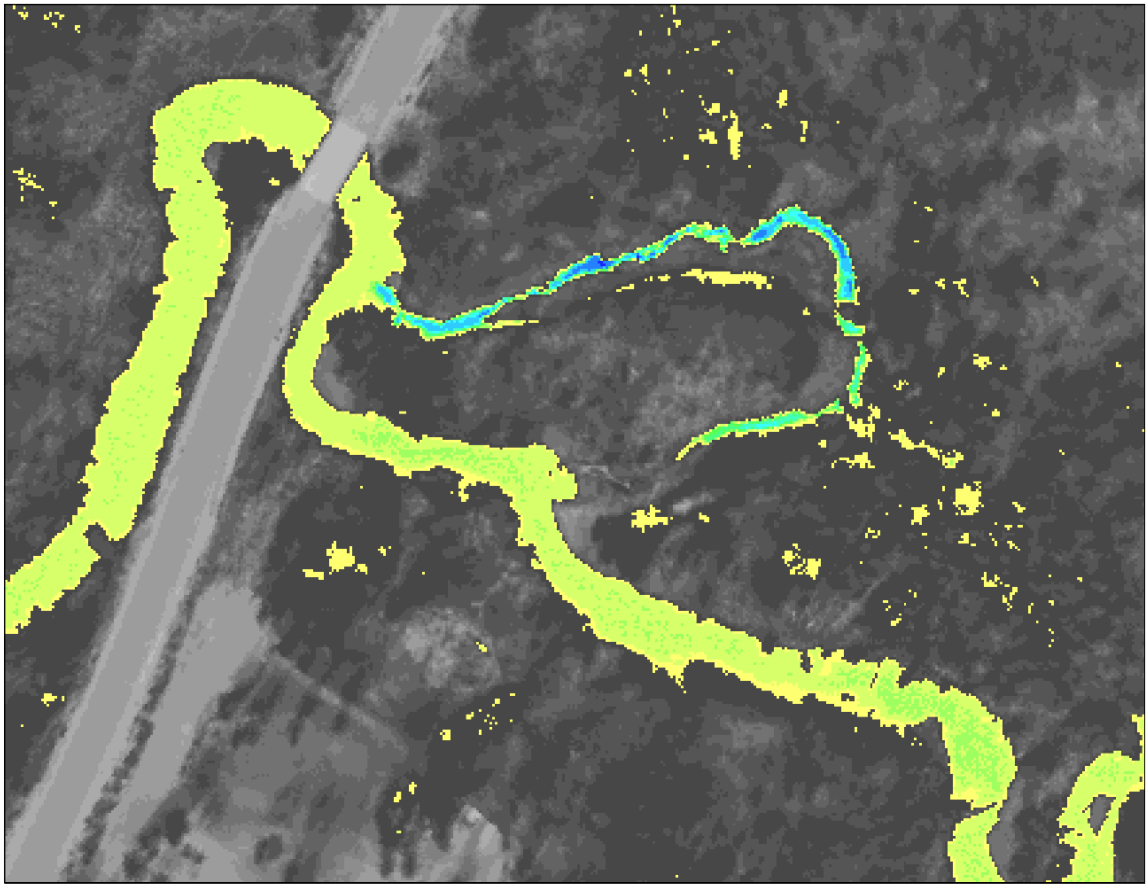
Survey: July 5, 2020
Report: January 7, 2021



Kenai Rivers - Thermal Infrared Airborne Imagery
Technical Data Report

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Cover Photo: Thermal infrared imagery a side channel (oxbow) or a potential spring at river km 0.5 of Funny River.

INTRODUCTION

Cook Inletkeeper contracted NV5 Geospatial (formerly, Quantum Spatial Incorporated) to collect thermal infrared (TIR) during the summer of 2020 along four streams on the Kenai Peninsula in southern Alaska: Beaver Creek, Crooked Creek, Funny River, and Moose River under a project name "Kenai Rivers". All streams were contracted to be flown in the summer of 2020 and during the afternoon hours in order to maximize the thermal contrast between the river's water and the banks. The survey extends for a total length of 59.1 km miles of the Kenai Rivers. The Data were collected to aid the Cook Inletkeeper team to identify the spatial variability in surface temperatures as well as thermal influence of point sources, tributaries, and surface springs. The data will also be used to identify high-value habitats for the salmonids population within the four streams.

This report documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset. The report accompanies the delivered TIR data and support files. TIR acquisition dates and times are shown in Table 1, a complete list of contracted deliverables provided to Cook Inletkeeper is shown in Table 2, and the project extent is shown in Figure 2.

Table 1: TIR acquisition dates and stream reaches collected on the Kenai Rivers site

River Survey Description		Survey Date	Survey Window (AKST)
Beaver Cr.	1st attempt (incomplete)	July 5, 2020	12:43 – 12:52
	2nd attempt		14:10 – 14:21
	3rd attempt (Final)		15:55 – 16:06
Crooked Cr.		July 5, 2020	13:05 – 13:56
Funny River		July 5, 2020	15:29 – 15:44
Moose River		July 5, 2020	14:30 – 14:35

Deliverable Products

Table 2: Products delivered to the Cook Inletkeeper

Kenai Rivers TIR 2020 Products Projection: UTM Zone 5 North Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: Meters, Celsius	
Rasters	Thermal Infrared Imagery (*.tif): • Calibrated and rectified image files (cell values = Celsius x 10) • Calibrated imagery mosaics (cell values = Celsius x 10) True Color Imagery (*.jpg) • Image frames
Vectors	Shapefiles (*.shp) • TIR image center points and sensor exterior orientation (EO) • Stream centerlines • Longitudinal temperature profile (LTP) • True color image exterior orientations
Supplemental	• "LTP" folder containing longitudinal temperature profiles and significant feature sampling in MS Excel format (*.xlsx) • "Color Ramps" folder containing customized layer files (*.lyr) for visualization • "Maps and Figures" folder containing maps and figures used for the report (*.png)

Thermal infrared imagery Acquisition Planning

Flight Planning and Timing

In preparation for data collection, NV5's team reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Kenai Rivers study areas and the desired data quality. The aircraft will follow the stream course keeping the stream in the center of the frame as possible and will fly additional lines where the entirety of the river was not captured in the frame. Furthermore, the flight direction is planned to start at the downstream most point of the river and progresses upstream. The direction might be reversed (from upstream to downstream) under exceptional wind conditions and turbulence. After discussing timing options with the Cook Inletkeeper team, NV5 planned to acquire the data during the afternoon hours to maximize the thermal contrast between the river water and the banks. The optimal weather conditions hoped for are a cloud-free sky, warm air temperatures, and a sunny day. The acquisition time window was planned to occur 13:00 – 17:00.

Thermal Infrared Sensor: FLIR SC6000

Thermal Infrared images are planned to be collected using a FLIR system SC6000 sensor (8 – 9.2 μm) mounted to a Bell Jet Ranger Helicopter. The sensor is contained in a composite fiber enclosure attached to the underside of the aircraft which is flown longitudinally along the stream channel (Figure 1). The FLIR SC6000 sensor uses a focal plane array of detectors to sample incoming radiation based on the technology of Quantum Well Infrared Photodetector (QWIP). The sensor's array records the change of state of electrons in a crystal structure reacting to incident photons. This technology is faster and more sensitive than polymer thermal detectors. A cooling mechanism is required for this sensor to stabilize its internal temperature and minimizes thermal drift during the acquisition. To resolve the challenge in achieving uniformity across the detector array and, a factory scheme is generated to reduces non-uniformity across the image frame; nevertheless, differences in temperature (typically <0.5° C) might be observed near the edge of the image frame. Flight planning ensures sufficient image overlap so that frame edges can be excluded from the river channel in the TIR image mosaics. The resulting thermal infrared image frames were recorded directly from the sensor to an on-board computer as raw counts which were then converted to radiant temperatures. Sensor and acquisition specifications for the Kenai Rivers TIR study are listed in Table 3.

To accurately solve for sensor's position and attitude, the positional coordinates of the airplane (geographic coordinates: latitude, longitude, and altitude) and the orientation (pitch, yaw, roll) are recorded continuously throughout the data collection missions. The geographical coordinates of the aircraft are measured twice per second (2 Hz) by an onboard differential GPS unit, while the orientation values are measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU). To allow for postprocessing procedure, the geographical coordinates and orientation are indexed by GPS time. TIR images are planned to be acquired at a rate of 1 image per second (1Hz) and flight speed not to exceed 50 knots and altitude of 300 – 400 meter above ground level (AGL). The time at which the images are taken is also indexed by GPS time (event time) and are matched to the coordinates and orientation of the aircraft. Flight parameters were selected to optimize contracted resolution while

providing an image ground footprint wide enough to capture the active channel with the stream occupying 30 – 60% of the image.

Table 3: Summary of TIR sensor and acquisition 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°
Sensor Focal Length	25 mm
Acquisition Dates:	July 5th, 2020
Planned Flying Height Above Ground Level (AGL):	400-500 meters
Image Footprint Width:	300 – 500 meters
Pixel Resolution:	0.5 meter

Figure 1: Sensor and aircraft setup (similar to the setup used for the project)

True-color (RGB) imagery was collected, concurrently, with the TIR imagery using a Sony Alpha ILCE – 7RM3 camera. Each image was stored in JPEG format along with EXIF data detailing camera settings and image timestamps (s). Camera specification can be found in Table 4, rough camera exterior orientation values were also provided as a deliverable based off image EXIF and air borne GPS data collected during the flight.

Table 4: Summary of Sony camera acquisition specifications

Sony Alpha ILCE – 7RM3	
Focal length:	40 mm
CCD pixel size	4.526 µm
Pixel array:	7,952 x 5,304
Spectral bands	Red, Green, Blue
Ground sampling distance (GSD):	< 10 cm

Ground Control

In Stream Temperature Sensors

Stream temperature data loggers were deployed along Kenai Rivers by the Cook Inletkeeper team (Figure 2). The team deployed a total of five data loggers: one logger for each of Beaver Cr, Moose R., and Funny R. and two loggers for Crooked Cr. The loggers collect temperature data during the survey period at 15-minute intervals. These records will be used for the radiometric calibration of the TIR images. The approach is to use the water temperature data in the calibration process and generate seamless mosaics for each of the contracted reaches.

Atmospheric Parameters

The atmospheric parameters required for the radiometric calibration are extracted from publicly available weather stations. Time series of air temperature and relative humidity are downloaded from nearby stations listed in Table 5 and shown in Figure 2.

Table 5: List of weather stations the data of which the atmospheric parameters were used for the radiometric calibration of thermal infrared imagery

Weather Station	Latitude	Longitude
Wild Angels Ranch- KAKSTERL10	60.55 °N	150.82 °W
Moose Range- KAKSTERL5	60.54 °N	150.93 °W
Poitry's House- KAKKASIL13	60.31 °N	151.31 °W
TEG Cardwell Rd., Soldotna- KAKSOLDO44	60.39 °N	151.16 °W
Hutto Weather Station- KAKKENAI32	60.56 °N	151.22 °W

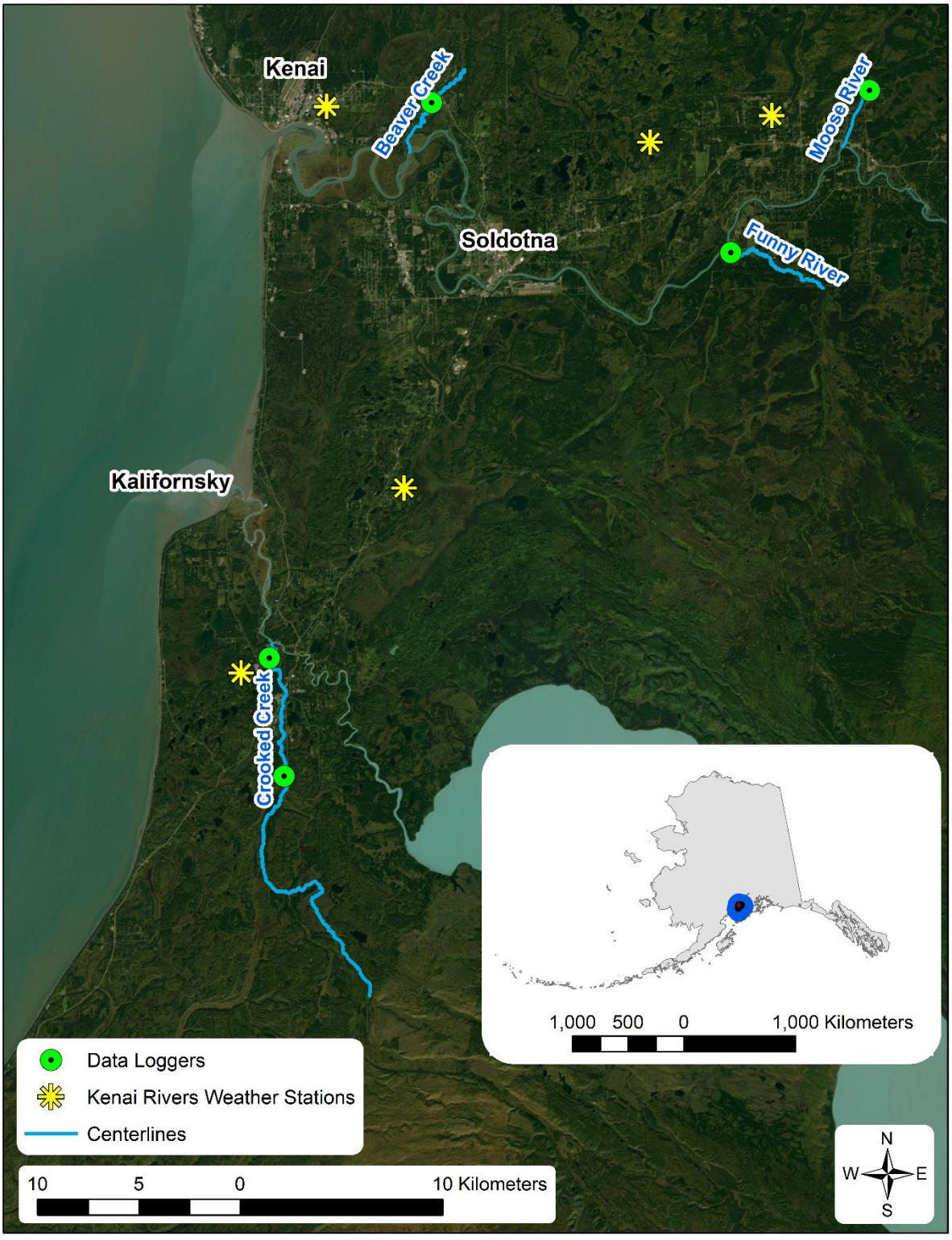

Figure 2: Extent of survey area, location of data loggers, and weather stations utilized in thermal calibration.

Airborne Survey Execution

A successful TIR imagery acquisition occurred during the afternoon on July 5th, 2020. The acquisition team was based in Anchorage, AK and flew out of Merrill Field Airport (PAMR) onboard of a Bell Jet Ranger Helicopter tail number 206L3. All four rivers were acquired in a two lifts between 12:43 and 16:10 PM on July 5th, 2020. While the crew managed to acquire Crooked Creek, Moose river, and Funny River in one attempt each, Beaver Creek required 3 attempts to be fully acquired. The first attempt to acquire Beaver Creek was aborted due to strong winds and overcast conditions at the upper half of the stream. The extent of this attempt covered the lower half of the river and didn't reach the site where the water temperature data logger was deployed. The second attempt was after acquiring Crooked Creek. This attempt was successful and achieved a complete coverage of the stream. The third and final attempt to acquire the TIR data for Beaver Cr. was after acquiring Moose River and Funny River.

The aircraft was flown longitudinally along the stream corridor to capture the river in the center of the image frame. In a few sections of the river it was necessary to make multiple passes to cover the channel due to channel width and/or sinuosity. TIR imagery was acquired within the planned ranges of flight speed, altitude, and image acquisition rate achieving a >60% forward overlap between images. Individual images were referenced with time, position, and heading information provided by a global positioning system (GPS) (Figure 3).

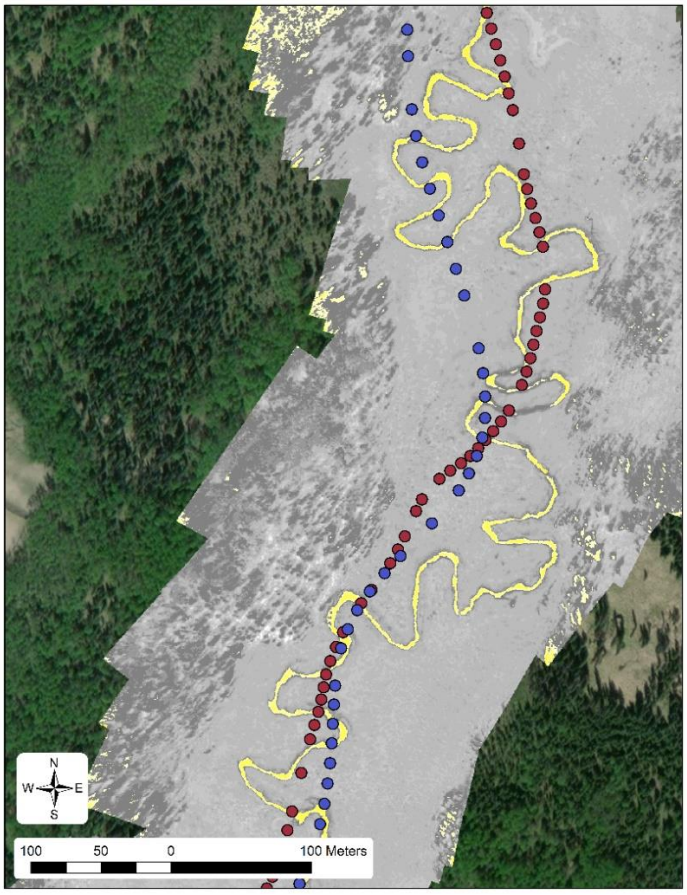

Figure 3: Each point on the map represents a thermal image event location.

Thermal Infrared Data Processing

Geo-Rectification

Initially, a series of corrections is applied to the aircraft trajectory and orientation using Applanix PPRTX data. Image timestamps were linked to the corrected trajectory to define the position and orientation of the sensor during each image event. Image location data and TIR images are input into Agisoft's Photoscan software and a mosaic is created using automatically generated tie-points and ground control data from reference base maps. No color balancing or seam feathering is used during the mosaic process to preserve the original temperature values of the TIR imagery.

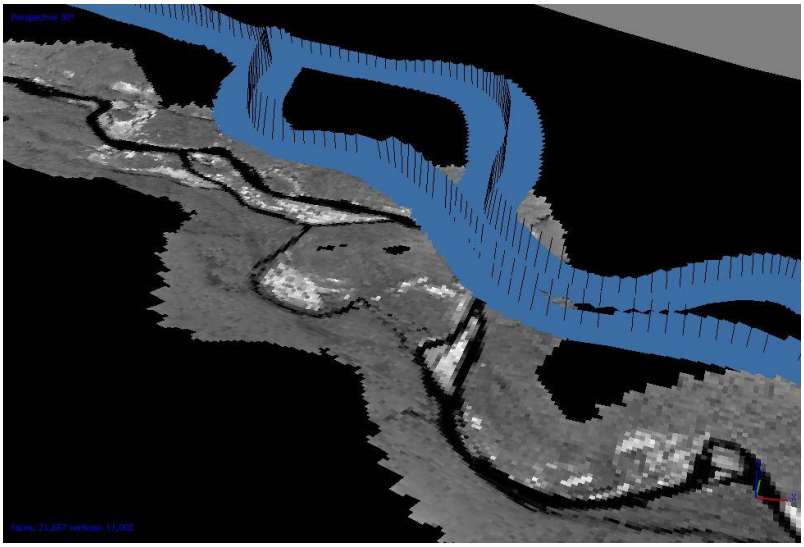

Figure 4: This figure shows an example of the TIR imagery mosaicking process inside Photoscan.

Thermal Infrared Imagery Calibration

Response characteristics of the TIR sensor are measured in a laboratory environment. 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. Thermal infrared radiation received at the sensor is the sum of emitted radiation from the water's surface (e), reflected radiation (r), and transmitted radiation.

$$emissivity + reflectivity + transmisivity = 1$$

This adjustment is performed to correct for attenuation path and the emissivity of natural water which is 0.98[1], reflectivity is .02 and transmissivity is 0. The calculated radiant temperatures are adjusted based on the kinetic temperatures recorded at each ground control location (water temperature data logger). The in-stream water temperature data are assessed at the time of image acquisition, with radiant values representing the median of ten points sampled from the image at the data logger location.

Temperature and Colorramps

The temperature values of the river occupy a relatively narrow range of the full 16bit histogram, thus visual representation of the imagery is enhanced by the application of a customized colorramp to the pixel values. Different colorramps also highlight different features that are relevant to the analysis such as spatial variability of stream temperatures and inflows (Figure 5). The colorramps for the TIR mosaics were developed to maximize the contrast of the majority of the surface water features and are unique by date. A NV5 TIR specialist customized unique colorramp for each mosaicked reach of the river to improve visual presentation and exported the colorramp as ESRI *lyr file. Color ramps are an important product that is delivered to the end user.

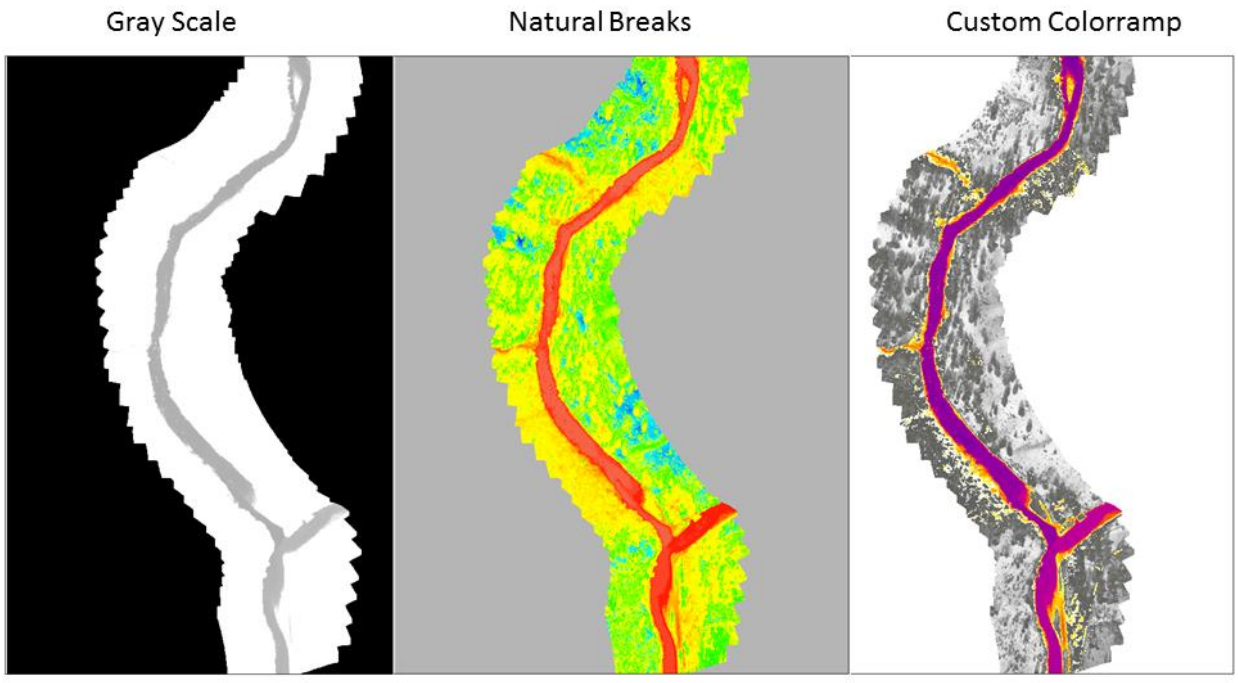

Figure 5: Examples of different colorramps applied to the same TIR image

Accuracy Assessment Methodology

The final TIR mosaic's accuracy is assessed by comparing sampled pixels of the mosaic (where water feature are present) at the data logger's location against the temperature recorded by the respective logger. Accepted temperature accuracy is less than ±0.5° C mean temperature difference between the mosaic and the logger-recorded values at the time of acquiring the TIR imagery. Since there are no

[1] Baldridge, A. M., S.J. Hook, C.I. Grove and G. Rivera, 2009. The ASTER Spectral Library Version 2.0. Remote Sensing of Environment, vol 113, pp. 711-715.

temperature data recorded by loggers for each flight line in order to radiometrically calibrate it (initial calibration), and a line-to-line calibration step is required (between adjacent flight lines), minor deviation from the initial calibration might be needed to achieve the best possible seamless mosaic. The diurnal fluctuation of stream temperature dictates that acquiring the TIR data in the shortest time window possible to stay close to the values achieved by the initial calibration. This plays an important factor both during the phase of designing the flight plan ahead of time when making decisions during the flight. Furthermore, the mosaic's accuracy relies on the recorded temperatures and deployment conditions of the data logger. Deploying the loggers following the guidelines below assists in reaching a valid accuracy:

1) In flowing waters such as river, or stream and not in pools or riffles sections.
2) In water column deeper than 0.5 m and shallower than 2 meters to allow for fully submerged data loggers and avoid stratified water column.
3) Within the channel's thalweg to measure a larger bulk of flowing water in the stream.
4) In water body with sufficiently exposed surface to the sky that can be detected by the sensor mounted to the aircraft.
5) Away from the bank where riparian vegetation may block the view from the aircraft.
6) In water stream reaches free from above-water surface features such as boulder and riparian and aquatic vegetation to allow for uniform water temperatures across the stream or the water body.

Positioning the data logger following above guidelines is essential factor to achieve the best mosaic possible because the TIR sensors only detect the heat signature at the surface of the object. In this case, water is also Opaque to longwave range and the only thermal infrared signal emitted from the water body is at its surface. It scientifically-sound to assume a thoroughly mixed water column in flowing stream and rivers no deeper than 3 meters. Additionally, deploying the sensor in shallow water, exposed to direct sun light has the potential to skew the recorded temperature by representing the temperature of the streambed, or the sensor itself, that has been absorbing heat all day.

Assessing the mosaic's accuracy becomes challenging where the logger is positioned where there is no cluster of pixels with uniform temperatures in the mosaic. Such sites lead to generate "blended pixels" in the TIR mosaic. A blended pixel is one that represents two or more objects with varying temperatures, i.e. water and non-water features. Examples of such sites are narrow channels, obscured water surface by above-water surface boulders and vegetation (riparian or aquatic), and the mixing zone of entering tributaries or point-source inflow.

The logger's position in most cases is being recorded using handheld GPS units with impeded few meters error. This error introduces another source of inaccuracy unless the logger's position is corrected based on the TIR imagery which is generated using survey grade positioning system. Adjusting the position relies on information from the field crew, or the client if the latter is providing the data, in order to position the logger in the stream (Figure 6).

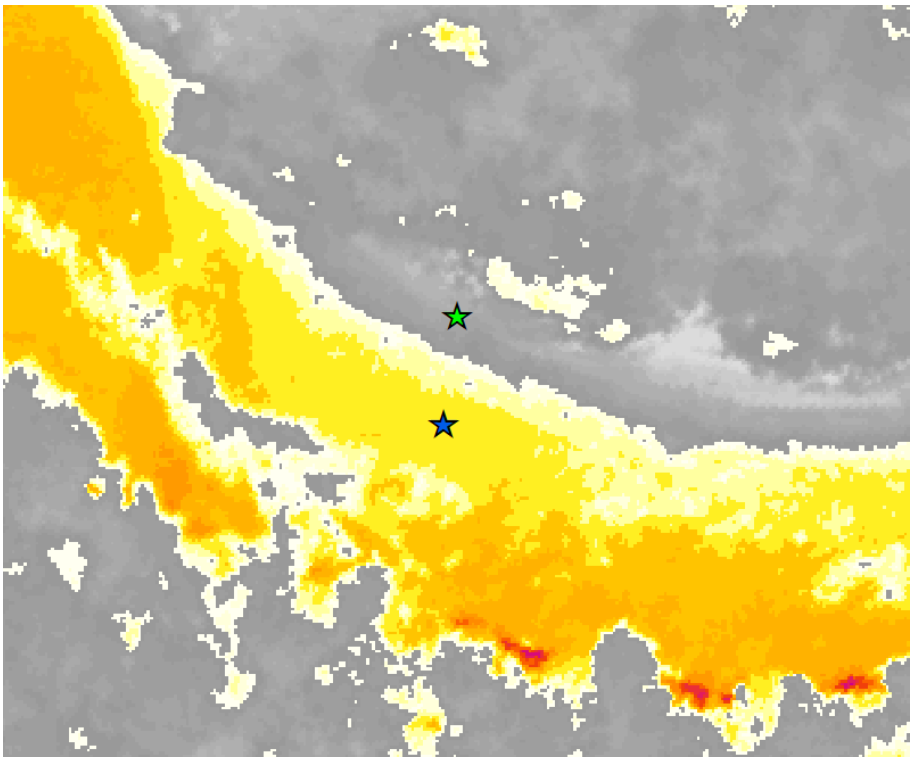

Figure 6: This image shows the position of the data logger based on handheld GPS unit (green) and it new position based on the TIR mosaic (blue).

Interpretation and Sampling

To begin interpretation of thermal infrared data, a trained analyst reviewed the final mosaics to obtain a detailed understanding of the temperature distribution across the survey area. An emphasis was put on identifying the thermal signature of water bodies and streams. This was also the first step in identifying the thermal signature and location of potential inflow sources of cold/hot water.

A stream centerline was digitized using the TIR mosaics including stream names (*at a scale of 1:5,000*). This step was performed for the entire length of the contracted rivers. As the streams were digitized, care was taken to avoid as many non-water features as possible; however, due to the nature of the streams, aquatic vegetation, boulders, bridges, and other obstructions this could not always be avoided. River lengths were measured cumulatively from the most downstream point in the AOI towards the most upstream point. Therefore, the calculated length represents only the streams within the surveyed AOI and is not relative to the overall river network outside the AOI.

Thermal Infrared Mosaic Sampling and Interpretation

Two analysis techniques were used to interpret the TIR data: an interval-based automated sampling of the stream, longitudinal temperature profile (LTP), and a manual point source sampling, significant feature sites (SFS).

Longitudinal Temperature Profile (LTP)

Longitudinal temperature profile (LTP) is a technique in which the water temperature is sampled (extracted from the TIR data mosaic) along the digitized centerline of stream. The LTP assists in identifying temperature gradient in the stream and changes due to potential influence of water inflows (tributaries, springs, groundwater upwelling, effluents, etc.). Using a proprietary algorithm, water temperature is sampled at a specified interval along the centerline where statistical data are provided for each temperature sample within a buffered distance (Figure 7). The statistical information includes average, mean, maximum, minimum, and standard deviation of the stream's temperature. Due to the nature of the automated sampling, some sample points inevitably fall on bridges or non-water features skewing the temperatures. These points can be identified as outliers by a high standard deviation and can be excluded from the final LTP. The resulting temperatures are plotted against river kilometers to develop the final LTP.

Significant Feature Sampling

Significant feature Sites (SFS) is a technique in which features of significant thermal anomalies in the TIR mosaic are identified and sampled to collect their statistical information. Such features may indicate a potential inflow from tributaries, springs, or an expression of subsurface activity or hyporheic inflow. The features are manually identified across the floodplain and the riparian zone where their thermal signature is higher or lower than the river's mainstem (Figure 8). The SFS is provided in two file formats: a shapefile and an *.xlsx table. The point attributes in either format summarizes pixel values within a specified buffer around each location. Due to the nature of the springs and seeps and the scale at which

the points were digitized, the statistics for smaller features inevitably include non-water pixels and might impact the statistical summaries. On the contrary, larger features will be under sampled. As such, the entirety of the statistical information should be considered in the analysis. The statistical information includes average, mean, maximum, minimum, and standard deviation of the feature's temperature. The findings were incorporated with the LTP plot to provide spatial context for interpreting temperature patterns.

Calculated Statistic Parameters for LTP and SFS

Each sampling point along the centerline holds information summarizing the statistical parameters of the 10 points within the defined buffer (Figure 7). The parameters are:

- Mean and median: define the mean and median temperature values of all 10 sampled points. The mean temperature is the value used in plots and figures. Median values can be used for further analyses and to identify outlier sampling points.
- Minimum and maximum: define the minimum and maximum temperature values among all sampled points.
- Standard deviation: defines the standard deviation across all sampled points. This value is important to identify sample points where non-water features fall within the defined buffer. While low standard deviation values represent homogeneous thermal features, high standard deviation indicate that the sample point was too close to a feature at temperature significantly different than the water body. The value of standard deviation is important in selecting invalid sampling points.

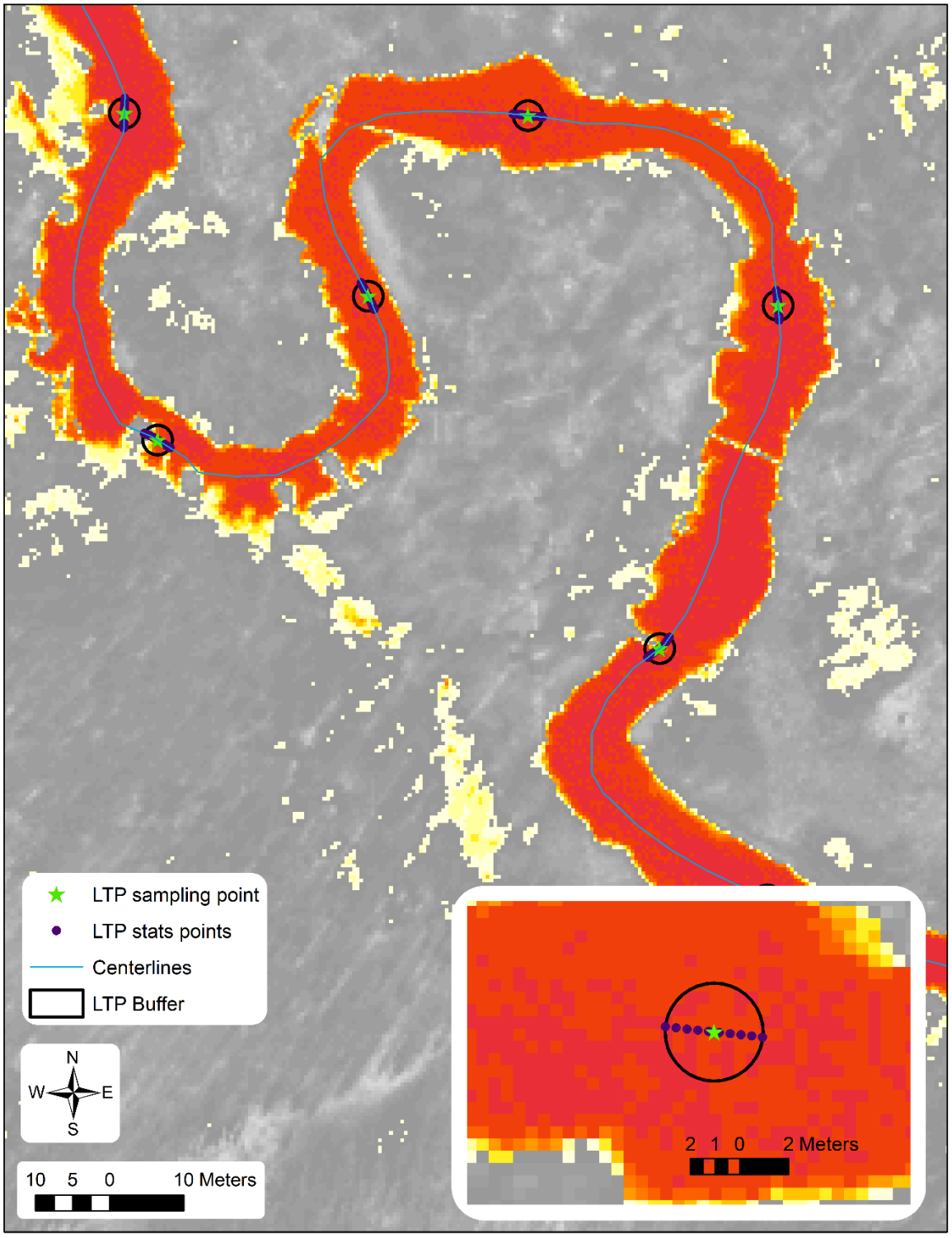

Figure 7: TIR image shows an example of the longitudinal temperatures along the stream's centerline.

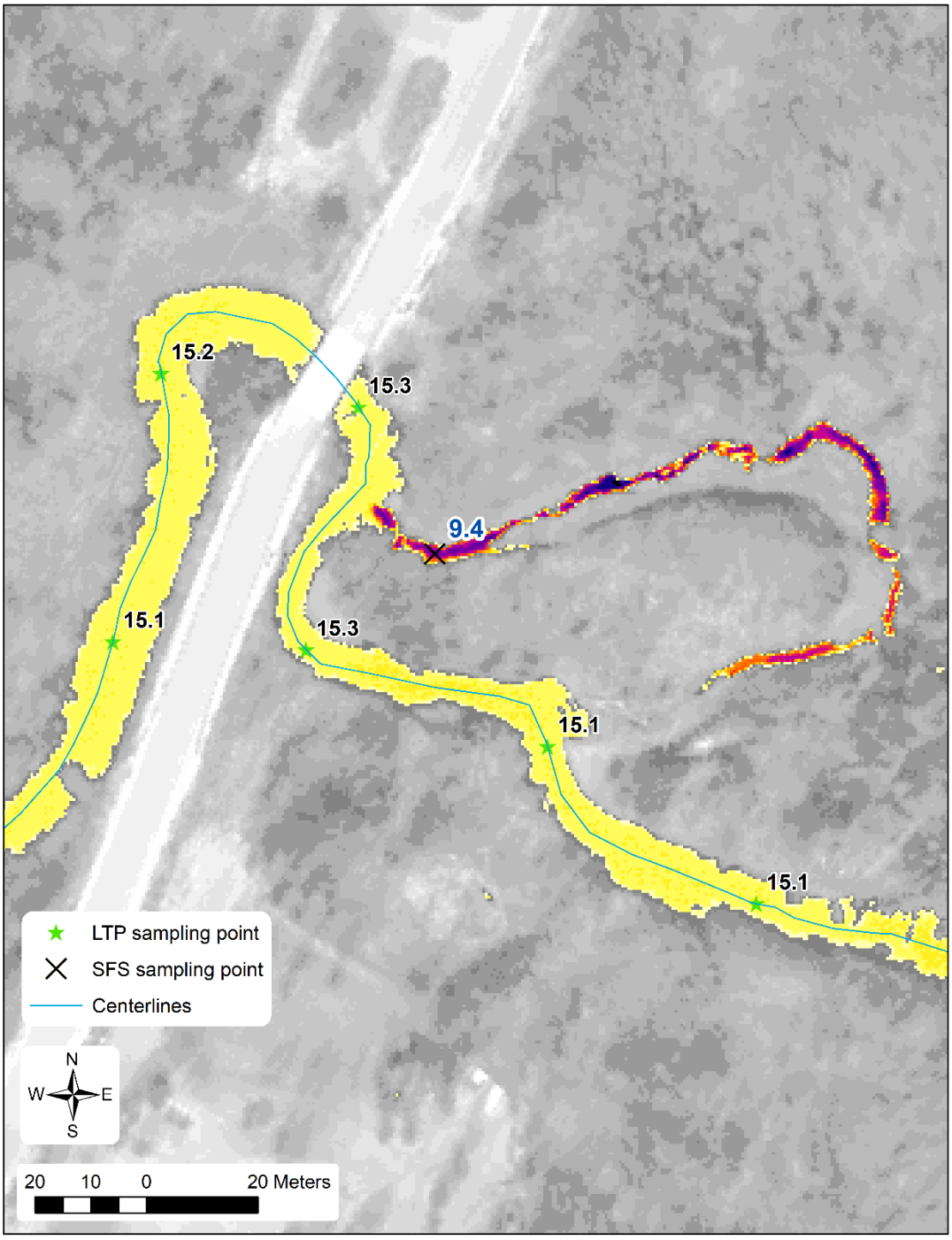

Figure 8: TIR image shows an example of significant feature sampling (SFS) that identifies a potential inflow from hyporheic zone or cold-water spring into the mainstem of Funny River. Note that water temperature in the river is 15.1-15.3 °C while the inflow is 9.4 °C.

Table 6: Summary of the processing and analyses steps used in the thermal analysis

Processing and Analyses Steps	Data File	Description	Software used
Calibrate thermal imagery	*<TIMESTAMP >.tif*	Convert raw TIR image digital number to radiance temperatures based on the sensor's factory calibration. Adjust radiant temperatures based on the ground control kinetic temperatures.	FLIR ResearchIR v. 4.40.6.26
Generate orthorectified imagery	*<TIMESTAMP >.tif*	Incorporate the spatial location and sensor's orientation into creating orthorectified imagery	OrthhoVista Or AgiSoft
colorramp	*<STREAM>_<SECTION>.lyr*	Develop a colorramp that highlights spatial variability of stream temperatures.	ArcMap v. 10.3
Digitize stream centerline along main flow path seen in TIR imagery	*Centerline_ <STREAM>.shp*	Streamlines were digitized and routed based on the final thermal mosaics in order to best represent the centerline/main flow path.	ArcMap v. 10.3
Longitudinal temperature Profile	*LTP_<STREAM>.shp*	Using automated NV5 tools, a GIS point layer was generated from the stream center line layer at 50-meter intervals. Each point was assigned a river kilometer measure and the TIR radiant temperature was sampled based on an average of 2-meter sample buffer radiating out from the center point along the centerline.	ArcMap v. 10.3 NV5 script
Identify and sample significant features	*SFS_<STREAM>.shp*	Manually digitize and sample significant features. The sampling utilizes NV5's customized tools.	ArcMap v. 10.3 NV5 script
Longitudinal profiles plots	*LTP_SFS_<STREAM>.xlsx*	Plot temperature against river km for the longitudinal profile and the manually identified features.	Excel

Thermal Infrared Analysis

The thermal infrared mosaic is analyzed to identify features that are relevant to the project's objectives. The analysis focuses on the stream's longitudinal thermal gradient, features at the edge of the stream's channel, point source and non-point source inflows (tributaries, seepage, effluents, springs, hyporheic) across the floodplain. Identifying such features is based on automated algorithms and visual inspection by a trained professional analyst. The analysis is quantitative and the final TIR mosaic accuracy assessment is provided. Two datasets summarize the analysis: the longitudinal temperature profile (LTP) and the Significant Feature Sites (SFS). The LTP is generated by plotting mean stream temperature at a specified interval against the stream's length. Later, the SFS along the river and in the survey area are incorporated into the LTP plot to provide spatial context for interpreting temperature patterns. Both datasets are provided in a geospatial (shapefile) and a tabular (Excel) formats.

Accuracy Assessment Results

TIR imagery was calibrated using in-stream temperature data loggers deployed by crew members from Cook Inletkeeper. Table 7 summarize the accuracy assessment, a comparison between the water temperatures recorded by the in-stream data logger and the radiant temperatures derived from the TIR mosaic. Data is considered within spec when the differences between TIR radiant and in-stream kinetic temperatures were within the target accuracy of ±0.5 °C. All loggers were within the ±0.5 °C threshold. Further statistical analysis is not possible because the calibration was based on the records of one water temperature logger per except Crooked Creek.

Table 7: Comparison of radiant temperatures derived from the TIR images and selected temperatures from the in-stream sensors (afternoon data July 5th, 2020).

Site ID	Calibration Temperature (°C)	Mean (°C)	Error[2] (°C)
Beaver Creek	15.0	15.1	0.1
Lower Crooked Creek	15.1	14.8	-0.3
Upper Crooked Creek	14.7	15.0	0.3
Funny River	15.1	15.2	0.1
Moose River	18.0	18.0	0.0

[2] Temperature difference is calculated by subtracted the temperature used for calibration from the mean temperature of sampled cells in the mosaic within a buffer of 1 meter from the location of the logger.

Longitudinal Temperature Profiles and Significant Features

A total of 59.2 km of stream centerlines were manually digitized and analyzed for the Kenia Rivers project (Table 8). The results were summarized in the main two datasets of the longitudinal temperature profile (LTP) and the significant feature sites (SFS) both of which are informative tools to detect stream temperature gradient and the potential effects of inflow sources on the mainstem. Mean channel temperatures were plotted against the river length to create the LTP plot for the Kenai Rivers. The final LTP data excludes most of the non-water features that were sampled using the automated algorithm. However, further refinement might be required by the end user based on local information and familiarity with the survey area. The SFS were manually identified representing tributaries, side channels, or point sources/sinks. The locations of the SFS were spatially aligned along the digitized centerline and their mean temperatures were plotted along with the final LTP.

Table 8: Total length of surveyed rivers.

Name	Length (km)
Crooked Creek	37.6
Moose River	3.8
Beaver Creek	8.4
Funny River	9.3
Sum	**59.2**

Crooked Creek, July 5th, 2020

The automated sampling tool successfully captured the longitudinal temperature profile (LTP) between the headwaters of Crooked Creek and its confluence with Kasilof River. The LTP for Crooked Cr. shows that the creek exhibits alternating thermal gradients throughout its course of 37.6 km and an overall warming gradient from 13.3 ^{o}C to 15.4 (Figure 9). A rapid downstream warming between river km (rkm) 37.6 to 32.7 and temperature ranging from 13.3 to 14.8 ^{o}C was followed by a rapid downstream cooling until rkm 29.5 where water temperature dropped back to 13.5. A more gradual warming gradient was shown to occur until rkm 15.4.

The identified significant features samples (SFS) showed several sites of cold water inflow to the mainstem Crooked Cr. which coincide with both the cooling reach at the upstream section and the stable thermal regime at the downstream reach (Figure 10). Such significant features represent either a tributary, hyporheic inflow, or seepage of cold water all of which are colder than the mainstem Crooked Cr. A number of the SFS locations are presented in Figure 11 to Figure 17.

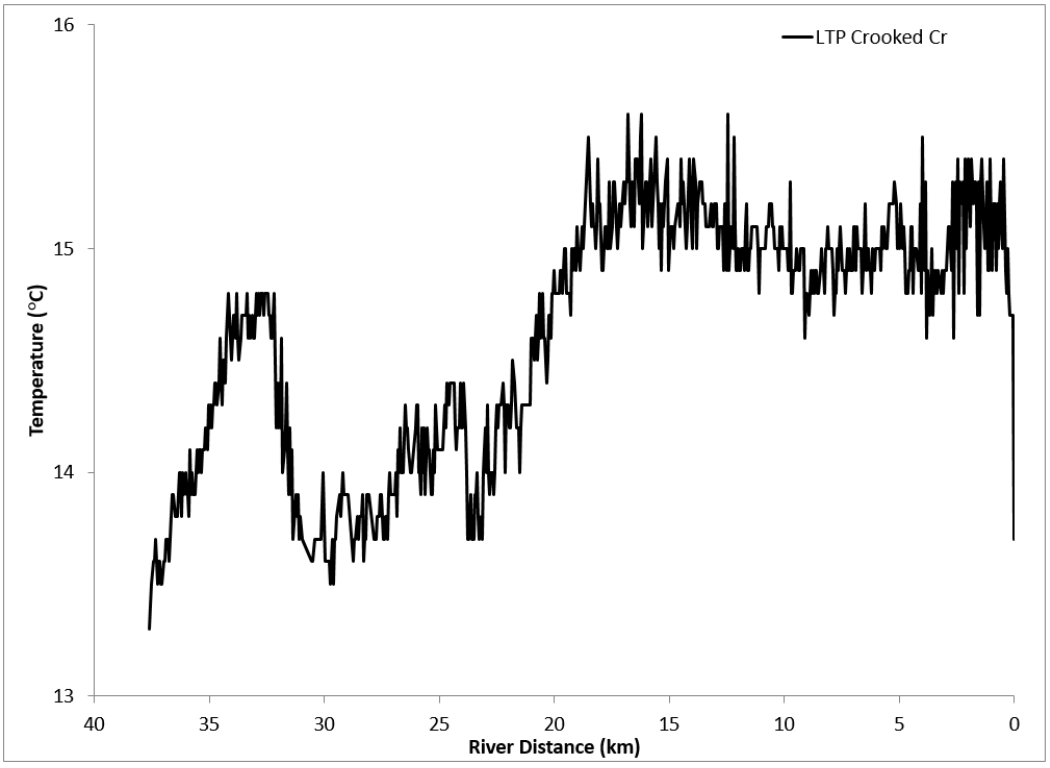

Figure 9: Plot of the longitudinal temperature profile for Crooked Cr. showing the alternating downstream warming and cooling gradients.

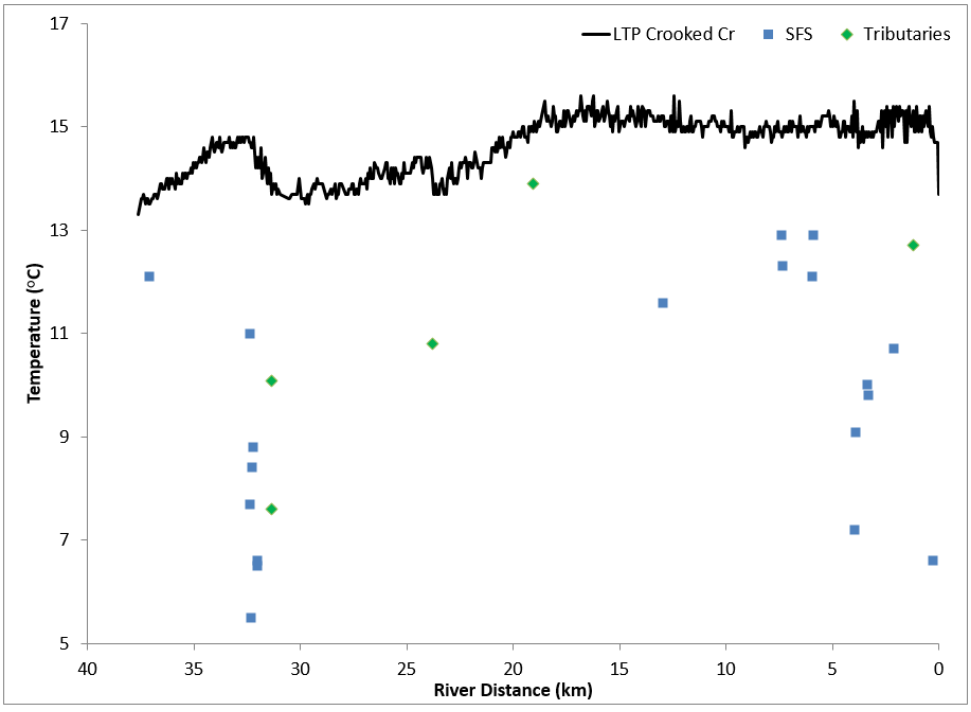

Figure 10: Plot of the longitudinal temperature profile and significant features of inflows from tributaries, hyporheic flow, seepage and/or springs for Crooked Cr.

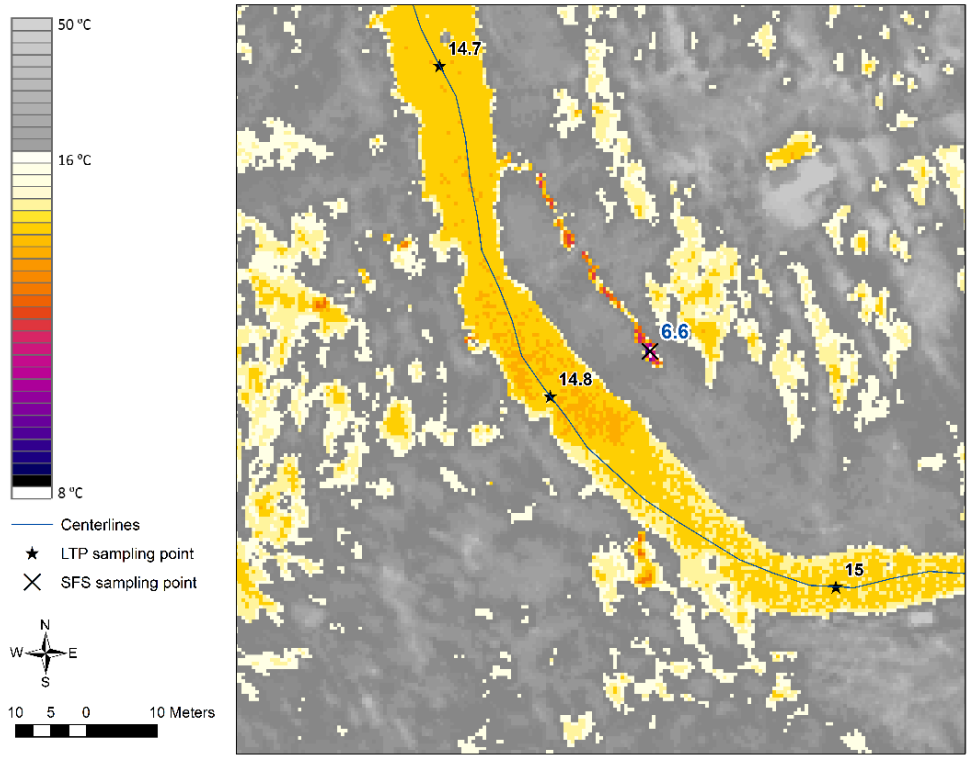

Figure 11: A figure highlighting a potential hyporheic flow adjacent to the main channel Crooked Cr at river km 0.25.

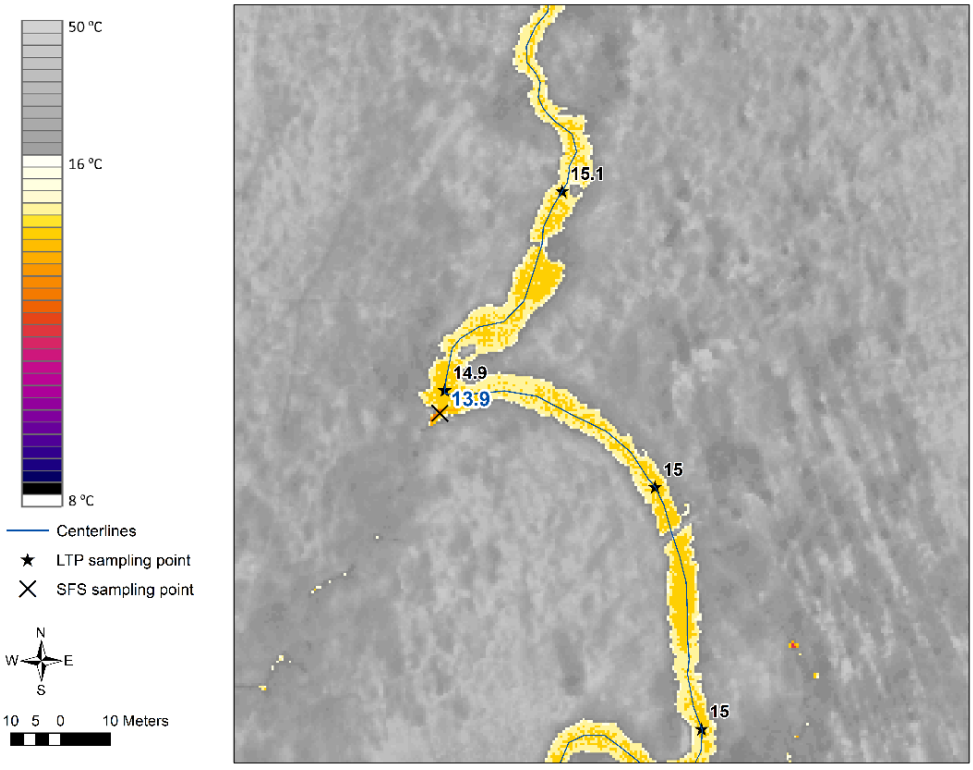

Figure 12: A figure highlighting a potential tributary inflow entering to the main channel Crooked Cr at river km 19.

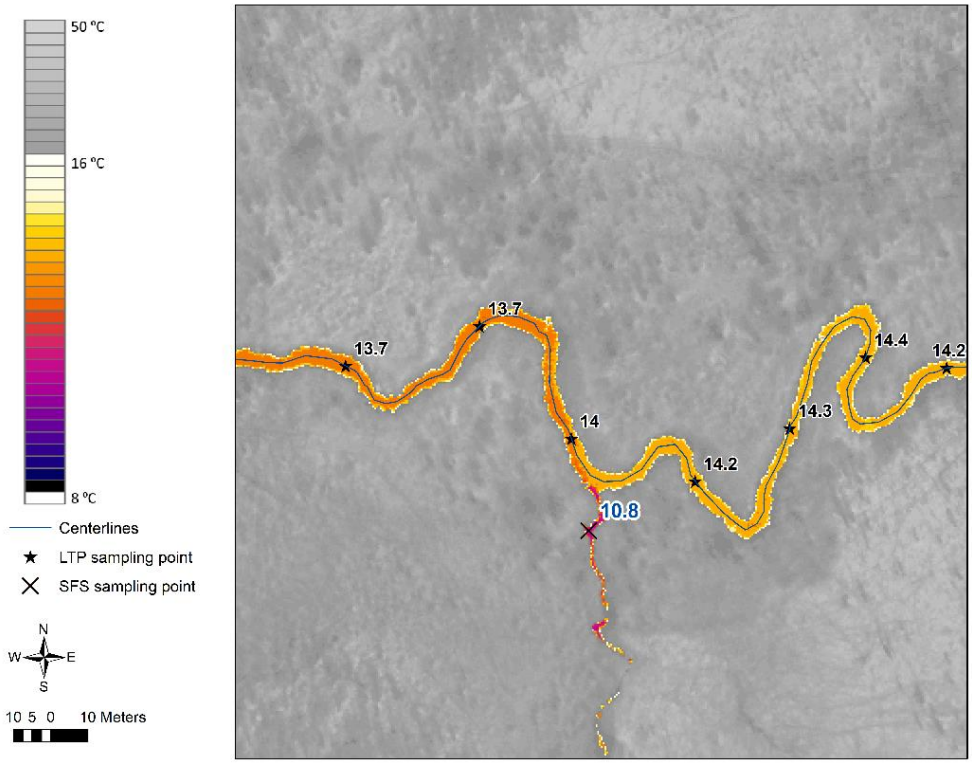

Figure 13: A figure highlighting a potential tributary inflow entering the main channel Crooked Cr at river km 23.

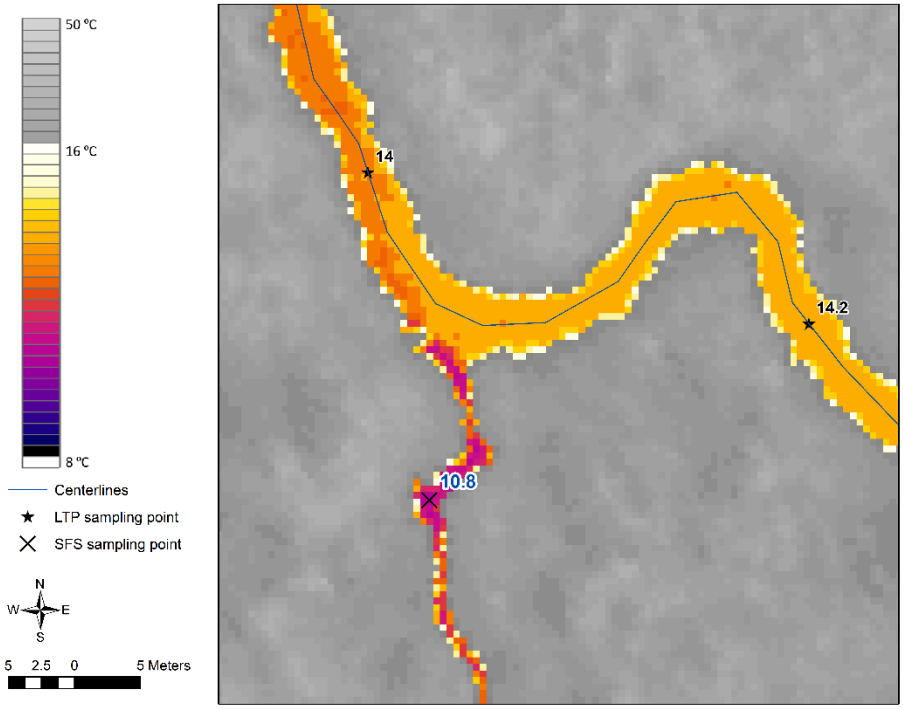

Figure 14: A figure highlighting a potential tributary inflow entering the main channel Crooked Cr at river km 23 (zoomed in).

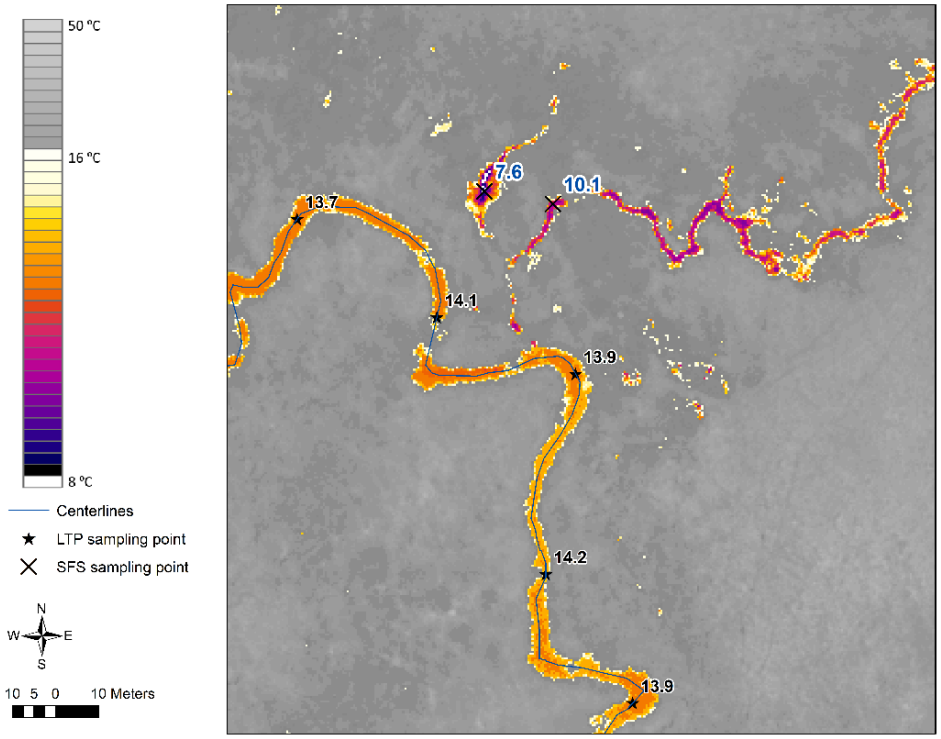

Figure 15: A figure highlighting a potential tributary inflow entering the main channel Crooked Cr at river km 31.

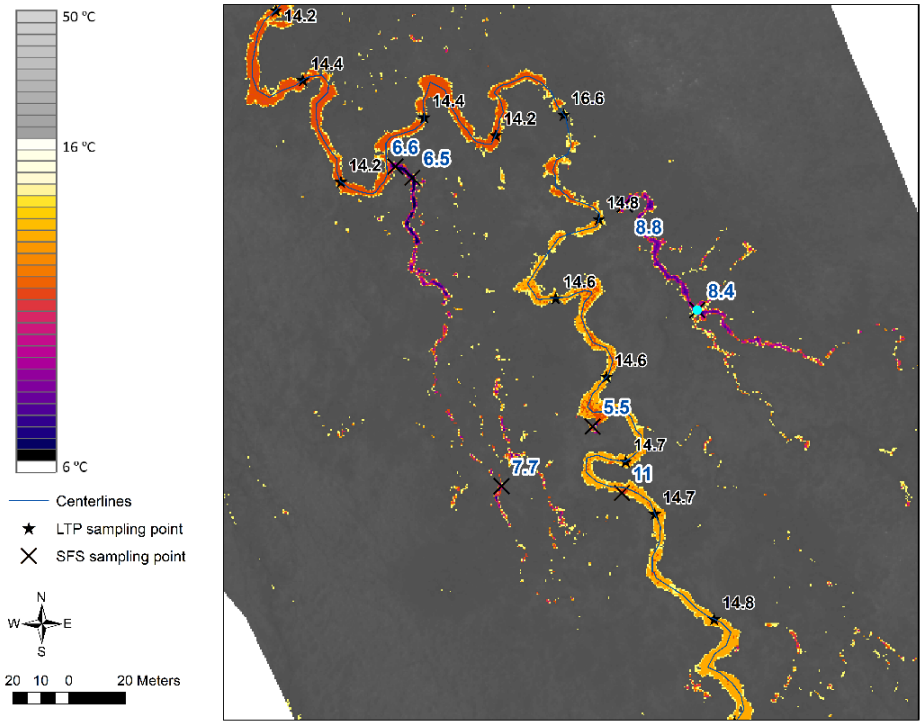

Figure 16: A figure highlighting a potential side channel and hyporheic inflow adjacent to the main channel Crooked Cr at river km 32.

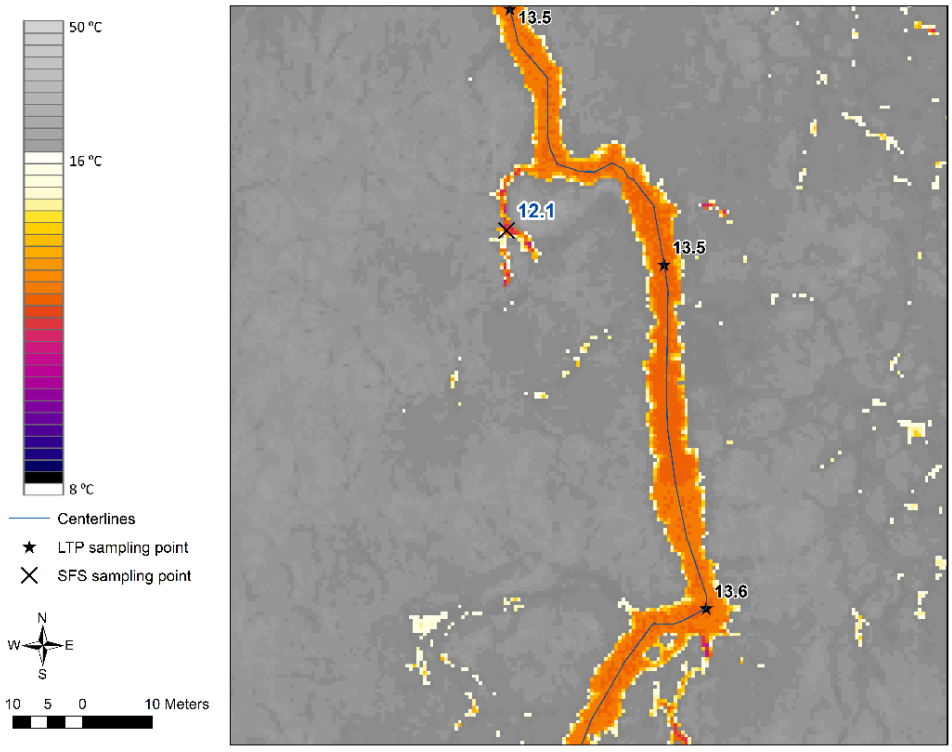

Figure 17: A figure highlighting a potential side channel and hyporheic inflow adjacent to the main channel Crooked Cr at river km 37.

Moose River, July 5th, 2020

The automated sampling tool successfully captured the longitudinal temperature profile (LTP) between the headwaters of Moose River and its confluence with Kenai River. The LTP for Moose R. shows an overall downstream warming gradient from 17.8 °C to 19.9 °C (Figure 18). All identified significant features samples (SFS) were at colder temperature than the mainstem Moose R., though they seem to have a negligible influence on the river's temperature. (Figure 19). Examples of the thermal signature of side channels, springs, and tributaries are presented in Figure 20 through Figure 23.

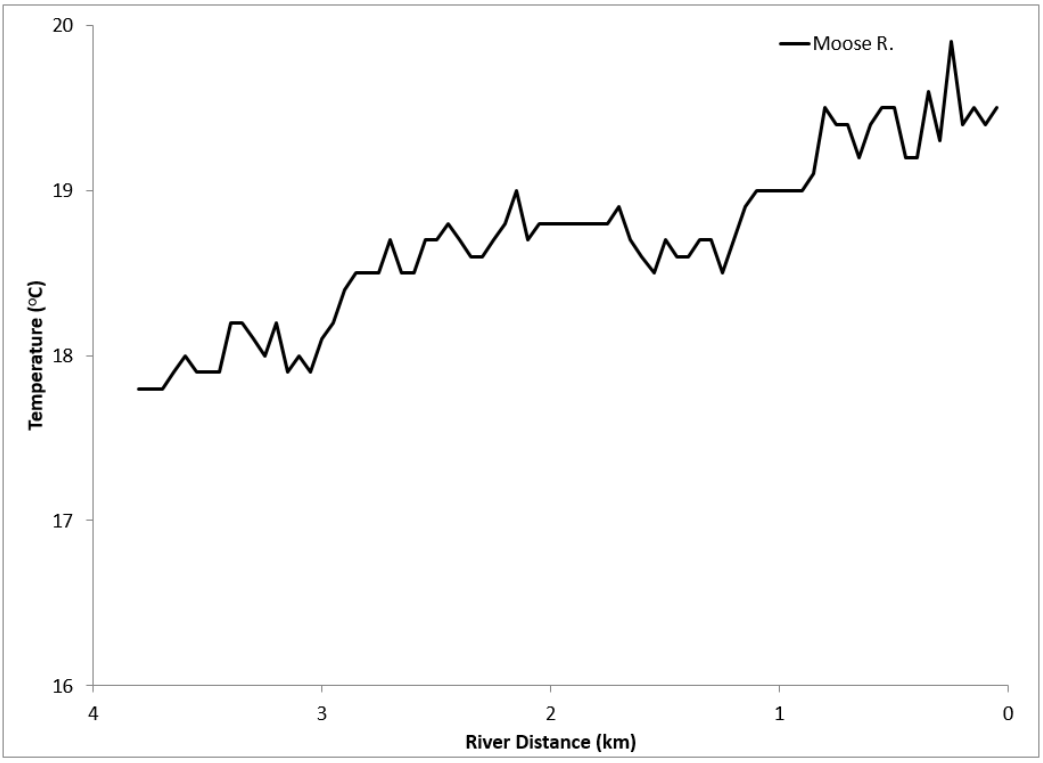

Figure 18: Plot of the longitudinal temperature profile for Moose River showing an overall downstream warming gradient.

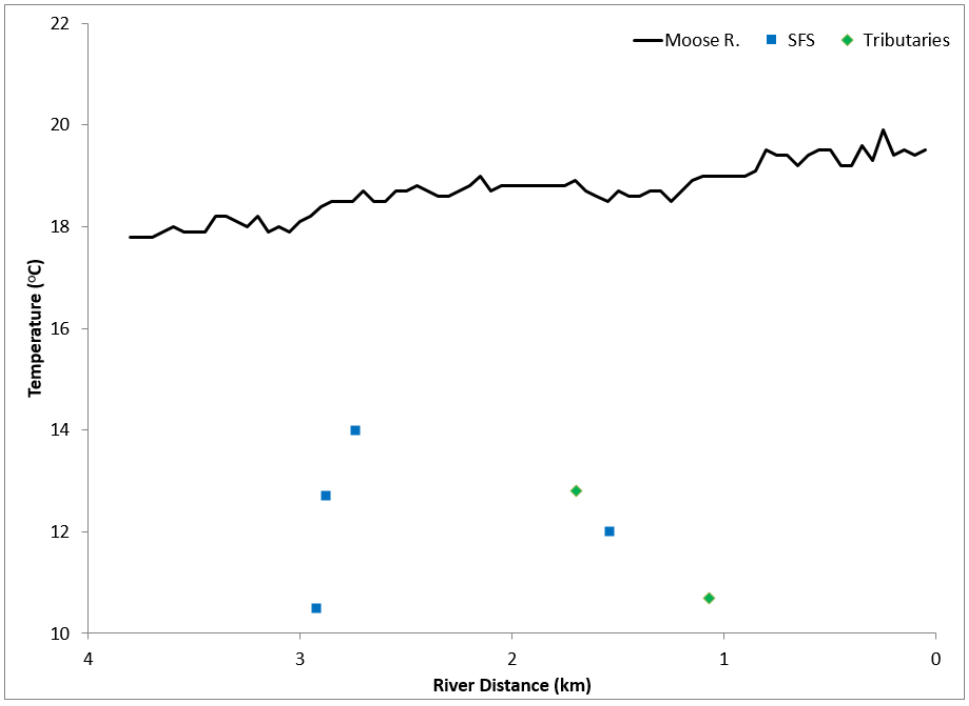

Figure 19: Plot of the longitudinal temperature profile and significant features of inflows from tributaries, hyporheic flow, seepage and/or springs for Moose River.

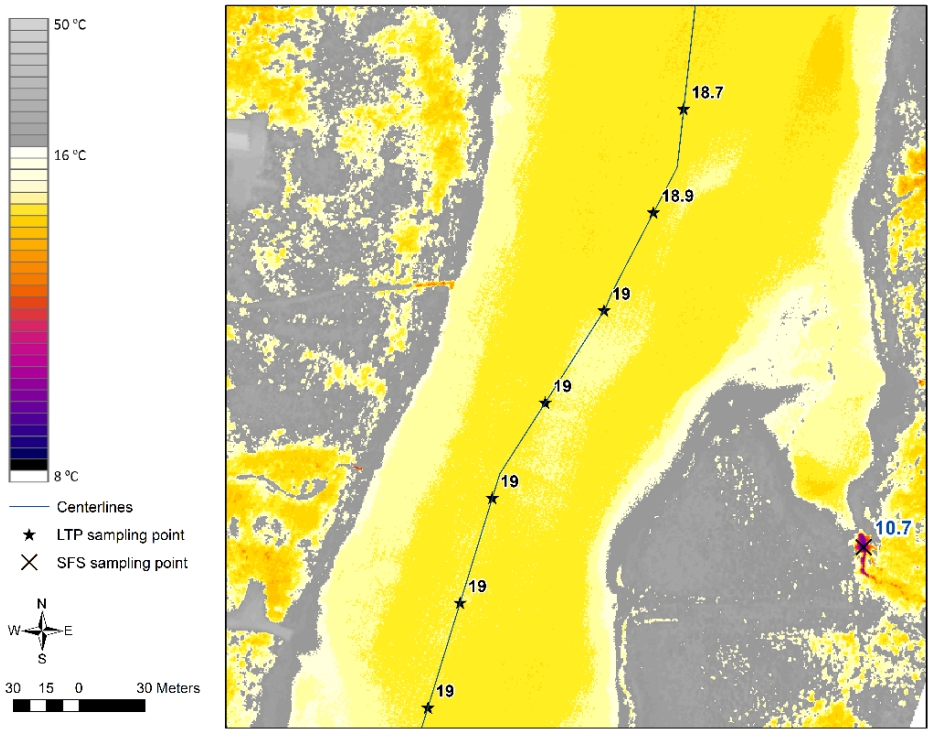

Figure 20: A figure highlighting a tributary entering the main channel Moose River at river km 1.

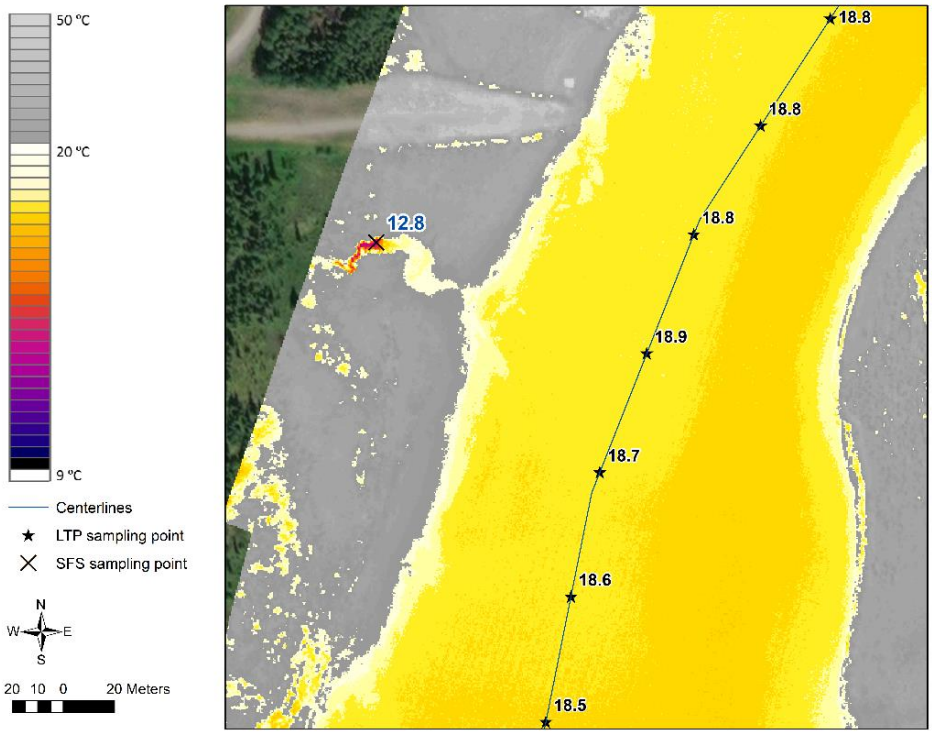

Figure 21: A figure highlighting a tributary entering the main channel Moose River at river km 1.7. Background visible color aerial imagery was publicly available.

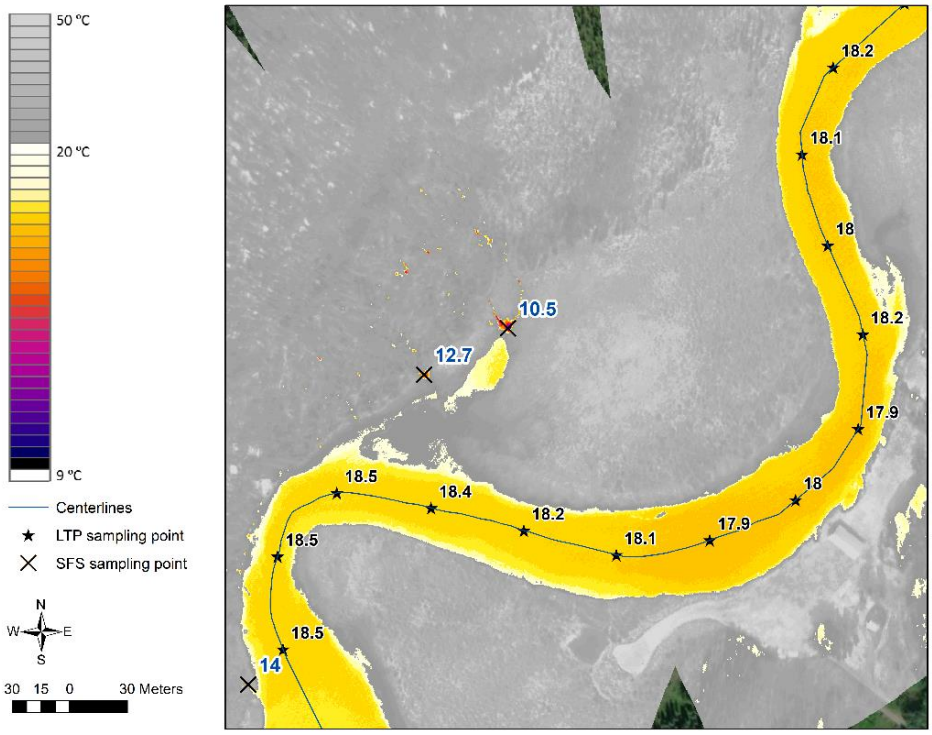

Figure 22: A figure highlighting a potential spring or seepage entering the main channel Moose River at river km 2.9. Background visible color aerial imagery was publicly available.

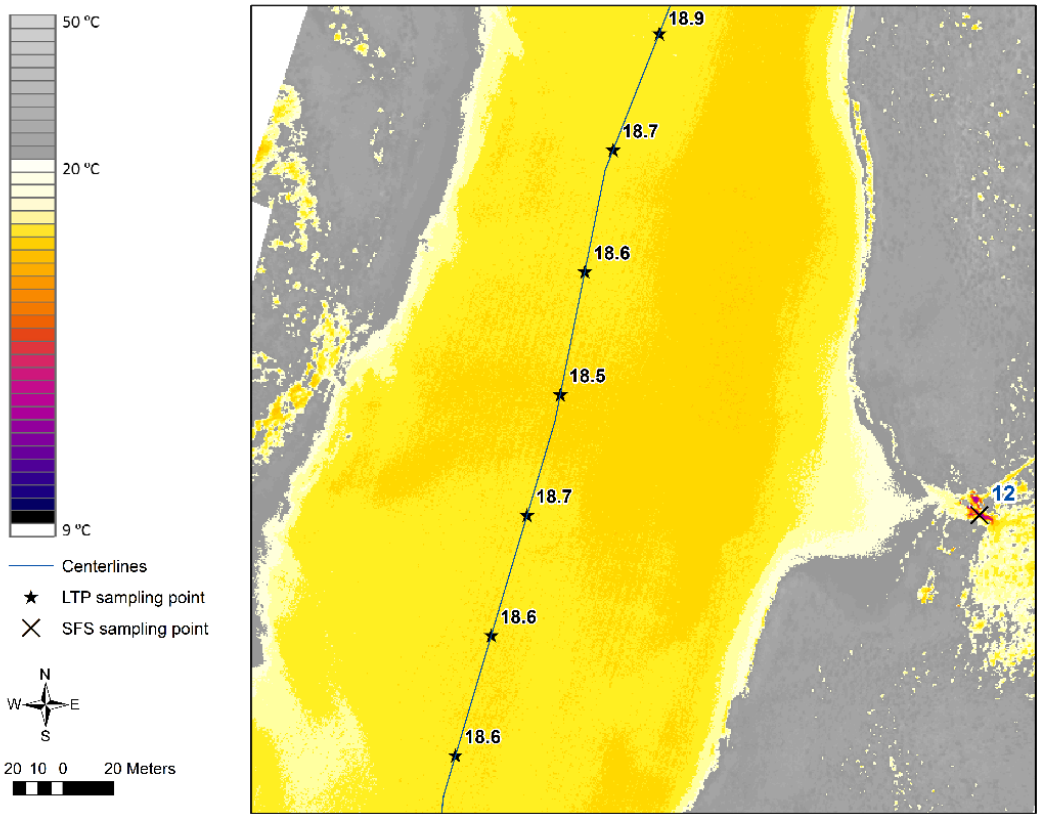

Figure 23: A figure highlighting an effluent entering the main channel Moose River at river km 1.5.

Beaver Creek, July 5th, 2020

The automated sampling tool successfully captured the longitudinal temperature profile (LTP) between the headwaters of Beaver Creek and its confluence with Kenai River. The LTP for Beaver Cr. shows that the upper half exhibits a downstream cooling gradient while its lower half exhibits a warming gradient. However, the change in temperature remained relatively stable, between 14.5 and 16 °C, throughout its 8.4 km length (Figure 24). Most side channels, springs, and tributaries were distributed between river km 2 and 6 which potentially could have been the driver for the mainstem's thermal regime. Water as cold as 9.2 °C entered the mainstem from side channels, hyporheic flows, and tributaries (Figure 25) with the majority were between 12 and 14 °C. Since the temperature of most side channels and hyporheic flows is close to the mainstem's temperature, this indicates to a high connectivity across the floodplain along Beaver Creek. Examples of identified significant features are presented in Figure 26 through Figure 30.

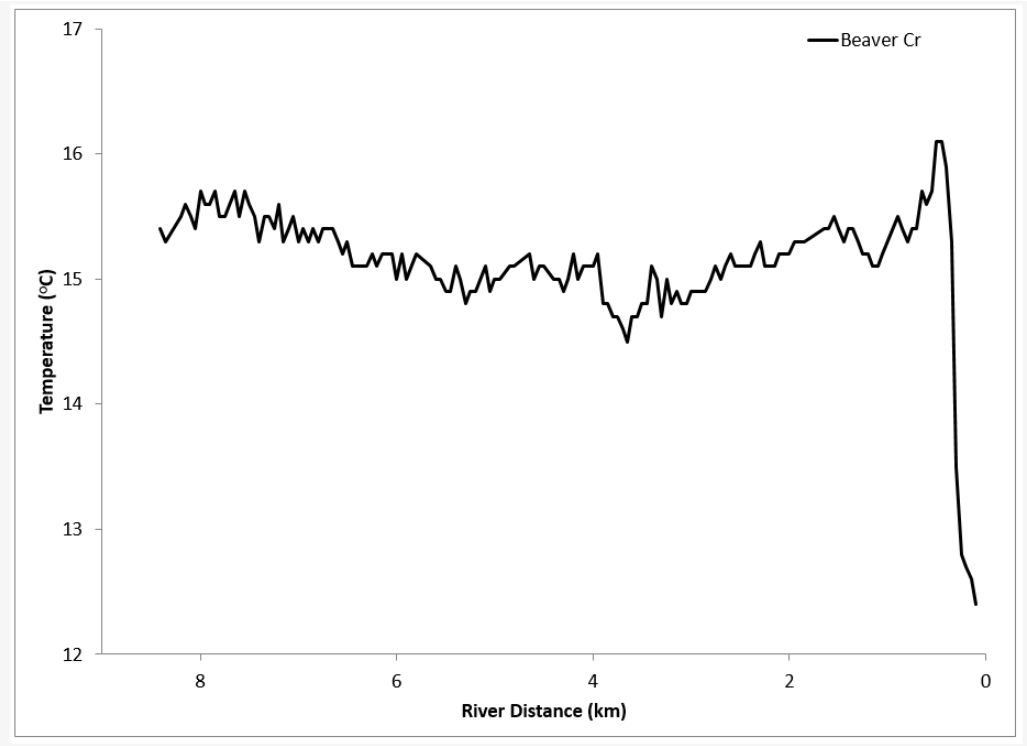

Figure 24: Plot of the longitudinal temperature profile for Beaver Cr. showing the downstream cooling followed by the warming gradient.

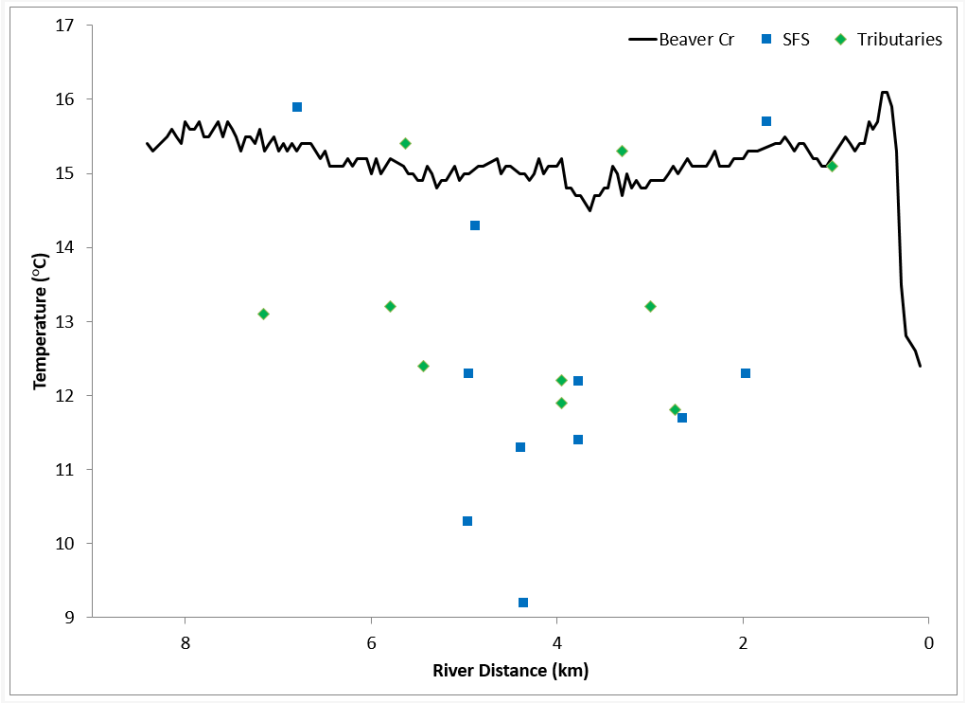

Figure 25: Plot of the longitudinal temperature profile and significant features of inflows from tributaries, hyporheic flow, seepage and/or springs for Beaver Cr.

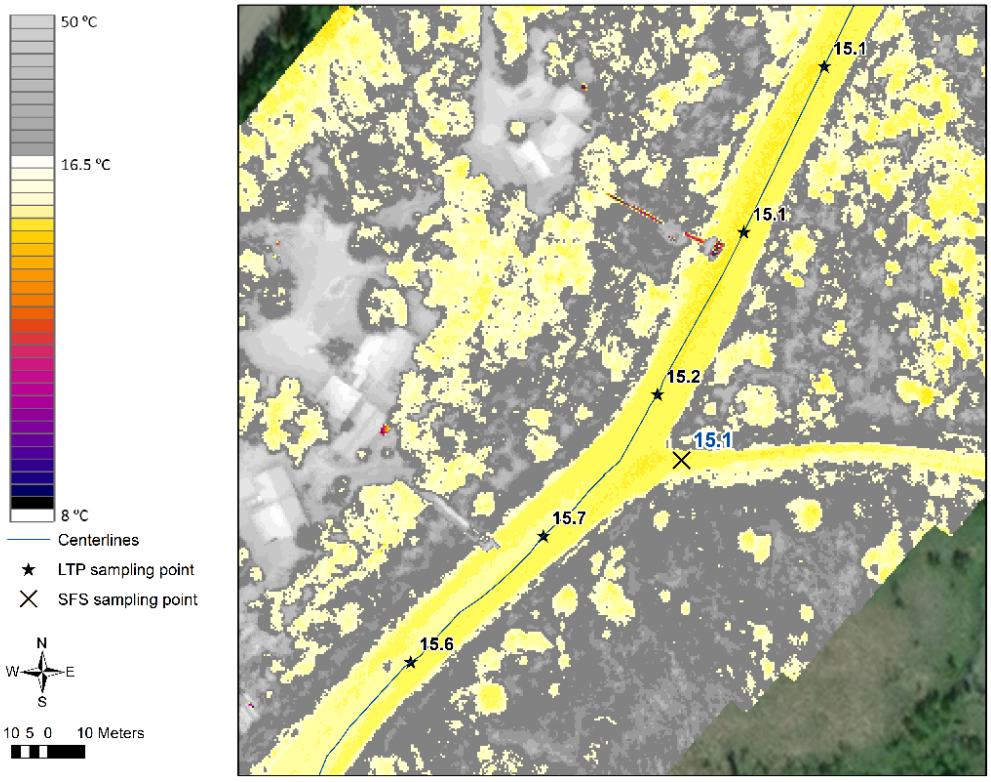

Figure 26: A figure highlighting a tributary entering the main channel Beaver Creek at river km 1. Background visible color aerial imagery was publicly available.

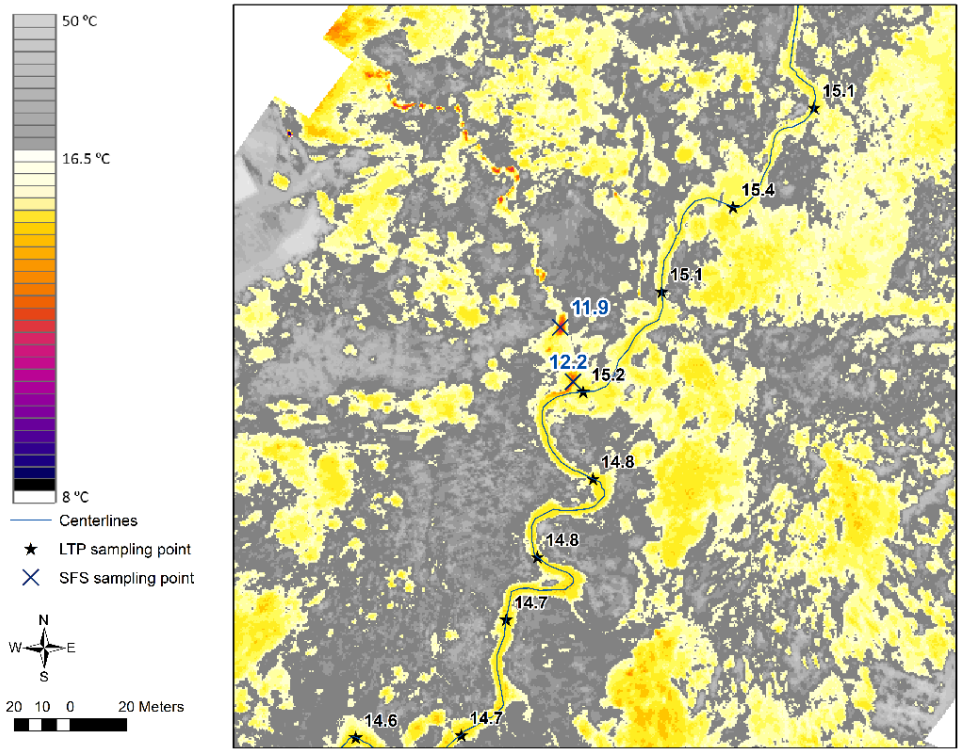

Figure 27: A figure highlighting a tributary entering the main channel Beaver Creek at river km 4.

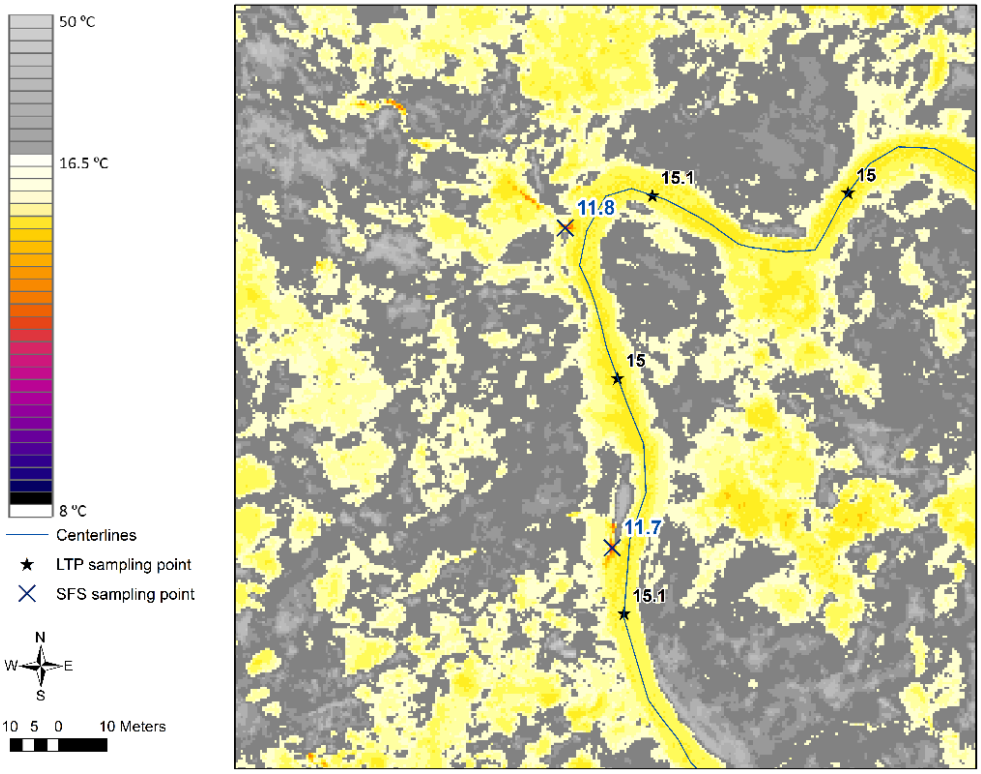

Figure 28: A figure highlighting a side channel or hyporheic flow entering the main channel Beaver Creek at river km 2.7.

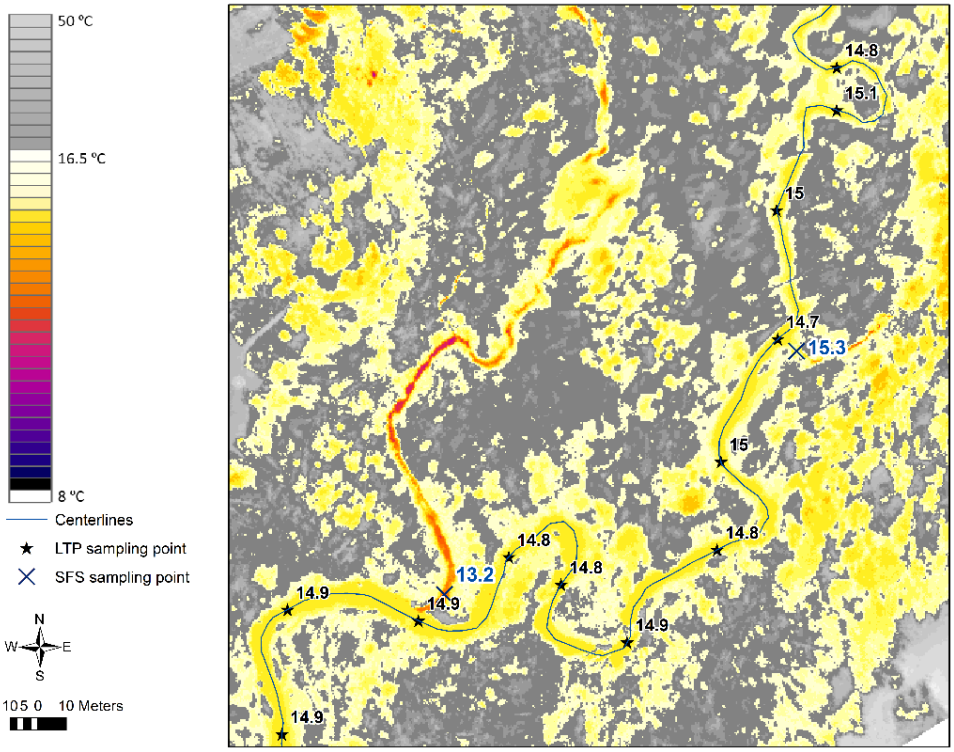

Figure 29: A figure highlighting a side channel or hyporheic flow entering the main channel Beaver Creek at river km 3.

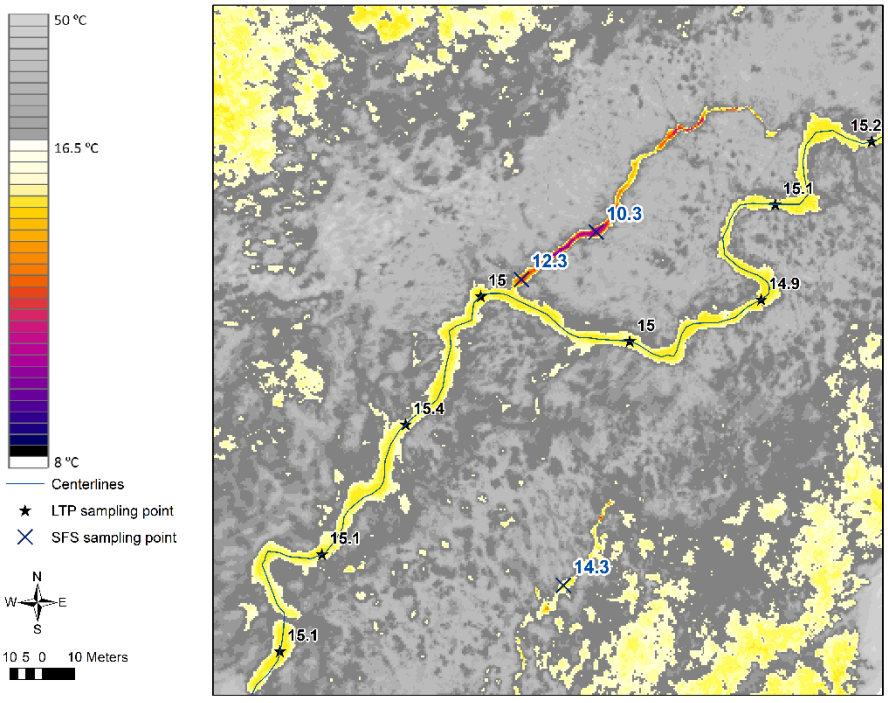

Figure 30: A figure highlighting a side channel or hyporheic flow entering the main channel Beaver Creek at river km 5.

Funny River LTP, July 5th, 2020

The automated sampling tool successfully captured the longitudinal temperature profile (LTP) between the headwaters of Funny River and its confluence with Kenai River. throughout the course of 9.3 kilometers, the stream's temperature ranged between 14.7 and 15.5 °C (Figure 31). Results show a relatively steady thermal profile with a slight downstream warming which was the due to cold side channels and oxbows along the stream floodplain (Figure 32).There was only one visible tributary contributing cold water to the mainstem (Figure 33). Examples of identified significant features are presented in Figure 34through Figure 36.

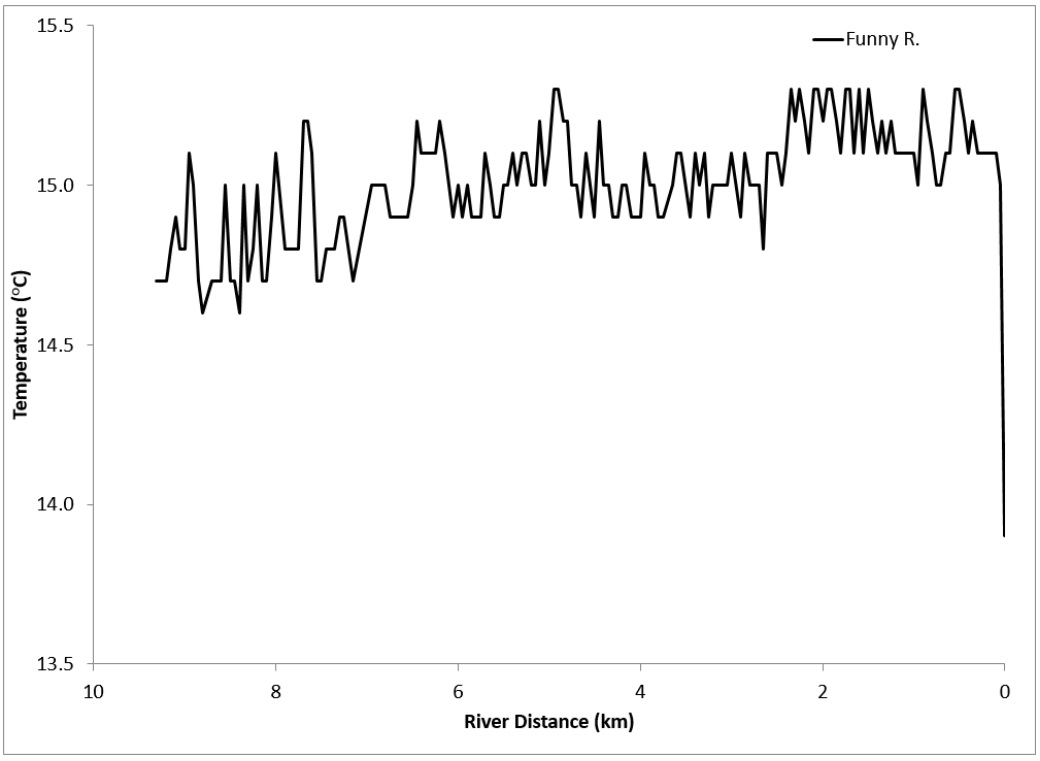

Figure 31: Plot of the longitudinal temperature profile for Funny River. Showing the alternating downstream warming and cooling gradients.

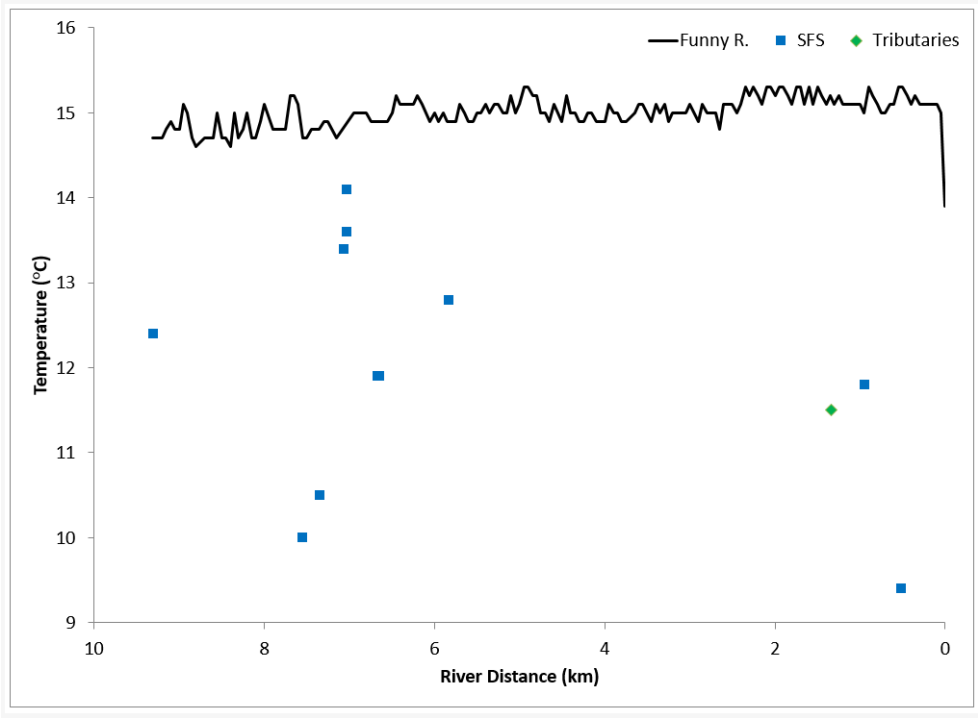

Figure 32: Plot of the longitudinal temperature profile and significant features of inflows from tributaries, hyporheic flow, seepage and/or springs for Funny River.

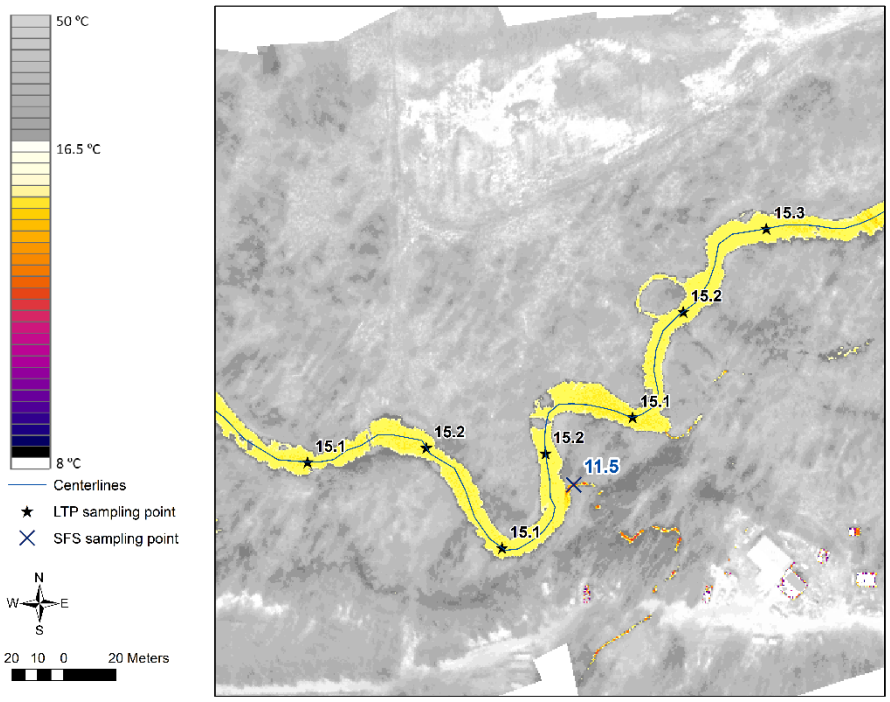

Figure 33: A figure highlighting a tributary entering the main channel Funny River at river km 1.3.

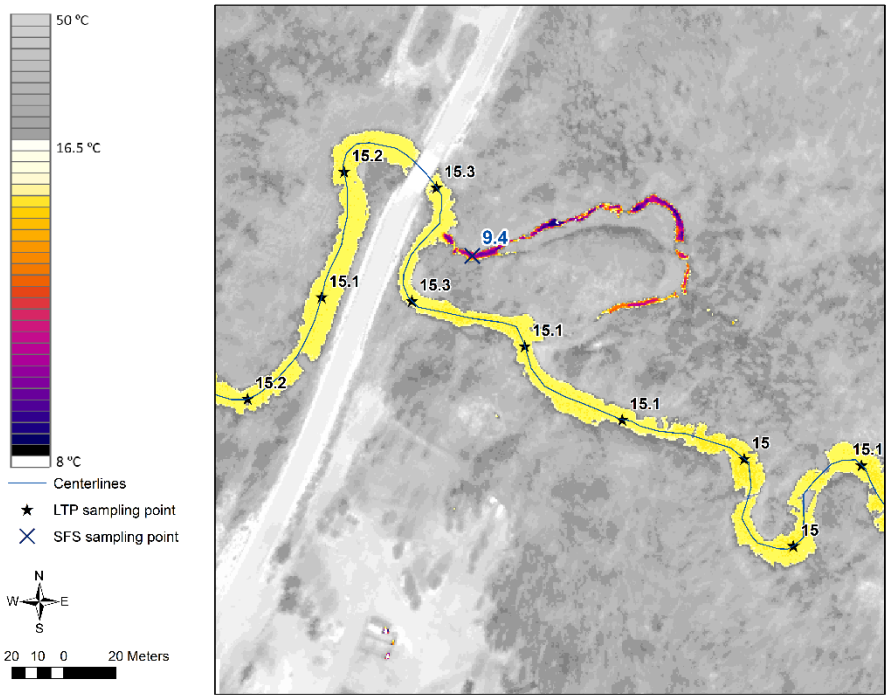

Figure 34: A figure highlighting a side channel entering the main channel Funny River at river km 0.5.

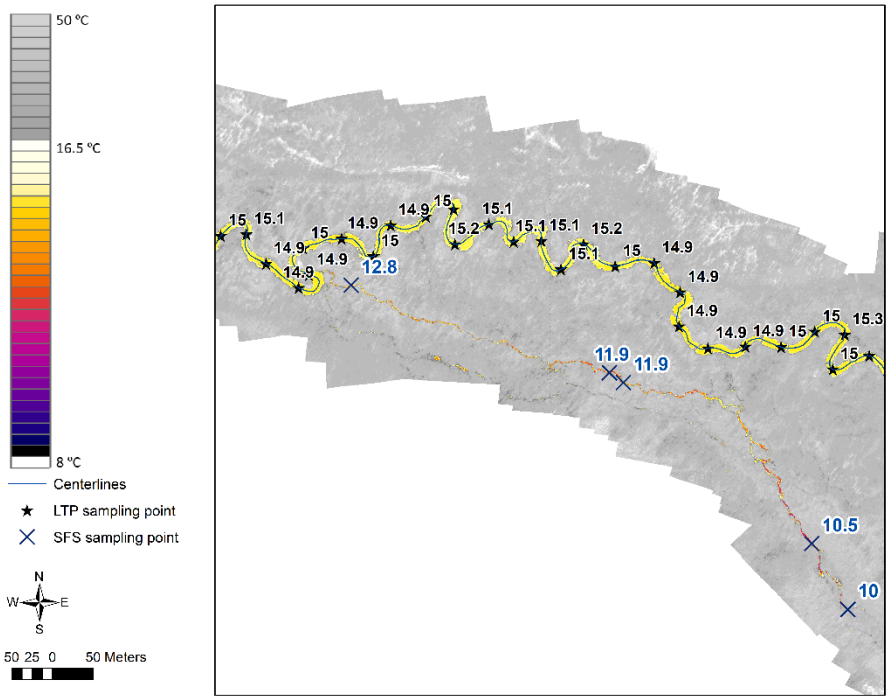

Figure 35: A figure highlighting a tributary flowing alongside and eventually entering the main channel Funny River at river km 5.8 through 7.5.

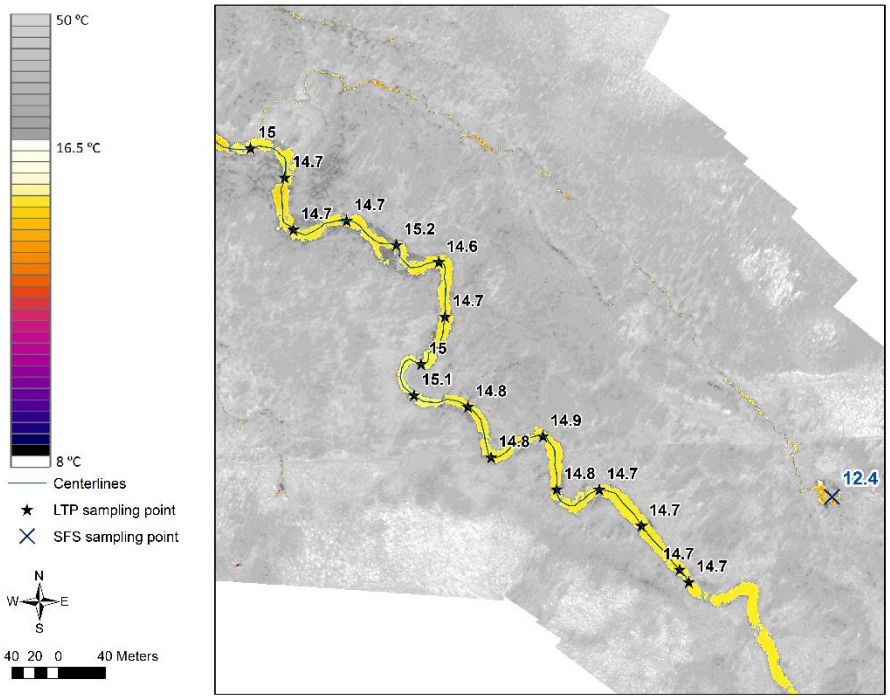

Figure 36: A figure highlighting a spring found at the upper most section (close to river km 9.3) of the survey area and the stream of water flowing alongside and eventually entering the main channel Funny River at river km 8.7.