute file.

Visible band images corresponding to the TIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the TIR images and provide a complete coverage of the stream. The video images were "linked" to the corresponding thermal image frame in the ArcView GIS environment.



*TIR/visible band color image*

Figure 2 – Image pair showing typical temperature sampling locations. Temperatures are presented in $^{o}$C.

## Data Limitations

TIR sensors measure thermal infrared energy emitted at the water's surface. Since water is essentially opaque to thermal infrared wavelengths, the sensor is only measuring water surface temperature. TIR data accurately represents bulk water temperatures in reaches where the water column is thoroughly mixed, however, thermal stratification can form in reaches that have little or no mixing. In the Deschutes River basin, thermal stratification was only detected in the larger reservoirs and directly upstream of impoundments. Areas of potential thermal stratification were noted in the survey database.

## Results

*Thermal Accuracy*

Temperatures from the in-stream data loggers were compared to radiant temperatures derived from the imagery for each survey (Table 3). The data were assessed at the time the image was acquired, with the radiant values representing the median of 10 points sampled from the image at the data logger location. Each surveyed stream was calibrated separately based on the meteorological conditions recorded at the time of the survey. If a consistent difference was observed for all the in-stream sensors, the parameters used to convert radiant values to temperatures were adjusted to provide a better fit to the in-stream sensors.

Three ground truth locations were incorporated in every flight. Twenty-five of the twenty-seven points showed differences less than ±0.5$^{o}$C between the in-stream and the radiant temperatures and the maximum difference was 1.0$^{o}$C. The average difference of 0.4$^{o}$C for all points is consistent with TIR surveys conducted in the PNW since 1994 (Torgersen et. al. 2001).

Table 3 – Comparison of ground-truth water temperatures with radiant temperatures derived from the TIR images, July 23-27, 2001. Temperatures are reported in $^{o}$C and river miles (rm) are cited for locations.

| ***Stream*** | ***Image*** | ***River mile*** | ***Time*** | ***In-stream Temp $^{o}$C*** | ***Radiant Temp $^{o}$C*** | ***Difference*** |
|---|---|---|---|---|---|---|
| | | | ***July 23*** | | | |
| Deschutes R. | tum0016 | 156.6 | 14:58 | 20.9 | 20.5 | 0.4 |
| Tumalo Cr. | tum0246 | 3.3 | 15:05 | 16.2 | 16.8 | -0.6 |
| Tumalo Cr. | tum0708 | 12.4 | 15:21 | 14.2 | 14.3 | -0.1 |
| Fall R. | fr0314 | 6.9 | 15:55 | 12.7 | 12.3 | 0.4 |
| Fall R. | fr0514 | 10.7 | 16:02 | 6.1 | 6.5 | -0.4 |
| Paulina Cr. | pal0516 | 7.9 | 16:26 | 21.4 | 21.1 | 0.3 |
| L. Deschutes R. | pal0905 | 15.7 | 16:46 | 22.1 | 22.6 | -0.5 |
| | | | ***July 24*** | | | |
| L. Deschutes R. | ld0587 | 76.1 | 14:30 | 17.8 | 18.2 | -0.4 |
| L. Deschutes R. | ld1317 | 61.2 | 14:55 | 23.9 | 23.5 | 0.4 |
| L. Deschutes R. | ld1574 | 54.9 | 15:05 | 22.6 | 22.2 | 0.4 |
| L. Deschutes R. | ld2677 | 15.7 | 15:41 | 22.8 | 22.3 | 0.5 |
| | | | ***July 25*** | | | |
| L. Deschutes R. | cred0050 | 54.9 | 13:50 | 21.2 | 21.0 | 0.2 |
| Crescent Cr. | cres0739 | 2.4 | 14:26 | 20.0 | 19.9 | 0.1 |
| Crescent Cr. | cres0088 | 20.3 | 14:12 | 19.5 | 19.2 | 0.3 |
| Odell Cr. | ode0095 | 3.8 | 14:43 | 22.0 | 21.0 | 1.0 |
| Odell Cr. | ode0488 | 10.2 | 14:56 | 14.9 | 15.3 | -0.4 |
| Deschutes R. | des0295 | 240.8 | 15:16 | 14.3 | 14.7 | -0.4 |
| Deschutes R. | des1034 | 213.4 | 15:45 | 16.5 | 16.3 | 0.2 |
| Deschutes R. | des1544 | 196.2 | 16:03 | 16.0 | 15.9 | 0.1 |
| Deschutes R. | des2117 | 178.8 | 16:22 | 16.5 | 16.5 | 0.0 |
| | | | ***July 26*** | | | |
| Deschutes R. | desb0540 | 156.7 | 15:40 | 21.2 | 21.0 | 0.2 |
| Deschutes R. | desb1146 | 143.5 | 16:04 | 23.1 | 22.8 | 0.3 |
| Deschutes R. | desb1723 | 131.7 | 16:26 | 24.9 | 25.3 | -0.4 |
| | | | ***July 27*** | | | |
| Lake Creek | lake0296 | 5.1 | 14:39 | 20.9 | 20.6 | 0.3 |
| Metolius R. | met0051 | 39.1 | 15:07 | 11.8 | 11.8 | 0.0 |
| Metolius R. | met0426 | 31.8 | 15:20 | 9.1 | 9.5 | -0.4 |
| Metolius R. | met0563 | 29.2 | 15:24 | 9.7 | 10.2 | -0.5 |

*Temporal Differences*

Figure 3 shows in-stream temperature variation at a single ground truth location for the Little Deschutes River and Deschutes River as well as the timing of the TIR remote sensing flights. The surveys of the Little Deschutes River (7/24) and the Deschutes River (7/25 and 7/26) were the longest in duration. Consequently, stream temperature changes that occur during the course of the survey may not be reflected in the longitudinal temperature profile. The TIR survey of the Little Deschutes River took place prior to the daily stream temperature maximum, which occurred at 17:00. At river mile 54.9, stream temperatures in the Little Deschutes River changed by almost 2.0$^{o}$C over the course of the survey. The survey of the Deschutes River upstream of Bend, OR (7/25) corresponded to the daily temperature maximum and little temperature difference was observed during the course of the survey. The survey of the Deschutes River downstream of Bend (7/26) took place prior to the daily maximum, which was recorded at 18:20. A stream temperature change of 1.2$^{o}$C occurred over the course of the survey at river mile 143.5.

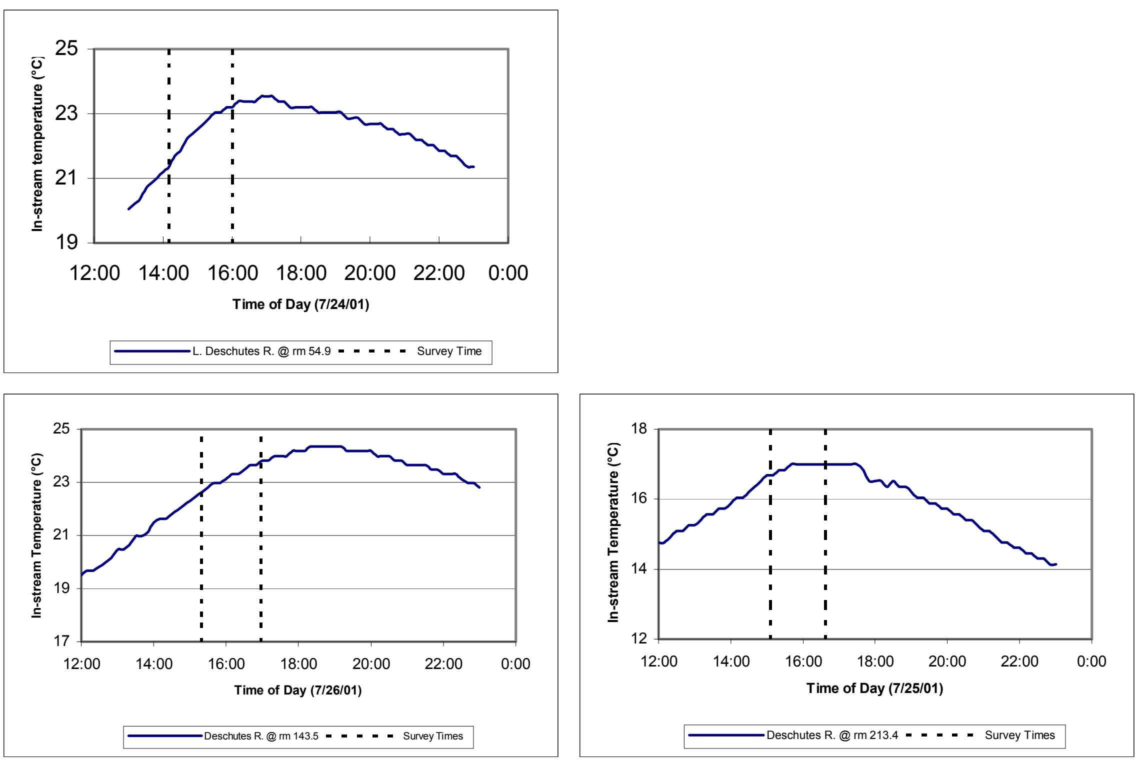



Figure 3 – Stream temperature variation and time of TIR remote sensing over flight for a single location in the three longest surveys conducted in the Deschutes River Basin.

*Longitudinal Temperature Profiles*

**Tumalo Creek**

The median temperatures for each sampled image of Tumalo Creek were plotted versus the corresponding river mile (Figure 4). The plot also contains the median temperature of all surface water inflows (e.g. tributaries, canals) and off-channel features (side-channels, backwaters) that were visible in the imagery. Tributaries are labeled in Figure 4 by river mile with their name and temperature listed in Table 4.

Tumalo Creek was surveyed from its mouth at the Deschutes River upstream to the confluence of the North and Middle Forks. Tumalo Creek temperatures were approximately 12.0°C at the North Fork confluence (rm 17.0). Between river miles 15.4 and 13.7, stream temperatures showed no net gain and had more local thermal spatial variability than noted in other portions of the survey. Multiple channels and several cool-water tributaries characterized this reach. Several side channels had temperatures that were cooler than the mainstream indicating the influence of springs or other cool water sources. However, in many cases the side channel did not appear to re-enter the mainstream as a cooling source. An example is a cool-water channel that paralleled the mainstream near the mapped location of the South Fork at river mile 14.3, but did not appear to re-enter Tumalo Creek as surface flow. Bridge Creek lowered the temperature of Tumalo Creek by $\approx$1.5°C at river mile 14.7 and had the most direct influence on mainstream temperatures through this reach.

A slight cooling trend was observed between river miles 11.0 to 7.7 and no tributaries were sampled in this segment. Tumalo Creek travels in a confined canyon through this reach and topography likely plays a large role in defining the watershed scale temperature patterns. Stream temperature began to warm again downstream and a consistent longitudinal heating rate of about 0.6°C per mile was observed between river miles 7.7 and 2.9. The longitudinal heating rate increases to 2.7°C per mile between river miles 2.9 and 1.5. This inflection in the longitudinal profile corresponds to the location of a diversion dam for the Tumalo Feed Canal. Ultimately, Tumalo Creek is a warming source to the Deschutes River.

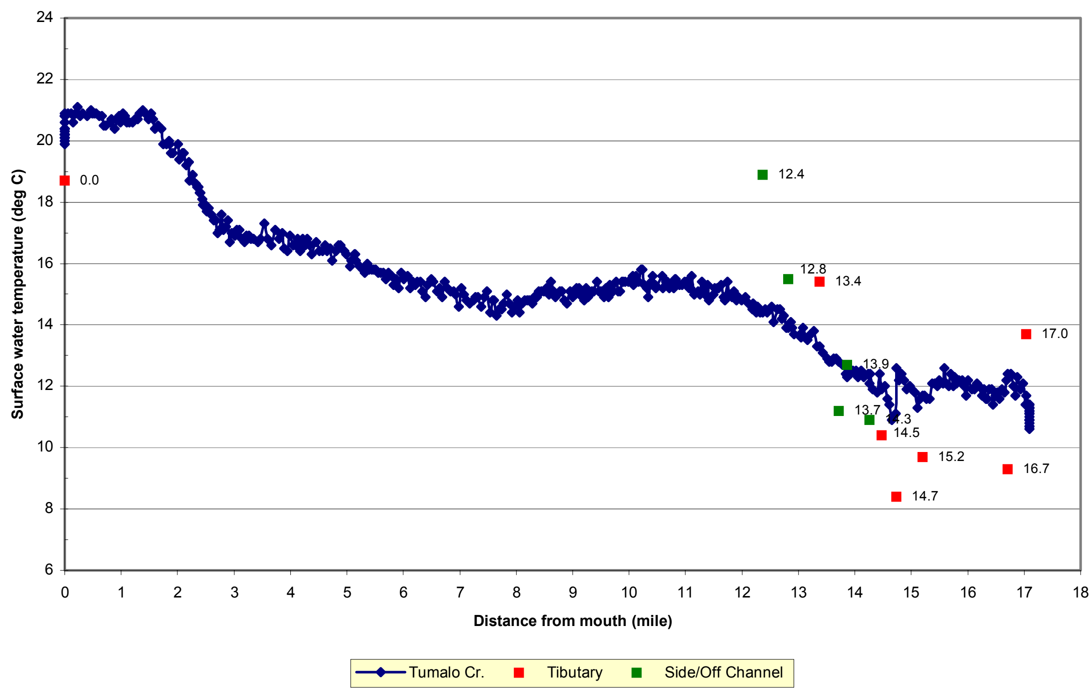



Figure 4 - Median channel temperatures versus river mile for Tumalo Creek, OR along with the location of tributary and side channel inputs (7/23/01).

Table 4 - Tributary and side channel temperatures for Tumalo Creek, OR. River miles correspond to data labels shown in Figure 4.

| Tributary Name | Image | km | mile | Tibutary Temp. °C | Tumalo Cr. Temp. °C | Difference |
|---|---|---|---|---|---|---|
| Deschutes River () | tum0071 | 0.0 | 0.0 | 18.7 | 20.2 | -1.5 |
| Spring Outlet (LB) | tum0759 | 21.5 | 13.4 | 15.4 | 13.3 | 2.1 |
| No Name (LB) | tum0830 | 23.3 | 14.5 | 10.4 | 11.9 | -1.5 |
| Bridge Creek (RB) | tum0845 | 23.7 | 14.7 | 8.4 | 12.6 | -4.2 |
| Spring (RB) | tum0867 | 24.5 | 15.2 | 9.7 | 11.7 | -2.0 |
| Bottle Creek (LB) | tum0966 | 26.9 | 16.7 | 9.3 | 12.4 | -3.1 |
| North Fork (LB) | tum0987 | 27.4 | 17.0 | 13.7 | 11.7 | 2.0 |
| **Side/Off Channel** | | | | | | |
| Side Channel (LB) | tum0708 | 19.9 | 12.4 | 18.9 | 14.4 | 4.5 |
| Side Channel (LB) | tum0730 | 20.6 | 12.8 | 15.5 | 13.9 | 1.6 |
| Off Channel (LB) | tum0775 | 22.1 | 13.7 | 11.2 | 12.8 | -1.6 |
| Side Channel (RB) | tum0780 | 22.3 | 13.9 | 12.7 | 12.3 | 0.4 |
| Off-Channel (RB) | tum0818 | 23.0 | 14.3 | 10.9 | 12.1 | -1.2 |

## Fall River

The median temperatures for each sampled image of Fall River were plotted versus the corresponding river mile (Figure 5). The plot also identifies the location of all surface water inflows that were visible in the imagery where they input into Fall River.

Fall River originates from a large spring located at river mile 11.2. Two additional springs inflows were detected at river miles 11.0 and 10.7, which contribute water temperatures characteristic of ground water (5-6$^{o}$C). From river mile 10.7, stream temperatures increase steadily in a downstream direction reaching a local maximum of 12.6$^{o}$C at river mile 7.6. Fall River showed a slight, but steady cooling trend between river mile 7.6 and its mouth. Two surface water inflows were detected in the lower 7.7 miles of Fall River and both contributed water that was warmer than the mainstream. Consequently, the source of the cooling through this reach was not apparent from the imagery. Fall River was 11.4$^{o}$C at its mouth and was a cooling source to the Deschutes River.

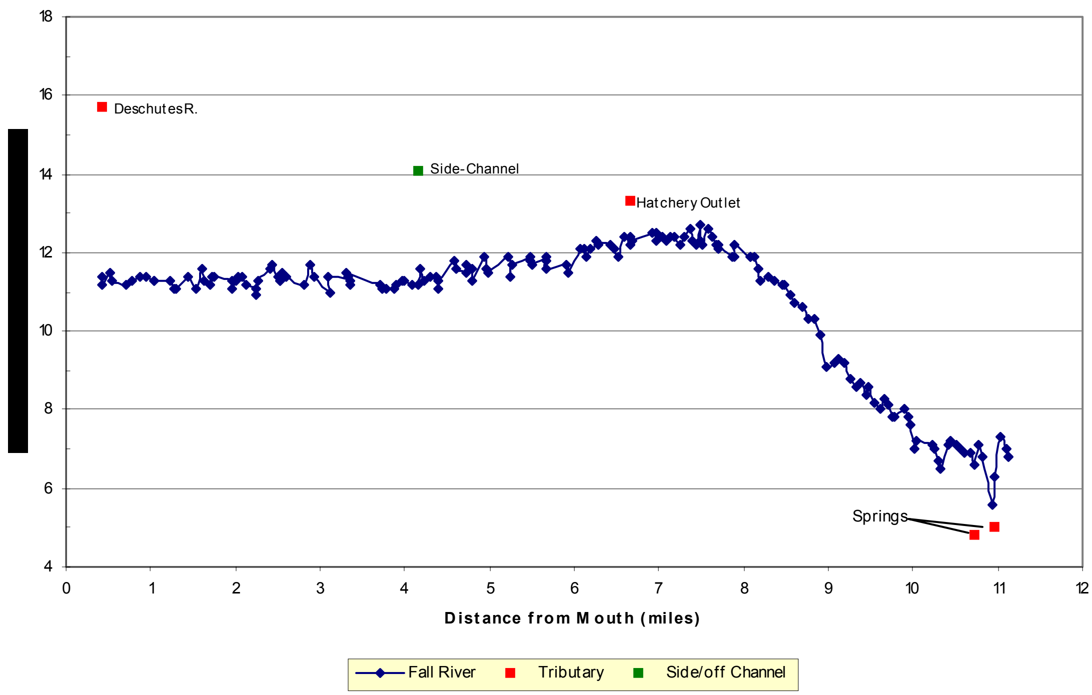



Figure 5 - Median channel temperatures versus river mile for Fall River, OR along with the location of surface water inflows (7/23/01).

## Paulina Creek

The median temperatures for each sampled image of Paulina Creek were plotted versus the corresponding river mile (Figure 6). The plot also shows the location of all surface water inflows and other thermal features noted during the survey.

Paulina Creek flows out of Paulina Lake (river mile 13.2) at a temperature of 19.0°C. An apparent spring was detected just downstream of the lake outlet (river mile 13.1), but it did not have a measurable effect on mainstream temperatures. At Paulina Creek Falls (river mile 12.9), an approximate 1.0°C drop in stream temperature was observed that appeared the result of several cool water inputs located near the base of the falls. However, these inputs could not be positively identified due to the number of cool regions created by visible shadows. Between river mile 12.8 and 8.0, stream temperatures increased by approximately 3.0°C with some local variability noted in the longitudinal heating rates. No surface water inflows were sampled through this reach and other potential sources of thermal variability were not apparent from the imagery. Downstream of river mile 8.0, stream temperatures were consistent (21.0°C) for about 2.5 miles before starting to increase again at river mile 5.5. The increased longitudinal heating rate at river mile 5.5 corresponds to the start of the Paulina Prairie and marks a transition from the canyon to a lower gradient meadow. Paulina Creek eventually dissipates in the prairie and there was only intermittent surface flow detected downstream of river mile 2.5.

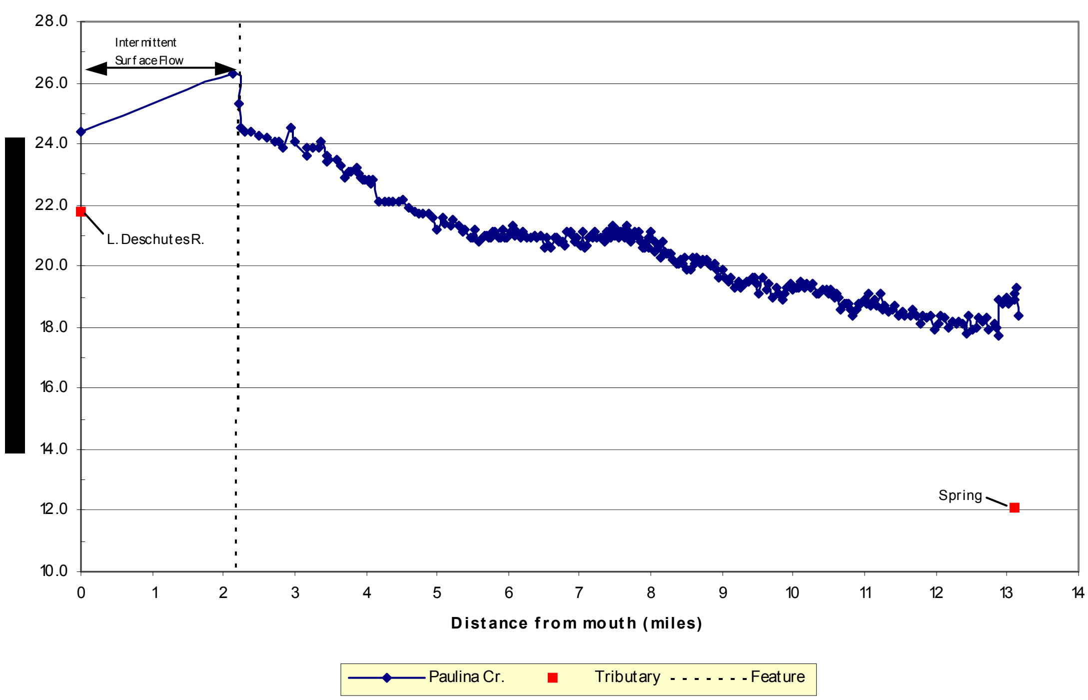



Figure 6 - Median channel temperatures versus river mile for Paulina Creek, OR along with the location of other surface water features (7/23/01).

**Little Deschutes River**

The median temperatures for each sampled image of the Little Deschutes River were plotted versus the corresponding river mile (Figure 7). The plot also contains the median temperature of all surface water inflows (i.e. tributaries, canals) and off-channel features (side-channels, backwaters) that were visible in the imagery. Tributaries are labeled in Figure 7 by river mile with their name and temperature listed in Table 5. The Little Deschutes River was characterized through much of its length by a number of meander bends and small oxbow ponds. These areas were sampled during the analysis as either a side channel or an off-channel feature. Surface water was identified as a side channel if it appeared to originate from and connect to the river. Surface water that was visible in the imagery, but did not appear to have surface exchange with the mainstream such as a pond was classified as an off-channel feature (Figure 8).

Water temperatures in the Little Deschutes River were approximately 12.0$^{o}$C at the upstream end of the survey (river mile 88.0). From this point, stream temperatures warmed in the downstream directions reaching 21.4$^{o}$C at river mile 64.2. While an overall warming trend was observed, the longitudinal profile shows locally cooler areas within this segment (e.g. between river miles 85.3 and 84.1; 81.8 and 80.1; 78.0 and 75.6; 72.7 and 71.5). There were 4 tributary inflows sampled through this reach and two of these were detected within the first 2.5 miles of the survey. The 2 other tributaries (rm 78.2 and 74.2) in this stream segment contributed water that was warmer than the mainstream.

A longitudinal heating rate of 1.6$^{o}$C per mile was measured between river miles 63.5 and 61.6 where stream temperatures reached a local maximum of 23.6$^{o}$C. Approximately 1.5 miles downstream at river mile 61.1, the Little Deschutes River flowed into a pond at the town of Gilchrist. The pond's surface showed signs of thermal stratification. The Little Deschutes River had considerably smaller channel widths between the pond's outlet and the confluence of Crescent Creek than were observed upstream of the pond. The flight altitude was maintained through this reach in order to have a consistent scale, however, it made it difficult to identify small-scale thermal features.

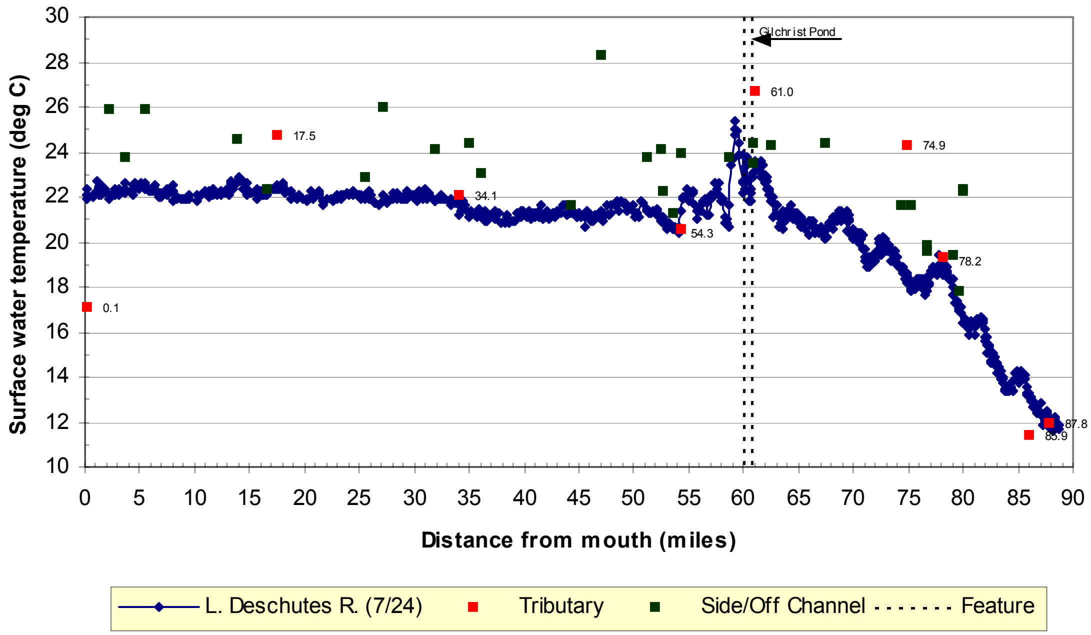



Figure 7 - Median channel temperatures versus river mile for the Little Deschutes River along with the location of tributary and side/off channel features (7/25/01).

Table 5 - Tributary temperatures for the Little Deschutes River, OR. River miles correspond to data labels shown in Figure 7.

| Tributary Name | Image | km | mile | Tributary Temp °C | L. Deschutes R. Temp °C | Difference |
|---|---|---|---|---|---|---|
| Deschutes River (LB) | ld3125 | 0.2 | 0.1 | 17.1 | 22.1 | -5.0 |
| No Name (LB) | ld2630 | 28.2 | 17.5 | 24.8 | 22.5 | 2.3 |
| No Name (LB) | ld2193 | 54.9 | 34.1 | 22.1 | 21.2 | 0.9 |
| Crescent Creek (LB) | ld1591 | 87.4 | 54.3 | 20.6 | 21.4 | -0.8 |
| Pond Outlet (LB) | ld1329 | 98.2 | 61.0 | 26.7 | 23.4 | 3.3 |
| No Name (LB) | ld0636 | 120.6 | 74.9 | 24.3 | 18.5 | 5.8 |
| Hemlock Creek (LB) | ld0485 | 125.8 | 78.2 | 19.3 | 18.5 | 0.8 |
| No Name ( LB) | ld0157 | 138.3 | 85.9 | 11.4 | 13.2 | -1.8 |
| No Name (LB) | ld0039 | 141.2 | 87.8 | 12.0 | 12.2 | -0.2 |

Table 5 (con't) - Side and off channel temperatures for the Little Deschutes River, OR.

| Name | Image | km | mile | Side/Off Channel Temp°C | L. Deschutes R. Temp °C | Difference |
|---|---|---|---|---|---|---|
| Off Channel (LB) | ld3060 | 3.6 | 2.3 | 25.9 | 22.1 | 3.8 |
| Side Channel (RB) | ld3011 | 5.9 | 3.7 | 23.8 | 22.4 | 1.4 |
| Off Channel (LB) | ld2973 | 8.8 | 5.5 | 25.9 | 22.4 | 3.5 |
| Side Channel (LB) | ld2746 | 22.3 | 13.9 | 24.6 | 22.6 | 2.0 |
| Side Channel (LB) | ld2654 | 26.8 | 16.7 | 22.4 | 22.1 | 0.3 |
| Off Channel | ld2412 | 41.1 | 25.5 | 22.9 | 21.9 | 1.0 |
| Side Channel (LB) | ld2379 | 43.6 | 27.1 | 26.0 | 21.8 | 4.2 |
| Side Channel (LB) | ld2255 | 51.3 | 31.9 | 24.1 | 21.8 | 2.3 |
| Side Channel (LB) | ld2164 | 56.3 | 35.0 | 24.4 | 21.1 | 3.3 |
| Side Channel (RB) | ld2132 | 58.0 | 36.0 | 23.1 | 21.2 | 1.9 |
| Side Channel (RB) | ld1892 | 71.3 | 44.3 | 21.6 | 21.3 | 0.3 |
| Off Channel (LB) | ld1808 | 75.7 | 47.1 | 28.3 | 21.4 | 6.9 |
| Side Channel (RB) | ld1692 | 82.5 | 51.2 | 23.8 | 21.4 | 2.4 |
| Off Channel (RB) | ld1652 | 84.4 | 52.4 | 24.1 | 20.9 | 3.2 |
| Side Channel (LB) | ld1648 | 84.6 | 52.6 | 22.3 | 21.1 | 1.2 |
| Side Channel (RB) | ld1612 | 86.3 | 53.6 | 21.3 | 20.6 | 0.7 |
| Off-Channel (LB) | ld1592 | 87.4 | 54.3 | 24.0 | 21.4 | 2.6 |
| Off Channel (RB) | ld1436 | 94.5 | 58.7 | 23.8 | 21.6 | 2.2 |
| Side Channel (LB) | ld1336 | 97.9 | 60.8 | 24.4 | 23.1 | 1.3 |
| Off Channel (RB) | ld1333 | 98.1 | 60.9 | 23.5 | 23.1 | 0.4 |
| Side Channel (LB) | ld1255 | 100.5 | 62.4 | 24.3 | 21.8 | 2.5 |
| Side Channel (RB) | ld1048 | 108.4 | 67.4 | 24.4 | 20.1 | 4.3 |
| Side Channel (RB) | ld0668 | 119.5 | 74.3 | 21.6 | 18.8 | 2.8 |
| Side Channel (LB) | ld0620 | 121.2 | 75.3 | 21.6 | 17.8 | 3.8 |
| Side Channel (RB) | ld0562 | 123.3 | 76.6 | 19.9 | 18.1 | 1.8 |
| Side Channel (LB) | ld0560 | 123.3 | 76.6 | 19.6 | 18.4 | 1.2 |
| Side Channel (RB) | ld0447 | 127.1 | 79.0 | 19.4 | 18.4 | 1.0 |
| Side Channel (LB) | ld0416 | 128.2 | 79.7 | 17.8 | 16.9 | 0.9 |
| Side Channel (LB) | ld0407 | 128.6 | 79.9 | 22.3 | 16.4 | 5.9 |
| Side Channel (RB) | ld0402 | 128.8 | 80.0 | 22.4 | 16.4 | 6.0 |


Figure 8 - The image on the left shows a feature that was sampled as side channel because it has visible surface connectivity to the mainstream. The image on the right shows an old oxbow that was sampled as an off channel feature.

For comparison purposes, the 6-mile segment between Gilchrist and Crescent Creek was resurveyed on July 25$^{th}$ at a lower altitude. Figure 9 shows how median channel temperatures varied through this reach on the two different days. The survey also showed a warm water discharge (33.3$^{o}$C) along the left bank of the pond (*Reference Appendix A*) Both surveys showed that stream temperatures warmed quickly from the outlet of the lake to river mile 59.2 where stream temperatures reached a maximum of 25.5$^{o}$C. Between river miles 59.2 and 58.6, a temperature drop of approximately 4.5$^{o}$C was observed on both days. A review of the imagery did not show any point source inputs at this location.

Crescent Creek at river mile 54.3 is a cooling source to the Little Deschutes River and seems to contribute significantly to the flow levels in the river. Stream temperatures warm by about 1.5$^{o}$C between the Crescent Creek confluence and river mile 34.1. Downstream of river mile 34.1, stream temperatures remained consistently around 22.0$^{o}$C to the mouth. Ultimately, the Little Deschutes River was a source of thermal loading to the Deschutes River. A total of 8 tributary inflows were sampled over the full survey extent. Of these 8, only Crescent Creek and two unnamed tributaries near the upstream end of the survey contributed water that was cooler than the mainstream. A total of 30 tributary and side channel features were sampled and all had surface temperatures warmer than the mainstream.

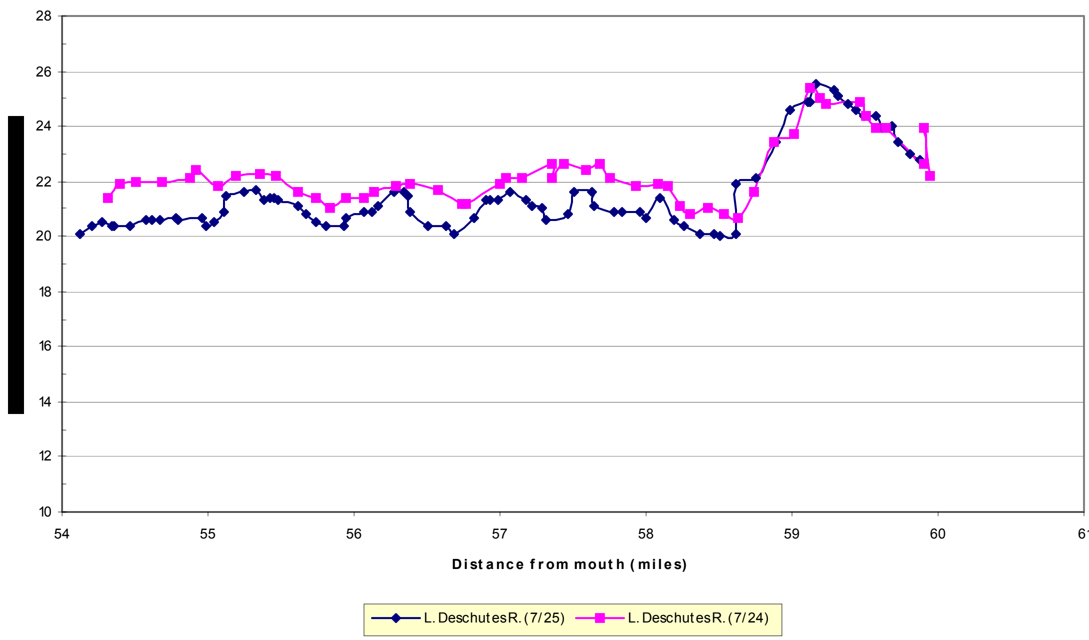



Figure 9 - Median channel temperatures versus river mile for the Little Deschutes River from Gilchrist downstream to Crescent Creek for two surveys conducted on July 24th and 25th, 2001.

### Odell Creek

The median water temperatures for each sampled image of Odell Creek were plotted versus river mile (Figure 10). The plot also contains the median temperature of all surface water inflows (e.g. tributaries, canals) and off channel features (side-channels, backwaters) that were visible in the imagery where they input to Odell Creek. Tributaries are labeled in Figure 10 by river mile with their name and temperature listed in Table 6. Odell Creek was surveyed from Odell Lake to Davis Lake. The stream routing used for the longitudinal temperature profile (Figure 10) considers the center of the lake as the start of the stream. Consequently, the mouth of Odell Creek, an inlet to Davis Lake, is river mile 2.5 in the longitudinal profile.

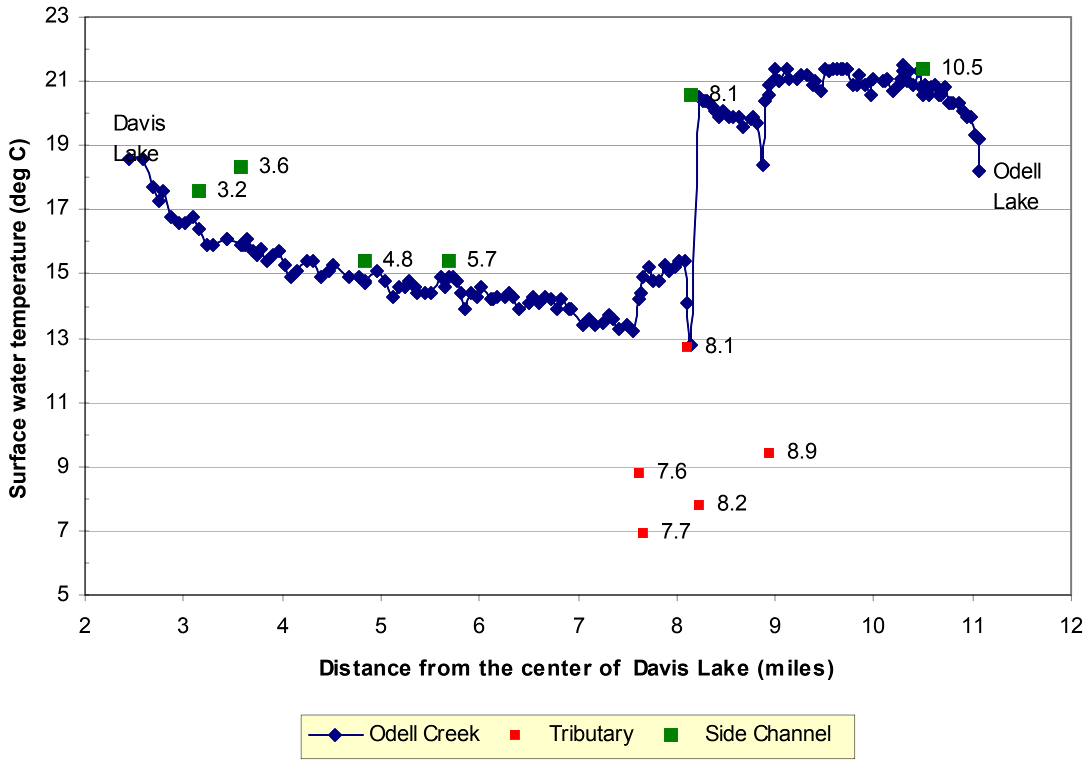



Figure 10 - Median channel temperatures versus river mile for Odell Creek along with the locations of tributary inputs (7/25/01).

Table 6 - Tributary and side channel temperatures for Odell Creek, OR. River miles correspond to data labels shown in Figure 10.

| **Tributary Name** | **image** | **Km** | **mile** | **Tributary Temp °C** | **Odell Cr. Temp °C** | **Difference** |
|---|---|---|---|---|---|---|
| Spring (RB) | Ode0248 | 14.4 | 8.9 | 9.4 | 20.9 | -11.5 |
| Spring (LB) | Ode0290 | 13.3 | 8.2 | 7.8 | 20.5 | -12.7 |
| Spring ( LB) | Ode0296 | 13.1 | 8.1 | 12.7 | 14.1 | -1.4 |
| Spring (LB) | Ode0321 | 12.3 | 7.7 | 6.9 | 14.9 | -8.0 |
| Maklak Creek (LB) | Ode0324 | 12.3 | 7.6 | 8.8 | 14.2 | -5.4 |
| Side Channels | | | | | | |
| Side Channel (LB) | Ode0075 | 16.9 | 10.5 | 21.4 | 20.6 | 0.8 |
| Side Channel ( RB) | Ode0294 | 13.1 | 8.1 | 20.6 | 12.8 | 7.8 |
| Side Channel (LB) | Ode0416 | 9.2 | 5.7 | 15.4 | 14.9 | 0.5 |
| Side Channel (RB) | Ode0451 | 7.8 | 4.8 | 15.4 | 14.7 | 0.7 |
| Side Channel (LB ) | Ode0504 | 5.8 | 3.6 | 18.3 | 15.9 | 2.4 |
| Side Channel (LB) | Ode0518 | 5.1 | 3.2 | 17.6 | 16.4 | 1.2 |

Three spring complexes largely define spatial temperature patterns in Odell Creek. Water temperatures out of Odell Lake were 19.0°C and warm to about 21.3°C within 1.5 miles downstream of the lake. The first spring at river mile 8.9 lowered stream temperatures by approximately 1.6°C (21.3°C to 19.7°C). Stream temperatures warm slightly before a second set of springs between river miles 8.1 and 8.2 again lowers mainstream temperatures by approximately 5.1°C. Neither of the spring complexes was identified on the 1:24k USGS topographic maps. However, the location of the second springs corresponded to the mapped location of a perennial stream. Approximately 0.3 miles downstream, another spring and Maklak Creek further lowered mainstream temperatures to approximately 13.2°C. This area was identified as McCord Cabin spring on the 1:24k USGS topographic map. Down stream of Maklak Creek (river mile 7.6), Odell Creek warms steadily and eventually reaches a temperature of 18.6°C at Davis Lake. Appendix A provides image mosaics of the springs observed during the survey of Odell Creek.

### Crescent Creek

The median temperatures for each sampled image of Crescent Creek were plotted versus the corresponding river mile (Figure 11). The plot also contains the median temperature of all surface water inflows (e.g. tributaries, canals) and off-channel features (side-channels, backwaters). Tributaries are labeled in Figure 11 by river mile with their name and temperature listed in Table 7. As noted on the Little Deschutes River, Crescent Creek had a number of meander bends and oxbow ponds. Ponds that were disconnected from the mainstream (at least on the surface) were sampled as off-channel features. Old meander bends that were still connected to the mainstream were sampled as side channels. The location of side and off-channel features are shown in the figure, however, data labels were not included in order to maintain the readability of the profile.

Crescent Creek flows out of Crescent Lake and stream temperatures were about 18.0°C at the lake outlet. From the lake, Crescent Creek warms in the downstream direction and reaches a local maximum of 20.6°C at river mile 18.8. Cold Spring Creek (river mile 24.5) is a source of thermal cooling in this reach. A cooling trend of about 1.6°C was observed between river miles 18.8 and 15.6. There were no tributary inflows detected through this reach. Stream temperatures are consistent (±0.5°) between river miles 15.6 and 4.0. River mile 15.6 roughly corresponds to a transition from a confined channel to a more meandering stream with a number of old oxbows. While the surface of the seven side and off-channels sampled during this reach had surface temperatures greater than the mainstream, sub-surface exchange through the old side channels and oxbows may effectually mitigate stream temperature gains through this reach. Over the lower 4 miles, stream temperatures increase by about 1.0°C to 19.8°C. At the time of the survey, Crescent Creek was the same temperature as the Little Deschutes River.

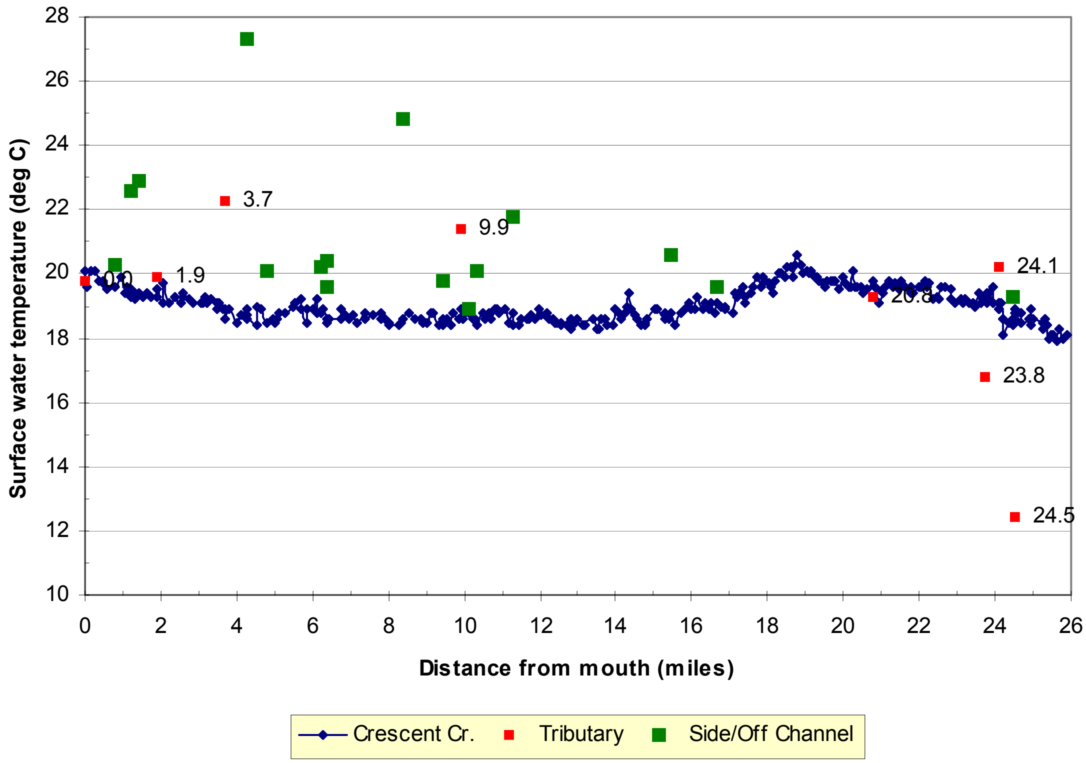



Figure 11 - Median channel temperature versus river mile for Crescent Creek along with the location of tributary inputs (7/25/01).

Table 7 - Tributary and side channel temperatures for Crescent Creek, OR. River miles correspond to data labels shown in Figure 11.

| Tribuary Name | Image | km | mile | Tributary Temp °C | Crescent Cr. Temp °C | Difference |
|---|---|---|---|---|---|---|
| Little Deschutes (RB) | cres0008 | 0.0 | 0.0 | 19.8 | 19.8 | 0.0 |
| No Name (LB) | cres0075 | 3.0 | 1.9 | 19.9 | 19.3 | 0.6 |
| No Name (LB) | cres0140 | 6.0 | 3.7 | 22.3 | 18.6 | 3.7 |
| No Name (LB) | cres0326 | 15.9 | 9.9 | 21.4 | 18.9 | 2.5 |
| Big Marsh Cr. (RB) | cres0762 | 33.5 | 20.8 | 19.3 | 19.8 | -0.5 |
| No Name (RB) | cres0896 | 38.2 | 23.8 | 16.8 | 19.2 | -2.4 |
| No Name (RB) | cres0932 | 38.8 | 24.1 | 20.2 | 18.9 | 1.3 |
| Cold Spring Cr. (LB) | cres0960 | 39.4 | 24.5 | 12.4 | 18.9 | -6.5 |
| **Side/Off Channel** | | | | | | |
| Side Channel (RB) | cres0039 | 1.3 | 0.8 | 20.3 | 19.6 | 0.7 |
| Off Channel (LB) | cres0053 | 2.0 | 1.2 | 22.6 | 19.3 | 3.3 |
| Off Channel (RB) | cres0062 | 2.3 | 1.4 | 22.9 | 19.4 | 3.5 |
| Off Channel (LB) | cres0153 | 6.9 | 4.3 | 27.3 | 18.9 | 8.4 |
| Side Channel (RB) | cres0166 | 7.7 | 4.8 | 20.1 | 18.5 | 1.6 |
| Side Channel (LB) | cres0213 | 10.0 | 6.2 | 20.2 | 18.8 | 1.4 |
| Off Channel (RB) | cres0219 | 10.3 | 6.4 | 20.4 | 18.6 | 1.8 |
| Off Channel (LB) | cres0220 | 10.3 | 6.4 | 19.6 | 18.5 | 1.1 |
| Off Channel (LB) | cres0273 | 13.5 | 8.4 | 24.8 | 18.6 | 6.2 |
| Side Channel (LB) | cres0308 | 15.2 | 9.5 | 19.8 | 18.4 | 1.4 |
| Side Channel (LB) | cres0333 | 16.3 | 10.1 | 18.9 | 18.8 | 0.1 |
| Side Channel (RB) | cres0341 | 16.6 | 10.3 | 20.1 | 18.4 | 1.7 |
| Side Channel (RB) | cres0372 | 18.1 | 11.3 | 21.8 | 18.8 | 3.0 |
| Side Channel (RB) | cres0548 | 24.9 | 15.5 | 20.6 | 18.8 | 1.8 |
| Side Channel (LB) | cres0591 | 26.8 | 16.7 | 19.6 | 19.1 | 0.5 |
| Side Channel (RB) | cres0958 | 39.4 | 24.5 | 19.3 | 18.6 | 0.7 |

**Deschutes River**

Due the length of the Upper Deschutes River, the survey was conducted over the course of two days (July 25th and 26th). Figure 12 shows the longitudinal temperature profile for the July 25th survey, which was conducted from Little Lava Lake downstream to the town of Bend, OR. The plot also contains the median temperature of all surface water inflows (e.g. tributaries, canals) and off-channel features (side-channels, backwaters). Tributaries are labeled in Figure 12 by river mile with their name and temperature listed in Table 8. The survey proceeded through both the Crane Prairie and Wickiup Reservoirs and Figure 12 shows the location of both reservoirs. The reservoir surfaces were thermally stratified and were not sampled as part of this analysis.

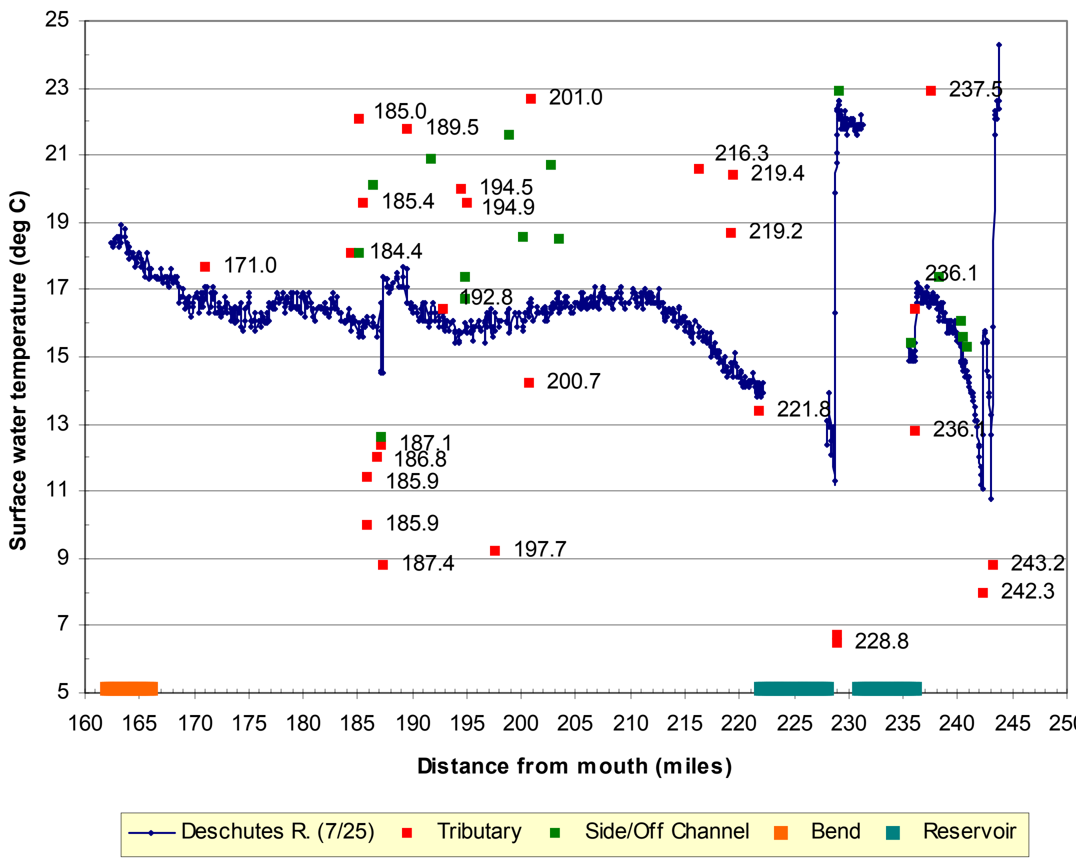



Figure 12 - Median channel temperatures versus river miles for the Deschutes River, OR between Little Lava Lake and Bend, OR along with the location of tributaries (7/25/01).

The Deschutes River was dry immediately downstream of Little Lava Lake, but springs at river miles 242.3 and 243.2 recharged the river at this location. These two springs were not documented on the 1:24K USGS topographic maps that were used as base maps for the analysis. Stream temperatures increased by 6.0°C between river miles 242.3 (11.1°C) and 236.1 (17.1°C). At river mile 236.1, Snow Creek is a source of thermal cooling to the mainstream. The Deschutes River entered Crane Prairie reservoir at ≈15.0°C. Water temperatures were 22.0°C at the outlet of Crane Prairie Reservoir (river mile 231.2) and increased to 22.6°C at river mile 229.1. A spring complex near Sheep Bridge Campground at river mile 229 had a dramatic influence on mainstream temperatures. The spring was located just upstream of the inlet to Wickiup Reservoir and cooled mainstream temperatures prior to entering the reservoir.

Table 8 - Tributary and side channel locations for Deschutes River, OR. River miles correspond to data labels shown in Figure 12 (7/25/01).

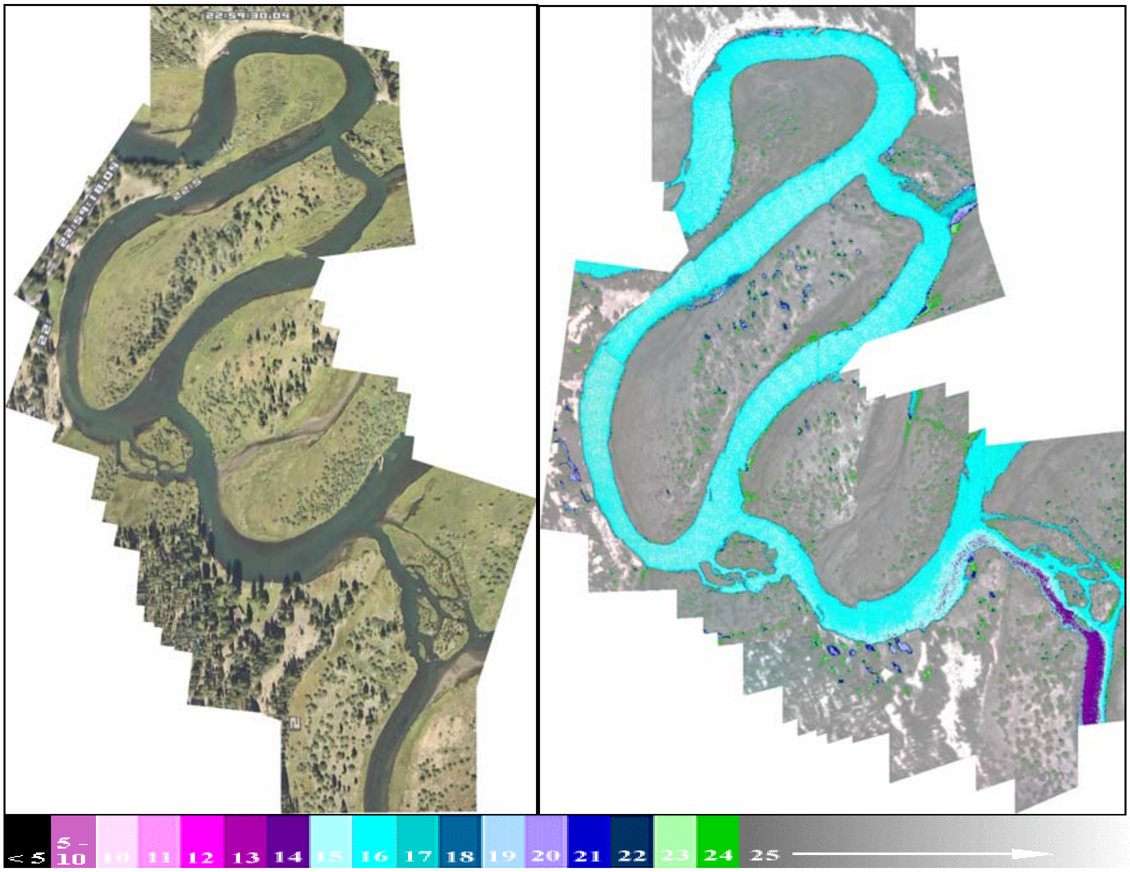
| Tributary Name | image | km | mile | Tributary Temp °C | Deschutes R. Temp °C | Difference |
|---|---|---|---|---|---|---|
| No Name (LB) | des2348 | 275.2 | 171.0 | 17.7 | 17.1 | 0.6 |
| Spring Outlet (LB) | des1942 | 296.7 | 184.4 | 18.1 | 16.1 | 2.0 |
| No Name (RB) | des1925 | 297.8 | 185.0 | 22.1 | 15.6 | 6.5 |
| No Name (LB) | des1910 | 298.4 | 185.4 | 19.6 | 16.1 | 3.5 |
| Spring (LB) | des1894 | 299.1 | 185.9 | 11.4 | 16.1 | -4.7 |
| Spring (LB) | des1891 | 299.2 | 185.9 | 10.0 | 16.0 | -6.0 |
| Spring (LB) | des1870 | 300.6 | 186.8 | 12.0 | 15.9 | -3.9 |
| Spring (LB) | des1866 | 301.0 | 187.1 | 12.4 | 16.6 | -4.2 |
| Spring River (LB) | des1850 | 301.6 | 187.4 | 8.8 | 17.4 | -8.6 |
| L. Deschutes R. (RB) | des1752 | 304.9 | 189.5 | 21.8 | 16.6 | 5.2 |
| No Name (RB) | des1632 | 310.3 | 192.8 | 16.4 | 16.3 | 0.1 |
| No Name (RB) | des1581 | 313.1 | 194.5 | 20.0 | 15.7 | 4.3 |
| No Name (RB) | des1572 | 313.7 | 194.9 | 19.6 | 15.9 | 3.7 |
| Spring (LB) | des1491 | 318.1 | 197.7 | 9.2 | 16.3 | -7.1 |
| Fall River (LB) | des1430 | 322.9 | 200.7 | 14.2 | 16.4 | -2.2 |
| No Name (RB) | des1415 | 323.4 | 201.0 | 22.7 | 16.5 | 6.2 |
| No Name (LB) | des0944 | 348.1 | 216.3 | 20.6 | 15.6 | 5.0 |
| No Name (RB) | des0847 | 352.8 | 219.2 | 18.7 | 14.6 | 4.1 |
| No Name (LB) | des0838 | 353.1 | 219.4 | 20.4 | 14.4 | 6.0 |
| No Name (LB) | des0760 | 357.0 | 221.8 | 13.4 | 13.9 | -0.5 |
| Spring (RB) | des0595 | 368.3 | 228.8 | 6.5 | 20.8 | -14.3 |
| Spring (RB) | des0593 | 368.4 | 228.9 | 6.7 | 21.1 | -14.4 |
| No Name (RB) | des0054 | 379.9 | 236.1 | 16.4 | 14.9 | 1.5 |
| Snow Creek (LB) | des0059 | 380.0 | 236.1 | 12.8 | 15.2 | -2.4 |
| No Name (RB) | des0135 | 382.2 | 237.5 | 22.9 | 16.8 | 6.1 |
| Spring (LB) | des0357 | 390.0 | 242.3 | 8.0 | 15.4 | -7.4 |
| Spring (LB) | des0387 | 391.4 | 243.2 | 8.8 | 15.9 | -7.1 |

Table 8 (con't) - Tributary and side channel locations for Deschutes River, OR. River miles correspond to data labels shown in Figure 12 (7/25/01).

| Tributary Name | image | km | mile | Side/Off Channel | Deschutes R. | Difference |
|---|---|---|---|---|---|---|
| Boat Ramp Outlet (RB) | des1919 | 298.0 | 185.2 | 18.1 | 16.0 | 2.1 |
| Slough ( RB) | des1880 | 300.1 | 186.4 | 20.1 | 15.9 | 4.2 |
| Side Channel ( LB) | des1863 | 301.1 | 187.1 | 12.6 | 15.8 | -3.2 |
| Side Channel (LB) | des1664 | 308.7 | 191.8 | 20.9 | 16.3 | 4.6 |
| Side Channel (LB) | des1574 | 313.7 | 194.9 | 17.4 | 15.8 | 1.6 |
| Side Channel (LB) | des1575 | 313.7 | 194.9 | 16.7 | 16.0 | 0.7 |
| Side Channel (LB) | des1464 | 320.0 | 198.8 | 21.6 | 15.7 | 5.9 |
| Side Channel (RB) | des1448 | 322.0 | 200.1 | 18.6 | 15.9 | 2.7 |
| Off-Channel (LB) | des1370 | 326.2 | 202.7 | 20.7 | 16.3 | 4.4 |
| Side Channel (LB) | des1339 | 327.5 | 203.5 | 18.5 | 16.4 | 2.1 |
| Side Channel (RB) | des0585 | 368.7 | 229.1 | 22.9 | 22.5 | 0.4 |
| Side Channel (LB) | des0034 | 379.3 | 235.7 | 15.4 | 15.1 | 0.3 |
| Side Channel (LB) | des0172 | 383.5 | 238.3 | 17.4 | 16.2 | 1.2 |
| Side Channel (LB) | des0265 | 386.6 | 240.2 | 16.1 | 15.3 | 0.8 |
| Side Channel ( LB) | des0276 | 386.9 | 240.4 | 15.6 | 15.3 | 0.3 |
| Side Channel (RB) | des0302 | 387.7 | 240.9 | 15.3 | 14.4 | 0.9 |

The Deschutes River flows out of Wickiup Reservoir (river mile 222.0) at a temperature of 14.2$^{o}$C. Downstream of the reservoir, stream temperatures increase steadily until reaching a local maximum of 17.1$^{o}$C at river mile 212.0. Stream temperatures then remain consistent (≈17.0$^{o}$C) between river mile 212.0 and 206.5. A cooling trend was observed between river mile 206.5 and 194.2. Fall River and an unnamed spring were both cooling sources to the mainstream in this reach. In addition, the Deschutes River had numerous meander bends and oxbow ponds through this reach (Figure 13). Although not visible in the imagery, the cooling suggests that sub-surface exchanges through the flood plain may mitigate temperature gains in this reach.

Stream temperatures increase from 15.4$^{o}$C to 17.4$^{o}$C between river miles 194.0 and 187.6. At river mile 187.4, Spring River is a cooling source to the Deschutes River. In addition to Spring River, four additional springs were sampled between river mile 187.4 and 185.9. Collectively the cold-water inputs lowered mainstream temperatures by ≈1.5$^{o}$C. Downstream of the spring complex to the town of Bend, stream temperatures showed a general warming trend with only local spatial variability.




*visible band/TIR image*

Figure 13 - Image mosaics (frames: des1430 – des1453) showing the Deschutes River between river miles 206.5 and 194.2. Flow direction is from the bottom to top of the image and the inflow of Fall River is visible at the bottom of the image.

Figure 14 shows a longitudinal temperature profile for the July 26$^{th}$ survey, which was conducted from the town of Bend, OR downstream to Lake Billy Chinook. As with the other profiles, tributaries are labeled in Figure 14 by river mile with their name and temperature listed in Table 9. The profiles from both survey days were combined in order to show basin scale temperature patterns (Figure 15). As illustrated, there was approximately a 10-mile overlap between the July 25$^{th}$ and 26$^{th}$ surveys.

Stream temperatures warmed steadily through the town of Bend at a rate of ≈0.3$^{o}$C per mile. Immediately downstream of the Pilot Butte Canal and Swalley Canal diversion (rm 162.5), the longitudinal heating rate increased to ≈2$^{o}$C per mile before reaching a local maximum 20$^{o}$C at river mile 161.3. A slight cooling trend (1.4$^{o}$C) was observed between river miles 161.3 and 159.3 although no surface inflows were detected through this reach. At river mile 159.3, stream temperatures began to warm again at a rate of ≈1.0$^{o}$C per mile before reaching a maximum of 23.8$^{o}$C at river mile 154.1. Tumalo Creek (19.4$^{o}$C) was the only surface inflow detected through this reach and had essentially the same temperature the Deschutes River. A drop in stream temperature (-2.4$^{o}$C) was observed over the next mile and no surface water inflows were detected that would contribute to the temperature decrease.

The longitudinal temperature profile (Figure 14) shows that stream temperatures varied between 21.1°C and 24.6°C over the next 11.2 miles. Local temperature maximums were observed at river miles 151.0 and 144.0 while minimums were observed at river miles 149.6 and142.0. A canal return at river mile 148.2 was the only surface water input sampled through this reach and it contributed water that was slightly warmer than the mainstream. The local minimum at river mile 142.0 (21.7°C) was located just downstream of Cline Falls. At this location, stream temperatures begin to warm again with a longitudinal heating rate of ≈1.5°C per mile observed between river miles 142 and 139. The warmest water temperatures (≈26.1°C) recorded during the Deschutes River survey were observed between river mile 139 and 138.3. At the location of Odin Falls (river mile 138), stream temperatures again dropped rapidly (4.0°C). A cold-water spring inflow (river mile 136) contributed to the cooling in this reach, however, the rapid temperature decrease over the two miles downstream of the falls suggests that diffuse sub-surface inputs may also occur through this reach.

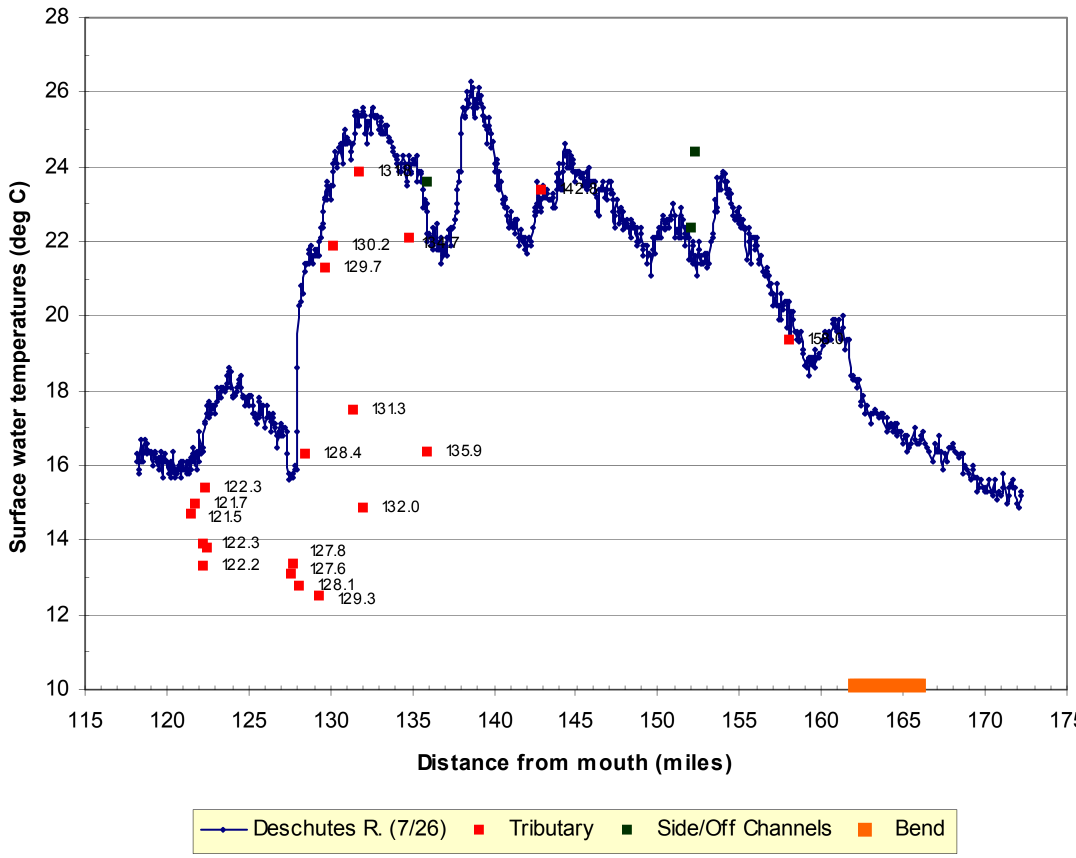



Figure 14 - Median channel temperatures versus river miles for the Deschutes River between Bend, OR and Lake Billy Chinook along with the location of tributaries (7/26/01).

Table 9 - Tributary and side channel locations for Deschutes River, OR. River miles correspond to data labels shown in Figure 14 (7/26/01)

| Tributary Name | Image | km | mile | Tributary Temp °C | Deschutes R. Temp °C | Difference |
|---|---|---|---|---|---|---|
| Spring (LB) | desb2322 | 195.5 | 121.5 | 14.7 | 15.9 | -1.2 |
| Squaw Creek (LB) | desb2301 | 195.9 | 121.7 | 15.0 | 16.3 | -1.3 |
| Spring (RB) | desb2270 | 196.6 | 122.2 | 13.3 | 16.4 | -3.1 |
| Spring (LB) | desb2262 | 196.8 | 122.3 | 13.9 | 16.5 | -2.6 |
| Spring (LB) | desb2258 | 196.9 | 122.3 | 15.4 | 17.2 | -1.8 |
| Spring ( LB) | desb2254 | 197.0 | 122.4 | 13.8 | 17.4 | -3.6 |
| Spring (LB) | desb1955 | 205.4 | 127.6 | 13.1 | 15.7 | -2.6 |
| Spring (LB) | desb1950 | 205.6 | 127.8 | 13.4 | 15.7 | -2.3 |
| Spring (LB) | desb1938 | 206.1 | 128.1 | 12.8 | 20.3 | -7.5 |
| Spring (RB) | desb1914 | 206.7 | 128.4 | 16.3 | 21.4 | -5.1 |
| No Name ( LB) | desb1869 | 208.1 | 129.3 | 12.5 | 21.6 | -9.1 |
| Spring (RB) | desb1849 | 208.7 | 129.7 | 21.3 | 23.1 | -1.8 |
| Spring (RB) | desb1817 | 209.5 | 130.2 | 21.9 | 24.1 | -2.2 |
| No Name (LB) | desb1753 | 211.4 | 131.3 | 17.5 | 24.6 | -7.1 |
| Spring Outlet (LB) | desb1731 | 212.1 | 131.8 | 23.9 | 25.1 | -1.2 |
| Spring ( LB) | desb1718 | 212.5 | 132.0 | 14.9 | 25.4 | -10.5 |
| Spring (RB) | desb1593 | 216.8 | 134.7 | 22.1 | 24.1 | -2.0 |
| Spring (RB) | desb1531 | 218.7 | 135.9 | 16.4 | 22.8 | -6.4 |
| Canal Outlet ( LB) | desb1176 | 229.8 | 142.8 | 23.4 | 22.8 | 0.6 |
| Tumalo Creek (LB) | desb0470 | 254.3 | 158.0 | 19.4 | 19.7 | -0.3 |
| **Side/Off Channels** | | | | | | |
| Side Channel (RB) | desb1519 | 218.7 | 135.9 | 23.6 | 22.2 | 1.4 |
| Side Channel (LB) | desb0734 | 244.7 | 152.1 | 22.4 | 21.5 | 0.9 |
| Side Channel (LB) | desb0723 | 245.1 | 152.3 | 24.4 | 21.6 | 2.8 |

Stream temperatures increased by ≈4.2°C between river mile 132.6 and 136.8. A spring inflow at river mile 134.7 contributes cooler water and adds to thermal variability in this reach. Between river mile 132.6 and the inlet of Lake Billy Chinook, a total of 16 cold water inputs (springs and tributaries) were sampled and contributed to cooling through the lower 14.4 miles of the survey. Nine of the spring inputs were clustered around two locations (river miles 122 and 127). Neither of these spring complexes were documented on the USGS 1:24k topographic maps. Squaw Creek at river mile 121.7 was observed as a source of thermal cooling.

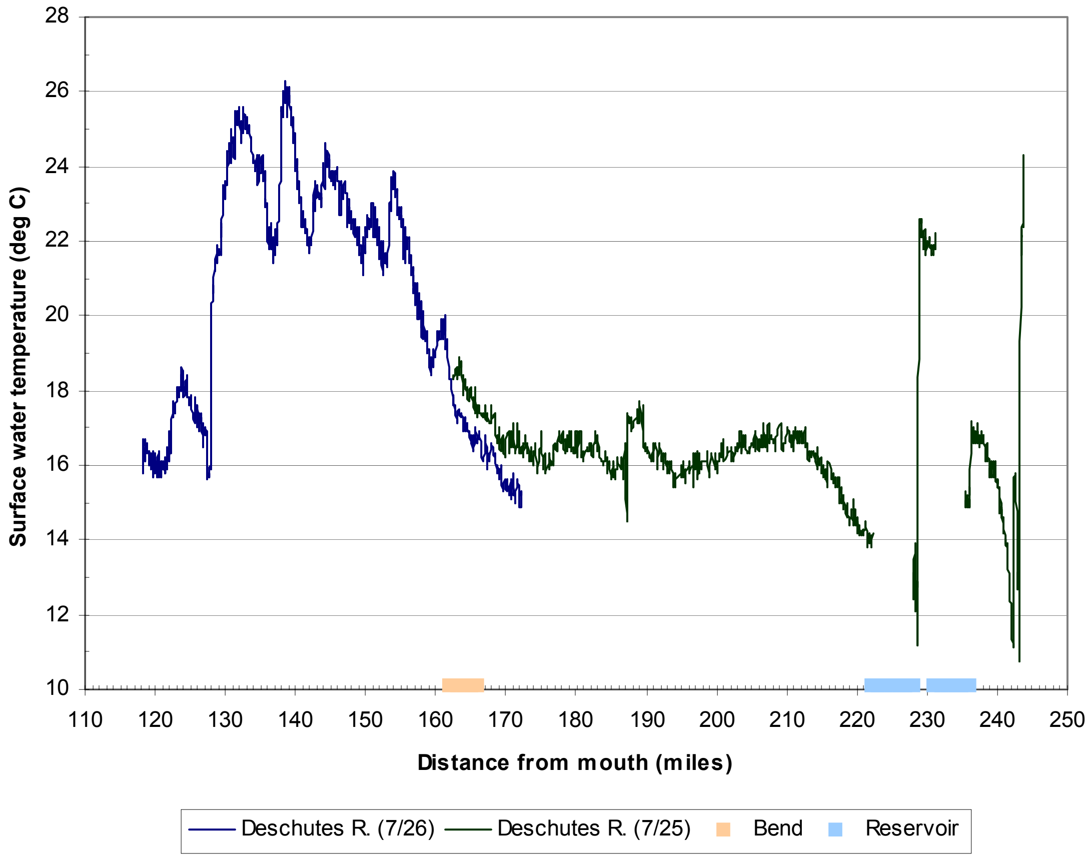



Figure 15 - Median channel temperature versus river mile for the Deschutes River, OR from Lake Billy Chinook to the headwaters at Little Lava Lake (7/25/01 – 7/26/01).

## Metolius River

The median water temperatures for each sampled image of Metolius River were plotted versus river mile (Figure 16). The plot also contains the median temperature of all surface water inflows (e.g. tributaries, canals) and off channel features (side-channels, backwaters) that were visible in the imagery where they input to the Metolius River. Tributaries are labeled in Figure 16 by river mile with their name and temperature listed in Table 10.

The Metolius River originates from two large headwater springs (9.8$^{o}$C) and warms by ≈2.3$^{o}$C immediately downstream of the headwaters. A series of springs and cold-water tributaries shapes the spatial temperature patterns in the first seven miles. At river mile 37.8, Lake Creek is a source of cooler water and contributes to a drop in mainstream temperatures at this location. Fifteen cold-water inputs were sampled between river mile 36.9 and 32.3, which collectively contribute to a minimum mainstream temperature of 8.9$^{o}$C at river mile 32.3. Stream temperatures warmed consistently between river mile 32.3 and the inlet to Lake Billy Chinook.

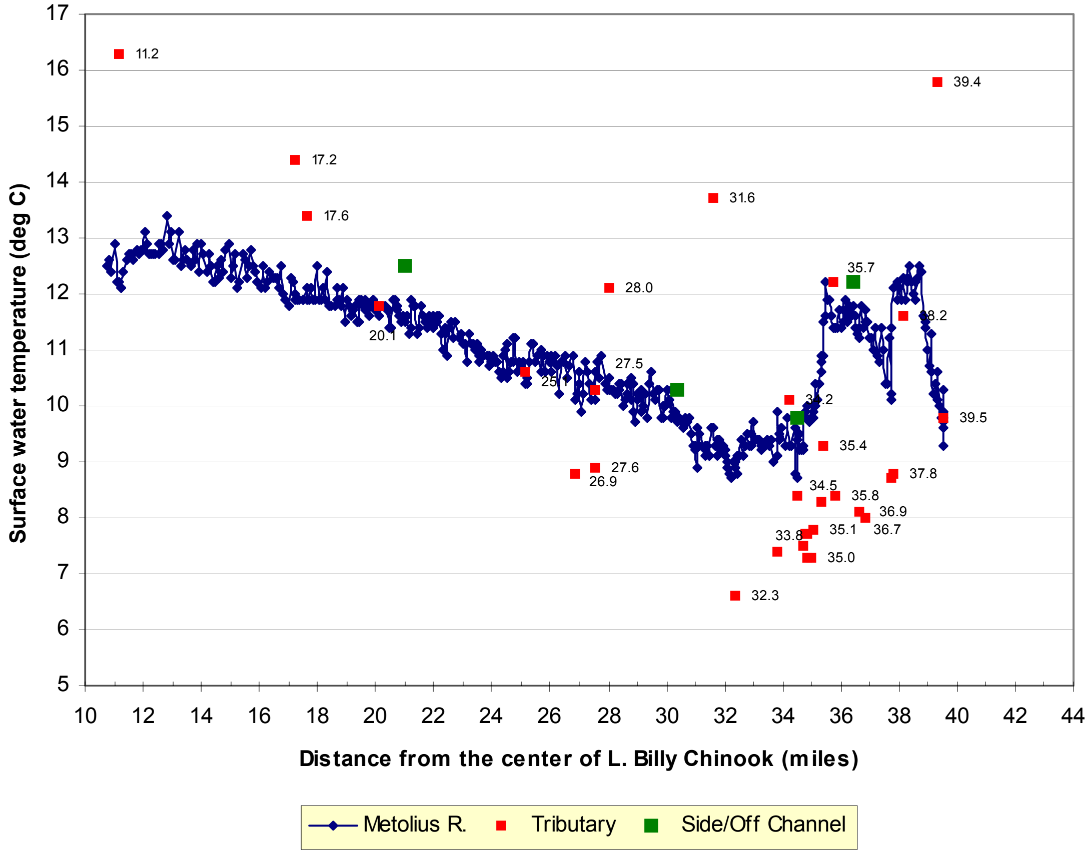



Figure 16 - Median channel temperatures versus river mile for the Metolius River, OR along with the location of tributaries (7/27/01).

Table 10 - Tributary and side channel locations for the Metolius River, OR. River miles correspond to data labels shown in Figure 16 (7/27/01)

| Tributary Name | image | km | Mile | Tributary Temp °C | Metolius R. Temp °C | Difference |
|---|---|---|---|---|---|---|
| Second Spring (LB) | met0019 | 63.6 | 39.5 | 9.8 | 9.9 | -0.1 |
| No Name (LB) | met0037 | 63.3 | 39.4 | 15.8 | 10.6 | 5.2 |
| MF Lake Cr (LB) | met0105 | 61.4 | 38.2 | 11.6 | 12.3 | -0.7 |
| NF Lake Cr (LB) | met0119 | 60.9 | 37.8 | 8.8 | 12.1 | -3.3 |
| No Name (LB) | met0124 | 60.7 | 37.7 | 8.7 | 10.2 | -1.5 |
| No Name (LB) | met0161 | 59.3 | 36.9 | 8.0 | 11.7 | -3.7 |
| No Name (LB) | met0171 | 59.0 | 36.7 | 8.1 | 11.4 | -3.3 |
| Spring (LB) | met0223 | 57.6 | 35.8 | 8.4 | 11.4 | -3.0 |
| First Creek (LB) | met0228 | 57.5 | 35.7 | 12.2 | 11.4 | 0.8 |
| Spring (RB) | met0246 | 57.0 | 35.4 | 9.3 | 11.5 | -2.2 |
| Spring (RB) | met0252 | 56.9 | 35.3 | 8.3 | 10.6 | -2.3 |
| Seeps (RB) | met0270 | 56.4 | 35.1 | 7.8 | 9.9 | -2.1 |
| Spring (LB) | met0274 | 56.3 | 35.0 | 7.3 | 9.8 | -2.5 |
| Spring (RB) | met0280 | 56.1 | 34.8 | 7.7 | 10.0 | -2.3 |
| Jack Cr (LB) | met0281 | 56.0 | 34.8 | 7.3 | 10.0 | -2.7 |
| Jack Cr (2) (LB) | met0284 | 55.9 | 34.8 | 7.7 | 9.9 | -2.2 |
| Spring (LB) | met0287 | 55.8 | 34.7 | 7.5 | 9.3 | -1.8 |
| Spring (RB) | met0297 | 55.5 | 34.5 | 8.4 | 9.4 | -1.0 |
| Canyon Cr (LB) | met0308 | 55.1 | 34.2 | 10.1 | 9.3 | 0.8 |
| Spring (RB) | met0326 | 54.4 | 33.8 | 7.4 | 9.9 | -2.5 |
| Seep (RB) | met0396 | 52.0 | 32.3 | 6.6 | 8.9 | -2.3 |
| No Name (LB) | met0437 | 50.9 | 31.6 | 13.7 | 9.6 | 4.1 |
| Abbot Cr (LB) | met0638 | 45.1 | 28.0 | 12.1 | 10.5 | 1.6 |
| Candle Cr (LB) | met0658 | 44.4 | 27.6 | 8.9 | 10.1 | -1.2 |
| Jefferson Cr (LB) | met0661 | 44.3 | 27.5 | 10.3 | 10.6 | -0.3 |
| Mariel Cr (LB) | met0689 | 43.2 | 26.9 | 8.8 | 10.1 | -1.3 |
| Walker Cr (LB) | met0766 | 40.4 | 25.1 | 10.6 | 10.4 | 0.2 |
| Racing Cr (LB) | met0988 | 32.4 | 20.1 | 11.8 | 11.6 | 0.2 |
| No Name (RB) | met1098 | 28.3 | 17.6 | 13.4 | 12.1 | 1.3 |
| Whitewater R. (LB) | met1114 | 27.7 | 17.2 | 14.4 | 12.0 | 2.4 |
| Backwater (RB) | met1348 | 18.0 | 11.2 | 16.3 | 12.2 | 4.1 |

Table 10 - (cont') Tributary and side channel locations for Metolius River, OR. River miles correspond to data labels shown in Figure 16 (7/27/01).

| Side/Off Channel | image | km | Mile | Side/Off Channel | Metolius R. | Difference |
|---|---|---|---|---|---|---|
| Side Channel (LB) | met0185 | 58.6 | 36.4 | 12.2 | 11.8 | 0.4 |
| Side Channel ( LB) | met0298 | 55.5 | 34.5 | 9.8 | 8.7 | 1.1 |
| Side Channel (RB) | met0503 | 48.9 | 30.4 | 10.3 | 9.7 | 0.6 |
| Side Channel (RB) | met0951 | 33.8 | 21.0 | 12.5 | 11.5 | 1.0 |

### Lake Creek

Lake Creek branches into three forks as it travels from Suttle Lake to the Metolius River. The South and Middle Forks rejoin prior to entering the river. However, the North Fork enters the Metolius River as a separate inflow. The TIR remote sensing survey included all three forks of Lake Creek. For each fork, the median water temperatures for each sampled image were plotted versus river mile (Figures 17, 18, 19). The plots also contain the median temperature of all surface water inflows (e.g. tributaries, canals) that were visible in the imagery where they input into Lake Creek. Tributaries are labeled in Figures 17,18, 19 by river mile with their name and temperature listed in Table 11.

The shape of the longitudinal temperature profile was very similar for all three forks of Lake Creek. Stream temperatures from Suttle Lake were ≈20.5$^{o}$C and remained near 20.5$^{o}$C in all three forks until the lower 0.5 miles. A series of springs starting at river mile 0.4 in the South/Middle Forks dramatically lower the stream temperatures and ultimately contributes cooler water to the Metolius River. Similarly, the North Fork temperatures remain consistent until the final 0.2 miles where the North Fork joins Spring Creek prior to entering the Metolius River.

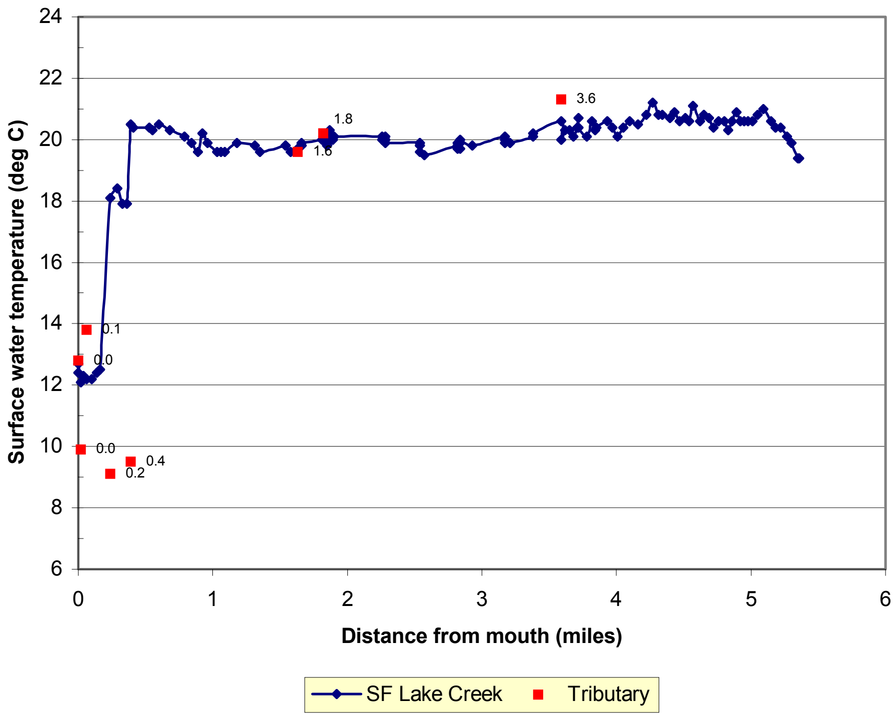



Figure 17 - Median channel temperatures versus river mile for the South Fork Lake Creek, OR along with the location of tributaries (7/27/01).

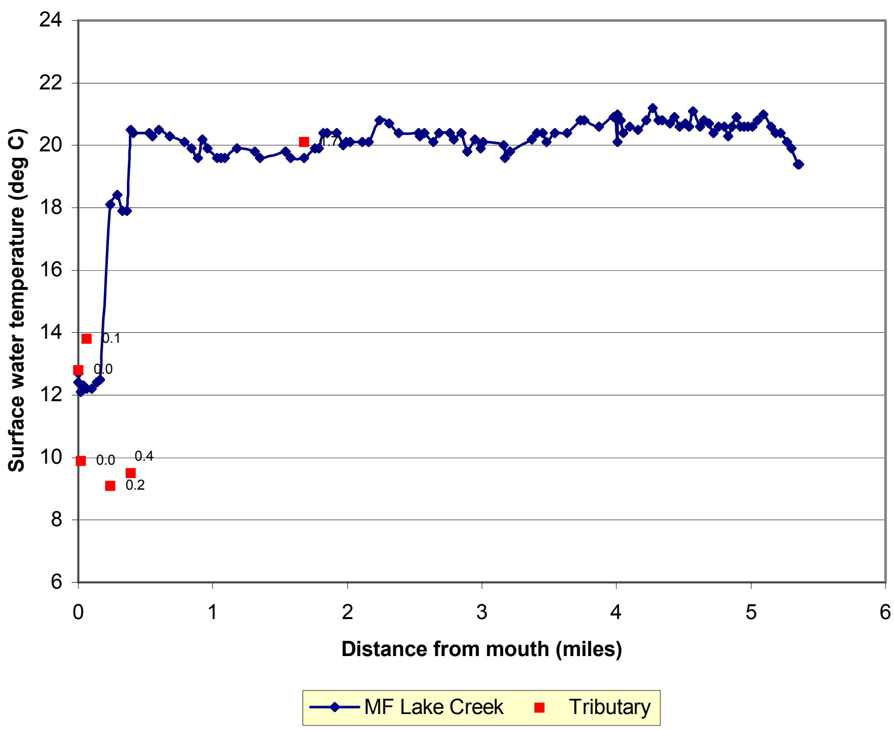



Figure 18 – Median channel temperatures versus river mile for the Middle Fork Lake Creek, OR along with the location of tributaries (7/27/01).

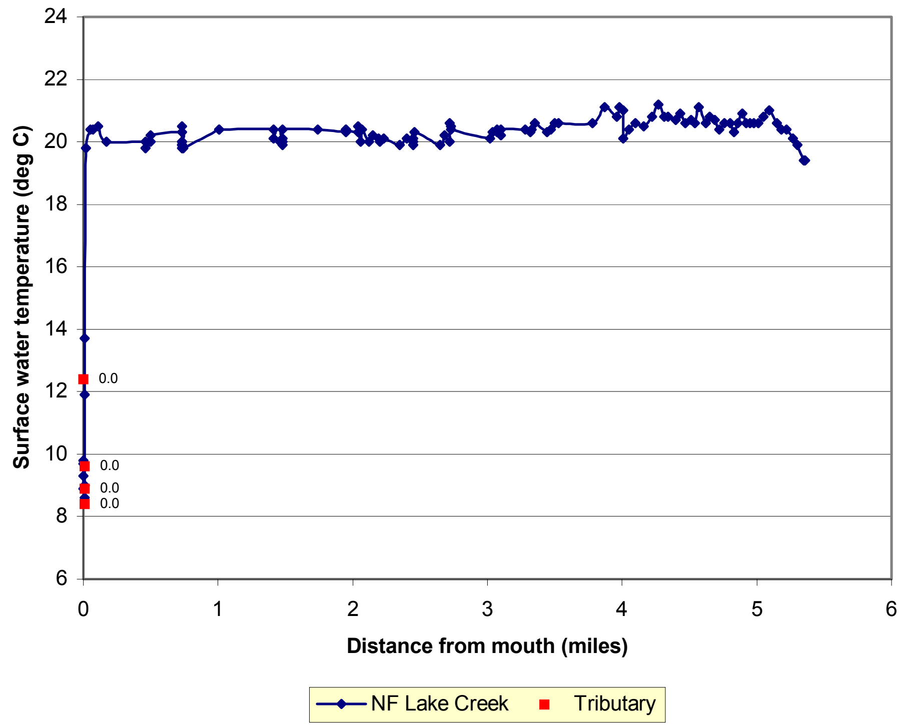



Figure 19 - Median channel temperatures versus river mile for the North Fork Lake Creek, OR along with the location of tributaries (7/27/01).

Table 11 - Tributary locations for Lake Creek, OR.

| Tributary Name | Image | km | mile | Tributary Temp °C | Lake Cr. Temp °C | Difference |
|---|---|---|---|---|---|---|
| *South Fork Lake Creek* | | | | | | |
| Metolius River (RB) | lake0003 | 0.0 | 0.0 | 12.8 | 12.4 | 0.4 |
| Spring (RB) | lake0009 | 0.0 | 0.0 | 9.9 | 12.1 | -2.2 |
| Spring (LB) | lake0011 | 0.1 | 0.1 | 13.8 | 12.2 | 1.6 |
| Spring (LB) | lake0019 | 0.4 | 0.2 | 9.1 | 18.1 | -9.0 |
| Spring ( LB) | lake0030 | 0.6 | 0.4 | 9.5 | 20.5 | -11.0 |
| Middle Fork (LB) | lake0084 | 2.6 | 1.6 | 19.6 | 19.7 | -0.1 |
| Cache Creek (RB) | lake0096 | 2.9 | 1.8 | 20.2 | 20.1 | 0.1 |
| No Name (LB) | lake0198 | 5.8 | 3.6 | 21.3 | 20.0 | 1.3 |
| *North Fork Lake Creek* | | | | | | |
| Metolius (RB) | lake0549 | 0.0 | 0.0 | 12.4 | 9.3 | 3.1 |
| Spring Outlet (RB) | lake0561 | 0.0 | 0.0 | 8.9 | 9.0 | -0.1 |
| Spring (LB) | lake0566 | 0.0 | 0.0 | 9.6 | 11.9 | -2.3 |
| Spring (RB) | lake0567 | 0.0 | 0.0 | 8.4 | 13.7 | -5.3 |

Table 11 (con't) - Tributary locations for Lake Creek, OR.

| Tributary Name | Image | km | mile | Tributary Temp °C | Lake Cr. Temp °C | Difference |
|---|---|---|---|---|---|---|
| *Middle Fork* | | | | | | |
| Metolius River (RB) | lake0003 | 0.0 | 0.0 | 12.8 | 12.4 | 0.4 |
| Spring (RB) | lake0009 | 0.0 | 0.0 | 9.9 | 12.1 | -2.2 |
| Spring (LB) | lake0011 | 0.1 | 0.1 | 13.8 | 12.2 | 1.6 |
| Spring (LB) | lake0019 | 0.4 | 0.2 | 9.1 | 18.1 | -9.0 |
| Spring ( LB) | lake0030 | 0.6 | 0.4 | 9.5 | 20.5 | -11.0 |
| South Fork (RB) | lake0336 | 2.70 | 1.68 | 20.1 | 19.6 | 0.50 |

## Discussion

TIR remote sensing was used to map stream temperatures for the Deschutes River and all major tributaries upstream of Lake Billy Chinook. The data were collected between July 23rd and 27th in order to assess low flow high summer temperatures in support of ODEQs Total Maximum Daily Load (TMDL) program in the Deschutes River basin. Air temperatures exceeded 80°F on each day of the survey with clear sky conditions. These conditions were considered ideal for the objectives of the survey. Analysis of the thermal accuracy of the TIR images compared to in-stream sensors was well within the specified tolerance of ±0.5°C.

Although spatial temperature patterns differed between streams, cold -spring inputs were common to every stream and play a major role in defining the shape of the basin scale temperature patterns. A review of the results showed that 65% of the spring inputs were not documented on the USGS 1:24k topographic maps that were used as base maps during the analysis (Figure 20). The imagery shows the points where cold water enters the mainstream and how they influence spatial temperature patterns. Diffuse sub-surface inputs also played a role in defining spatial temperature patterns on several streams. This was particularly true on the Little Deschutes River, the Deschutes River, and Crescent Creek, which had reaches characterized by large meanders and old oxbows. Unlike point source inflows, diffuse inputs are not detected directly from the imagery, but are inferred from the shape of the longitudinal temperature profiles.

The TIR surveys lay a basic groundwork to integrate the ODEQ TMDL process into watershed planning and restoration. In particular, water temperature modeling as conducted by ODEQ can provide a powerful tool to address the biophysical parameters that are driving stream temperature patterns and suggest multiple pathways for remediation. In addition, the longitudinal temperature patterns provide a robust and rigorous template to construct a monitoring program, in particular the deployment of in-stream temperature sensors.

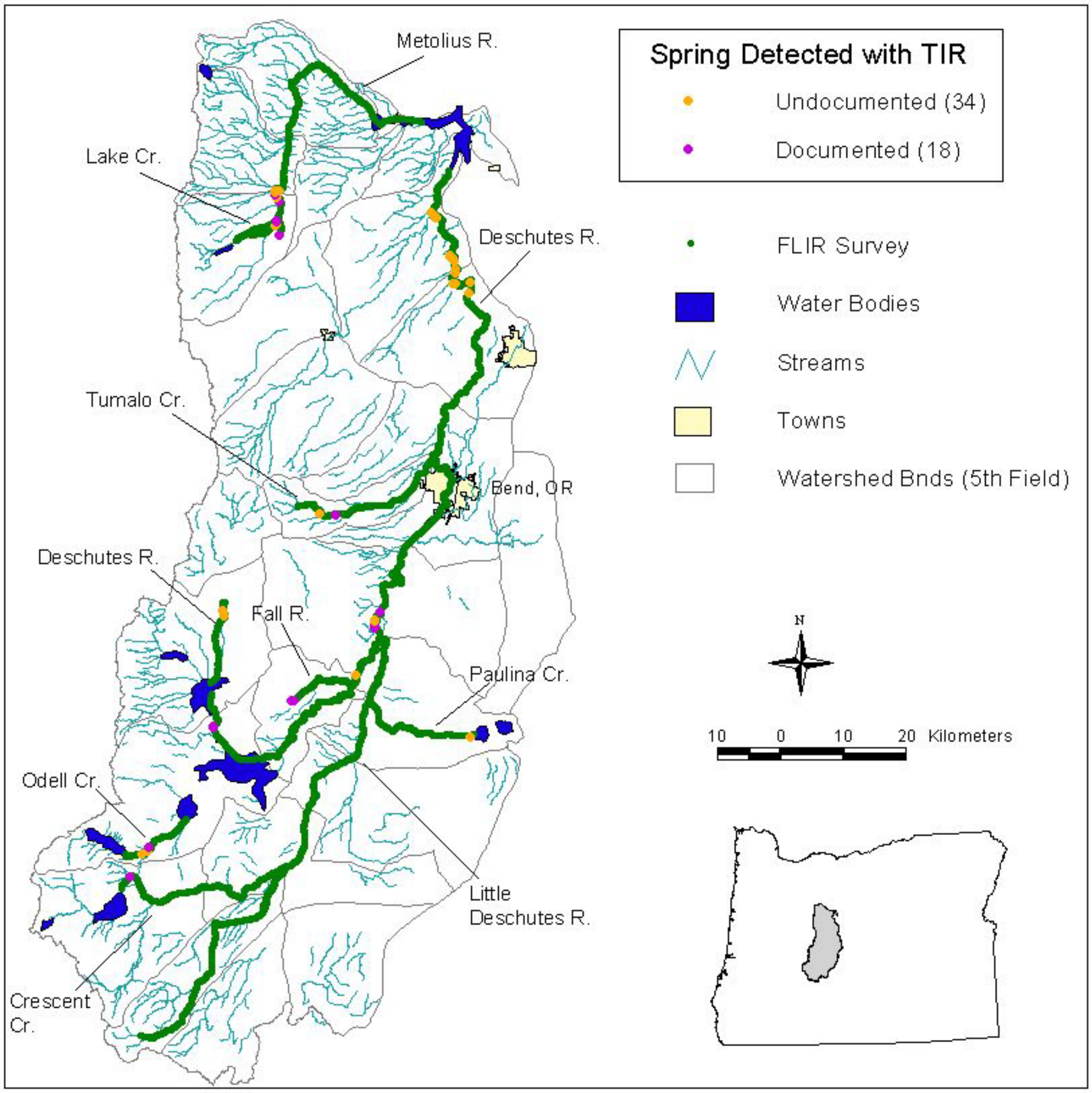



Figure 20 – The location of spring inputs detected and sampled using TIR remote sensing in the Deschutes River basin. The springs are distinguished as documented or undocumented depending on whether or not they were identified on USGS 1:24k topographic maps.

## Bibliography

Karalus, R.S., M.A. Flood, B.A. McIntosh, and N.J. Poage. 1996. ETI surface water quality monitoring technologies demonstration. Final Report. Las Vegas, NV: Environmental Protection Agency.

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Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.