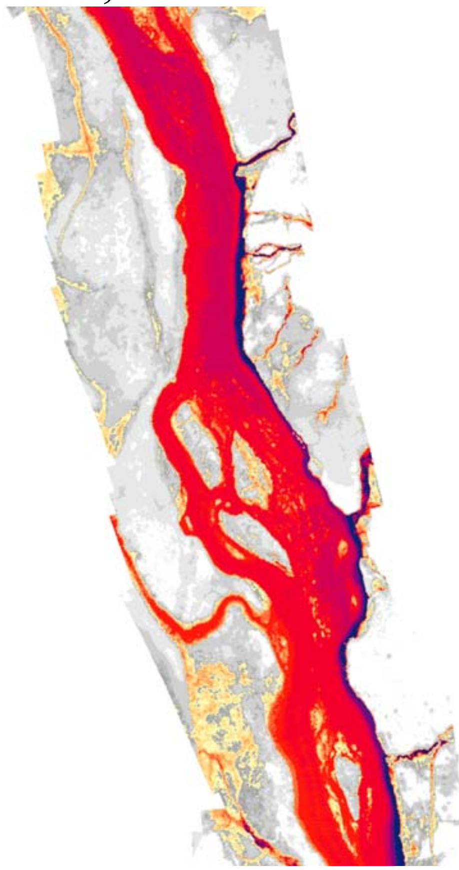
Airborne Thermal Infrared Remote Sensing

Bear River Basin, ID/WY/UT



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Overview

In 2006, Pacificorp and Trout Unlimited contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) and true color digital imagery of selected streams in the Bear River basin in Idaho, Wyoming, and Utah (Figure 1). Surveyed streams included the Bear River from Cutler Reservoir upstream to Cokeville, WY, Cub River, Thomas Fork/Salt Creek, and Smiths Fork/Hobble Creek. The data were successfully acquired from July 24-29, 2006, during the mid-afternoon hours (1:30 to 5:00 PM). Flight times and dates for specific stream segments (*primarily the Bear River and tributaries upstream from the town of Soda Springs, ID*) were coordinated with Ryan Hillyard at Idaho Fish and Game prior to the survey (Table 1).

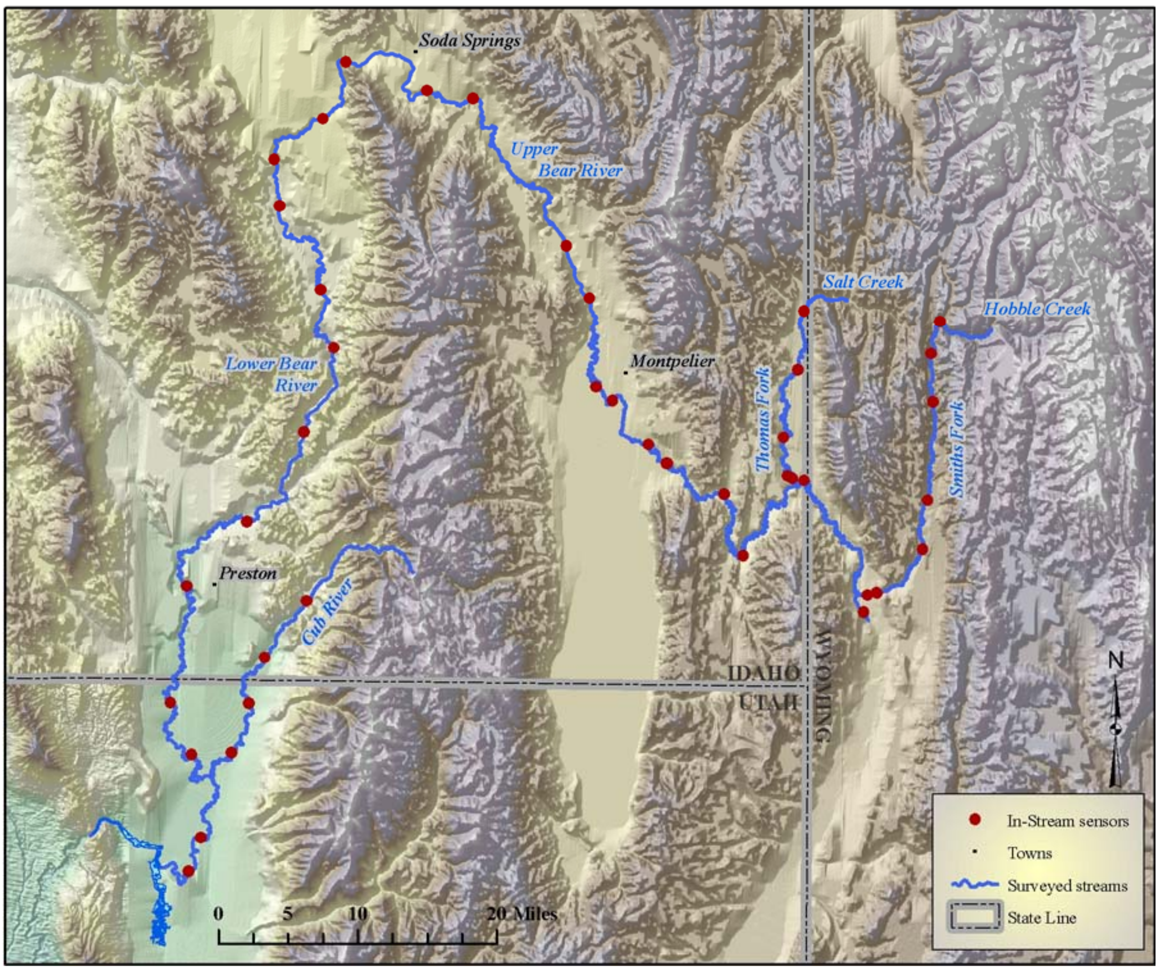


Figure 1 – Airborne Thermal Infrared Surveys in the Bear River Basin from July 24 – 29, 2006. The map shows the location of in-stream sensors deployed by Watershed Sciences, Inc. for the time span of the airborne surveys.

Table 1 – Dates, Flight Times, and Extents for TIR surveys conducted on the Bear River and selected tributaries.

Date	Time (MST)	Stream	Extent
24-Jul	13:51 - 15:42	Bear River	Thomas Fork to Hwy 89 near Montpelier, ID
25-Jul	13:51 - 15:08	Bear River	Hwy 89 Bridge to Alexander Reservoir
26-Jul	15:44 - 16:51	Smiths Fork Hobble Creek	Bear River Confluence to Hobble Creek Smiths Fork to Coantag Creek
27-Jul	14:14 - 15:06	Thomas Fork Salt Creek Bear River	Bear River Confluence to Salt Creek Thomas Fork to Dipper Creek Cokeville, WY to Thomas Fork
28-Jul	13:59 - 17:31	Bear River	Alexander Reservoir to Idaho/Utah State Border
29-Jul	13:46 - 14:56	Cub River Bear River	Bear River Confluence to ~ Hillyard Canyon Bear River from Idaho/Utah State Border to Cutler Reservoir

Methods

Data Collection

Instrumentation: Images were collected with a Space Instruments FireMapper 2.0 sensor (8-12µm) mounted on the underside of a Bell Jet Ranger Helicopter (Figure 2). The TIR sensor was co-mounted with a high-resolution true color digital camera (*Nikon D2X w/ 24mm lens, 6.9 mega-pixels*). Both cameras were positioned to look vertically down from the aircraft (nadir). The Firemapper 2.0 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 Jet 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 and flown longitudinally along the stream channel.

Table 2 - Summary of TIR sensor specifications

Sensor:	Space Instruments Firemapper 2.0
Wavelength:	8-12µm
Temperature Resolution:	0.01°C
Noise Equivalent Temperature Differences (NETD)	0.07°C
Pixel Array	320 (H) x 240 (V)
Encoding Level:	16 bit
Horizontal Field-of-View:	44.3°

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

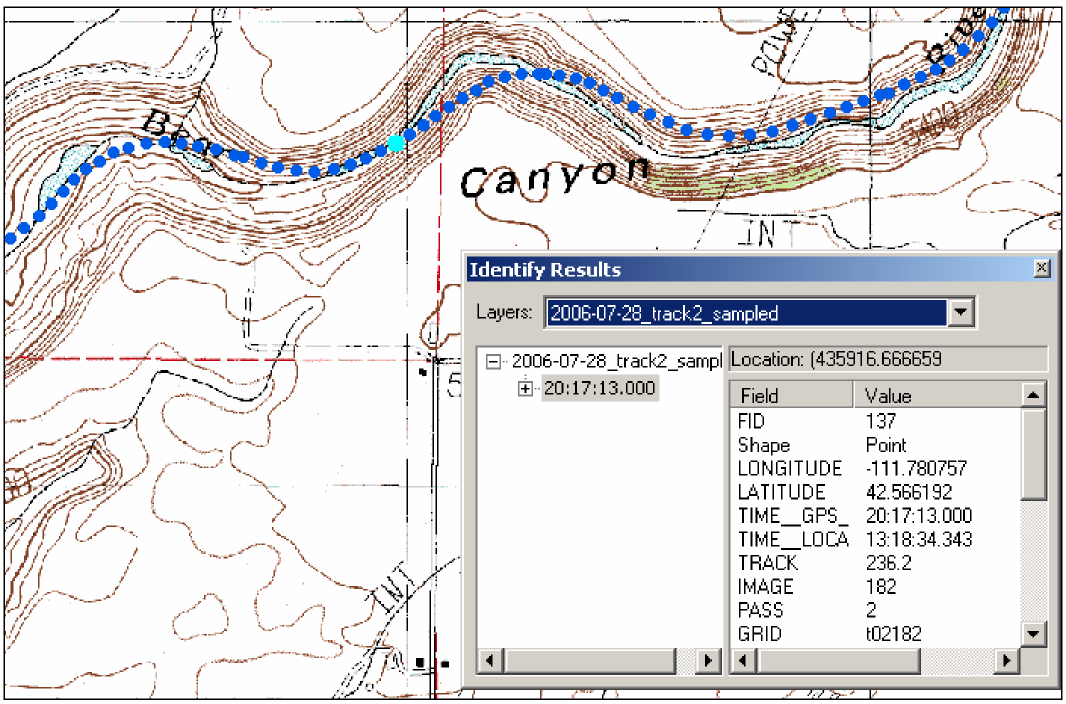


Figure 3 –Each point on the map represents a thermal image location. The inset box shows the information recorded with each image point during acquisition.

<u>Image Characteristics:</u> The aircraft was flown longitudinally along the stream corridor in order to have the river in the center of the display. The objective was for the stream to occupy 30-60% of the image. The TIR sensor is set to acquire images at its maximum rate (*~1 image/2 seconds*) resulting in considerable vertical overlap between images.

Flight altitude was selected based on stream size and sinuosity. Altitudes for the project ranged from 1000 ft to 1300 ft above ground level. The high degree of sinuosity on the lower reaches of the Smiths Fork and Thomas Fork required flights at slightly higher altitudes than originally planned. The native spatial resolution of the imagery ranged from 0.8 meter to 1 meter. A higher altitude pass was conducted over Alexander Reservoir in order to capture its full extent. Summary specifications of the acquisition parameters are listed in Table 3.

The airborne survey attempted to cover all connected surface water on the survey streams. Both channels were surveyed when multiple channels were encountered that could not be captured in a single pass. On the Bear River, the survey was conducted over both channels of the Bear River upstream of Rainbow Canal, although it appeared that the easternmost channel conveyed most of the flow.

Table 3 - Summary of Thermal Image Acquisition Parameters.

Dates:	July 24-29, 2006
Flight Above Ground Level (AGL):	1000 – 1300 ft (305 – 396 m)
Image Footprint Width:	822 – 1070 ft (251 – 326 m)
Pixel Resolution:	2.6 – 3.3 ft (0.8 – 1.0 m)

Ground Control: Watershed Sciences deployed in-stream data loggers (Onset Stowaways and TidBits) prior to the flight in order to calibrate and verify the accuracy of the TIR data. The data loggers were distributed at public access points along the survey extent. The sensors were placed on the bottom of the river in locations with good vertical mixing.

Data Processing

Calibration: Prior to the season, the response characteristics of the sensor are measured in a laboratory environment. The response curves related the raw digital numbers recorded by the sensor to emitted radiance from the black body. The raw TIR images collected during the survey initially contain raw digital numbers which are then converted to radiance ($W/m^2*sr*micron$) values based on the pre-season calibration.

The radiance values were adjusted based on a comparison of the measured radiance to the calculated radiance at each ground truth location. This adjustment was performed to correct for path length attenuation and the emissivity of natural water. The in-stream data were assessed at the time the image was acquired, with radiant values representing the median of ten points sampled from the image at the data logger location. The radiance values were then converted to surface temperatures using Planck's Black Body equation.

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

Temperature Profiles: The median temperatures for each sampled image were 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 main stem temperature patterns. Radiant temperatures were only sampled along what appeared to be the main flow channel in the river.

Geo-referencing: The images are tagged with a GPS position and heading at the time they are acquired (Figure 3). 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. 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 (UTM Zone 12, NAD83) of sensor location at time of capture. In order to provide further spatial reference, the TIR images were assigned a river mile based on a routed stream layer.

Geo-Rectification: When feasible, Leica Photogrammetry Suite (LPS)[1] was used for automated tie point generation and image ortho-rectification. Using LPS, images were geo-rectified to real world coordinates using the orientation of the imagery, ground control points, and a 10-meter digital elevation model (DEM) of the study area. This produced seamless geo-rectified mosaics of the TIR images. However, this method only worked on stream reaches with minimal sinuosity and accurate control points.

Where automated methods could not be used, individual frames were manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and existing orthophotos. The images were then warped using a 1st order polynomial transformation. Due to the low relief along the river bottom, the photos were not corrected for terrain displacement.

Thermal Image Characteristics

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 temperature. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed; however, thermal stratification can form in reaches that have little or no mixing. Thermal stratification in a free flowing river is inherently unstable due to variations in channel shape, bed composition, and in-stream objects (i.e. rocks, trees, debris, etc.) that cause turbulent flow and can usually be detected in the imagery. On the Bear River, thermal stratification was present in the larger reservoirs.

[1] Leica Geosystems Photogrammetry Suite (LPS)© is a collection of software tools that operates within ERDAS Imagine Software.

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%). However, variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.5°C (Torgersen et al. 2001[2]). However, the occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis. In general, apparent stream temperature changes of < 0.5°C are not considered significant unless associated with a surface inflow (e.g. tributary).

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.

Feature Size and Resolution: A small stream width logically translates to fewer pixels "in" the stream and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures. This is a consideration when sampling the radiant temperatures at tributary mouths and surface springs.

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 4).

[2] 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.

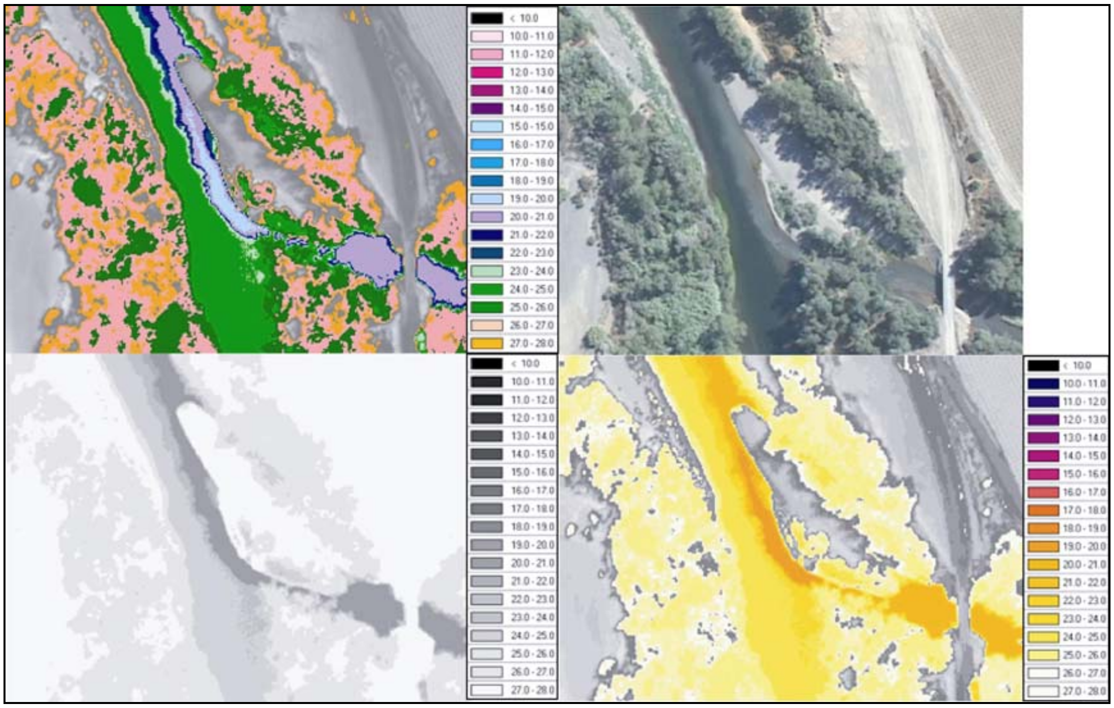


Figure 4 - Example of different color maps applied to the same TIR image.

<u>Image Uniformity:</u> 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. This sensor has an automatic correction scheme which nearly eliminates non-uniformity across the image frame.

Weather Conditions

Weather conditions were considered ideal for most of the survey days with warm air temperatures, relatively low humidity, and clear skies. On July 26, afternoon clouds formed over the upper reaches of the Smiths Fork and Hobble Creek. The presence of the clouds reduced the thermal contrast between the river and surrounding terrain, but otherwise did not influence the TIR imagery. Table 2 below summarizes the weather conditions during the dates of the survey. The weather data were acquired from local monitoring stations.

Image of the Bear River on 7/28/06. taken during the TIR survey.

Table 4 – Air temperatures measured in Soda Springs, ID during the time frame of the TIR surveys (source: http://www.wrh.noaa.gov/mesowest).

Time 24 hr	Air Temp *F	Time 24 hr	Air Temp *F	Time 24 hr	Air Temp *F
July 24		**July 26**		**July 28**	
13:00	80	13:00	82	13:00	89
14:00	82	15:10	77	14:00	89
15:00	84	17:00	73	15:00	91
16:00	84			16:30	91
July 25		**July 27**		**July 29**	
13:00	80	13:40	84	13:10	86
15:00	86	14:00	84	14:00	87
16:00	86	16:00	87	15:00	87
		17:00	89	17:00	87

Thermal Accuracy

Watershed Sciences deployed in-streams sensors at 46 locations in the Bear River basin during the time frame of the TIR surveys (Figure 1). The sensors were deployed at 5-15 mile intervals over the extent of the airborne surveys and provide a basis for calibration and assessing the accuracy of the radiant temperatures derived from the TIR imagery. Tables 5-8 summarize a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images for the Bear River and it tributaries.

Table 5 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitors – Bear River

BEAR RIVER 7/24-7/29						
Stream	**Sensor S/n**	**TIR Image**	**Time MST**	**Kinetic °C**	**Radiant °C**	**Difference °C**
7/27/2006 - Bear River						
Bear R.	1026266	t050024	16:26	23.2	23.1	0.15
Bear R.	1026267	t050861	16:53	23.3	23.0	0.30
Bear R.	1026264	t050922	16:55	22.8	22.9	-0.10
7/24/2006 – Bear River						
Bear R.	1026261	t020020	16:24	25.6	25.6	0.00
Bear R.	1026267	t040588	17:31	25.8	25.6	0.20
7/25/2006 – Bear River						
Bear R.	1026267	t010014	13:53	26.5	26.8	-0.25
Bear R.	540664	t020021	14:20	24.0	23.6	0.40
Bear R.	50663	t020215	14:27	24.9	25.0	-0.05
Bear R.	659413	t030011	15:49	25.1	25.1	0.05
Bear R.	540665	t030280	15:57	24.7	24.2	0.48
Bear R.	659412	t030641	16:09	23.0	23.3	-0.26
7/28/2006 - Bear River						
Bear R.	659412	t010050	14:02	21.8	21.8	0.03
Bear R.	1026267	t040032	14:29	19.1	19.0	0.15
Bear R.	1026260	t050027	14:37	23.5	23.3	0.20
Bear R.	1026262	t060008	15:02	21.7	21.7	0.00
Bear R.	1026259	t070024	15:16	23.8	23.6	0.20
Bear R.	1026261	t080065	16:30	23.8	23.7	0.10
Bear R.	1026264	t090016	16:48	26.7	26.6	0.10
Bear R.	1026266	t0100039	17:08	26.7	26.5	0.20
Bear R.	540664	t0100722	17:30	26.3	26.5	-0.20
7/29/2006 – ID/ Utah Line to Cutler Reservoir						
Bear R.	540664	t060018	15:56	26.8	26.6	0.20
Bear R.	659413	t070018	16:10	27.0	27.1	-0.10
Bear R.	540665	t080015	16:30	27.3	27.3	0.00
Bear R.	540663	t090011	16:39	27.2	27.2	0.02

Table 6 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitors – Smiths Fork.

SMITHS FORK - 7/26/06						
Stream	**Serial s/n**	**TIR Image**	**Time MST**	**Kinetic °C**	**Radiant °C**	**Difference °C**
Bear R.	659413	t030030	15:46	21.7	21.7	-0.04
Smiths Fork	766181	t030255	15:53	20.3	20.0	0.33
Smiths Fork	766182	t030636	16:06	18.1	17.9	0.16
Smiths Fork	882337	t030897	16:14	17.6	17.8	-0.16
Smiths Fork	882338	t031315	16:28	17.8	17.5	0.36
Smiths Fork	1026266	t031577	15:36	17.8	18.0	-0.15
Smiths Fork	1026262	t031752	16:42	16.8	16.5	0.25

Table 7 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitors – Thomas Fork.

THOMAS FORK – 7/27/06						
Stream	**Serial s/n**	**TIR Image**	**Time MST**	**Kinetic °C**	**Radiant °C**	**Difference °C**
Bear R.	1026267	t010056	14:17	22.0	21.9	0.15
Bear R.	1026264	t010122	14:20	21.6	21.5	0.10
Thomas Fork	540664	t010170	14:21	21.5	22.1	-0.60
Thomas Fork	540665	t020050	14:41	20.2	20.1	0.10
Thomas Fork	540663	t030025	15:11	19.0	19.2	-0.20
Thomas Fork	1026261	t040021	15:24	20.2	20.5	-0.30

Table 8 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitors – Cub River.

CUB RIVER - 7/29/06						
Stream	**Serial s/n**	**TIR Image**	**Time MST**	**Kinetic °C**	**Radiant °C**	**Difference °C**
Cub River	88238	t020007	14:06	22.1	22.1	0.00
Cub River	766182	t030016	14:20	25.9	25.7	0.20
Cub River	766181	t040038	14:34	24.7	24.6	0.10
Cub River	882337	t050014	14:46	15.9	15.8	0.10

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. However, since the in-stream data were used to compute an adjustment to the radiant temperatures, they should not be considered an independent check of radiant temperatures. For each flight, the correction was computed as an average offset from the raw radiant values for all sensor locations.

Results

Median channel temperatures were plotted versus river mile for the streams in the survey area. Tributaries, springs and incoming canals sampled during the analysis are included on the profile to provide additional context for interpreting spatial temperature patterns. These features are also listed in tables for each stream. Diversions, dams, and power plant outflows were also designated on the profiles.

Due to the nature of the project, the focus was on identifying cold water inflows and thermal refugia for fish. Given the warm temperatures on the days of the survey, features such as hot springs may have been 'washed out' in comparison to the surrounding terrestrial landscape. Only those hot spring features that were shown on USGS 7.5-minute quad maps were specifically sampled.

The sample images contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations.

Lower Bear River – Cutler Reservoir to Alexander Reservoir

Longitudinal Temperature Profile

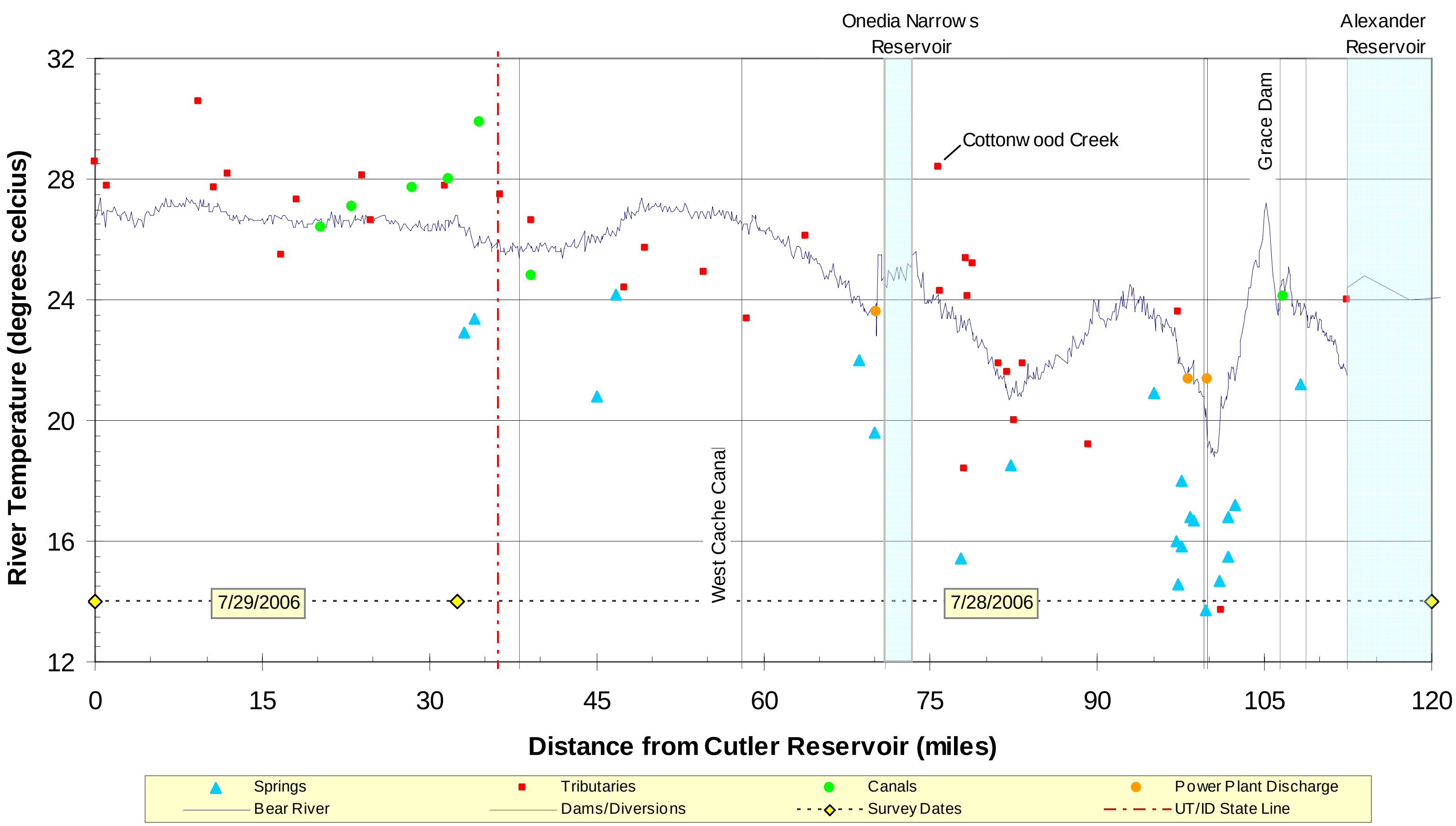


Figure 5 - Median channel temperatures plotted versus river mile for the Lower Bear River. The locations of detected surface inflows are illustrated on the profile and listed in Table 9..

Table 9 - Tributaries and other surface inflows sampled along the Lower Bear River with left or right bank designation (looking downstream). Other significant features such as dams and major diversion canals are also listed.

Tributaries	Kilometer	Mile	Tributary Temp (°C)	Bear River Temp (°C)	Difference
Cutler Reservoir	0.06	0.04	28.6	26.7	1.9
Lakes (L)	1.86	1.16	27.8	27.0	0.8
Warm lakes(R)	14.88	9.25	30.6	27.0	3.6
Summit Creek (L)	17.30	10.75	27.7	27.1	0.6
Slough (L)	19.18	11.92	28.2	26.8	1.4
Cub River (L)	29.27	18.19	27.3	26.6	0.7
Slough (L)	50.51	31.39	27.8	26.3	1.5
Unnamed Trib (R)	58.51	36.36	27.5	25.7	1.8
Unnamed Trib (R)	63.01	39.15	26.6	25.7	0.9
Fivemile Creek (R)	76.47	47.52	24.4	26.7	-2.3
Deep Creek (R)	79.49	49.39	25.7	26.9	-1.2
Unnamed Trib (R)	87.95	54.65	24.9	26.8	-1.9
Mink Creek (L)	102.71	63.82	26.1	25.6	0.5
Cottonwood Creek (R)	122.05	75.84	28.4	24.0	4.4
Unnamed Trib (R)	122.17	75.92	24.3	23.8	0.5
Williams Creek (L)	125.59	78.04	18.4	23.3	-4.9
Unnamed Trib (L)	125.74	78.13	25.4	23.0	2.4
Unnamed Trib (L)	126.21	78.42	24.1	23.3	0.8
Warm ox bow (R)	126.73	78.75	25.2	22.8	2.4
Spring Creek (L)	130.62	81.16	21.9	21.4	0.5
Unnamed Trib (R)	131.93	81.98	21.6	20.9	0.7
Kuntz Creek (L)	132.74	82.48	20.0	20.9	-0.9
Trout Creek (L)	134.07	83.31	21.9	21.0	0.9
Whiskey Creek (L)	143.51	89.17	19.2	22.9	-3.7
Unnamed Trib (R)	156.41	97.19	23.6	22.2	1.4
Springs	**Kilometer**	**Mile**	**Spring Temp (°C)**	**Bear River Temp (°C)**	**Difference**
cold drain (L)	26.84	16.68	25.5	26.7	-1.2
spring (R)	53.36	33.15	22.9	26.4	-3.5
springs (R)	54.90	34.11	23.4	25.7	-2.3
spring (L)	72.64	45.13	20.8	26.1	-5.3
springs (L)	75.14	46.69	24.2	26.1	-1.9
wetland drain (R)	94.27	58.57	23.4	26.5	-3.1
spring (R)	110.36	68.58	22.0	24.1	-2.1
spring (R)	112.56	69.94	19.6	23.7	-4.1
small spring (L)	125.01	77.68	15.4	23.3	-7.9
small spring (L)	132.35	82.24	18.5	20.8	-2.3
spring (L)	152.90	95.01	20.9	23.7	-2.8
spring (L)	156.19	97.05	16.0	22.6	-6.6
springs (L)	156.53	97.26	14.6	21.9	-7.3
springs (L)	156.92	97.50	15.8	21.9	-6.1
multiple spring fed tribs (L)	157.05	97.59	18.0	21.9	-3.9
spring (L)	158.29	98.35	16.8	21.7	-4.9
spring (R)	158.84	98.70	16.7	21.2	-4.5

Kackley Spring Outlet (L)	160.35	99.64	13.7	20.1	-6.4
spring (R)	162.42	100.92	14.7	19.7	-5.0
cold pond (R)	162.66	101.07	13.7	20.8	-7.1
big spring inflow (R)	163.72	101.73	15.5	21.1	-5.6
springs (R)	163.81	101.79	16.8	21.6	-4.8
spring (R)	164.81	102.41	17.2	21.4	-4.2
springs (R)	165.93	103.10	21.7	23.2	-1.5
spring	174.27	108.29	21.2	23.5	-2.3
Canals	**Kilometer**	**Mile**	**Tributary Temp (°C)**	**Bear River Temp (°C)**	**Difference**
canal (R)	32.75	20.35	26.4	26.7	-0.3
ditch/canal to Cub River (L)	37.17	23.09	27.1	26.5	0.6
drain from pond (L)	38.72	24.06	28.1	26.8	1.3
drain from ponds (R)	39.82	24.75	26.6	26.6	0.0
ditch/canal ( )	45.86	28.50	27.7	26.4	1.3
canal in (L)	51.07	31.73	28.0	26.4	1.6
Canal Out? (R)	55.57	34.53	29.9	26.1	3.8
canal (R)	63.03	39.17	24.8	25.8	-1.0
canal (L)	171.74	106.72	24.1	24.7	-0.6
Power Plants	**Kilometer**	**Mile**	**Effluent Temp (°C)**	**Bear River Temp (°C)**	**Difference**
Oneida Station Outlet (L)	112.96	70.19	23.6	22.8	0.8
Cove Power Plant (L)	157.90	98.11	21.4	21.8	-0.4
Grace Power Plant (L)	160.62	99.80	21.4	19.3	2.1
Dams/Diversions/Reservoirs	**Kilometer**	**Mile**			
East Canal / West Canal Diversion	61.35	38.13			
West Cache Canal Diversion (R)	93.37	58.03			
Oneida Narrows Dam	114.13	70.93			
Dam below Grace Power Plant	160.11	99.51			
Gentile Valley Canal	160.80	99.94			
Grace Dam	171.20	106.40			
Last Chance Dam/Canal	174.88	108.69			
Alexander Dam	180.85	112.40			

Observations

The Lower Bear River survey began at the outlet of Alexander Reservoir and was flown downstream concluding at Cutler Reservoir near Logan, UT. The flights were conducted over two days with the leg from Alexander Reservoir to Idaho/Utah border flown on July 28th and the Idaho/Utah border to the Cutler Reservoir flown on July 29th. The Lower Bear River was characterized by generally warm bulk water temperatures (>18.9^{o}C), but also with a large number of springs and cool water tributaries that contribute to the thermal complexity and structure of the river.

At the outlet from Alexander Reservoir, radiant water temperatures in the Bear River were ~21.5^{o}C and warmed quickly reaching ~24.7^{o}C just upstream of Grace Dam (mile 106.4). Downstream of Grace Dam, radiant water temperature exhibited a dramatic increase to 27.2°C within the first mile. Surface flow appeared very low within a mile of the dam and the dramatic increase is presumably due to normal heating processes on the reduced flow volume (*Lower Bear Image 1*). Moving downstream, a series of springs between river mile 97.6 and 102.4 both restore flow levels in the Bear River and reduce in-stream temperatures to a survey minimum of 18.8°C at mile 100.8 (*Lower Bear Image 2a and b*).

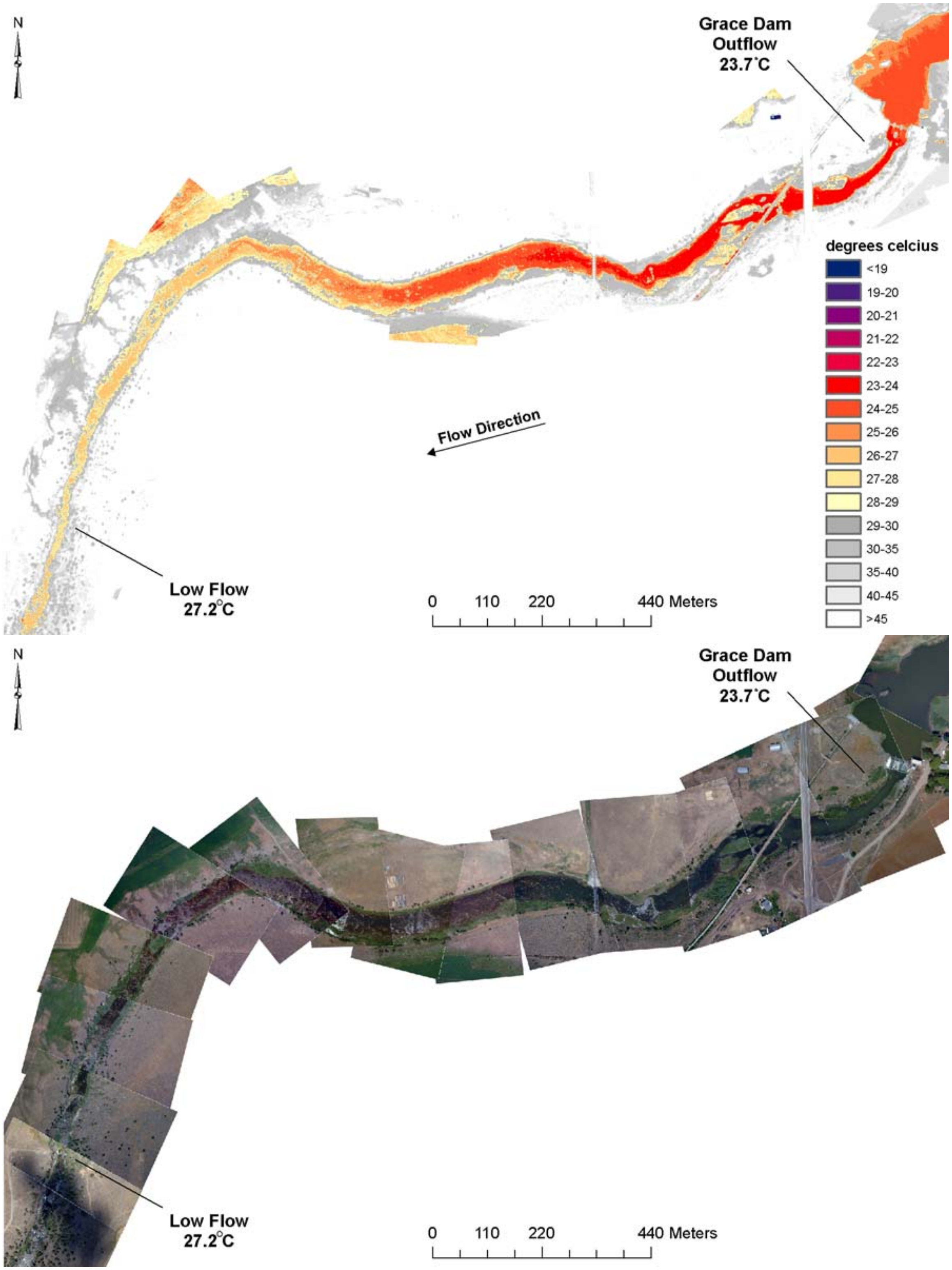
The Grace Power Plant discharge (21.4°C) at river mile 99.8 increased Bear River temperatures by 1.5°C. Radiant temperatures continued to increase downstream despite the contribution of multiple spring inflows between miles 99.8 and 95.0 reaching a local maximum of 24.4°C at river mile 93.2 (*Lower Bear Image 3*). Although the spring inflows did not appear to influence the prevailing reach scale trend, their influence on local temperature patterns was pronounced in the thermal imagery (*Lower Bear Image 4*).

A general cooling trend was observed between river mile 93.2 and mile 82.4 with stream temperatures reaching a local minimum of 20.8°C. Although, two cool water tributaries and one spring were detected through this reach, the reason for the downstream cooling trend was not apparent through inspection of the imagery. Further analysis should examine potential morphologic indicators such as changes in valley form or stream gradient. Stream temperature modeling will additionally provide information on differential heating rates for individual stream reaches due to topographic and riparian shading.

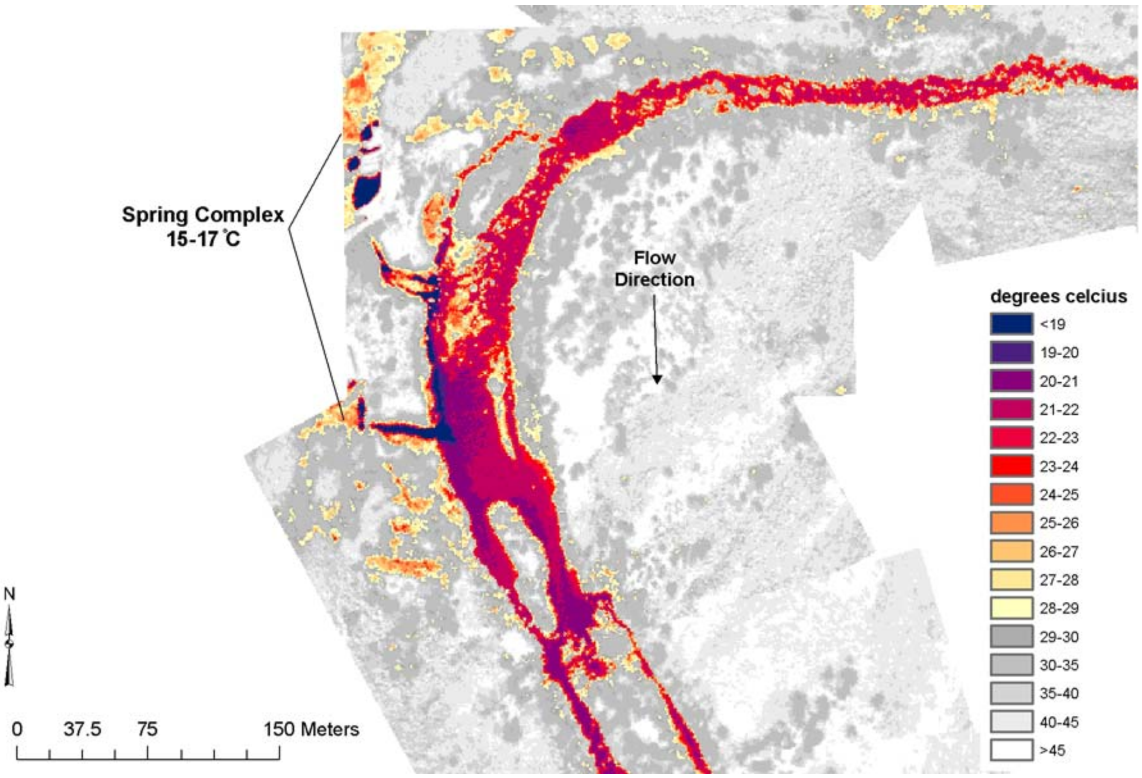
Stream temperatures warmed again between river miles 82.4 and the Inlet to the Onedia Narrows Reservoir (mile 74.0). Several hot springs are denoted on the USGS Topographic maps from river mile 74-77 which may contribute to the warming trend; however, because the survey was intended to highlight primarily cold water inflows, many of the hot thermal features are not distinguishable from the background terrestrial features in the imagery and were not sampled. A survey to highlight such features would be flown early in the day on a cold morning to maximize the thermal difference between the springs and the surrounding terrain (*Lower Bear Image 5*).

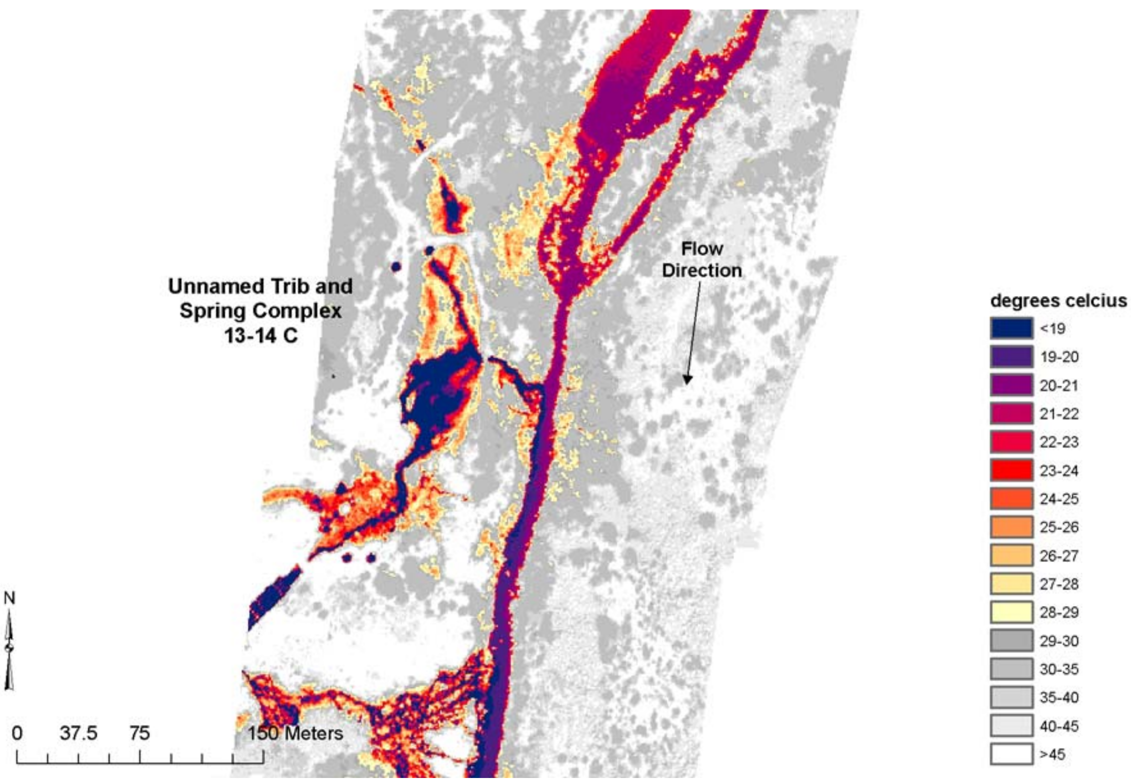
At 0.5 miles below the Oneida Reservoir, the power plant discharge lowered the water temperatures in the Bear River from ~25.5°C to ~22.8°C. From the Oneida Station Outlet, stream temperatures warmed steadily downstream reaching 27.2°C at mile 50.0. Radiant water temperatures remained relatively warm and consistent over the lower 50-miles, with variations between 25.4 and 27.4°C. However, four springs and three cool water tributaries were sampled during the analysis of the IR imagery. These sources may provide local thermal refugia in the predominantly warm lower river.

Sample Images

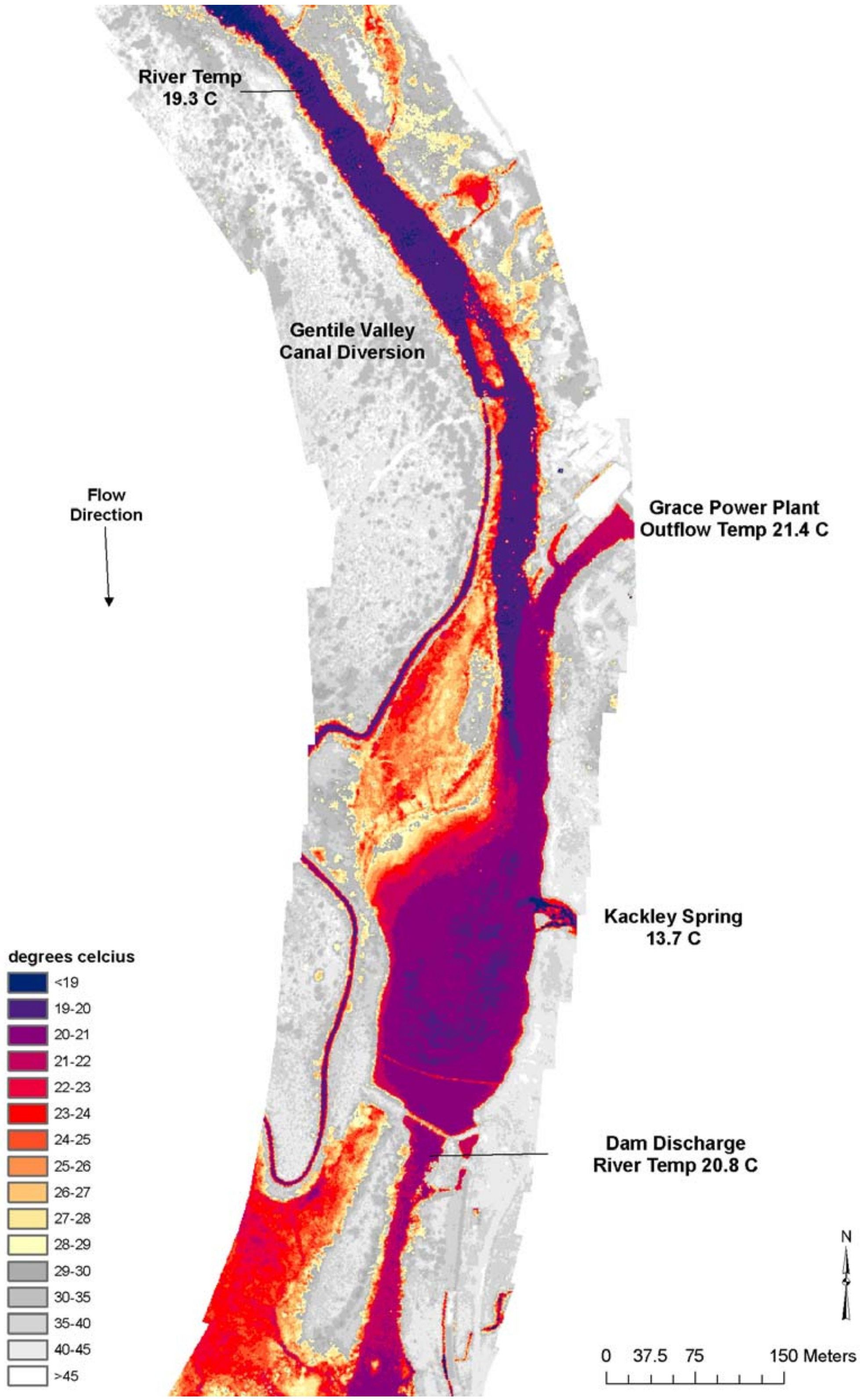


Lower Bear Image 1. TIR and true color images show low flow conditions downstream of the Grace Dam at mile 105.1. Stream temperatures showed a dramatic 3.5°C increase within 1-mile of the dam.

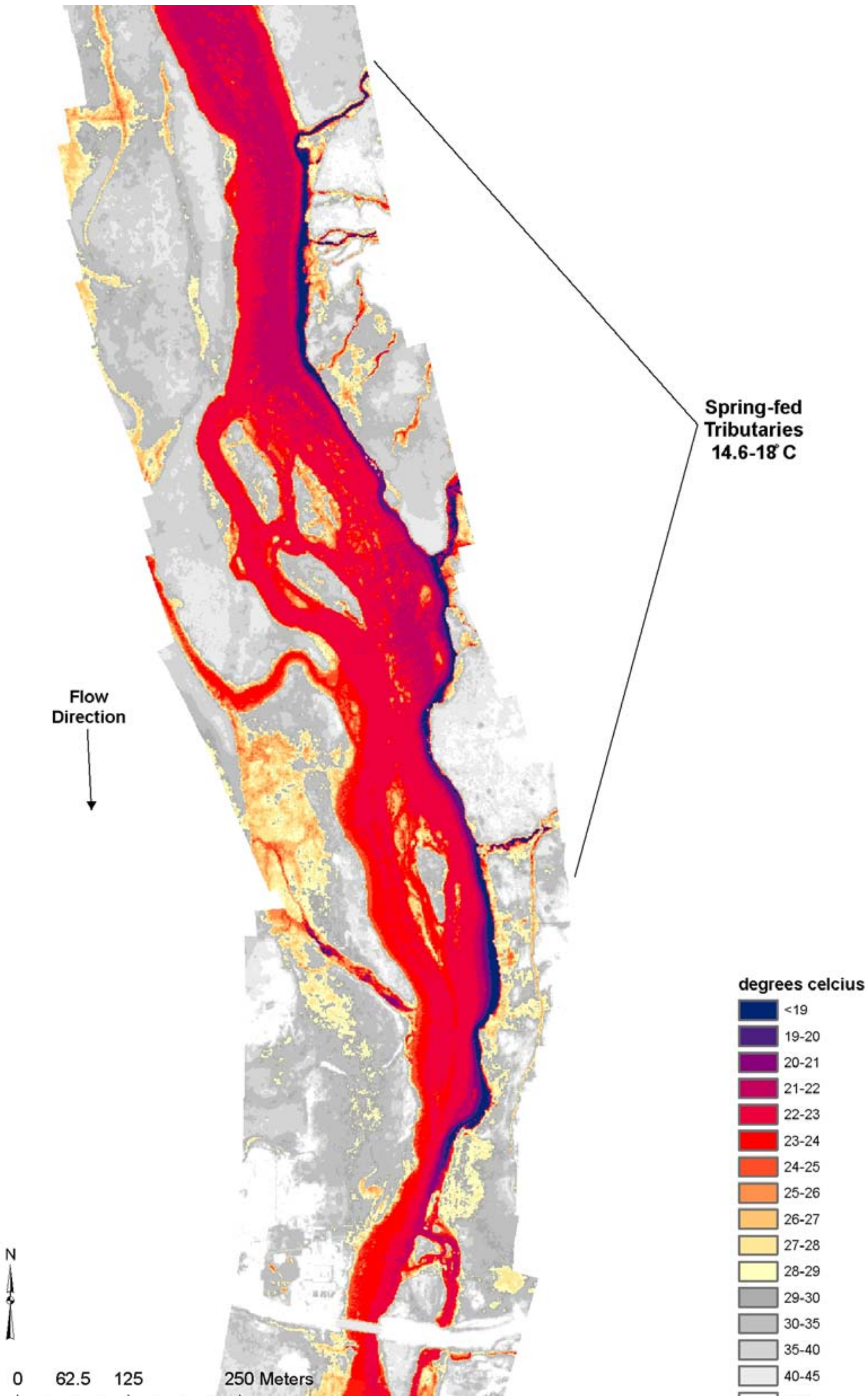




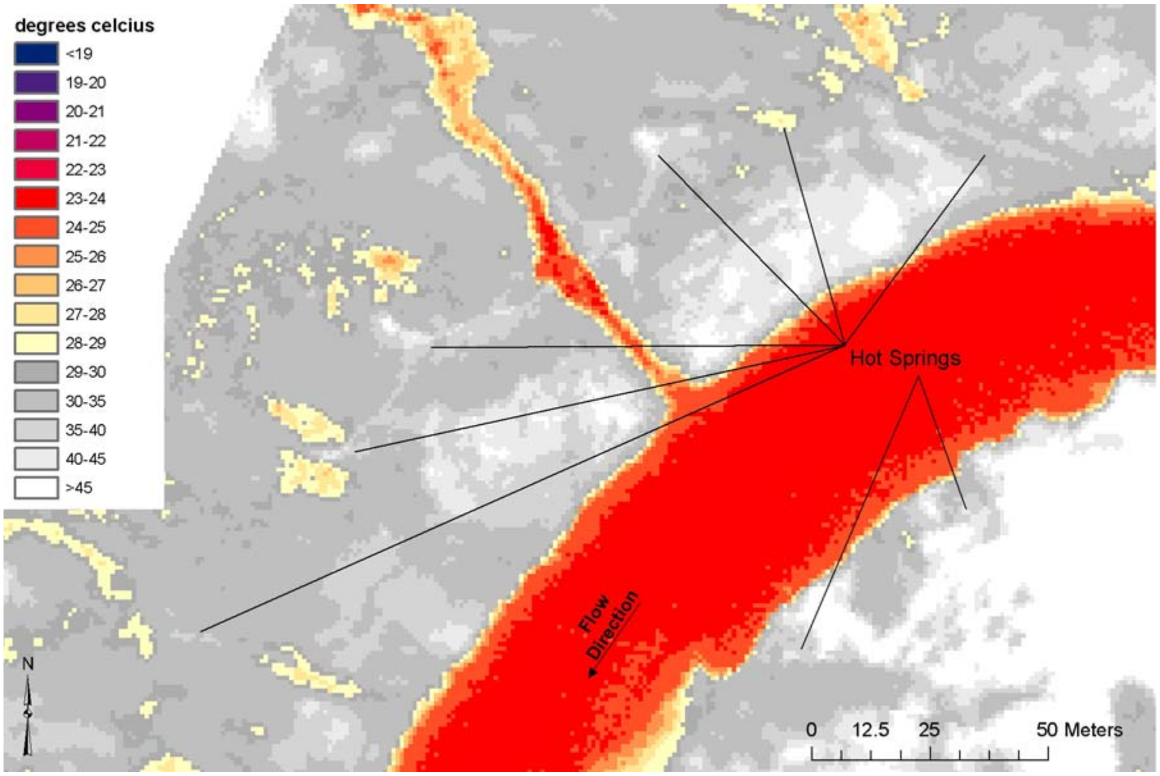
Lower Bear Image 2a and b. Two large spring complexes near river mile 101.75 and river mile 101.07 respectively. These two spring complexes drop the temperature of the Bear River from 21.6°C to a low of 18.8°C.

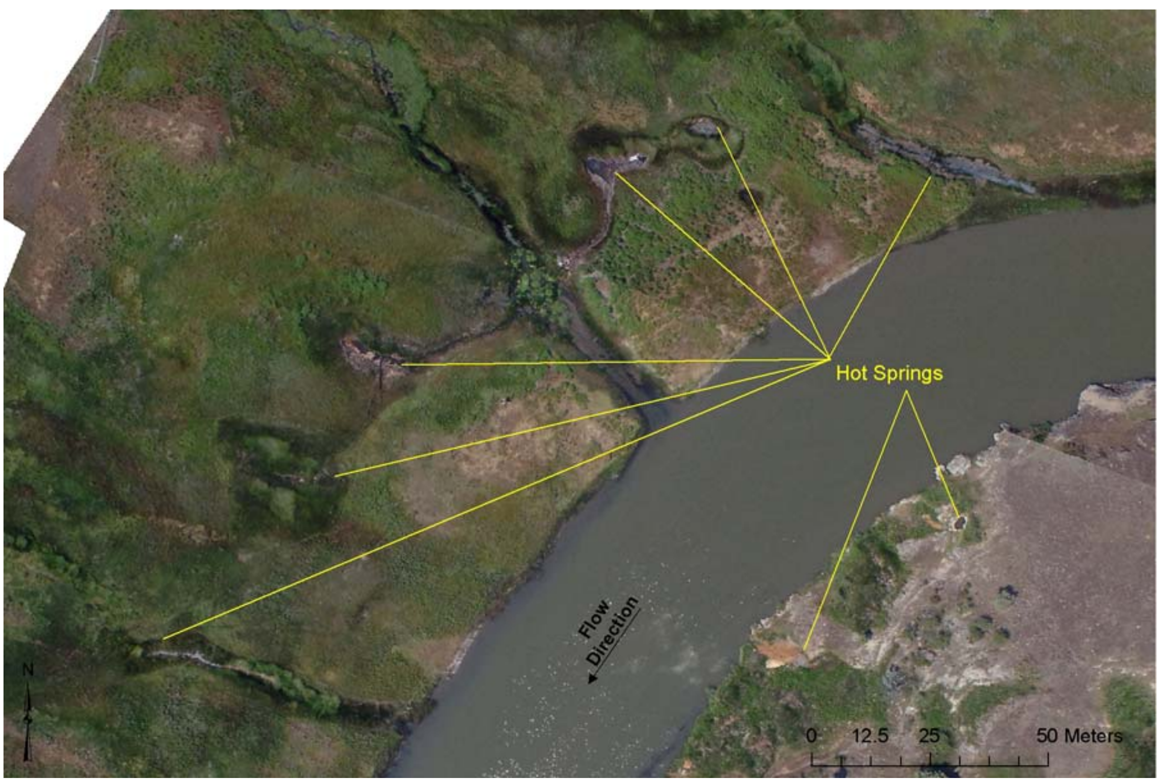


Lower Bear Image 3. Near river mile 100, multiple factors cause the river to warm significantly including a large canal diversion and the Grace Power Plant outflow. Even with a significant cold inflow at Kackley Spring and an impoundment below the power plant, the river warms 1.5°C over a ½-mile distance.



Lower Bear Image 4. TIR image showing the spring complex at mile 97.3. Although the springs do not appear to influence the overall temperature trend of the reach, there is significant local influence on the left bank.





Lower Bear Image 5. Thermal and true color images of the hot spring area at river mile 75.92. Because the project was intended to highlight primarily cold inflows, warm features tend to blend in with the surrounding terrain due to the warm afternoon temperatures.

Upper Bear River – Alexander Reservoir to Cokeville, WY

Longitudinal Temperature Profile

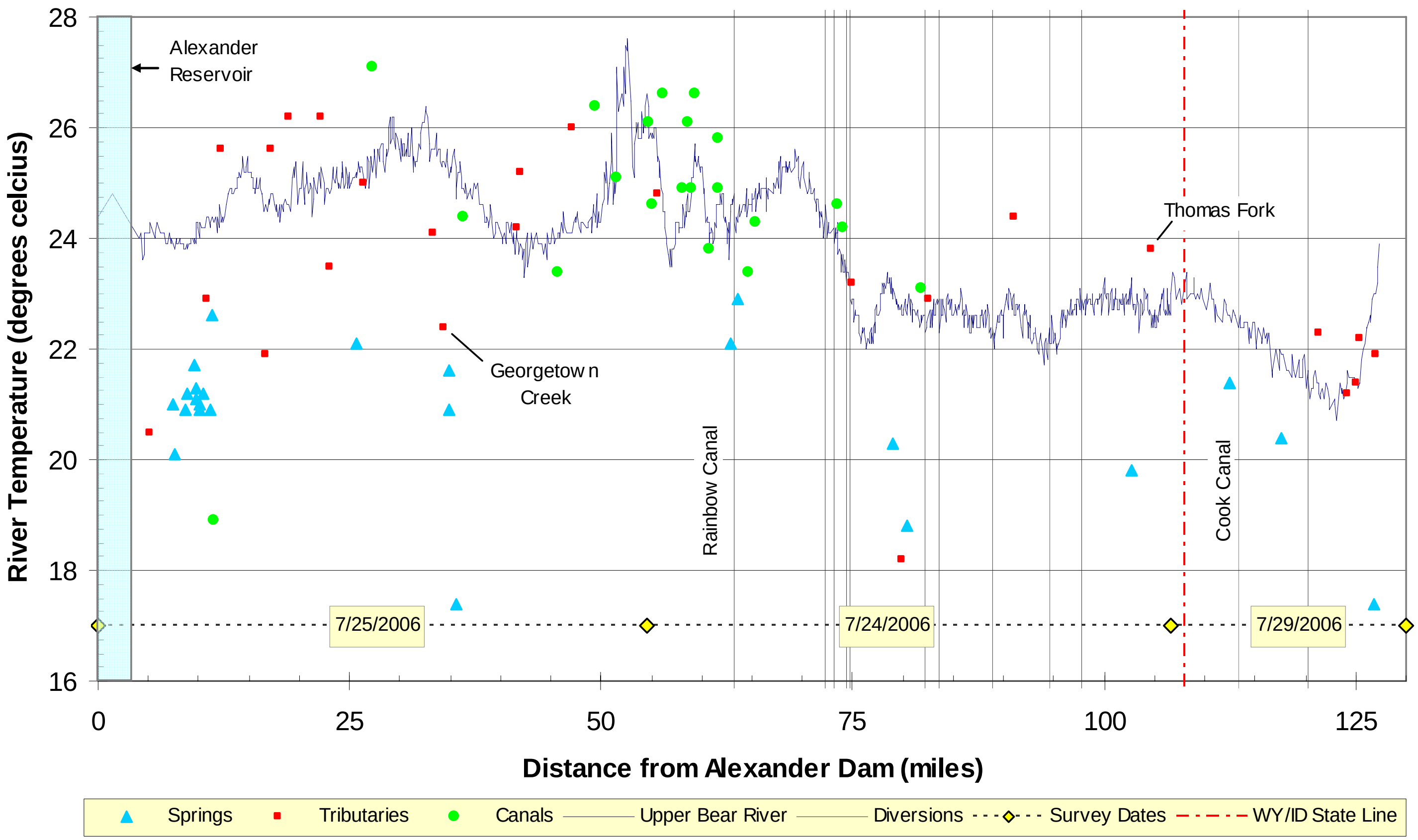


Figure 6 - Median channel temperatures plotted versus river mile for the Upper Bear River. The locations of detected surface inflows are illustrated on the profile and listed in Table 10.

Table 10 - Tributaries and other surface inflows sampled along the Upper Bear River with left or right bank designation (looking downstream). Major diversion canals are also listed by river mile.

Tributaries	Kilometer	Mile	Tributary Temp °C	Bear River Temp °C	Difference °C
Big Spring Creek Fish Hatchery (R)	8.35	5.19	20.5	24.3	-3.8
Bailey Creek/Marsh (L)	17.29	10.74	22.9	24.4	-1.5
Unnamed Trib(L)	19.77	12.28	25.6	24.3	1.3
Eightmile Creek (L)	26.84	16.68	21.9	24.6	-2.7
Unnamed Trib (R)	27.59	17.14	25.6	24.8	0.8
Trail Creek (L)	30.42	18.90	26.2	24.6	1.6
Unnamed Trib (L)	35.51	22.07	26.2	24.9	1.3
Unnamed Trib (R)	37.02	23.00	23.5	24.8	-1.3
Skinner Creek (L)	42.39	26.34	25.0	25.1	-0.1
Stauffer Creek (L)	53.48	33.23	24.1	25.6	-1.5
Georgetown Creek(R)	55.27	34.34	22.4	25.4	-3.0
Unnamed Trib (R)	67.05	41.66	24.2	24.0	0.2
Unnamed Trib(R)	67.50	41.94	25.2	23.9	1.3
Ovid Creek (L)	75.93	47.18	26.0	24.1	1.9
Montpelier Creek (R)	89.39	55.55	24.8	25.5	-0.7
pond (L)	120.59	74.93	23.2	22.8	0.4
Sheep Creek (R)	128.41	79.79	18.2	22.8	-4.6
Unnamed Trib (L)	132.89	82.58	22.9	22.6	0.3
Unnamed Trib (L)	146.54	91.06	24.4	22.8	1.6
Thomas Fork (R)	168.39	104.63	23.8	22.6	1.2
Dixon Slough (R)	195.36	121.39	22.3	21.2	1.1
Ryan Creek (R)	199.67	124.07	21.2	21.4	-0.2
Smiths Fork (R)	201.32	125.09	21.4	21.4	0.0
South Fork Smiths Fork (R)	201.79	125.39	22.2	21.4	0.8
Unnamed Inflow (R)	204.34	126.97	21.9	23	-1.1
Springs	**Kilometer**	**Mile**	**Tributary Temp °C**	**Bear River Temp °C**	**Difference °C**
seep on island	11.98	7.45	21.0	23.9	-2.9
cold seep (L)	12.14	7.54	20.1	23.8	-3.7
spring (R)	14.10	8.76	20.9	23.8	-2.9
cold marsh drain to river (L)	14.25	8.86	21.2	23.9	-2.7
cold seeps on L bank (L)	15.65	9.72	21.3	23.9	-2.6
spring (R)	15.76	9.79	21.1	24.3	-3.2
springs (L)	16.20	10.07	21.0	24	-3.0
cold marshy area adjacent to river	16.38	10.18	20.9	24.3	-3.4
cold seep/spring (R)	16.68	10.37	21.2	24.2	-3.0
spring (L)	17.96	11.16	20.9	24.3	-3.4
remnant slough (L)	18.11	11.26	22.6	24.4	-1.8
spring (R)	41.36	25.70	22.1	25.1	-3.0
small spring (R)	56.02	34.81	20.9	25.1	-4.2
Spring (R)	56.19	34.92	21.6	25.1	-3.5
Spring on side channel (R)	57.20	35.54	17.4	25.3	-7.9
cold seep from side slough (R)	101.17	62.86	22.1	24.5	-2.4
cold spot (R)	102.39	63.62	22.9	24.4	-1.5

cold field (R)	127.01	78.92	20.3	22.9	-2.6
Cold seep on island	129.31	80.35	18.8	22.7	-3.9
Small Spring (L)	165.20	102.65	19.8	23.3	-3.5
seep (L)	181.11	112.54	21.4	22.6	-1.2
small seep (R)	189.39	117.68	20.4	21.9	-1.5
cold inflow (R)	204.08	126.81	17.4	23	-5.6

Canals	Kilometer	Mile	Canal Temp °C	Bear River Temp °C	Difference °C
cold canal (R)	18.41	11.44	18.9	24.3	-5.4
canal (L)	43.91	27.29	27.1	25.2	1.9
canal (R)	58.48	36.34	24.4	24.9	-0.5
canal (R)	73.41	45.62	23.4	24	-0.6
canal (R)	79.48	49.38	26.4	24.4	2.0
Bear Lake Outlet (L)	82.85	51.48	25.1	24.8	0.3
canal (L)	88.14	54.77	26.1	25.8	0.3
canal (L)	88.79	55.17	24.6	25.9	-1.3
canal (L)	90.36	56.15	26.6	24.5	2.1
canal (R)	93.38	58.03	24.9	24.2	0.7
canal (R)	94.48	58.71	26.1	24.5	1.6
canal from pond (L)	94.80	58.91	24.9	24.8	0.1
incoming canal (R)	95.35	59.25	26.6	25.7	0.9
canal (L)	97.67	60.69	23.8	24.3	-0.5
incoming canal (L)	99.17	61.62	24.9	24.6	0.3
incoming canal (L)	99.31	61.71	25.8	24.6	1.2
slough/canal (R)	103.89	64.56	23.4	24.6	-1.2
canal (L)	105.29	65.43	24.3	24.5	-0.2
canal (R)	118.35	73.54	24.6	24.6	0.0
canal (R)	119.08	73.99	24.2	23.5	0.7
canal (L)	131.69	81.83	23.1	22.6	0.5

Diversions	Kilometer	Mile
Rainbow Canal	101.67	63.19
Montpelier Preston Canal	116.16	72.2
Black Otter Canal	117.77	73.20
Ream Crockett Canal	119.72	74.41
Unnamed	120.38	74.82
Unnamed	132.24	82.19
Unnamed	134.48	83.58
Sorensen Ditch	142.99	88.87
Nuffer Canal	152.30	94.66
Miller Ditch	157.16	97.68
Cook Canal	182.39	113.36
Noblitt Ditch	193.59	120.32

Observations

The airborne TIR survey of the Upper Bear River was conducted from the Cokeville-Utah Line Road bridge near Cokeville, WY downstream to Alexander Reservoir. The flight was conducted over a 3-day period (July 24, 25, 27) and covered ~125 river miles. River miles were measured upstream from Alexander Dam.

Radiant water temperatures decreased between the start of the survey and the Smiths Fork confluence reaching a local minimum of ~21.4°C. Although a cold spring was detected in this reach at river mile 126.8 (*Upper Bear Image 1*), the overall source of cooling was not apparent from the imagery. At their confluence, there was no significant temperature difference between the Bear River and the Smiths Fork. From the Smiths Fork, radiant water temperatures increased steadily downstream reaching a local maximum of 23.2°C at river mile 110.5. Two relatively small seeps were detected, which may indicate the location of localized cool water refugia in this reach.

Between river mile 110.5 and the location of Miller Ditch (mile 97.7), surface water temperatures in the Bear River remained relatively constant (±0.5°C) with no definitive warming or cooling trends. The Bear River is extremely sinuous through most of this reach with a large number of side channels, oxbows, and cut-off-meanders. The complexity of the channel combined with relatively consistent observed temperatures suggests a level of sub-surface exchange through historic pathways, which buffers stream heating processes (*Upper Bear Image 2*).

Oblique digital image showing the sinuosity in the Upper Bear River, ID.

The Thomas Fork (mile 104.6) contributed water that was ~1.2°C warmer than the Bear River. However, inspection of the longitudinal profile shows a slight ~0.6°C decrease in water temperatures near the Thomas Fork confluence. Although the magnitude of the decrease is consistent with noise levels normally associated with TIR remote sensing, the location suggests the possibility of sub-surface influence on the Bear River from the Thomas Fork valley.

Moving downstream, a slight decrease (~1.1°C) in surface water temperatures was observed between the Miller Ditch (mile 97.7) and the Nuffer Canal (mile 94.7). There were no tributaries or surface springs detected in this stream segment. Inspection of the topographic base maps show that the Bear River Valley changes from a southwestern to northern direction as it flows around the southern end of the Sheep Creek Hills near

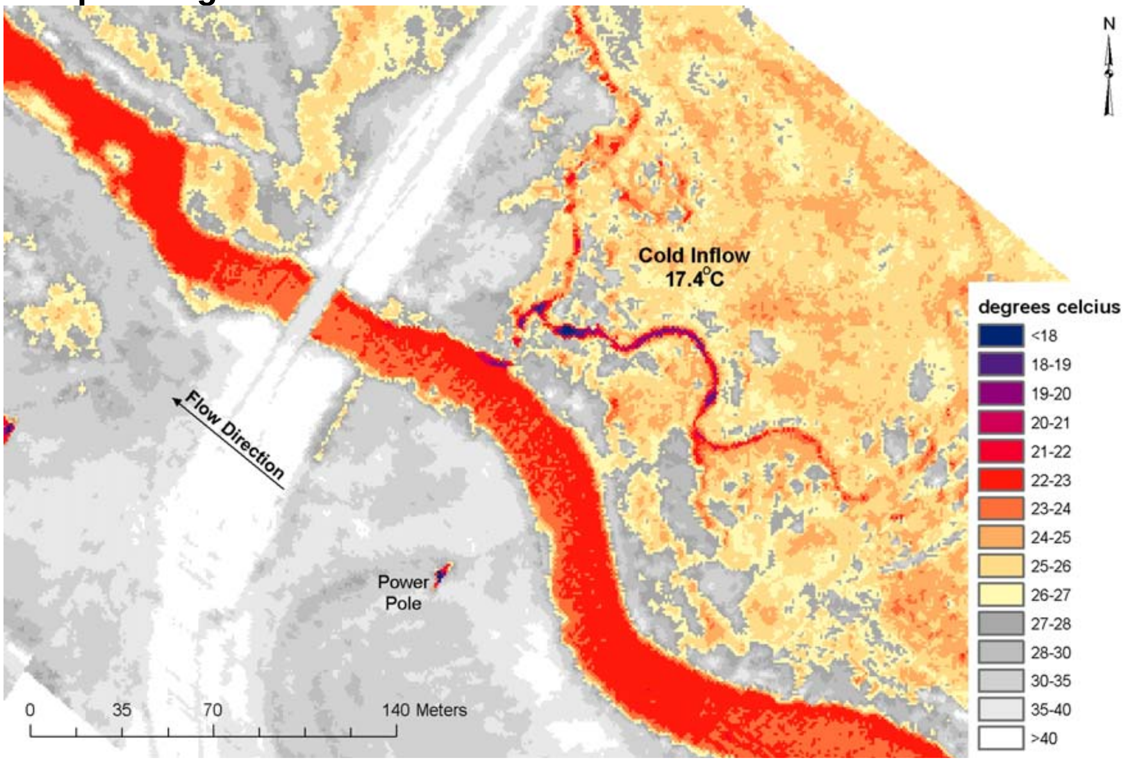
Pegram, ID. In past TIR surveys, observed changes in spatial stream temperature patterns are often consistent with changes in valley morphology. In this case, the change in river aspect and the constriction of the valley by the Sheep Creek Hills may cause shallow sub-surface flow to be forced back into the active channel resulting in some localized cooling. Downstream of Nuffer Canal, surface water temperatures increased again to 23.0°C before remaining relatively constant to about river mile 79.8. Sheep Creek at mile 79.8 and was observed as a source of cooling to the Bear River 22.8°C.

Downstream of the Sheep Creek confluence (mile 79.8), water temperatures in the Bear River exhibited a slight increase to mile 23.3°C (mile 78.8) before decreasing to ~22.0°C at mile 77.0°C. Moving downstream, stream temperatures exhibited a rapid increase in the longitudinal heating rate as the river transitions into the Bear Lake Valley. A local maximum of 25.6°C measured at mile 69.3. While further investigation is required to quantify the factors which contribute to the increased heating, inspection of the topographic base maps shows lower stream gradient and a decrease in the potential for topographic shading. Anthropogenic influences (i.e. canals, diversions, bridges, etc.) also appeared to increase in the Bear Lake Valley with four diversions and two canal returns observed in this seven mile reach.

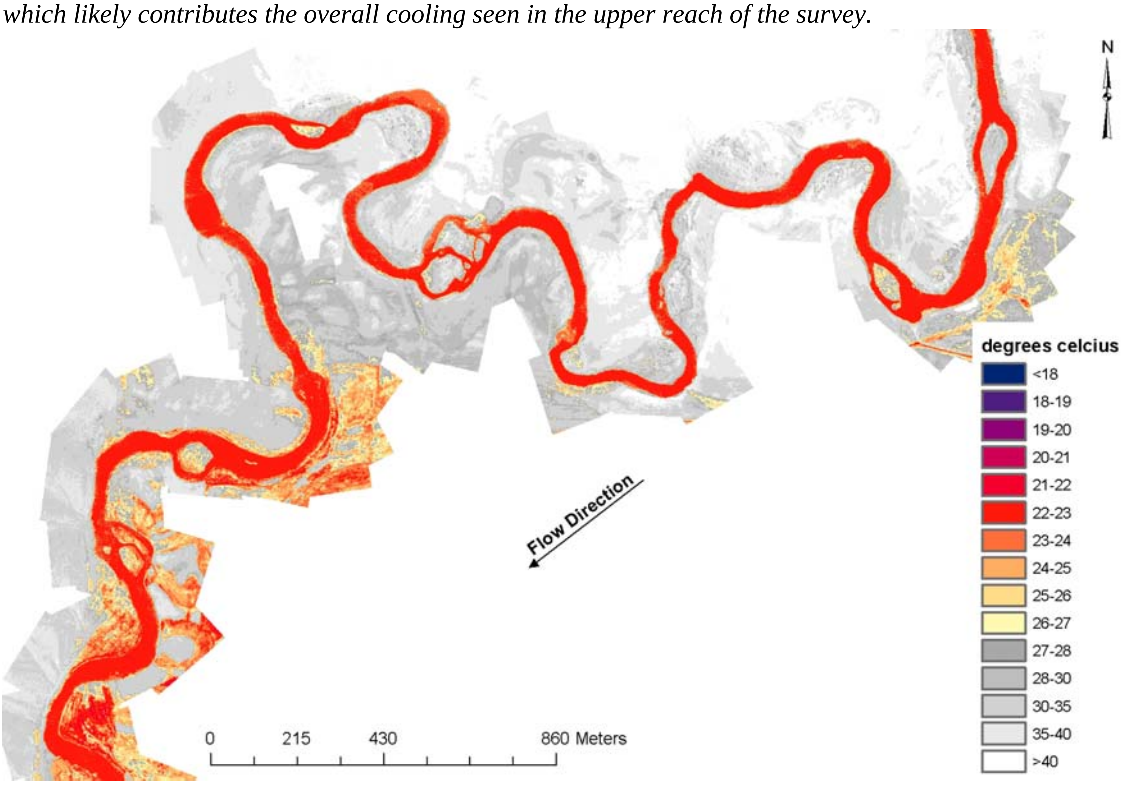
Radiant stream temperatures decreased by ~1.1°C between mile 69.5 and the Rainbow Canal at mile 63.2. Between the canal and mile 51.0, water temperatures exhibited a high degree of local spatial variability with measured temperatures ranging between 23.5°C and 27.6°C (*Upper Bear Image3*). Eleven canals were sampled through this reach including a large canal that diverts from the Bear River near Stewart Dam and rejoins the river at mile 55.2 (*just upstream of Montpelier Road*). The sharp increase in surface temperatures at mile 52.6 (`27.4°C) suggests the possibility of some level of thermal stratification and/or differential surface heating. However, common indicators of temperature stratification were not present in the imagery. The observed level of variability is also characteristic of very low flow conditions where relatively small discharges can have a dramatic influence on in-stream temperatures. The inflow of the Bear Lake Outlet (mile 51.5) resulted in decreased surface temperatures

From river mile 51.5 to the Alexander Reservoir, radiant water temperatures were generally warm with variations between 23.3°C and 26.3°C. A consistent warming trend was observed between river miles 42.4 and mile 26.3 (*at Skinner Creek*) followed by a slight, but consistent cooling trend between Skinner Creek and the inlet to the reservoir. A total of 16 springs/seeps and 6 cool water tributaries were detected in the lower 42 river miles including a cluster of springs between miles 7.5 and 11.3 (*Upper Bear Image 4*). While surface temperatures were generally warm (i.e. >24.0°C), the number of cool water sources to the river offer potential thermal refugia to cool water fish species within this reach.

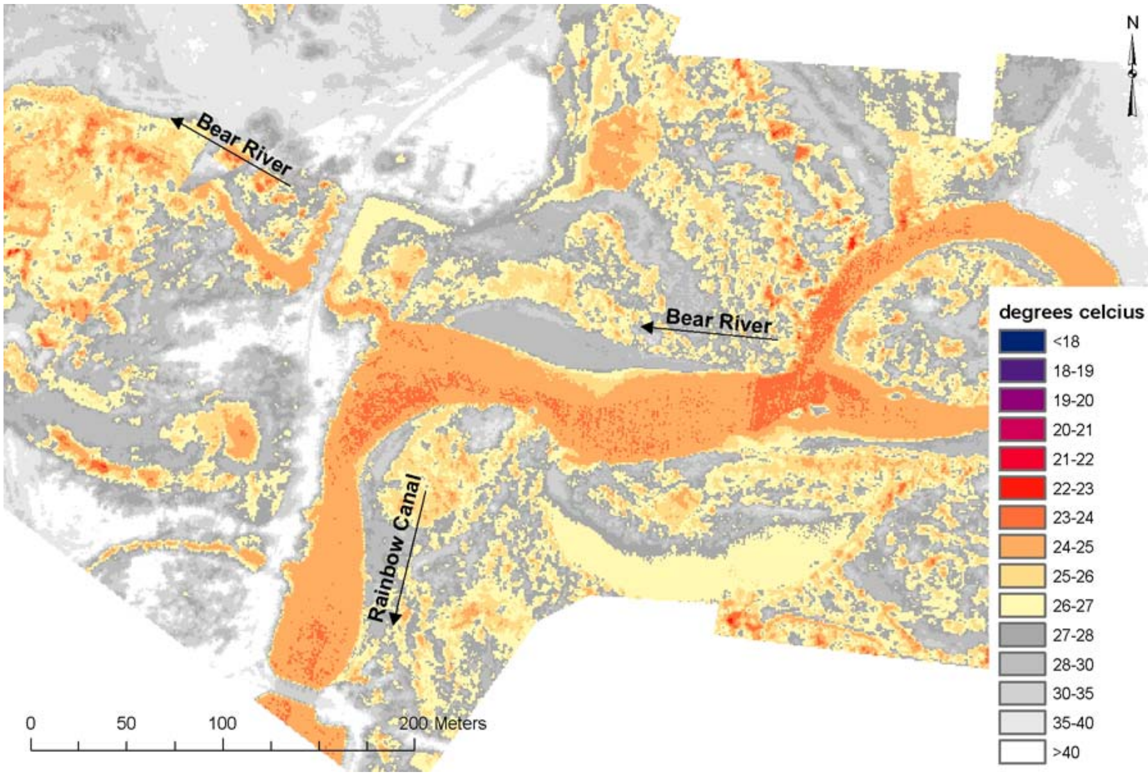
Sample Images

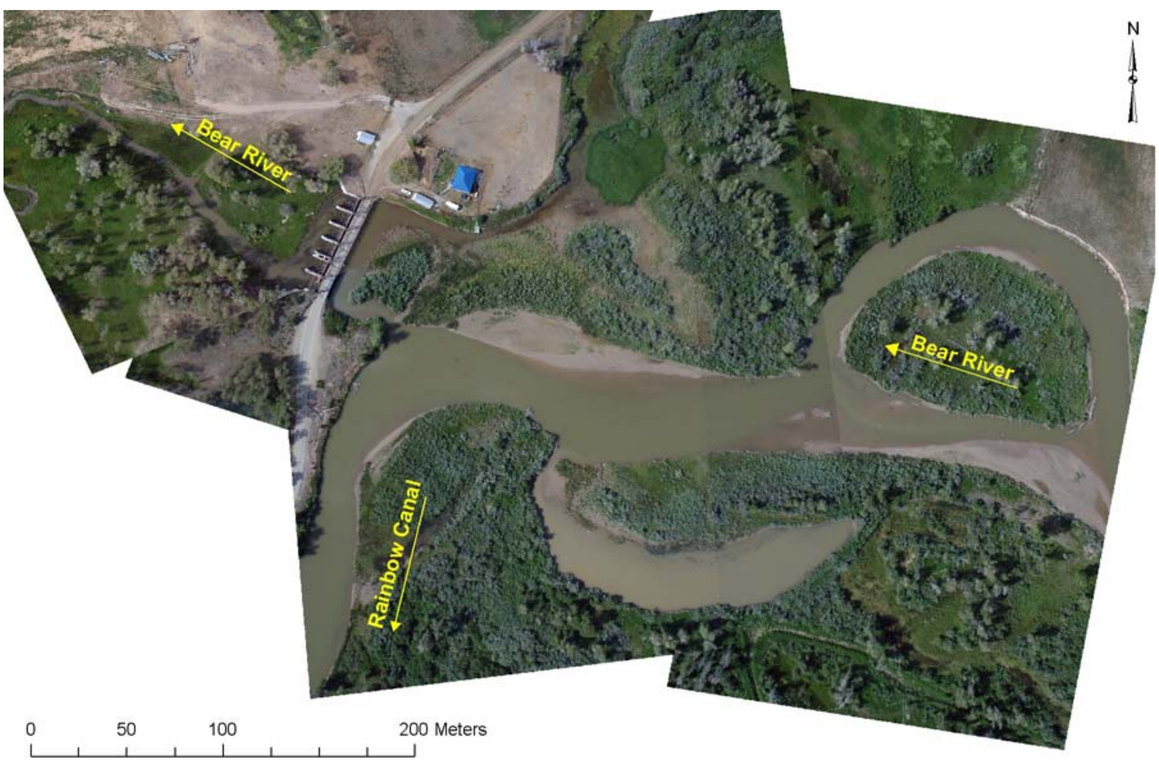


Upper Bear Image 1. TIR Image at river mile 126.81 (Cokeville-Utah Line Road) showing a cold inflow which likely contributes the overall cooling seen in the upper reach of the survey.

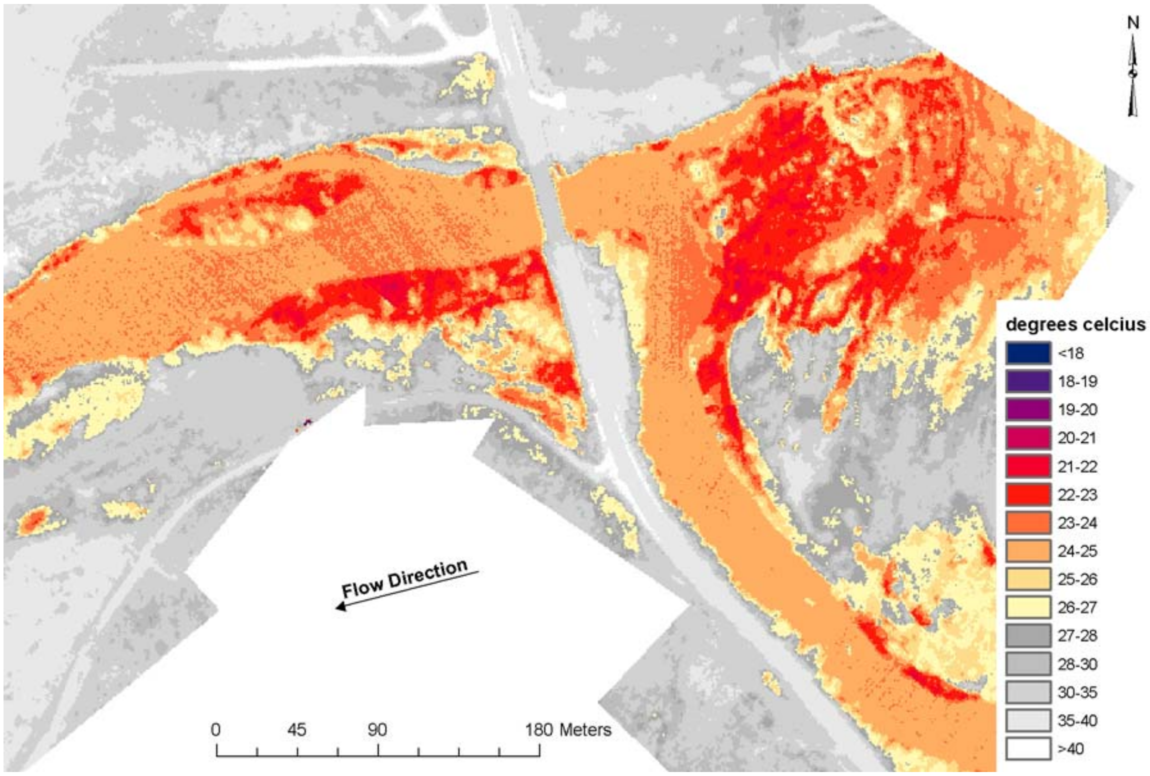


Upper Bear Image 2. TIR image from river mile 102 to 98. The river is highly sinuous between river miles 110 and 98. The sinuosity likely results in sub-surface pathways that buffer stream heating processes through this reach.





Upper Bear Image 3. TIR and true color image showing the Rainbow Canal at river mile 63.2. Radiant water temperatures in the Bear River were warmer with a considerably higher degree of local spatial variability downstream of the Rainbow Canal likely due to the large volume of water being diverted.



Upper Bear Image 4. TIR and true color images at river mile 10.14. The image provides an example of the cooler, marshy areas with multiple springs and diffuse seeps in vegetated areas found in the lower reaches of the Upper Bear River above Alexander Reservoir.

Cub River

Longitudinal Temperature Profile

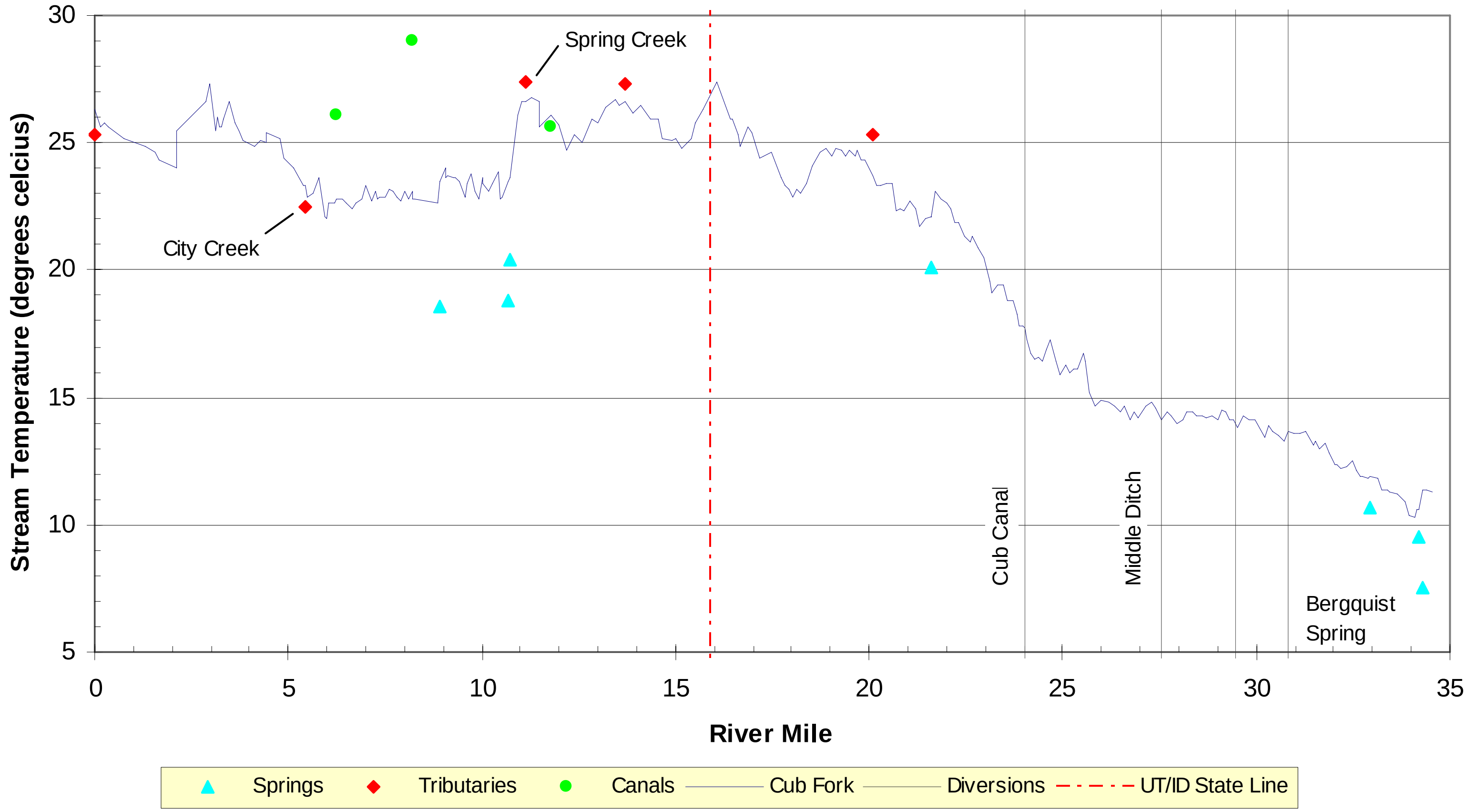


Figure 7 - Median channel temperatures plotted versus river mile for the Cub River. The locations of detected surface inflows are illustrated on the profile and are listed in Table 11.

Table 10 - Tributaries and other surface inflows sampled along the Cub River with left or right bank designation (looking downstream). Major diversion canals are also listed by river mile.

Tributaries	Kilometer	Mile	Tributary Temp °C	Cub River °C	Difference °C
Bear River	0.00	0.00	25.30	26.3	-1.00
City Creek (L)	8.73	5.42	22.50	23.30	-0.80
Spring Creek (L)	17.88	11.11	27.40	26.60	0.80
Worm Creek (R)	22.06	13.71	27.30	26.60	0.70
Maple Creek (L)	32.32	20.08	25.30	23.70	1.60
Springs	**Kilometer**	**Mile**	**Spring Temp °C**	**Cub River °C**	**Difference °C**
spring (L)	14.31	8.89	18.60	23.50	-4.90
small springs (L)	17.16	10.66	18.80	23.50	-4.70
cold wetland (L)	17.28	10.74	20.40	23.60	-3.20
spring (R)	34.80	21.62	20.10	22.10	-2.00
spring (L)	52.99	32.93	10.70	11.90	-1.20
spring (L)	55.00	34.17	9.50	10.60	-1.10
Bergquist Spring (L)	55.17	34.28	7.50	11.40	-3.90
Canals	**Kilometer**	**Mile**	**Canal Temp °C**	**Cub River °C**	**Difference °C**
canal (L)	10.07	6.26	26.10	22.80	3.30
canal (L)	13.18	8.19	29.00	23.10	5.90
canal (R)	19.00	11.80	25.60	26.10	-0.50
Diversions	**Kilometer**	**Mile**			
Cub Canal	38.68	24.04			
Middle Ditch	44.34	27.56			
Unnamed Diversion	47.37	29.44			
Cub River -Worm Creek Canal	49.59	30.82			

Observations

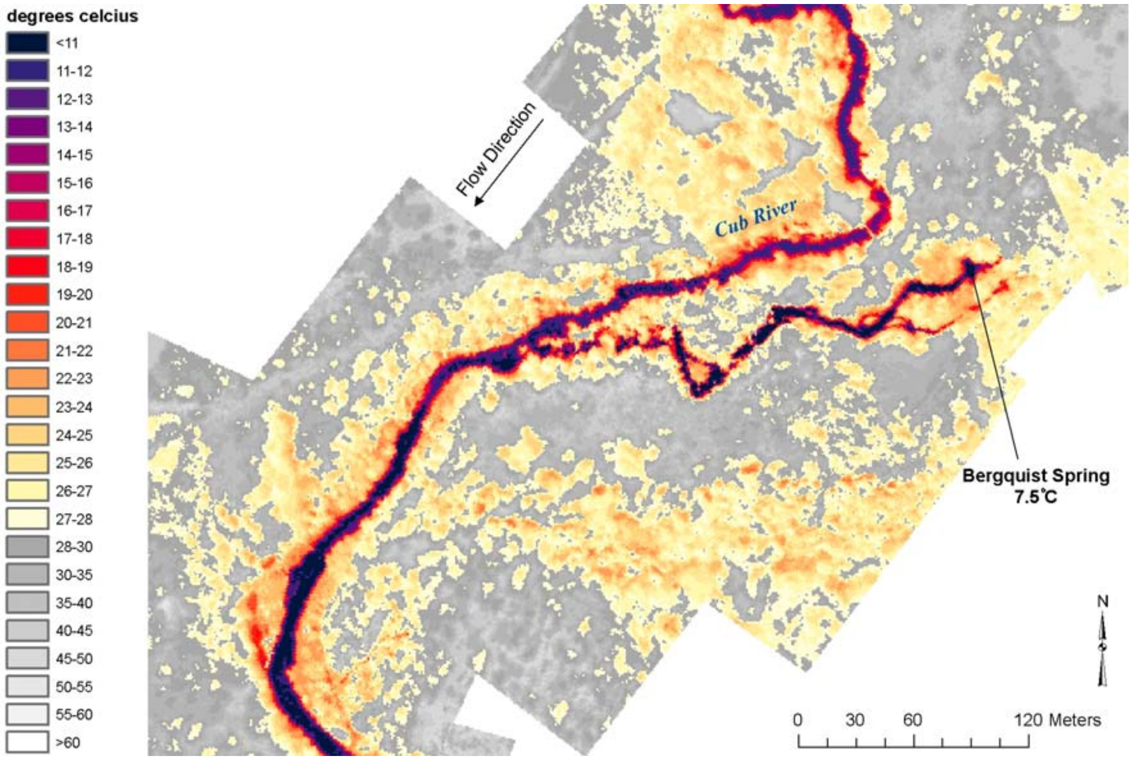
The Cub River was flown upstream from its mouth to Bergquist Spring, a distance of 34.3 miles. The nature of the Cub River changes dramatically as the stream flows from its headwaters in the Bear River Range to it confluence with the Bear River. The change as the Cub River transitions from a high gradient stream in the Caribou National Forest to a low gradient, meandering river is reflected in the longitudinal temperature profile.

At the upstream end of the survey, radiant water temperatures in the Cub River were measured at ~10.3°C[3]. Three springs, including Berquist Spring (7.5°C) were detected between river miles 32.9 and 34.3 (*Cub River Image 1*). Stream temperatures warmed steadily to ~13.6°C at mile 31.1. The trend continued downstream, although at a lesser rate, reaching14.9°C at mile 26.0. Near mile 26.0, the downstream heating rate increased dramatically with radiant temperatures increasing by ~9.8°C over the next 6.3 miles. The reach includes the diversion for the Cub Canal (*Cub River Image 2*) and incorporates the transition from the canyon upstream of the town of Mapleton, ID into the open Cache Valley.

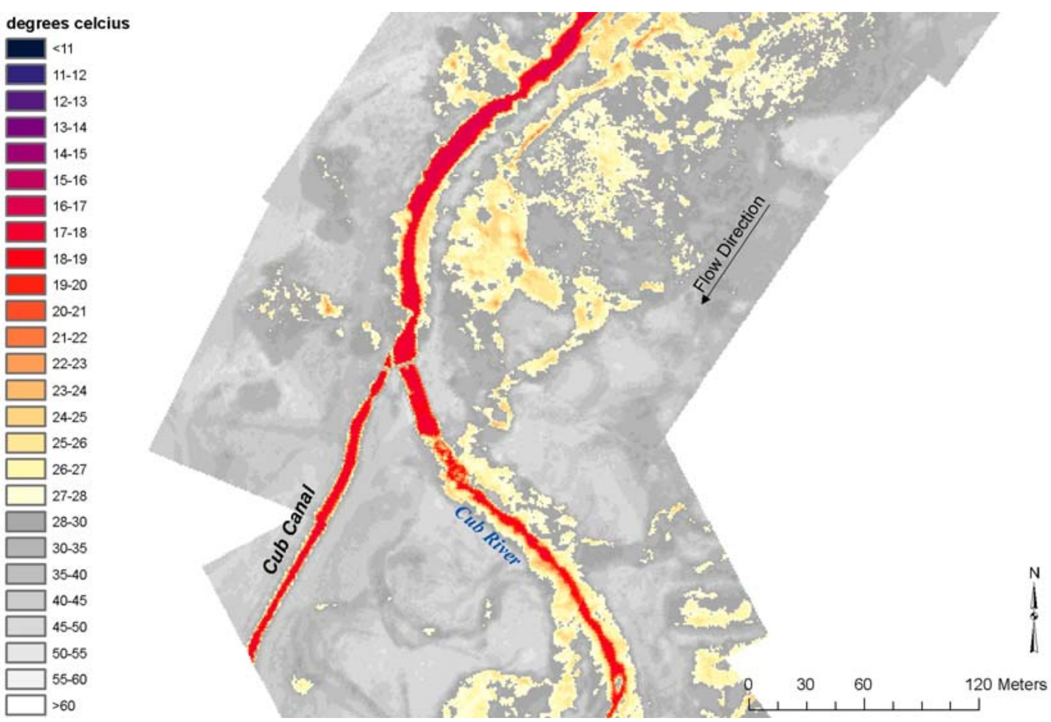
In the lower 20.0 miles, stream temperatures remained relatively warm varying between 22.0°C (mile 6.0) and 27.4°C (mile 16.1). Three apparent spring sources were sampled between river miles 8.9 and 10.7 (*Cub River Image 3*). The detection of the springs in this reach suggest that sub-surface upwelling contributes to cooler in-stream temperatures observed between river miles 10.5 and 6.0. A warm canal inflow at river mile 6.2 contributes to the warming trend seen in the lower five miles of the river (*Cub River Image 4*).

[3] Watershed Sciences did not have any in-stream monitors above mile 25.6 to verify the absolute temperatures measured by the thermal sensor.

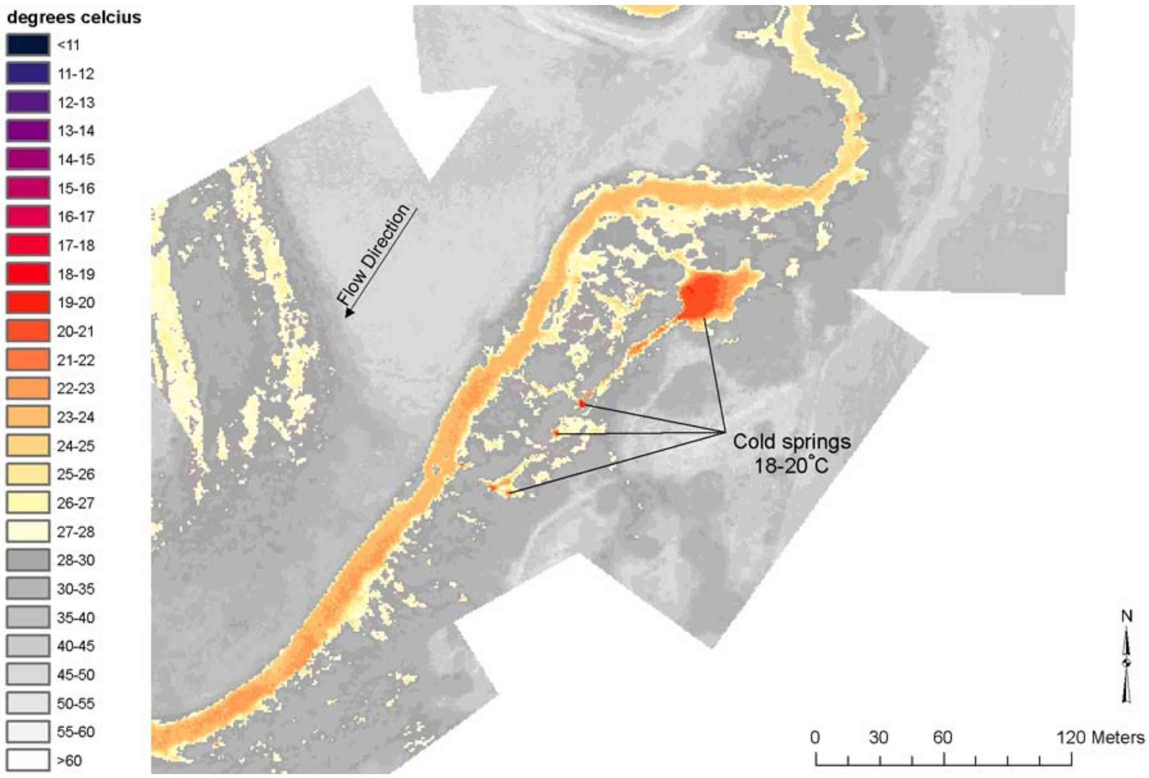
Sample Images



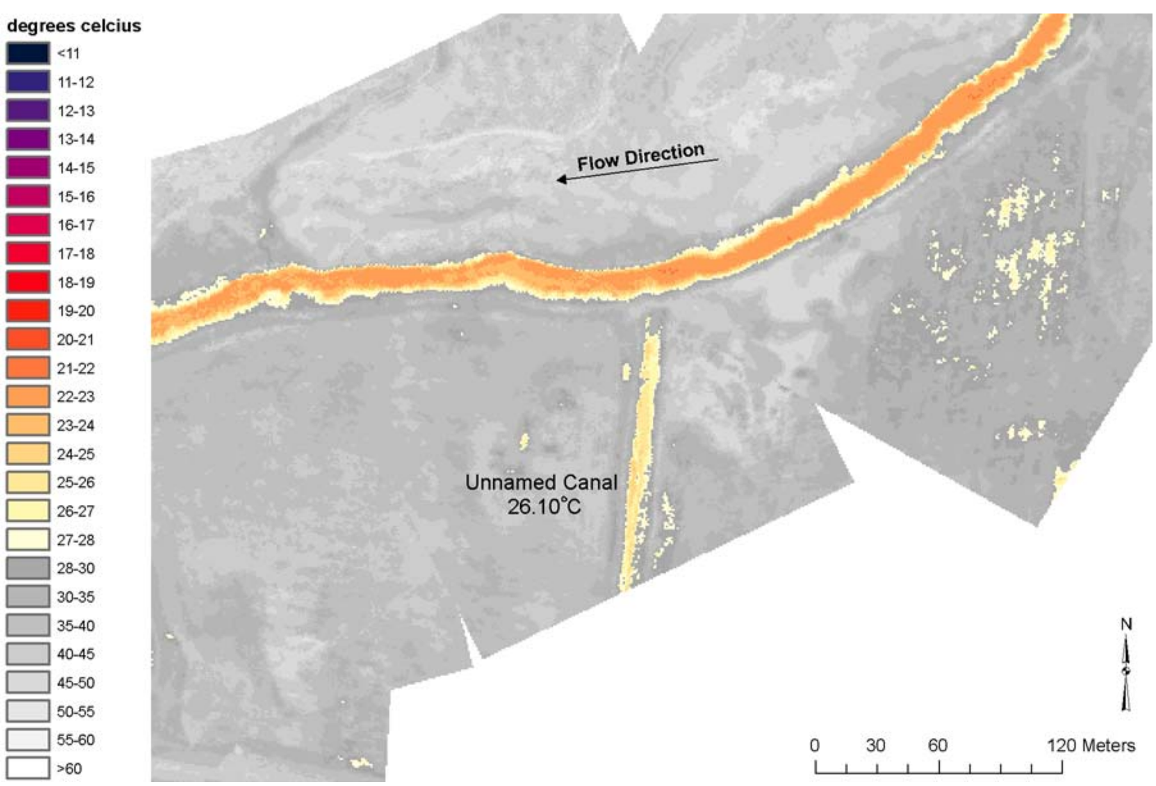
Cub River Image 1. TIR image of Bergquist Spring at river mile 34.28.



Cub River Image 2. TIR Image at river mile 24.04. River temperatures increase rapidly below the Cub Canal Diversion.



Cub River Image 3. TIR image of springs near river mile 10.74. These springs contribute to the cooling seen between river mile 8.9 and 10.7.



Cub River Image 4. TIR image near river mile 6.26. The warm canal inflow contributes to the warming trend seen in the lower five miles of the Cub River.

Smiths Fork/Hobble Creek

Longitudinal Temperature Profile

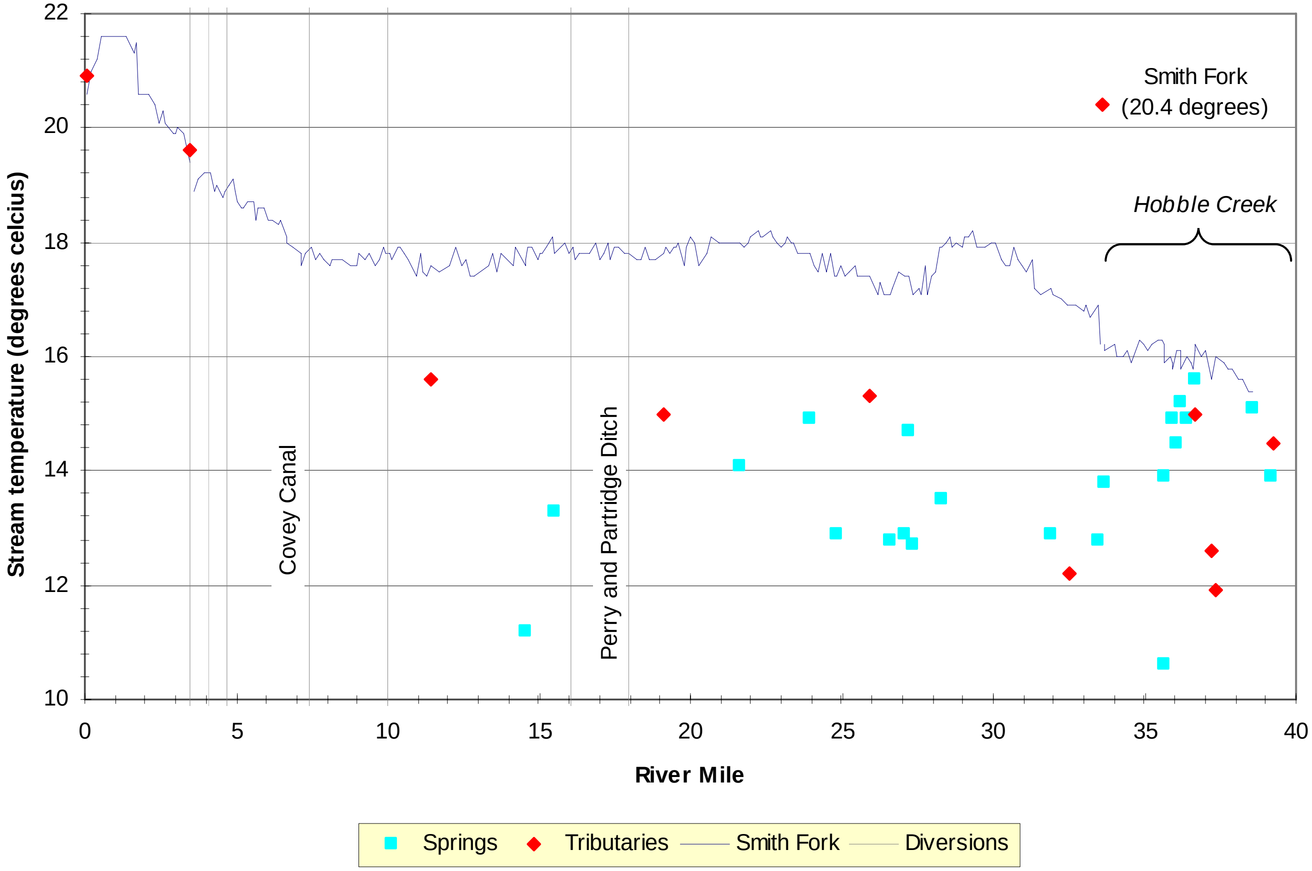


Figure 8 - Median channel temperatures plotted versus river mile for the Smiths Fork. The locations of detected surface inflows are illustrated on the profile and listed in Table12.

Table 12 - Tributaries and other surface inflows sampled along the Smiths Fork with left or right bank designation (looking downstream). Major diversion canals are also listed by river mile.

Tributaries	Kilometer	Mile	Tributary Temp °C	Smiths Fork °C	Difference °C
Bear River	0.10	0.06	20.90	20.60	0.30
South Fork (L)	5.64	3.50	19.60	19.40	0.20
Salt Creek (L)	18.38	11.42	15.60	17.60	-2.00
underground side drainage (L)	30.72	19.09	15.00	17.80	-2.80
cold slough (R)	41.69	25.90	15.30	17.40	-2.10
unnamed intermittent (L)	52.36	32.53	12.20	16.90	-4.70
Leave Smiths Fork (follow Hobble Creek)	54.07	33.55	20.40	16.20	4.20
Cliff Creek (R)	59.05	36.70	15.0	16.1	-1.1
Unnamed trib (L)	59.92	37.24	12.60	15.60	-3.00
Sams Creek and springs (L/R)	60.05	37.32	11.90	16.00	-4.10
Countag Creek - cold (L)	63.17	39.26	14.50	15.80	-1.30
Springs	**Kilometer**	**Mile**	**Spring °C**	**Smiths Fork °C**	**Difference °C**
cold spring (L)	23.45	14.57	11.20	17.70	-6.50
cold swale (R)	24.96	15.51	13.30	17.80	-4.50
cold spring (L)	34.80	21.62	14.10	18.00	-3.90
cold spring (R)	38.53	23.94	14.90	17.80	-2.90
spring in field (L)	39.98	24.84	12.90	17.40	-4.50
spring (R)	42.78	26.58	12.80	17.10	-4.30
spring (L)	43.54	27.05	12.90	17.40	-4.50
spring (island)	43.79	27.21	14.70	17.40	-2.70
spring (L)	43.99	27.34	12.70	17.10	-4.40
cold springs all around (R)	45.56	28.31	13.50	17.90	-4.40
springs (L)	51.37	31.92	12.90	17.20	-4.30
spring (R)	53.83	33.45	12.80	16.90	-4.10
spring (R)	54.19	33.68	13.8	16.10	-2.30
spring (L)	57.34	35.64	10.6	16.20	-5.60
spring (R)	57.39	35.67	13.9	15.90	-2.00
spring (R)	57.84	35.95	14.9	15.80	-0.90
spring (L)	58.04	36.07	14.5	16.10	-1.60
springs (R)	58.23	36.19	15.2	15.80	-0.60
spring (R)	58.52	36.37	14.9	16.00	-1.10
spring (R)	59.05	36.70	15.6	16.20	-0.60
spring (R)	62.03	38.55	15.1	15.4	-0.30
springs (R)	63.01	39.16	13.9	15.6	-1.70
Diversions	**Kilometer**	**Mile**			
Spring Creek/South Fork	5.6	3.50			
White Water Ditch	6.6	4.10			
Tanner Hunt Garrett Ditch	7.6	4.72			
Covey Canal	12.0	7.44			
Wheelock Ditch	16.1	9.99			
Emelle Ditch	25.8	16.03			
Perry and Partridge Ditch	28.9	17.95			

Observations

The TIR survey on the Smiths Fork started at its mouth and continued upstream to the confluence with Hobble Creek. The survey continued up Hobble Creek for 5.7 miles. Referenced river miles are measured cumulatively from the mouth of the Smiths Fork to the upper reaches of Hobble Creek, at its confluence with Countag Creek.

While the flight was conducted under generally good weather conditions, clouds formed over the upper reaches prior to the end of the survey. The cloud layer rapidly cooled terrestrial features resulting in lower thermal contrast between the river and the surrounding terrain. Because water has high thermal inertia, the clouds did not change in-stream temperatures or impact the accuracy of the radiant temperature measurements.

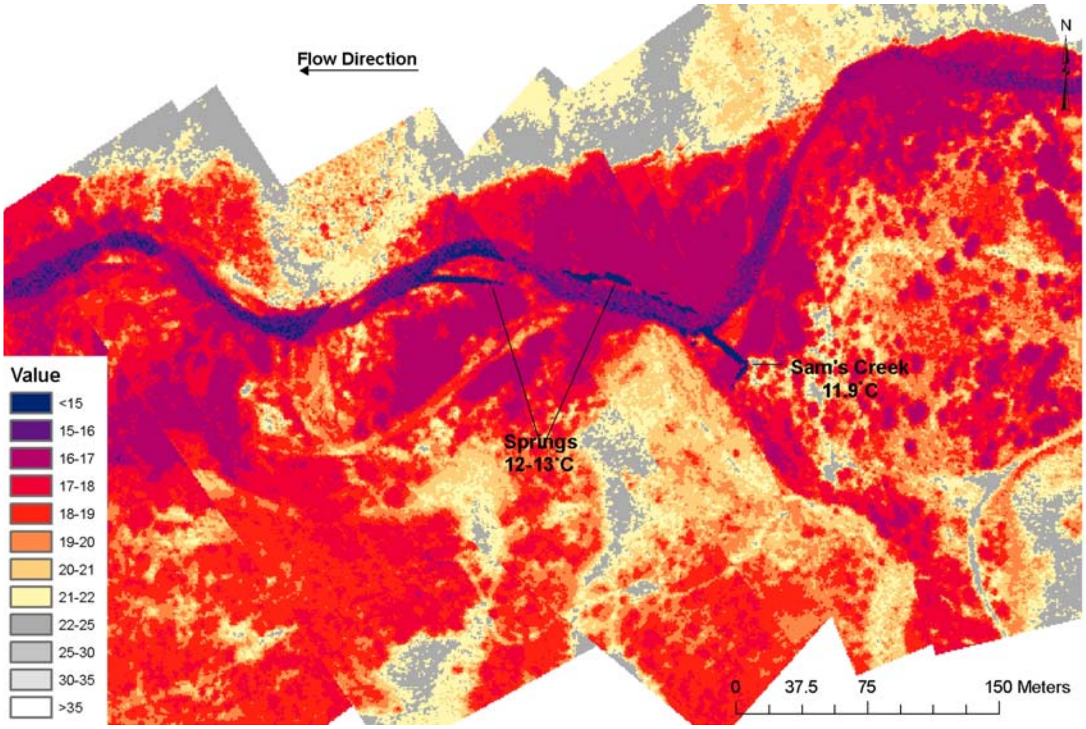
At the upstream end of the survey, radiant water temperatures in Hobble Creek were relatively cool (15.2°C) and warmed steadily (~1.0°C) to the confluence of the Smiths Fork. Four cool water tributaries and ten springs were sampled on Hobble Creek during the analysis. Of the ten springs, four appeared as areas of substantial discharge with radiant temperatures approaching groundwater temperatures (i.e. <13.0°C). The number and distribution of springs in the lower 5.7 miles of Hobble Creek suggests that they are a significant source of thermal regulation during the heat of the summer (*Smiths Fork Image 1 and 2*). While bulk water temperatures in Hobble Creek were generally cool at the time of the survey, the tributary and spring discharge locations may represent location of thermal refugia for trout and other cold-water fish species.

At the confluence of Smiths Fork and Hobble Creek, radiant water temperatures at the mouth of Hobble Creek were ~16.4°C compared to measured temperatures of 20.4°C in the Smiths Fork. The mixed water temperature was ~16.9°C indicating that the flow from Hobble Creek sets the thermal regime of the Smiths Fork at this point (*Smiths Fork Image 3*). Moving downstream, stream temperatures increased steadily to ~18.1°C at river mile 28.5. A series of springs were detected between mile 23.9 and 28.3, which consisted of six individual discharges with temperatures ranging between 13.7°C and 14.9°C. The influence of these springs resulted in decreased main stem temperatures (~17.1°C) between mile 28.0 and 24.2 (*Smiths Fork Image 4*).

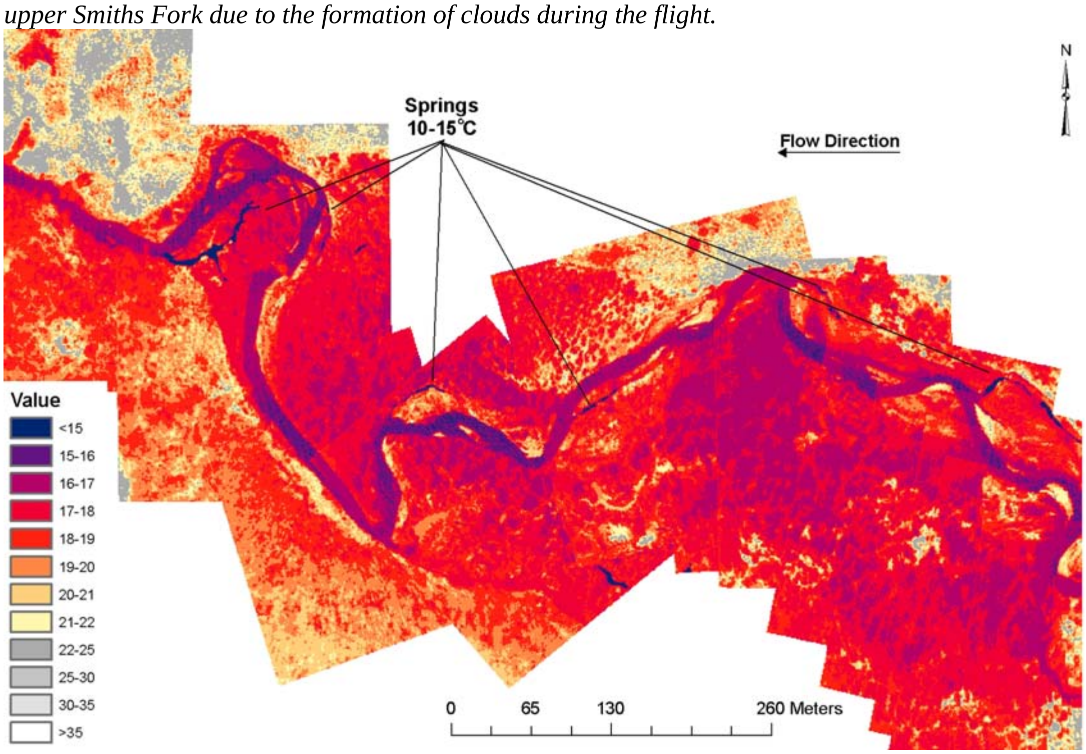
Radiant water temperatures reached ~18.0°C by river mile 23.4 and remained between 17.4°C and 18.2°C over the next 12.5 miles downstream to mile 6.9. The spatial temperature pattern is notable due to the overall lack of longitudinal heating observed in this reach. Two tributaries and three springs were detected through this reach. The channel was characterized by highly sinuous segments with some isolated meanders and oxbows and relatively low levels of riparian shading. The lack of heating combined with the channel conditions suggests that some level of sub-surface flow through the shallow alluvium must buffer the heating processes (*Smiths Fork Image 5*).

Stream temperatures in the Smiths Fork increased rapidly over the lower 6.9 miles reaching a survey maximum of 21.6°C at mile 0.5. The increase in temperature suggests the absence of the buffering processes observed upstream of river mile 6.9.

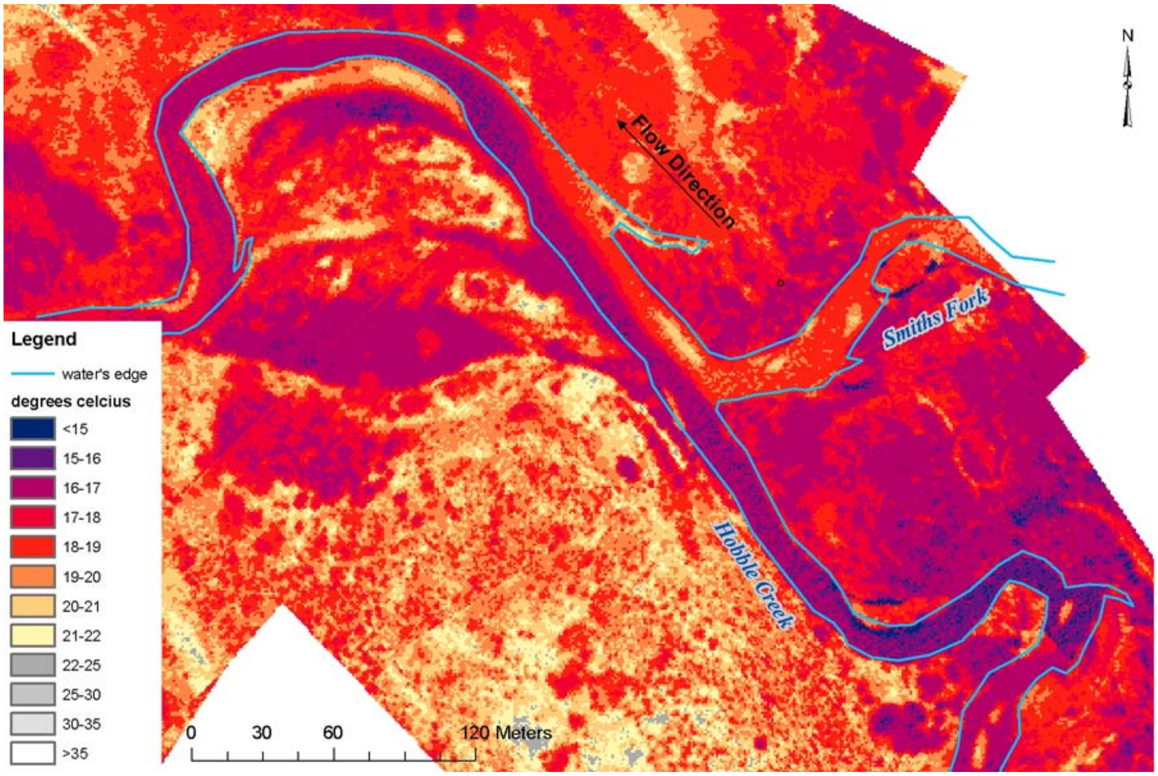
Sample Images

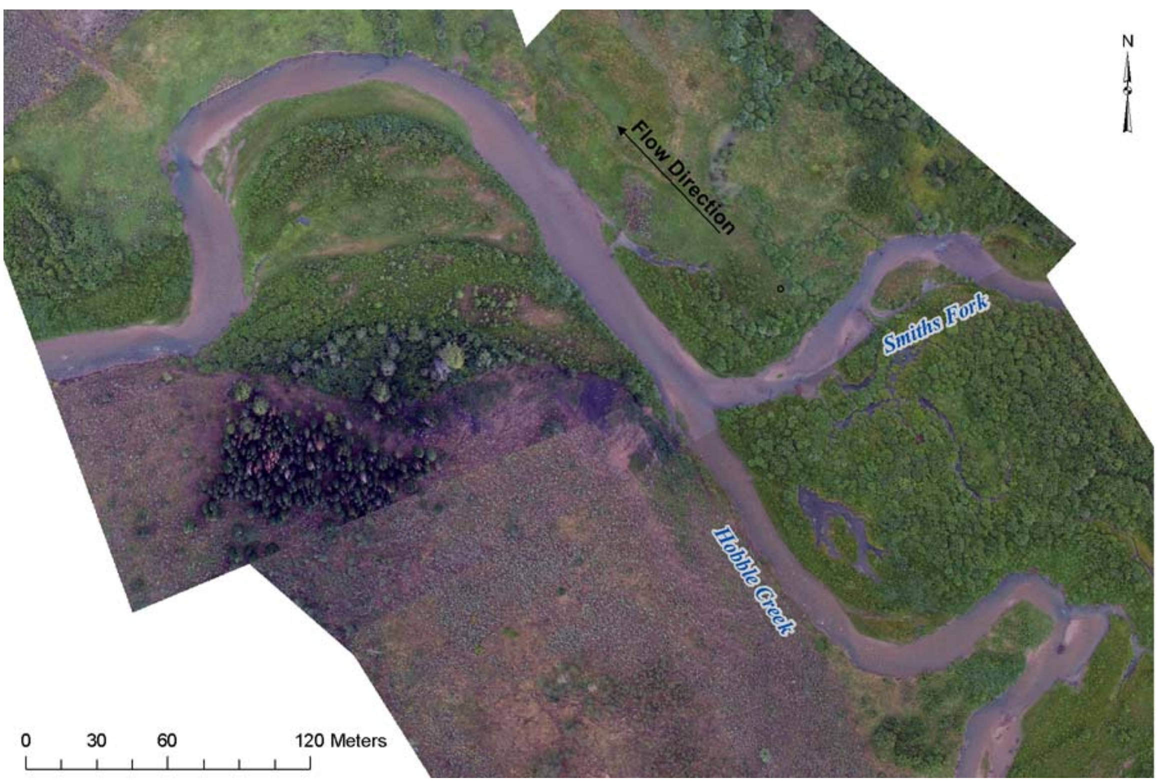


Smiths Fork Image 1. TIR images at river mile37.32. The inflow of Sam's Creek is visible along the left bank with spring discharges visible ~75 meter downstream on the right bank and 170 meters downstream on the left bank. The image also provides an example of the cooler terrestrial temperatures observed in the upper Smiths Fork due to the formation of clouds during the flight.

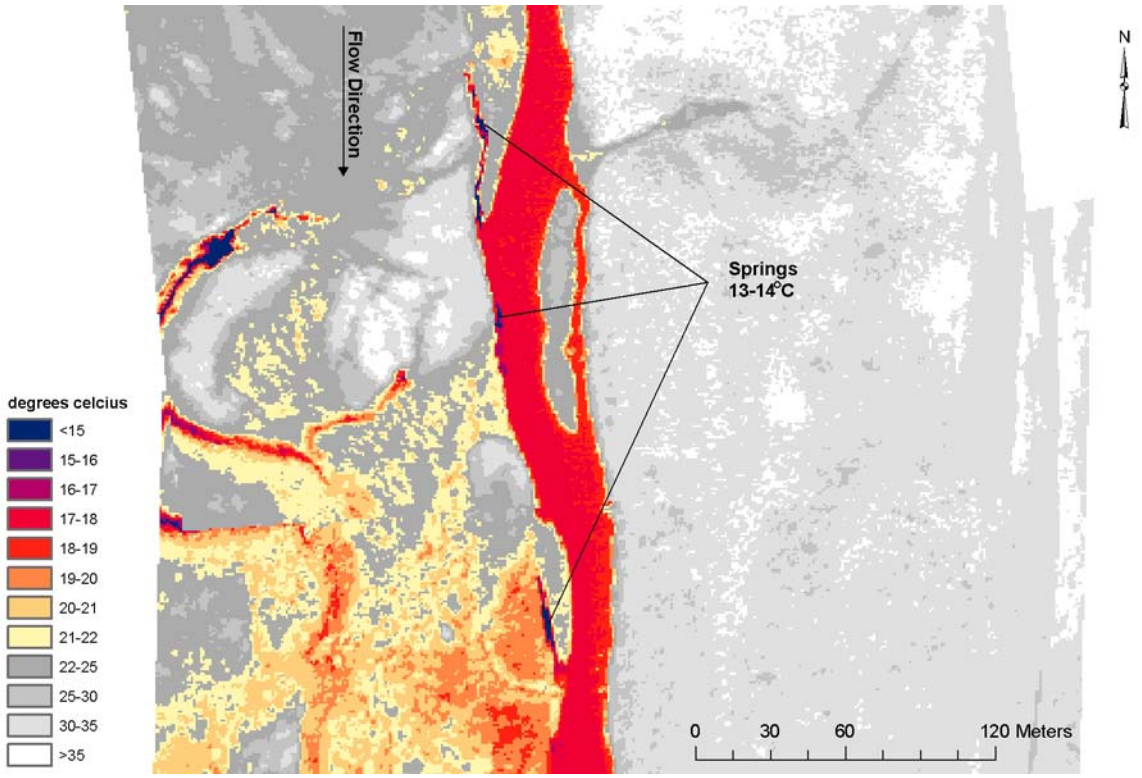


Smiths Fork Image 2. TIR Image near river mile 36 showing several of the ten springs sampled on Hobble Creek.

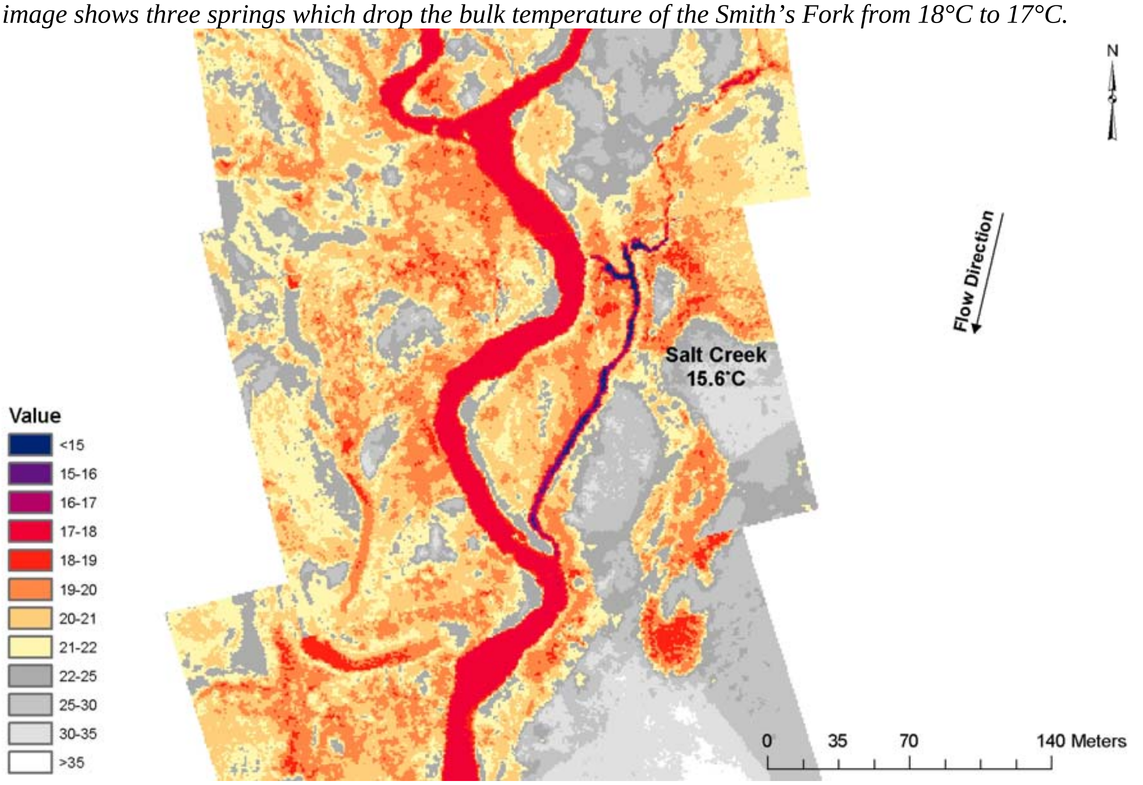




Smiths Fork Image 3. TIR and true color image of river mile 33.55, Hobble Creek – Smiths Fork confluence. Radiant water temperatures at the mouth of Hobble Creek were ~16.4°C compared to measured temperatures of 20.4°C in the Smiths Fork. The mixed water temperature was ~16.9°C indicating that the flow from Hobble Creek sets the thermal regime of the Smiths Fork at this point.



Smiths Fork Image 4. TIR image at river mile 28.3. A number of springs were detected between river mile 23.9 and 28.3, which appeared to contribute to lower main stem temperatures observed in this reach. This image shows three springs which drop the bulk temperature of the Smith's Fork from 18°C to 17°C.



Smiths Fork Image 5. The TIR image shows the inflow of Salt Creek into the Smiths Fork at river mile 11.4. Even with two cold tributaries and three springs, radiant water temperatures in the Smiths Fork remained relatively constant (i.e. 17.4°C to 18.2°C) between river mile 23.4 and 6.9.

Thomas Fork/Salt Creek

Longitudinal Temperature Profile

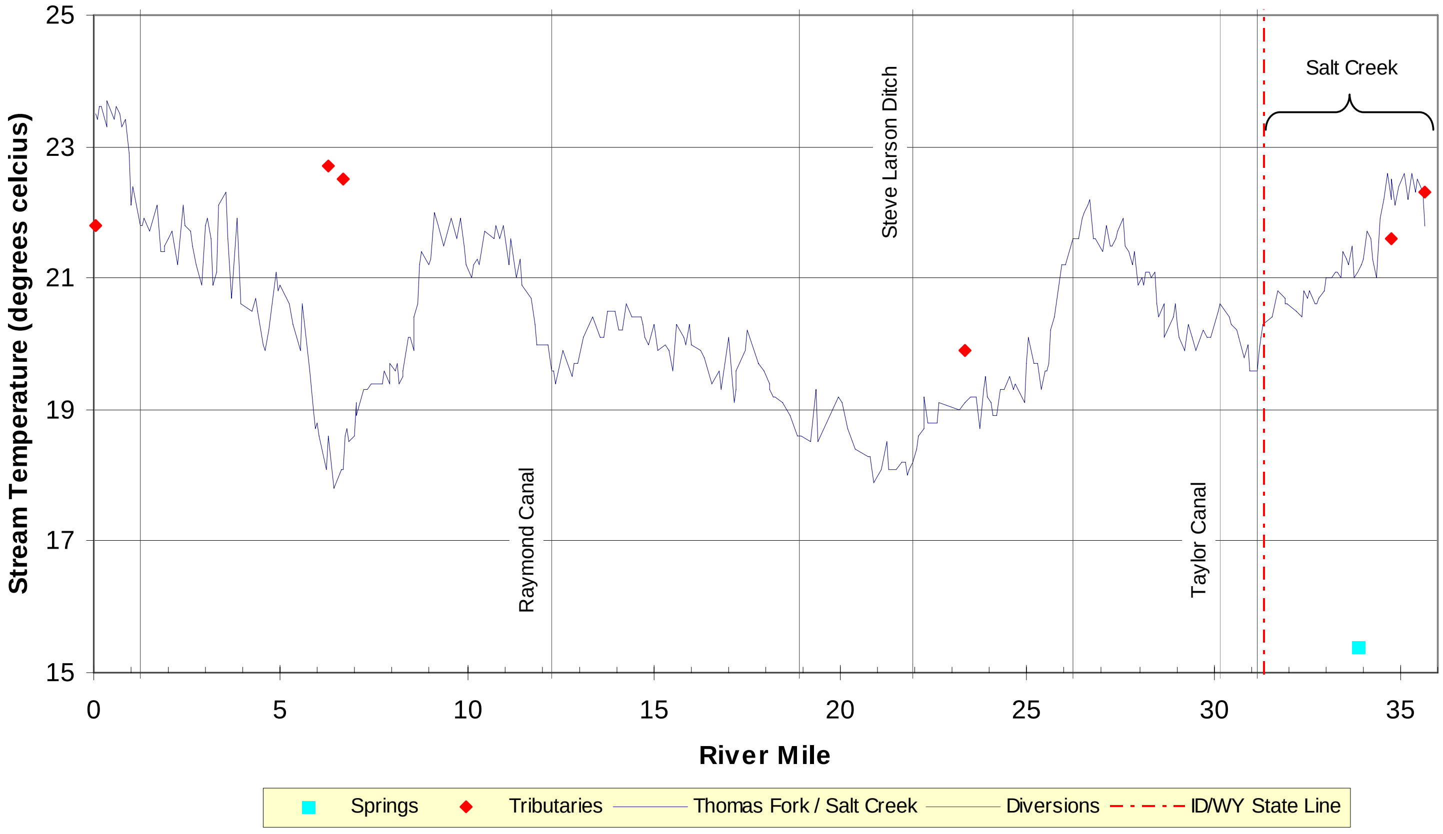


Figure 9 - Median channel temperatures plotted versus river mile for the Thomas Fork. The locations of detected surface inflows and diversions are illustrated on the profile and listed in Table 13.

Table 13 - Tributaries and other surface inflows sampled along the Thomas Fork with left or right bank designation (looking downstream). Major diversion canals are also listed by river mile.

Tributaries	Kilometer	Mile	Tributary Temp °C	Thomas Fork Temp °C	Difference °C
Bear River confluence	0.05	0.03	21.8	23.5	-1.7
Warm Slough (L)	10.73	6.67	22.5	18.1	4.4
Unnamed Trib (R)	37.56	23.34	19.9	19.1	0.8
Giraffe Creek (R)	55.94	34.76	21.6	22.5	-0.9
Coal Creek (L)	57.37	35.65	22.3	21.8	0.5
Springs	**Kilometer**	**Mile**	**Spring Temp °C**	**Thomas Fork Temp °C**	**Difference °C**
Small Spring (L)	54.49	33.86	15.4	21.1	-5.7
Diversions	**Kilometer**	**Mile**			
Unnamed	2.03	1.26			
Raymond Canal	19.73	12.26			
Unnamed	30.44	18.90			
Steve Larson Ditch	35.27	21.90			
Halls Ditch	42.19	26.20			
Taylor Canal	48.53	30.20			
Taylor/Salt Creek Split and diversion	50.15	31.20			

Observations

The Thomas Fork of the Bear River was flown upstream from its mouth to the confluence of Salt Creek, a distance of ~31.2 miles and continued along Salt Creek for about 4.5 miles. (*River miles on the longprofile and in the sample imagery are shown as overall mileages from the mouth of Thomas Fork through the upper reaches of Salt Creek.*) Overall, radiant water temperatures in the Thomas Fork varied between 17.8°C and 23.7°C with variability observed across spatial scales. Unlike the Smiths Fork and Hobble Creek, there was only one spring and no cool water tributaries detected during inspection of the TIR images.

Radiant water temperatures on Salt Creek were ~22.3°C at the end of the survey and showed a downstream cooling trend reaching ~20.3°C at the confluence of Dry Creek. Dry Creek, true to its name, had no visible surface flow at the confluence. Although Giraffe Creek provided some cooler water and a small spring was sampled at river mile 33.9 (*Thomas Fork Image 1 and 2*), the overall source of cooling observed on Salt Creek was not apparent through inspection of the TIR imagery.

Moving downstream on the Thomas Fork, stream temperatures increased steadily reaching ~22.2°C at mile 26.7. Within this reach, the Taylor Canal diversion dam is located at mile 30.2 and a slight (~0.7°C) decrease in radiant temperatures was observed downstream. TIR surveys conducted on other streams have also shown localized decreases in stream temperatures immediately downstream of impoundments (*especially earthen dams*). The source of cooling at these locations is presumed due to sub-surface flow around or under the impoundment, which has a localized cooling influence.

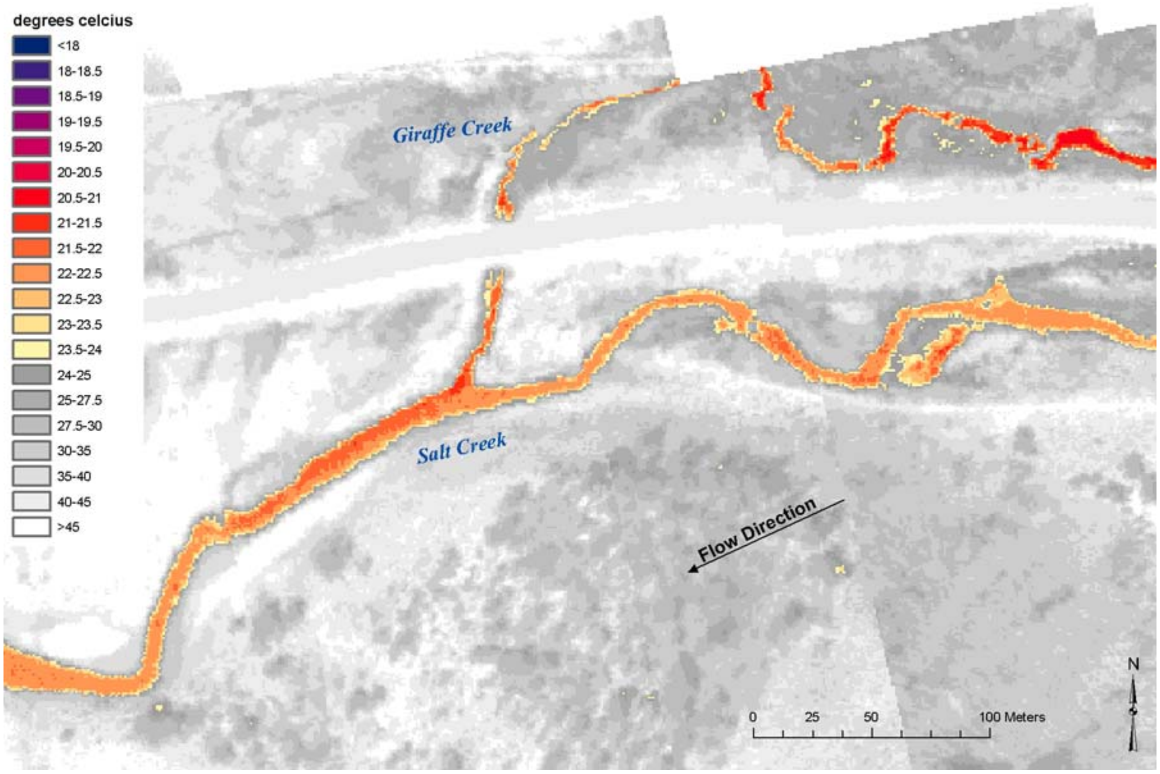
A rapid decrease in stream temperature of ~2.9°C was observed between miles 26.7 and 25.4, a distance of 1.3 miles. Inspection of the imagery and topographic base maps did not reveal any thermal or geomorphic features that would directly explain the source of cooling. However, a decrease in water temperatures over this short distance is typically related to mass transfer of cooler water into the channel. Consequently, the observed cooling is most likely related to the discharge of sub-surface flow into the channel within this reach. Further analysis may examine soils and additional morphology parameters (i.e. stream gradient) to determine the potential for sub-surface upwelling in this location. Follow-on field work may also target this segment for additional monitoring measurements.

Between river miles 25.4 and the Steve Larson Ditch (mile 21.9), radiant water temperatures decreased to a local minimum of ~18.1°C before increasing steadily to 20.4°C at mile 13.4. The longitudinal profile shows some local spatial variability with temperatures variations of between 0.5-1.0°C observed over relatively short distances. This level of variability is often observed under low flow conditions and/or with relatively slow vertical mixing rates where differential surface heating may occur. A ~1.0°C decrease in temperature was observed just upstream of Raymond Canal at mile 12.3. Just downstream of the Raymond Canal diversion, temperatures increased as would be expected with lower flows.

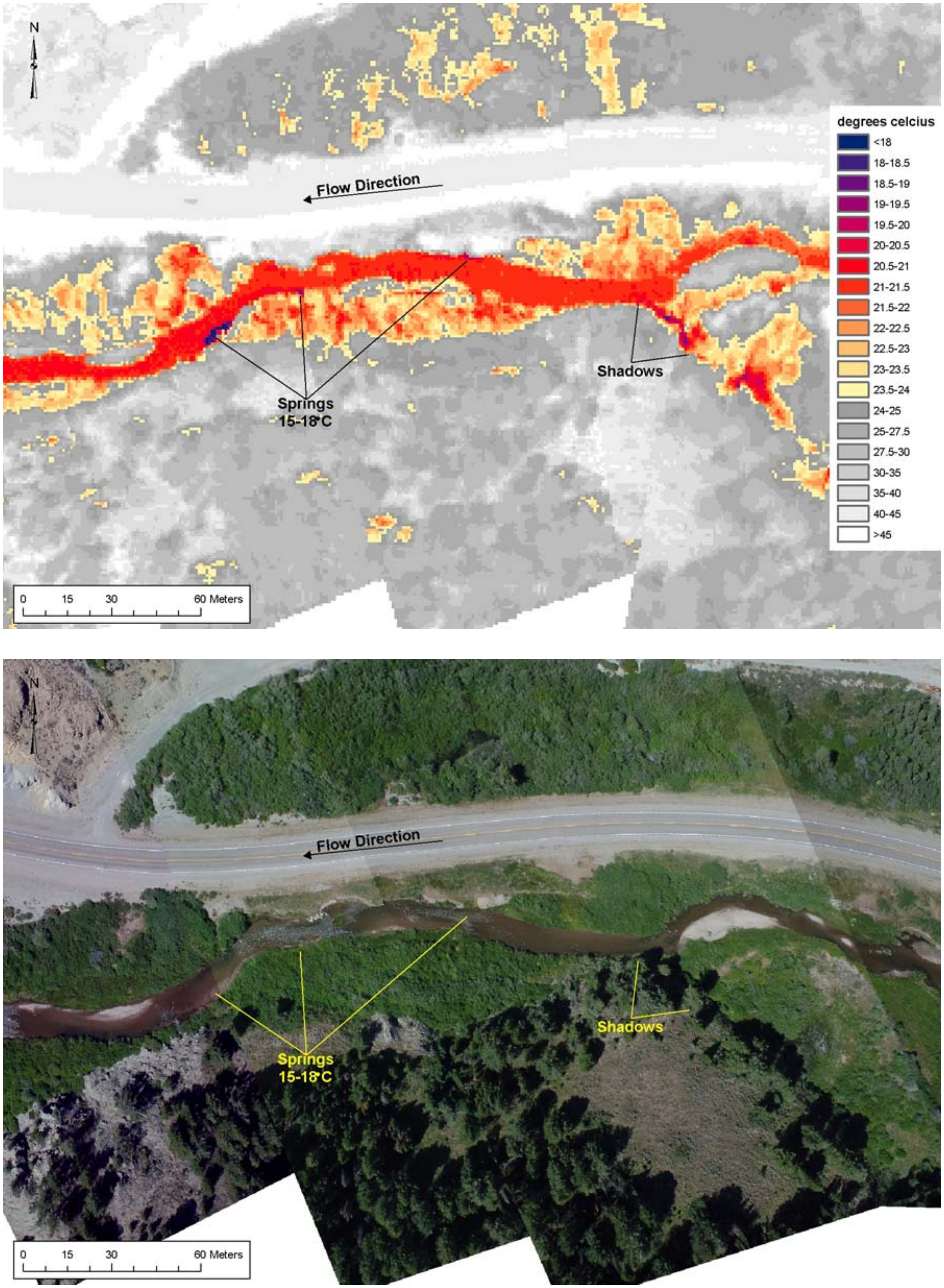
Another dramatic decrease in stream temperatures of ~4.2°C (22.0°C to 17.8°C) was observed between mile 9.1 and 6.4 (*Thomas Fork Image 3*). Similar to the decrease observed at mile 26.7, no surface inflows or obvious geomorphic features were detected that would indicate the source of cooling at this location. However, the magnitude of the decrease suggests a diffuse sub-surface influence of through this reach. Further analysis and field work should target this area to verify the source of cooling and to investigate whether it is used by cold-water fish species during the summer months as thermal refugia.

Water temperatures in the Thomas Fork climbed rapidly downstream of river mile 6.4 (17.8°C) reaching ~23.7°C at confluence of the Bear River. Two warm backwaters contribute to the warming (*Thomas Fork Image 4*). As with much of the Thomas Fork, stream temperatures exhibited a high degree of local variability in the lower 6.4 miles. The observed flow conditions in the lower river suggest the possibility of some differential surface heating within this reach.

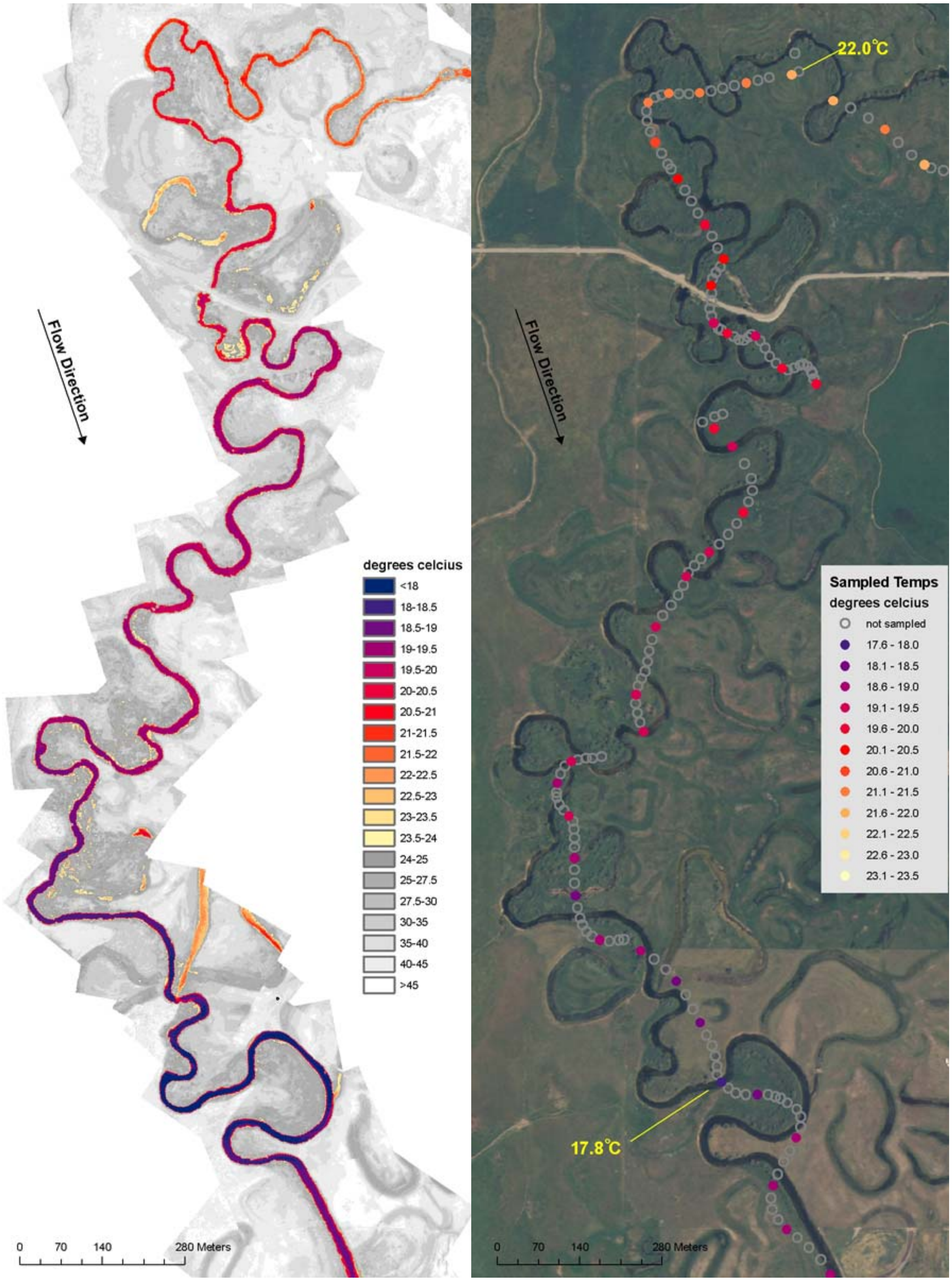
Sample Images



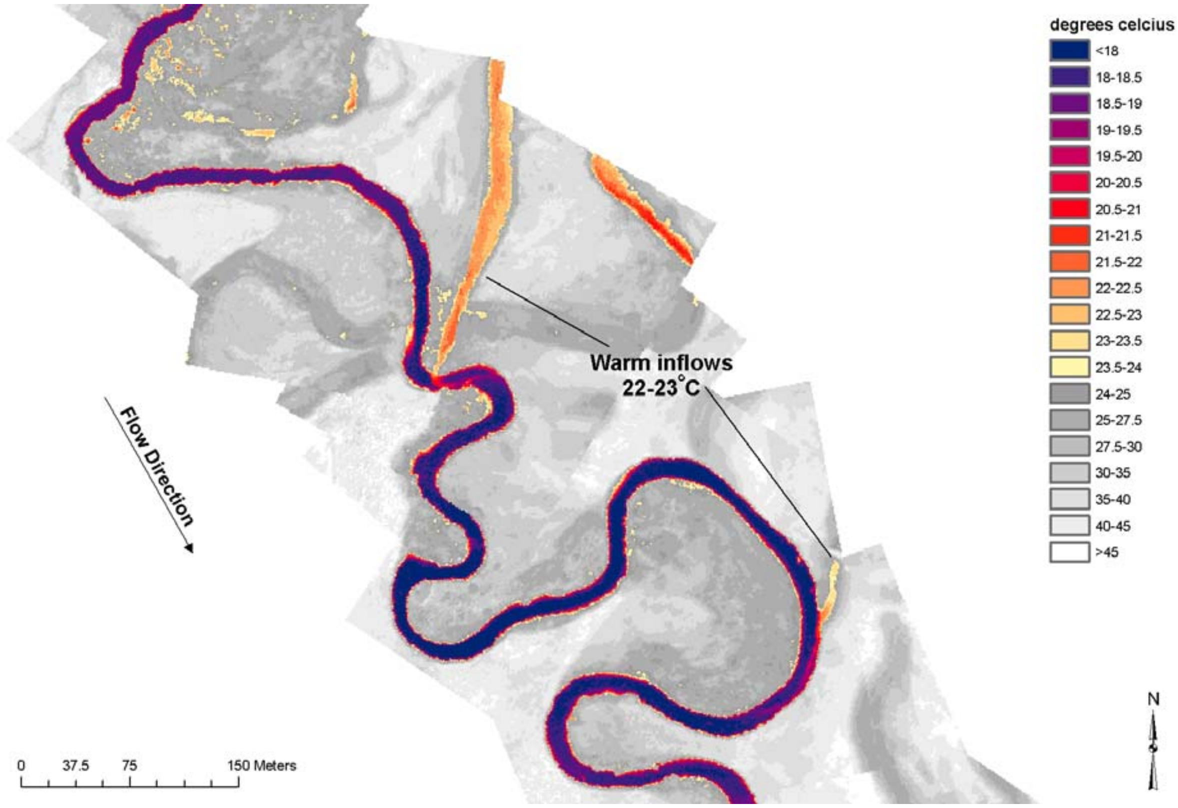
Thomas Fork Image 1. TIR image at the Giraffe Creek-Salt Creek Confluence (overall river mile 34.76). While Giraffe Creek is almost a full degree cooler than Salt Creek, it alone cannot account for the continued cooling seen throughout Salt Creek.



Thomas Fork Image 2. TIR and true color image showing springs on Salt Creek at overall river mile 33.9. Only the westernmost spring was large enough to be sampled accurately.



Thomas Fork Image 3. TIR and 2004 digital orthophoto with sample temperatures for river mile 9.1 to 6.4 showing the dramatic decrease in stream temperature. Similar to the decrease observed at mile 26.7, no surface inflows or obvious geomorphic features were detected that would indicate the source of cooling at this location.



Thomas Fork Image 4. TIR image and 2004 digital orthophoto showing warm inflows at mile 6.4.

Deliverables

The TIR imagery is provided in three forms: 1) individual un-rectified frames and 2) a continuous geo-rectified mosaic at 0.9 m resolution. The mosaic allows for easy viewing of the continuum of temperatures along the stream gradient, but also shows 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. A GIS point layer is included which provides an index of image locations, the results of temperature sampling, and interpretations made during the analysis.

Deliverables are provided on a set of DVD's:

Geo-Corrected Images are stored as: **UTM Zone 12, NAD83, Units = Meters.**

1. Rectified_Images
   a. Thermal_Mosaics - Continuous image mosaic of the geo-rectified TIR image frames at 0.9 meter resolution in geo-tiff format. GRID cell value = radiant temperature * 10.

2. Unrectified_Images
   a. Thermal_Unrectified - Calibrated TIR images in ESRI GRID Format. GRID cell value = radiant temperature * 10. Radiant temperatures are calibrated for the emissive characteristics of water and may not be accurate for terrestrial features. These images retain the native resolution of the sensor.
   b. Nikon_Unrectified – Unrectified true color images in jpg format. An index is provided to show the geographic location of the aircraft at the time the image was acquired.

3. Surveys - Point layers showing image locations, sampled temperatures, and image interpretations.

4. Longprofile - Excel spreadsheet containing the longitudinal temperature profiles.

5. Shapefiles – Relevant hydrography shapefiles