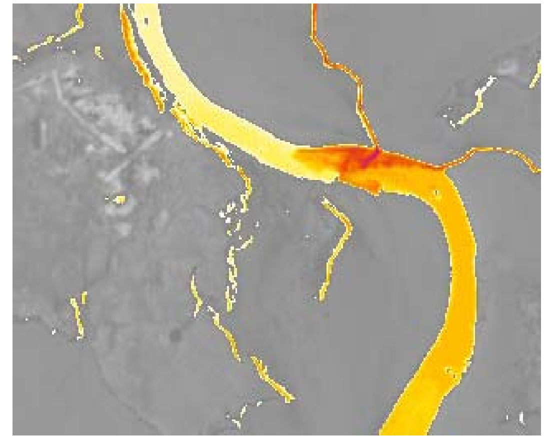
Aerial Survey of Skookum and Goldsborough Creeks, WA
Thermal Infrared and Color Videography



Report to:

Squaxin Island Tribe
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By:

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Report Date: January 26, 2005
Survey Date: August 13, 2004

Final Report

Table of Contents

Background

In 2004, Squaxin Island Tribe contracted with Watershed Sciences, Inc. to conduct an airborne thermal infrared (TIR) survey of Skookum and Goldsborough Creeks. The objective of the project was to exemplify the thermal characteristics of the river and to document surface water inflows and areas of potential sub-surface upwelling. The results are intended to support the Squaxin Island Tribe, the WRIA 14 Watershed Planning Unit, and the Department of Ecology's continued hydrologic and biologic assessments of streams in the Southern Puget Sound.

Water temperatures vary naturally, 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.

The imagery and derived data are contained in an associated geographic information system (GIS) database. This report provides a detailed description of the work performed, including methodology and quantitative assessments of data quality. In addition, the report presents and discusses the spatially continuous longitudinal temperature profiles derived from the imagery. These profiles provide a landscape scale perspective of how temperatures vary along the stream gradient and are the basis for follow-on analysis.

Methods

Data Collection

Sensor mount used for the TIR and color video surveys.

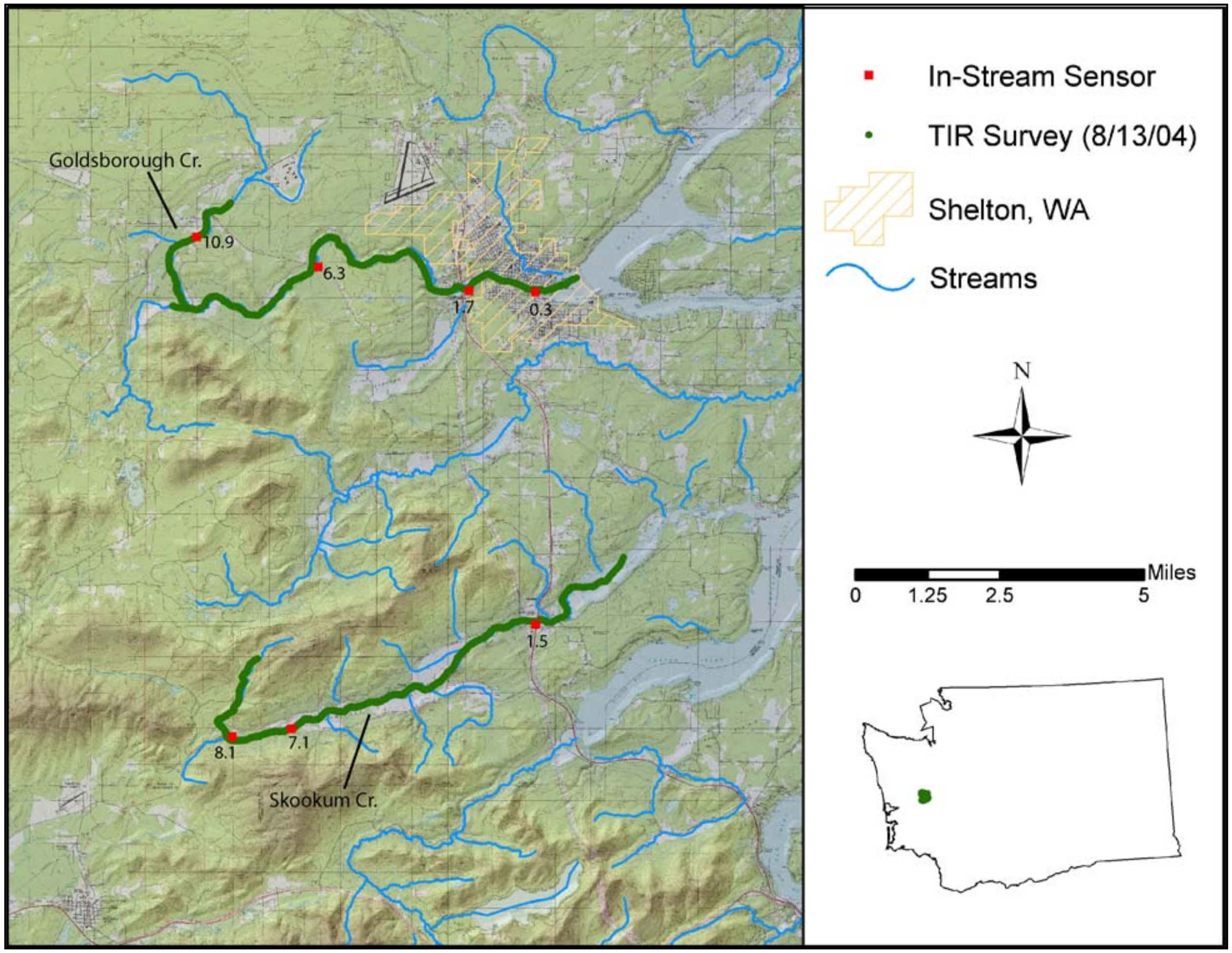
Instrumentation: Images were collected with TIR (8-12μ) and visible-band cameras attached to a gyro-stabilized mount on the underside of a helicopter. The two sensors were aligned to present the same ground area, and the helicopter was flown longitudinally along the stream channel with the sensors looking 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 individual images were referenced with time and position data provided by a global positioning system (GPS).

Flight Parameters: The survey of Skookum and Goldsborough Creeks was conducted upstream from their mouth at the Puget Sound. Both streams were surveyed from 1200 ft above ground level (AGL). The survey was conducted on August 13, 2004 between 1:45 PM and 3:00 PM.

Image Characteristics: Images were collected sequentially with 40% or greater vertical overlap. On the Skookum and Goldsborough survey, the TIR images presented a ground width of approximately 130 meters with a spatial resolution of ~0.41 meters.

Ground Control: Watershed Sciences deployed in-stream data loggers prior to the flight in order to ground truth (i.e. verify the accuracy of) the TIR data. The data loggers were placed at access points throughout the watershed with an average of one instrument deployed every ten river miles. The distribution of the in-stream data loggers allowed for checking radiant temperatures at regular intervals over the duration of the survey. Meteorological data including air temperature and relative humidity were recorded in the basin using a portable weather station (*Onset*) located at the Shelton Airport.

Study Area



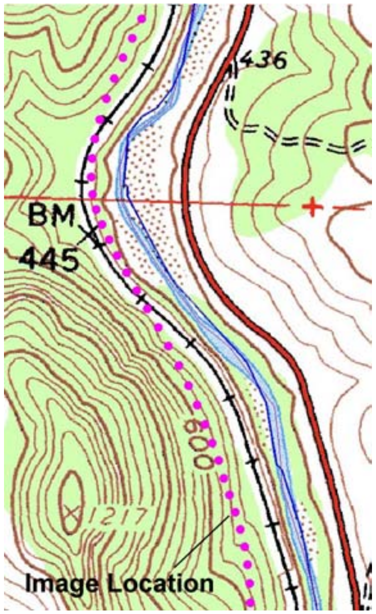
This map illustrates the extent of the airborne TIR surveys conducted near Shelton, WA on August 13, 2004. The map also shows the location of in-stream sensors used to ground-truth the imagery. The in-stream locations are labeled by river mile.

Data Processing

Calibration: 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's location. Calibration parameters were fine-tuned to provide the most accurate fit between the radiant and kinetic temperatures.

Interpretation and Sampling: Once calibrated, the images 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. 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.

Image showing TIR image points plotted over a USGS 1:24K topographic map. Each point represents a TIR and color video image pair acquired at that location.



Geo-referencing: The images are tagged with a GPS position at the time they are acquired. Since the TIR camera is maintained at vertical down-look angles, the geographic coordinates provide an accurate index to the location of the image scene. Due to the relatively small footprint of the imagery and independently stabilized mount, only the image pixels of areas of interest are individually registered to real world coordinates. In order to provide further spatial reference, the TIR images were assigned a river mile based on a routed stream layer.

Temperature Profiles: The median temperatures for each sampled image 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 those inflows influence the main stem temperature patterns.

Thermal Image Characteristics

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

Expected Accuracy: Thermal infrared radiation received at the sensor is a combination of energy emitted from the water's surface, reflected from the water's surface, and absorbed and re-radiated by the intervening atmosphere. Water is a good emitter of TIR radiation and has relatively low reflectivity (~ 4 to 6%). During 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 (e.g. 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[1]). 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 surface inflow (e.g. tributary).

Differential Heating: In stream segments with flat surface conditions (i.e. pools) and relatively low mixing rates, observed variations in spatial temperature patterns can be the result of differences in the instantaneous heating rate at the water's surface. In the TIR images, indicators of differential surface heating include seemingly cooler radiant temperatures in shaded areas compared to surfaces exposed to direct sunlight. Shape and magnitude distinguish spatial temperature patterns caused by tributary or spring inflows from those resulting from differential surface heating. Unlike with thermal stratification, surface temperatures may still represent bulk water conditions if the stream is mixed.

Feature Size and Resolution: A small stream width logically translates to fewer pixels "in" the stream and greater integration with non-water features such as rocks and vegetation. Consequently, a narrow channel (relative to the pixel size) can result in higher inaccuracies in the measured radiant temperatures (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.

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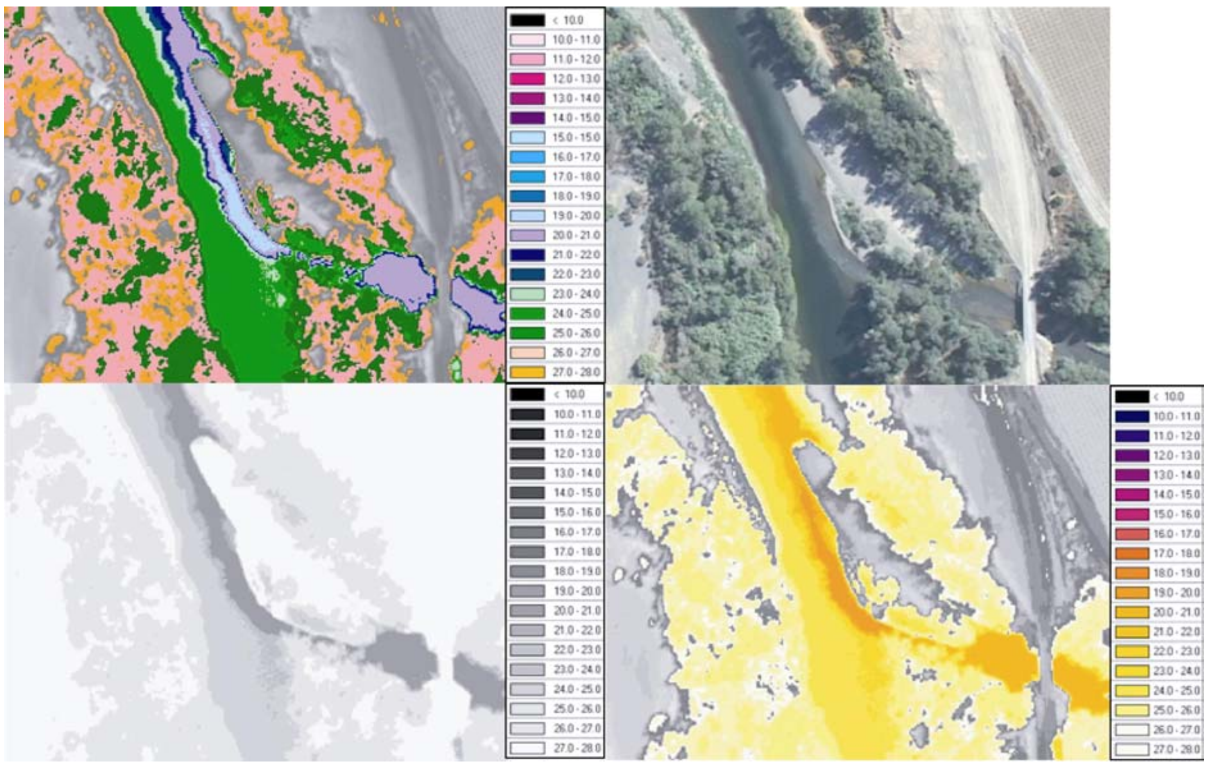
[1] Torgersen, C.E., R. Faux, B.A. McIntosh, N. Poage, and D.J. Norton. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. *Remote Sensing of Environment* 76(3): 386-398.

Temperatures and Color Maps: The TIR images collected during this survey consist of a single band. As a result, visual representation of the imagery *(in a report or GIS environment*) requires the application of a color map or legend to the pixel values. The selection of a color map should highlight features most relevant to the analysis (i.e. *spatial variability of stream temperatures*). For example, a continuous, gradient style color map that incorporates all temperatures in the image frame will provide a smoother transition in colors throughout the entire image, but will not highlight temperature differences in the stream. Conversely, a color map that focuses too narrowly cannot be applied to the entire river and will "washout" terrestrial and vegetation features. The method used to select a color map for the report images attempts to accomplish both. The map is based on using discrete colors to represent the range of water temperatures observed during the analysis based on 1°C or 0.5°C increments and a linear gray scale to represent temperatures above the maximum observed water temperature. The images below provide an example of three different color maps applied to the same thermal image.



Results

Weather Conditions

Weather conditions were considered ideal for the flight with warm air temperatures and clear skies. The table below summarizes the air temperatures and humidity measured at the Shelton Airport during the time frame of the flight.

Time	Air Temp °F	Air Temp °C	Rel. Humidity (%)
8/13/04 @ Shelton Airport			
12:00	83.7	28.7	37.4
13:00	88.0	31.1	53.8
14:00	92.5	33.6	47.6
15:00	96.3	35.7	40.9
16:00	96.3	35.7	26.3
17:00	97.0	36.1	24.9
18:00	95.5	35.3	35.4

Thermal Accuracy

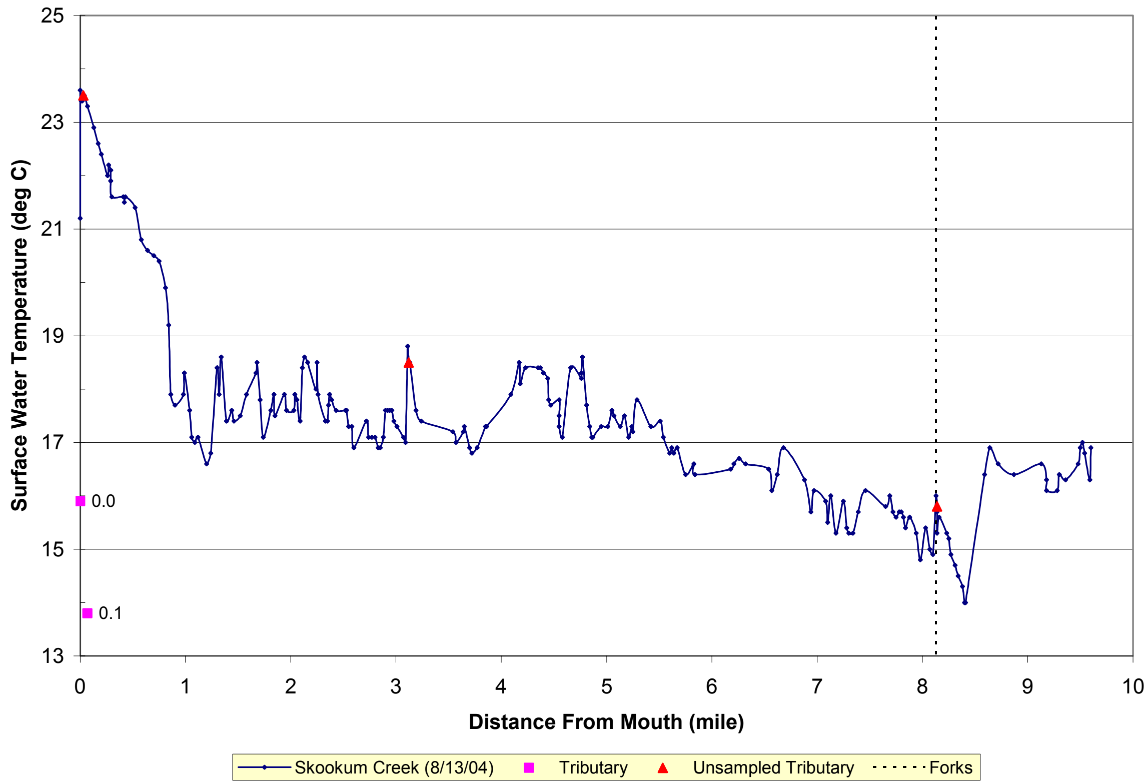
The table below summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images. On Goldsborough Creek, the temperature differences ranged from -0.5 to +0.5 and had an average absolute difference of 0.3°C. On Skookum Creek, there was no significant difference between the radiant and kinetic temperatures at the ground monitoring locations. The observed differences in temperature were consistent with target accuracies (*i.e. average difference ≤0.5°C*).

Image	Time 24 hrs	Mile	Kinetic Temp. °C	Radiant Temp °C	Difference °C
Goldsborough Creek (Avg. Abs. Diff = 0.3 C)					
gol0055	13:49	0.3	16.3	16.8	-0.5
gol0114	13:51	1.7	18.3	17.8	0.5
gol0356	14:00	6.3	17.4	17.2	0.2
gol0843	14:16	10.9	16.0	15.8	0.2
Skookum Creek (Avg. Abs. Diff = 0.0 C)					
sko0238	14:33	1.5	17.7	17.6	0.1
sko0709	14:49	7.1	15.5	15.5	0.0
sko0798	14:52	8.1	15.3	15.3	0.0

Skookum Creek

Longitudinal Temperature Profile

The figure below illustrates the median sampled temperatures plotted versus river mile for Skookum Creek. Two tributaries were sampled during the analysis and are labeled by river mile on the profile. The profile also shows the location of surface inflows that were detected in the imagery but were not sampled due to a small channel size and/or a lack of visible surface water due to masking by the riparian vegetation. Skookum Creek splits into two branches at river mile 8.1. The TIR survey followed the northern branch due to its longer length and greater apparent surface flow.



Observations and Analysis

Skookum Creek was heavily canopied through much of the survey extent. The canopy cover and low terrain relief near the Puget Sound made it difficult at times to follow the stream course. Despite the canopy, surface water was visible at regular intervals, which allowed for almost continuous sampling through most of its length. The exception was the reach upstream of the split (*labeled as forks on the longitudinal profile*) where the sampling was intermittent with very little visible surface water. Although temperatures were sampled from the main channel, the riparian canopy masked the edges of the stream and made it difficult to detect and sample tributaries and other surface inflows. Two surface inflows were sampled during the analysis and both were near the mouth. Three other tributaries were detected in the imagery but not enough surface water was visible to obtain an accurate temperature sample.

The longitudinal profile illustrates differences in heating rates along the stream gradient, which allows for segmentation of the profile into reaches with similar thermal characteristics. The following paragraphs discuss these reaches individually:

This image shows Skookum Creek just upstream of the forks (mile 8.1). The stream surface was difficult to detect through the forest canopy upstream of this location.

<u>Mile 9.9 – 8.1 (*Upstream of the split*):</u> At the upstream end of the survey, radiant temperatures were sampled when surface water was visible through the forest canopy. However, due to the small size of the stream, the sampling was intermittent and often limited to disconnected patches of visible surface water. The combination of stream size and canopy inevitably results in a greater number of hybrid pixels (*reference the Thermal Image Characteristics section of this report*) and a higher level of sample noise. A decrease in apparent water temperature of ~2.0^{o}C was observed between mile 8.6 and 8.4. The riparian canopy made it difficult to positively assess the source of cooling. However, the magnitude of the drop and the fact that canopy structure was similar over the 0.2 mile segment suggests a reasonably valid measurement. In addition, Skookum Creek changes from flowing in a Southwest direction to a more East North East heading through this location. Sharp transitions in stream direction and morphology are often observed as areas of groundwater upwelling. However, the canopy masking prevented directly observing any discharge (surface or subsurface) into the stream at this location.

Prior to the forks (*mile 8.4 to 8.1*), the stream was more easily detected through the canopy. Stream temperatures at river mile 8.4 were ~14.0^{o}C and warmed steadily to ~15.8^{o}C at the forks. An in-stream data logger just upstream of the forks recorded temperatures that were consistent with the sampled radiant temperatures. These results suggest that, although the stream channel was small and partially canopied, the sample consisted of enough “pure” pixels to provide an accurate radiant temperature.

Mile 8.1 to 4.9 (*downstream warming*): Water temperatures in Skookum Creek exhibited a slight decrease (~0.5°C) at the forks, before starting a general pattern of downstream warming to river mile 4.9. Radiant temperatures increased from ~15.3°C to ~17.1°C through this reach. Although the channel was still partially masked by the riparian canopy, the water surface was visible at regular enough intervals to obtain a relatively continuous sample of main stream temperatures. At river mile 7.7, Skookum Creek transitions from a more confined, higher gradient channel as it enters the laucustrine sediments of Kamilche Valley. However, towards the lower end of this section, it begins to incise well below the historic floodplain.

Mile 4.9 to 0.9 (*local spatial variability*) – Stream temperatures in this 4-mile reach are characterized by a higher degree of local spatial variability with little or no net temperature change. Stream temperatures varied between a low of 16.6°C (mile 1.2) and a high of 18.8°C (mile 3.1). The sources of variability were difficult to establish based entirely on visual inspection of the imagery. However, since air temperatures were in the mid 90's, the absence of an overall heating trend suggests the presences of some buffering processes. The spatial temperature pattern is characteristic of a small, low gradient stream that responds rapidly to any change in the balance of physical processes that govern water temperatures. For example, sub-surface discharge can result in a rapid response in bulk water temperatures depending on the volumetric relationship between the discharge and stream. Conversely, water lost or diverted from the channel reduces in-stream volumes and often results in an increase in the longitudinal heating rate. The riparian canopy can also reduce (or eliminate) heating by reducing direct solar loading and by lowering air temperatures near the channel. Conversely, in the absence of canopy, stream temperatures can increase rapidly.

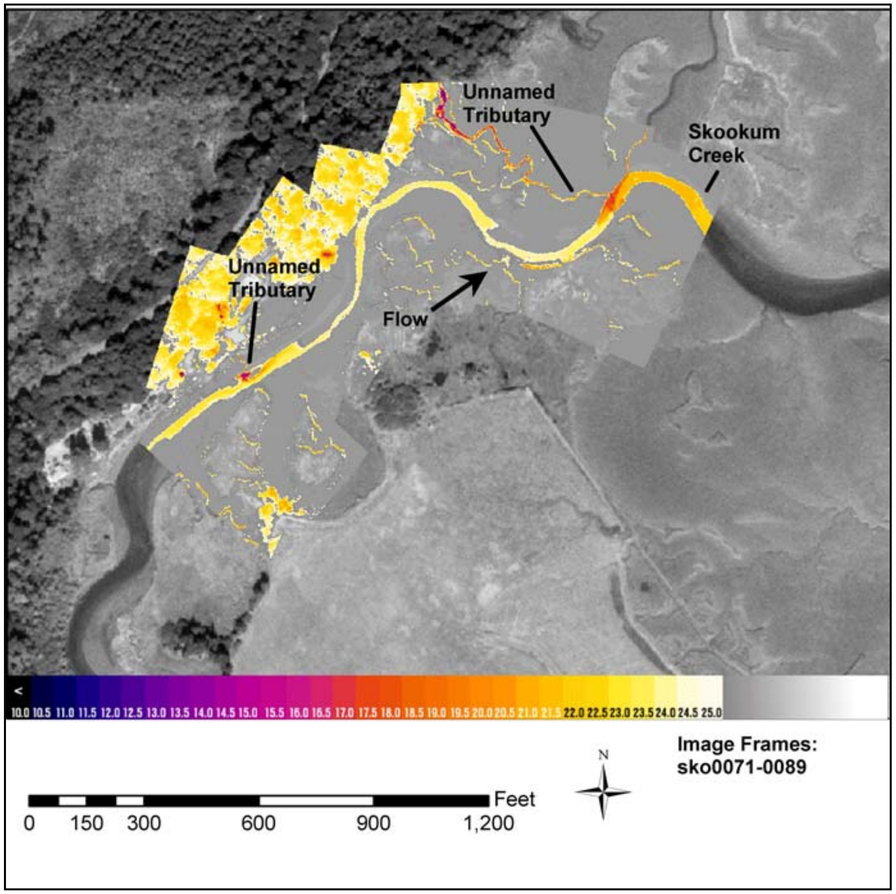
Within this reach, the longitudinal profile shows apparent drops in water temperatures between miles 4.7 and 4.6 (-1.3°C) and between miles 4.2 and 3.9 (~1.2°C). Inspection of the topographic base maps illustrates that these locations correspond to mapped tributary confluences. An unnamed tributary joins Skookum Creek at mile 4.7 and Kamilche Creek joins at mile 4.2. Although the confluence of these tributaries was not detected in the imagery, the temperature decrease suggests a cooling influence from these tributaries (either surface or sub-surface). Similar temperature decreases were noted near miles 3.1 and 1.2. Both of these locations were also proximate to mapped tributary confluences.

Mile 0.9 to Mouth (*rapid increase*) – Water temperatures exhibited a rapid increase from ~17.6°C to 23.5°C over the lower 1.0 river mile. Inspection of the imagery shows a more open channel with less riparian vegetation as Skookum Creek approaches the Puget Sound. The increase in solar loading over the lower mile presumably contributes to the observed increase in longitudinal heating.

Sample Images

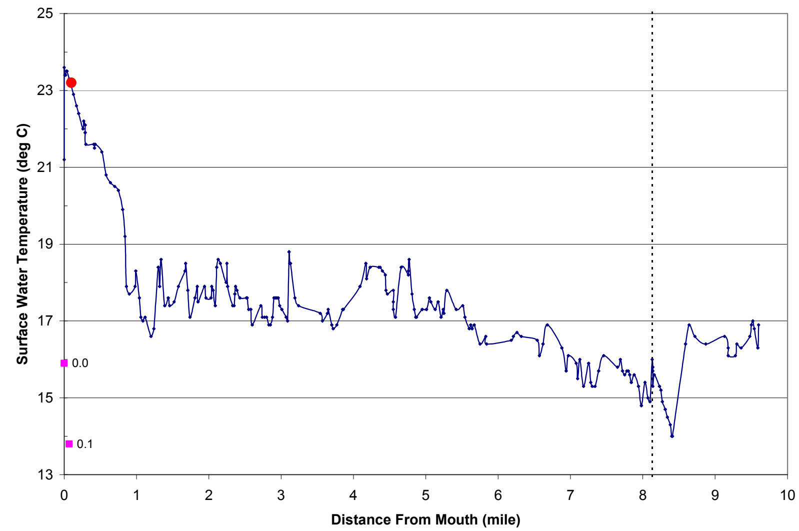
The following pages contain sample images from the TIR survey of Skookum Creek, which provide samples of thermal features and channel conditions observed during the survey.

Unnamed Tributaries at Skookum Creek Mouth (mile 0.1)

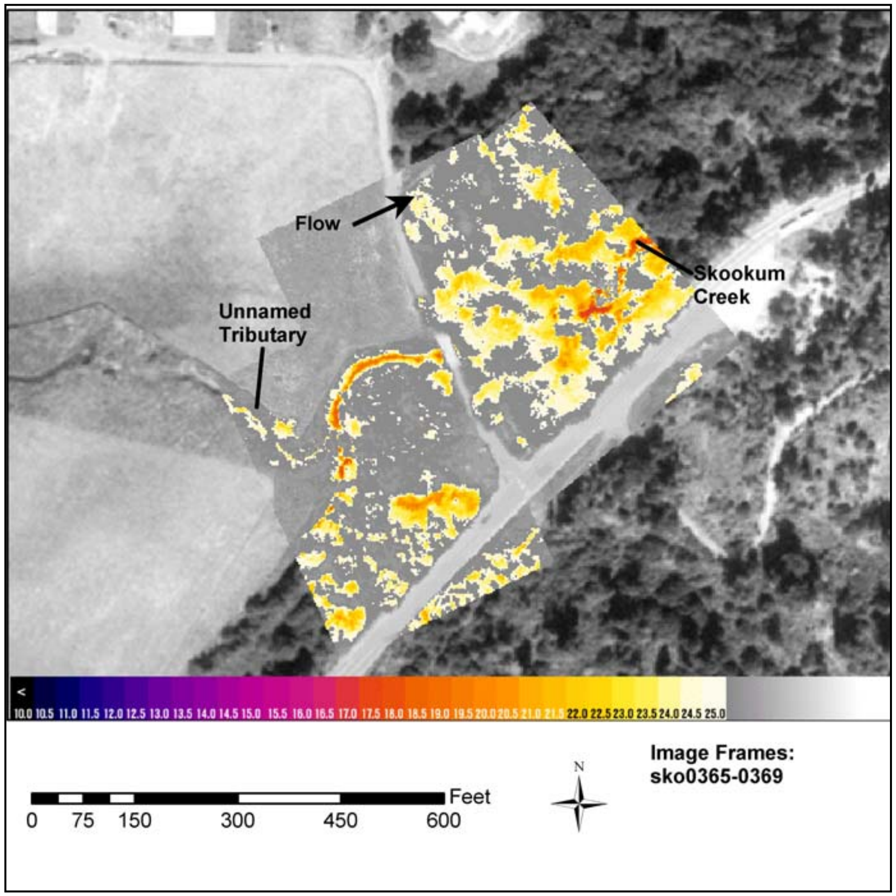


The image on the left shows two unnamed tributaries at the mouth of Skookum Creek. The upstream tributary (on the left side of the image) was 13.9°C while the downstream tributary was 15.9°C. These two tributaries cool the main stem Skookum Creek temperature from 23.3°C to 21.1°C.

The plot below shows the location of this image (red dot) along the longitudinal profile.

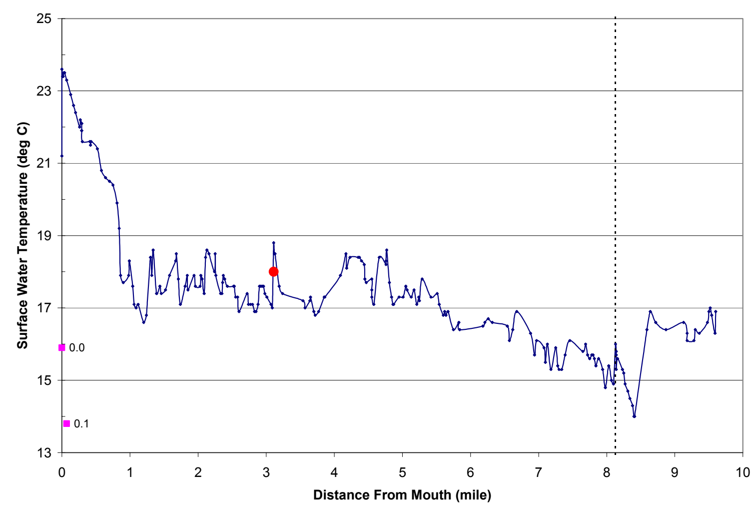


Unnamed Tributary (mile 3.1)

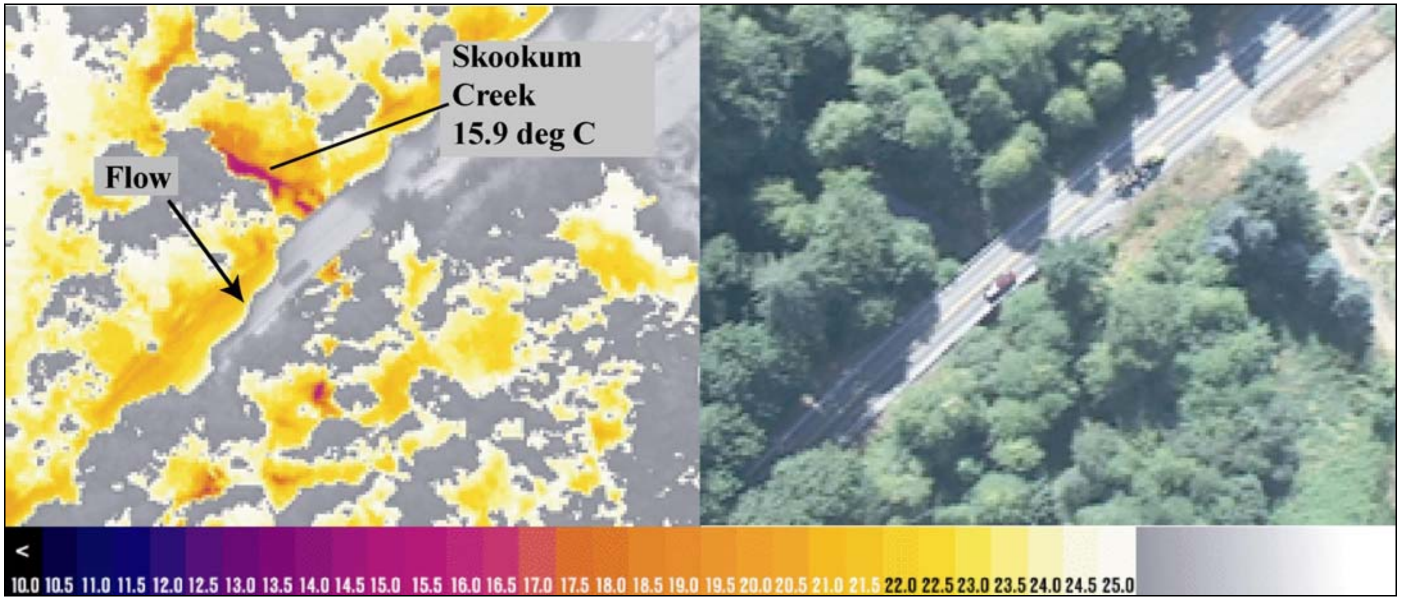


The image on the left shows an unnamed tributary on the left bank of Skookum Creek. The main stem Skookum Creek temperature changes from 18.8°C upstream of the bridge to 17.0°C downstream of the bridge.

The plot below shows the location of this image (red dot) along the longitudinal profile.

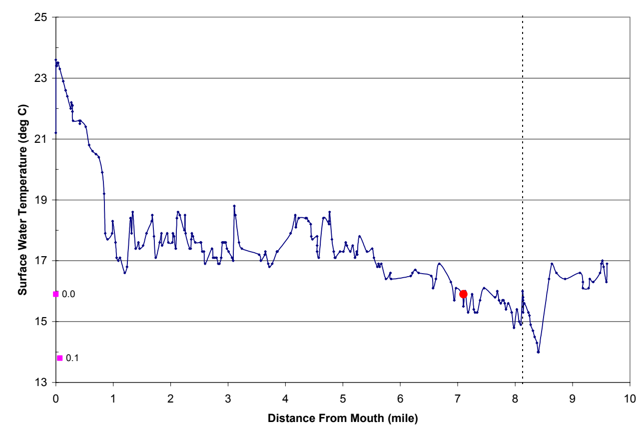


Canopy Masking (mile 7.1)

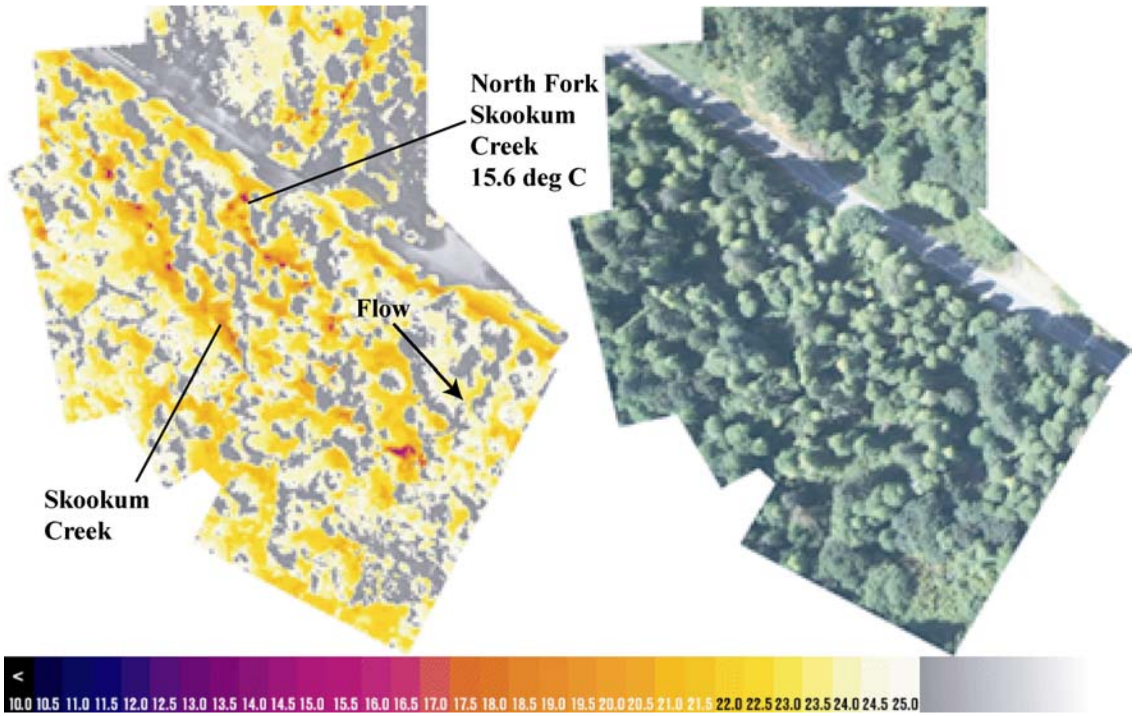


The TIR and true color image pair above shows the location of one of the in-stream sensors used to ground truth the Skookum Creek thermal data. This area of Skookum Creek (15.9°C) is representative of the canopy cover over much of the surveyed extent.

The plot on the right shows the location of this image (red dot) along the longitudinal profile.

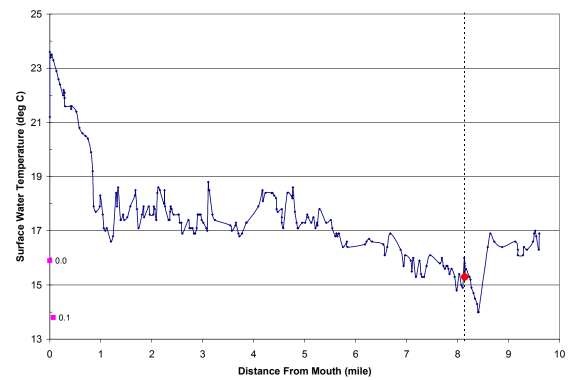


Skookum Creek (mile 8.1)



The image pair on the left shows the confluence of Skookum Creek and North Fork Skookum Creek (15.6°C). The survey followed the North Fork on the right, however, the stream was very difficult to see through the canopy above this location.

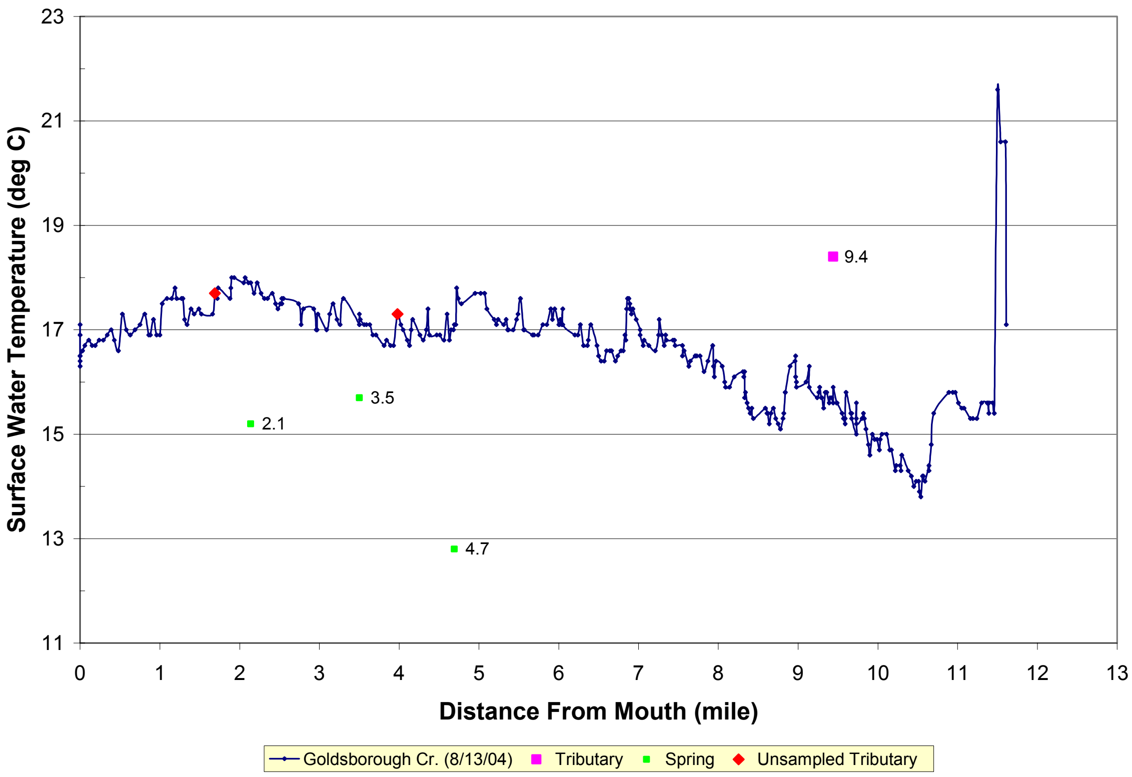
The plot below shows the location of this image (red dot) along the longitudinal profile.



Goldsborough Creek

Longitudinal Temperature Profile

The figure below illustrates the median sampled temperatures plotted versus river mile for Goldsborough Creek. The location of tributaries and other surface inflows (e.g. springs) detected during the analysis are also illustrated on the plot and labeled by river mile. In some cases, tributaries which were detected did not have enough visible surface water to obtain an accurate temperature sample. The locations of these "unsampled" tributaries are also shown on the profile. The table on the next page provides a summary of sampled inflows.



Tributaries, surface springs, and other detected surface inflows

Name	Image	km	mile	Tributary °C	Goldsborough Cr. °C	Difference °C
Tributary Name						
SF Goldsborough Cr (RB)	gol0643	15.2	9.4	18.4	15.9	2.5
Spring						
Spring (RB)	gol0136	3.4	2.1	15.2	17.9	-2.7
Spring (LB)	gol0189	5.6	3.5	15.7	17.3	-1.6
Spring (RB)	gol0245	7.5	4.7	12.8	17.1	-4.3

Observations and Analysis

Water temperatures in Goldsborough Creek exhibited variations in heating (*and cooling*) rates at different spatial scales along the 11.6-mile survey extent. The South Fork of Goldsborough Creek was the only tributary that was sampled during the analysis. Two additional tributaries were detected (Coffee Creek and an Unnamed Creek), but were not sufficiently visible in the TIR imagery to provide a reasonably accurate temperature sample. Three surface springs were also detected, indicating the role of sub-surface discharge in determining the thermal structure of Goldsborough Creek.

Inspection of the longitudinal temperature profile and TIR imagery illustrates reaches with common heating rates or thermal variability. The following paragraphs provide a discussion of these reaches. This segmentation of the profile is intended for the sake of discussion and alternate segmentations are certainly possible.

Mile 12.1 – 10.5 (*Marsh to Stream*): The TIR survey ended at Armstrong Lake (mile 12.1) near the headwaters of Goldsborough Creek. Moving downstream, no surface water was visible in the imagery until mile 11.6, where the stream is joined by two mapped forks from the west just upstream of the railroad crossing near the town of Dayton. The area at the confluence was marshy and surface temperatures of the first visible water was ~17.1°C, but warmed quickly to 21.6°C. At the outlet of the marsh and downstream of the rail and road crossing, Goldsborough Creek emerges considerably cooler (15.4°C). The stream warms slightly before entering another wetland/marsh area between river mile 10.9 and 10.5 where it appears to go sub-surface with little or no visible surface water. Near the downstream end of this marsh, surface water was again visible and stream temperatures were at a survey low of 13.8°C. The observed flows and relatively cool water (13.8°C) at the downstream end of the marsh suggest that it is a conduit for sub-surface flow. As such, the sub-surface exchange cools the channel and buffers heating processes such as direct solar, longwave radiation and convection.

Mile 10.5 – 6.9 (*Downstream Warming*): Water temperatures in Goldsborough Creek exhibited a relatively consistent heating rate between river mile 10.5 and 9.0. The South Fork Goldsborough Creek (18.4^{o}C) was sampled at mile 9.4. The South Fork was surveyed upstream for ~1/4 mile, but very little surface water was visible upstream of the mouth. Between mile 9.0 and 8.8, water temperatures decreased from ~16.5^{o}C to 15.1^{o}C, which interrupted the prevailing downstream heating trend. This decrease occurs through a series of bends just downstream of the South Fork confluence. Although no springs were detected in this reach, the relatively rapid temperature decrease coupled with the local topography, suggests this stream segment as an area of ground water upwelling. Between river mile 8.8 and 6.9, stream temperatures warmed again at a relatively consistent rate.

The image above shows Goldsborough Creek at mile 11.04. Although there is considerable surface flow at this point, surface water was intermittently visible in the marsh downstream of this location.

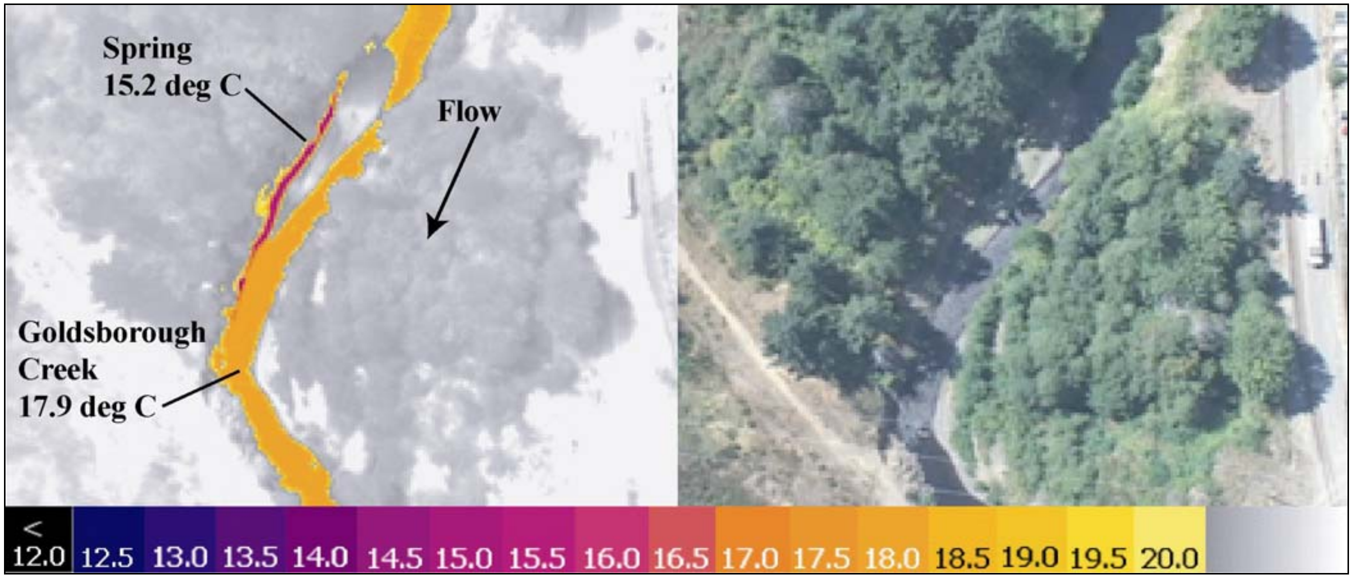
Mile 6.9 – 3.1 (*local variability, no net gain/loss*): Between mile 6.9 and 3.1, water temperatures ranged between 17.6^{o}C and 16.7^{o}C with some local variability, but no prevailing warming or cooling trend. At mile 6.9, stream temperatures dropped from a local maximum of 17.6^{o}C to 16.6^{o}C. Inspection of the TIR imagery did not show any point source inflows at this location. However, the topographic base map illustrated that this decrease occurs near the transition from an open, lower gradient segment to a more confined segment. This transition suggests a thermal response to the local change in morphology. Moving downstream, a ~0.9^{o}C decrease in temperatures was observed at mile 4.7 where a series of apparent springs were visible along the right bank. Visible shadows from the vegetation and bank made these springs somewhat difficult to positively identify in the imagery. However, their temperatures were considerably cooler than any other feature in the survey and a thermal response was observed in the main stem. A second spring was observed in this reach at mile 3.5. Through most of this reach, Goldsborough Creek travels through a well defined canyon and topography and riparian vegetation likely contribute to the general lack of heating through this reach.

Mile 3.1 – 1.9 (*downstream warming*): At river mile 3.1, water temperatures showed a fairly consistent downstream warming trend with temperatures gaining ~1.0^{o}C. This reach ends near the Highway 101 crossing.

Mile 1.9 – Mouth (*downstream cooling*): Water temperatures in Goldsborough Creek exhibited a pattern of downstream cooling from the Highway 101 crossing to its mouth, with temperatures decreasing from 18.0^{o}C to 16.6^{o}C at the time of the survey. This reach starts at the transition from the canyon reach to the more open topography through the town of Shelton. Although a change in stream temperature trends is common when topography changes, a cooling trend through the town was somewhat surprising.

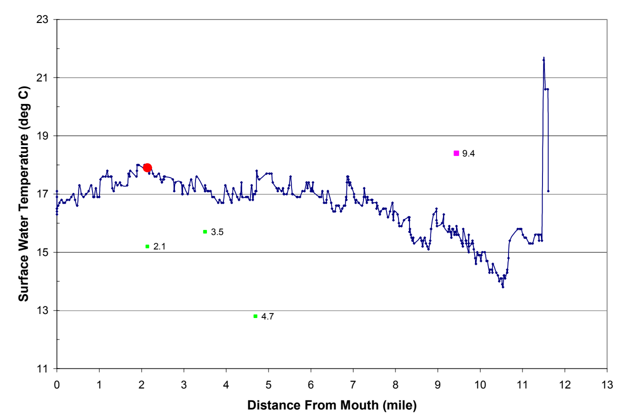
Sample Images

Spring (mile 2.1)

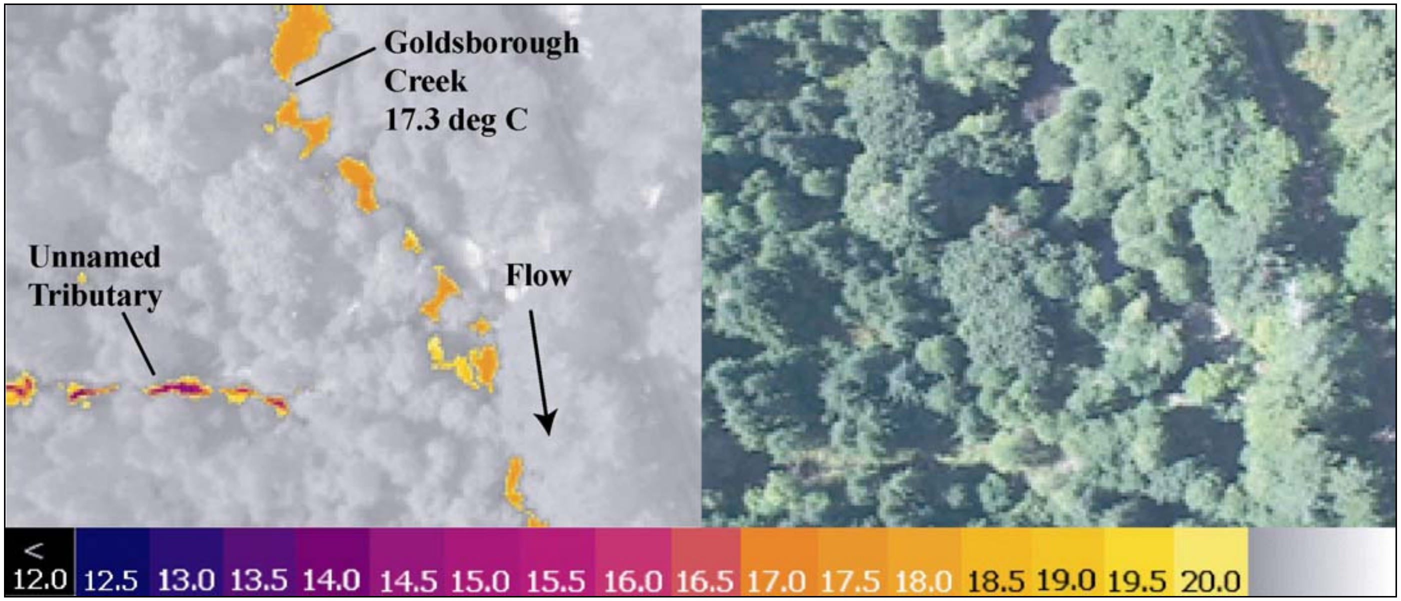


The image pair above shows a spring (152^{o}C) on the right bank of Goldsborough Creek (17.9^{o}C).

The plot on the right shows the location of this image (red dot) along the longitudinal profile.

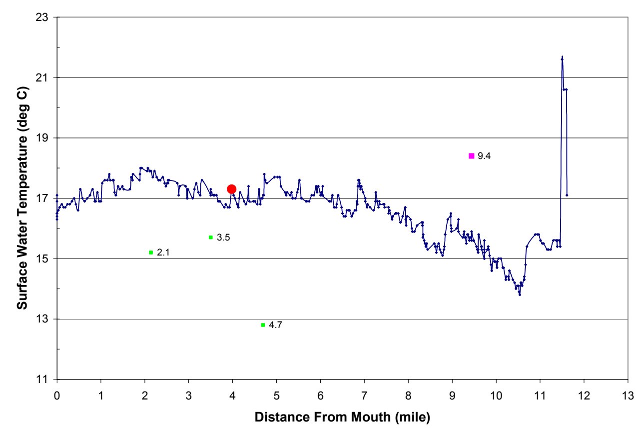


Unnamed Tributary (mile 4.0)

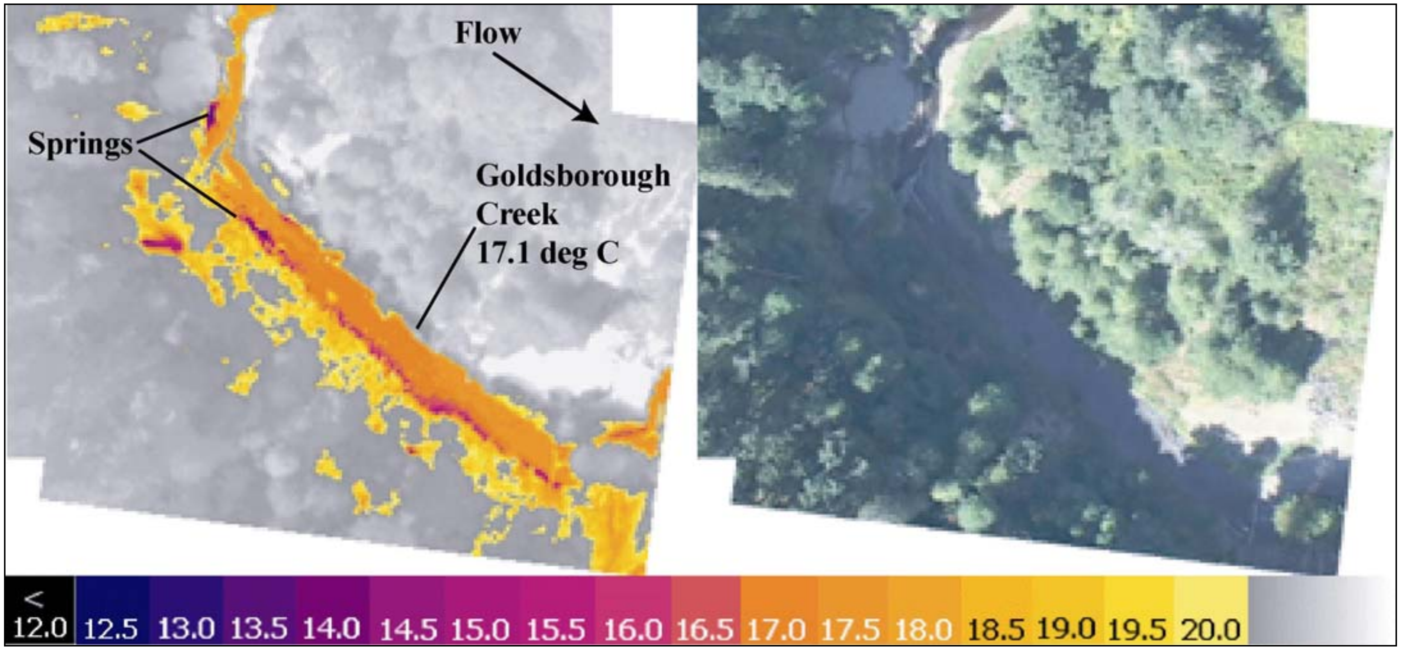


The image pair above shows an unnamed tributary on the right bank of Goldsborough Creek (17.3°C). The tributary was not sampled for temperature due to the lack of visible surface water at the confluence.

The plot on the right shows the location of this image (red dot) along the longitudinal profile.

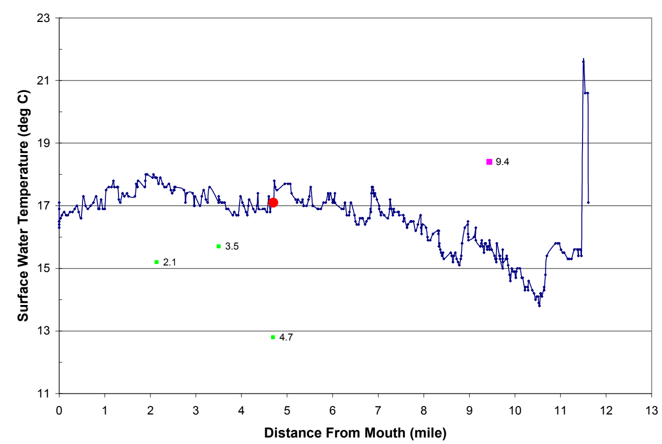


Springs (mile 4.7)



The image pair above shows two springs along the right bank of Goldsborough Creek (17.1°C). These springs are difficult to identify due to the complications caused by the shadows in the imagery; however, the drop in temperature of the main stem shown in the longitudinal profile supports the conclusion that they are springs and not just shadowed portions of vegetation along the bank.

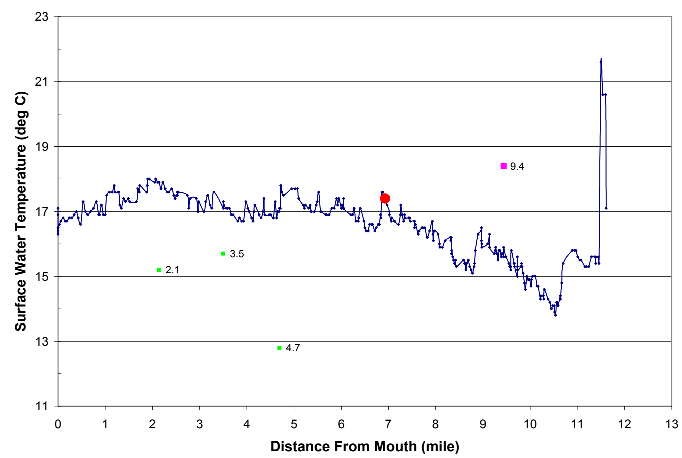
The plot on the right shows the location of this image (red dot) along the longitudinal profile.



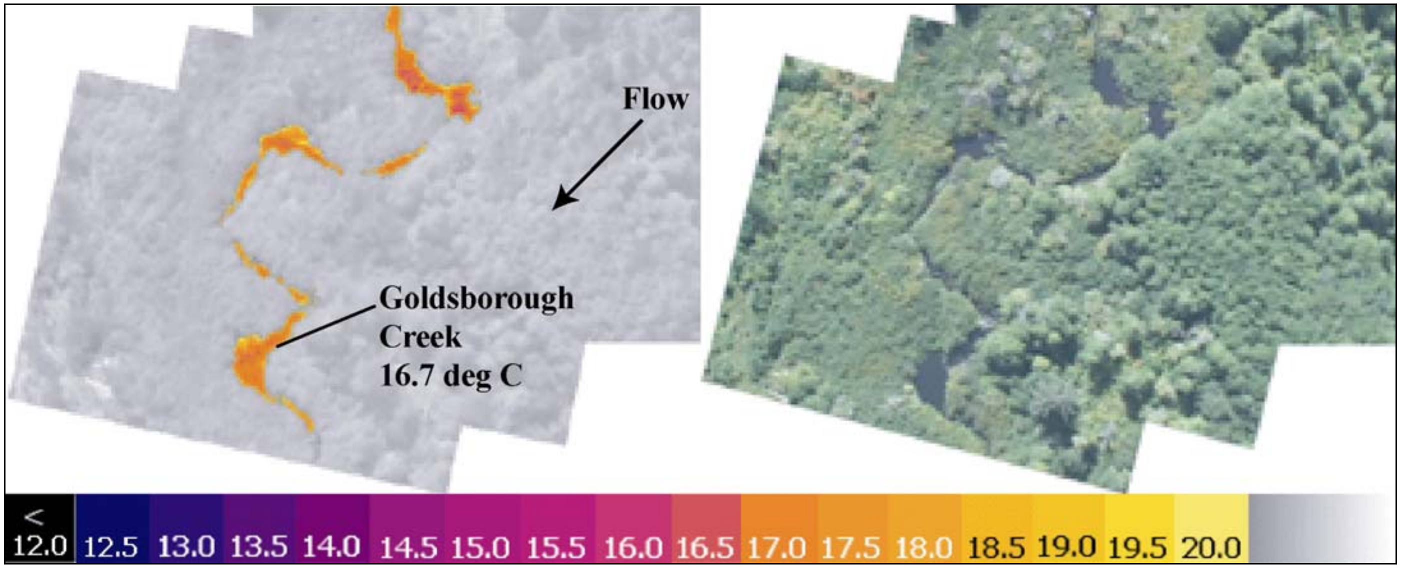
Warm Surface Water (mile 6.9)

The image pair above shows a region of Goldsborough Creek with warmer surface water in one of a few intermittent ponds. The main stem temperature was 17.4°C while the temperature of the warmer water was 19.8°C. The warmer water is presumably due to some thermal stratification at the pond surface.

The plot on the right shows the location of this image (red dot) along the longitudinal profile.

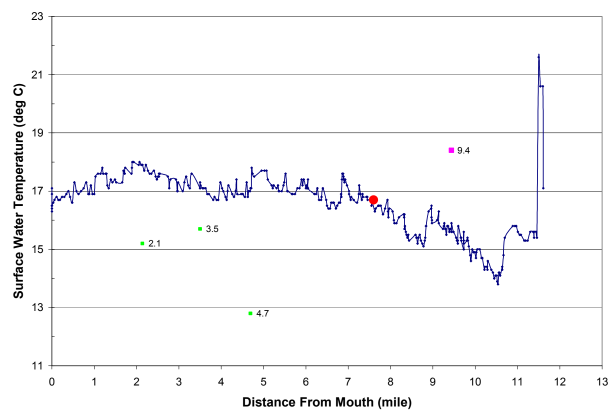


Intermittent Ponds (mile 7.6)

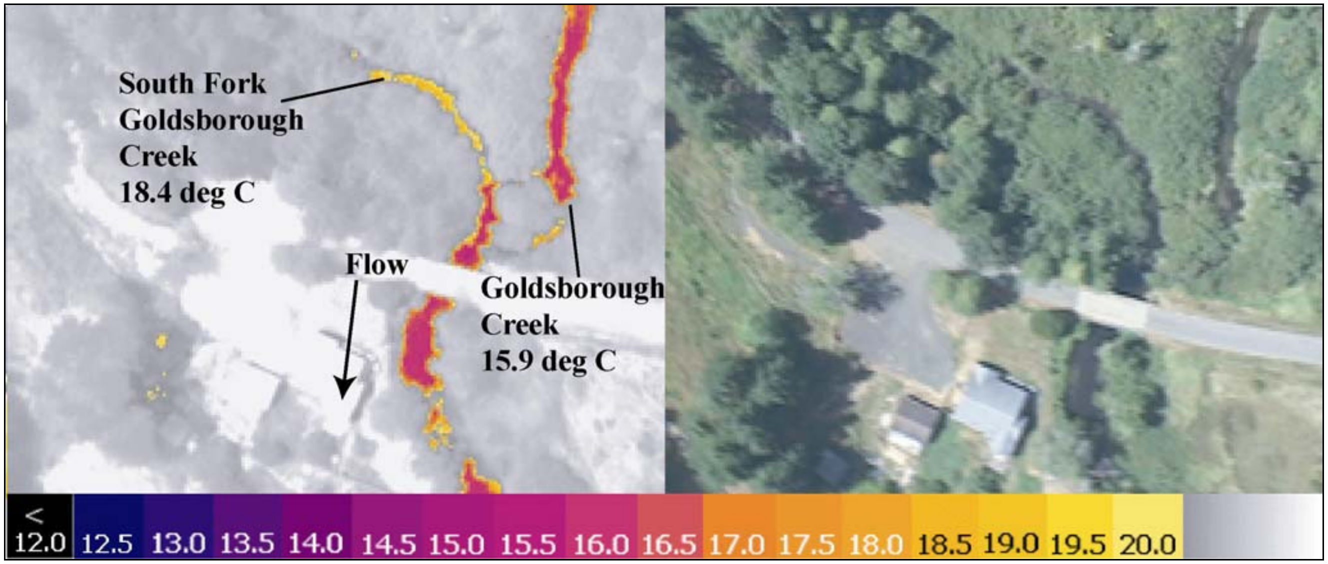


The image pair above shows a number of intermittent ponds in a marshy region of Goldsborough Creek (16.7^{o}C).

The plot on the right shows the location of this image (red dot) along the longitudinal profile.

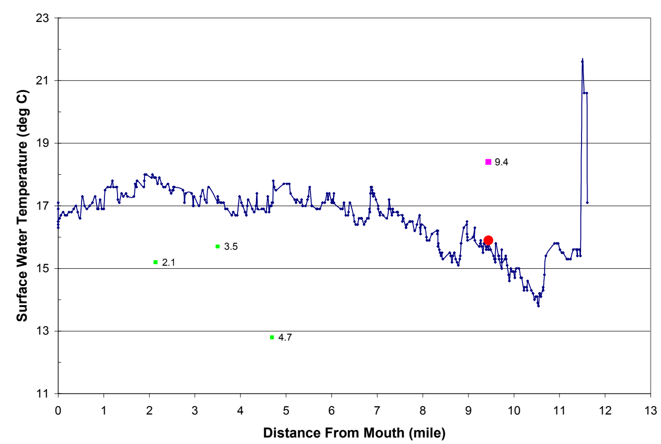


South Fork Goldsborough Creek (mile 9.4)



The image pair above shows the confluence of South Fork Goldsborough Creek (18.4°C) on the right bank of Goldsborough Creek (15.9°C).

The plot on the right shows the location of this image (red dot) along the longitudinal profile.



Summary of Survey Results

TIR images of Skookum and Goldsborough Creeks were successfully collected during the afternoon of August 13, 2004. The accuracy of the radiant temperatures was within specified values (i.e. ±0.5°C) when compared to kinetic temperatures recorded by in-stream data loggers deployed prior to the flight.

The results of the survey illustrate how water temperatures varied longitudinally in Goldsborough and Skookum Creeks and suggest the role of morphology, vegetation, and point discharges (surface and subsurface) in defining these patterns. In Goldsborough Creek, marsh areas appear to play a significant role in defining the observed spatial temperature patterns. At a large wetland area between river mile 10.6-10.9, water temperatures at the downstream end of the marsh were considerably cooler than those at the upstream end. This pattern (i.e. downstream cooling through a wetland) has been observed on other TIR surveys in the Pacific Northwest and suggests that the wetland/marsh is a conduit for sub-surface flow. In Skookum Creek, radiant water temperatures were sampled along the survey length to develop the longitudinal profile. The small stream size and forest canopy often made it difficult to directly detect the processes (i.e. surface spring or tributary) driving the observed temperature patterns. However, correlation with other data sets, such as surface hydrology and topography, will allow for the development of some hypotheses on the processes that may produce the observed patterns.

The TIR imagery and derived data sets provide a spatial context for analysis of seasonal temperature data from in-stream data loggers and for future deployment and distribution of in-stream monitoring stations. The TIR imagery directly illustrates the location and spatial extent of tributary and other surface inflows on overall temperature trends. This report provides some hypotheses on the processes influencing spatial temperature patterns at this scale, based on analysis of the TIR imagery and inspection of the topographic base maps. These hypotheses and observations are considered a starting point for more rigorous spatial analysis and fieldwork.

Individual TIR and color video image frames are organized in an ArcView database to allow for the viewing of temperature patterns and channel characteristics at finer spatial scales.