Aerial Surveys in the Umpqua River Basin
Thermal Infrared and Color Videography

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Report to:

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Final Report

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Introduction

In 2002, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC (WS, LLC) to conduct airborne thermal infrared (TIR) remote sensing surveys in the Umpqua River Basin, OR. The objective of the project was to characterize the thermal regime of selected stream segments to support ongoing stream temperature assessments in the basin. The TIR surveys were conducted from July 23 to July 28, 2002.

Thermal infrared remote sensing surveys were conducted on stream segments in each of the three subbasins (4th field hydrologic units) that collectively form the Umpqua River Basin (3rd field hydrologic unit). The subbasins include the Umpqua River, North Umpqua River, and South Umpqua River (Figure 1). This report is divided into three chapters that present the results of the TIR surveys from each subbasin separately. The same basic data collection and processing methods were used for each of the TIR surveys with adjustments made for individual stream characteristics.

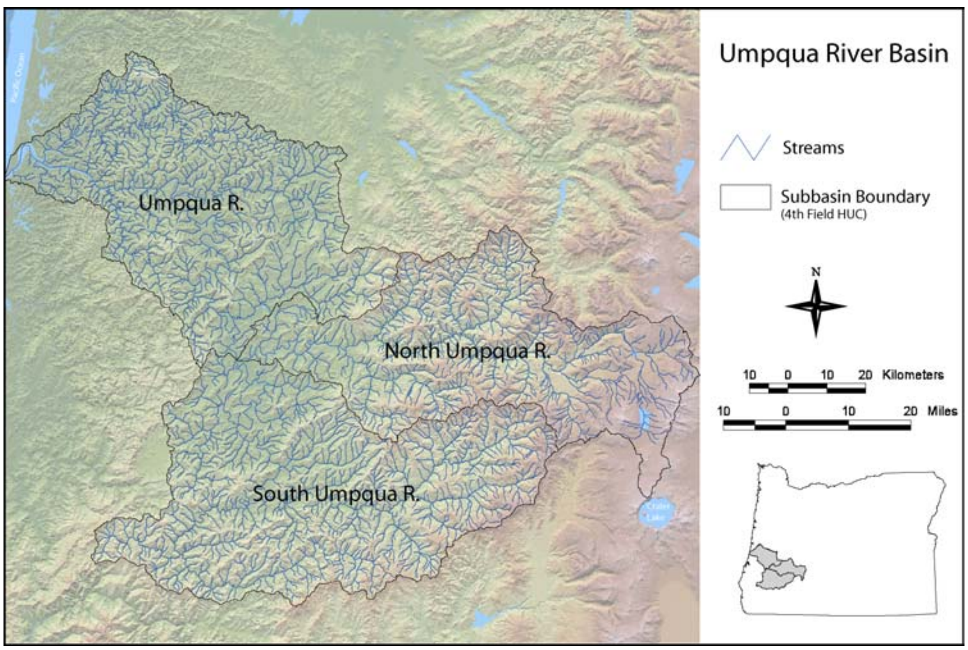

Figure 1 – Map showing the three subbasins (4th field hydrologic units) that collectively comprise the Umpqua River Basin.

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 within each basin. Thermal infrared 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.

[1] Geographic Information System

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. In flight, images were collected sequentially with approximately 40% vertical overlap. All flights were conducted in the mid-afternoon (13:30-17:00) in order to capture heat of the day conditions.

For each surveyed stream, Watershed Sciences, LLC deployed in-stream data loggers prior to the survey to ground truth (i.e. verify the accuracy) of the TIR data. The WS, LLC data loggers were supplemented with seasonal data loggers deployed by ODEQ. The in-stream data loggers were ideally located at intervals of 10 river miles or less over the survey route. Meteorological data including air temperature and relative humidity were recorded using portable weather stations (*Onset*) located at the confluence of the North and South Umpqua Rivers.

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. Atmospheric transmission calibrations 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 survey 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 were detected in the imagery, but were not sampled due to their small size (*relative to pixel size*) or due to the inability to see the stream through riparian vegetation are included on the profile to facilitate the interpretation of the spatial patterns.

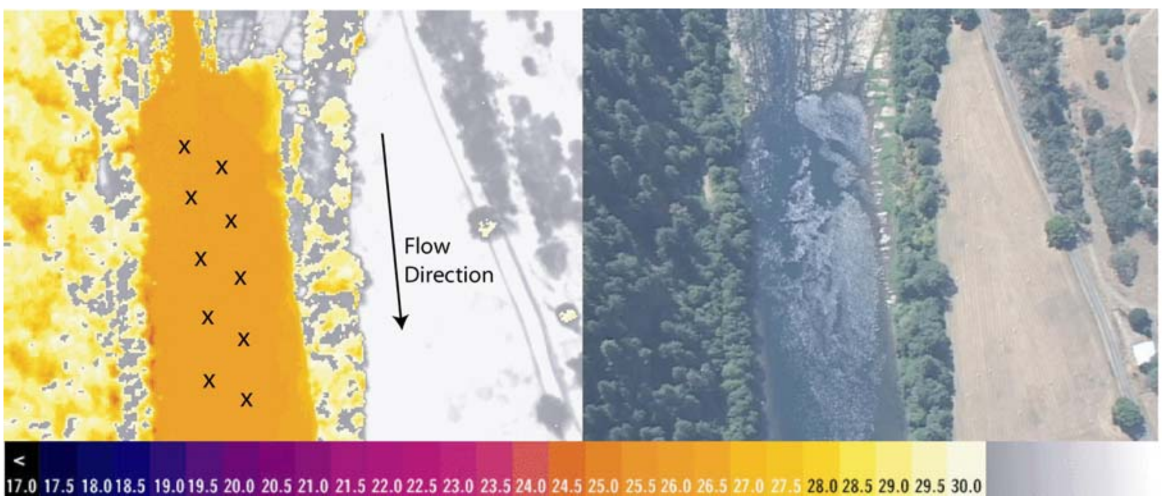

Figure 2 – TIR/color video image pair showing how temperatures are sampled from the TIR images. The black *X's* on the TIR image show typical sampling locations near the center of the stream channel. The recorded temperature for this image is the median of the sample points.

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 1) 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.

Umpqua River Basin

Overview

The TIR remote sensing surveys in the Umpqua River Basin were conducted on July 23-26, 2002 (Figure 3). The surveyed streams varied considerably in size, channel characteristics, and riparian vegetation and flight parameters were selected to best account for these factors. The Umpqua River was surveyed at a flight altitude that provided a wider image footprint (*lower spatial resolution*) to better capture the full width of the river and off-channel channel features. By contrast, smaller streams including Elk Creek and Calapooya Creek were flown at lower altitudes (*above ground level*) to provide higher spatial resolution and better visibility through the riparian vegetation. Hinkle Creek, a tributary to Calapooya Creek, was surveyed at two different altitudes. The lower altitude was intended to provide sufficient spatial resolution in the TIR images to allow for radiant temperature sampling. The higher altitude was intended to provide a wider image footprint to capture riparian vegetation and provide a spatial context for interpreting images from the lower altitude flight. Table 1 summarizes the survey times, extents, and image resolution for each surveyed stream in the Umpqua River Basin.

Table 1 – Summary of river segments surveyed with TIR and color video in the Umpqua River Basin from July 23-26, 2002.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent & Direction	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Umpqua R.	23 Jul	14:33-16:07	Hedden Co. Park to North Fork	81.5	376 (1234)	1.2 (3.9)
Elk Cr.	24 Jul	13:49-14:40	Mouth to Yoncalla Cr.	26.0	130 (423)	0.4 (1.3)
Calapooya Cr.	24 Jul	15:33-16:49	Mouth to forks	34.0	130 (423)	0.4 (1.3)
Hinkle Cr.	26 Jul	13:20-13:32	Mouth to headwaters of both North and South forks	6.5	110 (353)	0.3 (1.1)
Hinkle Cr.	26 Jul	13:40-13:59	Mouth to headwaters of both North and South forks	6.5	215 (776)	0.7 (2.2)

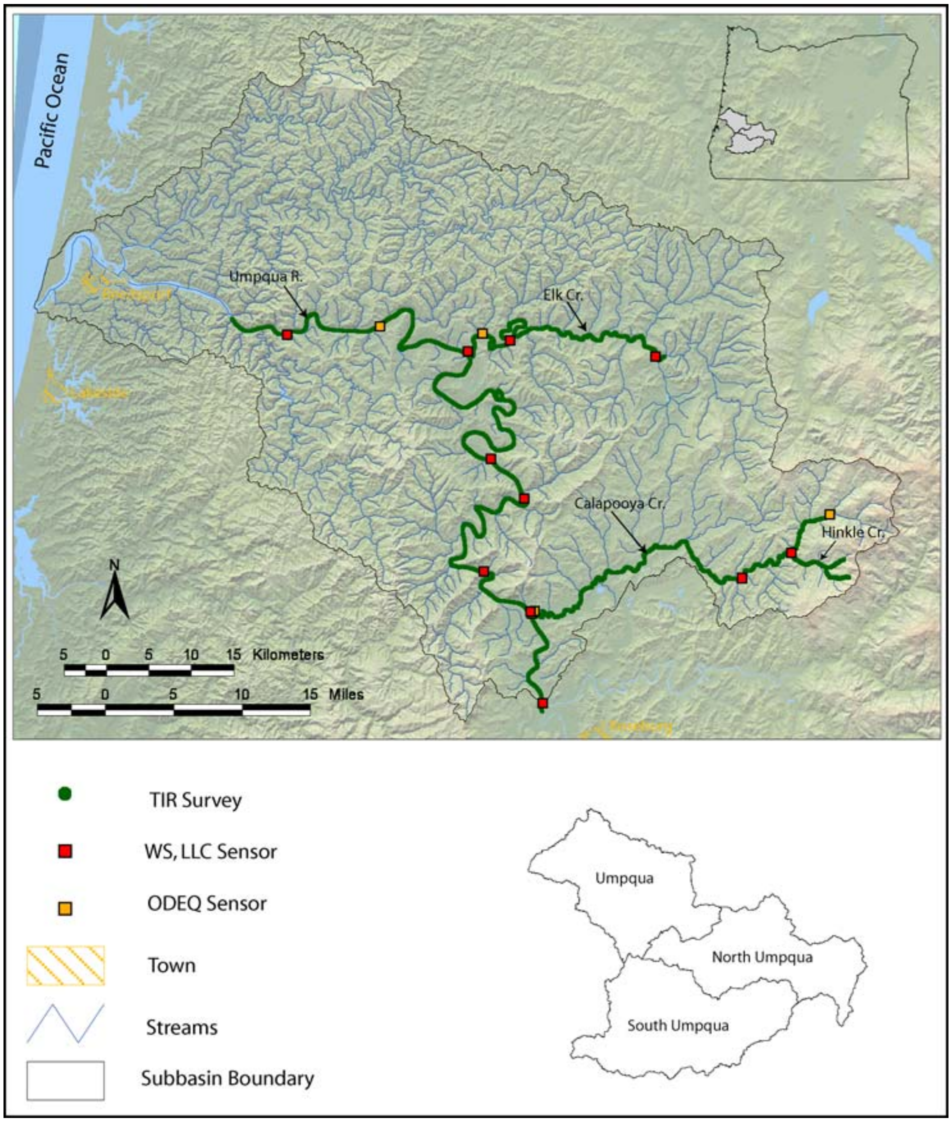

Figure 3 – Map showing the TIR remote sensing surveys conducted in the Umpqua River subbasin from July 23-25, 2002. The map also shows the distribution of in-stream sensors used to ground truth radiant temperatures derived from TIR images.

Weather conditions for the dates and times of the surveys are summarized in Table 2. A marine fog layer was present on the day of the Umpqua River survey (23 July), which extended inland approximately 10 miles. However, the fog did not extend upstream to Heddon County Park and was not considered a factor. Sky conditions were clear each day and overall conditions were considered ideal for the TIR surveys.

Table 2 – Meteorological conditions recorded at the confluence of the North and South Umpqua Rivers July 23-26, 2002.

Time	Temp °F	Temp °C	RH (%)
July 23, 2002			
4:00 PM	92.5	33.6	31.0
July 24, 2002			
2:00 PM	83.0	28.3	39.4
3:00 PM	85.1	29.5	37.4
4:00 PM	87.3	30.7	36.4
5:00 PM	88.0	31.1	37.4
July 26, 2002			
2:00 PM	81.5	27.5	50.2
3:00 PM	82.2	27.9	48.6
4:00 PM	83.0	28.3	47.6
5:00 PM	81.5	27.5	49.2

Results

Thermal Accuracy

With the exception of Calapooya Creek, 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°C) for each surveyed stream (Table 3). The average distances and range of values were also consistent with TIR surveys conducted in the Pacific Northwest over the past five years (Torgersen, 2001). On the Umpqua River, a difference of -0.8°C was observed between the radiant temperatures and the in-stream sensor located at mile 25.4. Although not enough information is available to identify error sources, the proximity to the river mouth suggests that tidal influences and/or changes in path transmission due the marine air may have contributed to reduced accuracy at this location. On Hinkle Creek, radiant temperatures were 0.8°C cooler than measured in-stream temperatures at river mile 0.1. The reason for this difference was unknown.

On Calapooya Creek, radiant temperatures were 2.0°C warmer than in-stream temperatures measured by the sensor located at river mile 0.3. However, in-stream measurements in the Umpqua River and at the mouth of Calapooya Creek (river mile 0.0) were consistent (±0.6°C) with radiant temperatures. Due to the acceptable comparison (kinetic versus radiant) of other sensors near the mouth of Calapooya Creek, the in-stream data at river mile 0.3 was suspect and the differences at this location are not considered a reflection of the accuracy of the TIR data. However, since this location was used to verify the accuracy of the TIR data and since the sensor itself passed quality assurance tests, the information from this sensor was left in the accuracy table (Table 3). The differences between the radiant temperatures and the kinetic temperatures at this location should provide a basis for reevaluating the data from this in-stream sensor or, conversely, provide additional context for assessing spatial temperature patterns observed near the mouth of Calapooya Creek.

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

Stream	Sensor	Image	River mile	Time 24 hr	Kinetic °C	Radiant °C	Difference °C
Umpqua River, July 23, 2002, Avg. =0.3							
Umpqua R.	WS, LLC	umpq0123	25.4	14:37	25.4	26.2	-0.8
Umpqua R.	ODEQ	umpq0358	34.4	14:46	27.1	26.6	0.5
Umpqua R.	WS, LLC	umpq0673	46.1	14:56	26.3	26.6	-0.3
Umpqua R.	WS, LLC	umpq1600	72.7	15:27	26.1	26.0	0.1
Umpqua R.	WS, LLC	umpq1724	76.8	15:31	26.1	26.1	0.0
Umpqua R.	WS, LLC	umpq2266	93.4	15:51	24.7	24.8	-0.1
Umpqua R.	ODEQ	umpq2505	101.4	15:59	25.5	25.3	0.2
N. Umpqua R.	WS, LLC	umpq2746	109.3	16:07	25.9	25.8	0.1
S. Umpqua R.	ODEQ	umpq2749	109.3	16:07	27.4	27.6	-0.2
Elk Creek, July 24, 2002, Avg. = 0.3							
Umpqua Cr.	WS, LLC	elk0011	0.0	13:50	25.6	25.8	-0.2
Elk Cr.	ODEQ	elk0167	2.3	13:56	24.9	25.0	-0.1
Elk Cr.	WS, LLC	elk0333	6.1	14:02	24.4	24.0	0.4
Elk Cr.	WS, LLC	elk1407	25.6	14:39	23.8	24.1	-0.3
Calapooya Creek, July 24, 2002, Avg. = 0.7							
Umpqua R.	ODEQ	calp0018	0.0	15:34	24.8	25.4	-0.6
Calapooya Cr.	WS, LLC	calp0017	0.0	15:34	27.4	26.9	0.5
Calapooya Cr.	ODEQ	calp0039	0.3	15:34	24.9	26.9	-2.0
Calapooya Cr.	WS, LLC	calp1511	25.2	16:23	23.9	23.7	0.2
Calapooya Cr.	ODEQ	calp2212	35.8	16:48	18.5	18.6	-0.1
Hinkle Creek, July 26, 2002, Avg. = 0.4							
Hinkle Cr.	ODEQ	hlo0083	0.1	13:39	19.2	18.4	0.8
Hinkle Cr.	WS, LLC	hlo0090	0.2	13:39	18.2	18.1	0.1
Hinkle Cr.	ODEQ	hlo0274	1.7	13:43	17.3	17.7	-0.4

Temporal Differences

Figure 4 shows in-stream temperature variations for four streams in the Umpqua River Basin during the afternoon of the TIR remote sensing surveys. The figure shows the temporal variations in stream temperatures at a single location on each stream and is intended to provide a sense of how stream temperatures changed during the time frame of the flight and the timing of the flight relative to the recorded daily maximum temperatures.

At river mile 72.7 on the Umpqua River, the TIR flight occurred just prior to the recorded daily stream temperature maximum, which occurred between 16:20 and 18:50. Stream temperatures increased by 0.4°C during the time span of the flight at this location. On Elk Creek, the daily stream temperature maximum occurred between 15:50 and 17:30 and stream temperature increased by 0.5°C during the time span of the flight at river mile 6.1. On Calapooya Creek at river mile 35.8, the timing of the TIR survey was consistent with the daily stream temperature maximum.

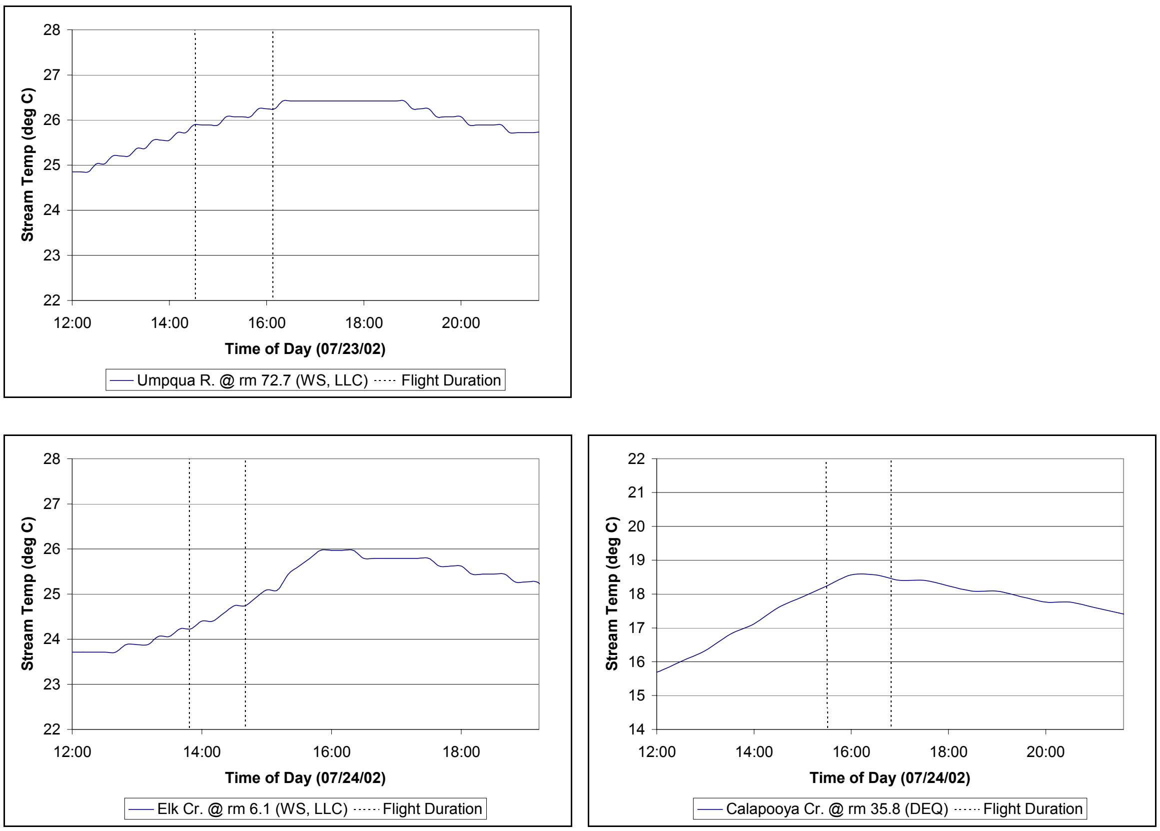

Figure 4 – Stream temperature variation and time of TIR remote sensing flight at single location on streams in the Umpqua River Basin.

Longitudinal Temperature Profiles

Umpqua River

Figure 5 illustrates the longitudinal temperature profile developed for the Umpqua River. The profile also shows the temperature and location of tributary inflows sampled during the analysis. The tributaries are labeled by name on the profile and summarized in Table 4. The profile also shows the location of the tributaries that were detected during the analysis, but could not be sampled due to the visibility in the TIR images. The longitudinal temperature profile is also presented in Figure 6 which also shows both the kinetic (in-stream) temperatures at the time of the survey and the maximum daily stream temperatures at the in-stream monitoring locations. This plot provides additional context for interpreting the spatial temperature patterns.

At their confluence, the North Umpqua River (25.8°C) was cooler than the South Umpqua River (27.5°C) and its flow defined water temperatures at the upstream end of the survey. A linear regression shows a general downstream warming trend over the full 81.5 mile length (Figure 6). However, the profile also shows thermal variability at shorter spatial scales with radiant temperatures ranging between 24.6°C and 27.4°C over the survey extent. A degree of local spatial variability (±0.5°C) may be attributed to noise levels common for TIR remote sensing (*see TIR image characteristics*). However, stream temperature decreases of 1.0-1.5°C from the prevailing temperature trend were observed through different segments of the river. These decreases were outside typical noise levels and represent actual variability in bulk temperature along the stream gradient. For example, an apparent decrease in bulk water temperatures of ≈1.5°C was measured between river miles 99.0 and 94.2. This decrease also was reflected in data from in-stream sensors located at river miles 101.4 and 93.4.

The source of cooling at different points along the profile was not directly apparent from the TIR images. A total of eight tributary inflows were sampled and only three contributed water that was cooler than the main stem (Figure 7). All sampled surface inflows had temperatures above 22.4°C at the time of the flight and no surface springs or in-channel seeps were detected during the analysis. Inspection of the longitudinal temperature profile does not reveal any obvious spatial associations between tributaries inflows (either sampled or not sampled) and the observed variability (cooling or warming) along the basin scale profile. While tributaries inflows may influence temperatures at a fine scale (10-100 meters), the detected tributaries did not appear to have sufficient volume or temperature differential to alter prevailing spatial temperature patterns at the basin scale.

An apparent general decrease in stream temperature was also observed between river miles 27.3 and 20.3. The source of the cooling is not apparent from the imagery or reference maps. Tidal influence may be a factor in defining these patterns. However, this was not investigated as part of this analysis.

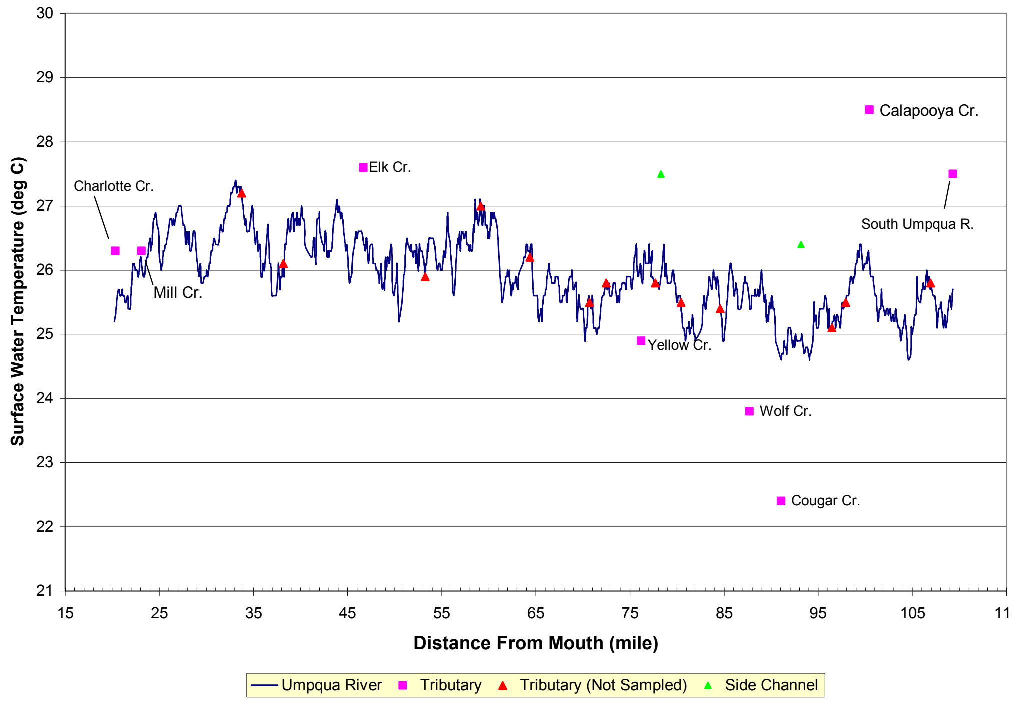

Figure 5 – Median channel temperatures versus river mile for the Umpqua River, OR along with the location of surface water inflows. The locations of tributaries that were detected in the TIR images, but not sampled, are also shown on the plot.

Table 4 – Tributary temperatures for the Umpqua River, OR

Tributary Name	Image	km	mile	Tributary °C	Umpqua R. °C	Difference °C
Charlotte Creek (LB)	umpq0008	32.7	20.3	26.3	25.3	1.0
Mill Creek (LB)	umpq0074	37.2	23.1	26.3	26.1	0.2
Elk Creek (RB)	umpq0690	75.2	46.7	27.6	26.4	1.2
Yellow Creek (RB)	umpq1710	122.7	76.2	24.9	25.9	-1.0
Wolf Creek (LB)	umpq2093	141.1	87.7	23.8	25.5	-1.7
Cougar Creek (LB)	umpq2185	146.6	91.1	22.4	24.6	-2.2
Calapooya Creek (RB)	umpq2480	161.6	100.4	28.5	26.1	2.4
South Umpqua R. (LB)	umpq2745	175.9	109.3	27.5	25.7	1.8
Side Channel						
Side Channel (LB)	umpq1787	126.0	78.3	27.5	25.9	1.6
Side Channel (LB)	umpq2257	149.9	93.2	26.4	24.9	1.5

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

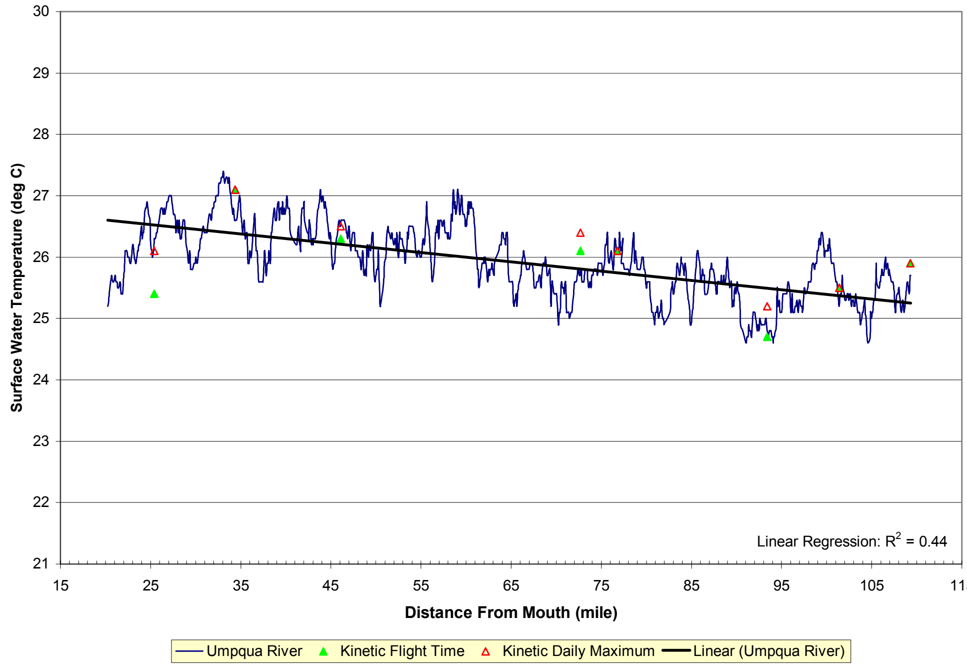

Figure 6 – Median temperatures in the Umpqua River, OR versus river mile. The plot shows the locations of in-stream temperatures with the recorded in-stream (kinetic) temperature at the time of the survey and recorded maximum temperature.

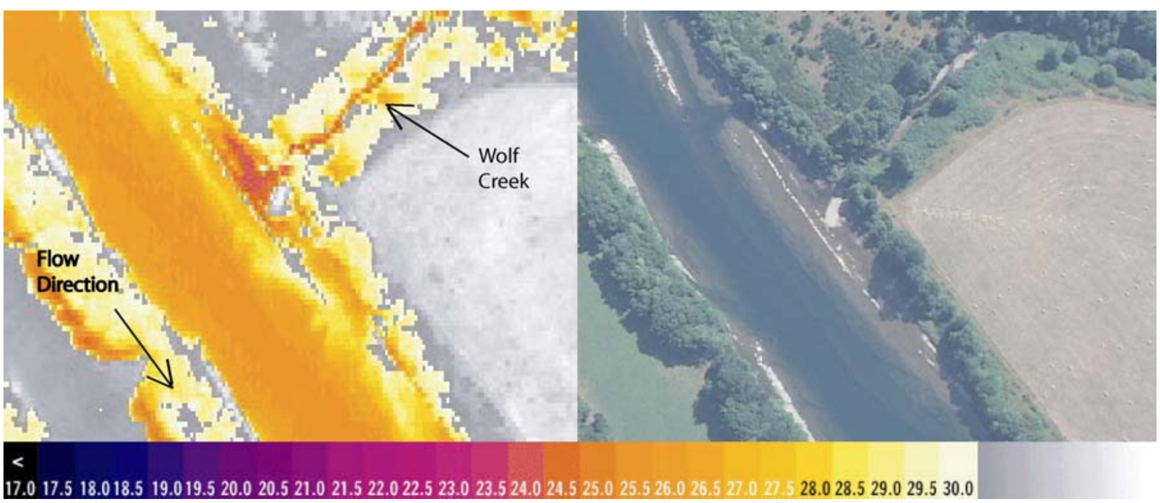

Figure 7 – TIR/color video image showing the confluence of Wolf Creek (23.8) and the Umpqua River (25.5) at river mile 87.7. Wolf Creek was one of three tributaries sampled during that analysis that contributed cooler water the Umpqua River. (*Frame: umpq2093*)

Bed rock outcroppings were observed at multiple locations along the Umpqua River. Stream flow in and around these outcroppings often resulted in side channels and pockets of water that were warmer than the main channel (Figure 8). With the exception of inflow of the three cooler tributaries, fine scale thermal variability observed laterally in the stream channel was always warmer than the flow in the main channel.

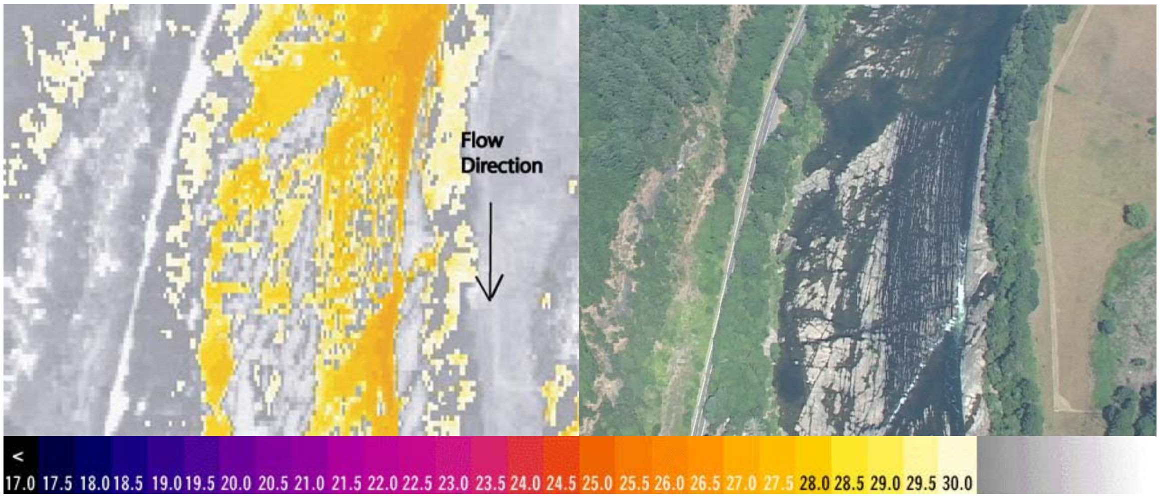

Figure 8 – TIR/color video image showing bed rock outcroppings in the Umpqua River 26.7°C) at river mile 36.6. The outcroppings are common along the river and often result in warmer pockets of water outside the main flow. (*Frame: umpq0419*)

Elk Creek

Figure 9 illustrates the longitudinal temperature profile developed for Elk Creek from the TIR images. The location and name of sampled tributaries are illustrated on the profile and summarized in Table 5. The profile also shows the location of tributaries that were detected during the analysis, but were not sampled due to a lack of visible surface water in the TIR images.

Radiant water temperatures in Elk Creek ranged between 22.3°C and 27.1°C over the survey extent. Surface temperatures showed a high degree of local spatial variability with apparent temperature changes greater than ±1.0°C observed over short longitudinal distances (i.e. 0.25 - 0.5 miles) at multiple points along the profile. Four tributary inflows were sampled during the analysis and each contributed cooler water to Elk Creek. Of the sampled tributaries, Tom Folly Creek at river mile 8.5 (21.2°C) had the greatest thermal contrast compared to the main stem. While tributary inflows contributed to the observed thermal variability, surface water inflows were not the primary source of variability along the stream gradient.

The spatial temperature patterns observed on Elk Creek are characteristic of a relatively warm, low gradient stream where bulk water temperatures are influenced locally by comparatively small mass transfers (i.e. surface inflows, surface/sub-surface exchanges). In these cases, the sources of cooling are often not apparent from the TIR images (Figure 10). In addition, general flow conditions in Elk Creek resulted in stream segments with smooth, mirror-like water surfaces and little evidence of turbulent mixing (i.e. riffles, rapids). Smooth surface conditions jointly increases reflectivity in the TIR band (Torgersen et al. 2001) and the potential for differences in the instantaneous heating rates at the water surface. The TIR images frequently showed evidence of differential heating with slightly cooler surface temperatures (typically 0.5-1.0°C) observed in the visible shadows. Although generally small, the differences in surface temperature increase the apparent spatial thermal variability at fine scales and confound the interpretation the TIR images.

In addition to a high degree of local variability, water temperatures in Elk Creek also exhibited general patterns of warming/cooling at the basin scale. For example, stream temperatures decreased by ≈3.0°C downstream of Yoncalla Creek at rm 26.0 before showing a general warming trend between rm 25.0 and 17.5. Stream temperatures also exhibited a general cooling trend between rm 17.5 and 13.8 before increasing again between rm 13.8 and 9.8.

The radiant temperatures measured at the time of the survey were cooler than the maximum daily stream recorded at the in-stream monitoring locations (Figure 11). At river miles 25.6 and 6.1, maximum daily stream temperatures were 1.6°C warmer that the radiant temperatures. However, recorded in-stream daily maximum temperatures were 3.2°C warmer than the radiant temperatures at river mile 3.2.

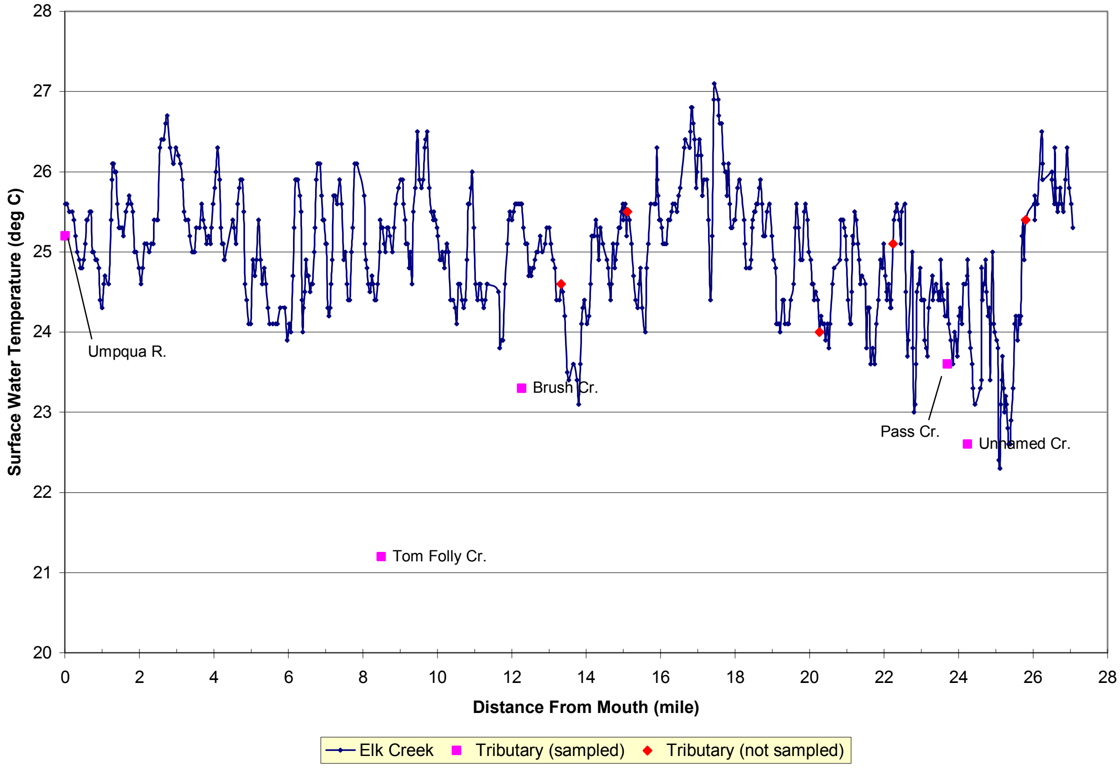

Figure 9 – Median channel temperatures versus river mile for Elk Creek, OR. The plot also shows the location and name of tributary inflows that were sampled during the analysis as well as the location of tributaries that were detected, but not sampled.

Table 5 - Tributary temperatures for Elk Creek.

Tributary Name	*Image*	*km*	*mile*	*Tributary °C*	*Elk Creek °C*	*Difference °C*
Umpqua River	elk0056	0.0	0.0	25.2	25.6	-0.4
Tom Folly Creek (RB)	elk0467	13.7	8.5	21.2	25.3	-4.1
Brush Creek (LB)	elk0659	19.7	12.3	23.3	25.6	-2.3
Pass Creek (RB)	elk1267	38.1	23.7	23.6	24.6	-1.0
Unnamed (RB)	elk1291	39.0	24.2	22.6	24.9	-2.3

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

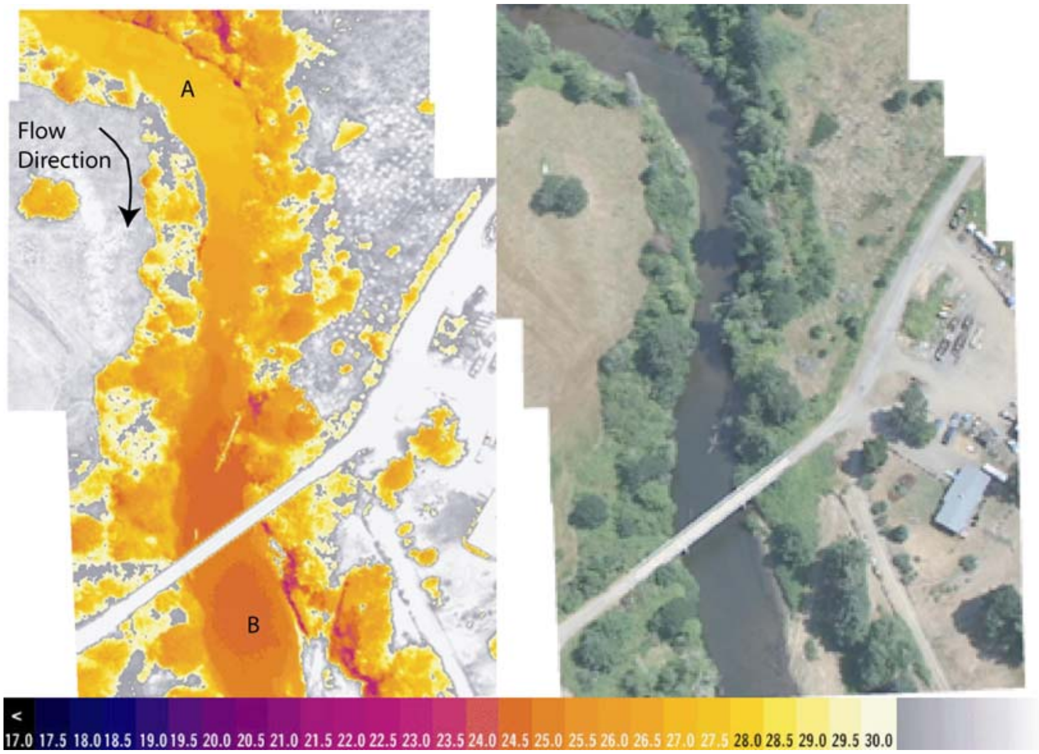

Figure 10 – TIR/color video image mosaic showing a decrease in Elk Creek water temperature from 26.9°C (*Location A*) to 24.5°C (*Location B*) at river mile 17.4. The source of apparent cooling is not evident from the imagery (*frames: elk0923-927*).

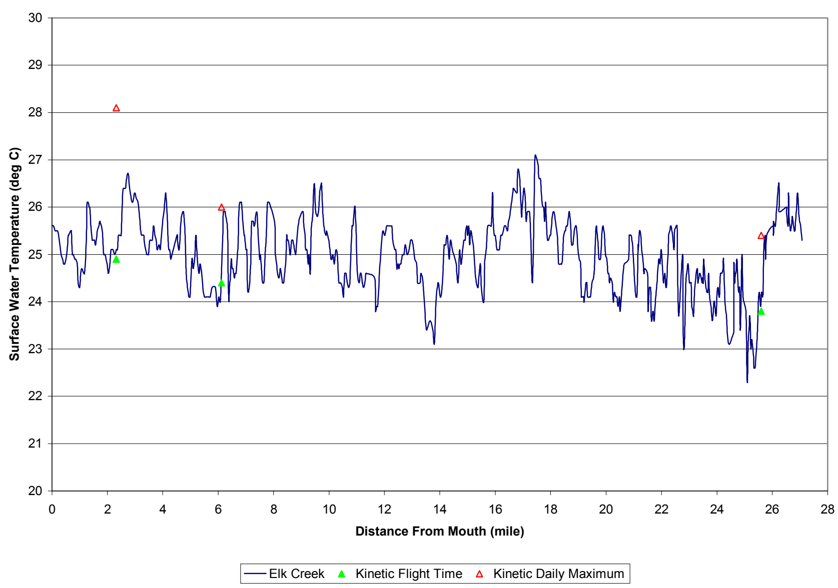

Figure 11 – Median channel temperatures versus river mile for Elk Creek, OR. The plot shows the locations of in-stream temperatures with the recorded in-stream (kinetic) temperature at the time of the survey and recorded maximum temperature.

Calapooya Creek

Figure 12 illustrates the longitudinal temperature profile developed for Calapooya Creek from the TIR images. Sampled tributaries are labeled on the plot by name and side channels and other surface inflows are labeled by river mile. All surface inflows sampled during the analysis are summarized in Table 6. The profile shows the location of tributaries that were detected during the analysis, but were not sufficiently visible in the TIR images to obtain a temperature sample. The tributaries that were not sampled were assigned the temperature of the main stem in order to illustrate their location on the profile.

At the upstream end of the survey (rm 36.1), water temperatures in Calapooya Creek were ≈18.3°C. The South Fork Calapooya Creek was detected in the TIR imagery, but surface water was not visible enough through the riparian canopy to obtain a radiant temperature sample. Downstream of the South Fork, stream temperatures in Calapooya Creek increased rapidly reaching ≈22.8°C at rm 34.0. At river mile 33.8, the inflow of Coon Creek (20.2°C) lowered bulk water temperatures in by ≈1.0°C. Water temperatures in Calapooya Creek continued to decrease downstream of rm 33.1 reaching a local minimum of ≈20.9°C at river mile 32.4. Timothy Creek (not sampled) enters the main stem at rm 33.1, but no surface water was visible through the riparian vegetation.

Between river miles 32.4 and 24.8, water temperatures in Calapooya Creek showed a general warming trend in the downstream direction with local variability observed within the overall warming trend. For example, stream temperature decreases of greater than 1.0°C were observed at river miles 28.9, 26.4, and 25.3. The apparent decreases at river miles 28.9 and 26.4 were not associated with any surface water inflows. However, both locations had large gravel bars in the stream channel, which may suggest shallow sub-surface flow as a possible cooling source. At river mile 25.3, the stream temperatures decrease was observed downstream of a weir labeled as a water plant on the 7.5' USGS topographic map (Figure 13). The source of cooling below the weir was not directly evident from the imagery. However, it may indicate a cooler hypolimnion upstream of the impoundment that is being released downstream. In addition, the image suggests that a cooler inflow occurs along the left bank. Downstream of the weir, stream temperatures quickly returned to ≈24.6°C.

Foster Creek (21.1°C) enters Calapooya Creek at river mile 23.6 and contributes to a decrease in stream temperatures of ≈2.3°C observed between river mile 23.8 and 23.2. An overall warming trend was observed between river mile 23.2 and 18.5, however, the spatial temperature pattern shows a high degree of local variability through this reach. The observed thermal variability was not associated with any surface water inflows (*sampled or not sampled*). At river mile 18.6, the longitudinal heating rate appeared to increase with surface temperatures reaching a survey maximum of ≈29.1°C at river mile 17.5. Stream temperatures decreased back to ≈25.4°C by river mile 15.4. Downstream of river mile 15.4, water surface temperatures in Calapooya Creek ranged between 25.1°C and 28.8°C with a high degree of local variability. Spatial stream temperature patterns in the lower 15.4 miles of Calapooya Creek were similar to those observed on Elk Creek with surface temperatures intermittently approaching recorded air temperatures.

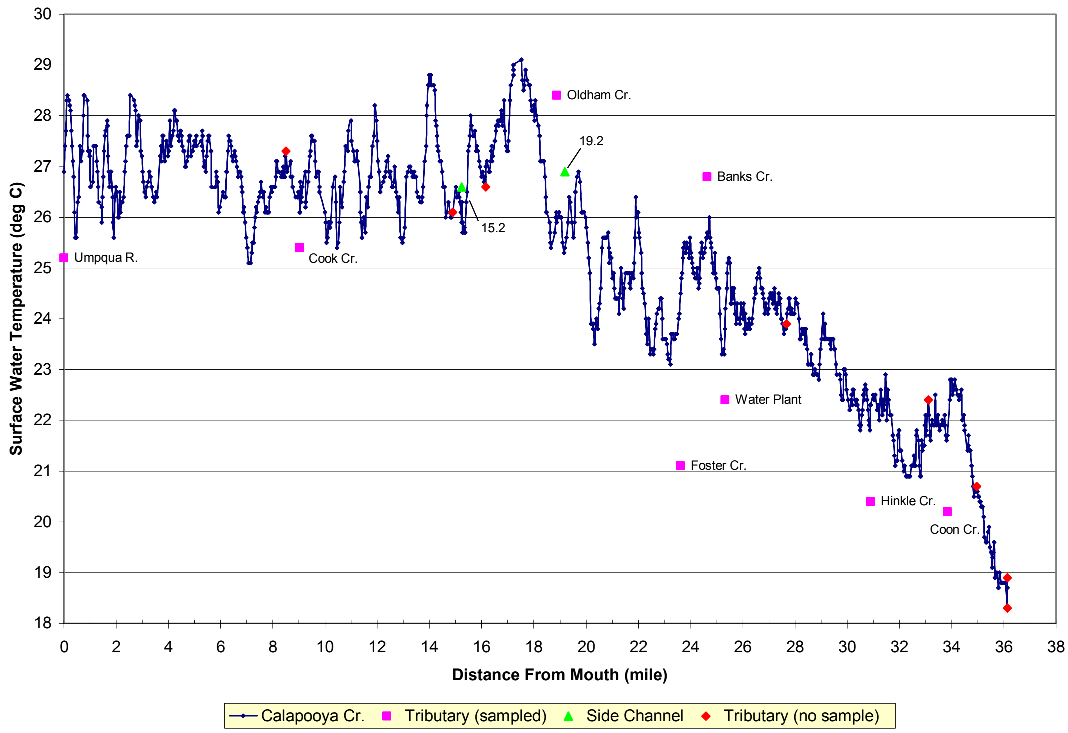

Figure 12 – Median channel temperatures versus river mile for Calapooya Creek, OR. The temperature of sampled tributaries and other surface inflows are shown on the profile and labeled by name.

Table 6 – Tributary temperatures for Calapooya Creek, OR.

Tributary Name	Image	km	mile	Tributary °C	Calapooya Cr. °C	Difference °C
Umpqua River	calp0017	0.0	0.0	25.2	26.9	-1.7
Cook Creek (LB)	calp0549	14.5	9.0	25.4	26.1	-0.7
Oldham Creek (RB)	calp1143	30.4	18.9	28.4	25.9	2.5
Foster Creek (LB)	calp1393	38.0	23.6	21.1	24.5	-3.4
Banks Creek (LB)	calp1472	39.6	24.6	26.8	25.7	1.1
Water Plant (LB)	calp1522	40.7	25.3	22.4	23.8	-1.4
Hinkle Creek (RB)	calp1936	49.7	30.9	20.4	22.3	-1.9
Coon Creek (RB)	calp2110	54.5	33.8	20.2	21.7	-1.5
Side Channel						
Side Channel (RB)	calp0926	24.5	15.2	26.6	25.9	0.7
Side Channel (RB)	calp1157	30.9	19.2	26.9	25.4	1.5

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

Two seasonal in-stream data loggers show that the radiant temperatures were consistent with recorded in-stream temperatures and that the time of the flight was consistent with maximum daily temperatures for July 24th (Figure 14). WS, LLC retrieved their in-stream sensors immediately after the TIR survey and consequently did not record maximum daily stream temperatures.

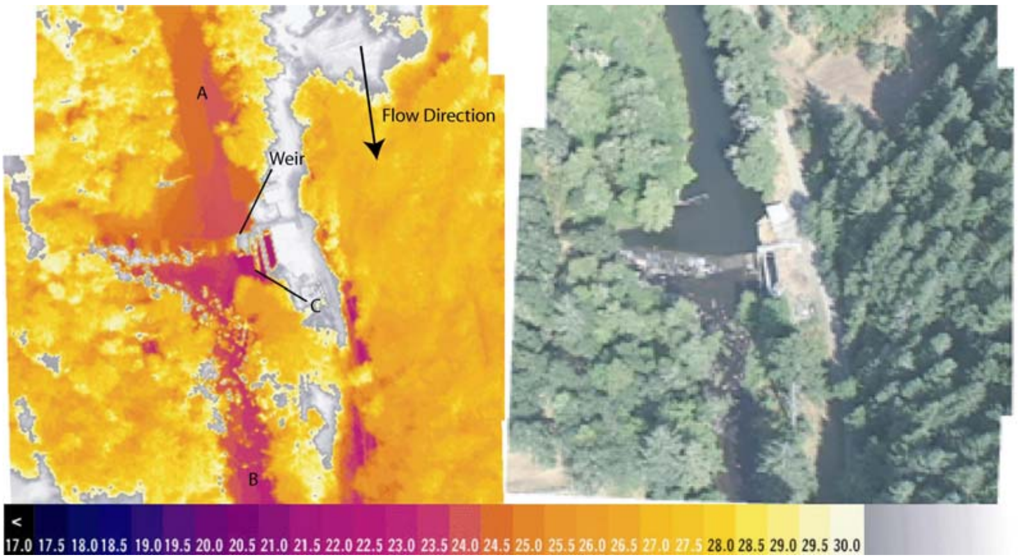

Figure 13 – TIR/color video image mosaic showing an apparent local temperature decrease from 24.6°C upstream of the weir (*A*) and 23.8°C downstream (*B*). The weir location is identified as water plant on the USGS 7.5' topographic base maps. The imagery shows an apparent cool water inflow (*C*) below the weir (*Frame: calp1521-1523*).

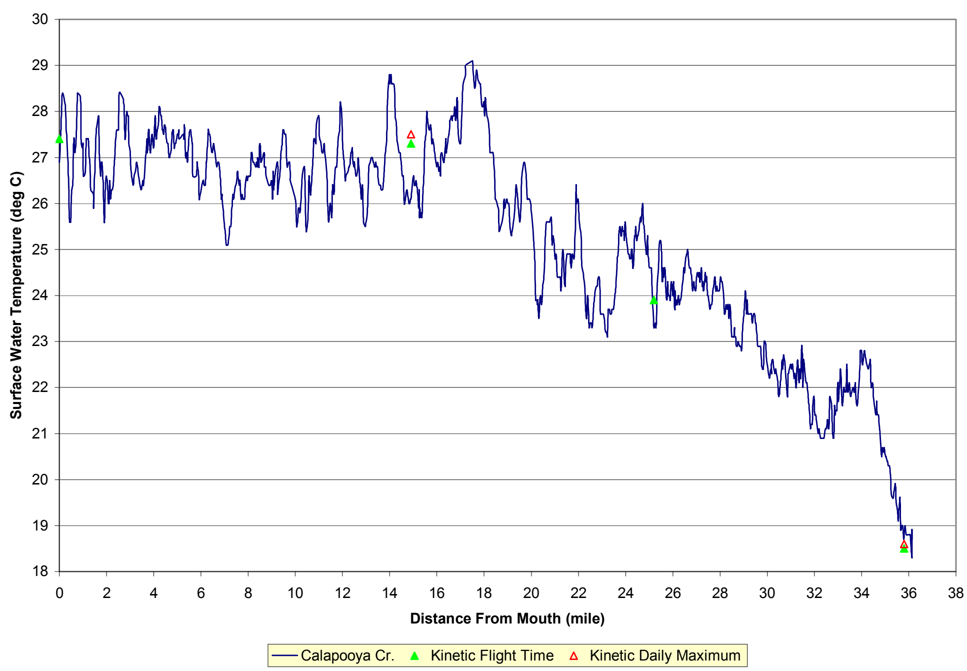

Figure 14 – Median channel temperatures versus river mile for Calapooya Creek. The plot also shows kinetic temperatures at the time of the survey and the recorded daily maximum temperatures at each in-stream monitoring location.

Hinkle Creek

Hinkle Creek was masked by riparian vegetation over much of its length, which precluded sampling radiant temperatures on the North and South Fork legs of the survey. A longitudinal temperature profile was developed for the main stem Hinkle Creek from its mouth to the forks (Figure 15). Radiant temperature samples were acquired where surface water was clearly visible in the TIR/color video image pair. However, even on the main stem, surface water was only visible intermittently through the riparian canopy (Figure 16). The TIR images show distinct thermal differences between the stream surface, riparian vegetation, and upland vegetation. However, due to the small stream width, radiant temperature samples presumably include a higher occurrence of hybrid pixels and hence increased sampling noise than typically observed in wider streams.

TIR images from the high altitude pass on Hinkle Creek were not sampled for temperatures due to a general inability to see surface water through the riparian vegetation and increased pixel size. As mentioned previously, the intent of the high altitude survey was to provide additional context for interpreting imagery from the low altitude flight and to provide broader color video imagery of the riparian zone.

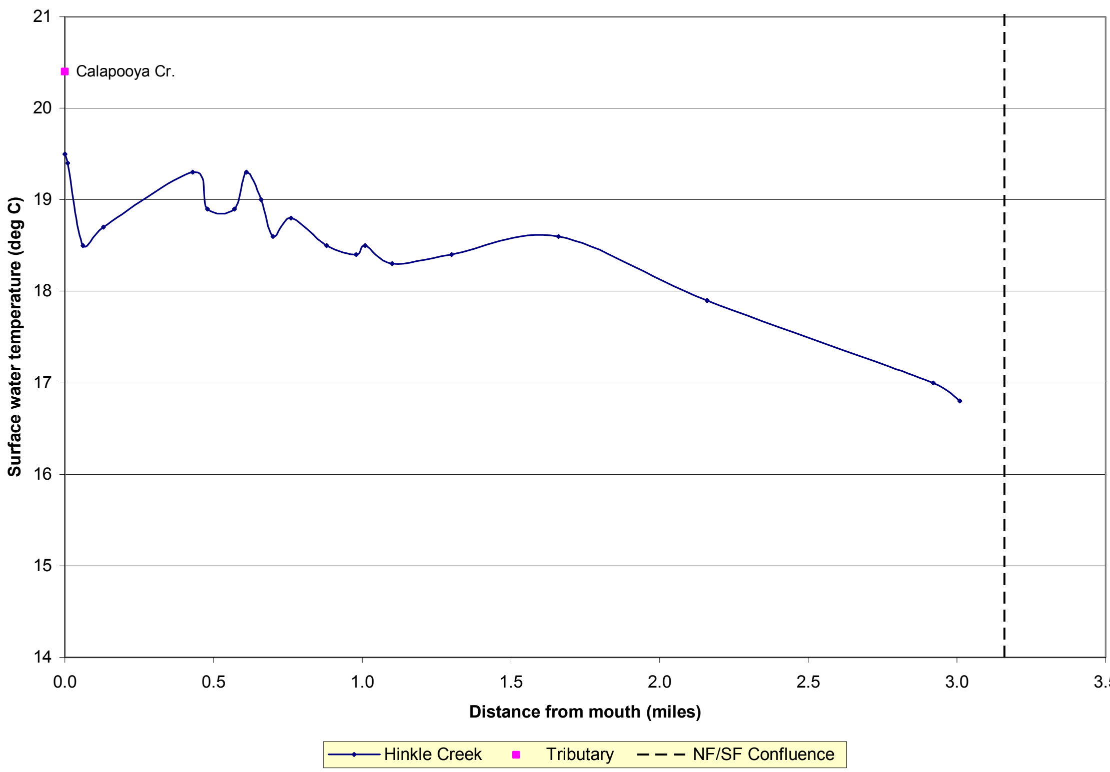

Figure 15 – Median channel temperatures versus river mile for Hinkle Creek, OR.

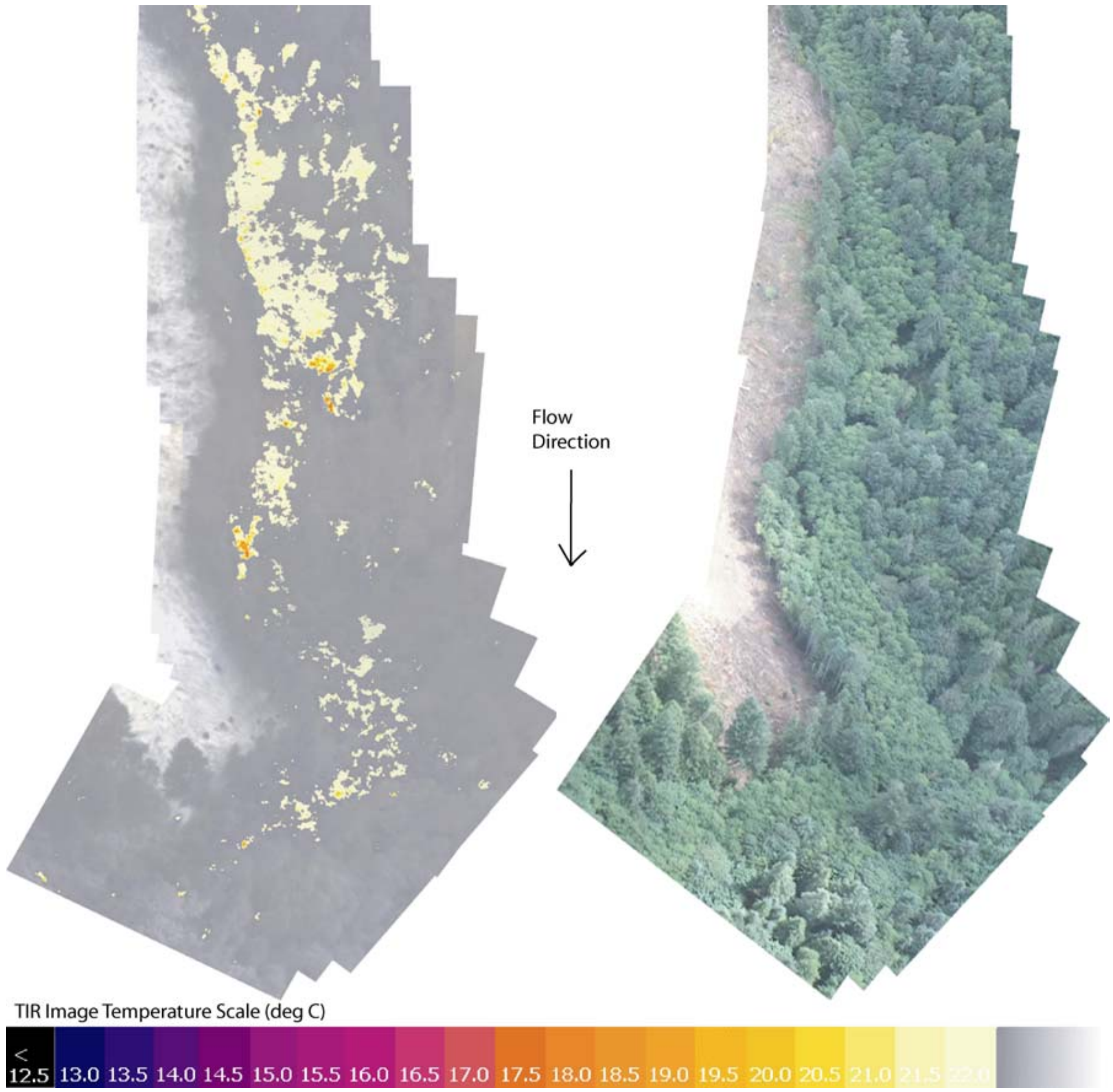

Figure 16 – TIR/color video image mosaic showing Hinkle Creek between river miles 2.6 and 2.8. Surface water was only intermittently visible through the riparian canopy over the survey length. Vegetation masking of the stream surface precluded sampling temperatures on the North and South Fork Hinkle Creeks (*frames: hinklelo0393-416*).

Discussion

TIR remote sensing surveys were successfully conducted on selected streams in the Umpqua River Basin. Longitudinal temperature profiles were produced for each surveyed stream, which illustrate broad scale spatial temperature patterns and the location and influence of tributary and surface water inflows. The following paragraphs provide a brief discussion of the thermal conditions observed on each of the surveyed streams.

Umpqua River: The high degree of spatial thermal variability observed in the Umpqua River is not uncommon in streams where water temperatures approach recorded air temperatures. Relatively small mass transfers and differential heating rates along the stream gradient may result in locally cool segments that heat rapidly once the cooling source is removed. The results showed that tributaries inflows did not have a significant influence on basin scale temperature patterns. Furthermore, the observed temperature changes along the profile were often just outside the ±0.5°C noise level common to TIR remote sensing. Consequently, the TIR images or topographic reference maps did not provide enough information to positively identify the sources of the observed thermal variability. Follow-on analysis should examine the geomorphic and channel features that may contribute to the observed thermal variability. Overall, the Umpqua River is warm (24.6°C to 27.4°C) over its entire length. Subsequent investigation may determine if cold-water fishes are seeking the cooler river segments even though these areas are only slightly cooler (1-1.5°C) than bulk temperatures.

Elk Creek: As with the Umpqua River, Elk Creek exhibited a high degree of local spatial thermal variability throughout the longitudinal profile. General flow conditions in the stream resulted in more incidences of artifacts (differential heating, thermal reflections, etc.) common to TIR remote sensing. These artifacts did not affect the quality of the information and provide insights on the general flow conditions within the stream. However, the high degree of thermal variability made it difficult to positively identify cooling sources.

Calapooya Creek: Calapooya Creek showed a pattern of rapid downstream warming in the upper reaches with generally warm temperatures observed in the lower 18 stream miles. The high degree of local thermal variability observed in the lower 18 miles was similar that observed on Elk Creek. Although no surface springs were detected, the areas of localized cooling upstream of river mile 18 suggest possible areas of sub-surface influence.

Hinkle Creek: The water surface of Hinkle Creek was only intermittently visible through the riparian canopy despite a low flight altitude (i.e. high pixel resolution). Consequently, TIR images have limited utility in defining continuous spatial temperature patterns in Hinkle Creek and quantifying the influence of surface water inflows (i.e. tributaries, surface springs, etc.). However, the TIR and color video images provide a baseline record of riparian vegetation and general thermal conditions along the stream corridor. Two flight passes along Hinkle Creek resulted in imagery at different spatial scales that facilitates the analysis of riparian conditions by showing relationship of near stream vegetation to existing upland conditions.

North Umpqua River Basin

Overview

The TIR remote sensing surveys in the North Umpqua River Basin were conducted on July 25-26, 2002 (Figure 17). The North Umpqua River was surveyed at a flight altitude that provided a wider image footprint (*lower spatial resolution*) to better capture the full width of the river and off-channel features. The North Umpqua River was also surveyed in a downstream direction starting at the confluence of Steamboat Creek and continuing to the mouth. By contrast, tributaries in the basin were surveyed at lower altitudes (*above ground level*) to provide higher spatial resolution and better visibility through the riparian vegetation. All tributaries were surveyed upstream starting from the stream mouth. Table 7 summarizes the survey times, extents, and image resolution for each surveyed stream in the North Umpqua River Basin.

Multiple wildfires were active in the North Umpqua River Basin during the dates of the TIR surveys. The TIR remote sensing flights were coordinated with the USFS helicopter base located near the town of Glide, OR and USFS protocols were followed explicitly while operating in the basin. The wildfires were not a factor during surveys of Rock Creek, Little River, Cavitt Creek, or the North Umpqua River. A wildfire on the ridge between Steamboat Creek and Canton Creek resulted in some smoke in the upper portions Steamboat Creek drainage. However, the smoke did not noticeably affect the quality of either TIR or color video imagery due to the short path length between the sensor and the stream. The survey along Steamboat Creek required additional coordination with airborne fire operations due to an active dip site along Steamboat Creek at river mile 11.9. Road closures prevented ground access to the upper reaches of both Steamboat Creek and Canton Creek, which limited the ability of WS, LLC to distribute in-stream data loggers upstream of river mile 1.0. Seasonal in-stream data from ODEQ sites were used to calibrate and ground truth the TIR images.

Weather conditions were hot and clear during the days of the surveys. With the exception of some smoke in the Steamboat Creek drainage, weather conditions were considered ideal for the surveys (Table 8).

Table 7 – Summary of river segments surveyed with TIR and color video in the North Umpqua River Basin from July 25-26, 2002.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent & Direction	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Steamboat Cr.	25 Jul	13:51-14:24	mouth to Horse Heaven Cr.	19.0	130 (423)	0.4 (1.3)
Canton Cr.	25 Jul	14:30-15:07	mouth to Pass Cr.	10.0	130 (423)	0.4 (1.3)
North Umpqua R.	25 Jul	16:07-17:27	Steamboat Cr. to mouth	52.0	258 (846)	0.8 (2.6)
Rock Cr.	26 Jul	14:07-14:37	mouth to NE Fork	12.0	130 (423)	0.4 (1.3)
Little R.	26 Jul	15:28-16:26	mouth Hemlock Cr.	26.0	110 (353)	0.3 (1.1)
Cavitt Cr.	26 Jul	16:36-17:05	mouth to Cultus Cr.	10.0	110 (353)	0.3 (1.1)

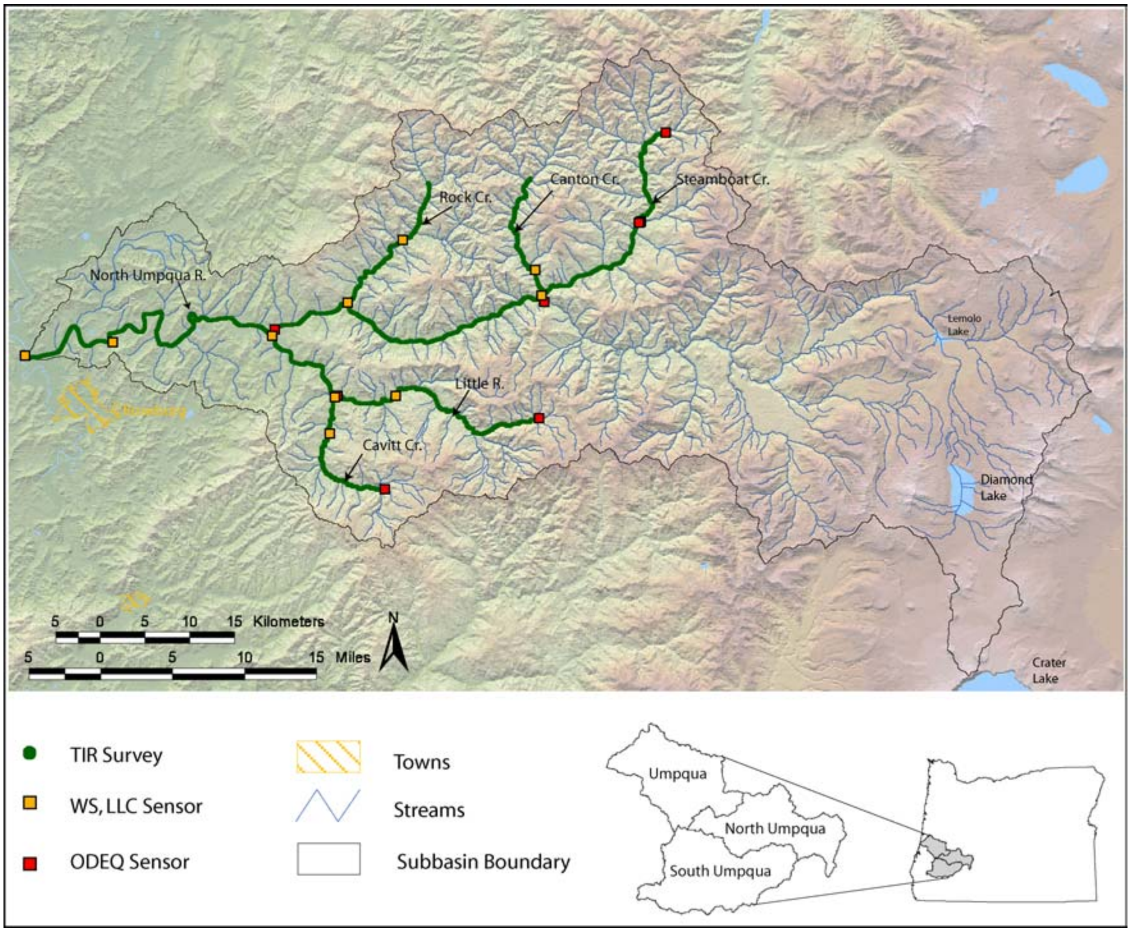

Figure 17 - Map showing the TIR remote sensing surveys conducted in the North Umpqua River Basin from July25-26, 2002. The map also illustrates the location of in-stream sensors used to ground truth the radiant temperatures derived from the TIR images.

Table 8 - Meteorological conditions recorded during the TIR surveys within the North Umpqua River Basin, OR on July 25-26, 2002. Conditions were recorded near the confluence of the North and South Umpqua River.

Time 24 hr	Air Temp ^{o}F	Air Temp ^{o}C	RH %
July 25, 2002			
14:00	83.0	28.3	40.4
15:00	85.8	29.9	35.4
16:00	86.6	30.3	33.9
17:00	86.6	30.3	32.9
July 26, 2002			
14:00	81.5	27.5	50.2
15:00	82.2	27.9	48.6
16:00	83.0	28.3	47.6
17:00	81.5	27.5	49.2

Results

Thermal Accuracy

The average absolute difference between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images was within the desired accuracy (< 0.5^{o}C) for the TIR surveys (Table 9). In addition, the average difference and the range of differences for each survey stream were consistent with TIR surveys conducted in the Pacific Northwest over the past five years (Torgersen, 2001).

With the exception of one location on Steamboat Creek, all locations showed differences within ±0.7^{o}C. On Steamboat Creek, radiant temperatures were 1.2^{o}C cooler than recorded in-stream temperatures at the monitoring site just upstream of Big Bend Creek (rm 11.1). No explanation is given for this difference. However, radiant temperatures were consistent with in-stream temperatures at the mouth of Big Bend Creek and at the other monitoring site at river mile 19.3. None-the-less, the differences at this location should be considering when evaluating spatial temperature patterns.

Temporal Differences

Figure 18 shows in-stream temperature variations during the afternoon of the TIR surveys at a single monitoring site on each of the streams in the North Umpqua River Basin. The plots are intended to provide a sense of how stream temperatures changed during the time frame of the flight and the timing of the flight relative to the recorded daily maximum temperatures.

On each surveyed stream, the TIR flight occurred prior to the recorded daily stream temperature maximum. At river mile 28.5 on the North Umpqua River, maximum temperatures occurred between 17:40 and 19:20 and stream temperatures increased by 0.3^{o}C during the time span of the TIR survey. On all of the surveyed tributaries, stream temperatures changes during the course of the survey ranged from 0.1^{o}C (Cavitt Cr.) to 0.5^{o}C (Little R.)

Table 9 – Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures derived from the thermal infrared images for streams surveyed in the North Umpqua River Basin.

Stream	Sensor Owner	Image	River Mile	Time 24 hr	Kinetic °C	Radiant °C	Difference °C
North Umpqua River, July 25, 2002, Avg = 0.3							
N Umpqua R.	WS, LLC	nfu0016	52.4	16:08	17	17.3	-0.3
Rock Cr.	WS, LLC	nfu0767	35.1	16:33	20.6	20.6	0.0
N Umpqua R.	ODEQ	nfu1031	29.0	16:42	20.6	20.9	-0.3
N Umpqua R.	WS, LLC	nfu1059	28.5	16:43	20.5	20.7	-0.2
N Umpqua R.	WS, LLC	nfu1921	8.5	17:16	23.8	23.7	0.1
Umpqua R.	WS, LLC	nfu2243	0.1	17:27	25.0	24.8	0.2
N Umpqua R.	ODEQ	nfu2243	0.1	17:27	24.1	24.8	-0.7
S Umpqua R.	ODEQ	nfu2243	0.1	17:27	26.6	26.4	0.2
Steamboat Creek, July 25, 2002, Avg = 0.5							
N Umpqua R.	WS, LLC	stm0010	0.1	13:52	15.9	16.1	-0.2
Steamboat Cr.	ODEQ	stm0471	10.7	14:08	18.5	18.2	0.3
Big Bend Cr.	ODEQ	stm0480	10.9	14:08	16.3	16.0	0.3
Steamboat Cr.	ODEQ	stm0488	11.1	14:08	23.3	22.1	1.2
Steamboat Cr.	ODEQ	stm0972	19.3	14:25	16.1	16.4	-0.3
Canton Creek, July 25, 2002, Avg= 0.3							
Canton Cr.	WS, LLC	cant0185	1.8	14:45	22.0	21.7	0.3
Rock Creek, July 26, 2002, Avg=0.4							
Rock Cr.	WS, LLC	rock0005	0.0	14:08	20	19.5	0.5
Rock Cr.	WS, LLC	rock0431	7.4	14:22	20.9	21.2	-0.3
Little River, July 26, 2002, Avg=0.4							
N Umpqua R.	WS, LLC	lr0025	0.0	15:29	20.0	20.5	-0.5
N Umpqua R.	ODEQ	lr0025	0.0	15:29	20.1	20.5	-0.4
Little R.	ODEQ	lr0443	7.6	15:43	23.8	23.5	0.3
Little R.	WS, LLC	lr0713	12.6	15:52	22.8	22.5	0.3
Little R.	ODEQ	lr2162	25.4	16:26	15.9	16.6	-0.7
Cavitt Creek; July 26, 2002, Avg=0.4							
Little R.	ODEQ	cav0029	0.0	16:37	24.3	24.2	0.1
Cavitt Cr.	WS, LLC	cav0092	0.5	16:38	22.3	21.8	0.5
Cavitt Cr.	WS, LLC	cav0459	3.3	16:44	22.5	22.7	-0.2
Cavitt Cr.	ODEQ	cav1718	10.8	17:06	16.6	17.3	-0.7

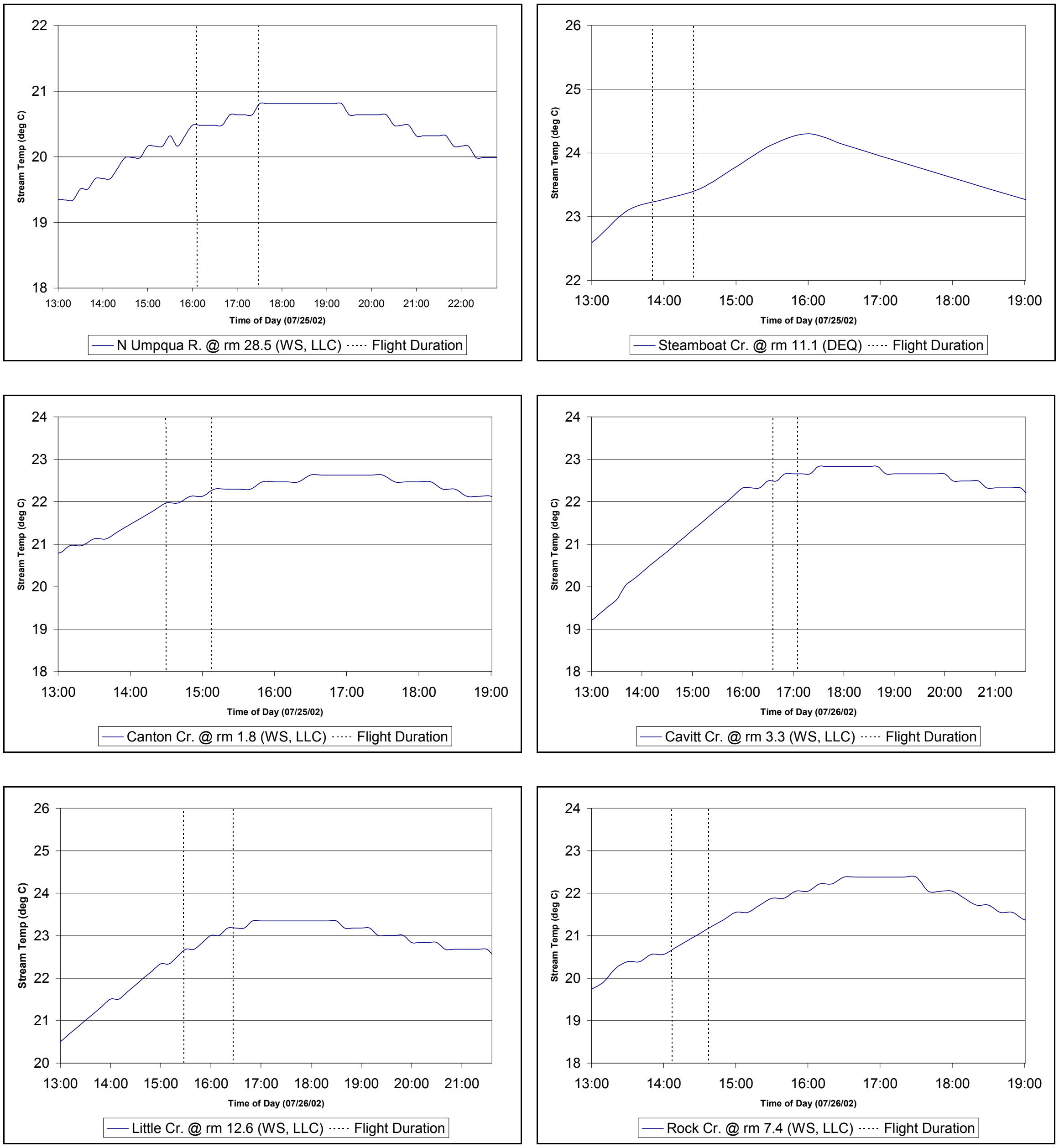

Figure 18 - Stream temperature variation and time of TIR remote sensing over flight at a single location on each surveyed stream in the North Umpqua River Basin.

North Umpqua River

Figure 19 illustrates the longitudinal temperature profile for the North Umpqua River developed from the TIR images. Surface water inflows (i.e. tributaries, side-channels) sampled during the analysis are illustrated on the profile and summarized in Table 10.

At the time of the survey, water temperatures in the North Umpqua River were ≈ 17.8°C immediately upstream of the Steamboat Creek (rm 52.4) confluence. Surface temperatures at the mouth of Steamboat Creek were ≈4.0°C warmer than the main stem and a thermal mixing plume was visible downstream of the confluence (Figure 20). Stream temperatures in the North Umpqua appeared to increase slightly downstream of the Steamboat Creek confluence reaching ≈17.9°C at river mile 49.2. Between river miles 49.2 and 41.6, stream temperatures showed a slight decrease (0.5°C). Fox Creek (rm 43.7) was the only tributary sampled through this reach and it contributed flow that was slightly cooler (0.6°C) than the main stem. Nine mapped tributaries were also detected in this river segment but could not be sampled due to their size or masking by the riparian vegetation (Figure 21). This was the highest concentration of surface inflows (sampled and not sampled) detected during the survey.

Figure 19 - Median channel temperatures versus river mile for the North Umpqua River, OR along with the location of surface water inflows. The locations of tributaries that were detected in the TIR images, but not sampled, are also shown on the plot.

Table 10 – Tributary temperatures for the North Fork Umpqua River.

Tributary Name	*Image*	*km*	*mile*	*Tributary °C*	*N. Umpqua R. °C*	*Difference °C*
Steamboat Creek (RB)	nfu0015	84.3	52.4	22.2	17.2	5.0
Fox Creek (LB)	nfu0381	70.3	43.7	16.9	17.5	-0.6
Rock Creek (RB)	nfu0767	56.5	35.1	21.0	19.8	1.2
Little River (LB)	nfu1048	46.2	28.7	25.3	20.9	4.4
South Umpqua R. (LB)	nfu2242	0.1	0.1	26.1	24.5	1.6
			Side Channel			
Side Channel (LB)	nfu0917	51.0	31.7	20.9	20.0	0.9
Side Channel (LB)	nfu1191	41.2	25.6	21.5	20.9	0.6
Side Channel (RB)	nfu1397	33.5	20.8	23.6	22.3	1.3

LB = left bank, RB = right bank looking downstream

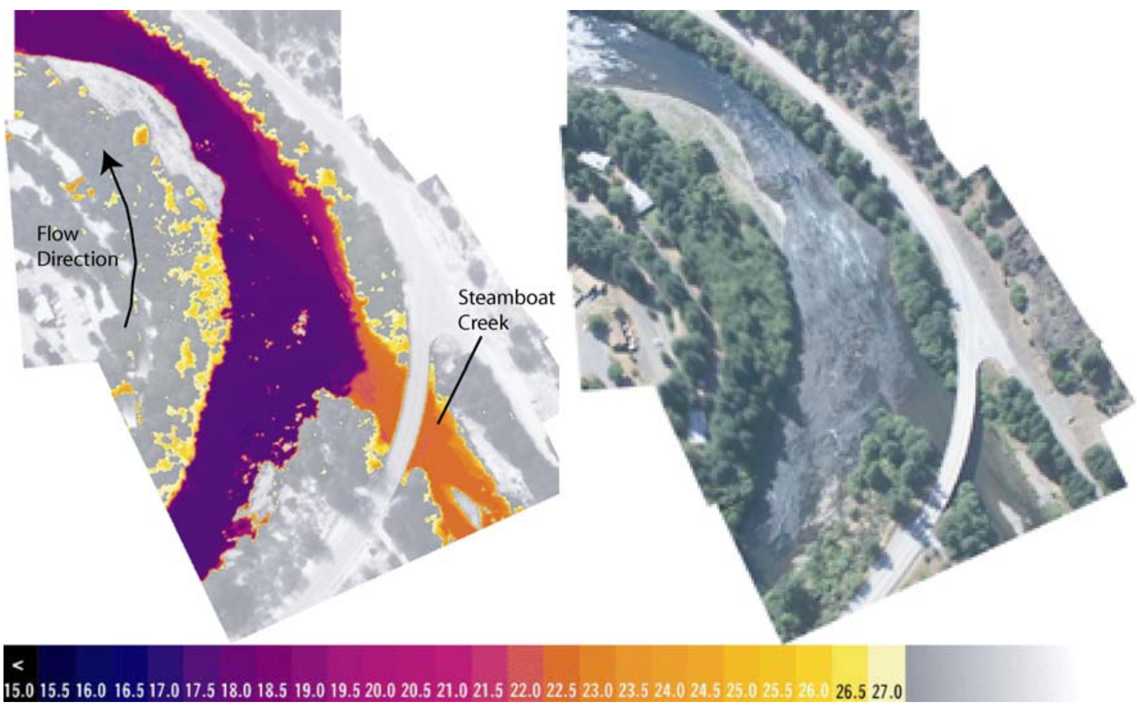

Figure 20 - TIR/color video image showing the confluence of the North Umpqua River (17.2°C) and Steamboat Creek (22.2°C) at river mile 52.4. The thermal mixing plume resulting from the inflow of Steamboat Creek is visible along the right bank (frames: nfu0015-0020).

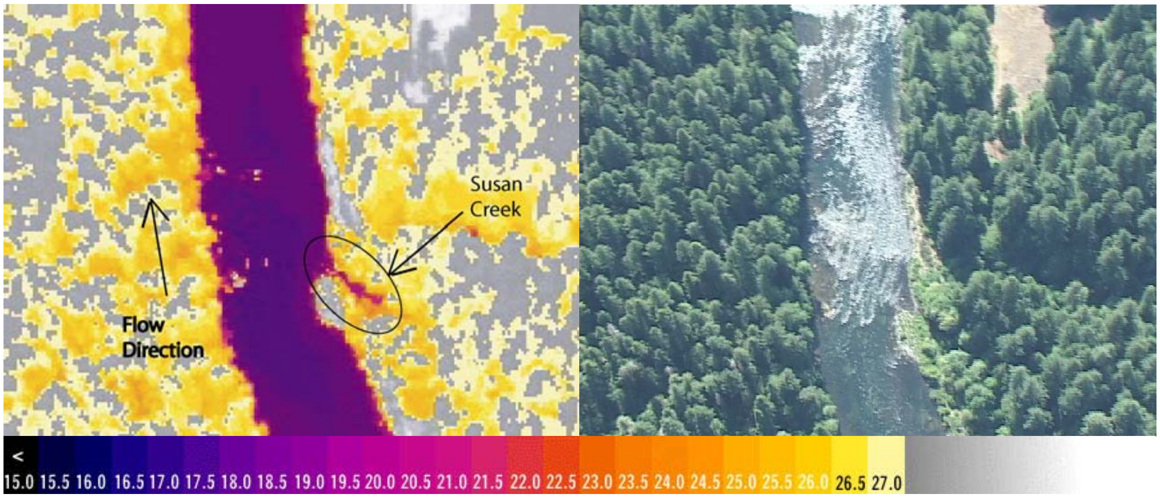

Figure 21 - TIR/color video image showing the confluence of the North Umpqua River (17.5°C) and Susan Creek at river mile 41.6. The location of the Susan Creek confluence was detected in the TIR images, but Susan Creek did not have enough visible surface water to obtain an accurate radiant temperature sample. (*frame: nfu0472*)

At river mile 46.1, water temperatures began to increase steadily downstream reaching 22.9°C at river mile 19.0. A linear regression on the radiant temperatures shows an average heating rate of 0.20°C/mile (R^2 = 0.96). Rock Creek (rm 35.1) and Little River (rm 28.7) were sampled through this reach and both contributed warmer water to the main stem. Between river mile 19.0 and the river mouth, water temperatures continued an overall downstream warming trend. However, the profile shows a general decrease in the longitudinal heating rate (0.11°C/mile) and slight decreases (0.6-0.8°C) in stream temperatures between river miles 19.0 and 16.4 and river miles 8.2 and 6.8. The factors contributing to these apparent cooler stream segments were not apparent from the TIR images or topographic reference maps.

Figure 22 illustrates the same longitudinal temperature profile for the North Umpqua River along with the kinetic (in-stream) temperatures at the time of the TIR survey and the recorded daily maximum temperatures at the in-stream monitoring locations. The radiant temperatures were consistent with both in-stream temperatures and maximum daily temperatures at each of the monitoring sites.

Figure 22 - Median channel temperatures versus river mile for the North Umpqua River, OR. The plot also shows the kinetic (in-stream) temperatures at the time of the survey and the recorded daily maximum temperatures at each of the in-stream monitoring locations.

Steamboat Creek

Median channel temperatures were plotted versus river mile for Steamboat Creek, OR (Figure 23). The profile shows the location and temperature of tributary inflows that were sampled during the analysis. The tributaries are labeled by name and summarized in Table 11. The profile also shows the locations of tributaries that were detected during the analysis, but were not sampled due to size or masking by riparian vegetation. These tributaries were included to provide additional context for interpretation of the longitudinal temperature profile and were assigned the temperature of the main stem in order to represent their location along the stream course.

Steamboat Creek exhibited a high degree of spatial thermal variation with radiant temperatures ranging by 5.6°C over the 19.3-mile survey. At the upstream end of the survey (rm 19.3) radiant stream temperatures were ≈16.6°C and increased to ≈21.3°C at rm 17.0. The profile shows a general stair-step pattern of warming in the downstream direction. For example, stream temperatures increased rapidly between rm 18.4 and 18.2, but showed no significant change between rm 18.2 and 17.7 before increasing rapidly (+1.2°C) again between rm 17.7 and 17.6. Stream temperatures showed an apparent decrease of ≈2.1°C between river mile 17.0 and 16.7. Inspection of the TIR images and topographic reference maps did not reveal any obvious sources of cooling at this location.

Downstream of rm 16.6, stream temperatures increased reaching a survey maximum of 22.8°C at rm 14.8. The spatial temperatures patterns again revealed a general stair-step pattern of downstream heating with maximum heating rates occurring between rm 16.6 and 16.4 and rm 15.6 and 15.3. Radiant stream temperatures remained about 22.5°C before sharply decreasing to ≈21.6 at river mile 14.4. Buster Creek (rm 15.0) contributed cooler water to the main stem through this reach. Over the next 3.4 miles (rm 14.3 to 10.9), radiant temperatures generally ranged between 20.9°C and 21.9°C with considerable local variability within this range. A notable exception within this reach was a sharp decrease (2.0°C) at river mile 12.4. The source of apparent cooling at this location was not obvious from the TIR images.

At the time of the TIR survey, the inflow of Big Bend Creek (16.4°C) lowered water temperatures in Steamboat Creek by ≈3.6°C (Figure 24). Downstream of Big Bend Creek, water temperatures showed a general pattern of downstream warming. However, variations were observed in the longitudinal heating rate with some segments warming more rapidly than others. Apparent cooling trends were observed between rm 4.6 and 4.2 and rm 1.4 and the river mouth. In general, the lower 10.9 stream miles showed less local spatial thermal variability than the upstream reaches, which is presumably due to the increased flow volume contributed by Big Bend Creek.

Eight tributaries were sampled during the analysis of Steamboat Creek. Of the eight, six contributed water that was significantly cooler (i.e. >0.5°C) than the main stem. A comparison of the radiant temperature profile to in-stream sensors shows that the TIR survey occurred prior to the observed daily maximum temperatures (Figure 25).

Figure 23 - Median water temperatures versus river mile for Steamboat Creek, OR. Sampled tributary inflows are labeled by name on the profile.

Table 11 - Tributary temperatures for Steamboat Creek, OR.

Tributary Name	Image	km	mile	Tributary °C	Steamboat Cr. °C	Difference °C
North Umpqua River (LB)	stm0010	0.1	0.1	15.7	20.1	-4.4
Canton Creek (RB)	stm0025	1.0	0.6	20.4	20.7	-0.3
Steelhead Creek (RB)	stm0219	8.8	5.5	18.5	20.3	-1.8
Deep Creek (LB)	stm0249	9.8	6.1	18.6	19.9	-1.3
Singe Creek (LB)	stm0281	11.2	7.0	19.1	20.1	-1.0
Johnson Creek (LB)	stm0435	16.2	10.1	18.0	18.5	-0.5
Big Bend Creek (LB)	stm0480	17.6	10.9	16.4	21.9	-5.5
Buster Creek (LB)	stm0706	24.2	15.0	17.5	22.4	-4.9
Little Rock Creek (RB)	stm0866	28.0	17.4	21.5	20.0	1.5

RB = right bank; LB = Left bank looking downstream

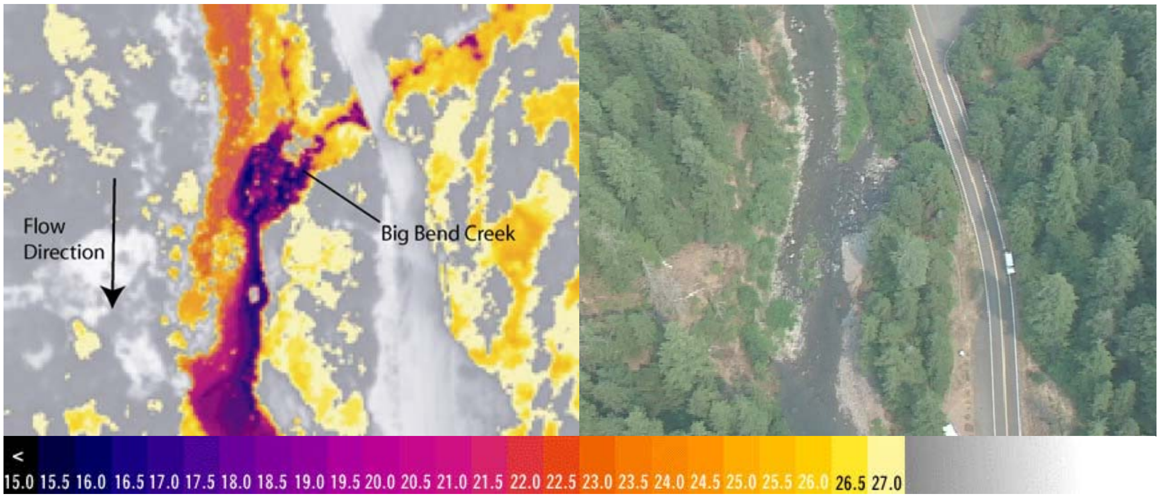

Figure 24 - TIR/color video image showing the confluence of Steamboat Creek and Big Bend Creek (16.4°C) at river mile 10.9. The inflow of Big Bend Creek lowered water temperatures in Steamboat Creek by ≈3.9°C at the time of the TIR survey. (*Frame: stm0479*)

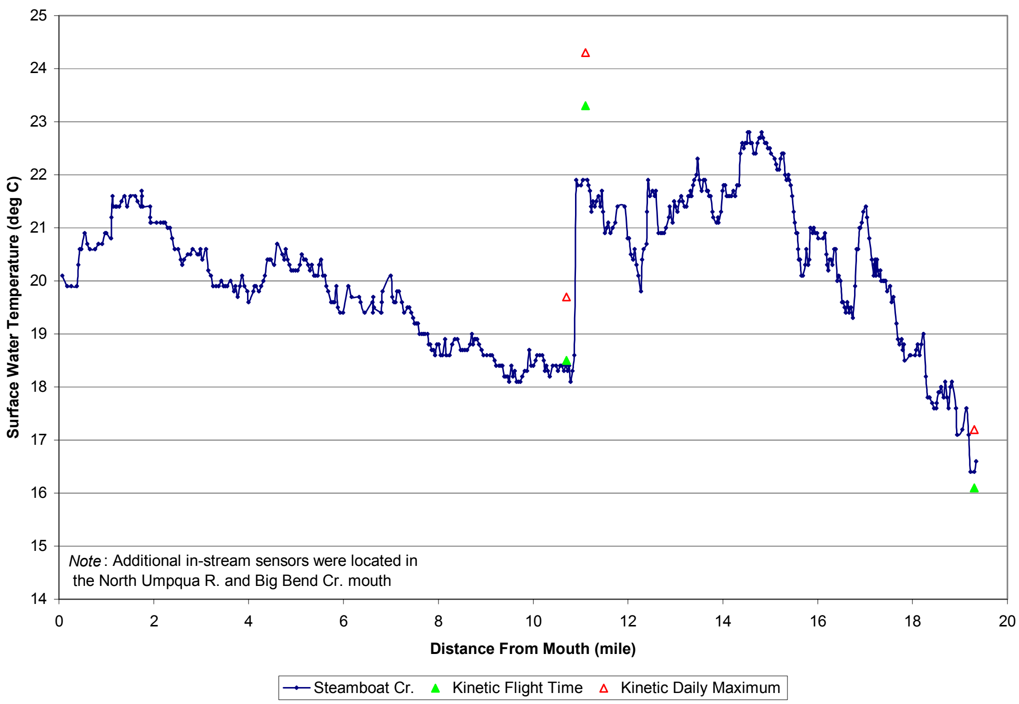

Figure 25 - Median channel temperatures versus river mile for Steamboat Creek. The profile also shows the kinetic temperatures measured at the time of the TIR survey and the recorded daily maximum temperatures.

Canton Creek

Figure 26 illustrates the longitudinal temperature profile of Canton Creek that was derived from the TIR images. Sampled tributary inflows are labeled by name on the profile and are summarized in Table 12. Canton Creek is a major tributary to Steamboat Creek and exhibited similar thermal characteristics. At the upstream end of the survey (rm 10.5), stream temperatures were ≈17.6°C and warmed downstream to the confluence of Pass Creek (rm 10.0). A cool tributary inflow, identified as Salmon Creek, was sampled at river mile 10.1. From Pass Creek, stream temperature generally increased in a downstream direction reaching ≈21.3°C at the confluence of Steamboat Creek. However, localized cooling was observed at distinct locations along the stream course. Radiant temperatures decreased by ≈1.5°C between rm 8.9 and 8.5, although the source of cooling at this location was not evident from the TIR images. A cool side channel at rm 7.9 (Figure 27) and Wolverine Cr. at rm 6.2 contribute to a ≈1.8°C decrease in temperatures between rm 6.5 and 6.2. Downstream of Wolverine Creek, stream temperatures generally increased again reaching 22.4°C at river mile 3.2. Another general decrease (≈1.6°C) in stream temperatures was observed between rm 3.2 and rm 2.5. The factors contributing the cooling through this reach were not apparent from the TIR images or topographic reference maps. Of the six surface inflows sampled during the analysis, five contributed cooler water to the main stem.

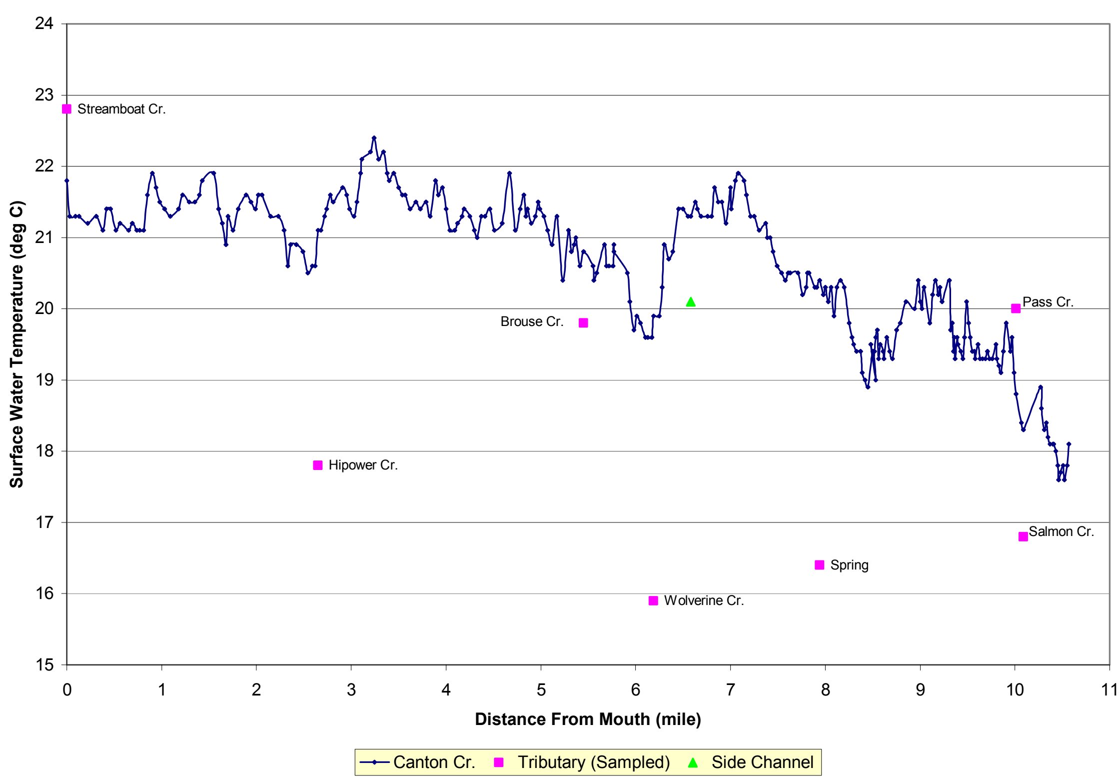

Figure 26 - Median channel temperature versus river mile for Canton Creek, OR. Tributary inflows are labeled by name on the plot.

Table 12 - Tributary temperatures for Canton Creek, OR.

Tributary Name	Image	km	mile	Tributary (Sampled) °C	Canton Cr. °C	Difference °C
Steamboat Cr.	cant0081	0.0	0.0	22.8	21.8	1.0
Hipower Cr. (LB)	cant0233	4.3	2.7	17.8	21.1	-3.3
Brouse Cr. (LB)	cant0426	8.8	5.5	19.8	20.8	-1.0
Wolverine Cr. (RB)	cant0474	10.0	6.2	15.9	19.9	-4.0
Spring (LB)	cant0596	12.8	7.9	16.4	20.4	-4.0
Pass Cr. (RB)	cant0903	16.1	10.0	20.0	18.8	1.2
Salmon Cr. (LB)	cant0914	16.2	10.1	16.8	18.3	-1.5
Side Channels						
Side Channel (LB)	cant0502	10.58	6.58	20.1	21.3	-1.2

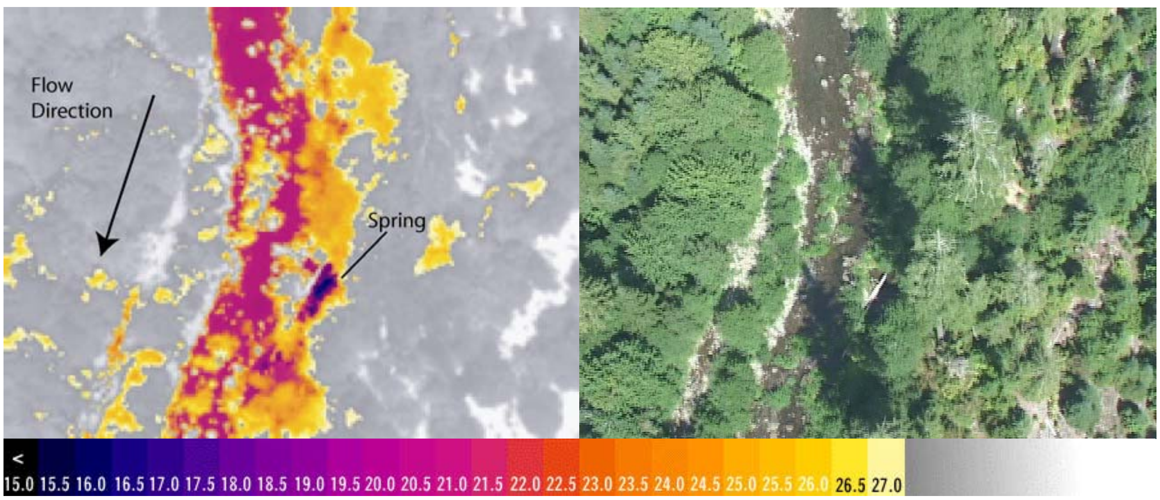

Figure 27 - TIR/color video image showing a cool side channel (20.1°C) (possibly a spring brook) at river mile 7.9. This side channel inflow and Wolverine Creek (rm 6.2) contribute to a decrease in Canton Creek water temperatures between rm 6.5 to 6.2. (*Frame: can0596*).

Little River

Figure 28 illustrates the longitudinal temperature profile for Little River developed from the TIR data. The location and name of sampled tributary inflows are illustrated on the profile and summarized in Table 13. The profile also shows the location of tributaries and other surface inflows that were detected during the analysis, but could not be sampled due to small size (*relative to pixel size*) or masking by riparian vegetation.

At the time of the survey, stream temperatures at rm 25.1 were ≈16.2°C and warmed steadily downstream reaching ≈21.9°C at river mile 17.0. Black Creek (rm 20.4) and a small unnamed tributary (rm 19.6) were sampled through this reach and both contributed cooler water to the main stem. In addition, this reach contained eight tributary inflows that were detected but not sampled. The tributary inflows contributed to the observed local spatial thermal variability in this reach. However, thermal variations were typically <1°C and the relative contribution of natural sources and the artifacts of TIR remote sensing were not evident from the images.

Negro Creek (rm 16.6) contributes to an apparent ≈2.0°C decrease in water temperature between river mile 17.2 and 16.6. The profile shows that the cooling trend begins between Negro Creek and the White Creek Campground (rm 17.6) and that stream temperatures begin to increase downstream of Negro Creek reaching ≈22.6°C by rm 13.6. Stream temperatures remained relatively consistent (±0.6°C) over the next 4.4 miles (rm 9.1) and Wolf Creek was a source of cooling through this reach. At river mile 9.1, the longitudinal heating rate increased with stream temperatures reaching ≈24.2°C at rm 8.5. Stream temperatures decreased by ≈1.9°C between river mile 8.5 and 6.7. Cavitt Creek and Jim Creek (rm 7.0) were sampled through this reach and both were cooler than the main stem (Figure 29). Downstream of rm 6.7, water temperatures continued to show a general downstream warming trend and Little River was observed as a source of thermal loading to the North Umpqua River.

Table 13 - Tributary temperatures for Little River, OR.

Tributary Name	Image	km	mile	Tributary °C	Little R. °C	Difference °C
North Umpqua R. (RB)	lr0031	0.0	0.0	20.7	24.3	-3.6
Fall Creek (LB)	lr0198	4.4	2.7	20.5	24.0	-3.5
Jim Creek (LB)	lr0416	11.3	7.0	19.5	23.0	-3.5
Cavitt Creek (LB)	lr0418	11.3	7.0	22.4	23.3	-0.9
Wolf Creek (LB)	lr0632	17.7	11.0	19.7	22.8	-3.1
Spring (LB)	lr0850	23.5	14.6	18.4	22.3	-3.9
Emile Creek (RB)	lr0858	23.6	14.7	21.0	22.1	-1.1
Negro Creek (LB)	lr0990	26.8	16.7	18.5	20.6	-2.1
Unnamed Trib. (LB)	lr1331	31.5	19.6	17.4	19.1	-1.7
Black Creek (LB)	lr1474	32.8	20.4	18.9	19.7	-0.8

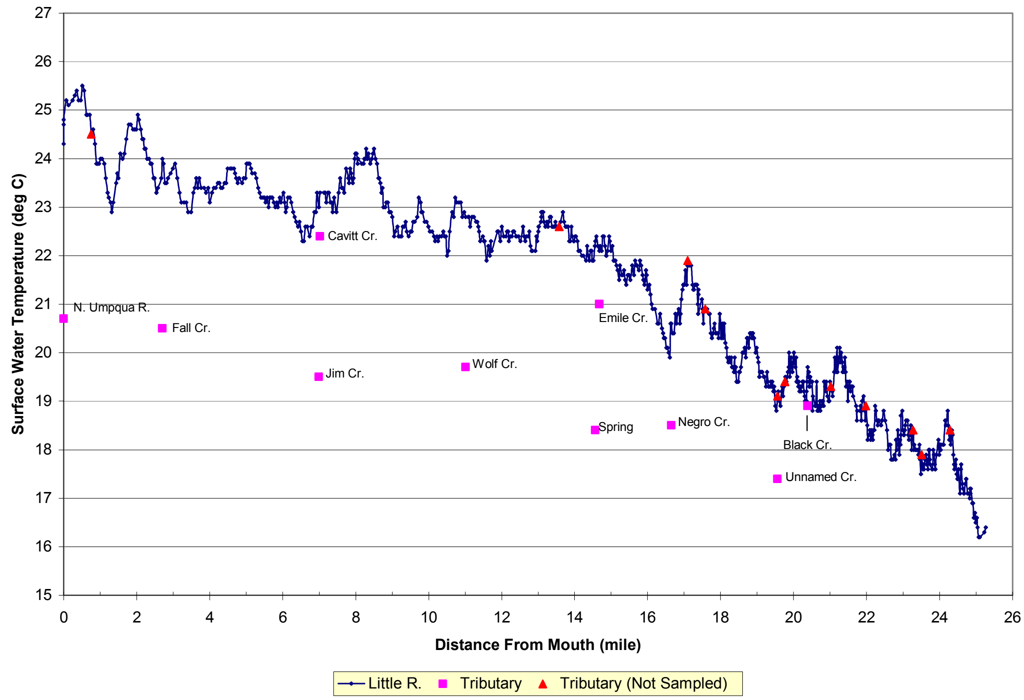

Figure 28 - Median channel temperatures versus river mile for Little River, OR. Sampled tributaries are labeled by name on the profile.

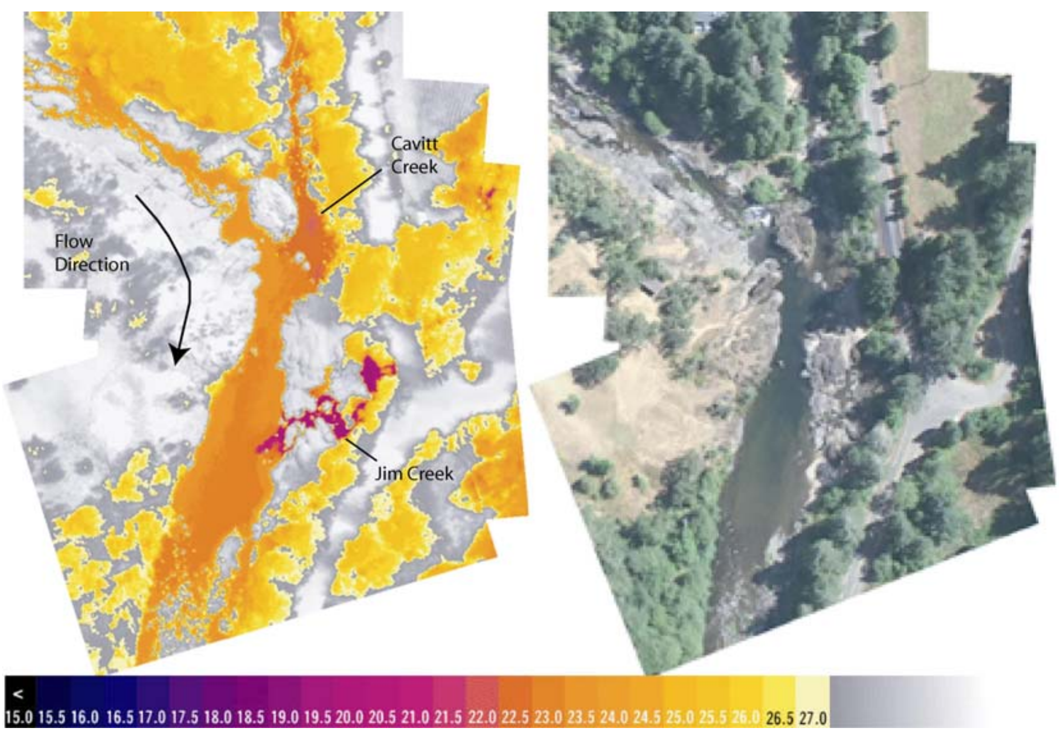

Figure 29 - TIR/color video image pair showing the confluence of Little River (23.0°C) and Jim Creek (19.5°C) and Cavitt Creek (22.4°C) at river mile 7.0 (*frames: lr0415-lr0419*).

Cavitt Creek

Figure 30 illustrates the longitudinal temperature profile for Cavitt Creek developed from the TIR data. The location and name of the tributary inflows sampled during the analysis are illustrated on the profile and also summarized in Table 14.

The survey ended at the confluence of Cavitt Creek and Cultus Creek (rm 10.7). Although the Cultus Creek confluence was detected in the TIR imagery, the surface of Cultus Creek was masked by riparian vegetation precluding an accurate temperature sample. At rm 10.7, water temperatures in Cavitt Creek were ≈17.4°C and generally warmed in the downstream direction reaching 23.4°C at rm 6.6. A maximum longitudinal heating rate was observed between river miles 10.2 and 9.5 with water temperatures gaining ≈3.8°C (rate = 5.4°C/mile). The factors contributing to rapid longitudinal heating through this reach were not obvious from the TIR images or topographic reference maps.

From river mile 6.6 to the mouth, water temperatures in Cavitt Creek generally remained above 21.0°C, but exhibited a higher degree of thermal variability than observed upstream of rm 6.6. A maximum survey temperature of 23.9°C was recorded between river miles 6.0 and 5.5. Water temperatures in Cavitt Creek at the Little River confluence were 22.6°C indicating a net decrease in stream temperatures through the lower 5.7 river miles at the time of the survey. McKay Creek (rm 2.6) and an apparent spring (rm 4.9) were the only two tributaries sampled through this reach and both supplied cooler water to the main stem. Three side channels were also detected during the analysis, which contained cooler water than the main stem (Figure 31). The cooler side channels are likely floodplain spring brooks and their occurrence suggests that shallow sub-surface flow is a contributing factor to the observed thermal variability in the lower 6 miles of Cavitt Creek.

Table 14 - Tributary temperatures for the Cavitt Creek, OR.

Tributary Name	Image	km	Mile	Tributary °C	Cavitt Cr. °C	Difference °C
Little River	cav0029	0.0	0.0	24.2	22.6	1.6
McKay Creek (LB)	cav0351	4.2	2.6	19.2	22.1	-2.9
Spring (LB)	cav0665	7.9	4.9	18.3	22.9	-4.6
Springer Creek (LB)	cav1157	12.7	7.9	19.9	22.9	-3.0
Side Channel						
Side Channel (LB)	cav0252	2.9	1.8	21.3	22.1	-0.8
Side Channel (LB)	cav0717	8.3	5.2	20.4	22.7	-2.3
Side Channel (LB)	cav0756	8.7	5.4	19.9	22.4	-2.5

RB – right bank; LB – left bank looking downstream

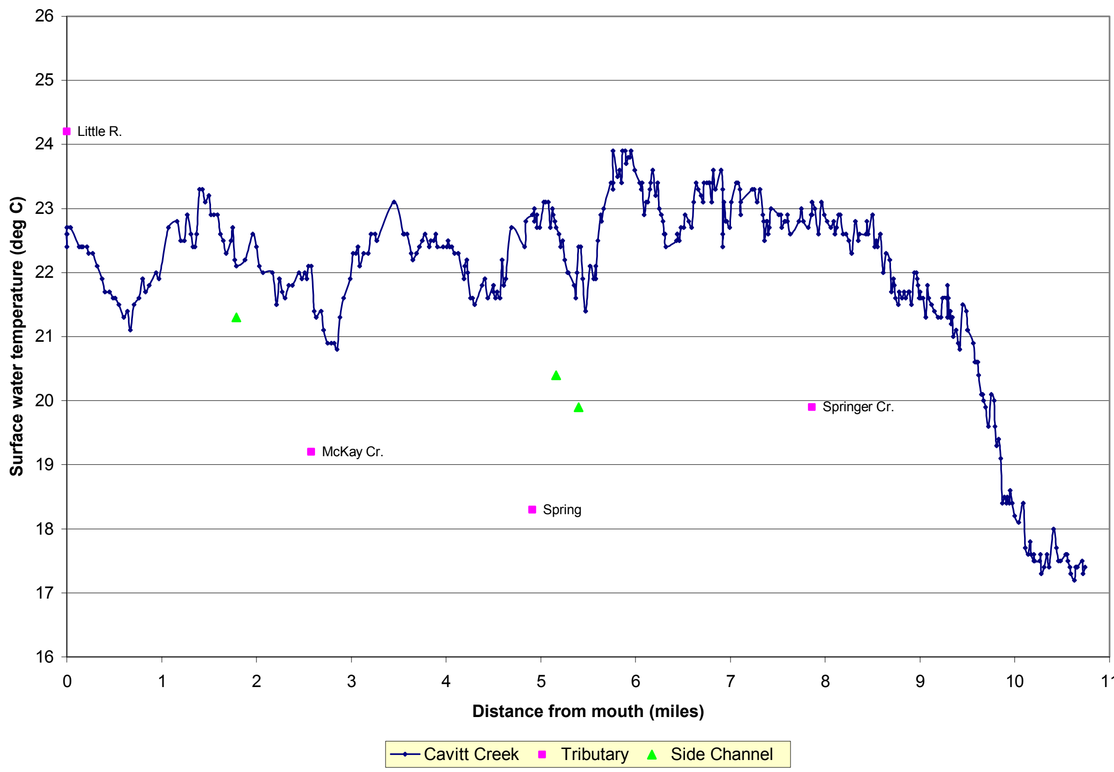

Figure 30 - Median channel temperatures versus river mile for Cavitt Creek, OR on July 26, 2003. The profile also shows the location and name of tributary inflows detected during the analysis.

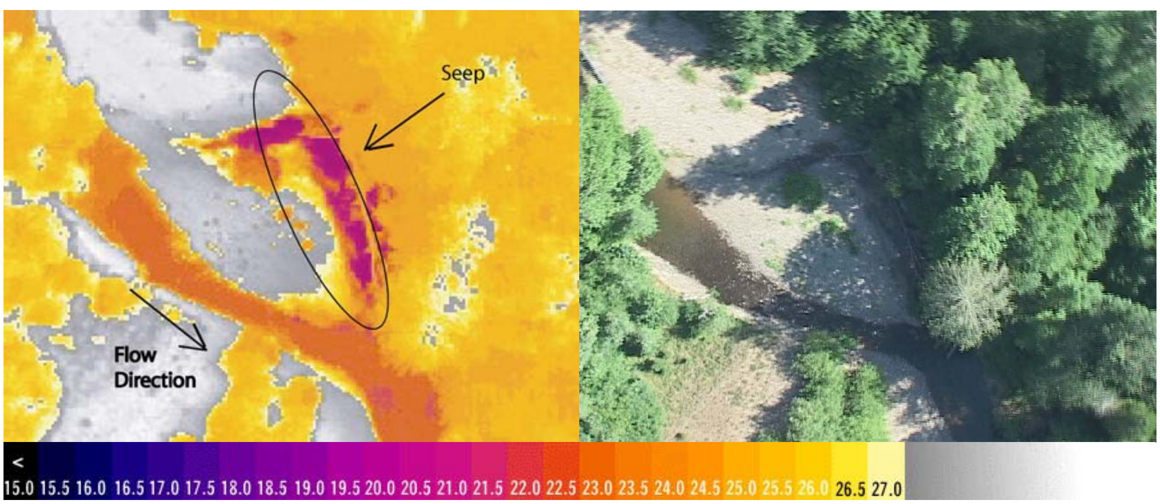

Figure 31 - TIR/color video image showing a cooler side channel (19.9°C) to Cavitt Creek (22.4°C) at river mile 5.4. The presence of cooler water in the side channel suggests shallow sub-surface flow through the floodplain as a possible cooling pathway (*Frame: cav0575*).

Rock Creek

Figure 32 illustrates the longitudinal temperature profile for Rock Creek developed from the TIR data. The location of tributary and side channel features sampled during the analysis are illustrated on the profile and also summarized in Table 15. The plot also shows the location of tributaries that were detected during the analysis, but not sampled due to small size and/or masking by riparian vegetation.

At the upstream end of the survey (rm 12.7), water temperatures in Rock Creek warmed from ≈18.7°C to ≈20.2°C at rm 12.0. Northeast Rock Creek was sampled at river mile 12.5, but showed no apparent thermal contrast to the main stem. Downstream of rm 12.0, Rock Creek continued to warm reaching ≈20.6°C at river mile 11.4 before showing a slight cooling trend (≈1.3°C) between river miles 11.4 and 10.7. Although no tributaries were detected, the topographic reference maps show that Pebble Creek (rm 11.3) and Cobble Creek (rm 10.9) enter Rock Creek within this reach. However, the source of apparent cooling between river miles 11.4 and 10.7 was not apparent from the TIR images. Stream temperatures increased again downstream of river mile 10.7 reaching ≈ 21.0°C at river mile 9.6.

Water temperatures in Rock Creek dropped again to ≈19.1°C at rm 8.8 in apparent response to the inflow of the East Fork Rock Creek (≈18.7°C) (Figure 33). Stream temperatures increased again downstream of the East Fork reaching ≈20.7°C at rm 7.7, but remained consistently around 20.7°C (±0.4°C) to river mile 4.5. A side channel that was slightly cooler (-0.5°C) than the main channel was sampled at river mile 5.0 and Harrington Creek (rm 6.8) and two unnamed tributaries (rm 7.2 and rm 7.7) were detected through this reach, but were not sufficiently visible to obtain an accurate temperature sample. Stream temperatures showed an apparent 1.0°C increase between river miles 4.5 and 3.8. At river mile 3.8, the longitudinal temperature profile shows a sharp 0.7°C decrease in stream temperature near the confluence of Conley Creek, which was detected, but not sampled. Between river miles 3.8 and 1.6, stream temperatures remained near 21.1°C with some local variability observed at river mile 2.6. An unnamed tributary (18.5°C) at river mile 1.9 and two side-channel/off-channel features were sampled through this reach. Between river miles 1.6 and 0.7, stream temperatures showed an apparent decrease of ≈2.2°C. McComas Creek (18.0°C) at river mile 1.6 contributes to the observed cooling. However, the cooling trend continues for ≈1.0 miles below the McComas Creek confluence suggesting that additional factors such as sub-surface exchanges contribute to the cooling.

Two in-stream sensors were used to ground truth the radiant temperatures derived from the TIR images. One sensor was located in the North Umpqua River just upstream of the mouth of Rock Creek and did not provide information on the diurnal temperature cycle in Rock Creek. The sensor at river mile 7.4 showed that stream temperatures at the time of the survey were ≈1.5°C less than the recorded daily maximum at this location (Figure 34).

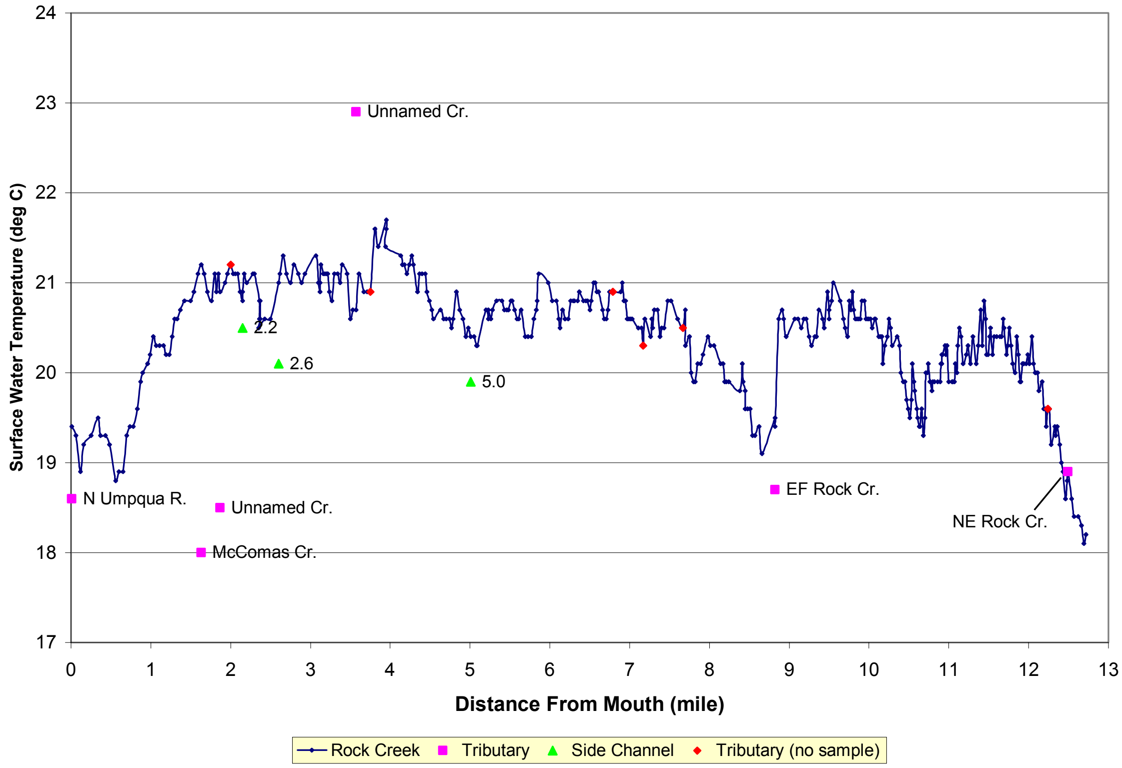

Figure 32 - Median channel temperatures versus river mile for Rock Creek, OR. The plot also shows the location of surface water inflows (i.e. tributaries, side channels, etc) that were sampled during the analysis. Tributaries are labeled by name, while side channel/off channel features are labeled by river mile. The plot also shows the location of tributaries that were detected in the imagery, but not sampled due to their small size.

Table 15 - Tributary temperatures from Rock Creek, OR.

Tributary Name	Image	km	mile	Tributary °C	Rock Cr. °C	Difference °C
North Umpqua R. (LB)	rock0006	0.0	0.0	18.6	19.4	-0.8
McComas Cr. (RB)	rock0078	2.6	1.6	18.0	21.2	-3.2
Unnamed (LB)	rock0091	3.0	1.9	18.5	20.9	-2.4
Unnamed (RB)	rock0189	5.7	3.6	22.9	20.7	2.2
EF Rock Cr. (LB)	rock0514	14.1	8.8	18.7	19.4	-0.7
NE Rock Cr. (LB)	rock0862	20.1	12.5	18.9	18.9	0.0
Side Channel/Off Channel						
Off-Channel (LB)	rock0108	3.5	2.2	20.5	20.9	-0.4
Side Channel (LB)	rock0135	4.2	2.6	20.1	21.0	-0.9
Off-Channel (LB)	rock0265	8.1	5.0	19.9	20.4	-0.5

RB – right bank; LB – left bank looking downstream

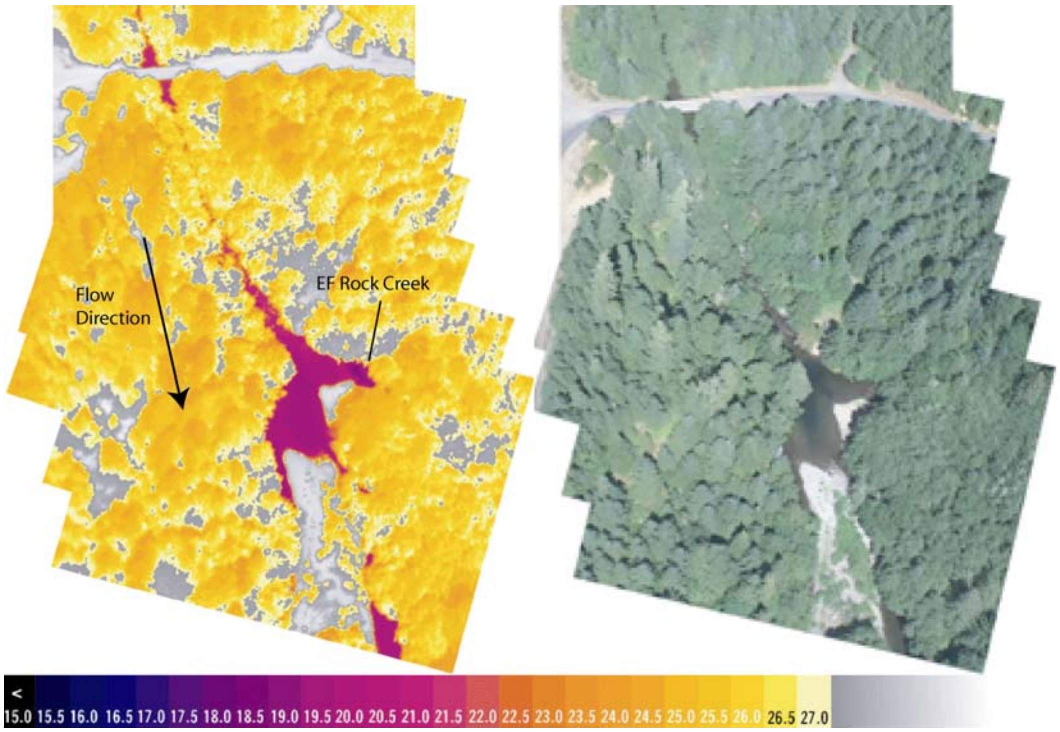

Figure 33 - TIR/color video image mosaic showing the confluence of Rock Creek and the EF Rock Creek (18.7^{o}C) at river mile 8.8. (*Frames: rock0513-0518*)

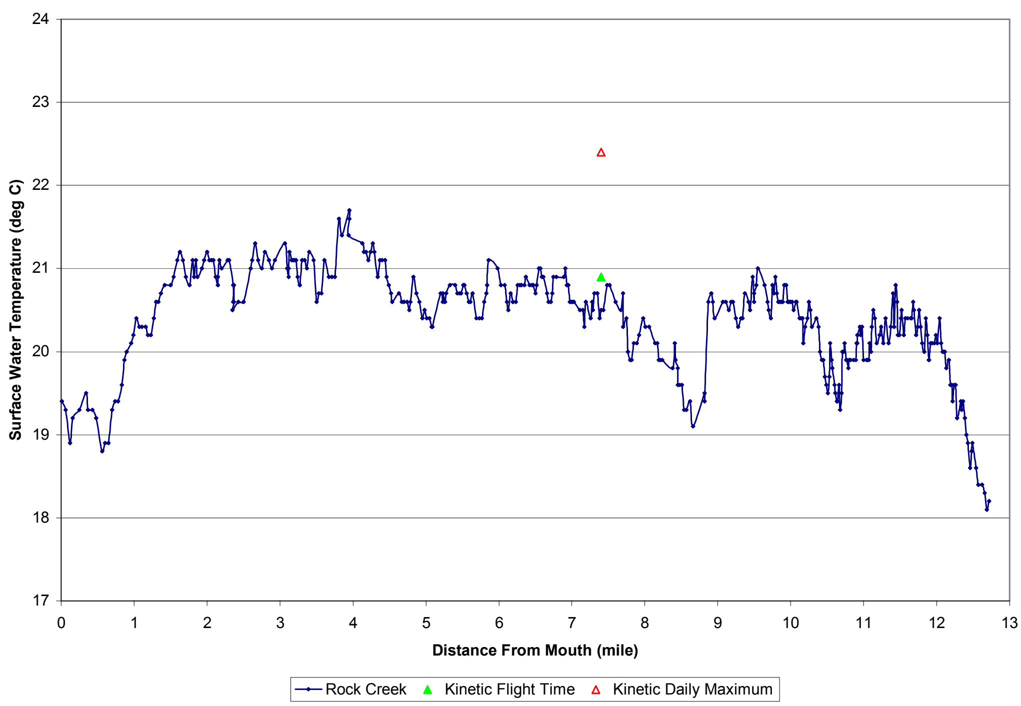

Figure 34 - Median channel temperature versus river mile for Rock Creek, OR. The plot also shows the kinetic (in-stream) temperatures at time of the flight and the recorded daily maximum temperatures at the ground truth locations.

Discussion

TIR remote sensing surveys were successfully conducted on selected streams and rivers in the North Umpqua River basin. The surveys were completed despite several wildfires burning in the basin through the cooperation and support of the USFS. Longitudinal temperature profiles were produced for each surveyed stream, which illustrate broad scale spatial temperature patterns and the location and influence of tributary and surface water inflows. The following paragraphs provide a brief discussion of the conditions found on each stream surveyed in the North Umpqua River Basin.

North Umpqua River: In the North Umpqua River, a shift in the longitudinal heating rate from slight cooling to steady downstream warming was observed near Susan Creek (river mile 46.1). The factors which contribute to the observed change in the spatial temperature patterns at this location warrant further investigation. Four tributaries were sampled during the analysis and all but Fox Creek contributed water that was warmer than the main stem. In addition, visual inspection of the topographic maps show that the North Umpqua River transitions from a confined canyon to a more open (lower gradient) topography near the confluence of Rock Creek (rm 35.1). Further analysis should consider the relationship of the spatial temperature patterns to stream gradient, topography, and channel characteristics.

The 2002 survey of the North Umpqua River compliments TIR remote sensing flights conducted on the North Umpqua River upstream of Steamboat Creek by WS, LLC in July 2001 (Figure 35). Although the TIR surveys were conducted in two different years, previous studies have shown that while absolute temperatures change, the spatial patterns of warming and cooling remain consistent between years. Comparison of the profiles at Steamboat shows that the absolute stream temperatures were warmer at the time of the July 25, 2002 TIR survey.

Steamboat: Steamboat Creek was the only TIR remote sensing survey in the North Umpqua River Basin affected by the wildfires. The proximity of the fires to Steamboat Creek watershed resulted in overhead smoke at some points along the survey route, which effectively reduced the level of direct sunlight reaching the stream. (Figure 36). The smoke did not influence the quality or accuracy of the TIR images. However, it gave the impression of a cloudy day at some points and also resulted in a slight haze on some of the color video images.

Spatial temperature patterns derived for Steamboat Creek show that it is a thermally complex system with a high degree of variation occurring along the stream gradient. Big Bend Creek plays a significant role in defining the thermal structure of Steamboat Creek and effectively resets water temperatures in the main stem at river mile 10.9. Upstream of Big Bend Creek, radiant temperatures showed a high degree of local spatial variability. This spatial variability and the observed stair-step pattern of heating suggest strong local variations in the factors or combination of factors driving stream temperatures between river mile 10.9 and 19.3. In general, surface temperatures exhibited

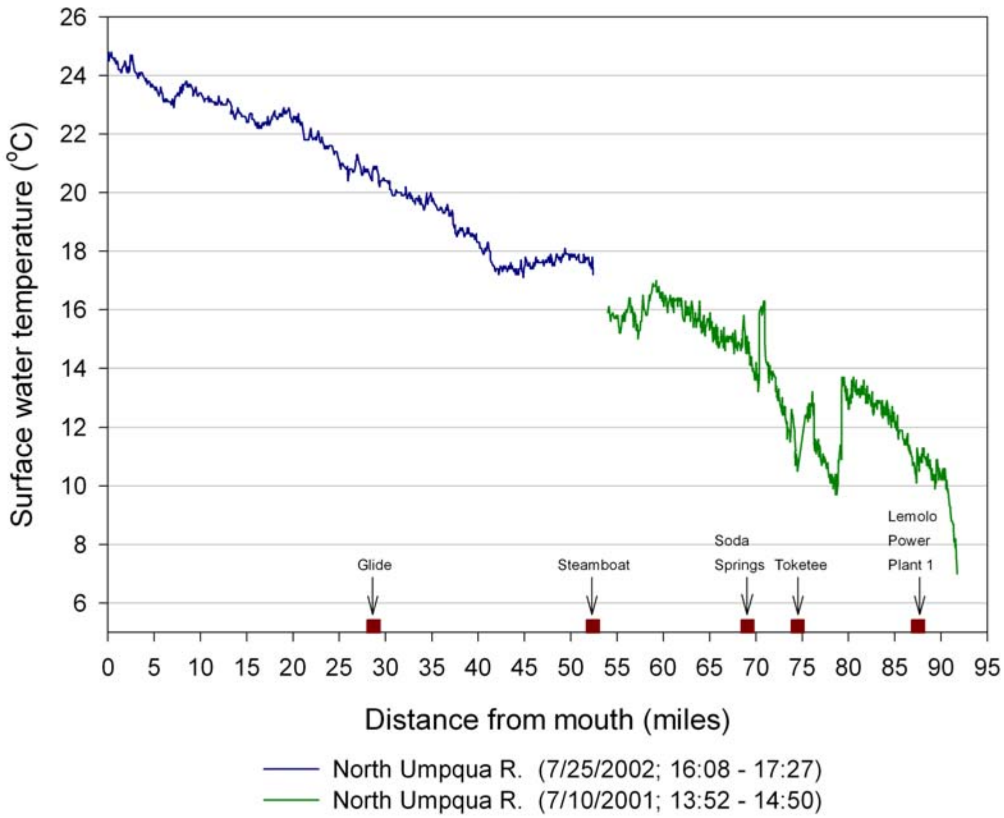

Figure 35 - Combined longitudinal temperature profiles from TIR remote sensing surveys of the North Umpqua River conducted on consecutive years. The combined surveys cover the full length of the North Umpqua River.

Figure 36 - Color video images of Steamboat Creek at rm 15.0 (left) and at rm 18.7 (right) showing the affect of smoke from fires proximate to the watershed. The two images show differences in the level of direct sunlight reaching the stream and overall sharpness of the color video images. (*frames: left = stm0706; right = stm0943*).

less local spatial thermal variability downstream of Big Bend Creek than in the upstream reaches, which is presumably due to the increased flow volume contributed by Big Bend Creek. A previous study showed preferential selection of pools with cool mean bottom temperatures (<19.0°C) by adult summer steelhead in Steamboat Creek (Baigum et. al. 1991). Thermal stratification in pools was not detected during the interpretation of the TIR images. However, the observed local spatial temperature variability may suggest subsurface flow entering deeper pools with subsequent rapid downstream warming in the shallow riffles and glides. This hypothesis requires further analysis and field verification.

Canton Creek: Water temperatures in Canton Creek exhibited both general downstream warming and local spatial thermal variability along the stream course. Tributaries and other surface inflows contributed to the observed variability. However, other areas of observed cooling were not associated with surface water inflows. Follow-on analysis may examine spatial associations between the observed temperature patterns and the geomorphic characteristics of the stream. Although Canton Creek is a tributary of Steamboat Creek, smoke from the regional wildfires was not detectable in the Canton Creek drainage.

Little River: Water temperatures in the Little River exhibited an overall pattern of downstream warming with only local variations.

Cavitt Creek: Cavitt Creek exhibited one of the more interesting basin scale temperature patterns in the basin. Stream temperatures showed a general cooling trend over the lower 5.5 miles with some local variability. The results of the survey suggest that the source of cooling may be shallow sub-surface exchanges within the channel floodplain. Further analysis or field work is required to verify this hypothesis.

Rock Creek: Overall, six tributary inflows were sampled during the analysis of Rock Creek and five contributed water that was cooler than the main stem. Three side channels were also sampled during the analysis and each were slightly cooler than the main stem suggesting sub-surface recharge as a possible cooling source in the side channels. The longitudinal temperature profile shows spatial variability throughout the profile, but not a lot of local variability. The most significant is the cooling observed near the mouth.

South Umpqua River Basin

Overview

The TIR remote sensing surveys in the South Umpqua River Basin were conducted on July 27-28, 2002 (Figure 37). As with the North Umpqua, the South Umpqua River was surveyed at a flight altitude that provided a wider image footprint (*lower spatial resolution*) to better capture the full width of the river and off-channel channel features. The South Umpqua River was also surveyed in a downstream direction starting at the confluence of Boulder Creek and continuing to the mouth. By contrast, tributaries in the basin were surveyed at a lower altitudes (*above ground level*) to provide higher spatial resolution and better visibility through the riparian vegetation. All tributaries were surveyed upstream starting from the stream mouth. Table 16 summarizes the survey times, extents, and image resolution for each surveyed stream in the basin.

Wildfires were active in the South Umpqua River Basin during the dates of the TIR surveys (Figure 38). The TIR remote sensing flights were coordinated with USFS personnel at the helicopter base located near the town of Tiller, OR and USFS protocols were followed explicitly while operating in the basin. The wildfires were not a factor during surveys of Olalla Creek, Myrtle Creek, or the South Umpqua River downstream of Jackson Creek. However, smoke from the wildfires did influence TIR surveys on Jackson Creek and the South Umpqua River upstream of Jackson Creek. On the South Umpqua River, the TIR survey was limited to reaches downstream of the Boulder Creek confluence due to poor visibility. This trimmed approximately 11.0 miles off the original survey extent, which was intended to go upstream to Castle Rock Fork Creek (rm 102.3). Smoke is visible in the color video imagery on portions of Jackson Creek and the South Umpqua River near Boulder Creek, but did not affect the quality of the TIR images.

Weather conditions were warm and clear and were considered ideal for the surveys. Recorded air temperatures and relative humidity during the time of the survey are summarized in Table 17.

Table 16 - Summary of river segments surveyed with TIR and color video in the South Umpqua River Basin from July 27-28, 2002.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent & Direction	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Olalla Cr.	27-Jul	13:39-14:23	Mouth to Berry Cr.	19.7	129 (423)	0.4 (1.3)
Myrtle Cr.	27-Jul	14:33-14:36	Mouth to forks	1.0	129 (423)	0.4 (1.3)
Jackson Cr.	27-Jul	15:43-16:36	Mouth to Falcon Cr.	20.0	129 (423)	0.4 (1.3)
South Umpqua R.	28-Jul	14:10-17:26	u/s of Boulder Cr. to Mouth	91.0	193 (635)	0.6 (2.0)

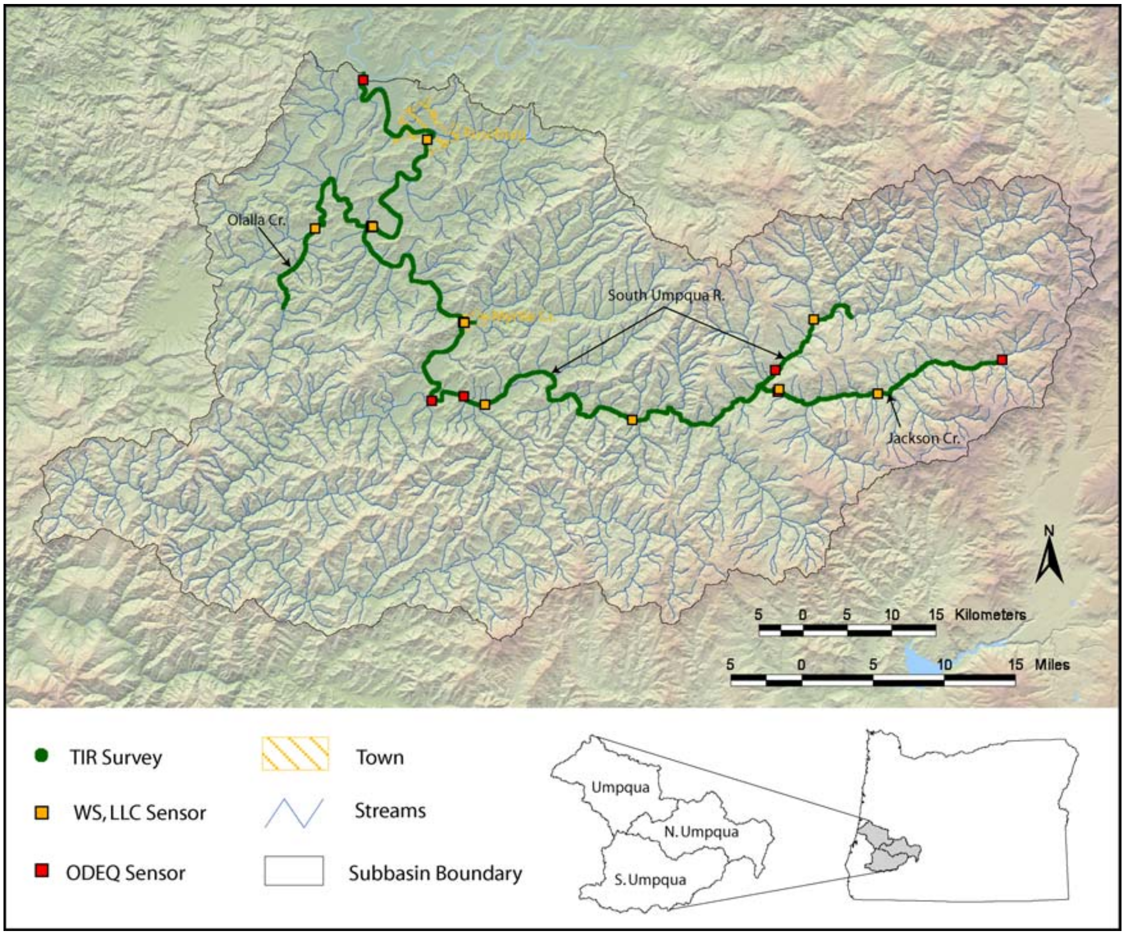

Figure 37 - Map showing TIR surveys conducted in the South Umpqua River basin. The map also shows the location of in-stream sensors used to ground truth the TIR images.

Figure 38 – Smoke from wildfires in the Upper South Umpqua River Basin hangs near the ridge tops.

Table 17 - Meteorological conditions recorded during the TIR surveys on July 27-28, 2002 at the confluence of the North and South Umpqua Rivers.

	July 27, 2002			July 28, 2002		
Time	Air Temp °F	Air Temp °C	RH %	Air Temp °F	Air Temp °C	RH %
1:30 PM	79.4	26.3	31.0	85.8	29.9	33.4
2:00 PM	80.8	27.1	30.5	88.0	31.1	31.0
3:00 PM	83.7	28.7	21.8	89.5	31.9	32.0
4:00 PM	84.4	29.1	24.4	89.5	31.9	31.0
5:00 PM	84.4	29.1	25.4	89.5	31.9	31.5
6:00 PM	83.7	28.7	24.0	89.5	31.9	32.0

Results

Thermal Accuracy

The average absolute difference between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images was within the desired accuracy (< 0.5°C) for Olalla Creek, Myrtle Creek, and Jackson Creek Table 18). On the South Umpqua River, comparison of radiant temperatures and kinetic temperatures showed a range of differences of -0.8°C to 0.9°C for eleven of the twelve in-stream monitoring sites. Although all eleven sites had differences within ±1.0°C, this range is greater than typically observed during TIR surveys. No definitive explanation is given for these differences, but the reduced accuracy should be considered in the interpretation of spatial temperature patterns on the South Umpqua River. At one location (rm 12.1), radiant temperatures were 1.7°C cooler than the recorded in-stream temperatures. The factors contributing to this difference were not evident from the TIR images or from quality checks on the in-stream sensor.

Table 18 - Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures for streams surveyed in the South Umpqua River Basin.

Stream	Sensor	Image	River mile	Time 24 hr	Kinetic °C	Radiant °C	Difference °C
Olalla Creek, July 27, 2002, Avg = 0.5							
Lookingglass Cr.	WS, LLC	oll0019	0.0	13:40	26.3	25.5	0.8
Lookingglass Cr.	ODEQ	oll0019	0.0	13:40	25.8	25.5	0.3
South Umpqua R.	ODEQ	oll0022	0.0	13:40	25.7	25.2	0.5
Olalla Cr.	WS, LLC	oll1589	11.60	14:06	19.6	19.8	-0.2
Myrtle Creek, July 27, 2002, Avg = 0.5							
South Umpqua R.	ODEQ	myr0058	0.0	14:34	25.4	24.6	0.8
Myrtle Cr.	WS, LLC	myr0059	0.0	14:34	22	22.2	-0.2
Jackson Creek, July 27, 2002, Avg=0.4							
Jackson Cr.	ODEQ	jack0179	1.3	15:46	22.6	22.2	0.4
Jackson Cr.	WS, LLC	jack0190	1.5	15:36	22.8	22.2	0.6
Jackson Cr.	WS, LLC	jack1102	9.6	16:01	20.3	20.7	-0.4
Jackson Cr.	ODEQ	jack2451	20.2	16:26	18.3	18.6	-0.3
South Umpqua R., July 28, 2002, Avg 0.6							
North Umpqua R.	WS, LLC	sfu6208	0.0	17:25	25.0	25.8	-0.8
South Umpqua R.	ODEQ	sfu6203	0.0	17:25	26.6	27.4	-0.8
South Umpqua R.	WS, LLC	sfu5759	12.1	17:10	27.3	25.6	1.7
South Umpqua R.	ODEQ	sfu5183	25.0	16:51	28.4	27.5	0.9
Olalla Cr.	ODEQ	sfu5186	24.9	16:51	27.7	27.0	0.7
South Umpqua R.	ODEQ	sfu4546	38.8	16:30	25.4	26.1	-0.7
South Umpqua R.	ODEQ	sfu4519	38.8	15:47	25.4	25.7	-0.3
Cow Cr.	ODEQ	sfu4066	46.9	15:32	27.3	27.1	0.2
South Umpqua R.	ODEQ	sfu3908	50.0	15:26	26.0	25.5	0.5
South Umpqua R.	WS, LLC	sfu2426	67.7	14:51	24.5	23.7	0.8
South Umpqua R.	ODEQ	sfu0923	82.0	14:26	22.3	22.4	-0.1
South Umpqua R.	WS, LLC	sfu0401	87.0	14:17	20.0	20.0	0.0

Temporal Differences

Figure 39 shows in-stream temperature variations for three of the four streams in the South Umpqua River Basin during the TIR remote sensing surveys. The figure shows the temporal variations in stream temperatures at a single point in each surveyed stream, except Myrtle, which was too short to warrant a temporal plot. The plots are intended to provide a sense of how stream temperatures changed during the time frame of the flight and the timing of the flight relative to the recorded daily maximum temperatures. On each stream, the TIR survey occurred prior to maximum daily temperatures. At the plotted site on Jackson Creek and Olalla Creek stream temperatures increased by 0.4°C and 0.5°C respectively during the time span of the TIR surveys. On the South Umpqua River, stream temperatures at river mile 50.0 increased by 3.2°C during the course of the 3 hour and 10 minute survey. Due to the relatively long time span of the TIR survey, the magnitude of temperature changes during the course of the survey should be a consideration when interpreting basin scale temperature patterns in the South Umpqua River.

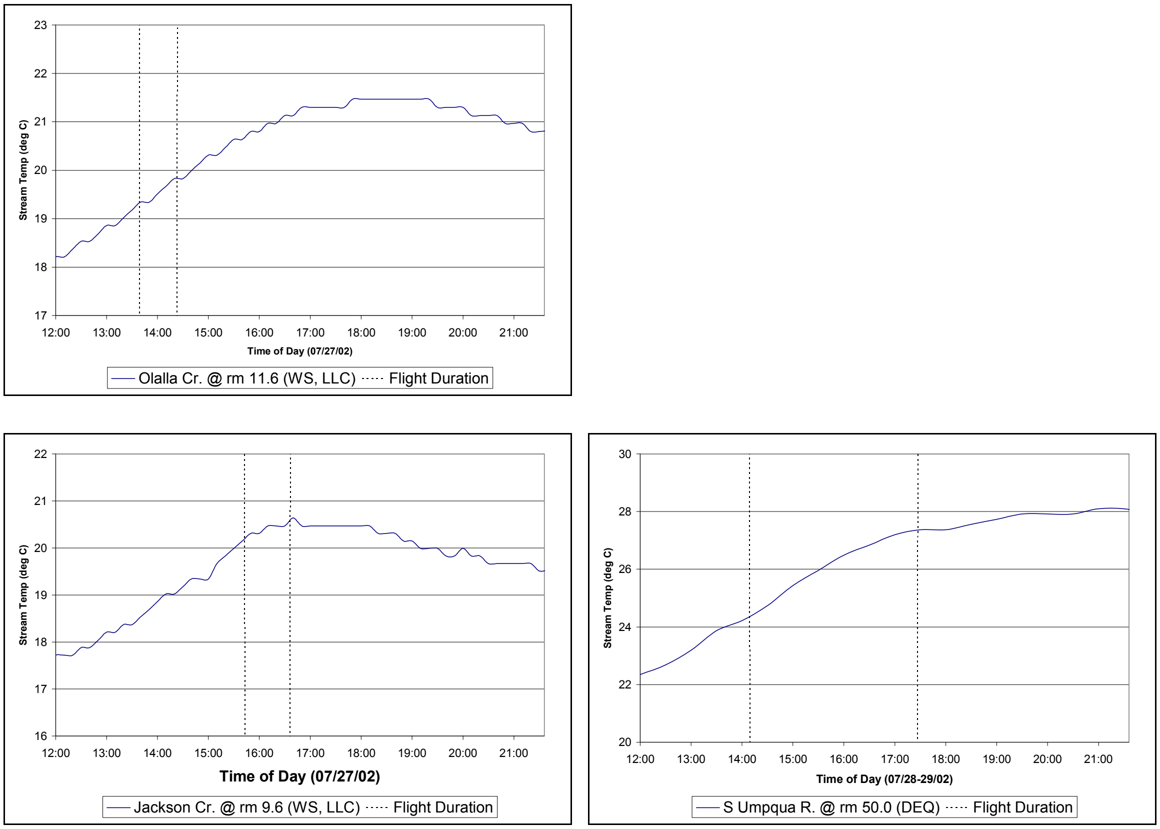

Figure 39 - Stream temperature variation and time of TIR remote sensing flight at locations on each surveyed stream in the South Umpqua River Basin except Myrtle Creek.

Longitudinal Temperature Profiles

Olalla Creek

Figure 40 shows the longitudinal temperature profile developed for Olalla Creek from the TIR data. The location and temperature of surface water inflows (i.e. tributaries, side channels) are also illustrated on the profile. Tributary names are shown on the profile and summarized in Table 19.

Berry Creek contributes cool water (≈9.3°C) to Olalla Creek and defined stream temperatures Olalla Creek at the upstream end of the survey (rm 18.9). The cool water from Berry Creek is presumably due to the outflow from Ben Irving Reservoir ≈0.6 miles upstream of Olalla Creek. Stream temperatures increased to ≈11.4°C by river mile 18.4, but remained consistently near 11.4°C (±0.6°C) to river mile 16.7. Stream temperatures increased steadily downstream of river mile 16.7 reaching ≈20.0°C at river mile 13.4. The local thermal decrease observed at river mile 15.8 occurred downstream of a small impoundment and appears to represents a transition from a partially stratified to a mixed condition (Figure 41). The longitudinal temperature profile also shows thermal response (*i.e. stratification behind impoundment with immediate decrease downstream*) to a similar impoundment at river mile 15.9. Although water temperatures generally warmed between river miles 16.7 and 13.4, no longitudinal heating was observed between river mile 15.0 and 14.4.

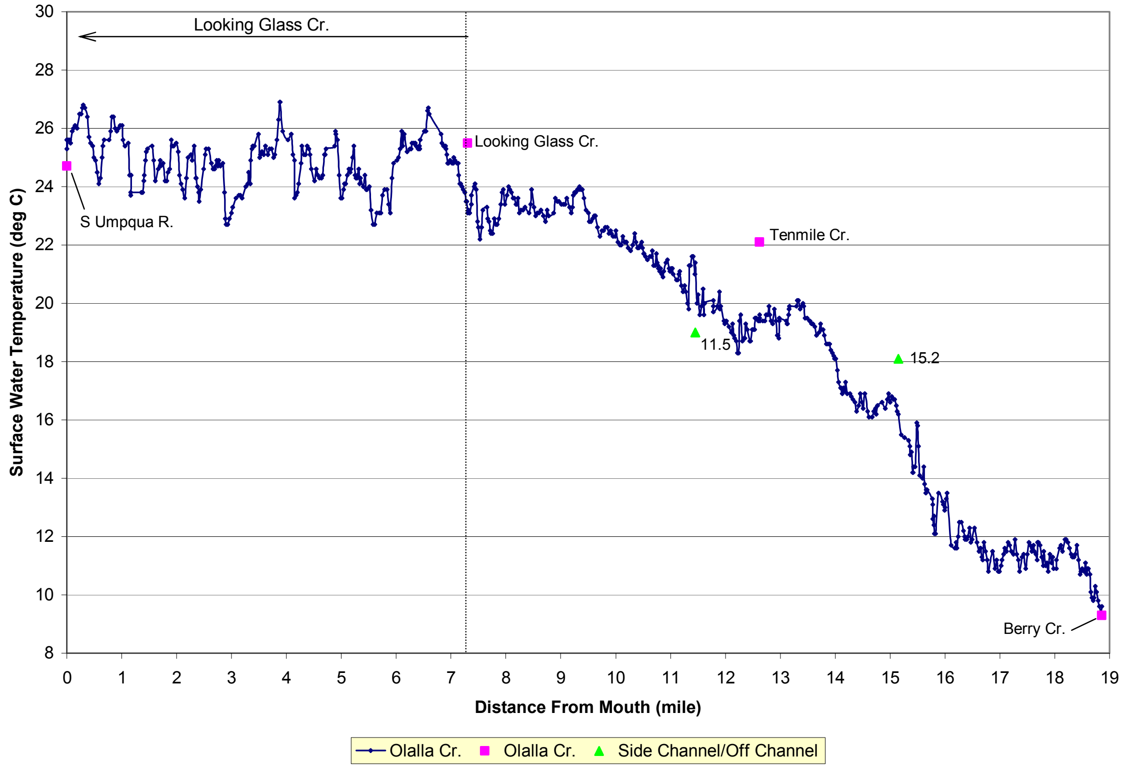

Figure 40 – Median channel temperatures versus river mile for Olalla Creek, OR. The profile also shows the location of surface water inflows.

Table 19 – Tributary temperatures for Olalla Creek, OR.

Tributary Name	*Image*	*km*	*mile*	*Tributary °C*	*Olalla Cr. °C*	*Difference °C*
South Umpqua (RB)	oll0017	0.0	0.0	24.7	25.6	-0.9
Lookingglass Creek (LB)	oll1035	11.8	7.3	25.5	23.1	2.4
Tenmile Creek (LB)	oll1705	20.3	12.6	22.1	19.6	2.5
Berry Creek (LB)	oll2579	30.4	18.9	9.3	9.6	-0.3
Side Channel/Off Channel						
Off-Channel (RB)	oll1560	18.4	11.5	19.0	21.4	-2.4
Side Channel (LB)	oll2069	24.4	15.2	18.1	16.2	1.9

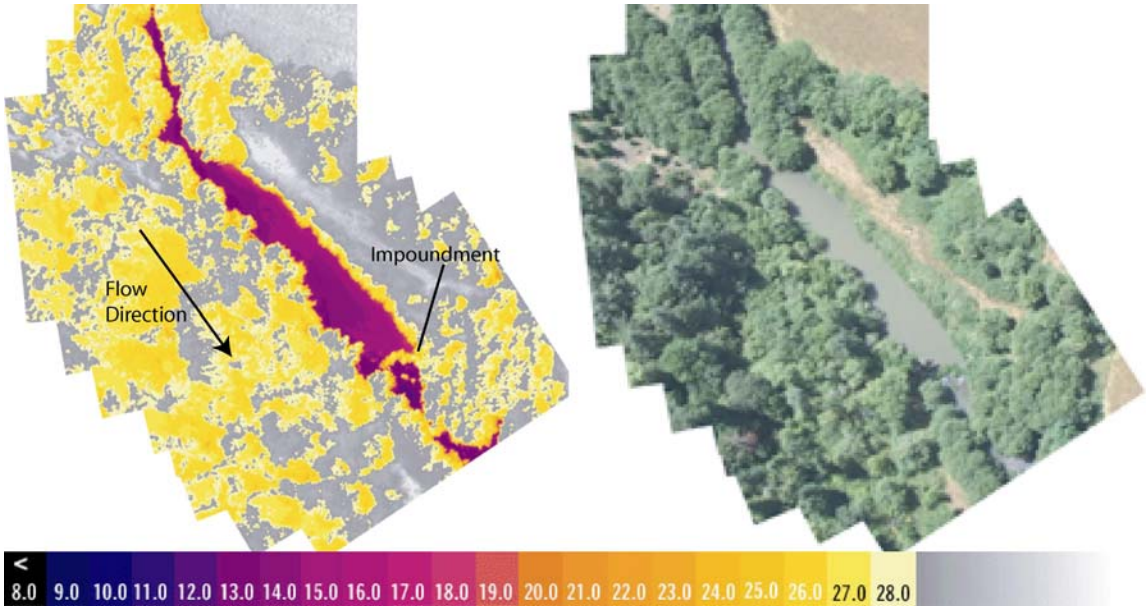

Figure 41 – TIR/color video image mosaic showing a decrease in surface temperatures downstream of a small impoundment in Olalla Creek. The temperature decrease is possibly due to a transition from a partially stratified to mixed condition (*Frames: oll2161-2170*).

Water temperatures in Olalla Creek showed a decrease of ≈1.6°C between river miles 13.4 and 12.3. Tenmile Creek (rm 12.6) enters the main stem through this reach and was observed as a source of thermal loading. Apparent cooling through this reach is likely due to either differential heating along the stream gradient (*due to changes in landscape variables such as channel morphology, terrain aspect, or vegetation*) or diffuse sub-surface discharge which buffers heating. Stream temperatures increase steadily again downstream of river mile 12.3, reaching a local maximum of 23.9°C at river mile 9.4. Variability in the downstream heating rate observed at river mile 11.3 appeared due to localized thermal stratification. Stream temperatures decreased to ≈23.1°C at river mile 9.2 and remained consistent (±1.0°C) to the confluence of Lookingglass Creek at river mile 7.3. As with other segments of Olalla Creek, local variability in radiant temperatures was observed at small in-stream impoundments (rm 7.8).

Olalla Creek joins Lookingglass Creek at river mile 7.3. Radiant temperatures exhibited a higher degree of local thermal variability in the Lookingglass Creek portion of the survey with temperatures ranging from ≈22.7°C to ≈26.9°C. Local variability in stream temperature is due to both thermal transitions at impoundments (river miles 1.5 and 3.3) and to some level of thermal stratification (river miles 4.2 and 5.6).

Myrtle Creek

Figure 42 illustrates the longitudinal temperature profile for Myrtle Creek and 0.2 miles of North Myrtle Creek. The temperature of the South Umpqua River is shown on the profile as well as the location of South Myrtle Creek. While the confluence of South Myrtle Creek was detected in the imagery, the water surface was masked by riparian vegetation, which precluded temperature sampling. Myrtle Creek was relatively small and partially masked by vegetation over much of its length. Stream temperature samples were acquired where surface water was visible in the TIR and color video images.

Radiant temperatures in Myrtle Creek showed an apparent decrease of ≈2.6°C between the end of the survey at river mile 0.0 and the South Myrtle Creek confluence. Another apparent decrease of ≈2.1°C was observed at river mile 0.3, which was not associated with any detected surface water inflows. Myrtle Creek was observed as a cooling source to the South Umpqua River.

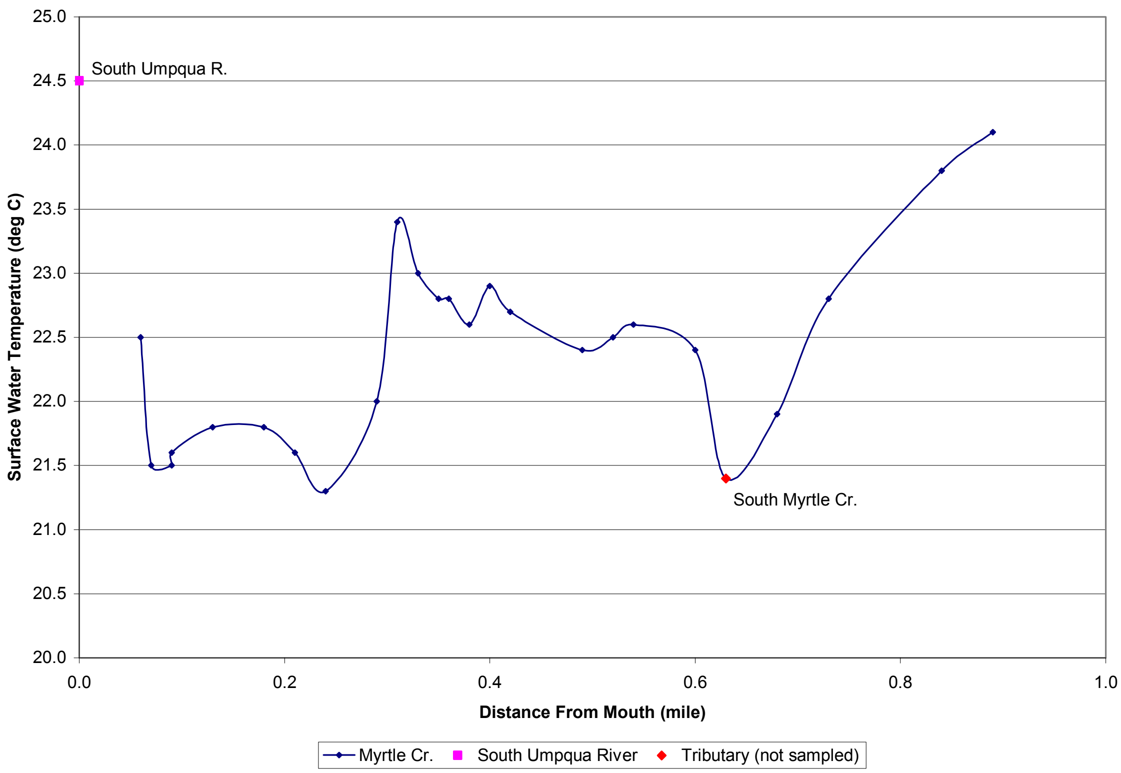

Figure 42 – Median channel temperature versus river mile for Myrtle Creek, OR.

Jackson Creek

Figure 43 illustrates the longitudinal temperature developed for Jackson Creek, OR from the TIR images. The plot also shows the location and temperature of surface water inflows sampled during the analysis and summarized in Table 20. Tributaries are labeled by name on the plot while springs and side channels are labeled by river mile.

At the upstream end of the survey (rm 20.2), water temperatures in Jackson Creek were ≈18.3°C and warmed in the downstream direction reaching ≈19.6°C by river mile 18.7. Falcon Creek (rm 20.0) was a source of cooling to the main stem in this reach. Downstream of river mile 18.7, stream temperatures decreased steadily reaching a survey minimum of 17.3°C at river mile 16.7. Cougar Creek (rm 17.9) and two unnamed tributaries contributed cooler water to Jackson Creek through this reach. In addition, two springs were sampled (rm 19.5 and 16.5) that were not identified on the USGS 7.5' topographic references, but contributed to localized cooling within this reach (Figure 44).

Between river miles 16.7 and 14.7, water temperatures in Jackson Creek increased steadily gaining ≈2.6°C over the two mile stream segment. Although a cooler side channel was sampled at river mile 15.2, stream temperatures exhibited little local spatial variability within this reach. Water temperatures in Jackson Creek continued to increase between river mile 14.7 and 11.0, but at a lower longitudinal rate then observed upstream. In addition to a cool spring at river mile 13.4, Edan Creek (rm 14.6), Luck Creek (rm 13.3), and an Unnamed Creek (rm 13.7) enter the main stem through this reach.

The inflow of Squaw Creek at river mile 11.0 lowers bulk water temperatures in Jackson Creek from ≈21.6°C to ≈19.9°C (Figure 45). The inflow of Squaw Creek has the effect of resetting main stem temperatures and is a pronounced attribute of the longitudinal temperature profile. Downstream of Squaw Creek, stream temperatures generally increased in the downstream direction reaching 22.8°C at river mile 3.3. The downstream heating was interrupted by areas of apparent localized cooling between river miles 8.4 and 8.2 and again at river mile 5.4. These locations were not associated with any detected or mapped surface water inflows. Whiskey Creek (rm 9.4) and Beaver Creek (rm 4.0) were detected through this reach and both contributed cooler water to Jackson Creek. At river mile 3.3 stream temperatures showed a decrease of ≈1.2°C in the downstream direction reaching ≈21.6°C at 2.5. Downstream of river mile 2.5, stream temperature increased rapidly reaching ≈25.1°C at the mouth. At their confluence, Jackson Creek was slightly warmer than the South Umpqua River (24.1°C).

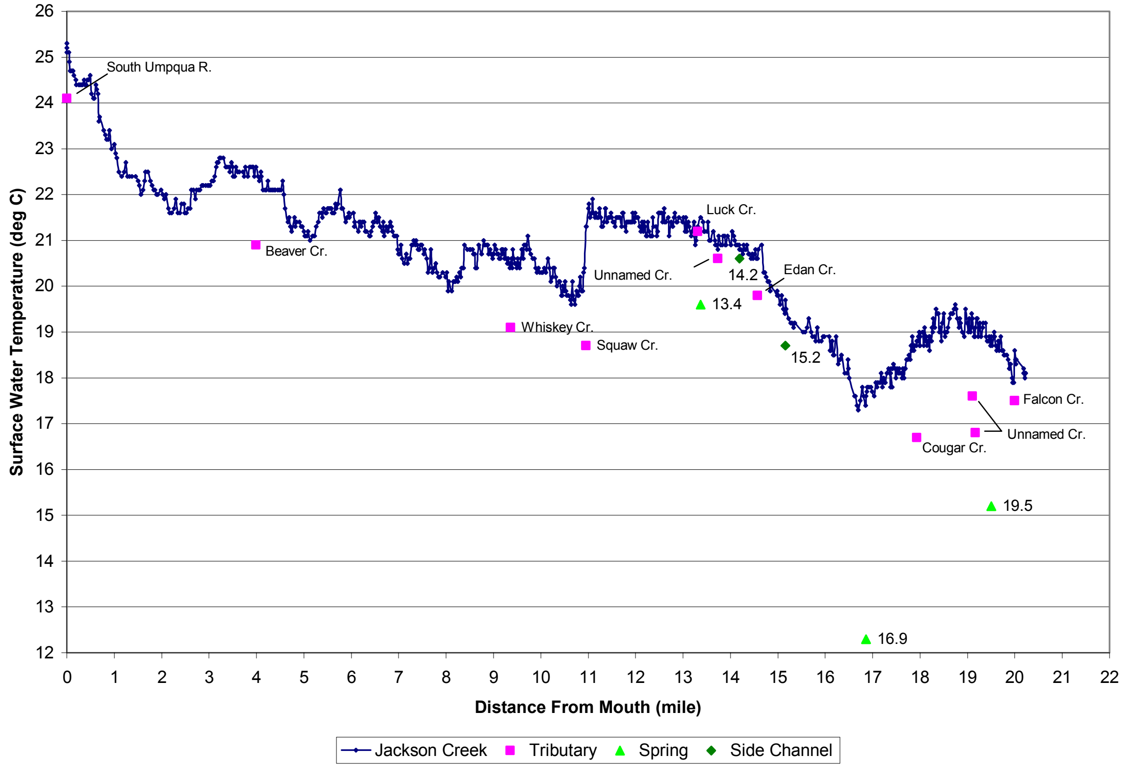

Figure 43 – Median channel temperatures versus river mile for Jackson Creek, OR. The plot shows the location and temperature of all sampled surface water inflows. Tributaries are labeled by name while springs and side channels are labeled by river mile.

Table 20 – Tributary temperatures for Jackson Creek, OR.

Tributary Name	Image	km	mile	Tributary °C	Jackson Cr. °C	Difference °C
South Umpqua River	jac0024	0.0	0.0	24.1	25.3	-1.2
Beaver Creek (LB)	jac0441	6.4	4.0	20.9	22.6	-1.7
Whiskey Creek (LB)	jac1065	15.1	9.4	19.1	20.5	-1.4
Squaw Creek (LB)	jac1358	17.6	11.0	18.7	21.3	-2.6
Luck Creek (RB)	jac1698	21.4	13.3	21.2	21.3	-0.1
Unnamed Trib (LB)	jac1741	22.1	13.7	20.6	20.8	-0.2
Edan Creek (LB)	jac1841	23.5	14.6	19.8	20.6	-0.8
Cougar Creek (LB)	jac2173	28.9	17.9	16.7	18.8	-2.1
Unnamed Trib (LB)	jac2332	30.8	19.1	17.6	19.3	-1.7
Unnamed Trib (RB)	jac2339	30.9	19.2	16.8	19.1	-2.3
Falcon Creek (LB)	jac2437	32.2	20.0	17.5	18.6	-1.1
Spring						
Spring (RB)	jac1705	21.5	13.4	19.6	21.5	-1.9
Spring (RB)	jac2040	27.1	16.9	12.3	17.6	-5.3
Spring (LB)	jac2378	31.4	19.5	15.2	18.9	-3.7
Side Channel						
Side Channel (RB)	jac1793	22.8	14.2	20.6	20.8	-0.2
Side Channel (LB)	jac1898	24.4	15.2	18.7	19.7	-1.0

RB = right bank; LB = left bank looking downstream

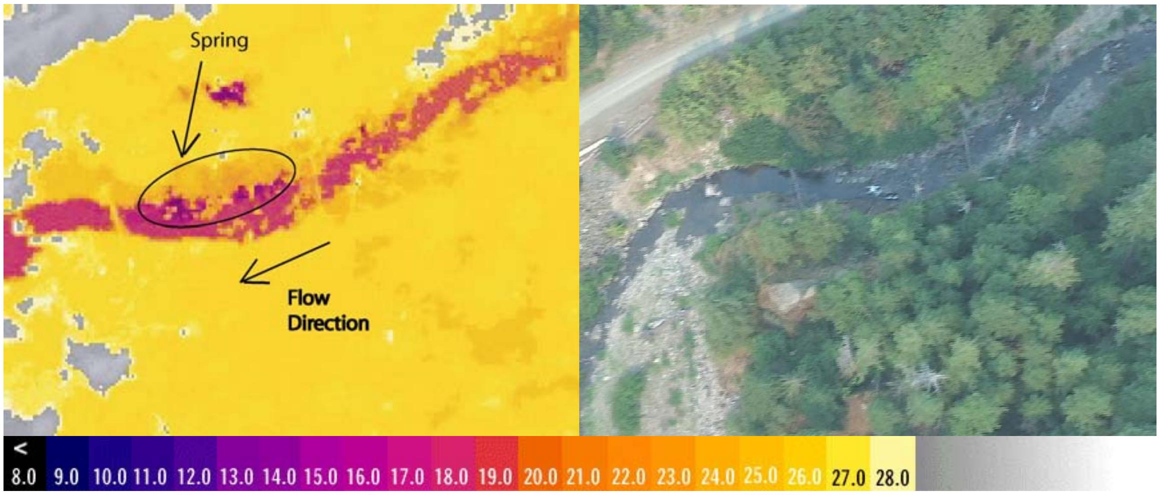

Figure 44 – TIR/color video image the spring (12.3°C) detected at river mile 16.9 on Jackson Creek (*frame: jac2040*).

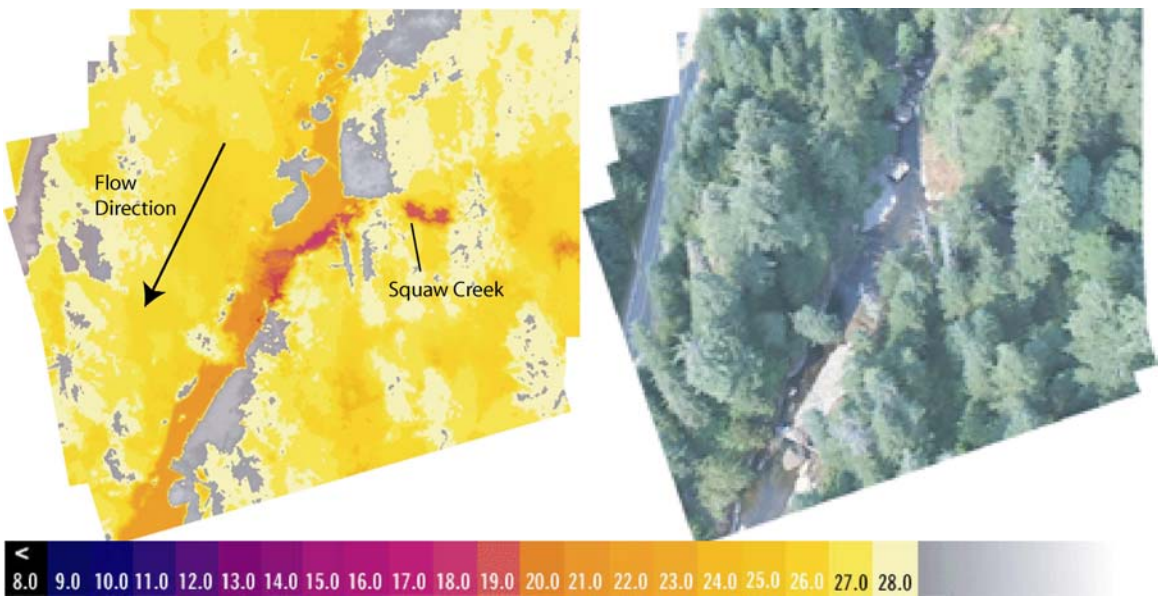

Figure 45 – TIR/color video image showing the confluence of Squaw Creek (18.7°C) and Jackson Creek (21.3°C) at river mile 11.0 (*frame: jac1358*).

South Umpqua River

Figure 46 illustrates the longitudinal temperature profile developed for the South Umpqua River from the TIR images. The profile also shows the temperature and location of surface water inflows sampled during the analysis. Tributaries are labeled by name on the profile and side channel temperatures are labeled by river mile. All surface inflows are summarized in Table 21. The South Umpqua River exhibited a general pattern of downstream warming with surface temperatures eventually approaching air temperatures. However, radiant temperatures also exhibited a high degree of local spatial variability throughout the profile.

At the upstream end of the survey (rm 98.7), stream temperatures were ≈18.2°C but increased rapidly in the downstream direction reaching ≈23.8°C at the Jackson Creek confluence (rm 80.0). Stream temperatures dropped by 1.2°C between river miles 83.8 and 82.5, but the source of cooling at this location was not evident from the imagery. Boulder Creek, Dumont Creek, and Deadman Creek all enter the South Umpqua River through this reach. Of the three, only Deadman Creek contributed water that was significantly cooler than the main stem. Downstream of Jackson Creek, water temperatures decreased reaching ≈22.0°C at river mile 76.9.

Between river miles 76.9 and 51.5, stream temperatures generally warmed in the downstream direction with a high degree of local thermal variability. Radiant stream temperature decreases of greater than 1.5°C were observed at four different locations within this reach. These locations were not associated with any detected surface water inflows and the cooling source was not evident from the TIR imagery. The TIR images also do not reveal any thermal stratification or differential surface heating near these locations that might contribute to the observed thermal variability.

Water temperatures in the South Umpqua River remained relatively warm over the lower 51.5 river miles with radiant stream temperatures ranging between 25.0°C and 28.0°C. Five tributary inflows were sampled over the lower 51 river miles. Of these, only Myrtle Creek (rm 38.8) and an unnamed inflow (rm 7.8) contributed water that was significantly cooler than the main stem. The lower South Umpqua River exhibited a high degree of local thermal variability that was not associated with detected surface water inflows.

Figure 47 also shows the longitudinal temperature profile for the South Umpqua River. The plot also shows the kinetic temperature at the time of the TIR survey and the daily stream temperature maximum three of the in-stream monitoring sites. Note that some sensors were removed immediately after the TIR survey and did not record a daily maximum.

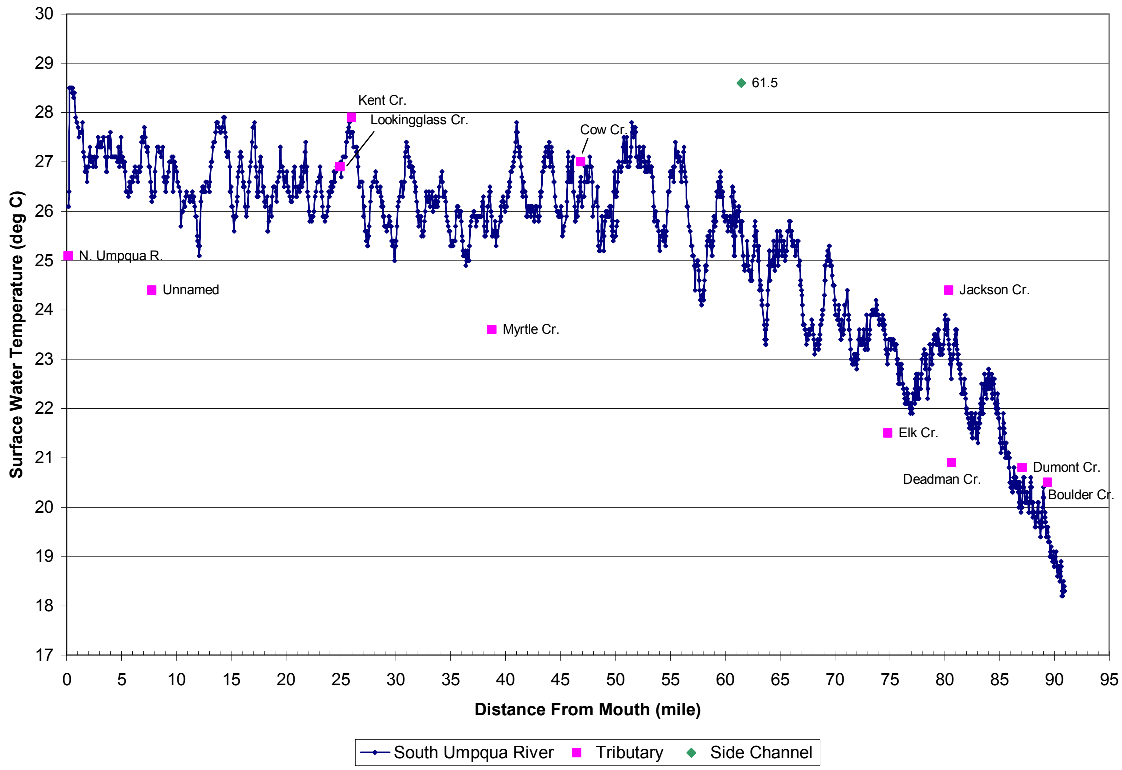

Figure 46 – Median channel temperatures versus river mile for the South Umpqua River, OR. Tributary and side channel temperatures are illustrated on the profile.

Table 21 – Tributary temperatures for the South Umpqua River, OR

Tributary Name	Image	km	mile	Tributary °C	S. Umpqua R. °C	Difference °C
Boulder Cr. (RB)	sfu0166	143.8	89.4	20.5	19.6	0.9
Dumont Cr. (RB)	sfu0392	140.1	87.0	20.8	20.1	0.7
Deadman Cr. (RB)	sfu1064	129.8	80.6	20.9	23.0	-2.1
Jackson Cr. (LB)	sfu1089	129.4	80.4	24.4	23.3	1.1
Elk Cr. (LB)	sfu1674	120.4	74.8	21.5	23.1	-1.6
Cow Cr. (LB)	sfu4067	75.4	46.9	27.0	26.7	0.3
Myrtle Cr. (RB)	sfu4516	62.4	38.8	23.6	25.5	-1.9
Kent Cr. (LB)	sfu5137	41.8	26.0	27.9	27.6	0.3
Lookingglass Cr. (LB)	sfu5186	40.1	24.9	26.9	26.9	0.0
Unnamed Inflow (LB)	sfu5906	12.5	7.8	24.4	26.2	-1.8
North Umpqua R. (RB)	sfu6207	0.3	0.2	25.1	26.1	-1.0
Side Channel						
Side Channel (LB)	sfu3013	98.9	61.5	28.6	25.8	2.8

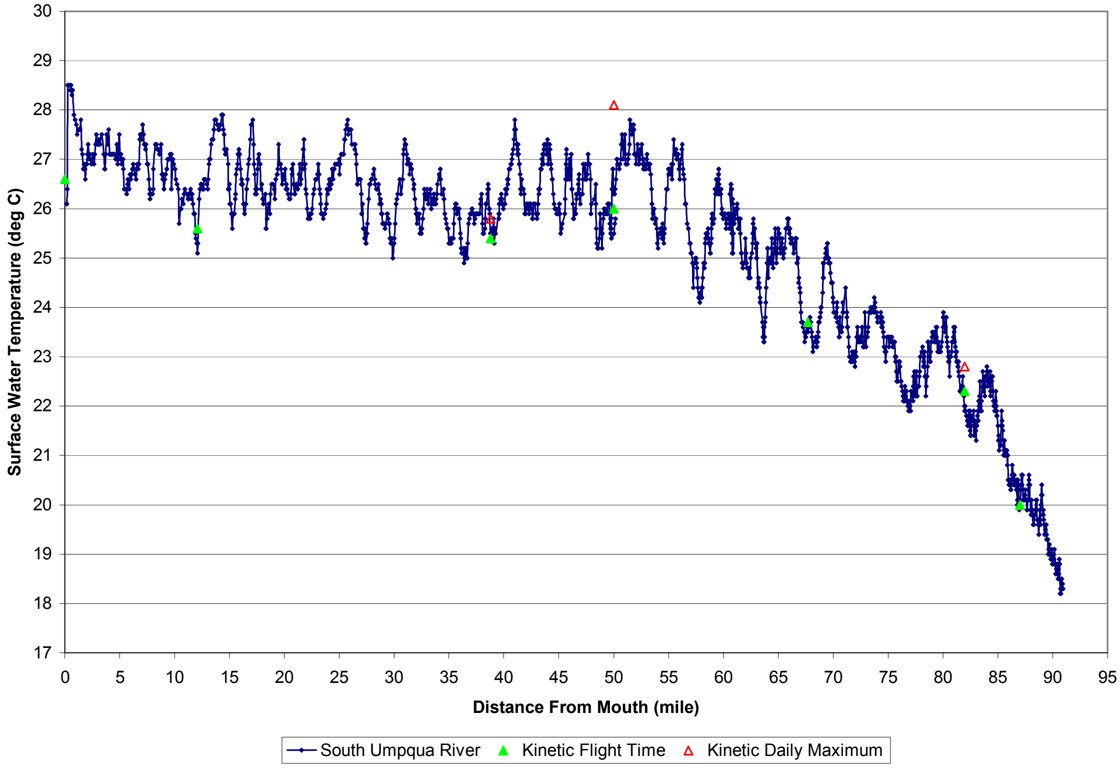

Figure 47 – Median channel temperatures versus river mile for the South Umpqua River. The profile also shows the kinetic temperatures at the time of the TIR flight and the recorded daily maximum stream temperature at monitoring sites which were not removed after the flight.

Discussion

TIR remote sensing surveys were successfully conducted on selected streams and rivers in the South Umpqua River basin. The surveys were conducted on all scheduled streams, although the South Umpqua River flight was reduced by 11.1 miles in the upper reaches due to smoke from active wildfires in the basin. Longitudinal temperature profiles were produced for each surveyed stream, which illustrate broad scale spatial temperature patterns and the location and influence of tributary and surface water inflows. The following paragraphs provide a brief discussion of the conditions found on each stream surveyed in the South Umpqua River Basin.

Olalla Creek/Lookingglass Creek: Olalla Creek showed a general pattern of downstream warming between Berry Creek and the Lookingglass Creek confluence. Stream temperatures on the Lookingglass Creek portion of the survey were generally warm (i.e. >22.7°C and exhibited a high degree of local spatial variability. The local thermal variability was not considered unusual for low gradient streams with relatively warm in-stream temperatures. On these systems, relatively small mass transfers (i.e. sub-surface exchanges) can change bulk temperatures locally. Thermal stratification was also observed in segments of Lookingglass Creek and exaggerates the apparent variability in the longitudinal profile. Throughout the survey extent, small impoundments in the stream channel often result in local thermal variations. At these locations, stratification behind the impoundments is a consideration in the observed temperature decreases. However, shallow sub-surface flow around and under the impoundment may also contribute to observed temperature decreases. Analysis of in-stream temperatures in mixed areas upstream of the impoundment is an indicator of possible sub-surface influences.

Myrtle Creek: The TIR remote sensing survey covered 0.9 miles of Myrtle Creek. The longitudinal temperature profile shows a distinct decrease in stream temperature at river mile 0.3 and a general pattern of cooling just upstream of the South Myrtle Creek confluence. Myrtle Creek was small (relative to pixel size) and partially masked by riparian vegetation. Consequently, a higher incidence of hybrid pixels is expected resulting in increased sampling noise. While a 2.0^{o}C decrease in stream temperature is considered significant, field measurements may be required to verify the temperature drop at river mile 0.3 and identify the source of cooling.

Jackson Creek: Jackson Creek showed distinct patterns of warming and cooling at the reach scale. Of the sixteen surface inflows sampled during the TIR survey, thirteen contributed water that was significantly cooler than the main stem. Three surface inflows were classified as springs and created locally cooler areas within the stream channel. Smoke from wildfires was not detectable at the mouth, but becomes noticeable in the color video images around mile 17.0. Due to the short path length between the sensor and the stream, the smoke was not considered a factor in the TIR images.

South Umpqua River: The TIR survey of the South Umpqua River occurred over a time span of 3 hours and 15 minutes. One consideration in the interpretation of the basin scale temperature patterns is how stream temperature changes during the course of the TIR survey may change the overall shape of the profile. The downstream flight direction should help to minimize this effect since daily temperature maximums are typically reached earlier in upstream reaches. In addition, a greater range of differences between the radiant and kinetic temperatures was observed on the South Umpqua River than on other streams in the basin. There was no evidence to suggest possible reasons for these differences.

Follow-on

This report presents the longitudinal temperature profiles and provides some hypotheses on the processes influencing spatial temperature patterns at this scale based on analysis 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 viewing temperature patterns and channel characteristics at finer spatial scales. The following is a list of potential uses for these data in follow-on analysis (based on Faux et. al. 2001 and Torgersen et. al. 1999):

1. 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 throughout the summer and among years?

2. The database provides a method to develop detailed maps and to combine the information with other spatial data sets. Additional data sets may include factors that influence heating rates such as stream gradient, elevation and aspect, vegetation, and land-use. In viewing the temperature patterns in relation to other spatial factors, correlations are often apparent that provide a more comprehensive understanding of the factors driving temperature patterns at different spatial scales.

3. What is the temperature pattern within critical reach and sub-reach areas? Are there thermal refugia within these reaches that are used by coldwater fish species during the summer months?

4. The TIR and visible band images provided with the database can be aggregated to form image mosaics. These mosaics are powerful tools for planning fieldwork and for presentations.

5. The longitudinal temperature profiles provided in this report provide a spatially extensive, high resolution reference for water temperature status in the basin. Because stream temperature patterns can change as a result of landscape alteration or disturbance, the data provided in this report can be used to assess the impacts of land-use practices and the effects of restoration efforts in the basin.

6. Stream temperature profiles provide a spatially continuous data set for the calibration of reach and basin scale stream temperature models.

7. Digitized color video images provide a means to evaluate in-stream habitat and riparian/floodplain conditions at the time of the survey.

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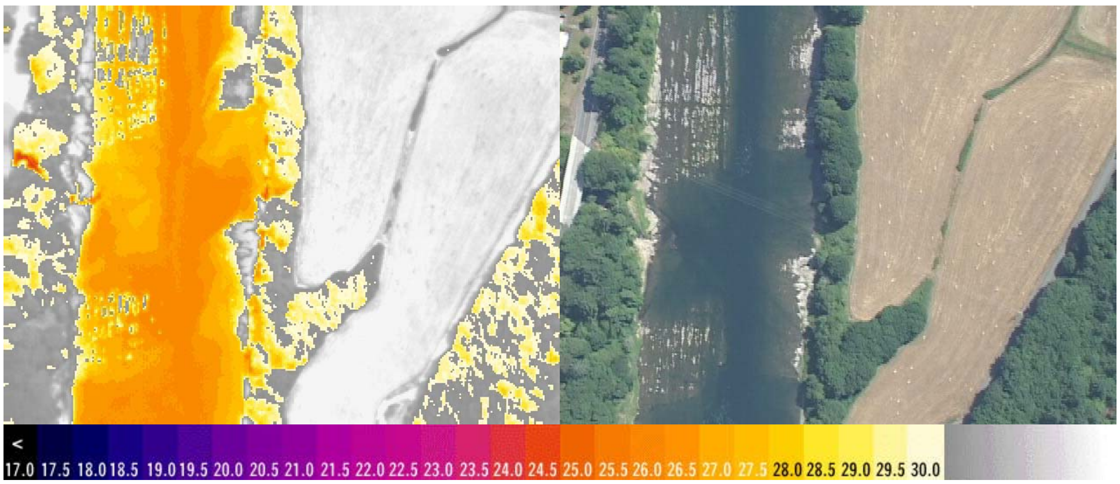
Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

Appendix A - Selected Images

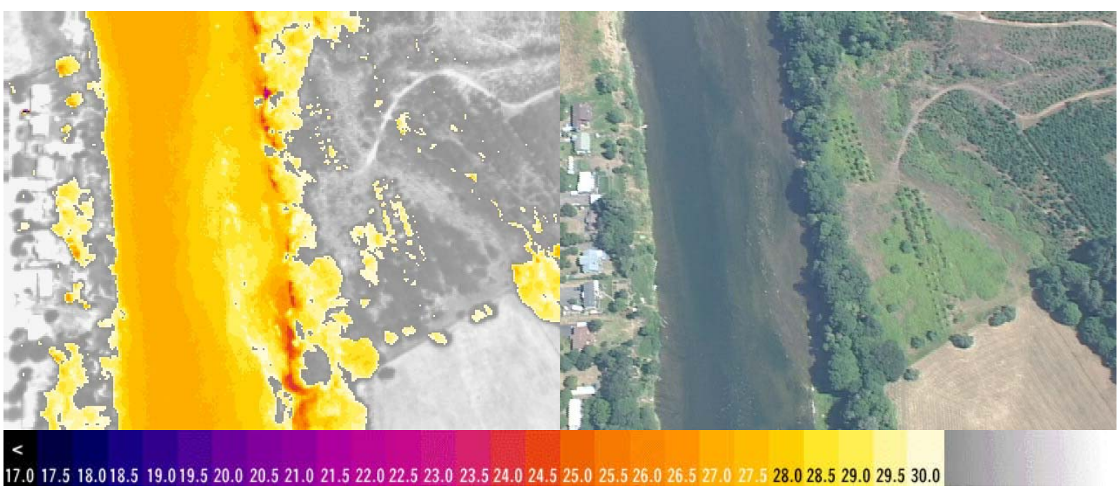
Umpqua River Subbasin

Umpqua River

The TIR remote sensing flight was conducted in the upstream direction on the Umpqua River. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.

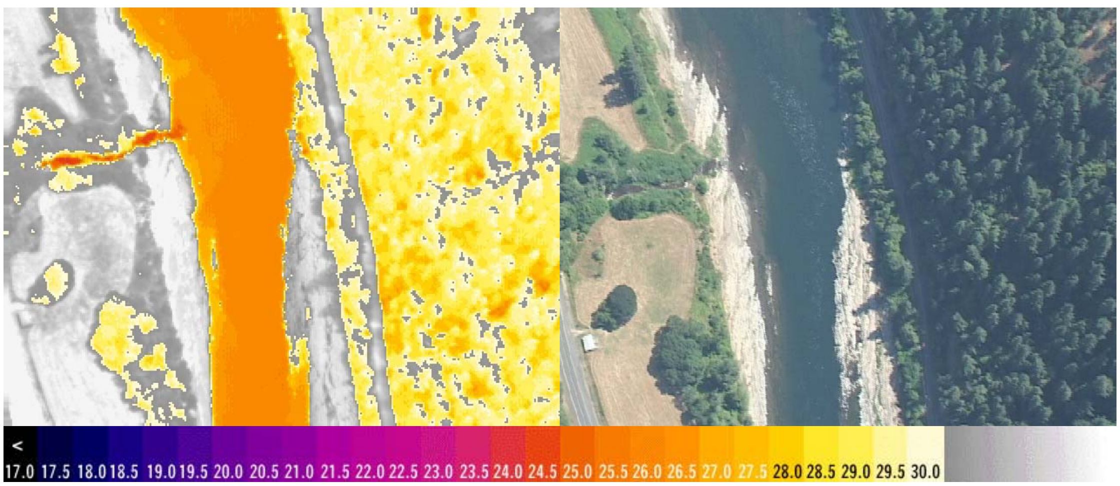


TIR/color video image pair showing Paradise Creek on the right bank of Umpqua River (26.1°C) at river mile 38.2. The image pair provides an example of detection of a stream that was too small to obtain a radiant temperature sample *(frame: umpq0456)*.



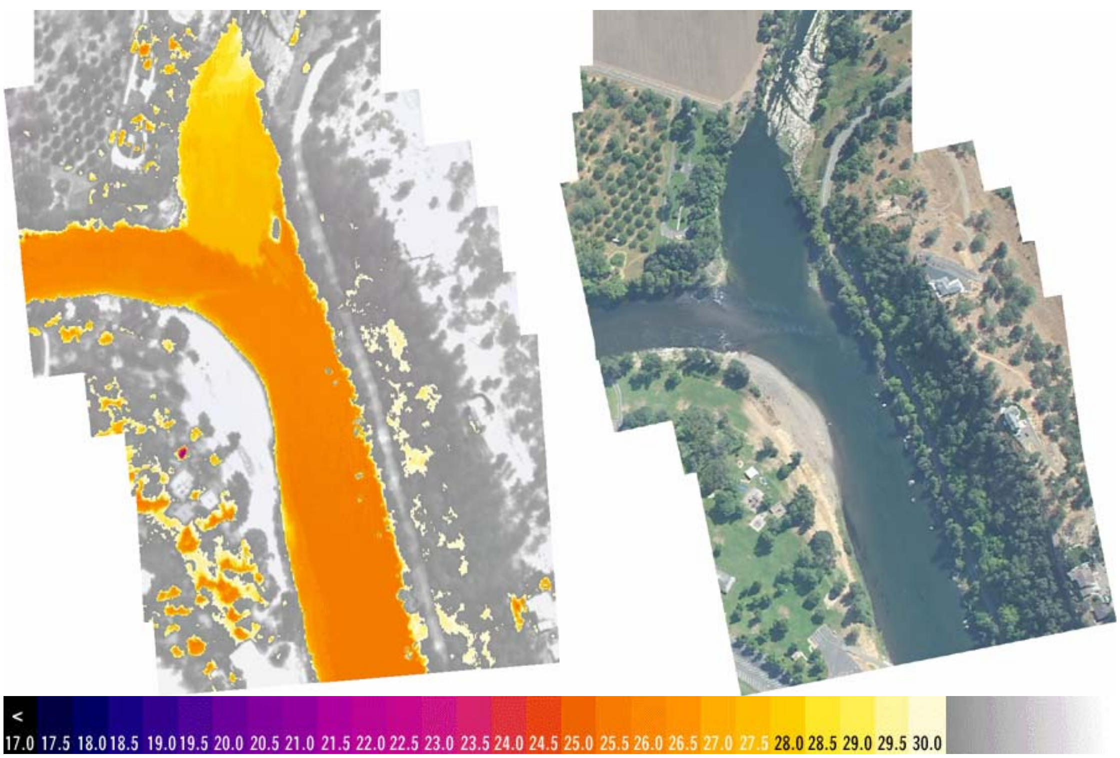
TIR/color video image pair showing a warm region of water along the left bank of Umpqua River (27.0°C) at river mile 44.1. The image is an example of thermal variability laterally across the stream channel *(frame: umpq0608)*.

TIR/color video image pair showing a segment of Umpqua River (25.8°C) at river mile 73.4 with cooler surface temperatures in the center channel, indicating a possible lack of mixing near the bank *(frame: umpq1625)*.



TIR/color video image pair showing Yellow Creek (24.9°C) along the right bank of Umpqua River (25.9°C) at river mile 76.2 *(frame: umpq1710)*.

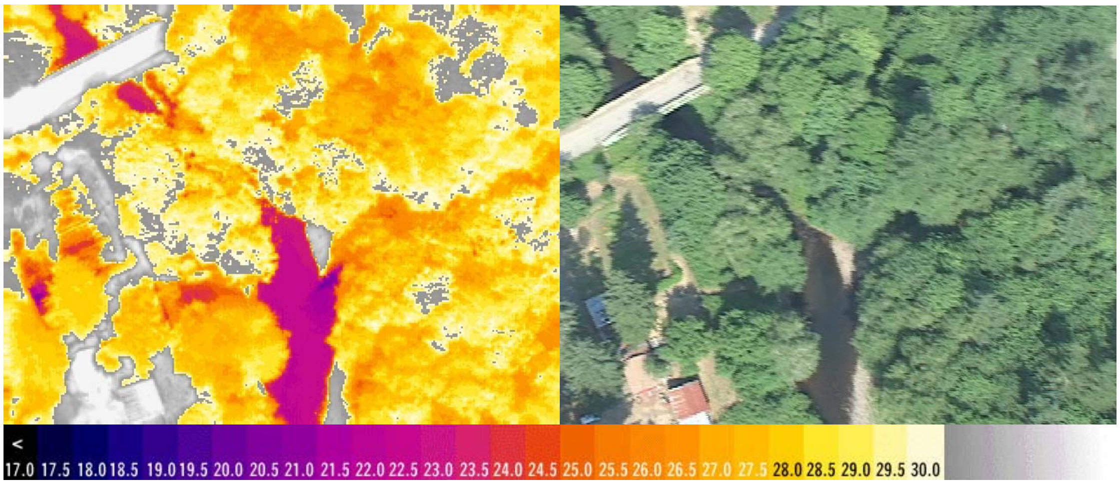
TIR/color video image pair showing the confluence of Calapooya Creek (28.5^{o}C) to the left bank of Umpqua River (26.1^{o}C) at river mile 100.4 *(frame: umpq2481)*.



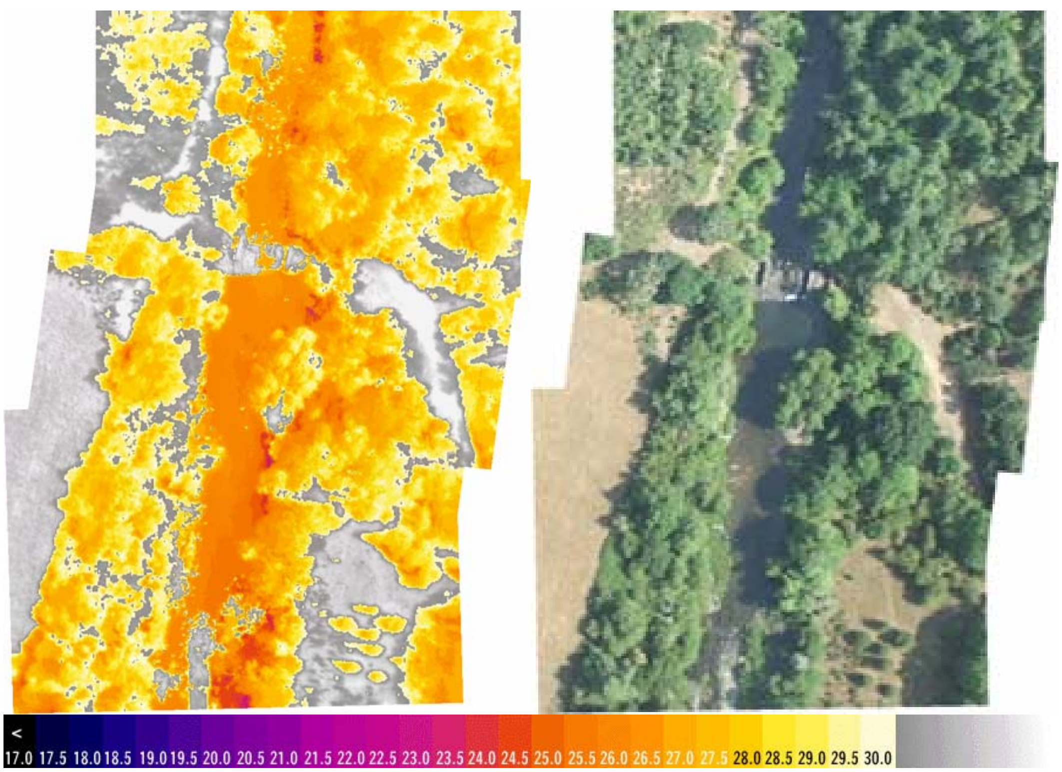
TIR/color video image pair showing the confluence of the South Umpqua River (27.5^{o}C) and the North Umpqua River (25.7^{o}C) at river mile 109.3 *(frames: umpq2741-2749)*. The North Umpqua River flows in from the left side of the image.

Calapooya Creek

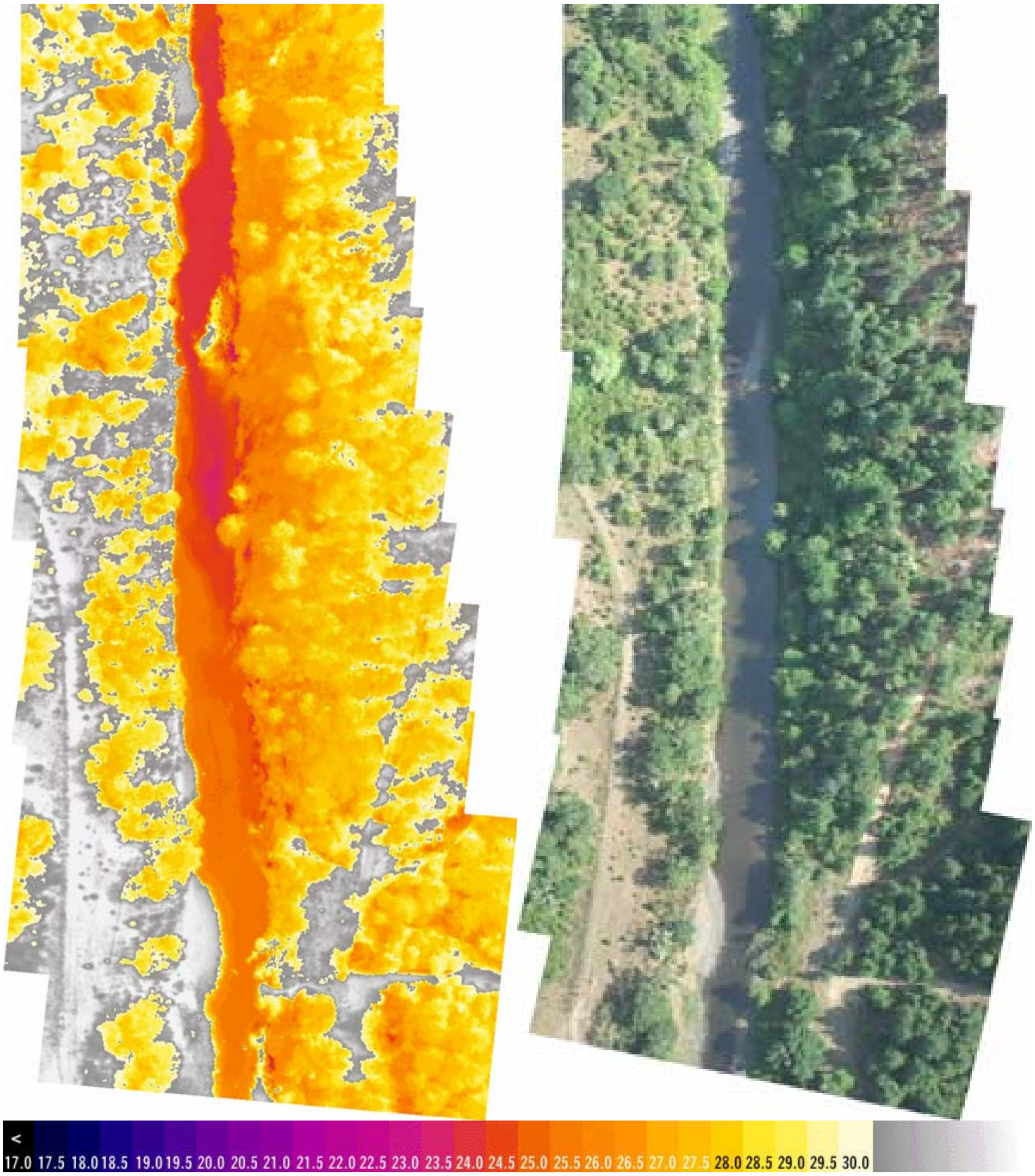
The TIR remote sensing flight was conducted in the upstream direction on Calapooya Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



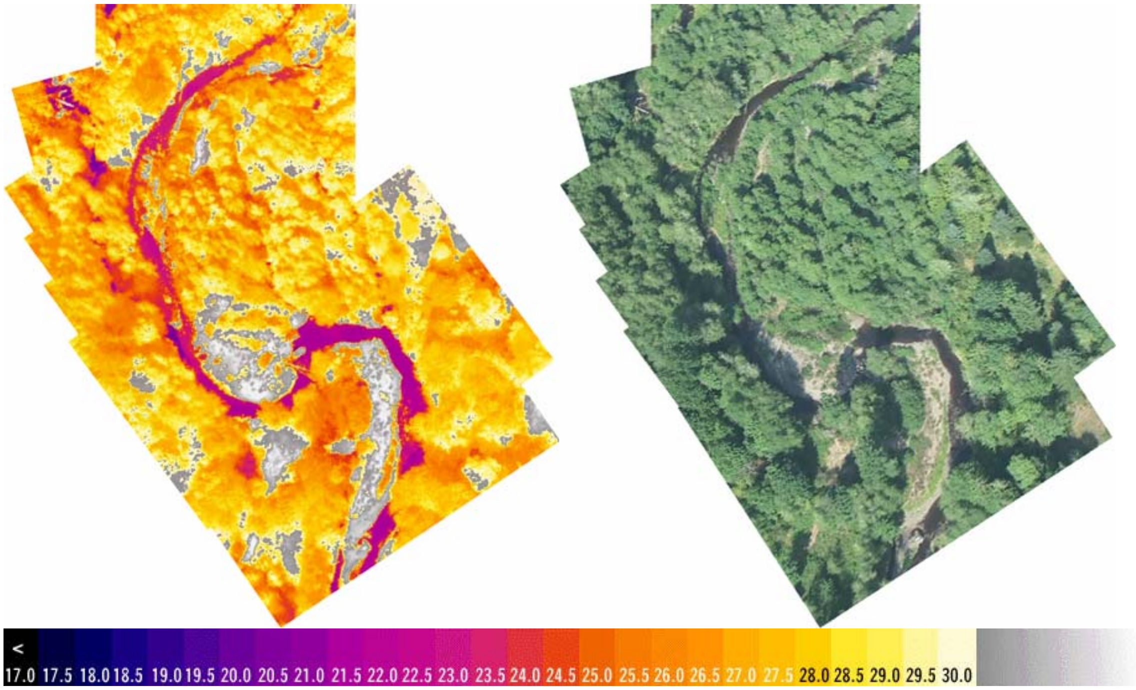
TIR/color video image pair showing the confluence of Hinkle Creek (20.4^{o}C) to the left bank of Calapooya Creek (22.3^{o}C) at river mile 30.9. Hinkle Creek enters from the right side of the image downstream of the bridge *(frame: calp1936)*.



TIR/color video image pair showing an impoundment in Calapooya Creek at river mile 19.6. A change in surface water temperature from 26.8^{o}C to 25.2^{o}C is observed from upstream to downstream of the impoundment *(frames: calp1170-1173)*.



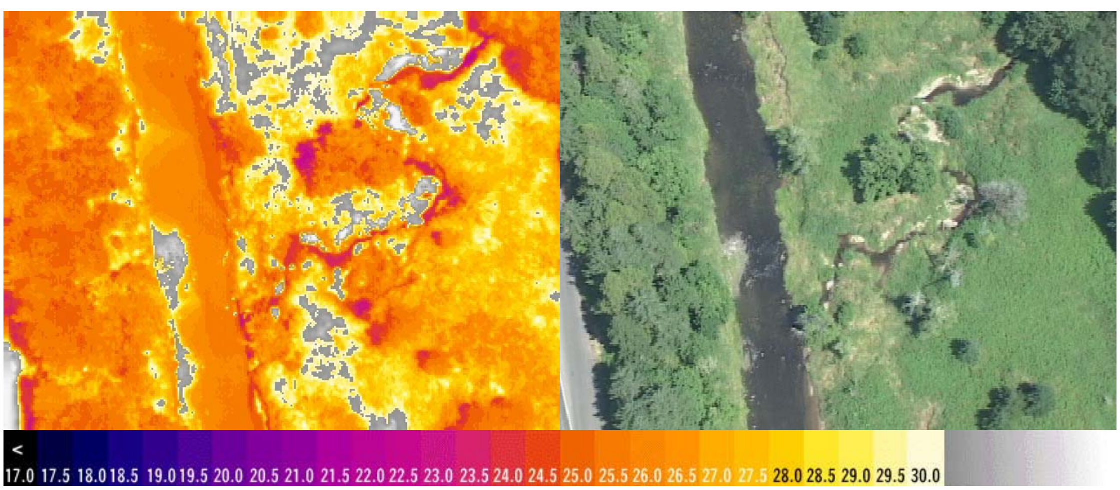
TIR/color video image pair showing a segment of Calapooya Creek at river mile 20.0 with a change in surface temperature from 23.8°C to 26.0°C, moving downstream. The rapid change in temperature may indicate differential heating at the water surface *(frames: calp1192-1200).*



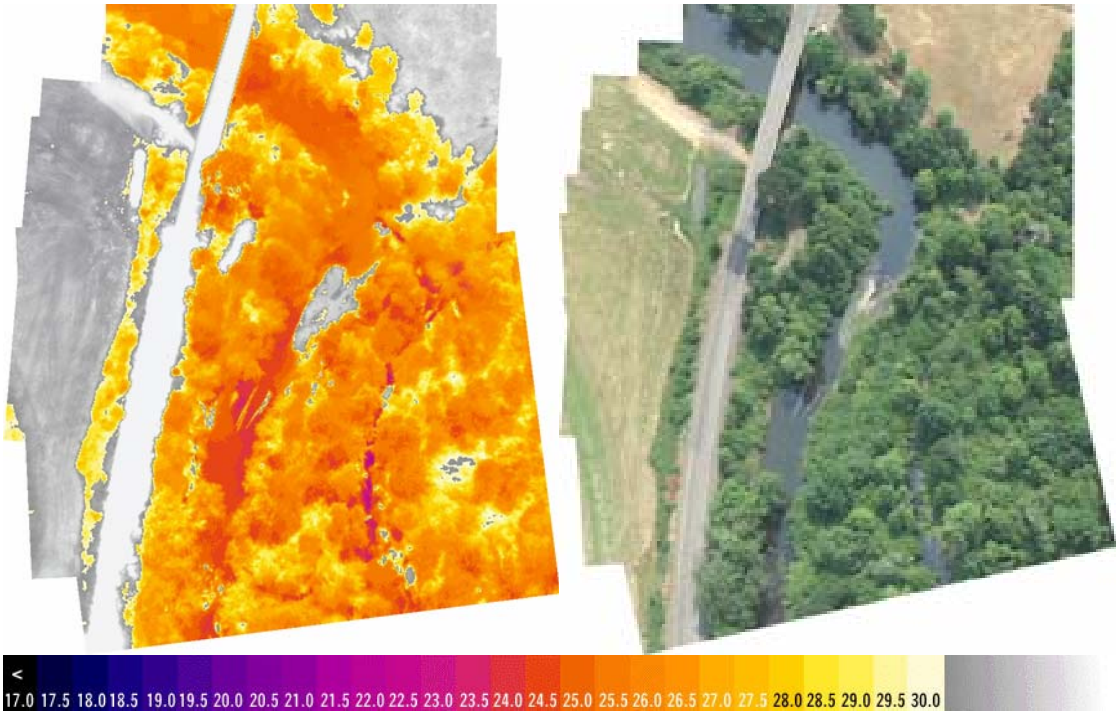
TIR/color video image pair showing Coon Creek (20.2°C) on the right bank of Calapooya Creek (21.7°C) at river mile 33.8 *(frames: calp2107-2114)*.

Elk Creek

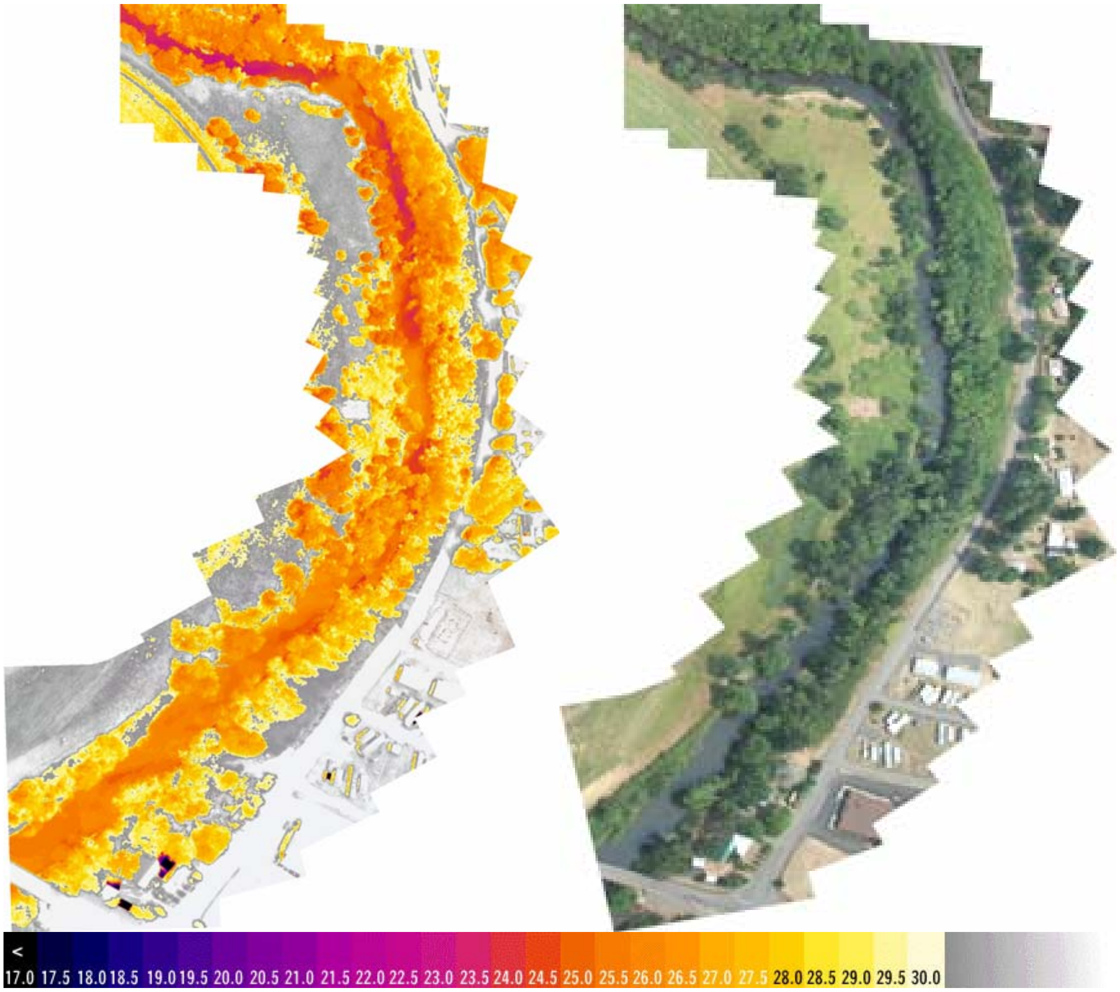
The TIR remote sensing flight was conducted in the upstream direction on Elk Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



TIR/color video image pair showing Brush Creek (23.3°C) on the left bank of Elk Creek (25.6°C) at river mile 12.3 *(frame: elk0659)*.



TIR/color video image pair showing the confluence of Billy Creek to the left bank of Elk Creek (24.4°C) at river mile 22.2. The mouth of Billy Creek was not sampled, but a shift in main stem temperatures 25.2°C to 24.3°C was observed downstream of the confluence *(frames: elk1186-1192).*

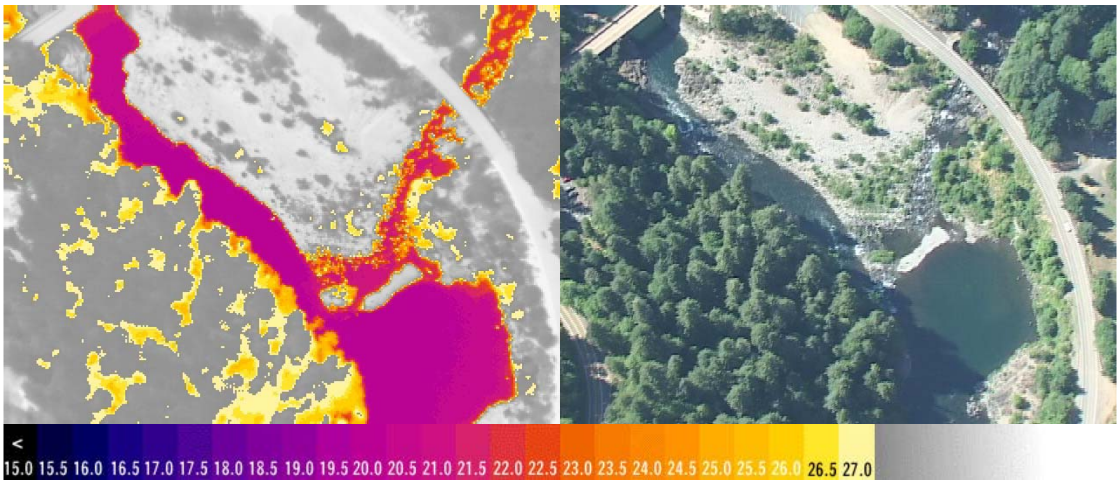


TIR/color video image pair showing an apparent temperature change in Elk Creek from 23.0^{o}C at river mile 22.8 to 25.5^{o}C at river mile 22.3. The mosaic provides an example of the rapid local changes in stream surface temperatures observed on Elk Creek *(frames: elk1196-1214)*.

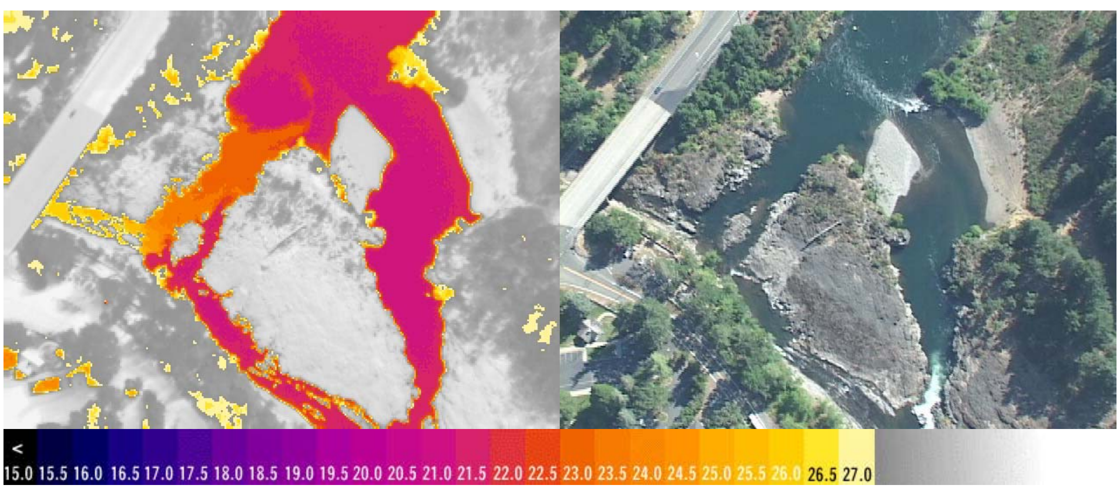
North Umpqua River Subbasin

North Umpqua River

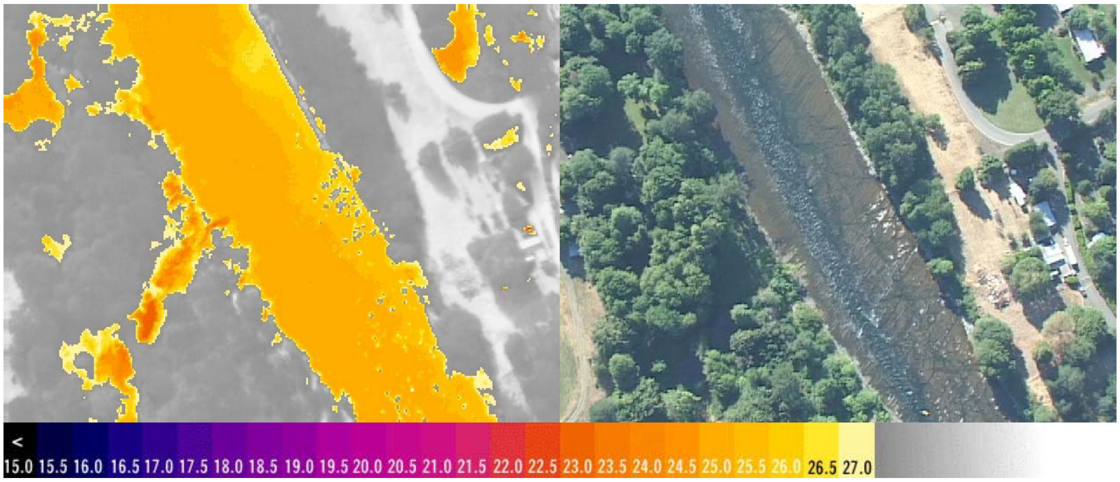
The TIR remote sensing flight was conducted in the <u>*downstream*</u> *direction on the North Umpqua River.. Therefore, flow direction in the imagery is from bottom to top of the images. References to right bank or left bank are considered looking downstream.*



TIR/color video image pair showing the confluence of Rock Creek (21.0°C) to the right bank of North Umpqua River (19.8°C) at river mile 35.1 *(frame: nfu0768)*.



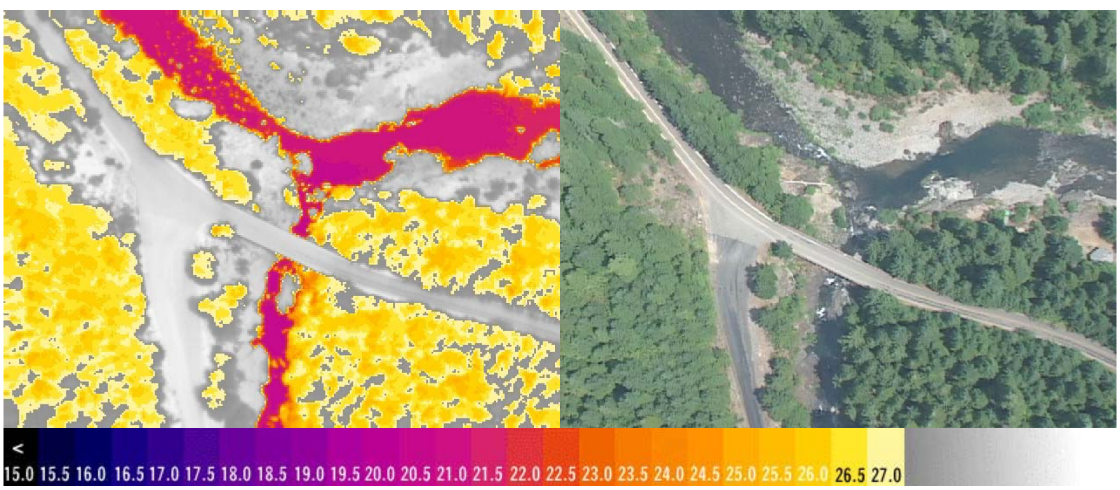
TIR/color video image pair showing Little River (25.3°C) on the left bank of North Umpqua River (20.9°C) at river mile 28.7 *(frame: nfu1048)*.



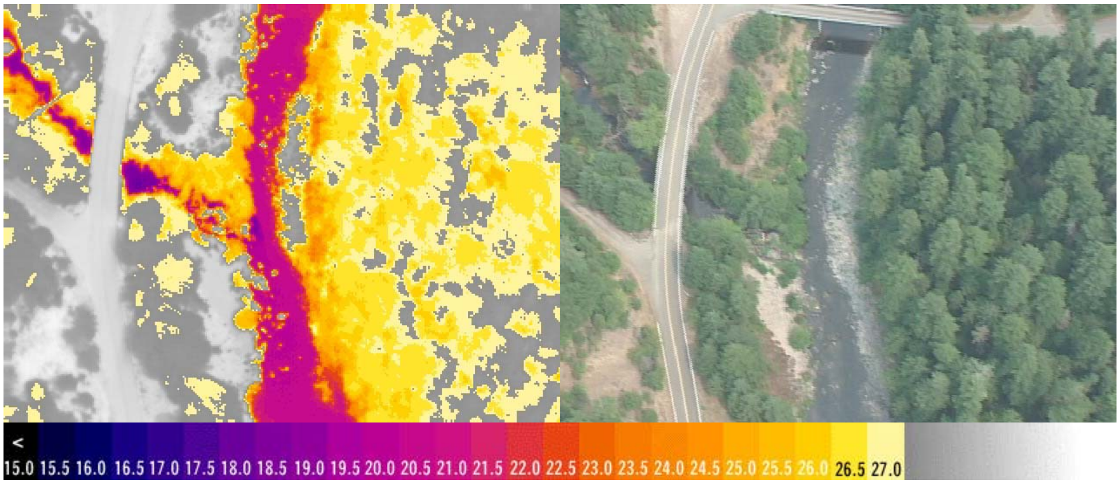
TIR/color video image pair showing a segment of North Umpqua River (24.8°C) at river mile 0.4 exhibiting lateral variability in temperature, visible in the color video image on the right*(frame: nfu2227)*.

Steamboat Creek

The TIR remote sensing flight was conducted in the upstream direction on Steamboat Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



TIR/color video image pair showing the confluence of Canton Creek (20.4°C) to the right bank of Steamboat Creek (20.7°C) at river mile 0.6 *(frame: stm0025)*.

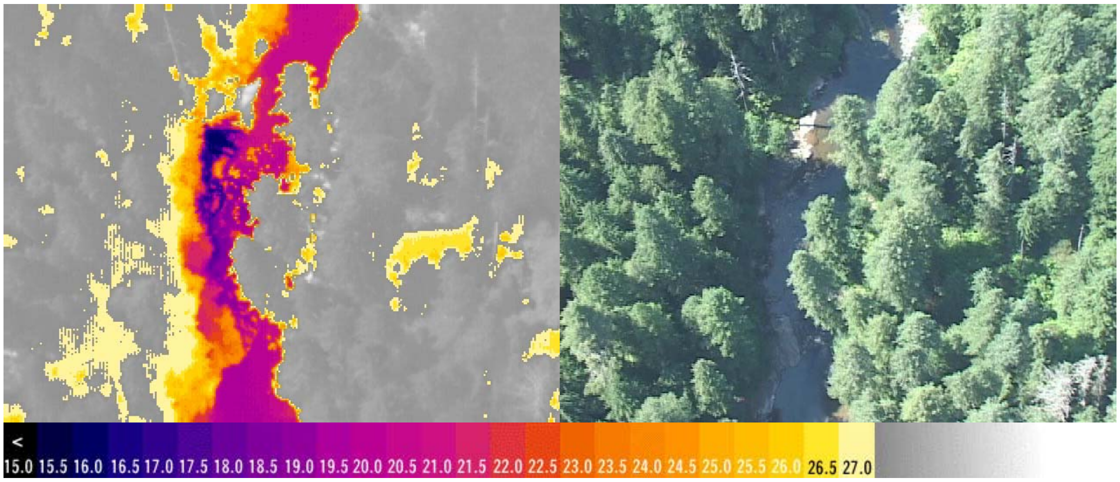


TIR/color video image pair showing Steelhead Creek (18.5°C) on the right bank of Steamboat Creek (20.3°C) at river mile 5.5 *(frame: stm0219)*.

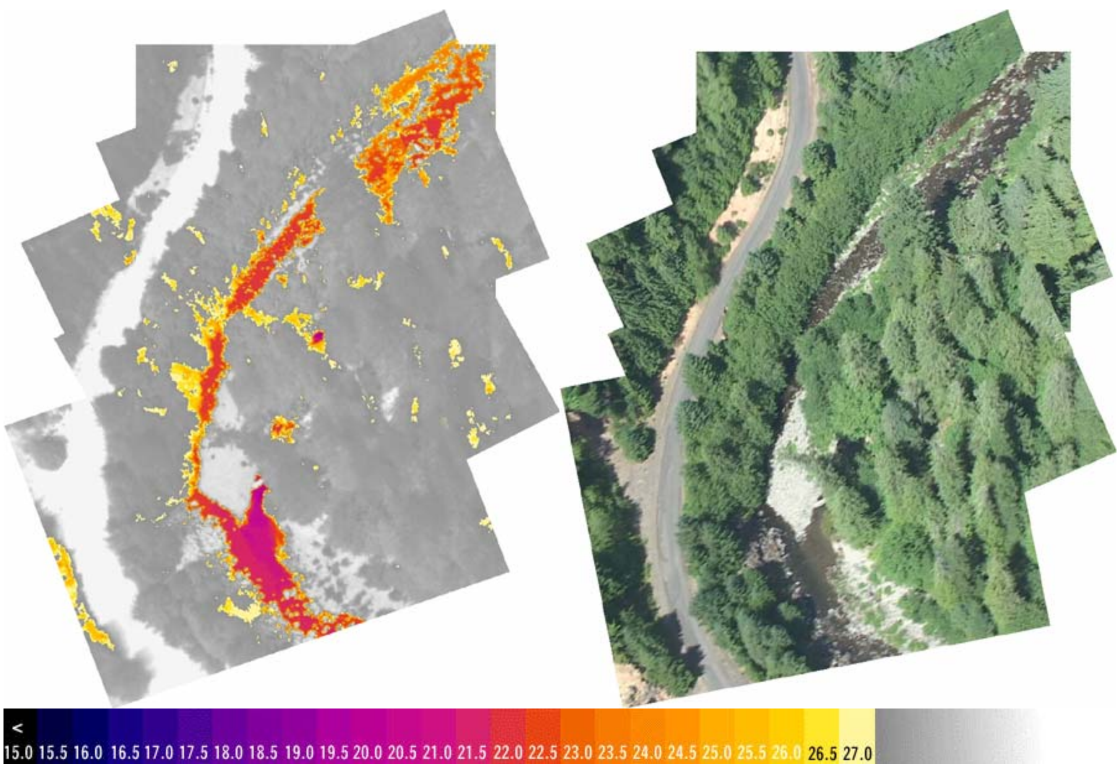
Canton Creek

The TIR remote sensing flight was conducted in the upstream direction on Canton Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.

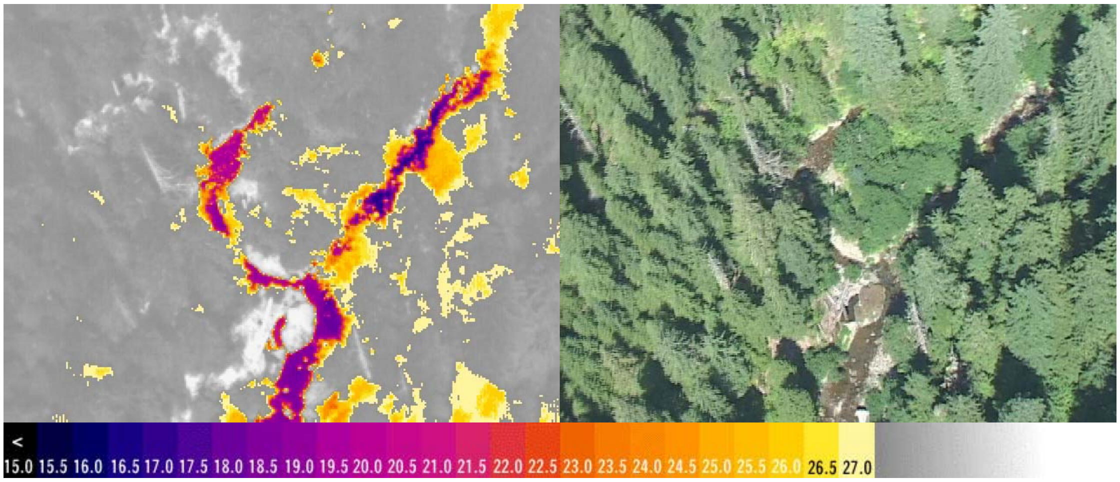
TIR/color video image pair showing a segment of Canton Creek (20.3°C) at river mile 5.3 which shows a riffle-pool-riffle sequence *(frames: can0406-0409)*.



TIR/color video image pair showing the confluence of Wolverine Creek (15.9°C) on the right bank of Canton Creek (19.9°C) at river mile 6.2 *(frame: can0474)*.



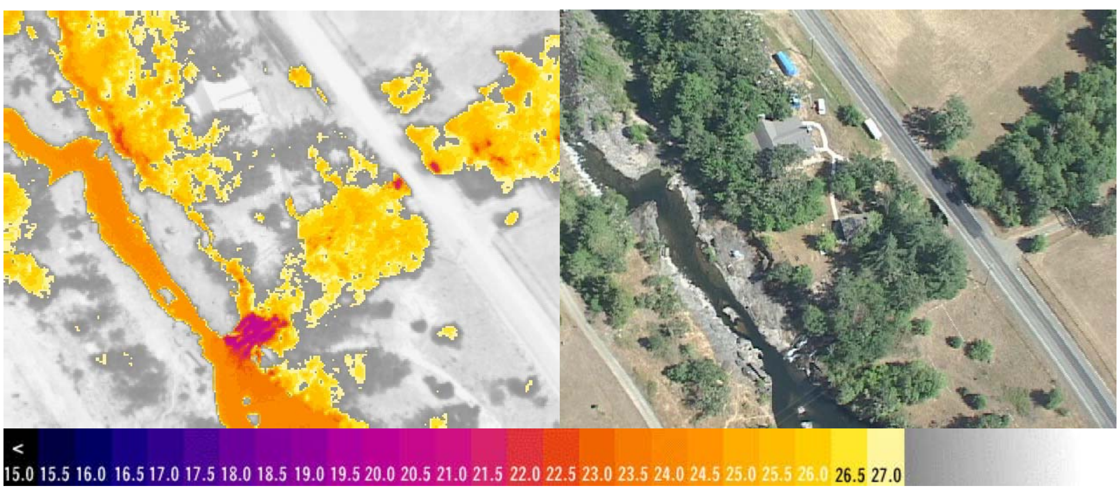
TIR/color video image pair showing a side channel (20.1°C) at river mile 6.6 contributing cooler water to Canton Creek (22.2°C) *(frames: can0502-0506)*.



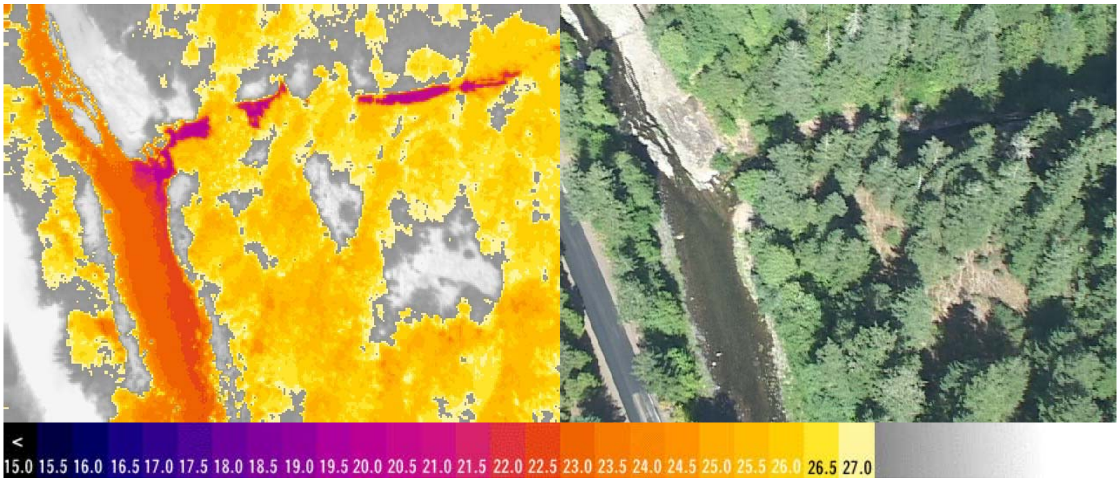
TIR/color video image pair the confluence of Salmon Creek (16.8°C) on the left bank of Canton Creek (18.3°C) at river mile 10.1 *(frame: can0914)*.

Little River

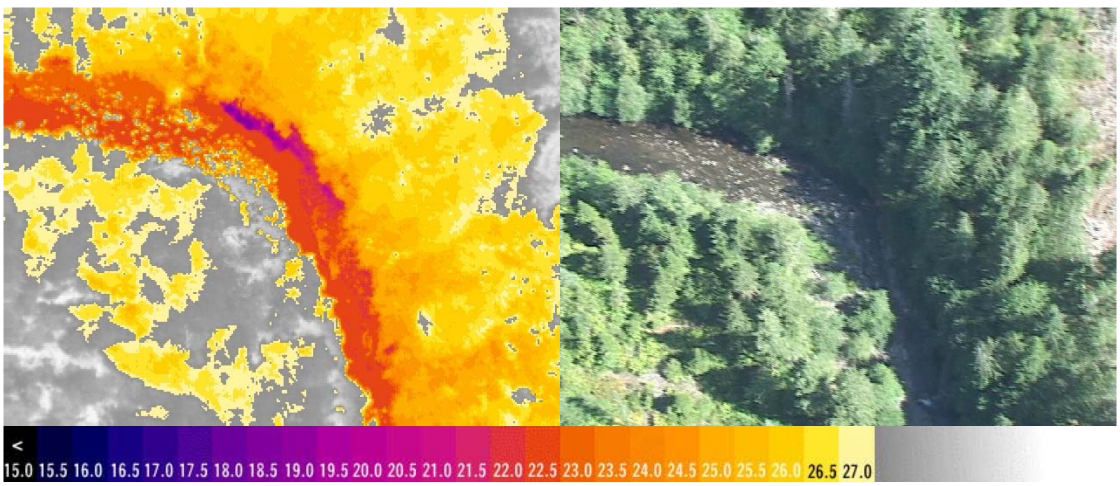
The TIR remote sensing flight was conducted in the upstream direction on the Little River. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



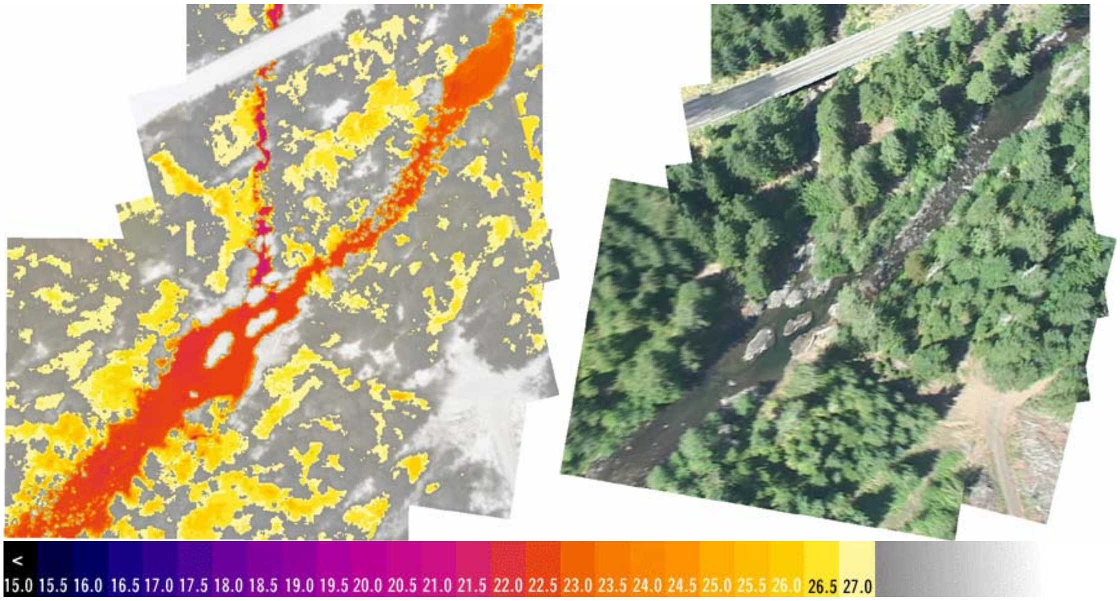
TIR/color video image pair showing the confluence of Fall Creek (20.5°C) to the left bank of Little River (24.0°C) at river mile 2.7 *(frame: lr0198)*.



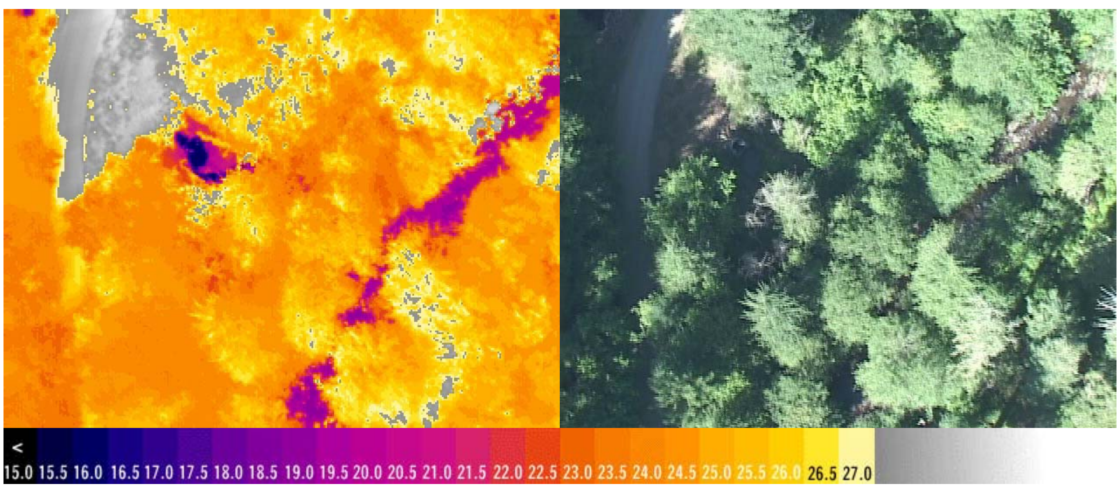
TIR/color video image pair showing the confluence of Wolf Creek (19.7°C) to the left bank of Little River (22.8°C) at river mile 11 *(frame: lr0632)*.



TIR/color video image pair showing an apparent spring (18.4°C) on the left bank of Little River (22.3°C) at river mile 14.6 *(frame: lr0850)*.



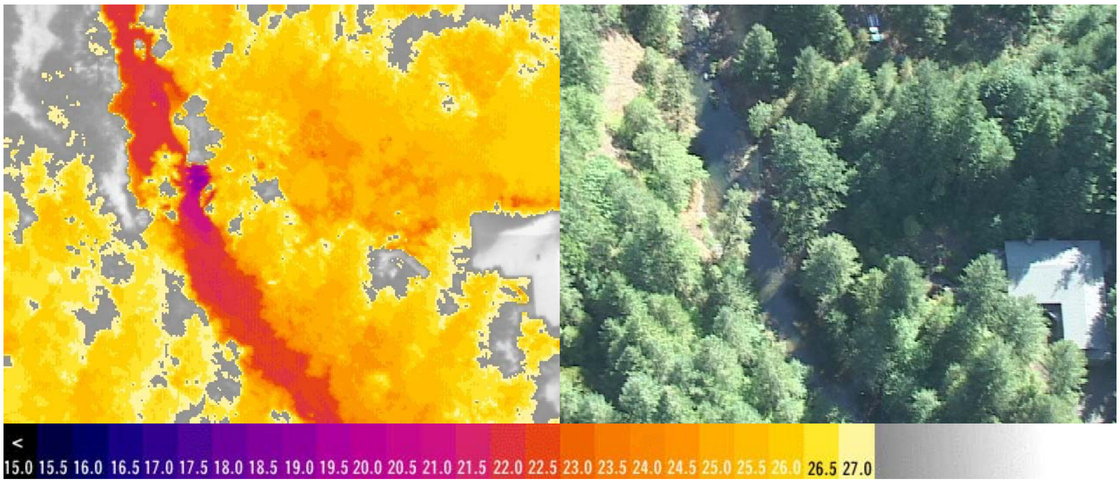
TIR/color video image pair showing the confluence of Eightmile Creek (21.0^{o}C) on the right bank of Little River (22.1^{o}C) at river mile 14.7 *(frames: lr0857-0861)*.



TIR/color video image pair showing the confluence of Taft Creek (approximately 15.7^{o}C) on the right bank of Little River (18.9^{o}C) at river mile 22.0 *(frame: lr1715)*.

Cavitt Creek

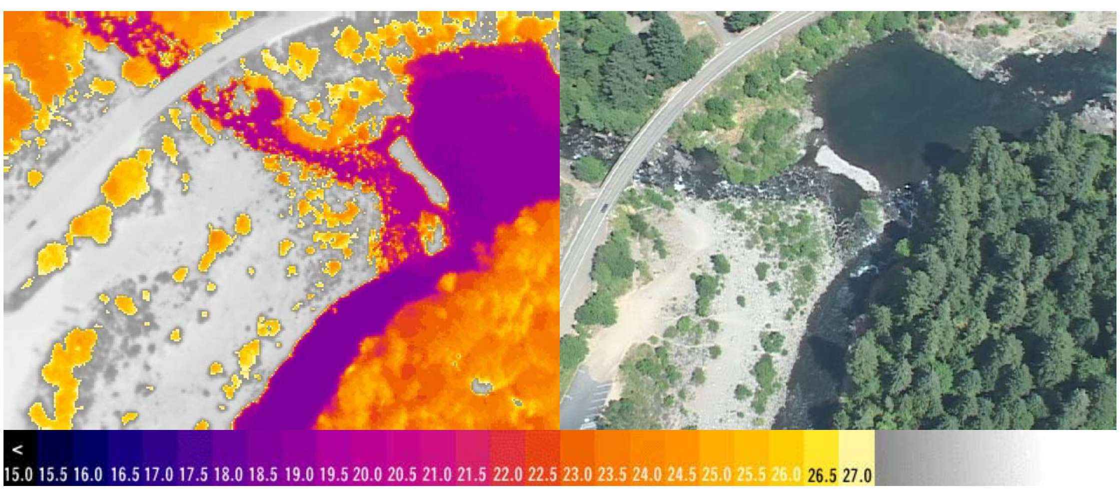
The TIR remote sensing flight was conducted in the upstream direction on Cavitt Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



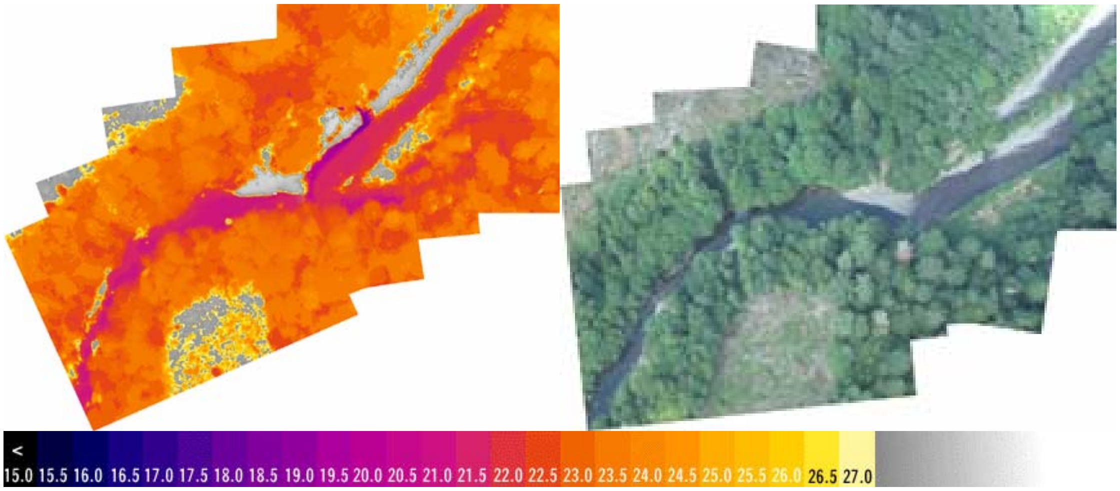
TIR/color video image pair showing the confluence of McKay Creek (19.2^{o}C) to the left bank of Cavitt Creek (22.1^{o}C) at river mile 2.6 *(frame: cav0352)*.

Rock Creek

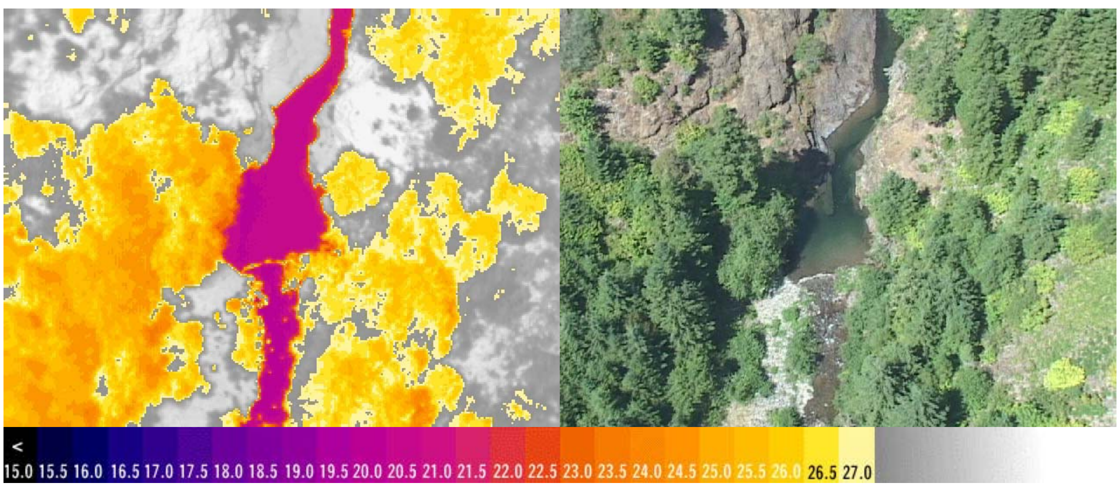
The TIR remote sensing flight was conducted in the upstream direction on Rock Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



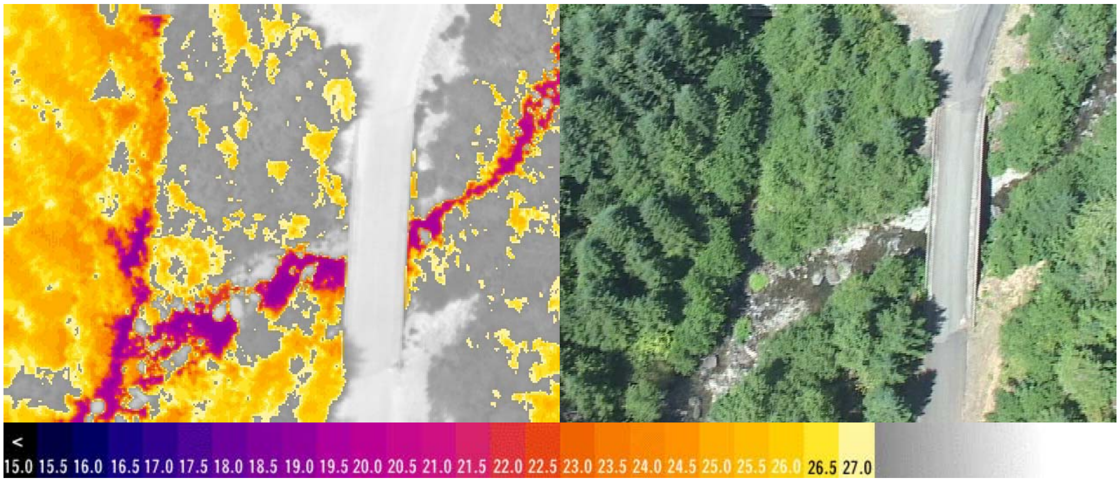
TIR/color video image pair showing the mouth of Rock Creek (19.4^{o}C) to North Umpqua River (18.6^{o}C) *(frame: rock0006)*.



TIR/color video image pair showing the confluence of McComas Creek (18.0°C) to the right bank of Rock Creek (21.2°C) at river mile 1.6 *(frames: rock0074-0078).*



TIR/color video image pair showing a large pool at the mapped confluence of Cobble Creek (not detected) at river mile 10.9 of Rock Creek (20.2°C) *(frame: rock0702).*

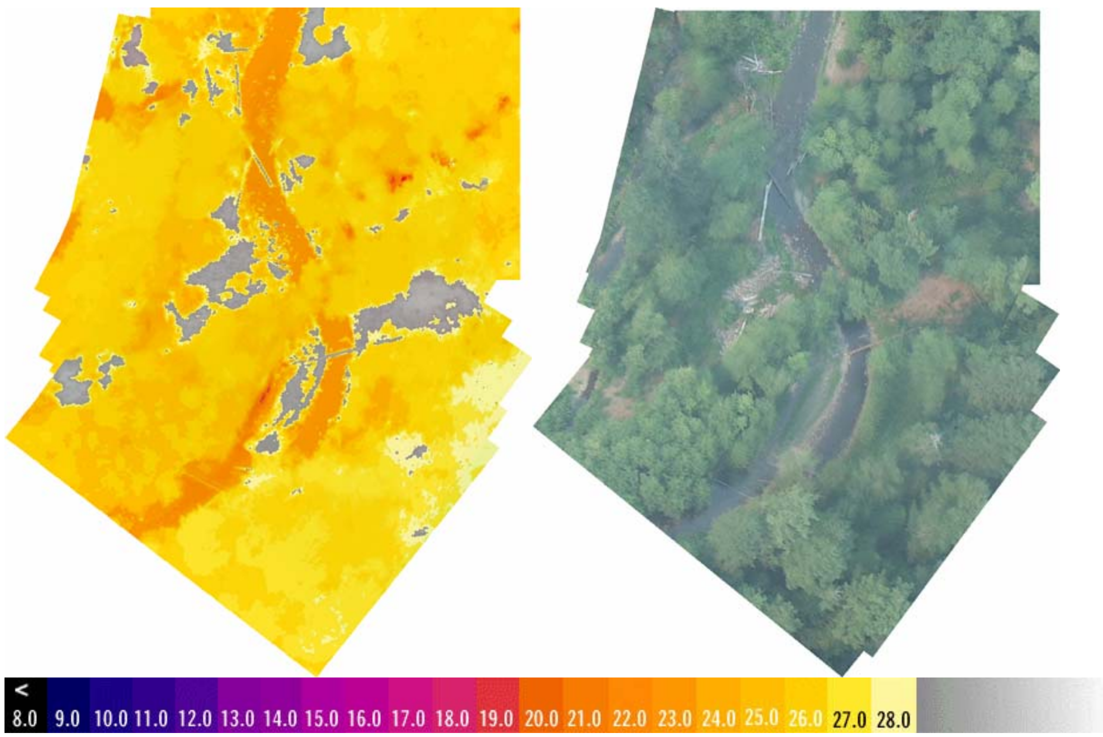


TIR/color video image pair showing Northeast Rock Creek (18.9°C) on the left bank of Rock Creek (18.9°C) at river mile 12.5 *(frame: rock0862)*.

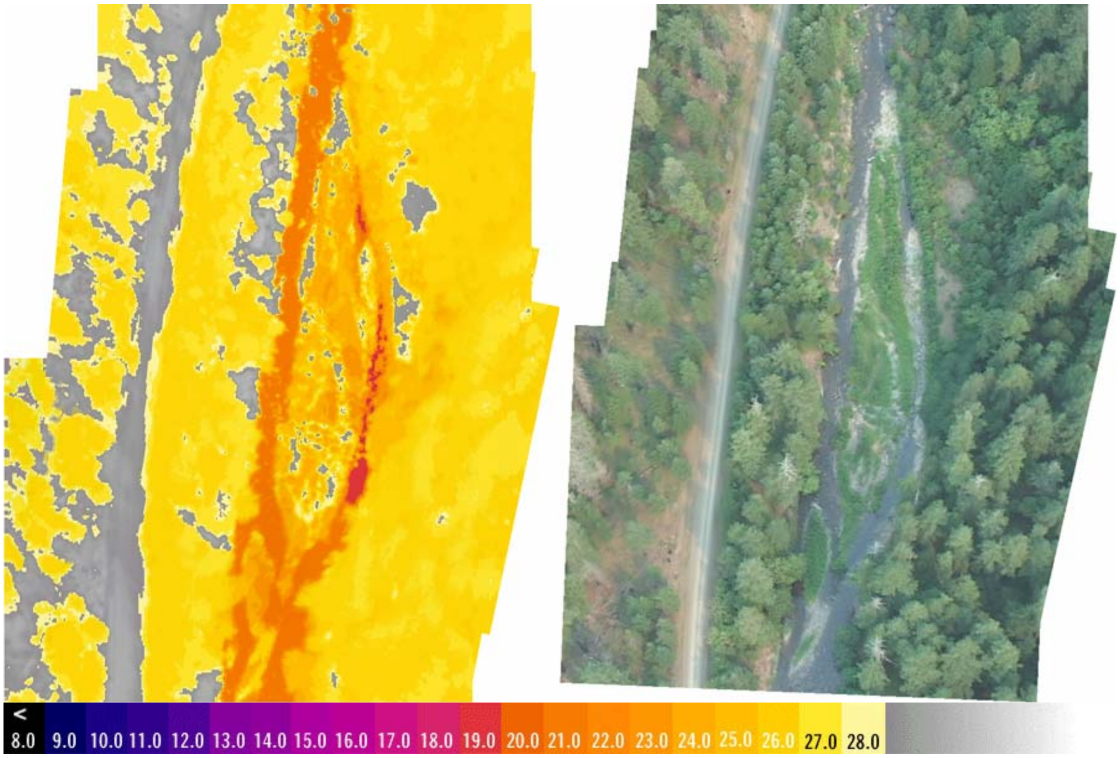
South Umpqua River Subbasin

Jackson Creek

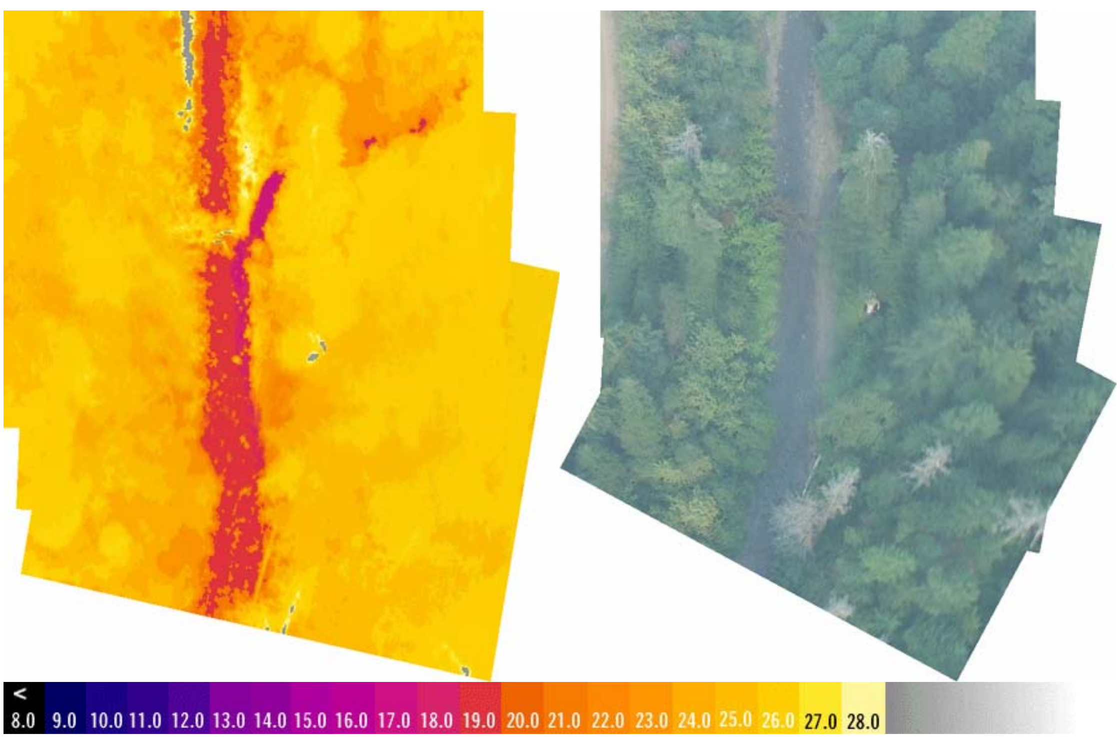
The TIR remote sensing flight was conducted in the upstream direction on Jackson Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



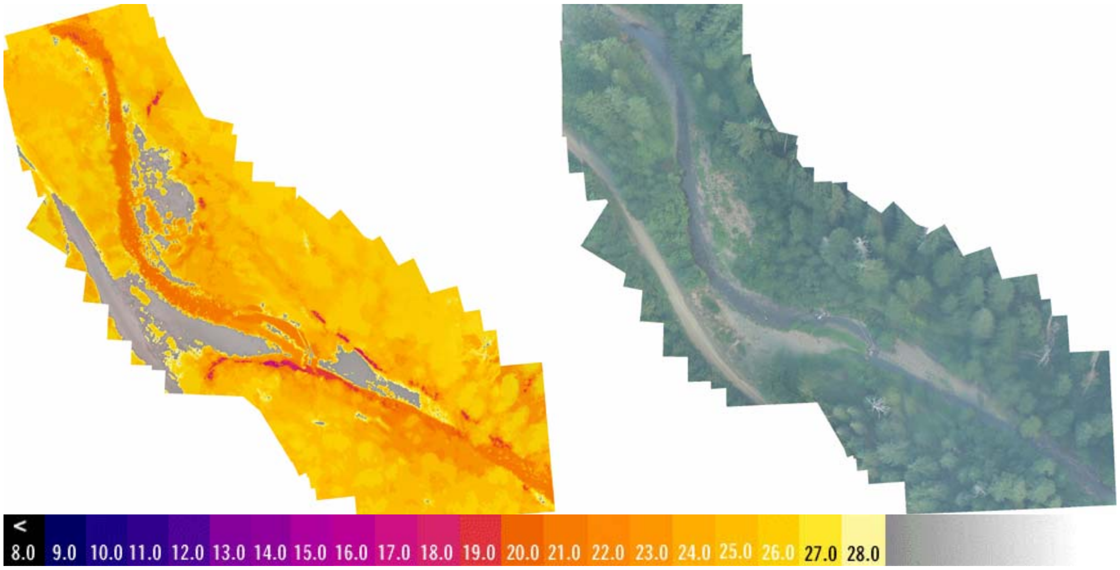
TIR/color video image pair showing a spring (19.6^{o}C) on the right bank of Jackson Creek (21.5^{o}C) at river mile 13.4. There is also an apparent inflow visible on the left bank that wasn't sampled due to the lack of visible water at its mouth *(frames: jac1705-1714)*.



TIR/color video image pair showing a spring (17.5°C) in the channel on the left bank of Jackson Creek (19.7°C) at river mile 15.2 *(frames: jac1898-1905)*.



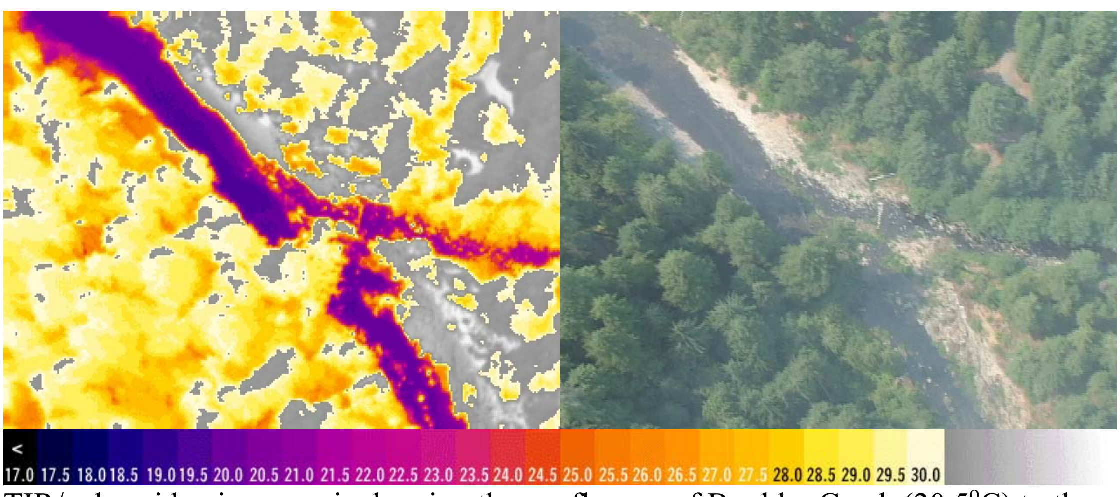
TIR/color video image pair showing the confluence of Cougar Creek (16.7°C) on the left bank of Jackson Creek (18.8°C) at river mile 17.9 *(frames: jac2171-2173)*.



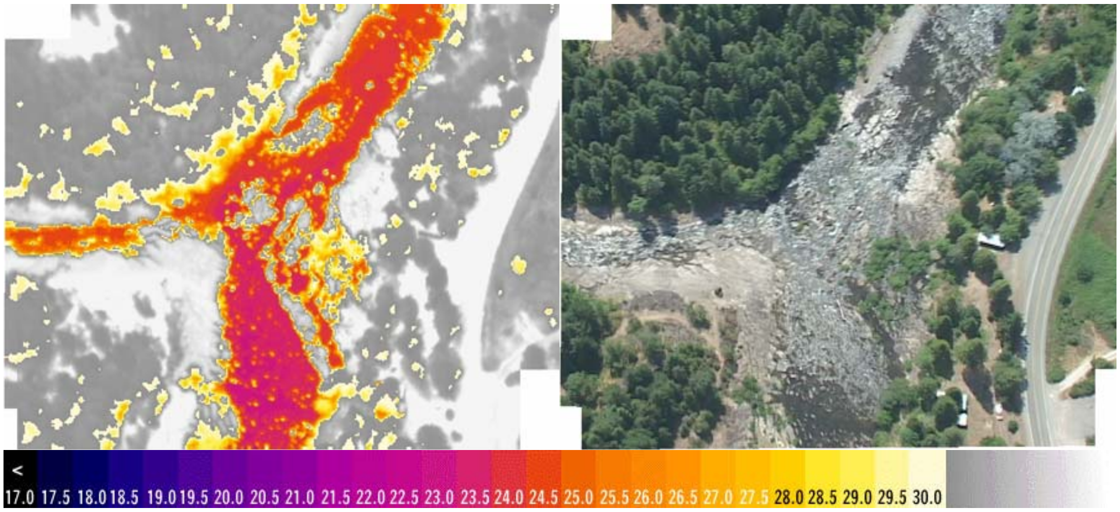
TIR/color video image pair showing an unnamed tributary (17.6°C) on the left bank of Jackson Creek (19.1°C) at river mile 19.2 An unnamed tributary (16.8°C) is visible on the right bank. *(frames: jac2332-2352).*

South Umpqua River

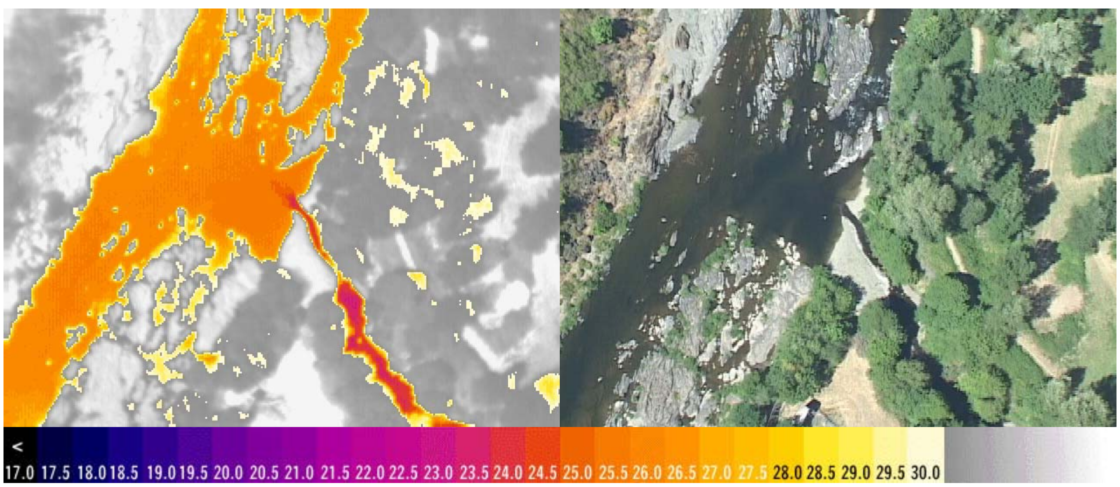
The TIR remote sensing flight was conducted in the <u>*downstream*</u> *direction on the South Umpqua River. Therefore, flow direction in the imagery is from bottom to top of the image. References to right bank or left bank are considered looking downstream.*



TIR/color video image pair showing the confluence of Boulder Creek (20.5°C) to the right bank of South Umpqua River (19.6°C) at river mile 89.4 *(frame: sfu0166).*



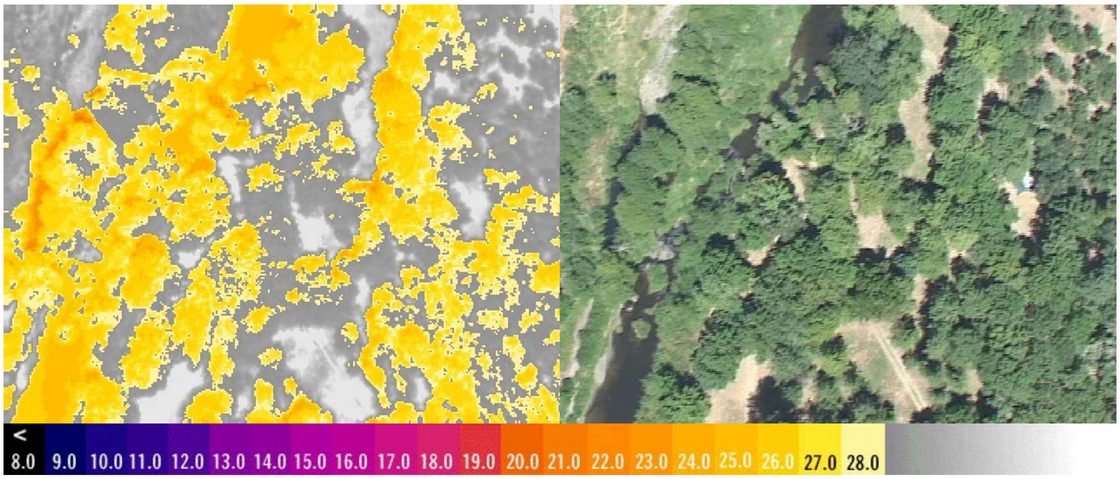
TIR/color video image pair showing Jackson Creek (24.4°C) on the left bank of South Umpqua River (23.3°C) at river mile 80.4 *(frames: sfu1089-1091)*.



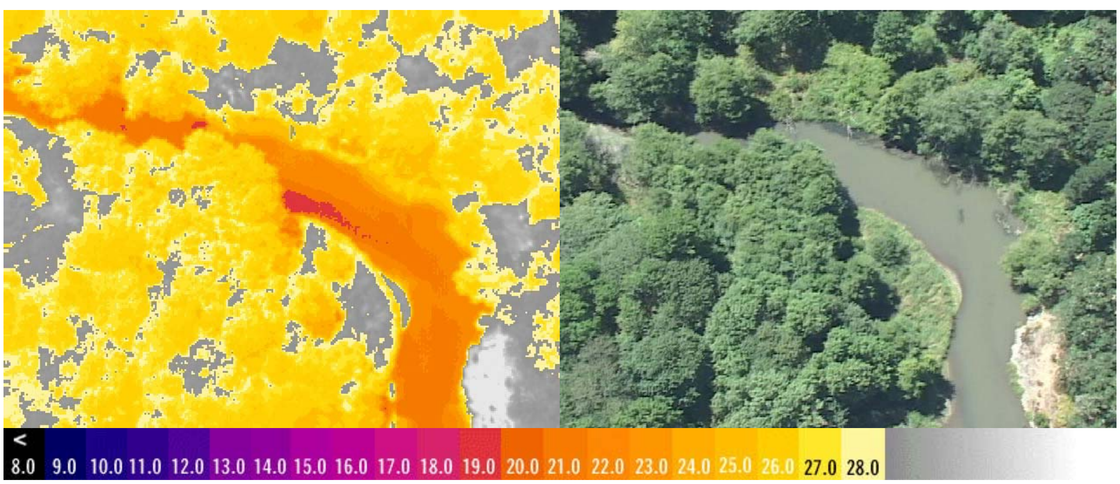
TIR/color video image pair showing the confluence of Myrtle Creek (23.6°C) to the right bank of South Umpqua River (25.5°C) at river mile 38.8 *(frame: sfu4516)*.

Lookingglass / Olalla Creek

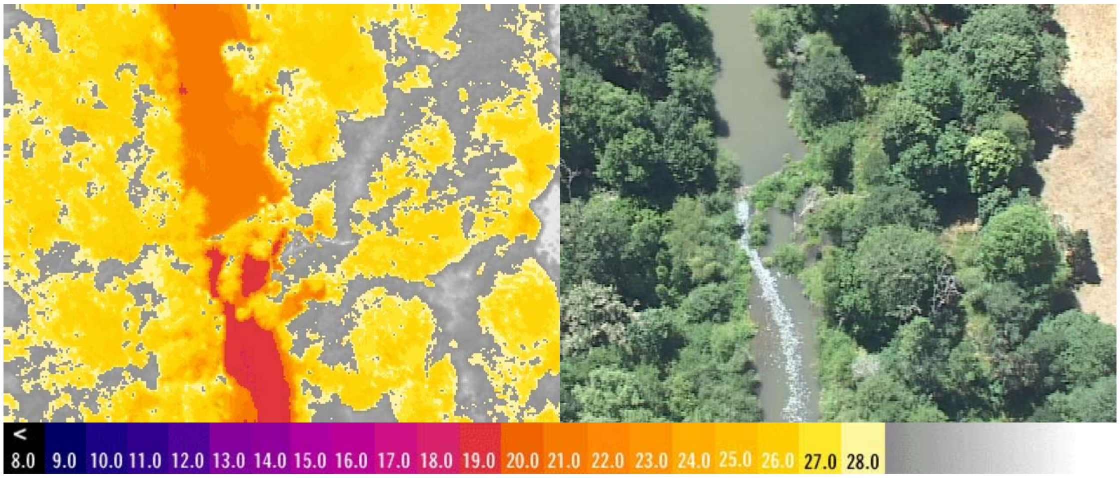
The TIR remote sensing flight was conducted in the upstream direction on Lookingglass Creek and Olalla Creek. Therefore, flow direction in the imagery is from top to bottom of the image. References to right bank or left bank are considered looking downstream.



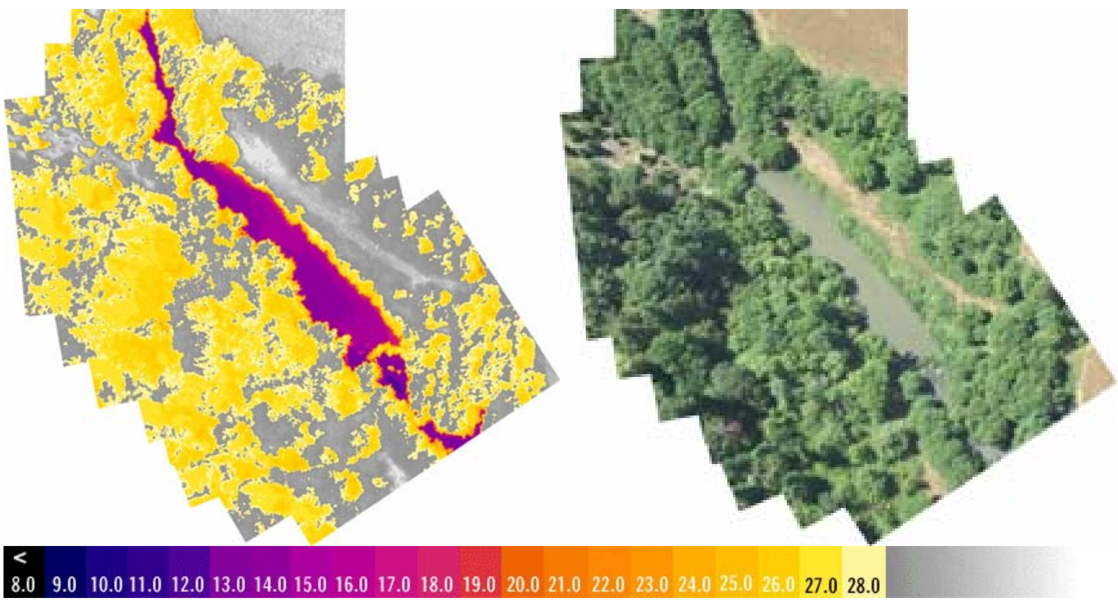
TIR/color video image pair showing an apparent spring on the right bank of Lookingglass Creek (23.8^{o}C) at river mile 1.2 Surface water is visible, but there was no obvious connectivity to the stream *(frame: oll0192).*



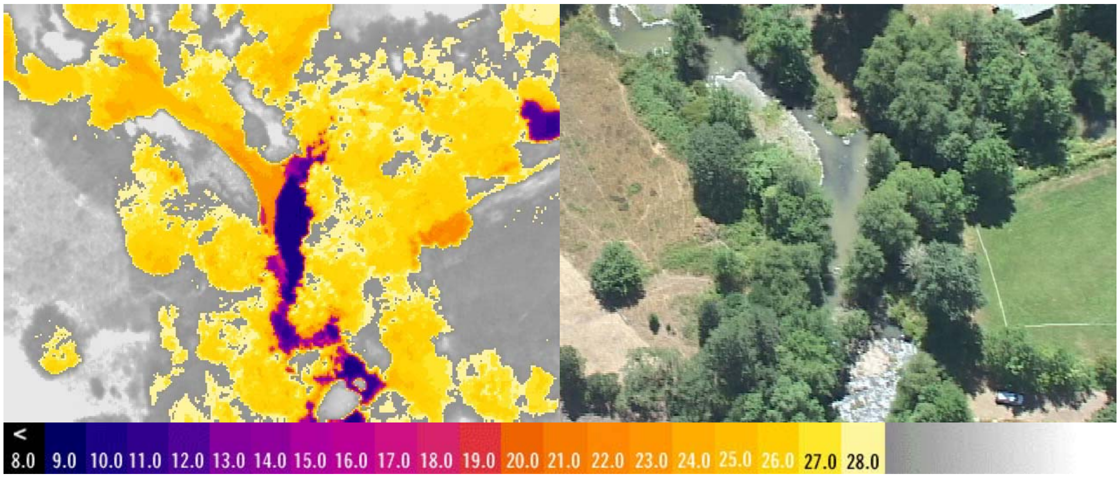
TIR/color video image pair showing an apparent spring (approximately 18.7^{o}C) on the right bank of Olalla Creek (20.5^{o}C) at river mile 4.7 *(frame: oll1581).*



TIR/color video image pair showing Olalla Creek at river mile 5.3. Surface temperatures decreased from 19.4^{o}C upstream of the impoundment to 18.3^{o}C downstream. The shift in temperature suggests possible stratification upstream of the impoundment *(frame: oll1662).*



TIR/color video image pair showing thermal conditions in Olalla Creek at river mile 9.0. Stream temperatures decrease from 13.5^{o}C upstream of the impoundment to 12.1^{o}C downstream. The shift in temperature suggests some level of stratification upstream of the impoundment *(frame: oll2161-2170).*



TIR/color video image pair showing the confluence of Berry Creek (9.3°C) on the left bank of Olalla Creek (23.1°C) at river mile 11.9 *(frame: oll2579)*.