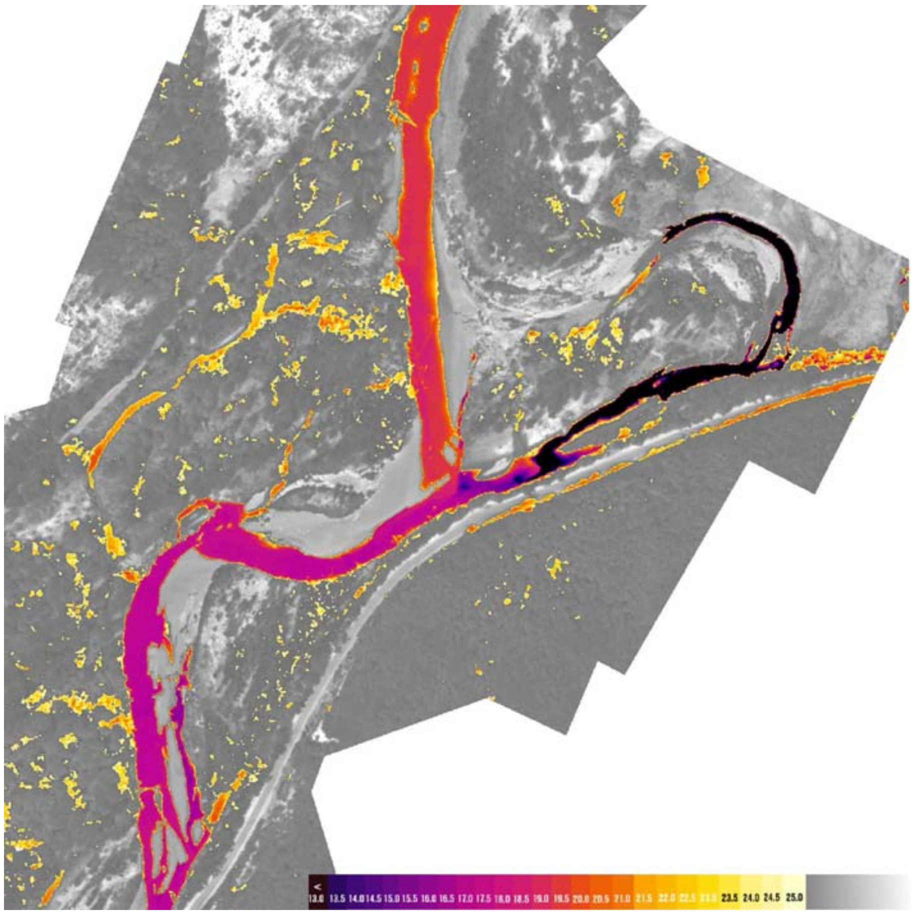
Airborne Thermal Infrared Remote Sensing

Coeur d'Alene River, Idaho



Submitted to:

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Overview

The USDA Forest Services contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) imagery of a portion of the Coeur d'Alene River, ID from the South Fork Coeur d'Alene River upstream to the confluence of Shoshone Creek (Figure 1). The objective of the image acquisition was to detect and map areas of cold water refuge within the river floodplain resulting from sub-surface upwelling and tributary inflows. The data were successfully acquired on August 9, 2007 during the mid-afternoon hours (1:50 PM to 3:52 PM).

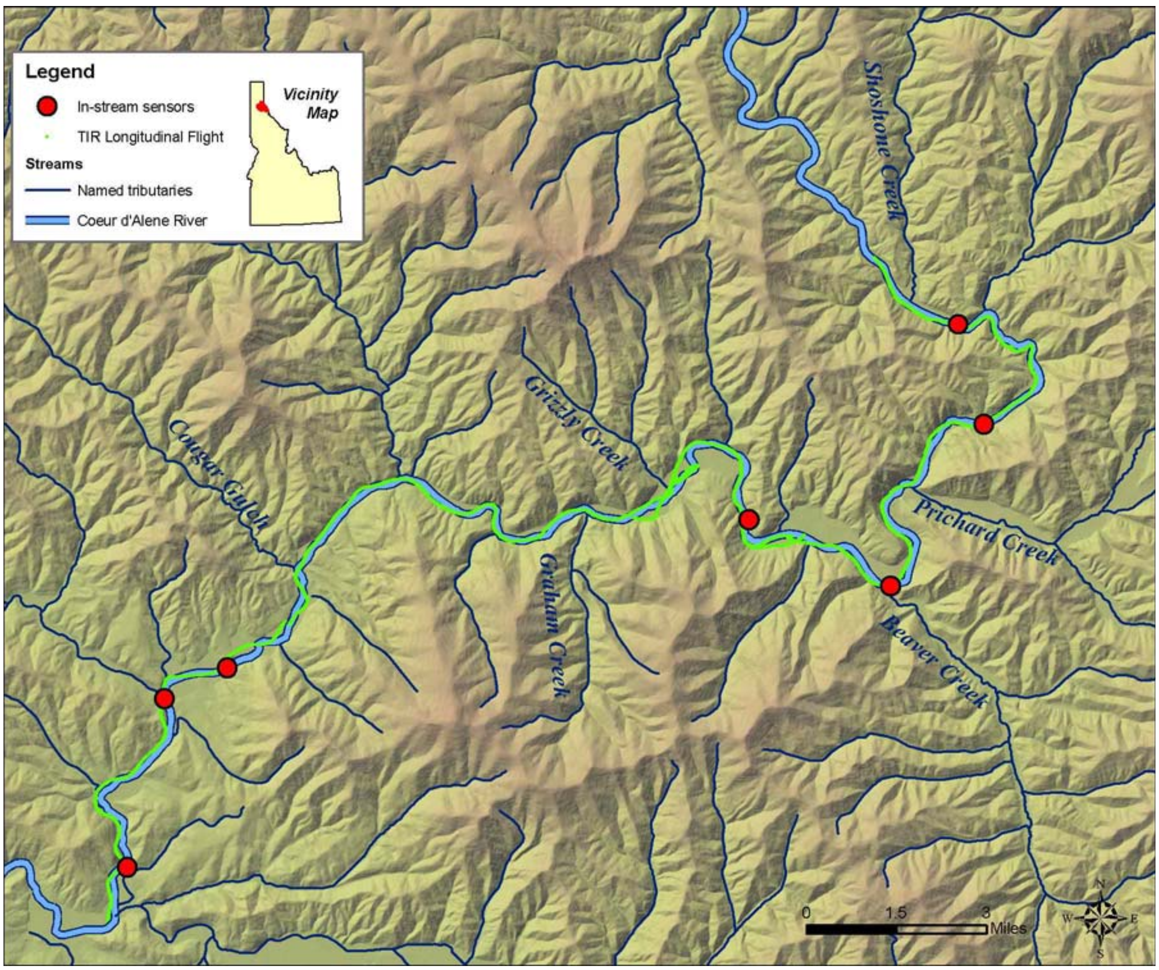

Figure 1 – An Airborne Thermal Infrared Survey of the Coeur d'Alene River was conducted on August 9, 2007.

Methods

Data Collection

Instrumentation: Images were collected with a FLIR system's SC6000 sensor (8-9.2μm) mounted on the underside of a Bell Jet Ranger Helicopter (Figure 2). The sensor was co-located with a 12.4 mega-pixel digital camera and positioned to look vertically down (nadir) from the aircraft to maintain a consistent path-length. 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 1.

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 1 - 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).

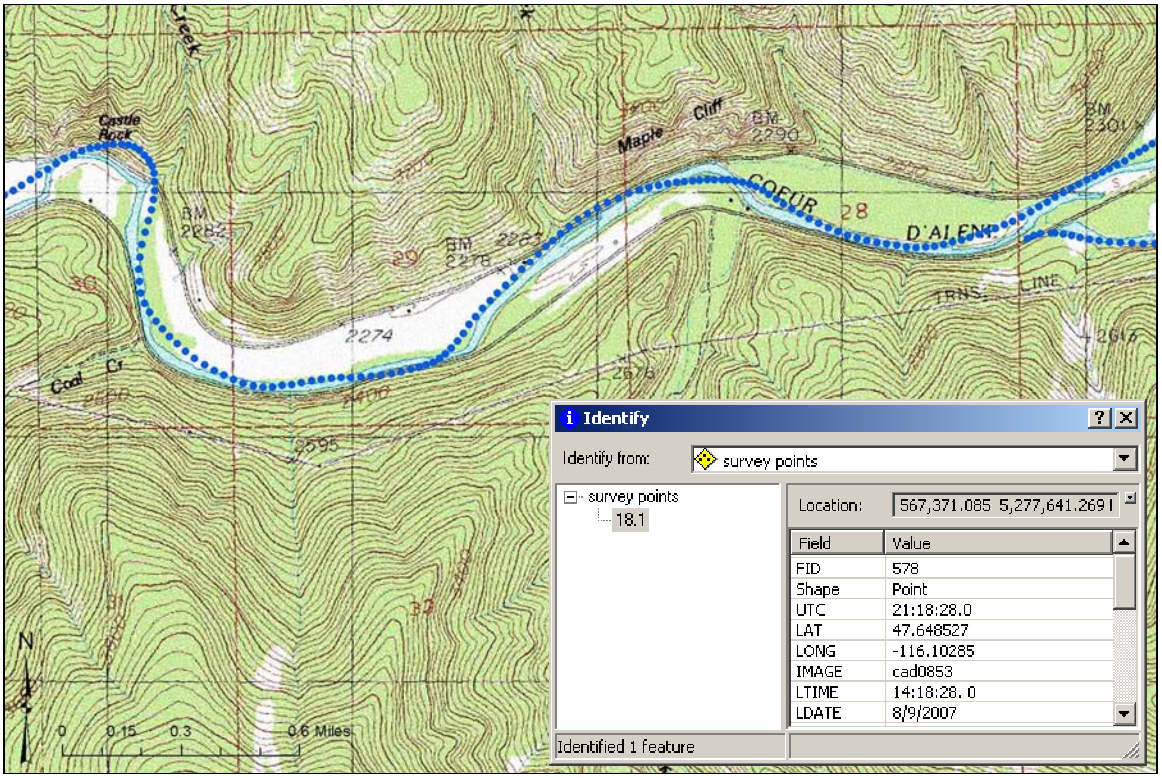

Figure 3 –Each point on the map represents a thermal image location. The inset box shows the information recorded with each image point during acquisition.

Image Characteristics: 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 a rate of 1 image every 2 seconds resulting in considerable vertical overlap between images.

The flight altitude of 670 meters (2200 ft) was selected to provide a pixel ground sample distance (i.e. pixel size) of just over 0.5 meters. The airborne survey attempted to cover all surface water within the floodplain including side channels and tributary junctions. If a side-channel or other surface water was not captured in the image field-of-view. The side-channel was flown separately so that all surface water was captured.

Table 2 - Summary of Thermal Image Acquisition Parameters.

Dates:	August 9, 2007
Flight Above Ground Level (AGL):	2100 - 2300 ft (640 – 701 m)
Image Footprint Width:	1344 – 1472ft (409 – 448 m)
Pixel Resolution:	2.1 – 2.3 ft (0.64 – 0.701 m)

Ground Control: Watershed Sciences deployed in-stream data loggers (Onset Stowaways and/or Hobo-Pros) 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 and set to record temperatures at 10-minute intervals. 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 digital numbers which are then converted to radiance temperatures based on the pre-season calibration.

The calculated radiant temperatures were adjusted based on the kinetic temperatures recorded 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.

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 temperature of detectable surface inflows (i.e. surface springs, tributaries) was 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 11, 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

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

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.

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^{o}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^{o}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

[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.

higher inaccuracies in the measured radiant temperatures. This is a consideration when sampling the radiant temperatures at tributary mouths and surface springs.

<u>Temperatures and Color Maps:</u> 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).

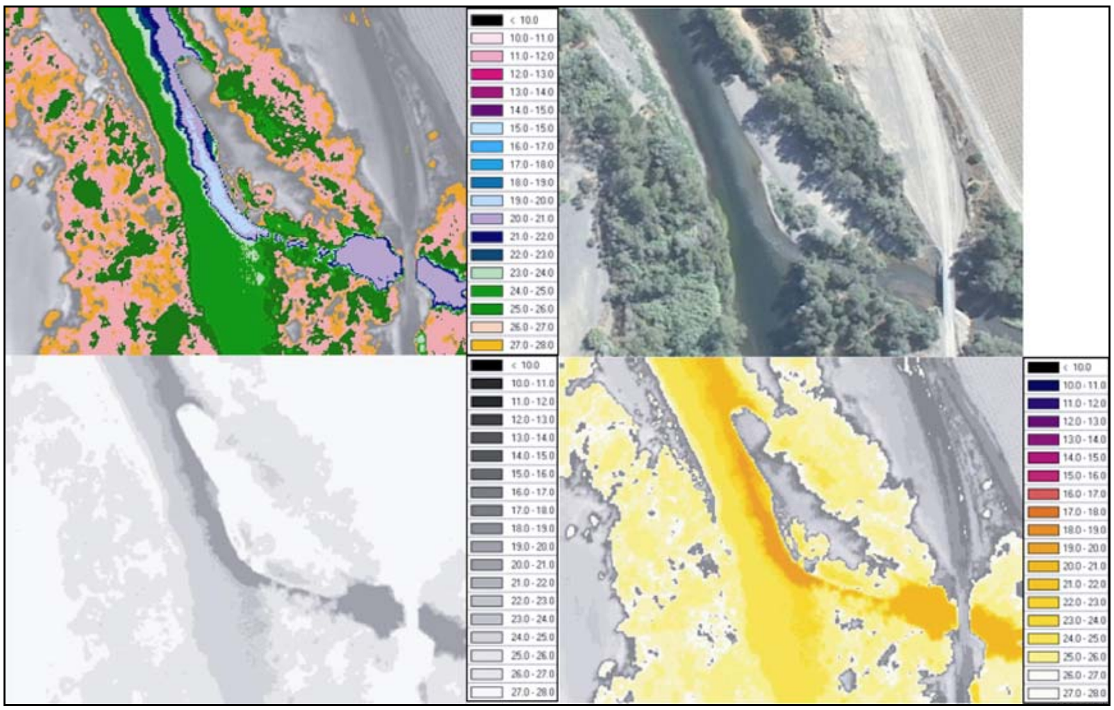

Figure 4 - Example of different color maps applied to the same TIR image.

<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 with relatively low humidity and clear skies. The air temperature was warm on the day of the flight, but was considered unseasonably cool the previous day (August 8). 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 3 summarizes the weather conditions observed in Coeur d'Alene, ID on August 9 (Figure 5).

Table 3 – Air temperatures measured in Coeur d'Alene, ID on August 9, 2007.

Time PDT	Air Temp °F	Air Temp °C	Relative Humidity %	Wind Direction	Wind Speed MPH	Conditions
1:15 PM	77.0	25.0	32	ESE	4.6	Clear
2:15 PM	80.6	27.0	28	SSW	6.9	Clear
3:15 PM	82.4	28.0	25	WSW	11.5	Clear
4:15 PM	82.4	28.0	25	WSW	10.4	Clear
5:15 PM	80.6	27.0	24	SSW	11.5	Clear
6:15 PM	80.6	27.0	23	South	10.4	Clear
7:15 PM	77.0	25.0	24	SW	10.4	Clear
8:15 PM	69.8	21.0	31	SW	4.6	Clear

Figure 5. The ground level photograph shows the Coeur d'Alene River, ID on August 8, 2007. Sky conditions were overcast on the 8th, but were clear and warm for the TIR image acquisition on the August 9.

Thermal Accuracy

Watershed Sciences deployed a network of seven in-stream data loggers (*Onset Stowaways and Hobo Pros*) during the time frame of the flight. The data loggers were placed at 5-10 mile intervals over the extent of survey and provide the basis for calibration and assessing the accuracy of the radiant temperatures derived from the TIR imagery. Sensor locations can be seen in Figure 1.

Table 4 summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images for the Coeur d'Alene River. 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^{o}C.

Table 4 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitor.

Coeur d'Alene River 8/9/2007						
Stream	**Sensor S/n**	**TIR Image**	**Time**	**Kenetic °C**	**Radiant °C**	**Difference °C**
Coeur d'Alene R.	540664	cad0013	13:51	17.6	17.3	0.3
Coeur d'Alene R.	659413	cad0240	13:55	18.2	18.4	-0.2
Coeur d'Alene R.	1026260	cad0427	14:04	18.6	18.5	0.1
Coeur d'Alene R.	659412	cad1178	14:31	18.9	18.7	0.2
Coeur d'Alene R.	540665	cad1448	14:40	19.3	19.8	-0.5
Coeur d'Alene R.	1026265	cad1621	14:45	19.5	19.5	0.0
Coeur d'Alene R.	1026259	cad1794	14:51	20.7	20.8	-0.1

Results

Median channel temperatures were plotted versus river mile for the streams in the survey area (Figure 6). Tributaries and springs sampled during the analysis are included on the profile to provide additional context for interpreting spatial temperature patterns. Three significant secondary channels were also plotted. All features are listed in Table 5.

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. The sample images (Figures 7-14) contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations.

Observations

The Coeur d’Alene River survey began at the confluence with the South Fork Coeur d’Alene and was flown upstream for approximately 31 miles to the confluence with Uranus Creek. Bulk water temperatures ranged between 17-21 ^{o}C and generally decreased in the downstream direction. A large number of springs and cool water tributaries were detected along the stream gradient that contributed to the thermal complexity and structure of the river. Of the 28 sampled surface inflows, 14 contributed water that was significantly cooler than the Coeur d’Alene River. In addition, 35 spring inputs were sampled during the analysis. A spring was classified as any distinct discharge that was not associated with a tributary or other obvious surface inflow.

In the absence of a cooling source, water temperatures typically show a warming trend in the downstream direction. The amount of warming depends on a number of factors including air temperature, direct solar loading (i.e. presence and absence of shade), width-depth ratio, and flow conditions. In the Coeur d’Alene River, the observed downstream cooling at the basin scale suggests that cool water tributaries and sub-surface discharge has a significant influence on moderating water temperatures along the stream gradient.

Inspection of the TIR imagery suggests that many of the detected springs and cold water areas are indicative of hyporheic exchange. Hyporheic flow is often identified in the imagery as cooler water emerging from within the channel floodplain. These discharges are often detected at the downstream end of gravel bars or as emergent cool water within an inactive channel. The inactive oxbow at river mile 16.7 and the detected spring at river mile 19.2 provide good examples (Figures 9 and 10). In the TIR imagery, hyporheic discharges often appear relatively small compared to tributaries and other inflows because they are more diffuse and often occur below the water surface. However, the detection of areas of hyporheic exchange is an indicator of the thermal processes occurring within each river segment and its contribution to both local and basin scale spatial temperature patterns.

Inspection of the longitudinal profile shows that groundwater discharges were frequently clustered in relatively short river reaches. These spring complexes often did not have detectable influence on bulk water temperatures in the reach, but offered multiple localized areas of thermal refugia. The spring complexes illustrate locations where the channel morphology and substrate are conducive to sub-surface discharge.

Longitudinal Temperature Profile

Figure 6 - Median channel temperatures plotted versus river mile for the Coeur d'Alene River. The locations of detected surface inflows are illustrated on the profile and listed in Table 9.

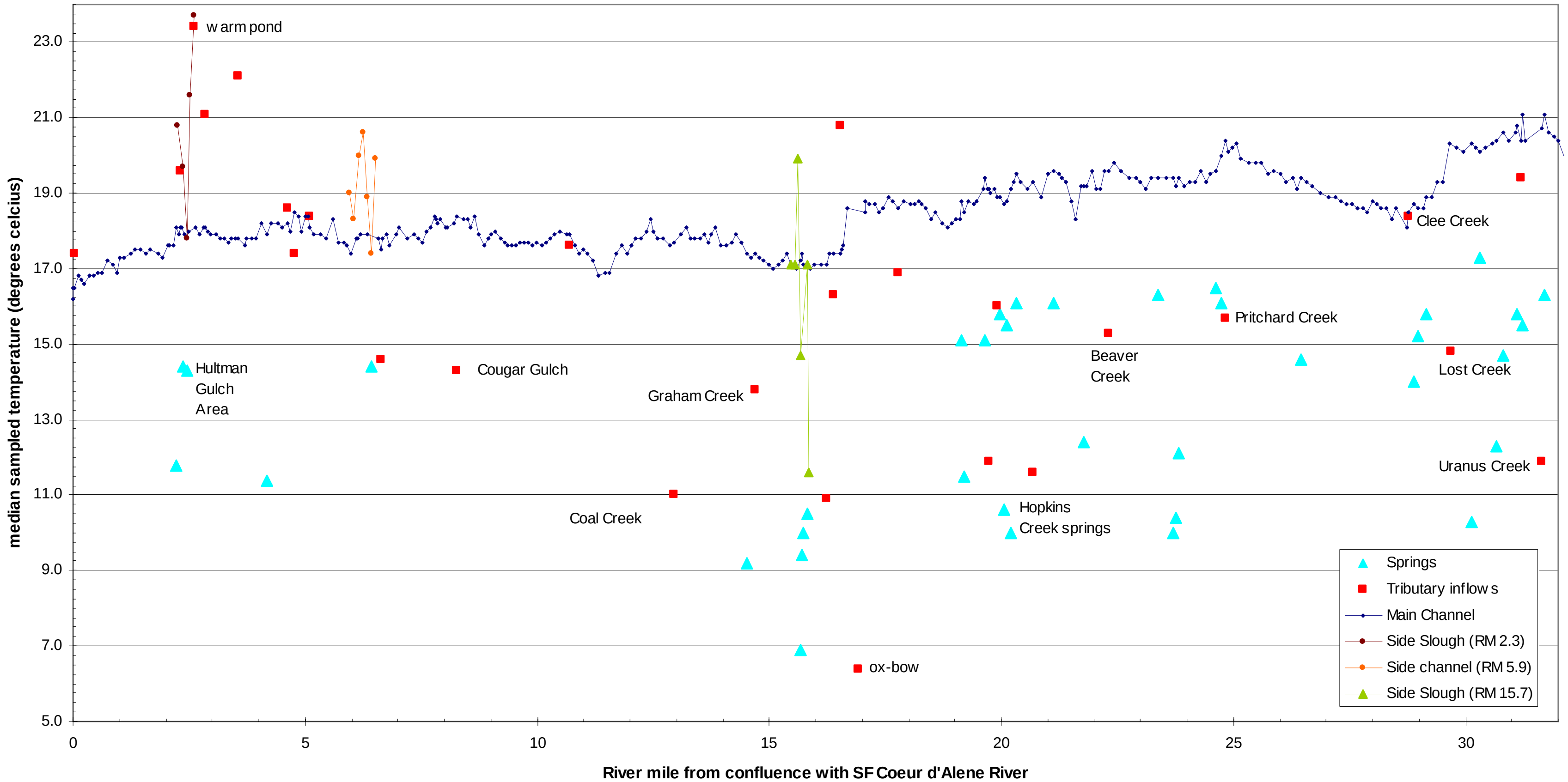

Table 5 - Tributaries and other surface inflows sampled along the Coeur d'Alene River with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (ºC)	Main Stem Temp (ºC)	Difference
SF Coeur d'Alene (L)	0.07	0.04	17.4	16.5	0.9
Prado Creek (R)	3.71	2.30	19.6	18.1	1.5
side slough (R)	4.57	2.84	21.1	18.1	3.0
old channel/slough (R)	5.75	3.57	22.1	17.8	4.3
NF Coeur d'Alene (R)	7.42	4.61	18.6	18.2	0.4
Lightner Draw (R)	7.69	4.78	17.4	18.5	-1.1
Studer Creek (R)	8.22	5.11	18.4	18.1	0.3
unnamed-cold (R)	10.66	6.63	14.6	17.5	-2.9
Cougar Gulch (R)	13.30	8.27	14.3	18.4	-4.1
Steamboat Creek (R)	17.22	10.70	17.6	17.9	-0.3
Coal Creek-very small (L)	20.85	12.95	11.0	17.7	-6.7
Graham Creek (L)	23.66	14.70	13.8	17.4	-3.6
Cinnabar Creek (L)	26.11	16.23	10.9	17.1	-6.2
cold side channel (L)	26.36	16.38	16.3	17.4	-1.1
side channel (R)	26.58	16.52	20.8	17.4	3.4
Brown Creek (R)	28.61	17.78	16.9	18.6	-1.7
side channel/shadow (L)	31.75	19.73	11.9	19.1	-7.2
Hopkins Creek (R)	32.06	19.92	16.0	18.9	-2.9
Hopkins Creek/spring (R)	32.29	20.07	10.6	18.7	-8.1
Cedar Creek (L)	33.30	20.69	11.6	19.3	-7.7
Beaver Creek (L)	35.89	22.30	15.3	19.6	-4.3
Prichard Creek (L)	39.95	24.82	15.7	20.4	-4.7
Clee Creek (L)	46.30	28.77	18.4	18.5	-0.1
Lost Creek (L)	47.71	29.65	14.8	20.3	-5.5
Shoshone Creek (L)	50.20	31.20	19.4	20.4	-1.0
Uranus Creek (R)	50.94	31.65	11.9	20.7	-8.8

Springs	Kilometer	River Mile	Spring Temp (ºC)	Main Stem Temp (ºC)	Difference
spring (R)	3.58	2.23	11.8	18.1	-6.3
spring (L)	6.72	4.17	11.4	17.9	-6.5
spring (L)	23.35	14.51	9.2	17.4	-8.2
spring (L)	25.23	15.68	6.9	17.2	-10.3
spring (L)	25.27	15.70	9.4	17.4	-8.0
spring (R)	25.34	15.74	10.0	17.1	-7.1
spring (L)	30.82	19.15	15.1	18.8	-3.7
spring (R)	30.89	19.19	11.5	18.5	-7.0
spring/shadow (L)	31.59	19.63	15.1	19.4	-4.3
small spring (L)	32.15	19.98	15.8	18.9	-3.1
spring (L)	32.37	20.11	15.5	18.8	-3.3
Spring on Hopkins (R)	32.52	20.21	10.0	19.1	-9.1
spring/very small (L)	32.71	20.33	16.1	19.5	-3.4
spring/shadow (L)	34.01	21.13	16.1	19.6	-3.5
spring/shadow (R)	35.04	21.77	12.4	19.2	-6.8
spring (R)	37.61	23.37	16.3	19.4	-3.1
spring (L)	38.16	23.71	10.0	19.4	-9.4
spring (L)	38.24	23.76	10.4	19.2	-8.8

spring (L)	38.35	23.83	12.1	19.4	-7.3
spring (L)	39.62	24.62	16.5	19.6	-3.1
spring (R)	39.80	24.73	16.1	20.0	-3.9
spring on side channel (R)	42.58	26.46	14.6	19.4	-4.8
spring (R)	46.48	28.88	14.0	18.7	-4.7
spring (R)	46.63	28.98	15.2	18.6	-3.4
spring (R)	46.93	29.16	15.8	18.9	-3.1
spring (R)	48.48	30.12	10.3	20.3	-10.0
spring (R)	48.79	30.31	17.3	20.1	-2.8
spring (R)	49.37	30.68	12.3	20.4	-8.1
spring (R)	49.59	30.82	14.7	20.6	-5.9
spring (L)	50.08	31.12	15.8	20.8	-5.0
spring (L)	50.26	31.23	15.5	21.1	-5.6
spring (R)	51.01	31.69	16.3	21.1	-4.8

Side Channel (RM 2.25-2.84)	**Kilometer**	**River Mile**	**Spring Temp (ºC)**	**Side channel Temp (ºC)**	**Difference**
Left bank slough	3.62	2.25	-	20.8	
slough and detached spring-Hultman (L)	3.84	2.38	14.4	19.7	-5.3
slough –below barrier and detached spring-Hultman (L)	3.97	2.47	14.3	17.8	-3.5
slough -above barrier	4.04	2.51	-	21.6	
slough -marsh area / pond (L)	4.18	2.60	23.4	23.7	-0.3
Side Channel (RM 5.96-6.11)	**Kilometer**	**River Mile**	**Spring Temp (ºC)**	**Side channel Temp (ºC)**	**Difference**
side channel	9.58	5.96	-	19.0	
side channel	9.73	6.05	-	18.3	
side channel	9.89	6.15	-	20.0	
side channel	10.06	6.25	-	20.6	
Devil's Elbow	10.21	6.34	-	18.9	
small spring/heavy shadow (L)	10.34	6.43	14.4	17.4	-3.0
side channel	10.50	6.52	-	19.9	
Side Channel (RM 15.48-15.86)	**Kilometer**	**River Mile**	**Spring Temp (ºC)**	**Side channel Temp (ºC)**	**Difference**
end side channel	24.91	15.48	-	17.1	
side channel	25.04	15.56	-	17.1	
side channel	25.12	15.61	-	19.9	
side channel-impoundments	25.22	15.67	-	14.7	
spring (in-channel)	25.48	15.83	10.5	17.1	-6.6
Side channel	25.52	15.86	-	11.6	

Sample Images

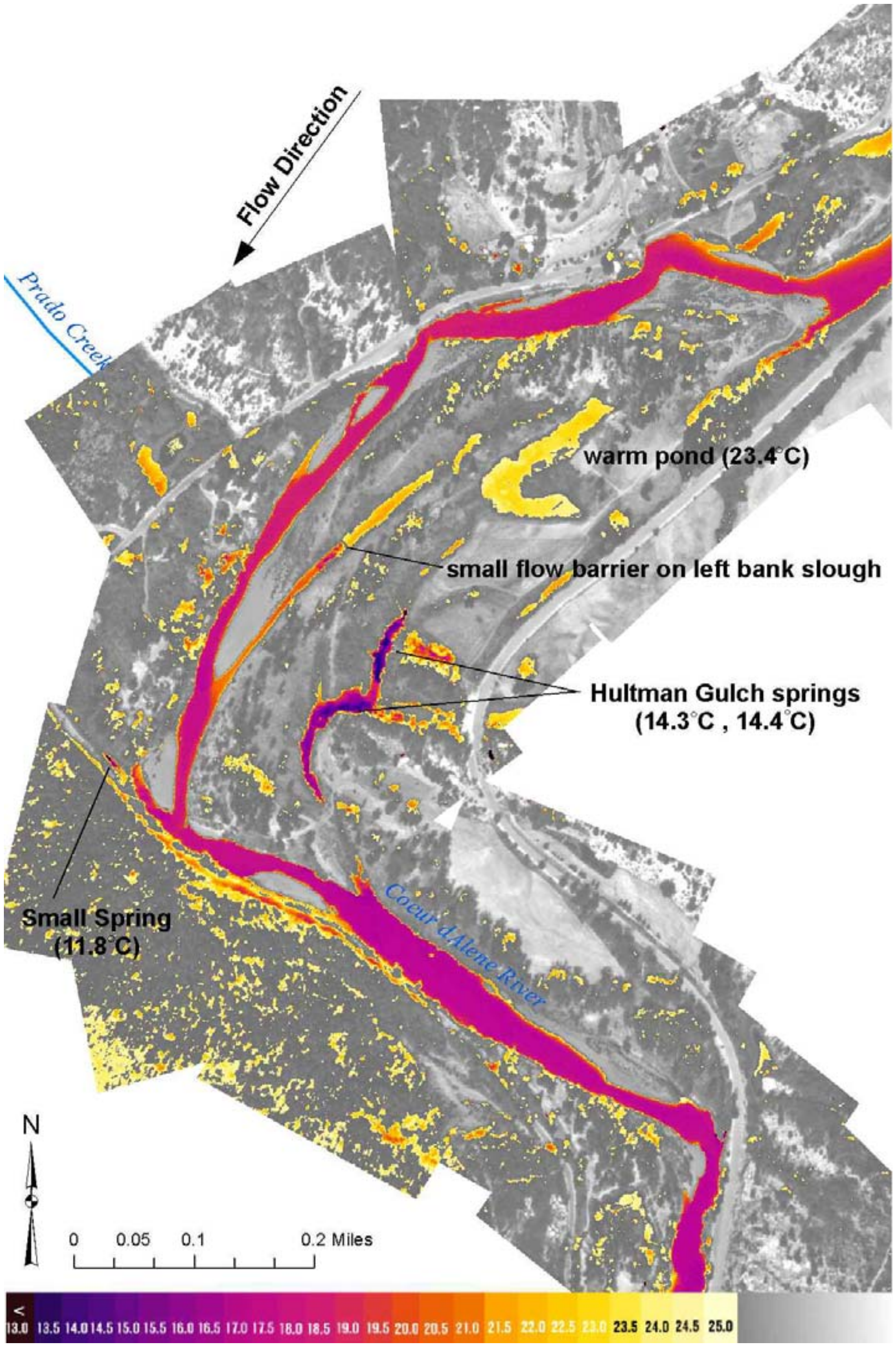

Figure 7 - River mile 2.3: In the area of Hultman Gulch and Prado Creek, a complex interaction of several features influence the overall temperature of the channel. A cold spring-fed feature and a small spring below Prado Creek influence the overall bulk water temperatures which drop from 18.0ºC to 17.5ºC in less than one mile. The overall cooling trend can be seen as far as the confluence with the South Fork Coeur d'Alene at the start of the survey area. Prado Creek and a smaller secondary slough on the left bank create localized warming, however, they have minimal impact on overall bulk temperature. The variability in the small slough on the left bank is also shown on the longprofile.

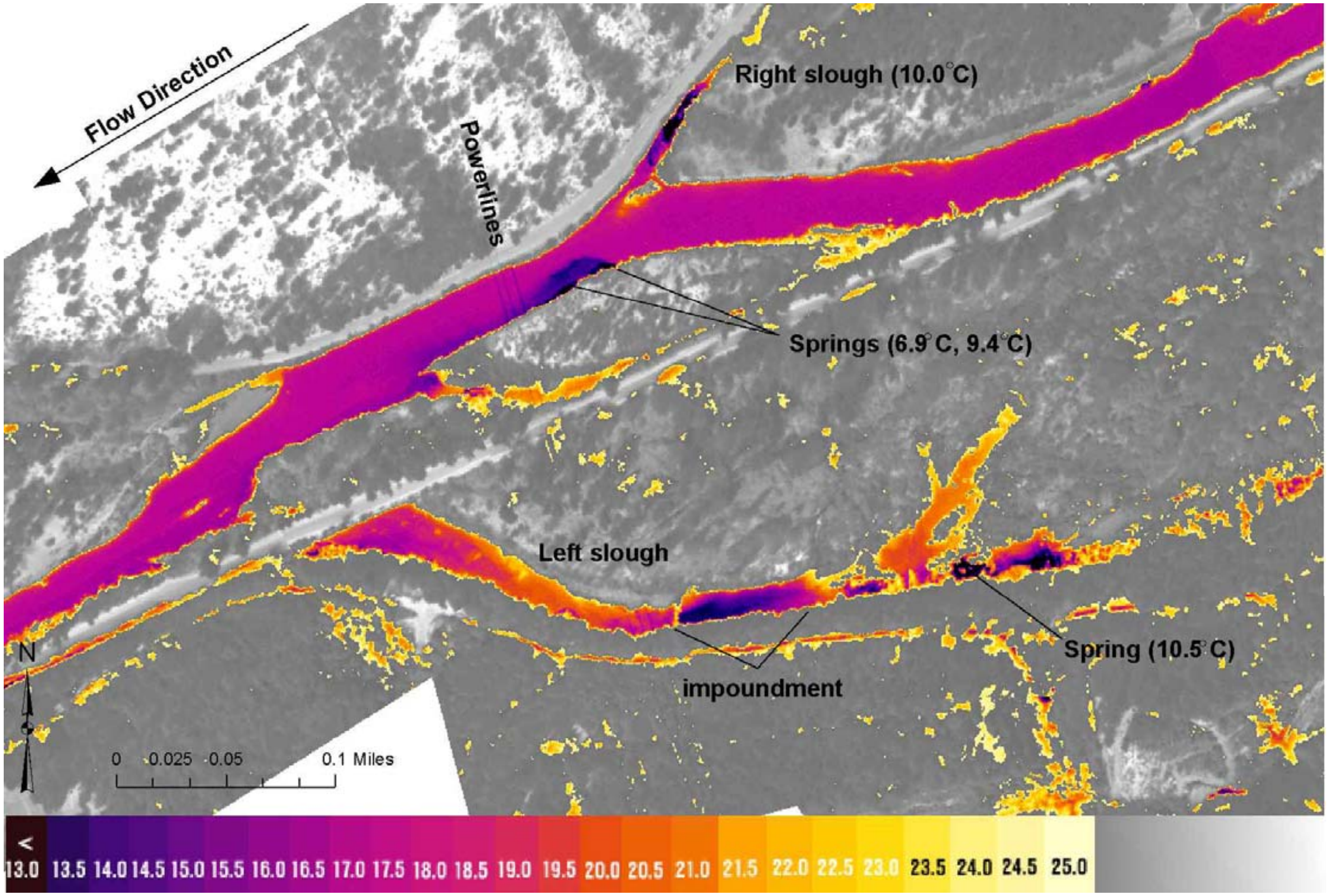

Figure 8 - River Mile 15.7: Two springs (6.9 and 9.4°C) are visible along the left bank which inputs directly into the main channel. Power lines are visible across the river just downstream of this spring. Two large side channels are also visible in the image. The slough along the right bank contains cool water (10.0°C) indicating a sub-surface influence and the potential for off-channel habitat. The slough on the left bank shows a wide range of temperatures, including potential springs and an impoundment, but seems to have little effect on the bulk water temperature of the main channel. The variability in the temperature profile of the left bank slough is shown on the longprofile.

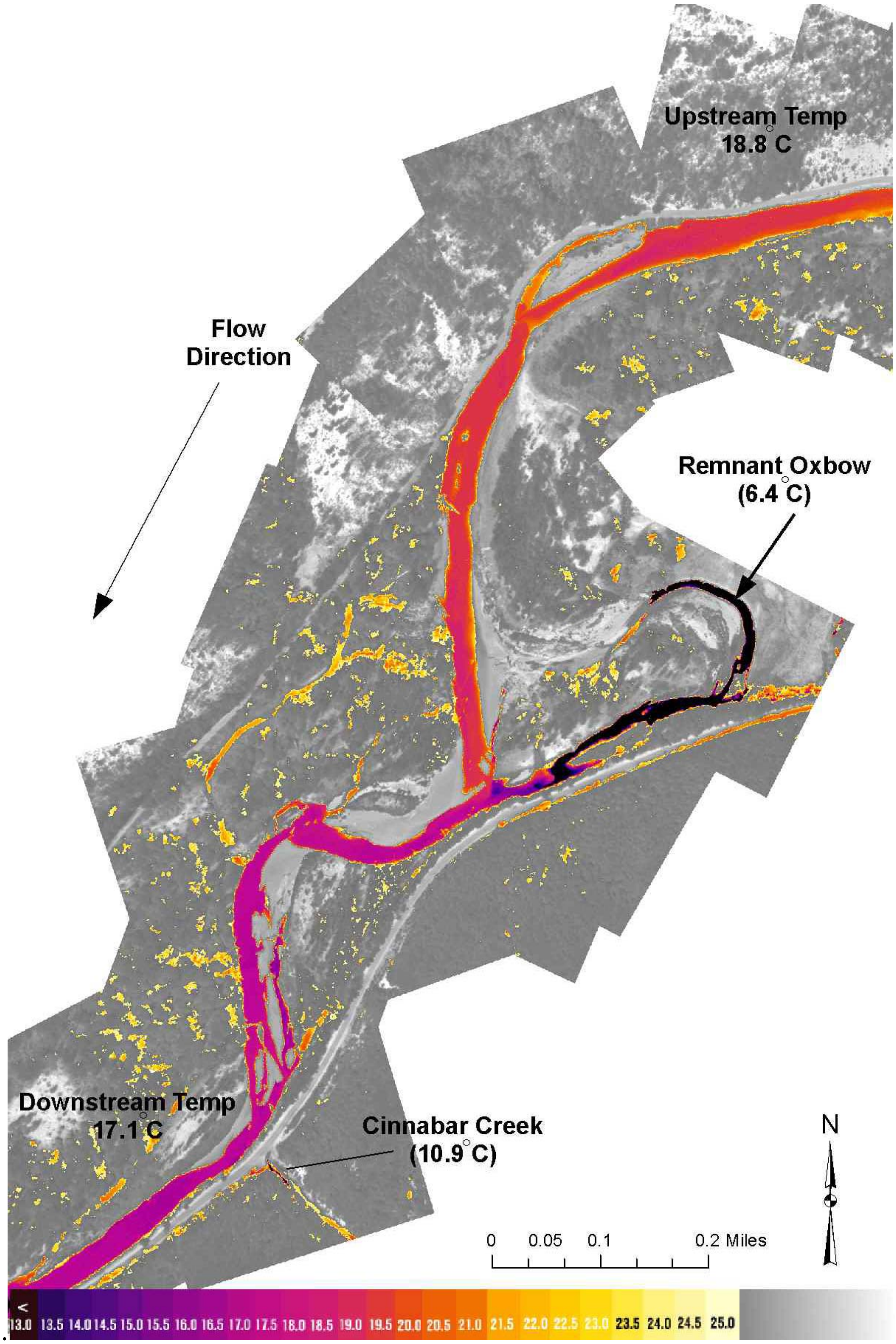

Figure 9 - River mile 16.5: A remnant ox bow is providing a large volume of cold water to the main stem resulting in a significant change in the temperature profile of the river. The bulk temperature changes 1.7°C in less than a half mile, and the temperature stays depressed for several miles downstream.

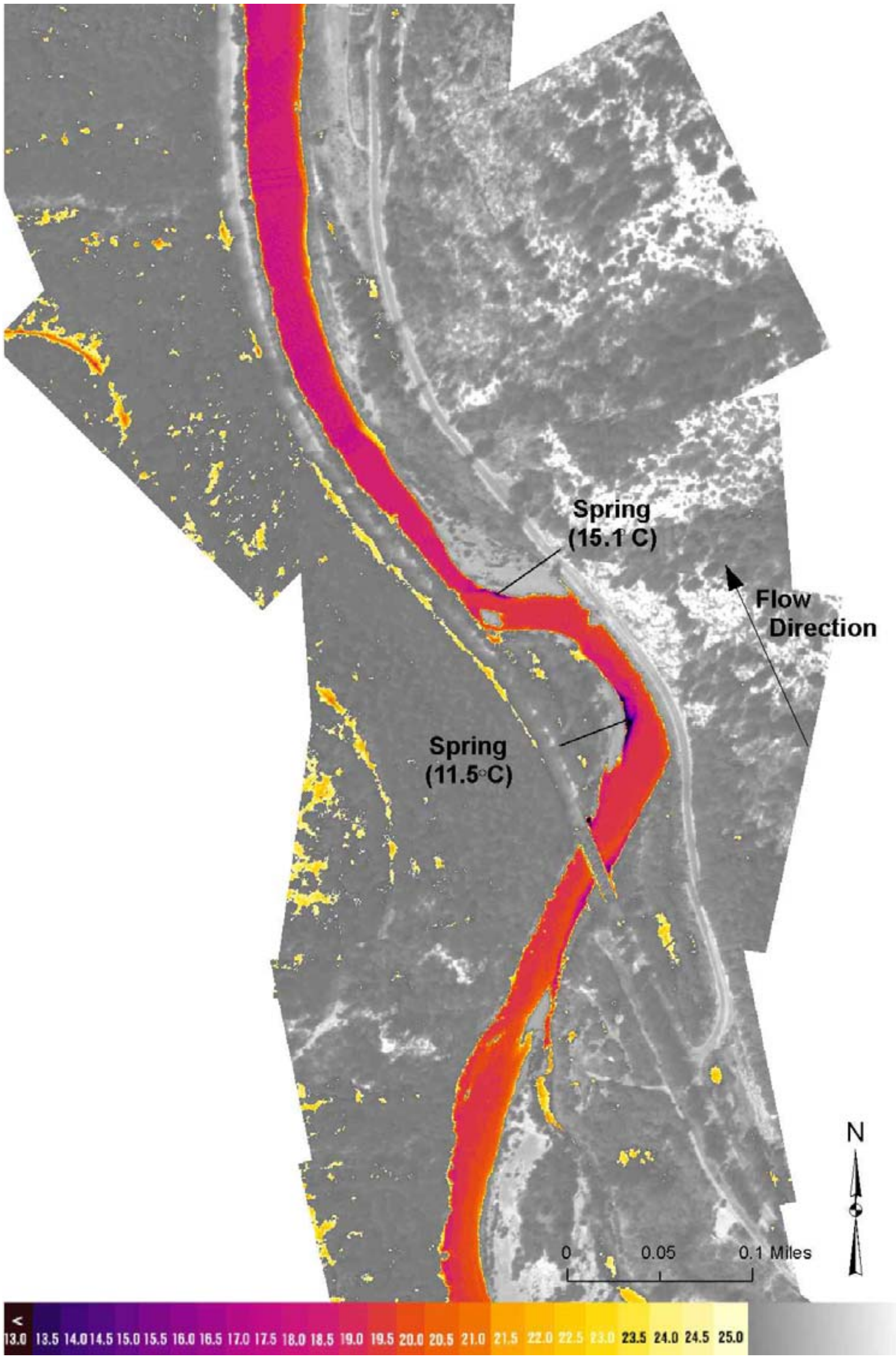

Figure 10 - River Mile 19.2: Sub-surface discharge is visible along the gravel bars on both banks of the river. The source of sub-surface flow is often not directly apparent in the imagery, but can often be inferred from its location relative to other floodplain features. In this case, the cold water discharge at the downstream end of the gravel bares suggests that the flow is through the hyporheic zone.

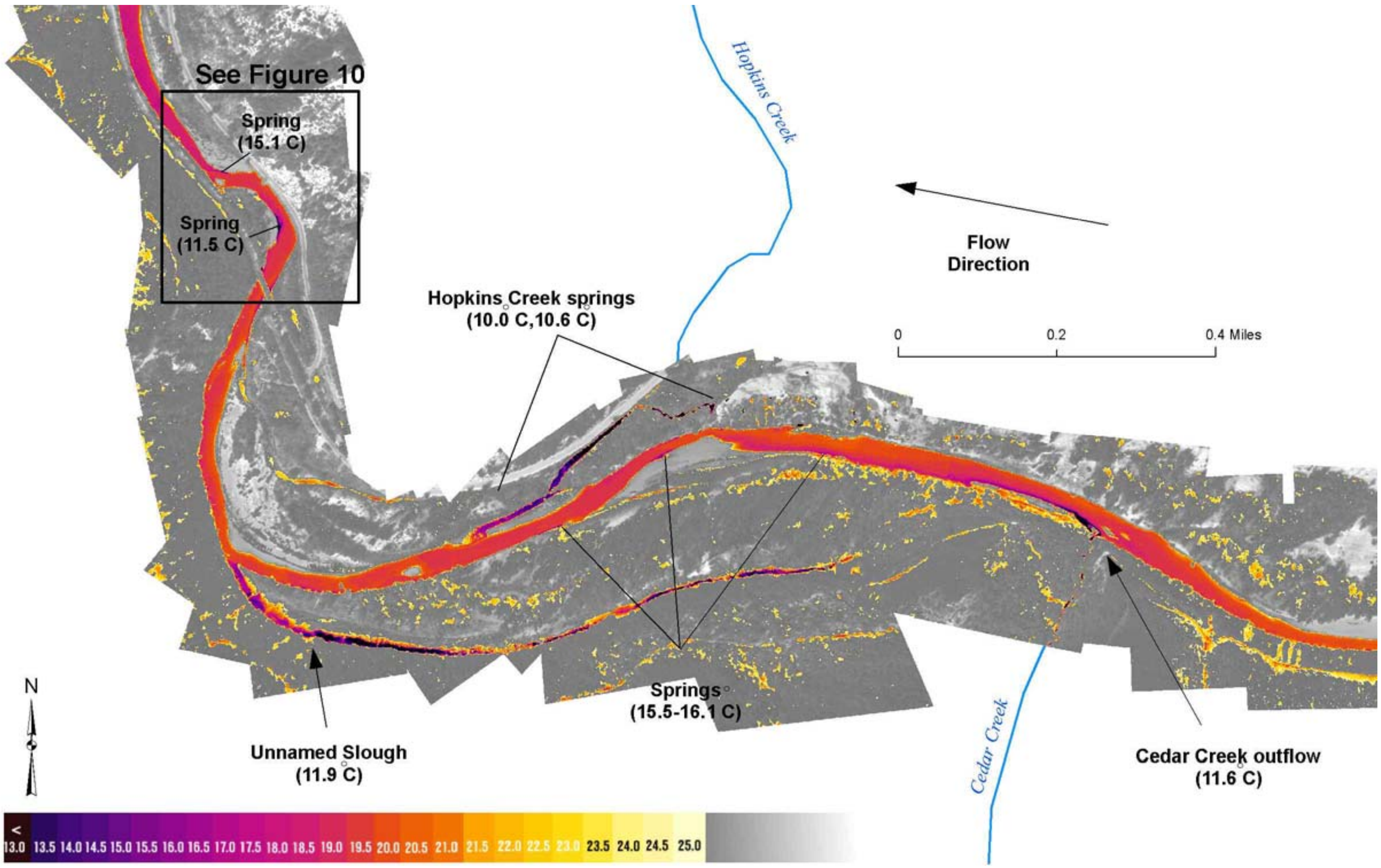

Figure 11 - River Mile 20.0: The river shows a pattern typical throughout the length of the survey, multiple small springs and cold inflows that provide local thermal refugia, but do not greatly affect the overall bulk water temperature. In this stretch of river, the bulk water temperatures average around 19°C, even with multiple springs, an unnamed slough and cold water inflows at Hopkins Creek and Cedar Creek.

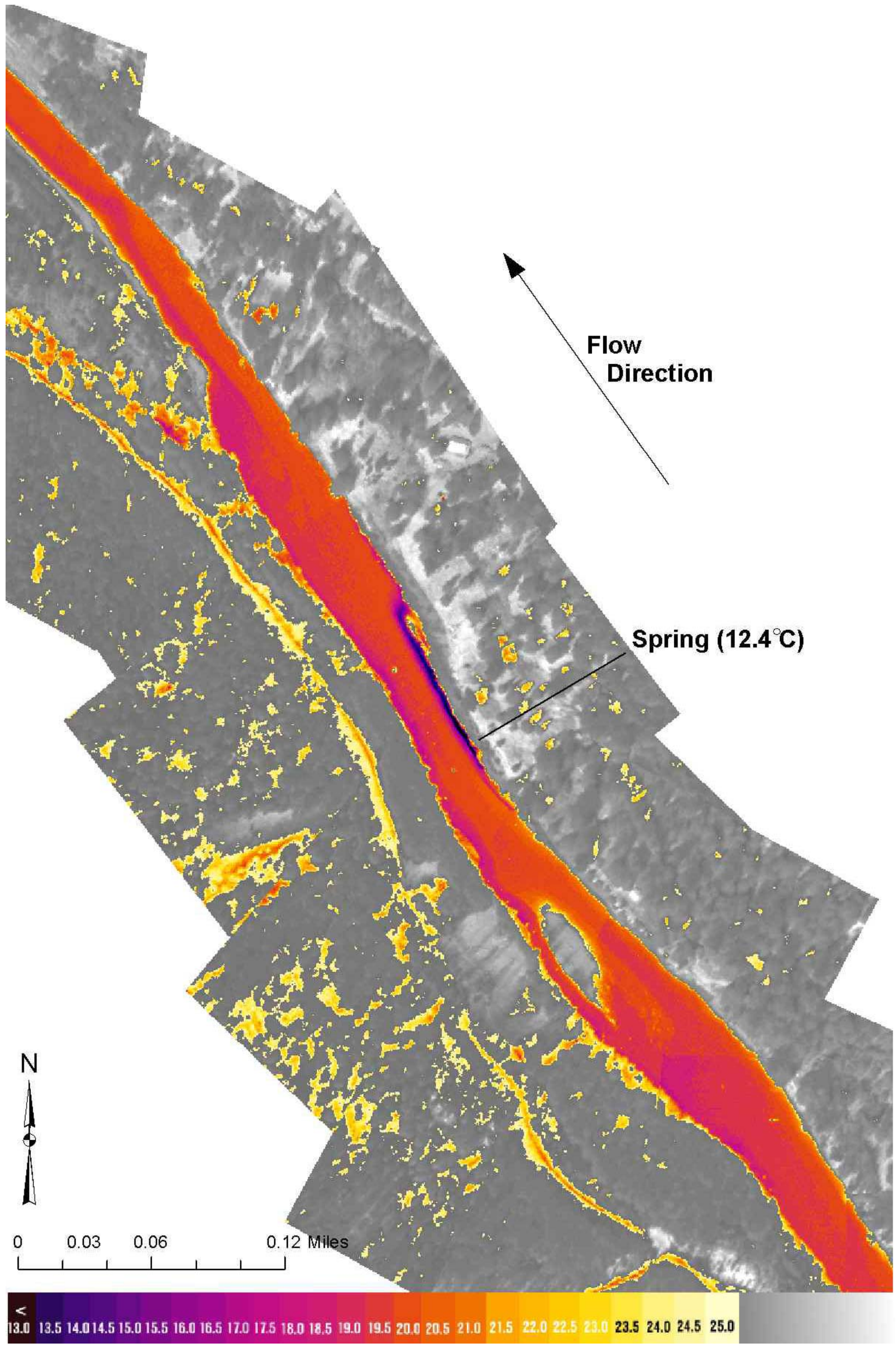

Figure 12 - River mile 21.8: A spring (12.4°C) was detected along the right bank at mile 21.8. The spring appears large in the imagery, but absence of obvious downstream mixing suggests that the discharge diffuses along the bank and the cold water may sink into the channel. In short, the spatial influence of this spring may be greater than what appears in the imagery.

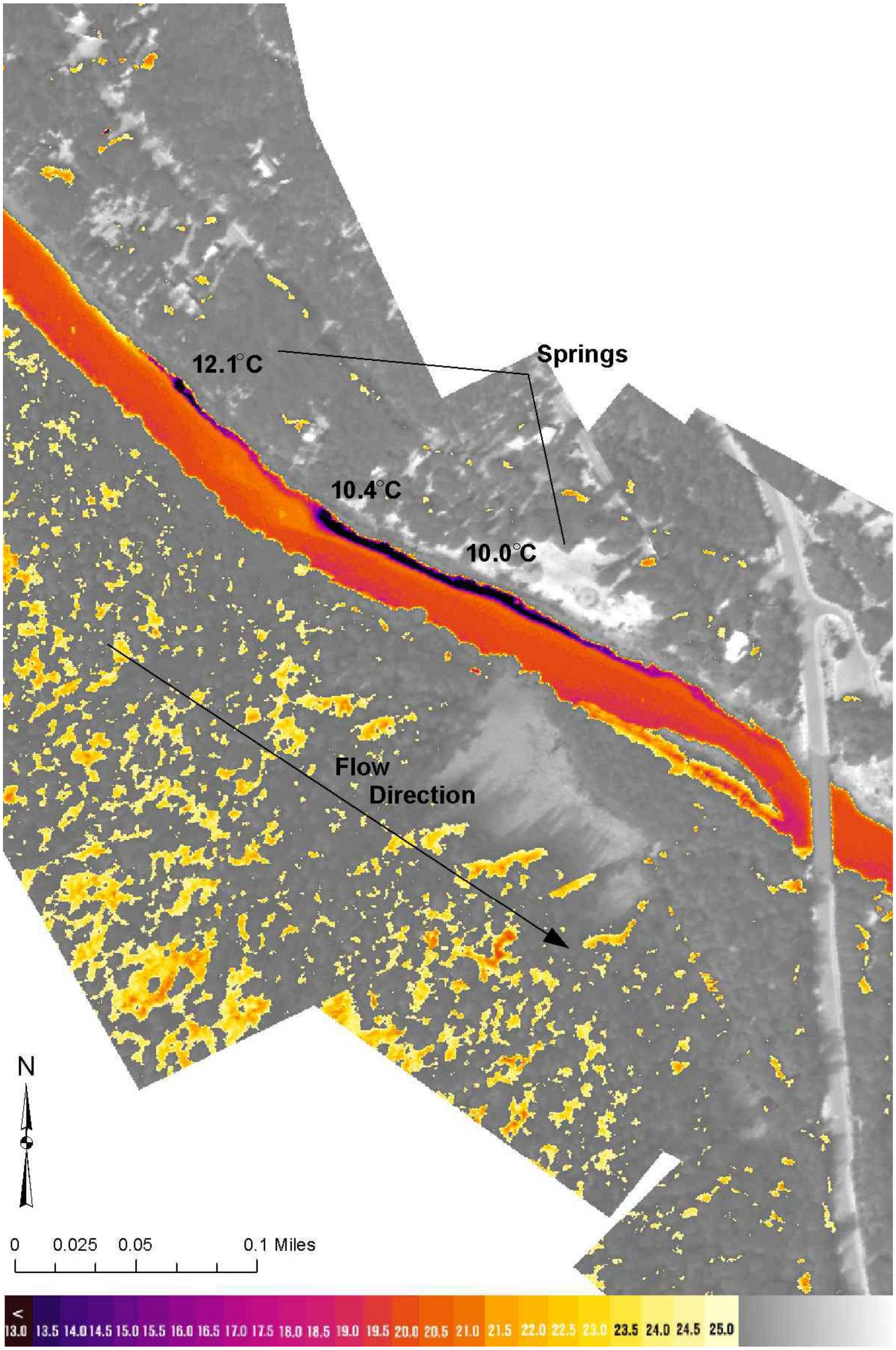

Figure 13 - Mile 23.8: A spring complex (~10.4°-12.1°C) detected along the left bank of the Coeur d'Alene River.

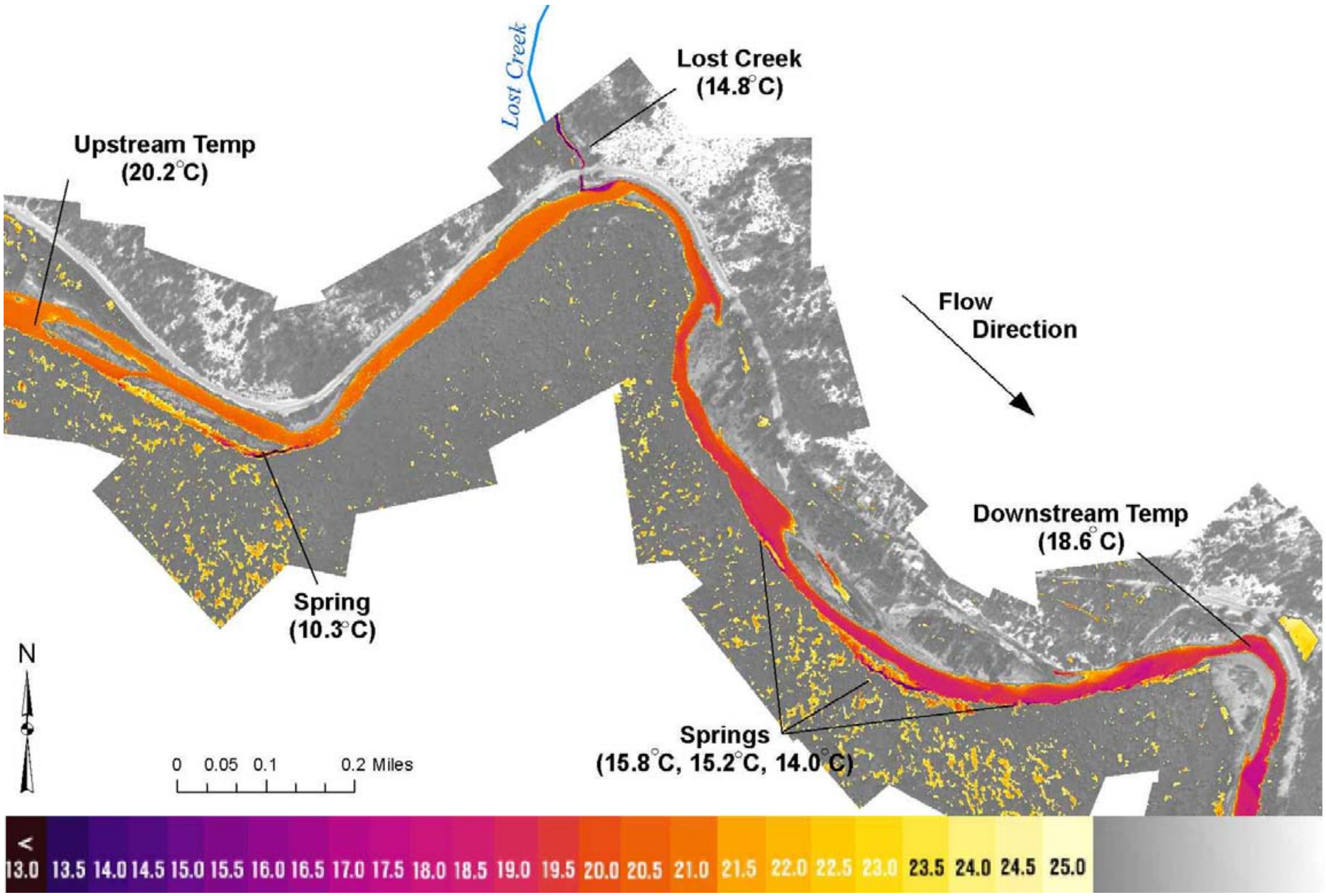

Figure 14 - River mile 30.0: Lost Creek enters the Coeur d'Alene River at river mile 30 and causes a significant decrease in bulk temperatures. A drop of 1.6ºC can be seen over a one mile stretch of river. Several smaller springs enter the river along this reach, but Lost Creek seems to be the major influencing factor for the temperature decrease. After approximately one mile, the river begins warming again, until a similar temperature drop (1ºC) can be seen at the confluence of Prichard Creek. A similar bulk decrease in temperature is also seen further downstream after the confluence with Coal Creek.

Deliverables

The TIR imagery is provided in two forms: 1) individual un-rectified frames and 2) a continuous geo-rectified mosaic at 0.8 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 (~0.6 m) 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 DVD:

Geo-Corrected Images are stored as: **UTM Zone 11, NAD83, Units = Meters.**

1. Thermal_Mosaics - Continuous image mosaic of the geo-rectified TIR image frames at 0.8 meter resolution in ESRI Grid 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. GCP files are included for rectification purposes.
    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. Includes layers for both the thermal and true color imagery.

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

5. Hydrography – Relevant hydrography shapefiles

6. Report – A copy of this report