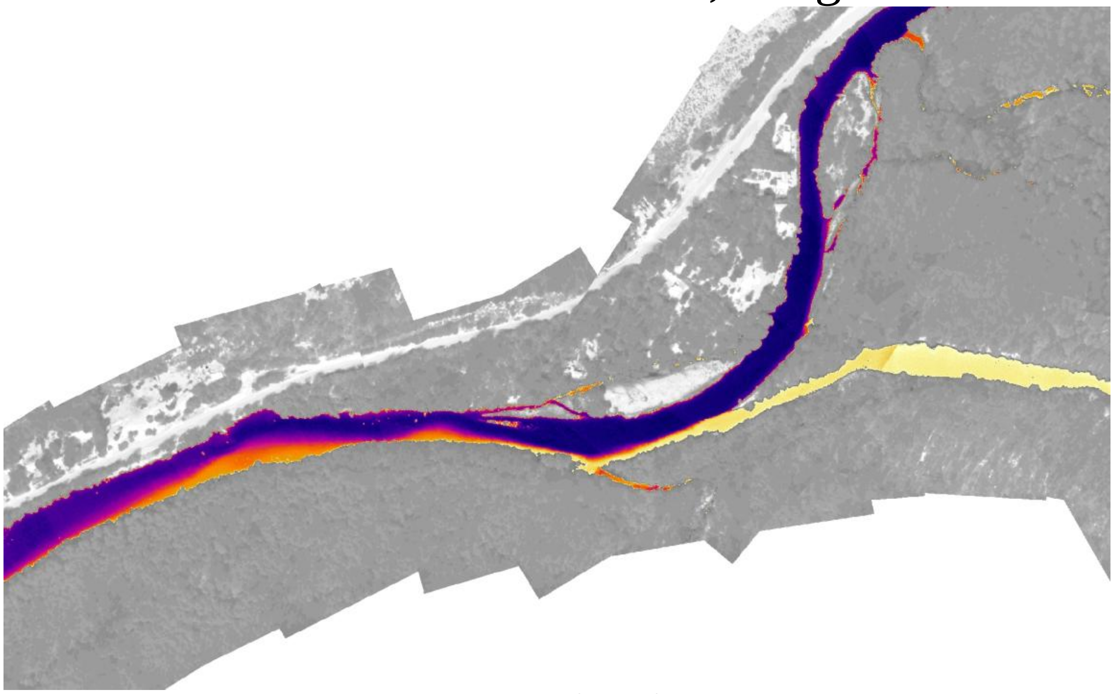
Airborne Thermal Infrared Remote Sensing

McKenzie River Basin, Oregon



Confluence of the McKenzie River and South Fork McKenzie River

Submitted to:

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Introduction

Project Overview

In 2009, the McKenzie Watershed Council contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) imagery for approximately 42 river miles in the McKenzie River Basin. The TIR acquisition included the McKenzie River, South Fork McKenzie River, and Elk Creek (*Figure 1, Table 1*).

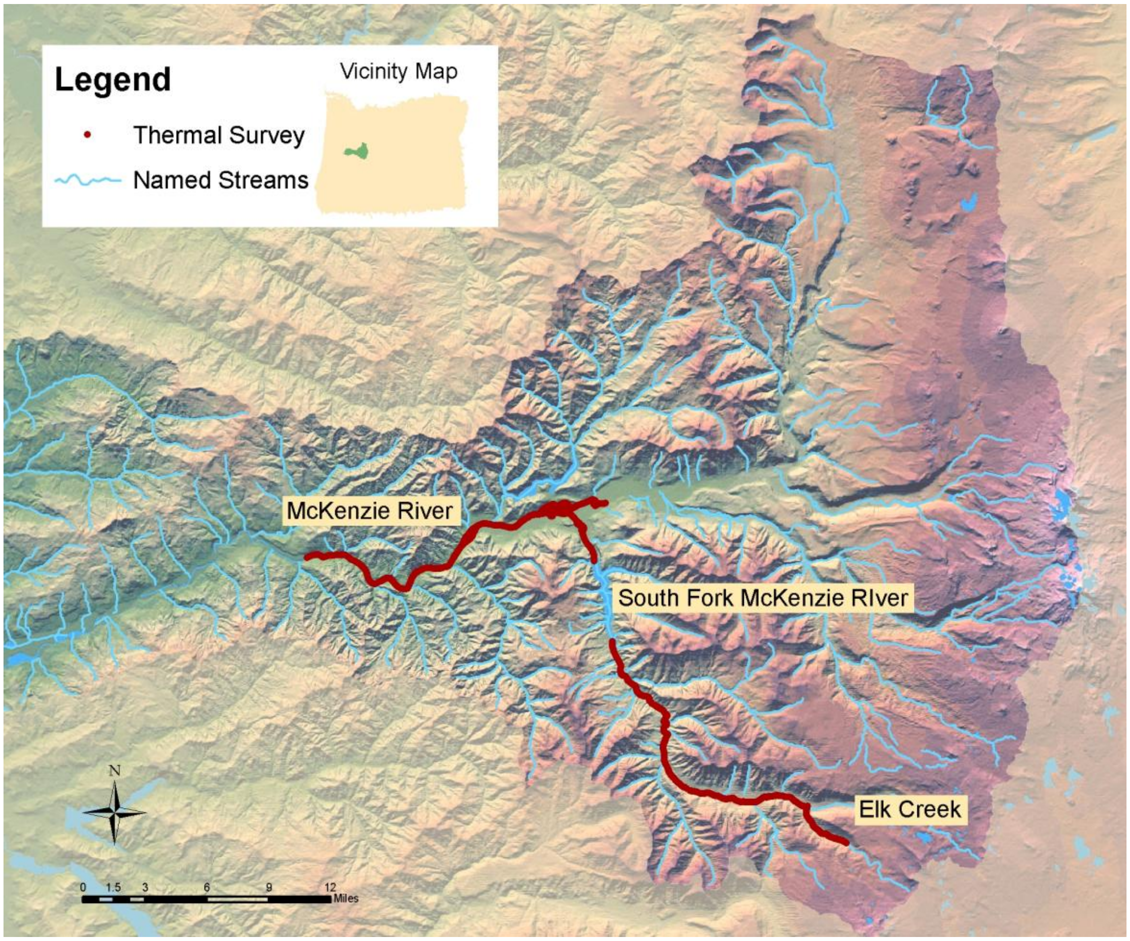


Figure 1 – An airborne thermal infrared (TIR) survey of the McKenzie River Basin was conducted on August 22, 2009.

Airborne TIR remote sensing has proven to be an effective method for mapping spatial temperature patterns in rivers and streams. These data are used to establish baseline conditions and direct future ground level monitoring. The TIR imagery illustrates the location and thermal influence of point sources, tributaries, and surface springs. When combined with other spatial data sets, the TIR data also illustrates reach-scale thermal response to changes in morphology, vegetation, and land-use.

Table 1 – Stream segments acquired with TIR data in the McKenzie River basin.

Stream Name	Date Flown	Miles Flown	Location
McKenzie River	8/22/2009	18.86	Martin Rapids to Rainbow
SF McKenzie River	8/22/2009	20.20	Mouth to Elk Creek (excluding Cougar Reservoir)
Elk Creek	8/22/2009	3.01	Mouth to River Mile 3.0

Project Objectives

The specific objectives of the TIR image acquisition were:

- Spatially characterize surface temperatures and stream flow conditions over 42 miles of streams in the McKenzie River basin.
- Develop a longitudinal temperature profile which illustrates basin scale stream temperature patterns.
- Identify and map cool water sources and thermal refugia.
- Create GIS compatible data layers (e.g. thermal image mosaics, spring locations, etc.) that can be used to plan future research, direct ground based monitoring and analysis, and protect and restore critical habitat.

Data Collection

Instrumentation: Images were collected with a FLIR system's SC6000 sensor (8-9.2μm) mounted on the underside of a Bell Jet Ranger Helicopter (*Figure 2*). The SC6000 is a calibrated radiometer with internal non-uniformity correction and drift compensation. General specifications of the thermal infrared sensor are listed in Table 2.

Figure 2 – Bell Jet Ranger equipped with a thermal infrared radiometer and high resolution digital camera. The sensors are contained in a composite fiber enclosure attached to the underside of the helicopter and flown longitudinally along the stream channel.

Table 2 - Summary of TIR sensor specifications

Sensor:	FLIR System SC6000 (LWIR)
Wavelength:	8-9.2 µm
Noise Equivalent Temperature Differences (NETD)	0.035°C
Pixel Array	640 (H) x 512 (V)
Encoding Level:	14 bit
Horizontal Field-of-View:	35.5°

Thermal infrared images were recorded directly from the sensor to an on-board computer as raw counts, which were then converted to radiant temperatures. The individual images were referenced with time, position, and heading information provided by a global positioning system (GPS) (*Figure 3*).

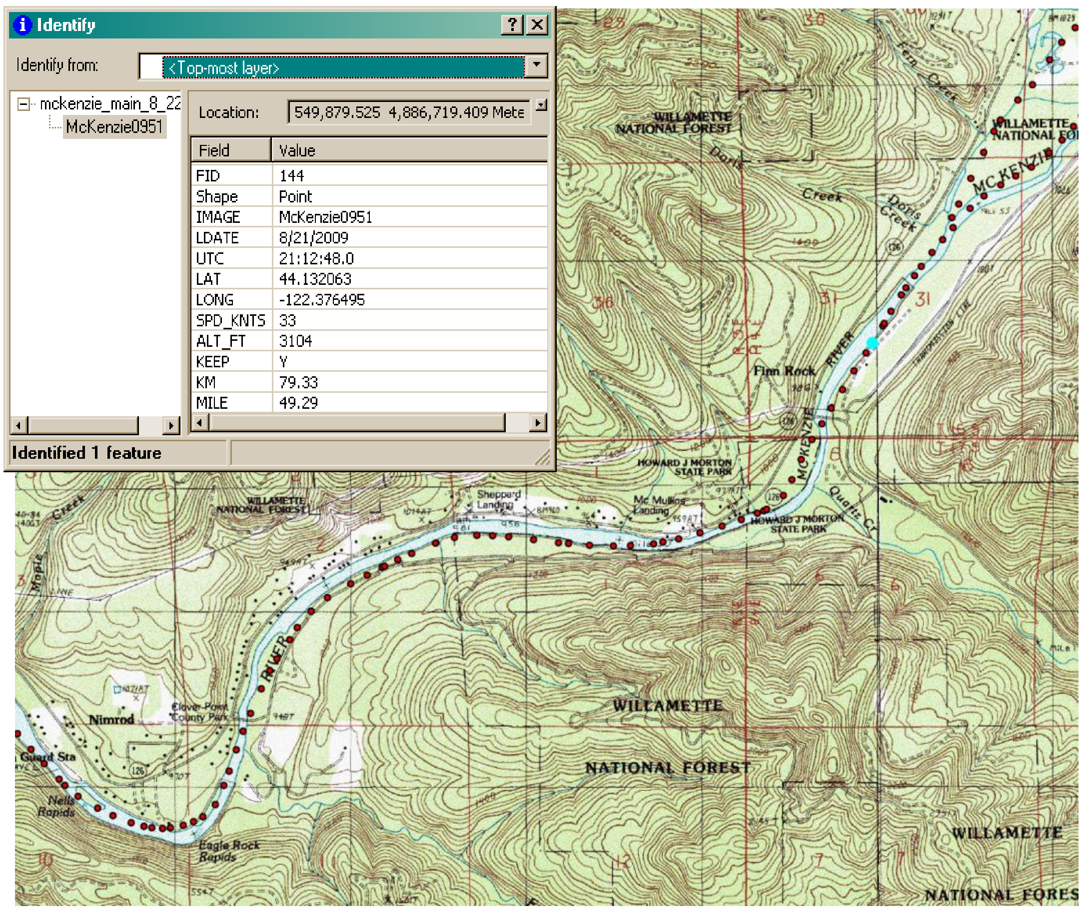


Figure 3 –Each point on the map represents a thermal image location. The inset box shows the information recorded with each image point during acquisition.

<u>Image Characteristics:</u> The aircraft was flown longitudinally along the stream corridor in order to have the river in the center of the display. The objective was for the stream to occupy 30-60% of the image. The TIR sensor is set to acquire images at a rate of 1 image every second resulting in 40-70% vertical overlap between images.

A flight altitude of 1900 ft (579 m) was selected for the McKenzie River which resulted in a native pixel ground sample distance of 0.6 m (2.0 ft). The flight altitude was selected in order to optimize resolution while providing an image ground footprint wide enough to capture the active channel. For the South Fork McKenzie River and Elk Creek, the flight altitude was 1400 ft (427 m) resulting in pixel ground sample distances of 0.43 m (1.4 ft). (Table 3).

Table 3 - Summary of Thermal Image Acquisition Parameters.

Date:	August 22, 2009
McKenzie River	
Flight Above Ground Level (AGL):	1900 ft (579 m)
Image Footprint Width:	1216 ft (371 m)
Pixel Resolution:	0.6 m (2.0 ft)
South Fork McKenzie and Elk Creek	
Flight Above Ground Level (AGL):	1400 ft (427 m)
Image Footprint Width:	896 ft (273 m)
Pixel Resolution:	0.43 m (1.4 ft)

The airborne survey attempted to cover all surface water within the floodplain including side channels and tributary junctions. If a side-channel or other surface water was not captured in the image field-of-view. The side-channel was flown separately so that all surface water was captured (*Figure 4*).

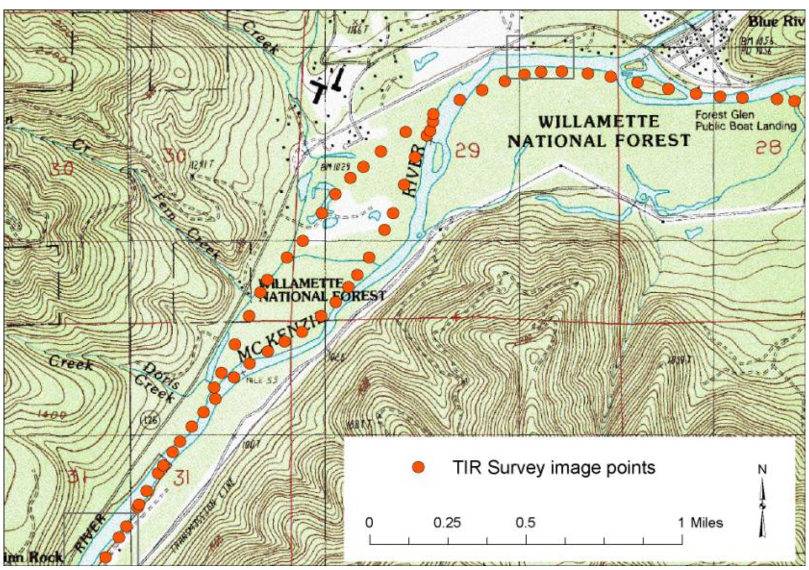


Figure 4 – Digital raster graphic (DRG) of the main stem McKenzie River near river mile 50.5 showing characteristic side channels. The TIR flight primarily followed the main channel of the river. However, if a side channel was outside the sensor field-of-view, the side-channel was flown separately in order to capture all visible surface water.

Ground Control: Watershed Sciences, Inc. deployed seven in-stream sensors during the time frame of the flight for calibrating and verifying the thermal accuracy of the TIR imagery. The data logger locations are illustrated in Figure 5. The Hobo Pro data loggers were set to record temperatures at 10-minute intervals and suspended in the water column in areas with good vertical mixing.

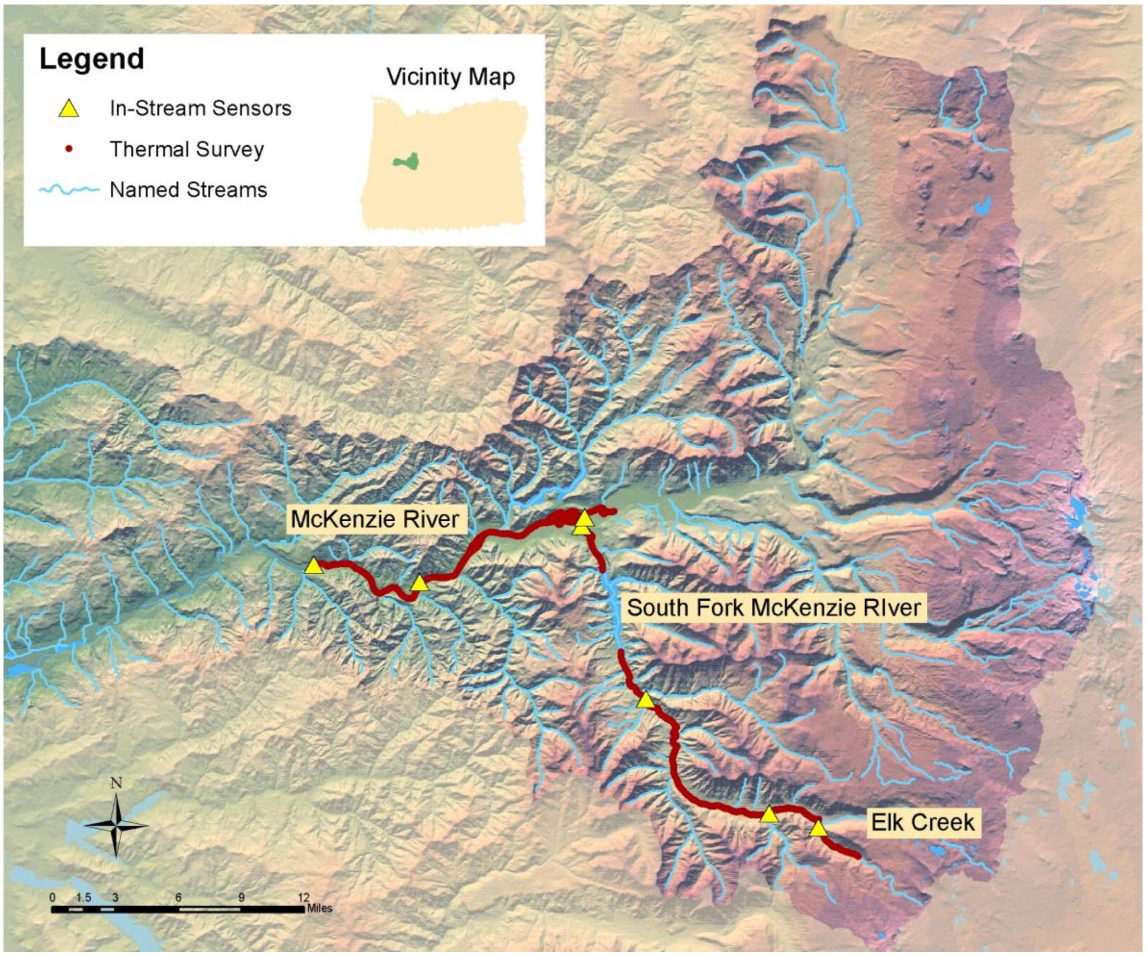


Figure 5 – Location of sensors deployed by Watershed Sciences.

Data Processing

Calibration: Prior to the season, the response characteristics of the TIR sensor are measured in a laboratory environment. The response curves relate the raw digital numbers recorded by the sensor to emitted radiance from the black body. The raw TIR images collected during the survey initially contain digital numbers which are then converted to radiance temperatures based on the pre-season calibration.

The calculated radiant temperatures are adjusted based on the kinetic temperatures recorded at each ground truth location. This adjustment was performed to correct for path length attenuation and the emissivity of natural water. 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.

Interpretation and Sampling: Once calibrated, the images 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. The temperature of detectable surface inflows (i.e. surface springs, tributaries) was also sampled at their mouths. During sampling, the analyst provided interpretations of the spatial variations in surface temperatures observed in the images.

Temperature Profiles: The median temperatures for each sampled image 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. Radiant temperatures were only sampled along what appeared to be the main flow channel in the river.

Geo-referencing: The images are tagged with a GPS position and heading at the time they are acquired (*Figure 3*). Since the TIR camera is maintained at vertical down-look angles, the geographic coordinates provide a reasonably accurate index to the location of the image scene. Due to the relatively small footprint of the imagery and independently stabilized mount, image pixels are not individually registered to real world coordinates. The image index is saved as an ESRI point shapefile containing the image name registered to an X and Y position (UTM Zone 10, NAD83) of sensor location at time of capture. In order to provide further spatial reference, the TIR images were assigned a river mile based on a routed stream layer.

Geo-Rectification: Individual frames were manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and existing NAIP imagery. The images were then warped using a 1^{st} order polynomial transformation. Due to the low relief along the river bottom, the photos were not corrected for terrain displacement.

Thermal Image Characteristics

Surface Temperatures: 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 and can usually be detected in the imagery.

Expected Accuracy: 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 (~ 4 to 6%). 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 0.5°C (Torgersen et al. 2001[1]). 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 < 0.5°C are not considered significant unless associated with a surface inflow (e.g. tributary).

Differential Heating: 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.

Feature Size and Resolution: 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. This is a consideration when sampling the radiant temperatures at tributary mouths and surface springs.

Temperatures and Color Maps: The TIR images collected during this survey consist of a single band. As a result, visual representation of the imagery *(in a report or GIS environment*) requires the application of a color map or legend to the pixel values. The selection of a color map should highlight features most relevant to the analysis (i.e. *spatial variability of stream temperatures*). For example, a continuous, gradient style color map that incorporates all temperatures in the image frame will provide a smoother

[1] 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.

transition in colors throughout the entire image, but will not highlight temperature differences in the stream. Conversely, a color map that focuses too narrowly cannot be applied to the entire river and will washout terrestrial and vegetation features (*Figure 6*).

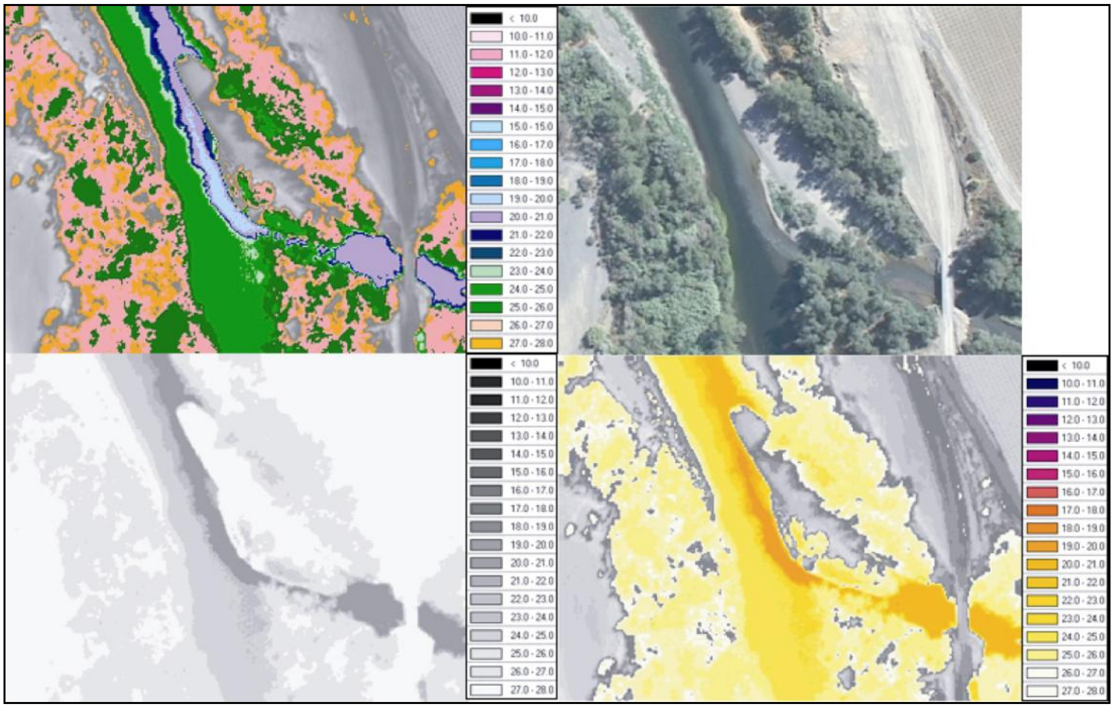


Figure 6 - Example of different color maps applied to the same TIR image.

Image Uniformity: The TIR sensor used for this study uses a focal plane array of detectors to sample incoming radiation. A challenge when using this technology is to achieve uniformity across the detector array. This sensor has a correction scheme which reduces non-uniformity across the image frame. However, differences in temperature (typically $<0.5^{o}$C) can be observed near the edge of the image frame. The uniformity differences within frames and slight differences from frame-to-frame are often most apparent in the continuous mosaics.

Weather Conditions

Weather conditions on the date of the survey were considered ideal with warm temperatures, low humidity and clear skies. Data from seasonal in-stream thermographs will be needed to assess how water temperatures on the day of the flight compare to average and maximum summer temperatures. Table 4 summarizes the weather conditions observed at Good Pasture Bridge, Vida, OR, on August 22, 2009.

Table 4 – Weather conditions measured at Good Pasture Bridge, Vida, OR on August 22, 2009 (http://www.wunderground.com).

Date	PDT	Air Temp (°F)	Air Temp (°C)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction
8/22/2009	1000	61.6	16.4	74	--	Calm
8/22/2009	1200	72.5	22.5	56	--	Calm
8/22/2009	1400	80.1	26.7	39	2.0	WSW
8/22/2009	1600	82.2	27.9	30	3.0	SSE
8/22/2009	1800	80.8	27.1	29	3	Calm

Thermal Accuracy

Watershed Sciences deployed a network of seven in-stream data-loggers (Onset Hobo-Pros) in the McKenzie River Basin during the time frame of the flight (*Figure 5*). Table 5 summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images for the McKenzie, South Fork McKenzie, and Elk Creek.

Table 5 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitor.

River	Sensor Type	Sensor ID	Time	In-stream Temp (°C)	Image	River Mile	Radiant Temp (°C)	Difference
McKenzie River (8/22/09)								
McKenzie	Hobo Pro	1026266	13:56	13.2	McKenzie0010	39.9	13.3	-0.1
McKenzie	Hobo Pro	1187769	14:09	13.4	McKenzie0720	46.8	13.2	0.2
McKenzie	Hobo Pro	1026267	14:30	11.5	McKenzie1865	56.8	11.7	-0.2
SF McKenzie River (8/22/09)								
SF McKenzie	Hobo Pro	1026259	14:44	16.2	McKenzie2472	2.06	16.2	0.0
SF McKenzie	Hobo Pro	1026264	14:57	11.1	McKenzie3034	11.8	11.1	0.0
SF McKenzie	Hobo Pro	1026261	14:17	9.7	McKenzie4136	22.6	9.9	-0.2
Elk Creek (8/22/09)								
Elk Creek	Hobo Pro	1187768	15.23	9.7	McKenzie4458	0.31	10.7	-1.0

In general, the differences between radiant and kinetic temperatures were consistent with other airborne TIR surveys conducted in the Pacific Northwest and within the target accuracy of ±0.5°C. In the McKenzie Basin, the differences between radiant and kinetic temperatures ranged between -1.0°C and 0.0°C.

The sensor on Elk Creek fell outside of the target accuracy of ±0.5°C. At this location the water surface was masked by riparian vegetation in the TIR imagery. The higher radiant temperatures at this location likely resulted due to mixed or hybrid pixels (i.e. water and vegetation or rocks) resulting in higher radiant temperatures. Much of Elk Creek had plant canopy masking the water surface (*Figure 7*). Radiant temperatures derived from these images should show general longitudinal trends, but caution should be used in interpreting localized temperatures in Elk Creek.

Figure 7 – The photo above shows the location of the HoboPro sensor on Elk Creek. The narrow width of the stream in addition to the heavy vegetation may account for the higher than normal radiant temperatures.

Results

Median channel temperatures were plotted versus river mile for the streams in the survey area. Tributaries sampled during the analysis are included on the profile to provide additional context for interpreting spatial temperature patterns. Significant features such as braids, impoundments and dam outflows were also plotted where relevant.

Due to the nature of the project, the focus of the survey was to depict the thermal conditions during peak temperatures. Given the warm temperatures on the days of the survey, features such as hot springs may have been 'washed out' in comparison to the surrounding terrestrial landscape. The sample images contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations. Figure 8 below provides a ground level photo of the South Fork McKenzie River on the day of the TIR survey.

Figure 8 – Ground level digital photo of the South Fork McKenzie River on the day of the TIR survey

McKenzie River

Longitudinal Temperature Profile

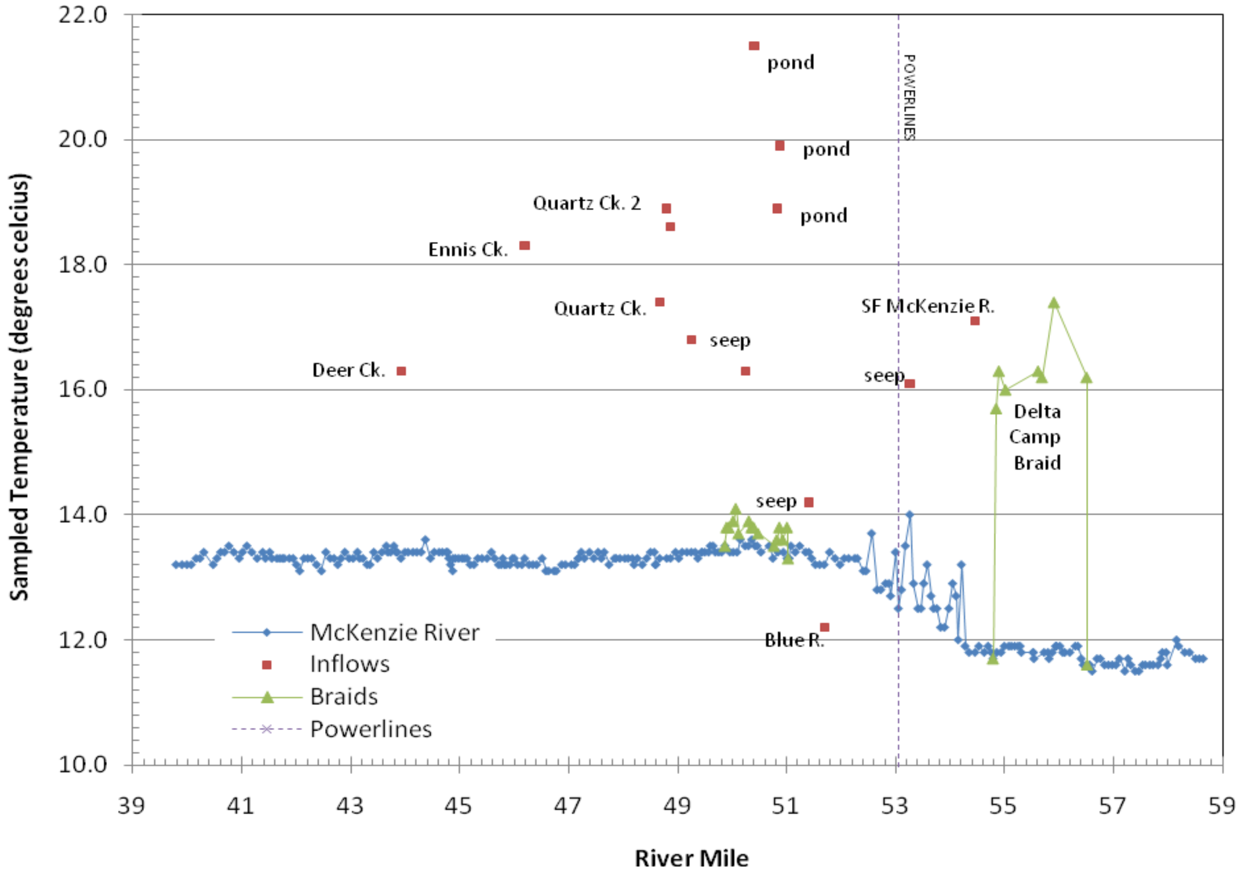


Figure 9 - Median channel temperatures plotted versus river mile for the McKenzie River. The locations of detected surface inflows are illustrated on the profile and listed in Table 6. Side channels longer than one mile are also displayed. All mileages are referenced from the mouth of the McKenzie River.

Table 6 - Tributaries and other surface inflows sampled along the McKenzie River with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Deer Creek (L)	70.69	43.92	16.3	13.3	3.0
Ennis Creek (L)	74.34	46.19	18.3	13.3	5.0
Quartz Creek 2 (L)	78.33	48.67	17.4	13.3	4.1
Quartz Creek (L)	78.53	48.80	18.9	13.3	5.6
unnamed (L)	78.65	48.87	18.6	13.3	5.3
warm seep off sandbar (M)	79.25	49.25	16.8	13.4	3.4
remnant channel (L)	80.86	50.24	16.3	13.5	2.8
pond (L)	81.11	50.40	21.5	13.8	7.7
pond (L)	81.79	50.82	18.9	13.6	5.3
pond (L)	81.86	50.87	19.9	13.8	6.1
warm seep off sandbar (M)	82.74	51.41	14.2	13.4	0.8
Blue River (R)	83.19	51.69	12.2	13.2	-1.0
warm seep off sandbar (L)	85.72	53.26	16.1	14.0	2.1
SF McKenzie (L)	87.65	54.46	17.1	11.8	5.3

Observations

Approximately 20 miles of the McKenzie River were surveyed on August 22, 2009 from river mile 39.71 at Martin Rapids upstream to river mile 59.29 near Rainbow, OR. Six tributaries, 3 ponds, 3 warm seeps, a remnant channel and multiple braids were sampled in the imagery. All braids were sampled; however, only those longer than one mile are shown on the longitudinal profile. Bulk water temperatures ranged from 11.5°C above the confluence with the South Fork McKenzie River to 14.0°C in the highly variable reach below the South Fork.

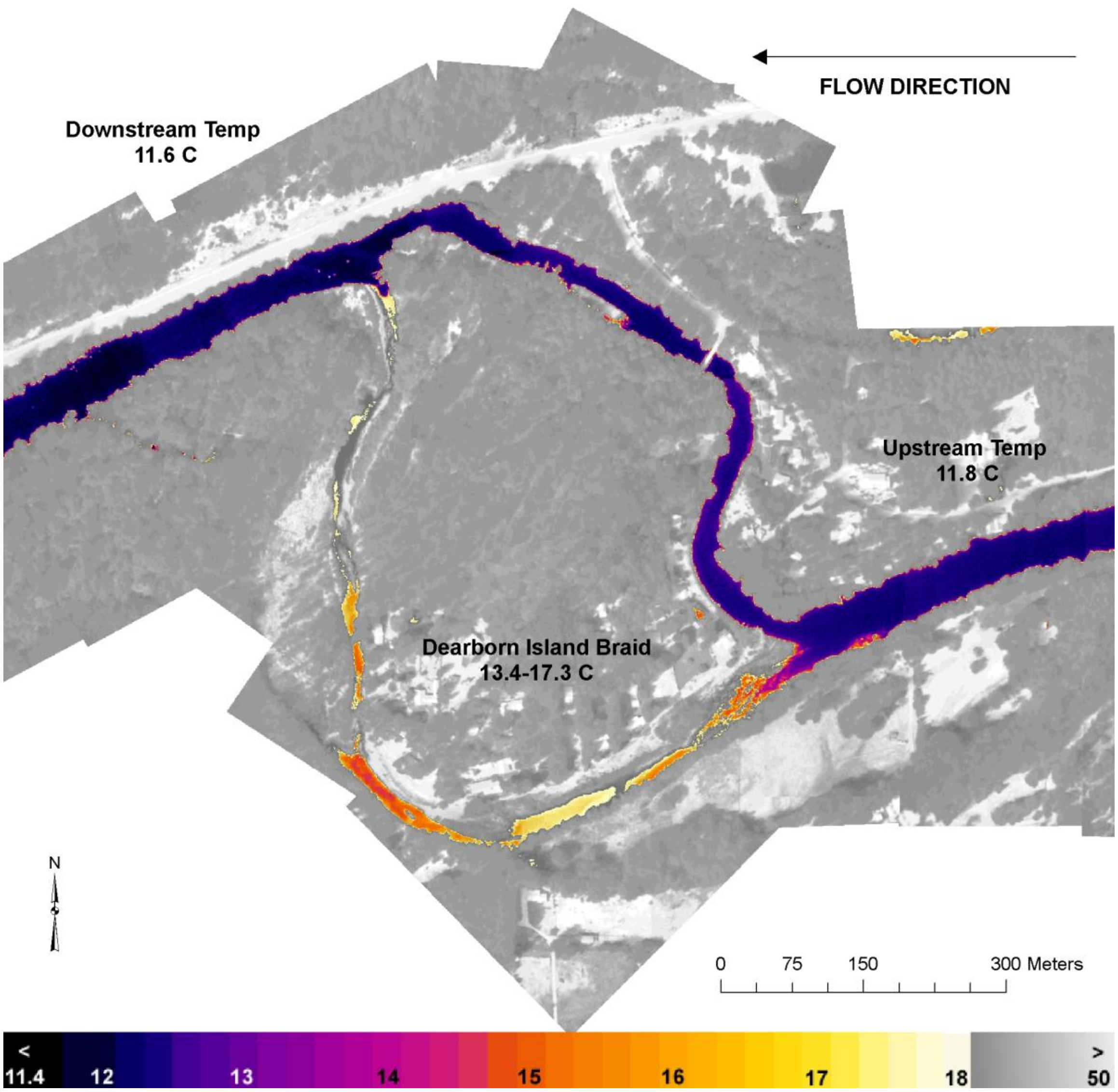
From Rainbow, OR downstream to the South Fork, temperatures remain stable between 11.5°C and 12.0°C. The warm braids around Dearborn Island and south of Delta Campground appear to have little effect on the mainstem temperatures in this reach (*McKenzie Image 1*).

At river mile 54.46, the South Fork McKenzie enters the mainstem at 17.1°C, raising the bulk water temperatures by 1.5°C over 2.5 miles (11.8→13.3°C). A high degree of variability was seen in the sampling for the 2.5 miles downstream of the confluence. It appears in the imagery and the longitudinal profile that the warm water of the South Fork does not readily mixing with the cooler water of the mainstem (*McKenzie Image 2*). The temperature profile stabilizes below Blue River indicating complete mixing.

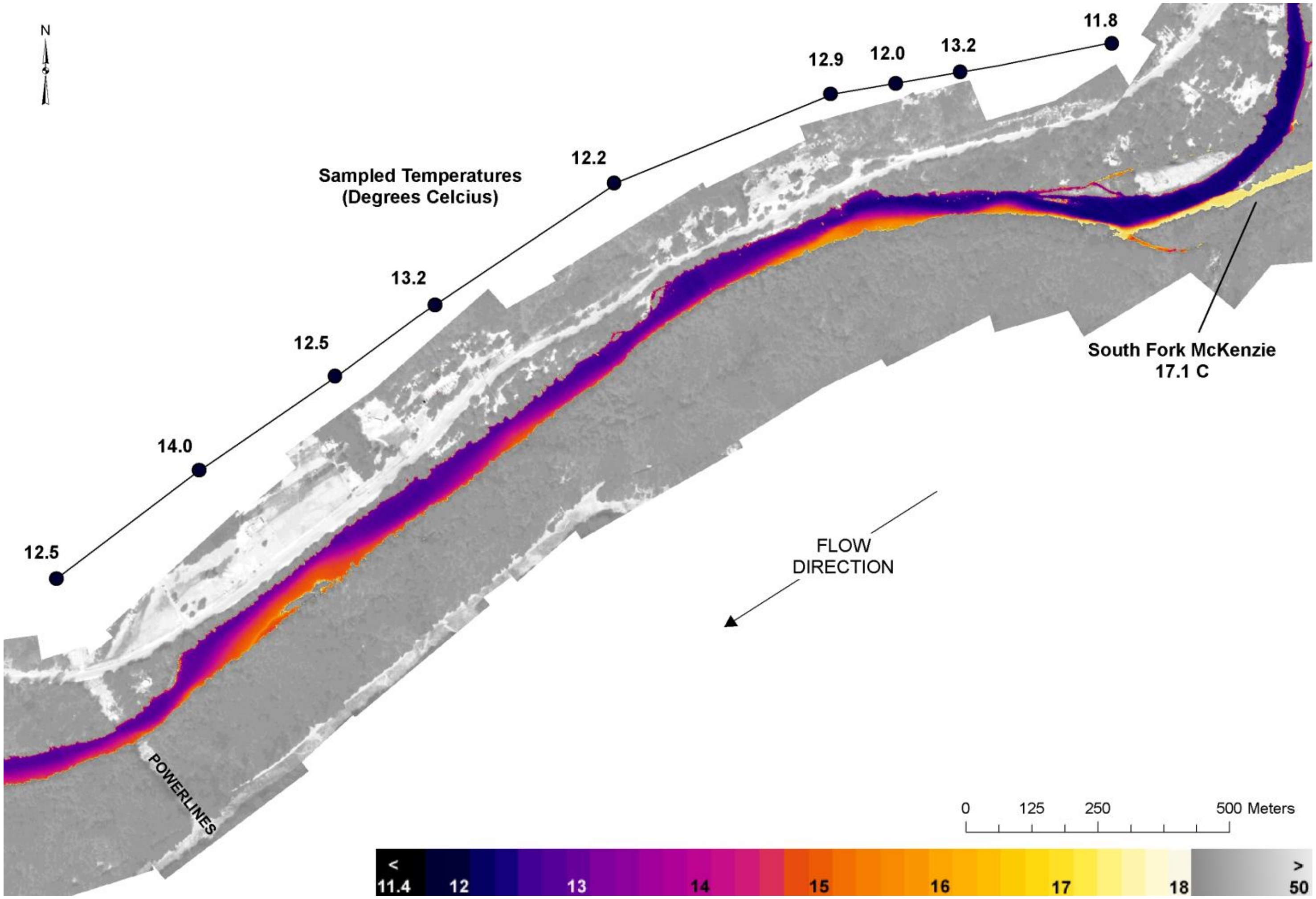
At river mile 51.69, Blue River enters the mainstem at 12.2°C. Though 1.0°C cooler than the bulk water temperatures of the mainstem, it appears to have little impact on the downstream temperature profile. Water temperatures below Blue River remained very stable downstream to Martin Rapids fluctuating only 0.5°C (13.1→13.6°C) for the lower ten miles of the survey. None of the other inflows or braids had a measurable impact on bulk water temperatures.

One unique feature seen in the mainstem are warm seeps that appear to originate in the shallow waters from the sandbars at river miles 49.25, 51.41, and 53.26. (*McKenzie Image 3*). Typically this type of hyporheic flow would be colder than the bulk water temperatures as the water flows through the interstitial spaces of the sediment and intermixes with groundwater. It is unclear why these seeps appear warmer than the bulk water temperatures.

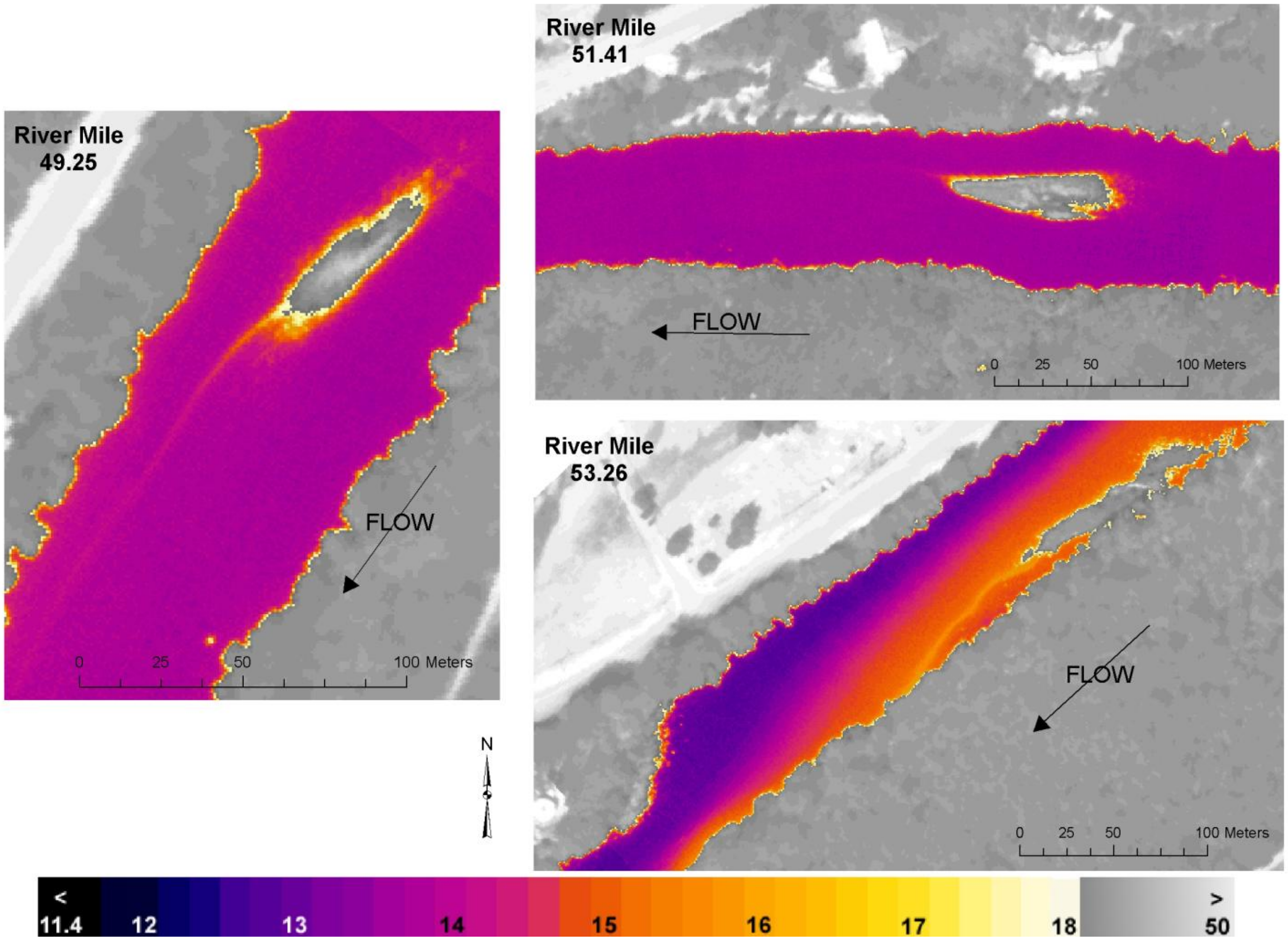
Sample Images



McKenzie Image 1 – The TIR image above shows the braid around Dearborn Island (river left near river mile 58.00). Despite temperatures of the braid being 2-6°C warmer than the mainstem, the low flows have no apparent impact on the overall bulk water temperatures. This braid is not shown on the longitudinal profile due to its short length of 0.4 miles.



McKenzie Image 2 – The TIR image above shows the thermal pattern immediately below the confluence of the mainstem McKenzie and the South Fork McKenzie from river mile 54.63-53.05. The variability seen in the temperature profile appears to be from incomplete mixing of the two water sources. Once thorough mixing occurs over a distance of 2.5 miles, the overall bulk water temperatures warm significantly from 11.8°C to 13.3°C.



McKenzie Image 3 – The TIR images above display the three seeps shown in the longitudinal temperature profile at river miles 49.25, 51.41, and 53.26. It is unusual that these seeps are warmer than the surrounding waters as they flow off of the sandbars. Typically this type of hyporheic flow would be colder than the bulk water temperatures as the water flows through the interstitial spaces of the sediment and intermixes with groundwater.

South Fork McKenzie River

Longitudinal Temperature Profile

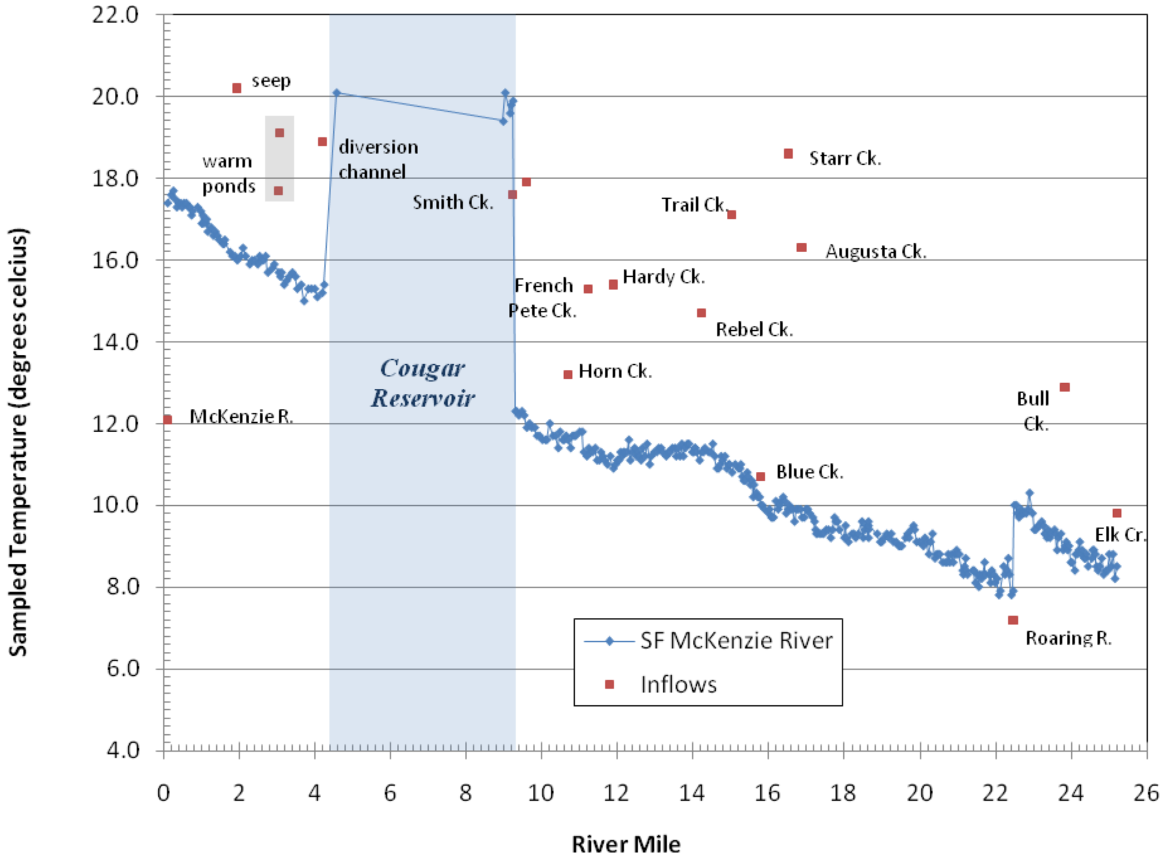


Figure 10 - Median channel temperatures plotted versus river mile for the South Fork McKenzie River. The locations of detected surface inflows are illustrated on the profile and listed in Table 7.

Table 7 - Tributaries and other surface inflows sampled along the South Fork McKenzie River with left or right bank designation (looking downstream)

Tributary	Kilometer	River Mile	Trib Temp (°C)	Mainstem Temp (°C)	Difference
McKenzie R. (L)	0.15	0.09	12.1	17.4	-5.3
warm seep? (L)	3.11	1.93	20.2	16.0	4.2
warm impoundments (L)	4.88	3.03	17.7	15.7	2.0
warm impoundments (L)	4.93	3.07	19.1	15.6	3.5
diversion channel (R)	6.72	4.18	18.9	15.2	3.7
Smith Creek (lakeshore) (R)	14.86	9.23	17.6	19.9	-2.3
unnamed (L)	15.44	9.59	17.9	11.9	6.0
Horn Creek (small) (L)	17.18	10.68	13.2	11.6	1.6
French Pete Ck (R)	18.07	11.23	15.3	11.4	3.9
Hardy Creek (L)	19.11	11.88	15.4	10.9	4.5
Rebel Creek (R)	22.87	14.21	14.7	11.3	3.4
Trail Creek (small sample) (R)	24.18	15.02	17.1	10.8	6.3
Blue Creek? (L)	25.41	15.79	10.7	10.0	0.7
Starr Creek (L)	26.61	16.53	18.6	10.0	8.6
Augusta Creek (L)	27.14	16.87	16.3	9.7	6.6
Roaring River (L)	36.14	22.46	7.2	7.9	-0.7
Bull Creek (small) (R)	38.35	23.83	12.9	9.0	3.9
Elk Creek (L)	40.56	25.20	9.8	8.5	1.3

Observations

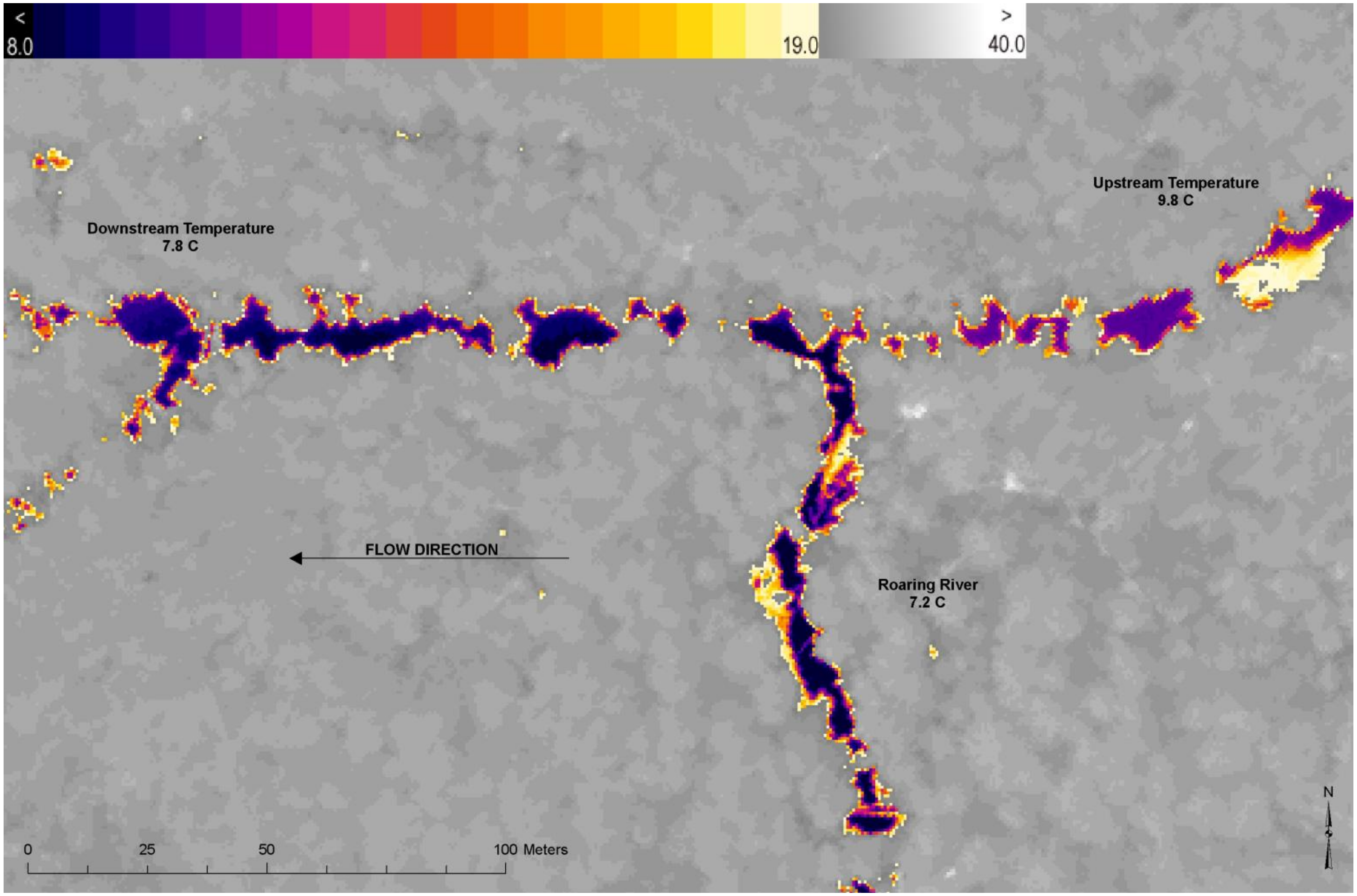
Approximately 20 miles of the South Fork McKenzie River were surveyed on August 22, 2009 from the mouth at the McKenzie River upstream to Elk Creek, excluding Cougar Reservoir (~RM 4.93 to 9.23). Fourteen tributaries, two impoundments, one warm seep and the diversion channel from Cougar Dam were sampled in the imagery. Bulk water temperatures ranged from 7.8°C at the confluence with the Roaring River (RM 22.46) to 17.4°C at the mouth of stream. Surface water temperatures of Cougar Reservoir were sampled near 20°C.

The river warms as it flows downstream from Elk Creek until river mile 22.49 where the Roaring River has a significant cooling effect on the temperature profile (*South Fork Image 1*). Temperatures drop 2.0°C over a distance of 0.1 miles (10.0°→7.8°C). All inflows except the Roaring River contributed warmer water to Elk Creek; however, none significantly impacted the overall temperature profile.

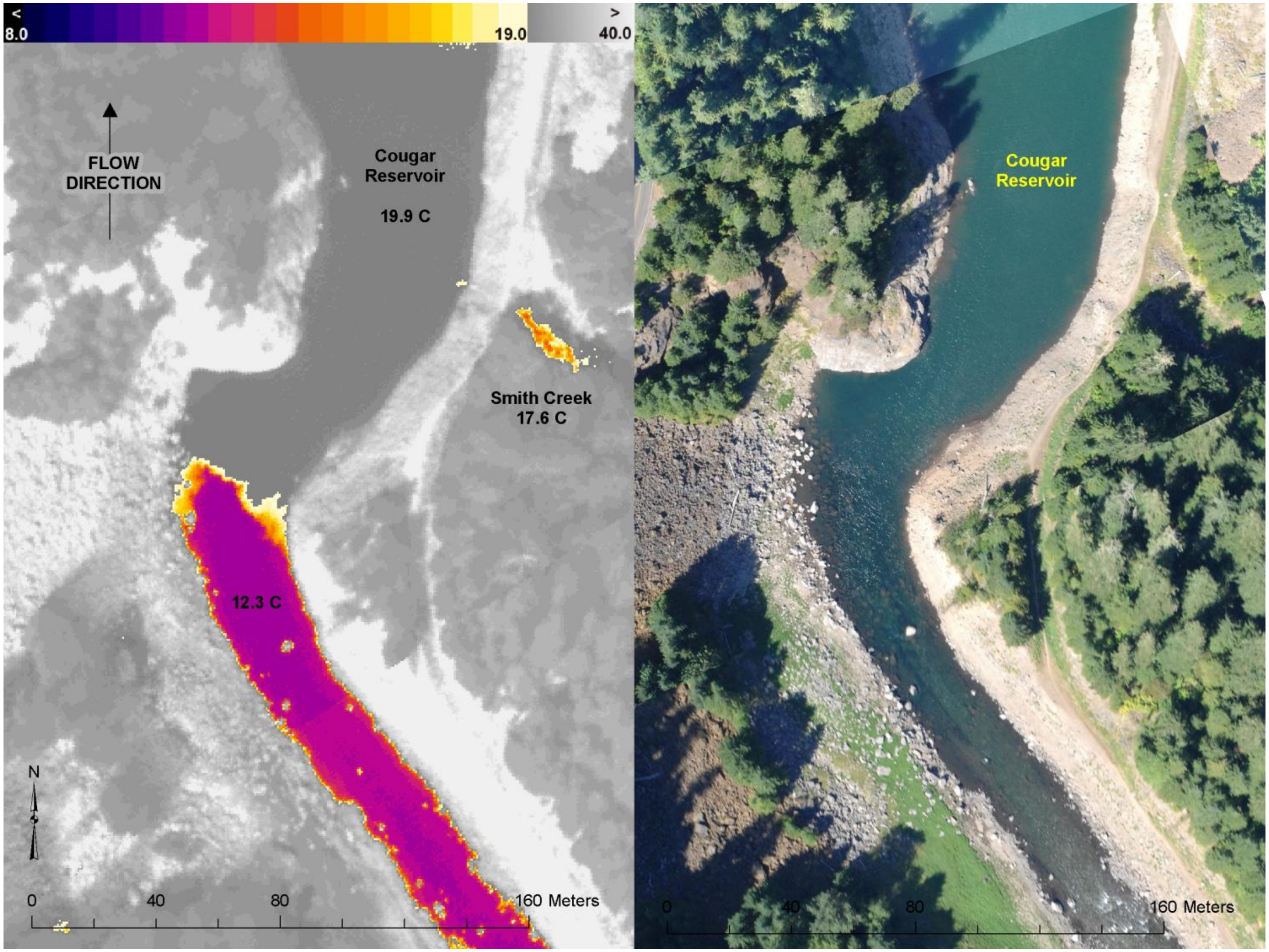
The rate of downstream warming is relatively consistent over the first six miles below Roaring River. Upstream of Blue Creek, a slight increase in the warming rate was observed followed by relatively consistent water temperatures between Blue Creek and Horn Creek (~4 miles). The longitudinal pattern suggests a change in the energy balance determining stream temperatures through this reach either through shallow sub-surface discharge or a change of valley form or both. Future analyses should further examine changes in channel form and valley morphology through this reach.

As the cooler water of the upper South Fork reaches Cougar Reservoir, there is a significant temperature increase as the cooler waters flow beneath the warm stratified layers of the reservoir (*South Fork Image 2*). At the head of the reservoir, these stratified waters are re-mixed before being released to the lower reaches of the South Fork. In 2005, the construction of a temperature control tower was completed in an effort to improve the downstream fisheries. The day of the survey, water was being released at 15°C (*South Fork Image 3*). Below the dam, the stream continues to warm at a consistent rate for the final reach before merging with the mainstem at 17.4°C

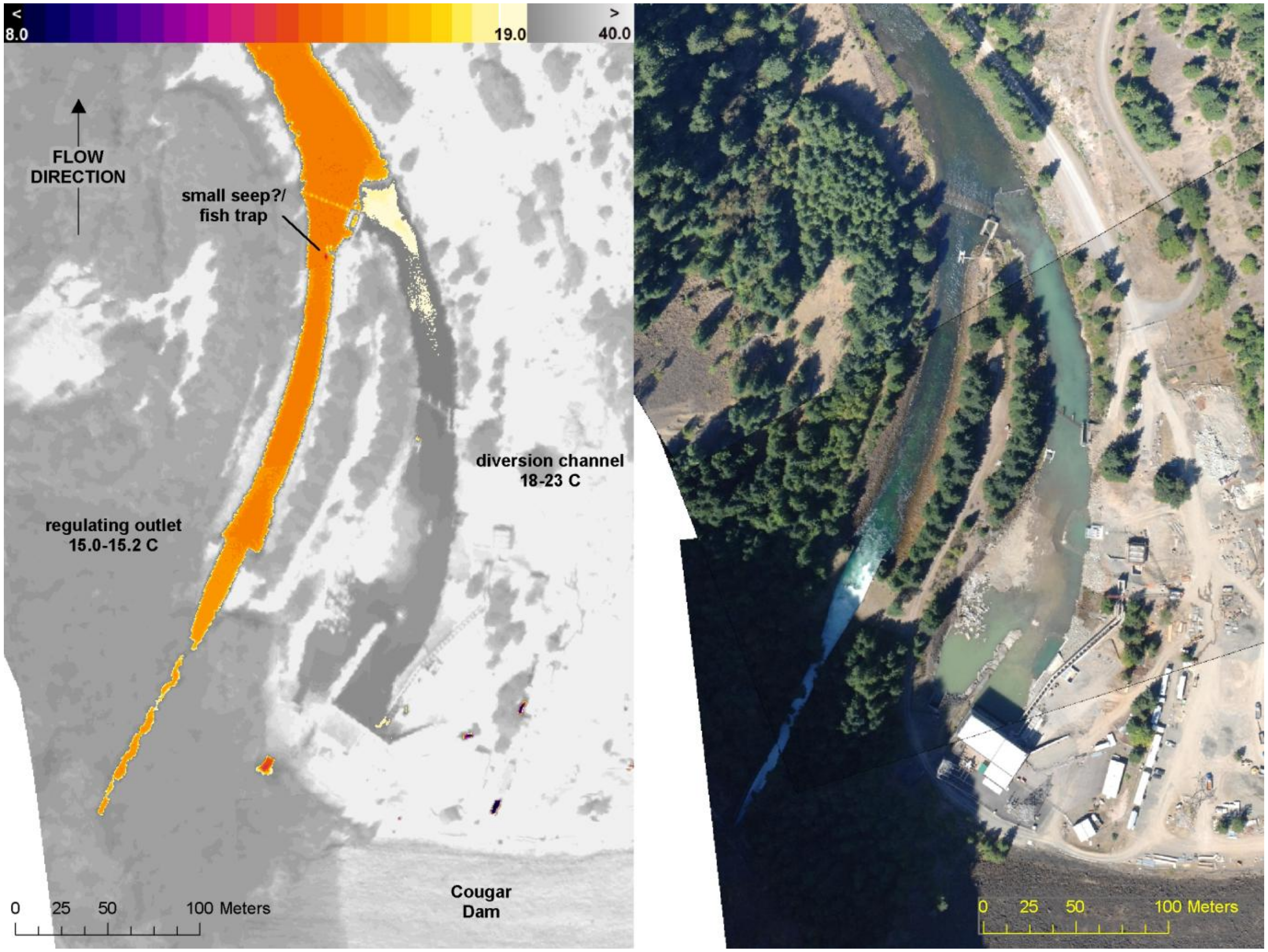
Sample Images



South Fork Image 1- The TIR image above shows the confluence of the Roaring River and the South Fork McKenzie at river mile 22.46. The Roaring River was the only cold water influence to the South Fork detected during the survey and results in a dramatic 2°C decrease in bulk water temperatures of the South Fork.



South Fork Image 2 – The TIR/true color image pair above shows the South Fork McKenzie River entering Cougar Reservoir. At this point, the cooler, denser water from the stream sinks below the warm surface waters of the Reservoir creating a stratified water column.



South Fork Image 3- – The TIR/true color image pair above shows the release of water from Cougar Dam to the lower South Fork McKenzie. With the construction of the temperature control tower in 2005, water temperature can be regulated to a degree beneficial to the downstream fisheries. The day of the survey, water was being released at 15°C. The diversion channel showed no signs of flow. A small seep was also detected next to the fish trap. It is unclear if this is a natural feature or an artifact of the thermal signature of the fish trap.

Elk Creek

Longitudinal Temperature Profile

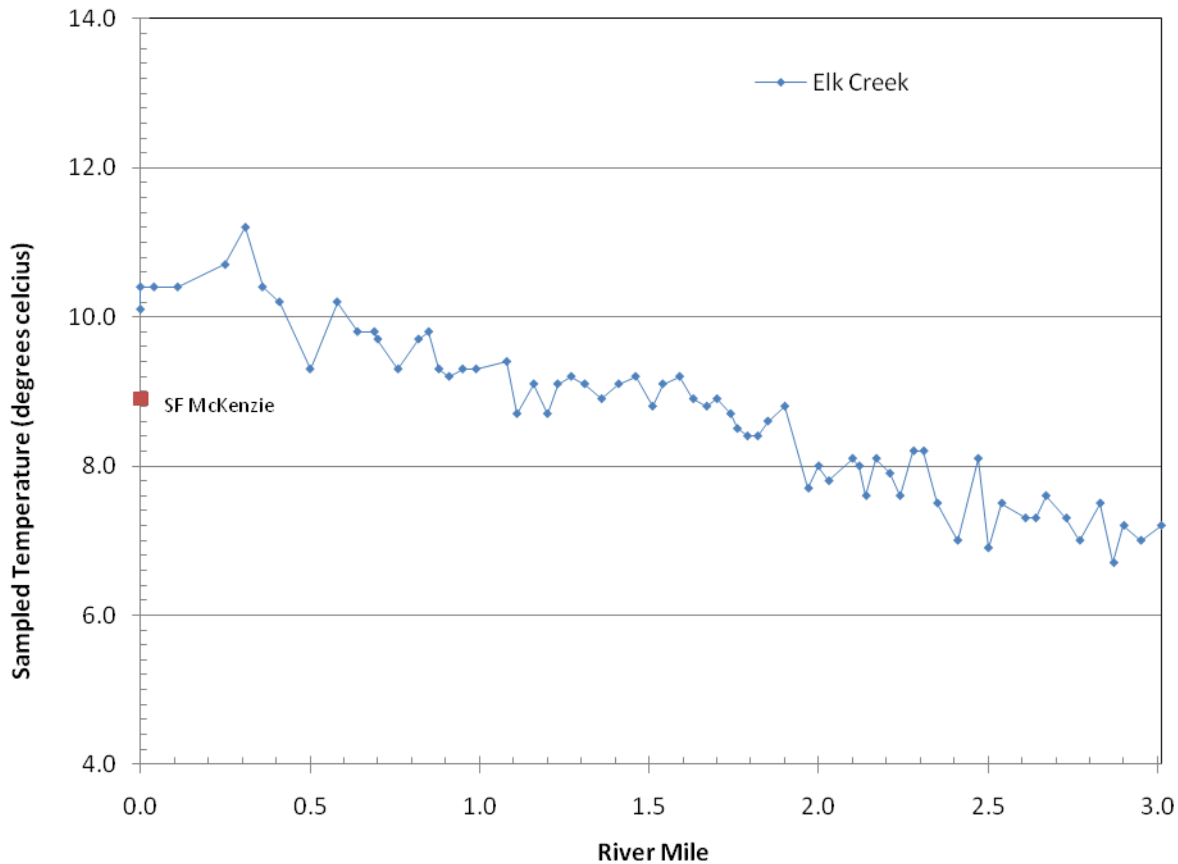


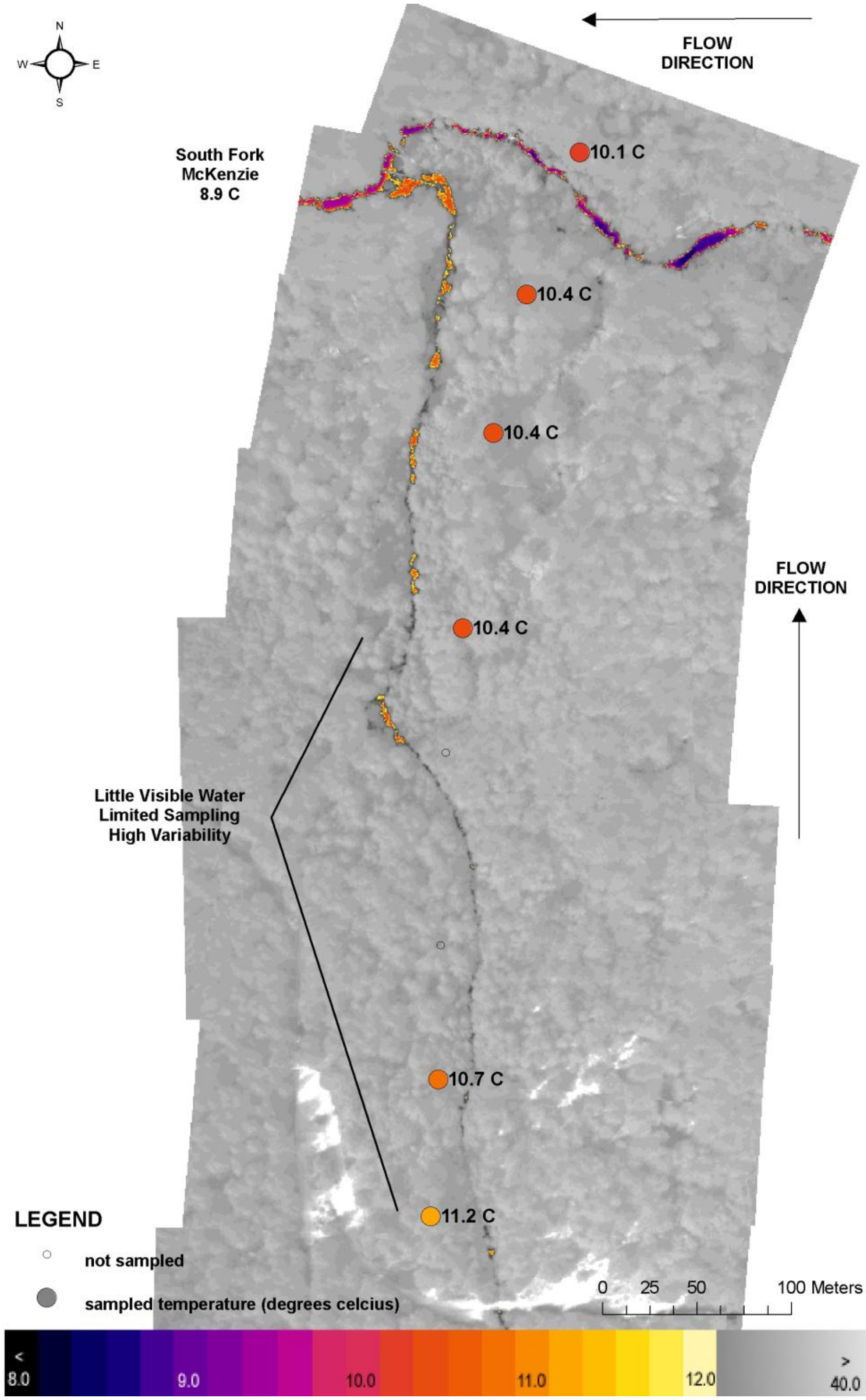
Figure 11 - Median channel temperatures plotted versus river mile for the Elk Creek. No significant inflows were detected on the date of the survey.

Observations

Approximately three miles of Elk Creek were surveyed on August 22, 2009 from the confluence with the South Fork McKenzie River. The stream flows through a heavily forested canyon with scattered clear-cut areas and had low flow volumes at the time of the survey. No significant inflows to the stream were detected.

Due to the small size of the creek and low water volume, caution must be used in interpreting the temperature profile. Bulk water temperatures ranged from 6.7°C to 11.2°C with the lowest temperatures occurring above river mile 2.5. The warmest temperature (11.2°C) occurred just before the confluence with the South Fork McKenzie at river mile 0.31 (*Elk Creek Image 1*). A general warming trend is seen from the upper reaches of the stream as the water flows down the canyon. This is a typical response on a hot summer day with no springs or tributaries to influence the bulk water temperatures.

Sample Images



Elk Creek Image 1 – Confluence of the South Fork McKenzie River and Elk Creek. Due to low water volumes and heavy vegetation, sampling was difficult and highly variable.

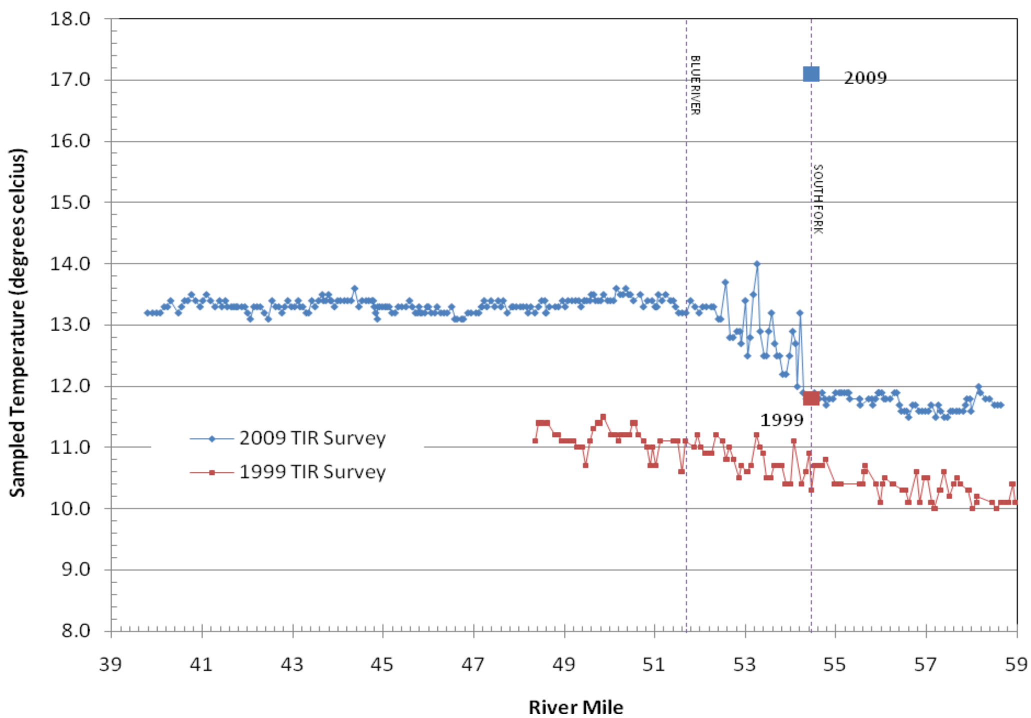
Profile Comparison (1999/2009)

An airborne TIR survey was also conducted on the McKenzie and South Fork McKenzie Rivers during the summer of 1999[2]. This section compares the longitudinal temperature profiles derived from the 1999 data and those generated from this study. The flow conditions from the USGS gauges are included for each data set to provide additional context (*Source*: USGS Surface-Water Daily Data for the Nation; URL: http://waterdata.usgs.gov/nwis/dv?).

McKenzie River

In 1999, the thermal survey covered the McKenzie River from river miles 48-75, overlapping the 2009 data for river miles 48-60. A comparable temperature profile can be seen in both surveys, though there was a 1-2 degree difference in absolute temperatures between surveys. There was also a less dramatic response to the effect of the South Fork on bulk water temperatures in the 1999 survey (*Figure 12*). The temperature differential between the South Fork and mainstem was much smaller in 1999 than in 2009 which would explain the smaller response to the inflow of the South Fork. The USGS gage near Vida, OR also recorded higher flows in the days before the survey in 1999 (*Table 8*) which would likely cause more rapid mixing downstream, lessening the impact of a warm water inflow.

Figure 12- Longitudinal temperature profile comparison of thermal survey from September 3, 1999 and August 22, 2009.



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[2] Torgersen, C.E., Faux, R.N., McIntosh, B.A., 1999, Aerial Survey of the Upper McKenzie River- Thermal Infrared and Color Videography: Oregon State University, p. 22. Catalog No: 2163

Table 8- Discharge rates measured at USGS Station 14162500 McKenzie River Near Vida, OR for the 10 days prior to each survey (highlighted in orange).

1999	**Discharge, ft3/s (Mean)**	**2009**	**Discharge, ft3/s (Mean)**
08/24/1999	935 A	08/12/2009	607 P
08/25/1999	935 A	08/13/2009	476 P
08/26/1999	815 A	08/14/2009	421 P
08/27/1999	744 A	08/15/2009	422 P
08/28/1999	749 A	08/16/2009	423 P
08/29/1999	748 A	08/17/2009	423 P
08/30/1999	752 A	08/18/2009	423 P
08/31/1999	750 A	08/19/2009	423 P
09/01/1999	738 A	08/20/2009	468 P
09/02/1999	736 A	08/21/2009	523 P
09/03/1999	741 A	08/22/2009	520 P
09/04/1999	747 A	08/23/2009	519 P
09/05/1999	745 A	08/24/2009	660 P
09/06/1999	750 A	08/25/2009	1070 P
09/07/1999	752 A	08/26/2009	612 P

A-Approved for publication -- Processing and review completed.
P-Provisional data subject to revision

South Fork McKenzie

The thermal survey on the South Fork McKenzie in 1999 only covered the reach below Cougar Dam (RM 0-4.20). A 5-6°C difference is seen between the two dates, with a slower rate of warming seen in 1999 as the river flows downstream. The temperature control tower had not been constructed, so water being released from the dam was coming from the cold depths of the reservoir. As in the McKenzie data, recorded flows were much higher in 1999 which explains the slower rate of warming.

Figure 13- Longitudinal temperature profile comparison of thermal survey from September 3, 1999 and August 22, 2009 for the South Fork McKenzie River below Cougar Dam.

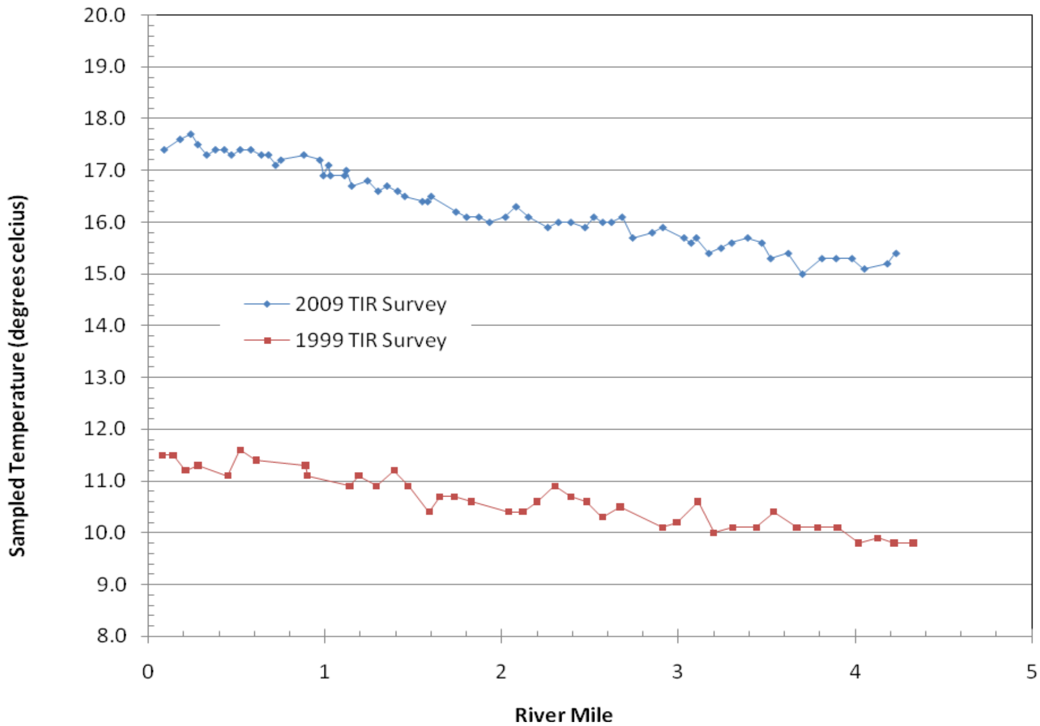

Table 9- Discharge rates measured at USGS Station 14159500 South Fork McKenzie near Rainbow, OR for the 10 days prior to each survey (highlighted in orange).

1999	Discharge, ft3/s (Mean)	2009	Discharge, ft3/s (Mean)
08/24/1999	2,960 A	08/12/2009	2,450 P
08/25/1999	2,920 A	08/13/2009	2,310 P
08/26/1999	2,820 A	08/14/2009	2,130 P
08/27/1999	2,730 A	08/15/2009	2,110 P
08/28/1999	2,720 A	08/16/2009	2,130 P
08/29/1999	2,710 A	08/17/2009	2,120 P
08/30/1999	2,750 A	08/18/2009	2,100 P
08/31/1999	2,760 A	08/19/2009	2,090 P
09/01/1999	2,690 A	08/20/2009	2,120 P
09/02/1999	2,670 A	08/21/2009	2,180 P
09/03/1999	2,650 A	08/22/2009	2,160 P
09/04/1999	2,630 A	08/23/2009	2,160 P
09/05/1999	2,600 A	08/24/2009	2,190 P
09/06/1999	2,610 A	08/25/2009	2,730 P
09/07/1999	2,750 A	08/26/2009	2,300 P

A-Approved for publication -- Processing and review completed.
P-Provisional data subject to revision

Deliverables

The TIR imagery is provided in two forms: 1) individual un-rectified frames and 2) a continuous geo-rectified mosaic at 0.8-m resolution for the McKenzie River and 0.6-m resolution for the South Fork McKenzie River and Elk Creek. The mosaic allows for easy viewing of the continuum of temperatures along the stream gradient, but also shows edge match differences and geometric transformation effects. The un-rectified frames are useful for viewing images at their native resolutions and are often better for detecting smaller thermal features. A GIS point layer is included which provides an index of image locations, the results of temperature sampling, and interpretations made during the analysis.

Deliverables are provided on DVD:

Geo-Corrected Mosaics, surveys, and shapefiles are projected in:
UTM Zone 10, NAD83, Units = Meters

1. Hydrography – Relevant hydrography shapefiles

2. Longprofiles - Excel spreadsheet containing the longitudinal temperature profiles

3. Thermal_Mosaics - Continuous image mosaic of the geo-rectified TIR image frames at 0.8-meter and 0.6-meter resolution in ERDAS Imagine (*img) format). Cell value = radiant temperature * 10.

4. Thermal_Surveys - Point layers showing image locations, sampled temperatures, and image interpretations.

5. TrueColor_Surveys - Point layers showing image locations.

6. Unrectified_Images
   a. Thermal_Unrectified - Calibrated TIR images in Erdas Imagine (*img) format. Cell value = radiant temperature * 10. Radiant temperatures are calibrated for the emissive characteristics of water and may not be accurate for terrestrial features. These images retain the native resolution of the sensor. GCP files are included for rectification purposes.
   b. TrueColor_unrectified – Unrectified Nikon color images in JPEG format.

7. Report – A copy of this report