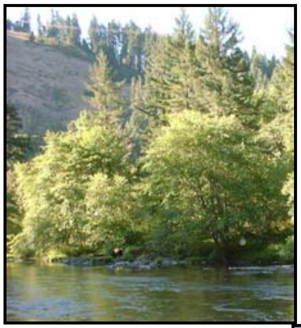
Aerial Surveys in the North Umpqua River Basin
Thermal Infrared and Color Videography

December 3, 2001



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Final Report

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Introduction

Thermal infrared remote sensing has been demonstrated as a reliable, cost-effective, and accessible technology for monitoring and evaluating stream temperatures from the scale of watersheds to individual habitats (Karalus et. al., 1996; Torgersen et. al. 1999; Torgersen et. al. 2001). In 2001, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC (WS, LLC) to map and assess stream temperatures in the North Umpqua River basin using thermal infrared (TIR) remote sensing.

This report presents longitudinal temperature profiles for each survey stream as well as a discussion of the thermal features observed in the basin. TIR 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. Appendix A presents a collection of selected TIR and visible band images from the surveys.

Methods

Data Collection

Data were collected using a TIR sensor and a visible band color video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally along the stream channel with the sensors in a vertical (or near vertical) position. Figure 1 illustrates the extent of the TIR surveys and Table 1 summarizes the dates and times of each survey.

TIR remote sensing surveys were conducted in the N. Umpqua River basin on the 9th and 10th of July, 2001. On July 9th, the N. Umpqua River was surveyed downstream from Lemolo Lake. The survey was discontinued at the Toketee Reservoir, a natural breakpoint, due to mechanical problems. On July 10th, the N. Umpqua River was resurveyed from Lemolo Lake to Steamboat Creek. Thunderstorms moved through the region throughout the morning and early afternoon of July 10th. While the surveys were able to continue, the weather conditions resulted in generally cooler thermal conditions in the basin. The Clearwater River was surveyed on both the 9th and 10th in order to provide a comparison between the two days. The N. Umpqua River was also resurveyed from Toketee Reservoir to Steamboat Creek in order to compare the two passes of the survey reach.

The TIR remote flights were coordinated with field crews from the ODEQ and USFS who measured stream flow levels. A forecast for continuing thunderstorms as well as several fire starts in the basin precluded postponing the surveys until later in the week.

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[1] Geographic Information System

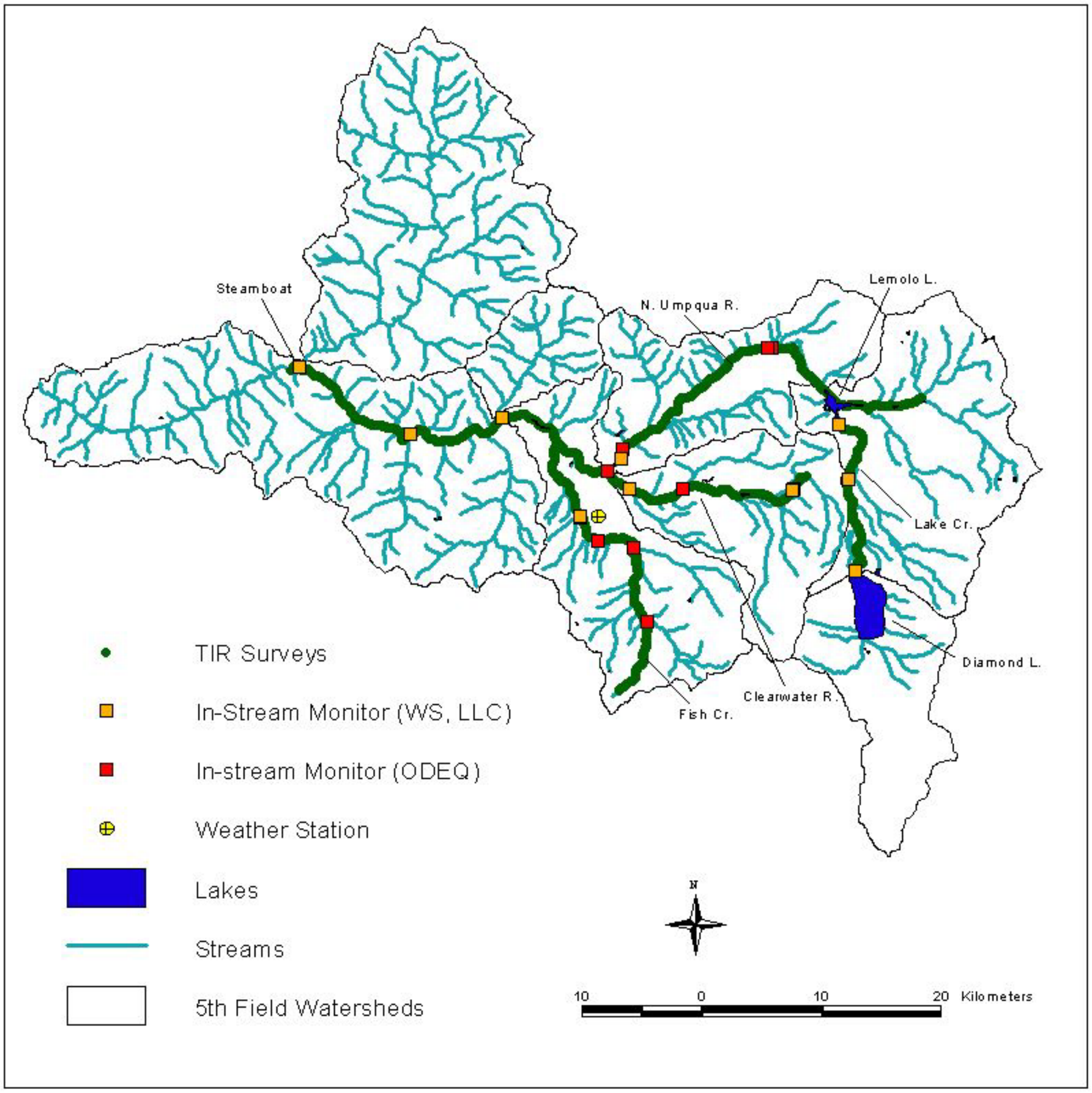


Figure 1 – Map of the North Umpqua River basin showing streams surveyed using TIR and visible band color video. The map also shows the location of in-stream sensors used to verify the accuracy of the radiant temperatures.

Table 1 - Time, date and distance for the North Umpqua River Surveys.

Stream	Date '01	Local Time (PM)	Extent
Clearwater River	9 July	2:25 – 3:10	Mouth to Headwaters
N. Umpqua River	9 July	3:16 – 3:53	Lemolo Lake to Toketee Res.
N. Umpqua River	10 July	1:51 – 2:50	Lemolo Lake to Steamboat Cr.
Fish Creek	10 July	3:27 – 4:00	Mouth to Headwaters
Lake Creek	10 July	4:08 – 4:30	Diamond Lake to Lemolo Lake
Clearwater River	10 July	4:34 – 4:53	Headwaters to Mouth
N. Umpqua River	10 July	5:07 – 5:37	Toketee Res. to Steamboat Cr.

The N. Umpqua River was surveyed at an altitude of 1800 ft above ground level (AGL). At this altitude, the image has a ground width of approximately 190 meters and a pixel resolution of 0.4 meters. The Clearwater River and Lake Creek were surveyed at an average flight altitude of 1200 ft AGL. At this altitude, the image presents a ground area of approximately 130 meters wide.

TIR images were collected digitally and recorded directly from the sensor to an on-board computer. The TIR sensor detects emitted radiation at wavelengths from 8-12 microns and records the level of emitted radiation in the form of an image. Each image pixel contains a measured value that can be directly converted to a temperature. The raw TIR images represent the full 12 bit dynamic range of the instrument and were tagged with time and position data provided by a Global Positioning System (GPS). Visible band color images were recorded to an on-board digital videocassette recorder at a rate of 30 frames/second. GPS time and position were encoded on the recorded video. The color video camera was aligned to present the same ground area as the TIR sensor.

WS, LLC distributed ten in-stream temperature data loggers (Onset Stowaways) in the basin prior to the survey in order to ground truth (i.e. verify the accuracy of) the radiant temperatures measured by the TIR sensor. The advertised accuracy of the Onset Stowaway's is $\pm 0.2^{o}$C. These locations were supplemented by data provided by ODEQ from ten additional in-stream temperature loggers. Figure 1 shows the location of the WS, LLC and ODEQ in-stream data loggers used to ground truth the imagery. Meteorological conditions were recorded using a field station located at the Toketee USFS Airstrip (Table 2) near Fish Creek.

Table 2 – Meteorological conditions recorded at the Toketee USFS Airstrip for the date and time of the TIR surveys conducted in the N. Umpqua River Basin.

Date	*Time*	*Temp(*F)*	*Temp(*C)*	*RH (%)*
7/9/2001	2:30 PM	87.3	30.7	23.1
7/9/2001	3:00 PM	88.0	31.1	23.5
7/9/2001	3:30 PM	88.7	31.5	24.0
7/9/2001	4:00 PM	88.7	31.5	24.4
7/9/2001	4:30 PM	88.7	31.5	25.8

Date	*Time*	*Temp (*F)*	*Temp (*C)*	*RH (%)*
7/10/2001	2:00 PM	77.3	25.2	34.4
7/10/2001	2:30 PM	70.4	21.3	73.8
7/10/2001	3:00 PM	76.6	24.8	49.7
7/10/2001	3:30 PM	78.0	25.6	38.4
7/10/2001	4:00 PM	75.9	24.4	47.6
7/10/2001	4:30 PM	79.4	26.3	35.4
7/10/2001	5:00 PM	82.2	27.9	27.2
7/10/2001	5:30 PM	83.0	28.3	24.9
7/10/2001	6:00 PM	83.7	28.7	26.7

Data Processing

A computer program was used to create an ArcView GIS point coverage containing the image name, time, and location it was acquired. The coverage provided the basis for assessing the extent of the survey and for integrating with other spatially explicit data layers in the GIS. This allowed WS, LLC to identify the images associated with the ground truth locations. The data collection software was used to extract temperature values from these images at the location of the in-stream recorder. The radiant temperatures were then compared to the kinetic temperatures from the in-stream data loggers.

The image points were associated with a river kilometer within the GIS environment. The river kilometers were derived from 1:100K "routed" stream covers from the Environmental Protection Agency (EPA). The route measures provide a spatial context for developing longitudinal temperature profiles of stream temperature.

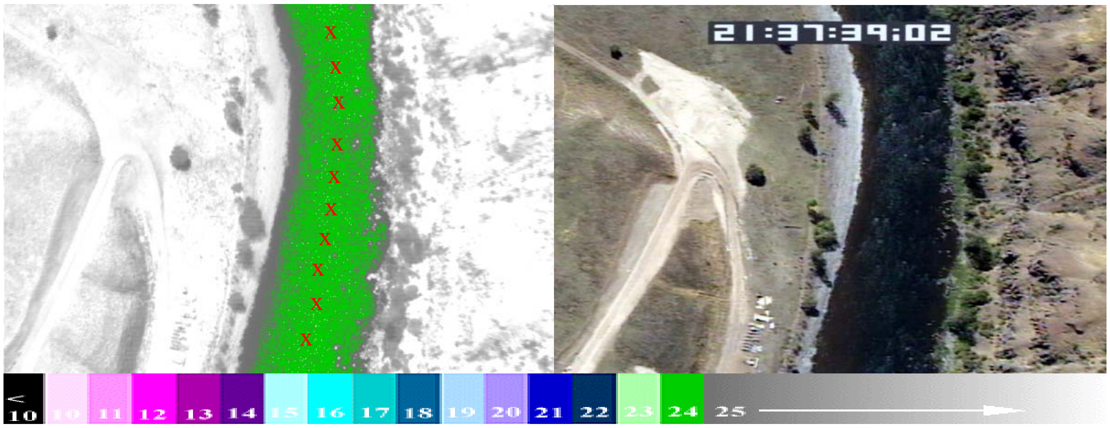
In the laboratory, a computer algorithm was used to convert the raw thermal images (radiance values) to ARC/INFO GRIDS where each GRID cell contained a temperature value. A GIS program was used to display the GRID associated with an image location selected in the point coverage. The GRID was color-coded to visually enhance temperature differences, enabling the user to extract temperature data.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, a computer program was used to sample the GRID cell (temperature) values in the stream channel.

Ten sample points were taken longitudinally in the center of the stream channel. Figure 2 provides an example of how temperatures are sampled. The red “x”s on the psuedo-color TIR image show typical sample locations. Samples were taken to provide complete coverage without sampling the same water twice. Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled. Side channels that had water temperatures different than the main channel were sampled as tributaries. For each sampled image, the sample minimum, maximum, median, and standard deviation was recorded directly to the point coverage attribute file. The median value is the most useful measure of stream temperatures because it minimizes the effect of extreme values.

The temperature of tributaries and other detectable surface inflows were also sampled from images. These inflows were sampled at their mouth using the same techniques described for sampling the main channel. If possible, the surface inflows were identified on the USGS 24K base maps. The inflow name and median temperature were then entered into the point coverage attribute file.

Visible band images corresponding to the TIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the TIR images and provide a complete coverage of the stream. The video images were “linked” to the corresponding thermal image frame in the ArcView GIS environment.



TIR/visible band color image

Figure 2 – Image pair showing typical temperature sampling locations. Temperatures are presented in ^{o}C.

Data Limitations

TIR sensors measure thermal infrared energy emitted at the water's surface. Since water is essentially opaque to thermal infrared wavelengths, the sensor is only measuring water surface temperature. TIR data accurately represents bulk water temperatures in reaches where the water column is thoroughly mixed, however, thermal stratification can form in reaches that have little or no mixing. In the N. Umpqua River Basin, thermal stratification was observed in the larger reservoirs and directly upstream of impoundments. Areas of potential thermal stratification were noted in the survey database.

Results

Thermal Accuracy

Temperatures from the in-stream data loggers were compared to radiant temperatures derived from the imagery for each survey (Table 3). The data were assessed at the time the image was acquired, with the radiant values representing the median of 10 points sampled from the image at the data logger location.

The radiant temperatures derived from the TIR images were consistent (±1.0°C) with the measured in stream temperatures for the N. Umpqua River (July 9th, Fish Creek and Lake Creek as well as for the second N. Umpqua River survey on July 10th. In the Clearwater River, the two sensors located near the headwaters (river mile 11.5 and 11.6) recorded temperatures warmer (≈1.6°C) than the radiant temperatures from the imagery for both the surveys (July 9th and 10th). Similarly, the two in-stream sensors located at river mile 87.5 on the N. Umpqua River were warmer then the derived radiant temperatures for both over flights (approximately 1.6°C on July 10th). Overall, the accuracy of the radiant temperatures was on average within ±0.6°C of in-stream temperatures recorded by the data loggers. This difference was larger then the average accuracy of ±0.4°C recorded using the same TIR sensor during surveys throughout the Pacific Northwest since 1998.

A large number of variables influence the accuracy of radiant temperature calculations. Consequently, it is difficult to definitively explain observed differences between radiant temperatures recorded by a TIR sensor and contact temperatures recorded by in-stream data loggers. Variables include atmospheric, ambient background, and stream surface conditions. For the N. Umpqua River basin, the largest differences were noted at the same locations for different days on the N. Umpqua and Clearwater Rivers. The impact that the temperature differences had on the observed temperature patterns is discussed later in this report. Furthermore, Table 2 illustrates how air temperature and relative humidity varied within the basin on the

Table 3 – Comparison of ground-truth water temperatures with radiant temperatures derived from the TIR images, 9-10 July 2001. Temperatures are reported in ^{o}C and river miles (rm) are cited for locations.

Location	Image Frame	Time (pm)	Stream Temp. (Ts)	Radiant Temp. (Tr)	Difference (Ts-Tr)
9 July 01					
Clearwater R. @ rm 0.1	Clr0057	2:29	9.5	10.2	-0.7
Clearwater R. @ rm 1.7	Clr0123	2:31	8.7	9.5	-0.8
Clearwater R. @ rm 4.9	Clr0380	2:43	9.8	9.8	0.0
Clearwater R. @ rm 11.5	Clr0837	3:06	9.5	8.4	1.1
Clearwater R. @ rm 11.6	Clr0841	3:06	8.9	7.3	1.6
N. Umpqua R. @ rm 87.5	Nfu0530	3:35	14.1	13.6	0.5
N. Umpqua R. @ rm 87.5	Nfu0535	3:35	13.2	12.3	0.9
N. Umqpua R. @ rm 76.5	Nfu1010	3:52	14.3	14.6	-0.3
N. Umpqua R. @ rm 75.8	Nfu1038	3:53	14.5	14.6	-0.1
10 July 01					
N. Umpqua R. @ rm 87.5	Njum0155	1:57	11.8	10.1	1.7
N. Umpqua R. @ rm 87.5	Njum0149	1:57	12.4	10.6	1.6
N. Umpqua R. @ rm 76.4	Njum0586	2:11	12.0	11.4	0.6
N. Umpqua R. @ rm 75.8	Njum0608	2:12	13.1	12.5	0.6
N. Umpqua R. @ rm 67.2	Njum0991	2:26	14.1	15.2	-1.1
N. Umpqua R. @ rm 98.3	Njum1269	2:39	15.8	16.1	-0.3
N. Umpqua R. @ rm 52.5	Njum1583	2:49	15.9	15.8	0.1
Fish Creek @ rm 4.8	Fc0300	3:36	17.4	17.4	0.0
Fish Creek @ rm 4.8	Fc0300	3:36	17.4	17.4	0.0
Fish Creek @ rm 6.6	Fc0413	3:40	16.4	16.0	0.4
Fish Creek @ rm 9.1	Fc0523	3:44	15.3	15.5	-0.2
Fish Creek @ rm 13.6	Fc0749	3:52	12.5	12.9	-0.4
Lake Creek @ rm 11.4	Lak0025	4:09	21.1	20.7	0.4
Lake Creek @ rm 5.2	Lak0402	4:22	18.8	19.0	-0.2
Lake Creek @ rm 1.1	Lak0631	4:30	18.7	19.1	-0.4
Clearwater R. @ rm 11.7	Clrb0050	4:35	6.2	4.5	1.7
Clearwater R. @ rm 11.6	Clrb0060	4:36	6.9	5.5	1.4
Clearwater R. @ rm 5.0	Clrb0369	4:46	10.3	10.6	-0.3
Clearwater R. @ rm 1.8	Clrb0500	4:50	8.4	9.1	-0.7
Clearwater R. @ rm 0.1	Clrb0569	4:52	8.7	9.3	-0.6
N. Umpqua R. @ rm 67.2	Nfb0271	5:17	14.8	15.8	-1.0
N. Umpqua R. @ rm 61.0	Nfb0512	5:24	15.8	15.7	0.1
N. Umpqua R. @ rm 52.6	Nfb0835	5:35	16.7	16.3	0.4

afternoon of July 10th (relative to July 9th), which can contribute variability to radiant temperature calculations especially on longer surveys. Spatial temperature patterns and the influence of differences in radiant and in-stream temperatures are discussed later in this report.

Temporal Differences

The in-stream temperature data loggers were used to compare temporal changes in stream temperatures for July 9th and 10th. Figure 3 shows in-stream temperature variation at a single ground truth location for each of the surveyed streams as well as the timing of the TIR remote sensing flights. The TIR surveys occurred at or near the maximum daily temperatures. However, stream temperatures were generally cooler on July 10th than on July 9th. The TIR imagery also showed generally cooler stream temperatures and surrounding terrain (Figure 4).

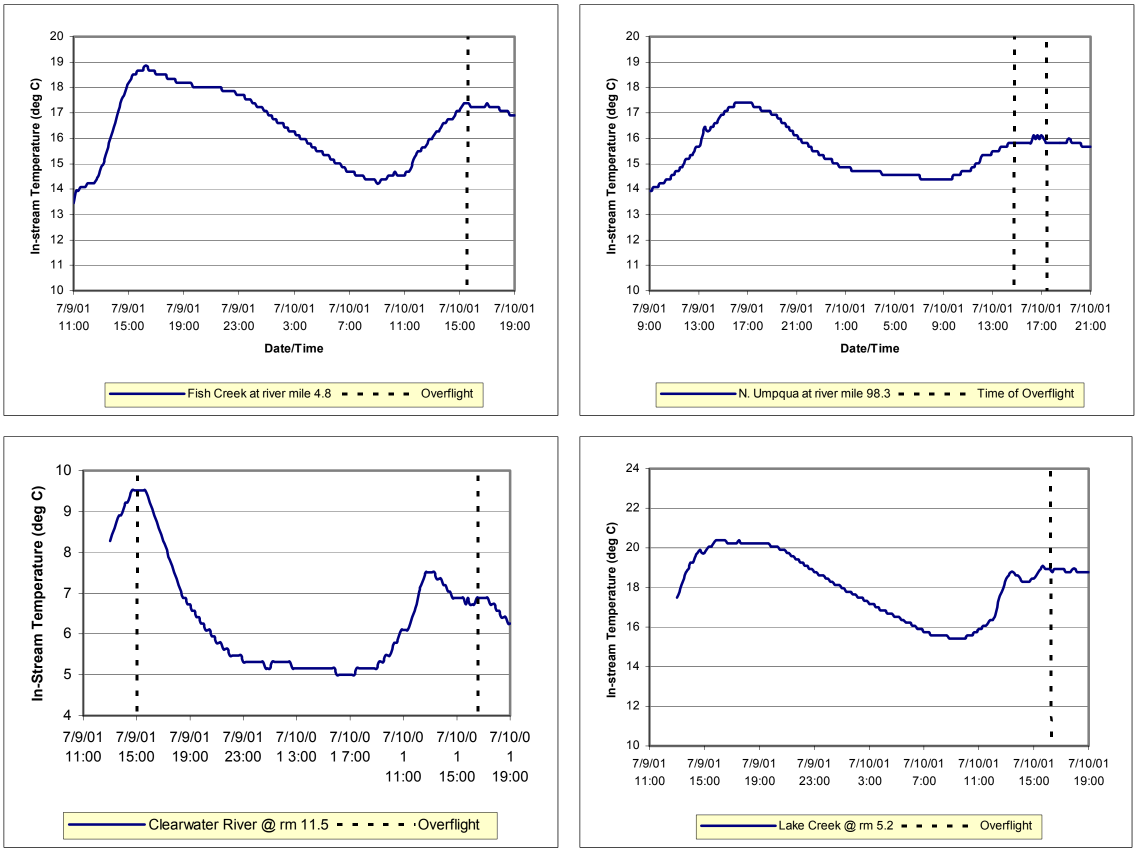


Figure 3 – Stream temperature variation and time of TIR remote sensing over flight for a single location in each of the surveyed streams in the North Umpqua River basin.

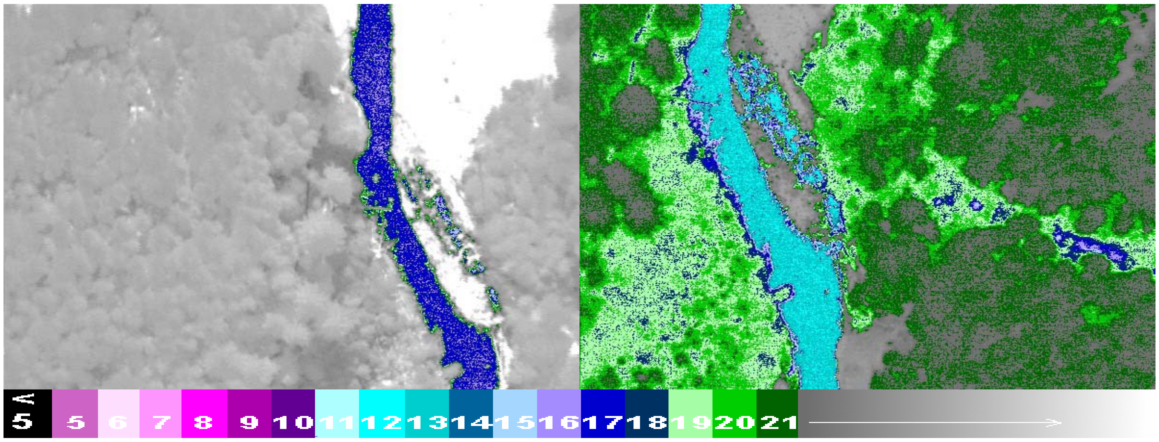


Figure 4 – TIR images taken on consecutive days on the North Umpqua River at river mile 81.25. The image on the left was acquired on 7/9/01 while the image on the right was acquired 7/10/01. The image on the right shows generally cooler thermal conditions both in-stream and in the surrounding environment.

Longitudinal Temperature Profiles

North Umpqua River

A longitudinal temperature profile was developed for each survey segment of the North Umpqua River (Figure 5, Figure 6, and Figure 7). The profiles illustrate how temperatures varied along the surveyed reach as a function of river mile. The profiles also show the location and temperature of tributary and other surface water inflows identified during the survey. Tributaries and sided channels are labeled in the profile by river mile and their name and temperature are listed in the associated tables (Table 4, Table 5, and Table 6).

The July 9th survey (Figure 5) started near the Kelsay Valley Campground and covered the four-mile stretch of river between the campground and the inlet of Lemolo Lake. Stream temperatures through this reach were dominated by a series of 7 springs and cool water tributaries, which lowered the mainstream temperature from 15°C near the campground to 6.8°C at Spring River (-8.2°C). Bradley Creek, Crystal Springs, and Spring River had the most predominant effect on the temperature profile through this reach. The large increase in stream temperatures at the Lemolo Lake inlet represents a transition between a well mixed and a thermally stratified condition.

The N. Umpqua River emerged from Lemolo Lake at temperatures representative of groundwater (7°-9°C) and warmed rapidly (≈1.7°C/mile) over the first 2.5 miles. A small-unnamed spring was detected at river mile 89.5, which had a local cooling affect on the mainstream. Form this point, water temperatures continued to warm slightly (≈1.0°C) to the Lemolo Power Plant #1 (river mile 87.5), which had a local cooling effect on mainstream temperatures.

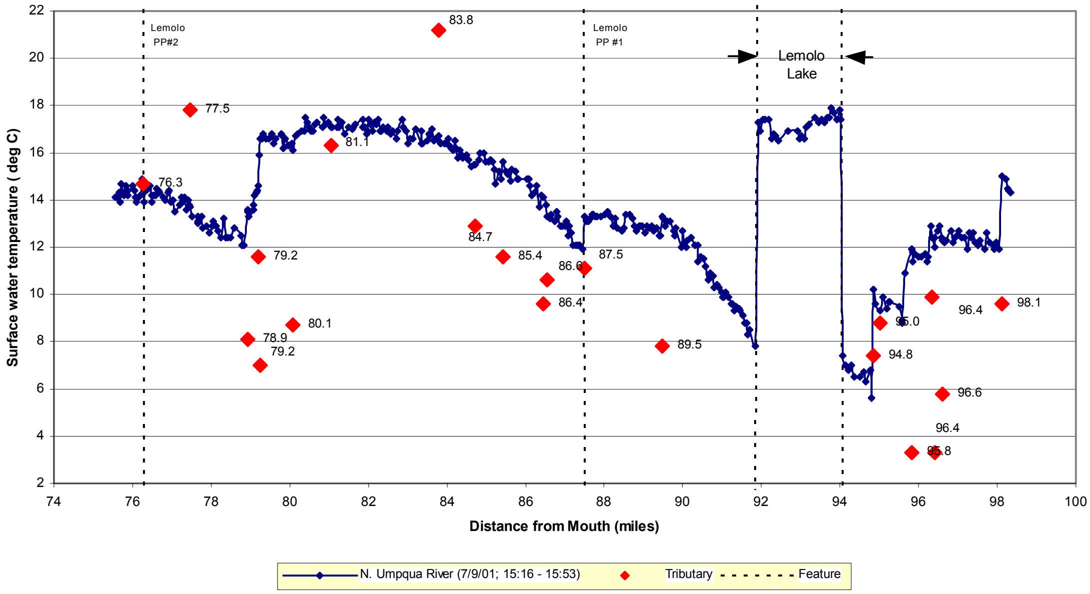


Figure 5 - Longitudinal Profile for the North Umpqua River (7/9/01; 3:16 – 3:53 pm). The survey started from upstream of Lemolo Lake and ended at the Toketee Reservoir.

Table 4 - Tributary and side channel temperatures for the North Umpqua River, OR. River miles correspond to data labels shown in Figure 5.

Tributary Name	Image	km	Mile	Tributary	N. Umpqua	Difference
Bradley Creek (RB)	nfu0021	157.9	98.1	9.6	15.0	-5.4
Spring (RB)	nfu0111	155.5	96.6	5.8	12.3	-6.5
No Name (RB)	nfu0123	155.2	96.4	3.3	12.4	-9.1
Side Channel w/ Trib (RB)	nfu0127	155.1	96.4	9.9	12.4	-2.5
Crystal Springs (RB)	nfu0173	154.2	95.8	3.3	11.9	-8.6
Spring (RB)	nfu0195	152.9	95.0	8.8	9.3	-0.5
Spring River (LB)	nfu0198	152.6	94.8	7.4	10.2	-2.8
Spring (LB)	nfu0442	144.0	89.5	7.8	13.3	-5.5
Substation Outlet (RB)	nfu0529	140.8	87.5	11.1	13.3	-2.2
Beverly Creek (RB)	nfu0575	139.3	86.6	10.6	13.3	-2.7
Helen Creek (RB)	nfu0580	139.1	86.4	9.6	14.1	-4.5
Dorothy Creek (RB)	nfu0619	137.5	85.4	11.6	15.6	-4.0
Potter Creek (RB)	nfu0645	136.3	84.7	12.9	15.5	-2.6
Nurse Creek (RB)	nfu0722	134.9	83.8	21.2	16.5	4.7
No Name (RB)	nfu0832	130.5	81.1	16.3	17.1	-0.8
Spring (LB)	nfu0868	128.9	80.1	8.7	16.1	-7.4
Loafer Creek (LB)	nfu0901	127.5	79.2	7.0	16.6	-9.6
Loafer Creek Current (LB)	nfu0903	127.5	79.2	11.6	14.6	-3.0
No Name (LB)	nfu0916	127.0	78.9	8.1	13.6	-5.5
Trib from Lemolo Canal (RB)	nfu0971	124.7	77.5	17.8	13.7	4.1
Lemolo Forebay Outlet (RB)	nfu1019	122.8	76.3	14.7	14.6	0.1

(LB = left bank, RB = right bank looking downstream)

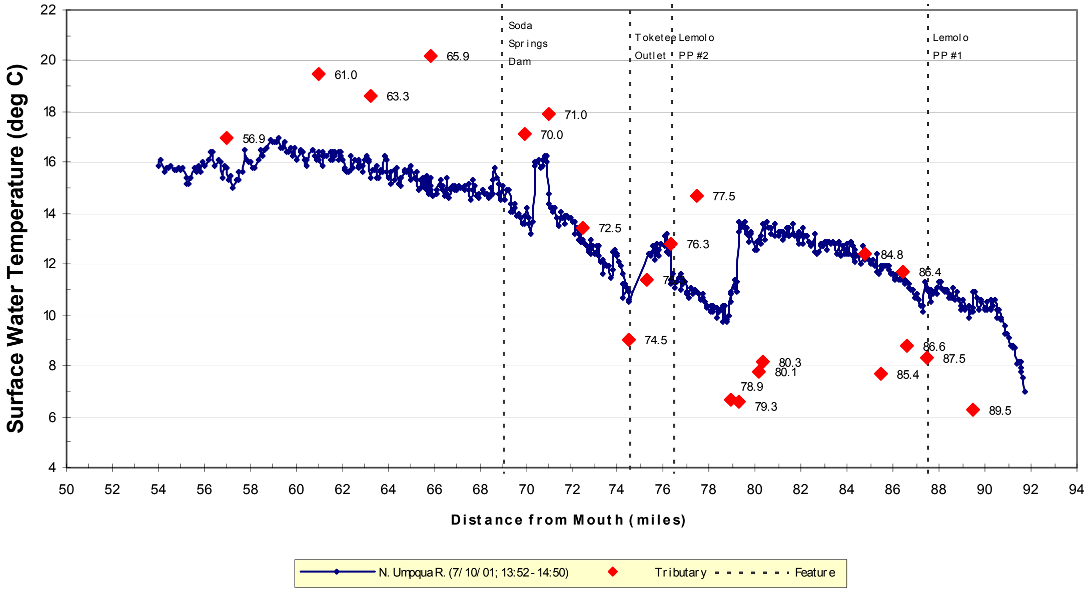


Figure 6 – Longitudinal temperature profile for the North Umpqua River (7/10/01; 15:16 – 15:53).

Table 5 - Tributary and side channel temperatures for the North Umpqua River, OR. River miles correspond to data labels shown in Figure 6.

Tributary	Image	km	mile	Tributary	N. Umpqua	Difference
Springs? (LB)	njum0080	144.0	89.5	6.3	10.1	-3.8
Warm Spring Creek (RB)	njum0151	140.8	87.5	8.3	11.0	-2.7
Beverly Creek (RB)	njum0176	139.4	86.6	8.8	11.3	-2.5
Helen Creek (RB)	njum0182	139.0	86.4	11.7	11.8	-0.1
Dorothy Creek (RB)	njum0217	137.5	85.4	7.7	11.9	-4.2
Potter Creek (RB)	njum0241	136.5	84.8	12.4	12.2	0.2
Springs (LB)	njum0416	129.3	80.3	8.2	13.6	-5.4
Springs (LB)	njum0424	129.0	80.1	7.8	13.0	-5.2
Loafer Creek (LB)	njum0464	127.6	79.3	6.6	13.3	-6.7
No Name (LB)	njum0479	127.0	78.9	6.7	10.5	-3.8
No Name (RB)	njum0542	124.7	77.5	14.7	10.9	3.8
Mill Creek (LB)	njum0586	122.8	76.3	12.8	12.7	0.1
Clearwater Forebay Outlet (LB)	njum0641	121.1	75.3	11.4	na	na
Clearwater River (LB)	njum0673	119.8	74.5	9.0	10.6	-1.6
Substation Outlet (RB)	njum0781	116.7	72.5	13.4	12.9	0.5
Fish Creek (LB)	njum0843	114.2	71.0	17.9	14.8	3.1
Medicine Creek (RB)	njum0883	112.6	70.0	17.1	13.6	3.5
Copeland Creek (LB)	njum1037	106.0	65.9	20.2	15.1	5.1
Deception Creek (LB)	njum1148	101.8	63.3	18.6	15.4	3.2
Calf Creek (LB)	njum1272	98.2	61.0	19.5	16.3	3.2
Limpy Creek (LB)	njum1432	91.6	56.9	17.0	15.8	1.2

(LB = left bank, RB = right bank looking downstream; a ? indicates some uncertainty in the interpretation).

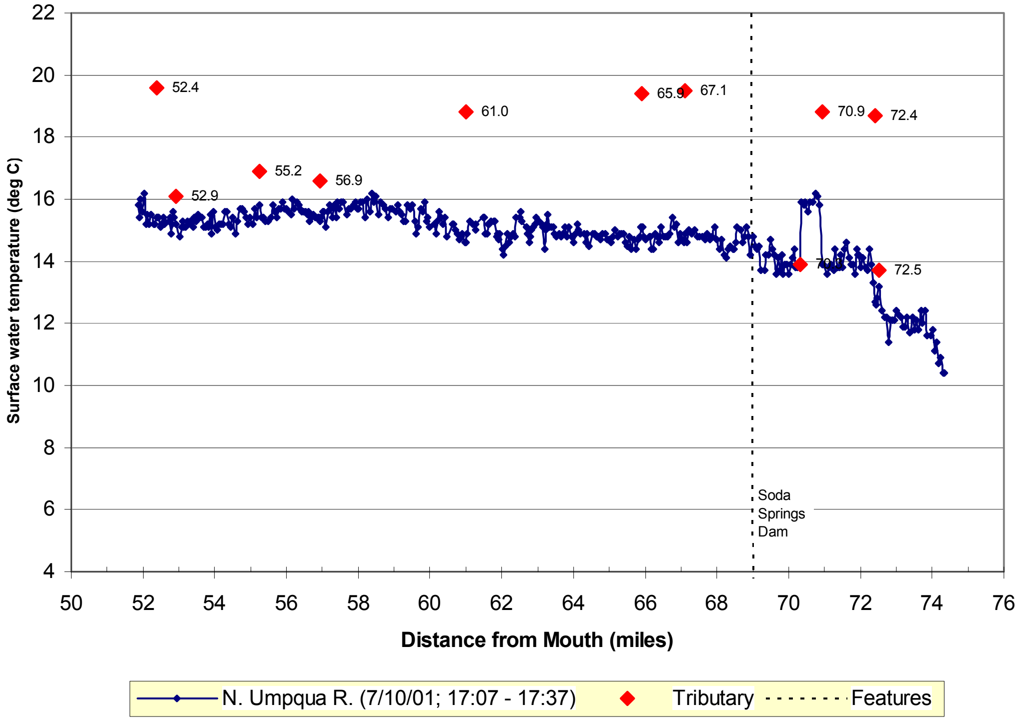


Figure 7 - Longitudinal temperature profile of the North Umpqua River (7/10/01; 17:07-17:37). The survey was conducted from the Toketee Reservoir outlet to Steamboat Creek.

Table 6 - Tributary and side channel temperatures for the North Umpqua River, OR. River miles correspond to data labels shown in Figure 7.

Tributary Name	Image	km	mile	Tributary	N. Umpqua R.	Difference
Substation Outlet (RB)	nfb0080	116.7	72.5	13.7	13.2	0.5
Fish Creek PP Outlet (LB)	nfb0084	116.5	72.4	18.7	12.7	6.0
Fish Creek (LB)	nfb0144	114.2	70.9	18.8	13.9	4.9
Slide Creek PP Outlet (RB)	nfb0164	113.2	70.3	13.9	13.9	0.0
Boulder Creek (RB)	nfb0272	108.0	67.1	19.5	14.9	4.6
Copeland Creek (LB)	nfb0315	106.1	65.9	19.4	15.1	4.3
Calf Creek (LB)	nfb0508	98.2	61.0	18.8	14.6	4.2
Panther Creek (LB)	nfb0661	91.6	56.9	16.6	15.3	1.3
No Name (LB)	nfb0729	88.9	55.2	16.9	15.8	1.1
Side Channel (RB)	nfb0816	85.2	52.9	16.1	15.2	0.9
Steamboat Creek (RB)	nfb0845	84.3	52.4	19.6	15.4	4.2

(LB = left bank, RB = right bank looking downstream)

The river continued to warm in the downstream direction between river miles 87.5 and 80.5. The spatial pattern of warming through this reach was consistent between the two survey days. However, the rate of warming and observed in-stream temperatures differed between the July 9th and July 10th surveys. For example, the maximum observed temperature in this reach on July 9th was 17.5°C at river mile 80.5. The maximum observed temperature in this reach was also recorded at river mile 80.5 on July 10th, but was 3.9°C cooler (13.6°C).

The inflow of a large spring (river mile 80.1) and Loafer Creek (river mile 79.2) reset temperatures in the mainstream to near those recorded at Lemolo Power Plant #1. On July 9th, mainstream temperatures dropped by 5.4°C between river miles 80.4 and 78.8. The spring (river mile 80.1) was located near the mapped location of the Umpqua Hot Springs on USGS 7.5' topographic maps. However, any warm water inflows from hot springs were not detected. Stream temperatures begin to increase downstream of Loafer Creek. Lemolo Power Plant #2 (river mile 76.3) was observed as a source of thermal loading during the July 10th survey. However, there was no significant change in mainstream temperatures at this location during the July 9th survey.

The Clearwater River and the Clearwater Forbay Outlet both entered the N. Umpqua River at the Toketee Reservoir. The TIR images showed that the surface of the Toketee Reservoir was thermally stratified, although some mixing was observed due to the two major inflows. The N. Umpqua River emerged from the Toketee Reservoir outlet at about 10.5°C on the July 10th survey. From the reservoir outlet, stream temperatures warmed in the downstream direction. The inflow of Fish Creek at river mile 71.0 resulted in an increase in mainstream temperatures, which was offset by the inflow of the Slide Creek Dam at river mile 70.3. Stream temperatures showed a general warming trend downstream of river mile 71.0 to river mile 60.0. Stream temperatures were relatively constant between river mile 60.0 and the end of the survey at river mile 52.0.

A total of 21 tributary and other surface water inflows were detected upstream of the Toketee Reservoir. Of the 21, all but three contributed water that was cooler then the mainstream temperatures. The tributary influence upstream of the reservoir had a significant role in defining the shape of the longitudinal temperature profile. Conversely, eleven surface inflows were detected and sampled downstream of the Toketee Reservoir outlet. Of these, only the Slide Creek Dam outlet contributed water that was cooler then the mainstream.

The three segments of the N. Umpqua River survey were combined on a single graph (Figure 8) in order to compare spatial temperature patterns. The figure shows that while the absolute temperatures changed between the July 9th and July 10th, the spatial patterns of warming and cooling were very consistent. The two surveys segments conducted downstream of the Toketee Reservoir on July 10th also showed similar spatial patterns. However, slightly cooler temperatures were observed between river mile 65.4 and 58.1 for the latter survey.

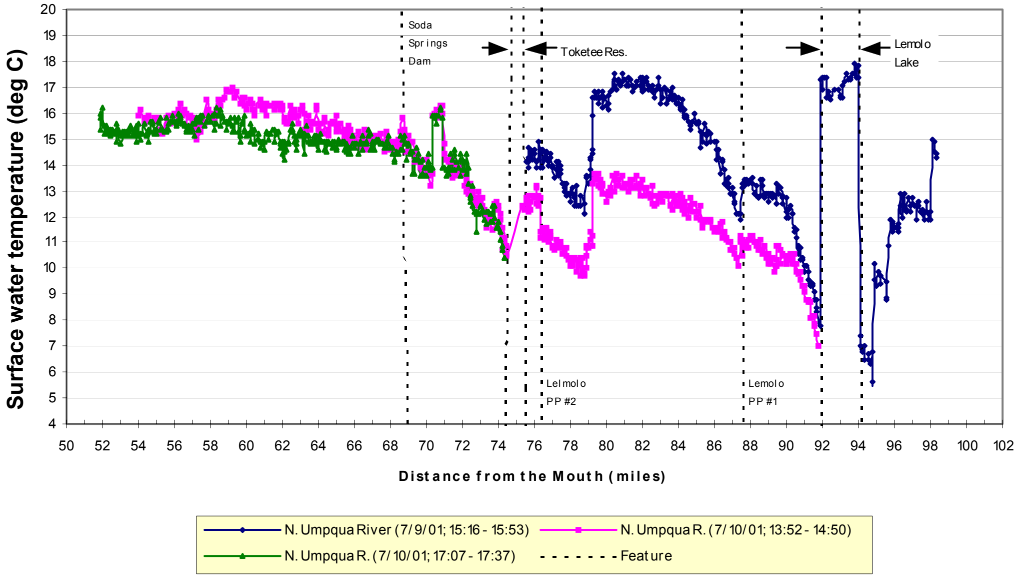


Figure 8 – Comparison of the longitudinal temperature profiles derived from TIR remote sensing surveys of the North Umpqua River on July 9th and 10th, 2001.

Clearwater River

A longitudinal temperature profile was developed for both the July 9th and 10th surveys of the Clearwater River from its mouth at the Toketee Reservoir to the headwater springs (Figure 9 and Figure 10). The location of tributaries and other surface inflows are identified on the profile. The tributaries are labeled on the profile by river mile with their name and temperature listed in the associated table. As with the N. Umpqua River, the two surveys were combined on the same graph in order to compare spatial temperature patterns.

While conditions were generally warmer on July 9th, the spatial temperature patterns were consistent between the two surveys. Stream temperatures started cool in the headwater springs and generally warmed downstream to river mile 10.5. Recall that in both surveys the in-stream monitors recorded temperatures approximately 1.5°C warmer then the radiant temperatures at river mile 11.5 (Table 3). This temperature difference may exaggerate the (cold) temperature of the headwaters in longitudinal profile; however, it does not change the overall shape of the observed temperature patterns.

The inflow of Lava Creek, Lost Creek, and an unnamed tributary cooled mainstream temperature between river mile 10.6 and 10.1. Stream temperatures then remained relatively consistent between river miles 10.0 and the inlet of Stump Lake (river mile 8.8). In both surveys, the Clearwater River showed an increase in stream temperature (≈2.7°C) through Stump Lake.

Stream temperatures generally warm between the Stump Lake outlet and Clearwater Power Plant #1 (river mile 5.3). The reach immediately downstream of the Stump Lake (river mile 8.4 to 7.3) was the only one where spatial temperature patterns differed between the two profiles. During the July 9th surveys, stream temperatures showed an approximately 1.0°C increase through this reach with some local variation. However, the July 10th survey showed a greater (2.0°C) temperature increase with less local variation. Both profiles showed a slight temperature decrease between river miles 7.1 and 6.6 although no tributaries were detected at this location.

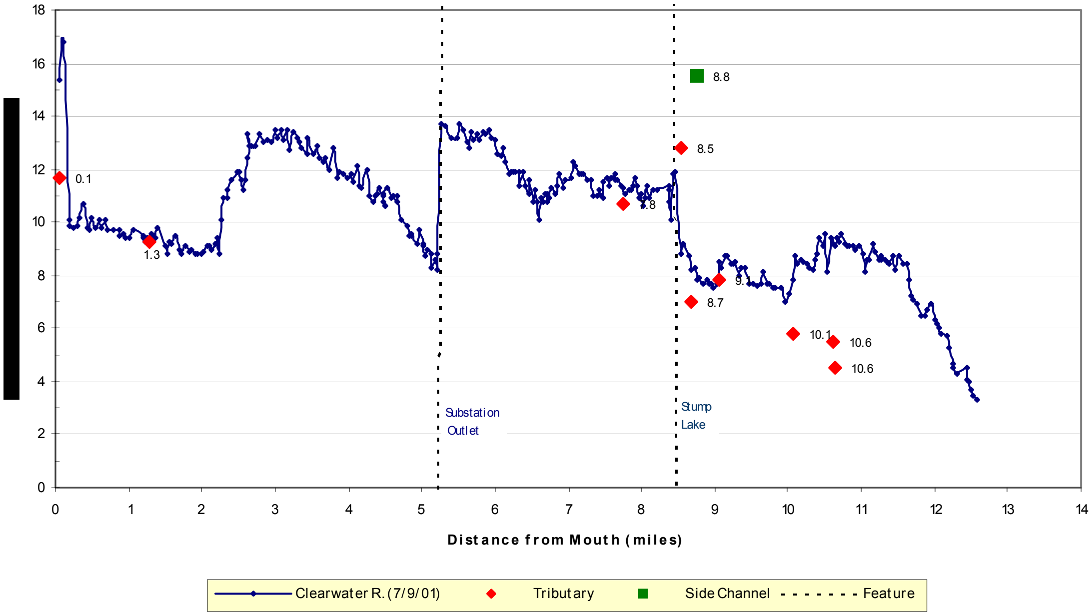


Figure 9 – Longitudinal temperature profile of the Clearwater River (7/9/01; 2:25 – 3:10)

Table 7 - Tributary and side channel temperatures for the North Umpqua River, OR. River miles correspond to data labels shown in Figure 9.

Tributary Name	Image	Km	Mile	Tributary	Clearwater R.	Difference
North Umpqua (LB)	clr0052	0.1	0.1	11.7	15.4	-3.7
Watson Creek (LB)	clr0103	2.0	1.3	9.3	9.3	0.0
Trap Creek (LB)	clr0621	12.5	7.8	10.7	11.3	-0.6
Bear Creek (LB)	clr0677	13.7	8.5	12.8	8.8	4.0
No Name (LB)	clr0685	14.0	8.7	7.0	8.2	-1.2
No Name (LB)	clr0708	14.6	9.1	7.8	8.5	-0.7
Lava Creek (RB)	clr0755	16.2	10.1	5.8	7.8	-2.0
Lost Creek (LB)	clr0785	17.1	10.6	5.5	9.2	-3.7
No Name (LB)	clr0786	17.1	10.6	4.5	9.1	-4.6
Side Channels						
Side Channel (RB)	clr0689	14.1	8.8	15.5	7.8	7.7

(LB = left bank, RB = right bank looking downstream)

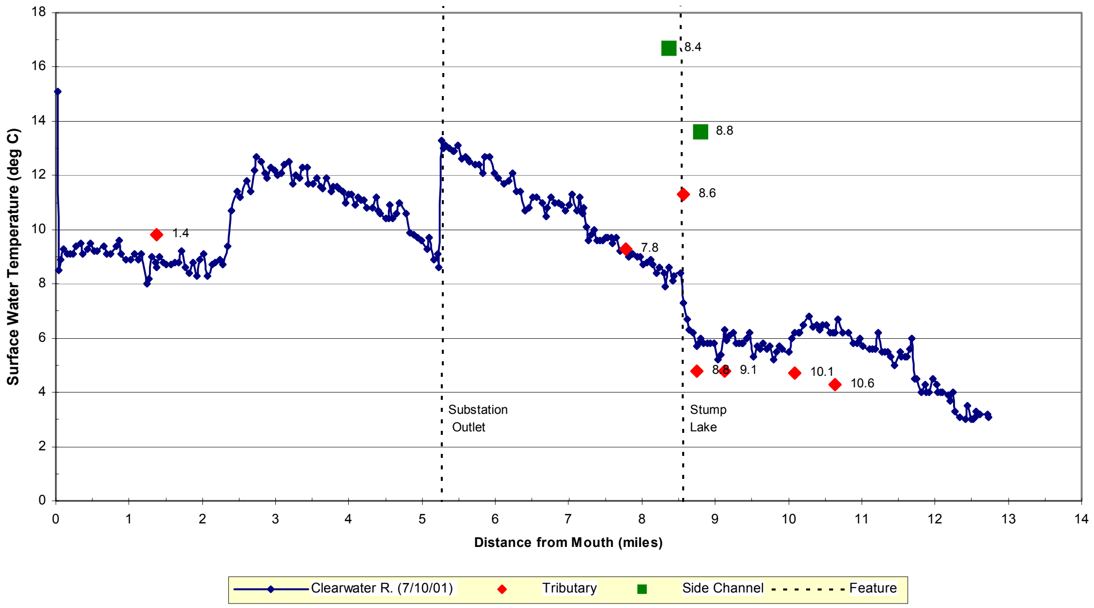


Figure 10 – Longitudinal temperature profile for the Clearwater River (7/10/01; 4:34 – 4:53).

Table 8 – Tributary and side channel temperatures for the Clearwater River, OR. River miles correspond to data labels shown in Figure 10.

Tributary Name	Image	km	Mile	Tributary	Clearwater	Difference
No Name (LB)	clrb0109	17.1	10.6	4.3	6.2	-1.9
Lava Creek (RB)	clrb0135	16.2	10.1	4.7	6.2	-1.5
No Name (LB)	clrb0178	14.7	9.1	4.8	6.3	-1.5
No Name (LB)	clr0194	14.1	8.8	4.8	5.7	-0.9
Bear Creek (LB)	clrb0204	13.8	8.6	11.3	7.3	4.0
Trap Creek (LB)	clrb0254	12.5	7.8	9.3	9.4	-0.1
Watson Creek (LB)	clrb0514	2.2	1.4	9.8	8.6	1.2
Side Channels						
Side channel (RB)	clrb0192	14.2	8.8	13.6	6.0	7.6
Off Channel Pond (LB)	clrb0219	13.5	8.4	16.7	8.6	8.1

(LB = left bank, RB = right bank looking downstream)

The outlet at Clearwater Power Plant #1 decreased mainstream temperatures by 4.7°C. Both absolute temperatures and spatial patterns were similar between the two surveys. Downstream of the Clearwater Power Plant, stream temperatures increased in the downstream direction. Between river miles 2.7 and 2.0, the Clearwater River again showed a sharp drop in stream temperature (-4.5°C). There were not point source inflows sampled through this reach. Apparent springs were noted at river mile 2.2, but were not sampled because there was no defined inflow point (Figure 12). USGS topographic maps also show the location Tunnel Creek within this reach. However, the creek inflow was not detected during the survey.

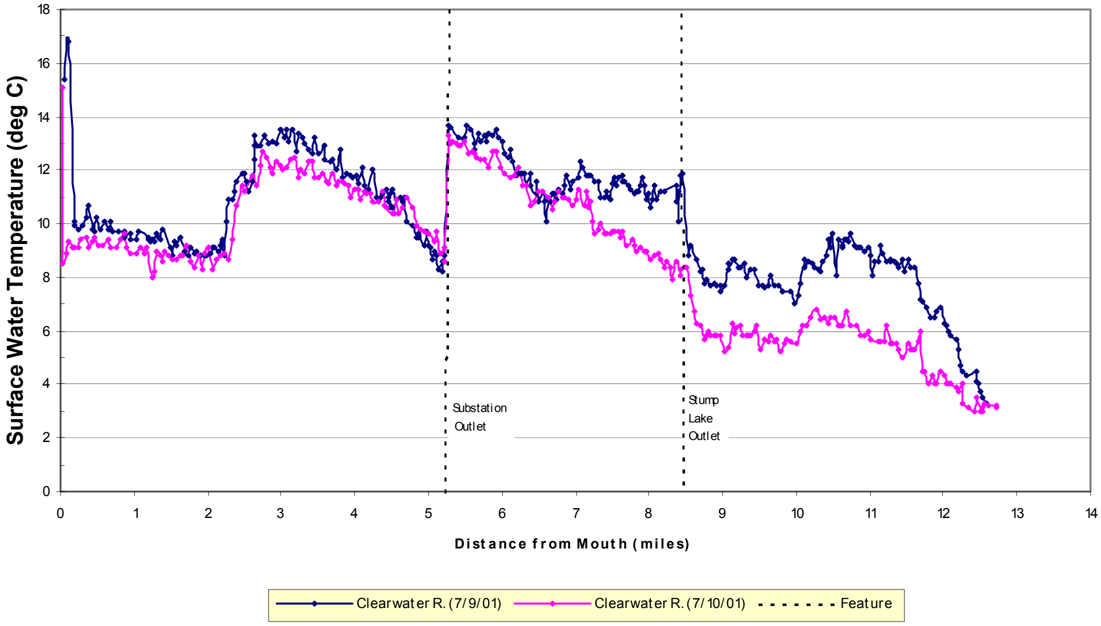
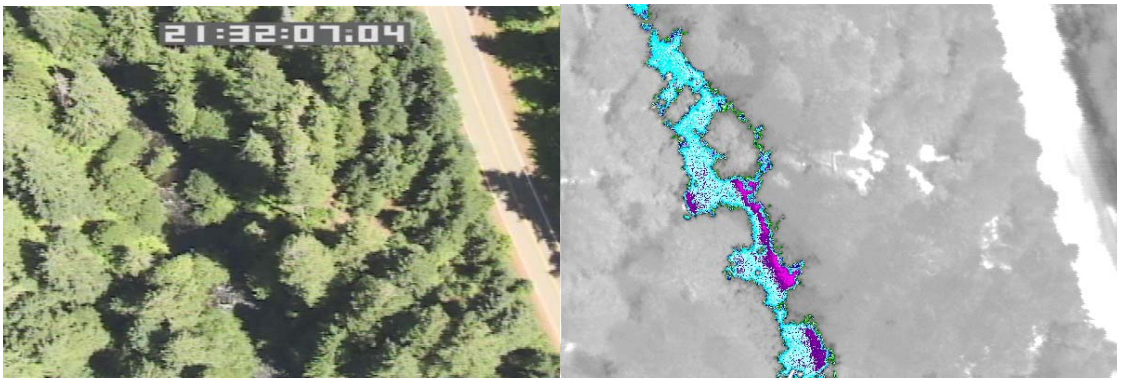


Figure 11 – Comparison of the longitudinal temperature profiles derived from TIR remote sensing surveys of the Clearwater River on July 9th and 10th, 2001.



visble band/TIR image

Figure 12 – Image pair showing the Clearwater River at river mile 2.2. The flow direction is from the top to bottom of the image and the TIR image on the right is color coded in 1°C increments to emphasize in-stream temperatures. Springs inflows may account for an observed drop in mainstream temperatures along this reach (river miles 2.7-2.0). However, the shadows on the visible band image and no definitive inflow points make positive identification difficult (frame: clr0152).

Fish Creek

As with the previous streams, a longitudinal temperature profile was developed for Fish Creek from its mouth to headwaters (Figure 13). Tributaries and side-channels are labeled on Figure 13 by river mile with their name and temperatures listed in the associated table (Table 9).

Stream temperatures varied from 15.6°C and 13.3°C between river miles 18.0 and 15.6. At river mile 15.5, a spring inflow lowered stream temperatures to less then 8.0°C. Downstream of the spring, stream temperatures increased consistently reaching 16.1°C at the Fish Creek diversion dam (river mile 6.8). Nine tributary and side channel inflows were noted through this reach. However, the inflows only had local influence on mainstream temperatures. A cold side channel was observed at river mile 12.2 indicating possible sub-surface discharge in the side channel. Stream temperatures increased approximately 1.0°C between river miles 6.8 and 2.6. A slight increase in the rate of heating was observed between river mile 2.6 and the confluence with the N. Umpqua River. Fish Creek was ultimately a source of thermal loading to the N. Umpqua River.

Lake Creek

The longitudinal temperature profile derived from the Lake Creek TIR remote sensing survey is shown in Figure 14. As with the previous profiles, Figure 14 identifies the location and temperature of tributary and spring inflows. Tributaries and side channels are labeled by river mile with their name and temperature listed in the associated table (Table 10).

An overall cooling trend was observed in Lake Creek between the Diamond Lake outlet (20.6°C) and the mouth (18.6°C) at Lemolo Lake. A total of five surface water inflows were detected during the survey and all contributed cooler water to the mainstream. Three springs were detected during the survey.

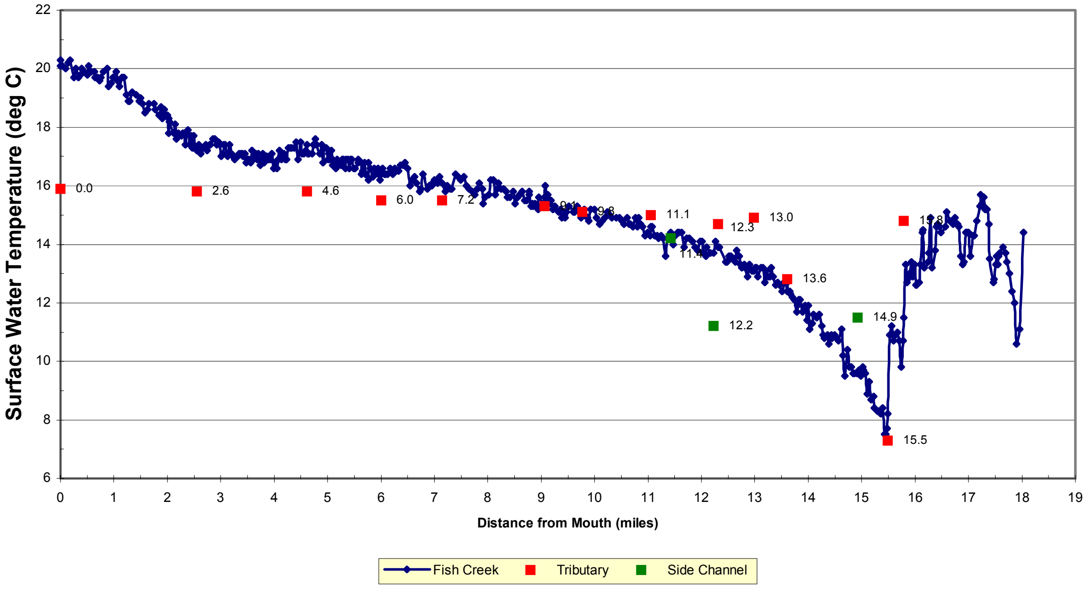


Figure 13 – Longitudinal temperature profile of Fish Creek (7/10/01; 3:27 – 4:00).

Table 9 - Tributary and side channel temperatures for Fish Creek. River miles correspond to data labels shown in Figure 13.

Tributary Name	Image	km	mile	Tributary	Fish Creek	Difference
North Umpqua R. ( )	fc0019	0.0	0.0	15.9	20.1	-4.2
Pie Creek (LB)	fc0152	4.1	2.6	15.8	17.2	-1.4
Eva Creek (LB)	fc0290	7.4	4.6	15.8	17.4	-1.6
Slipper Creek (LB)	fc0383	9.7	6.0	15.5	16.4	-0.9
No Name (LB)	fc0437	11.5	7.2	15.5	16.1	-0.6
Rough Creek (RB)	fc0523	14.6	9.1	15.3	15.6	-0.3
Brodie Creek (RB)	fc0564	15.7	9.8	15.1	15.1	0.0
Grave Creek (LB)	fc0621	17.8	11.1	15.0	14.6	0.4
Black Rock Creek (LB)	fc0679	19.8	12.3	14.7	13.9	0.8
No Name (LB)	fc0712	20.9	13.0	14.9	13.1	1.8
Clear Creek (RB)	fc0749	21.9	13.6	12.8	12.7	0.1
Spring (LB)	fc0852	24.9	15.5	7.3	8.2	-0.9
No Name (RB)	fc0868	25.4	15.8	14.8	11.5	3.3
Side Channels						
Side Channel (RB)	fc0638	18.4	11.4	14.2	14.4	-0.2
Side Channel (LB)	fc0674	19.7	12.2	11.2	13.7	-2.5
Side Channel (RB)	fc0820	24.0	14.9	11.5	9.6	1.9

(LB = left bank, RB = right bank looking downstream)

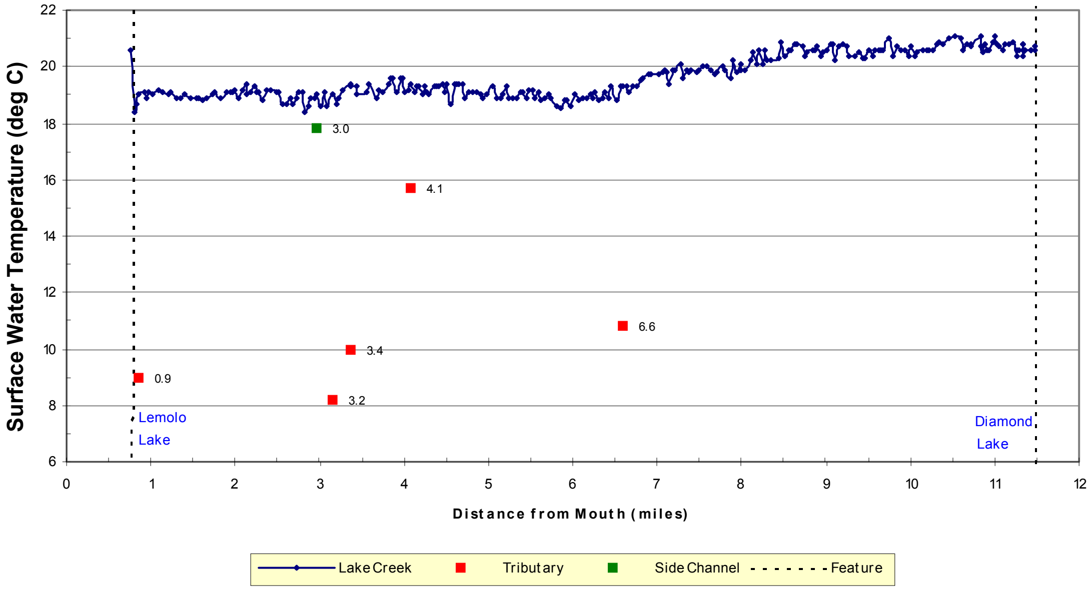


Figure 14 – Longitudinal temperature profile for Lake Creek (7/10/01; 4:08 – 4:30).

Table 10 - Tributary and side channel temperatures for Fish Creek. River miles correspond to data labels shown in Figure 14.

Tributary Name	Image	km	mile	Tributary	Lake Creek	Difference
Sheep Creek (RB)	lak0320	10.6	6.6	10.8	19.3	-8.5
Thielsen Creek (RB)	lak0474	6.6	4.1	15.7	19.4	-3.7
Spring? (LB)	lak0513	5.4	3.4	10.0	19.4	-9.4
Spring (RB)	lak0521	5.1	3.2	8.2	19.0	-10.8
Spring (LB)	lak0642	1.4	0.9	9.0	19.0	-10.0
Side Channel						
Side Channel (RB)	lak0529	4.8	3.0	17.8	19.0	-1.2

(LB = left bank, RB = right bank looking downstream)

Discussion

TIR remote sensing was used to map stream temperatures for the N. Umpqua River and three major tributaries. The data were collected on the 9th and 10th of July in order to assess low flow high summer temperatures in support of stream temperature analysis in the basin and were coordinated with field crews in the basin. In-stream temperatures and meteorological conditions were recorded continuously for the two days of the survey.

Spatial temperature patterns in the North Umpqua and Clearwater Rivers were defined by the collective contribution of natural inflows and the impacts of man-made hydroelectric projects. On both rivers, the survey found groundwater discharges that were not identified on the USGS 7.5’ topographic maps, but had a significant impact on spatial temperature patterns. Surface inflows such as Loafer Creek and Fish Creek on the North Umpqua River also directly impacted mainstream temperatures. Man-made influences included water withdraws, water returns, dams, and dam releases. In many cases, the direct impact of man-made features such as impoundments and water returns were apparent from the spatial temperature profiles. However, further analysis is needed to assess the collective impact of these features on instream flows and, consequently, stream temperatures.

Multiple over flights were conducted on the North Umpqua and Clearwater Rivers and provide a means to compare the spatial temperature patterns observed during both survey days. Weather conditions changed between the two days with generally cooler temperatures occurring on the second day (7/10/01). Comparison of the temperature patterns showed that while absolute stream temperatures changed, the spatial temperature patterns were consistent between surveys. Multiple profiles of the same reach can provide a better overall understanding of how the stream is thermally structured. For stream temperature modeling efforts, the multiple passes provide a robust set of calibration points under different meteorological (*and possibly in-stream flow*) conditions.

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