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

July 28, 2000

Report to:

Upper Deschutes Watershed Council
P.O. Box 1812
Bend, OR 97709-1812

By:

Watershed Sciences
712 NW 4th Street
Corvallis, OR 97330

Note: Since publication of this report, Squaw Creek has been re-named Whychus Creek. This document has not been modified to reflect that name change.

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Introduction

Forward Looking Infrared (FLIR) 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; Norton et al., Faux et al., 1998). In 2000, the Upper Deschutes Watershed Council contracted with Watershed Sciences, LLC (WS, LLC) to map and assess stream temperatures in Squaw Creek, Indian Ford Creek, and a short segment of the Deschutes River.

Traditional methods for monitoring stream temperatures have relied on in-stream temperature monitors. These monitors provide temporally continuous data, but furnish no insight into the spatial variability in temperatures. Remote sensing using FLIR offers a method to map stream temperatures across entire stream networks at the time of the survey. FLIR technology has proven to be a highly portable and cost-effective method to collect very detailed data over large areas in very little time. The combination of temporally and spatially continuous data provides very powerful tools for understanding the dynamics of stream temperature hierarchically across multiple scales (pools → reaches → streams → watersheds). Current research has identified cool versus warm streams within a watershed, cool reaches within a stream, and cool habitats within a reach (McIntosh et al., 1995; Torgerson et al., 1995; Torgerson et al., 1999).

The results and analysis presented here are at the watershed and tributary scales. This report provides longitudinal temperature profiles for each stream surveyed as well as a discussion of the thermal features observed in basin. FLIR and associated color video images are included in the report in order to illustrate significant thermal features. An ArcView GIS[1] database provided with this report includes all of the images collected during the survey and is structured to allow analysis at finer scales.

Methods

Data Collection

The Upper Deschutes Watershed Council contracted with Watershed Sciences, LLC of Corvallis, Oregon to collect and analyze thermal infrared and visible video imagery in the Upper Deschutes River Basin during the summer of 2000. Figure 1 illustrates the extent of the survey and Table 1 summarizes the time and distance for each survey stream. Squaw Creek along with Indian Ford Creek and a segment of the Deschutes River were surveyed on July 28, 2000. Data collection was timed to capture maximum daily stream temperatures, which typically occur between 2:00 PM and 5:00 PM.

[1] Geographic Information System

Table 1. Time and distance for the Upper Deschutes River Surveys on 7/28/00

Stream	Time	Distance (miles)
Deschutes River	3:57 – 4:04 PM	6.2
Squaw Creek	4:06 – 5:00 PM	36.2
Indian Ford Creek	2:08 – 2:43 PM	14.1
Total Miles		56.5

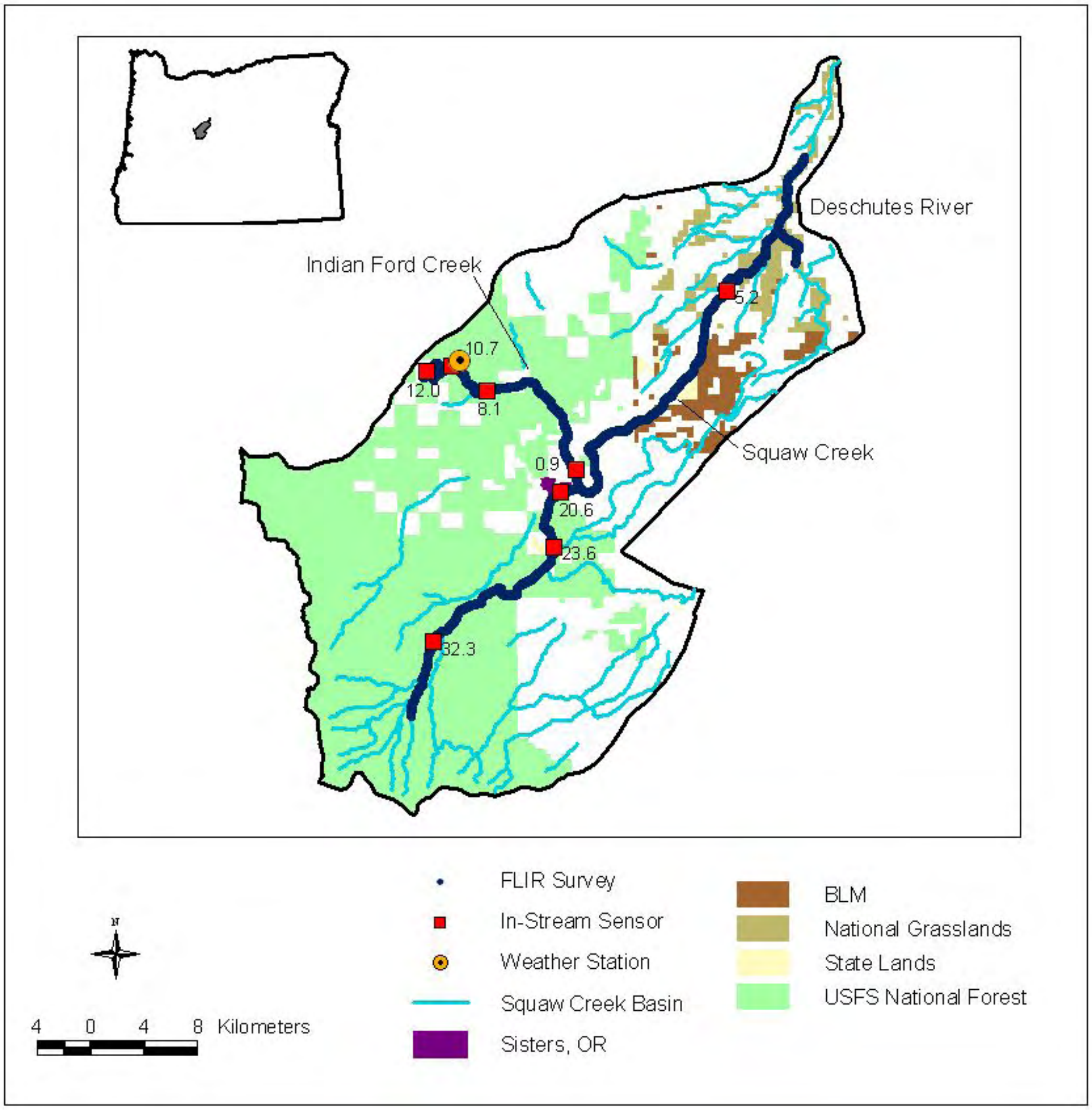

Figure 1 – Map of the Upper Deschutes Basin and streams surveyed with FLIR and visible band color video on 28 July 2000. The map also shows river miles associated with in-stream sensors.

Data were collected using a FLIR and a Day TV video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. All streams were surveyed upstream and flight altitude was selected based on the estimated average stream channel width. In general, the flight altitude was selected so that the stream channel occupied approximately 20% of the image frame. Squaw Creek and the Deschutes River were flown at an average altitude of 1400 ft (420 meters) above ground level. Indian Ford was surveyed at an average altitude of 800 ft (250 meters).

FLIR data were collected digitally and recorded directly from the sensor to an on-board computer. The FLIR 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 FLIR 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). Each thermal image frame covers a ground area of approximately 100 x 150 meters and has a spatial resolution of < 0.5 meters/pixel. For all other streams each thermal image covers a ground area of approximately 100 x 150 meters and has a spatial resolution of about 0.25 meters/pixel.

Day TV 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 Day TV sensor was aligned to present the same ground area as the thermal infrared sensor. The GPS time coding provides a means to correlate Day TV images with the FLIR images during post-processing.

Eight in-stream temperature data loggers (Onset Stowaways) were distributed in the basin during the survey to ground truth (i.e. verify the accuracy) the radiant temperatures measured by the FLIR. The data loggers also provide a temporal context for interpreting the FLIR imagery. The ground truth locations are shown in Figure 1. The in-stream data loggers were removed after the flight and the temperature information downloaded to a computer.

Meteorological conditions were recorded using a Hobo Pro Temperature/Relative Humidity data logger. The data logger was located in Black Butte Meadow, which was the approximate midpoint of the survey. The data logger was deployed on July 19, 2000 and retrieved on July 30, 2000. Table 2 summarizes the conditions for the time of the survey and Figure 2 shows the measured air temperatures centered on July 28, 2000. A maximum air temperature of 28.3 ^{o}C (82.7^{o}F) occurred at 2:55 PM.

Table 2. Meteorological Conditions for 28 July 2000 recorded at the weather station located in Black Butte Meadow, OR.

Time	Average Temperature	Average Relative Humidity	Sky Conditions	Winds
2:07 – 2:55	27.7 °C (81.9°F)	38%	Clear	Variable
4:00 – 5:00	27.2 °C (81.0°F)	40%	Clear	Variable

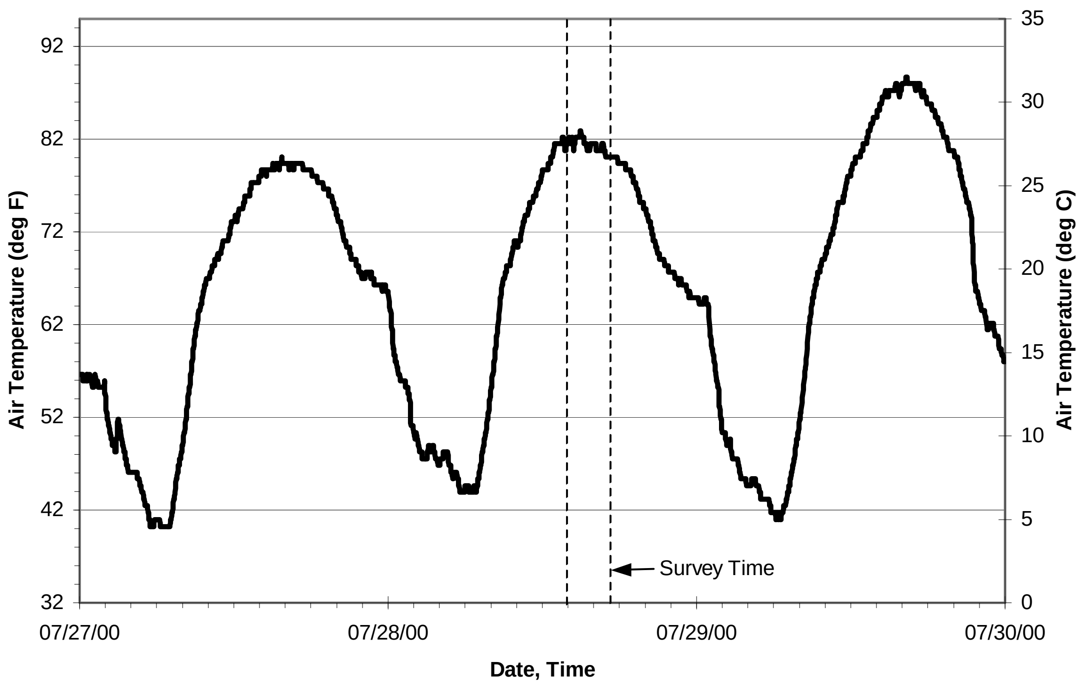

Figure 2 – Air temperature versus time in the study area for a 3-day span centered on the day of the FLIR survey.

Data Processing

A computer program was used to scan the FLIR imagery and 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 using the dynamic segmentation features of Arc/Info GIS software. 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 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. The GRIDS were classified in one-degree increments over the temperature range of 5 to 30^{o}C. Temperatures < 5^{o}C are black, temperatures between 30 and 50^{o}C were colored in shades of gray (darker tones -> lighter tones), temperatures > 50^{o}C are white.

Figure 3 illustrates a color coded GRID displayed in the ArcView environment. This GRID illustrates the confluence of Squaw Creek and the Deschutes River. The legend on the left of the "Grid View" specifies the temperature range associated with each color. The other view window shows the point coverage with the displayed GRID location highlighted in yellow. Each green point in the "Thermal Survey" view represents another image location.

Figure 4 illustrates the temperature GRID displayed in Figure 3 with its corresponding day TV image. Prominent thermal features are identified in each image. The Deschutes River and Squaw Creek are clearly visible in the image due to the high thermal contrast with the warmer terrain features. This is the standard format currently used to interpret and analyze the thermal image data.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, an ArcView 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. Samples were taken on every 5th image to provide complete coverage without sampling the same water twice (there is approximately 40-60% overlap between images). Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled. In cases where the channel was obscured by vegetation, as was the situation on many of the tributaries, the next image where the stream channel was clearly visible was sampled. For each sampled image, the sample minimum, maximum, median, and standard deviation was recorded directly to the point coverage attribute file.

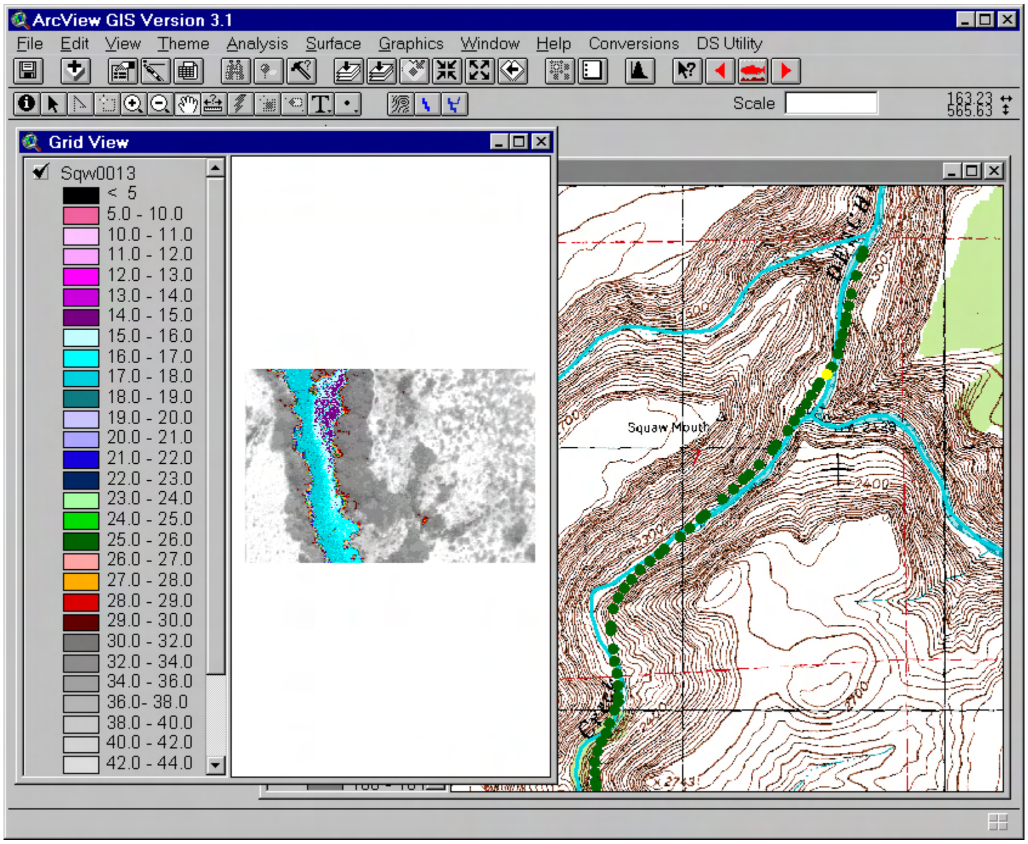

Figure 3 – ArcView display showing a color-coded temperature GRID in one window and the geographic location of the GRID in the other. The orientation of the image is always in the flight direction.

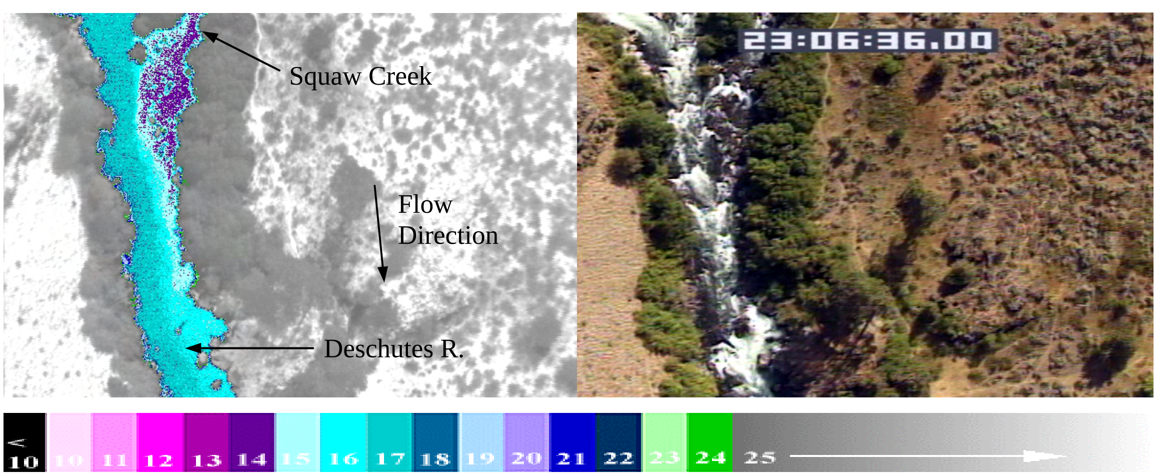

Figure 4 – Temperature Grid (left) and Corresponding Day TV image (right) showing the confluence of Squaw Creek and the Deschutes River. The temperature scale used for the FLIR image is shown at the base of the imagery.

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.

Day TV images corresponding to the FLIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the thermal infrared 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.

Data Limitations

FLIR systems measure thermal infrared energy emitted at the water surface. Since water is essentially opaque to thermal infrared wavelengths, the sensor is only measuring the water surface temperature. This is typically not an issue on streams where the water column is thoroughly mixed. Field measurements conducted on the Middle Fork of the John Day River, OR and on the Klamath River, CA confirmed that thermal stratification was insignificant or not present even in the deepest pools. However, stratification has been observed behind impoundments and in deep slow moving channels.

Thermal stratification is usually detectable on the FLIR images and there was no apparent stratification on the Deschutes River or Squaw Creek. However, some of the ponds located along Indian Ford Creek showed some distinctive signs of stratification.

Obtaining accurate temperatures from the FLIR images depends on having enough pixels "in the water". Indian Ford Creek is extremely narrow in some locations making accurate temperature readings difficult. The analysis identifies areas where WS, LLC could not make accurate measurements or where confidence in the measurements is low.

Results

Thermal Accuracy

Temperatures from in-stream data loggers were compared to radiant temperatures derived from the imagery for the Upper Deschutes River basin (Table 3). The data were assessed at the time the image was acquired. The radiant values represent the median of 10 points sampled from the image at the data logger location. Radiant temperatures from thermal imagery of the Squaw Creek were within ±0.6°C of in-stream temperatures recorded by data loggers. There were no data loggers in the surveyed portion of the Deschutes River. However, the thermal accuracy assessment of Squaw Creek is considered applicable to the Deschutes River due to proximity in time and distance. These results are consistent with average accuracy of ±0.4°C recorded during FLIR surveys throughout Oregon since 1994.

Figure 4 shows the change in temperature that occurred at these locations during the course of the survey. Because the FLIR survey is a snapshot of the stream temperature profile, Figure 4 provides a context for comparing temperature recorded at the beginning and end of the flight. In addition, the figure illustrates the time at which the survey was conducted in relation to diurnal temperature patterns. Survey timing on 28 July 2000 was slightly before daily maximum water temperature in Squaw Creek, which generally occurred between 5:30-6:00 PM. The largest temperature change during the flight (0.65^{o}C) was recorded at the town of Sisters (rm 20.6).

Table 3. Comparison of ground-truth water temperatures with radiant temperatures derived from thermal infrared images, 28 July 2000. Temperatures are reported in °C *(^{o}F)* and river mile (rm) measures are cited for locations.

Location	**Image frame**	**Time PM**	**Stream Temp. (T_s)**	**Radiant Temp. (T_r)**	**Difference ($T_r - T_s$)**	**Δ T_s during survey**
Squaw Creek						
Rd 6360 (rm 5.2)	sqw0223	4:13	26.4 *(79.5)*	26.9 *(80.4)*	-0.5 *(-0.9)*	0.35
Sisters (rm 20.6)	sqw0905	4:37	20.5 *(68.9)*	20.5 *(68.9)*	0.0 *(0.0)*	0.65
Squaw Cr. Canal (rm 23.6)	sqw1057	4:43	14.4 *(57.9)*	14.2 *(57.6)*	0.2 *(0.3)*	0.15
FS Rd 1514 (rm 32.3)	sqw1408	4:54	13.2 *(55.8)*	12.6 *(54.7)*	0.6 *(1.1)*	0.31
Indian Ford Creek						
Airport (rm 0.9)	if0128	2:09	20.8 *(69.4)*	21.3 *(70.3)*	-0.5 *(-0.9)*	1.20
Route 20 (rm 8.1)	if0942	2:24	16.9 *(62.4)*	15.8 *(60.4)*	1.1 *(2.0)*	0.21
BB* Corral (rm 10.7)	if1284	2:31	19.1 *(66.4)*	19.5 *(67.1)*	-0.4 *(0.7)*	0.86
Near Spring (rm 12.0)	if1464	2:34	6.5 *(43.7))*	5.9 *(42.6)*	0.6 *(1.1)*	0.16

*BB = Black Butte

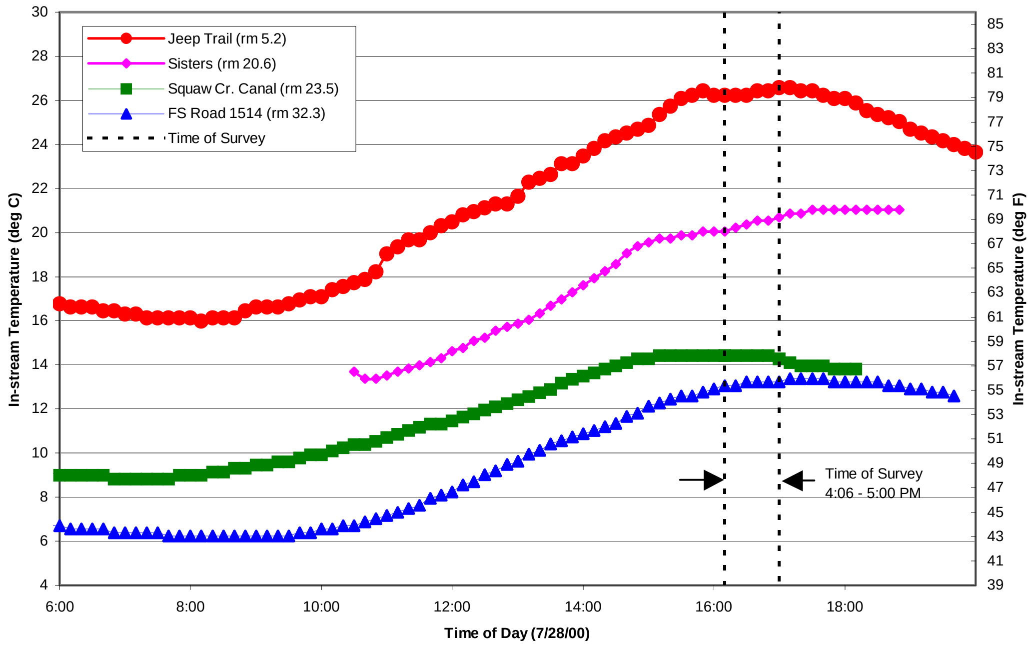

Figure 4 - Diurnal temperature curves from in-stream data loggers during thermal survey of Squaw Creek. Dashed vertical lines specify the timing and duration of the FLIR survey with respect to diurnal temperature fluctuations.

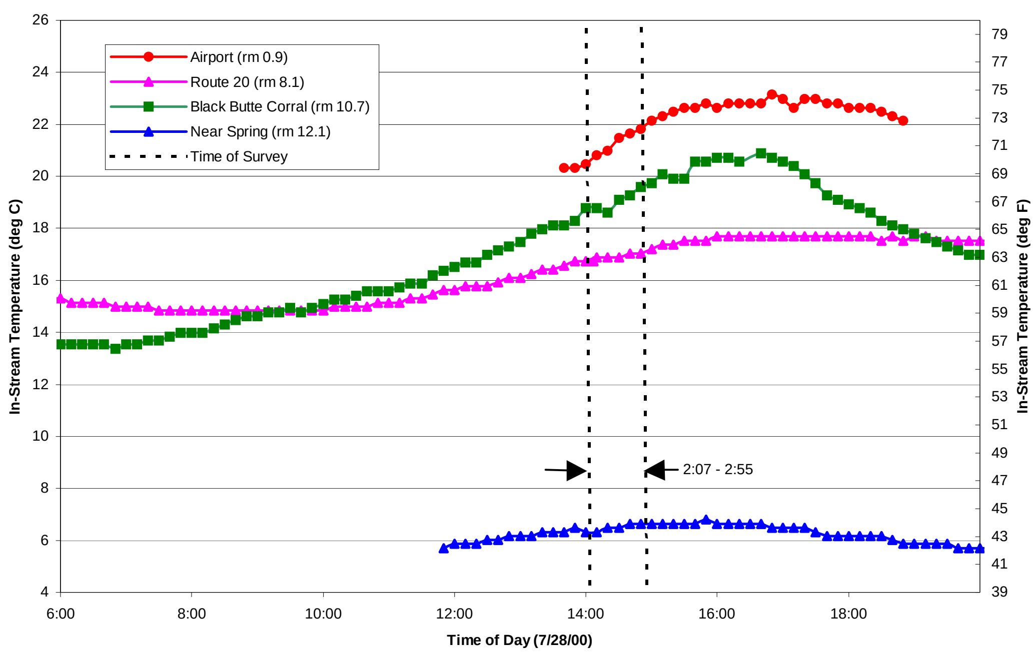

Figure 5 - Diurnal temperature curves from in-stream data loggers during thermal survey of Indian Ford Creek. Dashed vertical lines specify the timing and duration of the FLIR survey with respect to the diurnal temperature fluctuations.

Temperature Profiles

Deschutes River

The median temperature for each sample frame from the inflow to Lake Billy Chinook (rm 120) to approximately 2 ¼ miles upstream of the Squaw Creek confluence were plotted versus river mile (Figure 6). Figure 6 shows how temperature varied longitudinally along this reach and identifies the location and temperature of tributary and spring inflows.

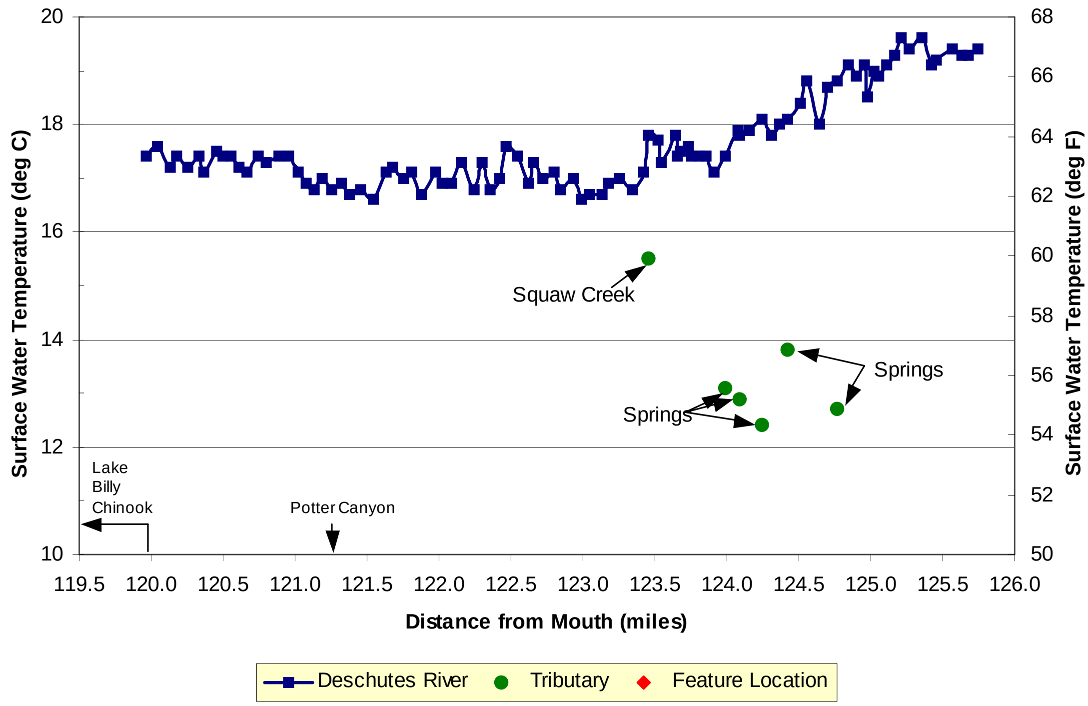

Figure 6 - Median stream temperature versus river mile for the Deschutes River. Tributaries and other surface inflows are identified.

Although only a short section of the Deschutes River was surveyed, the data showed some interesting results. A cooling trend of approximate 2^{o}C was observed between rm 125.7 and rm 123.4. A series of 5 spring inflows were detected between river miles 124.0 and 125.0, which were not identified on the USGS 1:24k topographic maps (Figure 7). The springs along with Squaw Creek are sources of thermal cooling (15.5^{o}C) to the Deschutes River (17.8^{o}C).

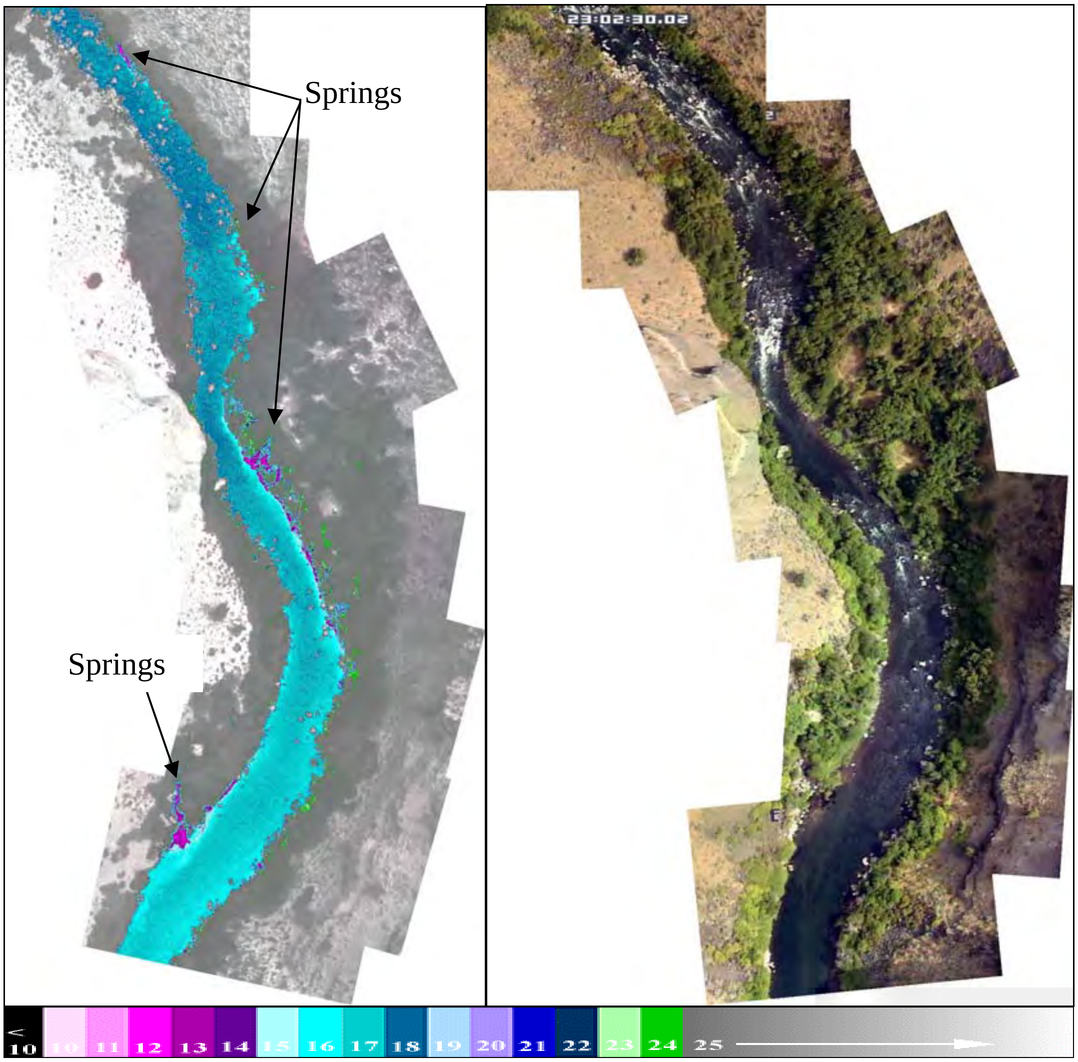

Figure 7 - FLIR/color video image (mosaic frames: des141 – des149) showing a series of spring inflows on the Deschutes River near river mile 124.0.

Squaw Creek

A longitudinal temperature profile was developed for Squaw Creek from the mouth to the Squaw Creek falls, a distance of 36.1 miles (Figure 8). The plot also includes the temperature of tributaries and other surface inflows that were visible in the imagery. Tributaries are labeled in Figure 8 by river mile with their name and temperature listed in the associated table. Only surface inflows that could be positively identified in the imagery were included. In some cases, tributaries and other surface water inflows may be obscured by riparian vegetation or outside the sensor field of view. Figure 9 shows the longitudinal temperature profile mapped over a shaded relief map of the watershed. This map provides an additional spatial context for viewing and analyzing the data.

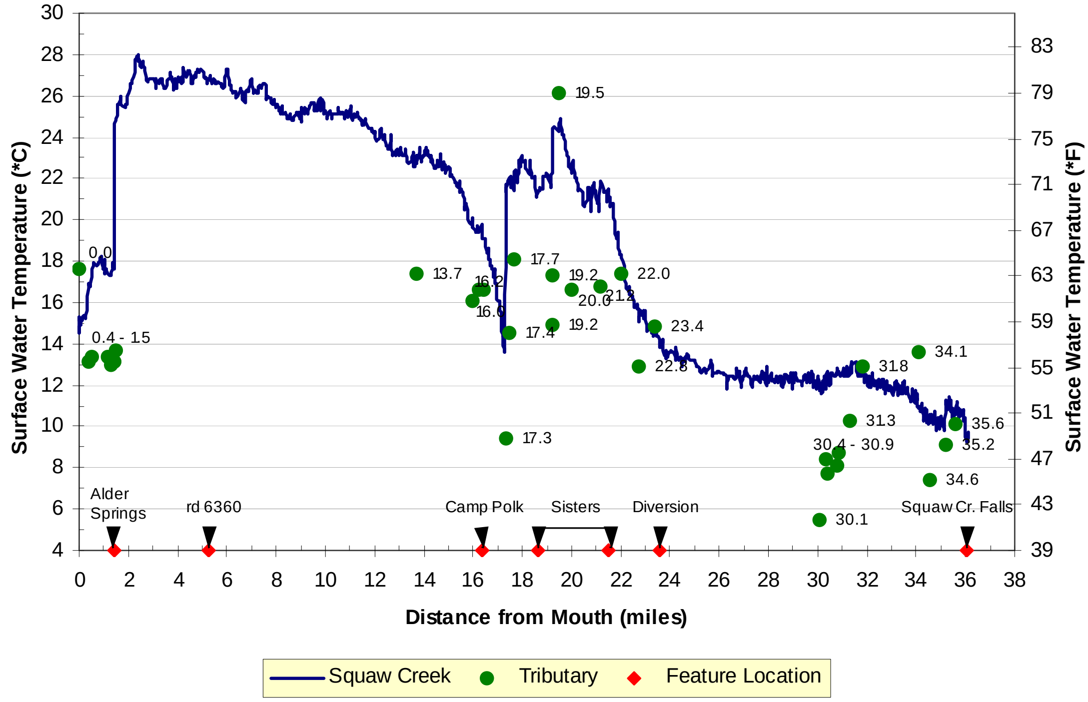

Figure 8 – Median stream temperature versus river mile for Squaw Creek. Tributaries and side channels are described in Table 4.

Stream temperatures in the headwater areas were comparable to groundwater temperatures (7-9^{o}C). Eleven tributary and spring inflows were detected in the first 5.5 miles downstream of Squaw Creek falls. Nine of these inflows contributed flows ranging from –0.5^{o}C to –6.5^{o}C cooler then Squaw Creek. The North Fork Squaw Creek was the only tributary contributing significantly warmer flows (+2.7^{o}C). While some fine-scale variability was observed, the longitudinal temperature profile showed no detectable change between river miles 30.0 and 26.3. There were also no surface inflows detected through this section.

Squaw Creek showed an almost exponential increase in stream temperatures over the next 4.8 river miles (rm 26.3 to rm 21.5). From river mile 26.3 to the Squaw Creek Canal diversion (rm 23.5), stream temperatures increase at a rate of 0.5^{o}C/mile. At the Squaw Creek canal diversion (rm 23.5) the rate of longitudinal heating increased to 2.7^{o}C/mile (*7.6^{o}C over 2.8 river miles*) in the downstream direction before leveling off at river mile 21.5. Three surface water inputs were detected in this section including inflow from a side channel (rm 23.4), a spring (rm 22.8), and an unidentified tributary (rm 22.0). The three surface water inputs contributed cooler water and influenced local temperatures, but did not alter the longitudinal heating pattern.

Table 4 – Tributaries and other surface inflows identified during the FLIR survey of Squaw Creek (LB = left bank, RB = right bank looking upstream).

Tributary	**River Mile**	**Tributary Temp °C (*°F*)**	**Squaw Cr Temp °C (°F)**	**Difference °C (*°F*) (trib-mainstem)**	**FLIR Image**
Deschutes River	0.0	17.6 *(63.7)*	14.8 *(58.6)*	2.8 *(5.0)*	sqw0014
Spring (RB)	0.4	13.1 *(55.6)*	16.9 *(62.4)*	-3.8 *(-6.8)*	sqw0030
Spring (LB)	0.5	13.4 *(56.1)*	17.2 *(63.0)*	-3.8 *(-6.8)*	sqw0034
Spring (RB)	1.2	13.4 *(56.1)*	17.4 *(63.3)*	-4.0 *(7.2)*	sqw0055
Spring (RB)	1.3	13.0 *(55.4)*	17.3 *(63.1)*	-4.3 *(-7.7)*	sqw0058
Alder Springs (LB)	1.4	13.1 *(55.6)*	17.6 *(63.7)*	-4.5 *(-8.1)*	sqw0063
Alder Springs (RB)	1.4	13.1 *(55.6)*	24.1 *(75.4)*	-11.0 *(-19.8)*	sqw0065
Spring (LB)	1.5	13.7 *(56.7)*	24.9 *(76.8)*	-11.2 *(-20.2)*	sqw0067
Spring (RB)	13.7	17.4 *(63.3)*	22.7 *(72.9)*	-5.3 *(-9.5)*	sqw0586
Spring (RB)	16.0	16.1 *(61.0)*	19.9 *(67.8)*	-3.8 *(-6.8)*	sqw0675
Camp Polk Springs (RB)	16.2	16.6 *(61.9)*	19.4 *(66.9)*	-2.8 *(-5.0)*	sqw0687
Spring (RB)	16.4	16.6 *(61.9)*	19.1 *(66.4)*	-2.5 *(-4.5)*	sqw0693
Spring (RB)	17.3	9.4 *(48.9)*	21.7 *(71.1)*	-12.3 *(-22.1)*	sqw0768
Spring (RB)	17.4	14.5 *(58.1)*	22.0 *(71.6)*	-7.5 *(-13.5)*	sqw0774
Unknown Tributary (RB)	17.7	18.1 *(64.6)*	22.3 *(72.1)*	-4.2 *(-7.6)*	sqw0788
Unknown Tributary (RB)	19.2	17.3 *(63.1)*	22.3 *(72.1)*	-5.0 *(-9.0)*	sqw0861
Side-Channel (LB)	19.2	14.9 *(58.8)*	24.4 *(75.9)*	-9.5 *(-17.1)*	sqw0863
Indian Ford Creek (RB)	19.5	26.1 *(79.0)*	24.3 *(75.7)*	1.8 *(3.2)*	sqw0868
Unknown Tributary (LB)	20.0	16.6 *(61.9)*	22.4 *(72.3)*	-5.8 *(-10.4)*	sqw0886
Dam outflow (RB)	21.2	16.8 *(62.2)*	21.9 *(71.4)*	-5.1 *(-9.2)*	sqw0936
Unknown Tributary (LB)	22.0	17.4 *(63.3)*	18.3 *(64.9)*	-0.9 *(-1.6)*	sqw0978
Spring (RB)	22.8	12.9 *(55.2)*	15.1 *(59.2)*	-2.2 *(-4.0)*	sqw1014
Side-Channel (LB)	23.4	14.8 *(58.6)*	15.0 *(59.0)*	-0.2 *(-0.4)*	sqw1052
Spring (RB)	30.1	5.5 *(41.9)*	12.0 *(53.6)*	-6.5 *(-11.7)*	sqw1311
Spring (RB)	30.3	8.4 *(47.1)*	11.8 *(53.2)*	-3.4 *(-6.1)*	sqw1322
Spring (RB)	30.4	7.7 *(45.9)*	12.7 *(54.9)*	-5.0 *(-9.0)*	sqw1326
Spring (LB)	30.8	8.1 *(46.6)*	12.5 *(54.5)*	-4.4 *(-7.9)*	sqw1342
Spring (RB)	30.9	8.7 *(47.7)*	12.7 *(54.9)*	-4.0 *(-7.2)*	sqw1344
Snow Creek (LB)	31.3	10.3 *(50.5)*	12.5 *(54.5)*	-2.2 *(-4.0)*	sqw1364
Side-Channel (RB)	31.8	12.9 *(55.2)*	12.6 *(54.7)*	0.3 *(0.5)*	sqw1390
North Fork Squaw Cr. (RB)	34.1	13.6 *(56.5)*	10.9 *(51.6)*	2.7 *(4.9)*	sqw1488
Unknown Tributary (LB)	34.6	7.4 *(45.3)*	10.3 *(50.5)*	-2.9 *(-5.2)*	sqw1513
South Fork Squaw Cr. (RB)	35.2	9.1 *(48.4)*	10.9 *(51.6)*	-1.8 *(-3.2)*	sqw1540
Park Creek (RB)	35.6	10.1 *(50.2)*	10.6 *(51.1)*	-0.5 *(-0.9)*	sqw1561

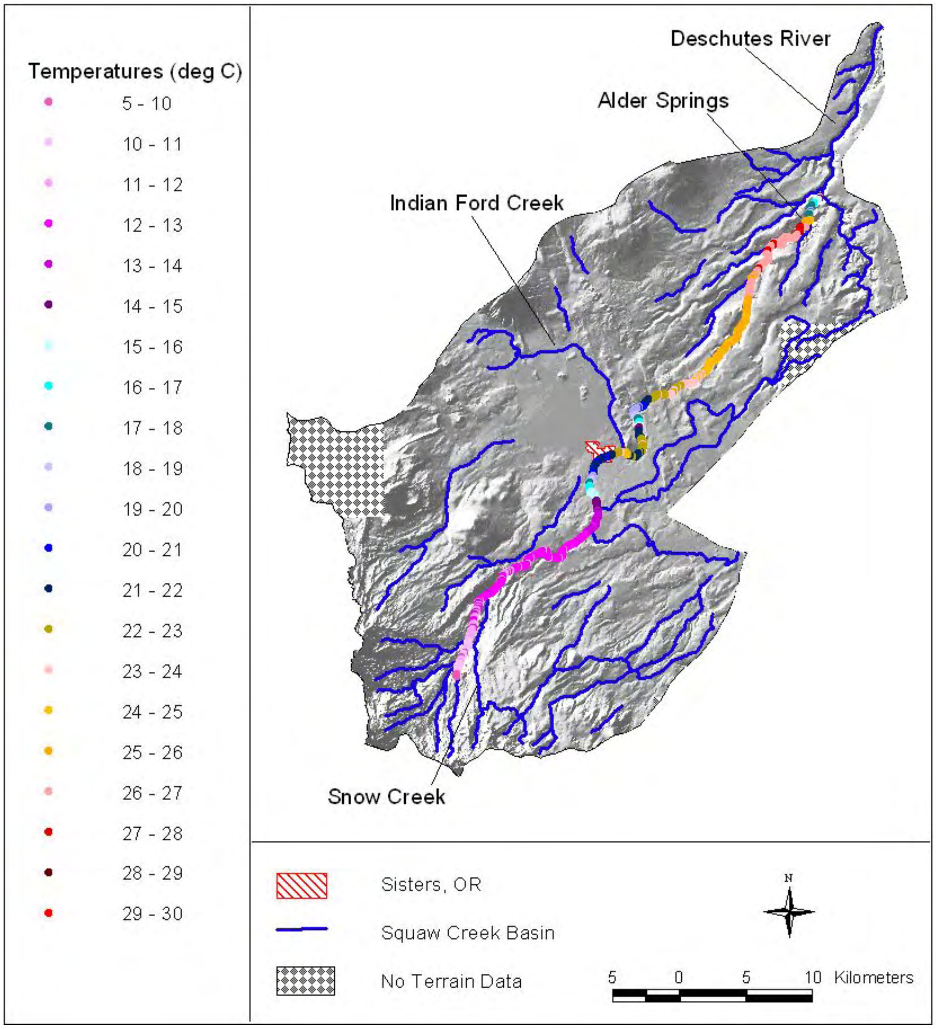

Figure 9 – Point pattern map of Squaw Creek temperatures plotted over a shaded terrain relief map.

A small (0.2°C – 0.5°C) net temperature increase was observed between rm 21.5 and rm 17.5[2]. Local thermal variability was observed throughout this reach with a 4.5°C range of stream temperatures of (*20.4°C to 24.9°C*). A local maximum was reached near the inflow of Indian Ford Creek, which contributed warmer water to Squaw Creek. However, Squaw Creek temperatures had already reached this maximum prior to the Indian Ford Creek inflow. The imagery suggests that volumetric flow from Indian Ford Creek is small relative to Squaw Creek and that direct thermal influence is strictly local. A dam outflow (Figure 10) at rm 21.2 and four surface inputs all contributed cooler water in this reach. The surface input at rm 19.2 (Figure 11) appears to be an upwelling of cooler water that originated in the stream and is flowing sub-surface through the floodplain[3]. The source of the other surface inputs could not be positively determined from the imagery.

[2] Reach includes the town of Sisters.
[3] This is also known as hyporheic flow.

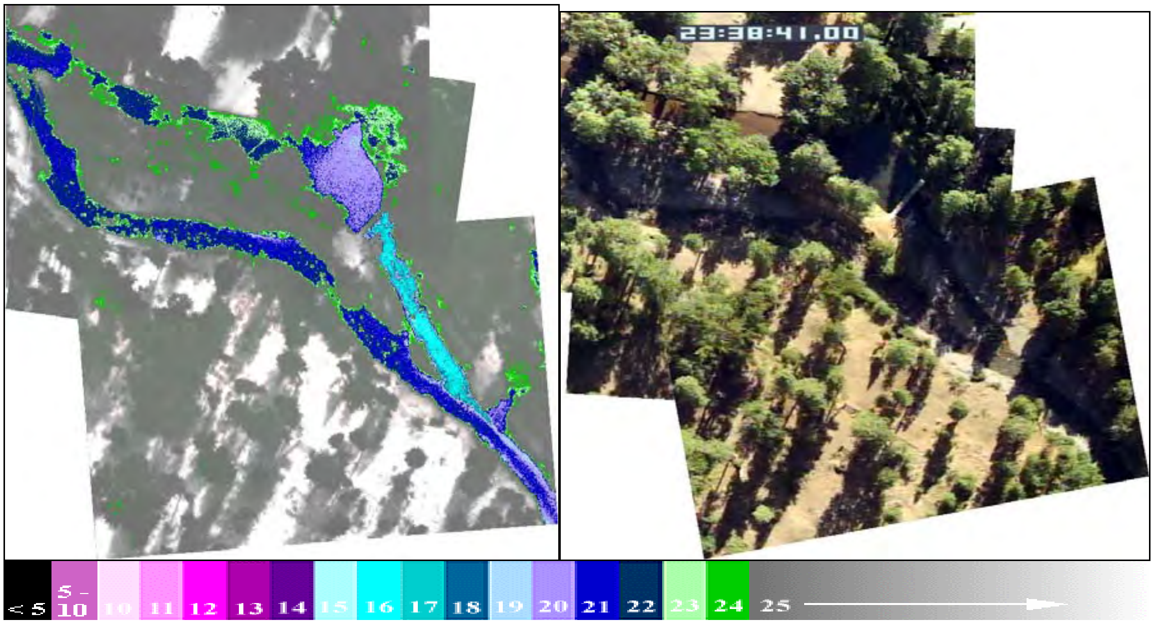

Figure 10 – FLIR/Color Video showing the outflow of a dam at river mile 21.2 (mosaic of frames: sqw936 to sqw939) contributing cooler water (16.8°C) to Squaw Creek (21.9°C). Stream flow is from the top to the bottom of the image.

A spring inflow (Figure 12) at river miles 17.4 and 17.3 results in a dramatic 8.0°C decrease in stream temperature. These springs were not identified on the USGS 7.5' Topographic Maps and occur approximately 1 mile upstream of the mapped location of Camp Polk Springs. From river miles 17.4 to 13.7, stream temperatures increase in the downstream direction at an average rate of 2.4°C/mile (*9.0°C over 3.7 miles*). A series of three springs were detected around Camp Polk Springs. These springs contribute cooler water, but do not alter the overall longitudinal heating trend in this reach. Stream temperatures continue to increase over the next 12.2 river miles with only local variability. No surface inputs were detected over this reach and stream temperatures approached the observed daily maximum air temperatures of 28°C.

A series of 5 spring inflows were detected between river mile 1.2 and 1.5, which included the mapped location of Alder Springs (Figure 13). The springs collectively lower the temperature of Squaw Creek by approximately 8.6°C. A second set of springs (Figure 14) were detected at river mile 0.5 to 0.4, which were not identified on the USGS 7.5' Topographic Maps. These springs further lower the temperature of Squaw Creek by 1.0°C. Due to the spring inflows in the lower 1.5 miles, Squaw Creek was ultimately a cooling source to the Deschutes River.

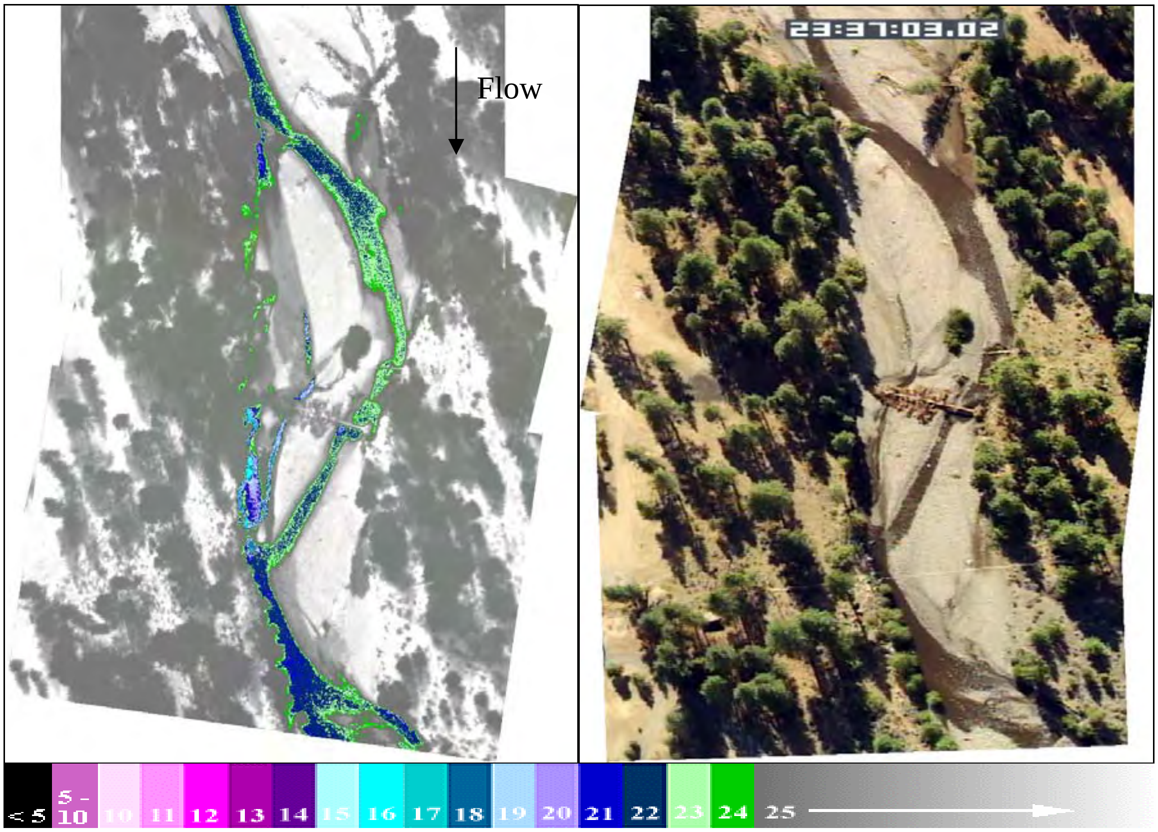

Figure 11 – Upwelling of cooler water at rm 19.2 that originated in the stream and flows through the flood plain (mosaic frames: sqw862-864).

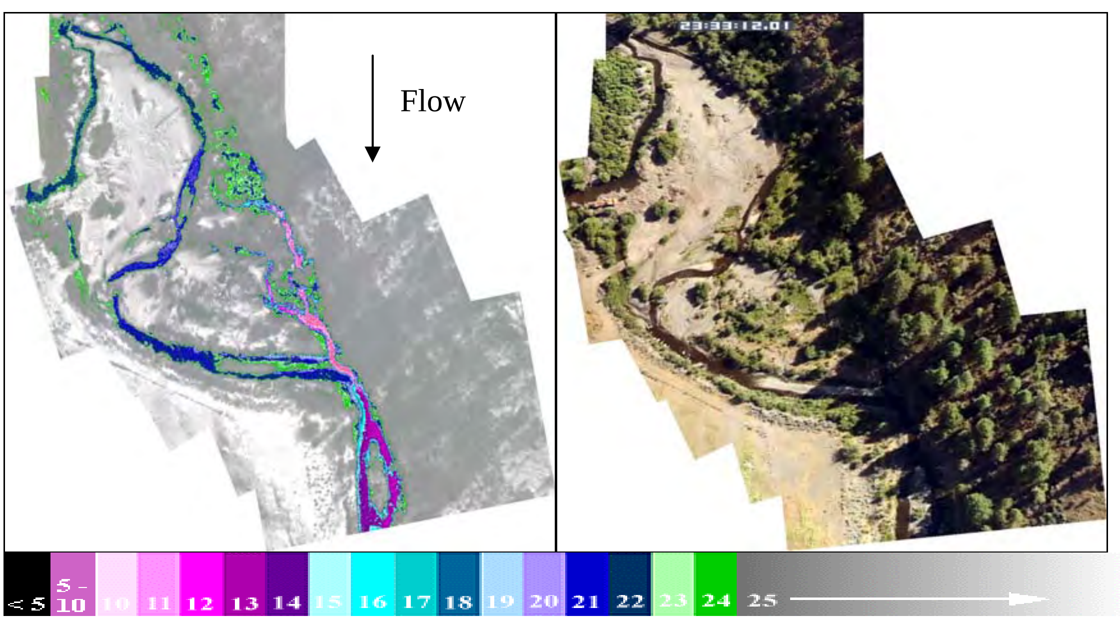

Figure 12 – Apparent spring detected at rm 17.3 that drops the temperature of Squaw Creek by 8^{o}C (mosaic: frames sqw767_7773).

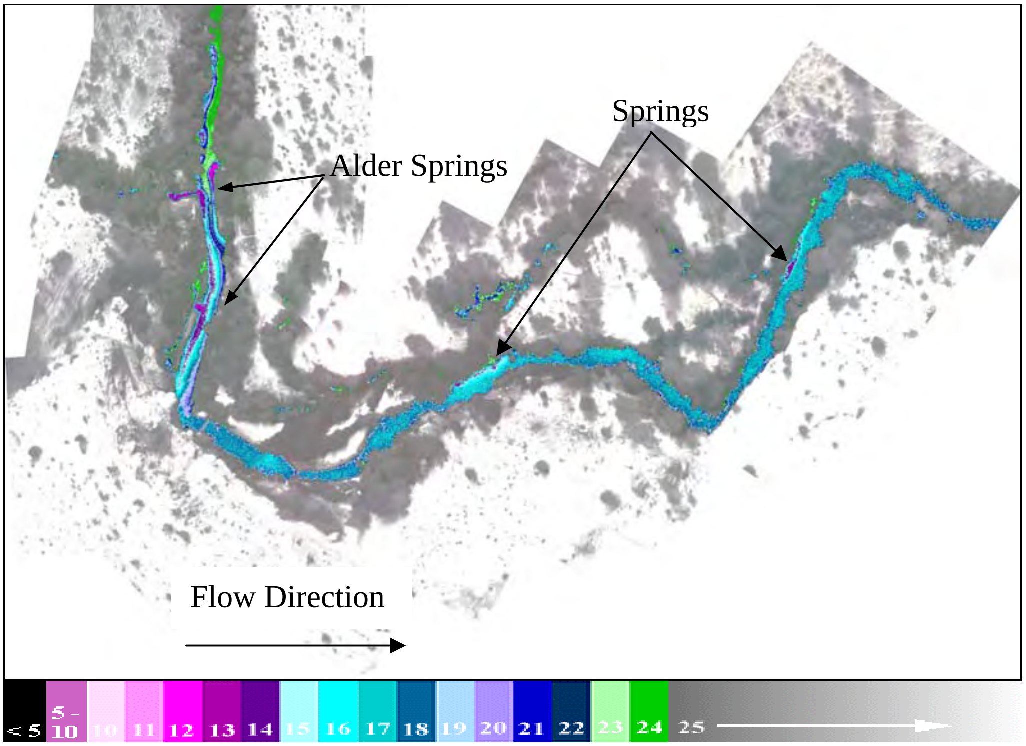

Figure 13 – FLIR images (mosaic frames: sqw0056_67) showing a series of spring inflows at Alder Springs (rm 1.2 to rm 1.5).

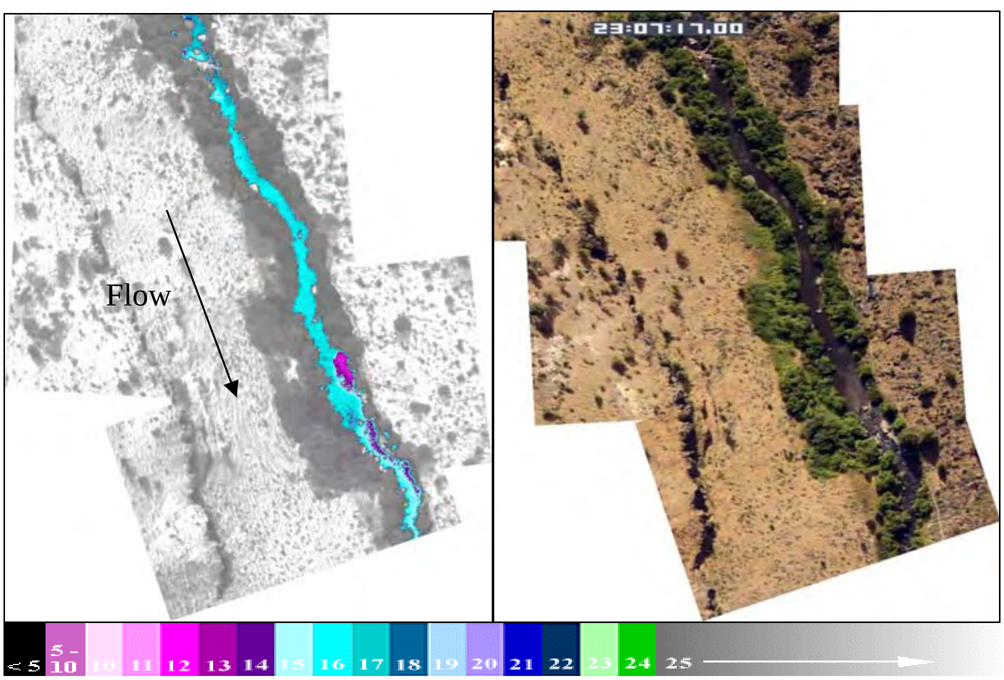

Figure 14 – FLIR image (mosaic frames: sqw30 to sqw34) showing a set of spring inflows at river mile 0.5.

Indian Ford Creek

A longitudinal temperature profile was developed for Indian Ford Creek from the confluence of Squaw Creek to the headwater springs (Figure 15). Near the headwaters, Indian Ford Creek divides into three branches that originate from two springs. The FLIR survey covered each of these branches in order to help understand the temperature regime in the headwater areas. The right and middle branches originate from Paulina Springs with the right branch flowing through a series of ponds. The left most branch originates from a separate spring. Indian Ford Creek had several reaches where no surface water was visible in the FLIR imagery. In these cases the survey followed cooler vegetation and willows. Temperatures were only sampled where surface water was visible and continuous. Figure 16 shows a point pattern map of Indian Ford Creek temperatures plotted over a shaded terrain relief map. This map provides an additional spatial context for longitudinal temperature profile along with reaches that could not be accurately sampled.

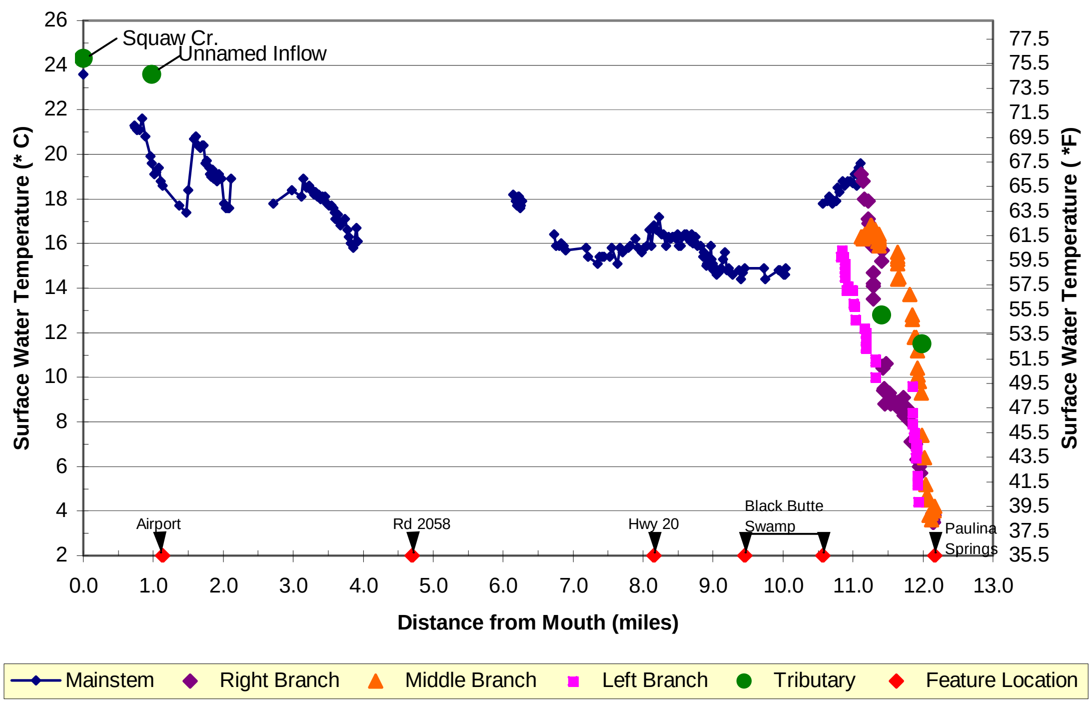

Figure 15 - Median stream temperatures versus river mile for Indian Ford Creek. Segments in the profile that do not have temperature data represent areas that could not be reliably be sampled due to little or no detectable surface water.

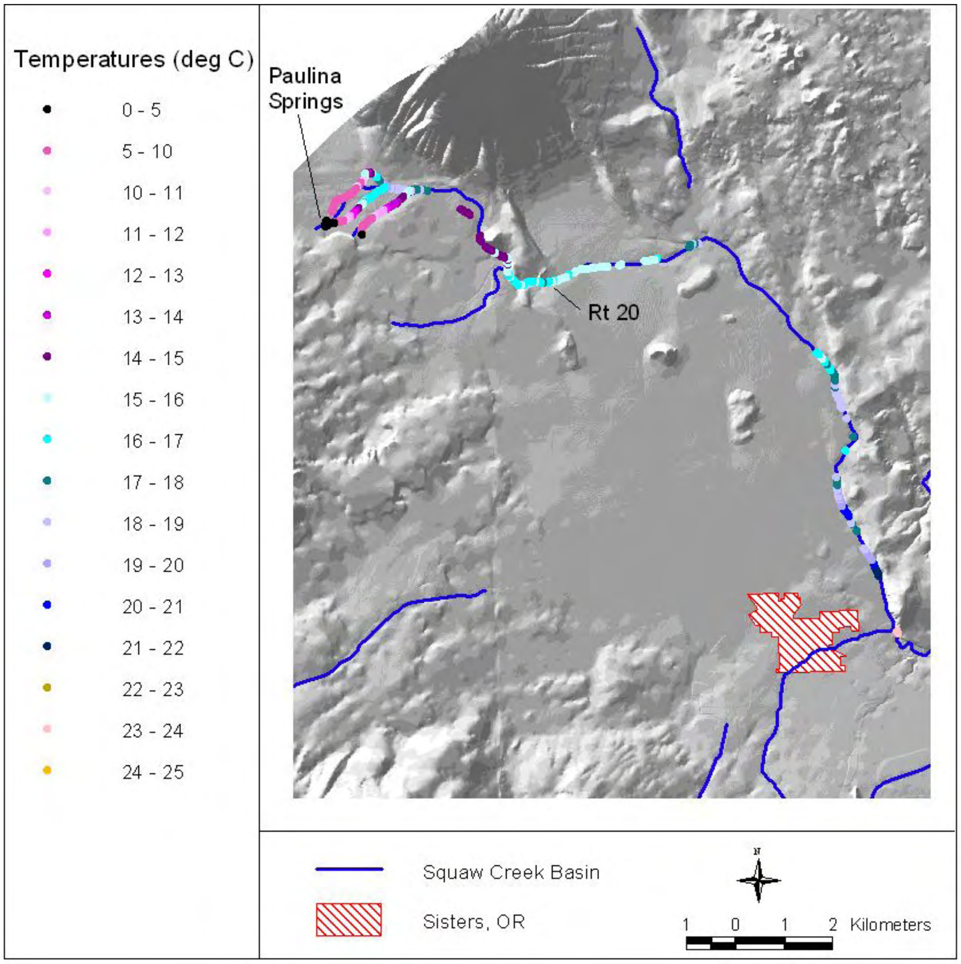

Figure 16 – Point pattern map of Indian Ford Creek temperatures plotted over a shaded relief map. The map also shows reaches that could not be accurately sampled.

The headwater springs in Black Butte Meadow showed the coldest temperatures measured in the basin (approximately 4^{o}C). From the headwaters, stream temperatures increased by approximately 11^{o}C over the first mile. There was no defined channel through Black Butte Swamp (rm 10.5) and there was little surface water detected. The longest continuous section of surface water in the stream was observed downstream of the swamp from rm 10.0 to rm 6.7. Temperatures in this reach showed local variability with an overall net increase of approximately 1.5^{o}C. The stream from mile 6.7 to mile 3.9 had few areas in which water temperatures could be reliably sampled in the imagery. Multiple small channels were often obscured by streamside willows and other vegetation making it difficult to detect surface water in these sections. Cooler vegetation along the stream corridor suggested shallow sub-surface flow where surface water was not detected. The lower 4 miles of Indian Ford Creek were characterized by intermittent surface flow.

Discussion

FLIR imagery was collected on Squaw Creek, Indian Ford Creek, and a 6-mile section of the Deschutes River. Analysis of the Squaw Creek flight in relation to the daily stream temperature cycle indicates that the timing of the Squaw Creek survey was consistent with maximum daily stream temperatures for July 28, 2000. The Indian Ford Creek survey occurred approximately 1 hour prior to recorded maximum daily temperatures. Longitudinal stream temperature patterns were developed for each survey stream and include the median temperature and location of surface water inflows. WS, LLC FLIR surveys over the past 4 years have shown that, while absolute temperatures change, the longitudinal patterns of warming and cooling remain consistent from year to year.

The 4.5^{o}C temperature difference between headwaters and mouth of Squaw Creek is not indicative of the large course scale variability observed in the longitudinal temperature profile. Of the 33 point source inflows detected during the survey, 30 contributed water cooler then the Squaw Creek mainstem. The point source inflows included three spring complexes (river miles 30.1-30.4, 16.0-17.4, and 1.2-1.5) that dramatically lowered stream temperatures and altered the longitudinal temperature pattern. The USGS 7.5' Topographic maps identified springs around Camp Polk that were detected in the FLIR imagery. However, these springs appeared to have a relatively small influence on mainstem temperatures compared to another spring located approximately 1 mile upstream of Camp Polk, which was not identified on the USGS topographic maps. A 4th spring complex was observed between river miles 30.1 and 30.9, which also caused local decrease in mainstem temperatures.

In addition to point source inputs, there were several distinct shifts in longitudinal heating rates. Figure 17 shows the longitudinal temperature patterns in relation to terrain elevation and location of physical features along Squaw Creek. The terrain elevation was derived from a 10-meter digital elevation model of the watershed and provides a general measure of stream gradient. The highest rate of longitudinal heating was observed between river miles 26.3 and 21.5. Two features are evident in this reach. First, stream gradient begins to decrease around river mile 26. This indicates a possible geomorphic shift and alteration of one or more of the parameters that that influence longitudinal heating rates including velocity (travel time), channel characteristics, and/or riparian community structure and composition. The second and more prominent feature is the diversion for the Squaw Creek Canal (Figure 18). While flow levels were not measured as part of the aerial survey, the longitudinal temperature profile suggests that flow reduction may play a significant role in the observed increase in stream heating rates.

Stream temperatures in Squaw Creek exceeded 20^{o}C through two different sections. The stream section between rm 17.7 and rm 21.5 showed local thermal variability, but generally did not increase in temperature. The stream section between rm 15.0 and rm 1.5 showed a gradual increase in stream temperatures. Cool water seeps were detected in both of these sections (Figure 11 and Figure 19), which contribute fine-scale thermal heterogeneity.

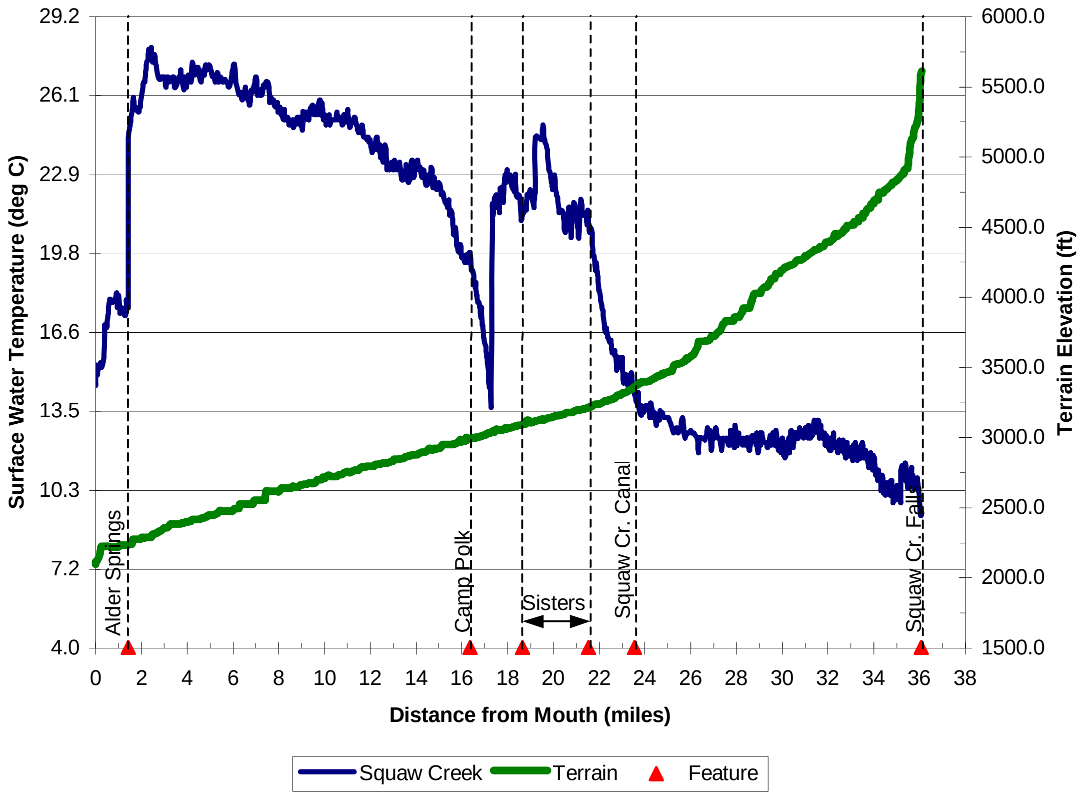

Figure 17 – Median stream temperature and terrain elevation versus river mile for Squaw Creek. The plot also shows feature locations along the stream.

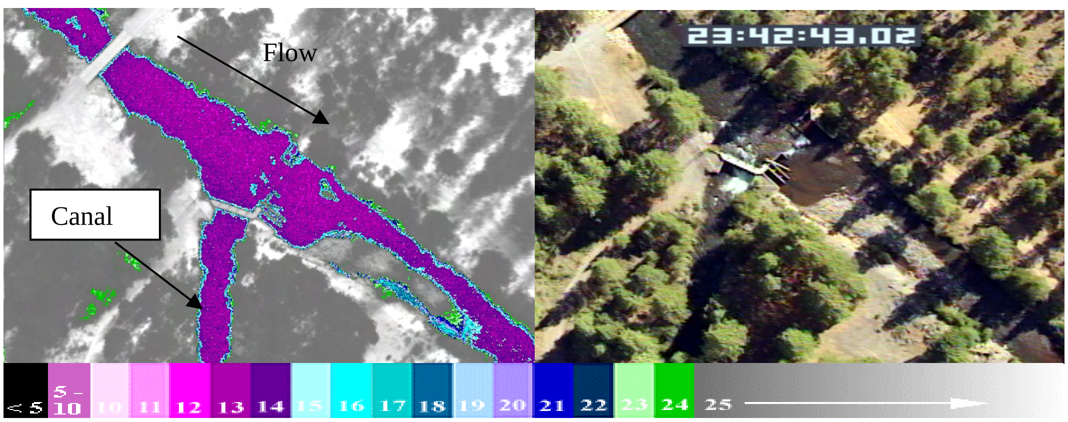

Figure 18 – FLIR/Color video image pair showing Squaw Creek Canal Diversion Squaw Creek (14.2°C) flows from the top left to bottom right of the image (frame: sqw1059).

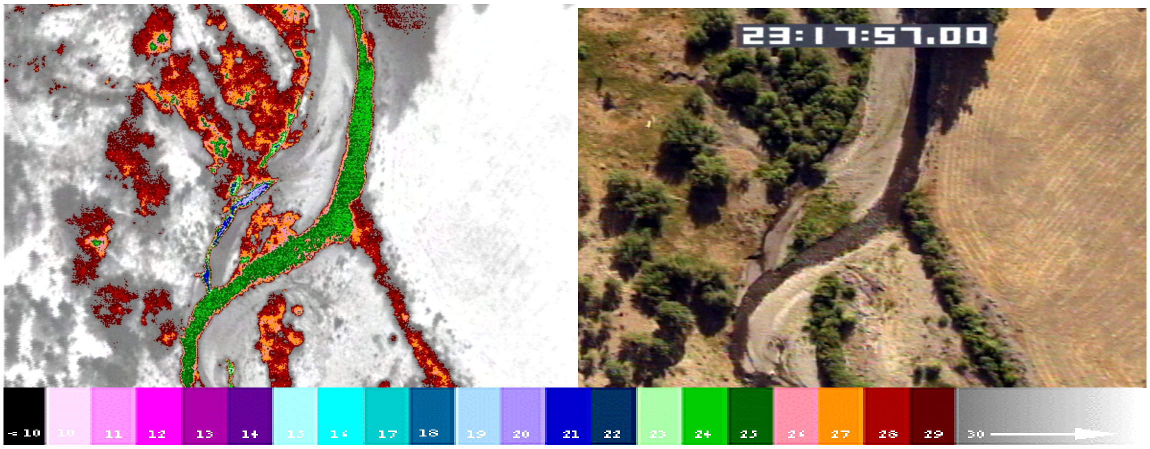

Figure 19 – FLIR/color video image showing upwelling of cooler water through the flood plain at river mile 8.5 (frame: sqw0354).

Indian Ford Creek was characterized by a series of connected wetlands. Due to intermittent visibility in the imagery, there is little continuity in the longitudinal temperature profile. Like Squaw Creek, flow regulation is part of the current hydrology of Indian Fork Creek. There are irrigation canals and several man-made ponds (Figure 20) along its length. Sub-surface flow through the stream channel and wetlands also influence the stream's temperature patterns. For example, a stream temperature of 18^{o}C was observed at the downstream end of Black Butte Meadow. However, the stream fans out in Black Butte swamp and emerges at approximately 15.0^{o}C. While it was generally not possible to sample water temperatures from the imagery in the wetland areas, image mosaics of the swamp (Figure 21) showed multiple small channels and cooler vegetation.

Indian Ford Creek had relatively little flow at the confluence of Squaw Creek. Further analysis of the thermal regime of Indian Ford Creek should examine current in-stream flows in relation to historic flow patterns.

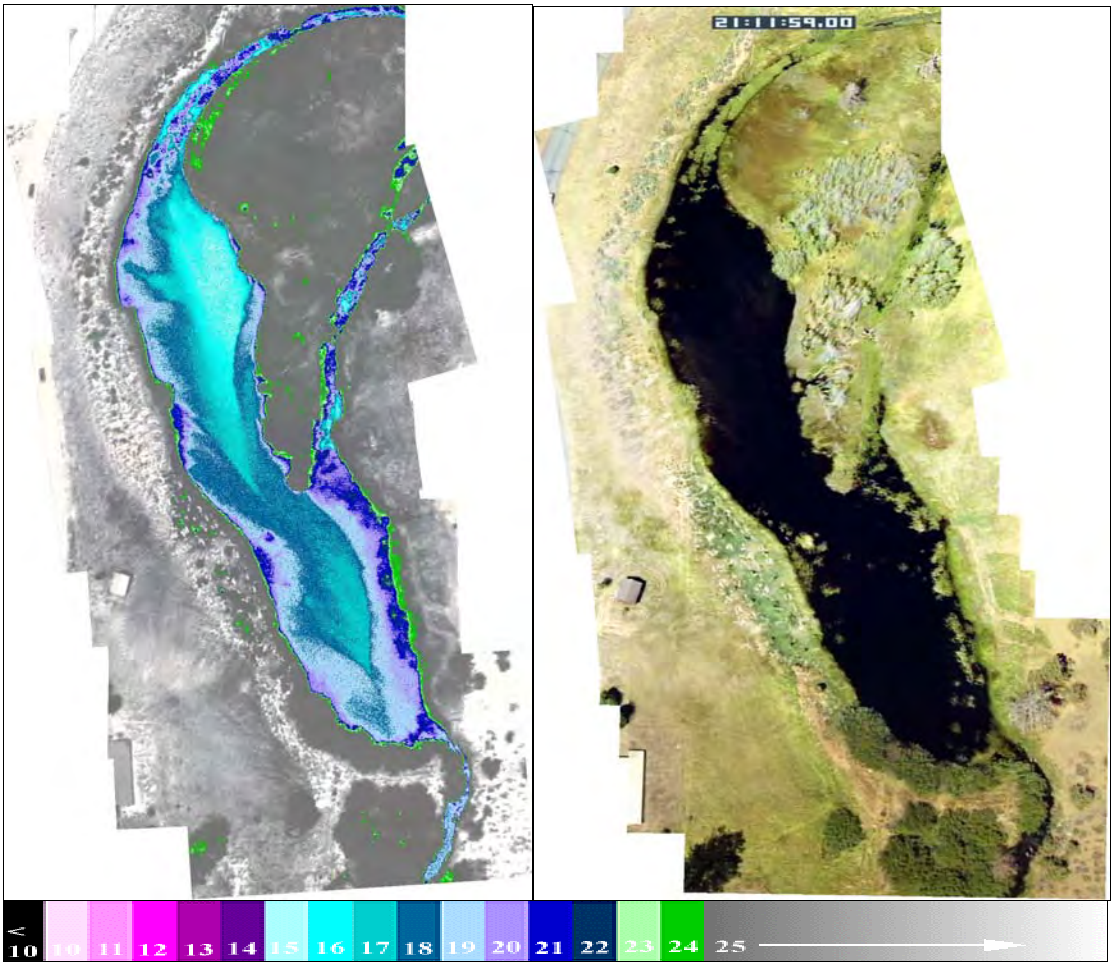

Figure 20 – FLIR/color video Image showing a pond in Indian Ford Creek (rm 2.1). Vegetation is visible on the water surface upstream of the pond. This was typical of several areas along Indian Ford Creek and precluded accurate temperature sampling from the image. The thermal patterns on the pond suggest thermal stratification in the downstream end of the pond (mosaic: frame if276- if278).

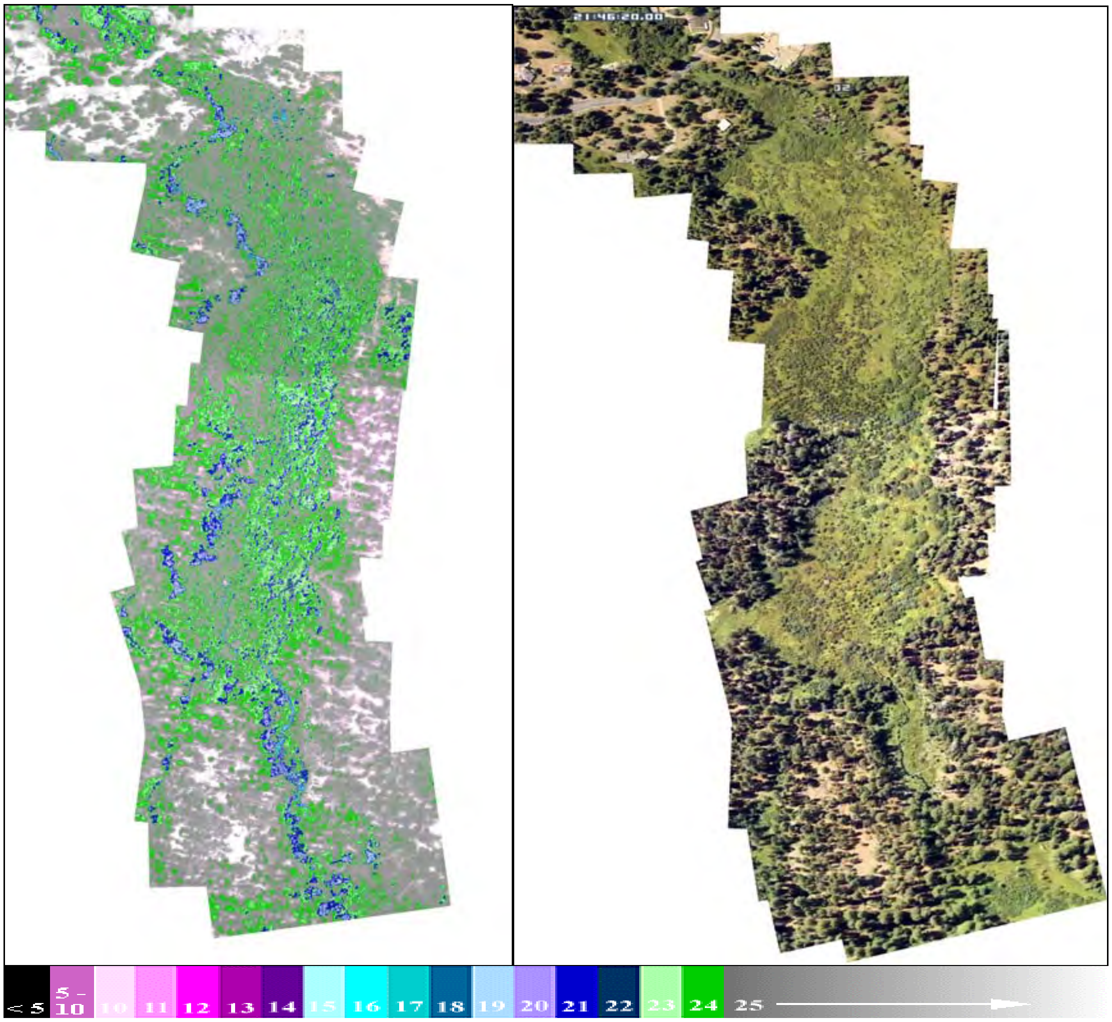

Figure 21 – FLIR/color video image mosaic (frames: vif1850 to vif1888) showing Indian Ford Creek through Black Butte Swamp. The imagery was collected at an altitude of 2000 ft above ground level in order to capture the approximate width of the swamp. The FLIR image mosaic shows generally cooler vegetation through the swamp. However, only a small section of surface water was detected in either image.

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