Aerial Surveys of the Middle Fork Hood River

Thermal Infrared and Color Videography

February 26, 2003

Report to:

Oregon Department of Environmental Quality
811 SW 6th Avenue
Portland, OR 97204

by:

Watershed Sciences, LLC
230 SW 3rd Street, Suite 202
Corvallis, OR 97333

Final Report

Table of Contents

Introduction

In 2002, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC (WS, LLC) to conduct an airborne thermal infrared (TIR) remote sensing survey of the Middle Fork (MF) Hood River including the perimeter of Laurance Lake. The objective of the project was to characterize the thermal regime of the river to support ongoing stream temperature assessments in the basin.

This report documents the methods used to collect and process the TIR images. This report also presents spatial temperature patterns derived through analysis of the imagery. 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.

Data Collection

A TIR remote sensing survey was conducted on the MF Hood River and Laurance Lake on August 2, 2002 (Figure 1). The survey started at the mouth of the MF Hood River and continued upstream to Laurance Lake. The flight then followed along the north bank of Laurance Lake and continued upstream on the Clear Branch for 3.1 miles. The width and shape of Laurance Lake precluded the capture of both banks of the lake within a single image frame during the MF Hood River flight. Therefore the lake perimeter was flown at a slightly higher altitude (*than that used for the MF Hood River survey)* in order to detect springs and other surface inflows. The flights were timed to best capture maximum daily stream temperatures, which typically occur between 14:00 and 17:00. Table 1 summarizes the time, image foot print, and extent of each survey segment.

Table 1 – Summary of river segments surveyed with TIR and color video in the Hood River sub-basins on August 2, 2002.

Stream	Survey Time (24 hr)	Survey Extent & Direction	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
MF Hood R.	14:08-14:36	Forks to Clear Branch (rm 3.1)	12.4	107 (353)	0.3 (1.0)
Laurance Lake	14:38-14:41	Perimeter	N/A	172 (564)	0.5 (1.8)

Watershed Sciences, LLC deployed two in-stream data loggers prior to the survey to ground truth (i.e. verify the accuracy) of the TIR data. WS, LLC measured in-stream temperatures at two locations on the MF Hood River. These sites were supplemented with data from four additional in-stream sensors furnished by the MF Hood Irrigation District. Meteorological data including air temperature and relative humidity were recorded using two portable weather stations (*Onset*). One station was located at the Dalles Airport, WA near the Columbia River. The second station was located in Mt Hood National Forest near Ramsey Creek *(Fifteenmile Creek Basin*). The in-stream data were assessed at the time the image was acquired, with radiant values representing the median of ten points

[1] Geographic Information System

sampled from the image at the data logger location. The parameters used to calibrate the TIR images were fined tuned to provide a best fit to the in-stream data.

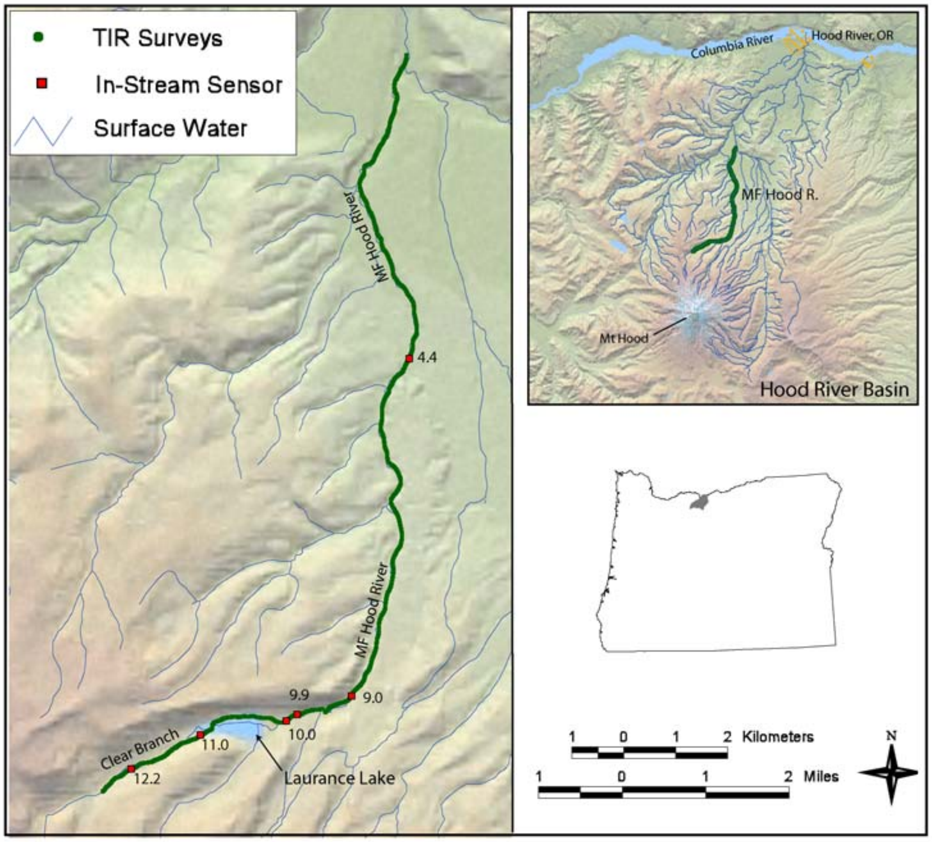


Figure 1 – Map showing the extent of the airborne TIR remote sensing survey of the MF Hood River and Laurance Lake on August 2, 2002. The map also shows the location of in-stream sensors used to ground truth the TIR images labeled by river mile.

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 varied based on the flight altitudes. On the MF Hood River and Clear Branch, the TIR images presented a ground width of approximately between 107 and a spatial resolution of between 0.3 meters (Table 1). The Laurance Lake perimeter was flown at an altitude that resulted in an image with of approximately 172 meters and a pixel resolution of 0.5 meters. All surveys were conducted in an upstream direction and the images were collected sequentially with approximately 40% vertical overlap.

Table 2 – Meteorological conditions for August 2, 2002 recorded using portable weather stations located at The Dalles Airport and along Ramsey Creek at river mile 13.1 *(Fifteenmile Creek Basin)*.

	Ramsey Cr. Weather Station			**The Dalles A/P Weather Station**		
Time	**Air Temp °F**	**Air Temp °C**	**Relative Humidity %**	**Air Temp °F**	**Air Temp °C**	**Relative Humidity %**
13:00	58.0	14.5	27.1	74.5	23.6	27.2
13:30	58.7	14.9	26.6	75.9	24.4	24.9
14:00	59.4	15.2	26.1	76.6	24.8	24.9
14:30	60.1	15.6	24.3	77.3	25.2	22.6
15:00	59.4	15.2	24.3	78.7	26.0	22.2
15:30	60.1	15.6	26.1	78.7	26.0	22.2

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. 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. The measures assigned from this coverage may not match stream measures derived from other map sources.

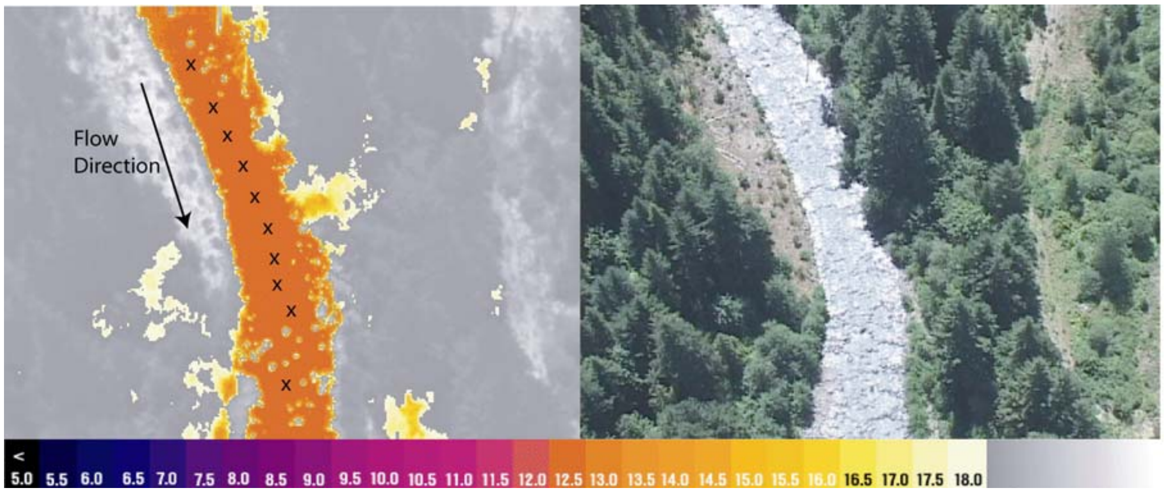


Figure 2 – TIR/color video image pair showing how temperatures are sampled from the TIR images. The black *X's* show typical sampling locations near the center of the stream channel. The recorded temperature for this image is the median of the sample points.

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.

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.

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.

Results

Thermal Accuracy

Temperatures from the in-stream data loggers were compared to radiant temperatures derived from the TIR images (Table 3). The average absolute difference (kinetic versus radiant) was 0.3°C, which was within the desired accuracy of ±0.5°C. Both the average difference and the range of differences were also consistent with TIR surveys conducted in the Pacific Northwest over the past 5 years (Torgersen et. al. 2001, Faux et. al. 2001).

Table 3 – Comparison of ground-truth water temperatures (kinetic) with the radiant temperatures derived from the TIR images for the MF Hood River.

Image	River mile	Date	Time 24 hr	Kinetic °C	Radiant °C	Difference °C
mfh0572	4.4	2-Aug	14:17	11.2	11.6	-0.4
mfh1090	9.0	2-Aug	14:26	11.5	11.0	0.5
mfh1281	9.9	2-Aug	14:30	10.9	10.5	0.4
mfh1303	10.0	2-Aug	14:30	10.6	10.9	-0.3
mfh1472	11.1	2-Aug	14:33	8.6	8.7	-0.1
mfh1641	12.2	2-Aug	14:36	8.2	8.1	0.1
Average Difference:						*0.3*

Temporal Differences

Figure 3 shows in-stream temperature variations at river mile 10.0 on the MF Hood River. The figure 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 this location on the MF Hood River, the survey took place during the daily maximum stream temperature, recorded at a consistent 10.6°C from 12:30 to 16:30. This in-stream site was considered representative of the in-stream sensors locations upstream of river mile 9.0. The in-stream sensor at river mile 4.4 was removed shortly after the TIR survey and therefore did not record a full daily temperature cycle.

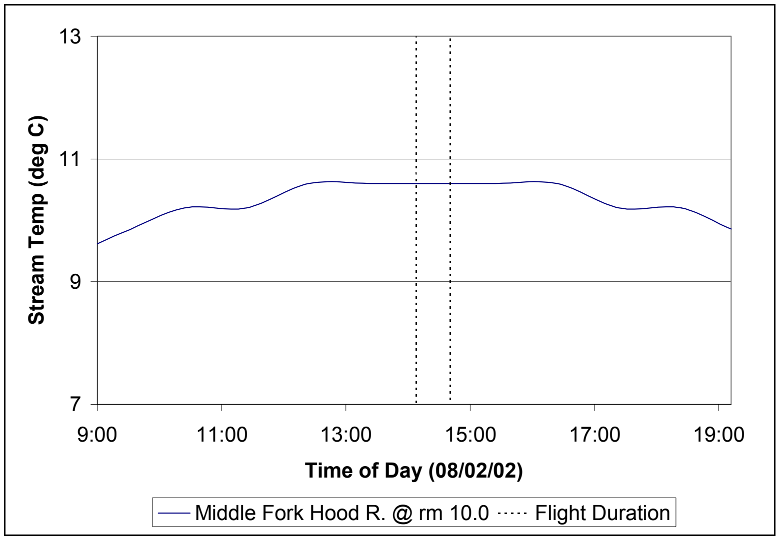


Figure 3 – Stream temperature variation and time of TIR remote sensing for the MF Hood River at river mile 10.0.

Longitudinal Temperature Profile

The median temperatures for each sampled image of the Middle Fork (MF) Hood River were plotted versus the corresponding river mile (Figure 4). Figure 4 also shows the name and location of surface water inflows (i.e. tributaries, surface springs) that were sampled during the analysis. The stream miles used to plot the longitudinal temperature profile (Figure 4) were routed from the mouth of the MF Hood River and include the 3.1 miles surveyed on the Clear Branch. The stream gained ≈2200 ft of elevation over the extent of the 12.6-mile survey. Consequently, flow conditions appeared turbulent with almost continuous rapids. Riparian vegetation extended to the channel at locations throughout the survey (Figure 5). This did not limit the ability obtain accurate and continuous radiant temperature samples from the main channel, but may have masked small tributaries and other surface inflows.

The MF Hood River showed a pattern of downstream warming with stream temperatures ≈7.2°C at the upstream end of the survey (river mile 12.6) and ≈12.9°C at the confluence with the East Fork (EF) Hood River. Four cold-water springs were detected between the outlet of Laurance Lake and the EF confluence. These springs were not identified on the USGS 7.5' topographic reference maps. Four tributaries and one side channel were also sampled during the analysis of the TIR images. Of these five inflows, Bear Creek and Coe Branch contributed water that was cooler than the main stem.

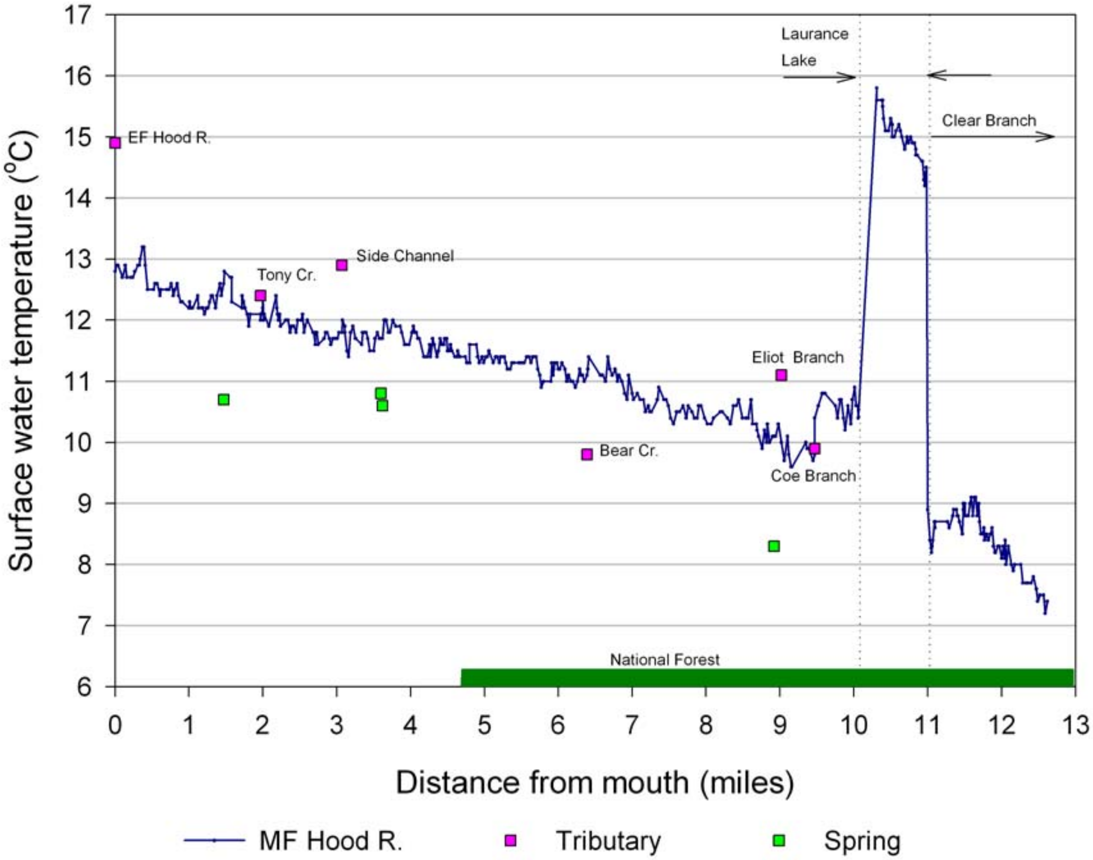


Figure 4 - Median channel temperatures versus river mile for the Middle Fork Hood River including the north bank of Laurance Lake. The plot also shows the location of tributary and spring inflows sampled during the analysis.

Figure 5 - Ground level image (left) and airborne video image (right) of the MF Hood River at river mile 4.3. The ground level photograph was taken from the bridge looking downstream. *(frame: mfh0570*).

Stream temperatures in the Clear Branch warmed steadily between river miles 12.6 and 11.6. An apparent 1.0°C decrease in stream temperatures was observed prior to the discharge of the Clear Branch into Laurance Lake. The TIR images showed a complex of springs near the mouth of the Clear Branch (Figure 6), which contributed to the observed cooling. Radiant temperatures recorded from the surface of Laurance Lake were between 14.3°C and 15.8°C. The sharp transition in temperatures at both ends of the lake indicate thermally stratified surface layer and, consequently, the radiant temperatures of the lake should not be considered representative of bulk water temperatures. Stream temperatures at the outlet of the Laurance Lake were ≈10.6°C (river mile 10.1), however, cool water inputs from Coe Creek at river mile 9.2 and a spring at river mile 8.9 decreased water temperatures in the MF Hood River to ≈9,6°C. Downstream of the spring (river mile 8.9), stream temperatures increased steadily to the mouth. Local temperatures variations between river miles 8.9 and the mouth were less than ±0.5°C and within the noise level characteristic of TIR remote sensing. On the perimeter flight of Laurance Lake, the springs at the mouth of Clear Branch (Figure 6) were detected along with the inflow of Pinnacle Creek.

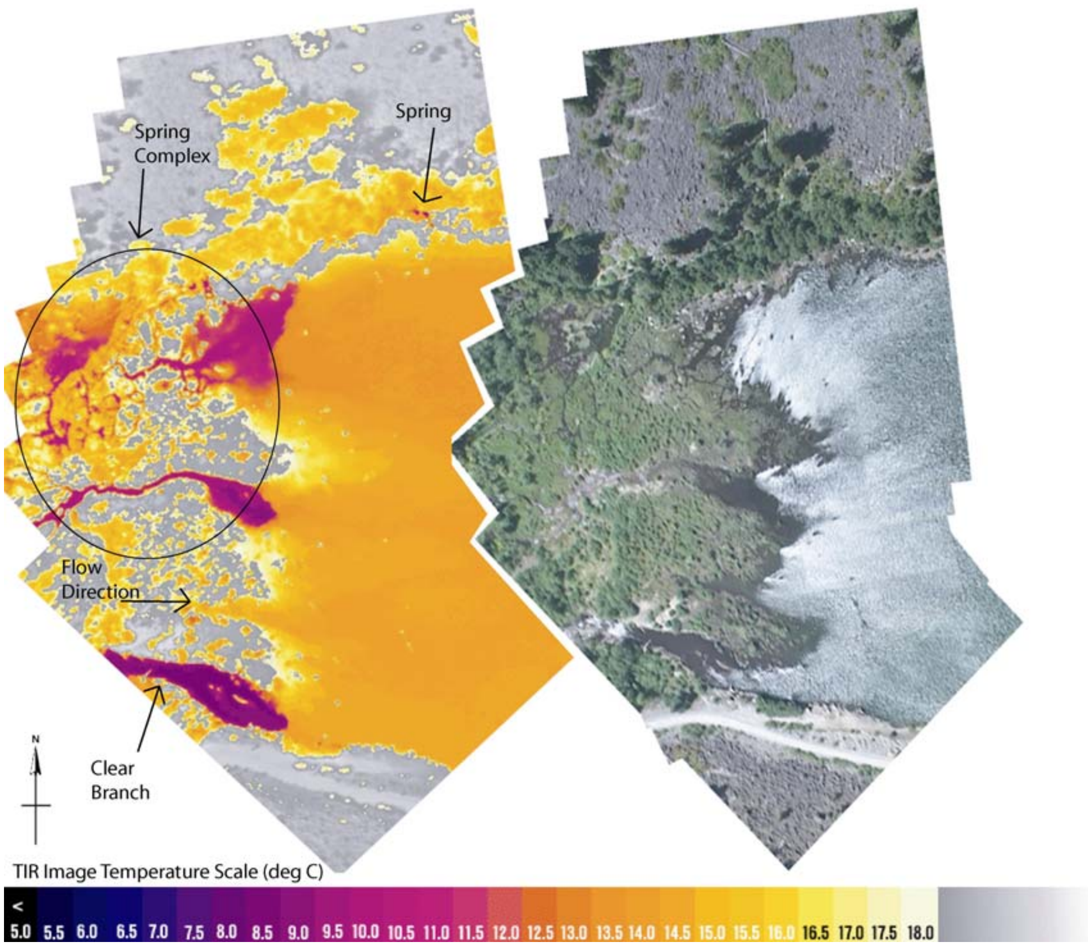


Figure 6 - TIR/color video image showing a spring complex at the mouth of the Clear Branch (8.7°C) at Laurance Lake (13.9°C) (*frames: ll1891-1899*).

Discussion

A TIR remote sensing survey was successfully conducted on the MF Hood River and along the perimeter of Laurance Lake. A longitudinal temperature profile was produced by sampling the TIR images, which illustrates broad scale spatial temperature patterns and the location and influence of tributary and surface water inflows. This report presents the longitudinal temperature profiles and provides some observations on spatial temperature patterns and detected thermal features. These observations 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.

Follow-on

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.

Bibliography

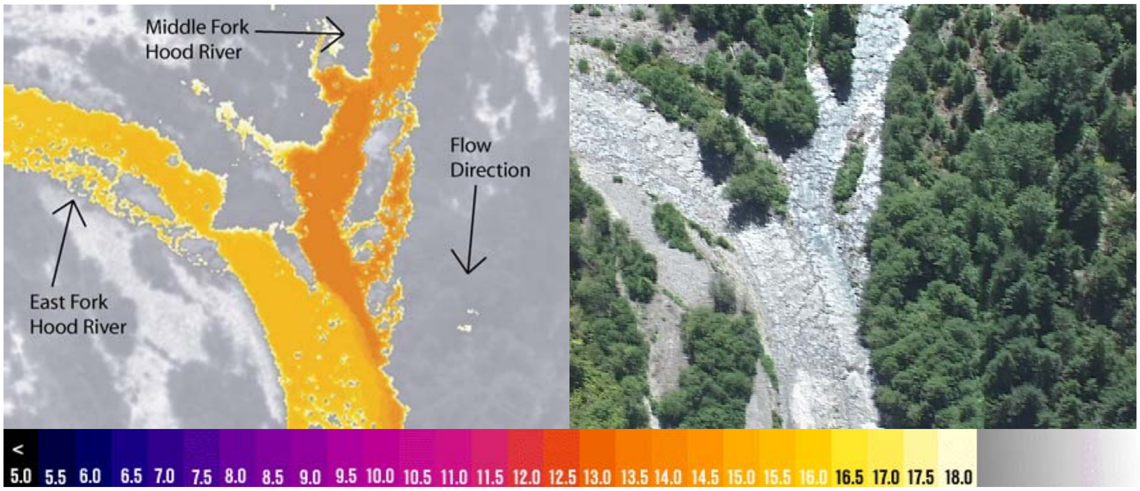
Faux, R.N., H. Lachowsky, P. Maus, C.E. Torgersen, and M.S. Boyd. 2001. **New approaches for monitoring stream temperature: Airborne thermal infrared remote sensing**. Inventory and Monitoring Project Report -- Integration of Remote Sensing. Remote Sensing Applications Laboratory, USDA Forest Service,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

Torgersen, C., R. Faux, and B. McIntosh. 1999. **Aerial survey of the Upper McKenzie River: Thermal infrared and color videography**. Report to the USDA, Forest Service, McKenzie River Ranger District.

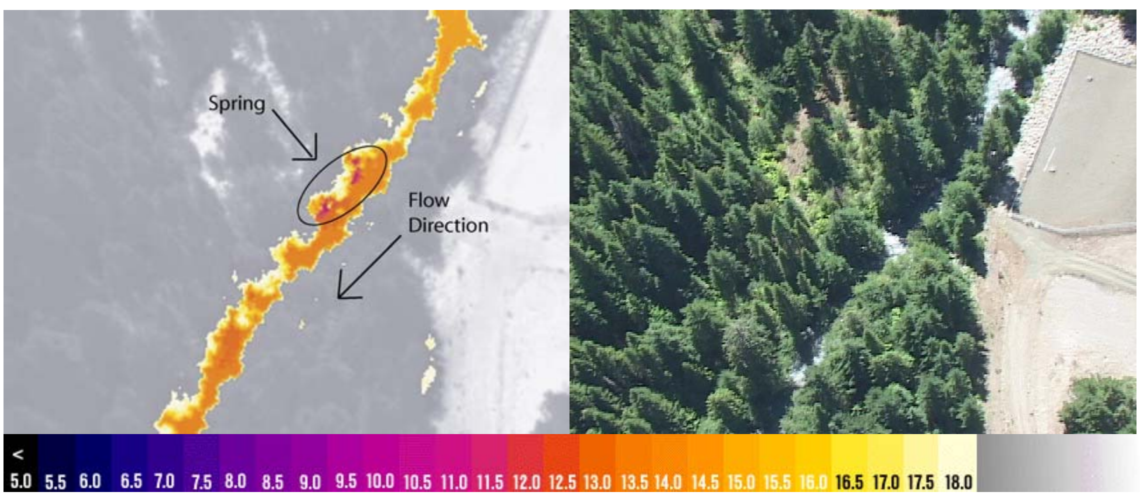
Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

Appendix A – Selected Images

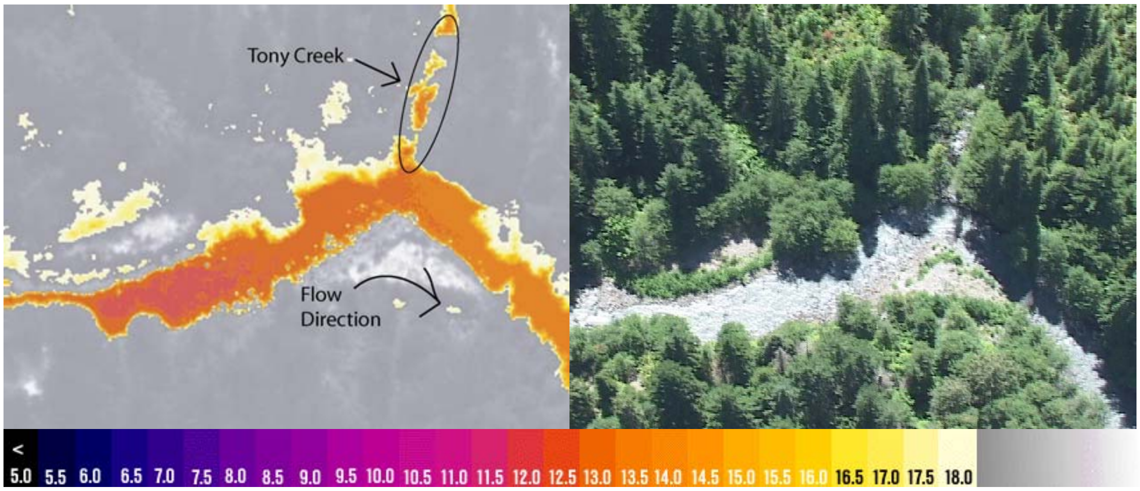
Middle Fork (MF) Hood River



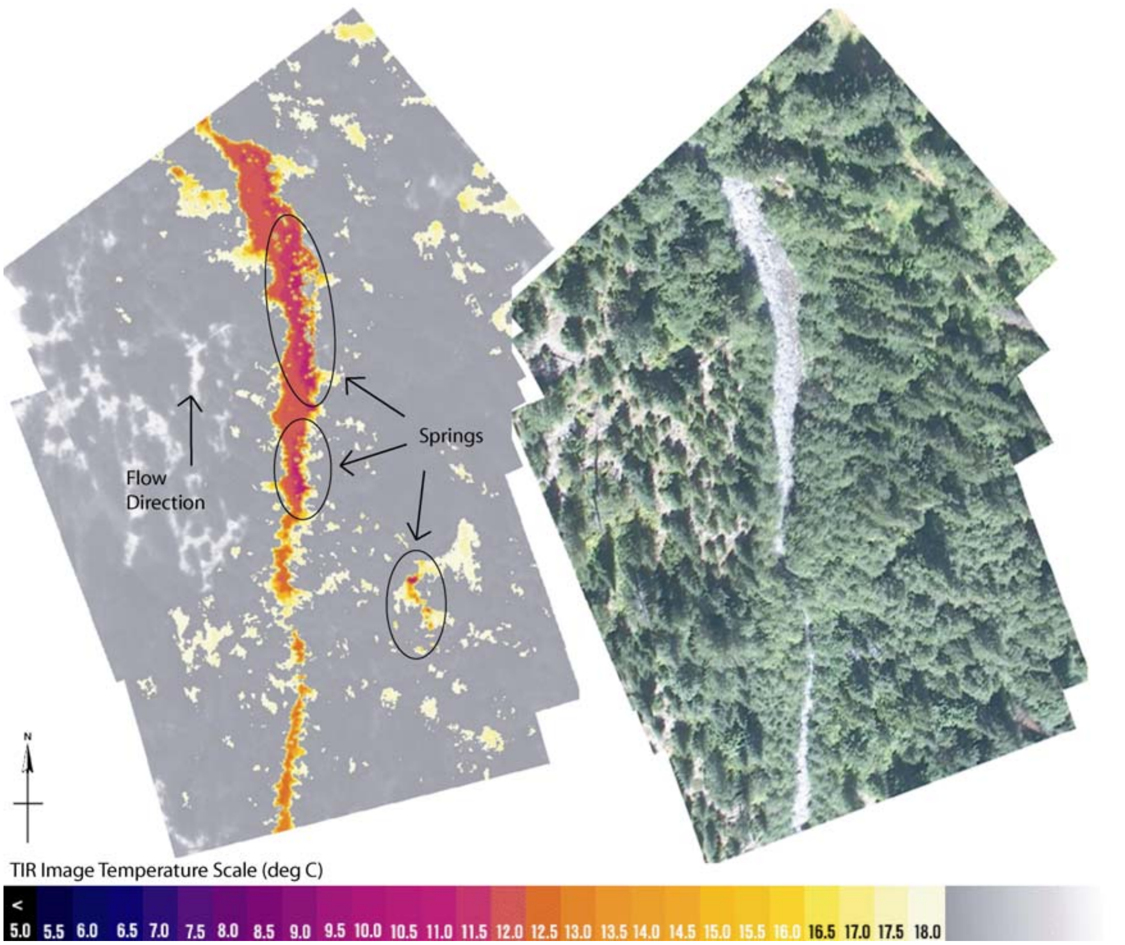
TIR/color video image pair showing the mouths of the MF Hood River (12.8°C) and East Fork Hood River (14.9°C) on its right bank (*frame: mfh0042*).



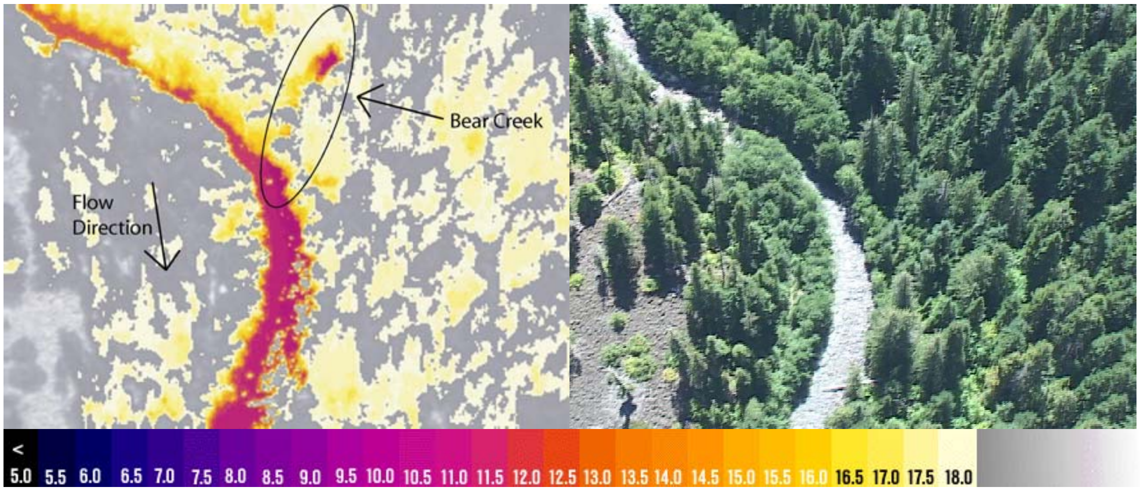
TIR/color video image pair showing a spring (10.7°C) on the right bank of MF Hood River (12.6°C) at river mile 1.5 (*frame: mfh0241*).



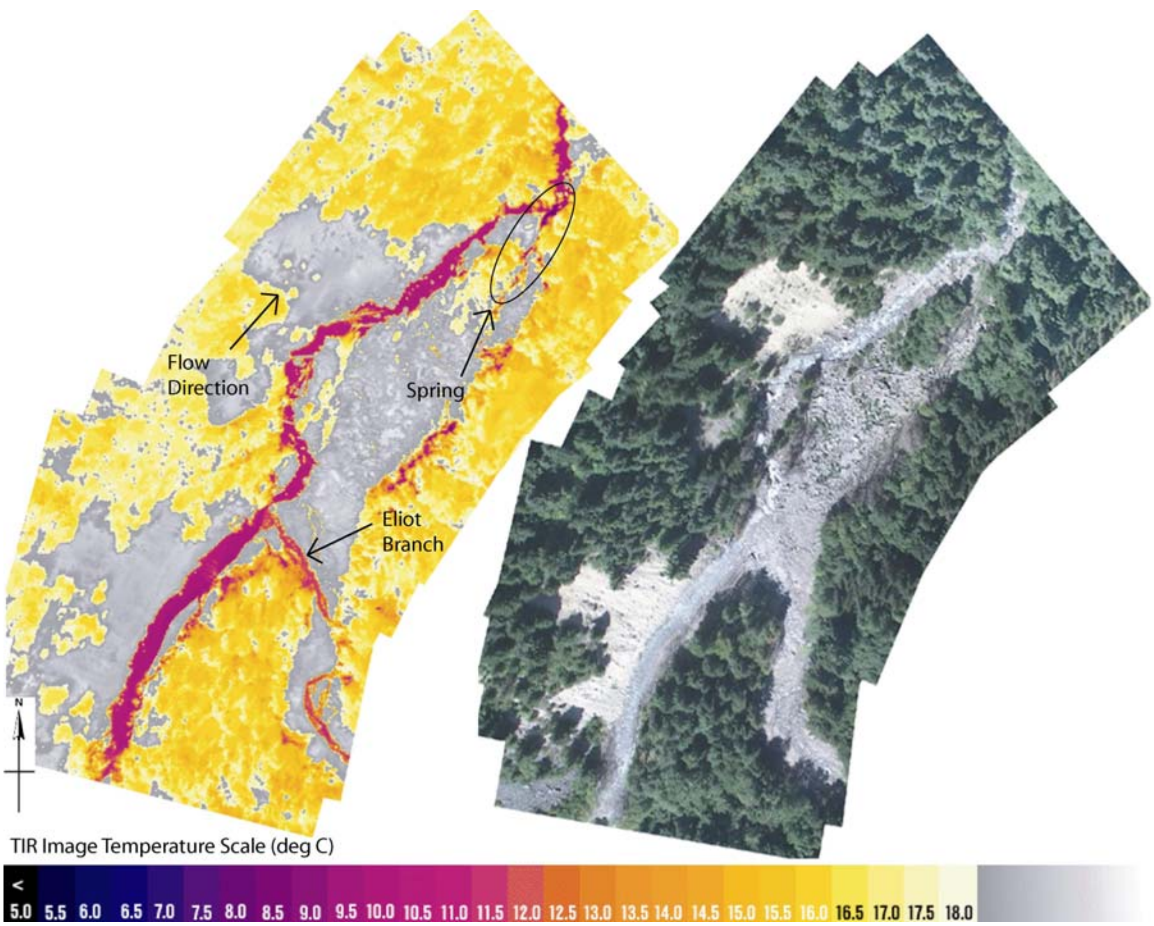
TIR/color video image pair showing the confluence of Tony Creek (12.4^{o}C) to the left bank of the MF Hood River (12.0^{o}C) at river mile 2.0 (*frame: mfh0292*).



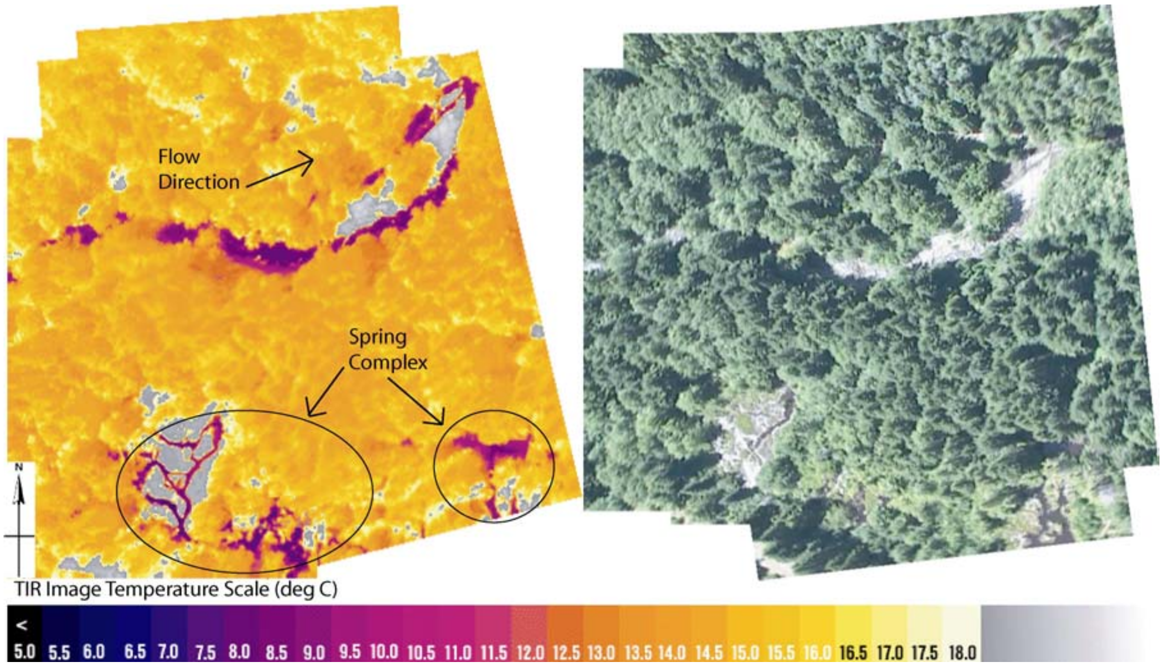
TIR/color video image pair showing two springs in the MF Hood River (11.7^{o}C) at river mile 3.6. The spring downstream (top of image) measured 10.8^{o}C while the spring upstream measured 10.6^{o}C. Another spring can be seen on the right bank but was not sampled due to the lack of visibility at the confluence with the MF (*frames: mfh0491-0498*).



TIR/color video image pair showing the confluence of Bear Creek (9.8°C) to the left bank of MF Hood River (11.1°C) at river mile 6.4 (*frame: mfh0829*).



TIR/color video image pair showing a spring (8.9°C) on the right bank just downstream of the confluence of Eliot Branch (11.1°C) to the right bank of MF Hood River (10.1°C) at river mile 8.9 (*frames: mfh1075-1091*).



TIR/color video image pair showing a spring complex on the right bank of Clear Branch (8.4°C) at river mile 12.5. The spring was not sampled as a tributary because the point of entry to the stream could not be discerned from the images (*frames: mfh1627-1631*).