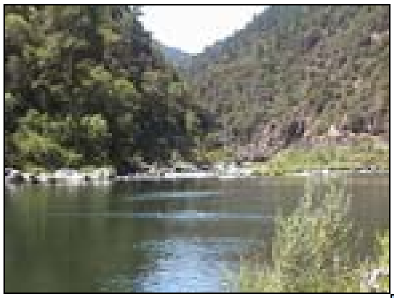
# *Aerial Surveys in the Rogue River Basin*
**Thermal Infrared and Color Videography**

March 9, 2004



*Report to:*

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**Final Report**

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## Introduction

In 2003, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC (WS, LLC) to conduct airborne thermal infrared (TIR) remote sensing surveys of selected streams in the Rogue River Basin in Oregon. The objective of the project was to collect TIR and color video imagery in order to characterize the thermal regime of these streams. The imagery and subsequent analysis are intended to support ongoing assessments of stream temperature and habitat quality in the basin.

Water temperatures vary naturally along the stream gradient due to topography, channel morphology, substrate composition, riparian vegetation, ground water exchanges, and tributary influences. Stream temperatures are also affected by human activities within the watershed. TIR images provide information about spatial stream temperature variability and can illustrate changes in the interacting processes that determine stream temperature. In most cases, these processes are extremely difficult to detect and quantify using traditional ground-based monitoring techniques.

It is the aim of this report to: 1) document methods used to collect and process the TIR images, 2) present spatial temperature patterns, and 3) highlight interesting features observed during image analysis. Thermal infrared and associated true color video images are included in the report in order to illustrate significant thermal features. An associated ArcView 3.2 GIS[1] database includes all of the images collected during the survey and is structured to allow analysis at finer scales.

## Methods

### *Data Collection*

Images were collected with TIR (8-12μ) and visible-band cameras attached to a gyro-stabilized mount on the underside of a helicopter. The two sensors were aligned to present the same ground area, and the helicopter was flown longitudinally along the stream channel with the sensors looking straight down. Thermal infrared images were recorded directly from the sensor to an on-board computer in a format in which each pixel contained a measured radiance value. The recorded images maintained the full 12-bit dynamic range of the sensor. The individual images were referenced with time and position data provided by a global positioning system (GPS).

A consistent altitude above ground level was maintained in order to preserve the scale of the imagery throughout the survey. The ground width and spatial resolution presented by the TIR image vary based on the flight altitudes. The flight altitude is selected prior to the flight based on the channel width and morphology. During the flights, images were collected sequentially with approximately 40% vertical overlap. All

[1] Geographic Information System

flights were conducted in the mid-afternoon (13:30-17:00) in order to capture heat of the day conditions.

Airborne surveys were conducted on the Rogue River, Evans Creek, WF Evans Creek and EF Evans Creek (Figure 1). Evans Creek and its forks were flown at a lower altitude (1200 - 1400 ft above ground level (AGL)) than the Rogue River (3200 - 4000 ft AGL). The lower altitude provided a high spatial resolution (≈1.5 ft) and better visibility through the riparian vegetation while also presenting a wide enough ground footprint to capture floodplain features and small meander bends. The Rogue River altitude provided imagery with a wider ground footprint and hence, a more synoptic view of the river and surrounding vegetation. Table 1 summarizes the survey times, extents, and image resolution for each surveyed stream.

Meteorological data including air temperature and relative humidity were recorded using a portable weather station (*Onset*) located at the confluence of the Rogue River and Grave Creek.

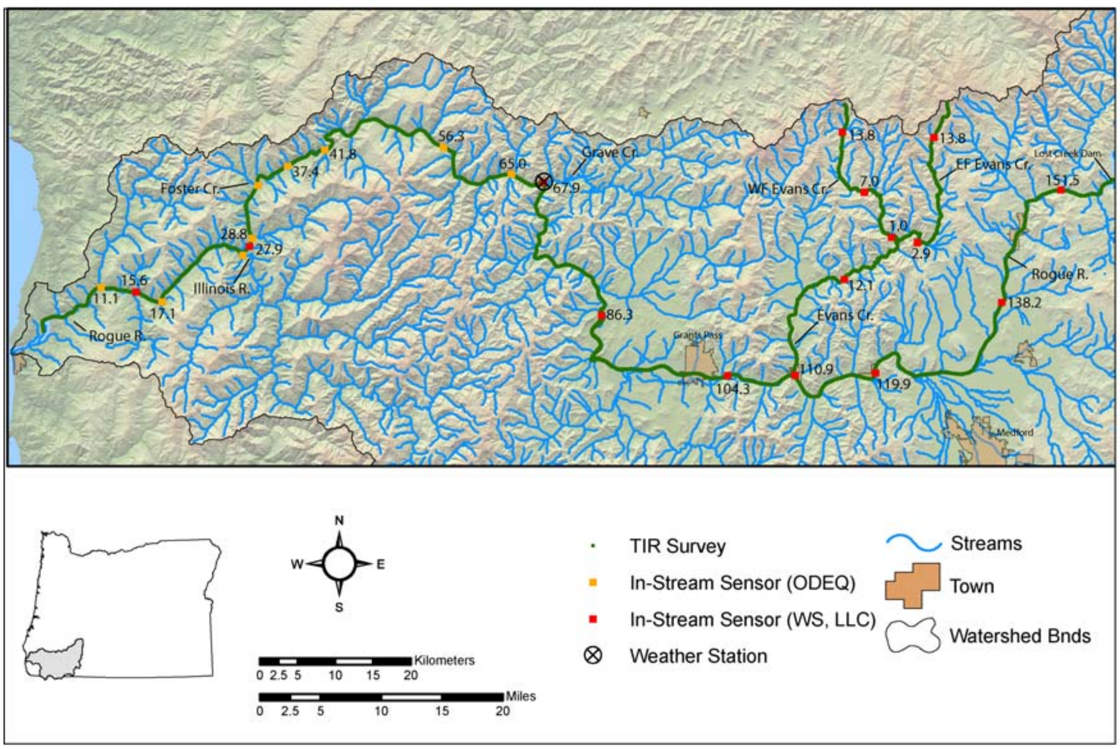



Figure 1 – Map showing the surveys conducted in the Rogue River Basin, OR from July 30 to August 1, 2003. The map also shows the location of in-stream sensors used to ground truth radiant temperatures derived from TIR images. The sensor locations are labeled by river mile (rm).

Table 1 – Summary of river segments surveyed with TIR and color video in the Rogue River Basin between July 30 and August 1, 2003.

| Stream | Survey Date | Survey Time | Survey Extent | River Miles | Image Width Meter (ft) | TIR Image Pixel Size Meter (ft) |
|---|---|---|---|---|---|---|
| Rogue R. (A) | 30-Jul | 14:30-15:59 | Ferry Hole Bar to Applegate R. | 91.9 | 342 (1128) | 1.09 (3.52) |
| Rogue R. (B) | 31-Jul | 14:20-15:29 | Pickett Cr. to Lost Creek Lake | 71.4 | 428 (1410) | 1.36 (4.40) |
| Evans Cr. | 1-Aug | 13:50-14:22 | Mouth to Forks | 19.1 | 150 (494) | 0.48 (1.54) |
| EF Evans Cr. | 1-Aug | 14:24-15:00 | Mouth to headwaters | 17.7 | 128 (423) | 0.41 (1.32) |
| WF Evans Cr. | 1-Aug | 15:10-15:41 | Mouth to headwaters | 16.3 | 128 (423) | 0.41 (1.32) |

For each surveyed stream, WS, LLC deployed in-stream data loggers prior to the survey in order to ground truth (i.e. verify the accuracy of) the TIR data. The in-stream data loggers were ideally located at intervals of 10 river miles or less over the survey route. The Rogue River was instrumented with 9 sensors by WS, LLC which were used for ground truthing, as well as 9 sensors provided by the Oregon Department of Environmental Quality. Evans Creek and its forks were instrumented with 7 sensors with relatively uniform distribution (as access allowed).

### *Data Processing*

Measured radiance values contained in the raw TIR images were converted to temperatures based on the emissivity of water, atmospheric transmission effects, ambient background reflections, and the calibration characteristics of the sensor. The atmospheric transmission value was modeled based on the air temperatures and relative humidity recorded at the time of the survey. The radiant temperatures were then compared to the kinetic temperatures measured by the in-stream data loggers. The in-stream data were assessed at the time the image was acquired, with radiant values representing the median of ten points sampled from the image at the data logger location. Calibration parameters were fine-tuned to provide the most accurate fit between the radiant and kinetic temperatures.

Once the TIR images were calibrated, they were integrated into a GIS in which an analyst interpreted and sampled stream temperatures. Sampling consisted of querying radiant temperatures (pixel values) from the center of the stream channel and saving the median value of a ten-point sample to a GIS database file (Figure 2). The temperatures of detectable surface inflows (i.e. surface springs, tributaries) were also sampled at their mouth. In addition, data processing focused on interpreting spatial variations in surface temperatures observed in the images. The images were assigned a river mile based on a 1:100k routed GIS stream coverage from the Environmental Protection Agency (*Note: measures assigned from this coverage may not match stream measures derived from other map sources*).

The median temperatures for each sampled image of each surveyed stream were plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient.

The location and median temperature of all sampled surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the main stem temperature patterns. Where applicable, tributaries or other features that were detected in the imagery, but were not sampled due to their small size (*relative to pixel size*) or the inability to see the stream through riparian vegetation, are included on the profile to facilitate the interpretation of the spatial patterns.

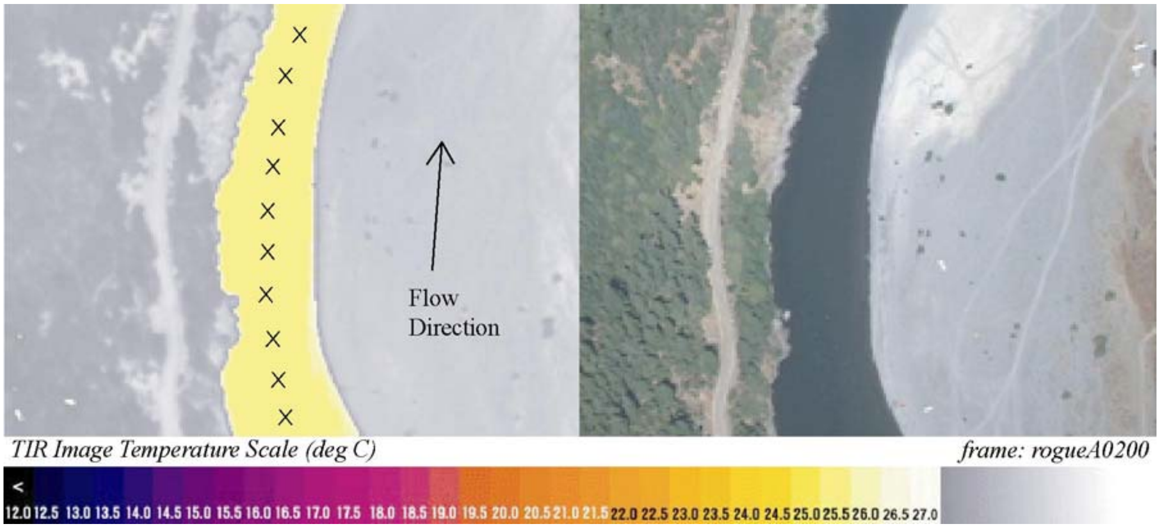


Figure 2 – TIR/color video image pair showing how temperatures are sampled from the TIR images. The black *X's* on the TIR image show typical sampling locations near the center of the stream channel. The recorded temperature for this image is the median of the sample points.

## TIR Image Characteristics

Thermal infrared sensors measure TIR energy emitted at the water's surface. Since water is essentially opaque to TIR wavelengths, the sensor is only measuring water surface temperature. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed; however, thermal stratification can form in reaches that have little or no mixing. Thermal stratification in a free flowing river is inherently unstable due to variations in channel shape, bed composition, and in-stream objects (i.e. rocks, trees, debris, etc.) that cause turbulent flow. In the TIR images, indicators of thermal stratification include cool water mixing behind in-stream objects and/or abrupt transitions in stream temperatures. Occurrences of thermal stratification interpreted during analysis are identified in the results section for each surveyed stream.

Thermal infrared radiation received at the sensor is a combination of energy emitted from the water's surface, reflected from the water's surface, and absorbed and re-radiated by the intervening atmosphere. Water is a good emitter of TIR radiation and has relatively low reflectivity (approximately 4 to 6% of the energy received at the sensor is due to ambient reflections). During image calibration, a correction is included to account for average background reflections. However, variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.6$^{o}$C (Torgersen et al. 2001). However, the occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis. In general, apparent stream temperature changes of < 0.6$^{o}$C are not considered significant unless associated with a point source.

In stream segments with flat surface conditions (i.e. pools) and relatively low mixing rates, observed variations in spatial temperature patterns can be the result of differences in the instantaneous heating rate at the water's surface. In the TIR images, indicators of differential surface heating include seemingly cooler radiant temperatures in shaded areas compared to surfaces exposed to direct sunlight. Shape and magnitude distinguish spatial temperature patterns caused by tributary or spring inflows from those resulting from differential surface heating. Unlike thermal stratification, surface temperatures may still represent bulk water conditions if the stream is mixed. Temperature sampling along the center of the stream channel (Figure 2) minimizes variability due to differences in surface heating rates. None-the-less, differences in surface heating combined with ambient reflection can confound interpretation of thermal features, especially near the riverbank.

A small stream width logically translates to fewer pixels "in" the stream and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures (Torgersen et. al. 2001). In some cases, small tributaries were detected in the images, but not sampled due to the inability to obtain a reliable temperature sample. [2]

[2] Features that are detected in the imagery, but not sampled for temperature are noted in the comment attribute of the flight point coverage.

# Results

## *Weather Conditions*

Weather conditions for the times of the surveys conducted in the Rogue River Basin from July 30 to August 1, 2003 are summarized in Table 2.

Table 2 – Meteorological conditions recorded at the mouth of Grave Creek, OR (river mile 68 on the Rogue River) on the afternoons of July 30, 31 and August 1, 2003.

| **Time** | **Air Temp (°F)** | **Air Temp (°C)** | **RH (%)** | **Air Temp (°F)** | **Air Temp (°C)** | **RH (%)** | **Air Temp (°F)** | **Air Temp (°C)** | **RH (%)** |
|---|---|---|---|---|---|---|---|---|---|
| | *7/30/03* | | | *7/31/03* | | | *8/1/03* | | |
| 13:00 | | | | 93.2 | 34.0 | 22.2 | 88.7 | 31.5 | 28.1 |
| 13:30 | | | | 94.7 | 34.9 | 19.6 | 91.0 | 32.8 | 26.3 |
| 14:00 | 101.0 | 38.3 | 16.3 | 97.0 | 36.1 | 17.9 | 91.7 | 33.2 | 24.9 |
| 14:30 | 101.0 | 38.3 | 14.7 | 97.0 | 36.1 | 16.3 | 92.5 | 33.6 | 24.4 |
| 15:00 | 102.6 | 39.2 | 14.3 | 97.8 | 36.6 | 15.9 | 94.0 | 34.4 | 24.4 |
| 15:30 | 102.6 | 39.2 | 13.5 | 97.8 | 36.6 | 15.5 | 94.0 | 34.4 | 24.9 |
| 16:00 | 103.4 | 39.7 | 13.1 | 98.6 | 37.0 | 14.7 | 94.0 | 34.4 | 24.0 |
| 16:30 | 103.4 | 39.7 | 13.1 | 97.8 | 36.6 | 13.9 | 94.7 | 34.9 | 25.4 |
| 17:00 | 103.4 | 39.7 | 13.5 | 97.8 | 36.6 | 13.5 | 93.2 | 34.0 | 25.8 |

### *Thermal Accuracy*

The average absolute differences between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images were within the desired accuracy (< 0.5$^o$C) for each surveyed stream (Table 3). With the exception of one location, the absolute differences were within ±0.6$^o$C. The only point outside this range was located at river mile 56.3 in the Rogue River and it recorded temperatures that were ≈0.9$^o$C cooler than the radiant temperatures. The available data (kinetic or radiant) did not provide any clues to the greater differences at this location. Appendix B of this report provides a plot of the kinetic temperatures and the spatial temperature patterns (radiant) derived from the TIR images.

Table 3 – Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures for streams surveyed in the Rogue River Basin, OR.

| Image | Time | RM | Kinetic $^o$C | Radiant $^o$C | Difference $^o$C |
|---|---|---|---|---|---|
| **Rogue River 7/30/03 (avg. diff. = 0.4$^o$C)** | | | | | |
| rogueA0215 | 14:37 | 11.1 | 25.6 | 25.3 | 0.3 |
| rogueA0304 | 14:40 | 15.6 | 25.4 | 25.2 | 0.2 |
| rogueA0375 | 14:43 | 17.1 | 25.6 | 25.4 | 0.2 |
| rogueA0653 | 14:52 | 27.2 | 25.6 | 25.8 | -0.2 |
| rogueA0670 | 14:53 | 27.9 | 25.2 | 25.4 | -0.2 |
| rogueA0691 | 14:53 | 28.8 | 24.9 | 25.3 | -0.4 |
| rogueA0829 | 14:58 | 33.6 | 21.8 | 22.4 | -0.6 |
| rogueA0920 | 15:01 | 37.4 | 25.1 | 24.5 | 0.6 |
| rogueA1074 | 15:06 | 41.8 | 24.7 | 24.8 | -0.1 |
| rogueA1478 | 15:20 | 56.3 | 23.8 | 24.7 | -0.9 |
| rogueA1771 | 15:31 | 65.0 | 24.2 | 24.3 | -0.1 |
| rogueA1860 | 15:34 | 67.9 | 25.0 | 24.5 | 0.5 |
| rogueA2382 | 15:51 | 86.3 | 24.5 | 23.9 | 0.6 |
| **Rogue River 7/31/03 (avg. diff. = 0.2$^o$C)** | | | | | |
| rogueB0018 | 14:21 | 86.4 | 23.3 | 23.2 | 0.1 |
| rogueB0499 | 14:37 | 104.3 | 19.3 | 19.3 | 0.0 |
| rogueB0670 | 14:42 | 110.9 | 21.1 | 20.8 | 0.3 |
| rogueB0943 | 14:52 | 119.9 | 18.4 | 19.0 | -0.6 |
| rogueB1430 | 15:08 | 138.2 | 16.7 | 16.7 | 0.0 |
| rogueB1860 | 15:24 | 151.5 | 14.0 | 13.8 | 0.2 |
| **Evans Creeks (avg. diff. = 0.3$^o$C)** | | | | | |
| evans0009 | 13:50 | 0.0 | 20.5 | 20.7 | 0.2 |
| evans0645 | 14:12 | 12.1 | 24.8 | 24.3 | -0.5 |
| **East Fork Evans Cr. (avg. diff. = 0.5$^o$C)** | | | | | |
| efevans0232 | 14:31 | 2.9 | 23.1 | 22.6 | -0.5 |
| efevans0910 | 14:54 | 14.3 | 16.0 | 16.6 | 0.6 |
| **West Fork Evans Creek (avg. diff. = 0.4$^o$C)** | | | | | |
| wfevans0072 | 15:12 | 1.0 | 21.1 | 21.2 | 0.1 |
| wfevans0383 | 15:23 | 7.0 | 20.0 | 20.6 | 0.6 |
| wfevans0799 | 15:37 | 13.8 | 19.1 | 18.6 | -0.5 |

### *Temporal Differences*

Figure 3 shows how in-stream temperatures varied temporally at two locations in the Rogue River on the afternoons of the flights. The figure is intended to provide a sense of how stream temperatures changed during the time frame of the flight. On the Rogue River at river mile 15.6, the flight was conducted just prior to the daily maximum stream temperature, which occurred between 16:05 and 16:35 on the afternoon of July 30, 2003. During the flight at this location, the stream temperature only increased by 0.2°C. At river mile 151.5 on July 31, the temperature similarly only increased by 0.3°C during the flight, which ended only 20 minutes prior to the daily maximum stream temperature, occurring at 15:50. Appendix B of this report compares the recorded daily maximum temperatures recorded at each in-stream location to the spatial temperature patterns derived from the TIR images.

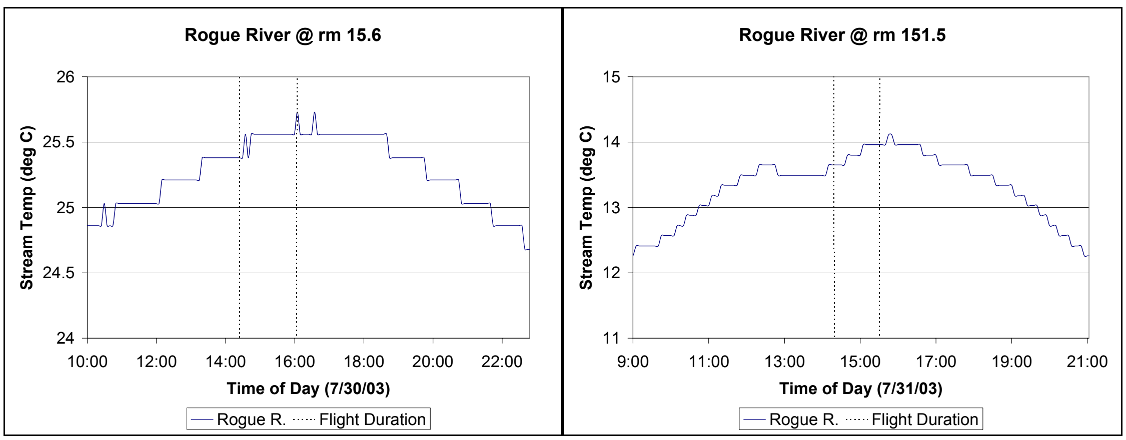


Figure 3 - Diurnal stream temperature variation during the afternoons of the TIR survey of the Rogue River. The plots show the variations in relation to the time of the flight at a sight during both surveys.

Figure 4 shows how in-stream temperatures varied at locations in Evans Creek and both Forks during the afternoon of August 1, 2001. At river mile 12.1 on Evans Creek, the survey was conducted prior to the daily maximum stream temperature at this location, with a water temperature increase of 0.5°C. Similarly with East Fork Evans Creek, at river mile 2.9, the survey was conducted before the local daily maximum stream temperature, with an increase of 0.5°C. On the West Fork Evans Creek, the survey was conducted just 20 minutes prior to the local maximum stream temperature at river mile 7.0, with a temperature increase of only 0.1°C.

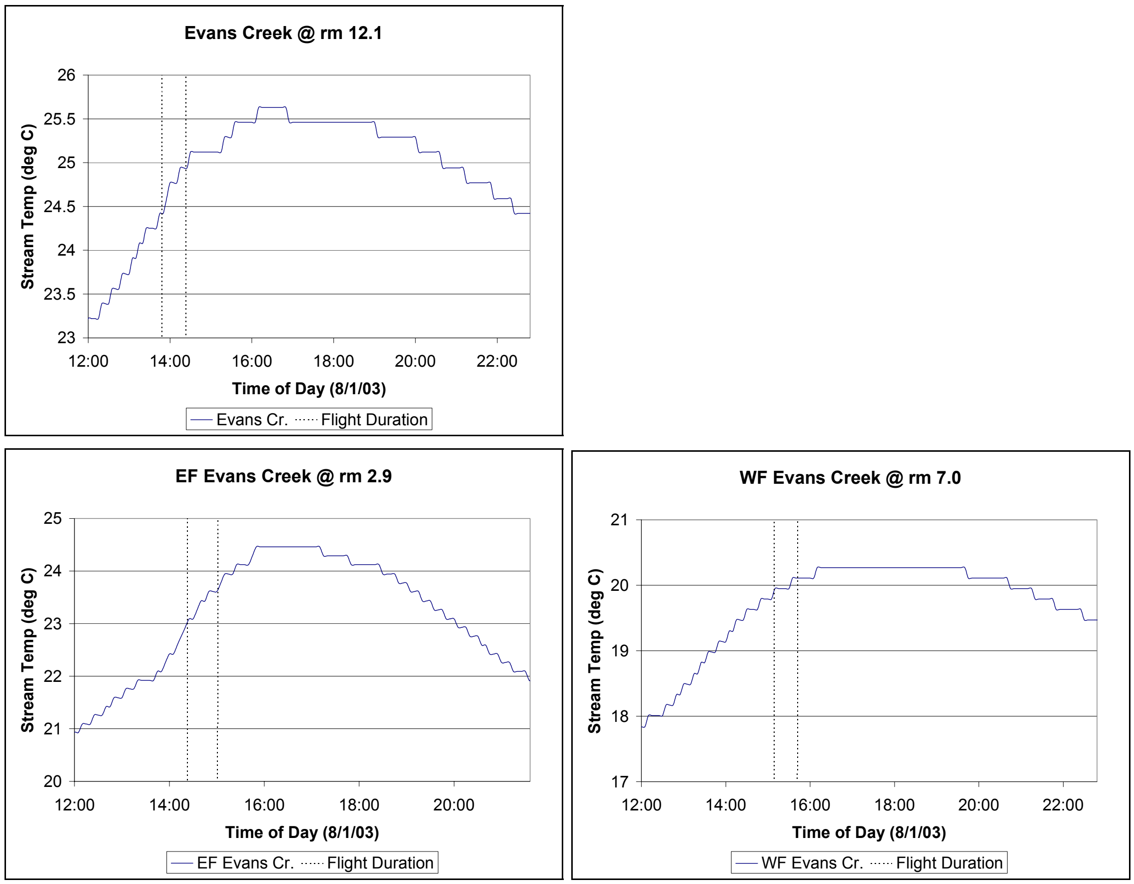



Figure 4 – Diurnal stream temperature variation during the afternoons of the TIR surveys measured at one monitoring site for each Evans Creek survey. The plots show the variations in relation to the time of the flight.

## *Longitudinal Temperature Profiles*

### Rogue River

Median radiant stream temperatures of the Rogue River were plotted versus river mile for the full extent of the TIR survey (Figure 5). The profile illustrates how bulk water temperatures vary spatially from the outlet of Lost Creek dam to the Rogue River tidewater near Gold Beach, OR (river mile 3.3). The location and temperature of surface inflows (tributaries and side channels) sampled during the analysis are labeled on the profile by river mile. As illustrated, the TIR surveys on July 30 and 31 overlapped by 8.2 river miles and the absolute temperatures were consistent between the two days.

Overall, water temperatures in the Rogue River showed a general pattern of downstream warming with cool water temperatures (≈12.4°C) below Lost Creek Dam gradually warming to ≈24.5°C near the Pacific Coast. Within the general pattern, distinct differences in the longitudinal heating rates were observed at the reach scale. In order to present a more detailed view of the reach scale patterns, the two different flight segments (July 30th and 31st) are presented separately.

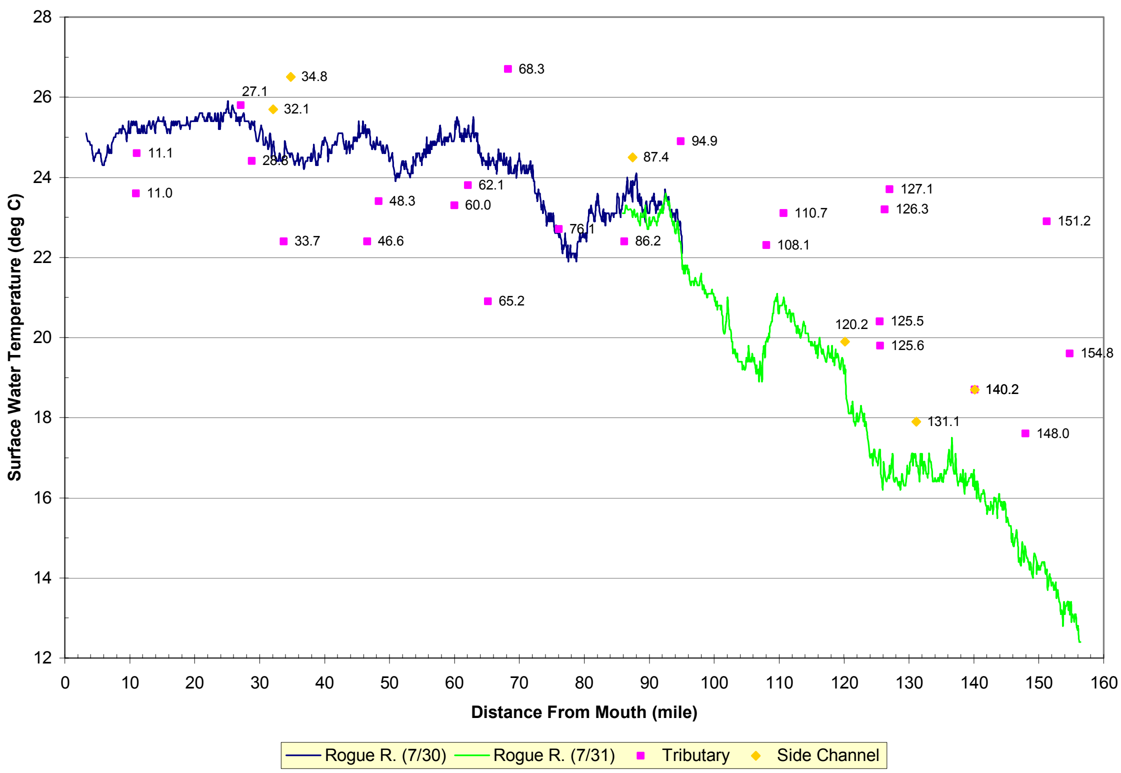



Figure 5 – Median channel temperatures versus river mile for the Rogue River, OR on July 30 and 31, along with the location of surface water inflows.

*Lost Creek Dam to Pickett Creek*

Figure 6 illustrates the longitudinal temperature profile for the Rogue River from Lost Creek Dam (river mile 156.4) downstream to the confluence of Pickett Creek (river mile 86.1). Surface inflows (tributaries, side channels, etc.) are labeled on the plot by river mile with their name and temperature listed in Table 4. In order to provide an additional context for discussing the profile, the plot also shows the location of dams/impoundments.

Below Lost Creek Dam, water temperatures in the Rogue River increased steadily and consistently in the downstream direction reaching 17.0°C at river mile 137.2. Over the next 12 miles to Gold Ray Dam, stream temperatures remained consistent with average radiant temperatures of 16.7°C (±0.5°C). The surface inflows sampled through this reach were all warmer than the Rogue River. However, visual inspection of the topographic base maps and imagery shows multiple side channels, sloughs, and off channel surface water within ≈8 miles upstream of Gold Ray Dam. These features suggest that the absence of longitudinal heating through this reach may be due sub-surface exchanges occurring through these pathways. However, these processes were not directly apparent from the imagery.

Stream temperatures increased again below Gold Ray Dam with water temperatures reaching ≈18.1°C at the diversion dam (river mile 122). Below a second diversion dam (river mile 120.7), water temperatures increased rapidly over the first 1.5 miles, but then exhibited a lower, more consistent heating rate before reaching a local maximum of 21.0°C at river mile 109.6. Stream temperatures then cooled by ≈2.0°C from river mile 109.6 to the Savage Rapids Dam (river mile 107.4). Possible factors contributing to this trend were not apparent from the TIR images or from inspection of the base maps.

Between Savage Rapids Dam and river mile 92.5, water temperatures in the Rogue River increased by ≈4.7°C. Visual inspection of the profile shows some local inflections in the overall warming trend. Near the town of Grants Pass (river mile 102.1), the longitudinal profile shows a quick increase in the heating rate followed by apparent cooling (≈0.9°C). Image analysis did not reveal any surface water or point source inflows that might explain the observed thermal response (warming or cooling). While "noise" characteristic of TIR remote sensing can cause apparent local variability (typically $<0.5$°C), the magnitude and spatial extent of this change suggests that it is not due to noise. Between river mile 95.3 and 92.5, the longitudinal heating rate appeared to increase with a 2.0°C gain over this 2.8 mile segment. The Applegate River is a major tributary that joins the Rogue River in this reach (river mile 94.9) and contributed warmer water to the main stem (Figure 7).

All inflows sampled between Pickett Creek and the Lost Creek Dam had surface temperatures warmer than the Rogue River. Of these, the Applegate River (river mile 94.9) was the only tributary with sufficient flow relative to the main stem to impact the basin scale temperature patterns in the Rogue.

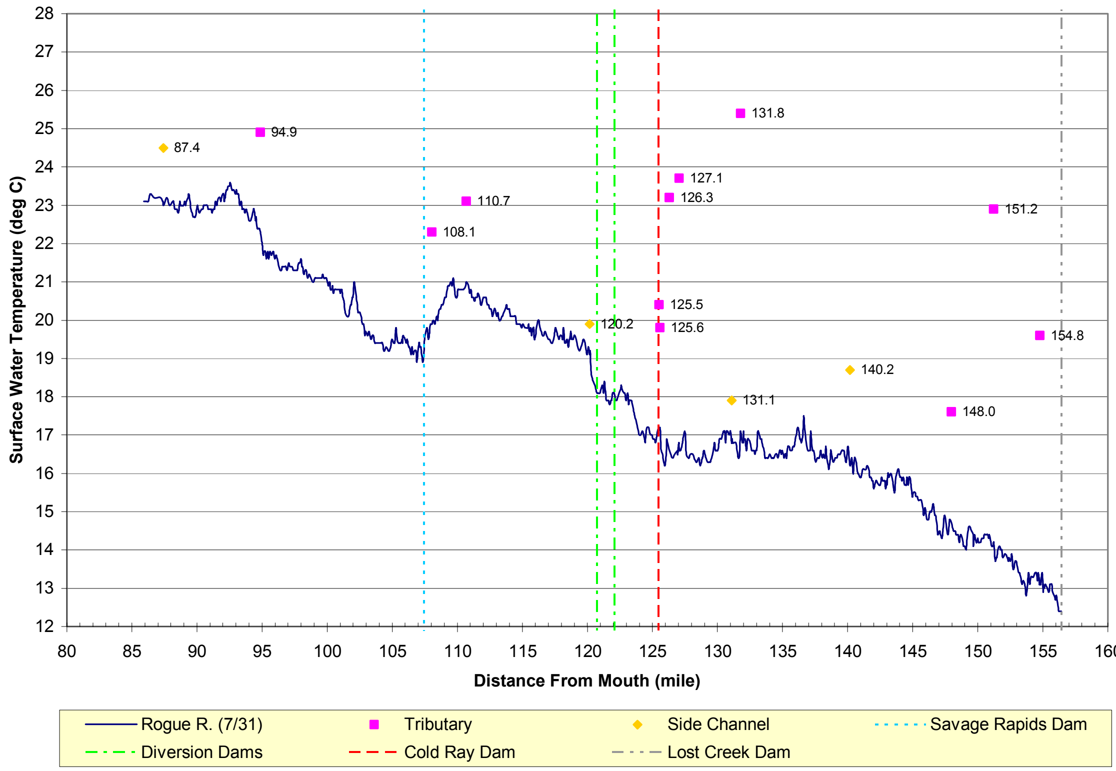



Figure 6 – Median radiant temperatures plotted versus river mile for the Rogue River from Pickett Creek to Lost Creek Dam for July 31, 2003. The plot also shows the location of surface water inflows sampled during the analysis.

Table 4 – Tributary temperatures for the Rogue River, OR (7/30/03).

| Tributary Name | Image | km | mile | Tributary °C | Rogue R. °C | Difference °C |
|---|---|---|---|---|---|---|
| **Tributary** | | | | | | |
| Applegate River (LB) | rogueB0225 | 152.7 | 94.9 | 24.9 | 22.3 | 2.6 |
| Savage Cr. (LB) | rogueB0590 | 173.9 | 108.1 | 22.3 | 19.9 | 2.4 |
| Evans Cr. (RB) | rogueB0665 | 178.2 | 110.7 | 23.1 | 21.0 | 2.1 |
| Middough Cr. (LB) | rogueB1092 | 202.0 | 125.5 | 20.4 | 17.2 | 3.2 |
| Kelly Slough (RB) | rogueB1093 | 202.1 | 125.6 | 19.8 | 17.2 | 2.6 |
| Bear Creek (LB) | rogueB1114 | 203.3 | 126.3 | 23.2 | 16.6 | 6.6 |
| Upton Slough (LB) | rogueB1126 | 204.5 | 127.1 | 23.7 | 16.6 | 7.1 |
| Little Butte Cr. (LB) | rogueB1253 | 212.1 | 131.8 | 25.4 | 17.1 | 8.3 |
| Trail Cr. (RB) | rogueB1769 | 238.1 | 148.0 | 17.6 | 14.7 | 2.9 |
| Elk Cr. (RB) | rogueB1856 | 243.4 | 151.2 | 22.9 | 14.2 | 8.7 |
| Big Butte Cr. (LB) | rogueB1942 | 249.1 | 154.8 | 19.6 | 13.2 | 6.4 |
| **Side Channel** | | | | | | |
| Side Channel (RB) | rogueB0034 | 140.7 | 87.4 | 24.5 | 23.0 | 1.5 |
| Side Channel (RB) | rogueB0948 | 193.4 | 120.2 | 19.9 | 19.1 | 0.8 |
| Side Channel (LB) | rogueB1231 | 211.0 | 131.1 | 17.9 | 16.8 | 1.1 |
| Side Channel (RB) | rogueB1481 | 225.6 | 140.2 | 18.7 | 16.2 | 2.5 |

*RB = right bank; LB = left bank looking downstream.*

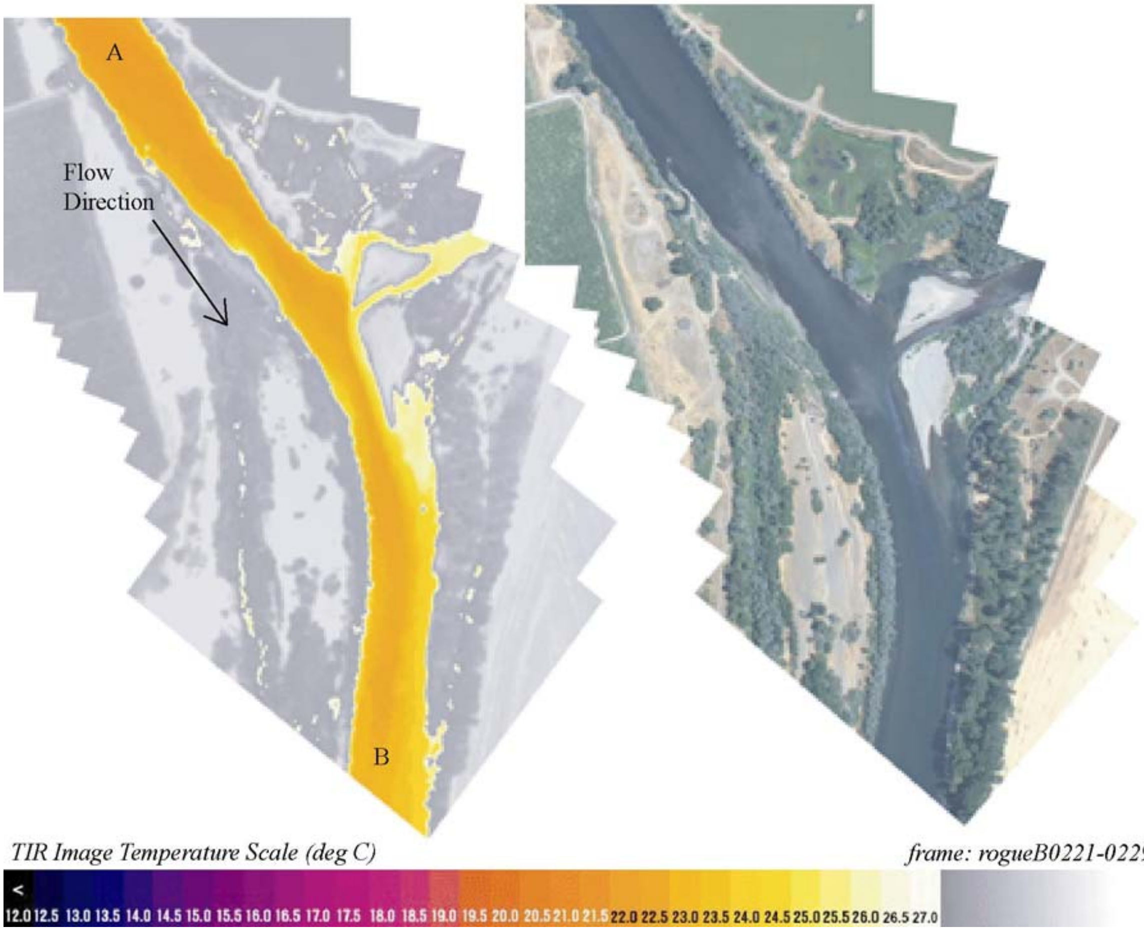


Figure 7 - TIR/color video image pair showing the confluence of the Applegate River (24.9°C) to the left bank of the Rogue River (22.3°C) at river mile 94.9. The Applegate River influence raises mainstream temperatures from 21.9°C (A) to 22.4°C (B).

*Applegate River to Tidewater*

Median radiant stream temperatures of the Rogue River on July 30 were plotted versus river mile (Figure 8). As with each profile, the location of sampled surface water inflows (i.e. tributaries, springs, and side channels) are illustrated on the plot by river mile and are listed in Table 5. Note that the overlapping section (river mile 95.0 to 86.1) surveyed on each day are illustrated on both plots (Figure 6 and Figure 8).

Overall, stream temperatures remained above ≈22.0°C on the day of the survey, but also exhibited distinct differences in longitudinal heating rates along the river gradient. The profile shows a general cooling trend with river temperatures decreasing from ≈ 24.1°C at river mile 88.0 to a local minimum of ≈22.0°C at river mile 78.8. This reach extends from the mapped location of Everton Riffle/Grade Creek downstream to the Taylor Creek Gorge and traverses from relatively open topography into Hellgate Canyon.

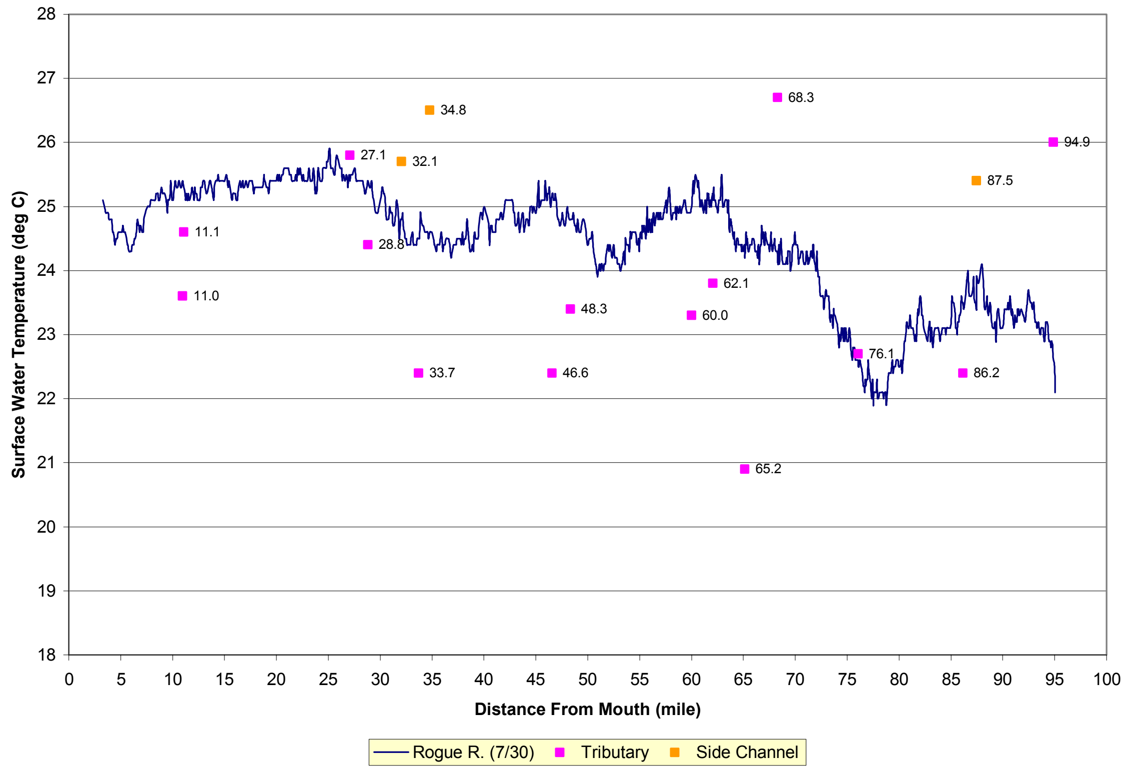



Figure 8 – Median channel temperatures versus river mile for the Rogue River, OR on July 30. The plot also shows with the location of surface water inflows sampled during the analysis

Table 5 – Tributary temperatures for the Rogue River, OR (7/30/03).

| Tributary Name | Image | km | mile | Tributary °C | Rogue R. °C | Difference °C |
|---|---|---|---|---|---|---|
| Lobster Cr. (RB) | rogueA0212 | 17.7 | 11.0 | 23.6 | 25.4 | -1.8 |
| Unnamed (LB) | rogueA0215 | 17.9 | 11.1 | 24.6 | 25.3 | -0.7 |
| Illinois R. (LB) | rogueA0652 | 43.6 | 27.1 | 25.8 | 25.4 | 0.4 |
| Shasta Costa Cr. (LB) | rogueA0692 | 46.4 | 28.8 | 24.4 | 25.4 | -1.0 |
| Foster Cr. (RB) | rogueA0829 | 54.3 | 33.7 | 22.4 | 24.5 | -2.1 |
| Stair Cr. (LB) | rogueA1207 | 75.0 | 46.6 | 22.4 | 25.2 | -2.8 |
| Mule Cr. (RB) | rogueA1258 | 77.8 | 48.3 | 23.4 | 24.8 | -1.4 |
| Big Windy Cr. (LB) | rogueA1588 | 96.6 | 60.0 | 23.3 | 25.0 | -1.7 |
| Howard Cr. (LB) | rogueA1649 | 99.9 | 62.1 | 23.8 | 25.1 | -1.3 |
| Rum Cr. (LB) | rogueA1775 | 104.9 | 65.2 | 20.9 | 24.2 | -3.3 |
| Grave Cr. (RB) | rogueA1867 | 109.9 | 68.3 | 26.7 | 24.2 | 2.5 |
| Galice Cr. (LB) | rogueA2084 | 122.4 | 76.1 | 22.7 | 22.5 | 0.2 |
| Pickett Cr. (LB) | rogueA2374 | 138.7 | 86.2 | 22.4 | 23.5 | -1.1 |
| Applegate R. (LB) | rogueA2606 | 152.7 | 94.9 | 26.0 | 22.6 | 3.4 |
| **Side Channel** | | | | | | |
| Side Channel (RB) | rogueA0781 | 51.6 | 32.1 | 25.7 | 24.8 | 0.9 |
| Side Channel (LB) | rogueA0855 | 56.0 | 34.8 | 26.5 | 24.6 | 1.9 |
| Side Channel (RB) | rogueA2410 | 140.8 | 87.5 | 25.4 | 23.9 | 1.5 |

Downstream of Taylor Creek Gorge, radiant water temperatures increased by 2.3°C over the first 6.7 miles before remaining ≈24.3°C to about river mile 64.7. Stream temperatures increased again between river mile 64.7 and 62.9 reaching a local maximum of 25.5°C near the location of Russian Creek. Visual inspection of the profile shows general downstream cooling trends between river miles 57.7 and 53.2 and again between 46.2 and 36.8. However, despite the spatial trends, medial water temperatures varied by less than ±1.0°C (24°C <-> 25.9°C) over the lower 63.0 river miles.

Of the 17 surface water inflows sampled from the July 30 survey (river mile 3.3 to river mile 95.0), ten contributed water cooler than the main stem. As might be expected, this is in contrast to the upper river (July 31 survey) where all sampled tributaries were warmer than the main stem. Image analysis of the July 30 survey revealed 42 additional tributary confluences that could not be sampled due to their small size (*relative to pixel size*) and/or masking of the tributary surface by riparian vegetation (Figure 9).

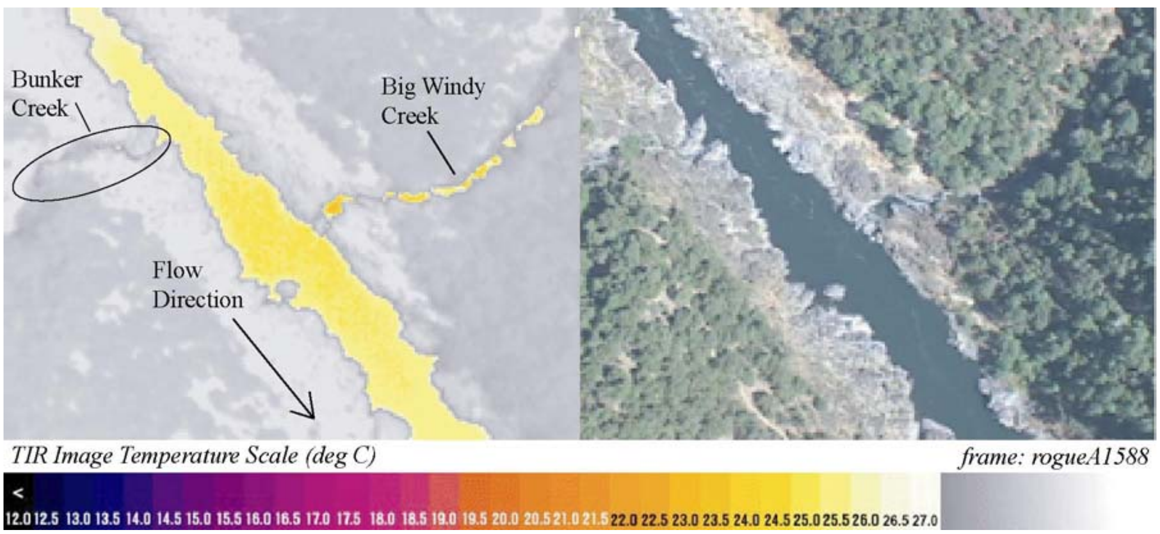



Figure 9 - TIR/color video image pair showing the confluence of Big Windy Creek (23.3°C) to the left bank of the Rogue River (25.0°C) at river mile 60.0. The Bunker Creek confluence is detected on the right bank (left side of the image), but was left unsampled due to its small size.

**West Fork Evans Creek and Evans Creek**

Median radiant stream temperatures of the West Fork Evans Creek and Evans Creek were plotted versus river mile from its confluence with the Rogue River (Figure 10). Surface inflows (i.e. tributaries, springs, and side channels) sampled during the analysis are labeled on the plot by river mile with their temperatures summarized in Table 6. The locations of dams and impoundments identified in the imagery are also shown on the plot. These locations provide additional spatial context for interpreting broad scale spatial temperature patterns. At the East and West Fork confluence (river mile 19.1), water temperatures in the West Fork dominated downstream temperatures in Evans Creek. Consequently, combining the longitudinal temperature profiles from both the West Fork and main stem on a single plot provides a more comprehensive picture of the spatial continuum of temperatures in the watershed (headwaters -> mouth).

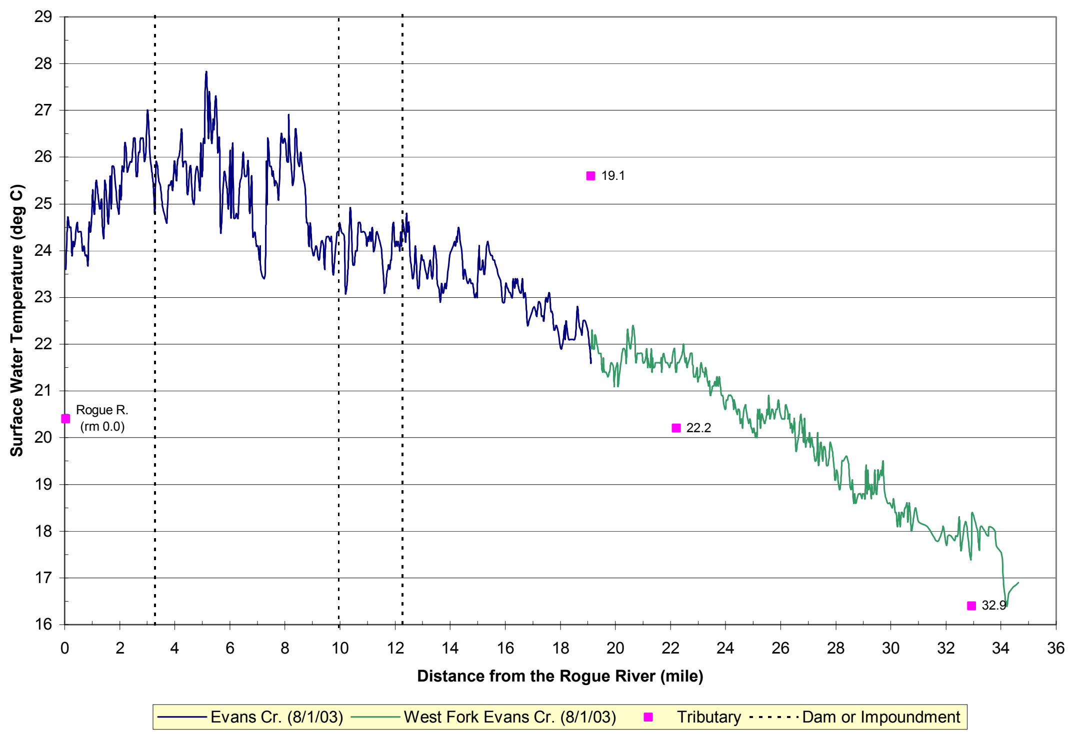



Figure 10 – Median channel temperatures versus river mile for Evans Creek and the West Fork Evans Creek, OR. The profile shows the location and temperature of surface water inflows sampled during the analysis.

Table 6 – Tributary temperature for Evans Creek and the West Fork Evans Creek.

| Tributary Name | Image | Km* | Mile* | Tributary °C | Mainstream °C | Difference °C |
|---|---|---|---|---|---|---|
| Rogue River | evans0101 | 0.1 | 0.0 | 20.4 | 23.6 | -3.2 |
| EF Evans Creek (LB) | evans0947 | 30.8 | 19.1 | 25.6 | 21.6 | 4.0 |
| Battle Creek (RB) | wfevans0182 | 35.8 | 22.2 | 20.2 | 21.4 | -1.2 |
| Cedar Creek (RB) | wfevans0799 | 53.0 | 32.9 | 16.4 | 18.9 | -2.5 |

**from Rogue River confluence*

In the West Fork, stream temperatures exhibited an overall pattern of downstream warming with radiant temperatures increasing from ≈16.5°C at river mile 34.2 to ≈21.6°C at the East Fork confluence (river mile 19.1). Although the survey extended to the headwaters (river mile 35.4), the combination of small stream size (*relative to pixel width*) and masking by riparian vegetation precluded sampling radiant temperatures above river mile 35.4. Two tributaries (Cedar Creek and Battle Creek) were sampled during the analysis and both contributed cooler water to the main stem. The confluences of Rock Creek, Sand Creek, and Split Rock Creek were also detected during the analysis, but were not visible enough to obtain a radiant temperature sample.

In general, the fine scale spatial variability observed in the temperature profile of the West Fork is within the noise levels[3] traditionally associated with TIR remote sensing. However, the profile showed localized cooling - or a notable lack of heating - through several segments. Although none were dramatic, the local variability represents a change in the overall temperature trend and may signify a potential cooling process. Between river mile 29.7 and 28.6 (*Ash Flats*), radiant temperatures decreased by ≈0.9°C. Between river miles 26.3 and 25.1 (*Willow Flat*), stream temperatures remained relatively constant (≈20.5°C) before decreasing by ≈0.5°C downstream of the Rock Creek confluence. Finally, radiant temperatures exhibited a decrease of ≈1.1°C just upstream of the East Fork confluence between river miles 20.6 and 20.2. The source of cooling was not directly apparent from the TIR images.

Stream temperatures continued a general warming trend on Evans Creek reaching ≈24.0°C at river mile 15.4. From river mile 15.4 to 10.1, stream surface temperatures ranged from 23.0°C to 24.9°C with an average temperature of 23.8°C. Analysis of this reach showed segments with the potential for thermal stratification. However, the TIR images revealed no evidence of thermal stratification associated with the temperature decreases recorded at river mile 15.0 (≈0.8°C) and between river miles 14.3 and 13.9 (≈ 1.3°C). Upstream of the impoundment at river mile 12.3, the water surface had indications of differential heating and, consequently, potentially cooler temperatures lower in the water column. Radiant water temperatures immediately downstream of the impoundment were ≈0.8 cooler than those upstream, which confirms a level of stratification, but also suggests that it was relatively weak and that thermal differences in the vertical water column were <1.0°C (Figure 11).

[3] Typically ±0.5°C, but possibly higher on very small streams due to a greater occurrence of hybrid pixels.

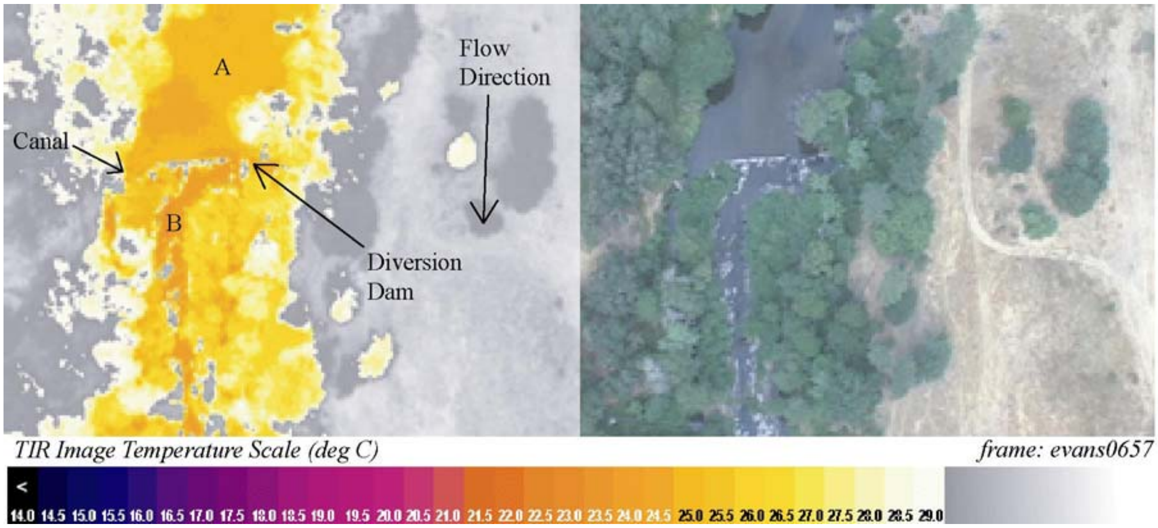


Figure 11 - TIR/color video image showing a diversion in Evans Creek at river mile 12.3. Surface temperatures upstream are 24.7°C (A) while those downstream are 23.9°C (B). The start of the *Williams and Whalen Ditch* is visible on the right side of the diversion.

Between the two dams (miles 12.3 and 10.1), stream temperatures continued to exhibit a similar degree of local spatial variability. The in-stream sensor at river mile 12.1 recorded water temperatures in excess of 24.3°C at the time of the TIR survey. Downstream of the monitoring site at river mile 11.6, stream temperatures decreased sharply to ≈23.1°C near the confluence of Homestead Gulch. No surface water was detected in Homestead Gulch and the source of cooling was not directly apparent from the imagery. Moving downstream, image analysis showed surface variability immediately upstream of the dam at river mile 10.1 that is indicative of some level of thermal stratification. However, as with the dam at river mile 12.3, the spatial temperature patterns suggest that any thermal stratification is unstable and relatively low in magnitude (i.e. due to lower mixing rates and instantaneous heating at the very surface, but does not represent a truly stratified layer).

Between river mile 9.0 and the dam at river mile 3.3, Evans Creek was generally warm with surface temperatures greater than 23.4°C. However, water temperatures exhibited a higher degree of local variability compared to upstream reaches. Surface temperatures in this reach ranged from a local minimum of 23.4°C (mile 7.3) to a survey maximum of 27.8°C (mile 5.2). The local temperature decrease of ≈3.0°C (26.4°C -> 23.4°C) near river mile 7.3 occurred at the downstream end of a gravel bar and the localized cooing suggests hyporheic flow through the substrate as a likely source of cooling (Figure 12). Similarly, the cooling (≈1.3°C) observed at river mile 5.7 also occurred at the downstream end of a gravel bar further suggesting the discharge of shallow sub-subsurface flow (Figure 13). Another sharp decrease in radiant temperatures of ≈2.5°C is observed in the profile at river mile 5.0. At this location, Evans Creek leaves the Evans Valley at river mile 5.0 and enters a more confined, higher gradient reach.

Due to the overall warm temperatures and to the relatively high degree of spatial thermal variability observed between the river mile 9.0 and the dam at river mile 3.3, the imagery was carefully reviewed for evidence of thermal stratification. This review did not reveal any classic indicators of significant thermal stratification within this reach. In the warmest segments, consistent[4] surface temperatures were recorded in pools and glides with not obvious mixing and succeeding mixed areas such as riffles.

Between the dam at river mile 3.3 and the confluence with the Rogue River, water temperatures in Evans Creek showed an overall cooling trend dropping from ≈27.0°C at river mile 3.0 to approximately 23.6°C at the confluence. A cool water seep was detected at river mile 2.0 which contributed to the cooling and also provides an indication of potential cooling processes in this reach. Areas of thermal stratification were detected near the mouth of Evans Creek. Radiant temperature samples were not acquired in areas that were stratified.

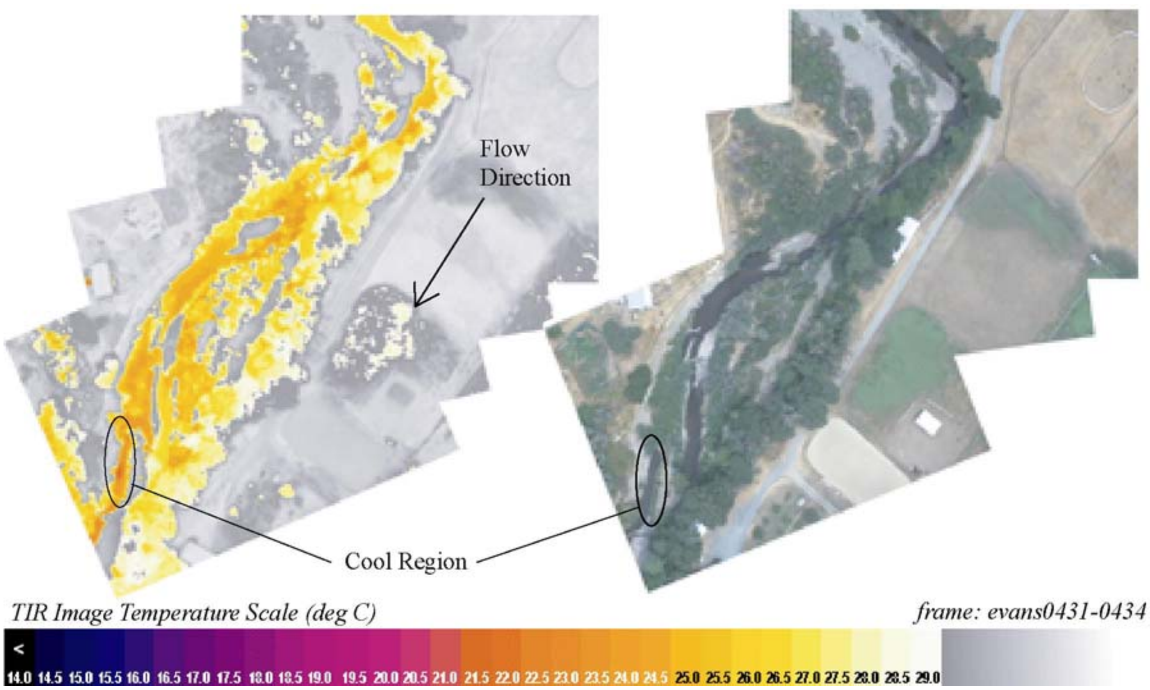


Figure 12 - TIR/color video image pair showing Evans Creek at river mile 7.3 where radiant temperatures cool locally downstream by ≈3.0°C. The cooling starts at the downstream end of the large gravel bar and an unidentified cool region along the left bank also appeared to contribute to the localized cooling.

[4] Within the ±0.5°C noise level typically associated with TIR remote sensing.

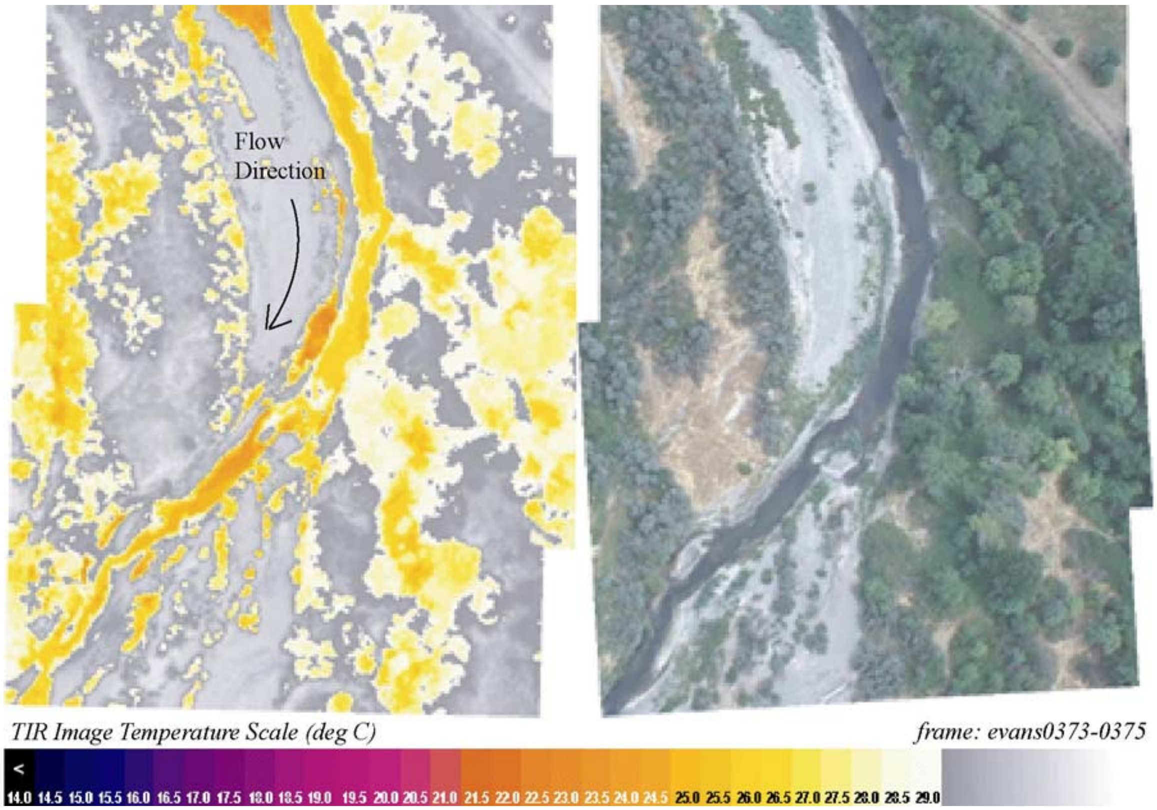


Figure 13 - TIR/color video image pair showing localized cooling downstream of the gravel bar of Evans Creek (24.4°C) at river mile 5.7.

### East Fork Evans Creek

Median radiant stream temperatures of the East Fork Evans Creek were plotted versus river mile (Figure 14). No tributary inflows were sampled along the East Fork due primarily to their small size and masking of the confluences by riparian vegetation. The East Fork was surveyed over its full length (≈17.8 miles). However, upstream of about river mile 12.7, the water surface was frequently masked by riparian vegetation and radiant temperature samples could only be acquired intermittently. Figure 15 provides a ground level and a corresponding airborne image of the stream at river mile 14.3. Only two radiant temperature samples were acquired upstream of this point.

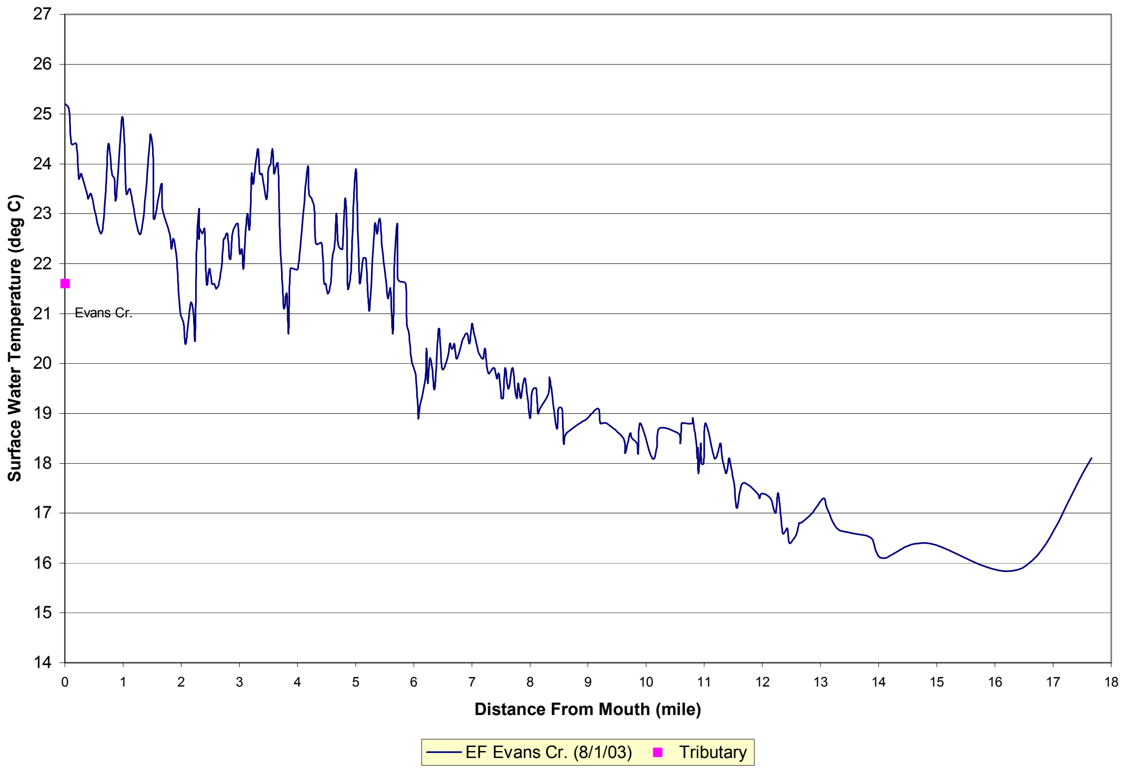



Figure 14 – Median channel temperatures versus river mile for EF Evans Creek, OR.

In the East Fork, stream temperatures at river mile 12.5 were relatively cool (≈ 16.4°C) and warmed steadily downstream reaching ≈20.8°C at river mile 7.0. A slight cooling trend was noted between river mile 7.0 and 6.1 before water temperatures increased rapidly to ≈21.6°C at river mile 5.9. Visual inspection of the USGS 7.5' topographic map shows that this cooling occurs where local topography constricts the stream valley. Conversely, the rapid longitudinal heating between river miles 6.1 and 5.9 occurs as the stream leaves the constricted segment and enters a broader, lower gradient valley (*labeled as the Meadows on the USGS topographic maps*). In general, the constricted area marked an abrupt transition in the thermal structure of East Fork Evans Creek.

Figure 15 - Ground level image (*left*) and corresponding airborne image (*right*) of the East Fork Evans Creek at river mile 14.3. Masking of the stream surface by riparian vegetation precluded sampling radiant temperatures in the upper reaches of the East Fork.

Between river mile 5.9 and the confluence of the West Fork, sampled water surface temperatures in the East Fork Evans Creek remained above 20.4$^{o}$C, but exhibited a higher degree of local spatial variability than observed in the upstream reaches. The source of the local spatial variability was not directly apparent from the imagery.

## Discussion

TIR surveys were successfully conducted on a 163.3 mile-segment of the Rogue River and over the full extent of Evans Creek including the East and West Forks. In-stream sensors were distributed prior to the surveys in order to quantify the accuracy of the radiant temperatures. A comparison of the kinetic and radiant temperatures showed that the radiant temperatures were within the desired accuracy of ±0.5$^{o}$C. Longitudinal temperature profiles were derived for each surveyed stream which illustrates broad scale temperature patterns along the stream gradient.

From the Lost Creek Dam to the Pacific Coast, the Rogue River is a relatively big system with flow levels of 1520 cfs (*source: waterdata.usgs.gov*) measured in Grants Pass, OR on the survey dates. Consequently, only the Applegate River had sufficient flow and temperature difference to directly alter the basin scale temperature patterns. However, cooler tributary inflows can create areas of finer scale thermal refugia in the mixing zones. While water temperatures in the Rogue were considered relatively warm (>24.0$^{o}$C) in the lower 63.0 river miles, a number of cool water tributaries were detected during the analysis. Follow-on analysis may determine if these areas represent thermal refugia for cold-water fish species during the summer months. These areas may be identified through additional, fine scale interpretation of the thermal and corresponding color video images. The analysis should consider the characteristics and limitations of the TIR images. Additional indicators (such as physical location in the stream channel) as well as field verification can help confirm fine scale thermal features.

In Evans Creek, the broad scale patterns showed that, although water temperatures are relatively warm, there was a high degree of local thermal variability in the lower reaches. The imagery illustrated localized cooling that resulted from seeps that were frequently found at the downstream end of gravel bars. As previously mentioned, the localized cooling suggests that shallow sub-surface exchange through the channel substrate is a primary contributor in the spatial thermal variability observed in Evans Creek. Although it is not possible to directly detect the level of surface flow lost to infiltration in the TIR images, the rapid longitudinal heating observed at specific locations along the profile suggest potential losing reaches. Follow-on analysis may seek to verify the processes contributing to the observed temperature patterns and potentially incorporate these inputs into physically based stream temperature models.

As with Evans Creek, the East Fork of Evans Creek exhibited considerably more local spatial variability in the downstream reaches (i.e. river mile 5.9 to mouth). Due to the small size of the stream and partial masking by riparian vegetation, it was difficult to directly detect the source of the thermal variability. However, the temperature patterns observed in the East Fork do suggest that the variability is due to some cool water inflow. Although riparian vegetation masked all of the mapped tributary confluences, the areas of observed cooling are not necessarily consistent with mapped tributary locations.

The longitudinal temperature profiles provided in this report provide a spatially extensive, high-resolution reference for water temperature status in the basin. The patterns provide a spatial context for analysis of seasonal temperature data from in-stream data loggers and for future deployment and distribution of in-stream monitoring stations. How does the temperature profile relate to seasonal temperature extremes? Are local temperature minimums consistent both throughout the summer and among years? Furthermore, the patterns provide baseline data for the calibration and validation of basin scale stream temperature models. The patterns not only show the influence of surface water, but also how main stem heating rates respond in response to changes in vegetation, geomorphology, and land-use.

This report provides some hypotheses on the processes influencing spatial temperature patterns at the basin scale based on interpretation of the TIR imagery and topographic base maps. Theses hypotheses are considered a starting point for more rigorous spatial analysis and fieldwork. Individual TIR and color video image frames are organized in an ArcView database to allow the viewing of temperature patterns and channel characteristics at finer spatial scales.

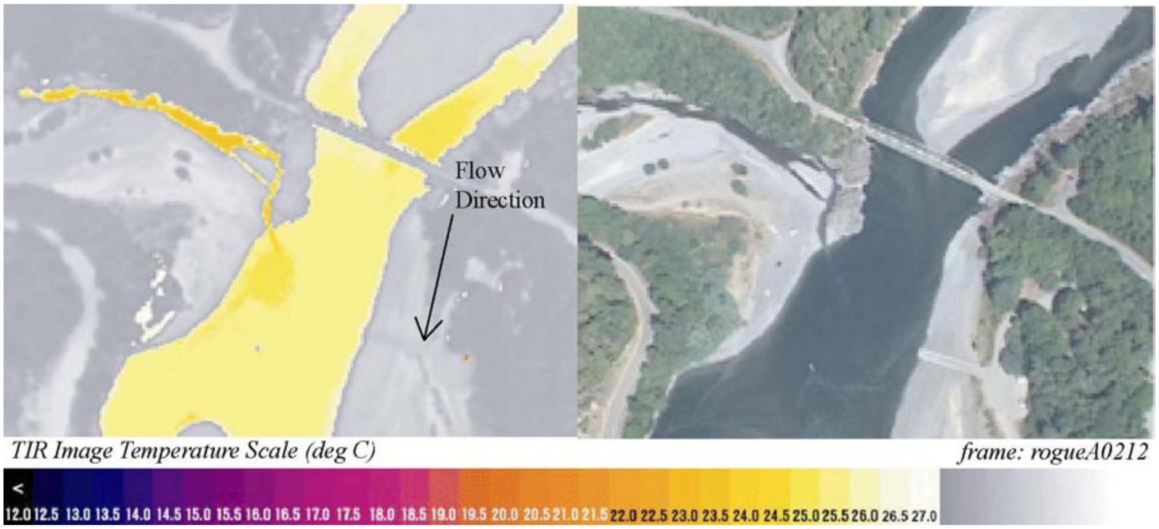
## Bibliography

Faux, R.N., H. Lachowsky, P. Maus, C.E. Torgersen, and M.S. Boyd. 2001. **New approaches for monitoring stream temperature: Airborne thermal infrared remote sensing**. Inventory and Monitoring Project Report -- Integration of Remote Sensing. Remote Sensing Applications Laboratory, USDA Forest Service, Salt Lake City, Utah.

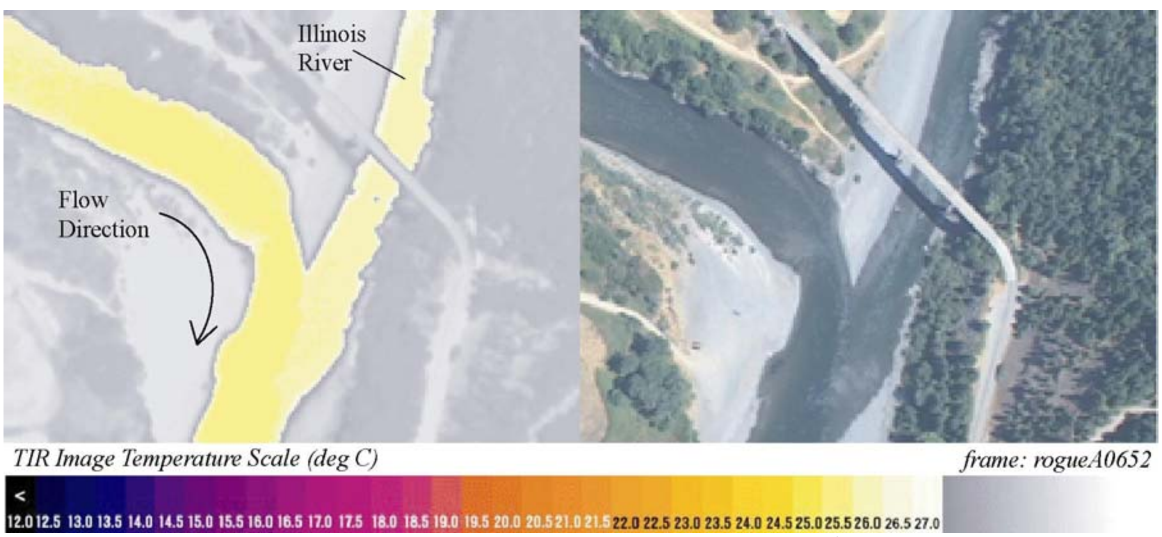
Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

## *Appendix A - Selected Images*

Rogue River (7/30/03)

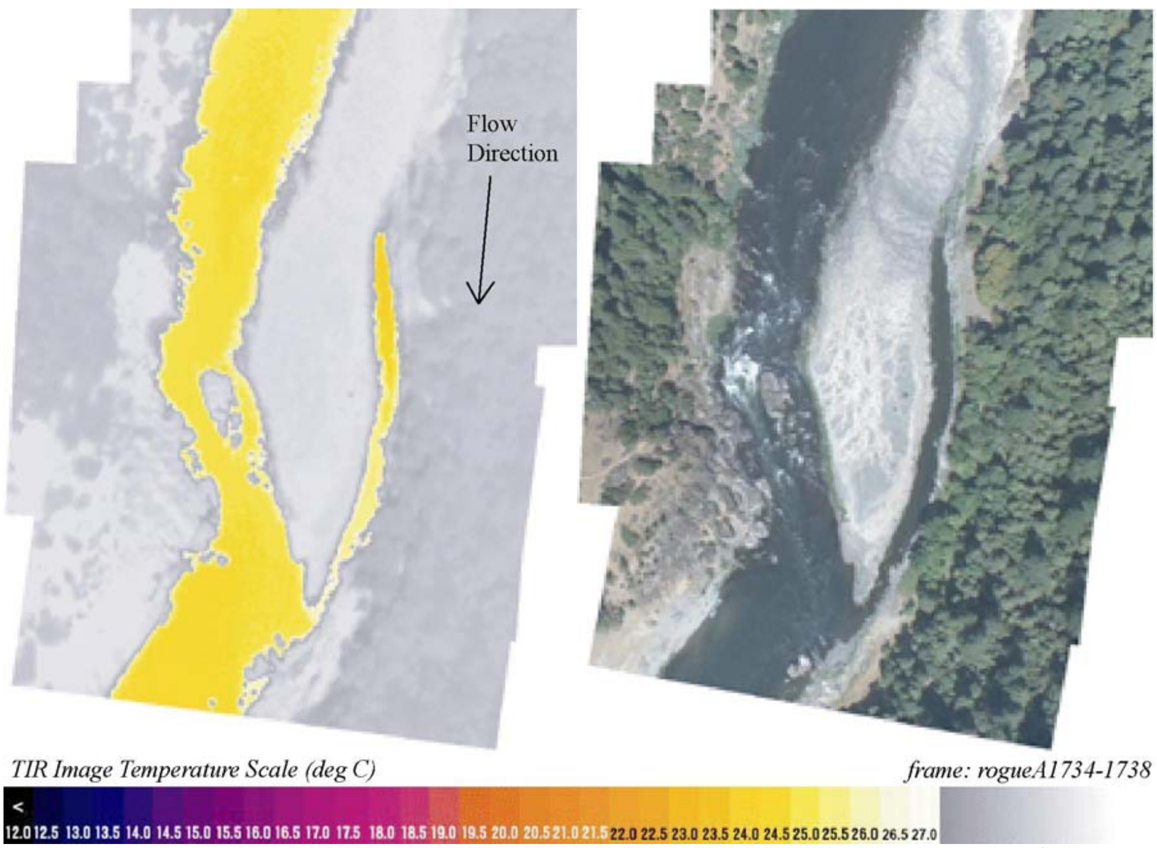



TIR/color video image pair showing the confluence of Lobster Creek (23.6$^{o}$C) to the right bank of the Rogue River (25.4$^{o}$C) at river mile 11.0.

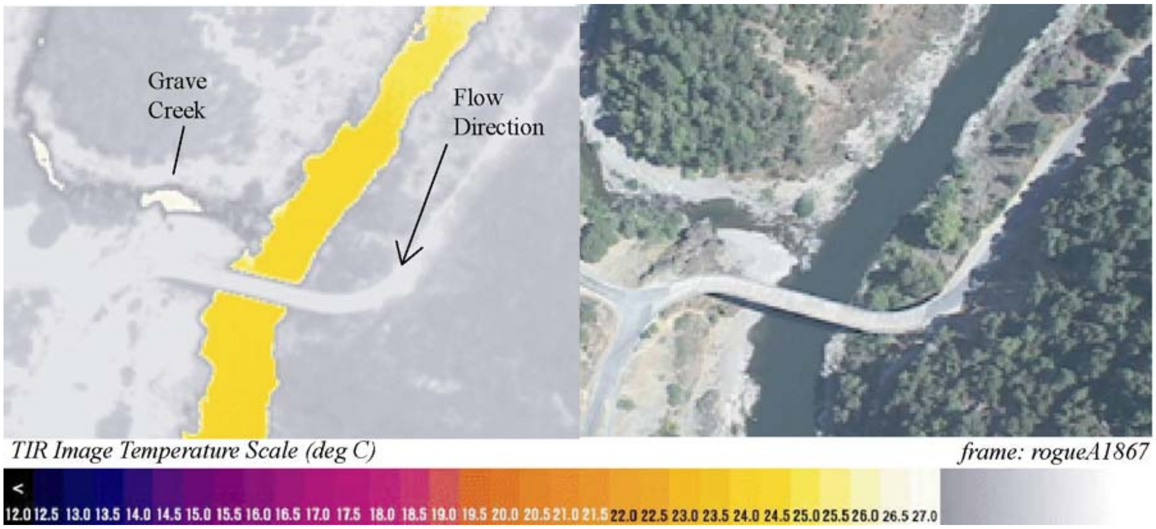



TIR/color video image pair showing the confluence of the Illinois River (25.8$^{o}$C) to the left bank of the Rogue River (25.4$^{o}$C) at river mile 27.1.


TIR/color video image pair showing the confluence of Shasta Costa Creek (24.4°C) to the left bank of the Rogue River (25.4°C) at river mile 28.8.

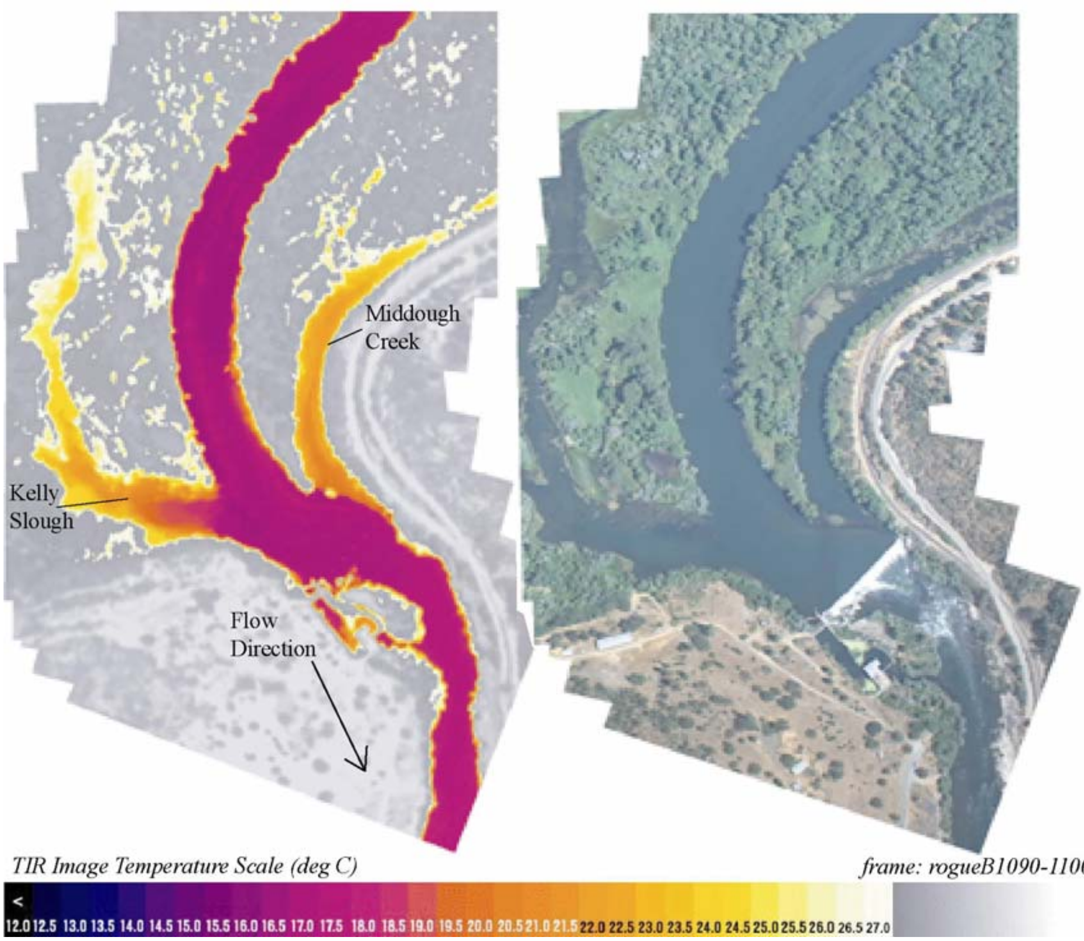



TIR/color video image pair showing a cool off-channel on the left bank of the Rogue River (24.7°C) at river mile 63.8.

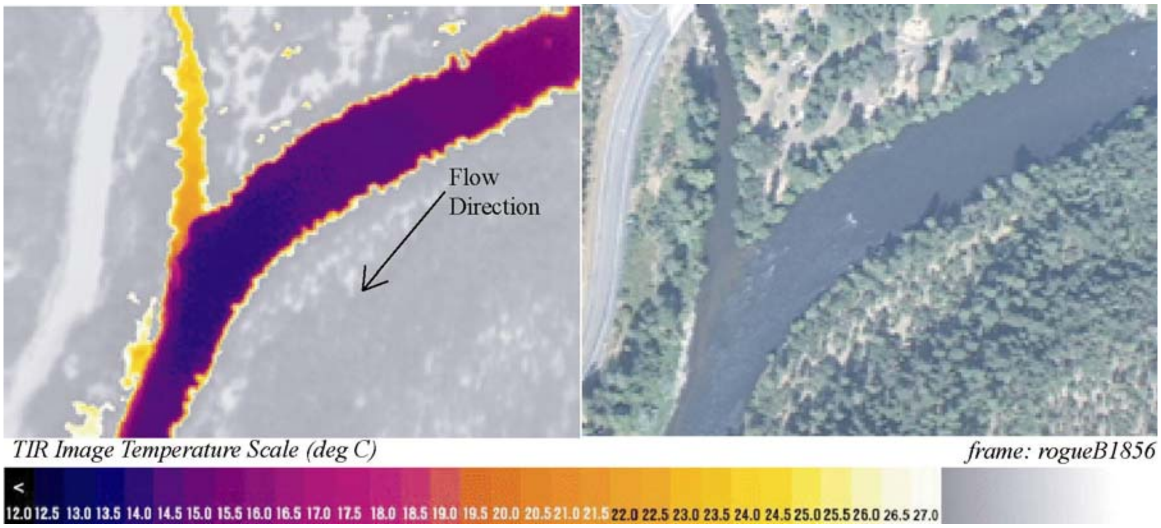



TIR/color video image pair showing the confluence of Grave Creek (26.7°C) to the right bank of the Rogue River (24.2°C) at river mile 68.3.

## Rogue River (7/31/03)

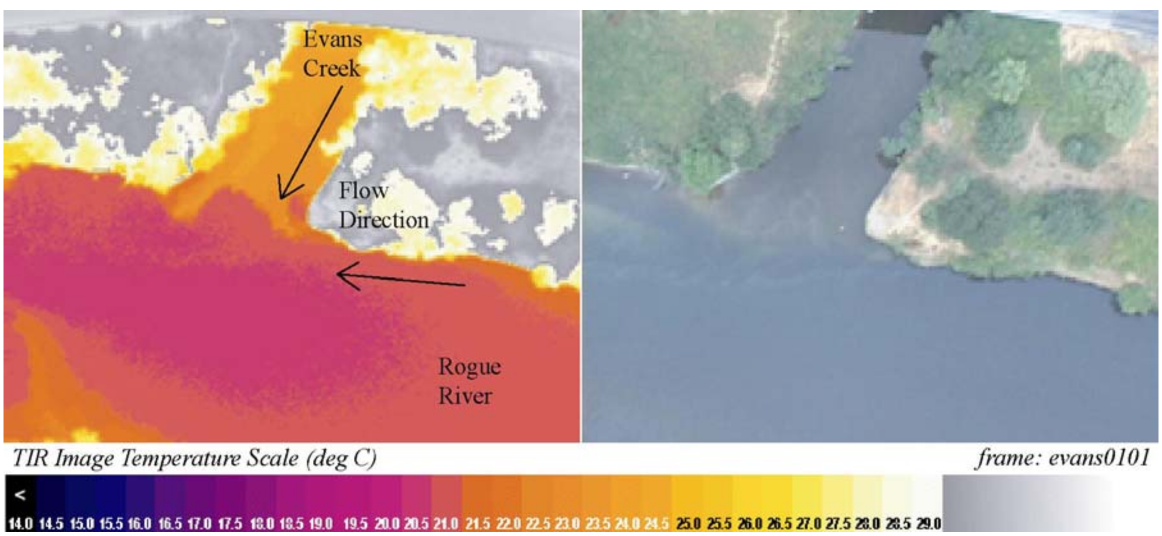



TIR/color video image pair showing the confluence of Middough Creek (20.4°C) to the left bank of the Rogue River just upstream of Gold Ray Dam at river mile 125.8. Also visible in the image is the confluence of Kelly Slough (19.8°C) to the right bank of the Rogue River (16.7°C).

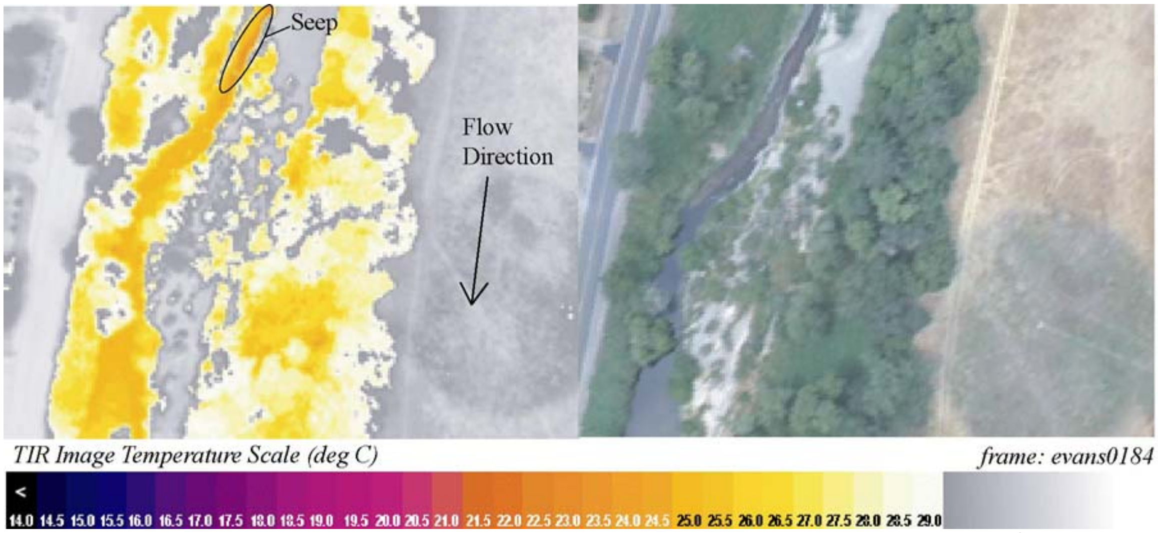


TIR/color video image pair showing Elk Creek (22.9°C) on the right bank of the Rogue River (14.2°C) at river mile 151.2.

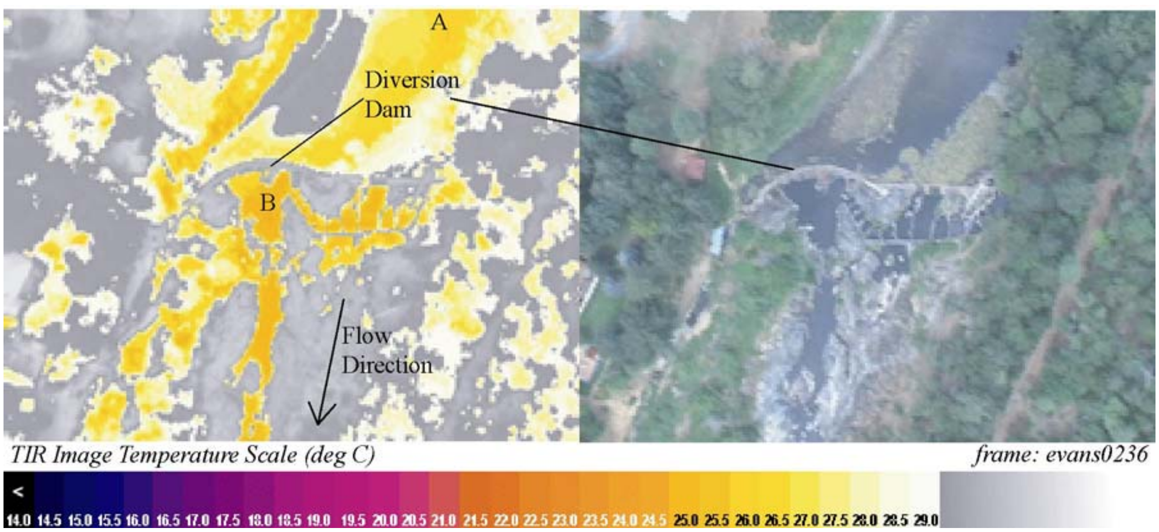
## Evans Creek



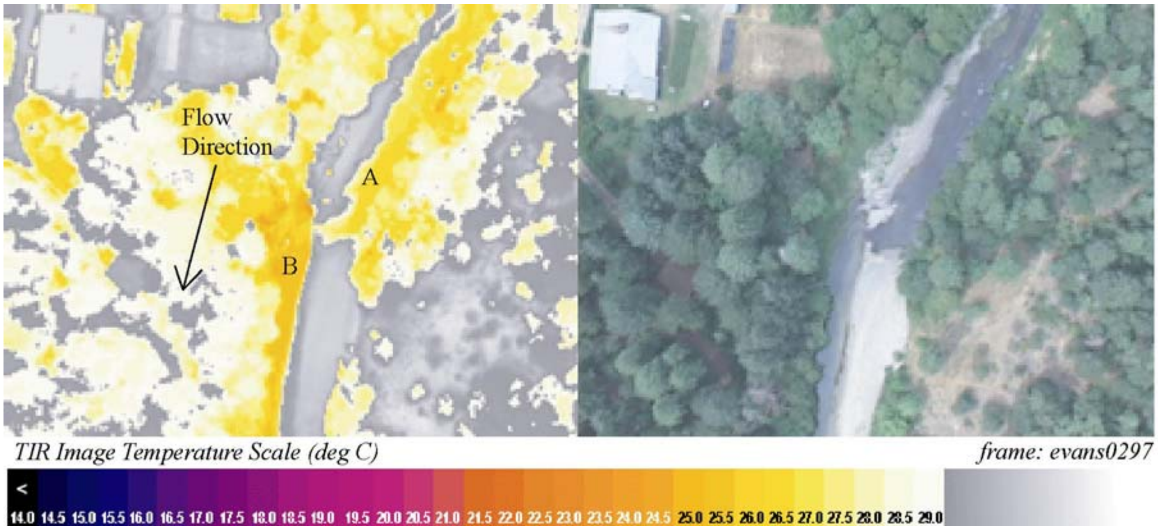
TIR/color video image pair showing the mouth of Evans Creek (23.6°C) on the right bank of the Rogue River (20.4°C).



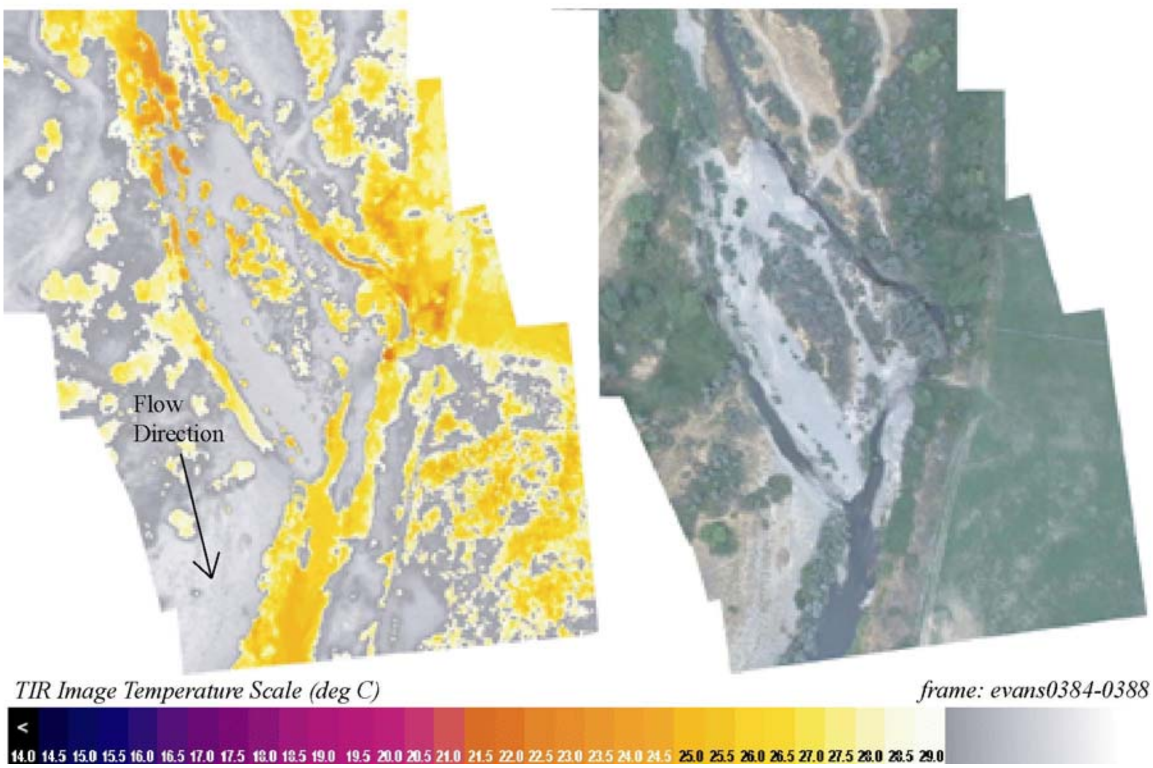
TIR/color video image pair showing an apparent seep along the left bank of Evans Creek (25.4$^{o}$C) at river mile 2.0.



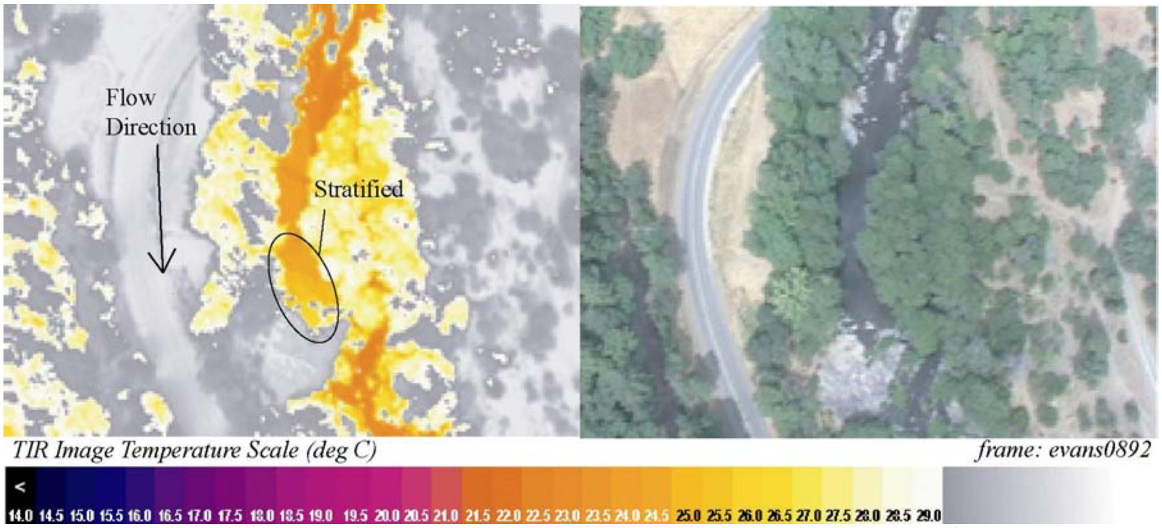
TIR/color video image pair showing a diversion dam at river mile 3.3 of Evans Creek. The mainstream temperature upstream of the dam (A) is 25.9$^{o}$C while the water downstream (B) is 24.8$^{o}$C.



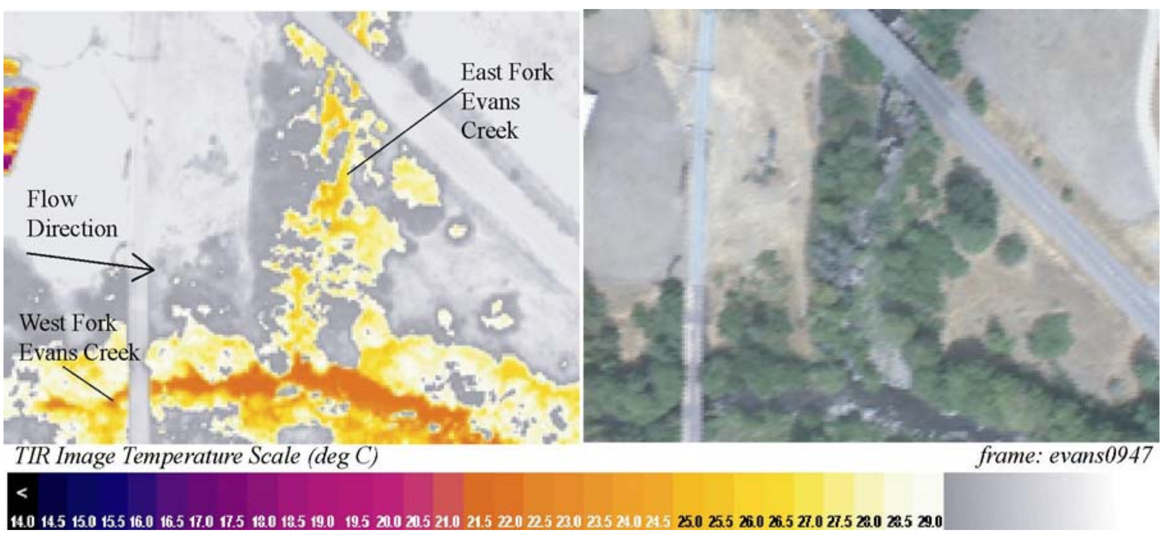

TIR/color video image pair showing a region of Evans Creek at river mile 5.0 with localized cooling, with the temperature changing in the downstream direction from 26.3°C (A) to 25.3°C (B).




TIR/color video image pair showing a segment of Evans Creek at river mile 6.0 with variable surface conditions due to the presence of multiple channels and discontinuity of the main stem.

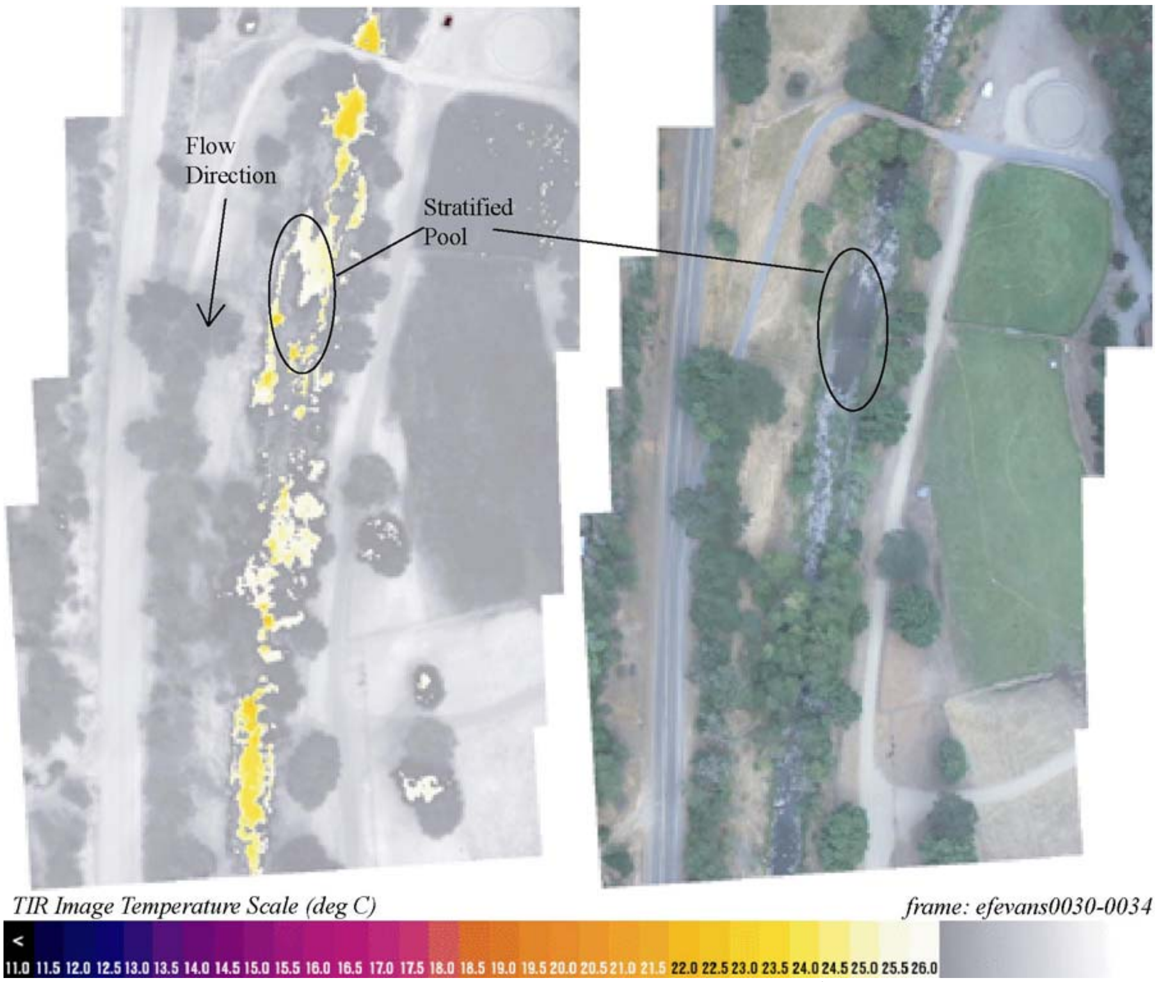



TIR/color video image pair showing apparent thermal stratification in Evans Creek (22.6°C) at river mile 17.7. The stratified area appears to be localized to the pool surface since water temperatures upstream and downstream of the pool were consistent. Thermal stratification detected in Evans Creek appeared to be of this nature and was not considered a problem in defining broad scale temperature patterns. None-the-less, this type of surface variability can confound interpretation of fine scale features.

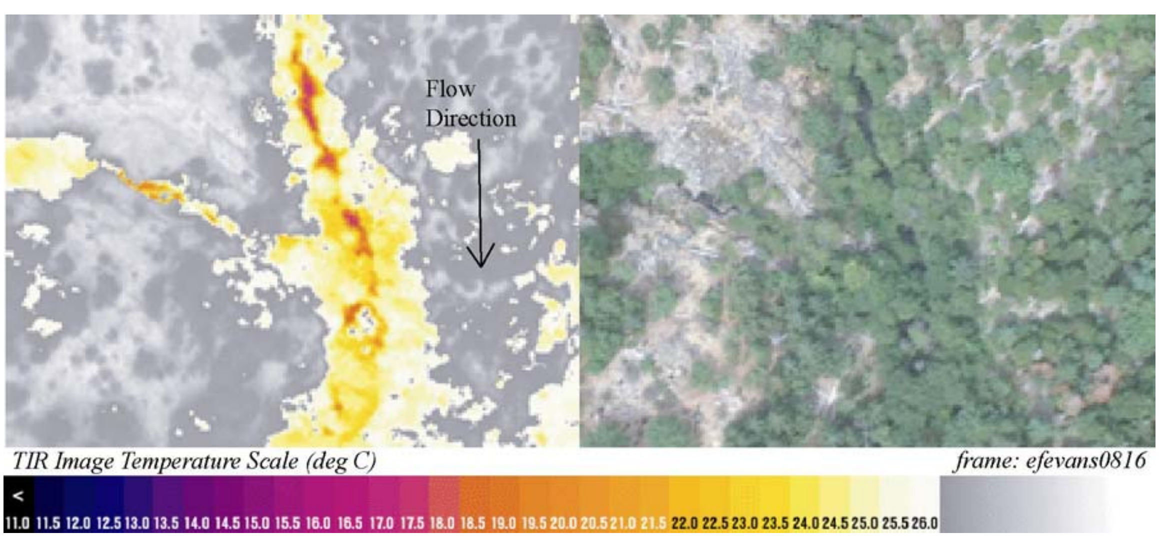



TIR/color video image pair showing the beginning of Evans Creek (rm 19.1) formed by the confluence of the West Fork Evans Creek (21.6°C) on the right bank and the East Fork Evans Creek (25.6°C) on the left bank.

East Fork Evans Creek

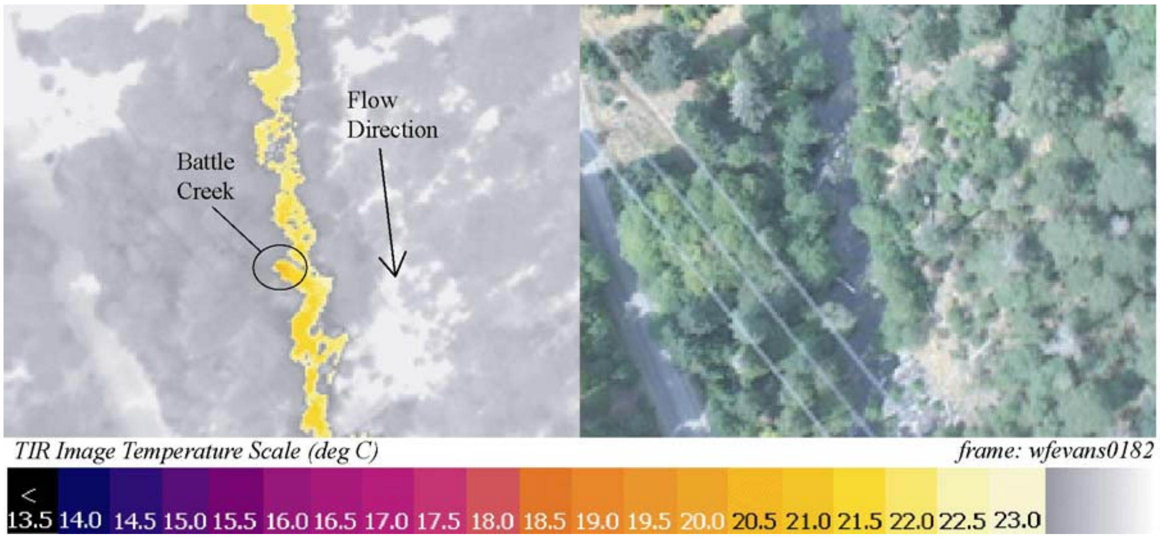



TIR/color video image pair showing shows the East Fork Evans Creek (23.8$^{o}$C) at river mile 0.3. The image illustrates the stream conditions and detection of a stratified pool in this segment.

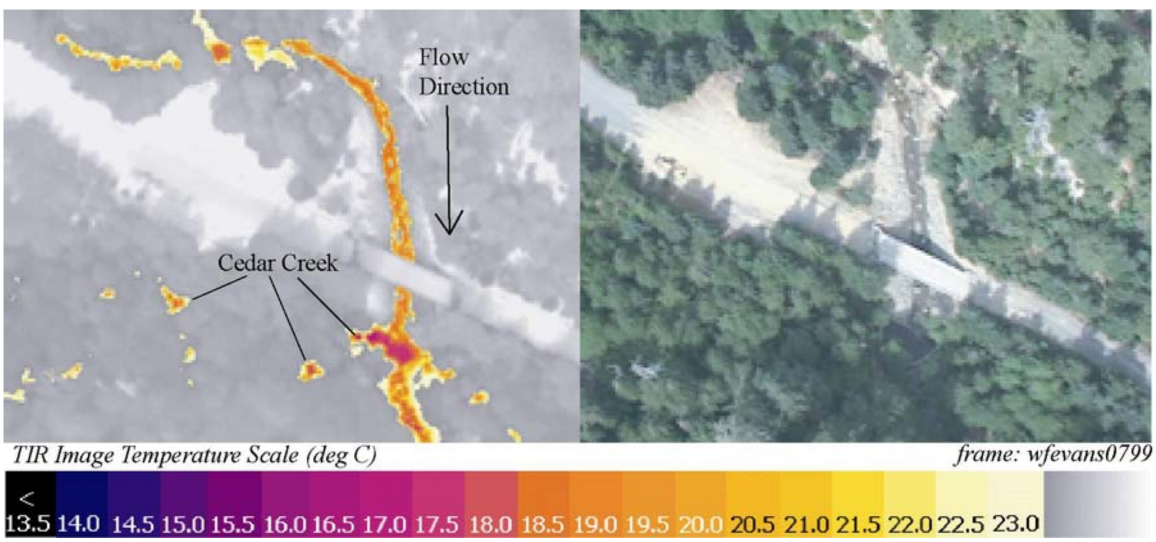



TIR/color video image pair showing the confluence of Coal Creek to the right bank of the East Fork Evans Creek (17.4$^{o}$C) at river mile 11.9. The temperature was not recorded for Coal Creek due to its small size.

West Fork Evans Creek



TIR/color video image pair showing the influence of Battle Creek (20.2$^o$C) on the right bank of the West Fork Evans Creek (21.4$^o$C) at river mile 3.1.



TIR/color video image pair showing the confluence of Cedar Creek (16.4$^o$C) to the right bank of the West Fork Evans Creek (18.9$^o$C) at river mile 13.8.

## *Appendix B –Kinetic Temperatures*

The longitudinal temperature profiles are also presented in Figures B-1 and B-2, which additionally shows the kinetic (in-stream) temperatures at each ground truth location both at the time of the Rogue River survey and when the data loggers were retrieved on the day of the survey.


Figure B-1 – Median channel temperatures versus river mile for the Rogue River, OR, on July 30, 2003.


Figure B-2 – Median channel temperatures versus river mile for the Rogue River, OR, on July 31, 2003.