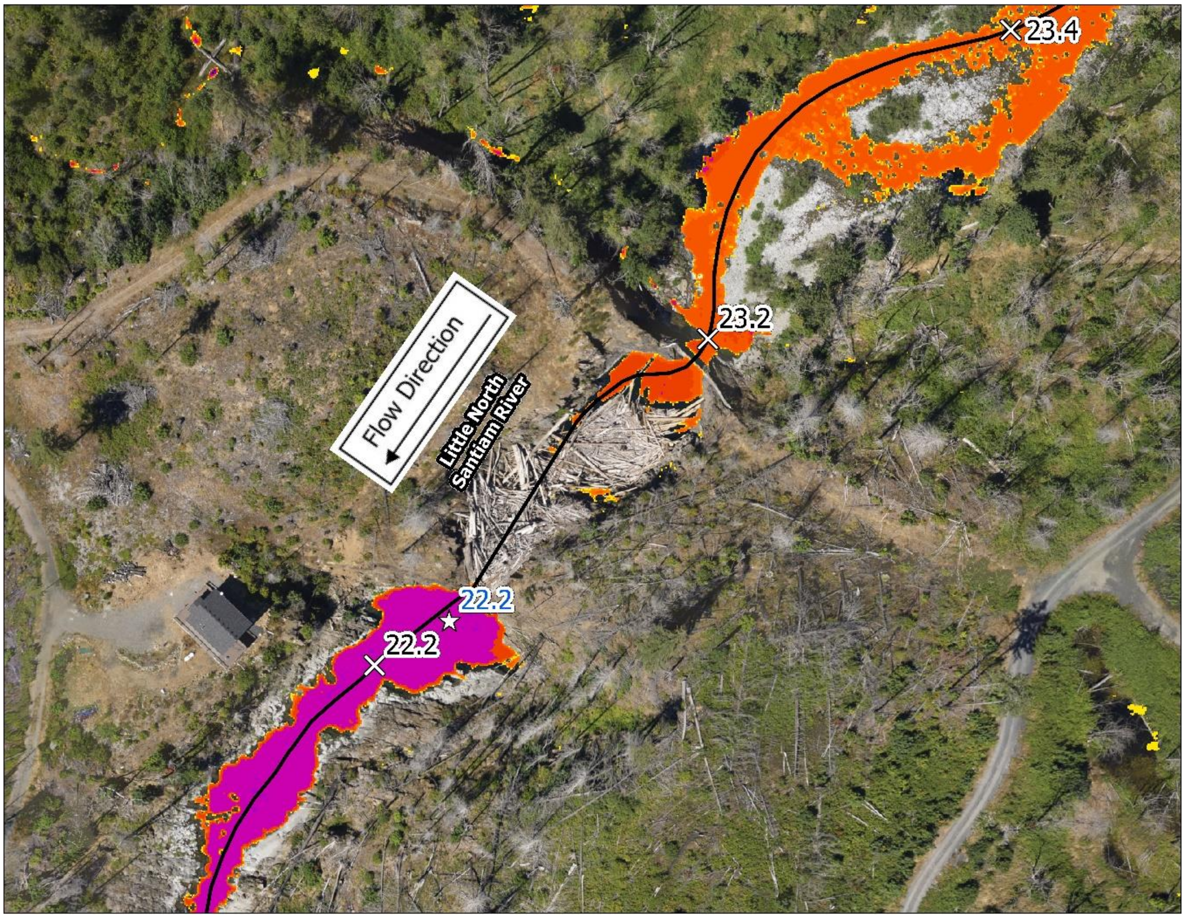
Survey: Jul 27 – Aug 2, Sep 5, 2024
Report: Jan 31, 2025



Santiam Rivers, Oregon

2025 Thermal Infrared and True Color Imagery Technical Data Report

USGS
science for a changing world

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Cover Photo: thermal infrared (TIR) of the water in the river channel and true color (RGB) of the banks and the log jam along the Little North Santiam River. The map show that the water upstream of the log jam is almost 1°C warmer than the water flow downstream. This may be attributed to a combination of factors such as vertical thermal stratification in the pool and potential hyporheic flow through the logs and the riverbed.

Thermal infrared and true color imagery was processed, analyzed, and reported by:
Mousa Diabat, Ph.D. - Hydrologist, Thermographer Level III
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INTRODUCTION

The U. S. Geological Survey contracted NV5 Geospatial Solutions to collect thermal infrared (TIR) and true color airborne imagery data during the summer of 2024 for the 8 tributaries in the Santiam River Basin in Oregon. The survey was conducted on August 31, 2024, and covered a total river length of 173.79 km (Figure 1). Prior to the TIR data collection, the U. S. Geological Survey and stakeholders deployed a series of data loggers throughout the survey area to record water temperature during the TIR acquisition period. The data records were shared with NV5 to use for radiometric calibration. Towards the end of July and just before the acquisition campaign started, several wildfire were in active state near the survey area. NV5's flight crew was forced to change flight plan in accordance with smoke conditions and airspace coordination with the firefighting assets in the air and on the ground. As a result, the data acquisition over a number of tributaries was split into different sections and the data processing and mosaicking was adapted to the timing of the coverage. Eventually, he crew had to halt the effort and free the airspace for the aviation assets taking part in fighting the fires as well due to smoke conditions that may both impact the crew and the image quality. The crew was able to resume the data collection and complete the survey on September 5. Acquisition dates and times are shown in Table 1, deliverable projection information is shown in Table 2, a complete list of contracted deliverables provided to U. S. Geological Survey is shown in Table 3, and the project extent is shown in Figure 1.

This report accompanies the delivered TIR data and support files, and documents the contract specifications, data acquisition procedures, processing methods, and analysis of the final datasets.

Table 1: TIR acquisition dates and stream reaches collected on the Santiam Rivers survey area.

River Survey Description	River Section	Date	Time
Little North Santiam	0-17.0	31-Jul-24	16:22-16:49
Little North Santiam	15.4-28.5	31-Jul-24	14:42-15:07
Little North Santiam	13.7-16.4	1-Aug-24	15:11-15:12
Breitenbush	0-5.7	1-Aug-24	16:32-16:50
Breitenbush	3.1-18.5	2-Aug-24	16:42-17:15
North Fork Breitenbush	0.9-8.9	2-Aug-24	14:42-15:03
North Fork Breitenbush	0-1.6	2-Aug-24	16:42-17:15
Quartzville Creek	all (0- 21.4)	31-Jul-24	13:16-14:09
Quartzville Creek	4.0-7.5	1-Aug-24	14:40-14:49
North Santiam	all (0-30.8)	2-Aug-24	13:25-14:31
Middle Santiam	0-22.1	1-Aug-24	13:29-14:31
Middle Santiam	all (0-24.2)	5-Sep-24	13:23-14:26
Pyramid Creek	all (0-0.6)	5-Sep-24	13:55-14:02
South Santiam	all (0-40.7)	27-Jul-24	14:15-16:04
South Santiam	0-1.9	31-Jul-24	12:53-12:56
South Santiam	27.3-28.4	31-Jul-24	13:05-13:06

Deliverable Products

Table 2: Deliverable product coordinate reference system information

Projection	Horizontal Datum	Vertical Datum	Units
UTM Zone 10 North	NAD83(2011)	NAVD88(GEOID18)	Meters, Celsius

Table 3: Products delivered to U. S. Geological Survey for the Santiam Rivers site.

Product Type	File Type	Product Details
Thermal Infrared Imagery Rasters	0.5m GeoTIFF (*.tif)	• Calibrated, rectified images (cell values = Celsius x 10) • Calibrated, rectified imagery mosaics (cell values = Celsius x 10)
3-Band (RGB) Digital Imagery Rasters	15 cm GeoTIFF (*.tif) 15 cm MrSID (*.sid)	• Tiled Imagery Mosaics • Rectified Frames • AOI Imagery Mosaic
Vectors	Shapefiles (*.shp)	• Stream centerlines • Temperature accuracy checks • TIR image center points and sensor exterior orientation (EO) • Longitudinal temperature profile (LTP) • Significant thermal features (STF)
Supplemental	MS Excel Format (*.xlsx)	• “xlsx” folder contains longitudinal temperature profiles (LTP) and significant thermal features (STF) in MS Excel format (*.xlsx)
Supplemental	Layer Files (*.lyrx)	• “Color ramps” folder contains customized layer files (*.lyrx) for visualization in ArcMap
Metadata	Extensible Markup Language (*.xml)	• FGDC (CSDGM) compliant Metadata
Reports	Adobe Acrobat (*.pdf)	• Flight report • Lidar Technical Data Report

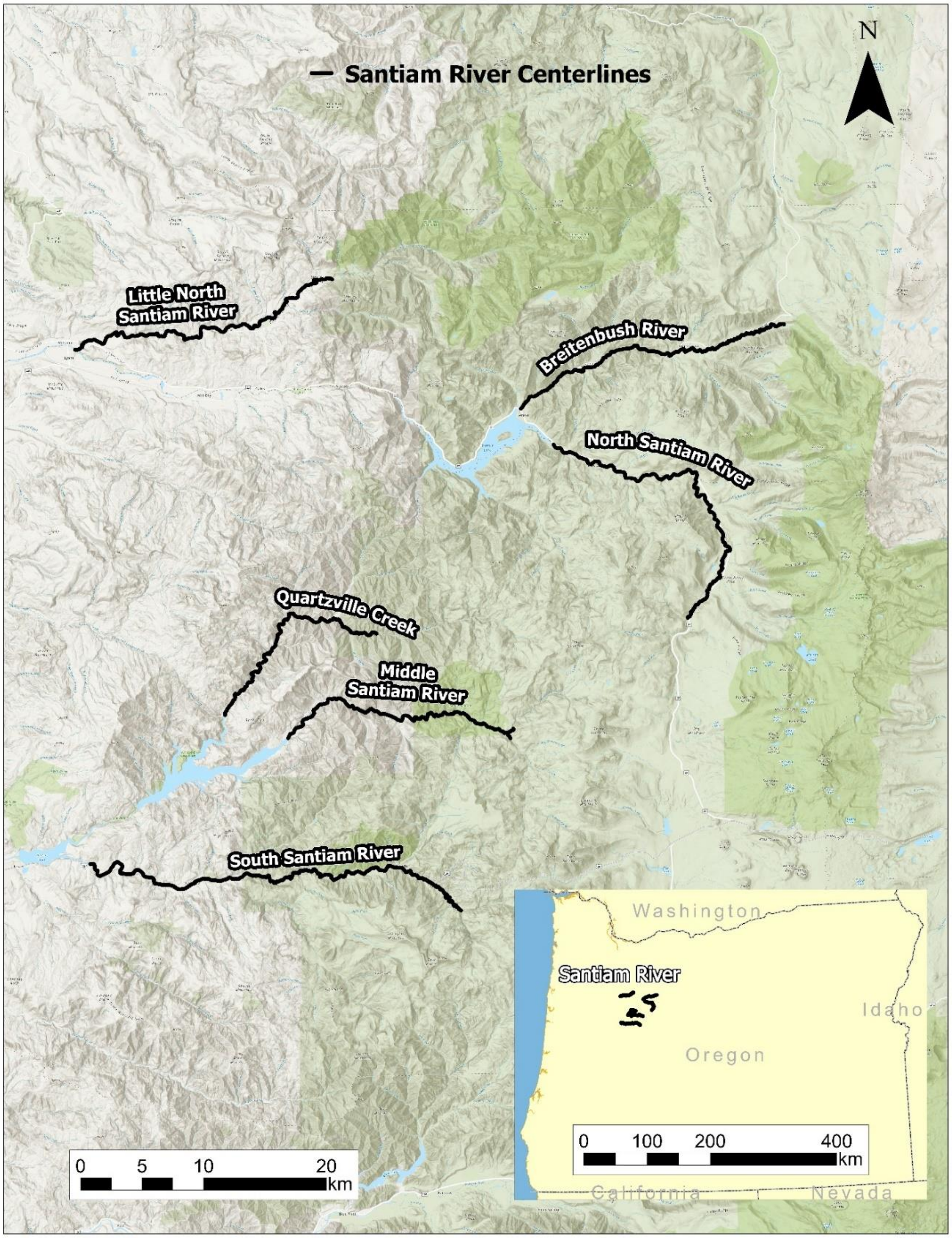

Figure 1: Map of the 173.8 km Santiam Rivers survey area.

Imagery Acquisition Planning and Execution

Data Acquisition

In preparation for data collection, NV5’s team reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Santiam Rivers Thermal Infrared and True Color Imagery study area. The project data were successfully acquired between July 27th to August 2nd, 2024, with a final flight on September 5th. All flights occurred between 12:53 – 17:15 PST, covering a total river length of 173.8 km. This time window ensured optimal conditions to maximize the thermal contrast between the river water and the banks. The timing targeted clear skies to ensure high solar loading of the riverbanks. Weather stations near the area of interest were monitored to meet these conditions. The aircraft was flown over the river where the active channel occupies the center of the frame. Multiple flight lines were needed along sections where the channel was wider than the image frame (Figure 2) or side channels were identified in the floodplain. The flight plan was designed using a helicopter aircraft to achieve a ground sampling distance (GSD) of less than 0.50 meters (m), targeting 0.3 m GSD where possible, at an altitude of 300 – 400 meters above ground level (AGL). The target was to fly as low as safely possible to and to reach a target of 0.3 meter.

Thermal Infrared Sensor: FLIR SC6000

Thermal infrared images were collected using a FLIR SC6000 LWIR sensor (8 – 9.2 mm) mounted to a Bell 206 Long Ranger helicopter. The sensor was installed in an enclosed stainless-steel capsule mounted at the bottom of the helicopter with a designated opening for the down-facing lens (Figure 3). 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 minimize thermal drift during acquisition. To achieve uniformity across the detector array, a factory scheme is generated to reduce non-uniformity across the image frame. Differences in temperature (typically <0.5 °C) might be observed near the edge of the image frame. Flight planning ensures sufficient image overlapping 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 photon counts which were then converted to radiant temperatures. Sensor and acquisition specifications for the Santiam Rivers TIR study are listed in Table 4.

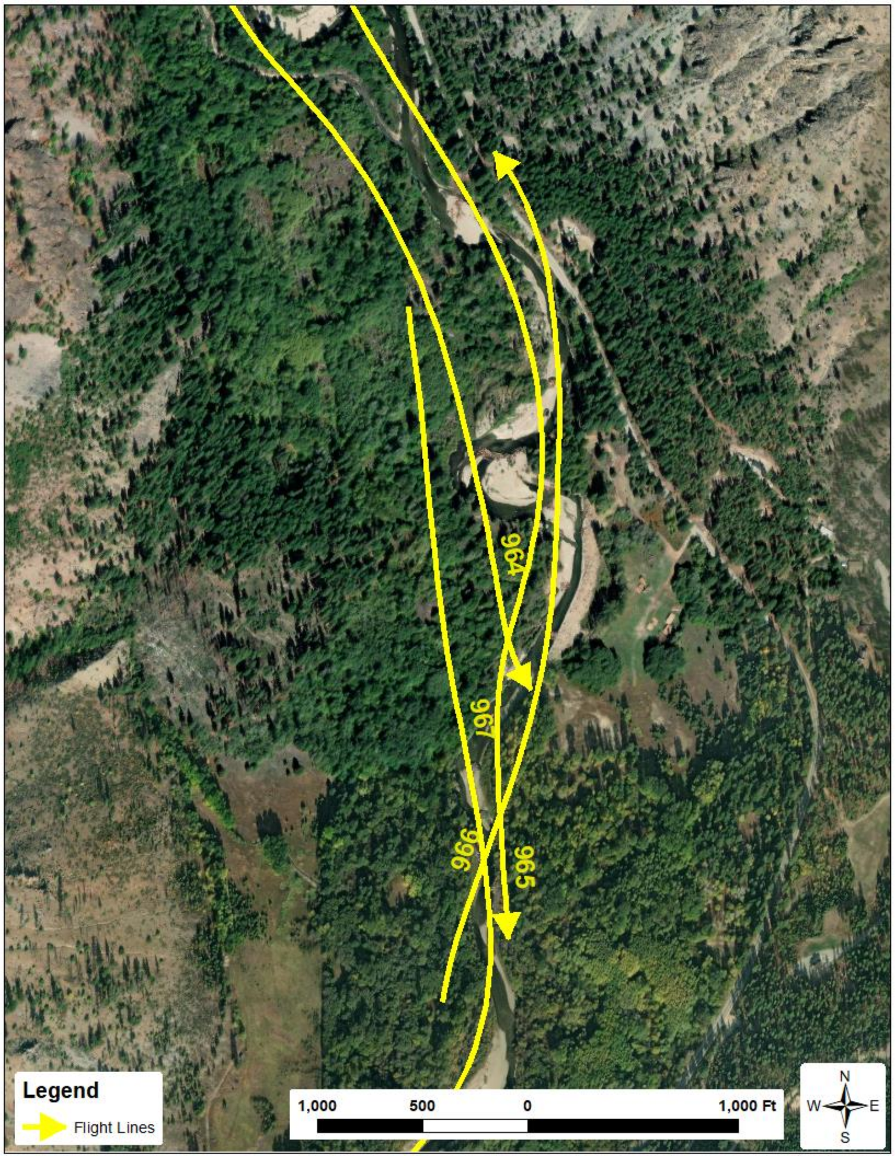

Figure 2: A general example of flight lines collected for TIR and True Color Imagery.

The positional coordinates of the aircraft (geographic coordinates: latitude, longitude, and altitude) and the orientation (pitch, yaw, roll) were recorded continuously throughout the data collection mission. The geographical coordinates of the aircraft were measured twice per second (2 Hz) by an onboard differential global navigation satellite system (GNSS), while aircraft attitude was measured 200 times per second (200 Hz) by an onboard inertial measurement unit (IMU). Airborne global positioning system (GPS) data were post-processed into a smoothed best estimate of trajectory (SBET) using Applanix PP-RTX data for corrections. To ensure sufficient image overlaps and ground sampling distance (GSD), TIR images were acquired at 1 image per second (1 Hz), flight speed was 30-40 knots on average, and flying altitude targeted 400 meters above ground level (AGL). Images were indexed by GPS time (event time) and paired with the SBET to resolve the exterior orientation of the sensor for each image event.

Table 4: Summary of TIR sensor and acquisition specifications

Parameter	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 27th – August 2nd, 2024 September 5th, 2024
Planned Flying Height Above Ground Level (AGL):	300-400 meters
Image Ground Footprint Width:	200-300 meters
TIR Ground Sampling Distance (GSD)	≤ 0.50 meter (targeting 0.3 m)

Figure 3: An example of the sensor installation setup similar to the one used for the project.

Water Temperature Ground Control

In-stream water temperature records and atmospheric data are required to calibrate the thermal infrared imagery to absolute temperature.

In-Stream Water Temperature Sensors

Water temperature recorded by in-stream temperature sensors are used to radiometrically calibrate the thermal signature of the imagery. A total of 17 stream temperature data loggers were deployed in the survey area by the USGS and stakeholders (Figure 4).
The data loggers recorded water temperature at 5-minute intervals for 11 of the sites and 15-minutes interval for the remaining 6 sites. The loggers used for this project were from different models: AquaTemp-100, Level TROSS 700H, Tidbit MX Temp 400, and YSI 600/600R.

Atmospheric Parameters

Radiometric calibration of the TIR imagery requires atmospheric data collected by local weather stations. Records of atmospheric parameters, namely air temperature and relative humidity, were extracted from the closest weather stations for the time of the flight.

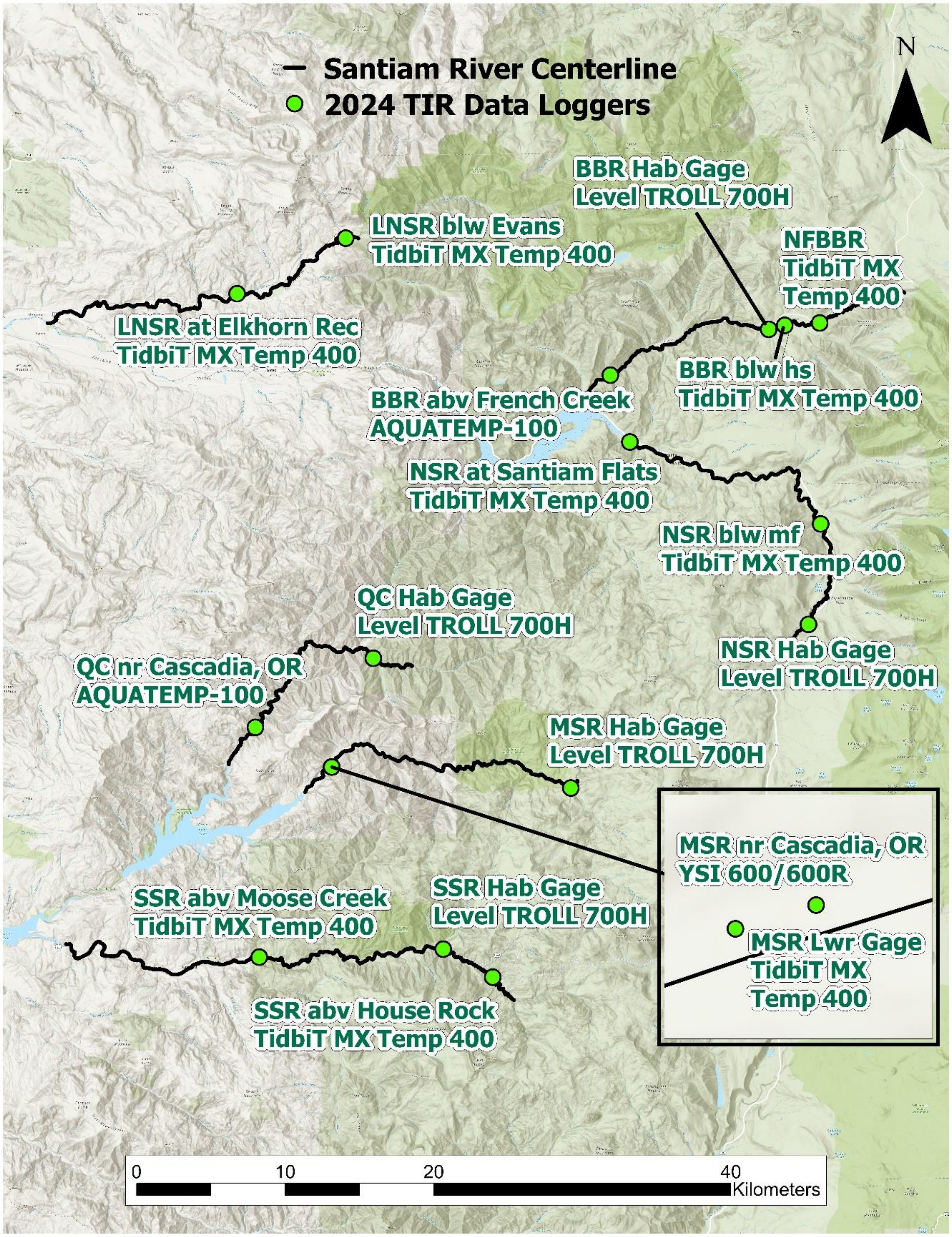

Figure 4: Map of survey area and location of water temperature data loggers.

True Color Sensor: PhaseOne iXM-RS150F

Aerial imagery was acquired using a PhaseOne iXM-RS150F digital camera (Table 5). The PhaseOne is a medium format aerial mapping camera which collects imagery in three spectral bands (Red, Green, Blue).

Table 5: Camera manufacturer's specifications for a PhaseOne iXM-RS150F

Parameter	PhaseOne iXU-RS150F Specification
Focal Length	50 mm
Spectral Bands	Red, Green, Blue
Pixel Size	3.76 μm
Image Size	14,204 x 10,652 pixels
Frame Rate	GPS triggered
FOV	56° x 43.6°
Date Format	8-bit TIFF

True color imagery was co-acquired, with the thermal data from July 27th to August 2^{nd,} and September 5th. Imagery was collected with at least 60% along track overlap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 15 cm. Orthophoto specifications particular to the Santiam Rivers project are in Table 6.

Table 6: Project-specific orthophoto specifications

Parameter	Digital Orthophotography Specification
Ground Sampling Distance (GSD)	≤ 15 cm
Along Track Overlap	≥60%
Cross Track Overlap	NA
Height Above Ground Level (AGL)	300-400 m
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6

Thermal Infrared Data Processing

Thermal Infrared Imagery Calibration

The process of TIR calibration connects the thermal radiation recorded by the FLIR sensor and the kinetic temperature of the targeted object. Response curves of the TIR sensor were measured in a laboratory environment as part of the periodic maintenance procedure stated by the sensor's manufacturer. In the laboratory environment, the sensor records thermal infrared radiation emitted by a black body as digital numbers which were used to generate the response curves. All objects have physical parameters of emitting, reflecting, and transmitting radiation with varying values as the following equation shows:

$$emissivity + reflectivity + transmisivity = 1$$

In theory, a black body has an emissivity (e) value of 1.0, and reflectivity (r) and transmissivity (t) values of 0.0. However, the TIR calibration is based on the recorded temperature of water which has an emissivity value of 0.98[1], reflectivity value of 0.02, and transmissivity value of 0.0. The water surface reflects thermal radiation of the atmosphere, while the water column is opaque and does not transmit radiation in the longwave thermal spectrum.

The process of thermal calibration adjusted for the distance between the water and the sensor and accounted for atmospheric conditions in order to adjust radiance at the sensor based on the kinetic temperatures recorded by water temperature data loggers. Imagery from flight lines that did not cover data loggers were calibrated based on overlapping imagery from adjacent lines, a technique that is referred to as "line-to-line calibration". Minor deviations from the initial calibration might be needed to achieve the best possible temperature continuity possible throughout the mosaic.

TIR Mosaic Generation

Initially, a boresight calibration flight was processed to calculate the misalignment angles between the sensor and IMU system; this step allows for direct georeferencing of imagery without aerial triangulation. For each production flight, a series of corrections were applied to the aircraft trajectory and orientation using Applanix PP-RTX processing methodologies. Image timestamps were linked to the corrected trajectory to resolve the exterior orientation (EO) of the sensor for each image event. The resulting EO, sensor interior orientation (IO), and calibrated TIR images were input into Inpho's OrthoMaster software to generate orthophotos using a publicly available digital elevation model (DEM). Finally, for the TIR ortho images, a mosaic was generated without applying color balancing and minimal seam line feathering to preserve the original temperature values of the TIR imagery as best as possible. The processing steps and software are detailed in Table 7.

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[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.

Table 7: Processing step for TIR mosaic generation

Orthophoto Processing Step	Software Used
Calculate camera misalignment angles from a system boresight flight conducted close to survey area.	Applanix CalQC v9.1
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Applanix POSPac MMS v9.1
Calculate exterior orientation (EO) for each image event by linking the event time stamps with the SBET.	Applanix POSPac MMS v9.1
Convert raw (*.ats) TIR data into thermally calibrated TIFF images.	FLIR ResearchIR v4.3
Import DEM and generate individual ortho images.	Inpho OrthoMaster v14.1
Mosaic orthorectified imagery, generating seams between individual photos.	OrthoVista v14.1

Temperature and Color Ramps

The final TIR mosaic contains pixel values of degrees Celsius multiplied by 10, stored in a 16-bit unsigned integer raster format. Temperature values occupy a relatively narrow range of the full 16-bit histogram; thus, visual representation of the imagery is enhanced by the application of a customized color ramp. Color ramps also highlight different features relevant to the analysis, such as spatial variability of stream temperatures and inflows (Figure 5). The color ramps for the TIR mosaics were developed to maximize contrast for most surface water features and are unique to each tributary or mosaic. A TIR specialist at NV5 customized unique color ramps to improve visual presentation of the TIR mosaic and exported the color ramps as ESRI layer files (*.lyrx). Color ramps are an important product that is delivered to the end user.

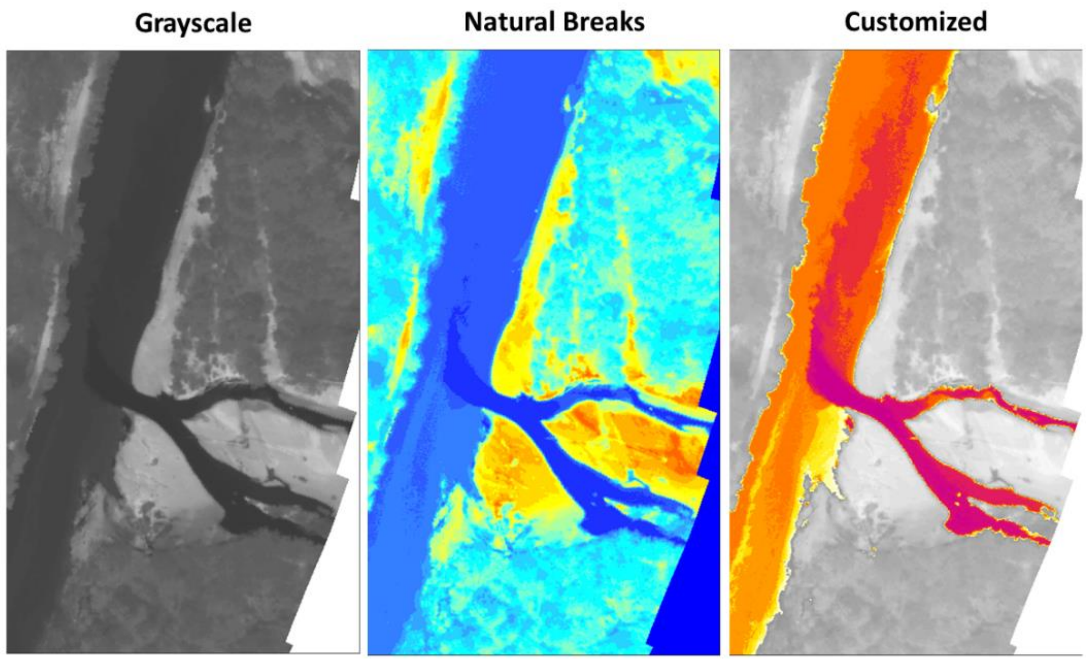


Figure 5: Examples of different color ramps applied to the same TIR image.

Accuracy Assessment Methodology

The radiometric accuracy of the final TIR mosaic was assessed by comparing sampled pixels of the mosaic (of water features) at the data logger locations against the temperature recorded by the respective logger. The goal was to reach a mean absolute error (MAE) of ≤1.0 °C temperature difference between the mosaic and logger-recorded values at the time of acquiring the TIR imagery. The threshold of MAE ≤1.0 °C accounts for factory reported errors of the water temperature data logger (≤0.2 °C) and the FLIR sensor (≤0.035 °C).

Temperature accuracy of the TIR mosaic relies on the recorded temperatures and deployment conditions of the data loggers. 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 "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, water surfaces obscured by above-surface boulders and vegetation (riparian or aquatic), and the mixing zone of tributaries or point-source inflow.

True Color Imagery Processing

As with the TIR data, the collected digital photographs went through multiple processing steps to create final orthophoto products. Initially, images were geometrically corrected for lens distortion using camera calibration parameters and output as 8-bit TIFF images. The onboard GPS (collecting at 2 Hz) and inertial measurement unit (IMU) (collecting at 200 Hz) data were post-processed using atmospheric corrections from Applanix PPRTX reference data providing cm level accuracy. The resulting final smoothed best estimate of trajectory (SBET) was then paired with image timestamps to resolve the exterior orientation (EO) parameters of the camera for each image event and allow for direct georeferencing of the imagery. Direct georeferencing forgoes the need for an aerial triangulation block adjustment, instead relying on the high precision of the onboard GPS/IMU instruments and camera to IMU rotational offset angles calculated from a boresight flight conducted prior to data acquisition. Images were orthorectified using the best publicly available bare-earth model to remove displacement effects from topographic relief inherent in the imagery. The surface model used may have come from multiple data sources and pixel resolutions to cover the entire AOI; it may also represent different ground conditions than those of the Santiam TIR and RGB data collection. Therefore, the orthorectification process may result in small spatial offsets in the imagery in areas where there have been temporal changes to the ground surface, or the resolution of the model is not high enough to support that of the imagery. In the final processing step, all images are mosaicked together using blockwide global color balancing and automated seamline generation. The processing workflow for orthophotos is summarized in Table 8.

Table 8: Orthophoto processing workflow

Orthophoto Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	POSPac MMS v.9.1
Generate camera exterior orientations (EO) by linking image events with the SBET file, resulting orientations are in Omega, Phi, and Kappa representing the image coordinate system.	POSPac MMS v.9.1
Convert raw imagery data into geometrically corrected TIFF images.	iX Capture v3.4
Apply EO to photos.	Inpho Match AT v14.1
Import DEM and orthorectify image frames	Inpho OrthoMaster v14.1
Mosaic orthorectified imagery, blending automated and manually drawn seams between photos and applying global color balancing to the project.	Inpho OrthoVista/Seameditor v14.1

Interpretation and Feature Extraction

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 contracted river length. As the centerline was digitized, care was taken to avoid non-water features where possible, such as aquatic vegetation, boulders, and overhanging canopy. However, a few non-water features cannot always be avoided, such as bridges. River length was measured cumulatively from the most downstream point in the area of interest (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 TIR data: 1) an interval-based automated sampling of the stream to generate a longitudinal temperature profile (LTP) and 2) a manual point source sampling to identify significant thermal features (STF).

Longitudinal Temperature Profile

The LTP is the result of sampling the TIR mosaic at fixed intervals (50, 100, or 50 meter) along the previously digitized centerline of the study area. The LTP contributes to interpretation of the temperature gradient along the stream due to potential influence from water inflows (e.g., tributaries, springs, groundwater upwelling, effluents, etc.). Using a proprietary algorithm, the sampling results were stored in a geospatial data file format (ESRI shapefile) and were plotted against river distance. For each interval, the algorithm extracted the pixel values from the TIR mosaic at 10 points along the centerline within a 5-meter distance from the interval point (Figure 6). The results were summarized in terms of statistical parameters of mean, median, maximum, minimum, and standard deviation. Sampling points with high standard deviation were marked as outliers because they could have fallen on non-water features.

Significant Thermal Features

STFs are thermal anomalies in the TIR mosaic that represent potential inflows from springs, hyporheic inflow, or tributaries. The anomalies were manually identified before running an algorithm to extract values of all pixels inside a 1-meter buffer area (Figure 7). The algorithm also measured their distance from the centerline and attributed them with a mark, containing the specific river km, along the centerline of the study area (closest point on the centerline). For each STF, temperature results were summarized in statistical parameters of mean, median, maximum, minimum, and standard deviation of the pixels inside the 1-m buffer. All values above were summarized in a geospatial data file format (ESRI shapefile) and plotted against river distance with the LTP results. The defined buffer area for the STF could be larger than the identified feature (e.g. a small spring or hyporheic zone) or smaller (e.g. inflow from tributary). Therefore, the minimum extracted value could better represent the STF in some cases, whereas the median could better represent others.

Calculated Statistic Parameters

The statistical parameters summarize the temperature values of all 10 sample points for the LTP and all pixels inside the buffered area for the STF.

- **Mean and median:** define the mean and median temperature values of all 10 sampled points/pixels.
- **Minimum and maximum:** define the minimum and maximum temperature values among all points/pixels. The minimum is used to plot STF results where the interest is to identify cold inflow, and the maximum is used to identify hot inflow.
- **Standard deviation:** defines the standard deviation across all sampled points/pixels. This value is important to identify sample points that represent non-water features. A low standard deviation indicates homogeneous thermal features among the sample points and a high standard deviation indicates that the set of sample points includes features (e.g., exposed rocks/boulders) with temperature significantly different than the water body. The value of standard deviation is important for identifying and removing invalid sample points.

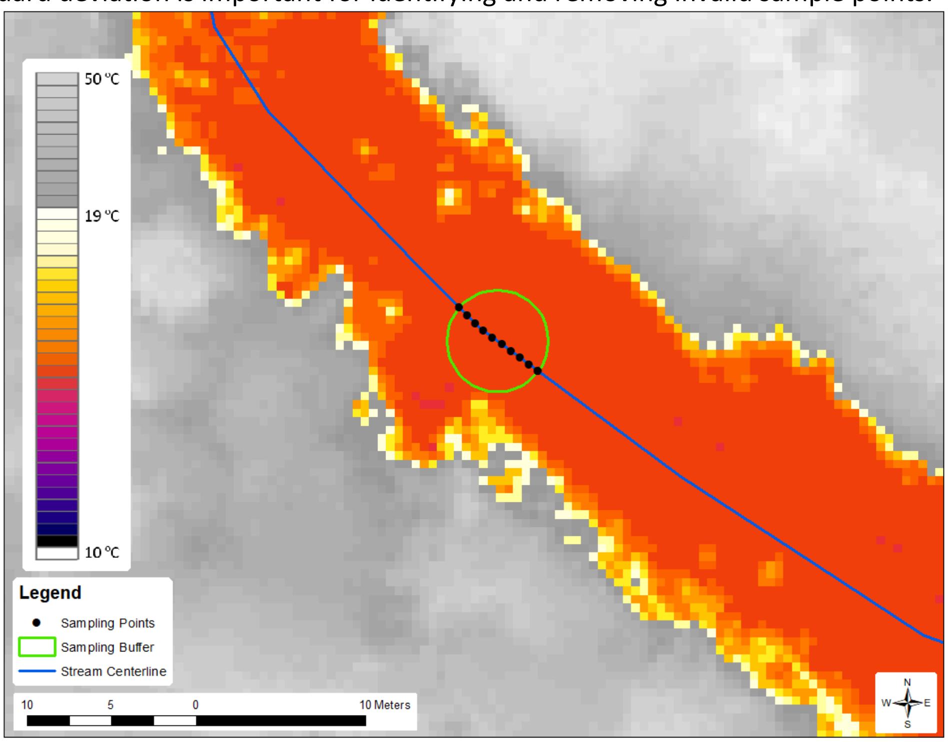


Figure 6: An example set of sample points (n = 10 per set) used to generate the longitudinal temperatures profile (LTP) with 50-meter intervals along the river centerline. Sample points were within 5-meter buffer along the digitized centerline. Water temperature is displayed in units of °C.

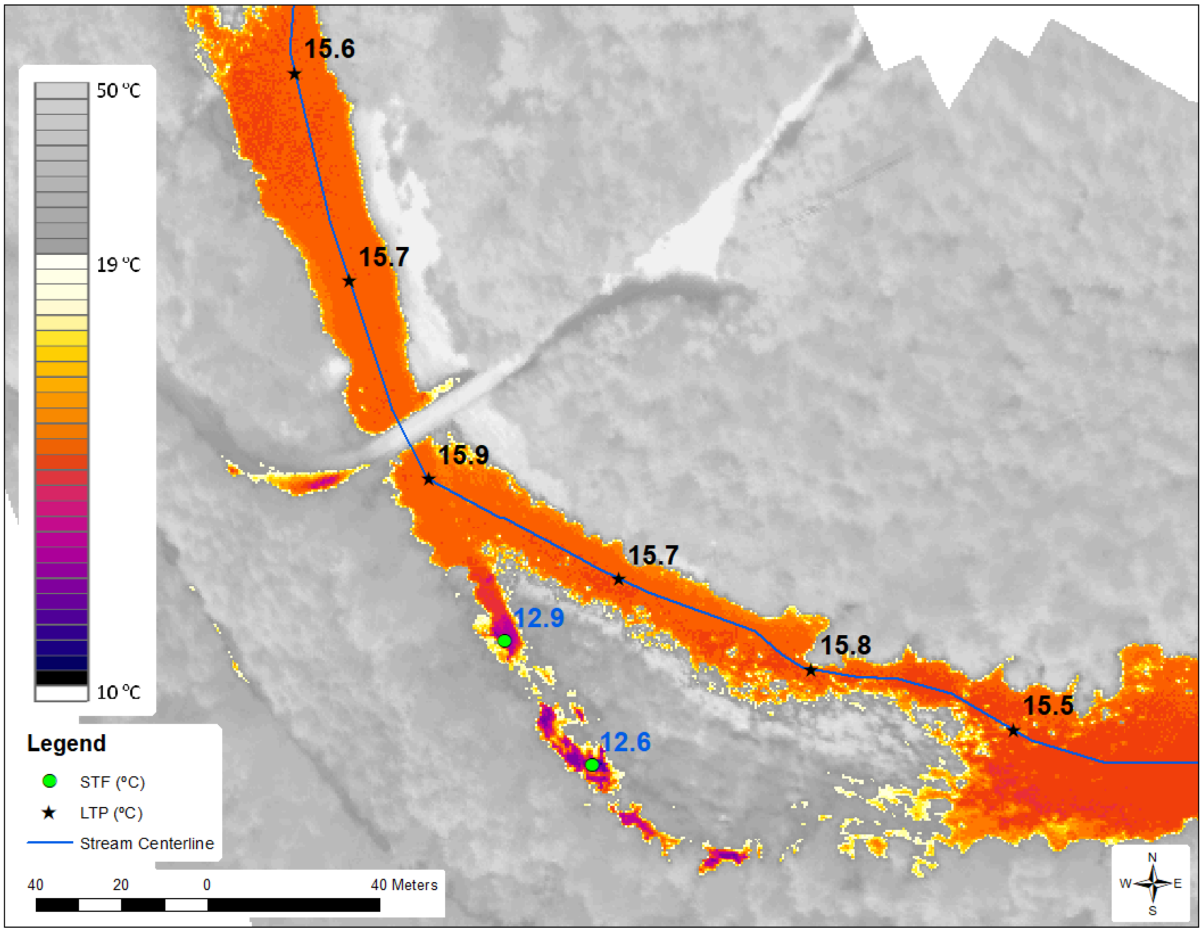


Figure 7: An example of a significant thermal features (STF) of a hyporheic inflow or a cold-water spring entering the main channel of the river. The map also shows the sampling points in the river, the longitudinal temperature profile (LTP).

Table 9: 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.x
Generate orthorectified thermal imagery	*<TIMESTAMP >.tif*	Incorporate the spatial location and sensor's orientation into creating orthorectified thermal imagery.	Inpho v14
Develop color ramp	*<STREAM>_<SECTION>.lyrx*	Develop a color ramp that highlights spatial variability of stream temperatures.	ArcGIS Pro
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.	ArcGIS Pro
Create 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 measurement and the TIR radiant temperature was sampled based on an average of 10 sample points located within a 5-meter, upstream and downstream, along the centerline.	ArcGIS Pro NV5 script
Identify and sample significant features sites	*STF_<STREAM>.shp*	Manually digitize and sample significant features sites. Sampling all pixels inside a 1-meter buffer area radiating from the digitized point.	ArcGIS Pro NV5 script
Plot longitudinal profiles	*LTP_STF_<STREAM>.xlsx*	Plot temperature against river km for the longitudinal profile and the manually identified features.	Excel

Thermal Infrared Analysis

The TIR analysis focused on utilizing the thermal signatures to identify features that were relevant to the project objectives. The analysis provides a review of the longitudinal thermal gradient of the stream, significant features at the edge of the stream channel, and point source and non-point source inflows (e.g., Tributary, side channels, groundwater upwelling, seepage, effluents, springs, and hyporheic flow) in the floodplain. Identification of such features relies on visual inspection by a trained analyst and automated sampling algorithms. While the visual inspection is qualitative, it assists in identifying the span of river water temperature and isolating it from the temperature of the banks. The results of running the automated sampling algorithms are quantitative and are provided in two statistical datasets: the LTP and STF. Both datasets are provided in shapefile and tabular formats. The LTP was generated by plotting the median stream temperature at a specified interval against the stream's length. Significant features along the river and in the survey area were incorporated with the LTP plot to provide spatial context for interpreting temperature patterns.

Accuracy Assessment Results

TIR imagery was calibrated using in-stream temperature data from the loggers that were distributed along the river channel. The accuracy of the calibrated TIR mosaics were assessed by comparing the water temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR mosaic, is summarized in Table 10. The final mosaic is considered within the specified accuracy requirements when the mean differences between TIR radiant and in-stream kinetic temperatures, also known as the mean absolute error (MAE), is ≤1.0 °C. The accuracy assessment is based on the data recorded by all data loggers within a single river section or mosaic. The thermal infrared mosaic was within this accuracy threshold (Table 10 and Table 11).

Table 10: Summary of accuracy assessment values grouped by TIR mosaic.

Mission Date / Mosaic	No. of Loggers Used	Low Error (°C)	High Error (°C)	Average Error (°C)
240731A_Little_North_Santiam	2	-0.71	0.66	-0.02
240731B_Little_North_Santiam	1	-0.04	-0.04	-0.04
20240801B_Breitenbush	1	0.10	0.10	0.10
20240802A_Breitenbush	1	0.09	0.09	0.09
20240802B_NF_Breitenbush	3	-0.19	0.18	0.00
20240731A_Quartzville	2	-0.40	0.36	-0.02
20240802A_North_Santiam	3	-0.63	0.51	0.00
20240801A_Middle_Santiam	2	-0.06	-0.02	-0.04
20240905A_Middle_Santiam	3	-2.30	1.34	0.04
20240727_South_Santiam	3	-0.44	0.51	-0.06

Table 11: Error values between radiant temperatures derived from the TIR mosaic and kinetic water temperature recorded by the in-stream data loggers.

Site Name	Location (River km)	Calibration Temperature (°C)	Mission Date and Time	TIR Sample Median (°C)	Error (°C)
BBR abv French Creek	23.0	17.2	240801 16:39	17.1	0.1
BBR blw hs	70.5	15.0	240802 16:57	15.2	-0.2
BBR Hab Gage	66.0	15.9	240802 16:54	15.7	0.2
LNSR blw Evans	93.8	21.8	240731 14:42	22.5	-0.7
LNSR at Elkhorn Rec	57.8	24.5	240731 15:07	23.8	0.7
LNSR at Elkhorn Rec	57.8	24.5	240731 15:07	24.5	0.0
MSR Lwr Gage	86.7	21.2	240801 14:22	21.3	-0.1
MSR nr Cascadia, OR	86.8	21.3	240801 14:22	21.3	0.0
MSR Lwr Gage	86.7	21.2	240801 14:22	19.9	1.3
MSR nr Cascadia, OR	86.8	21.3	240801 14:22	20.2	1.1
MSR Hab Gage	155.6	15.5	240905 13:55	17.8	-2.3
NFBBR	3.6	13.4	240802 15:03	13.3	0.1
NFBBR	3.6	13.4	240802 15:03	13.4	0.0
NSR Hab Gage	403.6	12.8	240802 13:28	13.4	-0.6
NSR at Santiam Flats	313.7	17.2	240802 14:30	16.7	0.5
NSR blw mf	375.8	15.4	240802 13:35	15.3	0.1
QC Hab Gage	84.9	18.1	240731 14:04	18.5	-0.4
QC nr Cascadia, OR	37.7	19.6	240731 13:23	19.2	0.4
SSR Hab Gage	326.1	16.2	240727 14:33	16.4	-0.2
SSR abv Moose Creek	274.3	18.5	240727 15:41	18.0	0.5
SSR abv House Rock	341.0	15.2	240727 14:19	15.6	-0.4

Longitudinal Temperature Profiles and Significant Thermal Features

The LTP of a stream is an informative tool to detect stream temperature gradients and the response to water inflow sources. It is common to draw the mean or the median water temperature against river length, though the other calculated statistical information can be used as well. The final LTP data excludes most of the non-water features that were accidentally sampled by the automated algorithm. An easy approach to exclude non-water features is by excluding results of high standard deviation and high minimum/maximum temperatures. However, further refinement might be required by the end user based on local information and familiarity with the survey area. For the purposes of this project's analysis, the centerlines were digitized at 100-meter intervals and used in the associated figures. An additional LTP was prepared and sampled at 50-meter intervals. The latter is provided as part of the deliverables package for further research by the end users.

Significant thermal features were identified based on their unique thermal signature and proximity to the active channel. The STF information assists in explaining the changes to LTP or localized water temperature differences. The STF identification focuses on locating tributaries entering the mainstem, hyporheic flow at the river edge, side channels, and agricultural backflow. The majority of identified STF were at temperatures colder than the mainstem, mostly leading to a cooling gradient. Warm inflow can also be identified along the water's edge. Significant thermal features such as tributaries, side channels, or point sources/sinks were identified and plotted along with the LTP. Groundwater upwelling appears colder than the mainstem in the summer, providing a strong indicator of the interaction between the stream and its floodplain. The method for sampling STF was to summarize statistics for all mosaic pixels within 1-meter radius of the STF center point. Tributaries and side channels are usually larger than the designated 1-meter buffer, while the hyporheic, spring, and groundwater inflows vary in size.

Little North Santiam River

A total length of 28.6 km of the Little North River was flown in two consecutive missions: on the 31st of July and a single line was reflown on the 1st of August to ensure optimal coverage. The first data acquisition lift covered the upstream section and the second lift. covered the downstream section. The TIR mosaic for Little North Santiam was split at river km 15.5 near the confluence of Bear Creek due to a time difference of an hour between both acquisition lifts (15:10 – 16:22). The centerline was digitized, and the thermal infrared mosaics were sampled at 100-meter intervals to generate the LTP. Along the mainstem of the Little North Santiam River, a total of 18 significant thermal features and 14 tributaries were identified, sampled, and plotted in Figure 8.

The thermal feature of the Little Santiam River showed:

1- The river experienced a number of alternating downstream warming and cooling with an overall warming trend that can be seen beginning with the headwaters. This area averaged around 21.0 °C, while the waters at the convergence of Little North Santiam with North Santiam were around 23.0 °C (Figure 9).
2- The majority of tributaries and STFs entering the main channel were colder than the latter (Figure 10). This can be one of the reasons the river did not experience a greater downstream warming.
3- More STFs from potential groundwater sources entered the main channel at the upstream section (above Couger Creek and Wonder Creek) than the downstream section, which was mostly influenced by inflows from tributaries.
4- The river section at 18 – 23 km experienced the most change in temperature where it drops rapidly and increases again. This section coincided with the highest density of inflows from tributaries and groundwater sources.

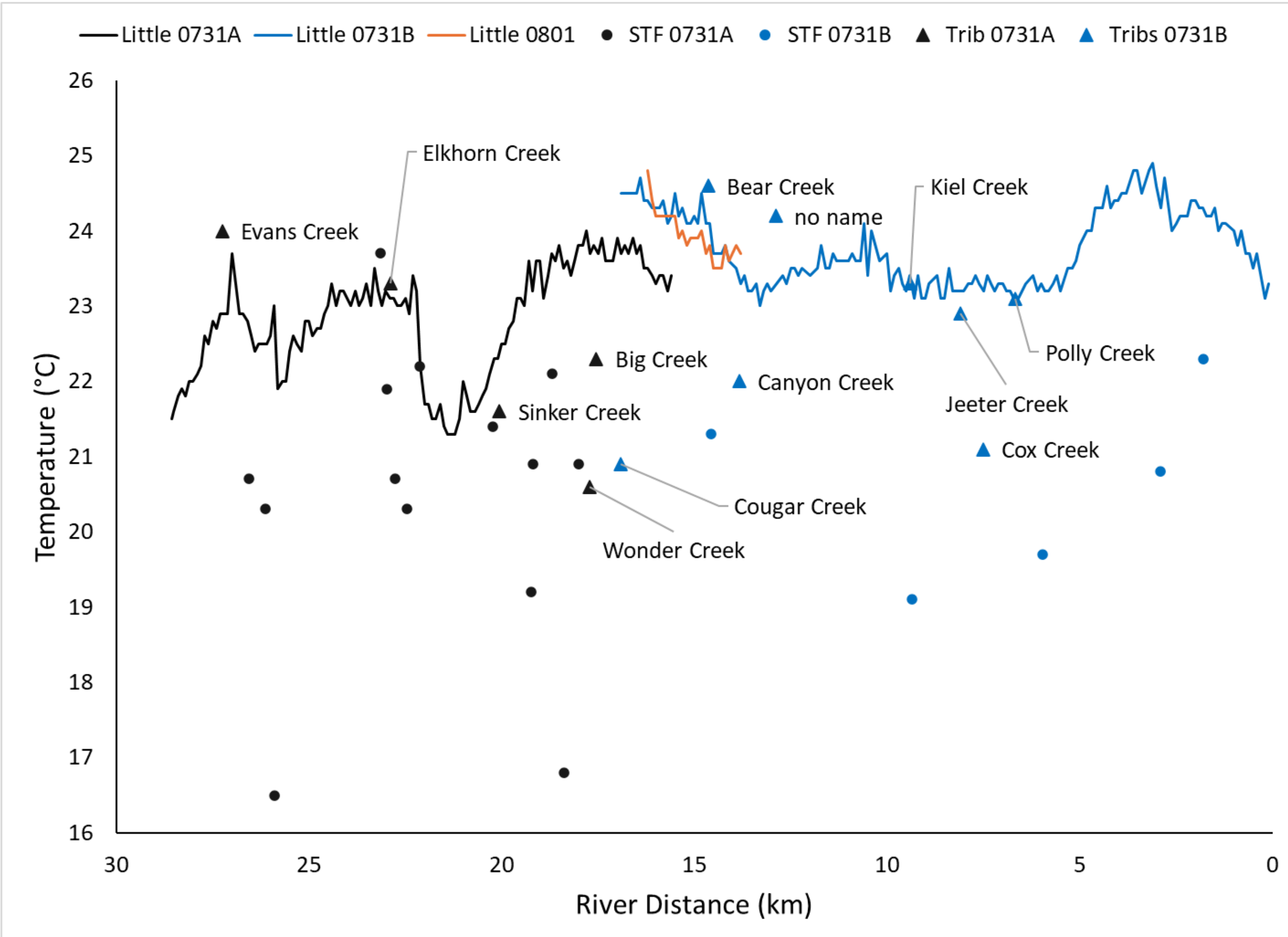


Figure 8: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, Little North Santiam River. The plot was prepared using the median values of the sampled pixels.

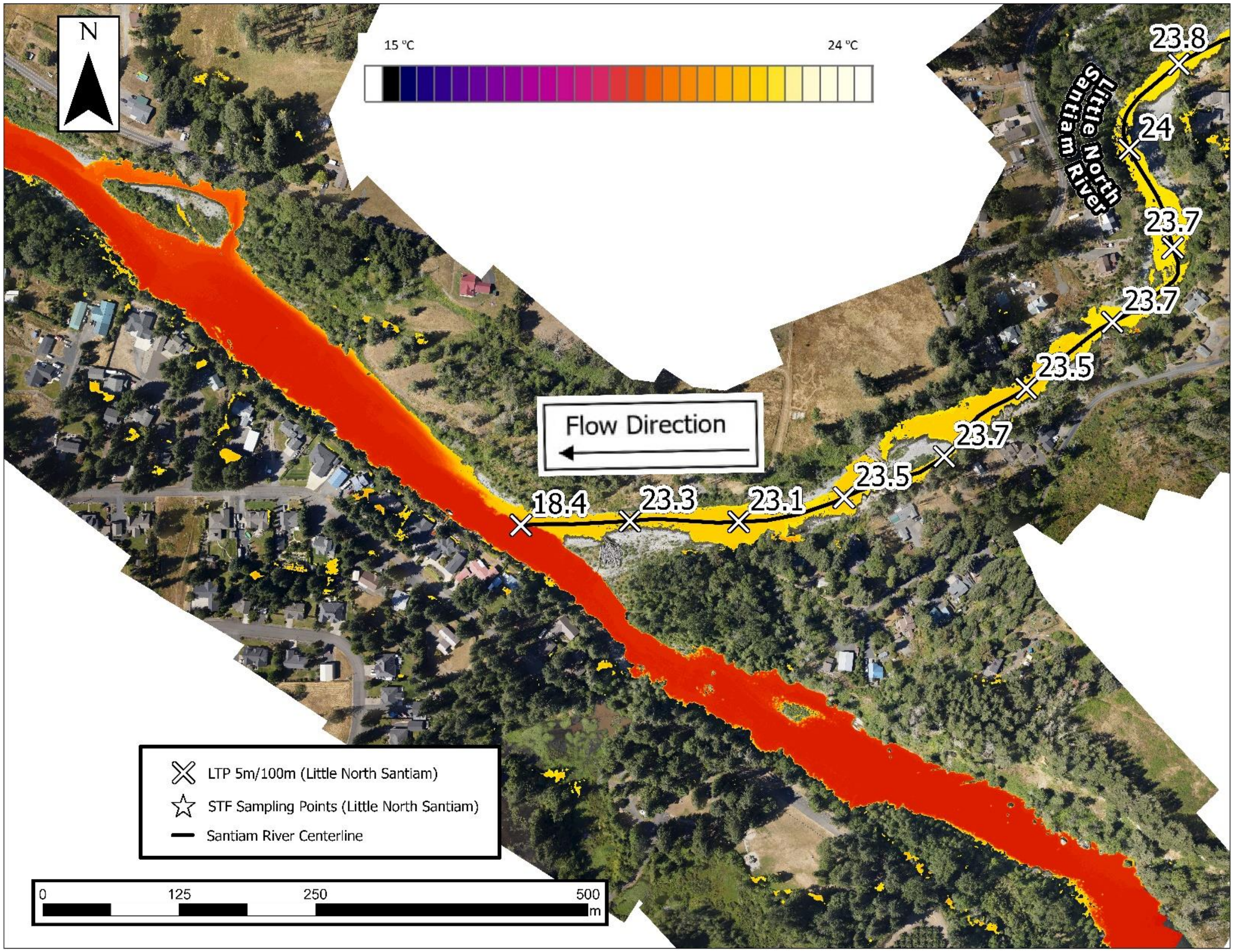


Figure 9: TIR and RGB map showing the Little North Santiam River flowing into the North Santiam River showing nearly º5 C difference, where the Little north Santiam was warmer.

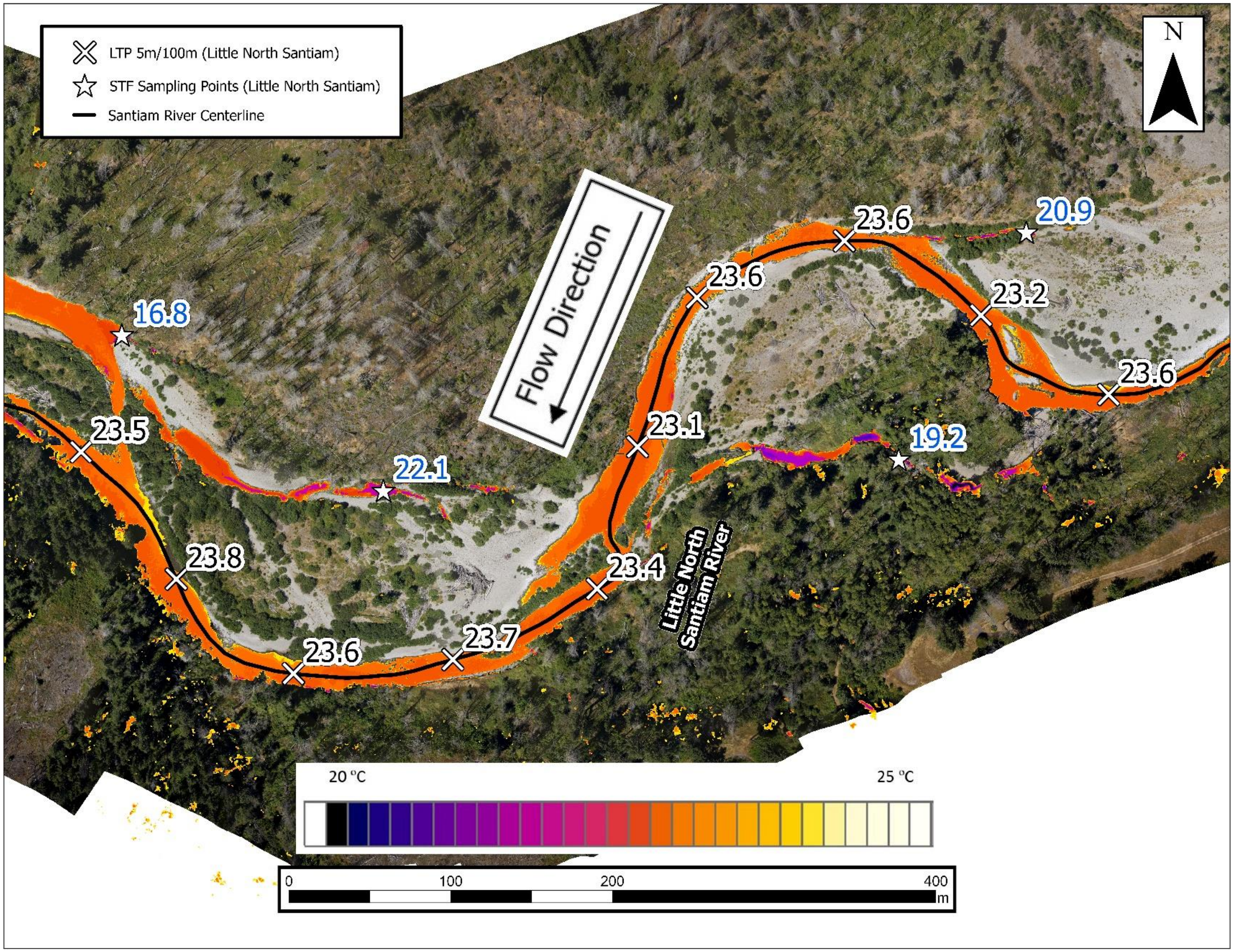


Figure 10: TIR and RGB map showing a number of hyporheic zones and inflows at river km 19 to 20 of Little North Santiam River.

Breitenbush River and North Fork Breitenbush River

A total of 18.5 and 8.9 river km of Breitenbush and the North Fork Breitenbush were flown on the 1st and 2nd of August, respectively. The centerline was digitized, and their thermal infrared mosaics were sampled at 100-meter intervals to generate the LTP. North Fork Breitenbush merges with South Fork Breitenbush to form the Breitenbush river at river km 18.5, this water then flows down and exits into Detroit Lake where we see a big jump in temperature from around 17.0°C to about 22.5°C .

A total of three significant thermal features and 15 tributaries were identified in the Breitenbush River, shown in Figure 11. Four significant thermal features were identified in the North Fork Breitenbush River, plotted in Figure 12.

The thermal feature of Breitenbush River showed:

1- A gradual and steady downstream warming of about 3°C can be seen throughout the 18-river km stretch.

2- While Breitenbush was flown in two lifts and on two consecutive days, the coverage overlapped, and the flights were conducted during similar times of the day. This allowed for the generation of comprehensive LTP and STF plots. The overlapping coverage also included two tributaries: Wind Creek and Bryars Creek, with both creeks having warmer temperatures on the first day.

3- Most of the STF and entering tributaries of Breitenbush Creek are warmer than that of the main channel (Figure 13), which may be one of the reasons for the downstream warming gradient.

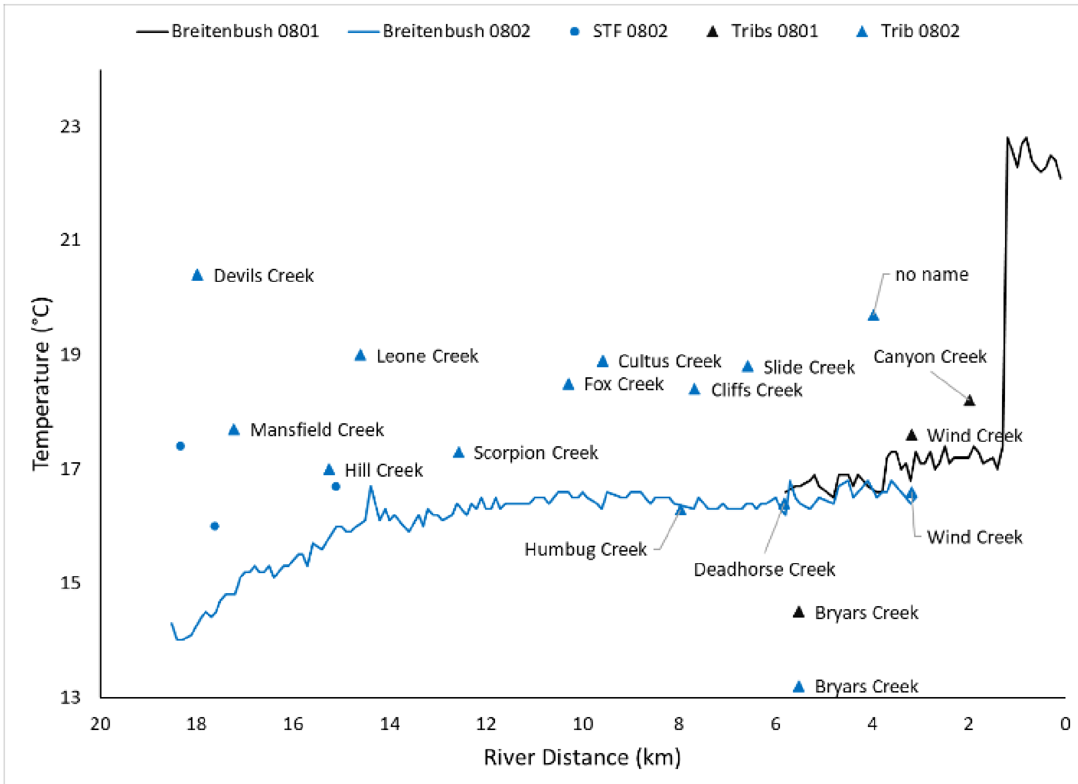


Figure 11: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, Breitenbush River.

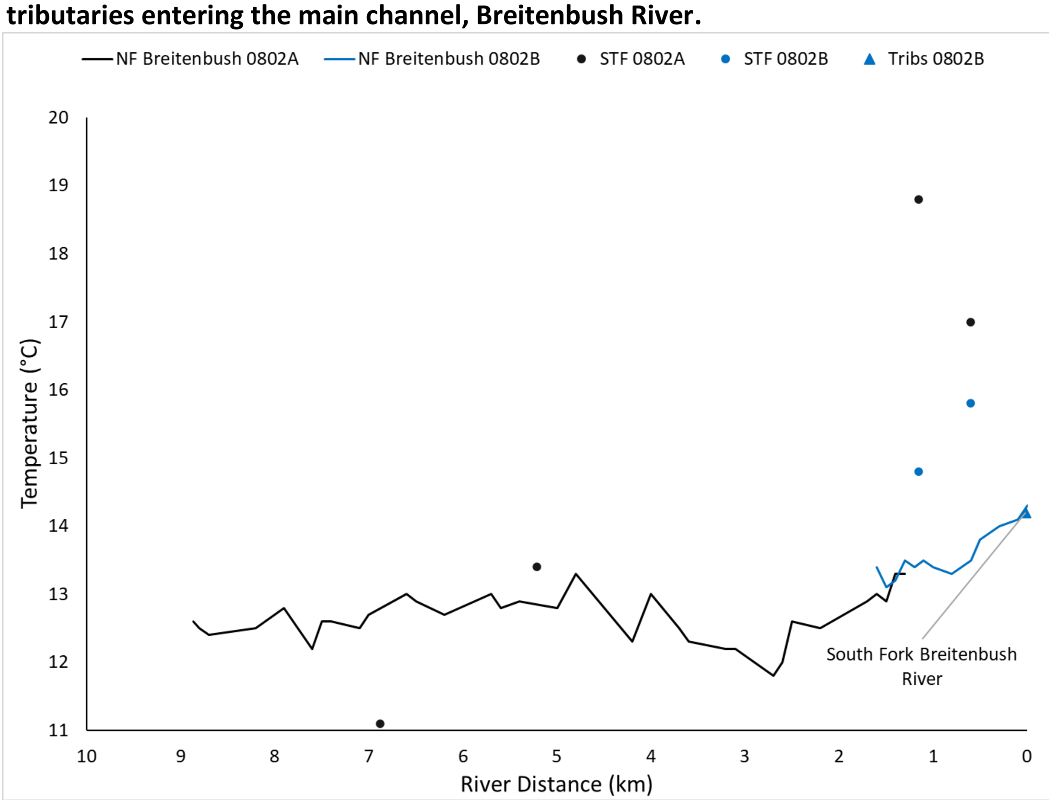


Figure 12: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, North Fork Breitenbush River.

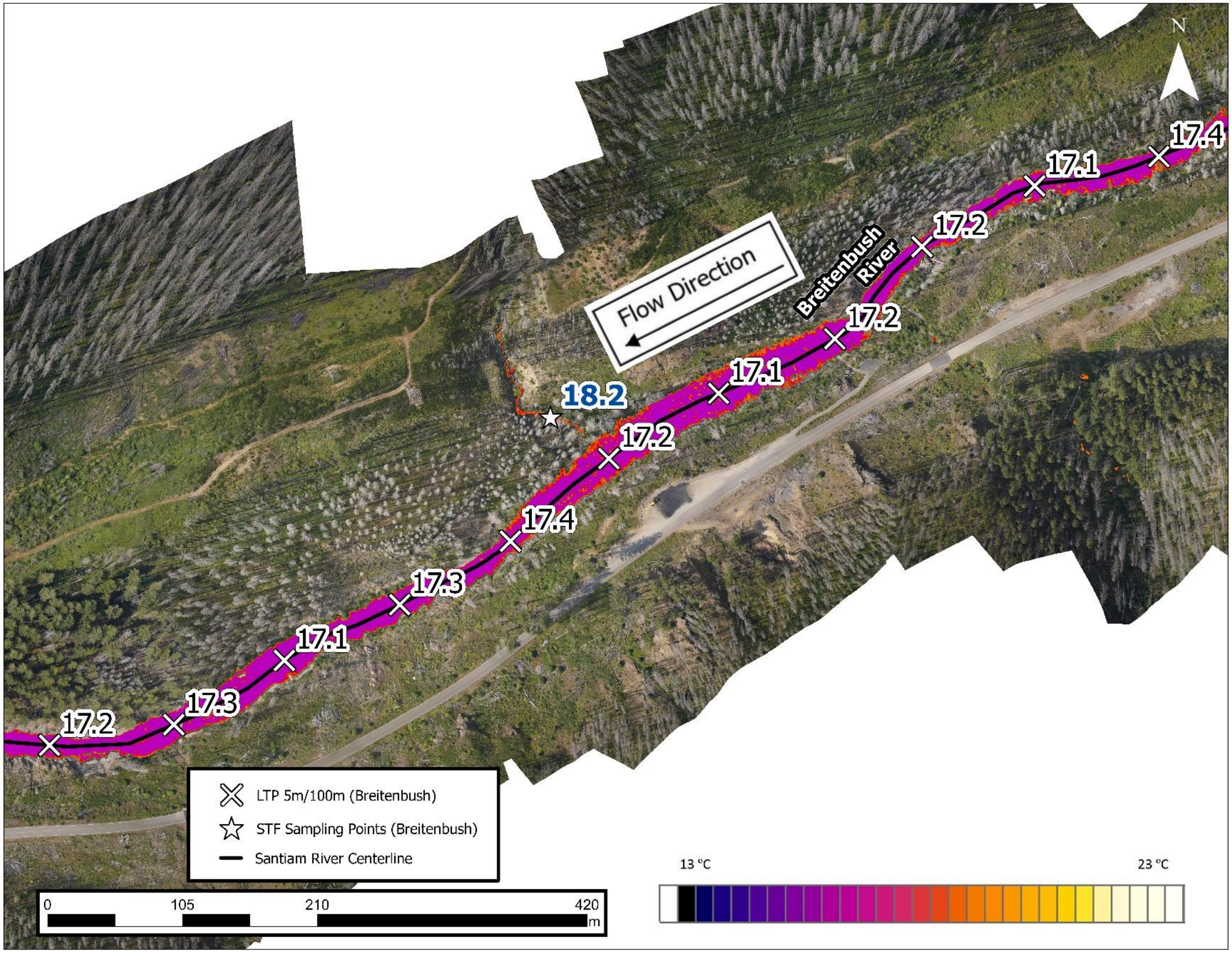


Figure 13: TIR and RGB map showing Canyon Creek flowing into the Breitenbush River. This tributary is warmer (18.2°C) than the main river (17.2°C).

North Santiam River

A total length of 30.8 km of the North Santiam River was flown on the 2nd of August, the centerline was digitized, and the TIR mosaics were sampled at 100-meter intervals to generate the LTP. A total of 17 significant thermal features were identified, most of which were identified as springs or groundwater inflow, and a total of five tributaries entering the North Santiam River were found, which can be seen in Figure 14.

The thermal feature of the North Santiam River showed:

1- An overall downstream warming gradient can be seen throughout the course of the channel where the headwater inflows were at 12.5 °C and the inflow into Detroit Lake was at 17.0 °C (Figure 15).

2- Inflows from tributaries and other sources of groundwater varied in their temperature relative to the main channel. The influence from the convergence of the much colder Pamelia Creek, with a median temperature value of 13.9 °C, was noticeable as it coincided with a localized drop in temperature. This can be seen in Figure 16.

3- The remaining tributaries appeared to be warmer than the main channel at the time of acquisition.

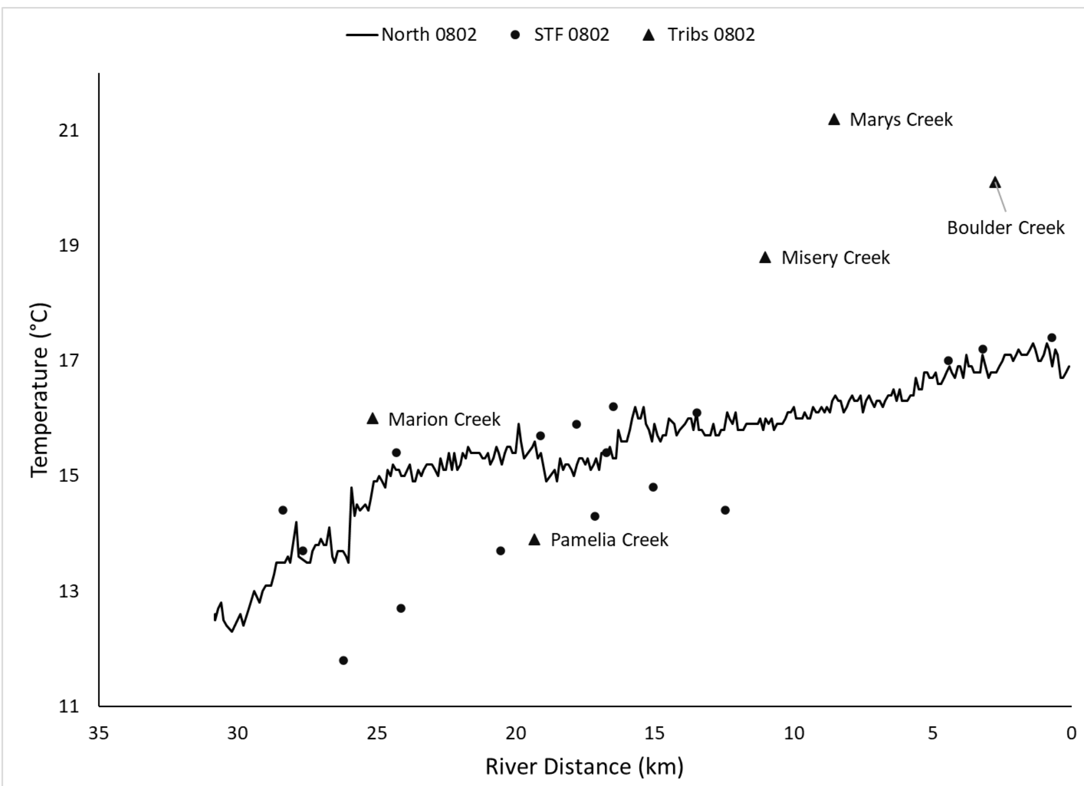


Figure 14: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, North Santiam River.

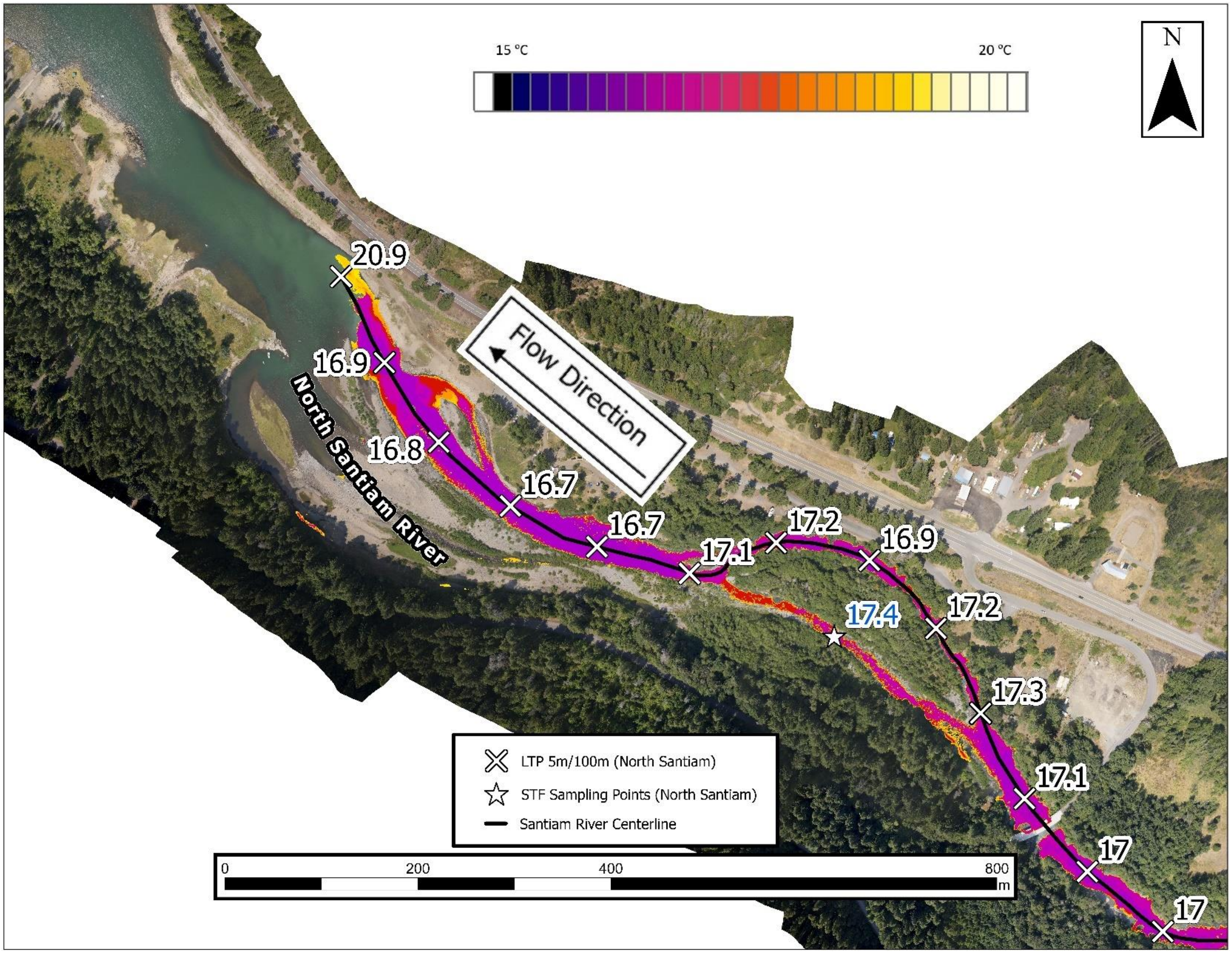


Figure 15: TIR and RGB map showing warmer water flowing into Detroit Lake starting at 16.9°C. A warmer side channel (17.4 °C) is also depicted.

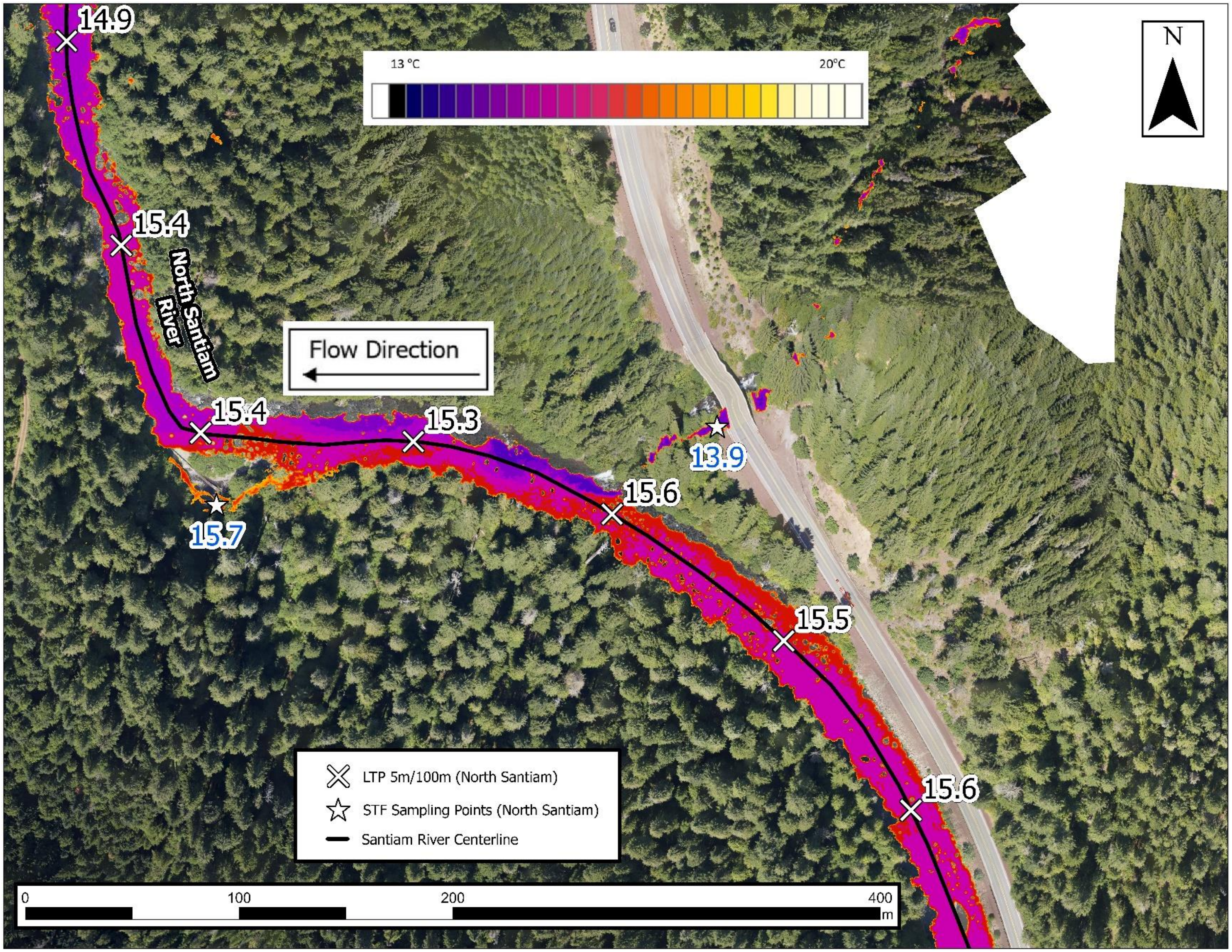


Figure 16: TIR and RGB map showing Pamelia Creek flowing into the main channel, North Santiam River. Pamela Creek entered the main change at temperature of 13.9 °C, which is 2 °C colder than the main channel.

Quartzville Creek

A total length of 21.47 km of Quartzville Creek was flown consecutively on the 31st of July and the 1st of August, the centerlines were digitized, and their thermal infrared mosaics were sampled at 100-meter intervals to generate the LTP.

Along the mainstem of Quartzville Creek, a total of 6 significant thermal features and 13 tributaries were identified, sampled, and plotted in Figure 17. The entire 21.47 km of Quartzville was collected on the 31st of July resulting in one continuous mosaic for the creek, however an additional flight was flown the flowing day to ensure optimal and full coverage. This second flight covered river kilometers 4.4 to 7.4.

The thermal feature of the Quartzville Creek showed:

1- While the flight the following day on the 1st of August was collected over an hour later than the day before, very similar temperature profiles were found between the two missions in the overlapping area.

2- All but two of the STF and tributaries in Quartzville Creek are at a lower temperature than that of the mainstream channel (Figure 18).

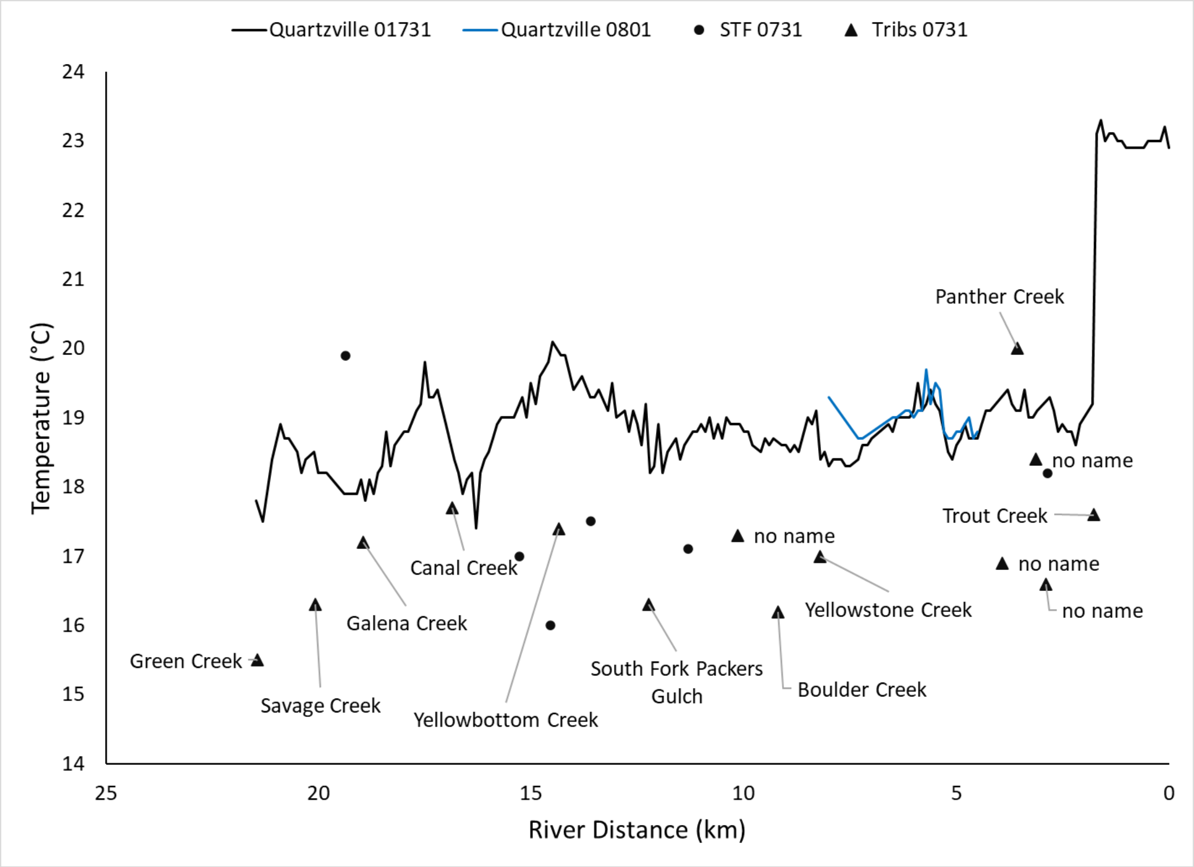


Figure 17: Plot showing the longitudinal temperature profile (LTP) and the tributaries entering the main channel, Quartzville Creek. The plot was prepared using the median values of the sampled pixels.

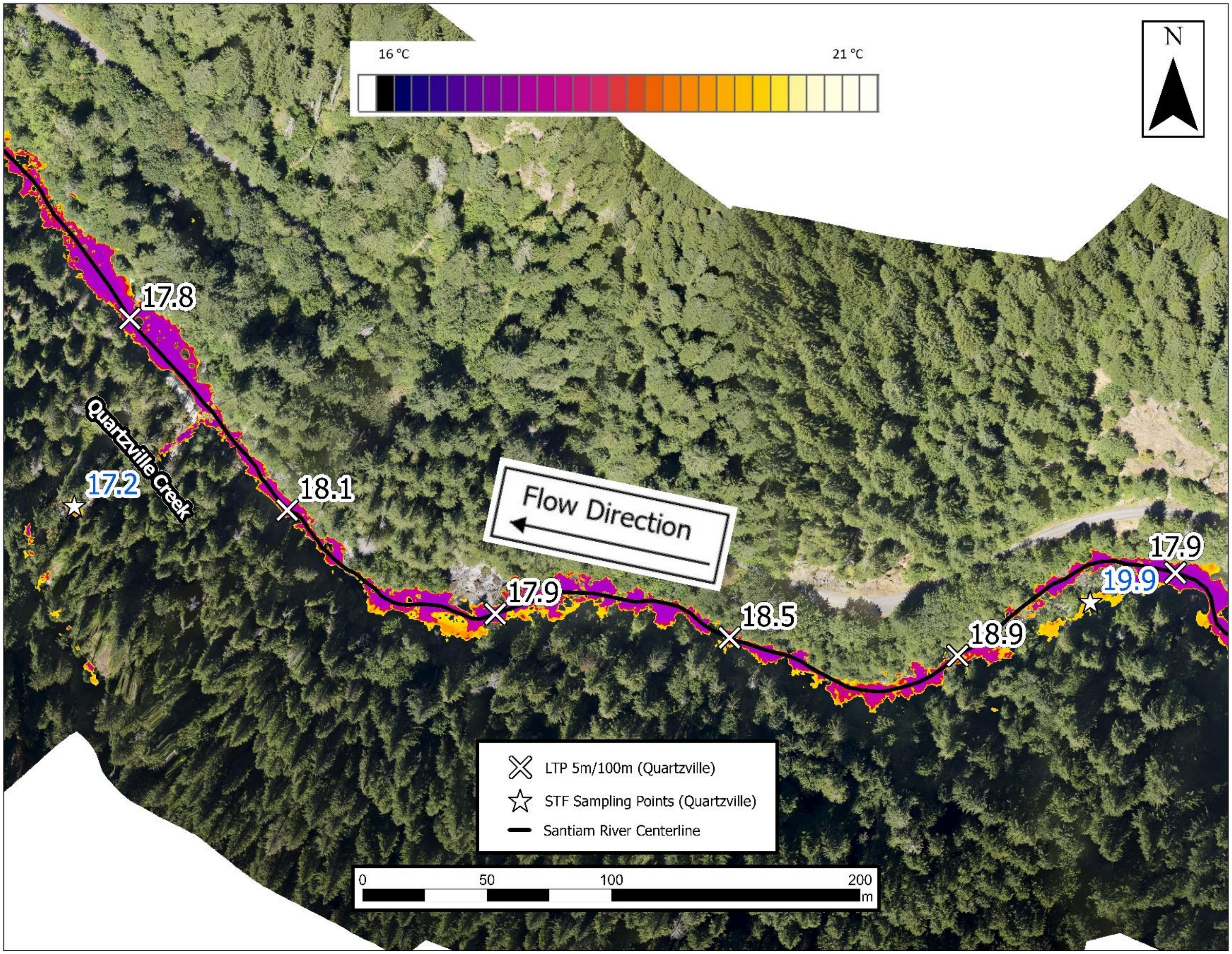


Figure 18: TIR and RGB map showing Galena Creek flowing into the main channel, Quartzville Creek, at 17.2 °C. It is possible to identify a warmer side channel on the eastern side of the map that is 19.9 °C. The main channel was flowing at 17.9 °C.

Middle Santiam and Pyramid Creek

A total length of 24.2 km of Middle Santiam River and 0.63 km of Pyramid Creek were flown, the centerlines were digitized, and their thermal infrared mosaics were sampled at 100-meter intervals to generate the LTP, shown in Figure 19 to Figure 22. The first flight of Middle Santiam occurred on the 1st of August, however due to fires in the area, a temporary flight restriction (TFR) was in place, covering the headwaters in the east-most section of this river's AOI. Once the TFR was lifted and the fires and smoke were under control, a second flight covering the entirety of the Middle Santiam was flown on the 5th of September.

Pyramid Creek merges with Middle Santiam River at the river's headwaters around river km 23.6 (Figure 23). Due to the short distance mapped and the narrow river, there were no significant thermal features or tributaries identified in Pyramid Creek, while Middle Santiam had a total of 10 significant thermal features and seven tributaries.

The thermal feature of the Middle Santiam showed:

1- Both flights took place at almost the exact same time window of day (between 13:23 and 14:31) a month apart.
2- The LTP plot shows that the river has a similar thermal profile, where the river in August was 1.8 °C warmer than in September on average. This was also confirmed by comparing the water temperature recorded by the logger MSR nr Cascadia, which was covered in both flights and showed a 2.12 °C difference in temperature at pacific standard time (PST) 13:40.

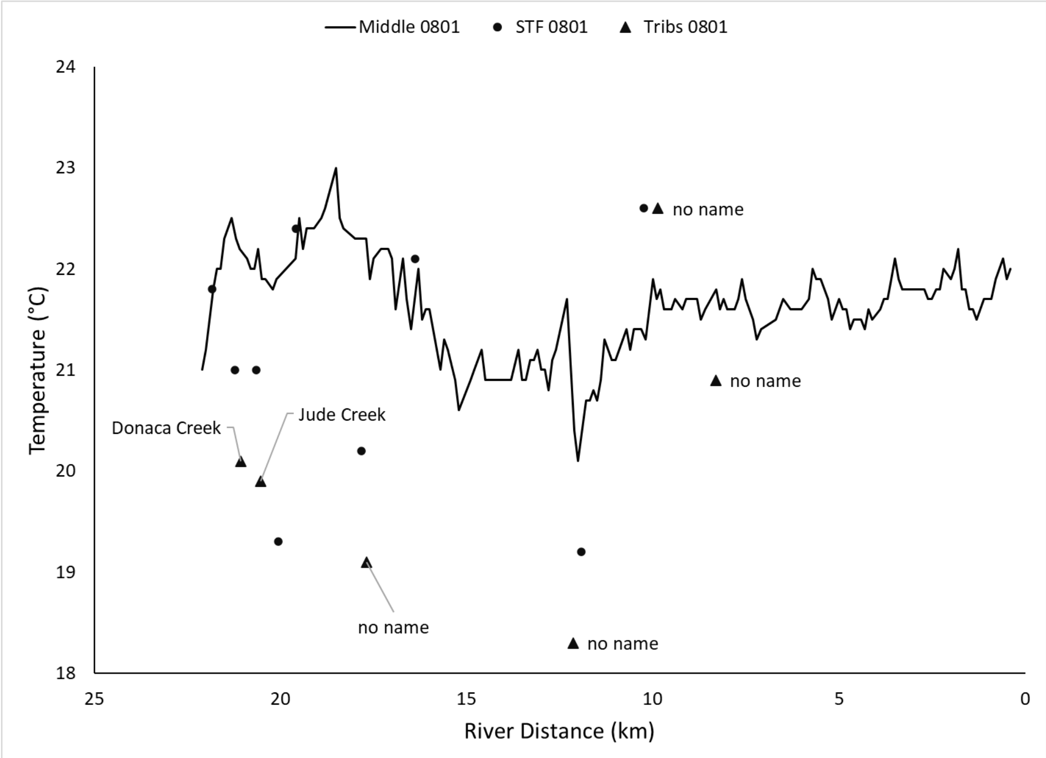


Figure 19: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, Middle Santiam River on the 1st of August.

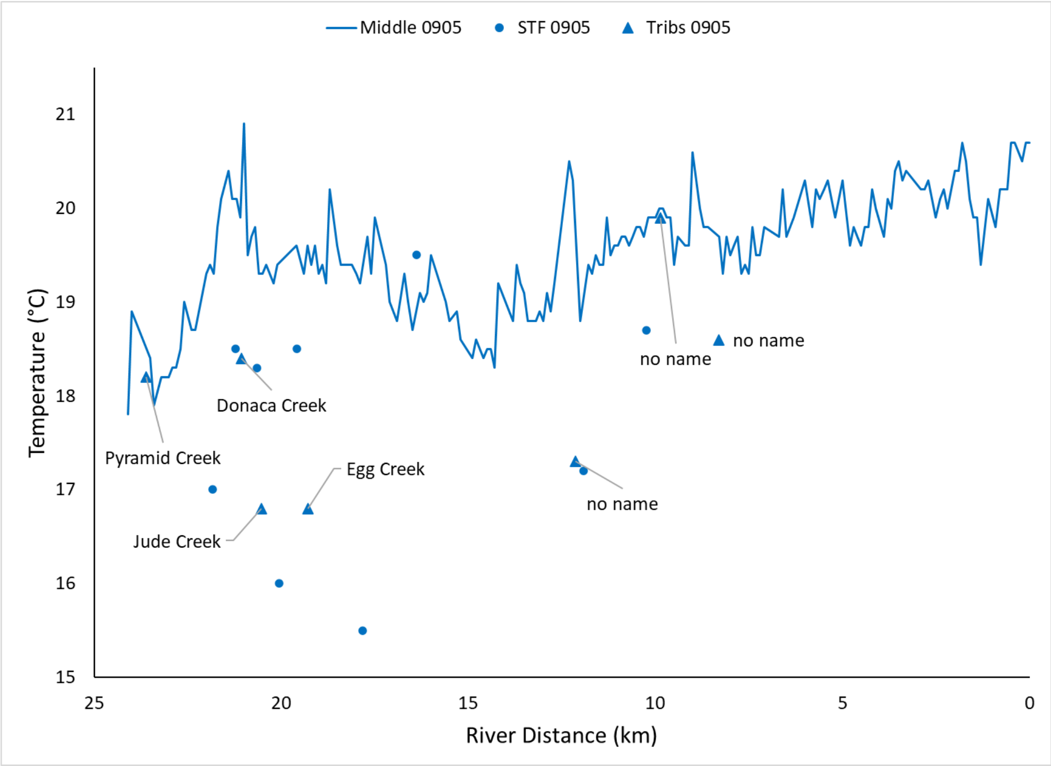


Figure 20: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, Middle Santiam River on the 5th of September.

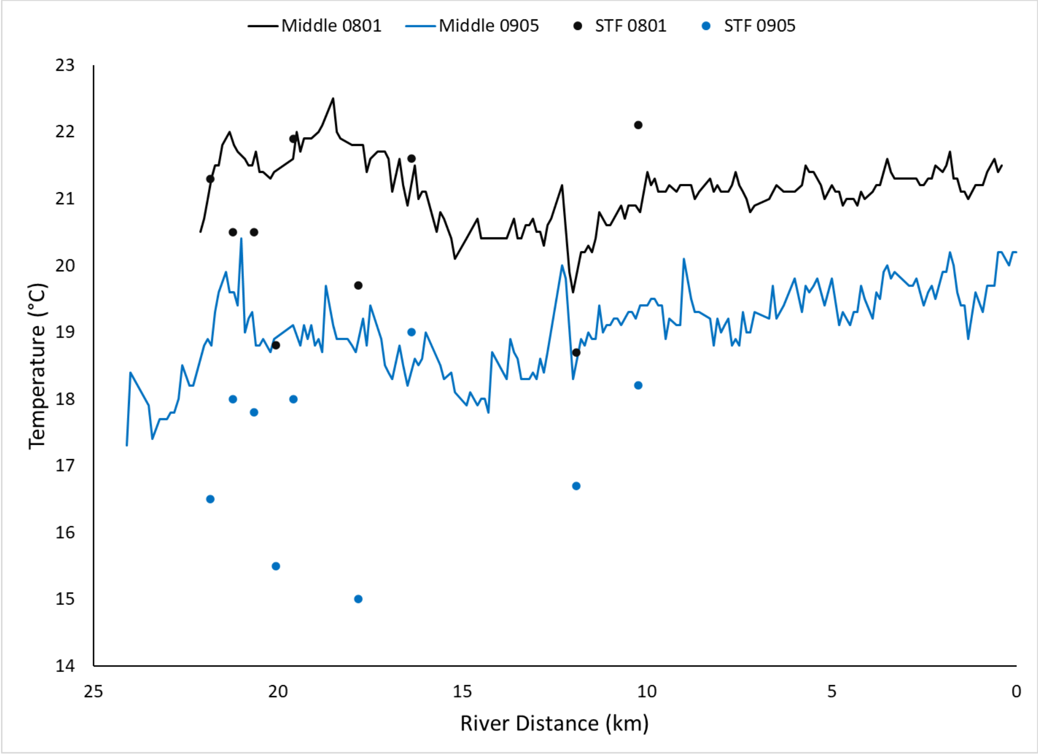


Figure 21: Plot showing the longitudinal temperature profile (LTP) and significant thermal features (STF) from both missions covering the Middle Santiam River.

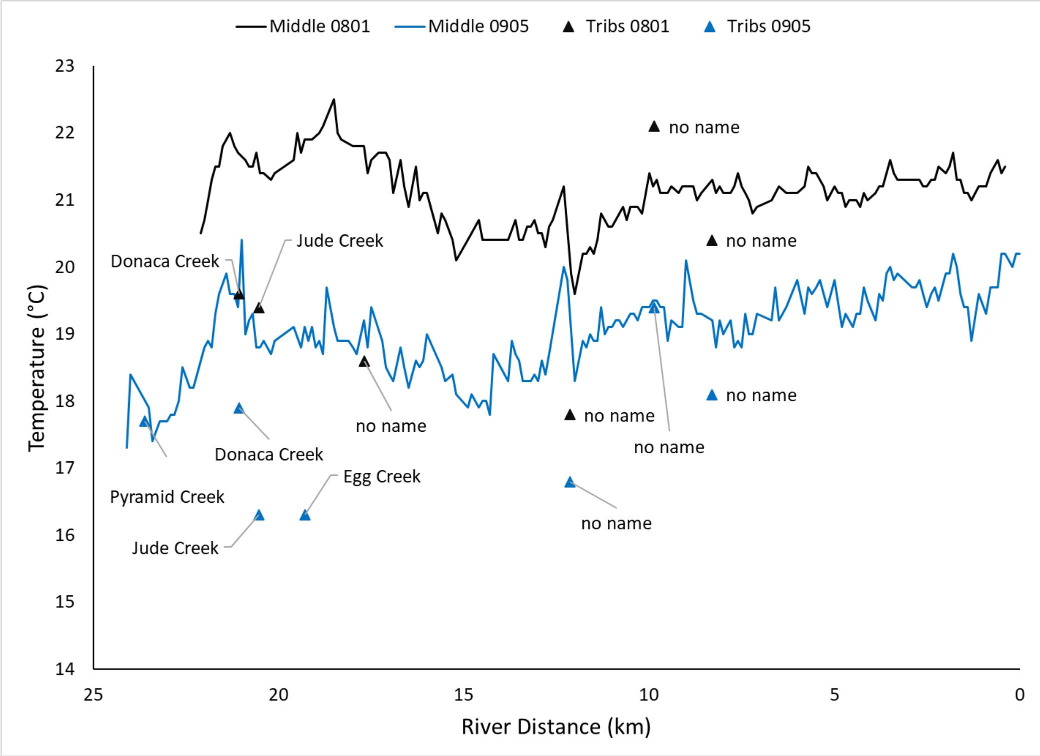


Figure 22: Plot showing the longitudinal temperature profile (LTP) and the tributaries entering the main channel of the Middle Santiam River from both missions.

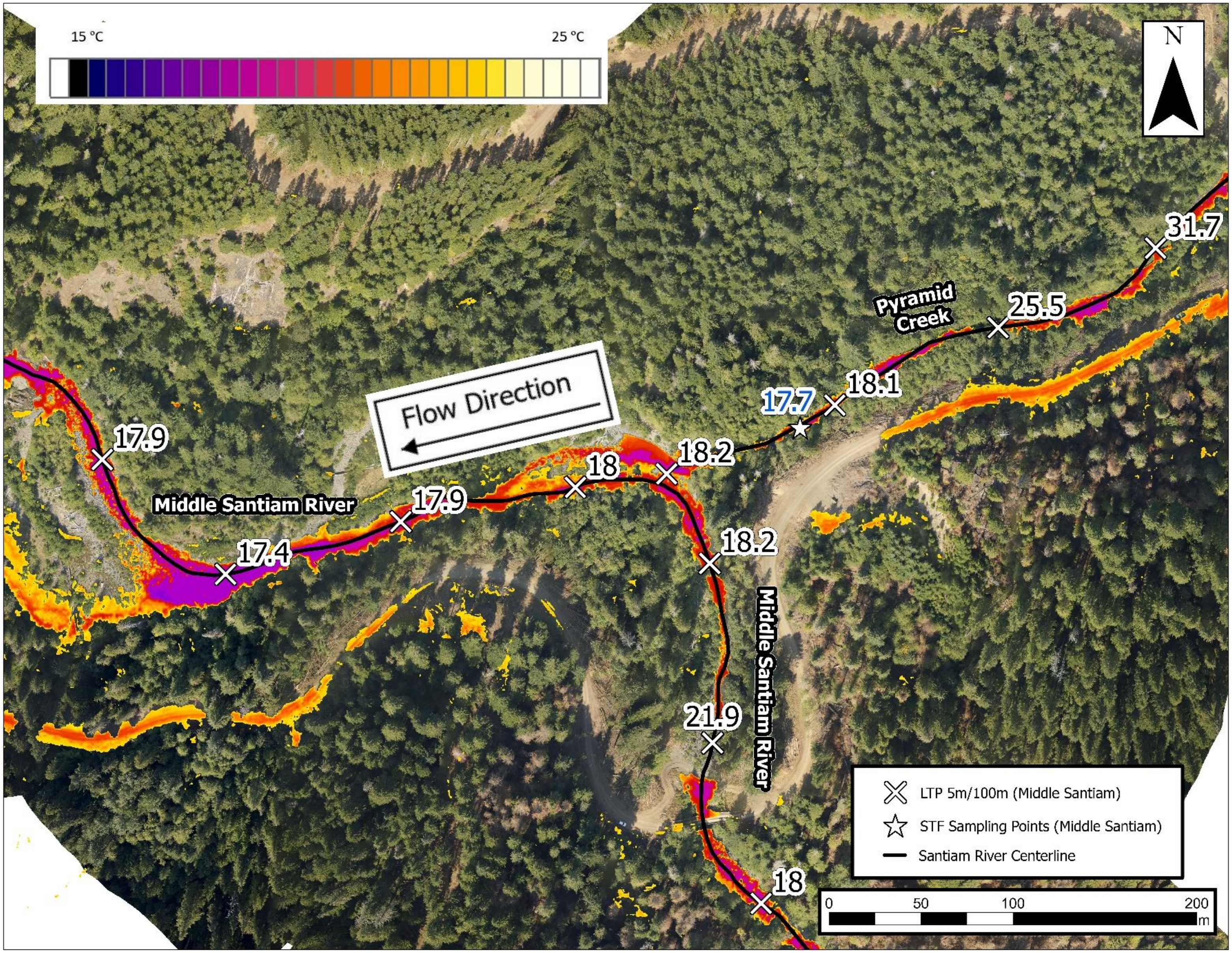


Figure 23: TIR and RGB map showing Pyramid Creek entering the Middle Santiam River at the depicted STF point (17.7°C).

South Santiam

A total length of 40.7 km of the South Santiam River was flown on the 27th of July. A second flight, taking place on the 31st of July, targeted two sections to cover potential data gaps, resulting in a total of three mosaics. The centerlines were digitized, and the thermal infrared mosaics sampled at 100-meter intervals to generate the LTP. There were a total of 9 significant thermal features and 16 tributaries identified in the South Santiam River which can be seen below in Figure 24. The LTP plot and analysis were mostly based on the main mosaic as the gap-filling mosaics were to complete the coverage over the banks.
The thermal feature of the South Santiam showed:

1- An overall downstream warming can be seen in the LTP plots, with discharge temperature starting at 15 °C at the headwaters and reaching 21.3 °C just before the flow drains into Foster Reservoir.

2- Cold-water inflows from tributaries at different location sites led to localized and immediate cooling.

3- High rate of downstream warming can be seen along the section of river km 12 to 8, this is where the river became much wider and, potentially, shallower than nearby sections (Figure 25).

4- Around river km 8 we see a decrease in temperatures, likely caused by cold water inputs such as Shot Pouch tributary (Figure 26) as well as several cold STFs in the form of springs.

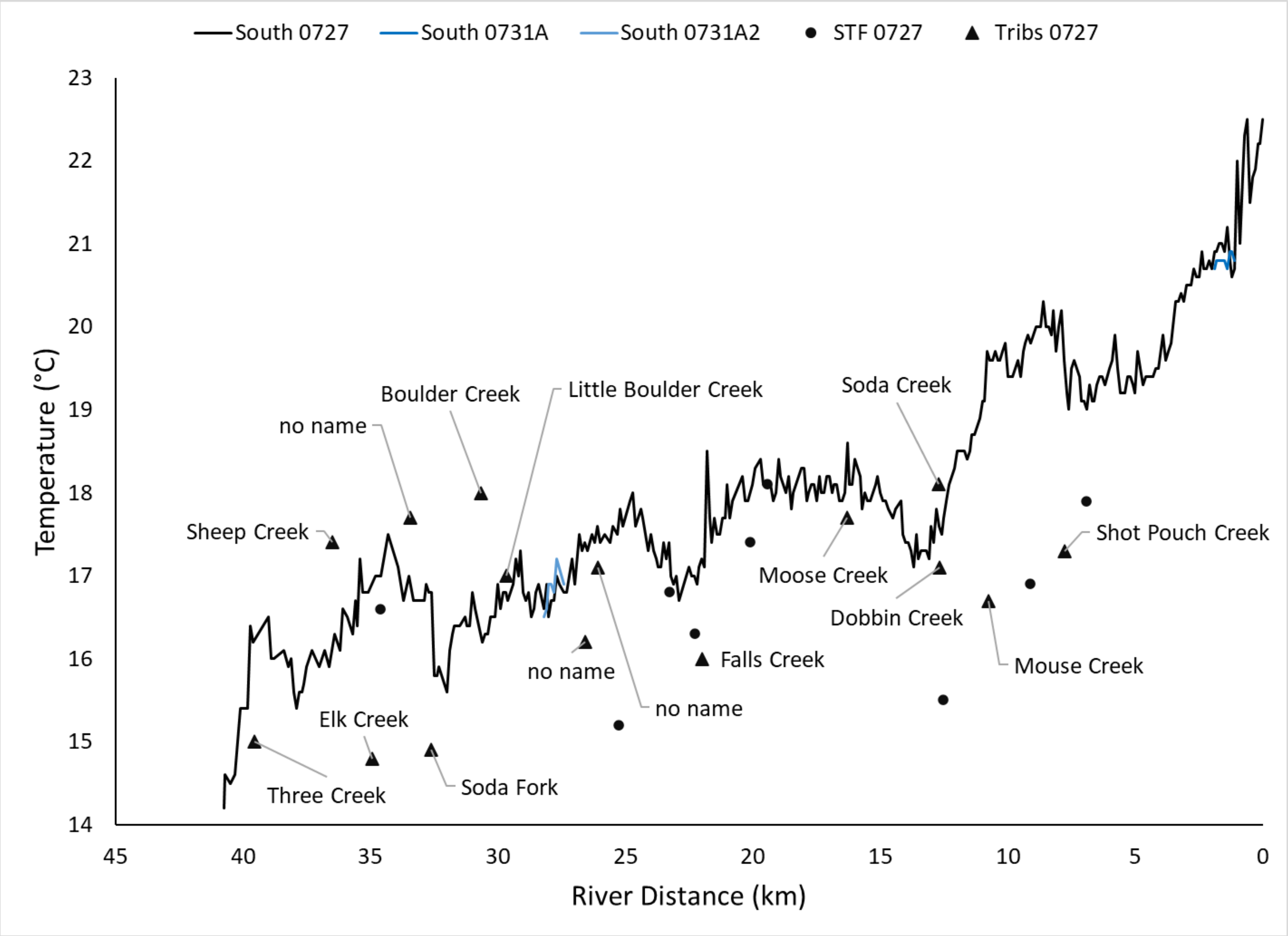


Figure 24: Plot showing the longitudinal temperature profile (LTP), significant thermal features (STF) and the tributaries entering the main channel, South Santiam River. The plot was prepared using the median values of the sampled pixels.

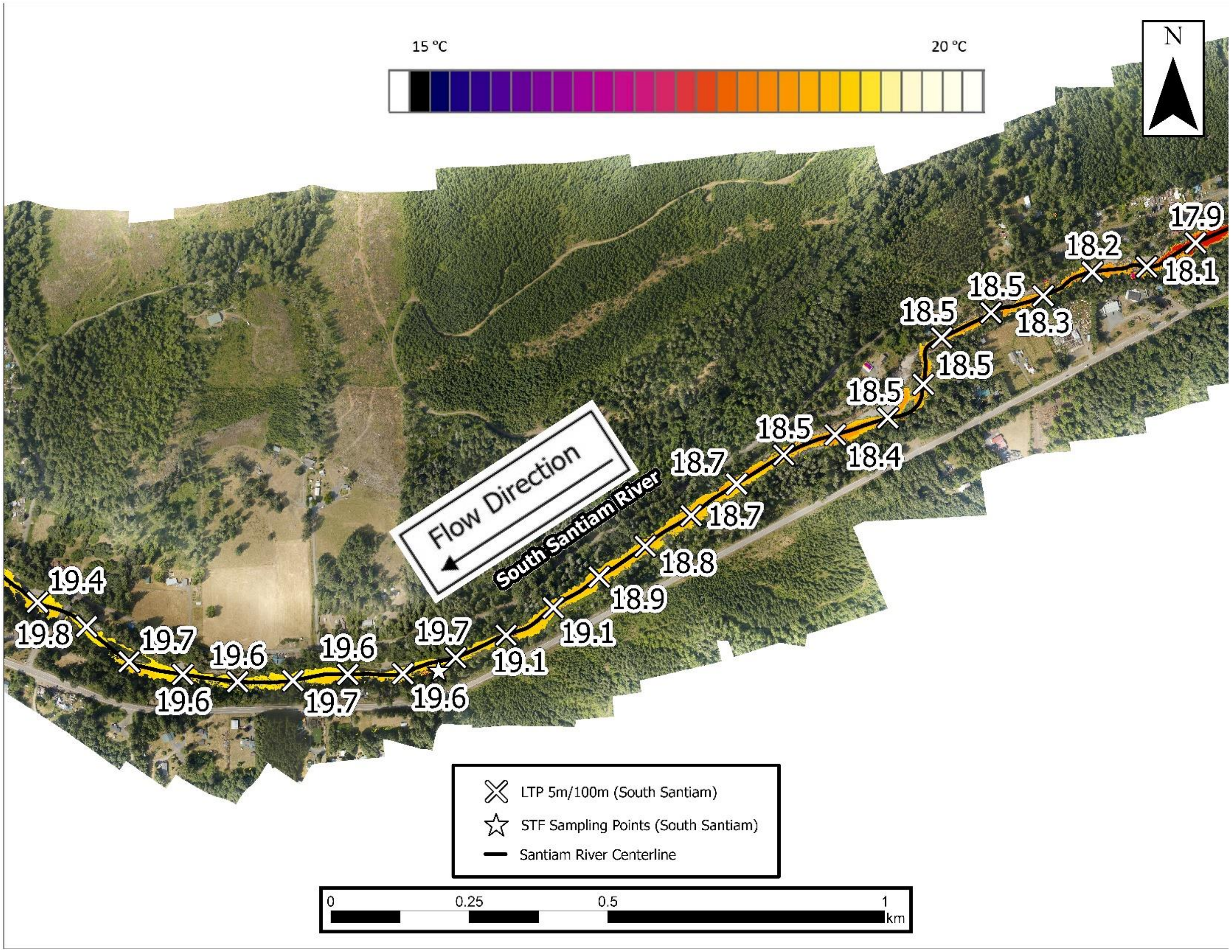


Figure 25: TIR and RGB map showing a warming trend from rkm 12 to 10 where water temperature in the channel increased from 17.9 °C to 19.4 °C along a distance of 2 kms. In this stretch, Moose Creek Tributary is also depicted around the same temperature as the main channel (19.6 °C).

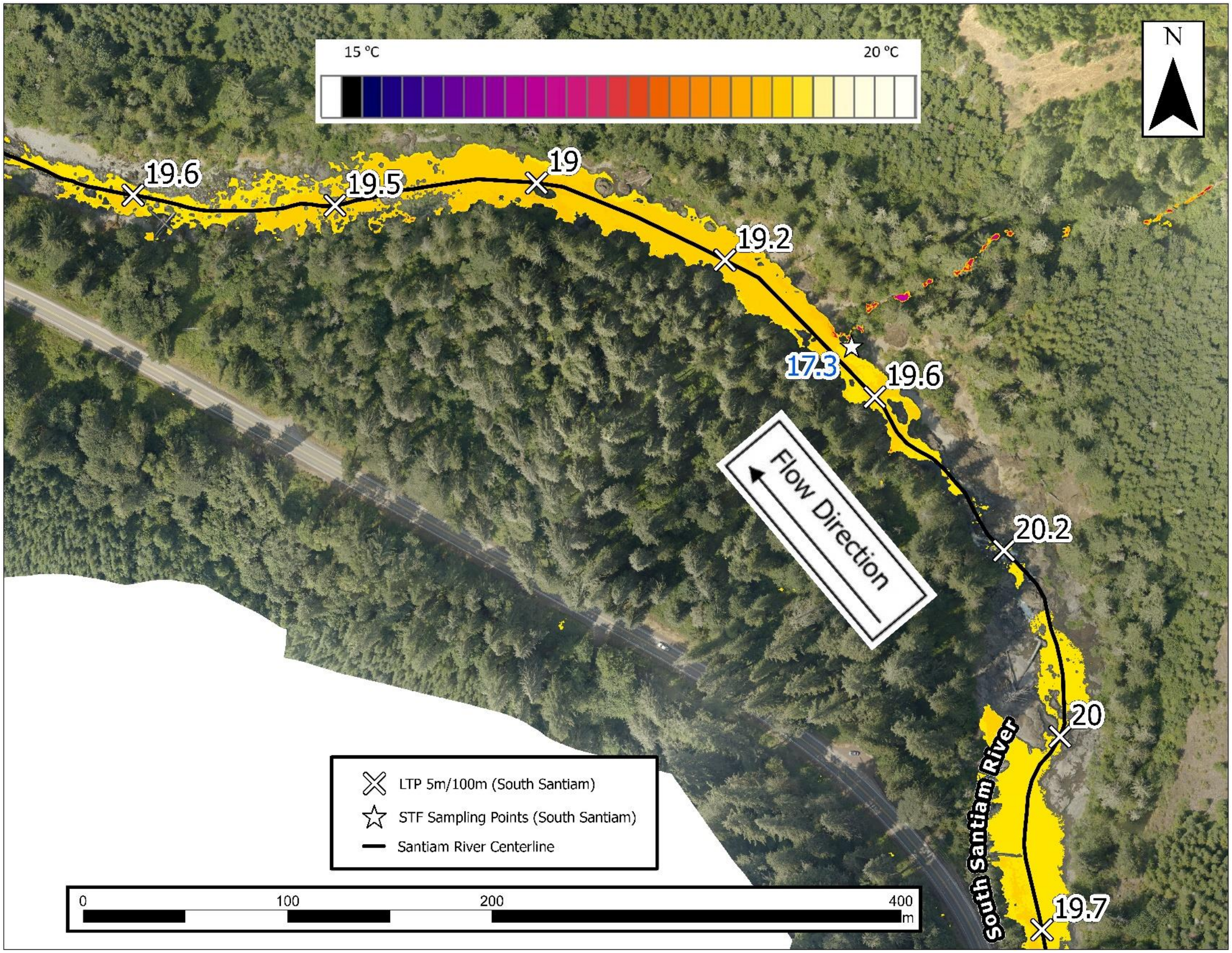


Figure 26: TIR and RGB map showing the confluence of the colder Shot Pouch Creek (17.3 °C) with the warmer South Santiam River main stem (19.6 °C).

Significant Thermal Features

The following table details temperature statistics for tributaries that were identified and sampled in the survey area.

Stream Name	Tributary	River (km)[2]	Mean (°C)[3]	Median (°C)[4]	Min (°C)[5]	Max (°C)[6]	Standard Deviation (°C)[7]
Breitenbush River	Bryars Creek	5.5	16.0	14.5	14.0	26.2	3.028
Breitenbush River	Bryars Creek	5.5	13.3	13.2	12.9	14.9	0.392
Breitenbush River	Canyon Creek	2.0	18.7	18.2	17.7	22.1	1.073
Breitenbush River	Cliffs Creek	7.7	18.4	18.4	18.2	19.1	0.174
Breitenbush River	Cultus Creek	9.6	19.1	18.9	18.4	21.0	0.624
Breitenbush River	Deadhorse Creek	5.8	17.4	16.4	15.3	22.7	2.231
Breitenbush River	Devils Creek	18.0	20.5	20.4	20.4	20.8	0.117
Breitenbush River	Fox Creek	10.3	18.7	18.5	16.6	22.0	1.270
Breitenbush River	Hill Creek	15.3	17.2	17.0	16.9	18.2	0.273
Breitenbush River	Humbug Creek	8.0	16.3	16.3	16.1	16.4	0.074
Breitenbush River	Leone Creek	14.6	19.0	19.0	18.6	20.1	0.385
Breitenbush River	Mansfield Creek	17.2	17.9	17.7	17.3	19.5	0.490
Breitenbush River	No name	4.0	19.8	19.7	18.1	22.4	1.149
Breitenbush River	Scorpion Creek	12.6	17.5	17.3	17.1	18.7	0.385
Breitenbush River	Slide Creek	6.6	18.8	18.8	18.6	19.5	0.212
Breitenbush River	Wind Creek	3.2	17.7	17.6	17.4	18.5	0.246
Breitenbush River	Wind Creek	3.2	16.7	16.6	16.4	17.3	0.190
Little North Santiam River	Bear Creek	14.6	24.8	24.6	23.3	26.6	0.917
Little North Santiam River	Big Creek	17.5	22.6	22.3	21.1	25.8	1.246
Little North Santiam River	Canyon Creek	13.8	22.1	22.0	21.6	23.1	0.366

[2] River distance (km) along the digitized centerline that is closest to the STF location
[3] Mean temperature (°C) of sampled pixels of the TIR mosaic inside the buffered area of STF sampling point
[4] Median temperature (°C) of sampled pixels of the TIR mosaic inside the buffered area of STF sampling point
[5] Minimum temperature (°C) of sampled pixels of the TIR mosaic inside the buffered area of STF sampling point
[6] Maximum temperature (°C) of sampled pixels of the TIR mosaic inside the buffered area of STF sampling point
[7] Standard deviation temperature (°C) of sampled pixels of the TIR mosaic inside the buffered area of STF sampling point

Stream Name	Tributary	River (km)[2]	Mean (°C)[3]	Median (°C)[4]	Min (°C)[5]	Max (°C)[6]	Standard Deviation (°C)[7]
Little North Santiam River	Cougar Creek	16.9	21.0	20.9	20.2	22.5	0.612
Little North Santiam River	Cox Creek	7.5	21.4	21.1	20.6	23.8	0.809
Little North Santiam River	Elkhorn Creek	22.9	23.3	23.3	23.2	23.4	0.062
Little North Santiam River	Evans Creek	27.3	24.0	24.0	23.9	24.2	0.075
Little North Santiam River	Jeeter Creek	8.1	23.1	22.9	22.5	24.5	0.481
Little North Santiam River	Kiel Creek	9.4	23.3	23.3	23.0	23.5	0.107
Little North Santiam River	No name	12.9	23.9	24.2	21.3	28.0	2.081
Little North Santiam River	Polly Creek	6.7	23.1	23.1	22.1	24.8	0.667
Little North Santiam River	Sinker Creek	20.1	21.7	21.6	21.5	22.2	0.204
Little North Santiam River	Wonder Creek	17.7	20.7	20.6	20.4	22.0	0.301
Middle Santiam River	Donaca Creek	21.1	19.7	19.6	19.3	21.6	0.446
Middle Santiam River	Donaca Creek	21.1	18.1	17.9	17.3	20.2	0.750
Middle Santiam River	Egg Creek	19.3	16.9	16.3	14.8	21.7	1.721
Middle Santiam River	Jude Creek	20.5	19.7	19.4	19.3	21.7	0.571
Middle Santiam River	Jude Creek	20.5	16.4	16.3	16.2	16.8	0.142
Middle Santiam River	No name	8.3	20.4	20.4	20.3	20.6	0.062
Middle Santiam River	No name	8.3	18.1	18.1	18.0	18.2	0.051
Middle Santiam River	No name	9.9	22.1	22.1	21.9	22.3	0.100
Middle Santiam River	No name	9.9	19.4	19.4	19.2	19.6	0.090
Middle Santiam River	No name	12.1	17.8	17.8	17.6	18.5	0.166
Middle Santiam River	No name	12.1	16.8	16.8	16.7	17.0	0.079
Middle Santiam River	No name	17.7	19.0	18.6	18.1	21.6	0.942
Middle Santiam River	Pyramid Creek	23.6	17.7	17.7	17.5	18.0	0.100
North Fork Breitenbush River	South Fork Breitenbush River	0.0	14.2	14.2	14.1	14.3	0.047
North Santiam River	Boulder Creek	2.8	20.2	20.1	19.9	21.0	0.302

Stream Name	Tributary	River (km)[2]	Mean (°C)[3]	Median (°C)[4]	Min (°C)[5]	Max (°C)[6]	Standard Deviation (°C)[7]
North Santiam River	Marion Creek	25.2	16.0	16.0	15.9	16.1	0.046
North Santiam River	Mary's Creek	8.6	21.4	21.2	21.1	23.6	0.438
North Santiam River	Misery Creek	11.0	18.8	18.8	18.5	19.0	0.150
North Santiam River	Pamelia Creek	19.3	13.9	13.9	13.8	14.0	0.054
Quartzville Creek	Boulder Creek	9.2	16.2	16.2	16.0	16.6	0.121
Quartzville Creek	Canal Creek	16.9	17.7	17.7	17.6	18.0	0.094
Quartzville Creek	Galena Creek	18.9	17.3	17.2	17.1	18.0	0.162
Quartzville Creek	Green Creek	21.4	15.8	15.5	14.8	18.3	0.874
Quartzville Creek	No name	2.9	16.9	16.6	15.9	19.6	0.870
Quartzville Creek	No name	3.1	18.5	18.4	17.2	19.8	0.811
Quartzville Creek	No name	3.9	16.9	16.9	16.7	17.1	0.082
Quartzville Creek	No name	10.2	17.4	17.3	16.7	18.5	0.469
Quartzville Creek	Panther Creek	3.6	20.3	20.0	19.5	22.2	0.696
Quartzville Creek	Savage Creek	20.1	16.7	16.3	15.8	20.5	1.046
Quartzville Creek	South Fork Packers Gulch	12.2	16.5	16.3	16.2	18.8	0.496
Quartzville Creek	Trout Creek	1.8	17.8	17.6	17.3	21.9	0.873
Quartzville Creek	Yellowbottom Creek	14.4	17.7	17.4	17.0	19.7	0.726
Quartzville Creek	Yellowstone Creek	8.2	17.2	17.0	16.9	18.7	0.404
South Santiam River	Boulder Creek	30.7	18.5	18.0	16.7	22.9	1.585
South Santiam River	Dobbin Creek	12.7	17.2	17.1	16.9	18.2	0.273
South Santiam River	Elk Creek	34.9	15.0	14.8	13.5	20.0	1.383
South Santiam River	Falls Creek	22.0	16.2	16.0	15.6	18.7	0.651
South Santiam River	Little Boulder Creek	29.7	17.4	17.0	16.0	20.5	1.063
South Santiam River	Moose Creek	16.3	17.7	17.7	17.6	18.0	0.076
South Santiam River	Mouse Creek	10.8	16.8	16.7	16.6	17.5	0.234
South Santiam River	No name	26.1	17.2	17.1	16.2	19.0	0.717

Stream Name	Tributary	River (km)[2]	Mean (°C)[3]	Median (°C)[4]	Min (°C)[5]	Max (°C)[6]	Standard Deviation (°C)[7]
South Santiam River	No name	26.6	16.2	16.2	16.0	16.8	0.151
South Santiam River	No name	33.4	17.9	17.7	17.2	19.3	0.570
South Santiam River	Sheep Creek	36.5	17.5	17.4	17.1	18.1	0.216
South Santiam River	Shot Pouch Creek	7.8	17.4	17.3	17.1	18.4	0.317
South Santiam River	Soda Creek	12.7	18.3	18.1	16.7	20.5	1.087
South Santiam River	Soda Fork	32.6	14.9	14.9	14.9	15.0	0.050
South Santiam River	Three Creek	39.5	15.1	15.0	14.8	16.4	0.401

Appendix B - Shapefiles Headers

The following are the headers details of the LTP, STF, and Temperature Loggers (Accuracy) shapefiles:

LTP:

Header	Explanation
GNIS_NAME	The river name
Rvr_meas_m	River length (meter) at which temperature was sampled, starting from the downstream end
Rvr_km	River length (km) at which temperature was sampled, starting from the downstream end
Rvr_mile	River length (mile) at which temperature was sample, starting from the downstream end
Mean	Mean water temperature, a result of 10 sampled points along the centerline within the specified buffer
Median	Median water temperature, a result of 10 sampled points along the centerline within the specified buffer
Min	Minimum water temperature, a result of 10 sampled points along the centerline within the specified buffer
Max	Maximum water temperature, a result of 10 sample points along the centerline within the specified buffer
Std_Dev	Standard deviation water temperature, a result of 10 sampled points along the centerline within the specified buffer

STF:

Header	Explanation
Id	Unused field- can be used by end users to recategorize points
notes	Note about the significant thermal feature
Strm_Name	Stream name closest to the location of the significant thermal feature
L_R_Bank	The location of the significant thermal feature, left or right bank, relative to the centerline
M_Off_str	Distance of the significant thermal feature from the closest stream (meter)
Rvr_meas_m	River length (meter) where the significant thermal feature was found, starting from the downstream end
Rvr_km	River length (km) at which temperature was sampled, starting from the downstream end
Rvr_mile	River length (mile) where the significant thermal feature was found, starting from the downstream end
Mean	Mean water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Median	Median water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Min	Minimum water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Max	Maximum water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Std_Dev	Standard deviation of the water temperature at the significant thermal feature, a result of all pixels within the specified buffer

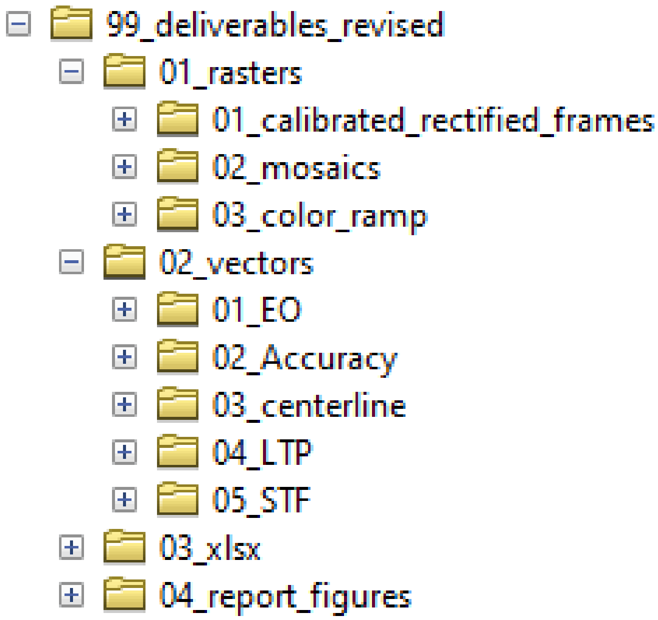
Temperature Loggers (Accuracy):

Header	Explanation
Name	Logger's name provided by client
Tw_C	Water temperature by the logger at the time of acquiring the specific flight line (see below)

Date_Time	Date and time at which the water temperature was recorded and coinciding with the time window of acquiring TIR flightlines that covers the logger's site
Flight_lin	Flightline's serial number covering the logger's site
Strm_Name	Stream name closest to the location of the significant thermal feature
L_R_Bank	The location of the significant thermal feature, left or right bank, relative to the centerline
M_Off_str	Distance of the significant thermal feature from the closest stream (meter)
Rvr_meas_m	River length (meter) where the significant thermal feature was found, starting from the downstream end
Rvr_km	River length (km) at which temperature was sampled, starting from the downstream end
Rvr_mile	River length (mile) where the significant thermal feature was found, starting from the downstream end
Mean	Mean water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Median	Median water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Min	Minimum water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Max	Maximum water temperature at the significant thermal feature, a result of all pixels within the specified buffer
Std_Dev	Standard deviation of the water temperature at the significant thermal feature, a result of all pixels within the specified buffer

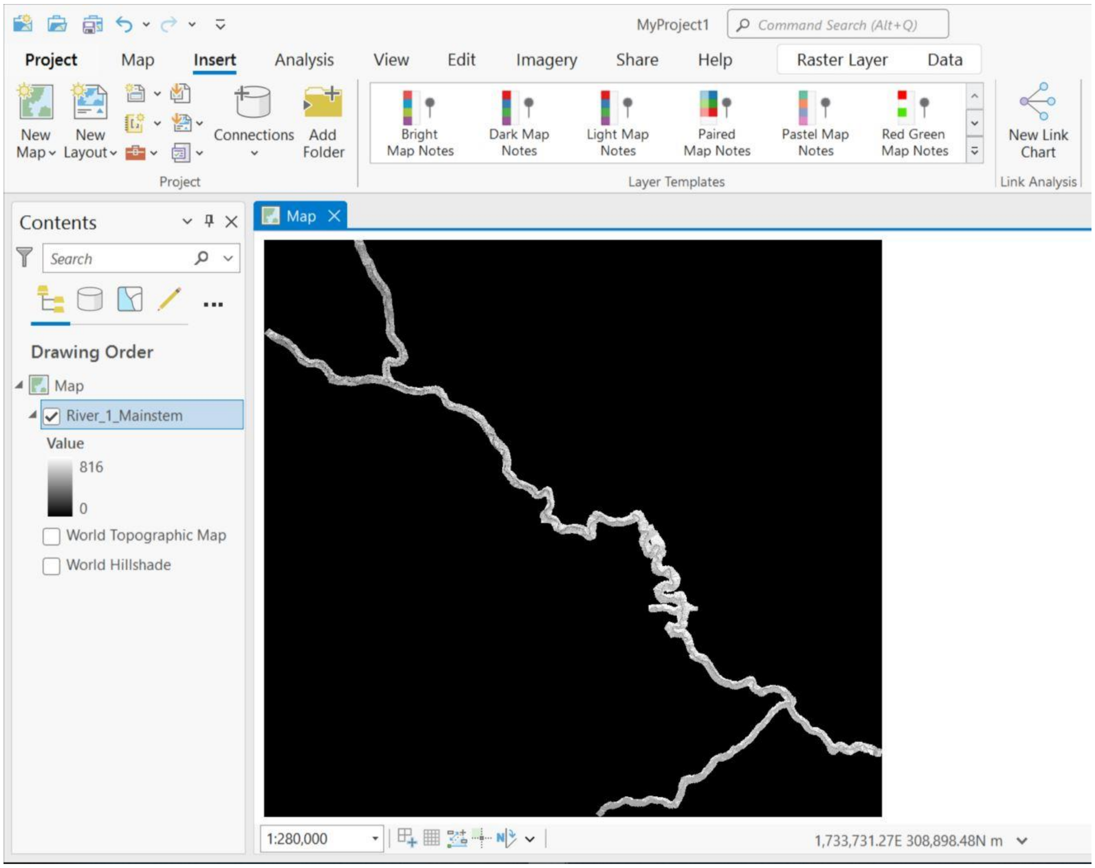
Navigating to Data Folders and Files in ESRI ArcCatalog

ArcCatalog is used to navigate data folders and files where data properties/metadata can be found. To load files into ArcMap, drag and drop files from ArcCatalog. It is also possible to drag and drop the *.shp/*.tif files using the local operating system navigation platform.



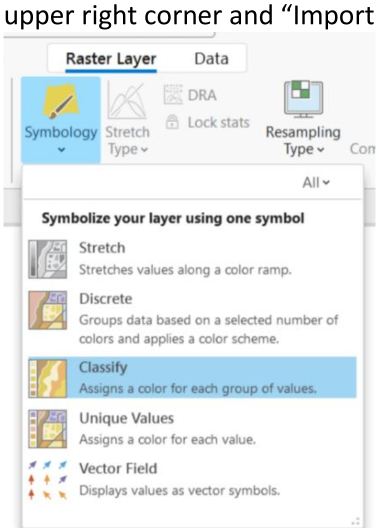
Load Mosaic Rasters

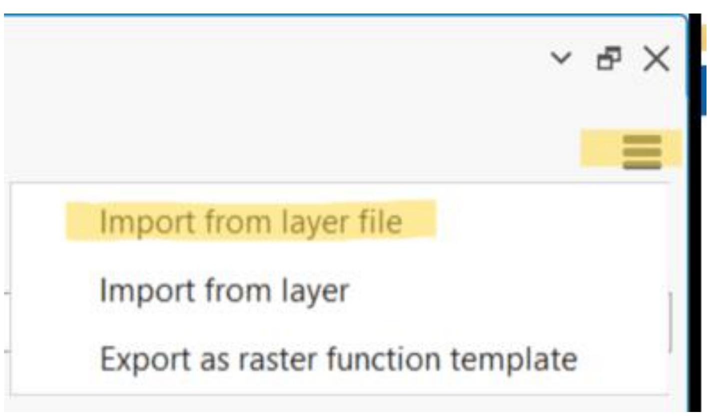
The main raster data used is the mosaicked imagery. Individual frames are provided for reference. Load the mosaic files (*.tif) of interest into ArcPro - the stretched color scheme of the file is automatically shown in grayscale. TIR mosaics are found in the mosaics folder.



Working with Color Ramps

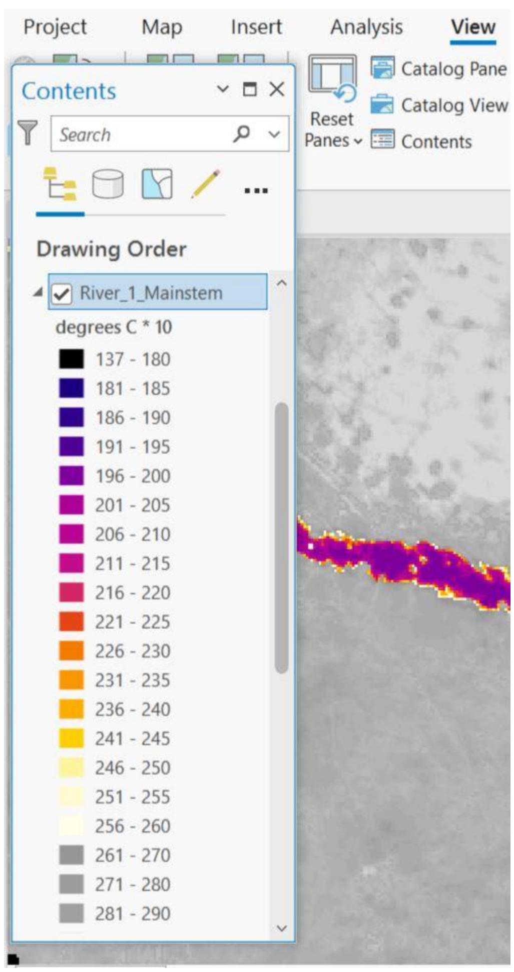
There are several different ways to bring up the symbology properties to apply the provided, customized color ramp file (*.lyrx). From the contents pane, either double click on the color bar under “Value” (see the image above) or right click symbology from the corresponding layer. Another way involves clicking on the mosaic in the contents pane, this will bring up a Raster Layer tab in the ribbon, then Symbology → Classify (below left image). In the symbology dialogue box, click on the three horizontal lines in the upper right corner and “Import from layer file” (bottom right image).

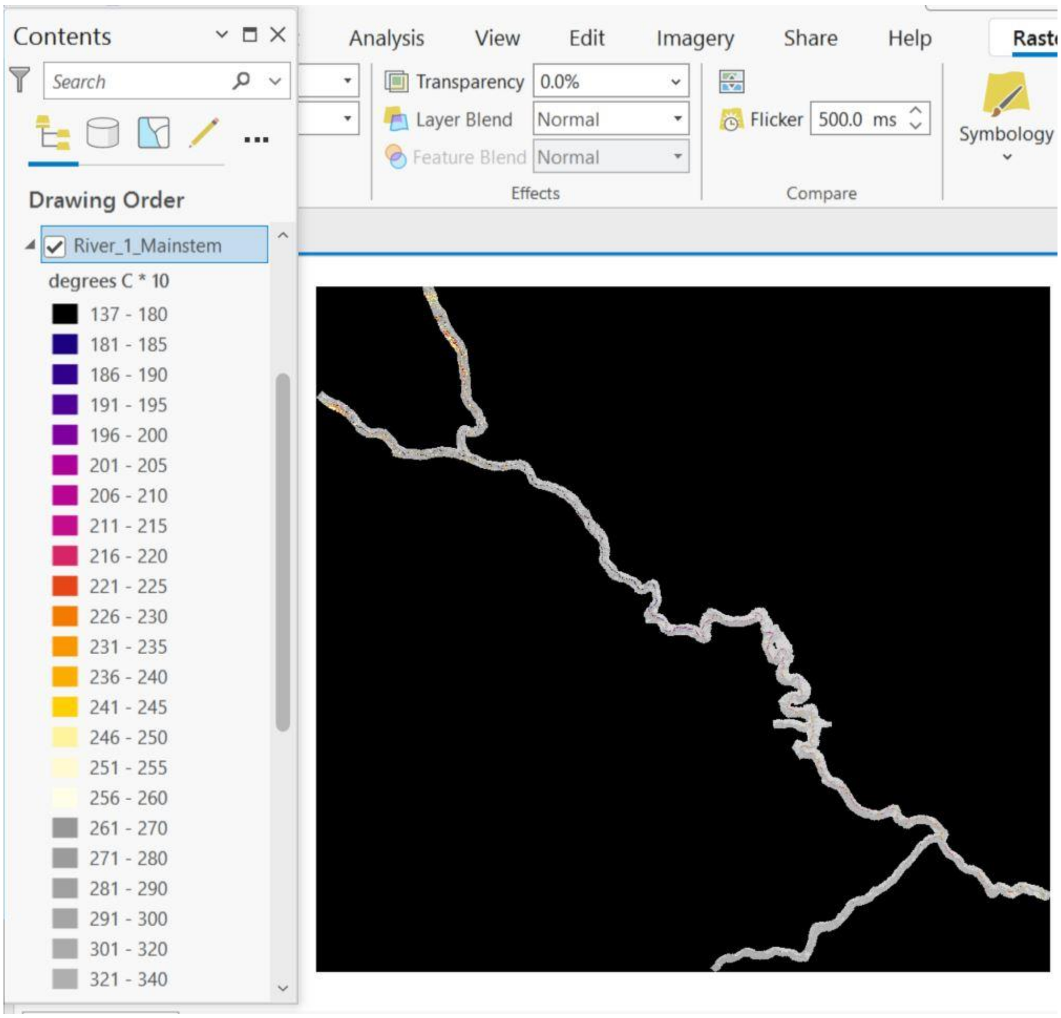




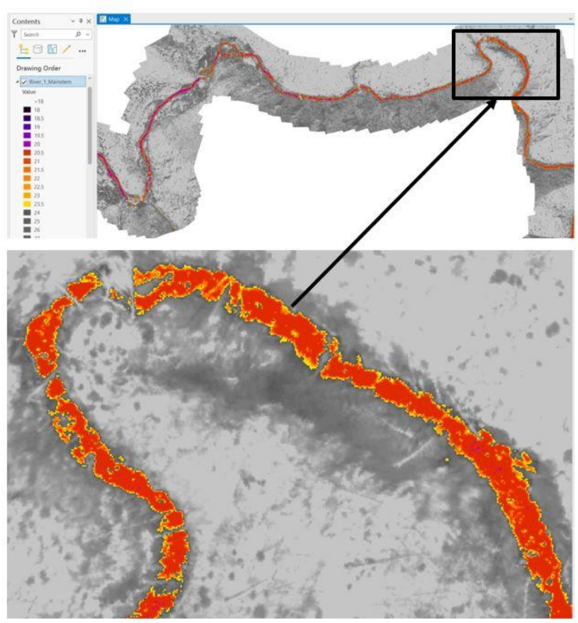
The color ramp layers, in the “color ramps” folder, can be arranged according to the names of tributaries of your project, according to customized temperature ranges, or a combination of both. The goal of customizing the color ramps is to highlight temperature anomalies of interest.

- The numbers in the color ramp file name symbolize the specific temperature range from cold to warm color scheme.
- Temperatures above the upper value visualize raster pixels in the grayscale.
- The first example below includes the temperature unit and the multiplication value: Celsius multiplied by 10.
- The second example highlights pixels values with temperatures 18 °C to 26 °C. The coldest pixel value is 18 °C and the warmest temperature range is 26 °C. Any temperature colder than 14 °C will be colored as 14 °C. Pixel values above 26 °C are in grayscale stretched to the warmest pixel value.
- The legend then shows the color ramps in the specified temperature. The values are edited to remove the multiplication. NOTE: This is not done automatically. If any of the values of the mosaic are changed in ArcGIS Pro, the original, imported color ramp will need to be changed or the colors might not accurately reflect the dataset. The name (selected in the first image) can be changed without changing the color ramp.





Zoom in and pan to review the mosaic:



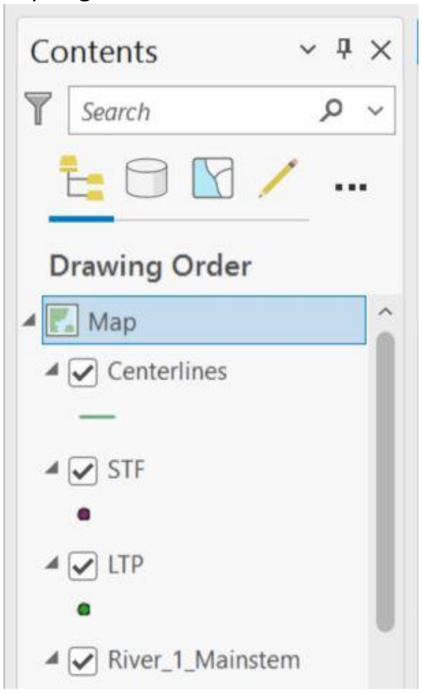
Load Vector Files

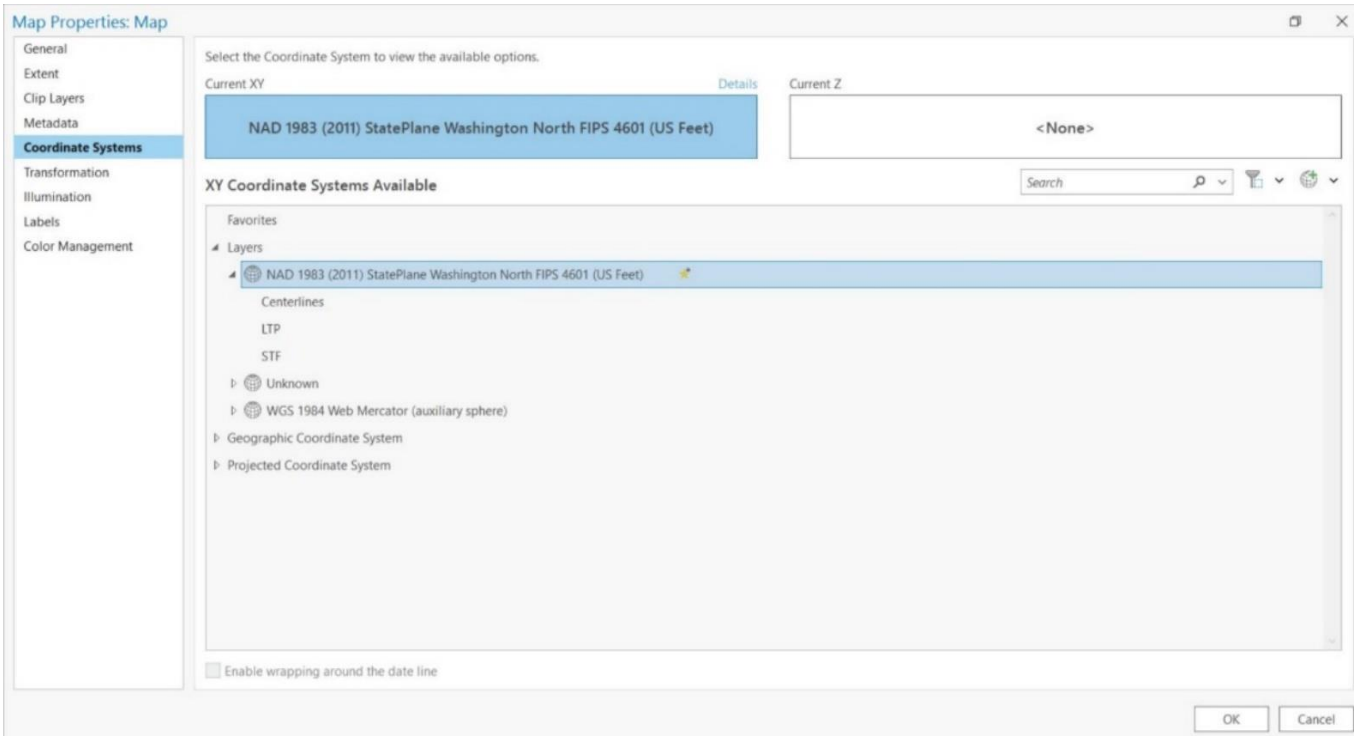
The vector files represent analyses of the thermal data in shapefile format:

1- The exterior orientation (EO) file is a point shapefile representing information related to each image frame used in the project.
2- The accuracy assessment point shapefile contains information of the water temperature data loggers that were used to calibrate the thermal infrared imagery. It also includes comparison analysis (accuracy assessment) between the recorded water temperature and the calibrated mosaic pixel values.
3- The centerline file is a polyline shapefile that was manually digitized to follow the river's thalweg based on the thermal mosaic and is used in generating the longitudinal temperature profile and significant thermal feature files.
4- The longitudinal temperature profile (LTP) is a point shapefile of the sampled mosaic at specified intervals.
5- The significant thermal feature (STF) is a point shapefile of the sampled features of interest for the project.

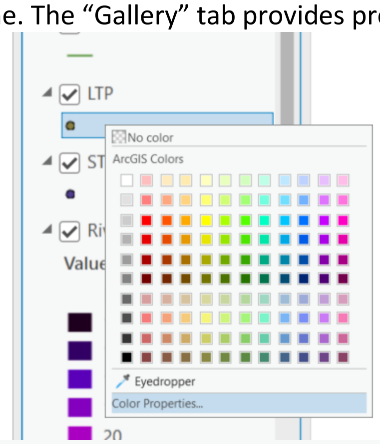
Working with Centerlines, LTP, and STF

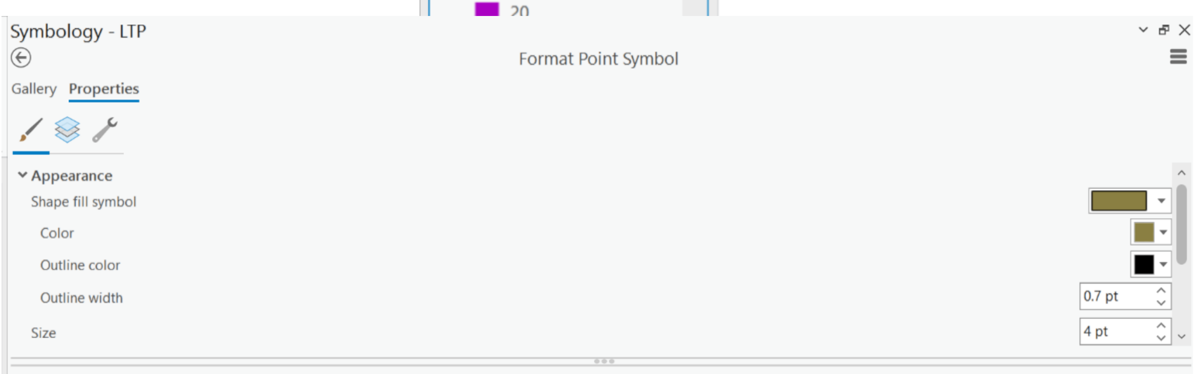
Make sure that when you load in the vectors that you set the coordinate system of the map to match the layers so that everything shows up together. Either double click or right click on the map layer.





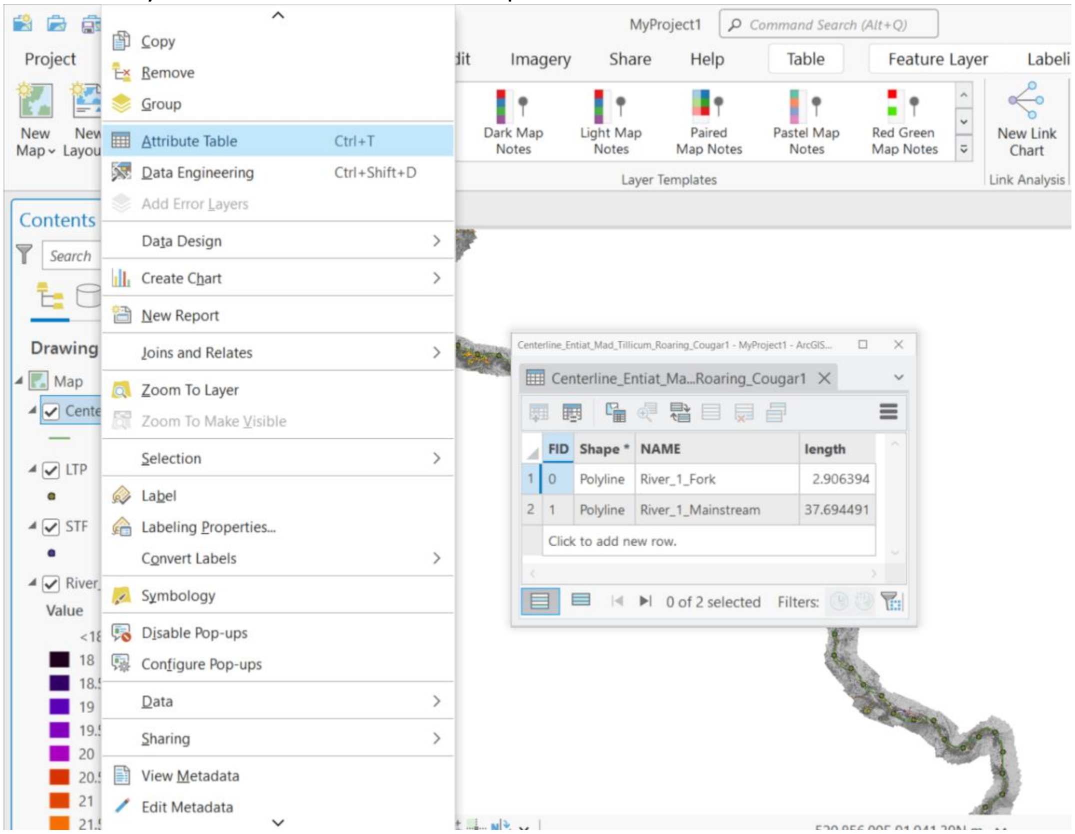
Note that any of the symbols can be adjusted for easier viewing by either double clicking or right clicking on the symbol in the contents pane. The "Gallery" tab provides pre-set shapes to use for the symbol.



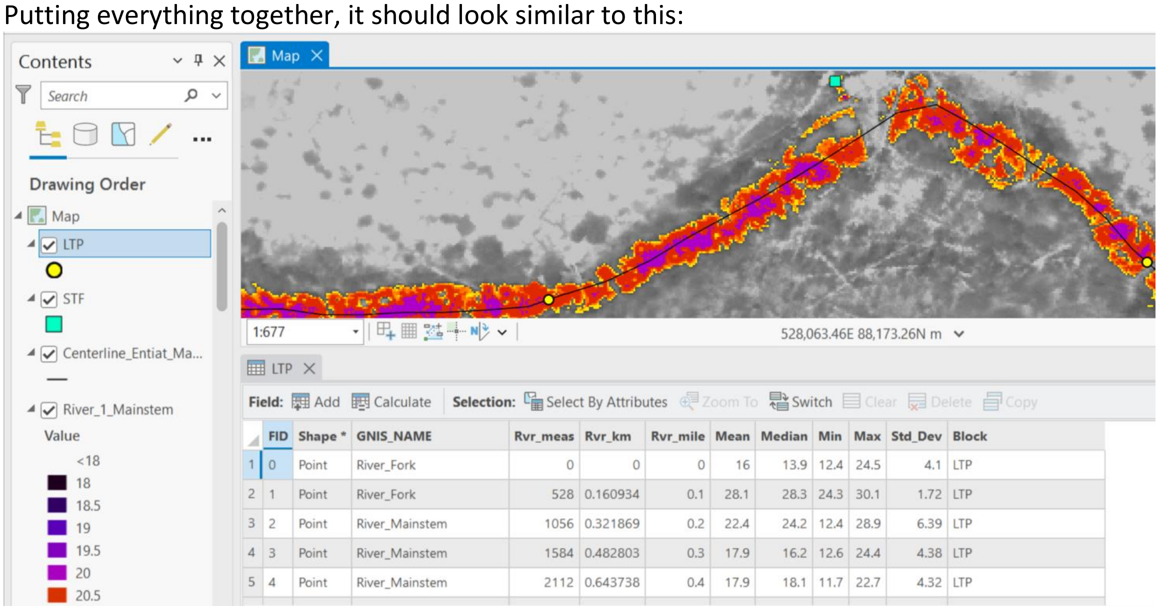


Attribute Tables

Open the attribute table to show feature details. Fields from the attribute tables are explained in the *.xlsx file. Select a feature and zoom in or pan across the TIR mosaic.
Right click on the layer of interest in the contents pane and select “Attribute Table”:



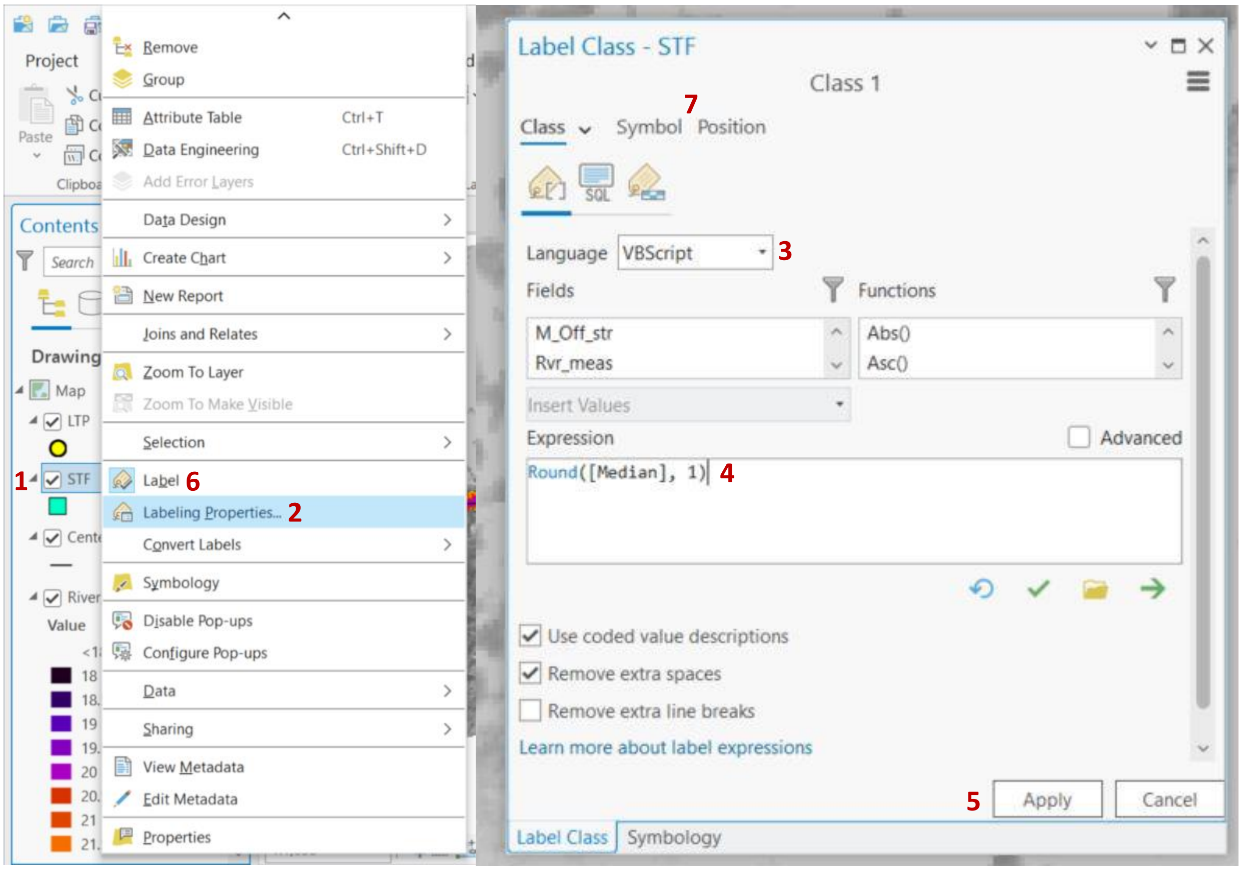
Putting everything together, it should look similar to this:



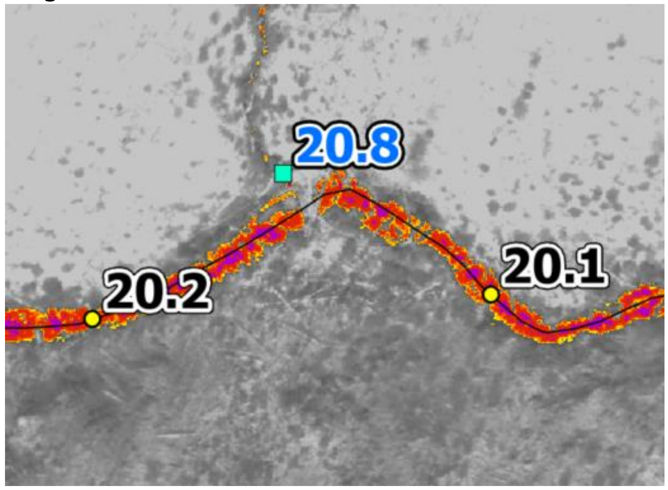
Vector Labels

Show vector labels of each feature for statistics and temperature values:

1. Right click on STF or LTP symbol in contents pane
2. Select “Labeling Properties”
3. Select script language; “VBScript” is used in this example. This should be done before typing in the script or the script will be erased.
4. Type in the correct script. The script used in this example is “Round([Median], 1).” Round means that it is rounding up, median is what it is labeling, and the 1 is number of decimal points. Double clicking a field in the “Fields” box will add that field to the script.
5. Click “Apply.”
6. Select label to see the label appear on the map. This can be done before changing the label properties, but the label will be the default feature.
7. The font, font style, size, background, etc. can be changed under the symbol tab, and the position of the label adjusted under the position tab. The “Appearance” and “Halo” subitems were modified under the symbol tab to produce the example image (at the top of the next page).

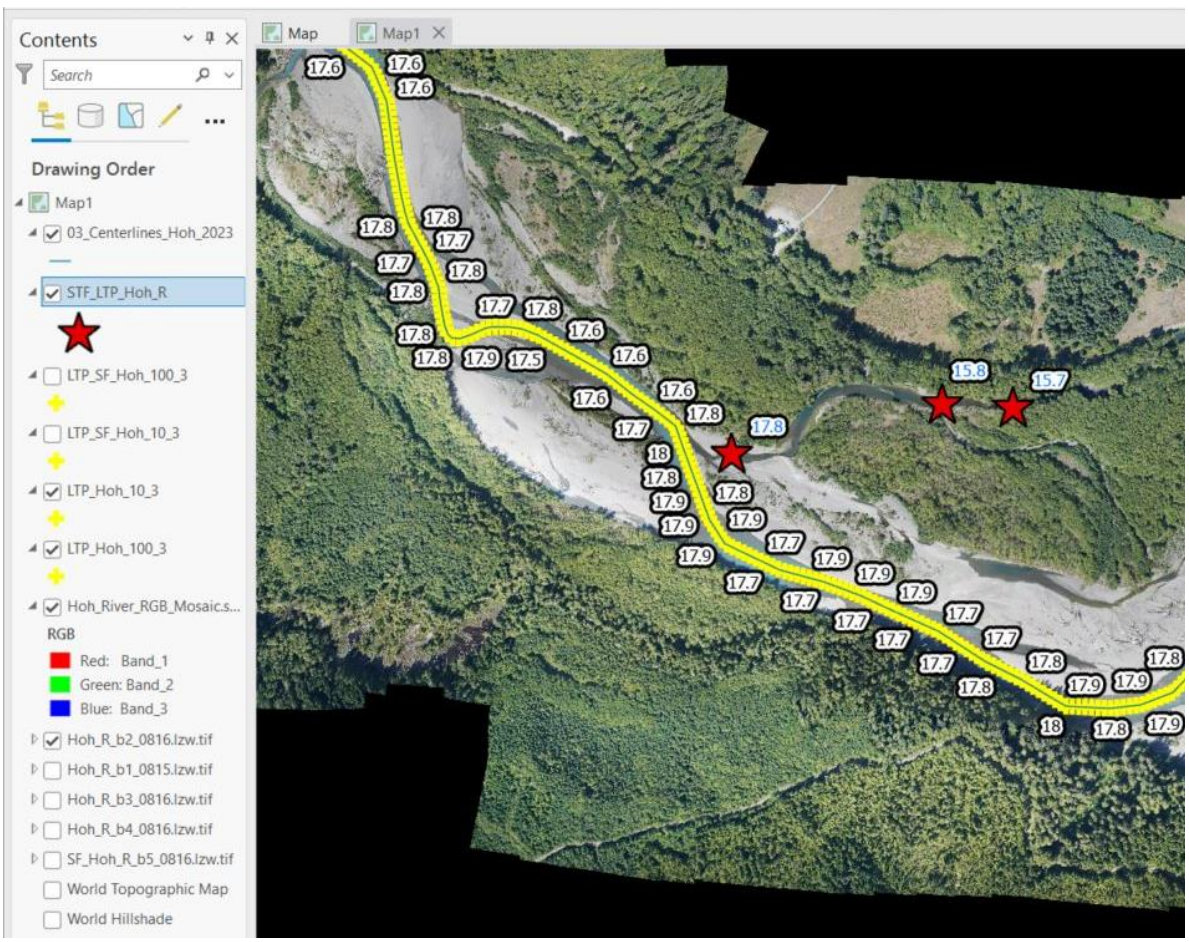


These steps produce an image like this:



Combined RGB and TIR Imagery:

See “Load Mosaic Rasters” section to see how to load the *.sid layer. Note that the HTML file has *.sid as the file extension but will not load in ArcPro.



To display the TIR mosaic with a color ramp overlaid onto the 3-band (RGB) imagery:

1. Add a color ramp to the TIR mosaic (see “Working with Color Ramps”)
2. Place the TIR mosaic above the RGB mosaic.
3. In the symbology dialogue box, select all the grey scale values, depicting the riverbanks and trees, using the shift key and select “No color”. Note that selecting the color itself will bring up a color palette for that specific item and will not allow multiple rows to be selected. Click on the line or other columns to select all the grey scale values.