Aerial Surveys in the Rogue River Basin

Thermal Infrared and Color Videography

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Report to:

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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 Rogue 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.

Table 1 - Time, date and extent for the Rogue River Surveys.

Stream	Date '01	Local Time (PM)	Extent
Rogue River	13 July	1:55 – 2:02	Cold Ray Dam to Little Butte Cr.
Little Butte Cr.	13 July	2:04 – 2:34	Mouth to Forks
S.F. Little Butte Cr.	13 July	2:34 – 3:07	Mouth to Headwaters
N.F. Little Butte Cr.	13 July	3:19 – 3:40	Mouth to Fish Lake
Fish Lake	13 July	3:41 – 3:48	Lake Shoreline
Antelope Cr.	13 July	2:08 – 2:12	Mouth to Quarter Branch
Elk Cr.	14 July	1:43 – 2:19	Mouth to Headwaters

The Rogue River was surveyed at an altitude of 2500 ft above ground level (AGL). At this altitude, the image has a ground width of approximately 270 meters and a pixel resolution of 0.4 meters. Little Butte Creek and tributaries were surveyed at an average flight altitude of 1400 ft AGL. At this altitude, the image presents a ground area

[1] Geographic Information System

of approximately 150 meters wide. Elk Creek was surveyed at an average altitude of 1200 ft AGL resulting in an image 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 eight 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 ±0.2^{o}C. These locations were supplemented by data provided by ODEQ from six in-stream temperature loggers located in Elk Creek. 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 near Fish Lake (Table 2).

Table 2 – Meteorological conditions recorded near Fish Lake for the date and time of the TIR surveys conducted in the Rogue River Basin.

Date	*Time*	*Temp (*C)*	*RH (%)*
07/13/01	14:00	25.2	32.8
07/13/01	14:30	25.2	30.4
07/13/01	15:00	25.2	28.9
07/13/01	15:30	26.0	27.5
07/13/01	16:00	26.7	25.2

Date	*Time*	*Temp (*C)*	*RH (%)*
7/14/01	13:30	22.9	44.3
7/14/01	14:00	23.6	42.2
7/14/01	14:30	24.0	38.2
7/14/01	15:00	23.6	37.2
7/14/01	15:30	24.4	35.7
7/14/01	16:00	25.6	32.8

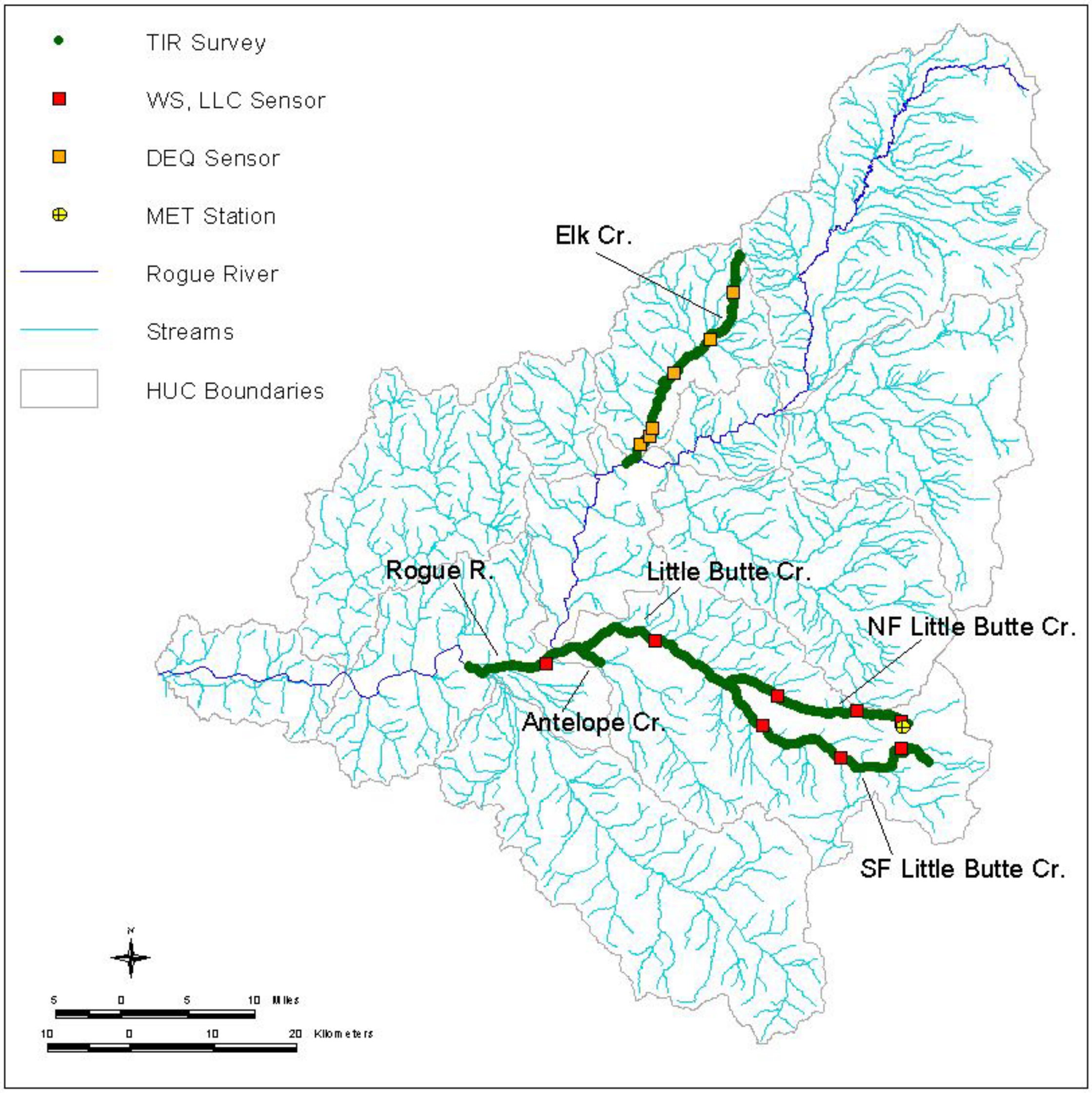


Figure 1 – Map of the Rogue River basin showing streams surveyed using TIR and visible band color video. The map also shows the location of in-stream sensors used to verify the accuracy of the radiant temperatures.

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.

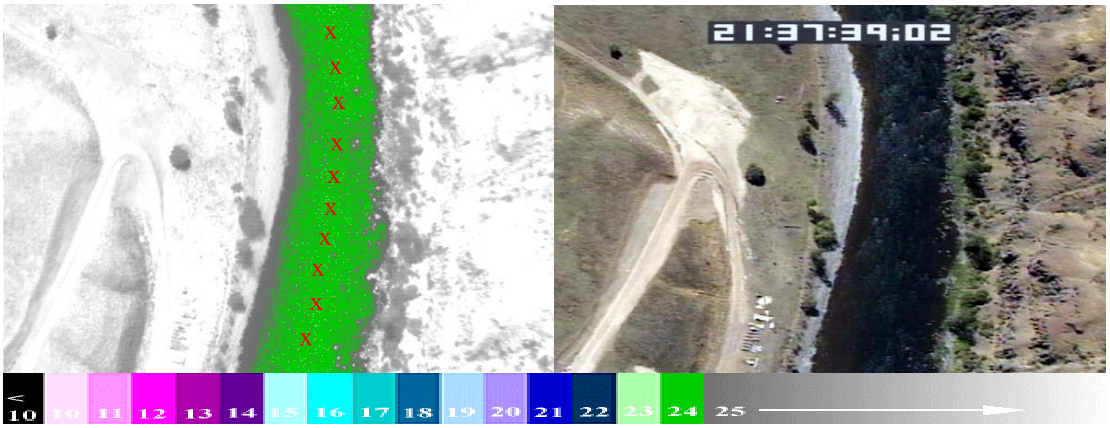
The image points were associated with a river kilometer within the GIS environment. The river kilometers were derived from 1:100K "routed" stream covers from the Environmental Protection Agency (EPA). The route measures provide a spatial context for developing longitudinal temperature profiles of stream 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 shows 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 Rogue River Basin, thermal stratification was not generally considered an issue in obtaining accurate stream temperatures. However, Fish Lake is thermally stratified and the TIR images of the lake represent only surface conditions.

The TIR sensor cannot see through canopy. Vegetation occasionally masked the stream and tributaries during the Rogue River basin surveys. This was observed mostly in the middle to upper reaches of Elk Creek. Even in heavily canopied areas, streams are often intermittently visible through breaks in the canopy allowing the development of a continuous longitudinal profile. The major issue of the vegetation masking in these areas was identifying small tributaries and other thermal features in the riparian zone.

There is a tradeoff between the ground area covered by the image and pixel resolution. Smaller channel widths (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures (Torgersen et. al. 2001). On Elk Creek and forks of Little Butte Creek several small tributaries were detected that were not sampled due to the inability to obtain a reliable temperature sample. In addition, mainstream temperatures were only sampled where channel widths allowed for accurate temperature measurements. There were several reaches on Elk Creek that could not be sampled due to the combination of canopy closure and narrow channel widths.

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.

On July 13th, the average accuracy for all eight points was ±0.4°C, which is consistent with previous work in the Pacific Northwest (Torgersen et. al. 2001, Faux et. al. 2001). Of the eight locations, five had a difference of less than 0.3°C between the TIR image and the in-stream data logger. The largest difference of 1.3°C was observed at the data logger at river mile 4.3 on the North Fork Little Butte Creek. A number of factors can influence the accuracy of the radiant temperatures and the reason for the difference at this location was unknown. However, the magnitude (1.3°C) of this difference did not influence the development or interpretation of spatial temperature patterns.

Table 3 – Comparison of ground-truth water temperatures with radiant temperatures derived from the TIR images, 13-14 July 2001. Temperatures are reported in °C and river miles (rm) are cited for locations.

Location	Image Frame	Time (PM)	Stream Temp (Ts)	Radiant Temp (Tr)	Difference (Ts-Tr)
13 July 2001					
Rogue R. @ rm 131.5	lb0192	2:01	18.8	18.7	0.1
L Butte Cr. @ rm 9.9	lb0779	2:24	24.4	24.3	0.1
SF L Butte Cr. @ rm 5.0	lb1271	2:41	24.6	25.3	-0.7
SF L Butte Cr. @ rm 12.3	lb1584	2:51	20.2	19.9	0.3
SF L Butte Cr. @ rm 18.5	lb1862	3:02	15.2	15.3	-0.1
NF L Butte Cr. @ rm 4.3	nflb0192	3:24	17.3	18.6	-1.3
NF L Butte Cr. @ rm 10.9	nflb0447	3:33	16.5	16.5	0.0
NF L Butte Cr. @ rm 14.8	nflb0600	3:38	17.4	16.7	0.7
14 July 2001					
Elk Cr. @ rm 1.5	elk0108	1:45	25.9	25.9	0.0
Elk Cr. @ rm 2.6	elk0167	1:47	26.9	25.4	1.5
Elk Cr. @ rm 3.4	elk0208	1:49	25.4	24.9	0.5
Elk Cr. @ rm 8.8	elk0460	1:57	22.1	21.6	0.5
Elk Cr. @ rm 13.0	elk0665	2:04	19.9	19.4	0.5
Elk Cr. @ rm 17.8	elk0877	2:11	14.1	14.8	-0.7

Larger differences were observed between the in-stream data loggers and the radiant temperatures during the survey of Elk Creek on July 14^{th}. The average difference for all six points was ±0.6°C. Radiant temperatures were cooler than the in-stream temperatures for the five most downstream points, but were warmer then the in-stream temperatures measured at river mile 17.8. The observed temperature difference at this point may reflect inaccuracies that occur when not enough pixels are available "in the stream" to get a truly accurate sample. The radiant temperature sample may therefore represent the integration of colder water with terrestrial features (bank vegetation, rocks in the channel, etc.) resulting in higher radiant temperatures. In reviewing the results of this paper and during follow on analysis, it is important to note that higher inaccuracies may exist for very narrow channel widths and for small tributary inputs than for mainstream temperatures.

Longitudinal Temperature Profiles

Rogue River

A longitudinal temperature profile was developed for the Rogue River (Figure 3). The profiles illustrate how temperatures varied along the surveyed reach as a function of river mile. The profile also shows 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).

Mainstream temperatures on the Rogue River were consistent (±0.5°C) over the 6.7-mile survey reach. Six tributary inputs were sampled and all contributed water that was warmer then the mainstream. In addition to tributaries, six surface water inputs were identified as either side channel or off channel features and all were warmer then the mainstream temperatures. The twelve surface water inputs contributed to local thermal variability near their mouth, but did not show a detectable impact on bulk mainstream temperatures within the surveyed reach. This was due to the relatively large volume of the Rogue River compared to the tributary or side channel inflow.

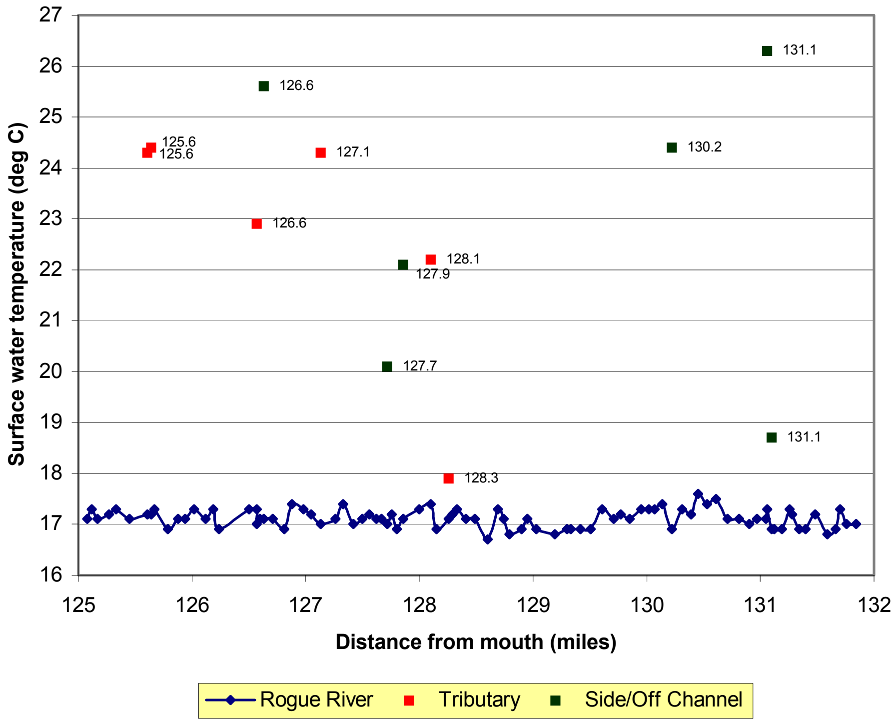


Figure 3 - Median channel temperatures versus river mile for Rogue River, OR along with tributary locations and temperatures (13 July 2001).

Table 4 - Tributary and side channel temperatures for the Rogue River, OR miles correspond to data labels shown in Figure 3.

	Image	km	mile	Tributary °C	Rogue R. °C	Difference
Tributary						
No Name (RB)	lb0015	202.2	125.6	24.3	17.2	7.1
No Name (LB)	lb0016	202.2	125.6	24.4	17.2	7.2
Bear Creek (LB)	lb0040	203.7	126.6	22.9	17.3	5.6
No Name (LB)	lb0059	204.6	127.1	24.3	17.0	7.3
Whetstone Creek (LB)	lb0088	206.2	128.1	22.2	17.4	4.8
Snider Creek (RB)	lb0094	206.4	128.3	17.9	17.1	0.8
Side/Off Channel						
Side Channel (LB)	lb0044	203.8	126.6	25.6	17.1	8.5
Side Channel (RB)	lb0077	205.5	127.7	20.1	17.0	3.1
Slough (RB)	lb0082	205.8	127.9	22.1	17.1	5.0
Side Channel (RB)	lb0155	209.6	130.2	24.4	16.9	7.5
Side Channel (RB)	lb0183	210.9	131.1	26.3	17.3	9.0
Side Channel (LB)	lb0184	211.0	131.1	18.7	16.9	1.8

RB = right bank, LB = left bank looking downstream

Little Butte Creek

A longitudinal temperature profile was developed for Little Butte Creek from the mouth to the forks (Figure 4). 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 5). The figure also shows the location of the town of Eagle Point, OR.

Stream temperatures in Little Butte Creek varied between 22.7°C and 26.2°C through the full length of the profile with a mean stream temperature of 24.9°C. Nine tributaries (excluding the NF Little Butte Creek at rm 16.6) were sampled. Of the nine, seven contributed water that was cooler then the mainstream temperatures. Salt Creek (rm 14.2) contributed water that was 3.5°C cooler than the mainstream and lowered mainstream temperatures to approximately 24.1°C. Downstream of Salt Creek, mainstream temperatures again increased reaching a local maximum of 25.6°C at river mile 11.1. A cooling trend was observed between river 10.3 and 7.9 with mainstream temperatures dropping by approximately 2.3°C. There were no surface water inflows detected through this reach. Stream temperatures increased rapidly downstream of river mile 7.9 and returned to approximately 25.5°C at river mile 6.9.

A distinctly cooler sample (22.7°C) is visible in the longitudinal profile at river mile 6.2. The sample image corresponds to the mapped location of Nichols Creek. However, Nichols Creek was only partially visible in the image and could not be sampled (reference Appendix A). Stream temperatures showed a rapid increase from the upstream end of Eagle Point (river mile 5.8), but are mitigated by cooler canal return at river mile 5.1. Ultimately, Little Butte Creek contributes water that is 8.4°C higher than the mainstream temperatures.

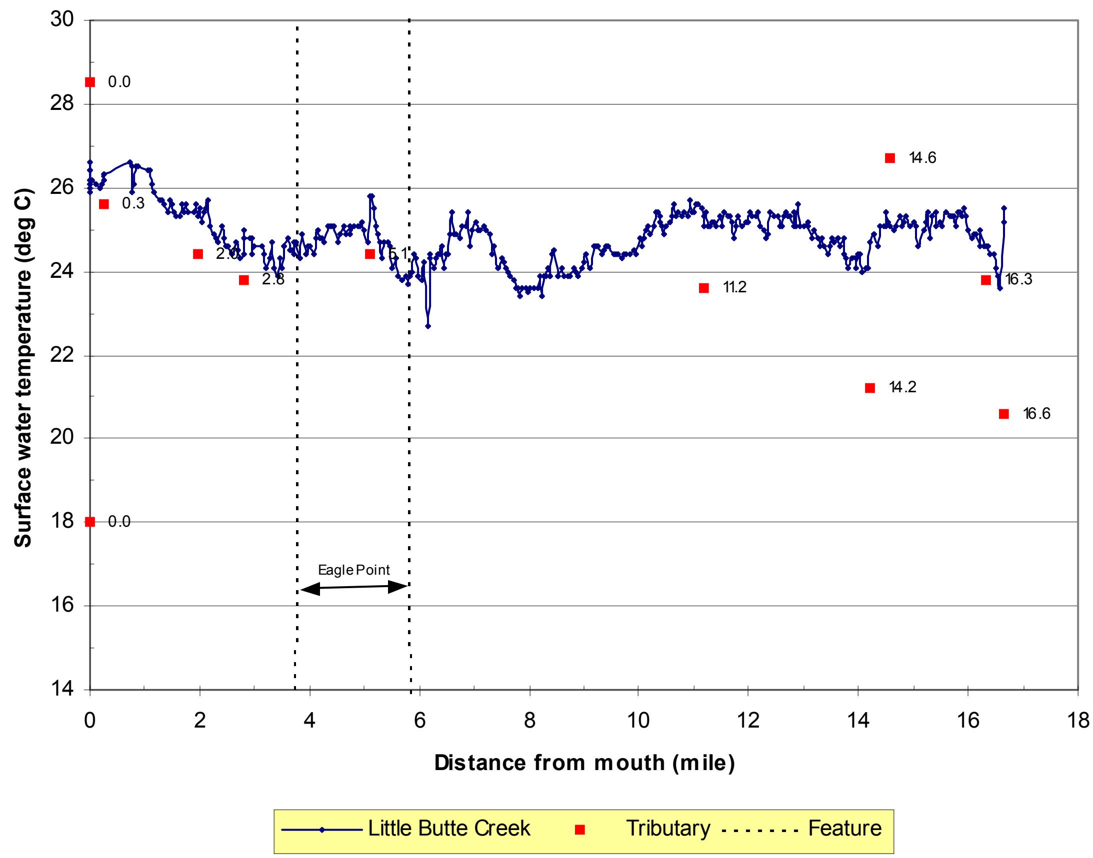


Figure 4 - Median channel temperatures versus river mile for Little Butte Creek, OR along with tributary locations and temperatures (13 July 2001).

Table 5 - Tributary temperatures for Little Butte Creek, OR miles correspond to data labels shown in Figure 4.

Tributary	Image	km	mile	Tributary °C	L. Butte Cr. °C	Difference
Rogue River	lb0251	0.0	0.0	18.0	26.4	-8.4
No Name (RB)	lb0261	0.0	0.0	28.5	25.9	2.6
Off Channel (RB)	lb0278	0.4	0.3	25.6	26.3	-0.7
No Name (RB)	lb0336	3.2	2.0	24.4	25.3	-0.9
Antelope Creek (LB)	lb0373	4.5	2.8	23.8	24.4	-0.6
Canal Return (RB)	lb0582	8.2	5.1	24.4	25.8	-1.4
Lick Creek (RB)	lb0837	18.0	11.2	23.6	25.1	-1.5
Salt Creek (RB)	lb0967	22.9	14.2	21.2	24.7	-3.5
Long Branch (RB)	lb0979	23.5	14.6	26.7	25.1	1.6
Randle Creek (LB)	lb1053	26.3	16.3	23.8	24.6	-0.8
NF Little Butte (RB)	lb1064	26.8	16.6	20.6	25.2	-4.6

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

South Fork Little Butte Creek

A longitudinal temperature profile was developed for SF Little Butte Creek (Figure 5). 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 are labeled in the profile by river mile and their name and temperature are listed in the associated tables (Table 6).

Upstream of river mile 20.2, SF Little Butte Creek was intermittently visible through the canopy and appeared to be dry in several locations. The longitudinal profile shows a high degree of thermal spatial variability upstream of this point, which is characteristic of small, intermittent streams. The survey concluded at river mile 21.7 because the stream was not visible and the pilot could not longer follow the stream course.

At river mile 20.2, a small, unnamed tributary contributes cooler water and increases flow in SF Little Butte Creek. SF Little Butte Creek warms approximately 3.4°C between river mile 19.8 and 19.0, but cools again (-2.7°C) between river mile 19.0 and 17.7. There were no surface water inflows detected through this reach. Stream temperatures remain near 13.0°C over the next mile before rising 11.1°C between river miles 16.6 and 10.3. This 6.3-mile reach showed consistent and relatively continuous longitudinal heating. There were 5 tributary inflows detected through this reach, but they did not alter the prevailing temperature trend.

Stream temperatures remained consistent (≈23.5°C) between river mile 10.0 and 7.4. A small, unnamed tributary at river mile 8.3 was a source of thermal cooling and contributed to local variability in the longitudinal profile. Stream temperatures again showed a warming trend between river mile 7.4 and 0.5. Three tributaries were detected through this reach. In addition, a number of apparent cold-water seeps were observed within the channel flood plain, which further contributed to thermal spatial variability. Stream temperatures drop sharply (-2.9°C) at river mile 0.5 as the result of an inflow that originated from the Medford Irrigation Canal.

NF Little Butte Creek

A longitudinal temperature profile was developed for NF Little Butte Creek (Figure 6). 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 are labeled in the profile by river mile and their name and temperature are listed in the associated tables (Table 7).

Starting at the outlet of Fish Lake (river mile 15.4), stream temperatures increased in the downstream direction until a small spring at river mile 14.1 dropped temperatures by 1.9°C. This spring was not identified on the 7.5' USGS topographic maps.

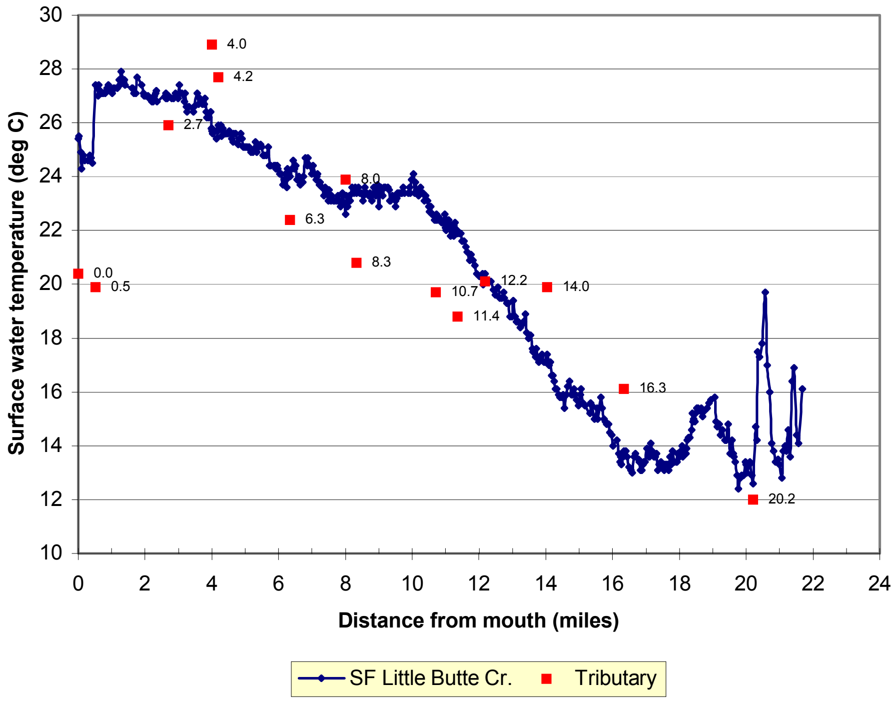


Figure 5 - Median channel temperatures versus river mile for the South Fork Little Butte Creek, OR along with tributary locations and temperatures (13 July 2001).

Table 6 - Tributary temperatures for South Fork Little Butte Creek, OR miles correspond to data labels shown in Figure 5.

Tributary	Image	km	mile	Tributary °C	SF Little Butte °C	Difference
NF Little Butte (RB)	lb1066	0.0	0.0	20.4	25.4	-5.0
Diverted from Canal (LB)	lb1087	0.8	0.5	19.9	27.4	-7.5
Side Channel (LB)	lb1167	4.3	2.7	25.9	27.0	-1.1
Lost Creek (LB)	lb1234	6.5	4.0	28.9	25.7	3.2
Side Channel (RB)	lb1240	6.8	4.2	27.7	25.9	1.8
No Name (RB)	lb1335	10.2	6.3	22.4	24.0	-1.6
Side Channel (RB)	lb1411	12.9	8.0	23.9	22.6	1.3
No Name (LB)	lb1425	13.4	8.3	20.8	23.4	-2.6
Grizzly Canyon (RB)	lb1524	17.2	10.7	19.7	22.4	-2.7
No Name (LB)	lb1553	18.3	11.4	18.8	21.9	-3.1
Dead Indian Creek (LB)	lb1582	19.6	12.2	20.1	20.4	-0.3
Ellick Creek (LB)	lb1652	22.6	14.0	19.9	17.4	2.5
Beaver Dam Creek (LB)	lb1752	26.3	16.3	16.1	13.8	2.3
No Name (RB)	lb1924	32.5	20.2	12.0	12.6	-0.6

RB = right bank, LB = left bank looking downstream

Downstream of river mile 14.1, stream temperatures gained 5.6°C before the confluence with the SF Little Butte Creek. There were two tributaries (river miles 12.0 and 11.5) that contributed cooler water and resulted in local thermal variability. Other mapped tributaries were detected, but could not be sampled due to small channel widths and canopy masking.

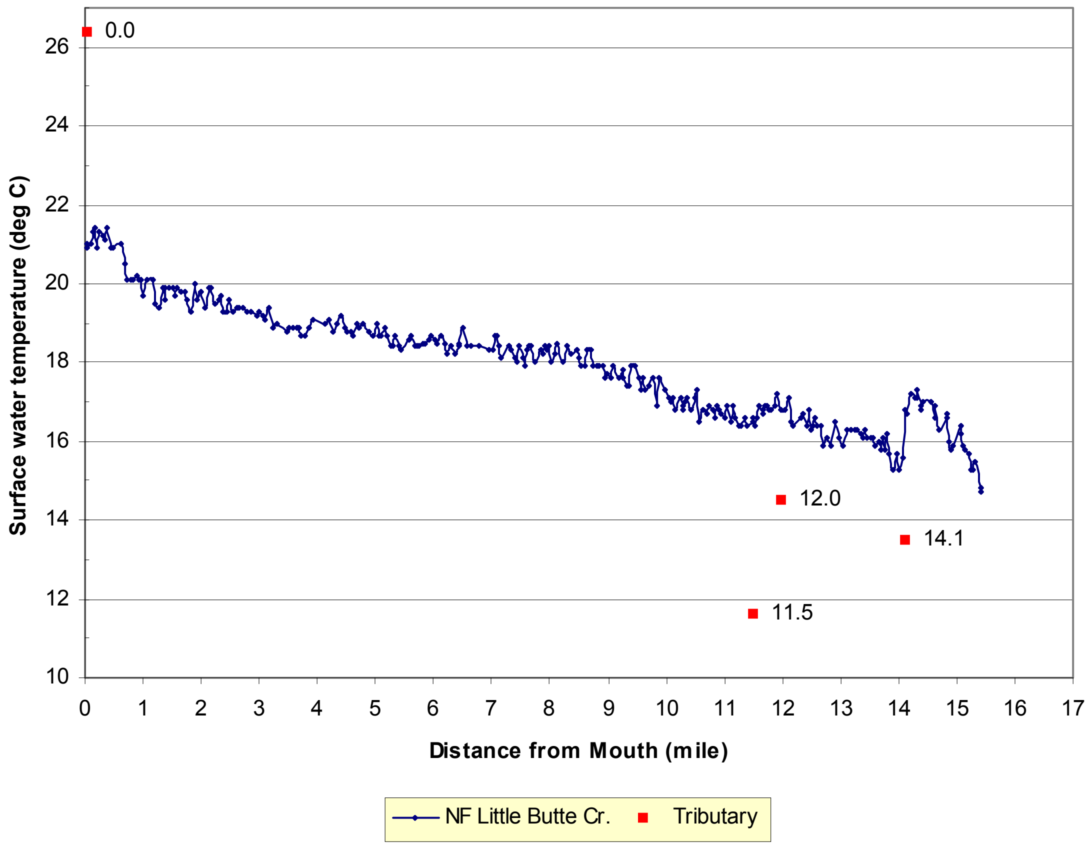


Figure 6 - Median channel temperatures versus river mile for the North Fork Little Butte Creek, OR along with tributary locations and temperatures (13 July 2001).

Table 7 - Tributary temperatures for North Fork Little Butte Creek, OR miles correspond to data labels shown in Figure 6.

Tributary	Image	km	mile	Tributary °C	NF Little Butte °C	Difference
SF Little Butte Cr. ( )	nflb0034	0.0	0.0	26.4	21.0	5.4
No Name (LB)	nflb0477	18.5	11.5	11.6	16.6	-5.0
Spring (LB)	nflb0500	19.3	12.0	14.5	16.8	-2.3
No Name (LB)	nflb0581	22.7	14.1	13.5	16.8	-3.3

RB = right bank, LB = left bank looking downstream

Antelope Creek

A longitudinal temperature profile was developed for 2.5-mile survey section of Antelope Creek (Figure 7). The profiles also shows the location and temperature of the two tributary identified during the survey. Tributaries are labeled in the profile by river mile and their name and temperature are listed in the associated table (Table 8).

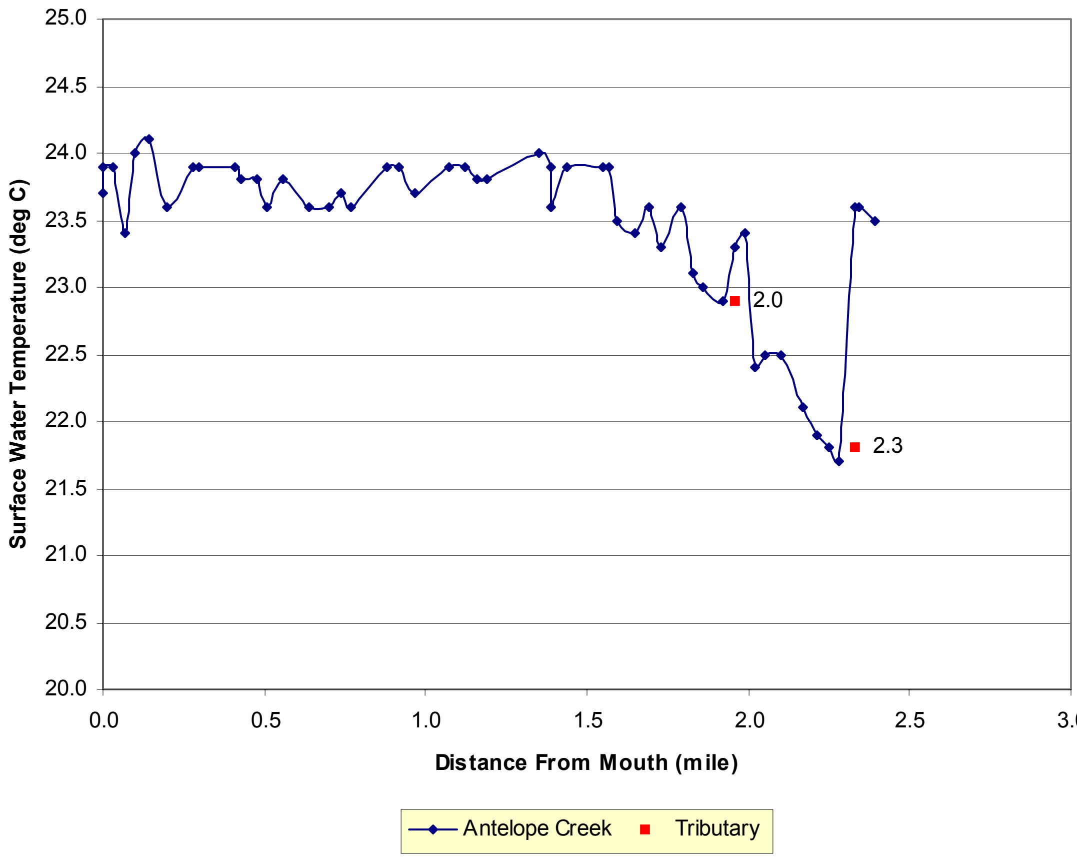


Figure 7 - Median channel temperatures versus river mile for Antelope Creek, OR along with tributary locations and temperatures (13 July 2001).

Table 8 - Tributary temperatures for Antelope Creek, OR miles correspond to data labels shown in Figure 7.

Tributary	image	km	mile	Tributary °C	Antelope Cr. °C	Difference
Dry Creek (LB)	lb0450	3.2	2.0	22.9	23.3	-0.4
Quarter Branch (RB)	lb0467	3.8	2.3	21.8	23.6	-1.8

RB = right bank, LB = left bank looking downstream

Elk Creek

As with the other surveys, a longitudinal temperature profile was developed for Elk Creek (Figure 8). 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 are labeled in the profile by river mile and their name and temperature are listed in the associated tables (Table 9).

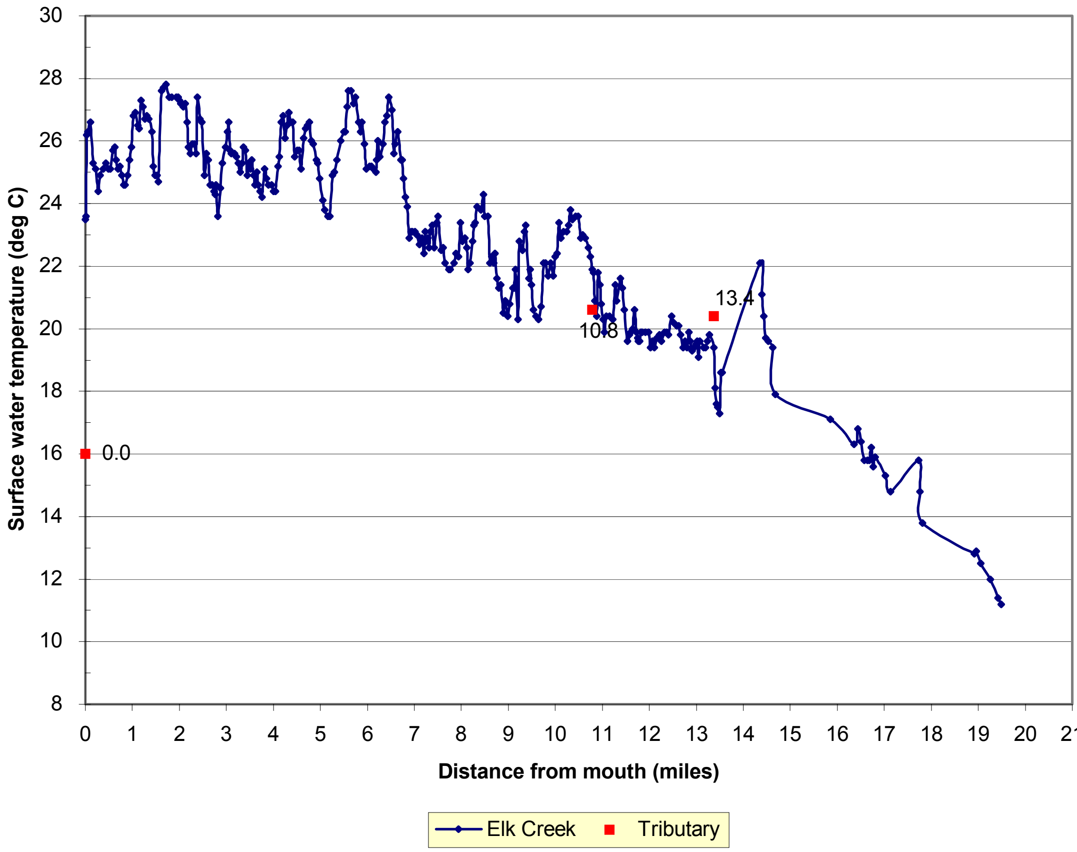


Figure 8 - Median channel temperatures versus river mile for Elk Creek, OR along with tributary locations and temperatures (14 July 2001).

Table 9 - Tributary temperatures for Elk Creek, OR miles correspond to data labels shown in Figure 8.

Tributary	Image	km	mile	Tributary °C	Elk Cr °C	Difference
Rogue River (RB)	elk0041	0.0	0.0	16.0	23.5	-7.5
Sugarpine Creek (RB)	elk0559	17.3	10.8	20.6	21.9	-1.3
Bitter Lick Creek (RB)	elk0683	21.5	13.4	20.4	19.4	1.0

RB = right bank, LB = left bank looking downstream

Stream temperatures start cool near the headwaters (≈11.0°C at river mile 19.5) and generally warm downstream. Between river miles 19.5 and 13.6, the small channel size combined with canopy masking made it difficult to accurately sample stream temperatures. As a result, the sampling frequency is less through this reach than in the lower 13.6 miles of the survey. At river mile 13.6, Elk Creek was visible enough to sample and temperatures were cooler than those immediately upstream. This location corresponds to the confluence of Swanson Creek and Elk Creek. While Swanson Creek could not be sampled, the profile suggests cool water inputs (possibly sub-surface) at this point. Bitter Lick Creek enters Elk Creek at river mile 13.4 and further contributes to mainstream flows.

Spatial variability was observed throughout the longitudinal temperature profile. Stream temperature changes of more than 3°C over spatial distances of 0.5 miles or less were recorded at multiple locations. An average temperature of 25.7°C was measured through the lower 7.0 miles of Elk Creek. The variability observed through this reach is characteristic of small; low flow streams where relatively small inputs (surface and sub-surface) can have strong local influences on bulk stream temperature.

Two tributary inflows were sampled during image processing. However, other tributaries were detected, but could not be sampled due to the combination of small channel widths and canopy masking. Although not sampled, these tributaries can contribute to the observed thermal spatial variability and may suggest sub-surface flow through the tributary channel substrate. For example, an approximate 1.8°C drop in stream temperature was observed at river mile 9.6, which corresponds to the mapped location of Jones Creek. Jones Creek was not visible in the TIR images and consequently not sampled, but may influence temperature patterns in Elk Creek.

Discussion

TIR remote sensing was used to map temperatures for selected stream reaches in the Rogue River basin. The data were collected on July 13th and 14th during the mid-afternoon in order to assess heat of the day, heat of the summer conditions. Meteorological conditions were recorded in the basin and showed air temperatures between 24°C and 27°C (75.2°F and 80.5°F) during the time of the surveys. In-stream data loggers were used to calibrate the TIR images and provide a measure of accuracy for the radiant temperatures derived from the images.

Longitudinal stream temperature profiles were developed for each surveyed stream reach. The temperature patterns differed significantly between streams and further analysis is required to fully understand physical factors driving the stream temperatures patterns. The TIR survey identified the location and temperature of tributaries and other surface water inputs. However, the influence of tributaries on the receiving streams depended on the characteristics of the individual stream. On Elk Creek and the two forks of Little Butte Creek riparian canopy was a factor in the ability to detect and interpret thermal features within the riparian zone such as small inflows.

However, inflections in longitudinal temperature patterns can indicate the presence of surface or sub-surface inputs even though these inputs may not have been detected directly

The TIR surveys lay a basic groundwork to integrate the ODEQ TMDL process into watershed planning and restoration. In particular, water temperature modeling as conducted by ODEQ can provide a powerful tool to address the bio-physical parameters that are driving stream temperature patterns and suggest multiple pathways for remediation. In addition, the longitudinal temperature patterns provide a robust and rigorous template to construct a monitoring program from, in particular the deployment of in-stream temperature sensors.

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