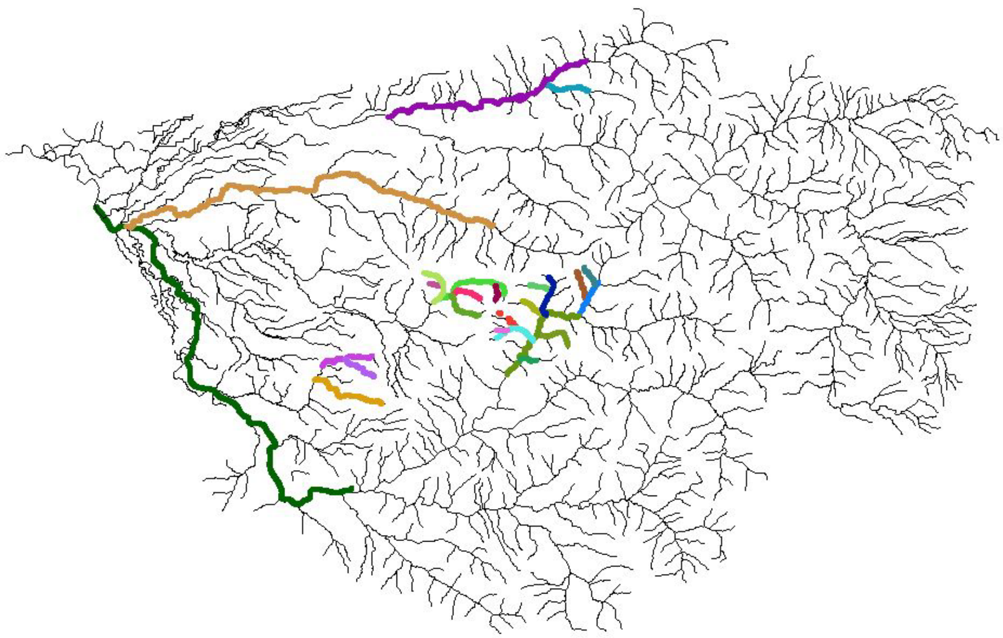
REMOTE SENSING SURVEY OF THE SANTIAM RIVER BASIN

Thermal Infrared and Color Videography



Watershed Sciences, LLC
712 NW Fourth Street
Corvallis, OR 97330

REPORT

Prepared for the
Oregon Department of Environmental Quality
Portland OR 98124-3755

March 19, 2009

Summary

A FLIR survey of select tributaries to the Santiam River basin was conducted from August 1 – 3, 2000. Twenty-five streams covering a distance of 141 miles were sampled over the survey period. The survey streams ranged from large mainstem rivers to small heavily forested headwater streams. Timing of the daily surveys was targeted at mid-afternoon to capture maximum daily stream temperatures.

Table of Contents

Introduction

Forward Looking Infrared (FLIR) 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; Norton et al., 1996; Faux et al., 1998). In 2000, the Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC to map and assess stream temperatures in portions of the Santiam River Basin.

Traditional methods for monitoring stream temperatures have relied on in-stream temperature monitors. These monitors provide temporally continuous data but furnish no insight into the spatial variability in temperatures. With the use of remote sensing, we have been able to map stream temperatures across entire stream networks for the time that is sampled. FLIR technology has proven to be a highly portable and cost-effective method to collect very detailed data over large areas in very little time. The combination of temporally and spatially continuous data provides very powerful tools for understanding the dynamics of stream temperature hierarchically across multiple scales (pools → reaches → streams → watersheds). Current research has identified cool versus warm streams within a watershed, cool reaches within a stream, and cool habitats within a reach (McIntosh et al., 1995; Torgersen et al., 1995; Torgersen et al., 1999).

The results and analysis presented here are at the watershed and tributary scales. This report provides longitudinal temperature profiles for each stream surveyed as well as a discussion of the thermal features observed in the Santiam River basin. FLIR and associated color video images are included in the report in order to illustrate significant thermal features. An ArcView GIS[1] database provided with this report includes all of the images collected during the survey and is structured to allow analysis at finer scales.

Methods

Data Collection

The ODEQ contracted with Watershed Sciences, LLC of Corvallis, Oregon to collect and analyze thermal infrared and visible video imagery for select tributaries in the Santiam River basin during the summer of 2000. The survey was conducted from August 1-3, 2000 and included 25 streams for a total of 141 river miles (Figure 1). Data collection was timed to capture daily maximum stream temperatures, which typically occur between 14:00 and 18:00 hours. Table 1 summarizes the date, time, and survey distance for each survey stream.

Data were collected using a FLIR and a Day TV video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. All streams were surveyed upstream and flight altitude was selected based on

---

[1] Geographic Information System

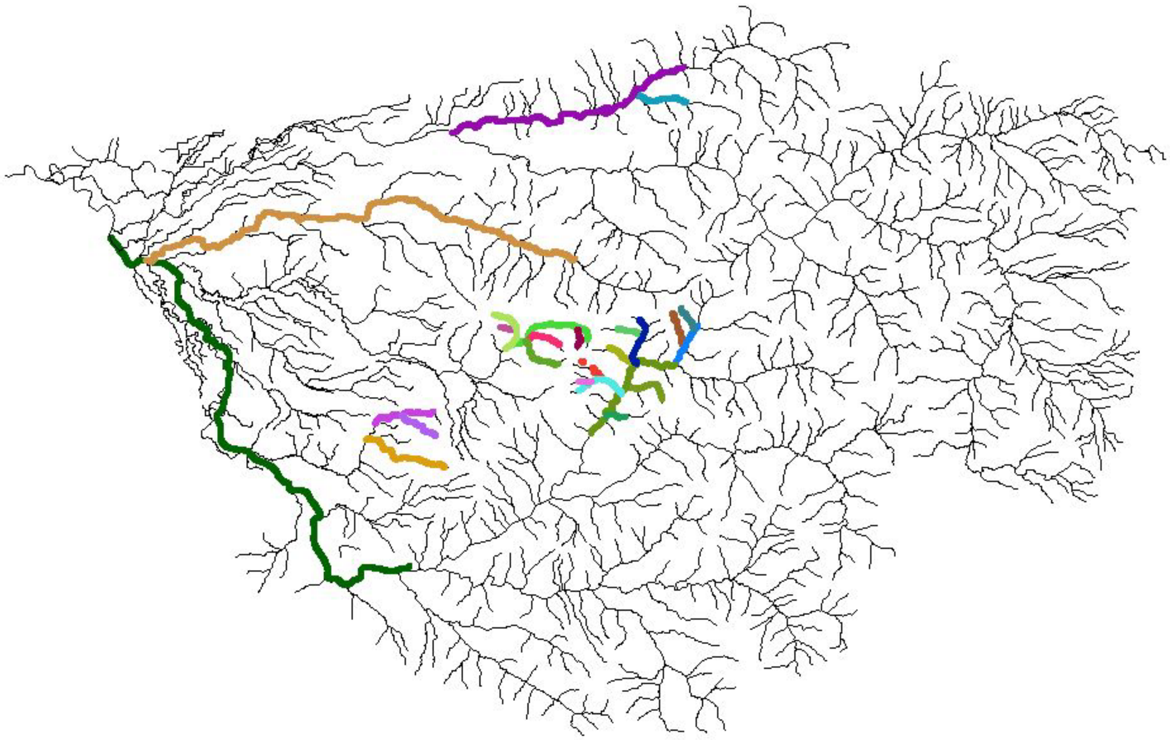


Figure 1 – Map of the Santiam River basin showing the extent of the FLIR and color video survey for the August 1-3, 2000 survey.

Table 1 – Date, time, and distance for streams surveyed in the Santiam River basin.

Stream	Date	Local Time (PM)	Miles Surveyed
North Santiam River basin			
Little North Fork Santiam River	1 August 00	14:33 – 15:00	16.8
Elkhorn Creek	1 August 00	15:04 – 15:10	3.3
South Santiam River basin			
South Santiam River	1 August 00	15:32 – 16:16	35.9
Thomas Creek (mouth – Neal Creek)	3 August 00	16:16 – 16:43	16.0
Thomas Creek (RM 22.2 – RM 35.8)	3 August 00	16:50 – 17:08	10.0
Quartzville Creek	2 August 00	15:43 – 15:59	8.9
Canal Creek	2 August 00	15:59 – 16:04	2.7
Pat Creek	2 August 00	15:34 – 15:37	1.4
Beverly Creek	2 August 00	15:24 – 15:31	2.3
Packers Gulch	2 August 00	15:05 – 15:14	3.0
South Fork Packers Gulch	2 August 00	15:01 – 15:05	1.8
West Fork Packers Gulch	2 August 00	15:14 – 15:19	1.5
Boulder Creek	2 August 00	14:51 – 14:57	2.9
Unnamed Tributary to Quartzville Ck	2 August 00	14:19 – 14:22	1.1
Yellowstone Creek	2 August 00	14:27 – 14:34	3.0
Unnamed Tributary to Yellowstone Ck	2 August 00	14:35 – 14:37	0.7
Unnamed Tributary to Yellowstone Ck	2 August 00	14:40 – 14:48	1.5
Crabtree Creek	2 August 00	16:13 – 16:25	6.1
Schafer Creek	2 August 00	16:13 – 16:25	1.2
Bonnie Creek	3 August 00	14:38 – 14:41	2.0
White Rock Creek	3 August 00	14:26 – 14:35	2.7
Unnamed Tributary to Crabtree Ck	3 August 00	14:11 – 14:18	2.6
Unnamed Tributary to Unnamed Trib	3 August 00	14:20 – 14:24	1.1
Hamilton Creek	3 August 00	13:38 – 13:51	3.8
Hamilton Creek South Branch	3 August 00	13:54 – 14:05	2.5
South Fork Hamilton Creek	3 August 00	13:22 – 13:33	5.3
Total Miles Surveyed			**141.0**

the estimated average stream channel width. In general, the flight altitude was selected so that the stream channel occupied approximately 20% of the image frame.

FLIR data were collected digitally and recorded directly from the sensor to an on-board computer. The FLIR 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 FLIR 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). Each thermal image frame covers a ground area of approximately 100 x 150 meters and has a spatial resolution of <0.5 meters/pixel. For all other streams each thermal image covers a ground area of approximately 100 x 150 meters and has a spatial resolution of about 0.25 meters/pixel.

Day TV 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 Day TV sensor was aligned to present the same ground area as the thermal infrared sensor. The GPS time coding provides a means to correlate Day TV images with the FLIR images during post-processing. The day TV video supplements the interpretation and analysis of the FLIR images. In addition, day TV video provides a record of the conditions in the basin at the time of the survey.

Data Processing

A computer program was used to scan the FLIR imagery and 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 us 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 using the dynamic segmentation features of Arc/Info GIS software. The river kilometers were derived from 1:100,000 "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 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. The GRIDS were classified in one-degree increments over the temperature range of 5 to 30ºC. Temperatures < 5ºC are black, temperatures between 30 and 50ºC were colored in shades of gray (darker tones -> lighter tones), temperatures >50ºC are white.

Figure 2 illustrates a color-coded GRID displayed in the ArcView environment. This GRID illustrates the confluence of the South Santiam River and Thomas Creek. The legend on the left of the "Grid View" specifies the temperature range associated with each color. The other view window shows the point coverage with the displayed GRID location highlighted in yellow. Each blue point in the "Thermal Survey" view represents another image location.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, an ArcView 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. Samples were taken on every 5th image to provide complete coverage without sampling the same water twice (there is approximately 40-60% overlap between images). Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled. In cases where the channel was obscured by vegetation, as was the situation on many of the tributaries, the next image where the stream channel was clearly visible was sampled. 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. Figure 3 shows a pseudo-color thermal image and corresponding day TV image. The red "x's" on the image show typical sample locations. Temperature sampling focuses on the center of the stream channel.

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.

Day TV images corresponding to the FLIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the thermal infrared 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.

Data Limitations

FLIR systems measure thermal infrared energy emitted at the water surface. Since water is essentially opaque to thermal infrared wavelengths, the sensor is only measuring the water surface temperature. This is typically not an issue on streams where the water column is thoroughly mixed. Field measurements conducted on the Middle Fork of the John Day River, OR and on the Klamath River, CA confirmed that thermal stratification was insignificant or not present even in the deepest pools. However, stratification has been observed behind impoundments and in deep slow-moving channels. We found no evidence of thermal stratification in the streams flown in the Santiam River basin.

Results

Thermal Accuracy

Temperatures from in-stream data loggers were compared to radiant temperatures derived from the imagery for the Santiam River basin (Table 1). The radiant temperature derived from the imagery represents the average of 10 points sampled from the image at the data logger location. The in-stream temperature at the date and time the image was acquired was then compared to the radiant temperature derived from the image. If a consistent difference was observed for all the in-stream sensors in given stream, the parameters used to convert radiant values to temperatures were adjusted to provide a better fit to the in-stream sensors.

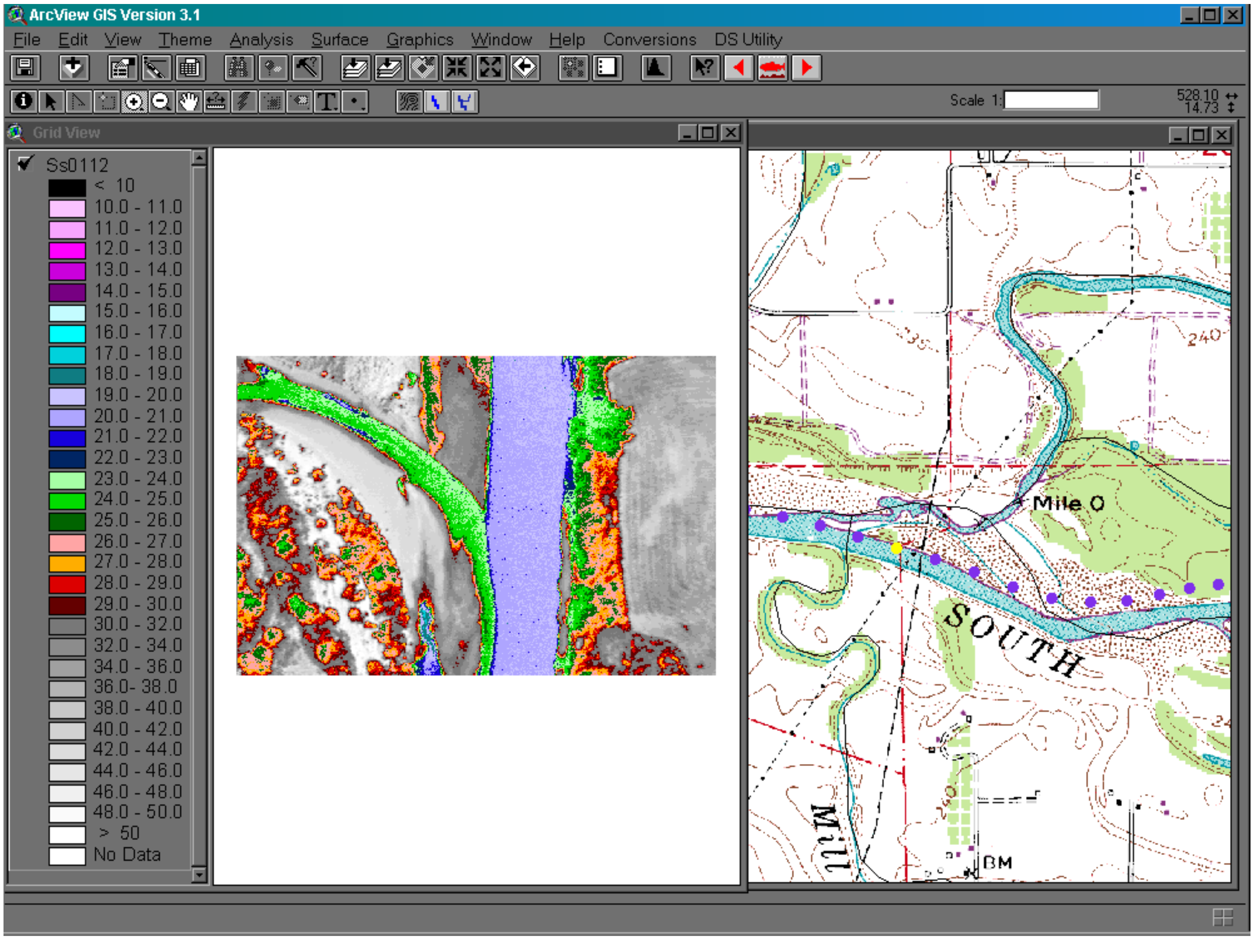


Figure 2 – ArcView display showing a color-coded temperature GRID in one window and the geographic location of the GRID in the other. The orientation of the image is always in the flight direction.

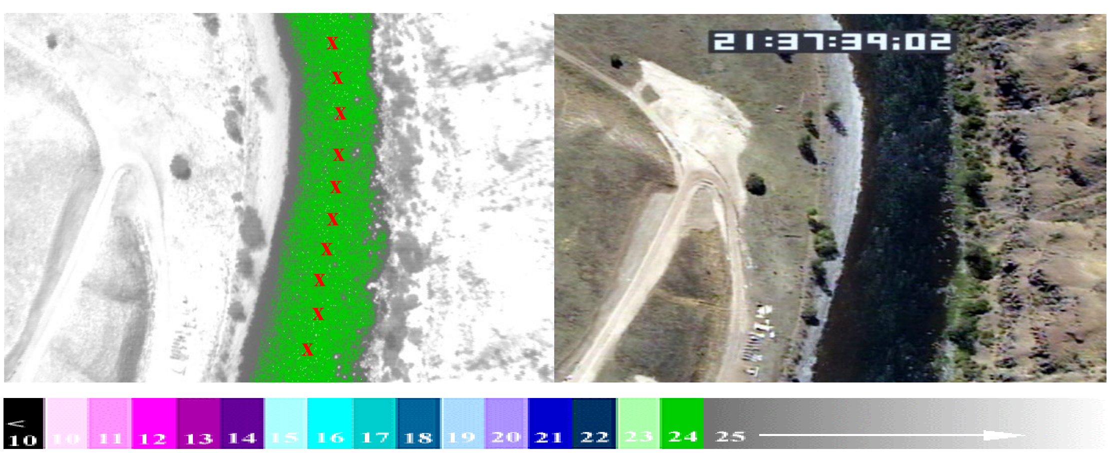


Figure 3 – Thermal/Day TV image pair showing typical temperature sampling locations

(red x's). These samples determine the median stream temperature for this image frame.

Table 1 provides a comparison of the in-stream and radiant temperatures. A total of 26 points were used to assess the temperature accuracy of the imagery. Of the 26 locations, 21 showed a difference of less then ±0.5ºC (contract specifications) between the FLIR image and the in-stream data logger. Overall, the accuracy for all 26 points was ±0.3ºC, which is consistent with previous work. The factors that influence the accuracy of the radiant temperature calculations are spatial. Therefore, it is important to consider accuracy on a stream-by-stream basis.

Table 1. Comparison of instream water temperatures with radiant temperatures derived from thermal infrared images for Santiam River basin streams, August 1-3, 2000. Temperatures are reported in °C and river mile measures are cited for locations.

Location	River mile	File ID	Image frame	Time PM	Stream Temp. (T_s)	Radiant Temp. (T_r)	Difference ($T_r – T_s$)
Little North Fork Santiam							
Green A-Frame	4.5	88442	Lnf0220	14:41	23.1	22.5	0.6
Canyon Creek	8.3	349766	Lnf0376	14:46	20.9	21.5	-0.6
Salmon Falls	15.2	68509	Lnf0671	14:57	20.8	20.6	0.2
South Santiam River							
Route 226 Bridge	7.3	90893	Ss0265	15:42	20.7	20	0.7
Waterloo Bridge	21.8	88411	Ss0769	16:01	16.1	15.9	0.2
Foster Reservoir	35.4	315269	Ss1206	16:16	11.6	12.0	-0.4
Thomas Creek							
Schimanek Bridge	11.3	68517	Thom0569	16:36	23.9	23.6	0.3
Jordan Bridge	17.9	345270	Thom0863	16:46	25.1	25.6	-0.5
Bridge	23.1	181257	Thom1105	16:54	20.9	20.7	0.2
Quartzville Creek							
Road Mile 18	7.0	345271	Qua0074	15:46	21.3	21.2	0.1
Mouth Yellowstone Ck	9.3	177711	Qua0187	15:50	17.1	17.1	0.0
Upstream of bridge	9.4	345268	Qua0195	15:50	21.6	21.4	0.2
Mouth Packers Gulch	11.7	68514	Qua0306	15:54	17.8	17.5	0.3
Mouth Canal Creek	14.4	349773	Qua0446	16:00	19.7	20.0	-0.3
Yellowstone Creek	0.0	177711	Yel0023	14:26	17.4	16.7	0.7
Packers Gulch	0.0	68514	Pck0026	15:00	17.6	17.9	-0.3
Crabtree Creek							
River Mile 32.6	32.6		Crab0117	16:16	15.3	15.2	0.1
Mouth Schafer Creek	35.6		Crab0283	16:22	12.6	12.9	-0.3
Mouth Schafer Creek	35.6		Crab0428	16:28	12.6	12.7	-0.1
White Rock Creek	1.5	BLM	Wr0187	14:33	12.2	12.3	-0.1
Unnamed Tributary	0.5	BLM	Unc270	14:21	8.7	8.9	-0.2
Hamilton Creek							
Mouth	0.0	88411	Sfs0005	13:17	14.9	14.4	0.5
River Mile 13.1	13.1	BLM	Ham0230	13:45	16.1	16.1	0.0
River Mile 14.3	14.3	BLM	Ham0306	13:50	15.7	16.3	-0.6
South Fork Scott Creek	1.3	BLM	Sfs0121	13:20	14.2	14.6	-0.4
South Fork Scott Creek	3.7	BLM	Sfs0280	13:30	12.1	11.8	-0.4

Analysis of Thermal Imagery

Little North Santiam River

The median temperatures for each sampled image of the Little North Santiam River from the confluence with the North Santiam River upstream 17.6 miles to the confluence with Henline Creek was plotted versus the corresponding river mile (Figure 5). The plot also contains the median temperature of all surface water inflows (e.g., tributaries, canals) that were visible in the imagery where they input into the Little North Santiam River. Tributaries in the Little North Fork Santiam River are listed by river mile with their name and temperature listed in Table 2. Only the surface water inflows that could be positively identified in the imagery were included. In some cases, tributaries and other surface water inputs were obscured by riparian vegetation or outside the sensor field of view and their image location could not be accurately determined. In general, stream temperatures increased in the downstream direction for the survey section, but temperatures did cycle up and down irregularly over the course of the study reach.

At the upstream end of the survey (RM 17.6) the Little North Santiam was relatively warm at 19.9ºC. From RM 17.6 to RM 16.0 stream temperatures increased rapidly to 21.9ºC. Over the next 0.6 miles stream temperatures decreased to 20.4ºC. From RM 15.4 to 13.2, stream temperatures increased steadily in the downstream direction to 23.2ºC. Over the next 0.4 miles to RM 12.8, stream temperatures decreased rapidly to 2.6ºC, possibly due to the colder input from Elkhorn Creek. From RM 12.8 to RM 11.2, stream temperatures increased to 23.1ºC. From this point downstream to RM 10.4 flow in the Little North Santiam was in two distinct channels. This reach was notable for the presence of several spring brooks that were contributing cooler subsurface flows to the channel. In general, this reach was somewhat cooler then the reach immediately upstream and this cooling trend continued downstream to RM 8.1 where the temperature was measured as 21.1ºC. From RM 8.1 to RM 2.0 there was a steady increase in stream temperatures to the survey maximum of 24.4ºC. Over the next 2 miles to the confluence with the North Santiam River stream temperatures decreased to 23.2ºC at the confluence. The Little North Santiam was contributing streamflow that was 8.0ºC warmer than the North Santiam River. For the survey reach, we detected 9 tributaries contributing flow to the Little North Santiam. Of the 9 tributaries we detected, 8 were contributing cooler flows (range = -8.0 to –0.3ºC) and one was contributing warmer flows (+0.7ºC) (Table 2).

One tributary to the Little North Santiam was flown, that was Elkhorn Creek (Figure 6). Elkhorn Creek was flown from the confluence with the Little North Santiam upstream 3.6 miles. Stream temperatures increased slowly in the downstream direction from a low of 15.6ºC at the

Table 2 – Tributaries and other surface inflows identified during the FLIR survey of Little North Santiam River (LB = left bank, RB = right bank looking downstream).

Tributary	River Mile	Tributary Temp (ºC)	Mainstem Temp (ºC)	Difference (trib-mainstem)	FLIR image
North Santiam River	0.0	15.2	23.2	-8.0	Lnf0040
Cox Creek (LB)	4.3	17.8	22.8	-5.0	Lnf0215
Beaver Creek (LB)	5.3	16.8	23.1	-6.3	Lnf0255
Canyon Creek (RB)	7.9	19.6	21.4	-1.8	Lnf0359
Spring Brook (LB)	10.2	17.8	22.4	-4.6	Lnf0449
Backwater (RB)	10.6	23.9	22.2	1.7	Lnf0461
Moorhouse Creek? (LB)	10.9	17.8	22.7	-4.9	Lnf0473
Spring Brook (LB)	10.7	17.6	21.9	-4.3	Lnf0511
Spring Brook (LB)	11.6	17.4	21.6	-4.2	Lnf0543
Elkhorn Creek (LB)	13.5	20.6	23.1	-2.5	Lnf0613
Fish Creek (RB)	13.6	23.8	23.1	+0.7	Lnf0617
Unnamed Tributary (RB)	16.1	17.8	21.5	-3.7	Lnf0703
Henline Creek (RB)	17.5	19.5	19.8	-0.3	Lnf0763

upstream end to survey maximum of 20.8ºC at the confluence with the Little North Santiam. At the time of the survey (15:04), Elkhorn Creek was contributing flows 3.5ºC cooler than the Little North Santiam River. We detected 3 tributaries in the survey with 2 contributing cooler flows and 1 contributing warmer flows.

South Santiam River

The South Santiam River was flown from the confluence with the North Santiam River to Foster Reservoir, a distance of 36.0 miles. Sampled images were plotted against river mile to produce a longitudinal temperature profile (Figure 7). As the profile indicates, discharge from Foster Reservoir is what controls stream temperatures in the South Santiam River. At the time of the survey (16:16), Foster Dam was discharging very cold water (11.7ºC) to the South Santiam River. From the dam to the confluence with the North Santiam, stream temperatures increased in a near linear function in the downstream direction. We detected five tributaries along the survey reach and all were contributing significantly warmer flows to the South Santiam River. All five tributaries were contributing warmer flow (range = +3.6 to 10.6ºC), but due to their small discharges they had no influence on mainstem temperatures (Table 3). We also detected 24 off-channel features such as side-channels, backwaters, and cold seeps over the survey reach. Most of these features were warmer then mainstem temperatures.

Tributaries in the South Santiam River basin

In addition to the South Santiam River, 22 tributaries in the South Santiam River basin were also flown for FLIR data collection (Table 3). Collecting FLIR data on the tributaries presented different challenges than the mainstem South Santiam River. Narrower channels, canopy cover, and low flow conditions confound the limitations of thermal remote sensing.

Table 3 – Tributaries and other surface inflows identified during the FLIR survey of the South Santiam River (LB = left bank, RB = right bank looking downstream).

Tributary	River Mile	Tributary Temp (ºC)	Mainstem Temp (ºC)	Difference (trib-mainstem)	FLIR image
North Santiam River	0.0	19.6	20.6	-1.0	Ss0028
Cold seep	2.4	18.3	20.0	-1.7	Ss0110
Thomas Creek (RB)	2.5	24.1	20.3	+3.8	Ss0112
Backwater	3.1	19.6	19.9	-0.3	Ss0126
Crabtree Creek (RB)	3.2	23.2	19.6	+3.6	Ss0132
Cold seep	6.5	17.1	19.4	-2.3	Ss0234
Backwater (RB)	7.1	17.2	18.9	-1.7	Ss0258
Backwater	9.3	22.1	18.8	+3.3	Ss0413
Side-channel (LB)	9.4	18.6	18.6	0.0	Ss0417
Gravel Bar (LB)	9.7	21.7	18.4	+3.3	Ss0425
Backwater (RB)	9.7	22.2	18.6	+3.6	Ss0429
Backwater (RB)	9.8	21.8	18.4	+3.4	Ss0431
Backwater (LB)	10.4	21.3	18.4	+2.9	Ss0449
Side-channel (RB)	10.7	18.4	18.3	+0.1	Ss0459
Side-channel (LB)	11.0	21.1	18.3	+2.8	Ss0467
Backwater (RB)	11.3	19.8	18.4	+1.4	Ss0475
Backwater (LB)	11.6	19.7	18.3	+1.4	Ss0485
Side-channel	13.2	18.1	18.1	0.0	Ss0529
Backwater (LB)	14.5	17.9	18.8	+0.9	Ss0561
Side-channel (LB)	14.9	20.4	17.3	+3.1	Ss0573
Side-channel (RB)	15.3	21.8	17.4	+4.4	Ss0583
Backwater (LB)	16.8	22.1	16.8	+5.3	Ss0621
Backwater (LB)	17.7	18.1	16.4	+1.7	Ss0647
First Creek (RB)	19.4	22.4	15.7	+6.7	Ss0697
Side-channel	23.6	18.2	15.4	+2.8	Ss0821
Side-channel	25.4	16.0	15.2	+0.8	Ss0875
McDowell Creek	25.8	21.5	15.5	+6.0	Ss0887
Backwater	26.3	16.9	15.2	+1.7	Ss0903
Side-channel	33.4	19.8	13.0	+6.8	Ss1138
Wiley Creek	35.2	22.3	11.7	+10.6	Ss1198
Unnamed Tributary (RB)	35.4	16.6	11.7	+4.9	Ss1206

We discuss our analysis of the FLIR data for tributaries in the upstream order that the tributaries occur.

Thomas Creek was flown from the confluence of the South Santiam River upstream 31.2 miles. The survey was terminated approximately 8 miles from the watershed divide. The sampled images were plotted versus river mile to create a longitudinal temperature profile (Figure 8). At the upstream end of the survey, Thomas Creek was relatively warm, measuring 20.9ºC. Over the next 4.6 miles, Thomas Creek cooled in the downstream direction to the survey low of 17.1ºC. This cooling trend seemed to be caused by the high density of tributaries in this reach contributing cooler flows to Thomas Creek. From RM 26.2 to RM 18.4, stream temperatures increase rapidly in the downstream direction to a local maximum of 25.6ºC. Over the next 18 miles, stream temperature patterns in Thomas Creek cycle between a low of 22.1ºC and a high of 26.4ºC. There were no apparent point sources causing this fluctuating pattern in stream temperatures, but the pattern does appear to coincide from the transition from a forested landscape to a more mixed forest/open part of the watershed in the lower reaches. Thomas Creek inputs in the South Santiam River at 24.1ºC. We detected 8 tributary inputs along the survey with 7 contributing cooler inputs to the mainstem.

Quartzville Creek was flown from the inflow to Green Peter Reservoir upstream 8.9 miles to Canal Creek. The sampled images were plotted versus river miles to create a longitudinal temperature profile (Figure 9). At the upstream end of the survey, Quartzville Creek was 19.9ºC with Canal Creek contributing 19.6ºC inflows. From Canal Creek downstream to Green Peter Reservoir, stream temperatures for Quartzville Creek were relatively constant, fluctuating between a low of 19.3ºC and a high of 21.9ºC. We detected 12 tributaries over the survey reach and they were all contributing cooler flows to Quartzville Creek. None of the tributary inputs appeared to significantly effect mainstem temperatures. An additional 10 tributaries of Quartzville Creek were flown for FLIR data collection. An unnamed tributary located near Cascade Falls was flown from the mouth upstream 1.1 miles (Figure 10). Stream temperatures were relatively warm at the upstream end of the survey (15.4ºC) and increased slightly in the downstream direction, inputting to Quartzville Creek at 16.4ºC. This tributary was quite small with low flow conditions and partially obscured by canopy cover throughout much of the survey.

Yellowstone Creek, a tributary of Quartzville Creek, was flown from the mouth upstream 3.0 miles (Figure 11). Stream temperatures at the upstream end of the survey were 11.1ºC and gradually increased in the downstream direction where the reached 17.3ºC at the confluence with Quartzville Creek. The maximum temperature for the survey was reached at RM 0.7 (21.3ºC). This appeared to be due to very little streamflow in this reach. Yellowstone Creek was contributing flow that was 3.0ºC cooler then Quartzville Creek. We detected 5 tributaries over the course of the survey with 1 contributing warmer flows and the other 4 being about the same temperature as Yellowstone Creek. An unnamed tributary on the right bank at RM 1.4 of Yellowstone Creek was surveyed from the mouth upstream 0.8 miles (Figure 12). At the upstream end of the survey temperatures were cool at 12.8ºC and warmed in the downstream direction reaching 15.4ºC at the mouth. Temperatures across the survey reach were quite variable due to variable and low flow conditions. An additional unnamed tributary on the right bank at RM 2.1 of Yellowstone Creek was also surveyed upstream about 1 mile (Figure 13). Temperature detection was very difficult for this stream due to significant canopy cover, a small stream channel and low flow conditions. Our analysis showed highly variable temperatures with temperatures decreasing in the downstream direction from 15.0 to 13.4ºC.

Boulder Creek was flown from the mouth upstream 2.6 miles (Figure 14). Temperatures were cool at the upstream end (11.4ºC) and warmed slowly in the downstream direction reaching 17.0ºC at the confluence with Quartzville Creek. No tributaries were detected over the survey reach.

Packers Gulch was flown from the confluence with Quartzville Creek upstream 3.0 miles (Figure 15). Stream temperatures were relatively cool at the upstream end of the survey (13.3ºC) and increased rapidly over the next mile, reaching the survey maximum (19.3ºC) at RM 2.0. From RM 2.0 to mouth stream temperatures decreased gradually in the downstream direction, inputting to Quartzville Creek at 18.4ºC. We detected 4 tributaries over the survey reach with 3 contributing cooler flows and 1 that was warmer. South Fork Packers Gulch was flown from the mouth upstream 1.8 miles (Figure 16). Stream temperatures were relatively warm at the upstream end (12.4ºC) and increased in the downstream direction with some local variation reaching a survey maximum (19.6ºC) at the confluence with Packers Gulch. One tributary was detected, and it was contributing warmer flow. West Fork Packers Gulch was flown from the mouth upstream 1.5 miles (Figure 17). Stream temperatures were cool at the upstream end (12.4ºC) and increased slowly to the confluence with Packers Gulch where they reached the survey maximum of 17.5ºC. Two tributaries were detected, and they were contributing warmer flows but didn't appear to effect mainstem temperatures.

FLIR imagery was collected on Canal Creek from the confluence with Quartzville Creek upstream 2.7 miles to the confluence with Elk Creek. At the upstream end of the survey, Canal Creek was 20.9ºC (Figure 18). Over the next 0.6 miles stream temperatures increase slowly to the survey maximum of 23.0ºC at RM 2.1. From RM 2.1 to RM 1.1 stream temperatures decrease gradually to the survey minimum of 18.1ºC. The cause of the decrease in temperature is not readily apparent, but there are 2 relatively cool tributaries at the survey minimum that contribute to the lower temperatures. From RM 1.1 to the mouth temperatures decrease gradually in the downstream direction, inputting into Quartzville Creek at 20.8ºC. We detected 7 tributaries contributing flow to Canal Creek with 4 contributing cooler flows and 3 that were about the same temperature as Canal Creek. Beverly Creek, a tributary of Canal Creek, was surveyed from the confluence with Canal Creek upstream 2.3 miles (Figure 19). Stream temperatures were 9.1ºC at the upstream end of the survey and increase gradually in the downstream direction to the confluence with Canal Creek at 19.6ºC. There were 2 tributaries detected in the survey with 1 contributing cooler flows and the other being a similar temperature as Beverly Creek. Pat Creek, another tributary of Canal Creek was surveyed from the mouth upstream 1.5 miles (Figure 20). At the upstream end of the survey Pat Creek was 12.8ºC and stream temperatures generally increased in the downstream direction, with some local variation, to the survey maximum at the confluence with Canal Creek of 21.5ºC. One tributary was detected in the survey, and it was contributing cooler flows to Pat Creek.

Crabtree Creek was flown from RM 30.7 to RM 36.8 for a total of 6.1 miles. The longitudinal profile (Figure 21) shows that stream temperatures at the upstream end of the survey were relatively cool (14.8ºC). Moving downstream temperatures decreased to the survey low of 12.8ºC at RM 35.6. From RM 35.6 to RM 32.7, stream temperatures increased slowly in the downstream direction to 14.4ºC. In the upper end of the survey stream temperatures were somewhat variable due to low flow conditions and dense riparian cover in places. From RM 32.7 to RM 30.7, stream temperatures increased rapidly in the downstream direction, reaching the survey maximum (20.9 ºC) at the beginning of the survey. We detected 3 tributaries over the survey reach and all were contributing cooler flows to Crabtree Creek. In addition, we collected FLIR data on 5 tributaries to Crabtree Creek.

The first tributary of Crabtree Creek we collected data on was an unnamed tributary on the right bank at RM 31.0 (Figure 22). This tributary was flown from the mouth upstream 2.4 miles. At the upstream end of the survey the stream was quite cold (11.6ºC). Over the next 2.4 miles stream temperatures increased gradually reaching a survey maximum at RM 0.1 of 17.3ºC. At the confluence with Crabtree Creek the tributary was contributing 16.2ºC input, a full 2.0ºC colder then Crabtree Creek. An unnamed tributary located to the unnamed tributary located at RM 0.8 was flown upstream for 1.1 miles (Figure 23). Survey conditions for this stream were quite challenging due to dense riparian vegetation, low flows, and a small channel causing temperature measurements to be taken at irregular intervals. At the upstream end of the survey, stream temperatures were relatively cool at 14.1ºC. Temperatures become cooler over the next 0.2 miles, reaching a low of 10.4ºC. Over the next 0.2 miles stream temperatures increased to the survey maximum of 14.3ºC. From RM 0.7 to RM 0.5, temperatures decrease rapidly to the survey minimum of 9.2ºC. In the next 0.4 miles temperatures again increase to 13.6ºC at the downstream end of the survey. We were unable to detect stream temperatures at the confluence with the unnamed tributary due to dense riparian vegetation.

White Rock Creek, a tributary to Crabtree Creek, was flown from the mouth upstream 2.6 miles (Figure 24). Survey conditions for this stream were also quite challenging due to dense riparian vegetation, low flows, and a small channel causing temperature measurements to be taken at irregular intervals in small patches of visible stream channel. At the upstream end of the survey stream temperatures were relatively warm (14.1ºC). Stream temperatures were highly variable but tended to decrease over the mile, reaching a survey minimum of 12.1ºC at RM 1.9. From RM 1.2 to the mouth, temperature tended to increase in the downstream direction, reaching 15.6ºC at the confluence with Crabtree Creek. White Rock Creek was 1.8ºC cooler then Crabtree Creek. Bonnie Creek was flown from the mouth upstream 2.0 miles (Figure 25). At the upstream end of the survey stream temperatures were quite cold at 12.1ºC. From RM 2.0 to the mouth stream temperatures were variable but tended to increase in the downstream direction. At the confluence with Crabtree Creek, Bonnie Creek was 15.1ºC, 2.5ºC cooler then Crabtree Creek. Shafer Creek was flown from the mouth upstream 1.2 miles (Figure 26). At the upstream end of the survey stream temperatures were very cold at 8.6ºC. Temperatures increased over the next 0.3 miles to a survey maximum of 14.8ºC. From RM 0.9 to the downstream end of the survey (RM 0.16) stream temperatures decreased slightly reaching 13.3ºC. From RM 0.16 to the mouth, we were unable to detect stream temperatures due to dense riparian vegetation.

Hamilton Creek, a tributary to the South Santiam Rover was flown from RM 11.4 upstream to RM 15.2 (Figure 27). At the upstream end of the survey stream temperatures were relatively warm at 14.7ºC. From RM 15.2 to RM 11.4 stream temperatures were variable but tended to increase in the downstream direction, reaching a survey maximum of 18.7ºC at RM 11.8). At the lower end of the survey stream temperatures were 18.0ºC. The South Fork Scott Creek was flown from the mouth upstream 5.1 miles (Figure 28). At the upstream end of the survey stream temperatures were cold (10.3ºC) but quite variable due to low flows, small channels and dense riparian vegetation. From RM 4.2 to the mouth stream temperatures were not near as variable but increased slowly in the downstream direction, reaching a survey maximum at the mouth (16.8ºC). The South Fork Scott was 0.4ºC warmer than Hamilton Creek (16.4ºC). The South Fork Hamilton Creek was flown from the mouth upstream 2.4 miles (Figure

29). At the upstream end of the survey stream temperatures were relatively warm (14.3ºC) and decreased over the next 0.3 miles to the survey minimum of 12.8ºC. From RM 2.1 to the mouth, stream temperatures increased slowly in the downstream direction reaching the survey maximum at the mouth (17.4ºC). The South Fork Hamilton Creek was 0.5ºC warmer than Hamilton Creek (16.9ºC) at the confluence.

Bibliography

Karalus, R.S., M.A. Flood, B.A. McIntosh, and N.J. Poage. 1996. ETI surface water quality monitoring technologies demonstration. Final Report. Las Vegas, NV: Environmental Protection Agency.

McIntosh, B.A., R.N. Faux, and J.R. Sedell. 1999. Aerial survey of the Applegate River: thermal infrared and color videography. Final Report. Rogue River National Forest. 27 pp.

McIntosh, B.A., D. M. Price, C.E. Torgersen, and H.W. Li. 1995. Distribution, habitat utilization, movement patterns, and the use of thermal refugia by spring chinook in the Grande Ronde, Imnaha, and John Day basins. Progress Report. Portland, OR: Bonneville Power Administration, Project No. 93-700. 16 pp.

Norton, D.J., M.A. Flood, B.A. McIntosh [and 14 others]. 1996. Modeling, monitoring and restoring water quality and habitat in Pacific Northwestern watersheds. Final Report. Washington D.C.: Environmental Program, Government Applications Task Force, Central Intelligence Agency, 68 pp.

Torgersen, C.E., D.M. Price, H.W. Li, and B.A. McIntosh. 1995. Thermal refugia and chinook salmon habitat in Oregon: applications of airborne thermal videography. In: Proceedings of the 15th Biennial Workshop on Color Photography and Videography in Resource Assessment. Terre Haute, ID: American Society for Photogrammetry and Remote Sensing. Pages 167-171.

Torgersen, C.E., D.M. Price, H.W. Li, and B.A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associates of chinook salmon in Northeastern Oregon. Ecological Applications. 9(1), pp 301 – 319.

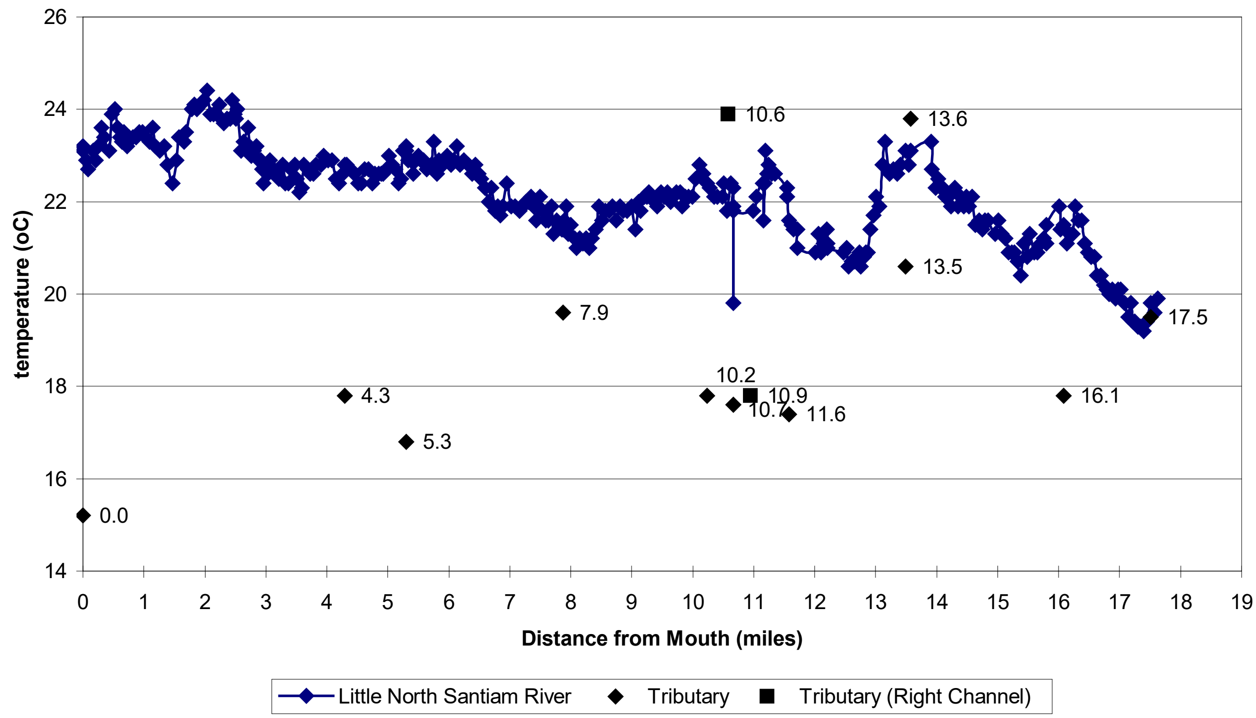


Figure 5. Longitudinal temperature profile of Little North Santiam River.

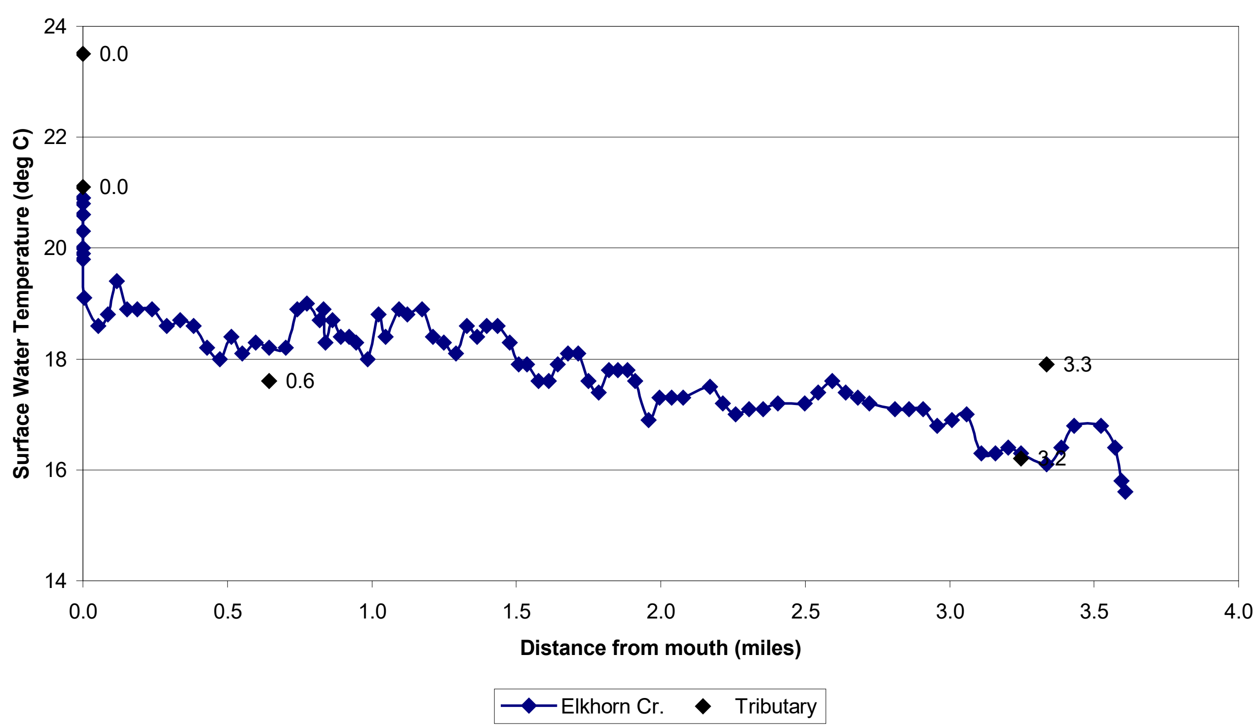


Figure 6. Longitudinal temperature profile of Elkhorn Creek.

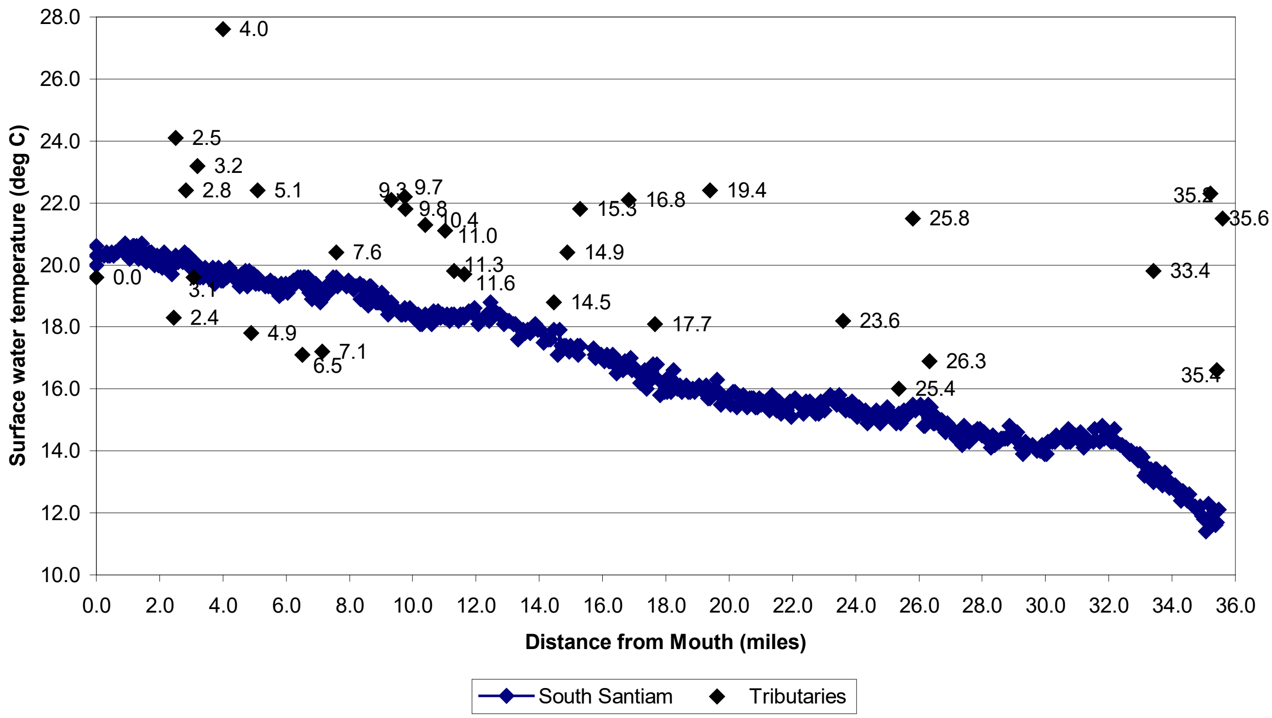


Figure 7. Longitudinal temperature profile of South Santiam River.

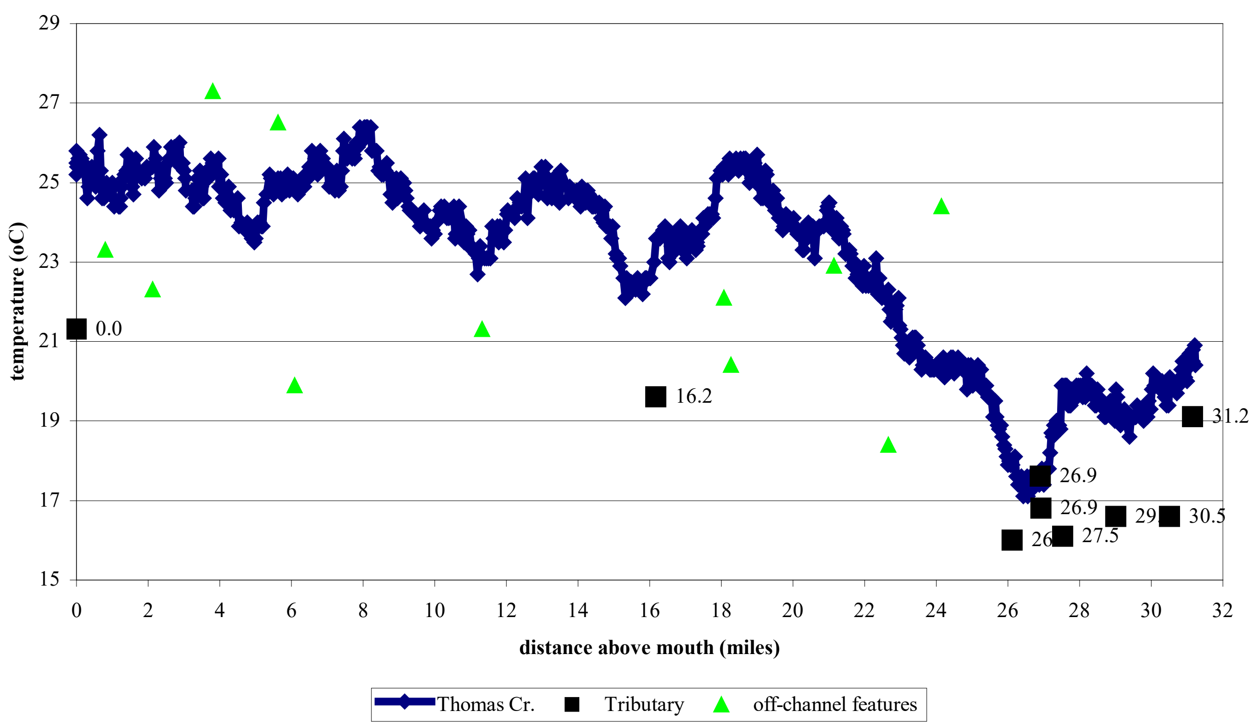


Figure 8. Longitudinal temperature profile of Thomas Creek.

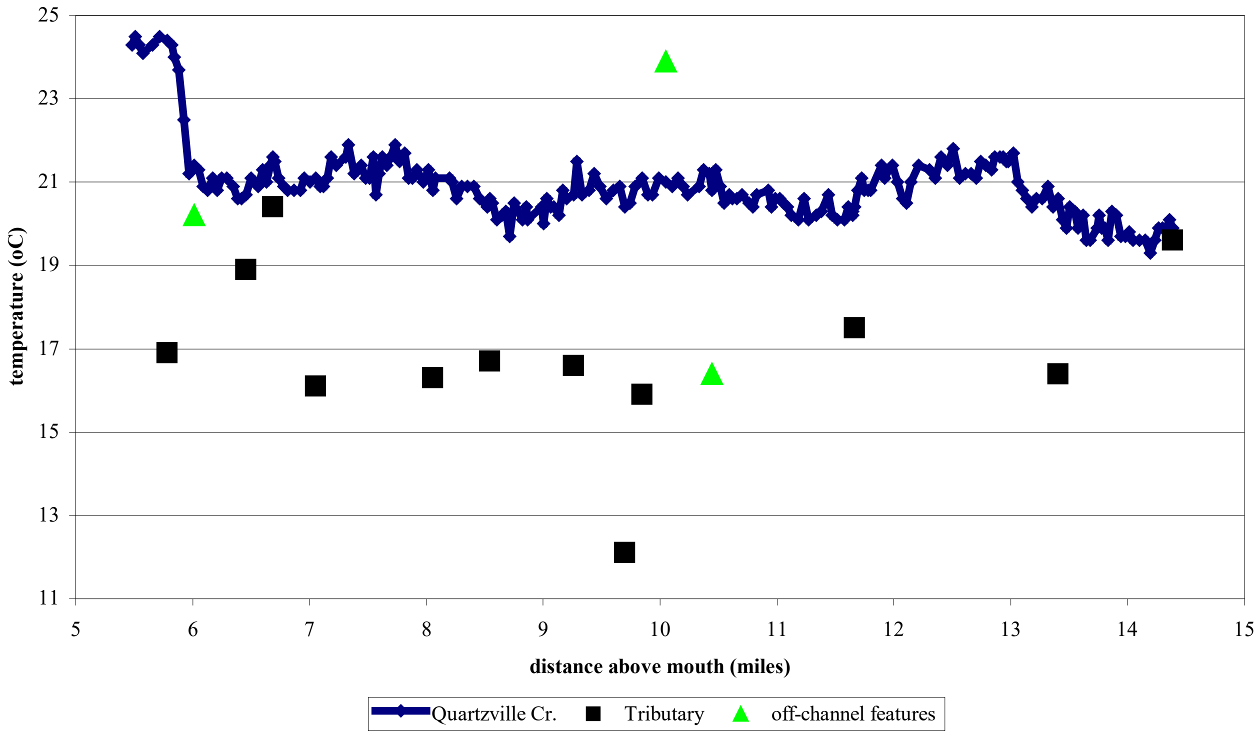


Figure 9. Longitudinal temperature profile of Quartzville Creek.

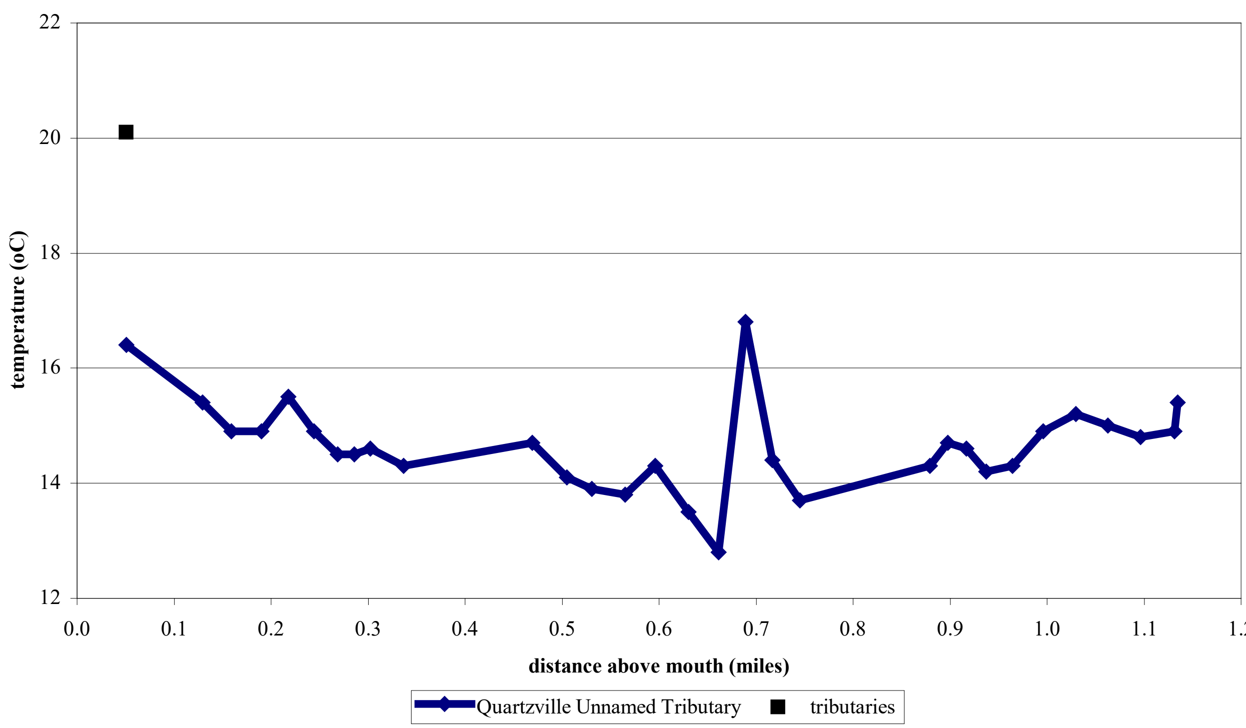


Figure 10. Longitudinal temperature profile of Unnamed tributary to Quartzville Creek.

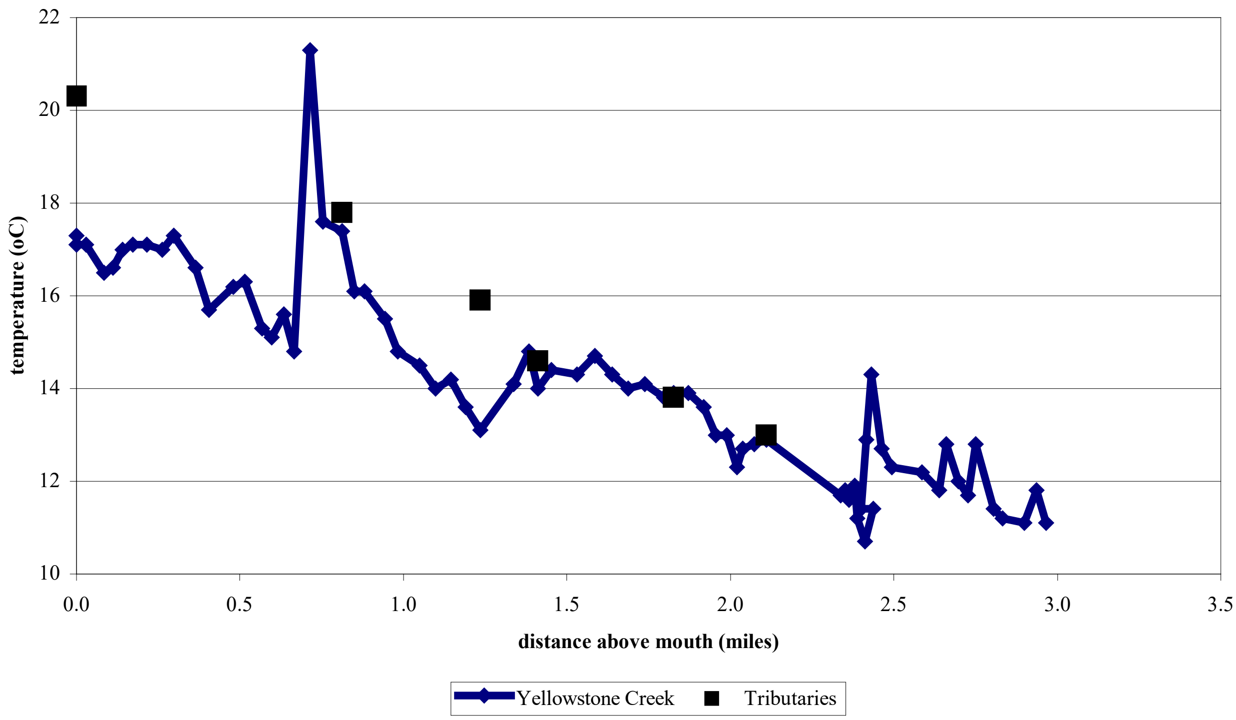


Figure 11. Longitudinal temperature profile of Yellowstone Creek.

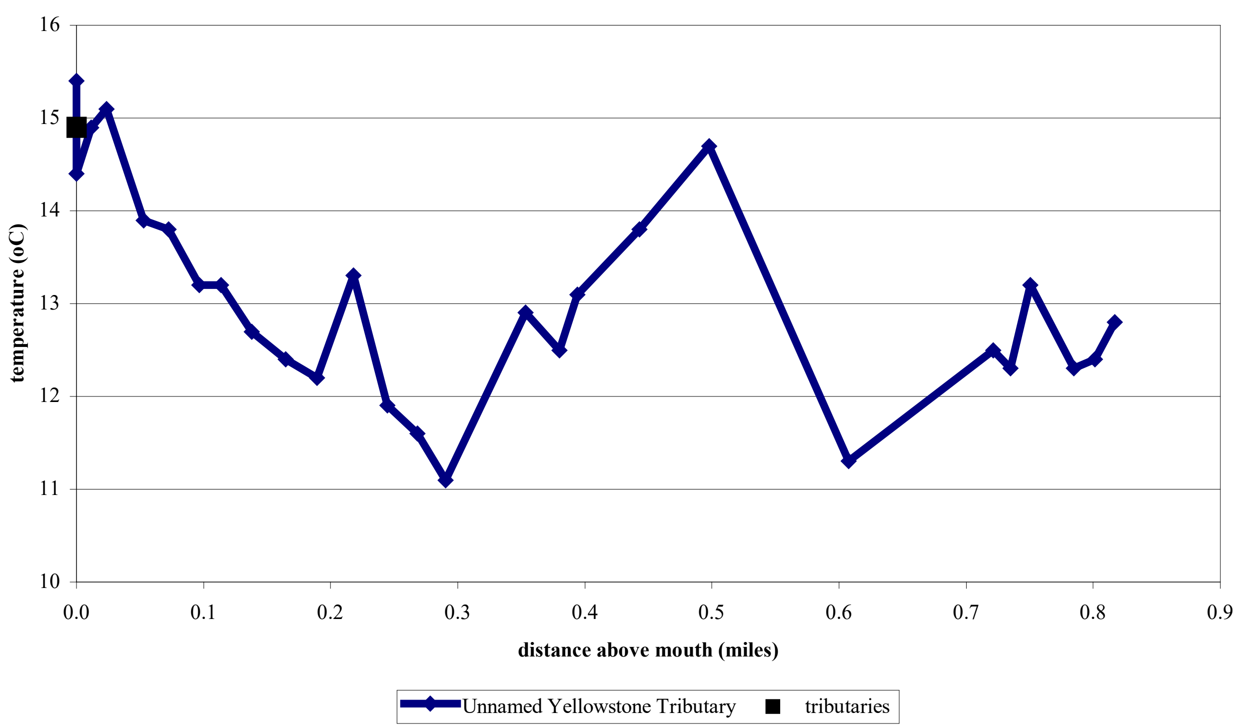


Figure 12. Longitudinal temperature profile of Unnamed tributary to Yellowstone Creek.

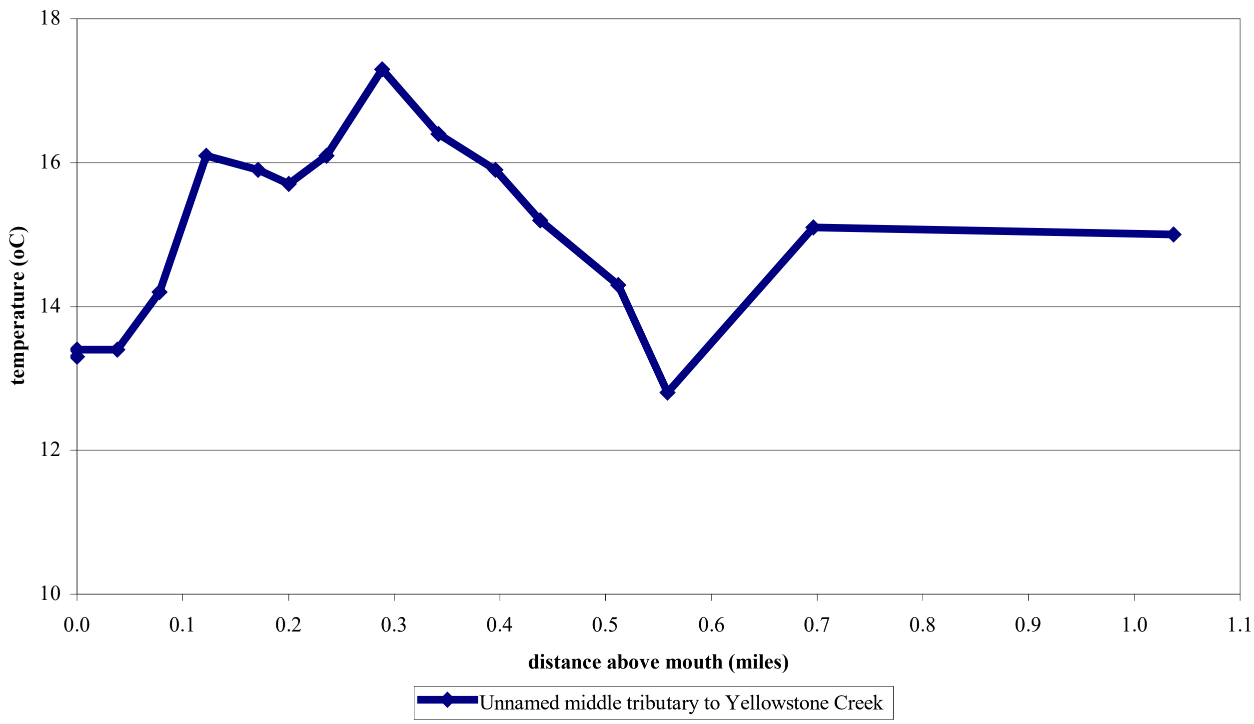


Figure 13. Longitudinal temperature profile of unnamed middle tributary to Yellowstone Creek.

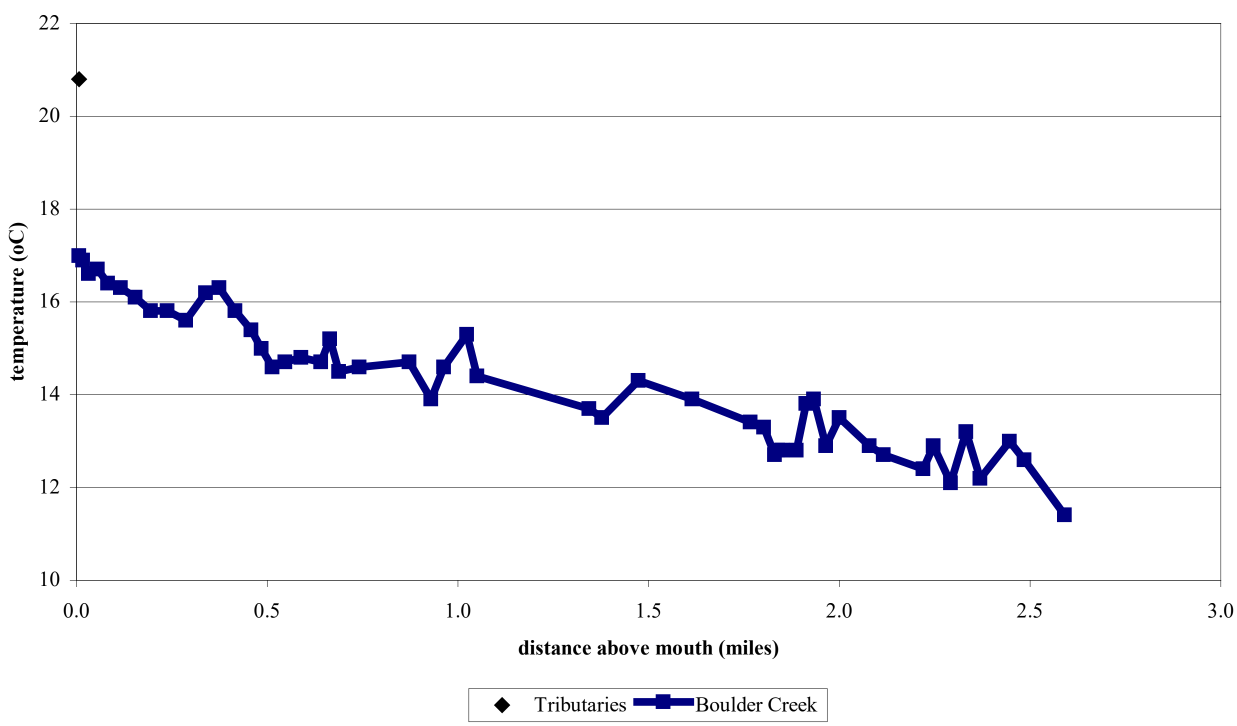


Figure 14. Longitudinal temperature profile of Boulder Creek.

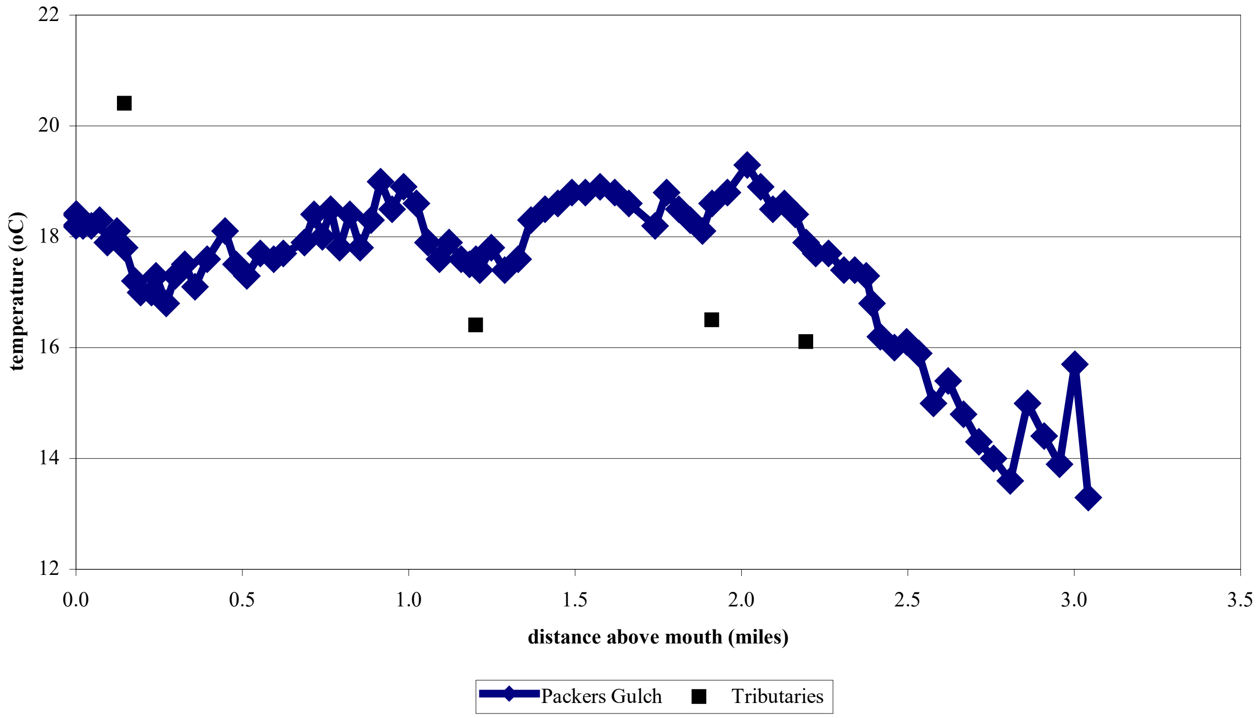


Figure 15. Longitudinal temperature profile of Packers Gulch.

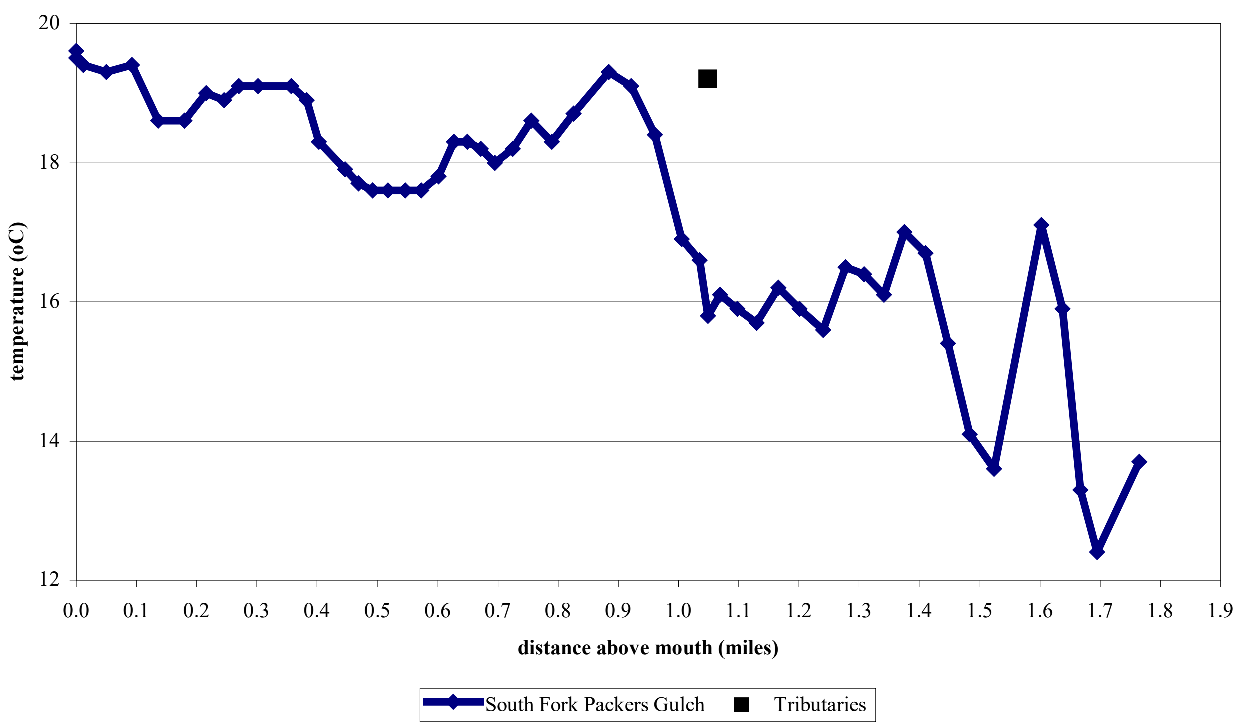


Figure 16. Longitudinal temperature profile of South Fork Packers Gulch.

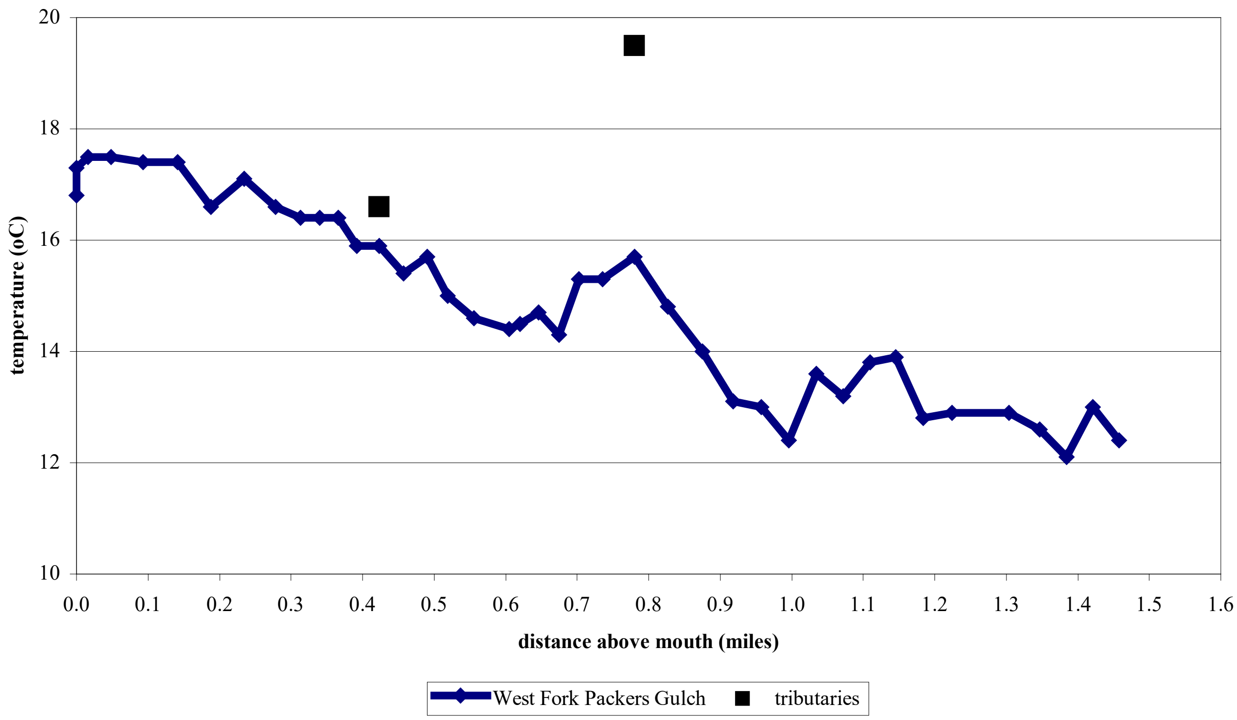


Figure 17. Longitudinal temperature profile of West Fork Packers Gulch.

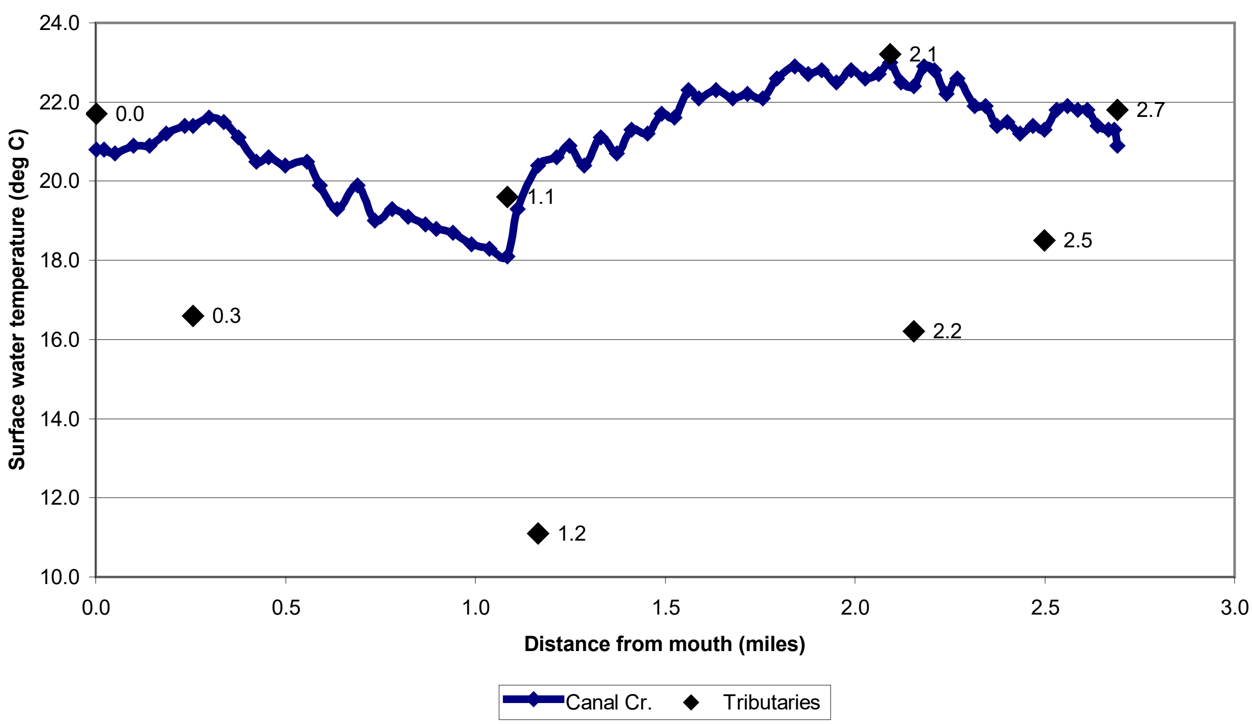


Figure 18. Longitudinal temperature profile of Canal Creek.

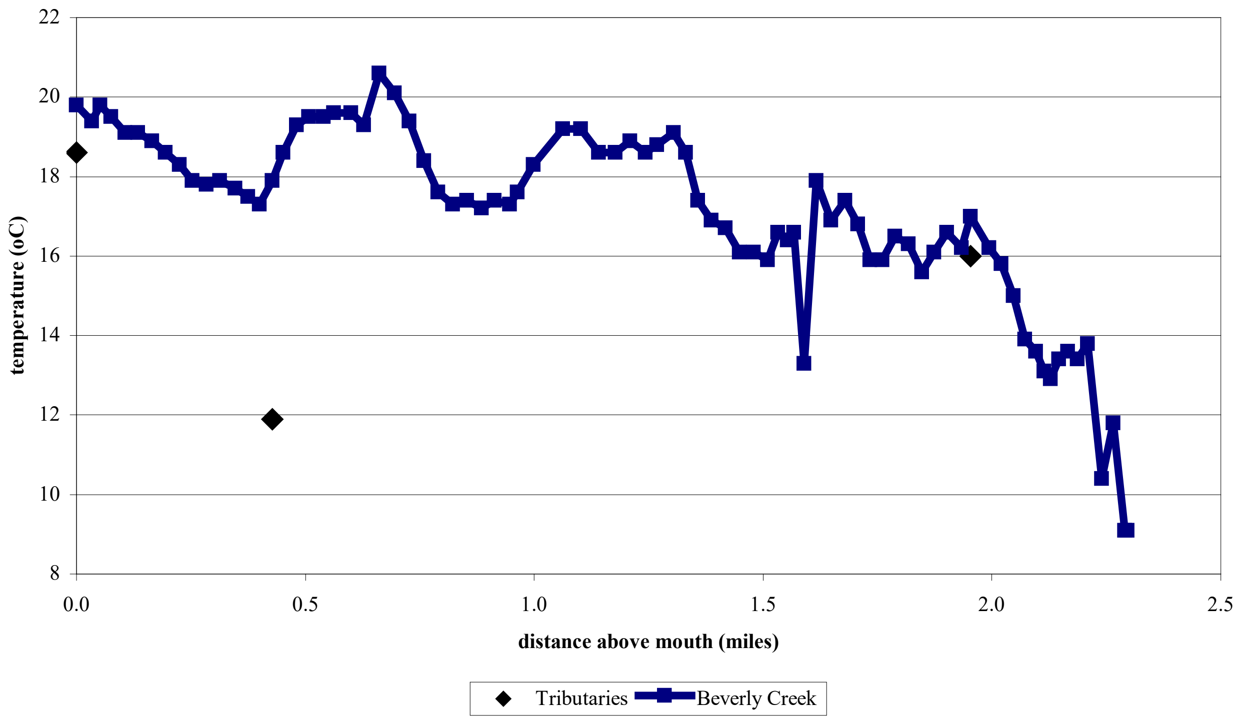


Figure 19. Longitudinal temperature profile of Beverly Creek.

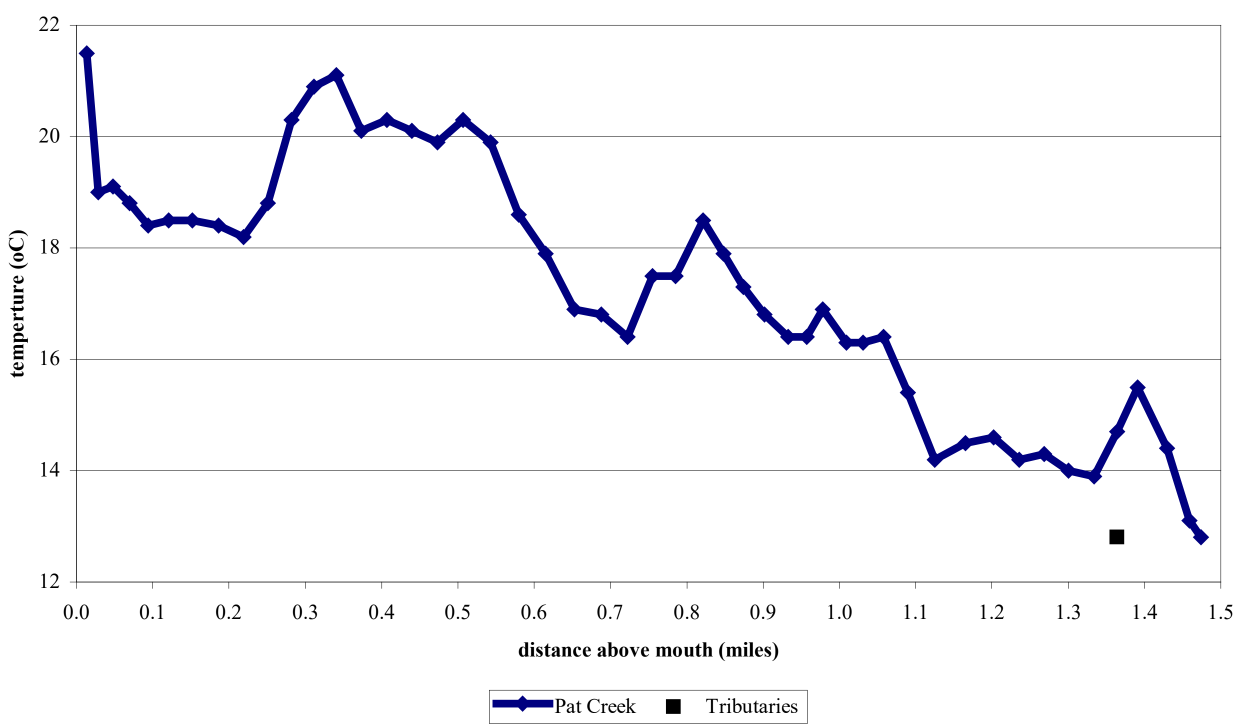


Figure 20. Longitudinal temperature profile of Pat Creek.

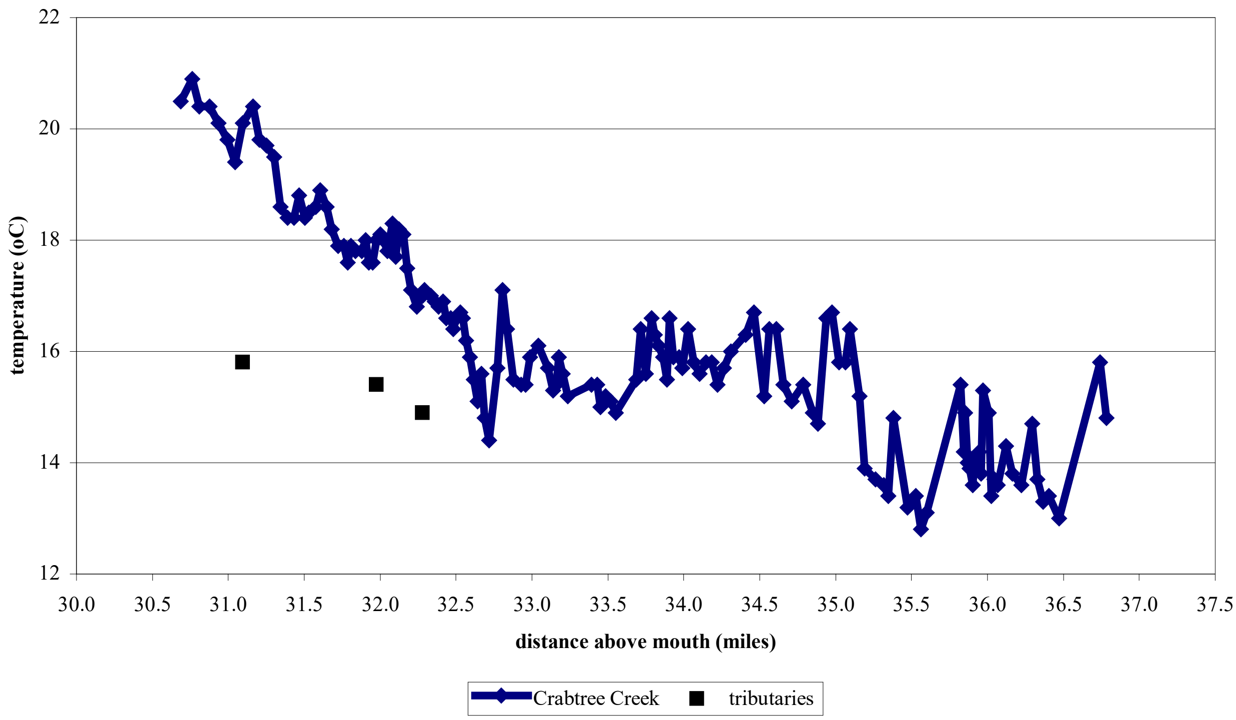


Figure 21. Longitudinal temperature profile of Crabtree Creek.

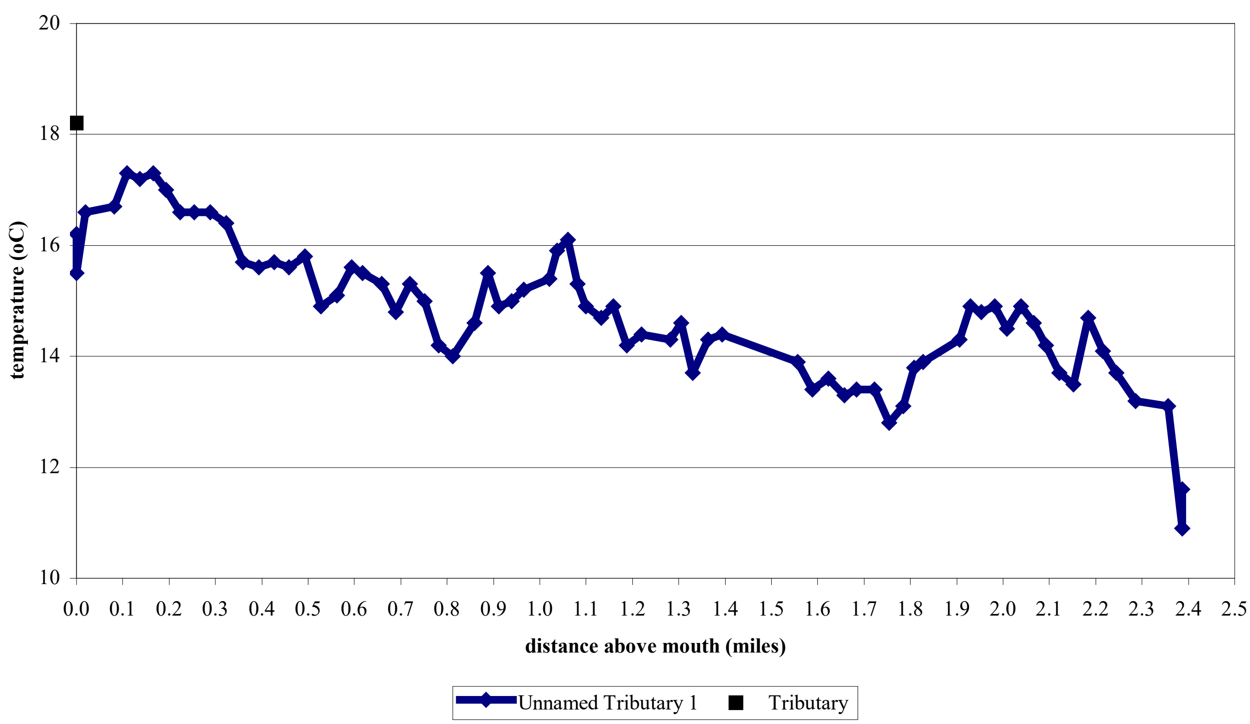


Figure 22. Longitudinal temperature profile of Unnamed Tributary 1 to Crabtree Creek.

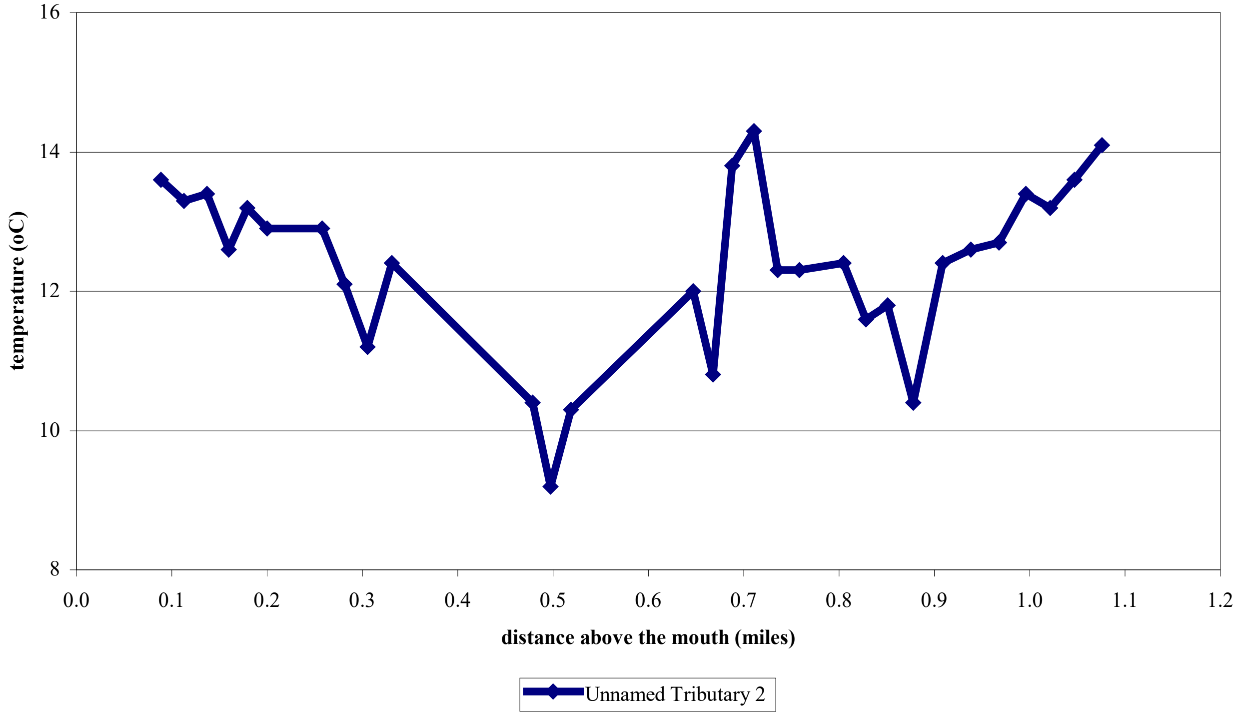


Figure 23. Longitudinal temperature profile of Unnamed Tributary 2 to Crabtree Creek.

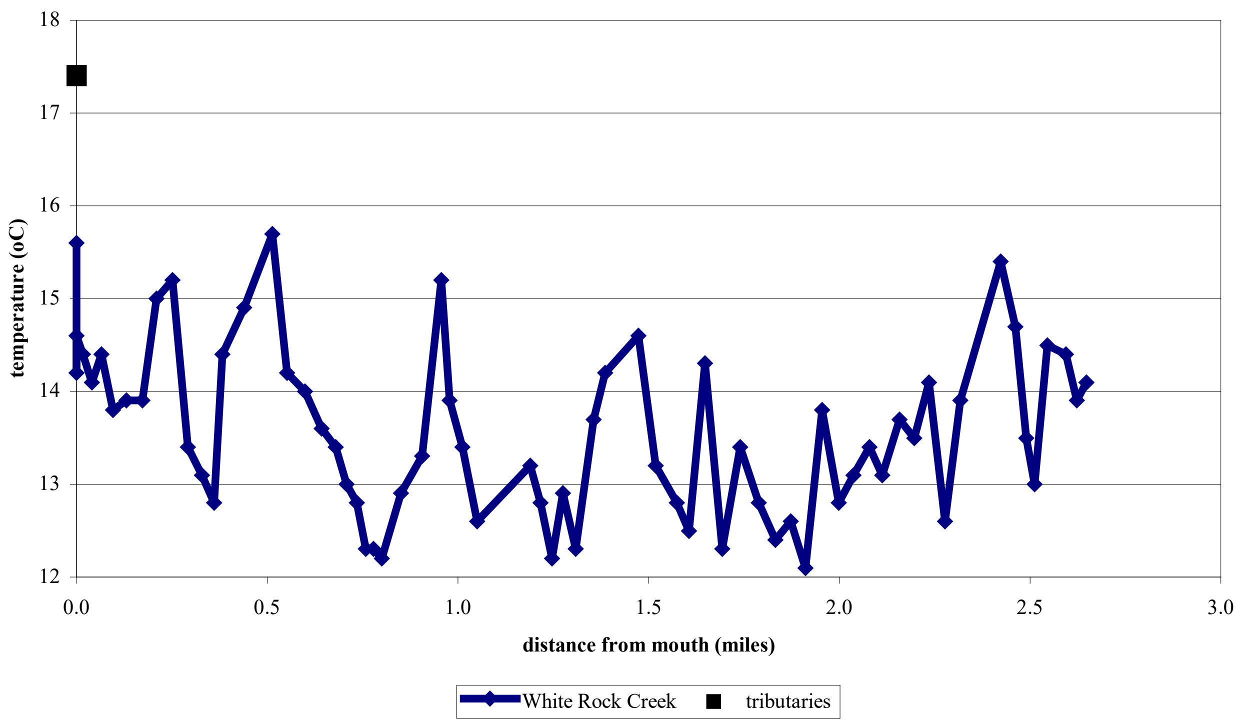


Figure 24. Longitudinal temperature profile of White Rock Creek.

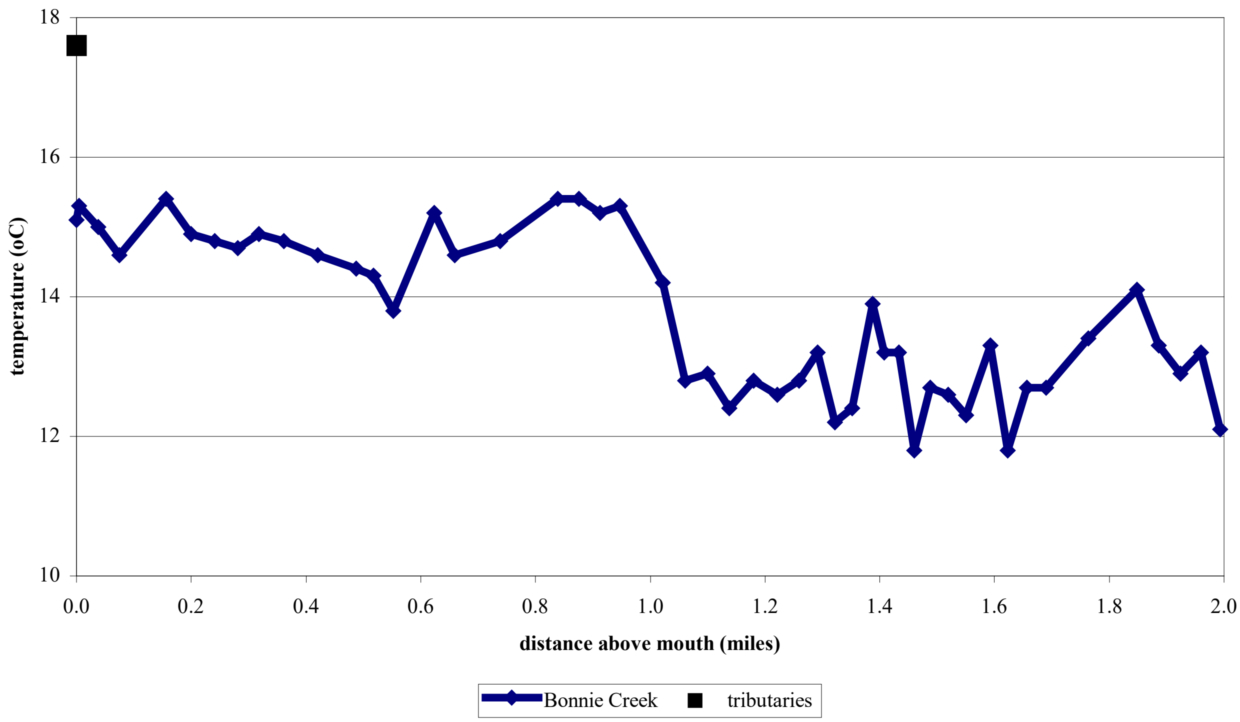


Figure 25. Longitudinal temperature profile of Bonnie Creek.

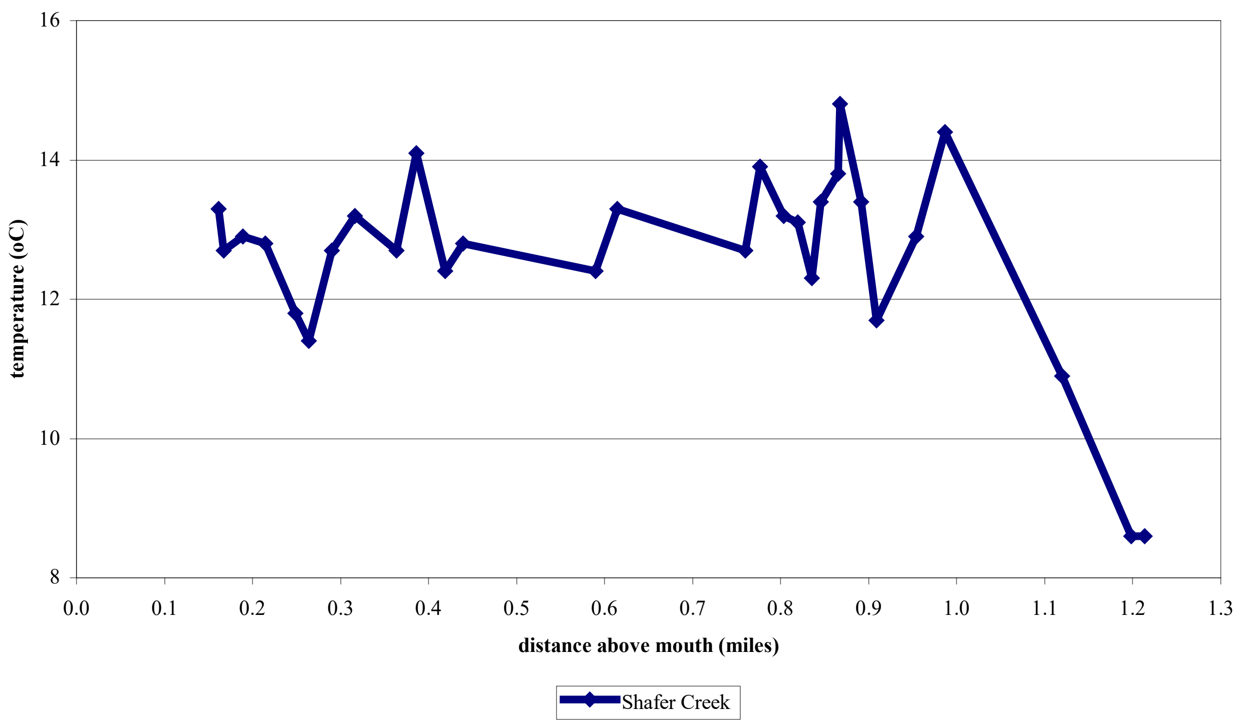


Figure 26. Longitudinal temperature profile of Shafer Creek.

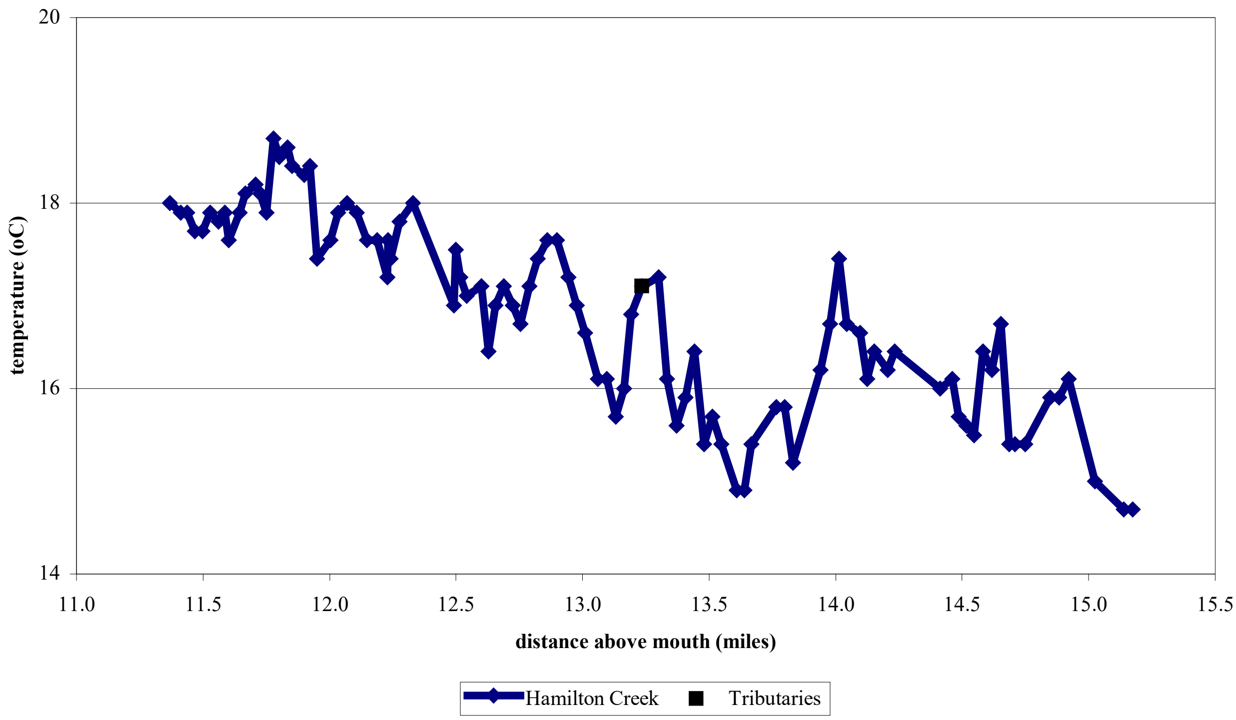


Figure 27. Longitudinal temperature profile of Hamilton Creek.

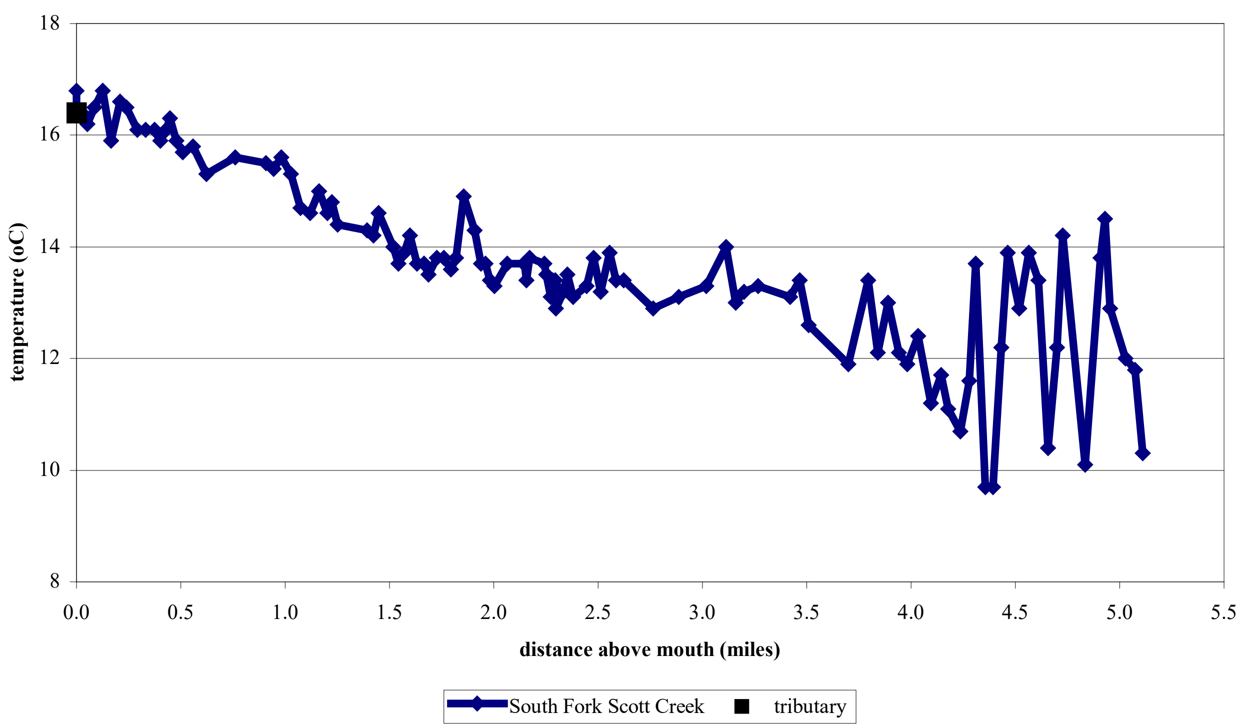


Figure 28. Longitudinal temperature profile of South Fork Scott Creek.

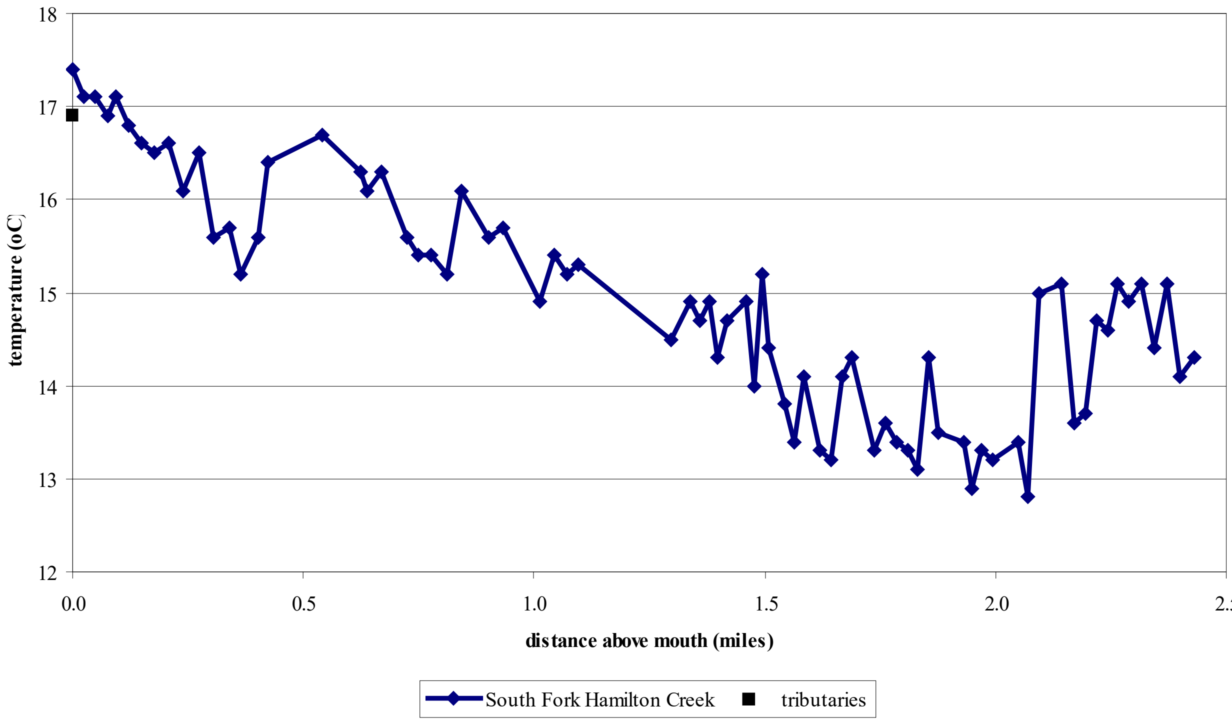


Figure 29. Longitudinal temperature profile of South Fork Hamilton Creek.