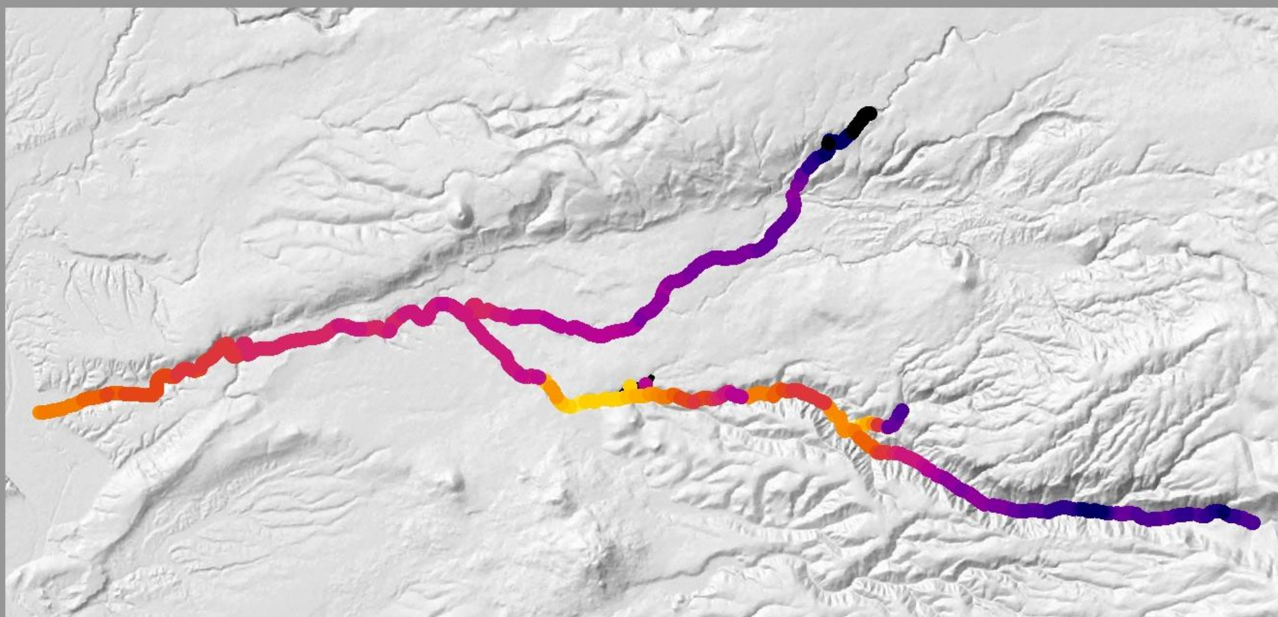
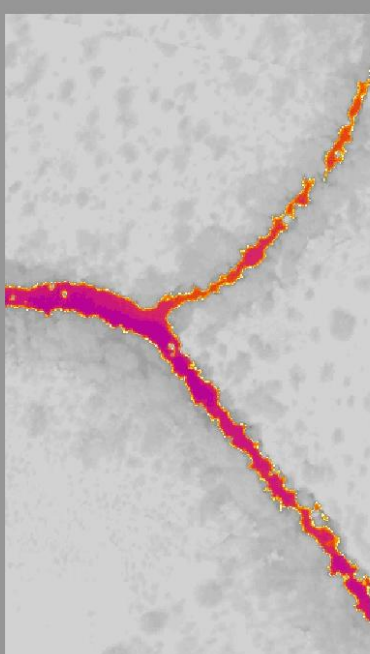
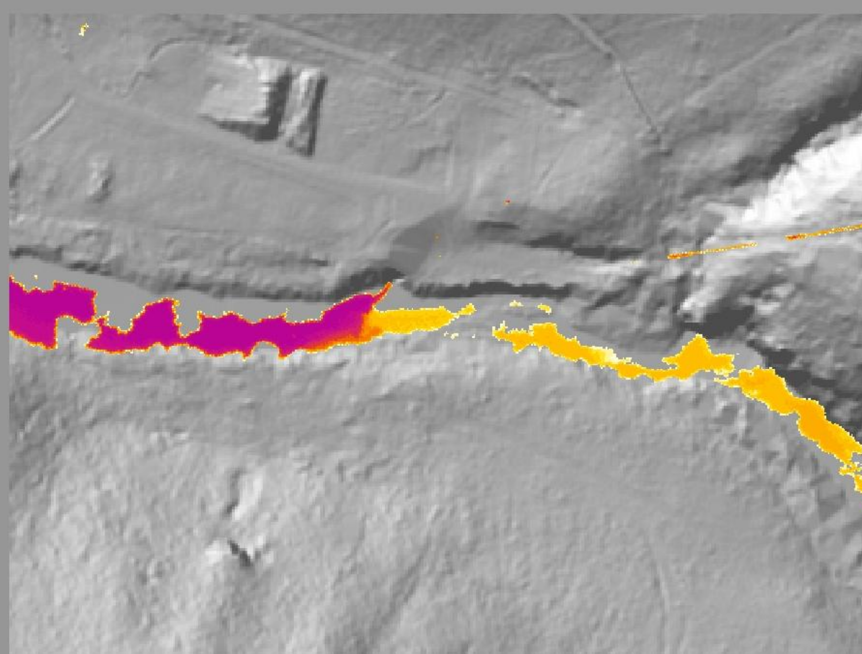
AIRBORNE THERMAL INFRARED REMOTE SENSING

BATTLE CREEK RESTORATION AREA -- CALIFORNIA

SURVEY DATE August 23, 2011 - REPORT DATE November 18, 2011







U.S. FISH AND WILDLIFE SERVICE

MATT BROWN - 10950 Tyler Road - Red Bluff, CA 96080

WATERSHED SCIENCES 517 SW 2nd Street, Suite 400 - Corvallis, OR 97333

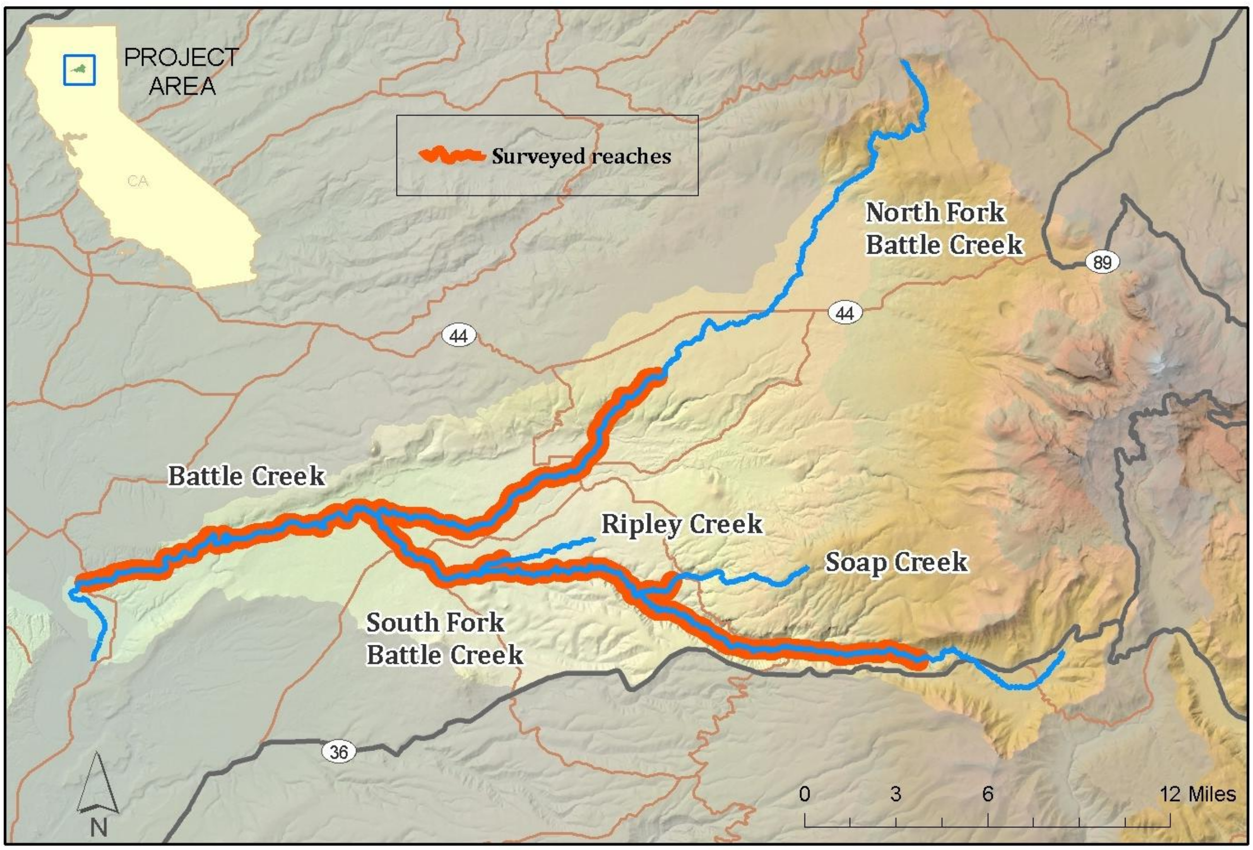
AIRBORNE THERMAL INFRARED REMOTE SENSING
BATTLE CREEK RESTORATION AREA, CALIFORNIA

TABLE OF CONTENTS

1. Overview

In 2011, the U.S. Fish and Wildlife Service contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) imagery for approximately 50 river miles in the Battle Creek Restoration Area. The thermal acquisition included portions of Battle Creek, North Fork Battle Creek, South Fork Battle Creek, Ripley Creek and Soap Creek (*Figure 1, Table 1*). The TIR project is an addition to the LiDAR and orthophoto data collection which occurred on August 19, 2011.[1] The LiDAR/Orthophoto deliverable included 0.5-m contours, as well as hydrography breaklines representing the edge of the wetted channel.

Figure 1. Watershed Sciences, Inc. conducted a TIR survey in the Battle Creek subbasin on August 23, 2011. LiDAR and orthophotos were collected independently on August 19, 2011.



[1] Final Report: "LiDAR Remote Sensing & Orthophoto Data Collection. Battle Creek, California." Delivered by Watershed Sciences, Inc. 10/31/2011

Table 1. Reaches obtained with airborne thermal infrared in the Battle Creek Subbasin

Stream Name	Date Flown	Miles Flown	Location
Battle Creek	8/23/2011	12.94	Coleman Fish Hatchery to North/South Fork confluence
North Fork Battle	8/23/2011	13.31	Battle Creek to Manton-Ponderosa Way
South Fork Battle	8/23/2011	23.12	Battle Creek to Road 140A
Ripley Creek	8/23/2011	0.93	South Fork Battle Creek to Diversion Dam
Soap Creek	8/23/2011	1.46	South Fork Battle Creek to Diversion Dam
TOTAL MILES:		**51.76**	

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

The specific objectives of the TIR image acquisition were:

- Spatially characterize surface temperatures and stream flow conditions for 52 miles of stream in the Battle Creek Restoration Area.
- Develop longitudinal temperature profiles which illustrate basin-scale stream temperature patterns.
- Identify and map cool water sources and thermal refugia for local populations of Chinook salmon and steelhead.
- Create GIS compatible data layers (e.g. thermal image mosaics, spring locations, etc.) that can be used to plan future research, direct ground based monitoring and analysis, and protect and restore critical habitat.

2. Acquisition

2.1 Airborne Survey - Instrumentation

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

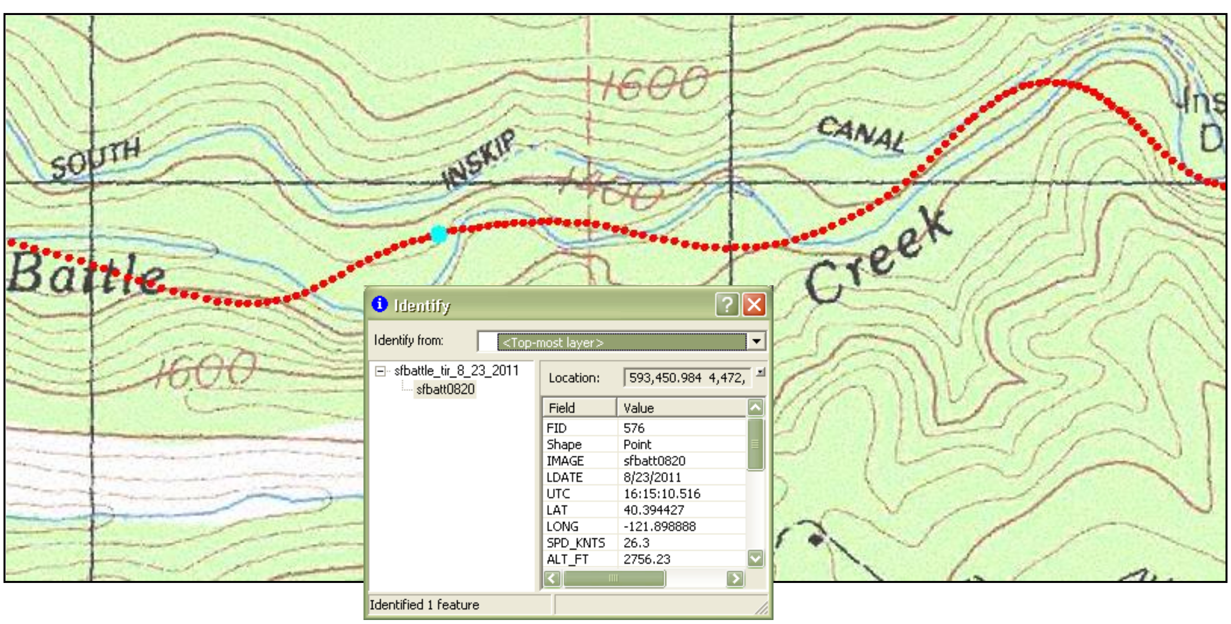
Figure 2. Bell Long Ranger equipped with a thermal infrared radiometer and high resolution digital camera. The sensors are contained in a composite fiber enclosure attached to the underside of the helicopter which is flown longitudinally along the stream channel.

Table 2. Summary of TIR sensor specifications

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

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

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



2.2 Image Collection

The aircraft was flown longitudinally along the stream corridor in order to have the river in the center of the display. The TIR sensor is set to acquire images at a rate of 1 image every second resulting in 40-70% vertical overlap between images. Flight altitudes were selected to optimize resolution while providing an image ground footprint wide enough to capture the active channel with the stream occupying 30-60% of the image. A planned flight altitude of 2000 ft (610 m) was selected for Battle Creek which resulted in a native pixel ground sample distance of 0.6m (2.0 ft) for the thermal imagery. Due to terrain variations, wind conditions, and stream size, altitudes can vary throughout the flight duration. A summary of flight acquisition parameters can be seen in Table 3.

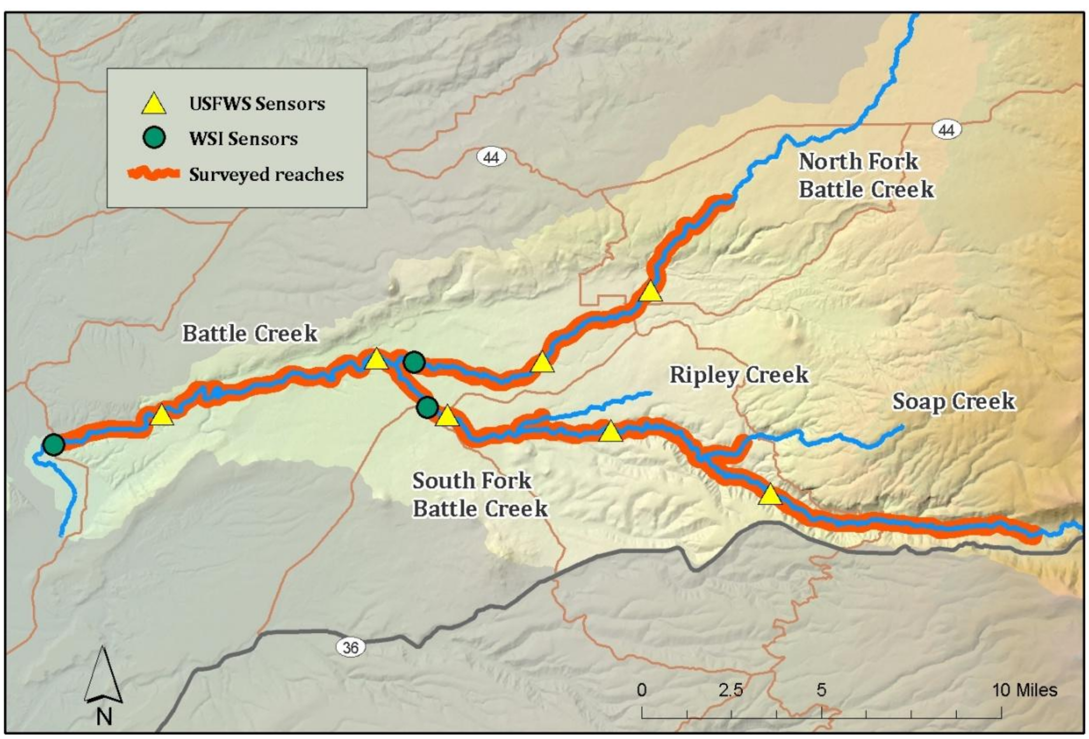
Table 3. Summary of Thermal Image Acquisition Parameters

Dates:	August 23, 2011
Flight Above Ground Level (AGL):	2000 ft (610 m)
Image Footprint Width:	1141 ft (348 m)
Pixel Resolution:	2.0 ft (0.60 m)

2.3 Ground Control

U.S. Fish and Wildlife provided data for 7 sensors active during the survey which collect water temperatures at 30 minute intervals. Watershed Sciences, Inc. deployed 3 in-stream sensors during the time frame of the flight for calibrating and verifying the thermal accuracy of the TIR imagery. The Hobo Pro data loggers were set to record temperatures at 10 minute intervals and suspended in the water column in areas with good vertical mixing. All data logger locations are illustrated in Figure 4.

Figure 4. Locations of sensors deployed by USFWS and Watershed Sciences.



2.4 Weather and Flow Conditions

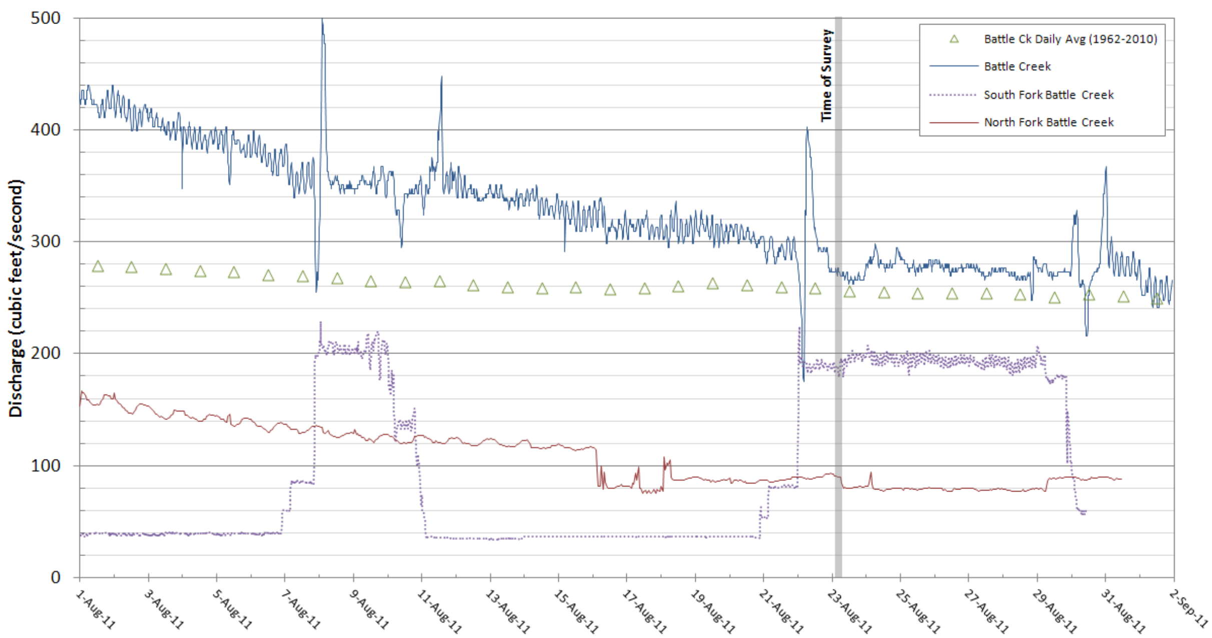
Weather conditions on the day of the survey were considered ideal with warm temperatures, low humidity and clear skies. Data from seasonal in-stream thermographs will be needed to assess how water temperatures on the day of the flight compare to average and maximum summer temperatures. Table 4 summarizes the weather conditions observed at the Red Bluff Airport (KRBL) on August 23, 2011[2].

Table 4. Weather conditions measured at Red Bluff Airport on August 23, 2011

Time (PDT)	Air Temp (˚F)	% Humidity	Wind Direction	Wind Speed (MPH)	Conditions
August 23, 2011					
11:54	91.0	22	Calm	Calm	Clear
12:54	93.9	20	Calm	Calm	Clear
1:54	96.1	15	Variable	5.8 mph	Clear
2:54	98.1	12	SSE	8.1 mph	Clear
3:54	98.1	14	SSE	10.4 mph	Clear
4:54	98.1	13	South	10.4 mph	Clear
5:54	96.1	17	South	12.7 mph	Clear

Three active flow gages were found in the survey area: the USGS gage on Battle Creek at the Coleman Fish Hatchery (USGS11376550)[3] and California Department of Water Resources gages on the North Fork near Manton (BNF) and South Fork near Manton (BAS)[4]. The gages show discharge rates were near base flow levels which is ideal for thermal surveys (*Figure 5*). It is unclear why there were drawdowns in South Fork Battle Creek earlier in August.

Figure 5. Discharge measured in the Battle Creek watershed at the time of the survey.



[2] Source: http://www.wunderground.com
[3] Source: USGS NWIS Site Information for USA: http://waterdata.usgs.gov/nwis/inventory?
[4] Source: California Data Exchange Center-Water Resources: http://cdec.water.ca.gov/riv_flows.html

3. Thermal Image Characteristics

3.1 Surface Temperatures

Thermal infrared sensors measure TIR energy emitted at the water's surface. Since water is essentially opaque to TIR wavelengths, the sensor is only measuring water surface temperatures. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed; however, thermal stratification can form in reaches that have little or no mixing. Thermal stratification in a free flowing river is inherently unstable due to variations in channel shape, bed composition, and in-stream objects (i.e. rocks, trees, debris, etc.) that cause turbulent flow. Stratification can usually be easily detected in the imagery.

3.2 Expected Accuracy

Thermal infrared radiation received at the sensor is a combination of energy emitted from the water's surface, reflected from the water's surface, and absorbed and re-radiated by the intervening atmosphere. Water is a good emitter of TIR radiation and has relatively low reflectivity (~ 4 to 6%). In general, apparent stream temperature changes of < 0.5^{o}C are not considered significant unless associated with a surface inflow (e.g. tributary). However, certain conditions may cause variations in the accuracy of the imagery.

3.2.1 Surface Conditions

Variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.5^{o}C (Torgersen et al. 2001[5]). The occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis.

3.2.2 Differential Heating

In stream segments with flat surface conditions (i.e. pools) and relatively low mixing rates, observed variations in spatial temperature patterns can be the result of differences in the instantaneous heating rate at the water's surface. In the TIR images, indicators of differential surface heating include seemingly cooler radiant temperatures in shaded areas compared to surfaces exposed to direct sunlight.

3.2.3 Feature Size and Resolution

A small stream width logically translates to fewer pure stream pixels and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher variability and inaccuracies in the measured radiant temperatures as more 'mixed pixels' are sampled. This is a consideration especially when sampling the radiant temperatures at tributary mouths and surface springs.

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

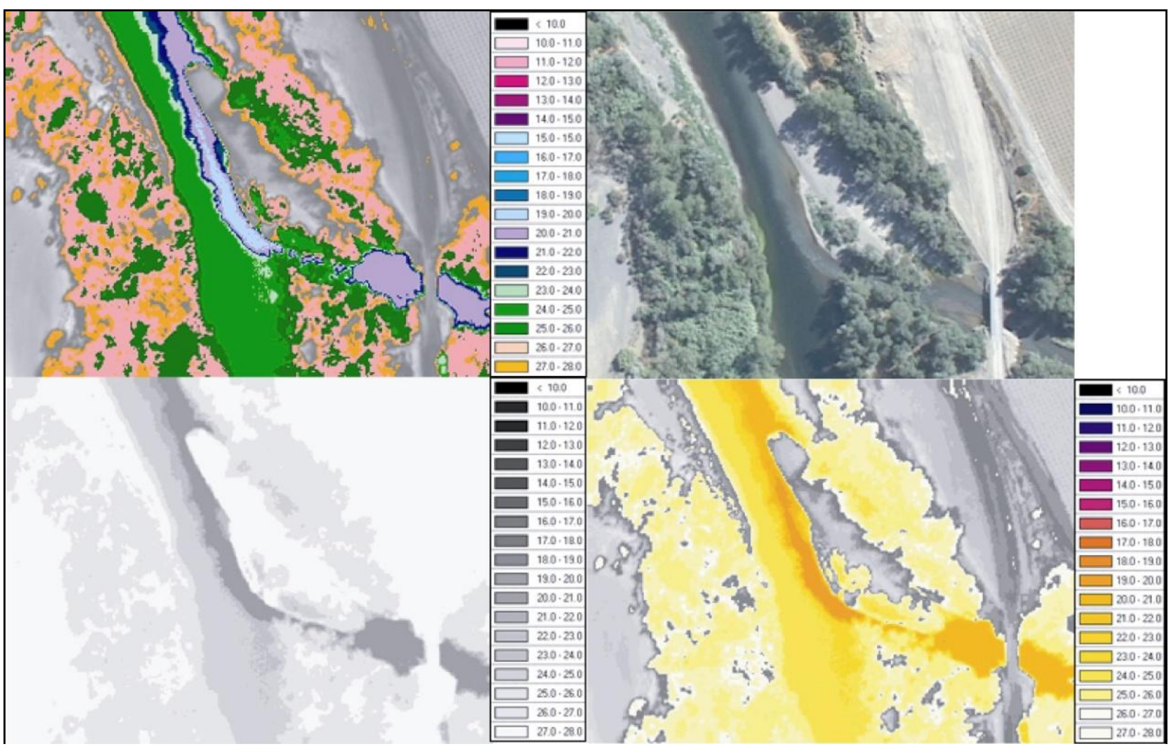
3.3 Image Uniformity

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

3.4 Temperatures and Color Maps

The TIR images collected during this survey consist of a single band. As a result, visual representation of the imagery *(in a report or GIS environment*) requires the application of a color map or legend to the pixel values. The selection of a color map should highlight features most relevant to the analysis (i.e. *spatial variability of stream temperatures*). For example, a continuous, gradient style color map that incorporates all temperatures in the image frame will provide a smoother transition in colors throughout the entire image, but will not highlight temperature differences in the stream. Conversely, a color map that focuses too narrowly cannot be applied to the entire river and will washout terrestrial and vegetation features (*Figure 6*).

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



4. Data Processing

4.1 Sensor Calibration

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

The calculated radiant temperatures are adjusted based on the kinetic temperatures recorded at each ground truth location. This adjustment is performed to correct for path length attenuation and the emissivity of natural water. The in-stream data are assessed at the time the image is acquired, with radiant values representing the median of ten points sampled from the image at the data logger location.

4.2 Geo-referencing

During the survey, the images are tagged with a GPS position and heading at the time they are acquired. Since the TIR camera is maintained at vertical down-look angles, the geographic coordinates provide a reasonably accurate index to the location of the image scene. However, due to the relatively small footprint of the imagery and independently stabilized mount, image pixels are not individually registered to real world coordinates. The image index is saved as an ESRI point shapefile containing the image name registered to an X and Y position of the sensor and the time of capture (*Figure 3*).

4.3 Geo-rectification

Individual TIR frames are manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and imagery available for the area. The images are then warped using a 1st order polynomial transformation. The 20-cm orthorectified imagery from the LiDAR project was used for the rectification. The focus of the rectification was aligning the stream channel. Due to the steep canyon walls in areas, upslope features may have significant offsets.

4.4 Interpretation and Sampling

Once calibrated, the images are integrated into a GIS in which an analyst interprets and samples stream temperatures. Sampling consists of querying radiant temperatures (pixel values) from the center of the stream channel and saving the median value of a ten-point sample to a GIS database file. The temperatures of detectable surface inflows (e.g. surface springs, tributaries) are also sampled at their mouths. During sampling, the analyst provides interpretations of the spatial variations in surface temperatures observed in the images.

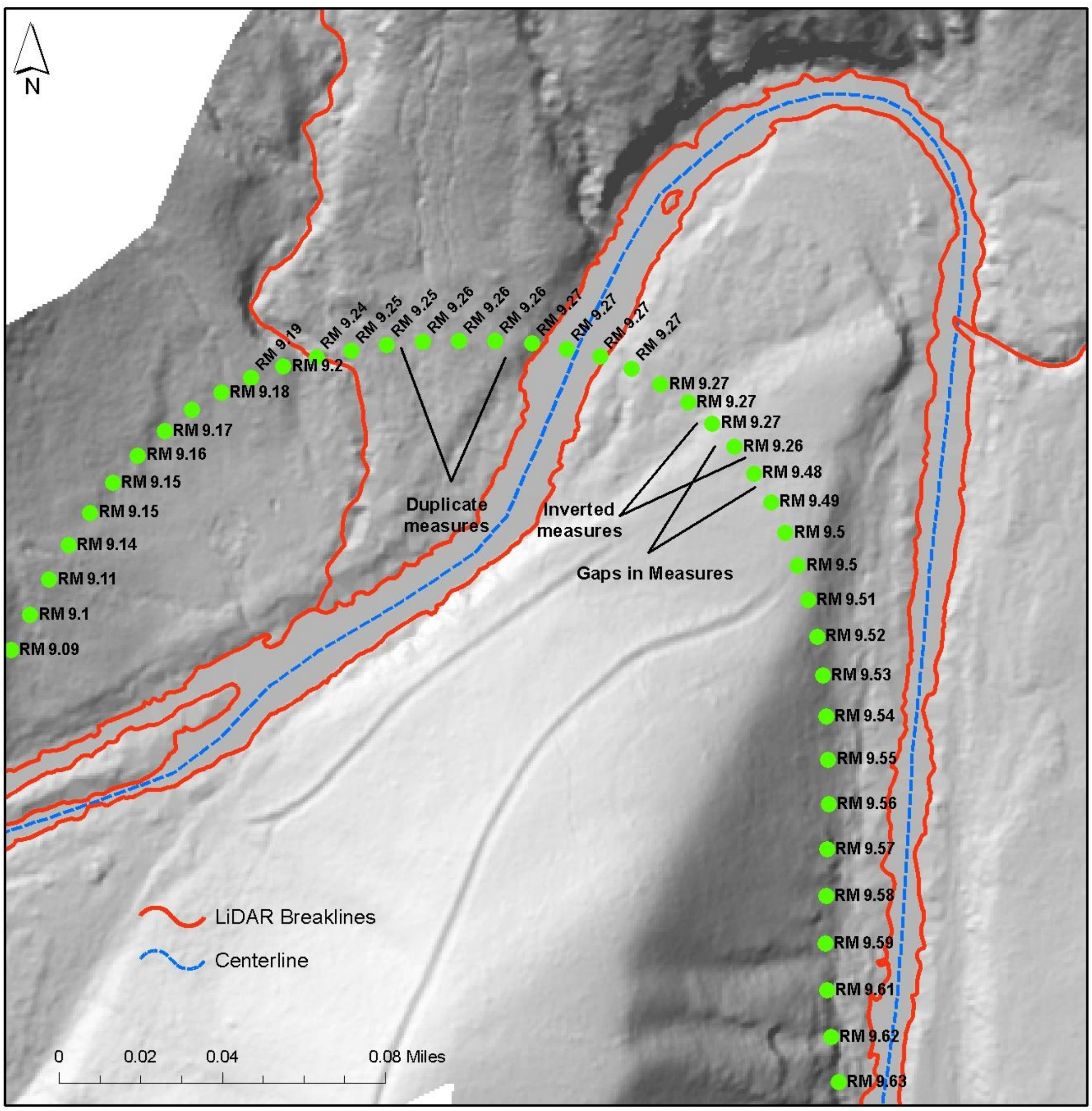
4.5 Temperature Profiles

In order to provide further spatial reference, the image index shapefile is assigned an approximate river mile based on a routed stream layer. The median temperature for each sampled image frame is plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient. The location and median temperature of all sampled surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the mainstem temperature patterns. Radiant temperatures are only sampled along the main flow channel in the river.

River miles in this report are only approximate as there is inherent difficulty in measuring a straight flight line against a sinuous river channel. River mile measures of tributaries and inflows should be used with discretion outside the scope of this report (*Figure 7)*.

The route measures are based on the LiDAR derived hydrography breaklines which represent the wetted channel (double line) for channel widths greater than 100 feet and the stream centerline for channel widths less than 100 feet. A stream centerline was manually digitized for the double-line reaches of river. For narrower channels such as the upper reach of North Fork Battle Creek, Ripley Creek and Soap Creek, single-line stream breaklines were used as the centerline.

Figure 7. The image below illustrates discrepancies which occur in assigning river miles to the TIR survey points along a sinuous channel such as Battle Creek. The digitized stream centerline is also shown based on the wetted channel breaklines.



5. Thermal Accuracy

Watershed Sciences used data from the USFWS's in-stream data loggers, as well as 3 additional Hobo Pro sensor placements, to calibrate and validate the thermal imagery (*Figure 5*). Table 5 summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images. The differences between radiant and kinetic temperatures were consistent with other airborne TIR surveys conducted in the Pacific Northwest and within the target accuracy of ±0.5°C with two exceptions.

The USFWS sensor at Eagle Canyon Dam fell well outside the accuracy limits with the in-stream sensor reading 17.8°C while the radiant temperature of the imagery was 14.2°C. There is no clear explanation of this discrepancy; however, because sensors upstream and downstream calibrated well, this sensor was not used in the calibration.

The USFWS sensor on South Fork Battle Creek below Coleman Canal (RM 2.41) appears to have been reading air temperature (31.1°C/ 88.0°C) and was therefore not used in the calibration. The WSI sensor just downstream at Long Road (RM 1.69) was within the target accuracy.

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

Stream	River Mile	Sensor Owner	Serial #	Image	Time	In-stream Temp (°C)	Radiant Temp (°C)	Difference
AUGUST 23, 2011								
Battle Creek								
Battle	3.90	WSI	9951845 @ Gover Road	Battle0085	14:09:55	19.0	19.1	-0.1
Battle	7.72	USFWS	BattleCabColemanPH Coleman@Creek7.5	Battle0419	14:15:29	17.3	17.6	-0.3
Battle	16.18	USFWS	BattleCBNSFconflDara SpringsAboveBaldwin	Battle1219	14:28:49	16.3	16.2	0.1
North Fork Battle Creek								
NF Battle	0.79	WSI	2386978 @ Wildcat Road	NFBatt 1402	14:31:00	16.6	16.7	-0.1
NF Battle	5.27	USFWS	BattleCNF @EagleCnynDam5.1	NFBatt 1857	14:39:00	17.8	14.2	3.6
NF Battle	9.49	USFWS	BattleCNF @NBattleFdrDam	NFBatt 2389	14:48:19	14.1	13.7	0.4
South Fork Battle, Ripley Creek, Soap Creek								
Battle	-	USFWS	BattleCBNSFconflDara SpringsAboveBaldwin	SFBatt0010	22:54:00	16.8	16.7	0.1
SF Battle	1.69	WSI	9951841 @ Long Road	SFBatt 0169	22:57:00	15.9	16.2	-0.3
SF Battle	2.41	USFWS	Battle CSFblColeman Canal	SFBatt 0234	22:58:05	**31.1**	16.3	14.8
SF Battle	8.07	USFWS	Inskip Canal	SFBatt 0914	23:16:44	15.9	15.6	0.3

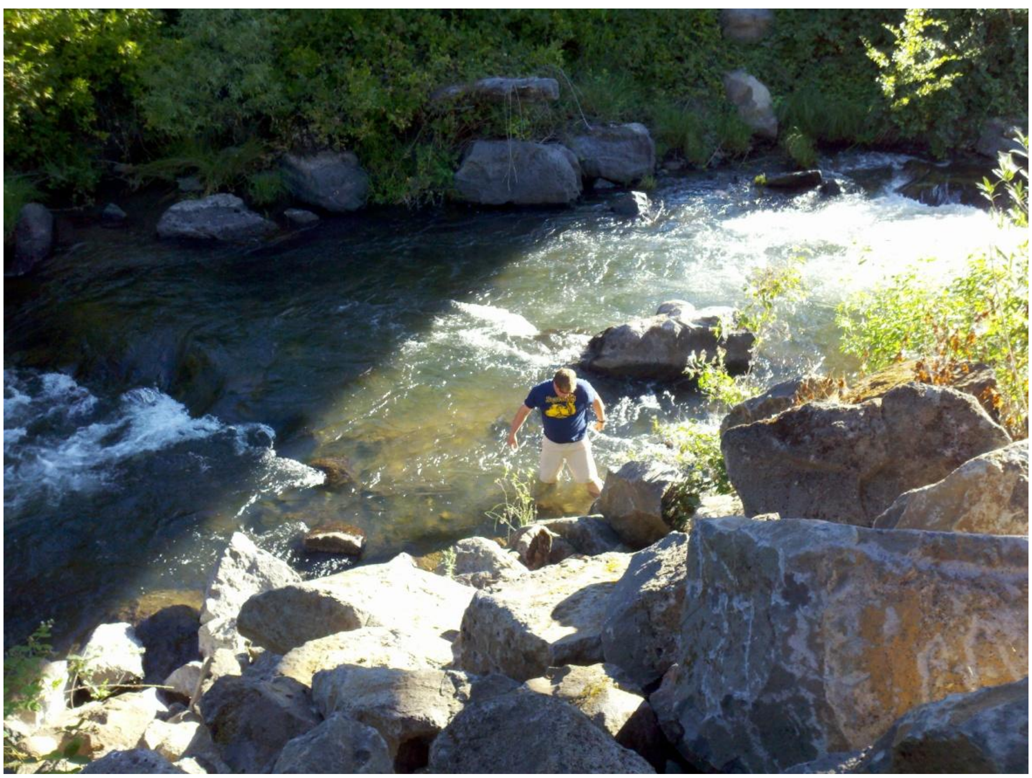
6. Study Area Results

Median channel temperatures were plotted versus river mile for the streams in the survey area. Tributaries, springs, and inflows sampled during the analysis are included on the longitudinal profiles, as well as diversions and relevant landmark features, to provide additional context for interpreting spatial temperature patterns. If there was any doubt about the source of a feature, it was flagged in the sampled shapefile. These locations should be verified in the field to confirm the presence of groundwater.

The stream gradient is also plotted on the longitudinal profiles. The stream centerline was used to extract elevation values in meters from the LiDAR digital elevation models.

Due to the nature of the project, the focus of the survey was to depict the thermal conditions during peak temperatures. Given the warm temperatures on the days of the survey, features such as warm canals or ponds may have been 'washed out' in comparison to the surrounding terrestrial landscape.

It is important to reiterate that temperature changes of less than ± 0.5°C in the absence of a point source should be interpreted with caution until verified in the field due to the inherent nature of the thermal imagery. The sample images contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations. Color ramps in the sample images are unique for each stream.



WSI field personnel placing a Hobo Pro in North Fork Battle Creek, August 23, 2011

6.1 Battle Creek

6.1.1 Longitudinal Temperature Profile

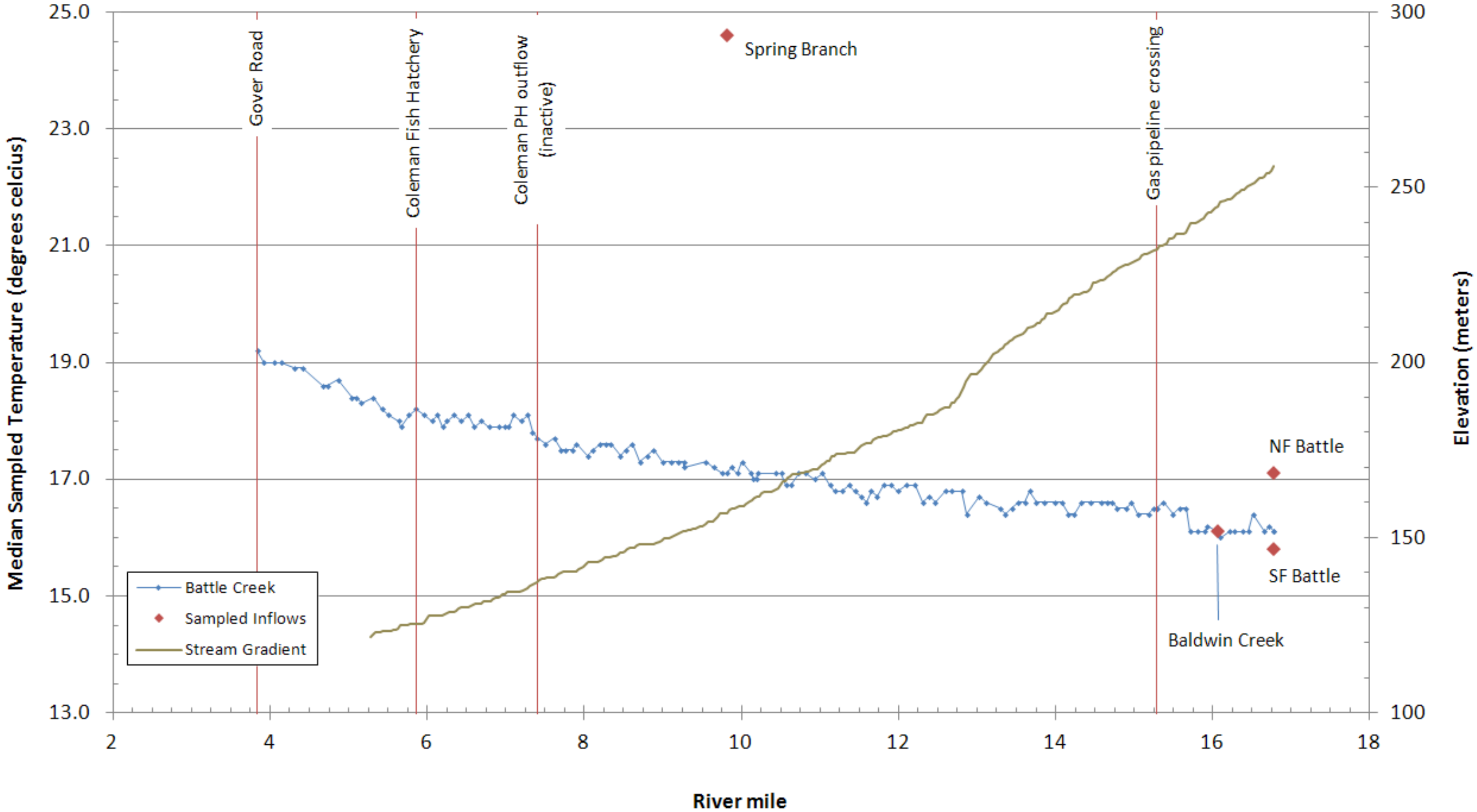


Figure 8. Median sampled temperatures versus river mile for Battle Creek with stream gradient on the secondary axis. The locations of detected surface inflows are illustrated on the profile and listed in Table 6. River miles are cumulative from the mouth of Battle Creek.

Table 6. Tributaries and other surface inflows sampled along Battle Creek with left or right bank designation (looking downstream)

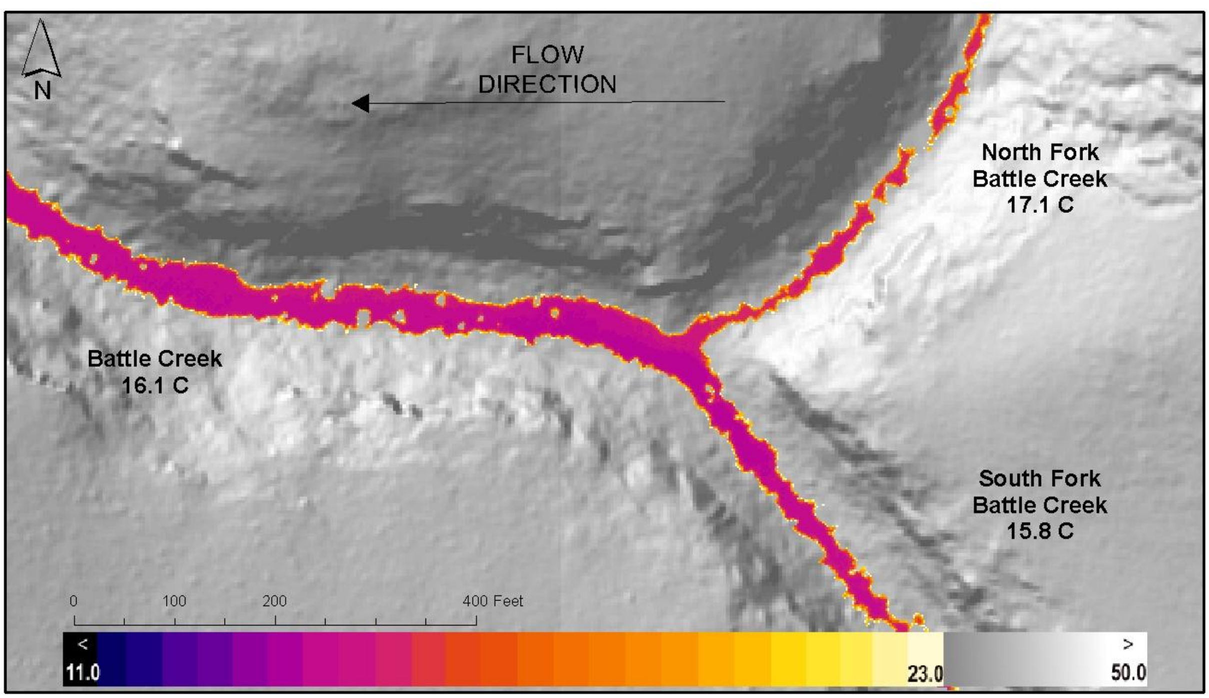
Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Spring Branch (L)	15.79	9.81	24.6	17.1	7.5
Baldwin Creek (R)	25.85	16.06	16.1	16.1	0.0
NF Battle Creek (R)	27.00	16.78	17.1	16.1	1.0
SF Battle Creek (L)	27.01	16.78	15.8	16.1	-0.3

6.1.2 Observations

Thirteen miles of Battle Creek were surveyed on August 23, 2011 from the Gover Road Bridge to the North Fork/South Fork Battle Creek confluence (*Figure 8*). Four tributaries were sampled in the imagery including South Fork and North Fork Battle Creek (*Table 6*). South Fork Battle Creek controlled the thermal regime at the upstream end of the survey by contributing a higher volume of water at colder temperatures (*Figure 9)*. Bulk water temperatures showed a gradual warming over the course of the survey from 16.1→19.2˚C as expected on a warm summer day in the absence of cool inflows.

Spring Branch and Baldwin Creek appeared to have no impact on the overall profile. At the time of the survey, the Coleman Powerhouse did not appear to be contributing return flows to the stream. The stream gradient did not appear to have any impact on the thermal regime of the stream.

Figure 9. The TIR/LiDAR bare earth hillshade below shows the confluence of North and South Fork Battle Creek. South Fork Battle Creek controls the thermal regime at this location, however, the bulk of the water volume in the South Fork is supplied by diversions from North Fork Battle Creek via the Inskip and South Powerhouse outlets.



6.2 North Fork Battle Creek

6.2.1 Longitudinal Temperature Profile

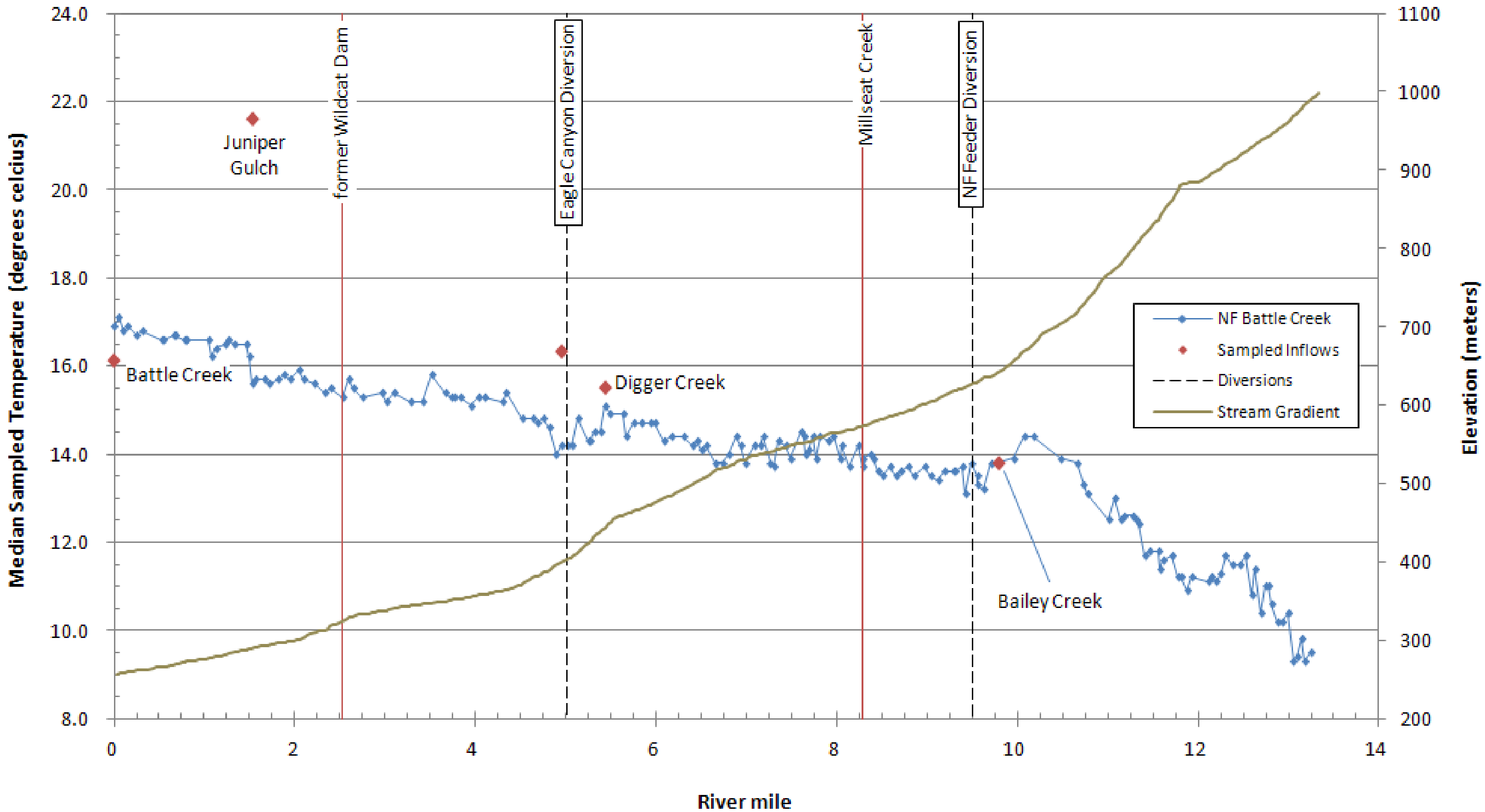


Figure 10. Median channel temperatures plotted versus river mile for North Fork Battle Creek with stream gradient on the secondary axis. The locations of detected surface inflows are illustrated on the profile and listed in Table 7.

Table 7. Tributaries and other surface inflows sampled along North Fork Battle Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Battle Creek	0.00	0.00	16.1	16.9	-0.8
Juniper Gulch (L)	2.46	1.53	21.6	15.6	6.0
Eagle Canyon Ditch (L)	7.96	4.95	16.3	14.2	2.1
Digger Creek (L)	8.74	5.43	15.5	15.1	0.4
Bailey Creek (L)	15.76	9.79	13.8	13.8	0.0

6.2.2 Observations

Thirteen miles of North Fork Battle Creek were surveyed on August 23, 2011 from the confluence with South Fork Battle Creek upstream to the Manton-Ponderosa Road crossing (*Figure 10*). Four tributaries were sampled in the imagery (*Table 7*). Temperatures ranged from 8.7˚C near the upstream end of the survey to 17.1˚C at the confluence.

Two diversions were noted in the imagery, the Eagle Canyon Diversion Dam (RM 8.08) and the North Fork Feeder Diversion Dam (RM 9.56). It is unclear from the imagery if the Eagle Canyon Diversion was actively diverting water; however, some warming was seen in the profile immediately downstream. The volume of water being diverted at the time of the survey by the North Fork Feeder Diversion did not appear to have a significant impact on the overall thermal properties of the stream (*Figure 11*).

Just above the confluence with Bailey Creek (RM 9.79), the warming seen in the upper reaches of the North Fork slowed dramatically as bulk water temperatures plateau near 14˚C. The canyon narrows at this location and the stream gradient lessens slightly. These types of morphology changes along with a convergence of two drainages typically result in an increase in groundwater interactions and cooling temperatures (*Figure 12*).

The thermal plateau continued downstream to Digger Creek (RM 5.43). Though Digger Creek (15.5˚C) sampled warmer than the North Fork, a slight drop in temperature occurred downstream of the confluence (15.1→14.5˚C). Due to the narrowness of the stream, this decrease could simply be due to mixed pixel sampling introducing variability or it could indicate increased groundwater interaction due to two intersecting drainages.

A second thermal plateau occurred downstream of the Eagle Canyon Diversion from river mile 4.34 to Juniper Gulch (RM 1.53) with temperatures stabilizing near 15.2˚C. This is an indication of increased groundwater interaction though no definitive point sources were seen in the imagery. Juniper Gulch (21.6˚C) was a warming influence to the North Fork raising bulk water temperatures from 15.6→16.2˚C.

Figure 11. The TIR/LiDAR hillshades below show the diversions on North Fork Battle Creek at Eagle Canyon and the North Fork Feeder. It was not possible to determine how much flow was being diverted in either location; however, the thermal profile shows little response indicating minimal flow diversions.

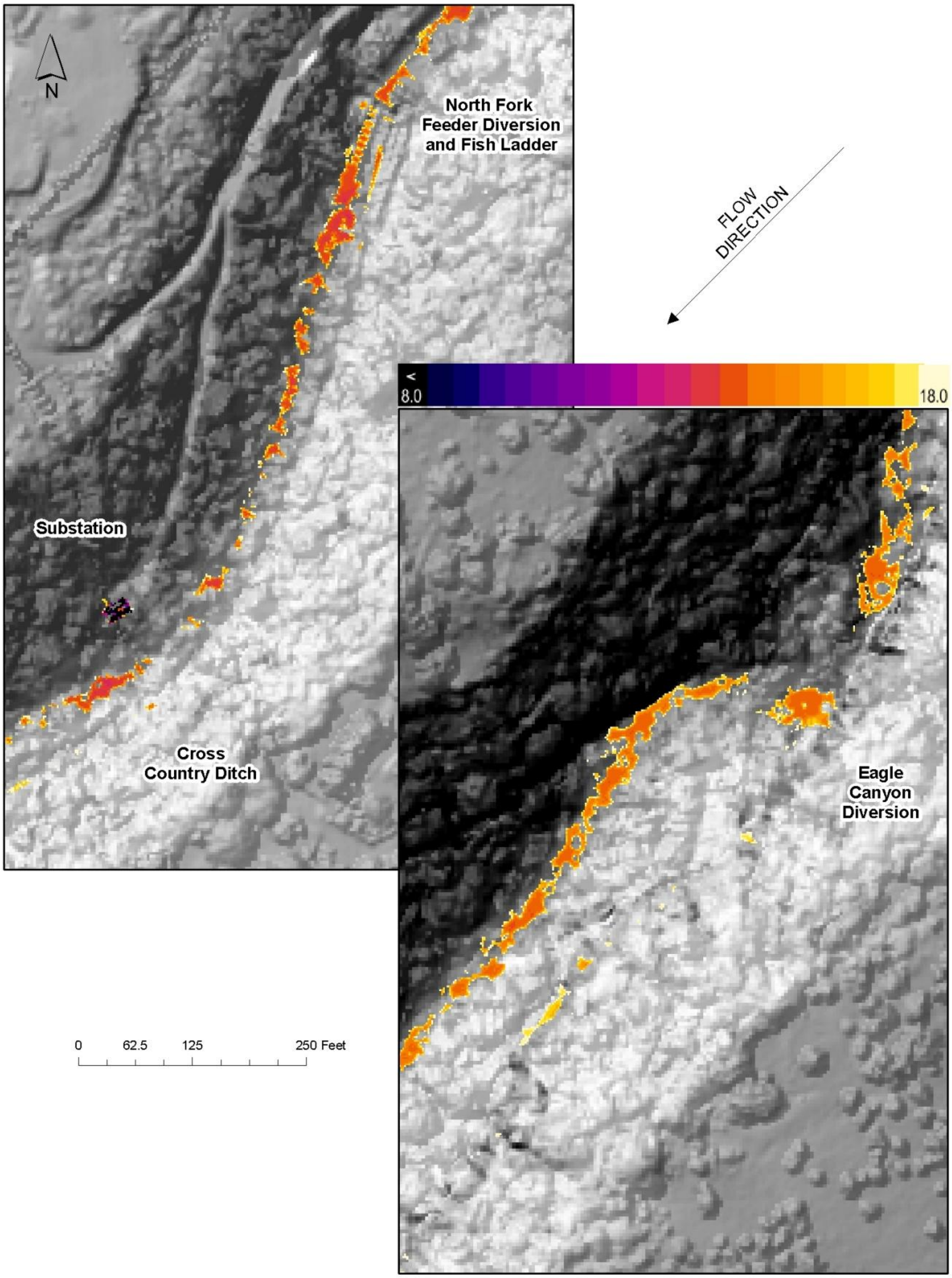
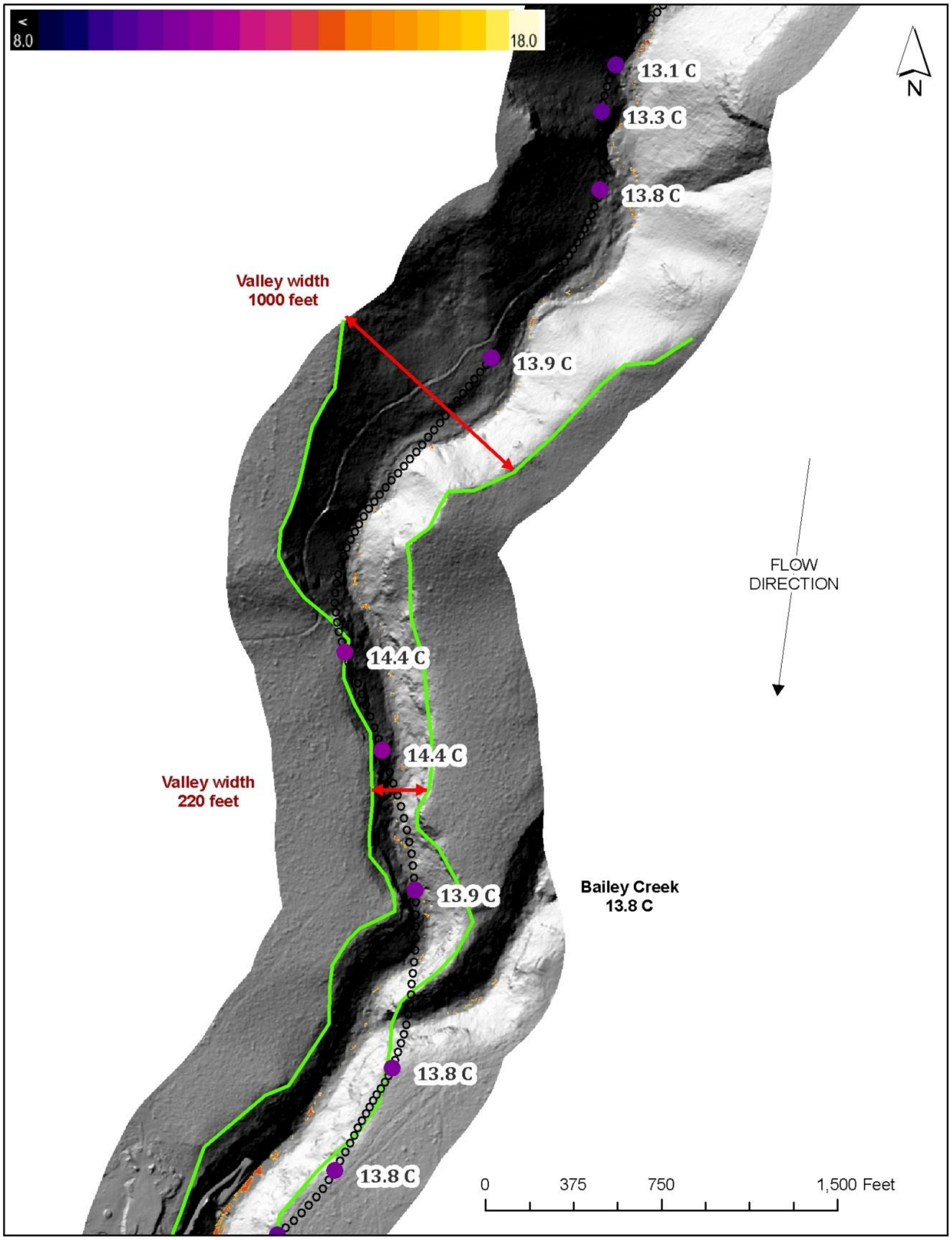


Figure 12. The TIR/LiDAR image below shows the narrowing of the canyon just upstream of the confluence of North Fork Battle Creek and Bailey Creek. The upstream warming trend changes to a thermal plateau near this location indicating cooler inflows and groundwater interactions.



6.3 South Fork Battle Creek

6.3.1 Longitudinal Temperature Profile

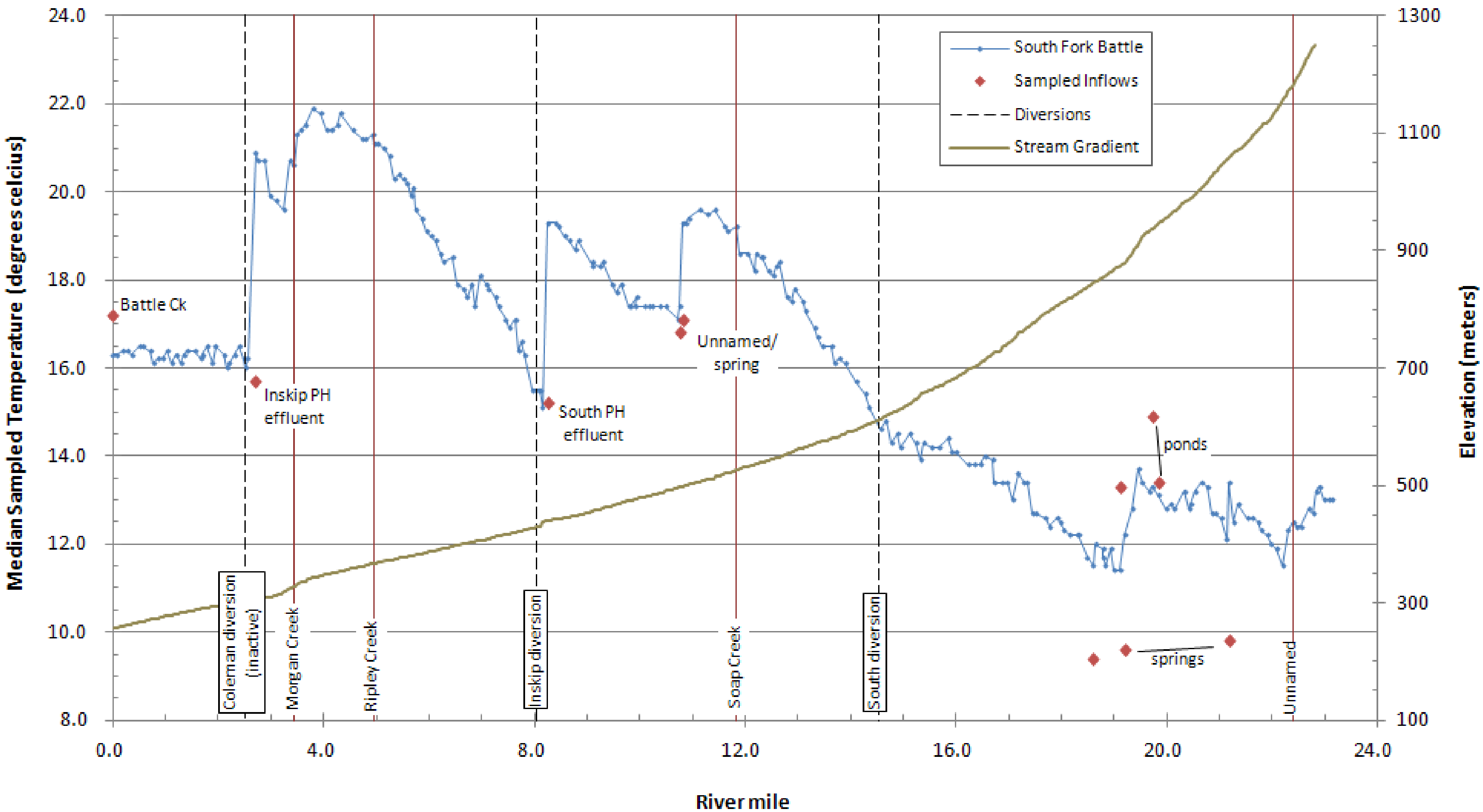


Figure 13. Median channel temperatures and stream gradient plotted versus river mile for South Fork Battle Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 8.

Table 8. Tributaries and other surface inflows sampled along South Fork Battle Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
NF Battle Creek (R)	0.00	0.00	17.2	16.3	0.9
Inskip PH Effluent (R)	4.34	2.70	15.7	20.9	-5.2
South PH effluent (R)	13.28	8.25	15.2	19.3	-4.1
Unnamed (R)	17.31	10.76	16.8	17.4	-0.6
spring? (L)	17.40	10.81	17.1	19.3	-2.2
Unnamed@Cline Ranch (L)	29.93	18.60	9.4	11.5	-2.1
Panther Creek (R)	30.74	19.10	13.3	11.4	1.9
spring (L)	30.90	19.20	9.6	12.2	-2.6
pond (L)	31.73	19.72	14.9	13.3	1.6
pond (L)	31.92	19.83	13.4	13.1	0.3
spring (L)	34.07	21.17	9.8	13.4	-3.6

6.3.2 Observations

Almost 23 miles of South Fork Battle Creek were surveyed on August 23, 2011 from the confluence with North Fork Battle Creek upstream to the Road 140A crossing (*Figure 13*). Eleven inflows were sampled in the imagery (*Table 7*). Three diversions were located along the survey reach: the South Diversion (RM 14.56), the Inskip Diversion (RM 8.07) and the Coleman diversion which appeared to be inactive at the time of the survey (RM 2.52).

In the upper portion of the survey (RM 18.60-21.17), an unnamed stream and two springs result in localized cooling with contributions of 9.4, 9.6, and 9.8°C water. Downstream of this reach, the stream begins warming in the absence of cool inflows. Downstream of the South Diversion (RM 14.56), the rate of warming increases with the decrease in flow. The South Diversion is scheduled for removal as part of the Battle Creek Restoration Project[6].

Near river mile 10.80, a spring (17.1°C) and an unnamed stream (16.8°C) lower the bulk water temperatures from 19.3 →16.8°C. Further warming continues downstream of this point until the inflow of the South Powerhouse (15.2°C) which drops the temperatures over 4°C (19.3→15.1°C). The South Powerhouse flows are sourced from a mix of cooler water from the South Diversion (14.6°C) and the North Fork Feeder Diversion (13.3°C). The South Powerhouse effluent will be re-routed away from the natural channel as part of the Restoration Plan (*Figure 14*).

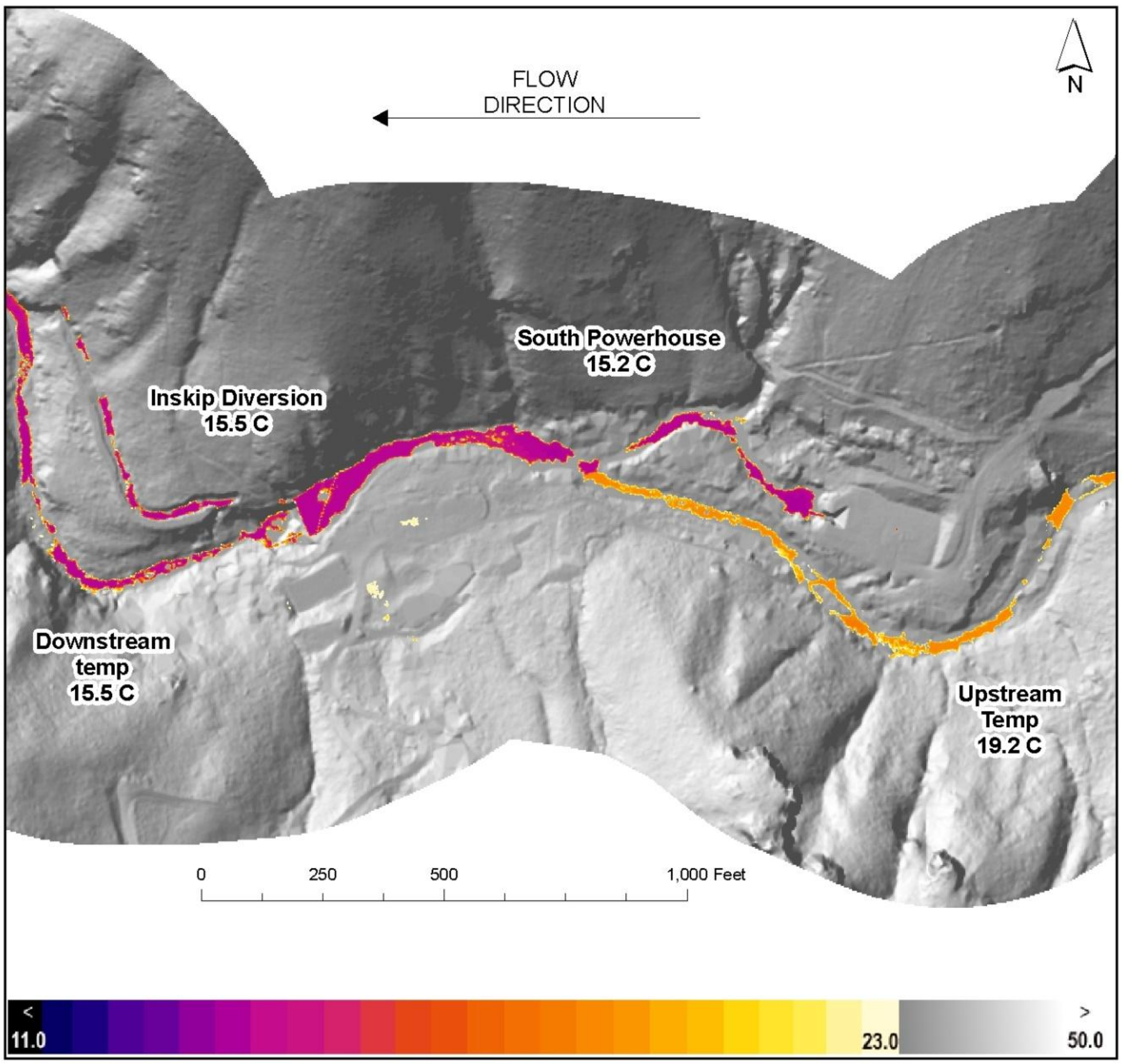
Immediately downstream of the South Powerhouse, the Inskip Diversion funnels water to the Inskip Canal. Over the next 4.25 miles, this loss of volume results in rapid warming downstream of the diversion from 15.2→21.9°C. At river mile 3.43, Morgan Creek and Mason Springs were just outside the footprint of the imagery; however, a significant amount of localized cooling can be seen in the temperature profile downstream of the confluence (*Figure 15*).

[6] Battle Creek Watershed Conservancy, Battle Creek Salmon & Steelhead Restoration Project Documents. http://www.battle-creek.net/restoration.html. Accessed November 2011.

At river mile 2.70, the Inskip Powerhouse effluent drops temperatures from 20.9→16.2°C (*lower right cover image*). The inflow is sourced from the Inskip Diversion (15.1°C) and the Eagle Canyon Diversion from North Fork Battle Creek, when active. After restoration is complete, no discharge from Inskip Powerhouse will enter the natural channel. The Coleman Diversion Dam just downstream (RM 2.52) was not actively diverting water at the time of the survey and will be decommissioned during Phase 2 of the restoration project[7].

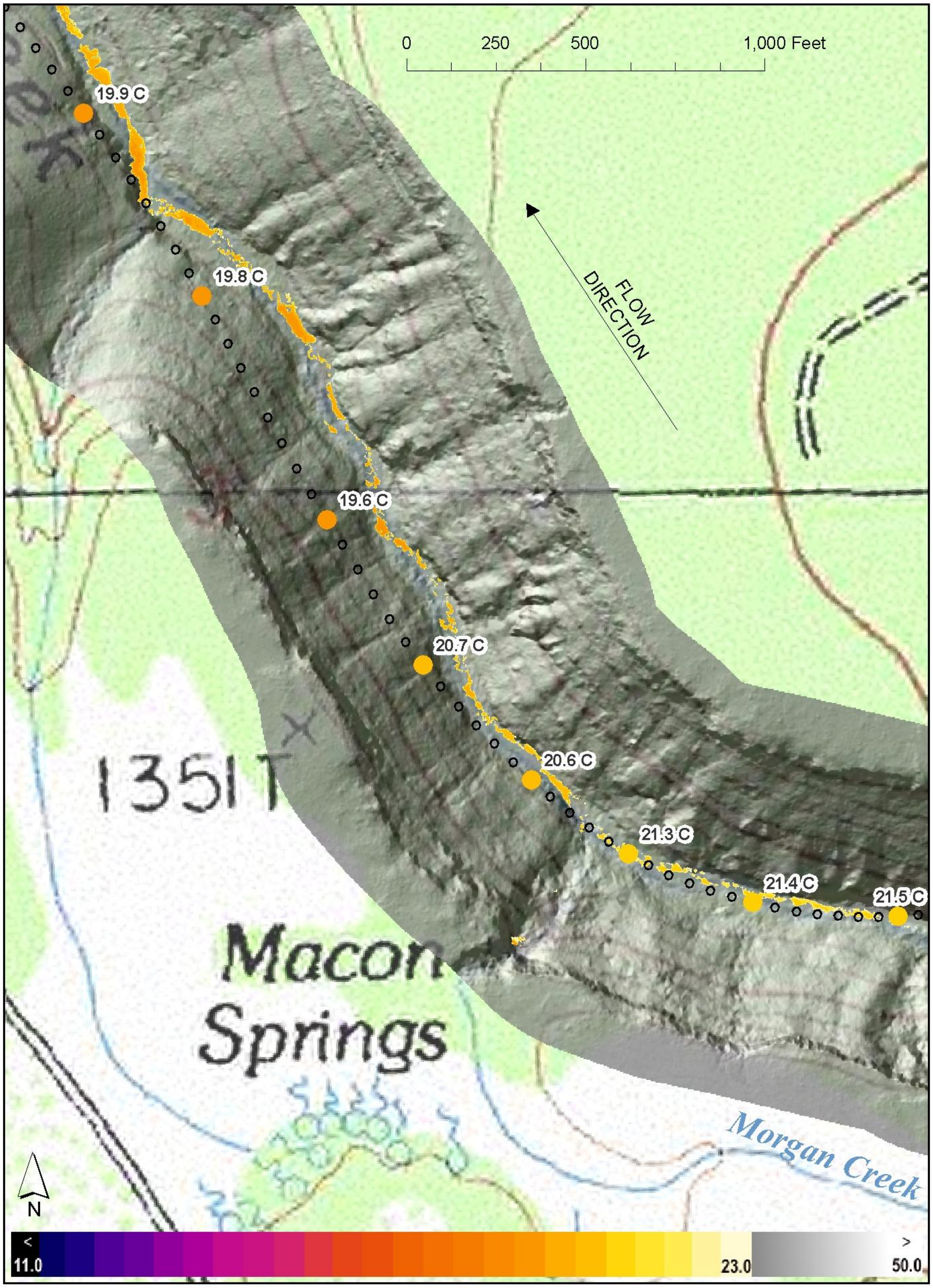
Temperatures plateau near 16.2°C along the final 2.7 miles in the lower reach of the South Fork. On the date of the survey, Soap Creek and Ripley Creek had no significant impact on the overall thermal profile due to lack of water. The consistent stream gradient also has little influence on the thermal profile.

Figure 14. The TIR/LiDAR hillshade below shows the South Powerhouse tailrace release at river mile 8.25. The inflow drops the bulk water temperatures in the natural channel 4.0°C.



[7] Battle Creek Watershed Conservancy, Battle Creek Salmon & Steelhead Restoration Project Documents. http://www.battle-creek.net/restoration.html. Accessed November 2011.

Figure 15. The TIR/LiDAR hillshade in conjunction with the digital raster graphic shows the localized cooling in the vicinity of Macon Springs and Morgan Creek. Though there was minimal surface water visible in the imagery, the cooling temperatures indicate groundwater influence.



6.4 Ripley Creek

6.4.1 Longitudinal Temperature Profile

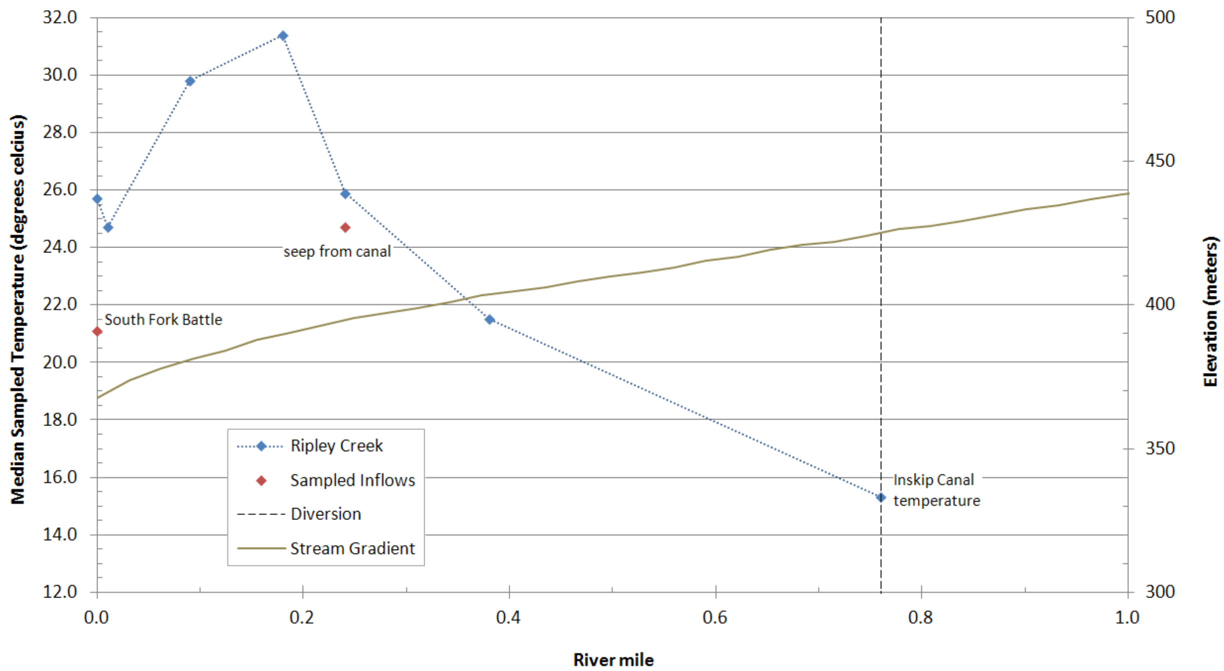


Figure 16. Median channel temperatures and stream gradient plotted versus river mile for Ripley Creek.

6.4.2 Observations

Less than one mile of Ripley Creek was surveyed on August 23, 2011. Above the Ripley Creek Diversion Dam there was no visible surface water in the stream channel. Downstream of the diversion, the heavy vegetation and limited water made sampling difficult. Due to the warm temperatures, it is possible that the sampled locations were standing pools.

6.5 Soap Creek

6.5.1 *Longitudinal Temperature Profile*

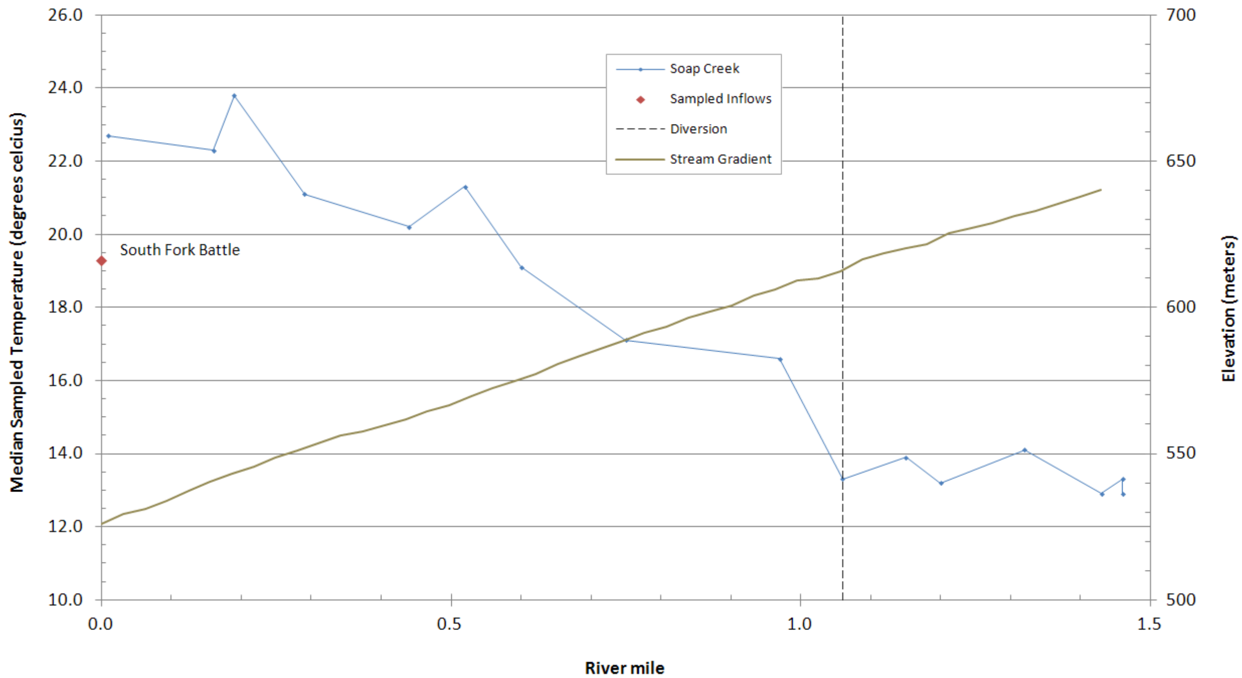


Figure 17. Median channel temperatures and stream gradient plotted versus river mile for Soap Creek.

6.5.2 *Observations*

Approximately 1.50 miles of Soap Creek were surveyed on August 23, 2011 from the confluence with South Fork Battle Creek upstream beyond the Soap Creek Feeder Diversion Dam. Due to the small size of the stream and the dense riparian vegetation, sample points were limited and sampled temperatures should not be considered absolute. Regardless, there is an obvious decrease in water volume and increase in temperature downstream of the diversion as temperatures rise from near 13.0°C to 24.0°C.

7. Summary

Fifty-two miles of stream in the Battle Creek Subbasin were surveyed on August 23, 2011. While bulk water temperatures of North Fork Battle Creek are generally cooler, ranging from 9-17°C, South Fork Battle Creek (11-22°C) currently controls the thermal regime of mainstem Battle Creek (16-19°C) due to the higher discharge rates. As restoration progresses, the longitudinal temperature profile of the South Fork should show less variability as diversions are decommissioned and powerhouse discharges are re-routed. Soap Creek and Ripley Creek did not contain enough water at the time of the survey to have an impact on the South Fork.

8. Projection/Datum and Units

Geo-corrected mosaics, surveys, and shapefiles are delivered in the following projection:

Projection:	UTM Zone 10
Horizontal Datum:	NAD83
Units:	meters

9. Deliverables

The TIR imagery is provided in two forms: individual un-rectified frames and a continuous geo-rectified mosaic at 0.6 m (2.0 ft) resolution. The mosaics allow for easy viewing of the continuum of temperatures along the stream gradient, but also show edge match differences and geometric transformation effects. The un-rectified frames are useful for viewing images at their native resolutions and are often better for detecting smaller thermal features. Radiant temperatures are calibrated for the emissive characteristics of water and may not be accurate for terrestrial features.

Vector Data:	• *Thermal Surveys*. Sampled TIR point shapefiles by stream, showing image locations, sampled temperatures, and image interpretations. • *Hydrography*. Stream Centerline shapefile
Raster Data:	• *Thermal Mosaics*. Continuous mosaics of the geo-rectified TIR image frames at varying resolutions in ERDAS Imagine (*.img) format. (Cell value = radiant temperature * 10) • *Thermal Frames Unrectified*. Calibrated TIR images in Erdas Imagine (*.img) format. (Cell value = radiant temperature * 10)
Spreadsheets:	*Long Profiles*. Excel spreadsheets by stream containing the longitudinal temperature profiles for each stream
Data Project:	*ArcMap 9.3 project* (*.mxd) containing the thermal surveys and thermal mosaics displayed with the corresponding colorramps.
Data Report:	Full report containing introduction, methodology, accuracy, and analysis