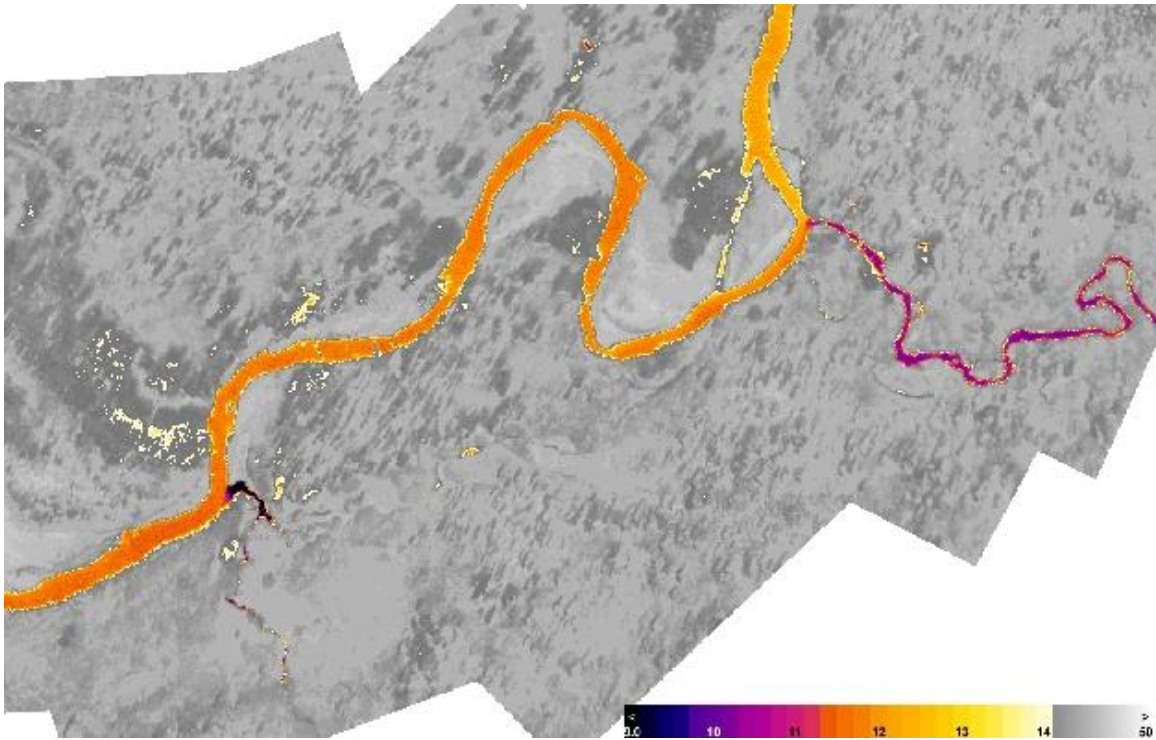# Airborne Thermal Infrared Remote Sensing
Anchor River Basin, Alaska

Confluence of South Fork Anchor River and Beaver Creek, Kenai Peninsula, Alaska

Submitted to:

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Data Acquisition: June 30, 2010
Report Date: September 17, 2010

Revised: September 20, 2010**

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**September 20 Revision – Update longitudinal profile and references to Ruby Creek at river mile 10.96. Update references to include South Fork Anchor River.

Introduction

Project Overview

In 2010, Cook Inletkeeper contracted with Watershed Sciences, Inc. to provide airborne thermal infrared (TIR) imagery for the Anchor River and South Fork Anchor River on the Kenai Peninsula. The survey extended from the mouth in Anchor Point, AK upstream for thirty-four miles to a location just below Bald Mountain (*Figure 1*).

Figure 1 – An airborne thermal infrared survey was conducted on June 30, 2010 in the Anchor River Basin.

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, the TIR data also illustrates reach-scale thermal response to changes in morphology, vegetation, and land-use.

Project Objectives

The specific objectives of the TIR image acquisition were:

- Spatially characterize surface temperatures for thirty-four miles of stream in the Anchor River Basin.
- Develop a longitudinal temperature profile which illustrates basin scale stream temperature patterns.
- Identify and map cool water sources and thermal refugia.
- Create GIS compatible data layers (e.g. thermal image mosaics, spring locations, etc.) that can be used to plan future research, direct ground based monitoring and analysis, and protect and restore critical habitat.

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 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)	$0.035^{o}C$
Pixel Array	640 (H) x 512 (V)
Encoding Level:	14 bit

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*).
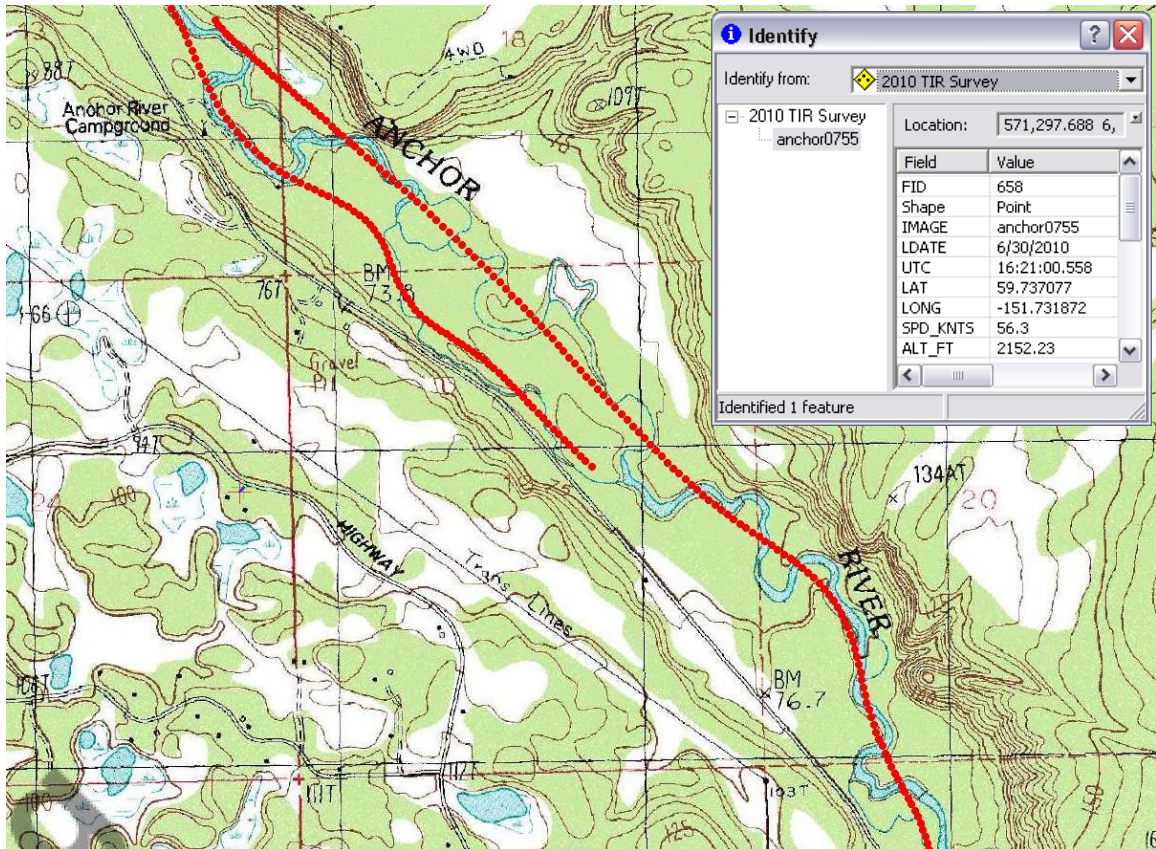

Figure 3 –Each point on the map represents a thermal image location as recorded by the onboard GPS. The inset box shows the information recorded with each image point during acquisition. In areas where the width of the floodplain exceeded the camera's field of view, a second pass was made to ensure coverage of all major side channels and braids.

Image Collection

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 second resulting in 40-70% vertical overlap between images.

A planned flight altitude of 2000 ft (1,200 m) AGL was selected for the Anchor River which resulted in a native pixel ground sample distance of 2 ft (0.6 m). The flight altitude was selected in order to optimize resolution while providing an image ground footprint wide enough to capture the active channel.

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 (Figure 3).

Table 2 - Summary of Thermal Image Acquisition Parameters

Dates:	June 30, 2010
Flight Above Ground Level (AGL):	2000 ft (1,200 m)
Image Footprint Width:	1267 ft (384 m)
Pixel Resolution:	2.0 ft (0.6 m)

Ground Control

Cook Inletkeeper provided data from four in-stream data loggers that were deployed during the survey and Watershed Sciences deployed three additional sensors in the upper reaches of the river. All seven sensors (Onset HoboPro and HoboPro V2) were used to calibrate and verify the TIR data. The data logger locations are illustrated in Figure 4.

In general, all sensors had pre/post deployment audits to verify functionality and accuracy. The in-stream data loggers were set to record temperatures at 15-minute intervals and suspended in the water column in areas with good vertical mixing.
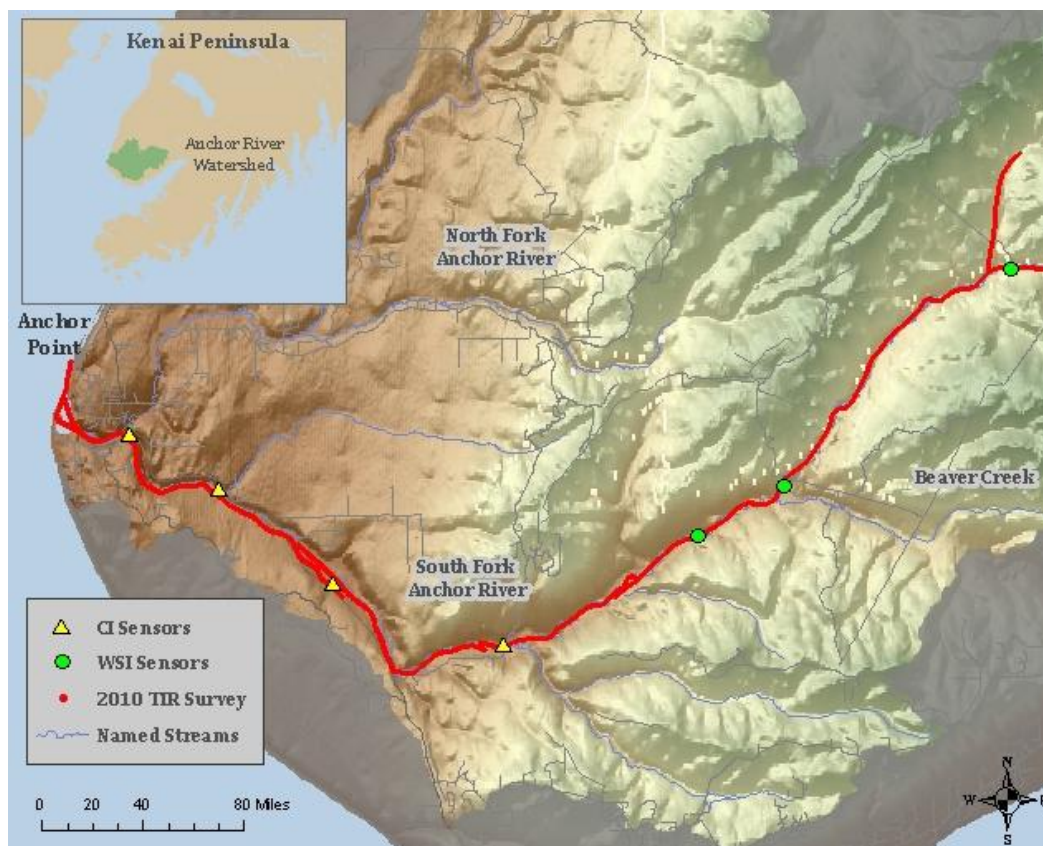

Figure 4 – Location of Cook Inletkeeper temperature sensors and sensors deployed by Watershed Sciences.

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. Stratification can usually be easily 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%). In general, apparent stream temperature changes of $< 0.5^{\circ}C$ 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.

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 $0.5^{\circ}C$ (Torgersen et al. 2001[1]). The occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis.

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.

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[1] 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.

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. This sensor has a correction scheme which reduces non-uniformity across the image frame. However, differences in temperature (typically $<0.5^{\circ}$C) can sometimes be observed near the edges of the image frame. The uniformity differences within frames and slight differences from frame-to-frame are often most apparent in the continuous mosaics. When the images are sampled for the longitudinal profile, temperatures are only measured in the center of the images.

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 5*).
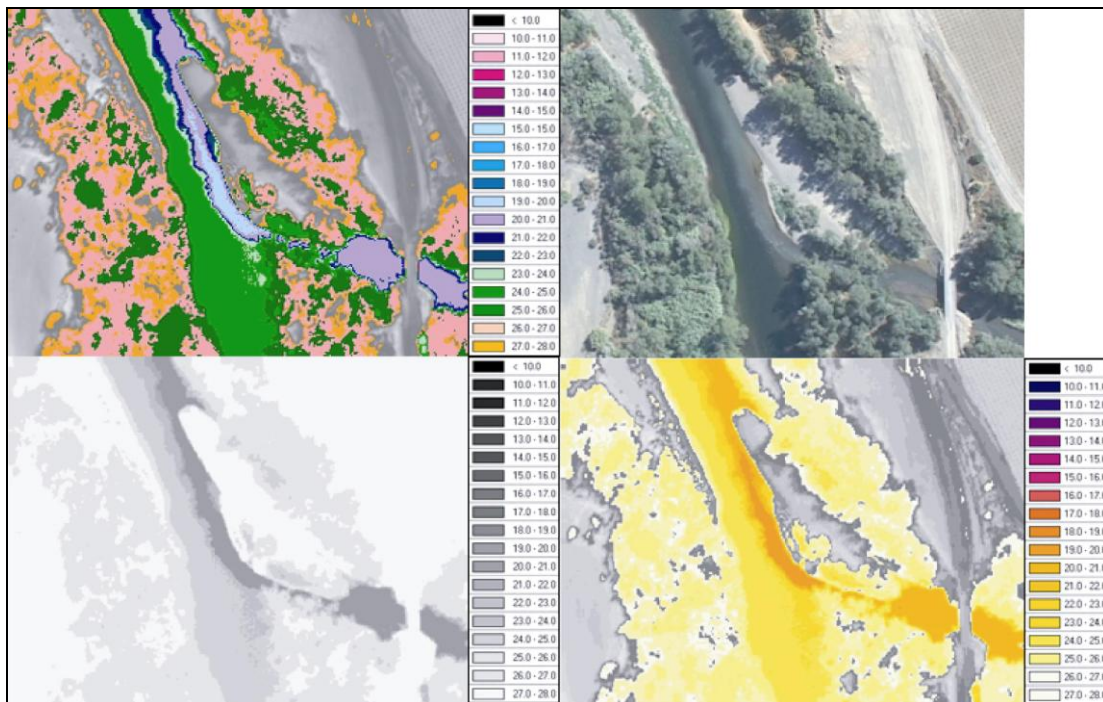

Figure 5 - Example of different color maps applied to the same TIR image.

Data Processing

Sensor Calibration

Prior to the season, 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 pre-season 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.

Geo-referencing

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

Geo-rectification

Individual TIR frames are manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and imagery available for the area. The images are then warped using a 1st order polynomial transformation. The 2003 Quickbird imagery was used as a base for the Anchor River rectification.

Interpretation and Sampling

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

Temperature Profiles

In order to provide further spatial reference, the image index shapefile is assigned an approximate river mile based on a routed stream layer. The median temperature for each sampled image frame is plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient. The location and median temperature of all sampled

surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the main stem temperature patterns. Radiant temperatures are only sampled along what appears to be the main flow channel in the river.

Due to the highly sinuous and dynamic nature of the South Fork Anchor River, river miles are approximate and based on a stream centerline digitized from the final thermal mosaics at a scale of 1:5000 (Figure 6). The 'River Mile 0' measure from the River Mile shapefile file found at the Kenai Peninsula Borough GIS website[2] was used as the starting location for the route.
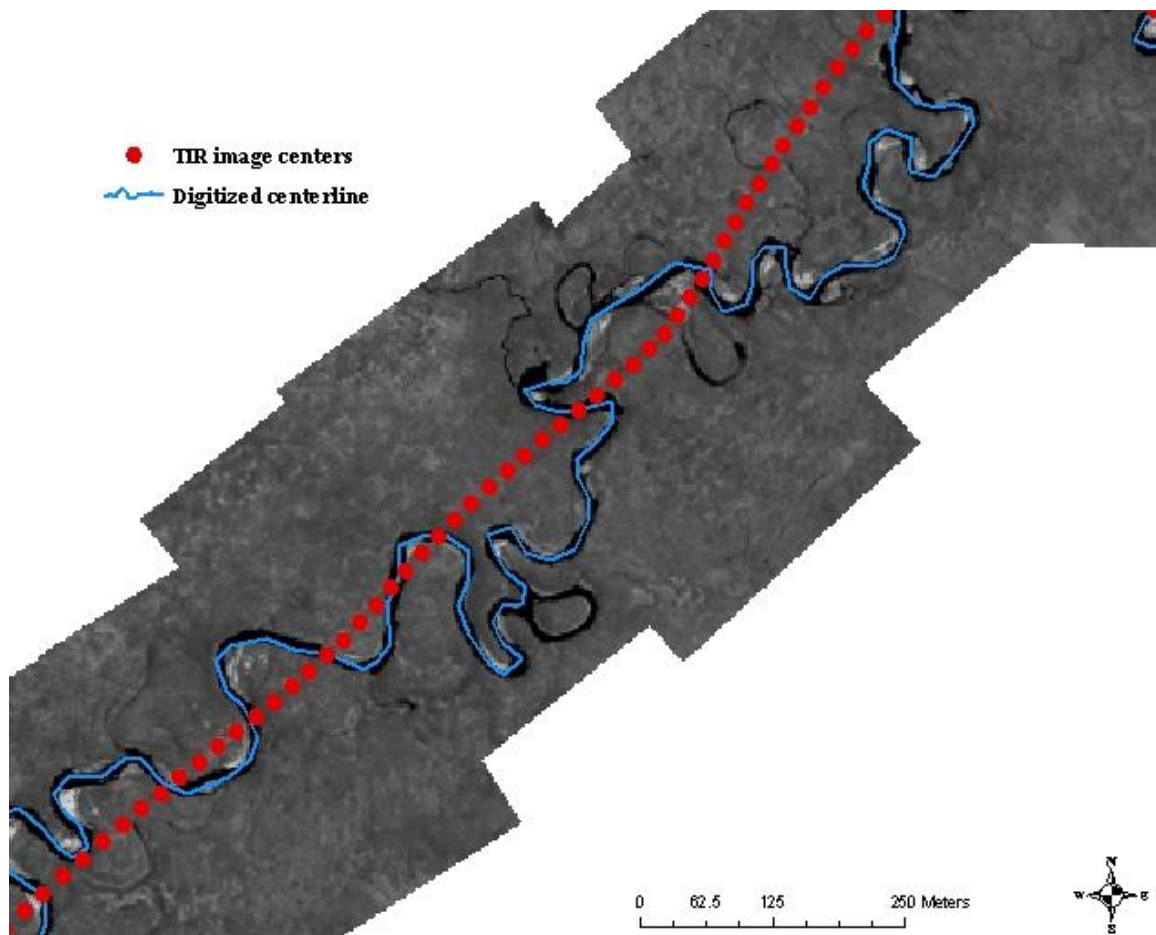

Figure 6 – Due to the highly sinuous nature of the South Fork Anchor River along certain reaches, it is difficult to apply an exact river mile to the TIR image points. Care should be used when referencing the river miles outside the scope of this report.

Weather and Stream Flow Conditions

Weather conditions on the day of the survey were cooler than desired for an ideal thermal analysis. Table 3 summarizes the weather conditions observed at Homer Airport (PAHO) weather station on the date of the survey.

Table 3 – Weather conditions measured at the Homer Airport (PAHO) weather station on June 30, 2010.

Date	PDT	Air Temp (°F)	Relative Humidity	Wind Speed (mph)	Wind Direction
6/30/2010	11:53	55.0	59%	8.1	West
6/30/2010	12:53	55.9	62%	10.4	West
6/30/2010	13:53	55.9	64%	12.7	WSW
6/30/2010	14:53	55.0	64%	11.5	West
6/30/2010	15:53	54.0	72%	16.1	WSW
6/30/2010	16:53	55.0	69%	15.0	West
6/30/2010	17:53	55.9	60%	12.7	West
6/30/2010	18:53	54.0	66%	12.7	WSW
6/30/2010	19:53	52.0	71%	13.8	WSW

During the time of the survey, one active USGS monitoring site was active near the intersection of Sterling Highway and Norman Lowell Road; however, temperature and precipitation data was unavailable for the monitoring site. The gage height graph for the time period before and after the survey can be seen in Figure 7[3]. 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.

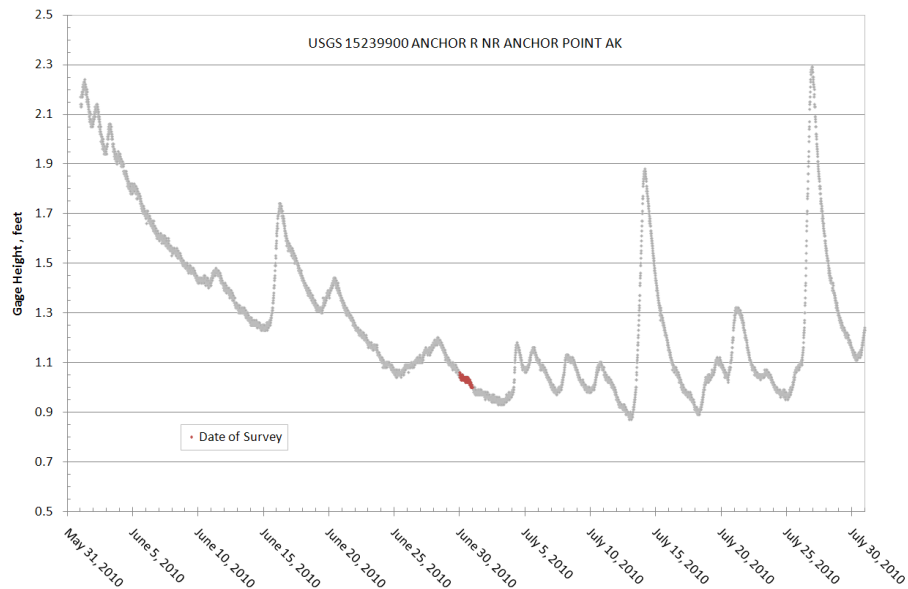*Figure 7- Stream flow graph for USGS gage '15239900-Anchor R NR Anchor Point AK' from May 31, 2010 to July 30, 2010.*

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[3] *Source: USGS National Water Information System:*
http://waterdata.usgs.gov/ak/nwis/uv/?site_no=15239900&PARAmeter_cd=00065,00060

Thermal Accuracy

Seven in-stream data loggers were deployed in the South Fork Anchor River during the time frame of the flight (*Figure 8*). 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. 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 $\pm0.5^{\circ}$C.

Table 4 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from in-stream sensors. Sensor locations can be seen in Figure 4.

Serial	Placement	Image	River Mile	Time	In-Stream Temp (°C)	Radiant Temp (°C)	Difference
2004052	CIW	anchor0314	1.99	15:12	13.5	13.9	-0.40
1189844	CIW	anchor0498	5.47	15:15	12.8	12.6	0.23
2004072	CIW	anchor0682	8.78	15:18	12.1	11.9	0.25
2004064	CIW	anchor1090	14.33	15:27	11.9	11.5	0.40
2004073	WSI	anchor1530	21.27	15:37	11.2	11.1	0.10
2004062	WSI	anchor1671	23.81	15:40	12.9	13.0	-0.10
2004055	WSI	anchor2042	33.18	15:46	9.6	9.9	-0.30

Figure 8- Watershed Sciences, Inc. deploying an in-stream data logger in the upper reaches of the South Fork Anchor River prior to the aerial TIR survey.

Results

Median channel temperatures were plotted versus river mile for the Anchor and South Fork Anchor Rivers (*Figures 9 and 10*). Tributaries, springs, and seeps sampled during the analysis are included on the longitudinal profile to provide additional context for interpreting spatial temperature patterns. Springs and seeps are generally differentiated by size and temperature; a feature is considered a spring when it has a defined source and is distinctly cooler than the surrounding waters. Features are called seeps when they are less defined spatially and in temperature; they most commonly occur on the edges of the river banks. If there was any doubt about the source of a feature, they were noted with a '?' in the sampled shapefile. These locations should be verified in the field to confirm the presence of groundwater.

Due to the nature of the project, the focus was on identifying cold water inflows and thermal refugia for fish. Small braids and side channels were not sampled unless they showed a significantly different temperature than the main channel. It is important to reiterate that temperature changes of less than ± 0.5°C in the absence of a point source should be interpreted with caution until verified in the field due to the inherent accuracy limitations of the thermal imagery. The sample images contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations.

Figure 9 – Oblique photo of the South Fork Anchor River taken the day prior to the survey.
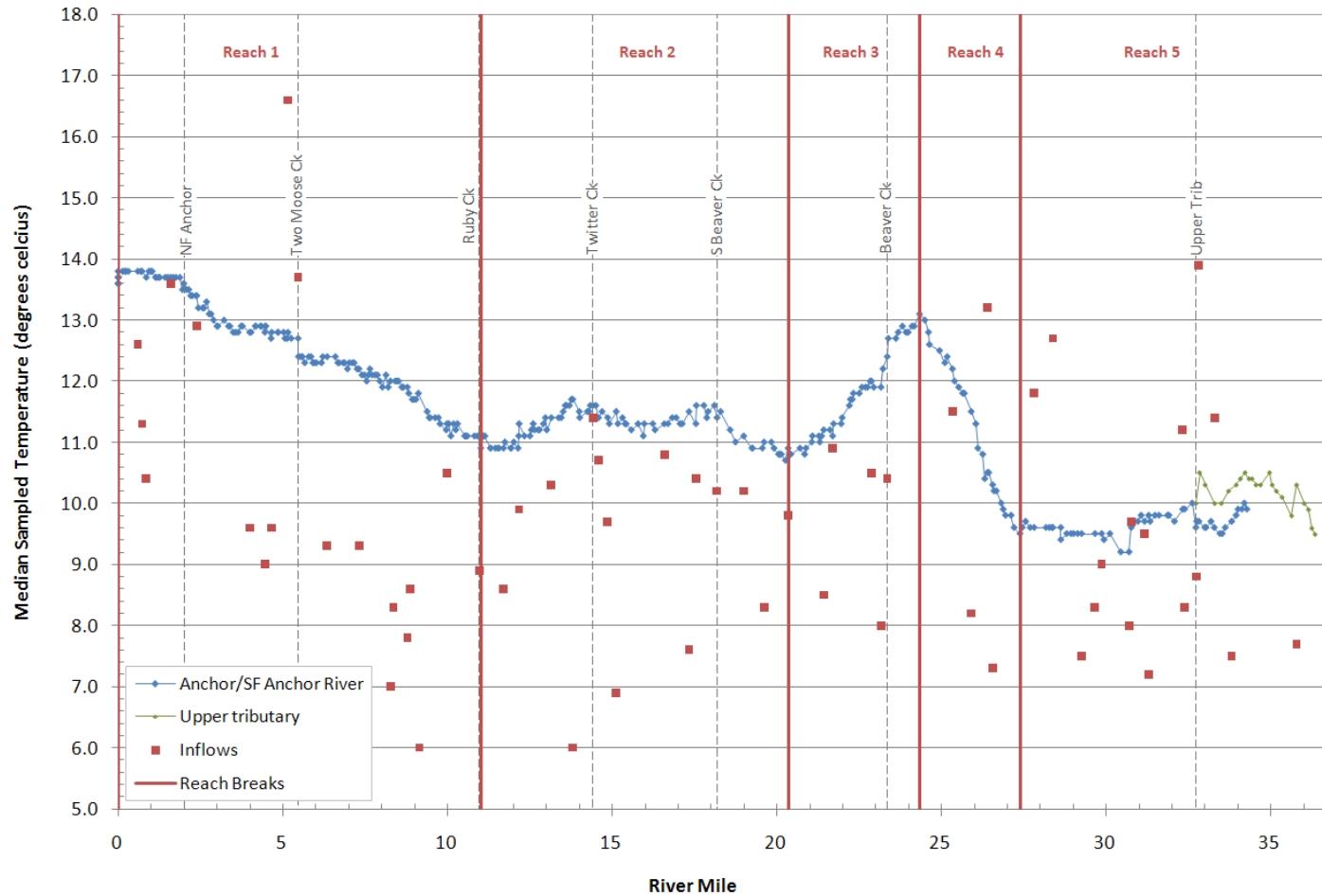
Longitudinal Temperature Profile

Figure 10 - Median channel temperatures plotted versus river mile for the Anchor and South Fork Anchor River. The locations of detected surface inflows are illustrated on the profile and listed in Table 5. The 'Reach Breaks' delineate the major thermal trends seen along the river.

Observations

Approximately thirty-four miles of the Anchor River and South Fork Anchor River were surveyed on June 30, 2010 from the mouth at Anchor Point, upstream along the South Fork to a confluence below Bald Mountain. Eighteen tributaries, 23 seeps and springs, 11 sloughs, and 9 small side channels and drains were sampled in the imagery (*Table 5*). Overall bulk water temperatures ranged from 9.2°C near river mile 30.69 to 13.8°C at the mouth.

Table 5 - Tributaries and other surface inflows sampled with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (ºC)	Mainstem Temp (ºC)	Difference
slough (tidal) (L)	0.96	0.59	12.6	13.8	-1.2
slough (tidal) (L)	1.16	0.72	11.3	13.8	-2.5
slough (tidal) (R)	1.37	0.85	10.4	13.7	-3.3
slough (R)	2.55	1.59	13.6	13.7	-0.1
NF Anchor River (R)	3.21	1.99	14.2	13.6	0.6
seep / hyporheic flow (L)	3.84	2.38	12.9	13.4	-0.5
seep (L)	6.42	3.99	9.6	12.8	-3.2
seep (L)	7.17	4.45	9.0	12.8	-3.8
seeps (L)	7.50	4.66	9.6	12.8	-3.2
slough (L)	8.29	5.15	16.6	12.8	3.8
Two Moose Creek (R)	8.79	5.46	13.7	12.4	1.3
seep (L)	10.21	6.34	9.3	12.4	-3.1
seep (L)	11.76	7.31	9.3	12.2	-2.9
spring on side channel (R)	13.30	8.26	7.0	12.0	-5.0
seep on side channel (L)	13.43	8.35	8.3	11.4	-3.1
seep (L)	14.13	8.78	7.8	11.9	-4.1
spring on side channel (L)	14.25	8.86	8.6	12.3	-3.7
spring on side channel (R)	14.71	9.14	6.0	6.8	-0.8
seep / hyporheic flow (R)	16.06	9.98	10.5	11.3	-0.8
Ruby Creek (L)	17.65	10.96	8.9	11.1	-2.2
spring? (R)	18.82	11.70	8.6	10.9	-2.3
unnamed tributary (L)	19.58	12.17	9.9	11.3	-1.4
spring on side channel (L)	21.17	13.15	10.3	11.4	-1.1
spring on side channel (R)	22.22	13.80	6.0	11.7	-5.7
Twitter Creek (L)	23.19	14.41	11.4	11.6	-0.2
side channel (L)	23.46	14.58	10.7	11.4	-0.7
seep (R)	23.91	14.86	9.7	11.4	-1.7
seep (R)	24.33	15.12	6.9	11.5	-4.6
small tributary (L)	26.69	16.58	10.8	11.3	-0.5
seep (L)	27.89	17.33	7.6	11.5	-3.9
unnamed tributary (L)	28.22	17.54	10.4	11.3	-0.9
South Beaver Creek (L)	29.26	18.18	10.2	11.4	-1.2
unnamed tributary (R)	30.57	18.99	10.2	11.1	-0.9

seep off channel (R)	31.56	19.61	8.3	11.0	-2.7
side channel (L)	32.74	20.34	9.8	10.9	-1.1
unnamed tributary (L)	34.47	21.42	8.5	11.2	-2.7
side channel (L)	34.90	21.69	10.9	11.1	-0.2
spring/slough off channel (R)	36.81	22.87	10.5	12.0	-1.5
unnamed tributary (L)	37.27	23.16	8.0	11.9	-3.9
Beaver Creek (L)	37.58	23.35	10.4	12.7	-2.3
drain (L)	40.76	25.33	11.5	12.2	-0.7
drain (R)	41.68	25.90	8.2	11.5	-3.3
slough (L)	42.47	26.39	13.2	10.5	2.7
side channel (L)	42.72	26.55	7.3	10.3	-3.0
slough (L)	44.76	27.81	11.8	9.6	2.2
slough (L)	45.67	28.38	12.7	9.6	3.1
seep on oxbow (L)	47.08	29.25	7.5	9.5	-2.0
unnamed tributary (R)	47.74	29.66	8.3	9.5	-1.2
slough (L)	48.05	29.86	9.0	9.5	-0.5
unnamed tributary (R)	49.40	30.69	8.0	9.2	-1.2
side channel (R)	49.50	30.76	9.7	9.6	0.1
side channel / tributary (R)	50.14	31.16	9.5	9.7	-0.2
unnamed tributary (L)	50.35	31.29	7.2	9.8	-2.6
slough (R)	52.01	32.32	11.2	9.9	1.3
spring (L)	52.12	32.38	8.3	9.9	-1.6
Upper tributary (R)	52.66	32.72	10.6	9.6	1.0
seep (R)	52.71	32.75	8.8	9.7	-0.9
slough (L)	52.80	32.81	13.9	9.7	4.2
side channel (L)	53.58	33.30	11.4	10.0	1.4
unnamed tributary (L)	54.42	33.81	7.5	9.7	-2.2
unnamed tributary (R)	57.57	35.78	7.7	10.3	-2.6

On the date of the survey, the Anchor River basin experienced generally sunny sky conditions with direct solar radiation in the drainage for most of the morning. However, in general, the Kenai Peninsula experienced an unseasonably cool, wet summer and overall weather conditions were less than ideal. In an ideal survey, hot summer temperatures warm the terrestrial features as well as the overall bulk water temperatures. Warm bulk water temperatures allow cool water inflows to sharply contrast with the main channel allowing for more thorough sampling. In the Anchor River basin, bulk water temperatures were very cool (9-14°C), however groundwater temperatures are near 3.0°C[4] allowing for enough contrast to locate thermal refugia along the river. Water temperatures in the weeks following the survey did not show any significant warming trends (*Figure 11*). Flow rates were also low which aided in the sampling process as high flows can cause small thermal features to be washed out in the imagery. In certain areas of the imagery, there is reduced contrast between the land and water features, but it did not negatively impact the analysis (*Anchor Image 1*).

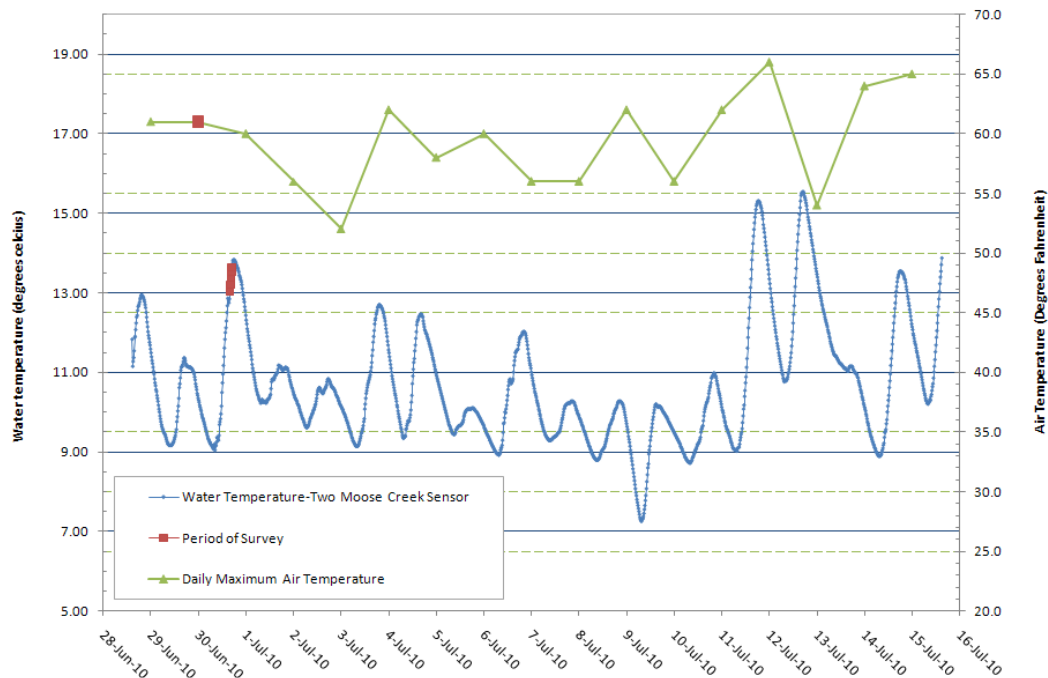[4] E-mail correspondence with Sue Mauger, Cook Inletkeeper.

Figure 11 – Comparison of water temperatures recorded at the Two Moose Creek Sensor and daily maximum air temperatures in the weeks following the survey.

At the watershed scale, three types of thermal trends can typically be seen in a longitudinal profile: increasing temperatures, stable temperature plateaus, and decreasing temperatures. On a warm summer day, radiant water temperatures would be expected to increase as the river flows downstream in the absence of any external inflows. Reaches with stable temperatures or decreasing temperatures indicate zones of groundwater influence or cool surface inflow. Subsurface contributions commonly appear in areas where there are changes in river morphology, geology or valley type. These groundwater interactions may result in detectable point sources (i.e. seeps and springs) or they may be more diffuse and only be apparent in the overall trends seen in the longitudinal profile.

The Anchor River's temperature profile shows five distinct temperature reaches, with smaller point source fluctuations within each reach. Beginning upstream, above river mile 27.38 to the end of the survey (Reach 5), the longitudinal profile shows stable temperatures hovering between 9-10°C. This type of thermal plateau typically indicates that daytime heating is being tempered by groundwater influences. Ten of the seventeen sampled inflows along this reach contribute cooler water to the mainstem negating any diurnal heating. This reach is also very sinuous and has a very low gradient which allows for increased groundwater interchange with the slow moving water (*Anchor Image 2*).

Below river mile 27.38 (Reach 4), the river straightens somewhat and the gradient increases greatly. This change in valley morphology results in decreased groundwater influence and increased temperatures (*Figure 12*). Only three cool water inflows were sampled in this reach, contributing only small volumes of water.
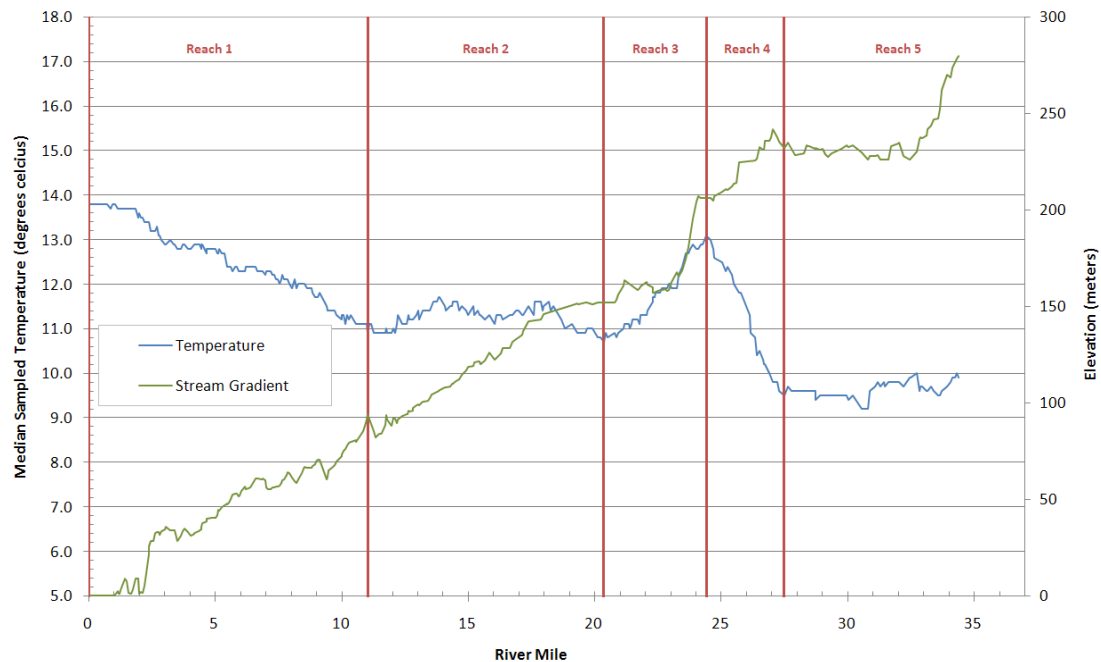
Figure 12- Thermal longitudinal profile as it relates to stream gradient. The transition in gradient seen between Reach 4 and 5 is a major contributing factor to the increase in temperatures seen in Reach 4. Stream gradient was coarsely calculated from the 30-meter Digital Elevation Model (DEM).

At river mile 24.33, bulk water temperatures take an abrupt downturn near the confluence with Beaver Creek (RM 23.35) and they continue to decrease for over four miles (Reach 3). This type of cooling is a typical response seen at the junction of two significant valleys. Beaver Creek is also contributing a significant amount of cool surface water (10.4°C), which results in a point source decrease in temperatures immediately below the confluence (12.7→11.9°C). The extended cooling trend indicates further groundwater influence. The four other cold water inflows sampled in this reach are examples of this influence.

Reach 2 (RM 11.01-20.35) shows a similar temperature trend to Reach 5, with temperatures that plateau between 11.0-12.0°C. Sixteen features were found to contribute cooler water to the mainstem buffering any temperature increases due to diurnal heating. The valley response seen at Beaver Creek in Reach 3 can also be seen at a much smaller scale at the confluence of the mainstem with both Twitter Creek (RM 14.41) and South Beaver Creek (RM 18.18). Neither tributary was contributing much surface water the day of the survey, but a slight decrease in temperatures is seen below each confluence indicating possible subsurface interactions (*Anchor Image 3*).

Downstream of river mile 11.01 (Reach 1), river temperatures resume warming in the final run to Cook Inlet. Two Moose Creek (RM 5.46) is the only tributary that was contributing warmer water to the mainstem resulting in a minor uptick in bulk water temperatures (12.4→12.7°C). Below the confluence with the North Fork Anchor River (RM 1.99) and Two Moose Creek, short plateaus are seen indicating more valley-confluence groundwater interactions (*Anchor Image 4*).

Sample Images
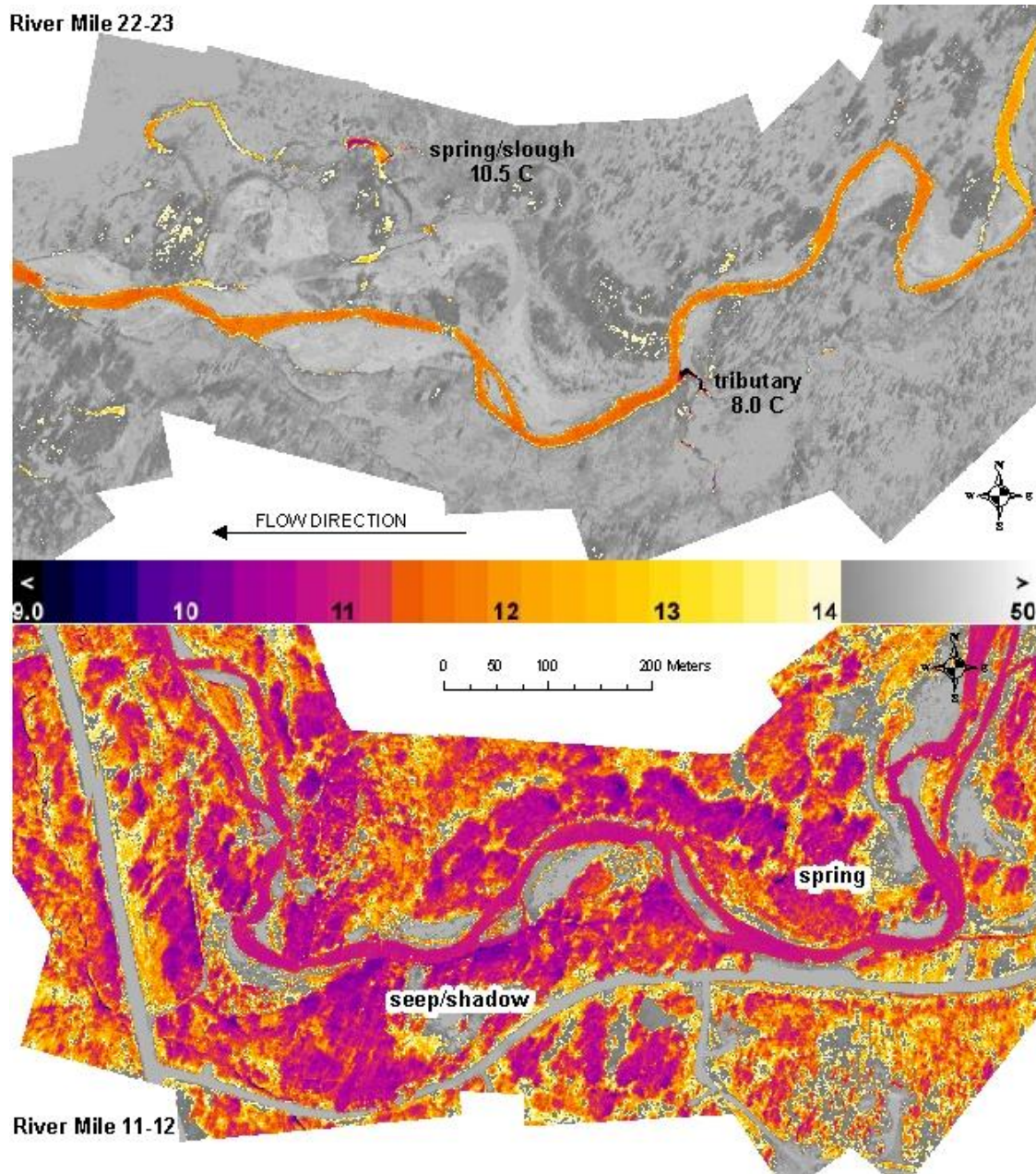
Anchor Image 1 – The two TIR image mosaics above show the difference in thermal returns with cooler temperatures and passing cloud cover. In the upper image, full solar radiation acts to warm terrestrial features allowing the water features to stand out. In the lower image mosaic, passing cloud cover changes the radiative properties of the vegetation resulting in decreased contrasts. However, with extremely cold groundwater temperatures and the availability of the true color imagery for visual comparisons, the overall analysis was not impacted.
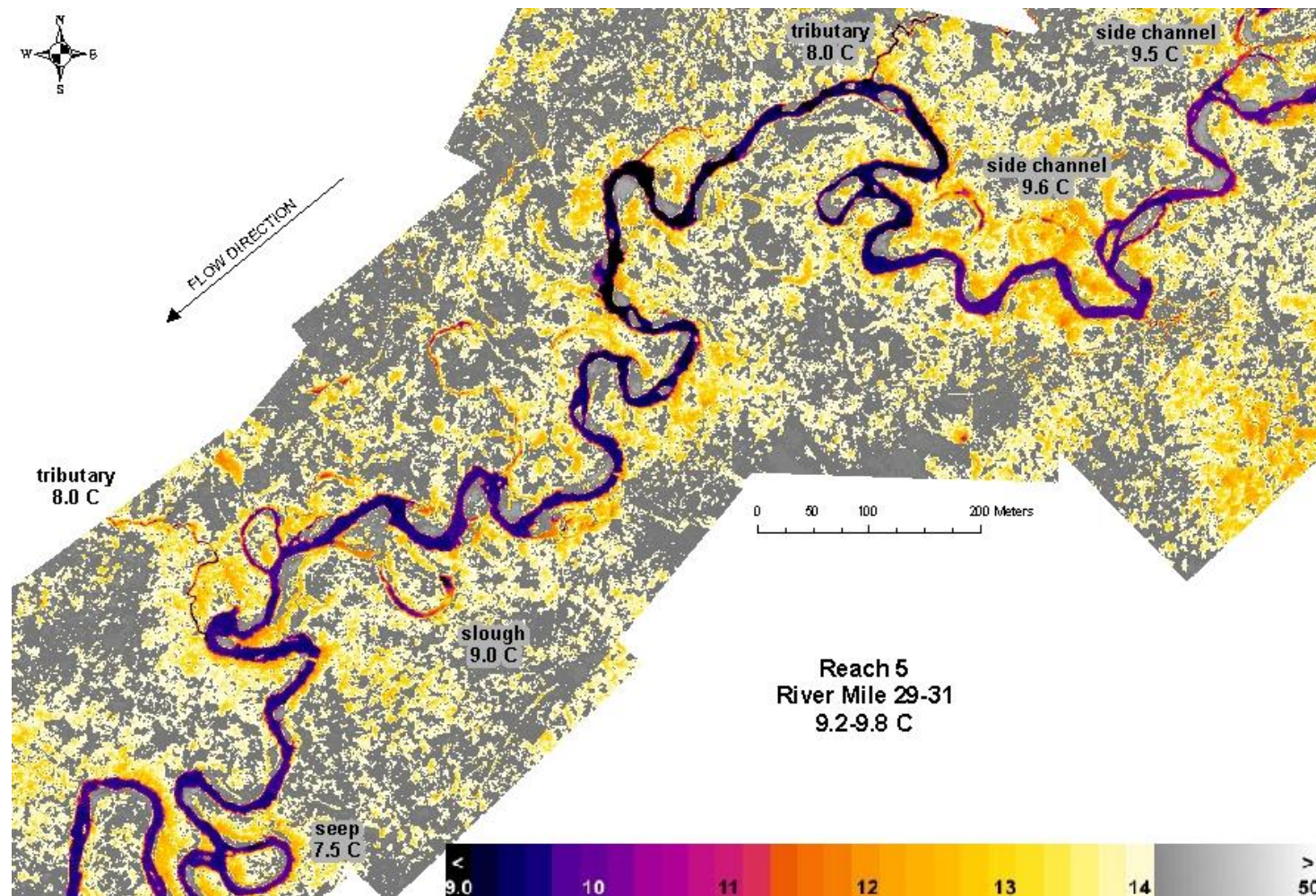
Anchor Image 2 – The TIR image mosaic above shows a portion of Reach 5 between river miles 29-31. Bulk water temperatures along this reach ranged from 9.2°C to 9.8°C with multiple tributaries and side channels contributing cooler water to the main channel. It is typical to see thermal plateaus in this type of sinuous morphology as slower flows increase the groundwater interaction, offsetting any diurnal warming that may occur. This portion of the survey also experienced a slight decrease in land/water contrast with passing cloud cover.
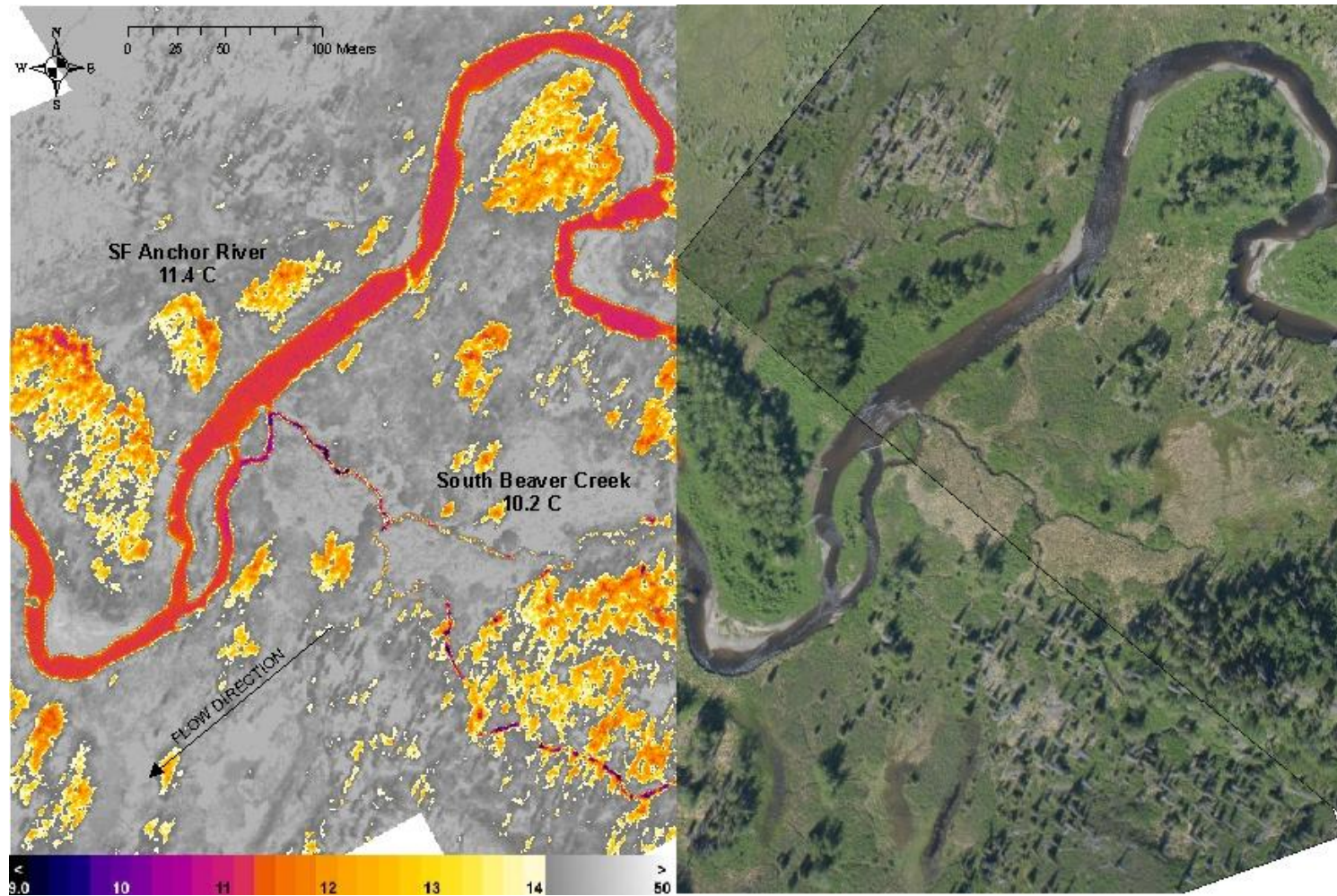
Anchor Image 3 – The TIR/true color image pair above shows the confluence of South Beaver Creek and the South Fork Anchor River at river mile 18.18. Though the stream was contributing little surface water, the trend of decreasing temperatures below the confluence indicates subsurface interaction which can occur at the junction of two valleys.
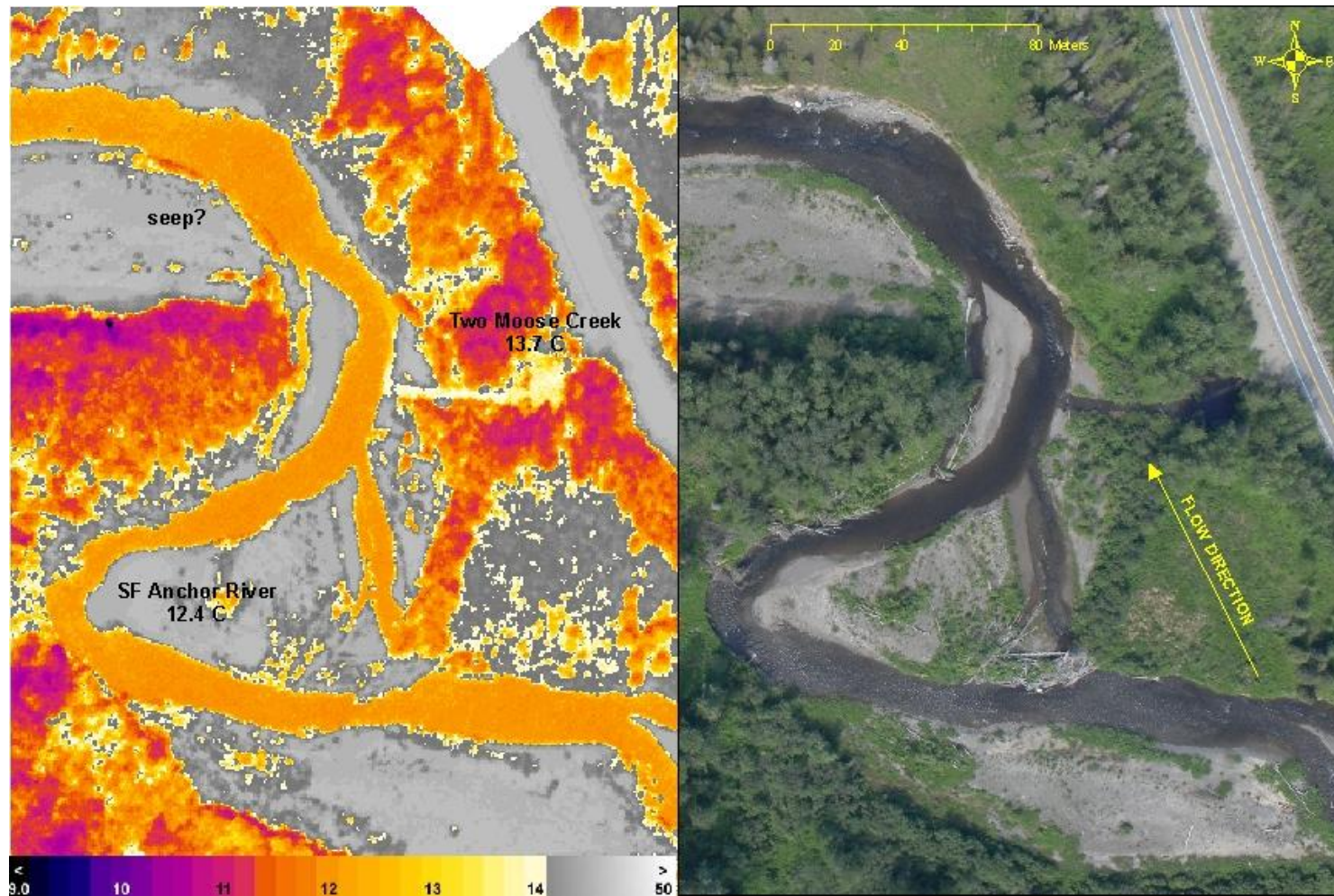
Anchor Image 4 – The TIR/True Color Image pair above shows the confluence of the South Fork Anchor River and Two Moose Creek at river mile 5.46. Two Moose Creek was the only tributary contributing warmer water to the mainstem, resulting in a slight warming of bulk water temperatures (12.4→12.7°C).

Deliverables

The TIR imagery is provided in two forms: 1) individual unrectified frames and 2) a continuous geo-rectified mosaic at 0.6 m (2.0 ft) 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.

Original deliverables were provided on a USB Flash drive. Revised deliverables were provided on DVD.

Geo-Corrected Images are provided in two projections:

- Alaska State Plane Zone 4, NAD83, Feet
- UTM Zone 5, NAD 83, Meters

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1. <u>Hydrography</u> – Relevant hydrography shapefiles

2. <u>LongProfile</u> - Excel spreadsheet containing the longitudinal temperature profiles

3. <u>Nikon_Survey</u>- Point index shapefile showing approximate location of the true color images.

4. <u>Nikon_Unrectified</u> – Unrectified true color images with image index.

5. <u>Thermal_Mosaics</u> - Continuous image mosaic of the geo-rectified TIR image frames at 0.6-meter resolution in Imagine *.img format. (cell value = radiant temperature * 10)

6. <u>Thermal_Surveys</u> - Point layers showing image locations, sampled temperatures, and image interpretations.

7. <u>Thermal_Unrectified</u> - Calibrated TIR images in Erdas Imagine *img format. 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.

8. <u>Report</u> – A copy of this report

9. <u>Projects</u> – ArcMap project files (*.mxd) containing thermal survey shapefile and mosaics with color ramps and hydrography files for reference. One project is in UTM Zone 5, one project is in Alaska State Plane.