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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Thermal Infrared Remote Sensing Pilot Test

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

URS Corporation
Watershed Sciences Inc.

February 2013

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	**Definition**
μm	micrometer
AEA	Alaska Energy Authority
AGL	above ground level
°C	degrees Celsius
EO	External Orientation
FERC	Federal Energy Regulatory Commission
ft	feet
GCP	ground control points
GIS	geographic information system
GPS	Global Positioning System
ILP	Integrated Licensing Process
ºK	degrees Kelvin
m	meters
NEPA	National Environmental Policy Act
Project	Susitna-Watana Hydroelectric Project
RM	river mile
TIR	Thermal Infrared Remote
WSI	Watershed Sciences Inc.

SUMMARY

This report provides the results of the 2012 Thermal Infrared Remote (TIR) Sensing Pilot Test. The purpose of this study was to attempt to determine locations with large groundwater influence along the Susitna River from Talkeetna to the proposed Project site (88 miles), using the differential in temperature between warm groundwater and colder surface water. The survey was conducted over a 4-day period in October 2012. Images were collected with a FLIR system's SC6000 sensor mounted on the underside of a Bell Jet Ranger Helicopter. To maximize thermal contrast the TIR sensor was flown during early morning when solar loading was minimized. In-stream sensors in the mainstem Susitna were used for calibrating and verifying the thermal accuracy of the TIR imagery.

Over 500 areas of increased groundwater activity were seen in the thermal imagery from large sloughs to small hyporheic seeps. The bulk of the groundwater activity (>90 percent) was seen between the Chulitna River and Slough 21 (RM 98-143). While the groundwater could be easily discerned in the imagery, the longitudinal temperature profile of the mainstem of the river is less informative due to the minimal fluctuations in bulk water temperatures. Apparent stream temperature changes of < 0.5°C (0.5 ºK) are not considered significant unless associated with a surface inflow (e.g., tributary).

The prevalence of groundwater downstream of RM 140 does appear to impact bulk water temperatures by increasing the overall temperature. The upward slope seen in the profile, particularly between Deadhorse Creek (RM 121) and Lane Creek (RM 113.5), is a reflection of this increase in temperatures. Temperatures increase almost 1°C (1.0 ºK) along this length of river.

Though it is not obvious in the longitudinal profile, Lane Creek (113.5), Lower Portage Creek, (RM 117.6) and the Indian River (138.6) are all contributing significantly warmer water to the mainstem. Ten sloughs of significant size and thermal influence were also noted in the imagery including Slough 8A (RM 126), Slough 9 (RM 129.2), and Slough 21 (RM 142).

1. INTRODUCTION

This report provides the results of the 2012 Thermal Infrared Remote (TIR) Sensing Pilot Test. The Alaska Energy Authority (AEA) is preparing a License Application that will be submitted to the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project (Project) using the Integrated Licensing Process (ILP). The Project is located on the Susitna River, an approximately 300-mile-long river in Southcentral Alaska. The Project's dam site would be located at river mile (RM) 184. This study provides data to inform the 2013–2014 licensing study program, Exhibit E of the License Application, and FERC's National Environmental Policy Act (NEPA) analysis for the Project license.

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

The thermal differential between bulk water temperatures in the Susitna and subsurface discharges are approximately 3°C during the fall months with the groundwater discharge typically being warmer than in-stream temperatures. Many studies have successfully used this type of work to delineate groundwater contribution to surface water. However, this type of study has rarely been performed in Alaska, and the temperature differential between surface water and groundwater is not as large as in other areas of the United States. For this reason, this study was considered a pilot test for the application of this technology to other parts of the Susitna River.

2. STUDY OBJECTIVES

The objectives of this study were as follows:

1. Collect thermal imagery from Talkeetna to the Watana Dam site during the late fall when the temperature differential between surface water and groundwater was at a maximum; and
2. Map the spatial dynamics and magnitude of groundwater discharge to establish baseline data for assessing the availability and spatial extent of thermal refugia in the Middle Susitna River.

3. STUDY AREA

The study area for this phase of the study includes the entire Middle River Segment of the Susitna River from the confluence with the Chulitna River (RM 98) upstream to Deadman Creek (RM 186.5) (Figure 1).

4. METHODS

4.1. Instrumentation

WSI (Watershed Sciences, Inc.) was contracted to collect airborne TIR imagery over a 4-day period in October 2012. To maximize thermal contrast between warmer groundwater discharge and colder river temperatures of the Susitna, the TIR sensor was flown during early morning when solar loading was minimized. Collected stream sections and extents are listed in Table 1.

Images were collected with a FLIR system's SC6000 sensor (8–9.2 micrometer [µm]) mounted on the underside of a Bell Jet Ranger Helicopter. The SC6000 is a calibrated radiometer with internal non-uniformity correction and drift compensation. The sensor is contained in a composite fiber enclosure attached to the underside of the helicopter which is flown longitudinally along the stream channel. General specifications of the thermal infrared sensor are listed in Table 2, and a picture of the apparatus is shown on Figure 2.

4.2. Image Collection

Due to the river's width, the aircraft was flown in parallel flight lines in order to capture the full floodplain extent of the Susitna River. The flight lines were designed for an image side-lap of 40 percent and the TIR sensor was set to acquire images at a rate of 1 image every second resulting in an image overlap of approximately 65 percent. Narrower locations upstream were collected with a single flight pass.

The TIR data acquisition was conducted at a flight altitude of 2,300 feet above ground level (AGL) resulting in pixel resolution of 2.3 feet (ft; 0.70 meter [m]). Due to terrain variations, wind conditions, and stream size, altitudes can vary throughout the flight duration. A summary of flight times and acquisition parameters can be seen in Table 3.

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).

4.3. Ground Control

Six in-stream sensors in the mainstem Susitna were used for calibrating and verifying the thermal accuracy of the TIR imagery. Data for other sensor locations in the River were either not available for the dates of the surveys or were in areas of increased thermal mixing and could not be used for calibration purposes. Data logger locations are illustrated in Figure 4.

4.4. Weather and Flow

Weather conditions on the mornings of the survey were considered ideal for detecting groundwater inflows to the Susitna River with cold temperatures, low humidity and clear skies. Table 4 summarizes the weather conditions observed in Talkeetna, Alaska (Station ID: CYFC) on the survey dates. No flights were conducted on October 14-16, 2012 due to warmer temperatures and low clouds in the area.

4.5. Surface Temperatures

Thermal infrared sensors measure TIR energy emitted at the water's surface. Since water is essentially opaque to TIR wavelengths, the sensor is only measuring water surface temperatures. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed; however, temperature differences can form in the vertical water column in areas that have little or no mixing. Given the cold temperatures, it is possible that ice was present in areas of the survey.

4.6. 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 percent). In general, apparent stream temperature changes of < 0.5°C are not considered significant unless associated with a surface inflow (e.g., tributary). However, certain conditions may cause variations in the accuracy of the imagery.

4.7. Surface Conditions

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

4.8. Feature Size and Resolution

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

4.9. Image Uniformity

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

4.10. Temperatures and Color Ramps

The TIR images collected during this survey consist of a single band. As a result, visual representation of the imagery (in a report or geographic information system [GIS] environment) requires the application of a color ramp or legend to the pixel values. The selection of a color ramp should highlight features most relevant to the analysis (i.e., spatial variability of stream temperatures). For example, a continuous, gradient style color ramp 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 ramp that focuses too narrowly cannot be applied to the entire river and will wash out terrestrial and vegetation features (Figure 5).

The color ramps for the TIR mosaics were developed to maximize the contrast of the majority of the surface water features and are unique by date. The color ramp can be modified by the end user to highlight features or temperature ranges of interest.

4.11. Sensor Calibration

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

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

4.12. Geo-referencing

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

4.13. Geo-rectification

Due to the complexity and width of the river, both manual and automated rectification techniques were used to process the imagery. All imagery was rectified to the high resolution true-color imagery. In narrower portions of the river, individual TIR frames were manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and imagery available for the area. The images were then warped using a first order polynomial transformation and mosaicked into a final image. All TIR imagery collected on October 17 and 18, 2012, was manually rectified.

The wider areas of river flown on October 12 and 13 were rectified using automated techniques due to the multiple flight lines which needed to be tied together. Trajectory and GPS data for the entire flight survey session were incorporated into an External Orientation (EO) file that contains accurate and continuous aircraft positions and heading. Ground control points were created by identifying permanent structures (boulders, high contrast landform shapes, and edges of man-made structures) in the true color orthoimagery that were also easily discernible in the TIR imagery. The coordinates for these points (x,y,z) are recorded from a 10-meter bare earth Digital Elevation Model obtained from the NRCS's National Elevation Dataset and used to rectify the imagery. The ground control points and EO file are loaded into Leica Photogrammetry Suite, which aerial triangulates the thermal images and ties them together. Images are then output into orthorectified mosaics using OrthoVista software. No adjustments were made to cell values so temperature information was preserved.

4.14. Interpretation and Sampling

Once calibrated and rectified, the images are integrated into a GIS in which an analyst interprets and samples stream temperatures. The Susitna thermal mosaics were qualitatively inspected for groundwater presence or absence based on water temperatures. A polygon shapefile was digitized to highlight areas of increased groundwater activity. In general terms, the bulk water river temperatures were colder than the emergent groundwater, making subsurface activity easily detectable. Because temperatures exist on a continuum, the polygons should not be used to quantitatively define groundwater flows.

4.15. Temperature Profiles

In order to provide further thermal interpretation, the median bulk water temperature for the river was sampled at 500-foot intervals and plotted versus river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient and highlights any landscape scale trends. The locations of named surface water inflows (e.g., tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the mainstem temperature patterns.

The profile was created directly from the TIR image mosaic using the following steps:

1. A stream line was digitized and routed based on the final thermal mosaics to best represent the centerline of the channel.
2. A GIS point layer was generated from the routed stream layer at 500-foot intervals and each point was assigned the appropriate river mile measure. Mapped river miles were adjusted to closely match URS in-stream sensor river miles.
3. The points were buffered by 25 feet to create polygons within the stream center. For points which fell on non-water features or were obvious errors due to image mosaic artifacts were discarded.
4. The Zonal Statistics feature of ArcGIS was then used to calculate the median radiant temperature and associated statistics contained in each polygon from the TIR image mosaic.

5. The median radiant temperatures were then assigned back to the center point and the temperatures were plotted in Microsoft Excel versus river mile.
6. A similar process was followed for larger tributaries and sloughs. However, rather than automated spacing of points based on the centerline, points were hand placed at the mouths of the tributaries or in wider areas of sloughs and assigned a river mile. Due to the smaller size of the features, tributary and slough points were only buffered by 10 feet for sampling. The tributary analysis was not meant to be comprehensive, but to act as further reference for the longitudinal profile and to highlight significant features.

As mentioned, data from six mainstem sensors were used to calibrate the thermal imagery (Figure 4). Table 5 summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images. Due to the multiple flight lines in the lower portion of the river, the same sensor may be cross-checked across multiple images.

The differences between radiant and kinetic temperatures were consistent with other airborne TIR surveys previously conducted at other sites, and within the target accuracy of ±0.5°C; however, there were some discrepancies seen between the in-stream sensors that were not used and the calibrated radiant temperatures of October 17.

The studies only used sensors that were in the mainstem Susitna and not in areas of potential mixing to evaluate bulk temperatures. Three sensors had data available on October 17 but were not used in the accuracy assessment:

- At RM 140.0 the in-stream sensor recorded a temperature of -3.63°C, which was considered suspect.
- A second sensor downstream of Portage Creek (RM 148) was located in an area of mixing, which also caused a discrepancy between in-stream and radiant values.
- The sensor at RM 142.0 (Slough 21) was in an area of apparent groundwater discharge and therefore reading higher than bulk water temperatures.

The sensor upstream of Portage Creek (RM 148) did not have available data for October.

No in-stream sensor data were available for the imagery flown on October 18 so the calibration focused on matching bulk water temperatures with the calibration on October 17. Given the conditions at the time of the survey and the lack of sensors to confirm in-stream temperatures, water temperatures in the thermal imagery are below freezing. The calculation of negative temperatures is based on the calibration of the lower sensors and the calculation of parameters to match the October 17 imagery. We opted to retain the areas of negative temperatures in order to maintain consistency in the calibration and the relative temperatures along the stream gradient.

Due to the lack of available in-stream sensor data for the upstream portion of the 17th and full extent of the 18th, temperatures seen in those extents should not be considered absolute; however, upwelling activity can still be confirmed due to the contrast between groundwater temperatures and bulk river temperatures.

5. DEVIATIONS FROM STUDY PLAN

There were some adjustments that had to be made using the aerial photos and temperature confirmation sensors in the river; however, these types of adjustments are not atypical for this type of work, and were anticipated as part of the study. The initial conception of the study was to survey a smaller area of the river, from approximately Talkeetna to Devils Canyon. However, during initiation of the study, it was determined that the additional cost to survey the river between Devils Canyon and the proposed dam site was relatively small, and the environmental conditions at the time were ideal for surveying.

6. RESULTS

The results of this study are available in Appendix 1 (Examples in Figures 5 and 6). Due to the nature of the study, the focus of the survey was to highlight groundwater sources that were warmer than bulk water temperatures on a cold winter morning. The cold air temperatures act to suppress mainstem and terrestrial temperatures and allow the warmer groundwater to stand out in the imagery. Over 500 areas of increased groundwater activity were seen in the thermal imagery from large sloughs to small hyporheic seeps (Figure 7). The bulk of the groundwater activity (>90 percent) was seen between the Chulitna River and Slough 21 (RM 98-143).

Median channel temperatures were also plotted versus river mile for the Susitna River. Significant tributaries and sloughs sampled during the analysis are included on the longitudinal profiles to provide additional context for interpreting spatial temperature patterns (Figure 8). While the groundwater could be easily discerned in the imagery, the longitudinal temperature profile of the mainstem of the river is less informative in this type of winter survey due to the minimal fluctuations in bulk water temperatures. Apparent stream temperature changes of < 0.5°C (0.5 K) are not considered significant unless associated with a surface inflow (e.g., tributary).

The prevalence of groundwater downstream of RM 140 does appear to impact bulk water temperatures by increasing the overall temperature. The upward slope seen in the profile, particularly between Deadhorse Creek (RM 121) and Lane Creek (RM 113.5), is a reflection of this increase in temperatures. Temperatures increase almost 1°C (1.0 ºK) along this length of river.

Though it is not obvious in the longitudinal profile, Lane Creek (RM 113.5), Lower Portage Creek at RM 117.6, and the Indian River (RM 138.6) are all contributing significantly warmer water to the mainstem (Figure 9). Ten sloughs of significant size and thermal influence were also noted in the imagery including Slough 8A (RM 126.0), Slough 9 (129.2), and Slough 21 (RM 142.0).

With air temperatures in the teens on October 18, parts of the river appeared to be freezing over, likely causing the increase in variability seen in the temperature profile on that date. The imagery also reflects the colder temperatures and the ‘colder’ color ramp that was necessary for the upper section of the river (Figure 10).

7. DISCUSSION

Thermal infrared imagery was collected for the Susitna River over a 4-day period in October of 2012. Given the difficult conditions involved in surveying the Susitna and the limited window of weather conditions that will allow for groundwater detection in this type of glacial river, the survey was highly successful. Hundreds of areas of groundwater activity were detected in the imagery, from large sloughs to small hyporheic seeps. Based on the results of this study, the pilot test appears to have been a complete success. Based on the success of this study, AEA plans to replicate this work in the Lower River Segment in 2013.

8. REFERENCES

AEA (Alaska Energy Authority). 2012. Revised Study Plan: Susitna-Watana Hydroelectric Project FERC Project No. 14241. December 2012. Prepared for the Federal Energy Regulatory Commission by the Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/study-plan.

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.

9. TABLES

Table 1. Surveyed Stream Lengths and Acquisition Dates

Survey Date	Approximate River Miles Flown
10/12/2012	9
10/13/2012	23
10/17/2012	37
10/18/2012	19
Total:	88

Table 2. Summary of TIR Sensor Specifications

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°

Table 3. Summary of Thermal Image Acquisition Parameters

Acquisition Parameters	
Dates:	October 12,13,17,18, 2012
Flight Above Ground Level (AGL):	2,300 feet
Image Footprint Width:	1,472 feet (449 meters)
Pixel Resolution:	2.3 feet (0.7 meters)

Table 4. Weather Conditions on the Survey Dates in Talkeetna, Alaska

Time (ADT)	Air Temp. (°C)	Humidity	Wind Direction	Wind Speed	Conditions
12-October-2012					
5:53 AM	30.0°F	51%	Calm	Calm	Clear
6:53 AM	27.0°F	61%	Calm	Calm	Clear
7:53 AM	28.0°F	56%	North	5.8 mph	Clear
9:53 AM	30.0°F	49%	North	4.6 mph	Clear
10:53 AM	33.1°F	46%	North	4.6 mph	Clear
13-October-2012					
5:53 AM	28.9 °F	47%	North	4.6 mph	Clear
6:53 AM	28.9 °F	47%	North	4.6 mph	Clear
7:53 AM	28.9 °F	45%	North	4.6 mph	Clear
8:53 AM	28.0 °F	47%	Calm	Calm	Clear
9:53 AM	27.0 °F	53%	North	4.6 mph	Clear
17-October-2012					
5:53 AM	26.1 °F	92%	Calm	Calm	Clear
6:53 AM	21.9 °F	96%	Calm	Calm	Clear
7:53 AM	19.9 °F	100%	Calm	Calm	Clear
8:53 AM	19.0 °F	92%	Calm	Calm	Clear
9:53 AM	21.0 °F	92%	Calm	Calm	Partly Cloudy
18-October-2012					
5:53 AM	14.0 °F	88%	Calm	Calm	Clear
6:53 AM	14.0 °F	88%	Calm	Calm	Clear
7:53 AM	15.1 °F	84%	NNW	3.5 mph	Clear
8:53 AM	16.0 °F	88%	Calm	Calm	Clear
9:53 AM	23.0 °F	68%	NNW	5.8 mph	Clear

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

River Mile	Sensor ID	Image Frame	Time	In-stream Temp (°C)	Radiant (°C)	Difference
Figure 1. October 12, 2012						
103.3	103.3_Talkeetna	Susitna1076	8:38:59	1.26	1.3	-0.01
103.3	103.3_Talkeetna	Susitna0957	8:34:23	1.26	1.1	0.16
Figure 2. October 13, 2012						
126.1	1014217_1-_Oct-126.1	Susitna2705	9:41:24	0.08	0.3	-0.22
126.1	1014217_1-_Oct-126.1	Susitna2560	9:35:06	0.08	0.3	-0.22
130.8	10174222_1-_Oct-Oct-130.8-LRX35	Susitna2239	9:22:15	0.11	0.4	-0.29
130.8	10174222_1-_Oct-Oct-130.8-LRX35	Susitna2822	9:45:18	0.11	0.3	-0.19
103.8	10174222_1-_Oct-Oct-130.8-LRX35	Susitna0032	7:33:16	0.10	1.0	-0.90
Figure 3. October 17, 2012						
130.8	10174222_1-Oct-130.8-LRX35	Susitna0156	8:05:57	0.16	-0.3	0.46
136.5	10174295_0-Oct_136.5-Susitna Near Gold Creek	Susitna0567	8:26:21	0.14	0.2	-0.07
138.7	10174225-_Oct-138.7-Susitna Above Indian River	Susitna0973	8:45:06	0.02	-0.2	0.22
140.1	1014282_Oct-140.1-LRX 53	Susitna0950	8:44:14	0.14	-0.1	0.24
Figure 4. October 18, 2012						
Although there were mapped sensor locations above this point, no actual sensor data was available for this date. Calibration focused on matching bulk water temperatures to the prior days' temperatures. While the relative temperatures of the survey are still considered accurate and highlight groundwater activity, pixel values should not be considered absolute.						

Table 6. Summary of Information Provided in Appendix A

Projection: Alaska State Plane Zone 4 FIPS 5004 Horizontal Datum: NAD83 Units: Feet	
Rasters	• Thermal Mosaics (ERDAS Imagine) ▪ Continuous mosaics of rectified TIR image frames. Layer files included for display by temperature class. ▪ Cell Values = Kelvin*10
Vectors	▪ Groundwater Activity (ESRI polygon shapefile) ▪ Sampled TIR centerline points (ESRI point shapefile) ▪ Sampled TIR inflow points (ESRI point shapefile) ▪ Flightline image locations (ESRI point shapefiles) ▪ Hydrography ▪ Routed stream centerline based on TIR image mosaics ▪ NHD stream network (ESRI Geodatabase)
Spreadsheets	• Longitudinal temperature profile (Microsoft Excel)
Analysis	• ArcMap 10.0 project (*.mxd) • Thermal hydrologic analysis (PDF Report)

10. FIGURES

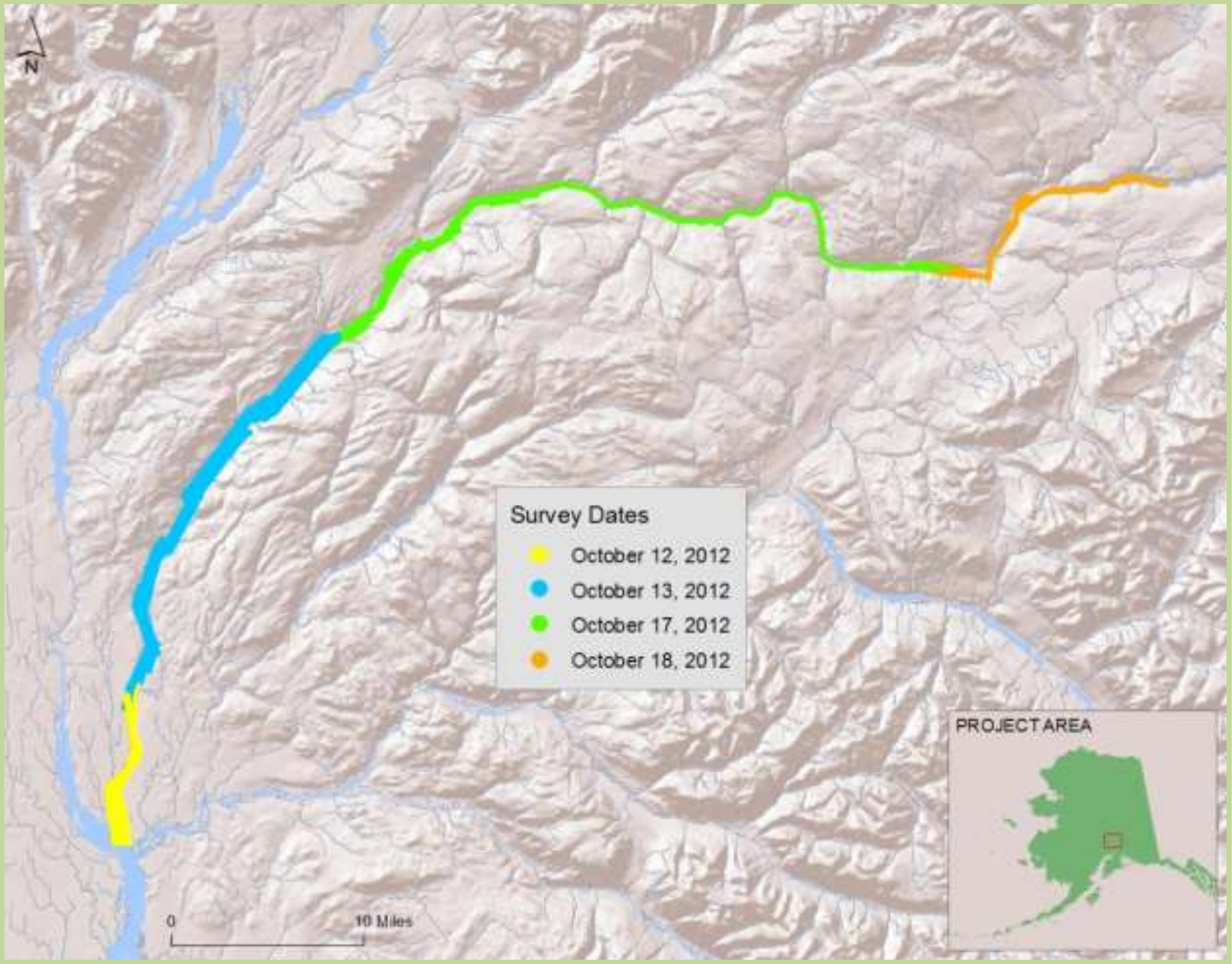
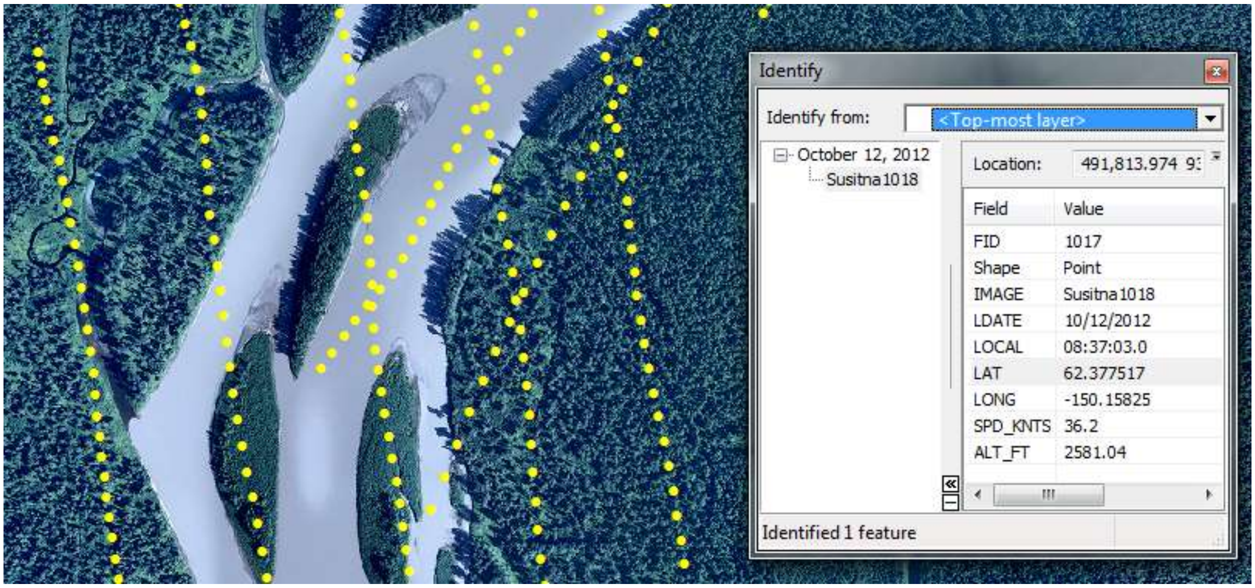


Figure 1. Susitna River sections surveyed in October 2012.

Figure 2. Bell Jet Ranger equipped with mounted FLIR sensor.



Identify from: <Top-most layer>

October 12, 2012
Susitna1018

Location: 491,813.974 9

Field	Value
FID	1017
Shape	Point
IMAGE	Susitna1018
LDATE	10/12/2012
LOCAL	08:37:03.0
LAT	62.377517
LONG	-150.15825
SPD_KNTS	36.2
ALT_FT	2581.04

Identified 1 feature

Figure 3. Thermal image locations.

Each location is represented by a yellow dot. The inset box shows the information recorded with each image during acquisition.

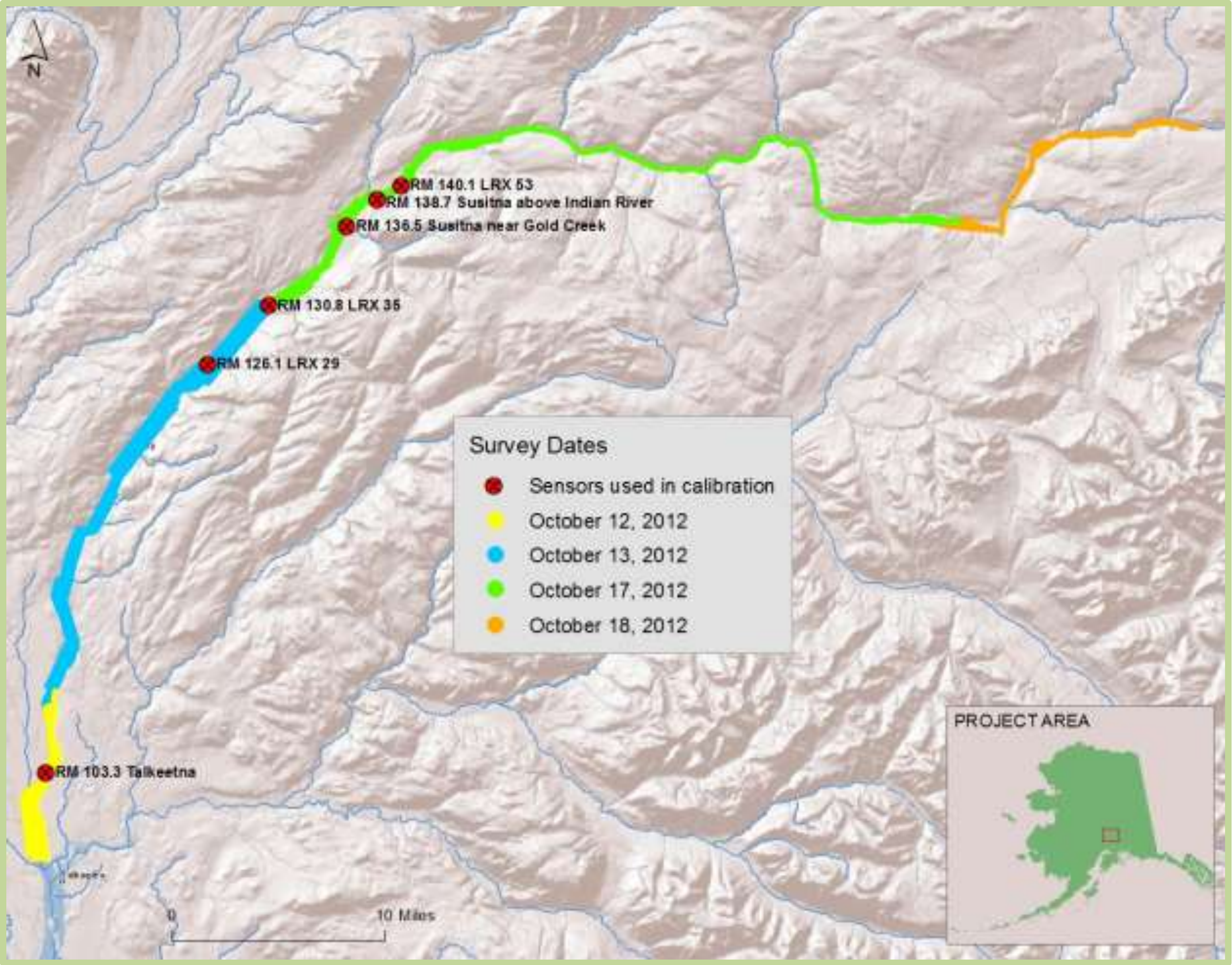


Figure 4. Location of temperature sensors used for calibration.

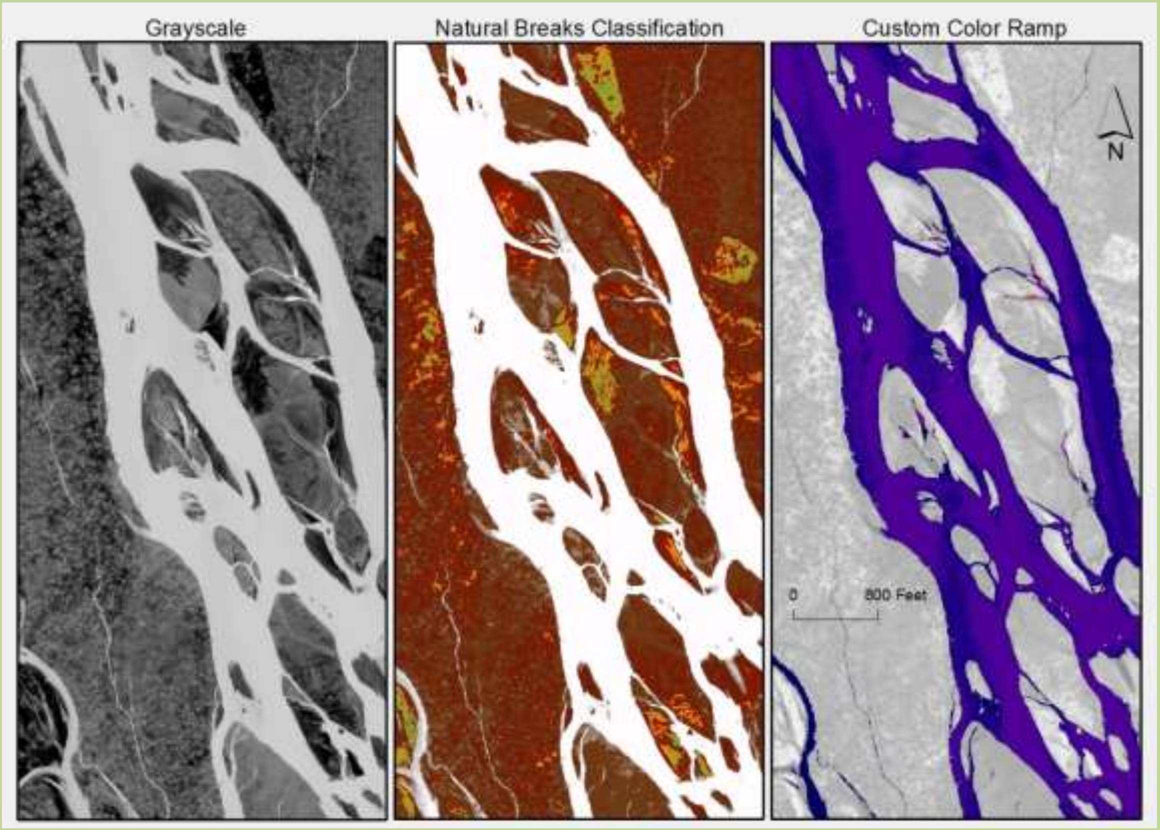


Figure 5. Examples of different color ramps applied to the same TIR image.

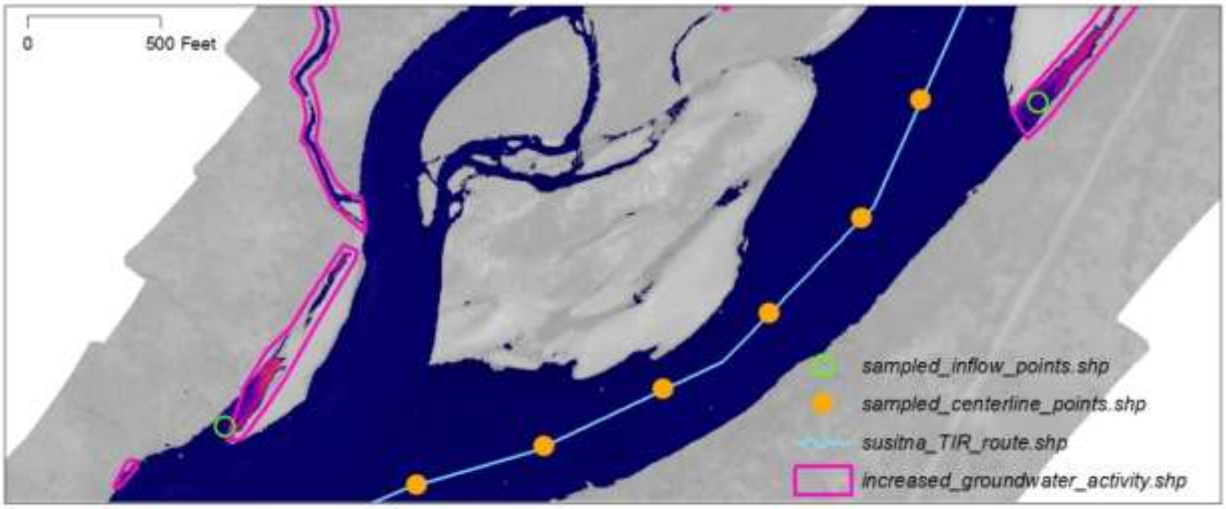


Figure 6. Example of Appendix A map.

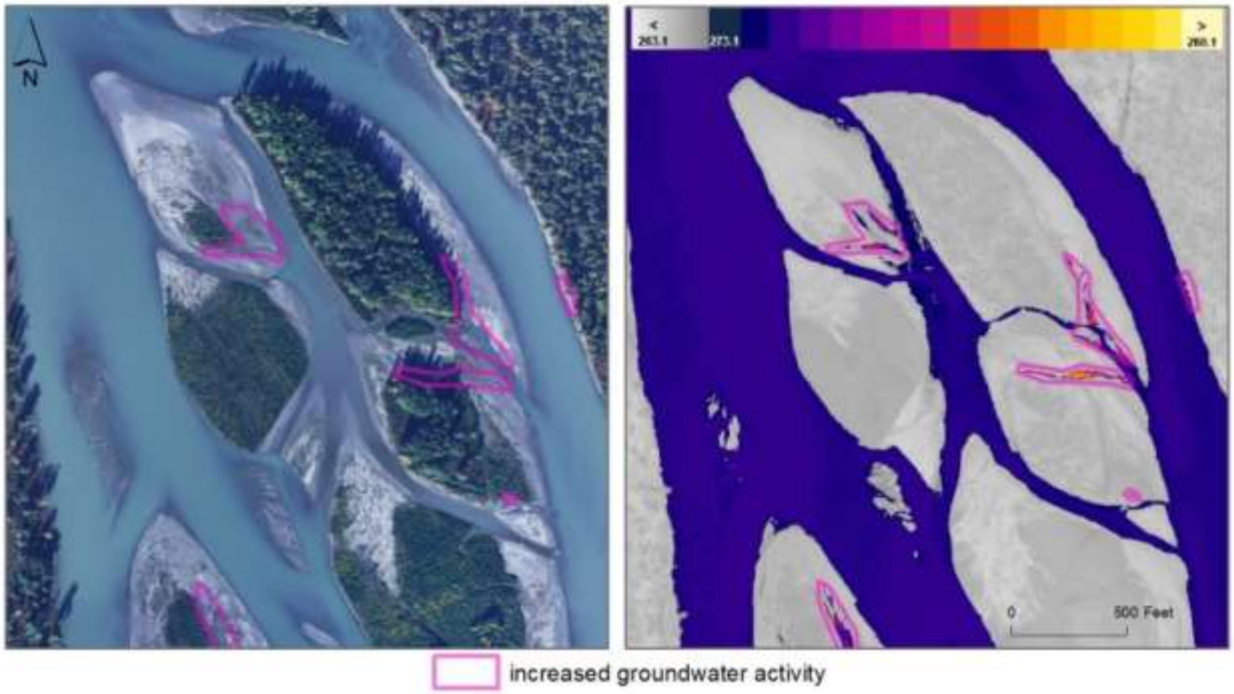


Figure 7. TIR/True Color Image Comparison.

The TIR/true color image pair above shows an example of the small hyporheic seeps that were detected in the thermal imagery, particularly in the exposed gravel beds.

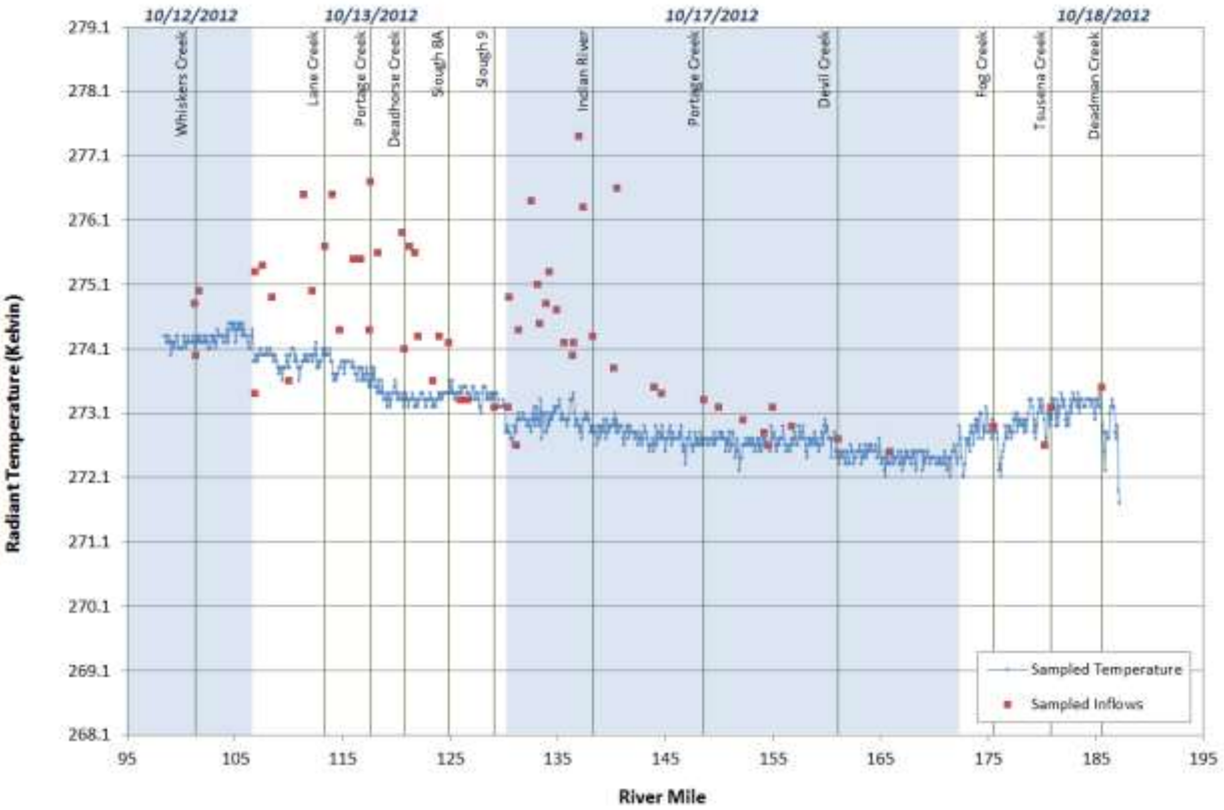


Figure 8. Longitudinal temperature profile for the Susitna River and sampled inflows.

Select named tributaries are shown for reference.

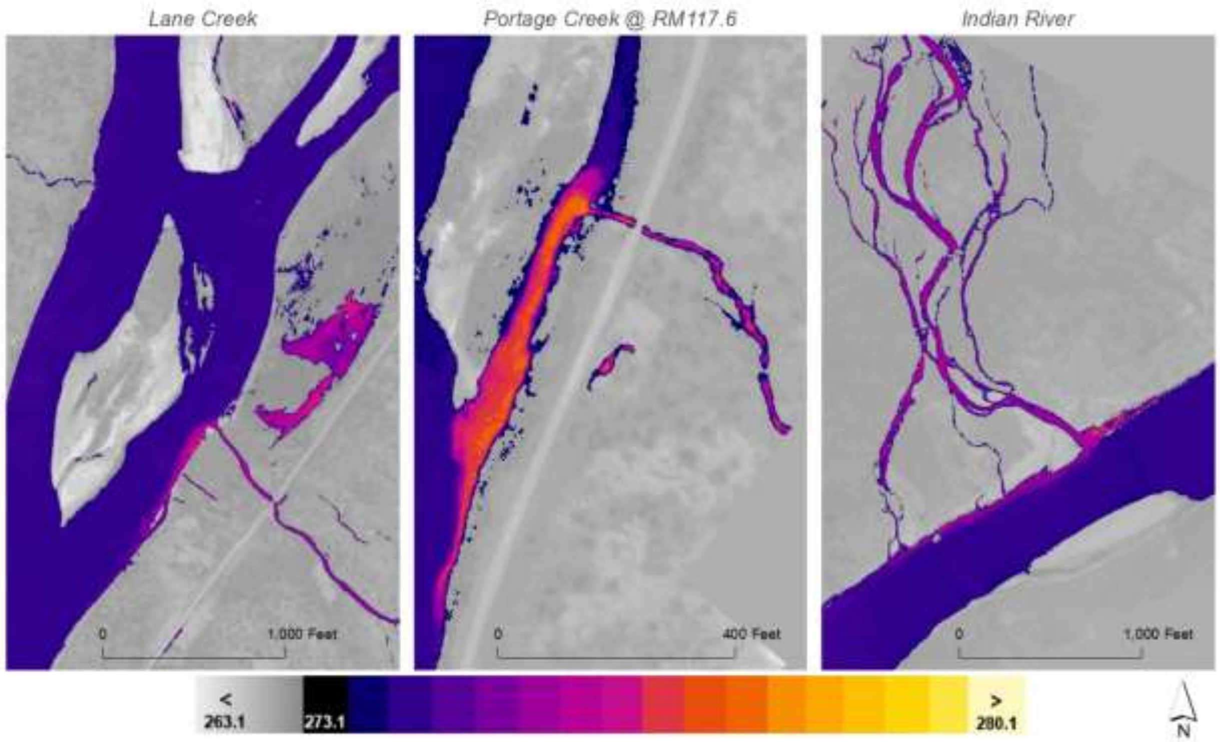


Figure 9. The TIR images of three significant tributaries to the Susitna River.

While the majority of tributaries were either frozen or at the same temperature as the mainstem, Lane Creek (RM 113.5), Portage Creek (lower) (RM 117.6), and Indian River (RM 138.6) were all contributing warmer water to the mainstem. Note there is more than one tributary named "Portage Creek" on the Susitna River. This map refers to the lower Portage Creek, near Talkeetna.

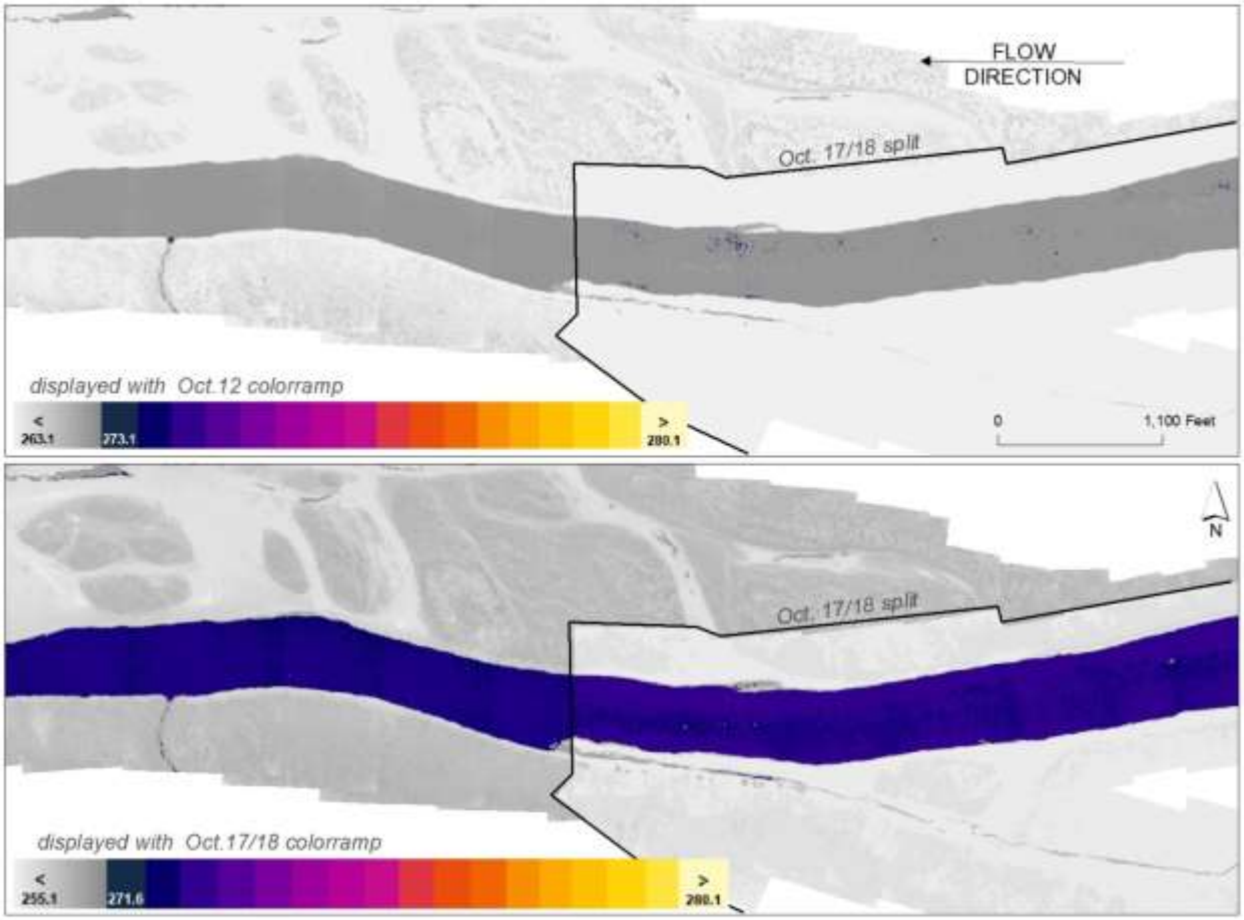


Figure 10. Junction between acquisition days October 17 and 18, 2012.

Air temperatures were colder on October 18, 2012, which affects the display of the terrestrial features in the imagery. Bulk water temperatures were significantly colder on October 17 and 18, 2012 when compared to October 12 and 13, 2012, requiring a color ramp that displayed water temperatures below freezing.

Appendix A – TIR Field Data