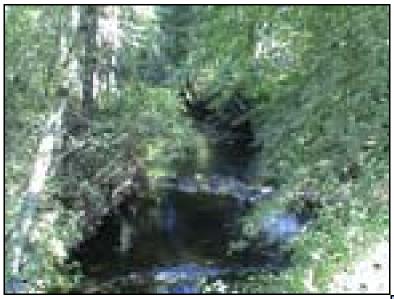
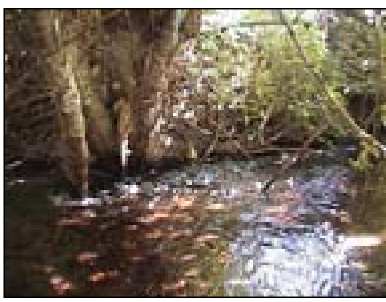
Aerial Surveys of Mill, Cranberry and Johns Creeks

Thermal Infrared and Color Videography

Shelton, Washington

January 27, 2004





Report to:

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Final Report

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Introduction

In 2003, the Squaxin Island Tribe contracted with Watershed Sciences, LLC (WS, LLC) to conduct airborne thermal infrared (TIR) remote sensing surveys on three streams located near the town of Shelton, WA. The objective of the project was to collect TIR and color video imagery in order to characterize the thermal regime of the selected stream segments. The imagery and subsequent analysis are intended to support ongoing stream temperature assessments in the basin. The surveys were conducted on August 18, 2003.

Water temperatures vary naturally along the stream gradient due to topography, channel morphology, substrate composition, riparian vegetation, ground water exchanges, and tributary influences. Stream temperatures are also affected by human activities within the watershed. TIR images provide information about spatial stream temperature variability and can illustrate changes in the interacting processes that determine stream temperature. In most cases, these processes are extremely difficult to detect and quantify using traditional ground based monitoring techniques.

It is the aim of this report to: 1) document methods used to collect and process the TIR images, 2) present spatial temperature patterns, and 3) highlight interesting features within each basin. Thermal infrared and associated true color video images are included in the report in order to illustrate significant thermal features. An associated ArcView GIS[1] database includes all of the images collected during the survey and is structured to allow analysis at finer scales.

Methods

Data Collection

Images were collected with TIR (8-12μ) and visible-band cameras attached to a gyro-stabilized mount on the underside of a helicopter. The two sensors were aligned to present the same ground area, and the helicopter was flown longitudinally along the stream channel with the sensors looking straight down. Thermal infrared images were recorded directly from the sensor to an on-board computer in a format in which each pixel contained a measured radiance value. The recorded images maintained the full 12-bit dynamic range of the sensor. The individual images were referenced with time and position data provided by a global positioning system (GPS).

A consistent altitude above ground level was maintained in order to preserve the scale of the imagery throughout the survey. The ground width and spatial resolution presented by the TIR image vary based on the flight altitudes. The flight altitude is selected prior to the flight based on the channel width and morphology. During the flight, images were collected sequentially with approximately 40% vertical overlap. All flights

[1] Geographic Information System

were conducted in the mid-afternoon (13:30-17:00) in order to capture heat of the day conditions.

Airborne surveys were conducted on Mill Creek, Cranberry Creek, and Johns Creek (Figure 1). Each stream was surveyed at an altitude of 1400 ft above ground level (AGL). This altitude provided a high spatial resolution (≈1.5 ft) and better visibility through the riparian vegetation while also presenting a wide enough ground footprint to capture floodplain features and small meander bends. Between Brockdale Road (river mile 4.6) and Johns Lake (river mile 8.2), Johns Creek meanders through a wetland area that could not be adequately captured using a single flight line. Consequently, three parallel flight paths were used to capture the full stream width through this segment (Figure 2). A fourth pass was additionally made over this segment at an altitude of 3000 ft AGL. This pass provided imagery with a wider ground footprint and hence, a more synoptic view of the wetland area. Table 1 summarizes the survey times, extents, and image resolution for each surveyed stream.

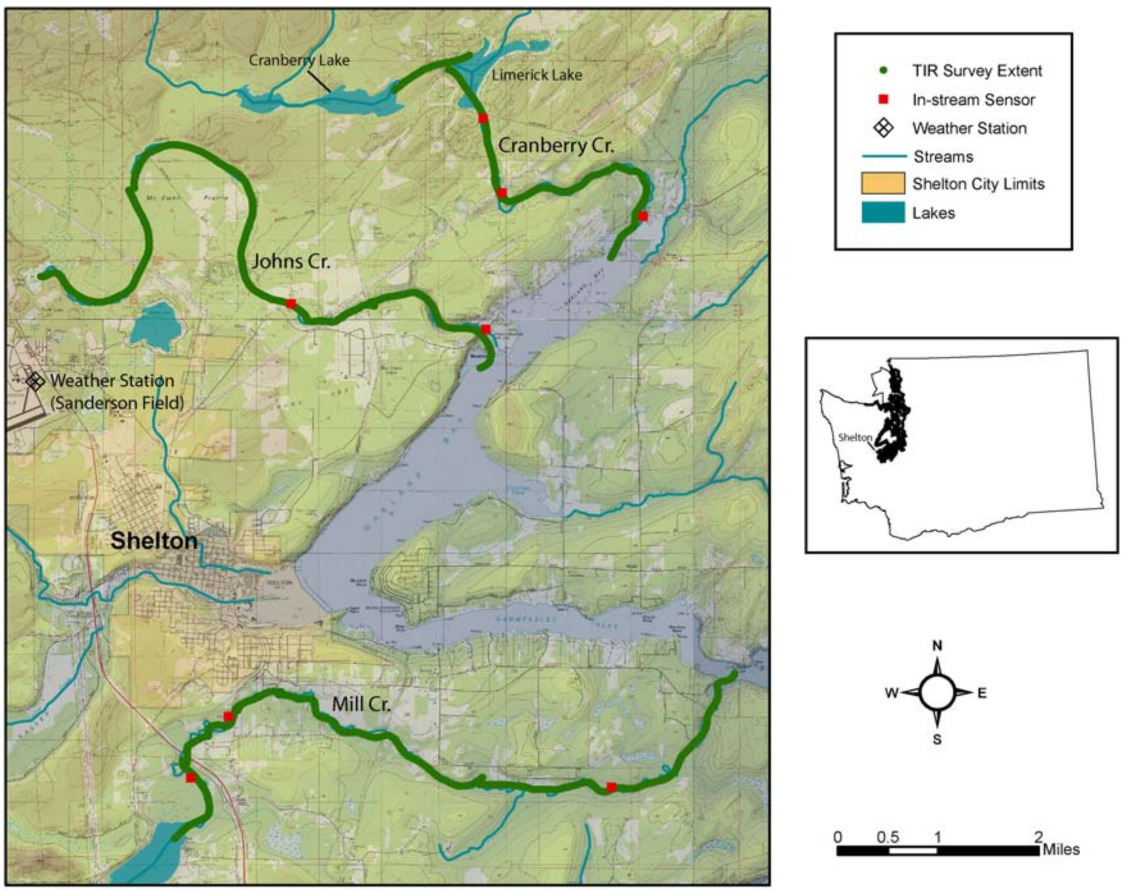


Figure 1 – Map showing the three streams surveyed near the town of Shelton, WA on August 18, 2003. The map also shows the location of in-stream sensors used to ground truth radiant temperatures derived from TIR images.

Table 1 – Summary of river segments surveyed with TIR and color video near the town of Shelton WA, on August 18, 2003.

Stream	Survey Date	Survey Time (24 hr)	Survey Extent	River Miles	Image Width Meter (ft)	TIR Image Pixel Size Meter (ft)
Mill Cr.	18-Aug	13:28-14:04	Mouth to Isabella Lake	9.9	150 (494)	0.5 (1.5)
Cranberry Cr.	18-Aug	14:10-14:27	Mouth to Cranberry Lake	4.9	150 (494)	0.5 (1.5)
Johns Cr.	18-Aug	14:37-15:20	Mouth to Johns Lake	8.2	150 (494)	0.5 (1.5)
Johns Cr. Plain	18-Aug	14:57-15:16	Brockdale Road to Johns Lake	3.5	150 (494)	0.5 (1.5)
Johns Cr. High	18-Aug	15:16-15:20	Brockdale Road to Johns Lake	3.5	321 (1058)	1.0 (3.3)

Figure 2 – Map showing multiple flight lines used on Johns Creek between river miles 4.6 and 8.2 to capture the wetland areas near Mc Ewen Prairie.

For each surveyed stream, WS, LLC deployed in-stream data loggers prior to the survey in order to ground truth (i.e. verify the accuracy of) the TIR data. On Mill and Cranberry Creeks, an in-stream data logger was located both near the beginning and end of the survey extent with an additional data logger located in the middle as access permitted. On Johns Creek, a data logger was located near the beginning and middle of the survey extent.

Meteorological data including air temperature and relative humidity were recorded using a portable weather station (*Onset*) located at Sanderson Field, Shelton, WA.

Data Processing

Measured radiance values contained in the raw TIR images were converted to temperatures based on the emissivity of water, atmospheric transmission effects, ambient background reflections, and the calibration characteristics of the sensor. The atmospheric transmission value was modeled based on the air temperatures and relative humidity recorded at the time of the survey. The radiant temperatures were then compared to the kinetic temperatures measured by the in-stream data loggers. The in-stream data were assessed at the time the image was acquired, with radiant values representing the median of ten points sampled from the image at the data logger location. Atmospheric transmission calibrations were fine-tuned to provide the most accurate fit between the radiant and kinetic temperatures.

Once the TIR images were calibrated, they were integrated into a GIS in which an analyst interpreted and sampled stream temperatures. Sampling consisted of querying radiant temperatures (pixel values) from the center of the stream channel and saving the median value of a ten-point sample to a GIS database file (Figure 3). The temperatures of detectable surface inflows (i.e. surface springs, tributaries) were also sampled at their mouth. In addition, data processing focused on interpreting spatial variations in surface temperatures observed in the images. The images were assigned a river mile based on a 1:100k routed GIS stream coverage from the Environmental Protection Agency (*Note: measures assigned from this coverage may not match stream measures derived from other map sources due to differences in scale and routing methods*).

The median temperatures for each sampled image of each survey stream were plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient. The location and median temperature of all sampled surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the main stem temperature patterns. Where applicable, tributaries or other features that were detected in the imagery, but were not sampled due to their small size (*relative to pixel size*) or the inability to see the stream through riparian vegetation are included on the profile to facilitate the interpretation of the spatial patterns.

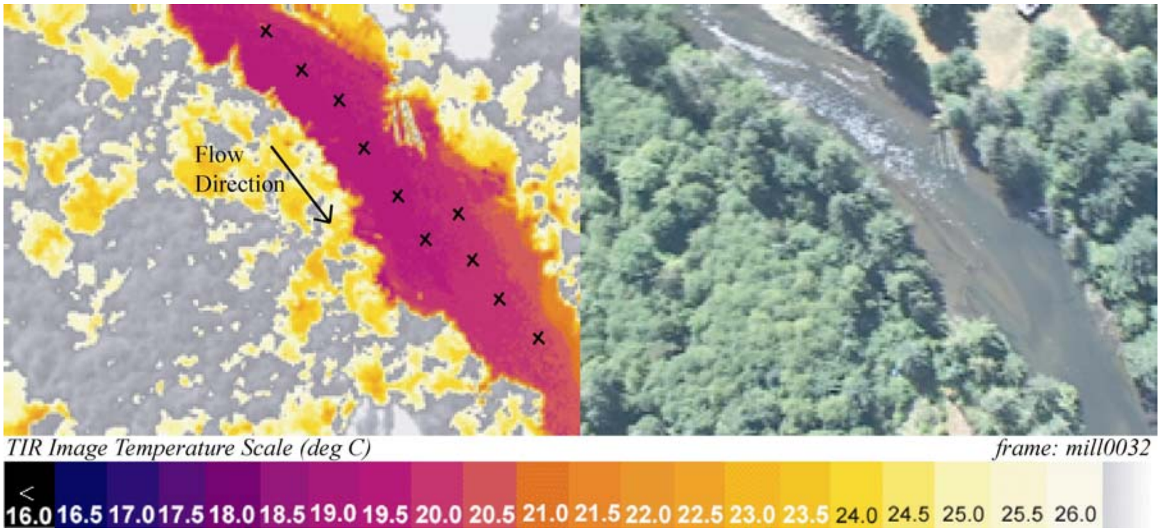


Figure 3 – TIR/color video image pair showing how temperatures are sampled from the TIR images. The black *X's* on the TIR image show typical sampling locations along the center of the stream channel. The recorded temperature for this image is the median of the sample points.

TIR Image Characteristics

Thermal infrared sensors measure TIR energy emitted at the water's surface. Since water is essentially opaque to TIR wavelengths, the sensor is only measuring water surface temperature. Thermal infrared data accurately represents bulk water temperatures where the water column is thoroughly mixed, however, thermal stratification can form in reaches that have little or no mixing. Thermal stratification in a free flowing river is inherently unstable due to variations in channel shape, bed composition, and in-stream objects (i.e. rocks, trees, debris, etc.) that cause turbulent flow. In the TIR images, indicators of thermal stratification include cool water mixing behind in-stream objects and/or abrupt transitions in stream temperatures. Occurrences of thermal stratification interpreted during analysis are identified in the results section for each surveyed stream.

Thermal infrared radiation received at the sensor is a combination of energy emitted from the water's surface, reflected from the water's surface, and absorbed and re-radiated by the intervening atmosphere. Water is a good emitter of TIR radiation and has relatively low reflectivity (approximately 4 to 6% of the energy received at the sensor is due to ambient reflections). During image calibration, a correction is included to account for average background reflections. However, variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.6^{o}C (Torgersen et al. 2001). However, the occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis. In general, apparent stream temperature changes of < 0.6^{o}C are not considered significant unless associated with a point source.

In stream segments with flat surface conditions and relatively low mixing rates (i.e. pools), observed variations in spatial temperature patterns can be the result of differences in the instantaneous heating rate at the water's surface. In the TIR images, indicators of differential surface heating include seemingly cooler radiant temperatures in shaded areas compared to surfaces exposed to direct sunlight. Shape and magnitude distinguish spatial temperature patterns caused by tributary or spring inflows from those resulting from differential surface heating. Unlike thermal stratification, surface temperatures may still represent bulk water conditions if the stream is mixed. Temperature sampling along the center of the stream channel (Figure 3) minimizes variability due to differences in surface heating rates. None-the-less, differences in surface heating combined with ambient reflection can confound interpretation of thermal features especially near the riverbank.

A small stream width logically translates to fewer pixels "in" the stream and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures (Torgersen et. al. 2001). In some cases, small tributaries were detected in the images, but not sampled due to the inability to obtain a reliable temperature sample.[2]

Results

Weather Conditions

Weather conditions for the times of the surveys are summarized in Table 2. Sky conditions were clear on the 18th of August and overall conditions were considered ideal for the TIR surveys.

Table 2 – Meteorological conditions recorded at Sanderson Field, Shelton, WA on August 18, 2003 during the time span of the TIR surveys.

Time	Temp °F	Temp °C	RH (%)
1:00 PM	81.5	27.5	43.3
1:30 PM	78.7	26.0	47.4
2:00 PM	80.1	26.7	44.8
2:30 PM	80.1	26.7	44.8
3:00 PM	81.5	27.5	43.3
3:30 PM	84.4	29.1	38.7
4:00 PM	84.4	29.1	41.2

[2] Features that are detected in the imagery, but not sampled for temperature are noted in the comment attribute of the flight point coverage.

Thermal Accuracy

The average absolute differences between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images were within the desired accuracy (< 0.5°C) for each surveyed stream (Table 3). The average distances and range of values were also consistent with TIR surveys conducted in the Pacific Northwest over the past five years (Torgersen, 2001).

The close physical proximity of the streams and the relatively short time between surveys on individual streams resulted in similar data collection conditions over the course of the afternoon. Consequently, the in-stream data loggers were well distributed not only for checking the radiant temperature accuracy on each stream, but also for assessing the calibration parameters collectively.

Table 3 – Comparison of ground-truth water temperatures (Kinetic) with the radiant temperatures for streams surveyed near Shelton, WA.

Stream	Image	River mile	Time 24 hr	Kinetic °C	Radiant °C	Difference °C
Mill Creek, August 18, 2003, Avg. = 0.4						
Mill Cr.	mill0123	1.9	13:39	20.0	20.2	-0.2
Mill Cr.	mill0659	7.2	13:57	22.1	22.6	-0.5
Mill Cr.	mill0829	8.8	14:03	23.1	22.7	0.4
Cranberry Creek, August 18, 2003, Avg. = 0.3						
Cranberry Cr.	cran0061	0.3	14:12	18.0	18.2	-0.2
Cranberry Cr.	cran0255	2.7	14:19	20.8	20.7	0.1
Cranberry Cr.	cran0387	3.6	14:23	24.4	23.9	0.5
Johns Creek, August 18, 2003, Avg. = 0.1						
Johns Cr.	john0026	0.1	14:37	16.4	16.4	0.0
Johns Cr.	john0218	2.7	14:44	19.0	19.1	-0.1

Temporal Differences

Figure 4 shows in-stream temperature variations at a single location on each of the three surveyed streams during the afternoon of August 18th. The figure is intended to provide both a sense of how stream temperatures changed during the time span of the flight and the timing of the flight relative to the recorded daily maximum temperatures.

At river mile 7.2 of Mill Creek, the TIR flight occurred prior to the recorded daily stream temperature maximum, which occurred between 17:50 and 18:00. On Cranberry Creek, the daily stream temperature maximum occurred between 15:10 and 15:30 at river mile 3.6. On Johns Creek near the mouth, the timing of the TIR survey was consistent with the daily stream temperature maximum.

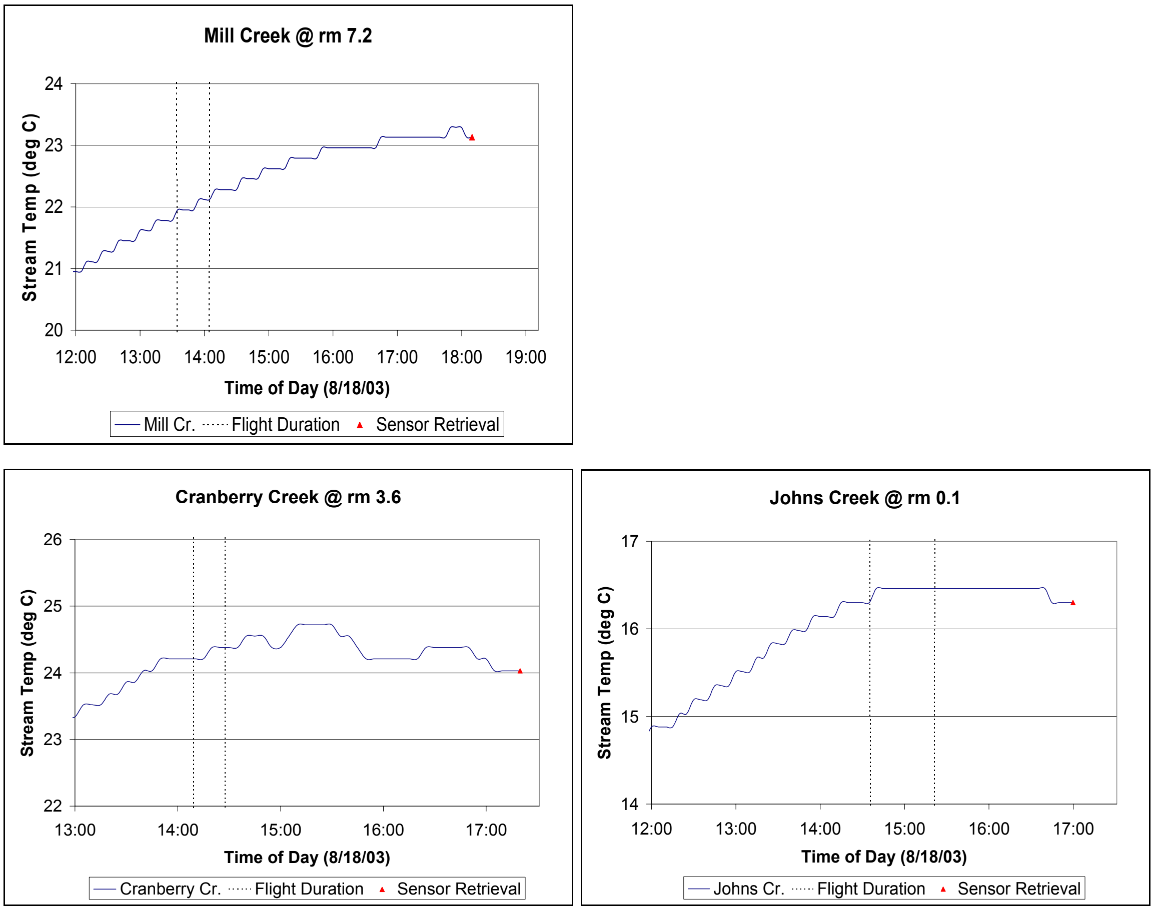


Figure 4 – Stream temperature variation and time of TIR remote sensing flight at a single location on each surveyed stream.

Longitudinal Temperature Profiles

Mill Creek

Figure 5 illustrates the longitudinal temperature profile developed for Mill Creek. The profile also shows the temperature and location of Hammersley Inlet and Isabella Lake. No tributaries or surface springs were detected over the 9.9-mile length of Mill Creek. However, bank-side vegetation, which in some locations almost completely masked the stream surface, may have concealed tributaries or other point source inflows.

At the time of the TIR survey, radiant (*or apparent*) temperatures were ≈22.9°C at the outlet of Isabella Lake and cooled to a survey minimum of ≈18.7°C at river mile 0.4. Although no point source inflows were detected, relatively sharp decreases in stream temperatures were noted at two distinct locations along the stream gradient. Moving downstream from Isabella Lake, an apparent drop in water temperature of ≈1.0°C was observed between river miles 7.3 (22.6°C) and 7.0 (21.8°C). Although the magnitude of this decrease was close to the ±0.5°C noise level commonly observed in TIR remote sensing, stream temperatures remained consistent (≈21.8°C) downstream of river mile 7.0 creating a step pattern in the longitudinal profile. This step pattern is not characteristic of noise in the TIR and most often indicates a discharge into the stream. A second decrease of ≈2.0°C was observed between river miles 5.0 and 4.2. This magnitude of cooling suggests possible ground water influence.

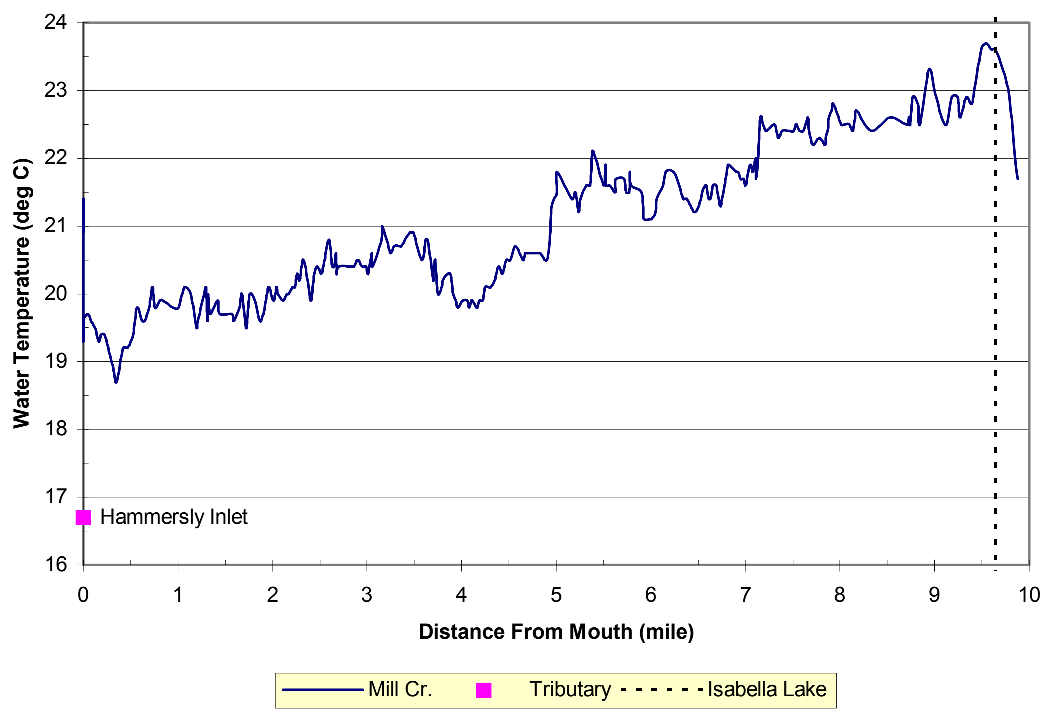


Figure 5 – Median channel temperatures versus river mile for Mill Creek, WA along with the location of surface water inflows.

The longitudinal temperature profile is also presented in Figure 6 which additionally shows the kinetic (in-stream) temperatures at each ground truth location both at the time of the survey and when the data loggers were retrieved on the day of the survey. This plot provides additional context for interpreting the spatial temperature patterns. As illustrated, stream temperatures continued to increase at each location after the time of the flight, but the overall downstream cooling pattern remained consistent.

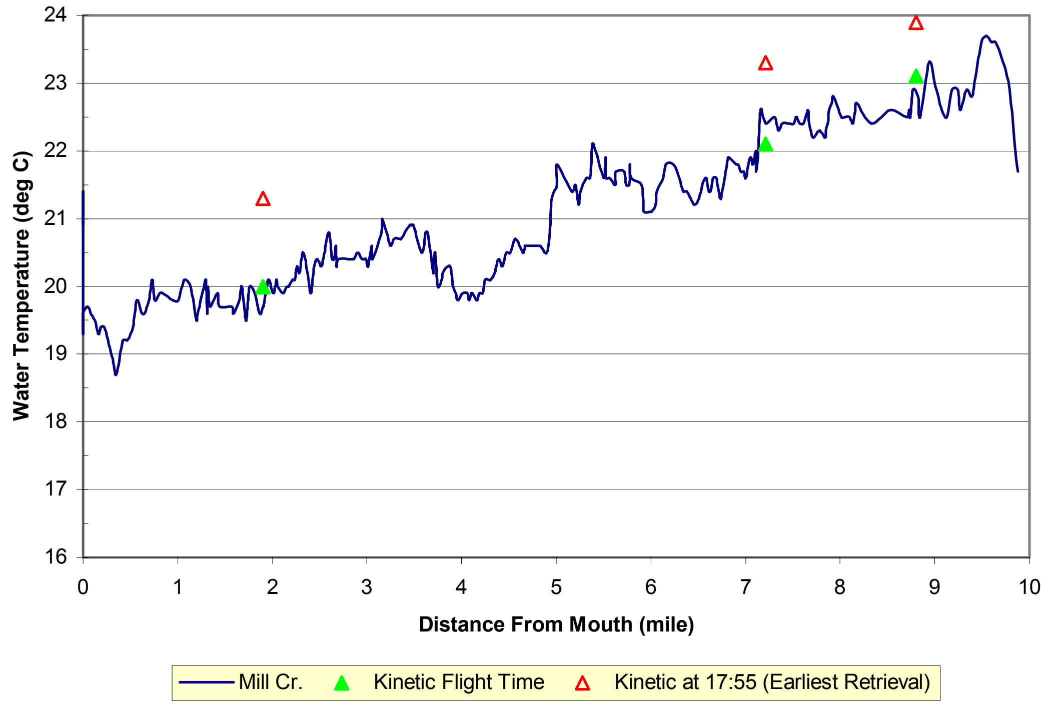


Figure 6 – Median radiant temperatures in Mill Creek, WA versus river mile. The plot shows the locations of in-stream sensors with the recorded in-stream (kinetic) temperature at the times of both the survey and sensor retrieval.

Cranberry Creek

Median radiant temperatures were plotted versus river mile for Cranberry Creek, WA (Figure 7). No surface water inflows (i.e. tributaries, surface springs, etc.) were sampled during the analysis. As with Mill Creek, riparian vegetation canopied the stream surface intermittently over the survey and may have masked smaller tributaries.

Cranberry Lake was thermally stratified with lake surface temperatures ≈23.9°C. Moving downstream from the lake, spatial temperature patterns in the channel show a transition from a stratified condition near the lake outlet to a mixed condition prior to entering Lake Limerick. The surface of Lake Limerick was also stratified and the TIR imagery shows variations in temperature patterns due to differences in mixing rates and instantaneous heating rates (e.g. between shadowed and exposed areas) on the lake surface. The survey generally followed along the west bank of the lake.

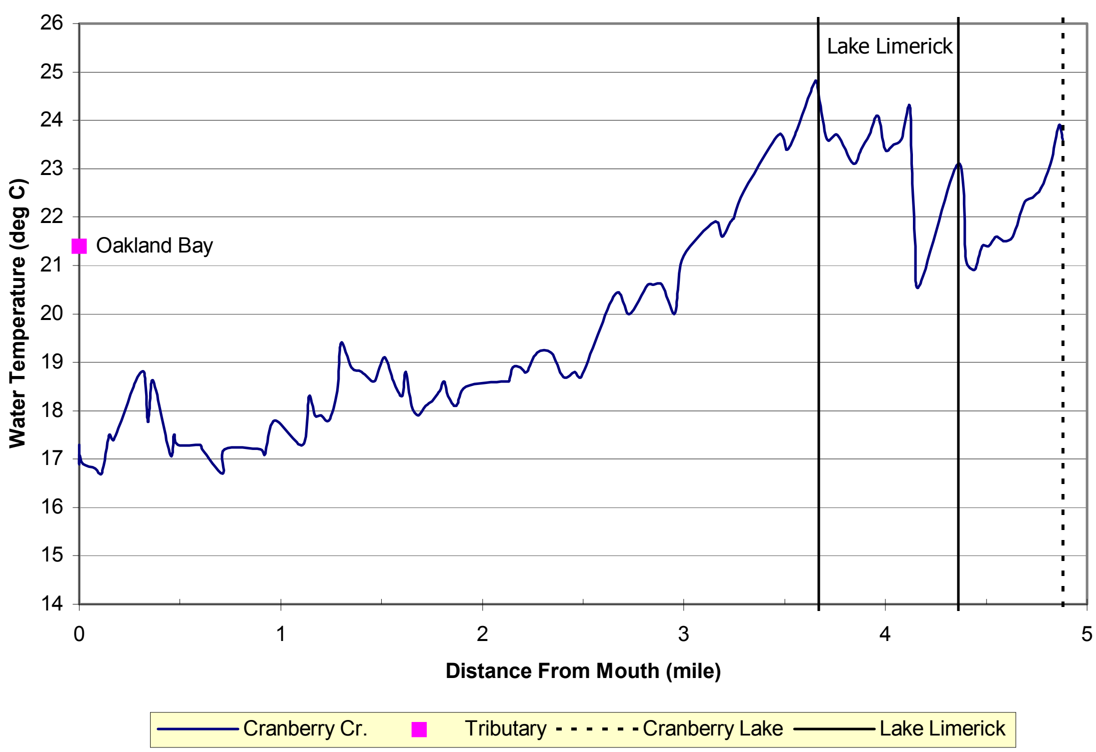


Figure 7 – Median channel temperatures versus river mile for Cranberry Creek, WA.

Stream temperatures generally decreased between Lake Limerick and the mouth of Cranberry Creek at Oakland Bay. Radiant stream temperatures in the Limerick Lake spillway (river mile 3.7) were ≈24.5°C. Downstream of the spillway, Cranberry Creek was only intermittently visible through the streamside vegetation. Consequently, radiant temperatures could only be acquired when the stream surface was visible in the TIR images (Figure 8). The plot of the sampled temperatures showed an apparent decrease in water temperatures to 18.7°C by river mile 2.5. Enough samples were acquired to indicate a gradual decrease in temperatures over this 1.2-mile segment as opposed to a sharp drop that might result from a single point source.

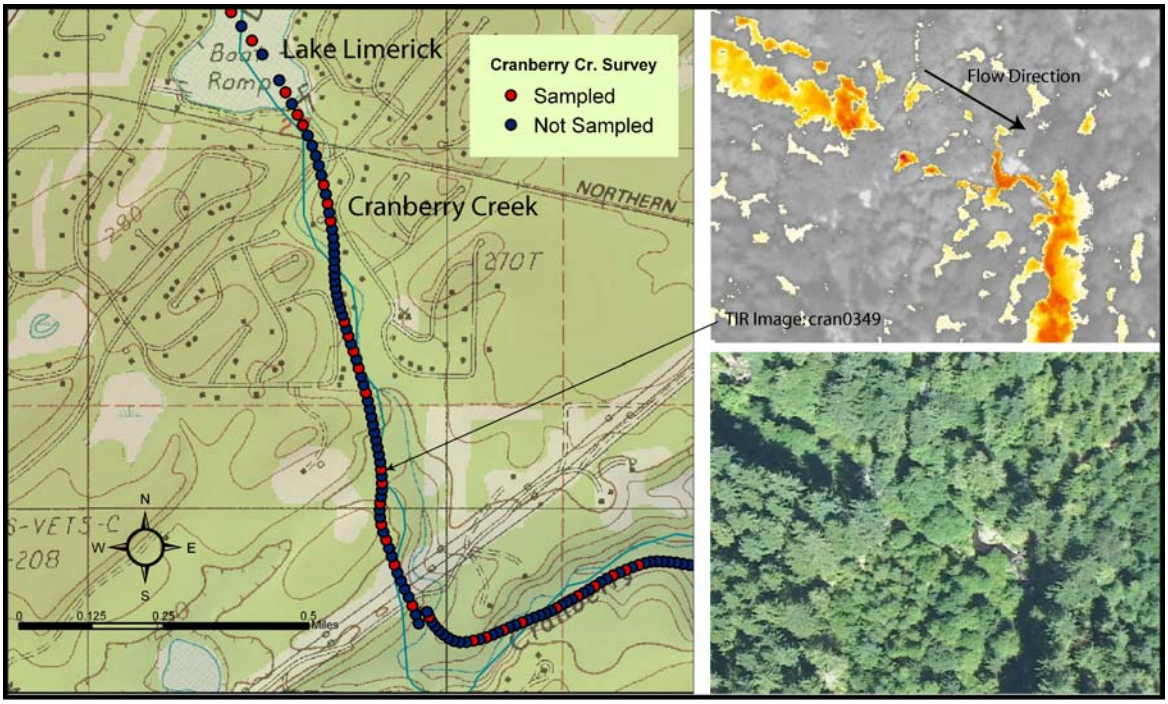


Figure 8 – Point pattern map showing intermittent sampling along Cranberry Creek just downstream of the outflow of Limerick Lake. The red points represent images where the stream was sufficiently visible through the riparian canopy to obtain a radiant temperature sample. The blue points represent images in which no temperature sample was acquired.

Stream temperatures continued to decrease downstream of river mile 2.5 reaching ≈17.0°C at the stream mouth. Local spatial variability was observed through this reach with sampled temperatures ranging from 16.7 and 19.4°C. However, as with the upstream reaches, the level of riparian masking of the stream only allowed sampling where the stream surface was visible and made it difficult to identify all possible sources of variability.

The longitudinal temperature profile developed for Cranberry Creek is also presented in Figure 9 which additionally shows the kinetic (in-stream) temperatures at each ground truth location both at the time of the survey and when the data loggers were retrieved on the day of the survey. This plot shows that stream temperatures changed by

<=0.5°C between the time of the survey and the time the in-stream data loggers were retrieved.

Figure 9 – Median radiant temperatures in Cranberry Creek, WA versus river mile. The plot shows the locations of in-stream sensors with the recorded in-stream (kinetic) temperature at the times of both the survey and sensor retrieval.

Johns Creek

The median temperatures for each sampled image of Johns Creek were plotted versus the corresponding river mile (Figure 10). The plot also contains the median temperature and name of all surface water inflows (e.g. tributaries, surface springs, etc.) that were visible in the imagery.

Sampled radiant temperatures through Mc Ewen Prairie (river mile 4.6 to 8.2) showed a high degree of local variability with temperatures ranging between 26.4°C and 18.7°C. Secondary and multiple side channels were observed within the floodplain and differences were observed in the amount of surface water visible in the main channel through this reach. The variations in surface water suggest at least some measure of shallow sub-surface exchange between the channel and the floodplain. During low flow conditions, these exchanges can result in local variability in the stream temperatures. In addition, interpretation of the TIR images indicated possible surface stratification on some of the pools within the floodplain (Figure 11).

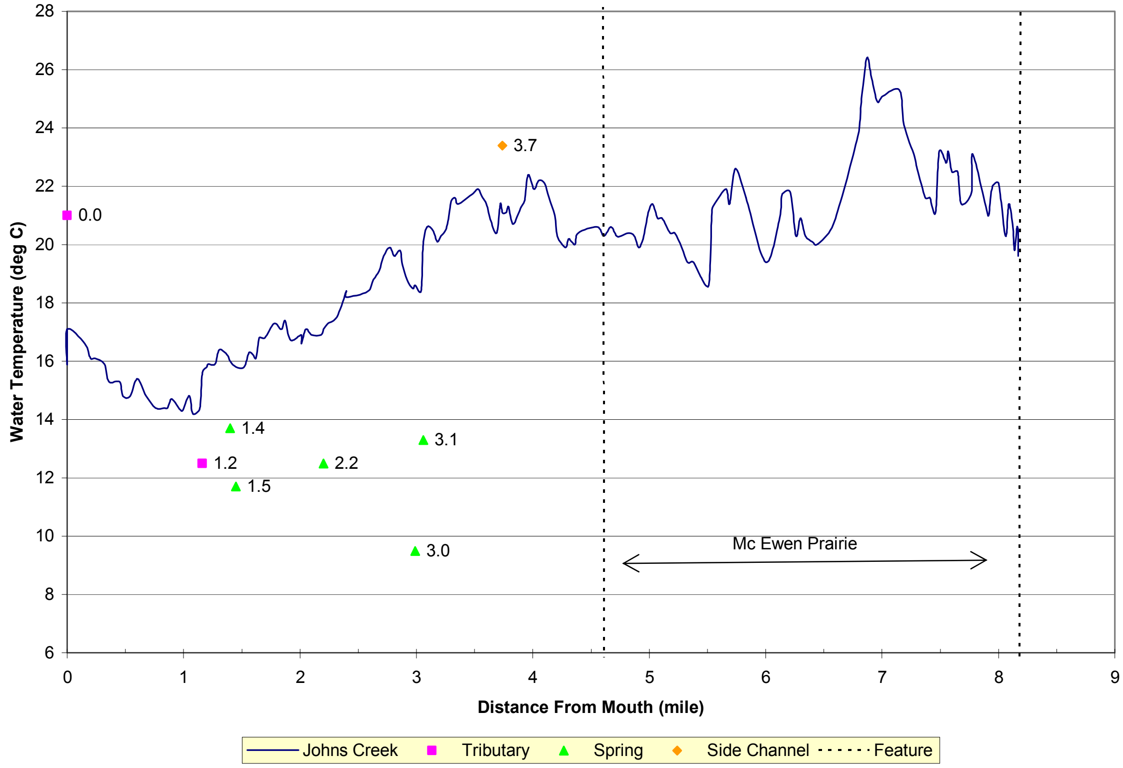


Figure 10 – Median channel temperatures versus river mile for Johns Creek, WA. The temperature of sampled tributaries and other surface inflows are shown on the profile by river mile and are listed in Table 4.

Table 4 – Tributary temperatures for Johns Creek, WA

Tributary	Image	km	Mile	Tributary °C	Johns Cr °C	Difference °C
Oakland Bay (LB)	john0003	0.0	0.0	21.0	17.0	4.0
Unnamed Trib (LB)	john0076	1.8	1.2	12.5	15.6	-3.1
Spring						
Spring (RB)	john0090	2.2	1.4	13.7	16.0	-2.3
Spring (LB)	john0093	2.3	1.5	11.7	15.8	-4.1
Spring (RB)	john0190	3.5	2.2	12.5	17.1	-4.6
Spring (RB)	john0237	4.7	3.0	9.5	18.6	-9.1
Spring (LB)	john0240	4.9	3.1	13.3	20.1	-6.8
Side Channel						
Side Channel (RB)	john0277	5.9	3.7	23.4	21.1	2.3

(looking downstream RB = right bank, LB = left bank)

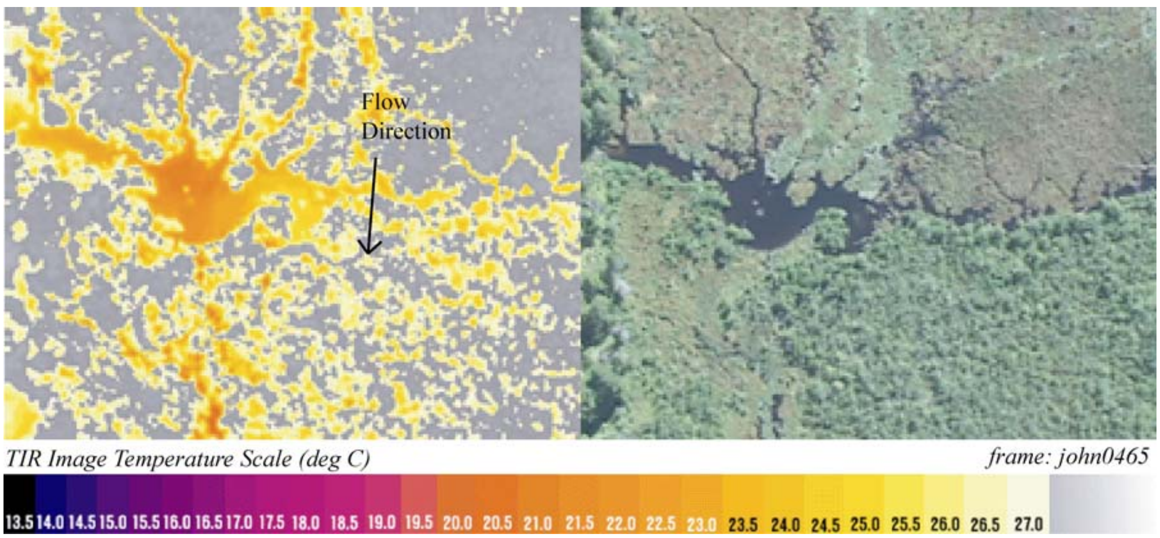


Figure 11 - TIR/color video image pair showing a stratified pool at river mile 6.6 of Johns Creek. Although the water flow is from the top of the image to the bottom, the water's temperature varies from 20.9°C on the left side of the pool (right bank) to 23.4°C on the right-hand portion of the pool (left bank).

As observed on Mill and Cranberry Creeks, stream temperatures generally cooled over the lower 4 river miles. Unlike the other streams, five spring inflows were detected that contributed to the overall cooling trend and further suggest ground water influence as the source of Johns Creek's cooling trend. At river mile 1.4-1.5, two springs were somewhat difficult to identify due to their small size and masking by shadows and riparian vegetation. However, their physical location on the stream and cool temperature relative to other features (surface water, vegetation, etc.) provided sufficient evidence to interpret these areas as surface springs (Figure 12).

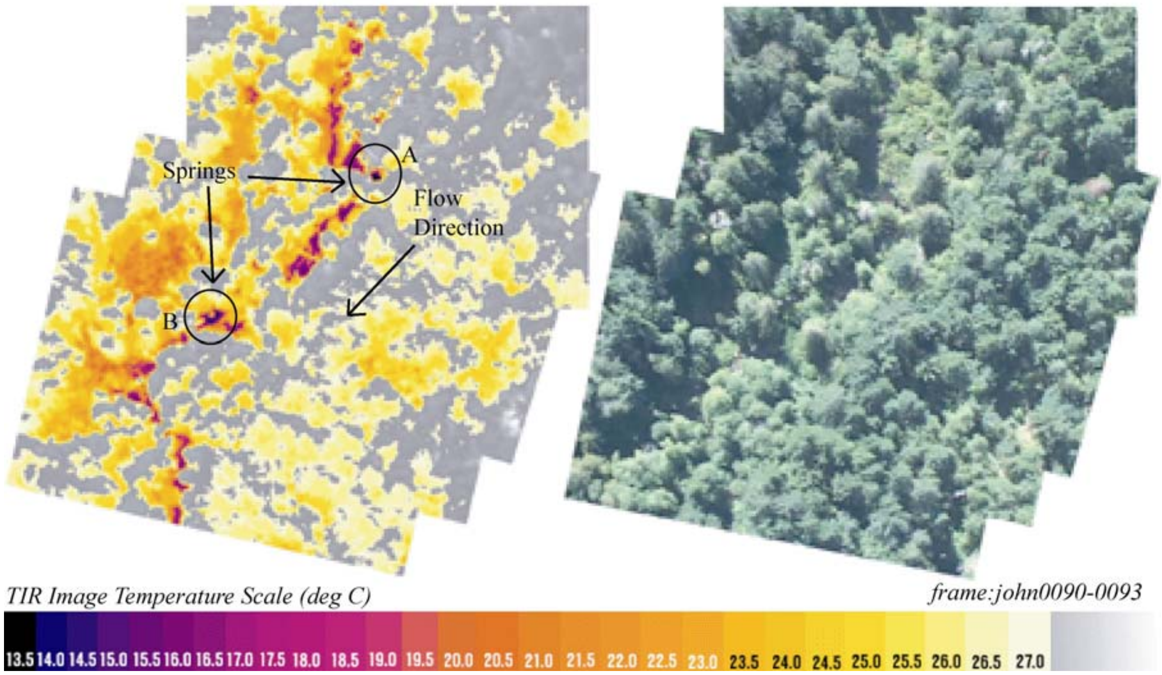


Figure 12 - TIR/color video image pair showing two springs in Johns Creek (15.9°C) at river mile 1.4. The upstream spring (A) on the left bank measures 11.7°C while the downstream spring (B) measures 13.7°C.

The longitudinal temperature profile is also presented in Figure 13, which shows both the kinetic (in-stream) temperatures at the time of the survey and the temperature at the earliest sensor retrieval time at the in-stream monitoring locations. This plot provides additional context for interpreting the spatial temperature patterns. The plot shows sensor at river mile 2.7 recorded a change of +0.8°C between the time of the survey and the retrieval of the sensors. The sensor at river mile 0.1 recorded no significant change.

Discussion

Thermal infrared remote sensing surveys were successfully conducted on Mill, Cranberry, and Johns Creeks. Longitudinal temperature profiles were produced for each surveyed stream, which illustrate broad scale spatial temperature patterns and the location and influence of tributary and other surface water inflows.

All three surveys ended at the outlet of a lake and, in each case, stream temperatures showed a general cooling trend from the lake outlet to the stream mouth at Oakland Bay. All three creeks showed a conspicuous lack of downstream heating despite clear conditions and afternoon air temperatures in excess of 26.0°C (79.0°F). Riparian vegetation often masked the water surface and at times made the streams difficult to follow from the air. This masking would be expected to buffer solar radiation from the water surface and hence reduce heating due to direct solar loading during the course of the day. Depending on flow velocity and aspect, the streams may heat differentially along theirs courses, resulting in segments with cooler downstream temperatures. On Johns Creek, however, five surface springs were identified in the TIR image showing subsurface influence on the thermal regime of this stream. Although no surface springs were detected on Mill Creek, the longitudinal profile illustrated two locations (river miles 7.0 and 5.0) where temperatures dropped sharply indicating a probable cooling source. On Cranberry Creek, stream temperatures dropped sharply ($\approx$7.0^{o}C over 1.1 miles) downstream of the Lake Limerick outflow. The riparian cover made it impossible to detect surface inflows (tributaries or surface springs) through this reach.

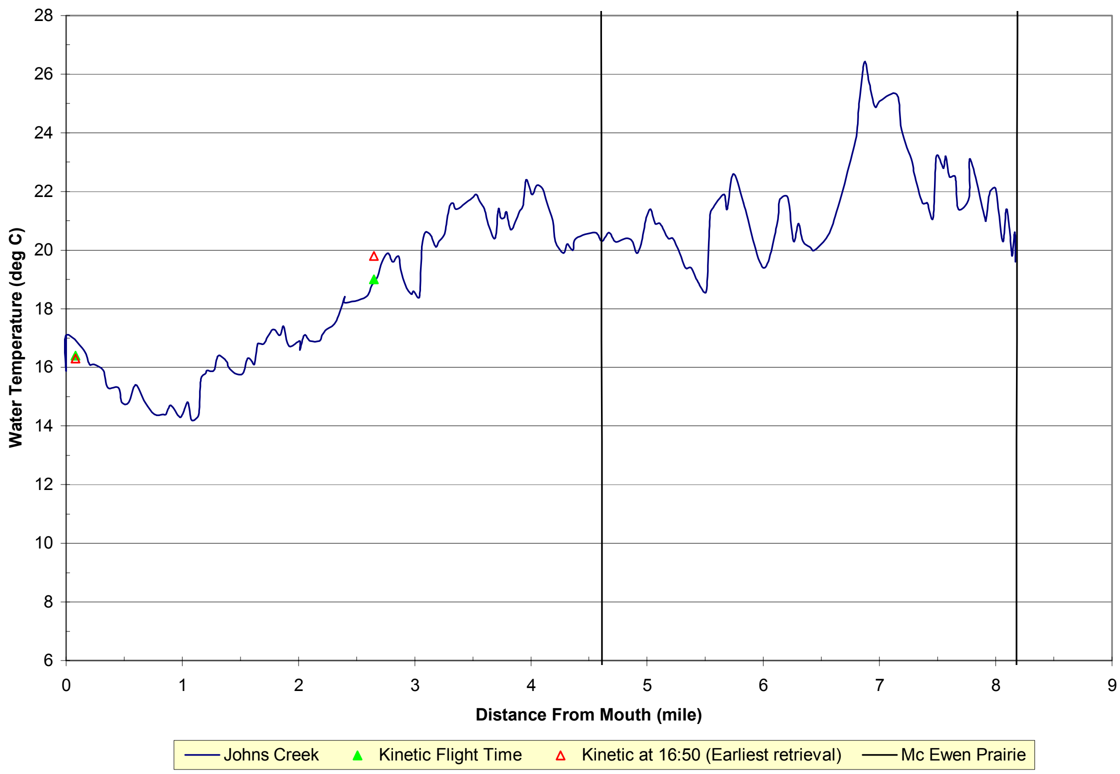


Figure 13 – Median channel temperatures versus river mile for Johns Creek, WA. The plot also shows kinetic temperatures at the time of the survey and the recorded temperatures at the time of sensor retrieval.

This report presents the methods used to collect and process airborne TIR images of Mill, Cranberry, and Johns Creek, WA. The report also presents the spatial temperature patterns derived from the imagery and presents hypotheses on the processes that may have contributed to the observed patterns. The ArcView database contains the TIR and color video images and allows further analysis of these data. Follow-on analysis should combine this information with other spatially explicit data sets in order to further understand the primary processes driving the thermal regime of the surveyed streams. Additional data sets may include factors that influence heating rates such as stream gradient, elevation, aspect, vegetation, and land-use. The stream temperature profiles also provide a spatially continuous data set for the calibration of reach and basin scale stream temperature models.

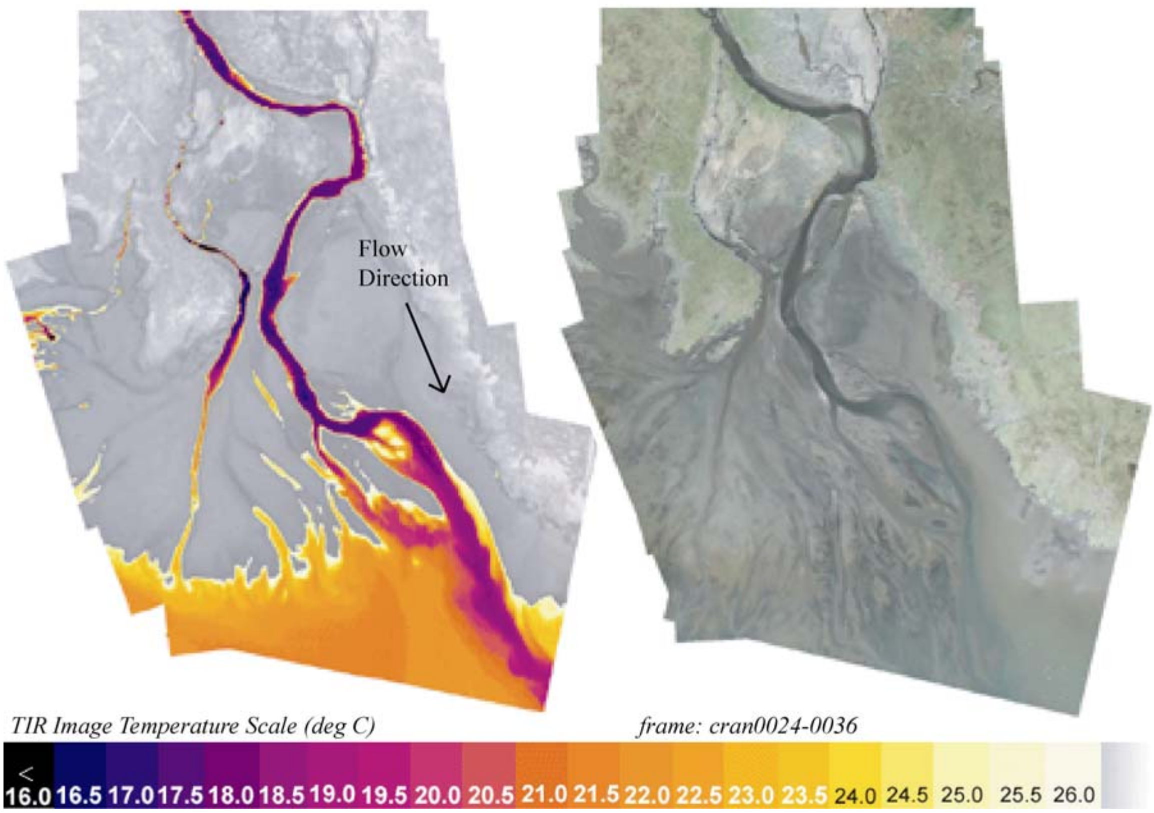
Bibliography

Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

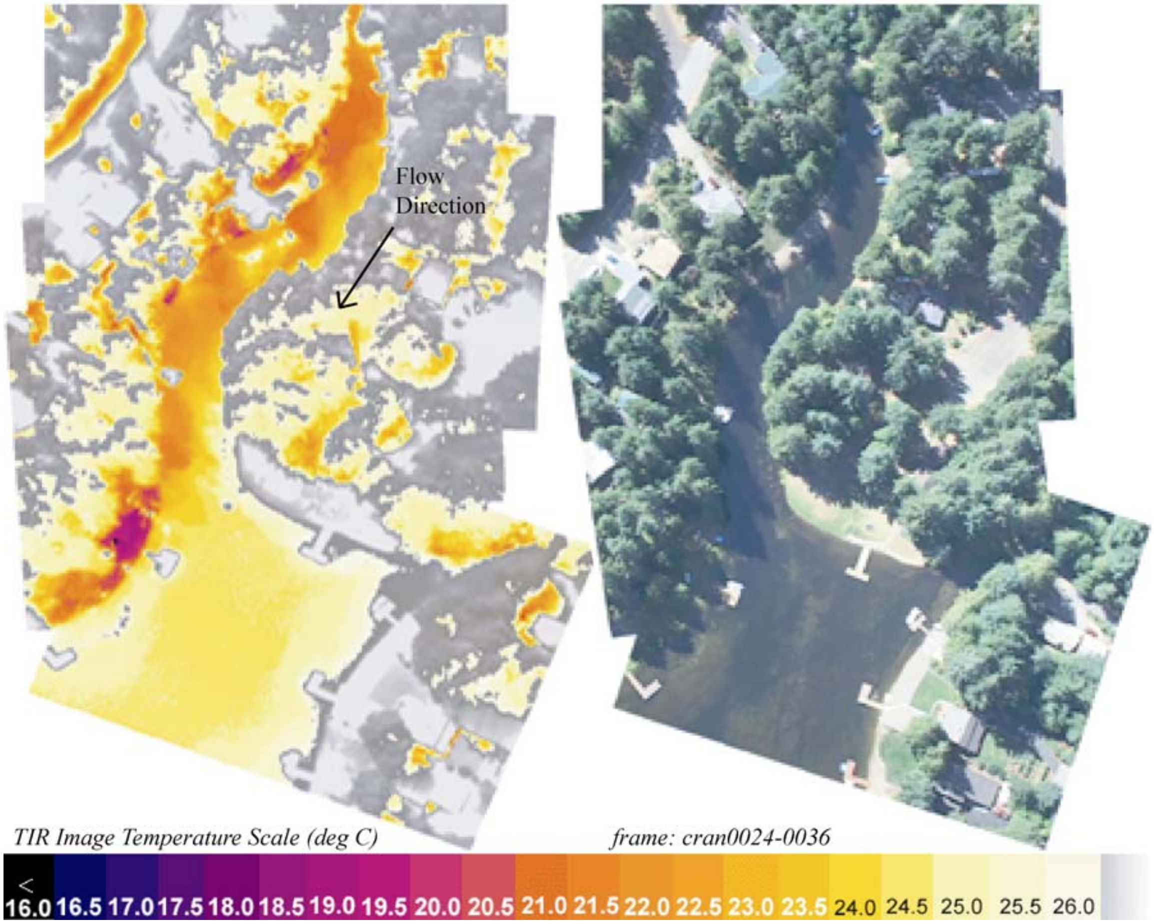
Appendix A – Selected Images

Note: Due to a wider range of temperatures observed on Johns Creek, a different color map was applied to Johns Creek than was used on Mill and Cranberry Creeks. The color maps were selected to best represent the range of radiant temperatures observed in the streams. The color map is located at the bottom of each image pair and provides an index to the temperatures associated with each color.

Cranberry Creek

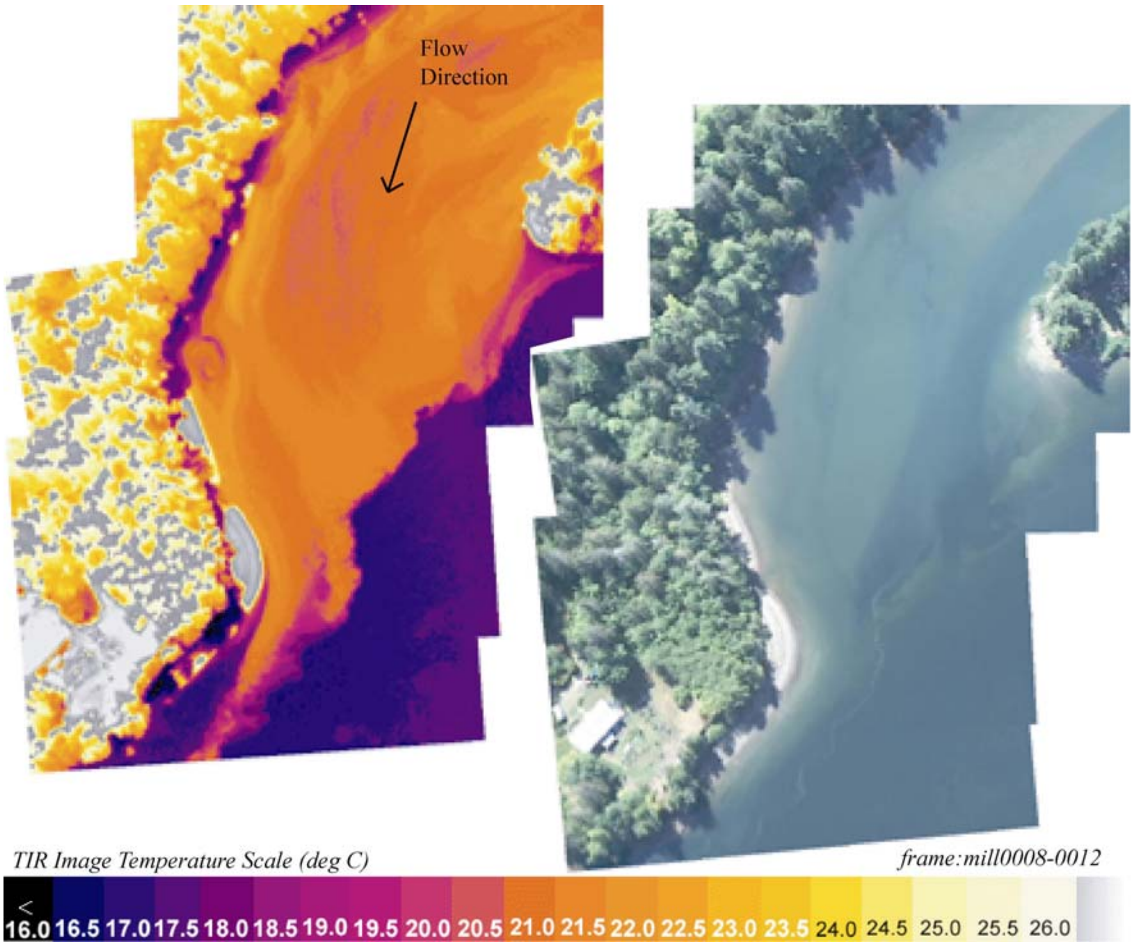


TIR/color video image pair showing the mouth of Cranberry Creek (17.3^{o}C) at Oakland Bay (21.4^{o}C).

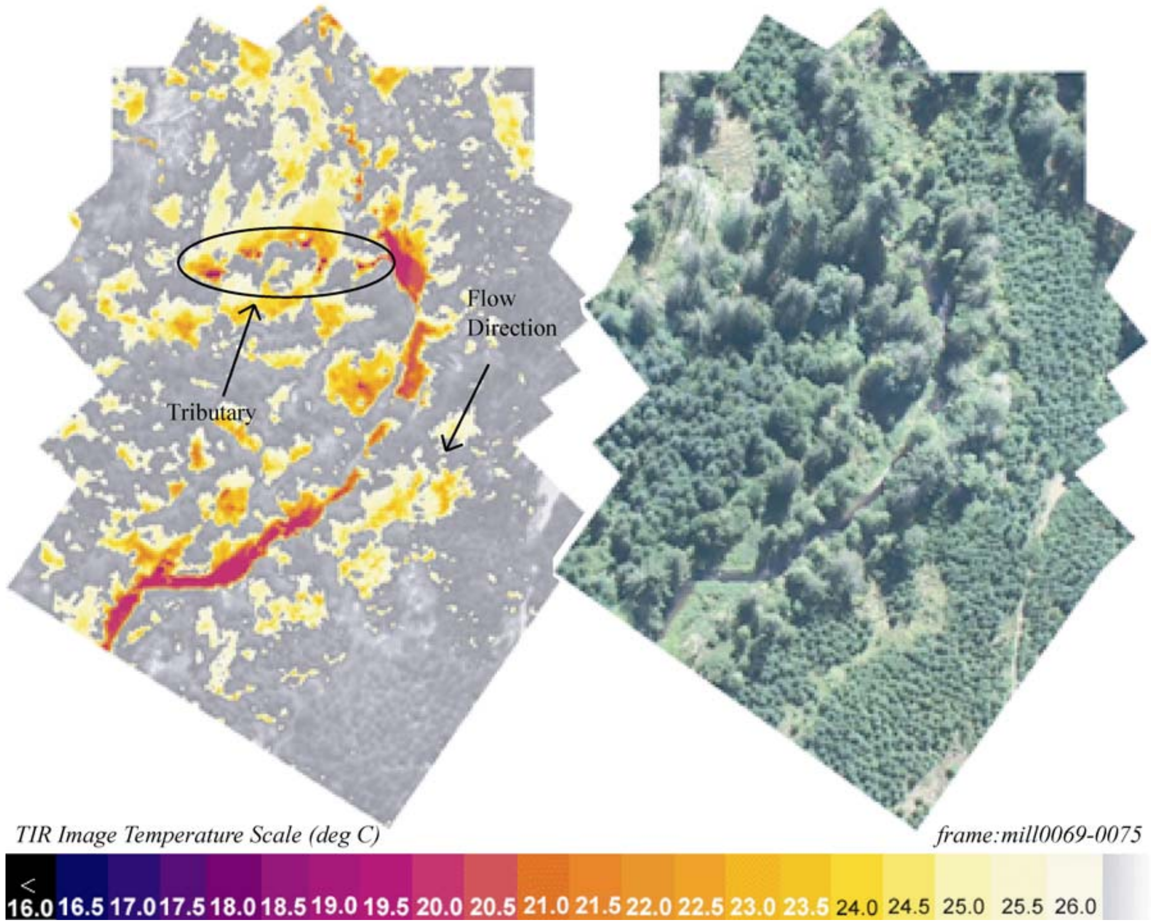


TIR/color video image pair showing the flow of Cranberry Creek (20.9^{o}C) into Limerick Lake (24.3^{o}C) at river mile 4.3. The image illustrates a thermal transition from at least a partially mixed condition in Cranberry Creek to the stratified lake surface. The image also illustrates slightly cooler surface temperatures in the shadowed areas along the right bank of Cranberry Creek. These cooler areas are often an indication of differential heating on the stream's surface.

Mill Creek

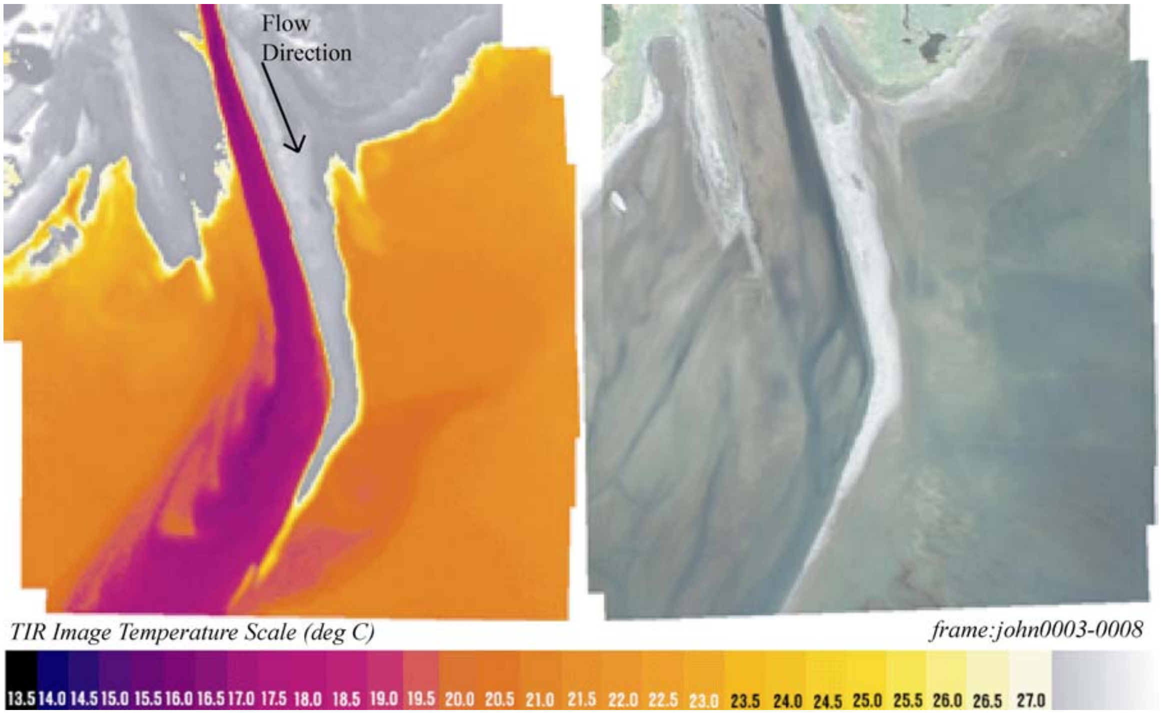


TIR/color video image pair shows a transition in surface temperatures from the mouth of Mill Creek (21.4^{o}C) to Hammersley Inlet (16.7^{o}C). The cooler areas along the right bank are due to cooler shadows on the bank.

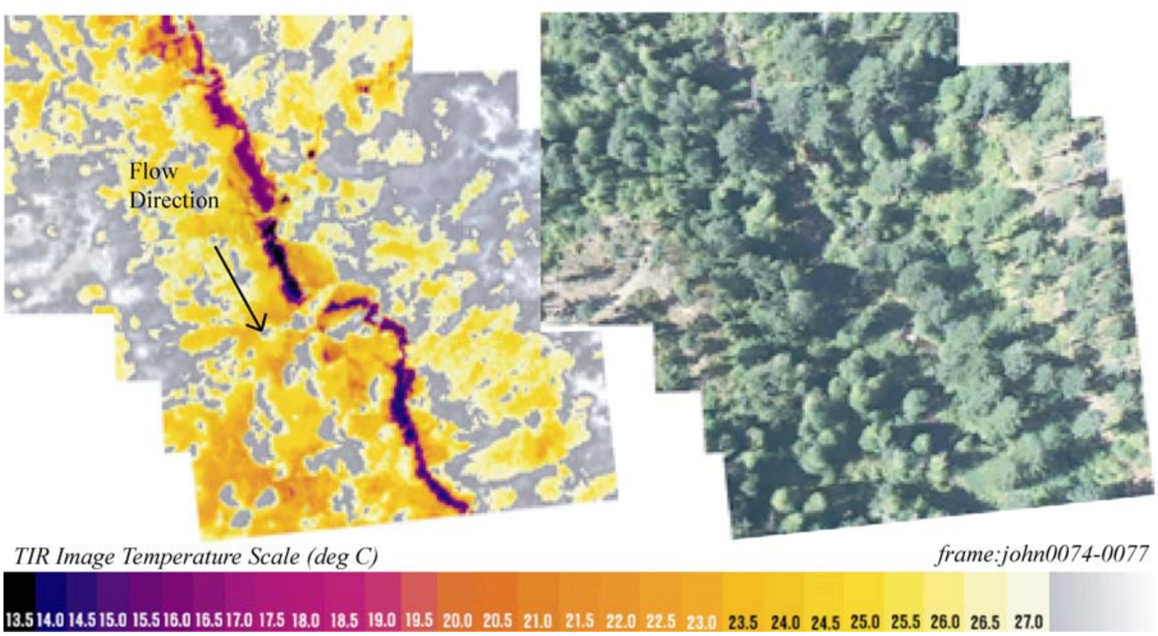


TIR/color video image pair showing general conditions on Mill Creek (19.9°C) at river mile 0.8. A potential tributary inflow was detected at this location, but could not be positively identified due to masking by stream-side vegetation.

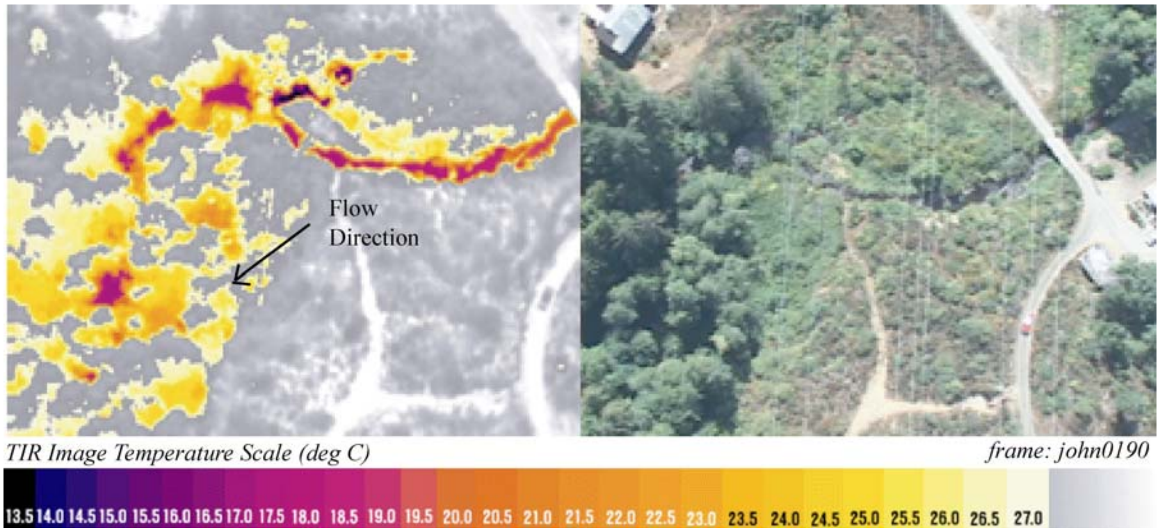
Johns Creek



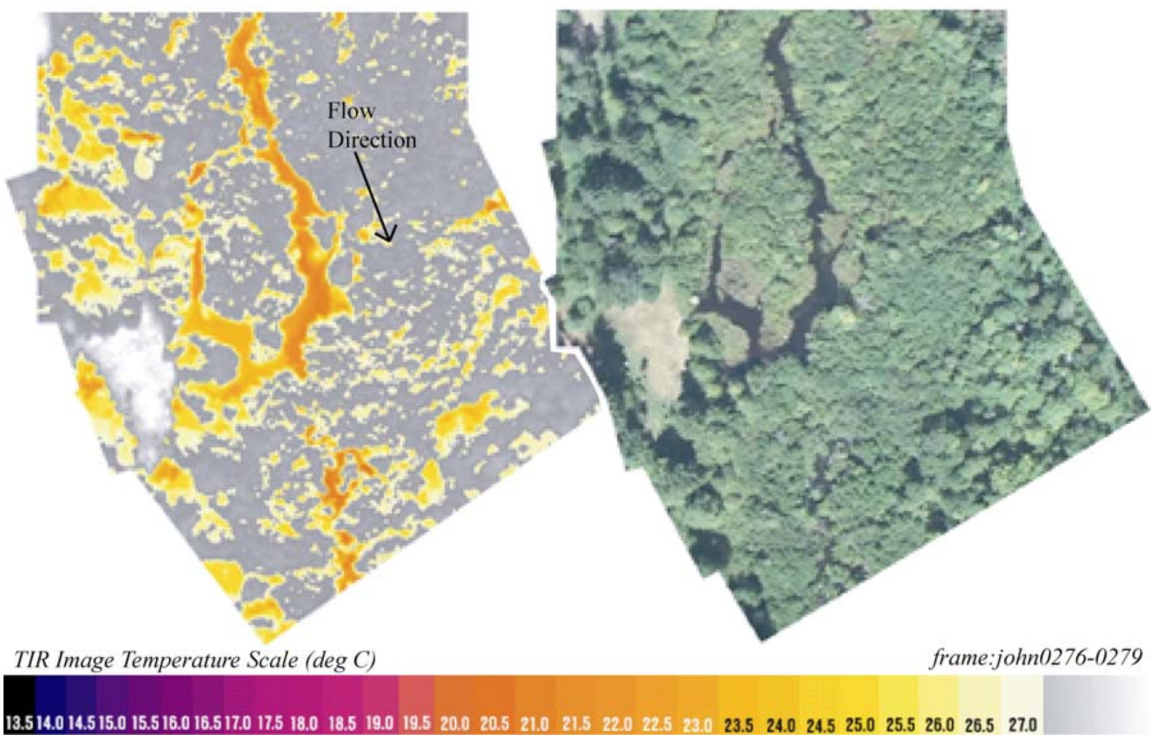
TIR/color video image pair showing the mouth of Johns Creek (17.0°C) at Oakland Bay (21.0°C).



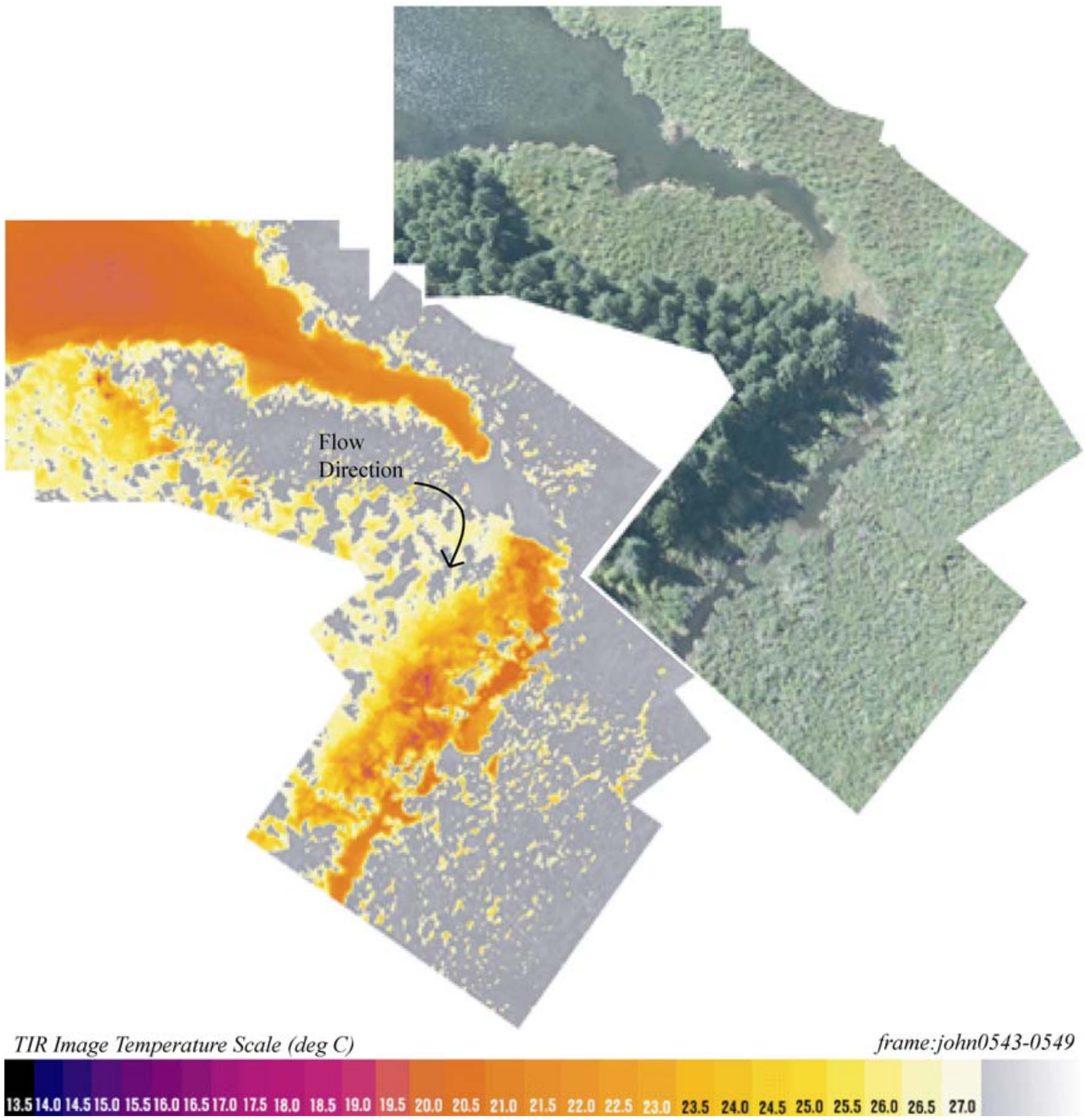
TIR/color video image pair showing an unnamed tributary on the left bank of Johns Creek at river mile 1.2. Although the mouth is obstructed, the temperature upstream is 12.5 degrees C, causing the main stem Johns Creek temperatures to drop from 15.6 to 14.4 degrees C in the downstream direction.



TIR/color video image pair showing an unmapped spring (12.5°C) on the right bank of Johns Creek (17.1°C) at river mile 2.2.

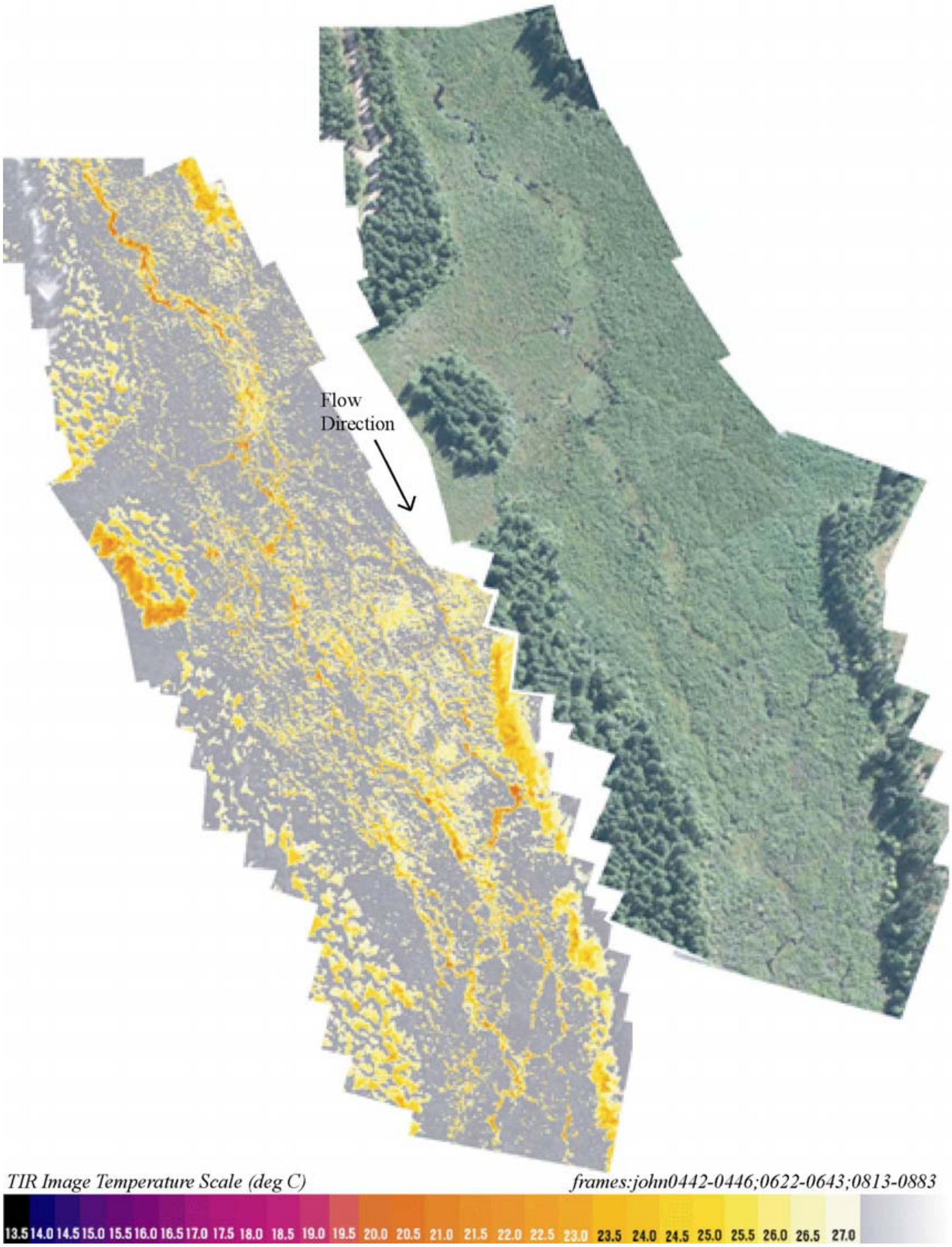


TIR/color video image pair showing a side channel (23.4°C) on the right bank of Johns Creek (21.1°C) at river mile 3.7.

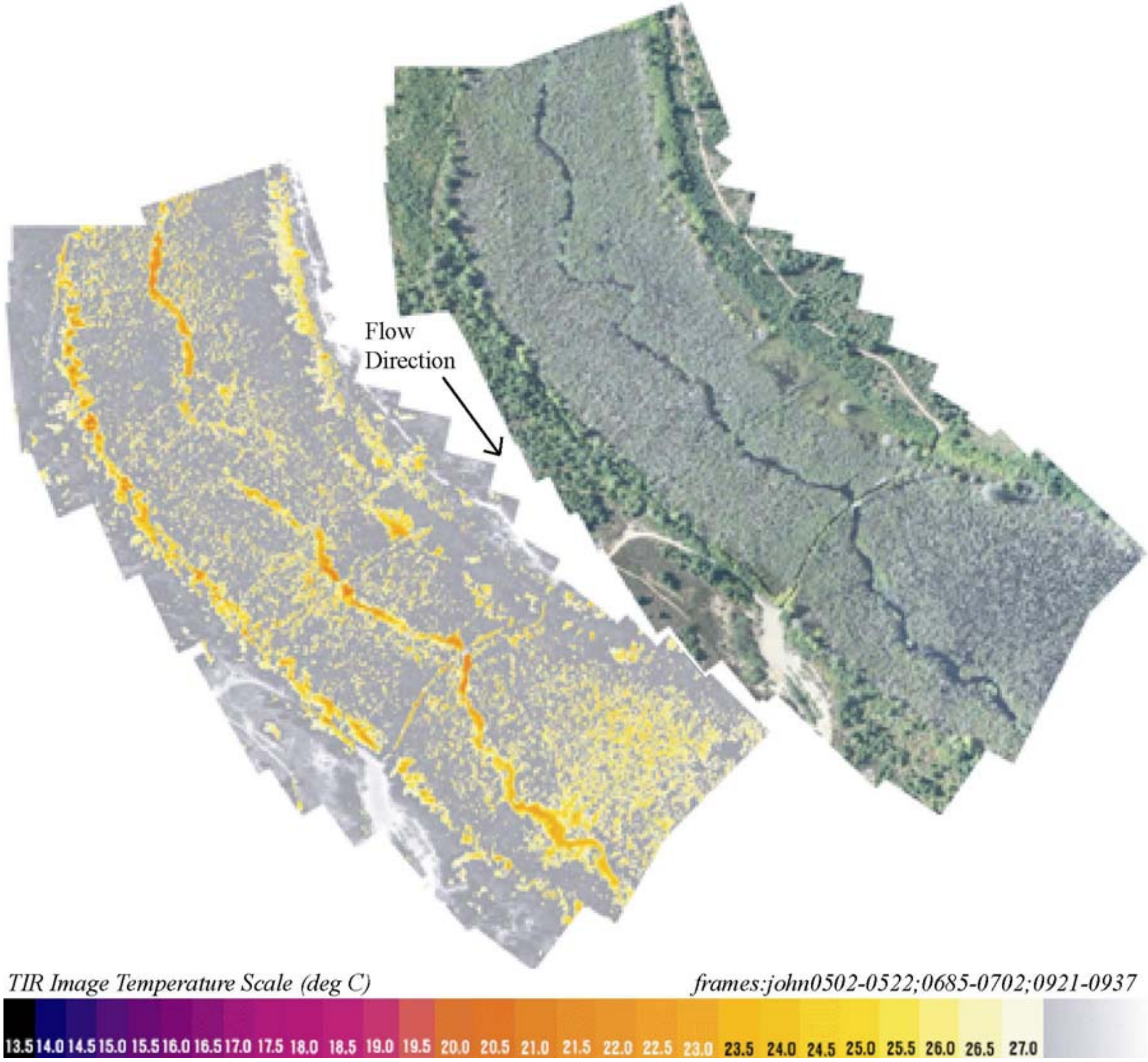


TIR/color video image pair showing the origin of Johns Creek (20.7^{o}C) from Johns Lake (19.6^{o}C) at river mile 18.2, including a short segment of sub-surface flow which doesn't appear to influence the temperature of Johns Creek.

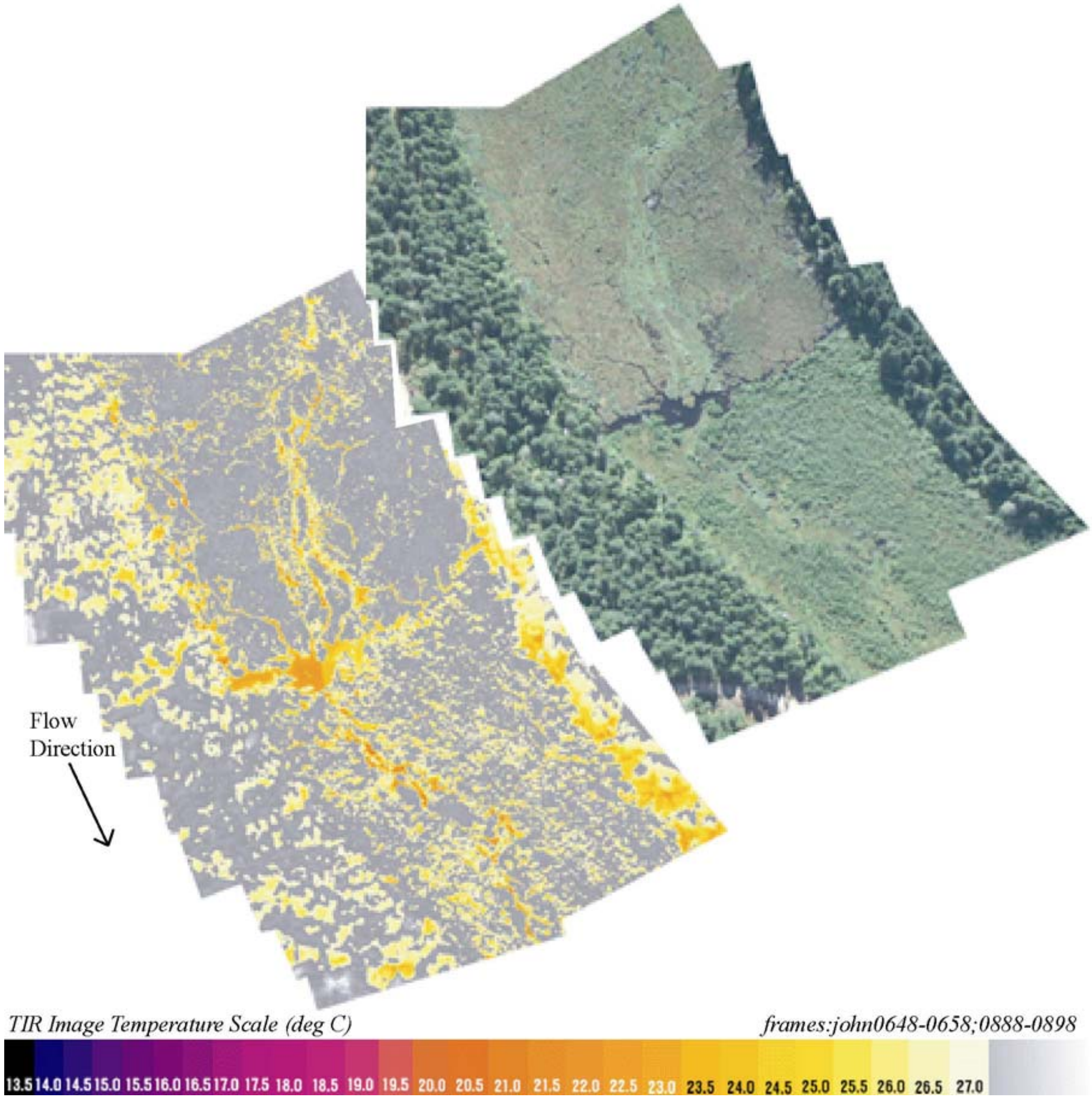
Johns Creek Floodplain (Low Altitude, Multiple Paths)



TIR/color video image mosaic showing the width of the Johns Creek through the Mc Ewen Prairie area. The image illustrates the small channel widths, vegetation masking, and multiple channels that were characteristic of this reach (river miles 5.8 to 6.4).



TIR/color video image mosaic of Johns Creek in the Mc Ewen Prairie area between river miles 6.5 and 6.7. The images illustrate a more defined main channel and localized variations in stream surface temperature.



TIR/color video image mosaic of Johns Creek between river miles 7.3 and 7.7. The image shows almost no visible surface flow in the stream channel. The pool in the center of the image shows signs of thermal stratification. The intermittent surface water in Mc Ewen Prairie area results in a high degree of local spatial variability in stream temperatures.