2023 CMAR Thermal Rivers

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Executive Summary

Over the month of September 2023, the Applied Geomatics Research Group (AGRG) collected thermal and RGB imagery data using the DJI Matrice 300 RTK remotely piloted aircraft system (RPAS) with the DJI H20T sensor payload. The data collected covers three rivers across Nova Scotia, Round Hill, Gold River, and Skye River, as requested by the Center for Marine Applied Research (CMAR). In each of these rivers, the data collected covers 2 kilometers upstream and downstream of Onset HOBO U22 temperature loggers deployed by CMAR. This data was processed into orthorectified and mosaicked rasters per-flight, then corrected with an equation developed by AGRG to bring the temperature values closer to temperature values expected from the same U22 temperature sensors deployed by CMAR. While relative differences in temperature are well represented in the data (cool versus warm water in each flight) the absolute recorded temperatures fluctuate greatly when compared to in-situ measurements. Data collection and processing best practices have been refined to address these issues in future.

Data Products:

- Round Hill
    - **19 rasters** (thermal and RGB, each) across **3 days**
    - Dates:
        - September 7th, 2023
        - September 8th, 2023
        - September 21st, 2023
- Gold River
    - **18 rasters** (thermal and RGB, each) across **4 days**
    - Dates:
        - September 12th, 2023
        - September 13th, 2023
        - September 22nd, 2023
        - September 26th, 2023
- Skye River
    - **8 rasters** (thermal and RGB, each) for **1 day** of collection
    - Date:
        - September 27th, 2023

1. Introduction

Over the summer of 2023, the Applied Geomatics Research Group (AGRG) of the Nova Scotia Community College (NSCC) and the Center for Marine Applied Research (CMAR) entered discussions on possible work to map out river water temperatures using RPAS technology. CMAR had temperature loggers deployed in rivers across the province in the interest of monitoring river water temperatures in relation to fish habitats. River water temperature data is invaluable in monitoring the viability of rivers as habitats for marine life, but the amount of data collected spatially is very limited when using individual temperature sensors that only record temperatures at a single point. AGRG's expertise in remotely sensed data and RPAS operation gave an opportunity for collaboration though AGRG's collection of airborne thermal imagery of the rivers of interest to CMAR. Collecting the rivers with a thermal camera mounted to an RPAS allowed large stretches of river to be collected and mapped with their surface temperatures. After an initial discussion, CMAR chose the three rivers to be collected with AGRG's DJI M300 RTK RPAS with the H20T thermal and RGB camera payload. By September, all the required data had been collected and AGRG had begun work processing the data to satisfy the deliverables of the project, being the thermal and RGB orthomosaics.

Figure 1. Map of CMAR's temperature loggers deployed across all three study areas, Round Hill, Gold River, and Skye River.

2. Methods

2-1 Site selection

After an initial set of project planning meetings between AGRG and CMAR, it was decided which of the rivers they were monitoring were their priority that they wanted to have AGRG collect and map. The three rivers chosen by CMAR were Round Hill near Annapolis Royal, Gold River near Chester, and Skye River in Cape Breton. The length of these rivers is substantial and flying their entire length would be cost-prohibitive. It was agreed that the priority areas in these rivers were the stretches of the river up and downstream of the water temperature monitoring sensors deployed earlier in the year by CMAR. The final decision was made to collect 2 km stretches of the river up and downstream of each of CMAR's sensors. Three sensors were deployed in Round Hill, another three in Gold River, and a final four were deployed in Skye River.

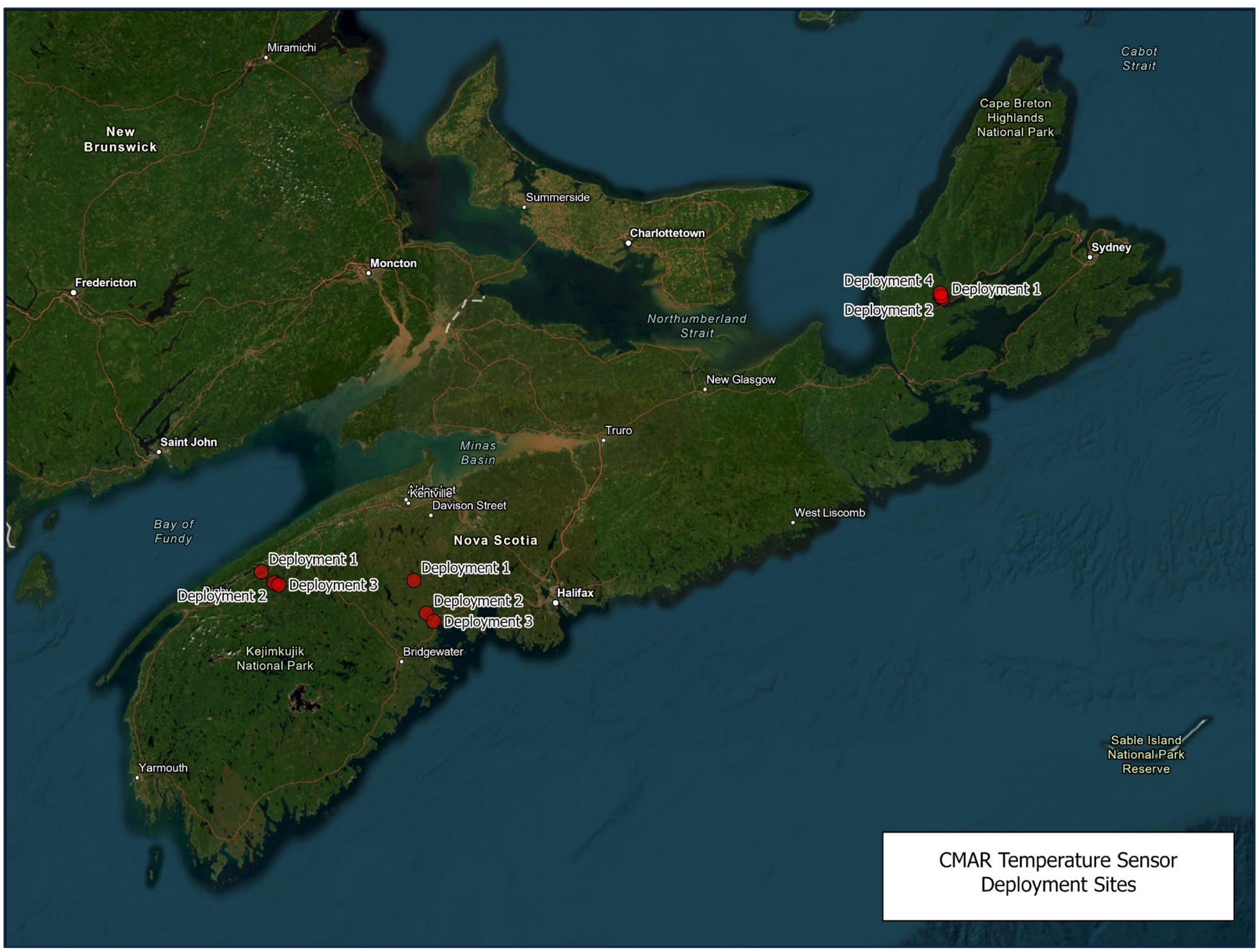


Figure 2. CMAR temperature sensor deployment sites across all three rivers.

2-2 Equipment

To capture thermal imagery for this project, AGRG's DJI Matrice 300 RTK (M300) RPAS was used in conjunction with DJI's H20T RGB/thermal payload. The M300 is an enterprise-grade RPAS meant for professional use, capable of accepting a variety of different sensor payloads depending on the use-case. The H20T sensor was selected for its thermal image sensor, not on the base H20 payload. The sensor is equipped with a 20 MP zoom camera, 12 MP wide angle camera, 640x512 pixel thermal camera, and laser rangefinder. AGRG used the 12 MP wide angle camera and thermal camera to create RGB and thermal orthomosaic imagery products. This workflow will be discussed later in this report.

Figure. 3. AGRG's DJI M300 RTK RPAS with the H20T thermal/RGB sensor attached.

AGRG's Leica GS14 antenna and CS20 controller were used to map out ground truth data and position the targets so they can be found within the imagery collected by the RPAS. This equipment is part of a survey-grade GNSS system (*Figure 4)* that is mounted to a pole for use in the field (*Figure 7)*. The GNSS system receives real-time corrections to its positions for better accuracy without needing to post-process the data back in the office.

Figure 4. AGRG's Leica GNSS system, comprised of a GS14 antenna and CS20 controller. The antenna and controller are mounted to a pole in the field for data collection.

Three sensors, in addition to the H20T, were used for gathering temperature data in the field. An Onset HOBO U22 water temperature sensor, provided by CMAR, was used to collect data on the temperature of the water for each ground truth site. This sensor was provided by CMAR for testing as it is the same model as those deployed across all the rivers being flown by AGRG. A handheld IR temperature sensor (Etekcity Lasergrip 1080) was used for its similarity to the technology used in the H20T's thermal camera sensor. Lastly, a handheld temperature probe (ThermPro TP-03H) was used for one more source of temperature data for ground truthing (*Figure 5*, *Figure 6)*.

Figure 5. **A** – Onset HOBO U22 water temperature logger. **B** – Etekcity Lasergrip 1080 infrared temperature sensor. **C** – ThermPro TP-03H temperature probe.

2-3 Ground Truth

Temperature data was collected to serve as ground truth for the processed thermal imagery datasets when the river being flown was safely accessible from the RPAS deployment site. The HOBO U22 sensor borrowed from CMAR was set to record data at a 1-minute interval, zip-tied to a rock, and placed in the water before the flight, and left in for the duration of the flight. The ThermPro temperature probe and Etekcity IR sensors were also used to measure the temperature of the water for the ground truth location. The flight times were used to pick out the record from the U22 data to use for validation of the thermal imagery. The U22 data especially is of interest, with the additional sensors being supplementary data to help identify if there are any issues or inconsistencies with the U22 data.

To find the location of the ground truth data in the imagery, a black and grey square target (*Figure 6*) is placed on land as close as possible to the U22 sensor. A GNSS point is also collected in the centre of the target for further location data (*Figure 7)*.

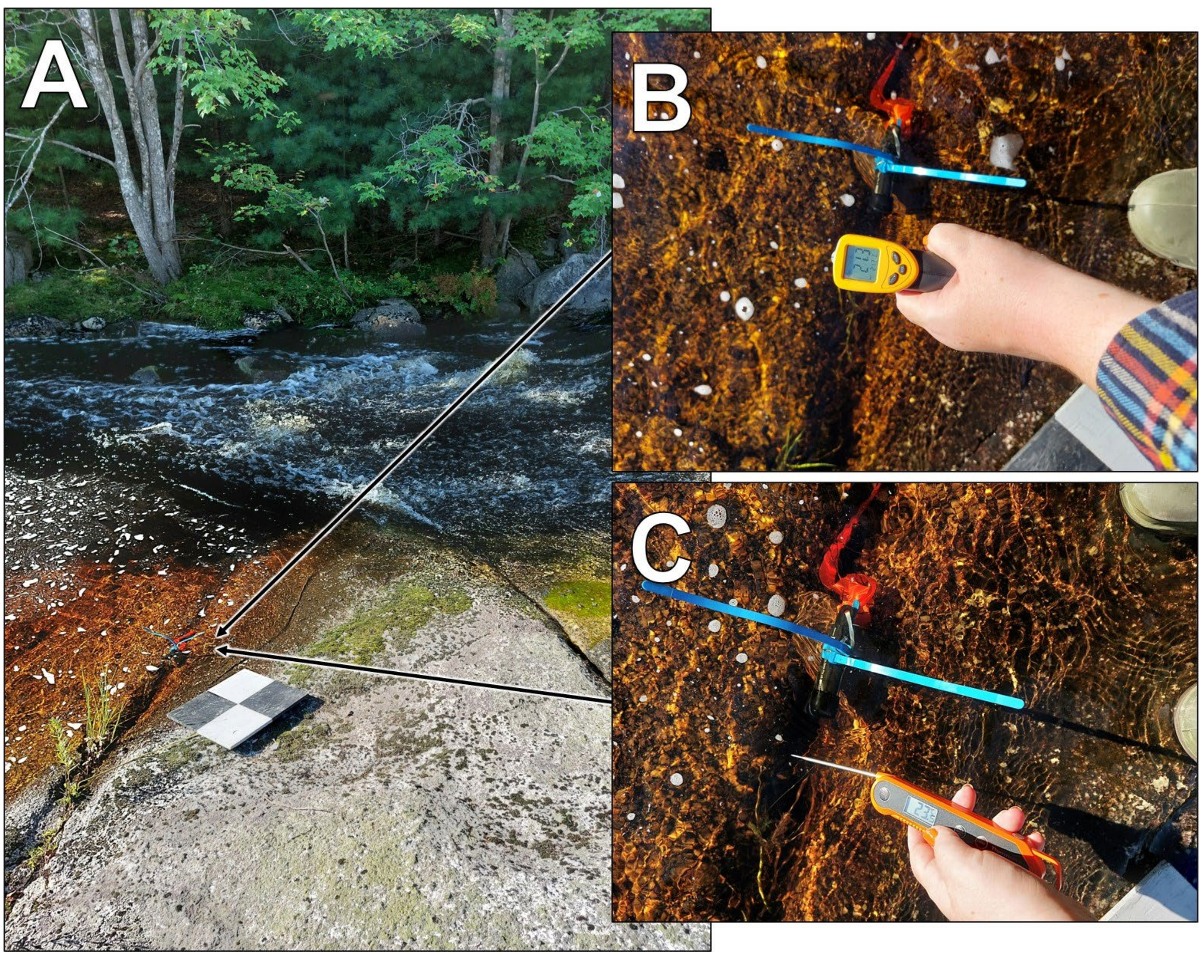


Figure 6. **A** – One of the ground truth sites in the Round Hill AOI, taken September 7th, 2023 **B** – The water near the U22 temperature logger being measured with a handheld infrared sensor. **C** – The water near the U22 temperature logger being measured with a temperature probe.

Field log sheets were created by AGRG to record the ground truth temperature data in the field. Temperatures for the water in the river were collected at the start and end of the flight, and temperatures were collected for the black and grey sections of the target to be used as additional validation data if needed. A sample of the format of these sheets can be seen in the Appendix at the end of this report.

Figure 7. Using the Leica GS14 to collect a point for a ground truth location in Gold River on September 22nd, 2023.

2-4 Planning

Planning is a very important aspect of RPAS operations, and several project-specific and RPAS-specific factors needed to be considered when planning when to fly. Firstly, weather limits when the RPAS may be flown. While the M300 RTK used in this project can be flown in high winds and rain, the quality of data collected by the H20T sensor would be negatively impacted. We also want to fly in weather as hot as possible, to give the greatest contrast between cold water inputs and pools vs the rest of the river. Though not as important as the high temperatures, overcast days are ideal to avoid sun glint in the imagery and consistency in lighting conditions it provides is valued as well. Days where the sun is constantly popping in and out of cloud cover will negatively impact the consistency of the imagery across the collection in both the thermal and RGB. Secondly, we want to consider the height of the water in the river as well. Lower is better, again for picking out the contrast in temperatures from pools and cold-water inputs, but again consistency is key. Ideally, we want to collect data for each river when the water is at roughly the same level each day of collection. To achieve this, Environment Canada-maintained stream gauges were used as they are easily and freely accessible online. Three gauges were selected for monitoring, one for each river by proximity to the rivers being flown. The LaHave River was selected for Gold River, the Cornwallis River was selected for Round Hill, and Middle River Cape Breton was selected for Skye River. In the case of Round Hill, no nearby gauges were deemed suitable, so the Cornwallis River gauge was chosen as it was expected to behave similarly to Round Hill while the gauges inland near Keji were not (*Figure 9*, *Figure 10*, *Figure 11*).

When planning flights, AGRG attempted to collect data on consecutive days when the weather was as hot as possible. When consecutive days of collection were not possible, the Environment Canada stream gauges were consulted to determine how close the water level of the river was to the last day of collection.

One final consideration when planning flights is the height above the ground at which the RPAS operates. The lower the height you fly at, the better the resolution/detail of the image on the ground. This is especially important for thermal imagery, as the H20T's thermal camera offers a relatively coarse resolution of just 640x512 pixels, compared to the 4056x3040 pixel resolution of its wide-angle camera. This is typical of thermal cameras. However, the lower you fly, the less area on the ground is covered in one image. Ideally, we want to capture the entire river in one pass, so we want to make sure we're flying just high enough to do that reliably. A flight elevation of 100 meters above ground level (AGL) was settled on, as it's below the 120-meter limit for standard RPAS operations in Canada, and high enough to collect most of the areas across all the river in one pass. Aside from simplifying logistics and saving battery time, letting more area be flown in a day, collecting the river in one pass minimizes the influence of the orientation of the drone relative to the sun on temperature readings that can cause banding. In *Figure 8* we can see banding in the orthomosaic because of this lake section of Gold River being covered in more than one pass of the drone, in different directions.

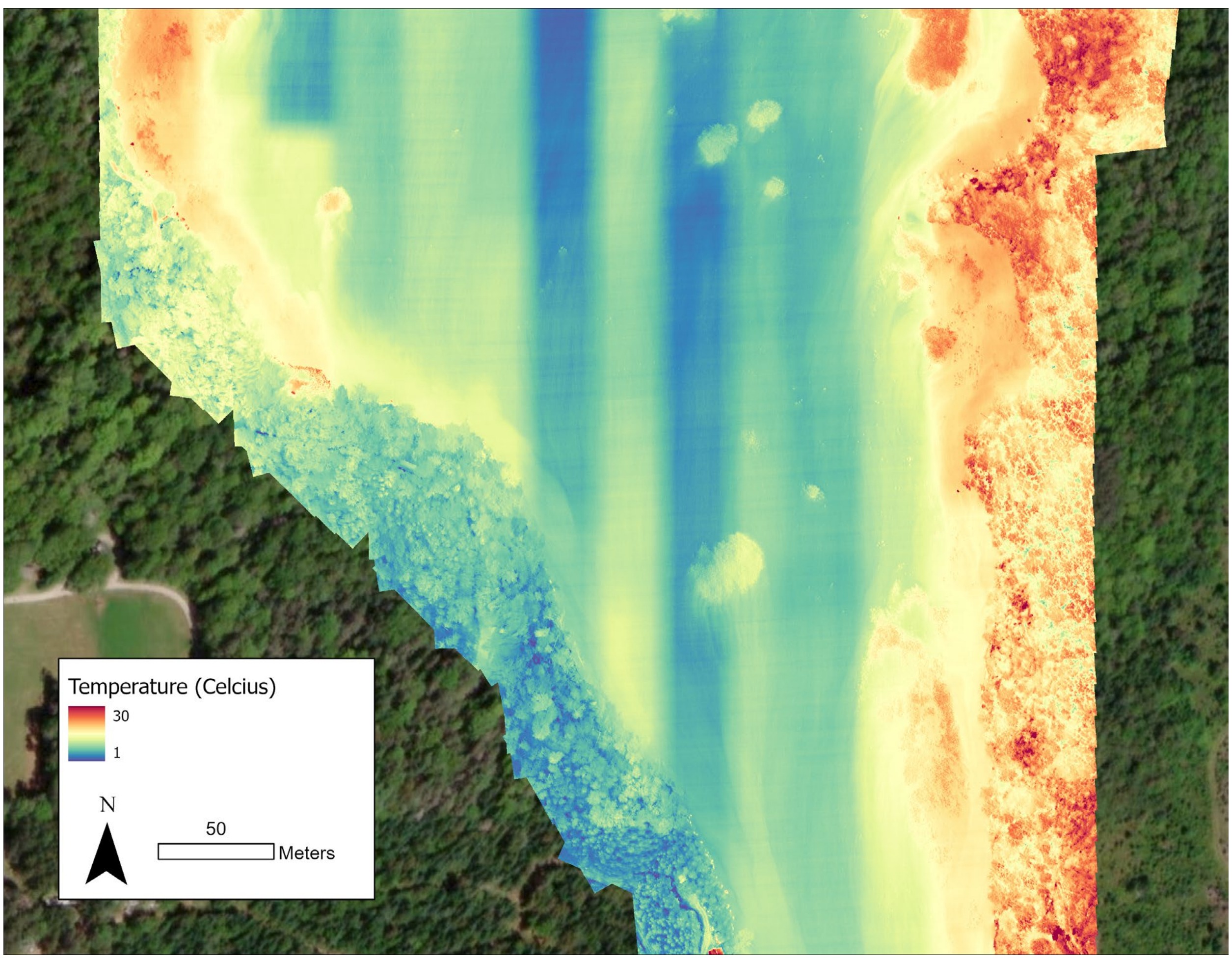


Figure 8. Sample of an area of the thermal orthomosaic in Gold River showing banding from multiple passes of the H20T.

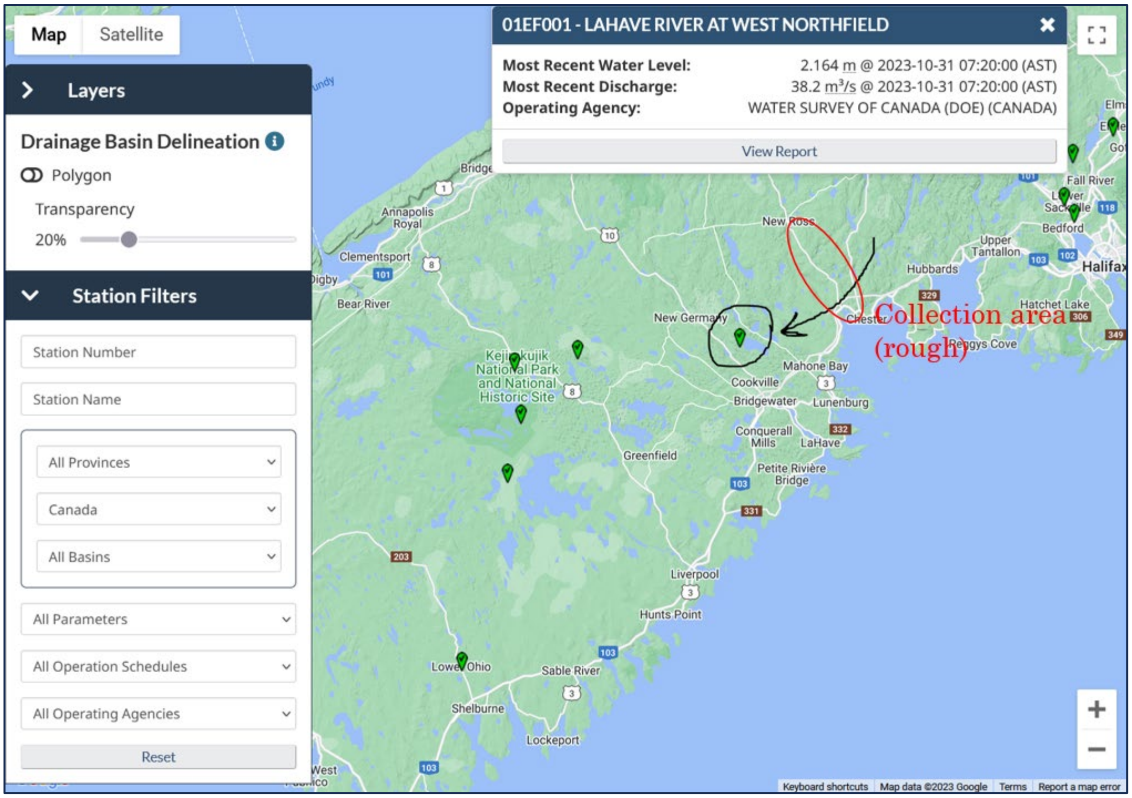


Figure 9. Location of the LaHave River gauge relative to the Gold River collection area.

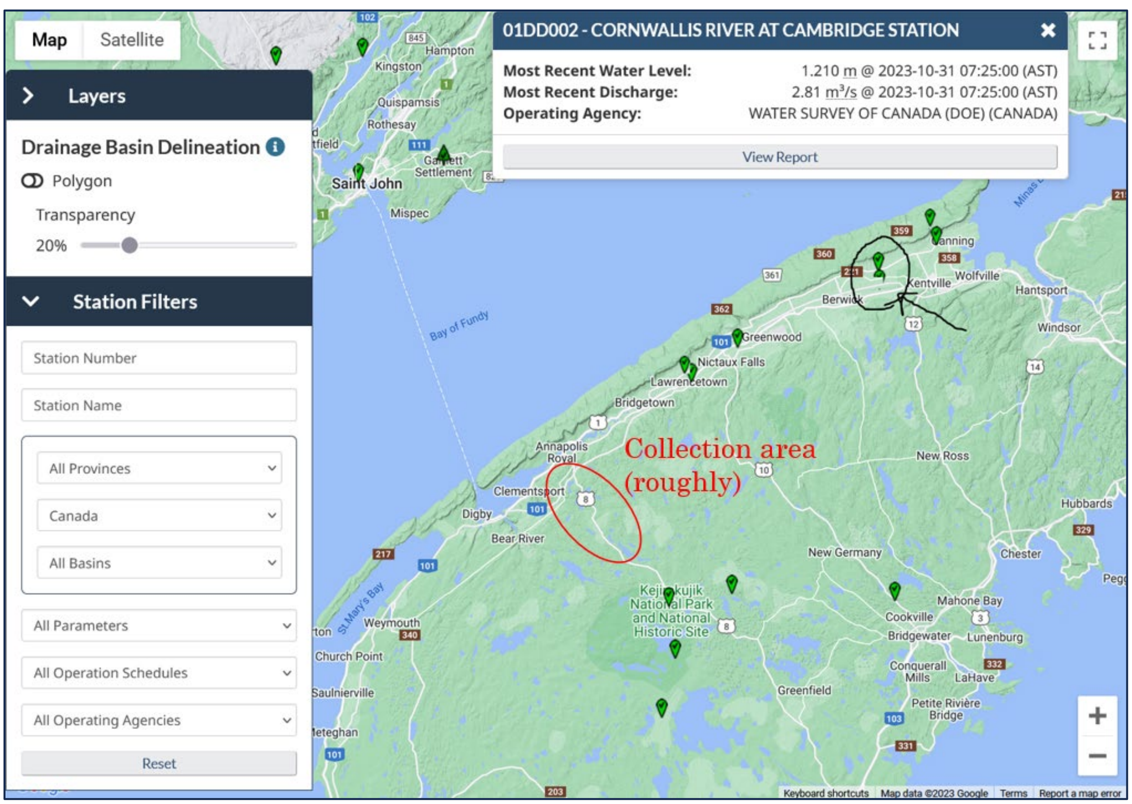


Figure 10. Location of the Cornwallis River gauge relative to the Round Hill collection area.

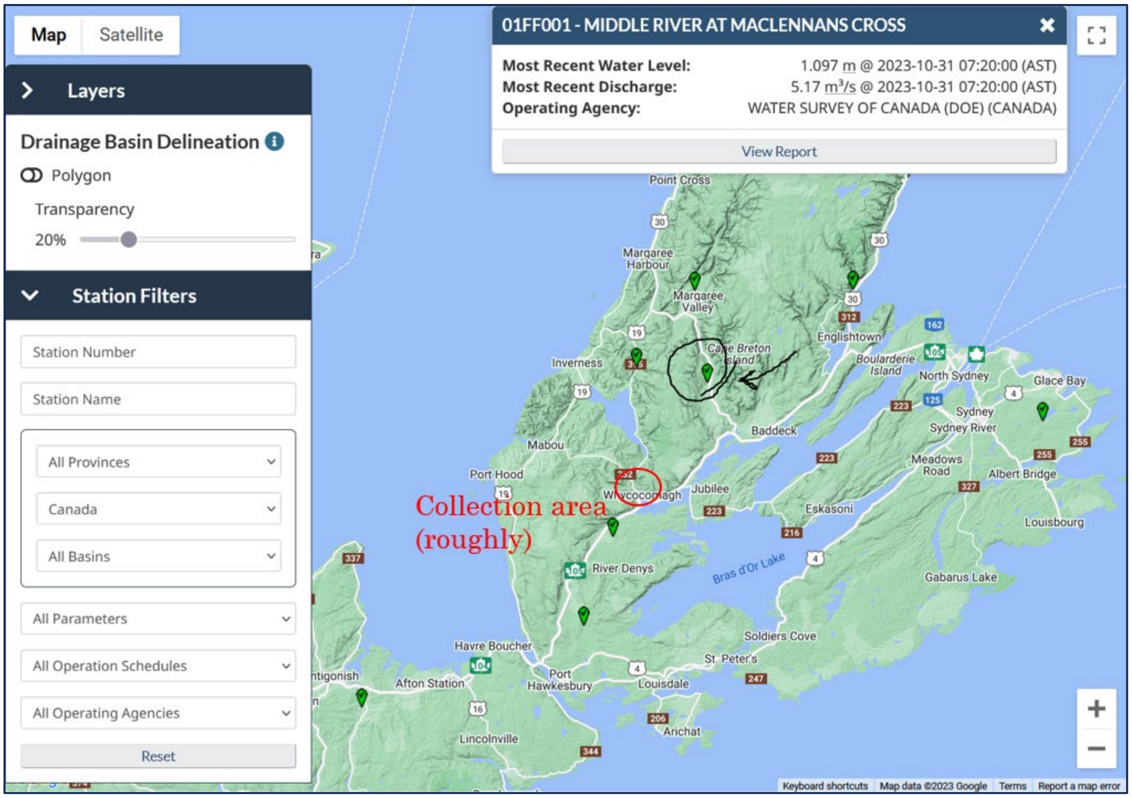


Figure 11. Location of the Middle River gauge relative to the Skye collection area.

2-5 Processing methods

After collecting a series of imagery spanning the length of a flight over the river, the objective in processing is to get the imagery combined into orthomosaics that map out the temperatures across the study area. To outline the process, after getting back from collecting data, the RGB and thermal imagery is downloaded from the H20T's SD card. When the thermal imagery is downloaded from the H20T, the values in the images are in an 8-bit greyscale format with pixel values from 0 to 255. This makes the images easier to display and understand with standard image viewing software but does not let the user query the temperature of areas in the image. We then must take these thermal JPEG images and decode and convert them to imagery with pixel values in degrees Celsius using DJI's official thermal imagery software development kit (SDK). Next, the imagery is georeferenced to be able to be displayed as spatial data and orthorectified to correct distortion due to terrain and characteristics of the camera's lens. Imagery is then mosaicked on a per-mission/flight basis to create an initial thermal orthomosaic product, then adjusted in ArcGIS Pro with an equation based on the curve AGRG developed to compensate for the difference between the H20T's temperature values and the "real" values based on the sensors CMAR uses. Lastly, if needed, further adjustments to the orthomosaic temperature values can be made after a comparison to the ground truth data.

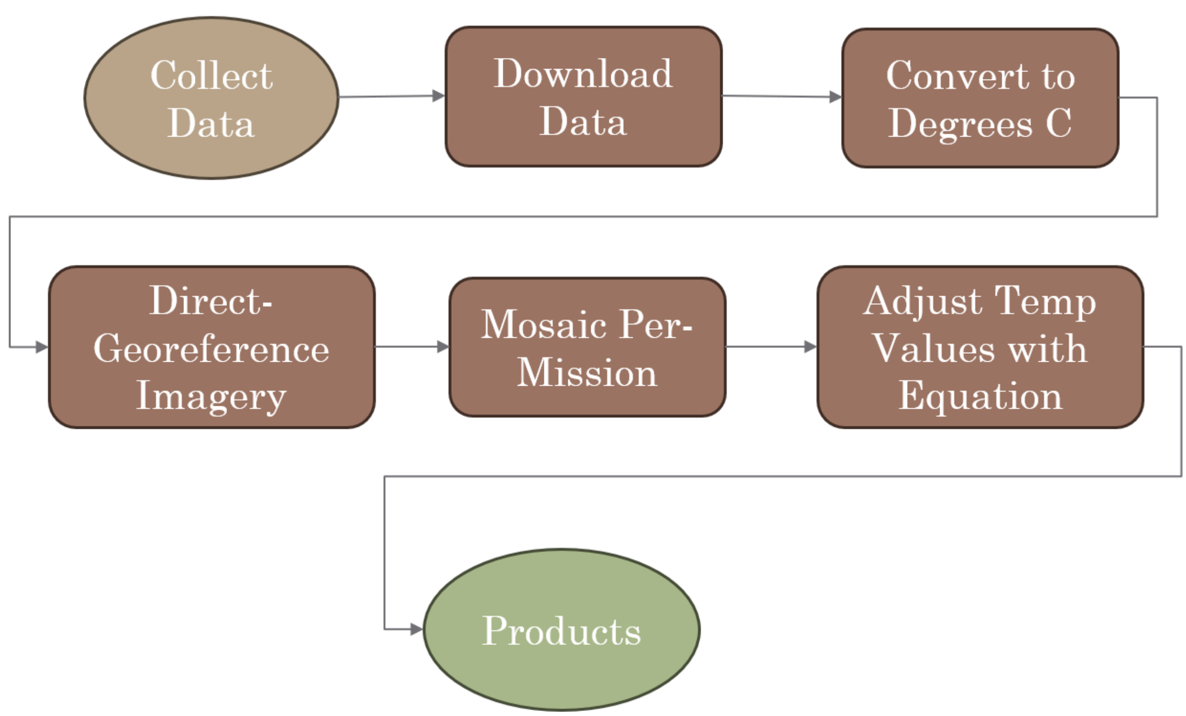


Figure 12. Data processing flow chart.

To adjust the initial temperature values after mosaicking the decoded thermal imagery, we use an equation from a curve developed by AGRG. Three insulated coolers were filled with water (*Figure 13*). These three coolers were filled with water of different temperatures, cool, warm, and hot. Cool and warm were meant to represent different water temperatures we'd expect to see in doing fieldwork with the H20T over the summer, with the hot water serving as an additional data point to develop the correction equation. HOBO temperature loggers were placed in the bottom of each of these coolers to represent the true temperature, while the M300 with the H20T was flown above these coolers at varying heights, capturing images to get temperature values of the coolers with. Of particular interest to us were the 85 meter, 100 meter, and 120 meter images, as these would be elevations we could reasonably expect to be flying at when doing fieldwork. The true temperatures were then plotted against the temperatures from the H20T imagery and fitted with a linear best fit line in Excel to get the equation to use for corrections (*Figure 14*, *Figure 15*, and *Figure 16*). All this work was done to help to correct for environmental factors in the field that affect the accuracy of the temperature readings from the H20T's thermal camera that are otherwise unaccounted for.

Figure 13. Water coolers used in the experiment.

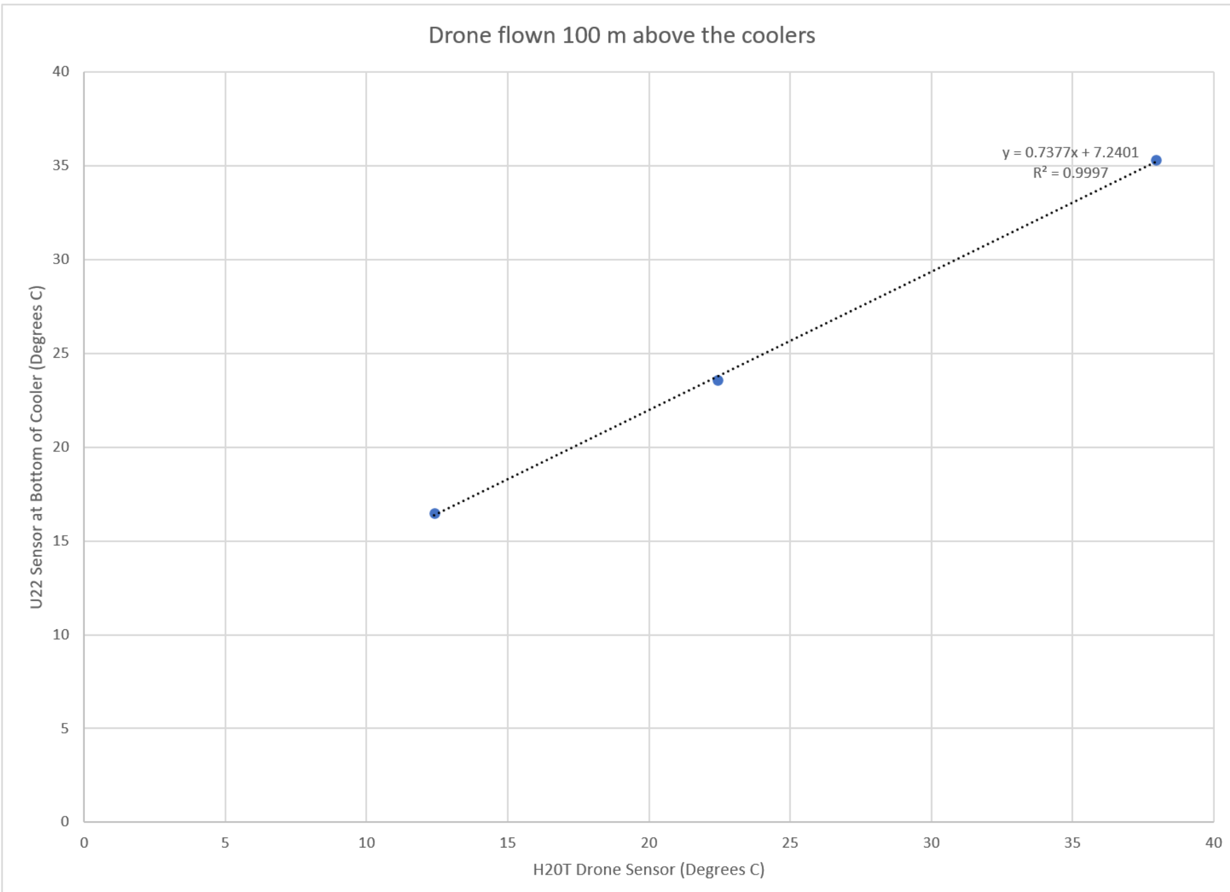


Figure 14. H20T 100 meter AGL calibration curve. This is the curve with the equation used to adjust the H20T temperature values to better reflect the "real" temperature.

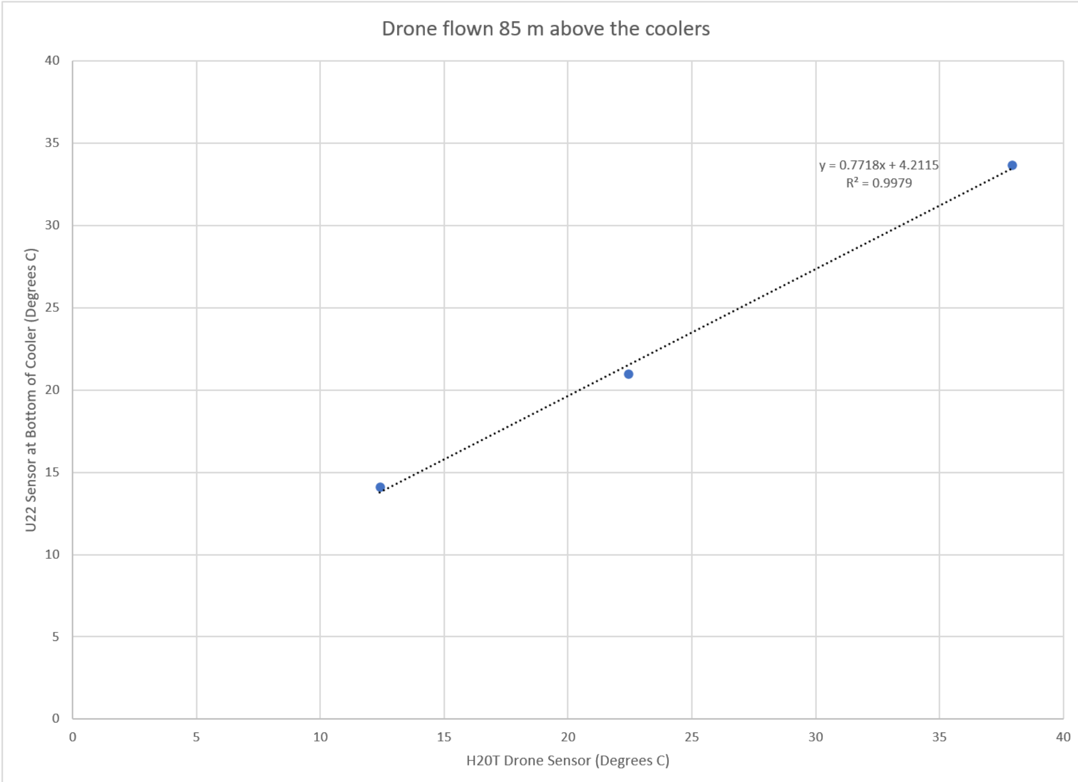


Figure 15. H20T 85 meter AGL calibration curve.

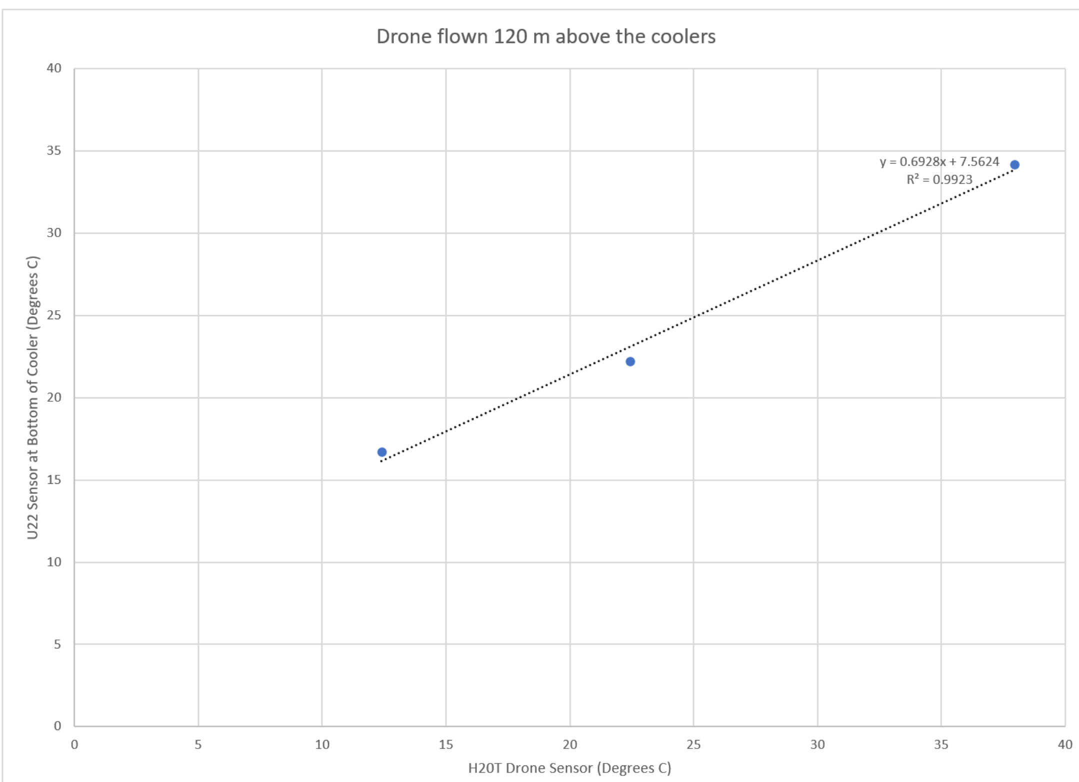


Figure 16. H20T 120 meter AGL calibration curve.

3. Results

3-1 Raster Datasets

All three rivers were collected in their entirety in the month of September 2023. Round Hill was completed across three days, yielding 19 thermal rasters. Gold River was completed across four days, yielding 18 thermal rasters. Lastly, Skye River was completed in one day, yielding 8 thermal rasters. Further information can be found in *Table 1*. For each thermal orthomosaic raster, there is a corresponding RGB orthomosaic generated from the RGB imagery that was collected during the same flight. The RGB orthomosaics cover a slightly larger area than the thermal rasters because of the size of the individual RGB image frame and camera field of view. Thermal imagery and orthomosaic data products cover the entirety of the river AOIs as the flight planning was done with this taken into consideration.

Table 1. Data products by river and day.

River/Collection Area	Date	Rasters
Round Hill	September 7th, 2023	5 thermal, 5 RGB
	September 8th, 2023	9 thermal, 9 RGB
	September 21st, 2023	5 thermal, 5 RGB
Gold River	September 12th, 2023	5 thermal, 5 RGB
	September 13th, 2023	3 thermal, 3 RGB
	September 22nd, 2023	9 thermal, 9 RGB
	September 26th, 2023	1 thermal, 1 RGB
Skye River	September 27th, 2023	8 thermal, 8 RGB

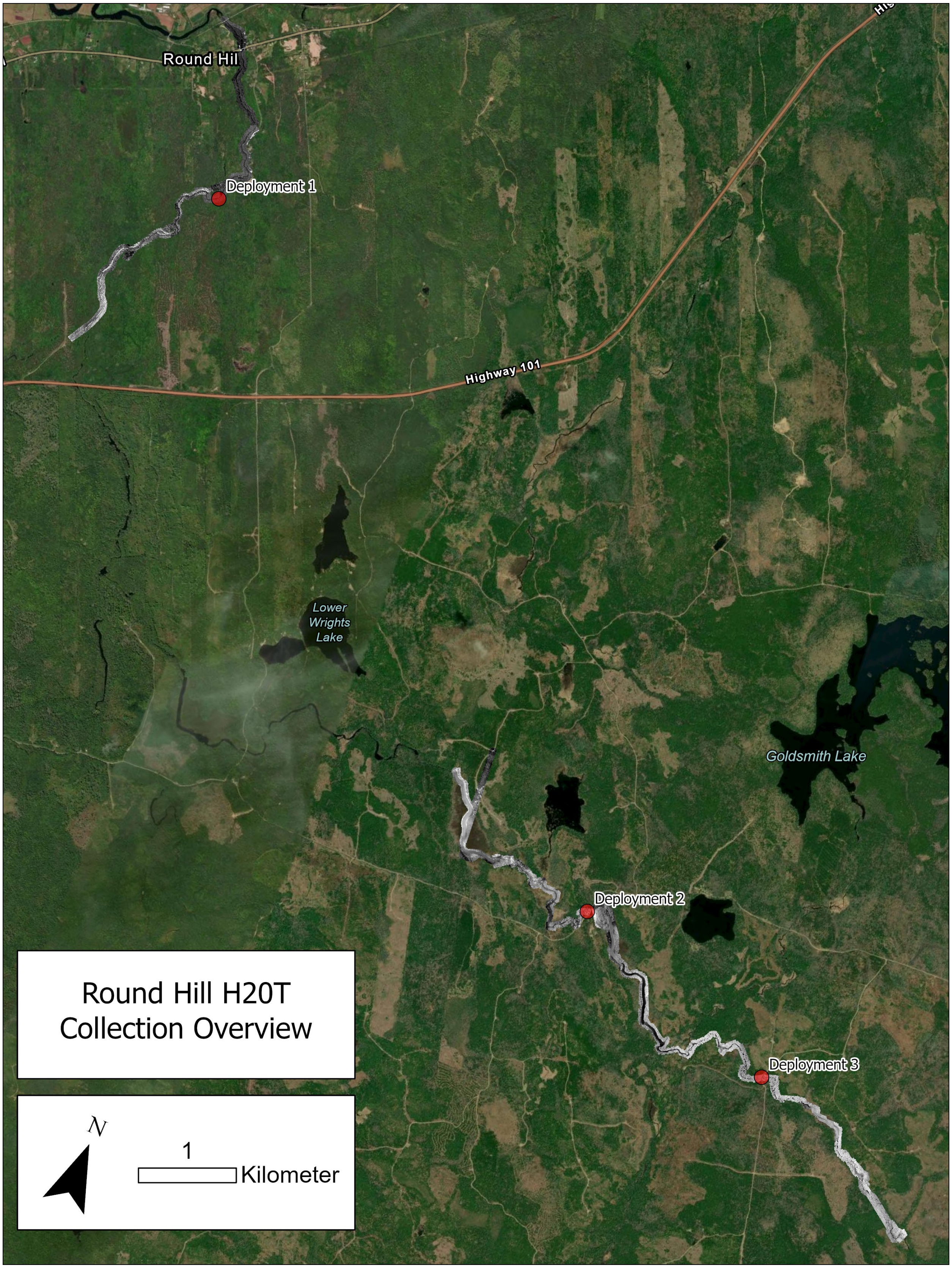


Figure 17. Round Hill collection data overview. CMAR's temperature sensor deployments marked.

Figure 18. Round Hill downriver data overview. CMAR's temperature sensor deployments marked.

Figure 19. Round Hill upriver data overview. CMAR's temperature sensor deployments marked.

Figure 20. Gold River data collection overview. CMAR's temperature sensor deployments marked.

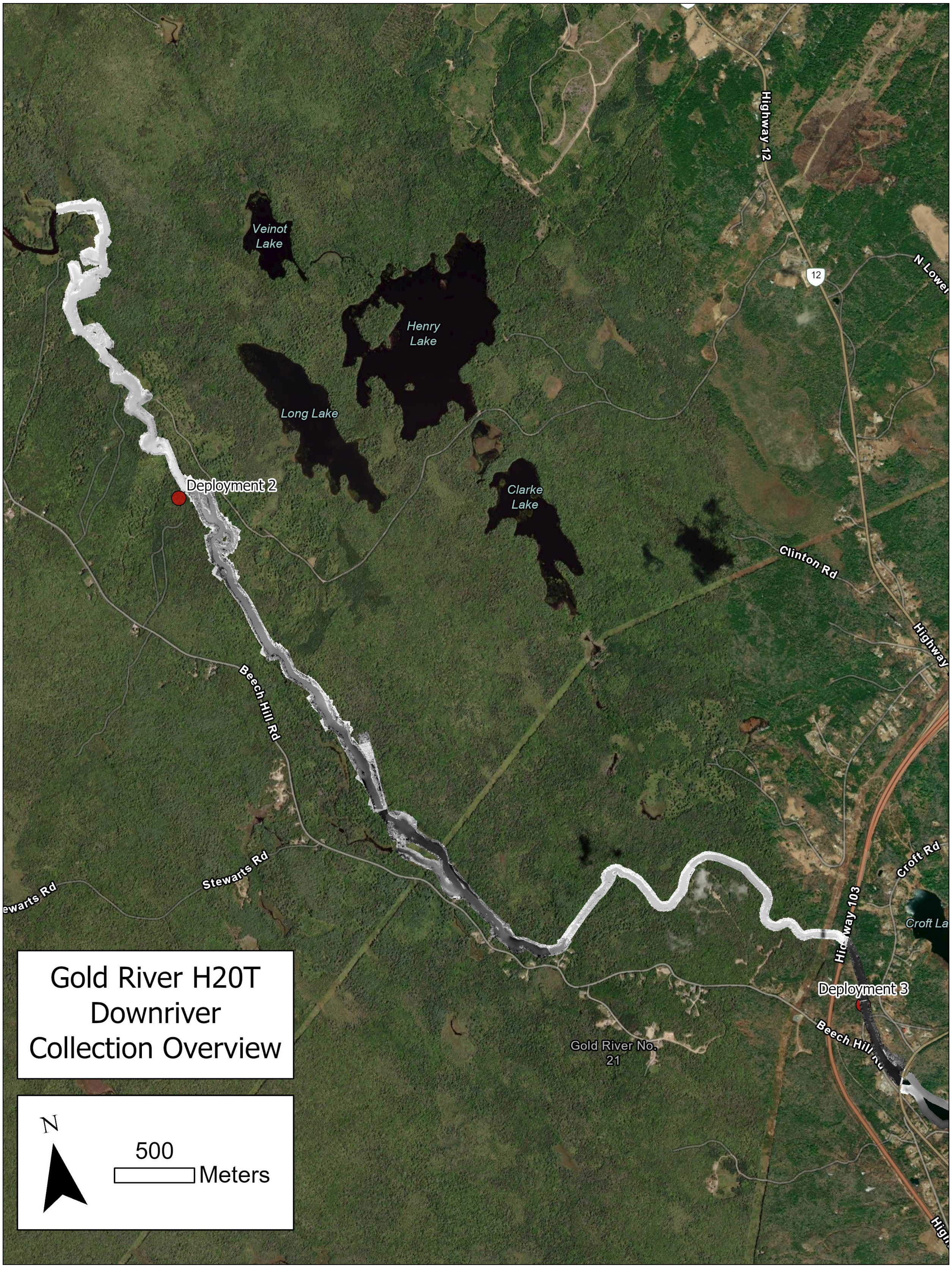


Figure 21. Gold River downriver data collection overview. CMAR's temperature sensor deployments marked.

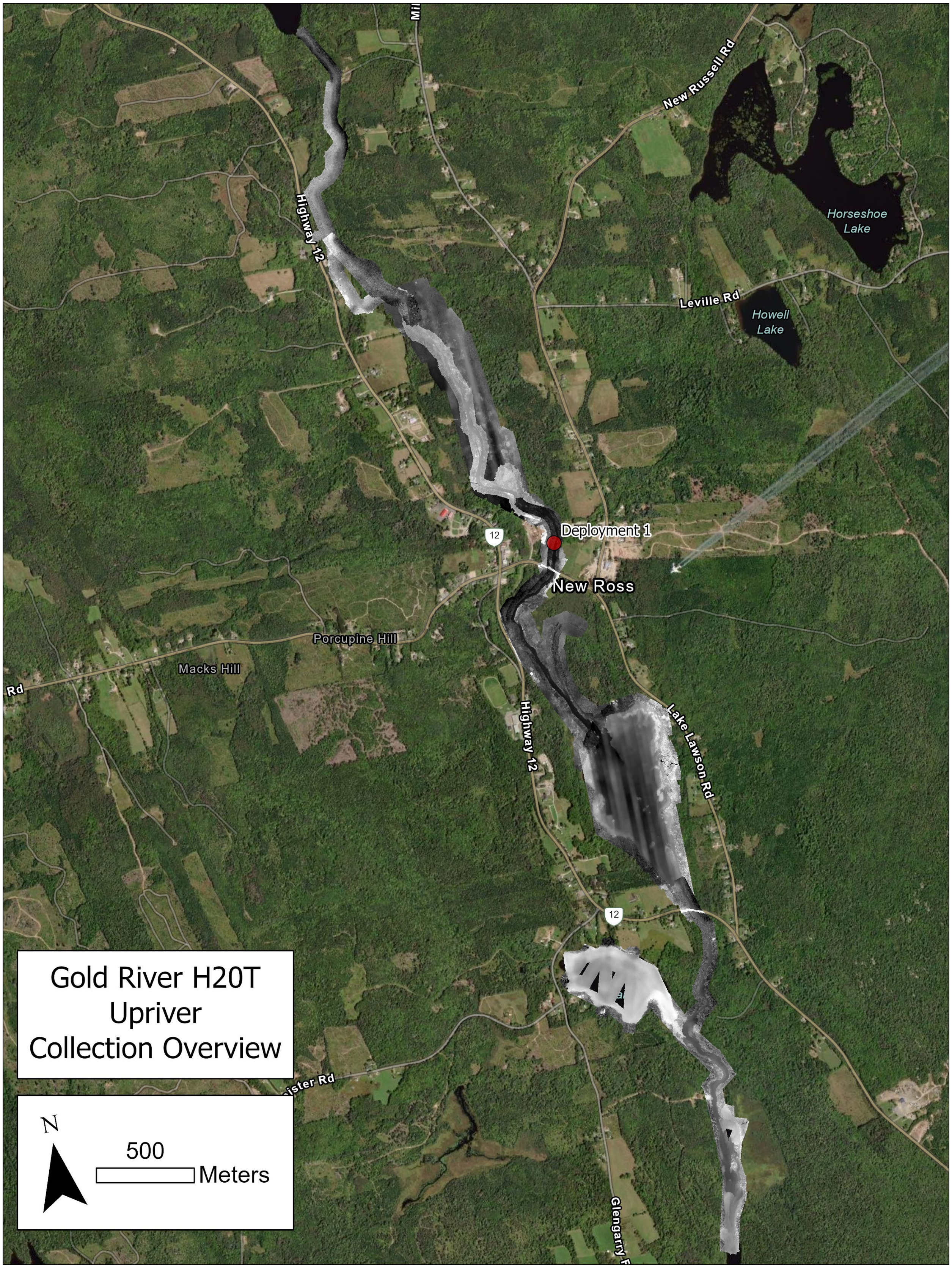


Figure 22. Gold River upriver data collection overview. CM'R's temperature sensor deployment location marked.

Figure 23. Overview of the data collected for the Skye River AOI. CMAR's temperature sensor deployments marked.

4. Discussion

4-1 Challenges

Throughout the duration of the project, AGRG was met with various challenges to adapt and respond to. The weather proved to be a challenge, and determining when to fly came with the need to prioritize risks. Due to the timing on when the project was approved and signed off on, AGRG was left without much summer weather to heat up the river water across all the sites. Multiple days of rain across September also left AGRG waiting days at a time for water levels to drop back down to what they were on previous days of collection. Towards the end of September, Skye had to be flown when it was relatively cold, as waiting any longer would have risked it being even colder, or having it rain again and further delay the collection.

Poor cell network coverage in rural areas limited the use of RTK for the duration of the trip. For the M300 or GS14 to receive their real time corrections, they need access to the internet. Being mobile devices meant for use in the field, the M300 and GS14 each have their own SIM cards and subscription to cell network data plans that provide them with internet wherever there is coverage. As mentioned, many of the areas flown early in the project were very rural and had no or extremely limited network reception. This meant that RTK was not available to the field crew. Post-processing procedures were developed early in the project to assure RTK availability was not a limiting factor.

Perhaps the most challenging aspect of the fieldwork portion of the project was finding locations to take off to fly a given section of the river. When choosing where to take off and land, the RPAS operator needs to consider where there’s enough space to takeoff and land safely. For the section of the river being flown, the RPAS needs to be visible to the operator and the visual observer, restricting how far can be flown from the point of takeoff. Round Hill proved to be the most challenging of all the areas by far. There were few roads near the river, even fewer of which were paved the further you travel upriver, with some of the “roads” marked on Google Maps being completely overgrown by trees. Two examples of these conditions can be seen in *Figure 24* and *Figure 25*. Closely related to this issue is the issue of access to the rivers themselves. Areas that were both suitable for RPAS operations and had access to the river to collect ground truth data often did not overlap, leaving fewer than desired ground truth points to work with.

Figure 24. Trees blocking a path in Round Hill.

Figure 25. Example of the "roads" used for river access seen around Round Hill.

4-2 River Conditions

With the exception of Skye River, which was collected all in one day, effort was made to fly each river at roughly the same water level based on the gauge being monitored. However, due to reasons discussed in the previous section, flying at the same water level each time was not possible. As we can see in *Figure 26, Figure 27*, and *Figure 28*. Water levels for the Middle River Cape Breton gauge monitored for Skye River with the day flown indicated. AGRG managed to collect data while avoiding peaks in water level.

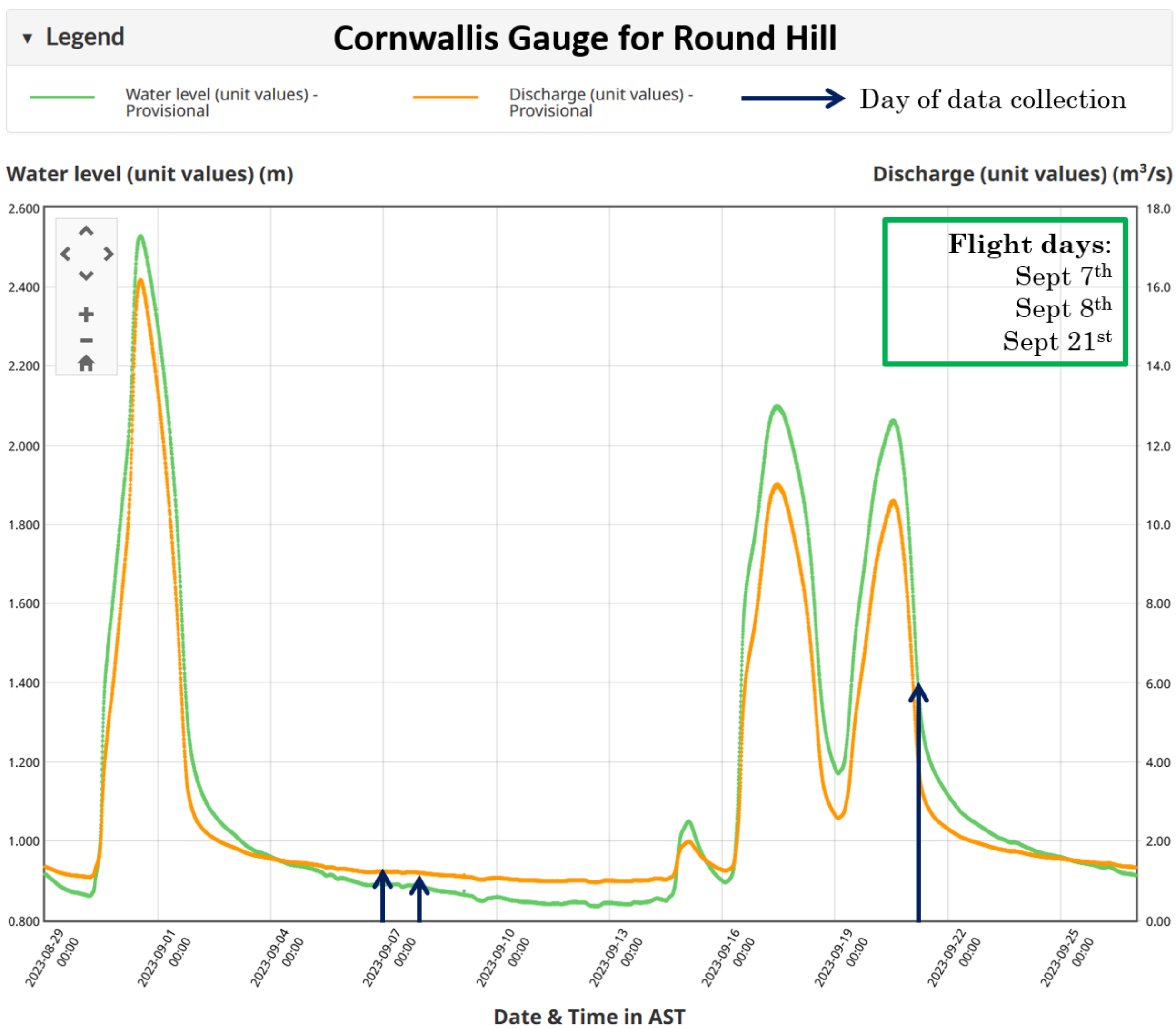


Figure 26. Water levels for the Cornwallis gauge monitored for Round Hill with days flown indicated.

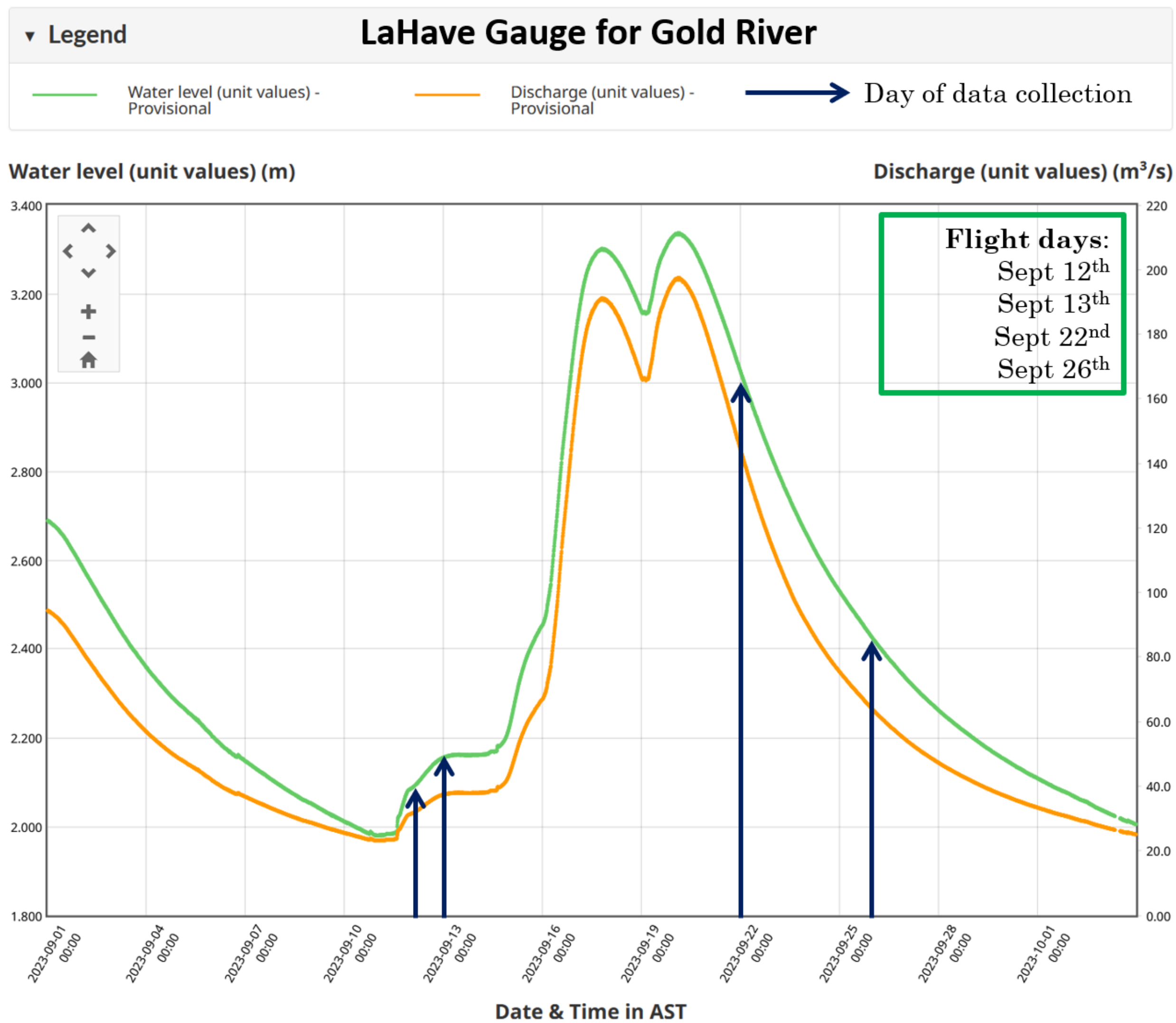


Figure 27. Water levels for the LaHave gauge monitored for Gold River with days flown indicated.

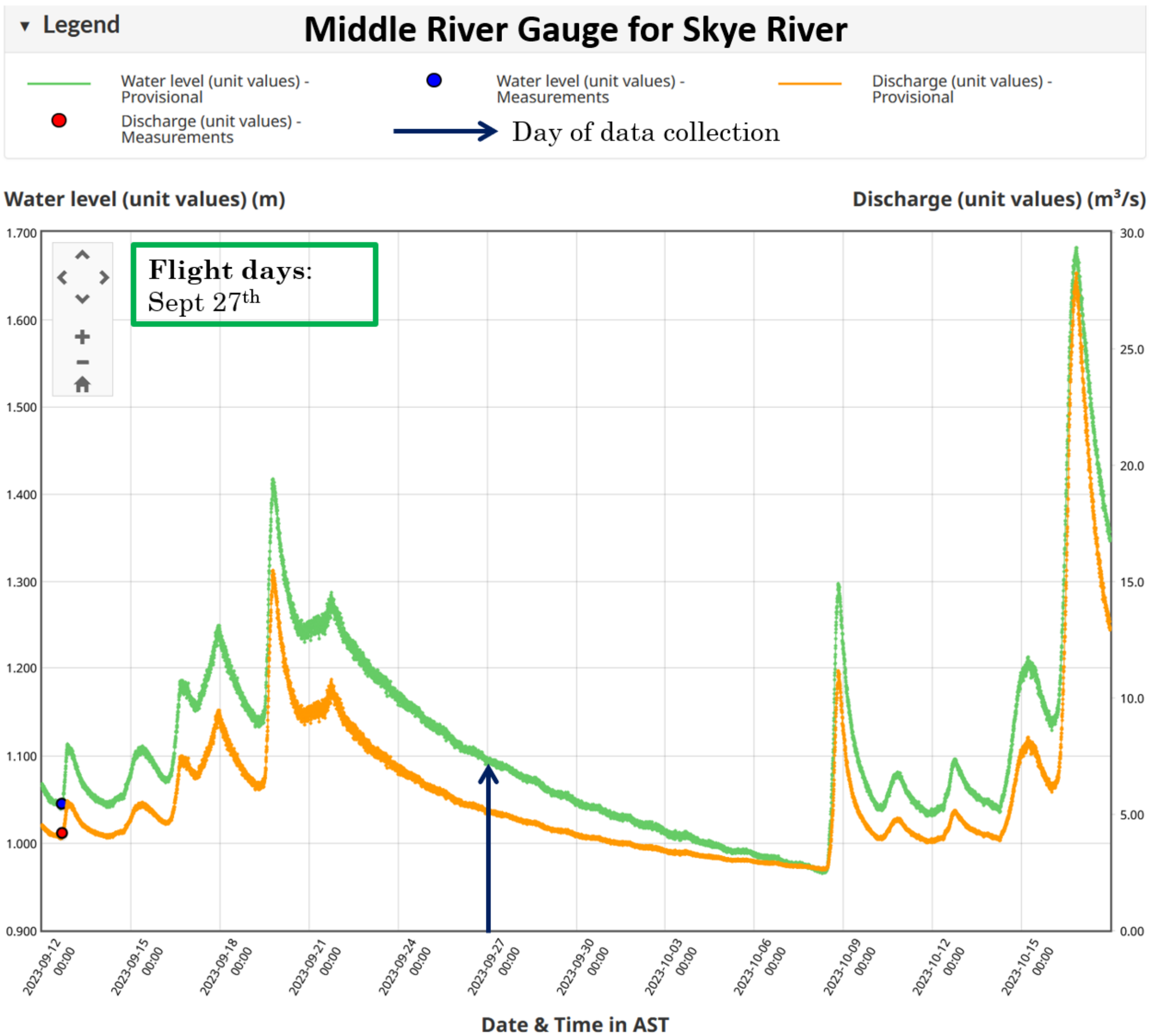


Figure 28. Water levels for the Middle River Cape Breton gauge monitored for Skye River with the day flown indicated.

4-3 Ground Truth

Across all rivers, a total of 16 ground truth points were collected. The majority of these were gathered in Gold River (9), with 5 in Round Hill, and two in Skye. Additionally, AGRG was provided with data from CMAR's U22 sensors deployed in the rivers flown to use for ground truth. Unfortunately, many sensors were lost over the field season, leaving only one sensor from Gold River, and three in Round Hill. None were retrieved from Skye River.

Comparison of in-situ temperature observations to H20T measurements yielded variable results (*Table 2*, *Figure 29*). Several factors were identified as having an impact on the H20T measured values including cloud cover, ambient temperature, local humidity, sun angle, wind, and image orientation. Unfortunately, the impact of these variables on H20T values were ambiguous and could not be resolved to systematically improve results. While we are confident that local frames can be adjusted to better match the in-situ measurement points, too few points exist to extend this confidence to the larger flight areas. It is advised that: additional care be taken to record pertinent environmental data during the thermal flights, additional in-situ measurements are taken to better represent a larger ranges of temperature values, the H20T locked in a fixed, or sun-facing orientation for all flights.

Table 2. In-situ U22 temperature logger measurements versus H20T pixel temperature values showing a tendency to underestimate remotely sensed values.

PointID	u22 Observation (°C)	H20T Pixel (°C)	Residual (°C)
SR002	10.93	9.60	-1.33
GR001	22.49	18.31	-4.18
GR002	23.04	16.54	-6.50
GR003	23.23	16.90	-6.33
GR004	22.61	20.30	-2.31
GR005	16.88	13.88	-3.00
GR006	17.06	11.52	-5.54
GR007	16.99	12.70	-4.29
GR008	16.96	12.77	-4.19
GR009	12.34	7.46	-4.88
RH001	21.68	19.34	-2.34
RH002	21.15	15.06	-6.09
RH003	21.1	16.54	-4.56
RH004	20.89	17.05	-3.84
RH005	23.16	17.72	-5.44
GRC01	15.581	12.26	-3.32
RHC01	20.412	15.50	-4.91
RHC02	21.079	15.58	-5.50
RHC03	20.222	16.54	-3.69

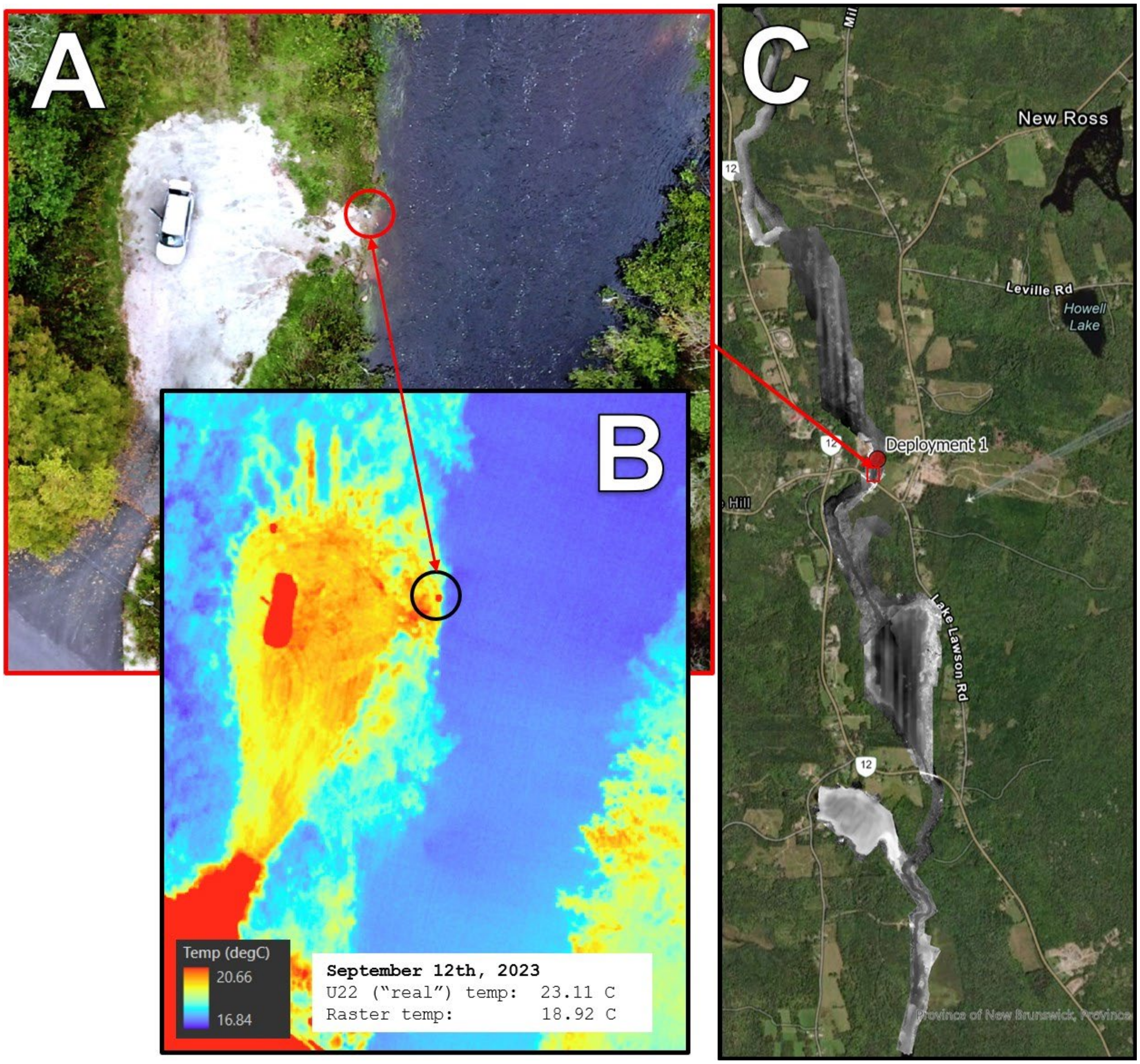


Figure 29. Example ground truth site from Gold River on September 12th, 2023. **A** – RGB orthomosaic for the data seen in B. **B** – Thermal image for the corresponding frame in A. Note the difference between the "real" temperature from the ground truth sensor and the temperature value from the adjusted H20T data (correction has been applied). **C** – Location of data in an overview of the upriver section of Gold River.

It should be noted that relative temperature fluctuations are well represented in the data despite poor absolute recordings. These relative differences are important in identifying warmwater intrusion (*Figure 30*) and cool water pools (*Figure 31*).

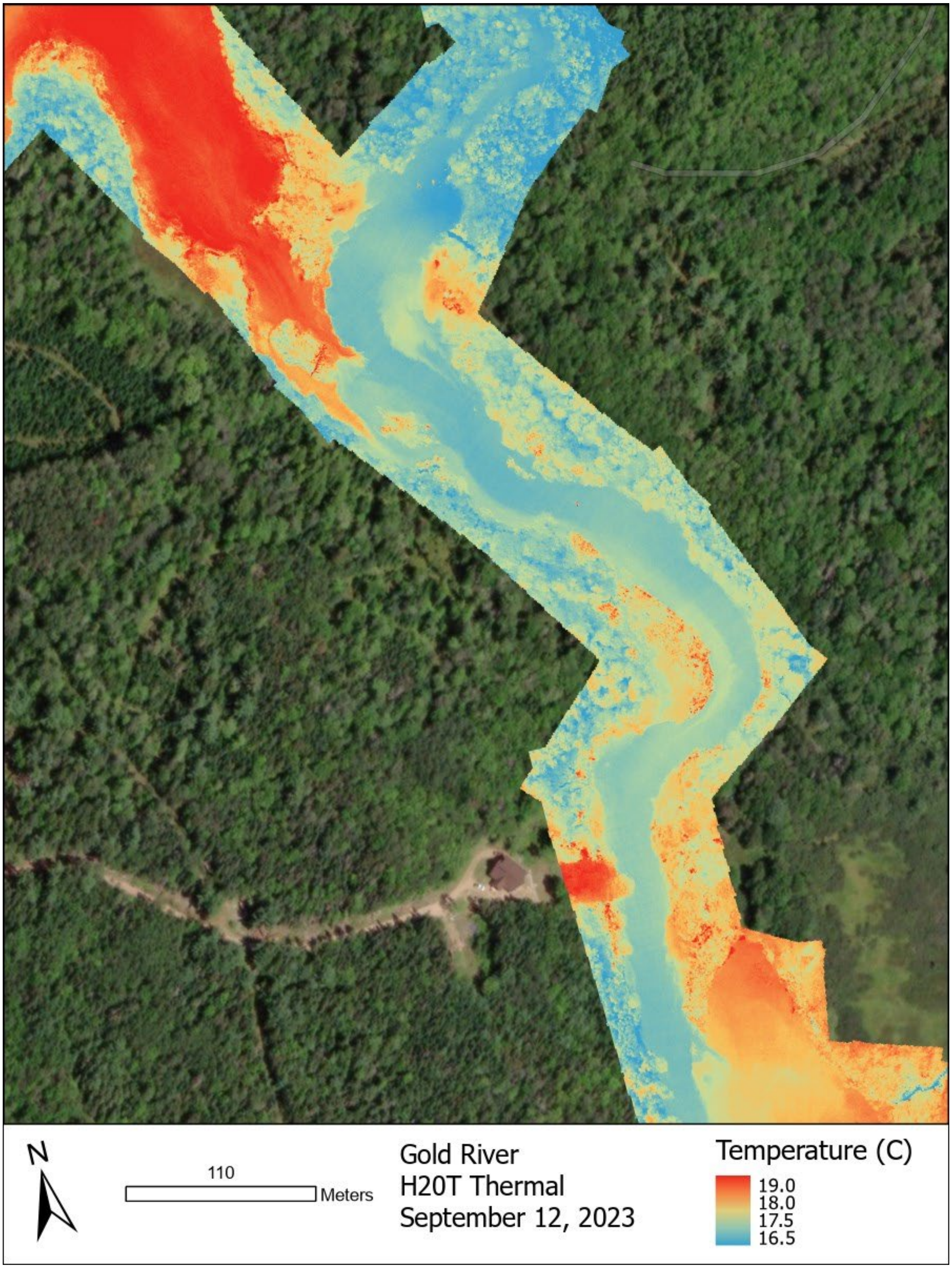


Figure 30. H20T imagery showing a warm western body of water mixing with the cooler main branch of Gold River.

Figure 31. H20T thermal imagery showing a cool pool and reach of water separated by warmer bend.

5. Appendix

Stream gauge data source:

https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html

Official DJI equipment specifications:

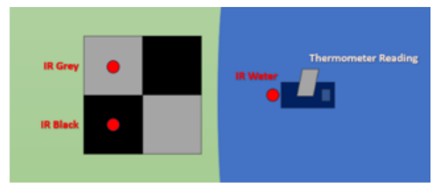
https://enterprise.dji.com/zenmuse-h20-series/specs

https://enterprise.dji.com/matrice-300/specs

Sample ground truth data field sheet:

Thermal Sampling of Drone Flights

Temperature Readings in C.
Please take photos of each measurement.
Time in UTC.
River names and section identification to match drone flight plan.



River:	Section:	GNSS Point:	
Takeoff Time:			
IR Black:	IR Grey:	IR Water:	Thermometer:
Landing Time:			
IR Black:	IR Grey:	IR Water:	Thermometer:
Comment:			