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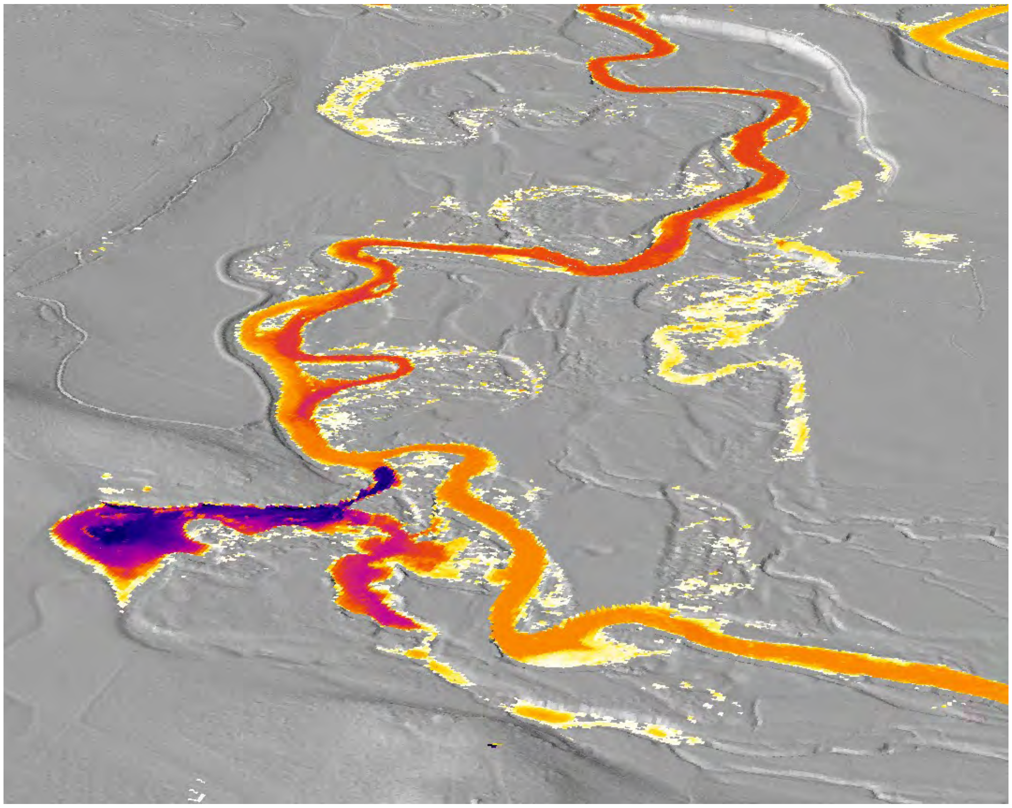
Ex. 280-US-446

Watershed Sciences, Inc.

Airborne Thermal Infrared Remote Sensing
Sprague River Basin, Oregon



Thermal infrared image over LiDAR-based bare earth hillshade
Kamkaun Spring, Sprague River

Submitted to:

The Klamath Tribes
Natural Resource Department
501 Chiloquin Blvd.
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Airborne Thermal Infrared Remote Sensing
Sprague River Basin, Oregon

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Introduction

Project Overview

In 2007, the Klamath Tribes contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) imagery for approximately 188 river miles in the Sprague River Basin. The TIR acquisition included the Sprague River, North Fork Sprague River, South Fork Sprague River, and portions of the Sycan River, Fivemile Creek, Meryl Creek, Brownsworth Creek and Whitworth Creek (Figure 1, Table 1).

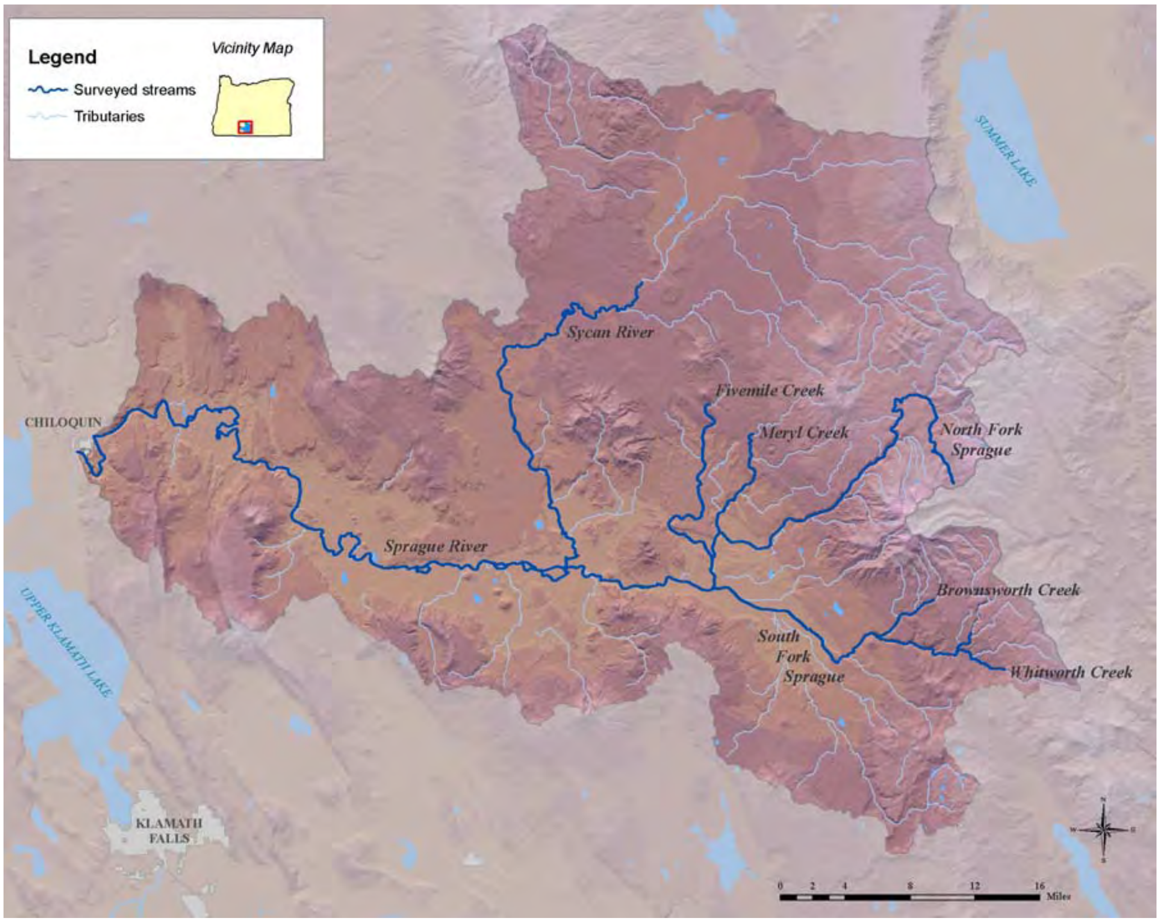


Figure 1 – An airborne thermal infrared survey of the Sprague River Basin was conducted from July31 through August 5, 2007.

Airborne TIR remote sensing has proven to be an effective method for mapping spatial temperature patterns in rivers and streams. These data are used to establish baseline conditions and direct future ground level monitoring. The TIR imagery illustrates the location and thermal influence of point sources, tributaries, and surface springs. When combined with other spatial data sets, the TIR data also illustrates reach-scale thermal response to changes in morphology, vegetation, and land-use.

Table 1 – Stream segments acquired with TIR data in the Sprague River basin.

Stream Name	Date Flown	Miles Flown	Survey Extent
SF Sprague R.	7/31	22.3	Mouth to Buckboard Creek
Whitworth Cr.	7/31	3.6	Three miles upstream from mouth
Brownsworth Cr.	7/31	4.6	Mouth to Road 34 Crossing
Sycan R.	8/1	34.5	Mouth to Road 27 Crossing
Sprague R.	8/2	84.4	Mouth to North Fork/South Fork Confluence
NF Sprague R.	8/4	33.5	Mouth to headwaters spring
Meryl Cr.	8/5	7.9	Mouth to Meryl Spring
Fivemile Cr.	8/5	5.6	Mouth to dry creek bed

Project Coordination

The Klamath Tribes are the technical lead on the project (e.g., TIR acquisition and ground based monitoring) with coordination of the Environmental Protection Agency and regional and local stakeholders. A Quality Assurance Project Plan (QAPP) governing the airborne remote sensing effort and associated ground level monitoring was developed jointly between Watershed Sciences and the Klamath Tribes prior to commencing work on the project. The QAPP was submitted to the US Environmental Protection Agency and approved in June 2007.

The project tasks and procedures outlined in the QAPP were followed closely during this project. The Klamath Tribes provided most of the ground level monitoring including in-stream data logger placement and retrieval as well as flow level monitoring. The dates of the TIR acquisition were coordinated with the Klamath Tribes in order to capture seasonal maximum temperature extremes.

Project Objectives

The specific objectives of the TIR image acquisition were:

- Spatially characterize surface temperatures and stream flow conditions over 188 miles of streams in the Sprague River basin.
- Develop a longitudinal temperature profile which illustrates basin scale stream temperature patterns.
- Identify and map cool water sources and thermal refugia.
- Create GIS compatible data layers (e.g., thermal image mosaics, spring locations, etc.) that can be used to plan future research, direct ground based monitoring and analysis, and protect and restore critical habitat.

Data Collection

Instrumentation: Images were collected with a FLIR system's SC6000 sensor (8-9.2μm) mounted on the underside of a Bell Jet Ranger Helicopter (Figure 2). The SC6000 is a calibrated radiometer with internal non-uniformity correction and drift compensation. General specifications of the thermal infrared sensor are listed in Table 2.

Figure 2 – Bell Jet Ranger equipped with a thermal infrared radiometer and high resolution digital camera. The sensors are contained in a composite fiber enclosure attached to the underside of the helicopter and flown longitudinally along the stream channel.

Table 2 - Summary of TIR sensor specifications

Sensor:	FLIR System SC6000 (LWIR)
Wavelength:	8-9.2 μm
Noise Equivalent Temperature Differences (NETD)	0.035^{o}C
Pixel Array	640 (H) x 512 (V)
Encoding Level:	14 bit
Horizontal Field-of-View:	35.5^o

Thermal infrared images were recorded directly from the sensor to an on-board computer as raw counts, which were then converted to radiant temperatures. The individual images were referenced with time, position, and heading information provided by a global positioning system (GPS) (Figure 3).

Image Characteristics: The aircraft was flown longitudinally along the stream corridor in order to have the river in the center of the display. The objective was for the stream to occupy 30-60% of the image. The TIR sensor is set to acquire images at a rate of 1 image every 2 seconds resulting in 40-70% vertical overlap between images.

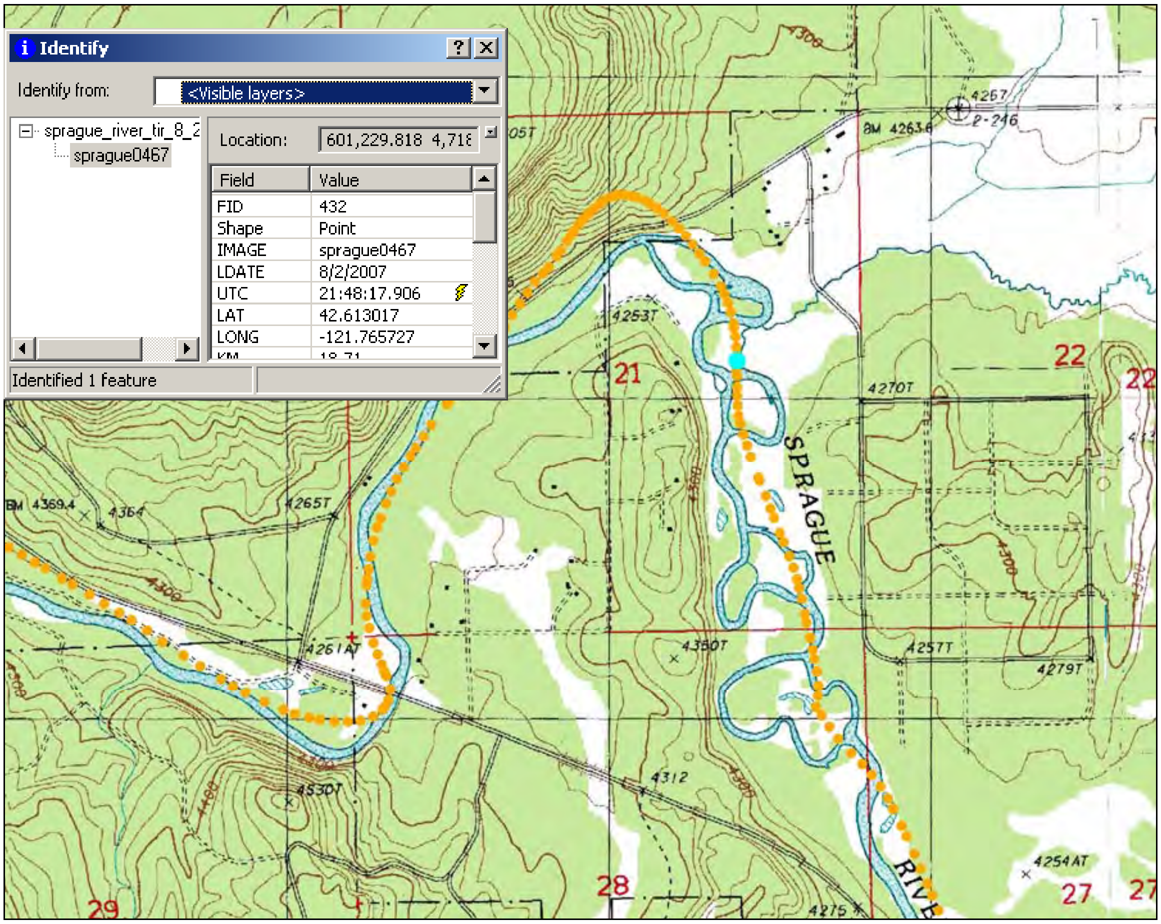


Figure 3 –Each point on the map represents a thermal image location. The inset box shows the information recorded with each image point during acquisition.

A flight altitude of 2500 ft (762 m) was selected for the Sprague River which resulted in a pixel ground sample distance of 2.5 ft (0.75 m). The flight altitude was selected in order to optimize resolution while providing an image ground footprint wide enough to capture the active channel. For the Sycan R., North Fork Sprague R., and South Fork Sprague R., the flight altitude was systematically changed during the course of the survey account for the progressive narrowing channel widths (moving upstream). For these streams flight altitudes of between 1,800 and 2,300 ft (549 and 701 m) were used for the resulting in pixel ground sample distances of between 1.8 ft and 2.2 ft (0.54m and 0.67 m). On the smaller tributaries, a constant flight altitude of 1,800 ft was maintained resulting in a native pixel size of 1.7 ft (0.52 m) (Table 3).

The airborne survey attempted to cover all surface water within the floodplain including side channels and tributary junctions. If a side channel or other surface water was not captured in the image field-of-view, the side channel was flown separately so that all surface water was captured (*Figure 4*).

Table 3 - Summary of Thermal Image Acquisition Parameters.

Dates:	July 31 – August 5, 2007
Sprague River	
Flight Above Ground Level (AGL):	2500 ft (762 m)
Image Footprint Width:	1601 ft (488 m)
Pixel Resolution:	2.5 ft (0.76 m)
Tributaries	
Flight Above Ground Level (AGL):	1800 – 2300 ft (549 and 701 m)
Image Footprint Width:	1,152 – 1472 ft (351 – 449 m)
Pixel Resolution:	1.8 ft and 2.2 ft (0.54 and 0.67 m)

Figures 4 – Oblique digital image of the main stem Sprague River showing characteristic horseshoe bends and side channels. The TIR flight primarily followed the main channel of the river. However, if a side channel was outside the sensor field-of-view, the side channel was flown separately in order to capture all visible surface water.

Ground Control: The Klamath Tribe and Watershed Sciences jointly developed a ground sampling plan for calibrating and verifying the thermal accuracy of the TIR imagery (*QAPP, June 2007*). The Klamath Tribe maintained a network of 24 in-stream data loggers that were used to calibrate and verify the TIR data. Watershed Sciences also deployed 6 in-stream data loggers during the time frame of the flight. A seventh data logger deployed near the USGS gauge on the North Fork Sprague River was lost. The data logger locations are illustrated in Figure 5.

The ground sampling plan included seasonal monitoring locations typically maintained by the tribe and supplemental locations that were strategic to the TIR flight. The sensor deployment locations and pre/post-quality assurance checks followed the procedures outlined in the QAPP document. In general, all sensors had pre/post-deployment audits to verify functionality and accuracy. The in-stream data loggers were set to record temperatures at 10-minute intervals and suspended in the water column in areas with good vertical mixing.

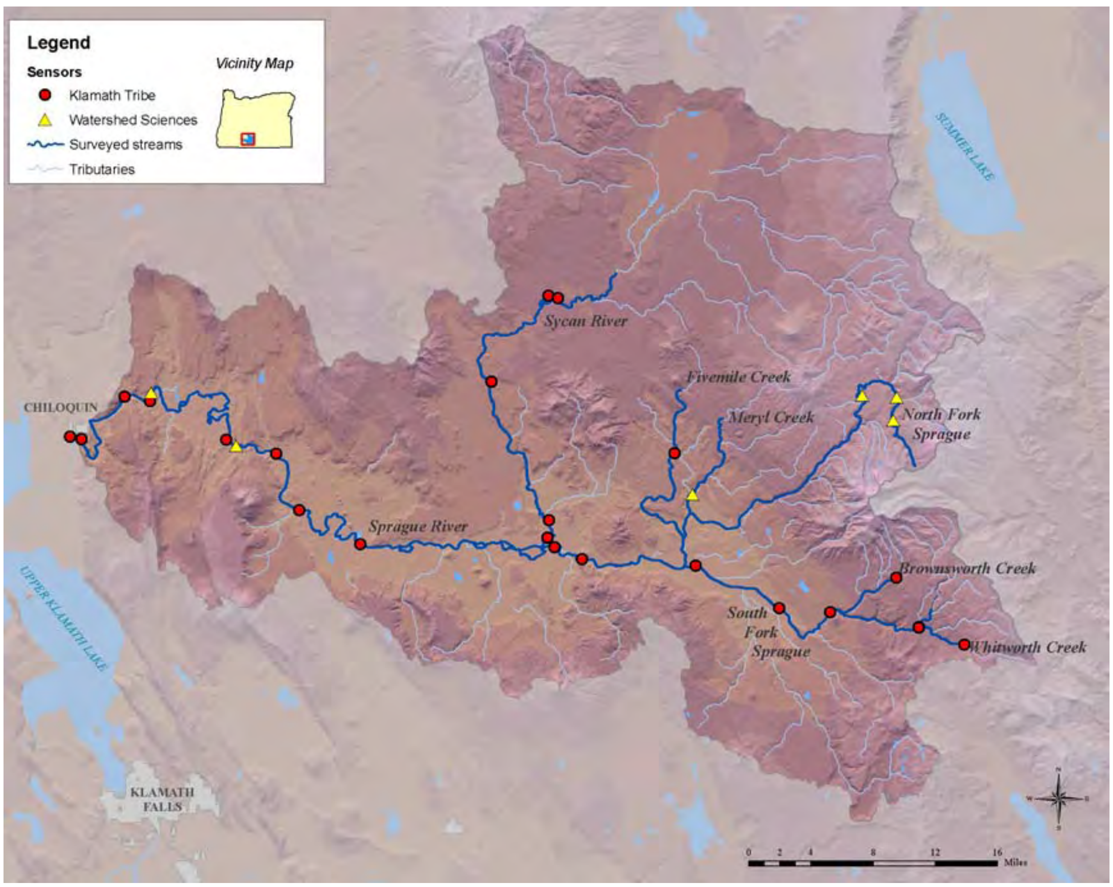


Figure 5 – Location of Klamath Tribe temperature sensors and sensors deployed by Watershed Sciences.

Data Processing

Calibration: Prior to the season, the response characteristics of the TIR sensor are measured in a laboratory environment. The response curves related the raw digital numbers recorded by the sensor to emitted radiance from the black body. The raw TIR images collected during the survey initially contain digital numbers which are then converted to radiance temperatures based on the pre-season calibration.

The calculated radiant temperatures were adjusted based on the kinetic temperatures recorded at each ground truth location. This adjustment was performed to correct for path length attenuation and the emissivity of natural water. 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.

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 temperature of detectable surface inflows (i.e. surface springs, tributaries) was also sampled at their mouths. During sampling, the analyst provided interpretations of the spatial variations in surface temperatures observed in the images.

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 these inflows influence the main stem temperature patterns. Radiant temperatures were only sampled along what appeared to be the main flow channel in the river.

Geo-referencing: The images are tagged with a GPS position and heading at the time they are acquired (Figure 3). Since the TIR camera is maintained at vertical down-look angles, the geographic coordinates provide a reasonably accurate index to the location of the image scene. Due to the relatively small footprint of the imagery and independently stabilized mount, image pixels are not individually registered to real world coordinates. The image index is saved as an ESRI point shapefile containing the image name registered to an X and Y position (UTM Zone 10, NAD83) of sensor location at time of capture. In order to provide further spatial reference, the TIR images were assigned a river mile based on a routed stream layer.

Geo-Rectification: Individual frames were manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and existing NAIP imagery. The images were then warped using a 1st order polynomial transformation. Due to the low relief along the river bottom, the photos were not corrected for terrain displacement. Due to the transformation of the images, the mosaicked image frames are resampled at a larger pixel size then the native resolution.

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.

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%). 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 0.5^{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 < 0.5^{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.

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. This is a consideration when sampling the radiant temperatures at tributary mouths and surface springs.

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

[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.

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 (Figure 6).

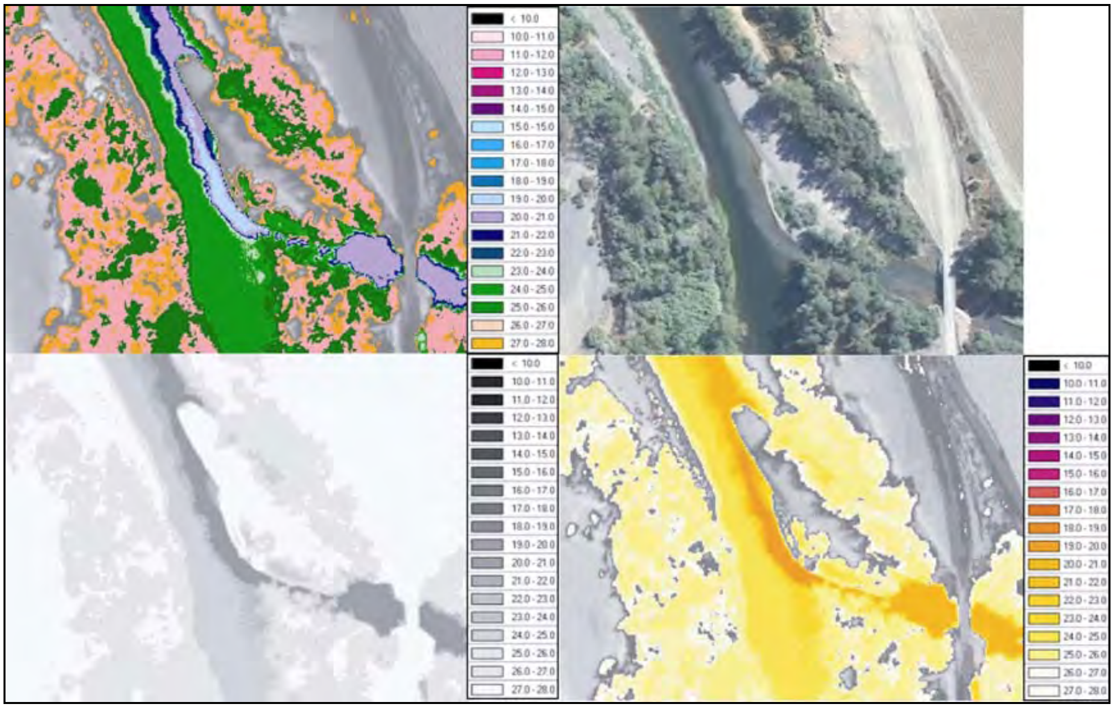


Figure 6 - Example of different color maps applied to the same TIR image.

<u>Image Uniformity:</u> The TIR sensor used for this study uses a focal plane array of detectors to sample incoming radiation. A challenge when using this technology is to achieve uniformity across the detector array. This sensor has a correction scheme which reduces non-uniformity across the image frame. However, differences in temperature (typically <0.5^{o}C) can be observed near the edge of the image frame. The uniformity differences within frames and slight differences from frame-to-frame are most apparent in the continuous mosaics.

Weather Conditions

Weather conditions were considered ideal with relatively low humidity and clear skies. The air temperature was warm on the days of the survey though somewhat cooler on August 4th and 5th with some cloud cover on the 5th. Data from seasonal in-stream thermographs will be needed to assess how water temperatures on the day of the flight compare to average and maximum summer temperatures. Table 4 summarizes the weather conditions observed at the USFS Remote Automated Weather Station (RAWS) station in Chiloquin, OR July 31-August 5, 2007. No flights were conducted on August 3 because of technical issues.

Table 4 – Weather conditions measured in Chiloquin, OR on July 31-August 5, 2007.

Date	PDT	Air Temp (°F)	Air Temp (°C)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction
South Fork Sprague River, Whitworth Creek, Brownsworth Creek						
7/31/2007	1000	71.0	21.7	24	5	NNE
7/31/2007	1200	83.0	28.3	21	4	E
7/31/2007	1400	89.0	31.7	24	6	W
7/31/2007	1600	91.0	32.8	16	9	NW
7/31/2007	1800	90.0	32.2	16	6	NNW
Sycan River						
8/1/2007	1000	76.0	24.4	19	7	NNE
8/1/2007	1200	86.0	30.0	16	4	NNW
8/1/2007	1400	91.0	32.8	19	6	WNW
8/1/2007	1600	95.0	35.0	13	6	SSW
8/1/2007	1800	87.0	30.6	26	13	WNW
Sprague River						
8/2/2007	1000	80.0	26.7	24	4	NE
8/2/2007	1200	87.0	30.6	22	5	SE
8/2/2007	1400	91.0	32.8	18	7	SSE
8/2/2007	1600	88.0	31.1	24	14	NE
8/2/2007	1800	83.0	28.3	33	11	NW
North Fork Sprague River						
8/4/2007	1000	73.0	22.8	31	0	NE
8/4/2007	1200	79.0	26.1	23	6	W
8/4/2007	1400	81.0	27.2	19	6	NNW
8/4/2007	1600	81.0	27.2	13	11	NNW
8/4/2007	1800	78.0	25.6	17	11	ENE
Meryl Creek, Fivemile Creek						
8/5/2007	1000	68.0	20.0	36	0	NW
8/5/2007	1200	75.0	23.9	27	4	N
8/5/2007	1400	81.0	27.2	16	8	SE
8/5/2007	1600	77.0	25.0	20	12	E
8/5/2007	1800	70.0	21.1	32	5	NNW

Thermal Accuracy

As mentioned earlier, the Klamath Tribe and Watershed Sciences maintained a network of 30 in-stream data-loggers (Onset Hobo-Pro and Stowaways) in the Sprague River Basin during the time frame of the flight (Figure 5). Table 5 summarizes a comparison between the kinetic temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR images for the Sprague River and the sampled tributaries.

Table 5 – Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitor.

River	Owner	Sensor Type	Sensor ID	Time	In-stream Temp (°C)	Image	River Mile	Radiant Temp (°C)	Difference
South Fork Sprague River (7/31/07)									
SF Sprague	Klamath Tribe	Hobo	1026264	15:38	26.6	sfsprague0051	0.89	26.6	0.0
SF Sprague	Klamath Tribe	Hobo	927268	15:54	26.1	sfsprague0519	7.34	26.0	0.1
SF Sprague	Klamath Tribe	Hobo	1026267	16:05	24.1	sfsprague0848	13.38	23.9	0.2
SF Sprague	Klamath Tribe	Hobo	1026266	16:17	22.0	sfsprague1239	20.56	22.0	0.0
Whitworth Cr	Klamath Tribe	Hobo	1026262	16:26	23.1	sfsprague1239	20.56	24.4	-1.3
Whitworth Cr. (7/31/07)									
Whitworth Cr	Klamath Tribe	Hobo	1026262	16:26	23.1	sfsprague1505	0	23.5	-0.4
Whitworth Cr	Klamath Tribe	Hobo	1187769	16:33	17.2	sfsprague1721	3.6	18.8	-1.6
Brownsworth Cr. (7/31/07)									
Brownsworth	Klamath Tribe	Hobo	1026261	16:46	16.3	brown0213	4.6	17.0	-0.7
Sycan River (8/1/07)									
Sycan River	Klamath Tribe	Hobo	927273	15:35	25.1	sycan0098	0.93	25.8	-0.7
Sycan River	Klamath Tribe	Hobo	927276	15:38	25.9	sycan0180	2.94	25.7	0.2
Sycan River	Klamath Tribe	Hobo	927265	15:58	27.3	sycan0702	15.30	26.7	0.6
Sycan River	Klamath Tribe	Hobo	927248	16:12	21.0	sycan1209	26.22	21.2	-0.2
Sycan River	Klamath Tribe	Hobo	927263	16:15	21.8	sycan1278	28.02	21.9	-0.1
Sprague River (8/2/07)									
Williamson R.	Klamath Tribe	Hobo	224112	14:33	15.1	spargue0027	0.0	16.2	-1.1
Sprague River	Klamath Tribe	Hobo	927257	14:34	24.9	sprague0053	0.3	24.2	0.7
Sprague River	Klamath Tribe	Hobo	927249	14:43	25.2	sprague0328	8.0	25.2	0.0
Sprague River	Klamath Tribe	Hobo	927272	14:46	24.0	sprague0405	9.7	23.9	0.1
Sprague River	WS, Inc.	Stowaway	540665	14:47	23.9	sprague0426	10.5	24.0	-0.1
Sprague River	Klamath Tribe	Hobo	739103	15:18	26.4	sprague1369	28.0	26.1	0.3
Sprague River	WS, Inc.	Stowaway	540664	15:19	25.8	sprague1414	29.5	26.3	-0.5
Sprague River	Klamath Tribe	Hobo	551565	15:23	26.0	sprague1523	32.7	26.0	0.0
Sprague River	Klamath Tribe	Hobo	927157	15:28	27.3	sprague1667	38.0	26.9	0.4
Sprague River	Klamath Tribe	Hobo	927267	15:40	24.5	sprague2039	49.7	24.9	-0.4
Sprague River	Klamath Tribe	Hobo	927270	16:14	23.4	sprague3056	66.9	23.5	-0.1
Sprague River	Klamath Tribe	Hobo	224117	16:19	22.7	sprague3195	69.8	22.9	-0.2
SF Sprague	Klamath Tribe	Hobo	1026264	16:32	27.2	sprague3582	78.9	27.2	0.0
North Fork Sprague (8/4/07)									
N. Fk. Sprague	WS, Inc.	Hobo	1026260	16:39	22.6	nfsprague1396	23.02	22.3	0.3
N. Fk. Sprague	WS, Inc.	Hobo	1026259	16:48	17.6	nfsprague1922	28.05	17.4	0.2

River	Owner	Sensor Type	Sensor ID	Time	In-stream Temp (°C)	Image	River Mile	Radiant Temp (°C)	Difference
N. Fk. Sprague	WS, Inc.	Hobo	1026265	16:50	12.8	nfsprague2062	29.93	13.1	-0.4
Fivemile Creek (8/5/07)									
Fivemile Creek	Klamath Tribe	Hobo	927262	15:19	20.5	fivemile600	10.54	20.4	0.1
Meryl Creek (8/5/07)									
Meryl Creek	WS, Inc.	Stowaway	540664	15:55	17.8	meryl0841	1.56	18.0	-0.2

In general, the differences between radiant and kinetic temperatures were consistent with other airborne TIR surveys conducted in the Pacific Northwest and within the target accuracy of ±0.5^{o}C. In the Sprague Basin, the differences between radiant and kinetic temperatures ranged between -1.6^{o}C and +0.7. In some cases, the TIR imagery will provide clues as to why a difference was observed between kinetic and radiant temperatures. In these instances, the imagery may reveal that the data-logger was in a stratified area or an obvious mixing zone. However, in most cases, the reason for the difference is not known. The sensor locations which had temperature differences (kinetic versus radiant) greater than ±0.5^{o}C are discussed in greater detail below.

South Fork Sprague R.: The data logger in the South Fork Sprague immediately upstream of Whitworth Creek was consistent with radiant temperatures while the data logger at the mouth of Whitworth Creek recorded cooler temperatures. Whitworth Creek was considerably smaller than the South Fork and it is possible that the radiant temperatures measured at the mouth of Whitworth were artificially high due to sampling of hybrid pixels.

Whitworth Creek: The two Whitworth Creek sensors both recorded kinetic temperatures that were cooler than the radiant temperatures. The TIR imagery was calibrated to be consistent with the in-stream temperatures recorded near the mouth. Whitworth Creek was very small (relative to pixel size) near the headwaters and it is expected that the radiant temperatures consisted of hybrid pixels and were artificially high.

Brownsworth Creek: Similar to Whitworth Creek, Brownsworth Creek was very small near the headwaters and it is expected that radiant temperatures were artificially high due to hybrid pixels in the sample.

Sycan River: The most downstream data logger (mile 0.9) recorded temperatures that were 0.7^{o}C cooler than the observed radiant temperatures. The reason for this difference is not apparent from the imagery. However, the flow conditions in this river segment suggest possible differential heating or thermal stratification at the water surface.

Sprague River: The data logger in the Williamson River was 1.1^{o}C cooler than recorded radiant temperatures while the data logger in the Sprague River was 0.7^{oC} warmer then the radiant temperatures. The reason for these differences could not be determined from the imagery. However, the other 11 Sprague data loggers were consistent with radiant temperatures.

Results

Median channel temperatures were plotted versus river mile for the streams in the survey area. Tributaries, springs, seeps, and canals sampled during the analysis are included on the profile to provide additional context for interpreting spatial temperature patterns. Significant diversions and other features such as remnant ox-bows, ponds and marshes were also plotted where relevant. For the purpose of this study, springs and seeps were generally differentiated by size and temperature. A feature was called a spring when it had a defined source and was distinctly colder than the surrounding waters. Features were called seeps when they were less defined spatially and in temperature; they most commonly occurred on the edges of the river banks.

Due to the nature of the project, the focus was on identifying cold water inflows and thermal refugia for fish. Given the warm temperatures on the days of the survey, features such as hot springs may have been 'washed out' in comparison to the surrounding terrestrial landscape. Aquatic vegetation on the water surface was common in many reaches in the basin and cause spatial temperature variability on the water surface (Figure 7). The sample images contained in this report are not meant to be comprehensive, but provide examples of river features and interpretations.

Figure 7 – Ground level digital photo of the Sprague River on the day of the TIR survey. The Sprague River exhibits a number of flow conditions and in some locations has mats of aquatic vegetation on the water surface (visible along both banks of the river). These mats often cause surface temperature variability in the imagery.

Sprague River

Longitudinal Temperature Profile

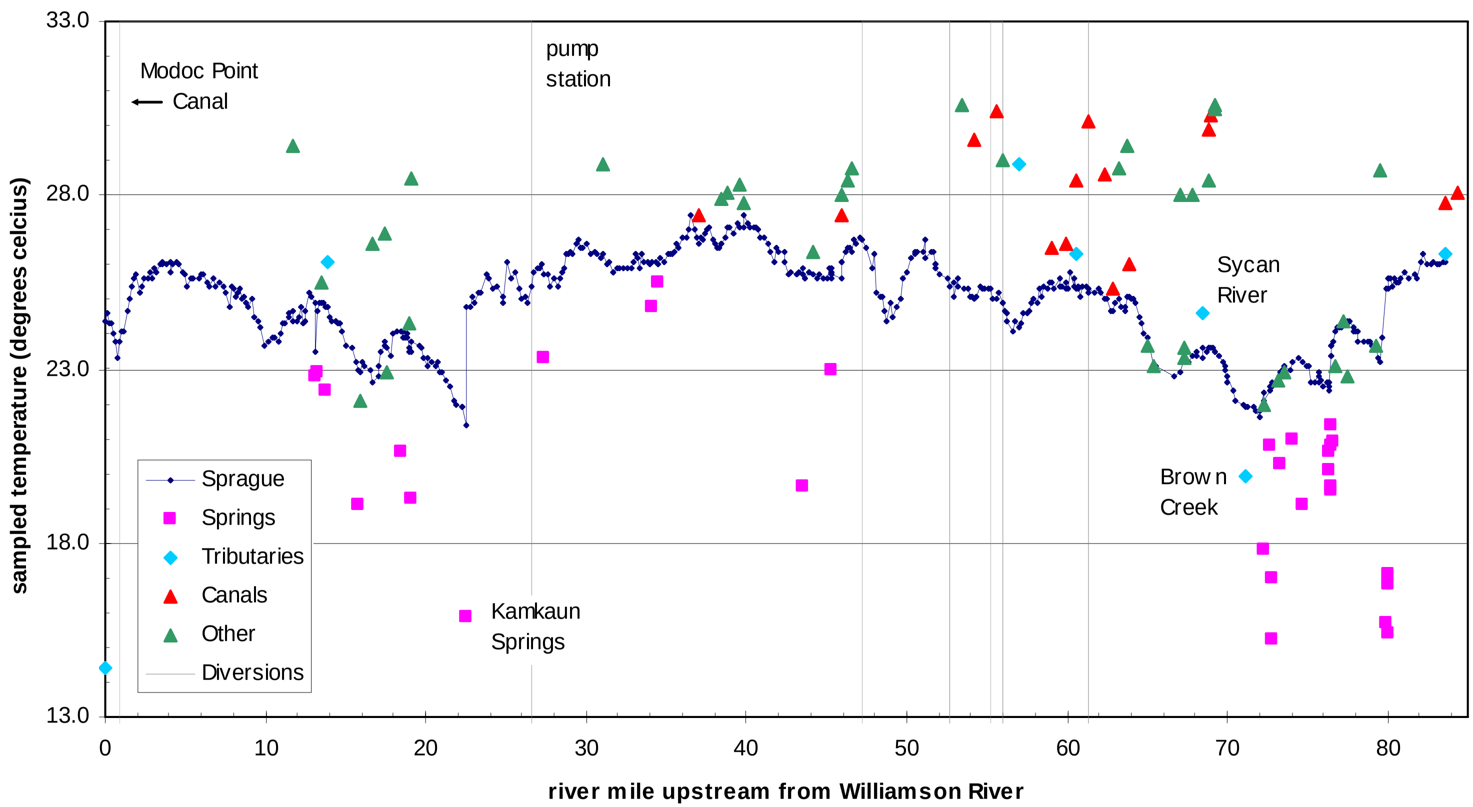


Figure 8 - Median channel temperatures plotted versus river mile for the Sprague River. The locations of detected surface inflows are illustrated on the profile and listed in Table 6.

Table 6 - Tributaries and other surface inflows sampled along the Sprague River with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (ºC)	Mainstem Temp (ºC)	Difference
Williamson River	0.00	0.00	14.4	24.4	-10.0
Copperfield Creek (L)	22.22	13.81	26.1	24.8	1.3
Rock Creek-minimal water (L)	91.70	56.98	28.9	24.2	4.7
Whisky Creek/braid(L)	97.42	60.54	26.3	25.3	1.0
Sycan River (R)	110.23	68.49	24.6	23.3	1.3
Brown Creek (L)	114.56	71.18	19.9	21.9	-2.0
SF Sprague	134.44	83.54	26.1	26.1	0
NF Sprague (R)	134.44	83.54	26.3	26.1	0.2
Springs	**Kilometer**	**River Mile**	**Spring Temp (ºC)**	**Mainstem Temp (ºC)**	**Difference**
spring (L)	21.02	13.06	22.8	24.9	-2.1
spring (L)	21.24	13.20	22.9	24.7	-1.8
cold pool (L)	22.20	13.79	22.4	24.8	-2.4
spring-fed pond (R)	25.41	15.79	19.1	23.0	-3.9
spring (L)	29.66	18.43	20.6	24.1	-3.5
spring (very small) (L)	30.77	19.12	19.3	23.5	-4.2
Kamkaun Spring (L)	36.33	22.58	15.9	24.8	-8.9
spring (L)	44.13	27.42	23.3	25.7	-2.4
small spring? (L)	54.93	34.13	24.8	26.1	-1.3
small spring? (L)	55.47	34.47	25.5	26.0	-0.5
off channel spring(R)	70.11	43.57	19.6	25.7	-6.1
spring (L)	72.95	45.33	23.0	25.7	-2.7
spring (R)	116.30	72.26	17.8	22.3	-4.5
cold seep from pond (R)	116.86	72.61	20.8	22.4	-1.6
spring in pond(R)	117.07	72.74	17.0	22.5	-5.5
flow to Spring Creek (L)	117.13	72.78	15.2	22.6	-7.4
spring at Beatty Gap (R)	117.93	73.28	20.3	22.9	-2.6
spring (R)	119.15	74.04	21.0	23.2	-2.2
spring (R)	120.19	74.68	19.1	23.2	-4.1
small spring (L)	122.77	76.29	20.1	22.4	-2.3
small springs (L/R)	122.89	76.36	20.6	22.6	-2.0
small springs (L/R)	123.05	76.46	19.5	23.4	-3.9
multiple small springs (L/R)	123.04	76.46	20.8	23.4	-2.6
small springs (L)	123.14	76.51	19.6	23.7	-4.1
small springs (R)	123.15	76.52	21.4	23.7	-2.3
small spring (L)	123.29	76.61	20.9	23.8	-2.9
spring complex (R)	128.69	79.96	15.7	25.3	-9.6
spring complex (R)	128.75	80.00	15.4	25.3	-9.9
spring complex (R)	128.83	80.05	16.8	25.6	-8.8
spring complex (R)	128.89	80.09	17.1	25.6	-8.5
Canals	**Kilometer**	**River Mile**	**Canal Temp (ºC)**	**Mainstem Temp (ºC)**	**Difference**
irrigation canal-in (L)	59.54	37.00	27.4	26.6	0.8
irrigation canal (L)	73.94	45.95	27.4	26.1	1.3
canal in (L)	87.15	54.16	29.6	25.0	4.6
canal in (L)	89.56	55.65	30.4	25.0	5.4
canal off old oxbow (L)	94.93	58.99	26.5	25.5	1.0

canal-incoming (L)	96.44	59.92	26.6	25.5	1.1
canal on right braid (R)	97.54	60.61	28.4	25.7	2.7
remnant canal-in (L)	98.69	61.32	30.1	25.2	4.9
canal in (R)	100.28	62.31	28.6	25.3	3.3
canal in (L)	101.15	62.85	25.3	24.7	0.6
canal (R)	102.74	63.84	26.0	25.1	0.9
old canal? (R)	110.85	68.88	29.9	23.6	6.3
old canal? (R)	110.95	68.94	30.3	23.6	6.7
canal (R)	134.60	83.64	27.8	26.5	1.3
Leonard Slough/Fritz Creek canal	135.84	84.41	28.1	27.1	1.0
Diversions	**Kilometer**	**River Mile**	**Diversion Temp (ºC)**	**Mainstem Temp (ºC)**	**Difference**
Modoc Point Canal (Out) (L)	1.41	0.88	22.9	23.8	-0.9
pump station-out (L)	42.74	26.56	25.9	26.4	-0.5
canal-out (R)	75.91	47.17	26.9	26.7	0.2
canal-out (L)	84.87	52.74	26.9	25.4	1.5
canal out (L)	88.87	55.22	27.0	25.3	1.7
canal out (L)	90.12	56.00	27.9	24.9	3.0
canal out (R)	98.68	61.32	25.8	25.3	0.5
Other Features	**Kilometer**	**River Mile**	**Temp (ºC)**	**Mainstem Temp (ºC)**	**Difference**
Whitehorse Spring marsh (R)	18.82	11.69	29.4	24.4	5.0
standing water (L)	21.71	13.49	25.5	24.9	0.6
pond (R)	25.60	15.91	22.1	22.9	-0.8
old meander (R)	26.75	16.62	26.6	22.6	4.0
warm pond (R)	28.10	17.46	26.9	23.8	3.1
remnant ox-bow (R)	28.22	17.53	22.9	23.6	-0.7
old braid (L)	30.50	18.95	24.3	23.5	0.8
old channel (R)	30.81	19.14	28.5	23.8	4.7
old meander (R)	49.90	31.01	28.9	26.3	2.6
old meander (R)	61.93	38.48	27.9	26.6	1.3
old meander (R)	62.48	38.82	28.1	27.1	1.0
old meander (R)	63.75	39.61	28.3	27.1	1.2
old channel (R)	64.18	39.88	27.8	27.4	0.4
marshy area (R)	70.99	44.11	26.4	25.7	0.7
remnant oxbow (R)	73.85	45.89	28.0	25.6	2.4
pond (L)	74.62	46.36	28.4	26.5	1.9
old braid (L)	74.87	46.53	28.8	26.4	2.4
wetland area (R)	85.92	53.39	30.6	26.1	4.5
wetland area (R)	90.09	55.98	29.0	24.9	4.1
old channel (L)	101.68	63.18	28.8	25.0	3.8
warm slough (L)	102.65	63.78	29.4	25.1	4.3
retention pond (L)	104.62	65.01	23.7	23.9	-0.2
side channel (R)	105.23	65.39	23.1	23.1	0.0
remnant oxbow (L)	107.92	67.06	28.0	22.9	5.1
secondary channel (R)	108.26	67.27	23.3	23.3	0.0
secondary channel (R)	108.37	67.34	23.6	23.3	0.3
remnant channel (L)	109.23	67.87	28.0	23.4	4.6
remnant slough (L)	110.74	68.81	28.4	23.6	4.8
old oxbow (L)	111.39	69.21	30.6	23.5	7.1
old channel (L)	111.50	69.28	30.5	23.5	7.0

cold pothole (R)	116.33	72.28	22.0	22.1	-0.1
cold pothole (L)	117.70	73.14	22.7	22.6	0.1
cold hole (L)	118.46	73.61	22.9	23.1	-0.2
cold pond (R)	123.39	76.67	23.1	24.1	-1.0
wetland pond (R)	124.26	77.21	24.4	24.3	0.1
wetland pond(R)	124.66	77.46	22.8	24.4	-1.6
pool-road (R)	127.60	79.28	23.7	23.6	0.1
old channel (R)	127.98	79.52	28.7	23.2	5.5

Observations

Approximately 85 miles of the Sprague River were surveyed on August 2, 2007 from the confluence of the Williamson River upstream to the confluence of the North and South Fork Sprague Rivers. Five tributaries, 30 springs and seeps, 15 canals, 7 diversions and 38 ‘other’ features (sloughs, remnant meanders, secondary channels, ponds, etc.) were sampled in the imagery.

Bulk water temperatures ranged from 21.4°C to 28.6°C with the lowest temperatures occurring immediately after the emergence of Kamkaun Spring at river mile 22.58. The warmest temperatures occur between Eagle Butte and Trout Creek (river miles 37-40) and on a shallow secondary channel between river miles 64.14 and 68.54.

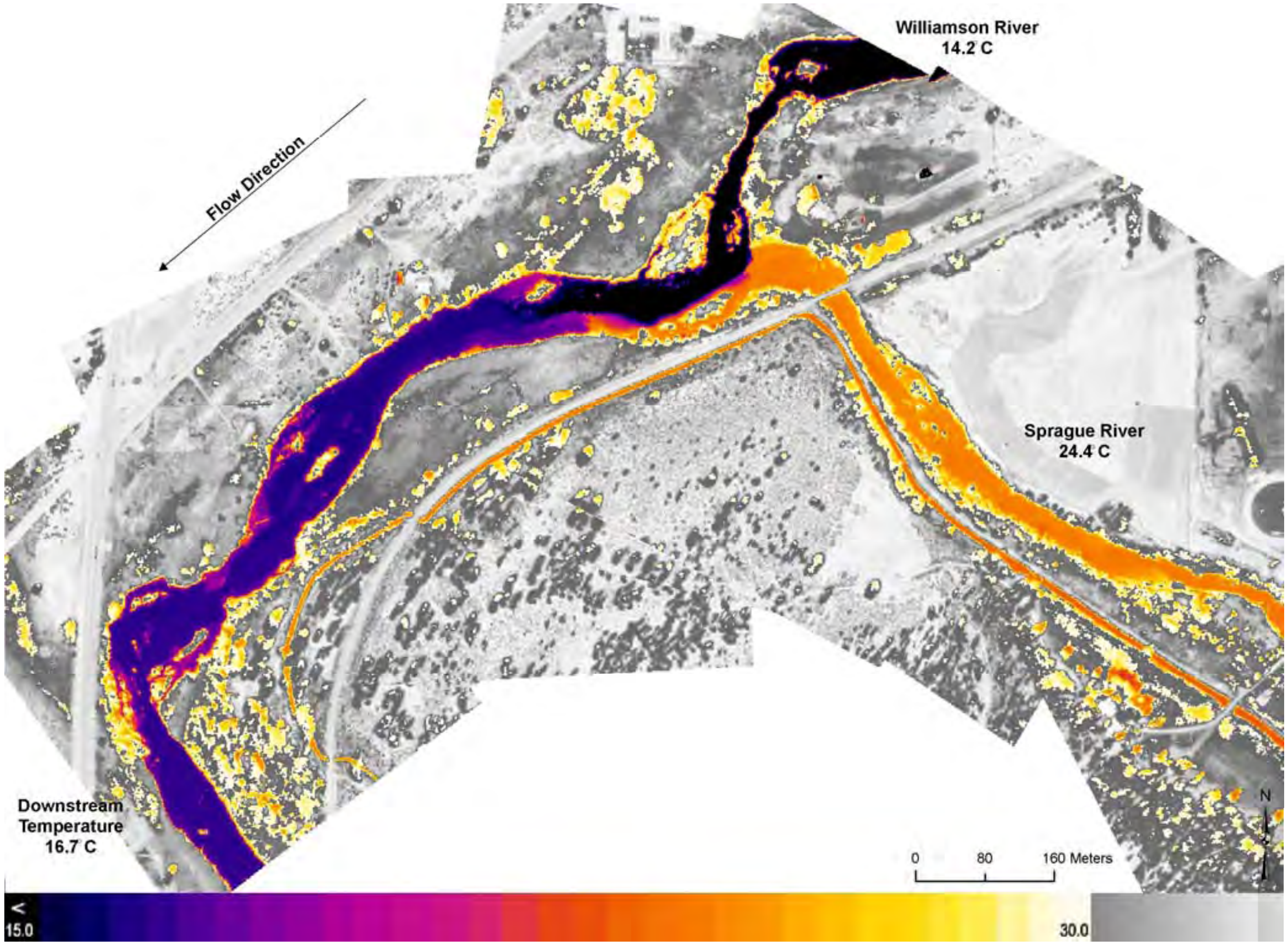
A general cooling trend is seen at the upper end of the River between river miles 71.99-83.54 with 14 springs sampled in the reach above Beatty Gap. This stretch of river falls between Medicine Mountain and Ferguson Mountain and is relatively confined compared to upstream reaches of the North and South Fork Sprague. It is common to see subsurface upwelling, springs and seeps in areas where there is a significant change in valley morphology.

Kamkaun Spring has a dramatic cooling effect on the temperature profile, dropping the bulk water temperatures by almost 3.5 degrees (24.8°→21.4°C) (Sprague River Image 3). Two other significant spring complexes can also be seen at river mile 76.46 and river mile 80.05 (Sprague River Image 7). Less dramatic cooling sources can be seen just downstream of Kamkaun with two springs at river mile 15.79 and 18.43. (Sprague River Image 2).

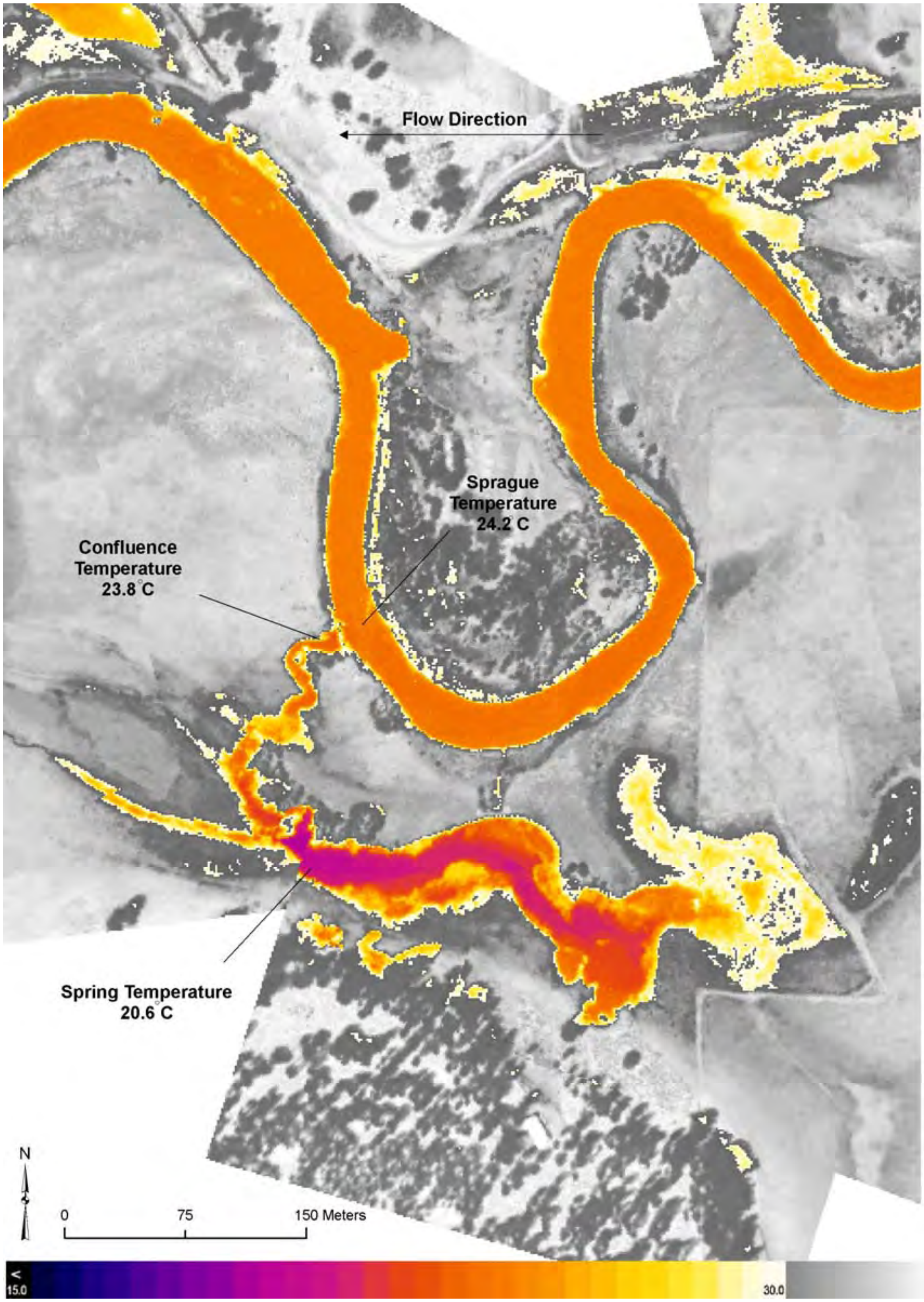
All of the sampled tributaries are a warming influence on the mainstem except for Brown Creek (Sprague River Image 6) which contributes water that is 2.0°C cooler than the Sprague. At river mile 71.18, just below Beatty Gap, Brown Creek is likely influenced by subsurface upwelling, but this cannot be confirmed by the imagery.

None of the diversions or canals seems to have a major impact on the temperature profile except the Modoc Point Canal at river mile 0.88.

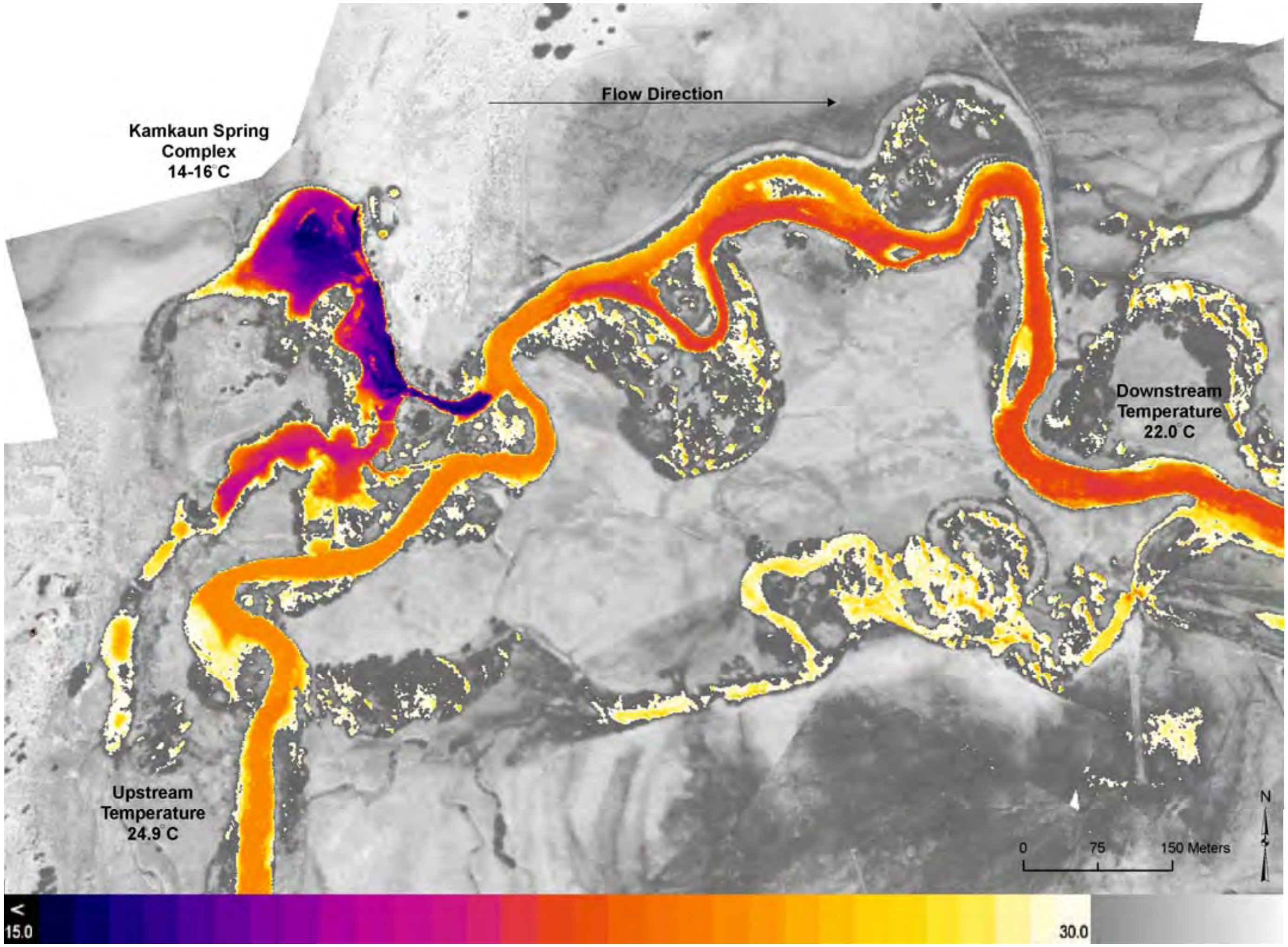
Sample Images



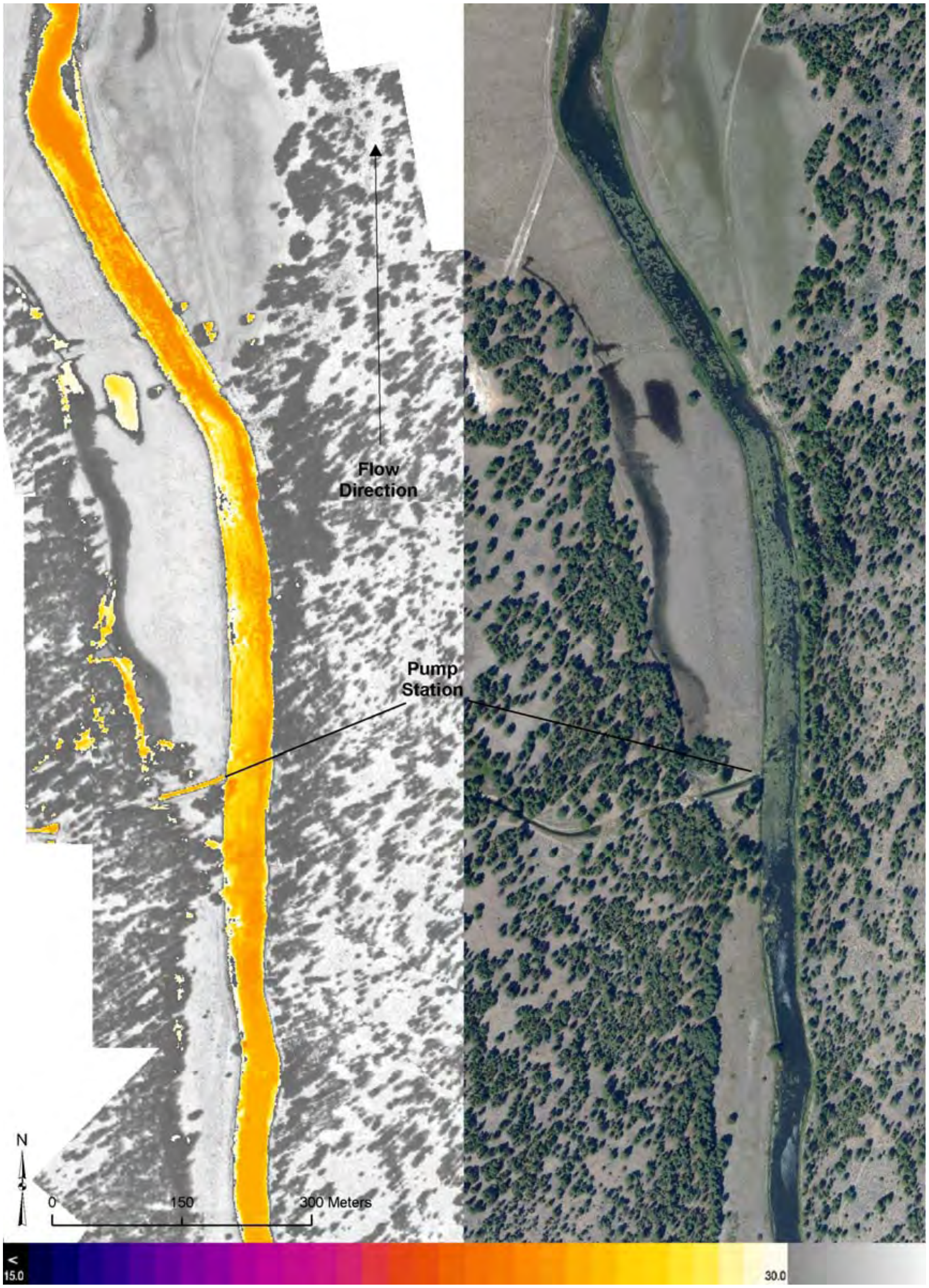
Sprague River Image 1 – Confluence of the Sprague River and Williamson River. The Williamson River is very cold (14.2°C) compared to the Sprague River (24.4°C). The influence of the Sprague increased the radiant temperatures in the Williamson River by ~2.5°C.



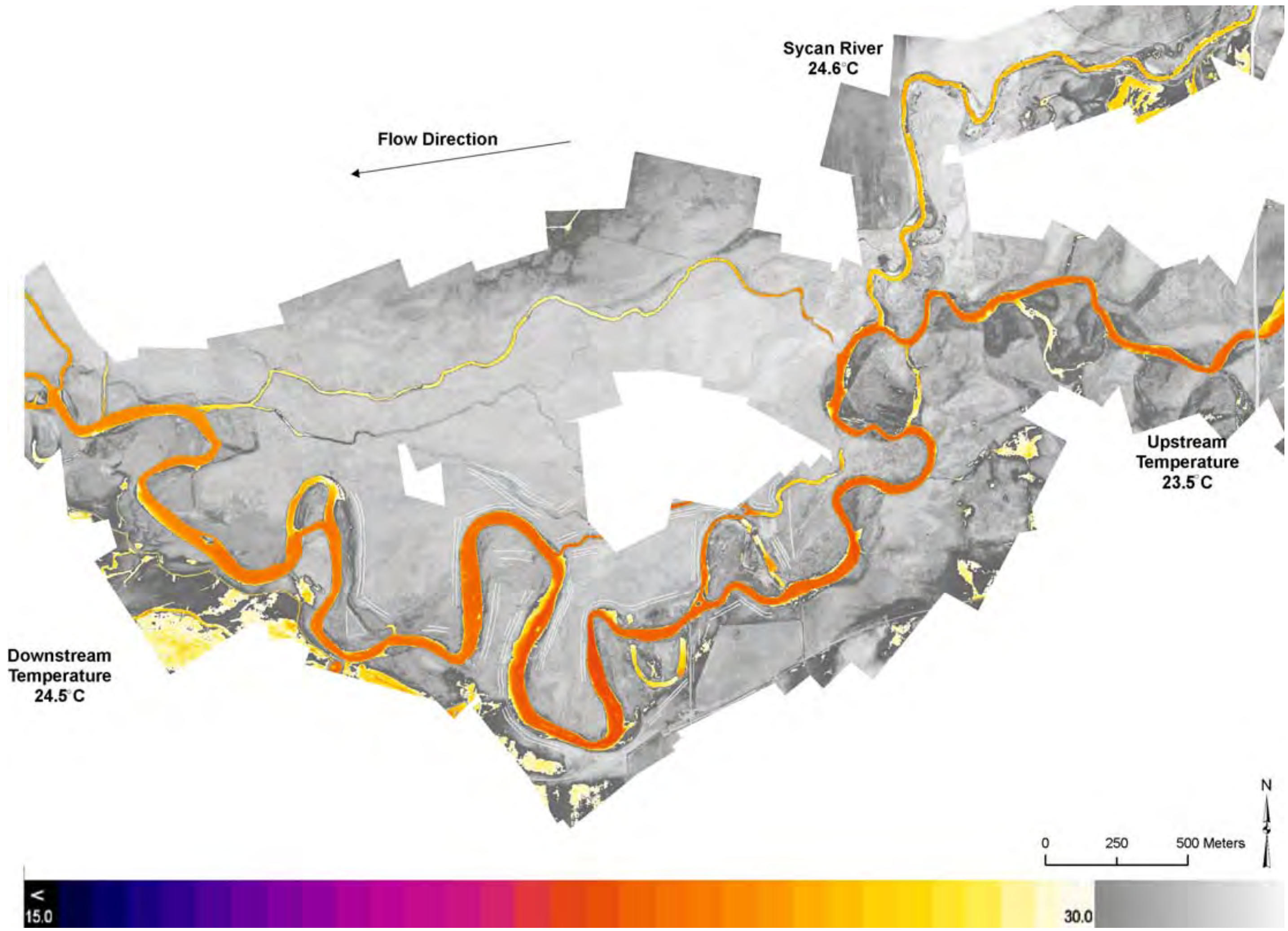
Sprague River Image 2 – This large surface spring (20.6°C) was observed near the left bank of the Sprague River at mile 18.43. However, the radiant temperature of the spring outflow at the confluence (23.8°C) was only slightly cooler to those observed in the Sprague River (24.2°C).



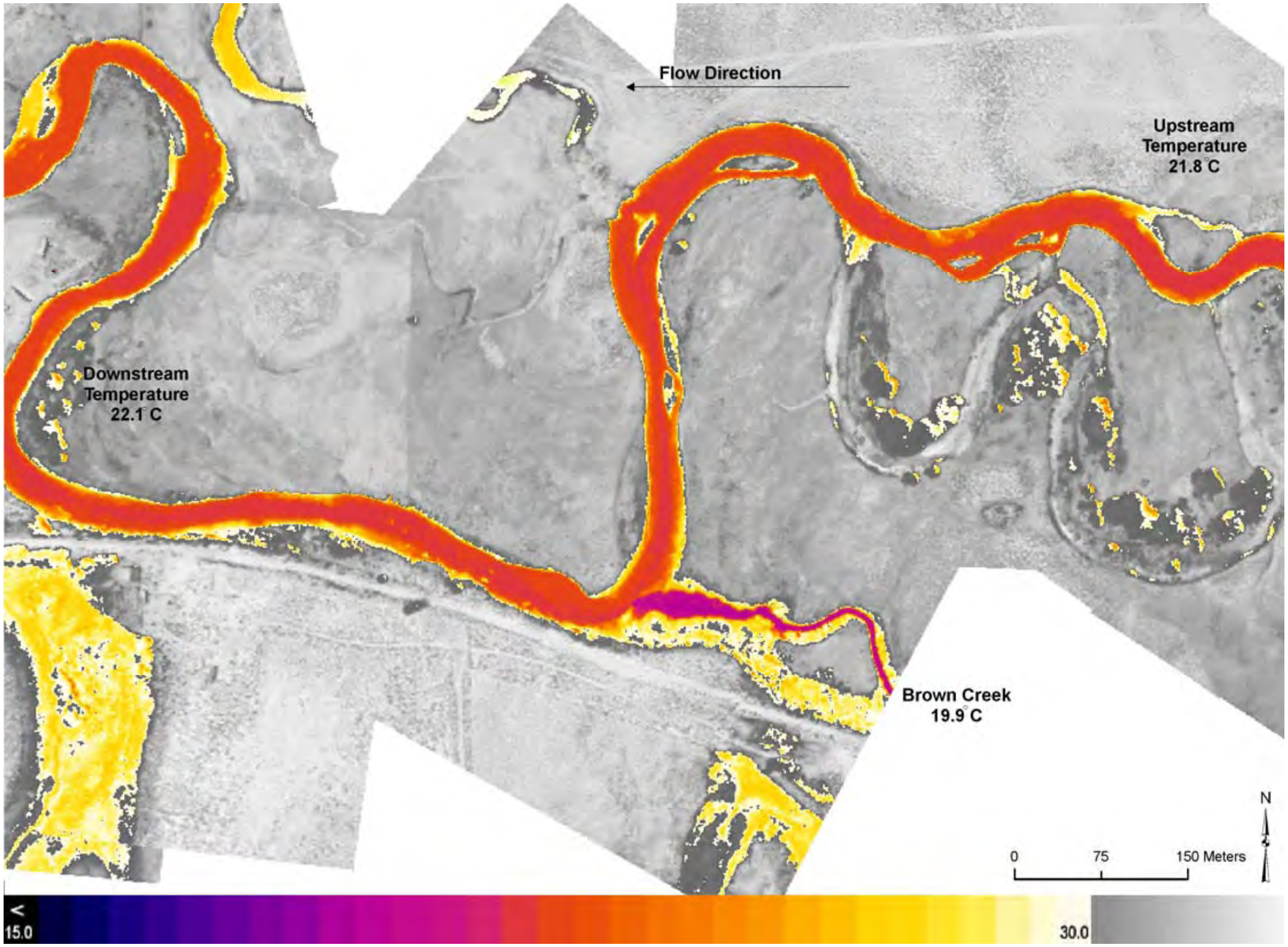
Sprague River Image 3 - Kamkaun Spring at river mile 22.58 has a dramatic influence on the temperature profile of the Sprague. The bulk water temperatures drop close to 3 degrees over a one mile reach. As the cool water exits the spring, it appears to dive below the warm surface water for approximately 150 meters before significant mixing and cooling is reflected in the surface temperatures.



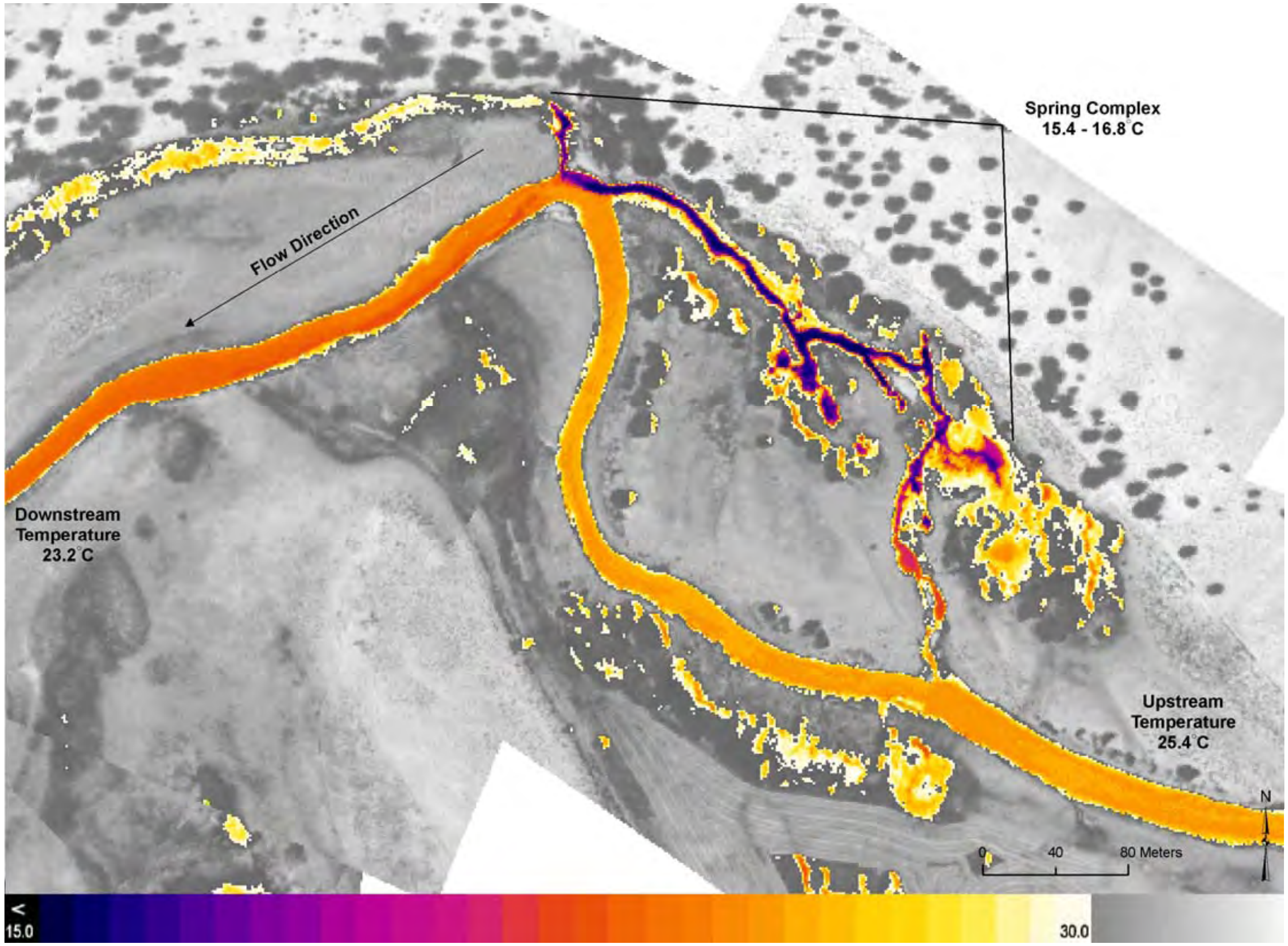
Sprague River Image 4 – The TIR/true color image pair above illustrates the Sprague River at mile 26.56. The outflow of a pump station is visible along the left bank. The surface temperatures are highly variable along this reach suggesting vegetation on the surface and low vertical mixing rates.



Sprague River Image 5 – The TIR image above illustrates the confluence of the Sprague River (23.3°C) and Sycan River (24.6°C) at mile 68.49. The image shows the sinuosity of the river through this reach including the large number of secondary channels.



Sprague River Image 6 – The TIR image above illustrates the confluence of the Sprague River(21.9°C) and Brown Creek (19.9°C) at mile 71.18. Brown Creek was the only tributary observed as a cooing source to the Sprague, but it appears to have only a localized effect on the overall temperature profile.



Sprague River Image 7 - This spring complex at river mile 80.05 is similar to the spring complex seen at river mile 76.46. The spring supplies enough cool water to lower the bulk river temperature by over 2 degrees in less than one mile.

North Fork Sprague River

Longitudinal Temperature Profile

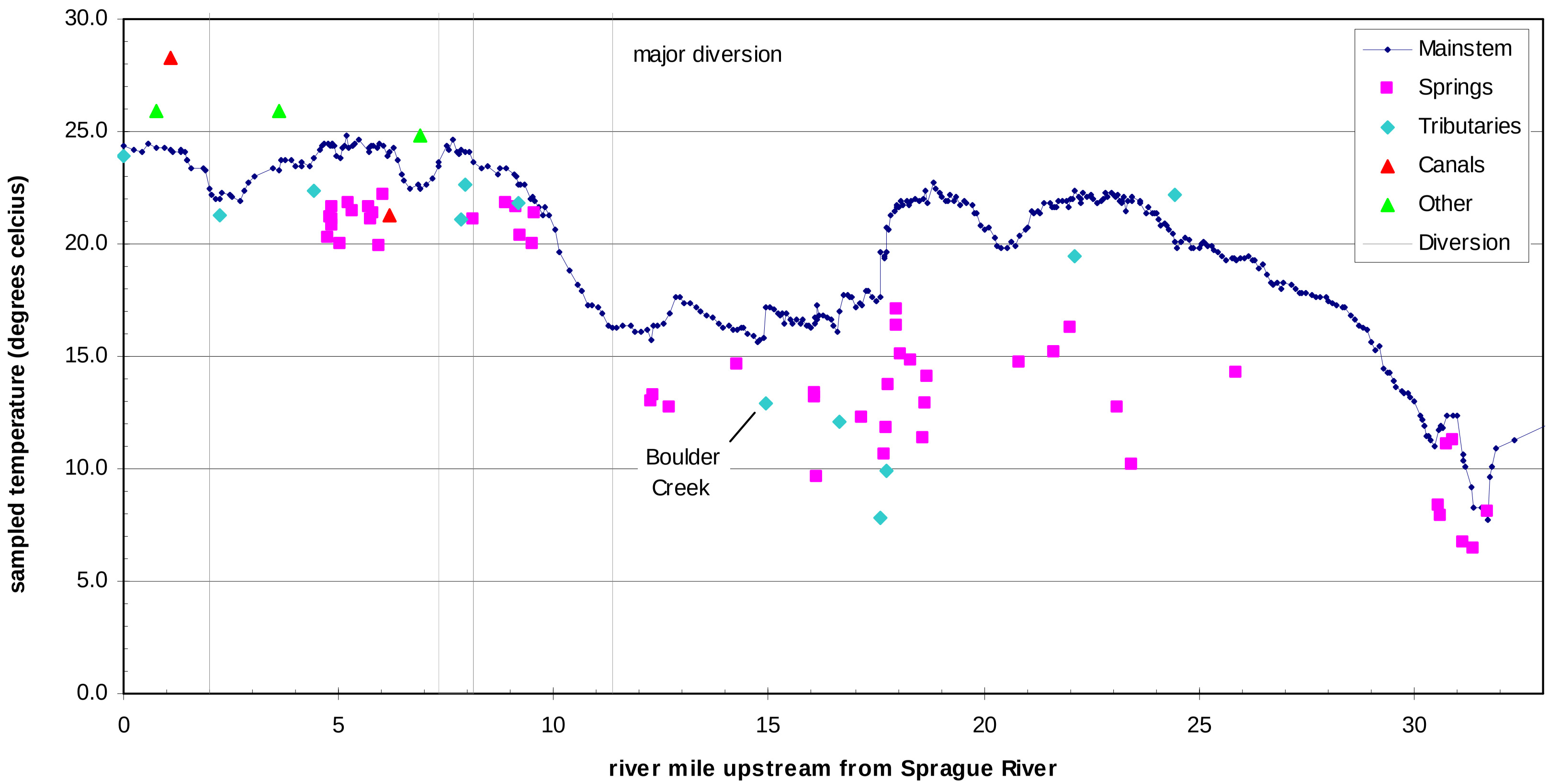


Figure 9 - Median channel temperatures plotted versus river mile for the North Fork Sprague River. The locations of detected surface inflows are illustrated on the profile and listed in Table 7.

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Table 7 - Tributaries and other surface inflows sampled along the North Fork Sprague River with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
South Fork Sprague (L)	0.00	0.00	23.9	24.4	-0.5
Fivemile Creek (R)	3.57	2.22	21.3	22.0	-0.7
Meryl Creek (L)	7.11	4.42	22.4	23.8	-1.4
unnamed drainage (L)	12.62	7.84	21.1	24.2	-3.1
unnamed drainage(L)	12.78	7.94	22.6	24.1	-1.5
cold-Bailey Flat (L)	14.81	9.20	21.8	22.6	-0.8
Boulder Creek (L)	24.04	14.94	12.9	17.2	-4.3
Sheepy Creek (L)	26.80	16.66	12.1	17.0	-4.9
unnamed trib/spring (R)	28.35	17.61	7.8	19.6	-11.8
unnamed trip/spring (R)	28.57	17.75	9.9	20.7	-10.8
Cold Creek (R)	35.59	22.12	19.5	22.4	-2.9
unnamed trib (R)	39.34	24.45	22.2	20.1	2.1
Springs	**Kilometer**	**River Mile**	**Spring Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
Small seep (L)	7.64	4.75	20.3	24.5	-4.2
small spring (R)	7.75	4.81	21.2	24.4	-3.2
Small seeps(L)	7.79	4.84	21.2	24.5	-3.3
spring (R)	7.83	4.86	21.6	24.4	-2.8
Small seeps(L)	7.84	4.87	20.8	24.5	-3.7
spring (L)	8.08	5.02	20.0	23.8	-3.8
seep(L)	8.41	5.23	21.8	24.3	-2.5
spring (L)	8.58	5.33	21.5	24.4	-2.9
spring (R)	9.21	5.72	21.6	24.3	-2.7
seep (L)	9.28	5.77	21.1	24.4	-3.3
spring (R)	9.30	5.78	21.4	24.4	-3.0
long seep (L)	9.55	5.93	19.9	24.5	-4.6
seep (L)	9.71	6.04	22.2	24.4	-2.2
spring (L)	13.10	8.14	21.1	23.6	-2.5
spring (R)	14.30	8.89	21.8	23.4	-1.6
spring (R)	14.72	9.15	21.6	23.0	-1.4
shadow/spring (L)	14.87	9.24	20.4	22.6	-2.2
springs (L)	15.28	9.50	20.0	22.1	-2.1
spring? (L)	15.36	9.55	21.4	21.9	-0.5
spring (R)	19.78	12.29	13.0	15.7	-2.7
spring from hillside (R)	19.83	12.32	13.3	16.4	-3.1
seeps (R)	20.43	12.70	12.7	16.9	-4.2
spring (R)	22.96	14.27	14.6	16.2	-1.6
spring/deep shadow? (R)	25.84	16.05	13.2	16.5	-3.3
spring? (R)	25.89	16.09	13.4	16.7	-3.3
spring? (R)	25.92	16.10	9.6	16.6	-7.0
small spring (L)	27.63	17.17	12.3	17.3	-5.0
spring (R)	28.49	17.70	10.6	19.5	-8.9
small spring (R)	28.51	17.72	11.8	19.6	-7.8
spring? (R)	28.65	17.80	13.7	20.6	-6.9
Seep (R)	28.90	17.96	17.1	21.6	-4.5
spring? (L)	28.95	17.99	16.4	21.7	-5.3
spring (L)	29.12	18.09	15.1	21.9	-6.8
spring? (R)	29.50	18.33	14.8	21.9	-7.1

spring (R)	29.92	18.59	11.4	22.0	-10.6
spring (R)	30.01	18.65	12.9	22.4	-9.5
spring (R)	30.05	18.67	14.1	21.8	-7.7
spring/deep shadow? (R)	33.52	20.83	14.7	20.4	-5.7
spring? (L)	34.81	21.63	15.2	21.6	-6.4
spring (L)	35.45	22.03	16.3	22.0	-5.7
spring (R)	37.16	23.09	12.7	22.2	-9.5
spring (R)	37.71	23.43	10.2	22.1	-11.9
spring\shadow (R)	38.80	24.11	16.8	20.8	-4.0
spring? (L)	41.59	25.85	14.3	19.3	-5.0
spring (R)	49.18	30.56	8.4	11.7	-3.3
spring (R)	49.25	30.60	7.9	11.9	-4.0
spring (R)	49.53	30.78	11.1	12.4	-1.3
spring (R)	49.71	30.89	11.3	12.4	-1.1
large spring (R)	50.13	31.15	6.7	10.4	-3.7
spring (L)	50.52	31.39	6.5	8.3	-1.8
Small spring (L)	51.05	31.72	8.1	7.7	0.4
Canals	**Kilometer**	**River Mile**	**Canal Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
canal (L)	1.73	1.08	28.3	24.2	4.1
canal (R)	9.97	6.20	21.3	24.1	-2.8
Other Features	**Kilometer**	**River Mile**	**Feature Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
remnant braid (R)	1.19	0.74	25.9	24.3	1.6
old braid (L)	5.83	3.62	25.9	23.3	2.6
slough (L)	11.12	6.91	24.8	22.5	2.3
Diversions	**Kilometer**	**River Mile**			
diversion	3.21	2.00			
Diversion	11.80	7.33			
diversion	13.10	8.14			
canal-out	18.29	11.37			

Observations

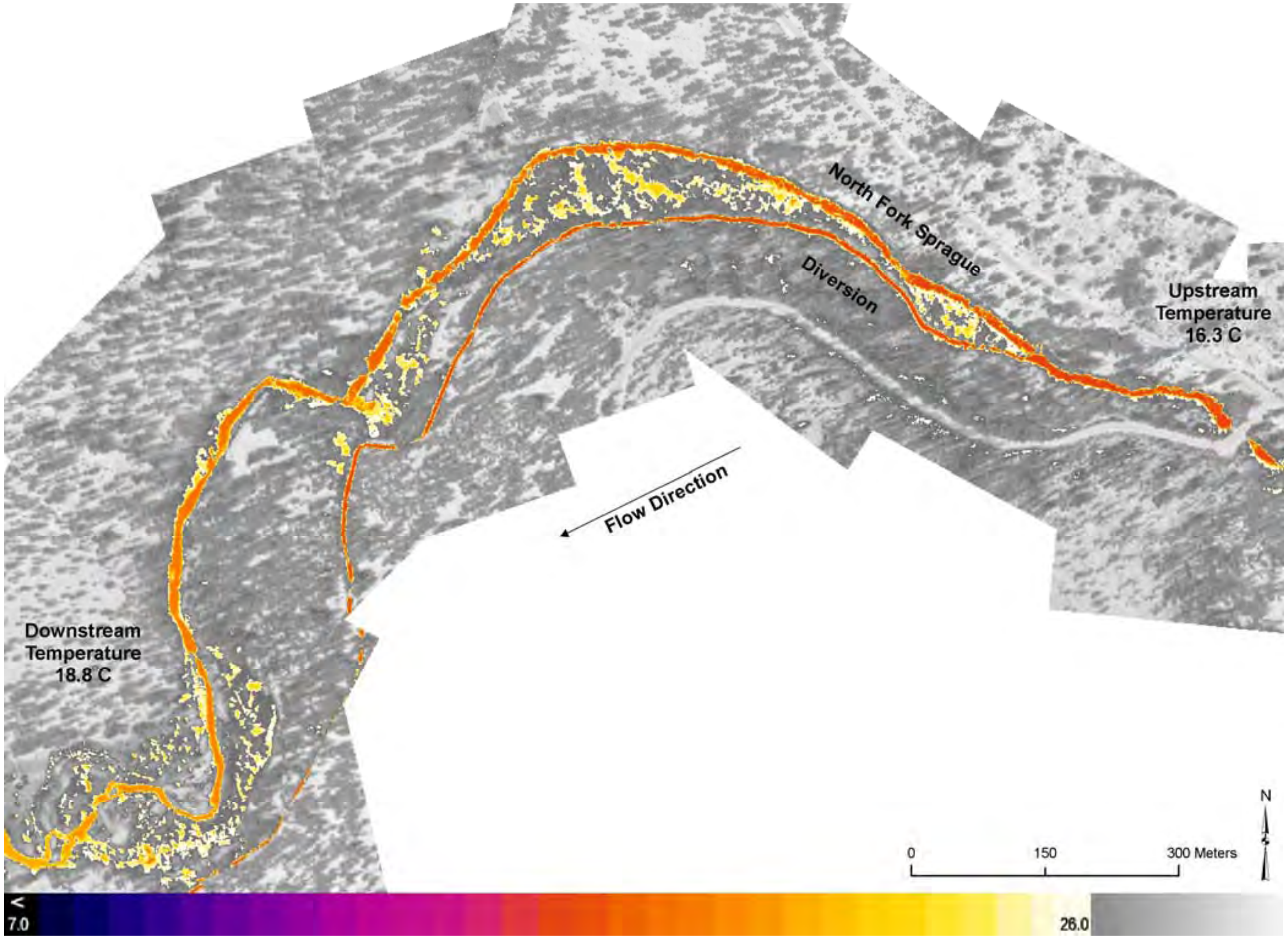
Approximately 54 miles of the North Fork Sprague River were surveyed on August 4, 2007 from the mouth at the Sprague River upstream to the headwaters at 'Head of River Spring.' Eleven tributaries, 51 springs and seeps, 2 canals, 4 diversions and 3 remnant channel features were sampled in the imagery. Bulk water temperatures ranged from 7.7°C at the headwaters to 24.8°C in the lower 8 miles of stream below Bailey Flat.

The overall temperature trend matches closely with the valley morphology. Cold spring complexes feed the headwaters and warm as the river flows downstream. This warming generally continues until river mile 18 where the river enters a narrow canyon and many seeps, springs, and cold water tributaries enter the river.

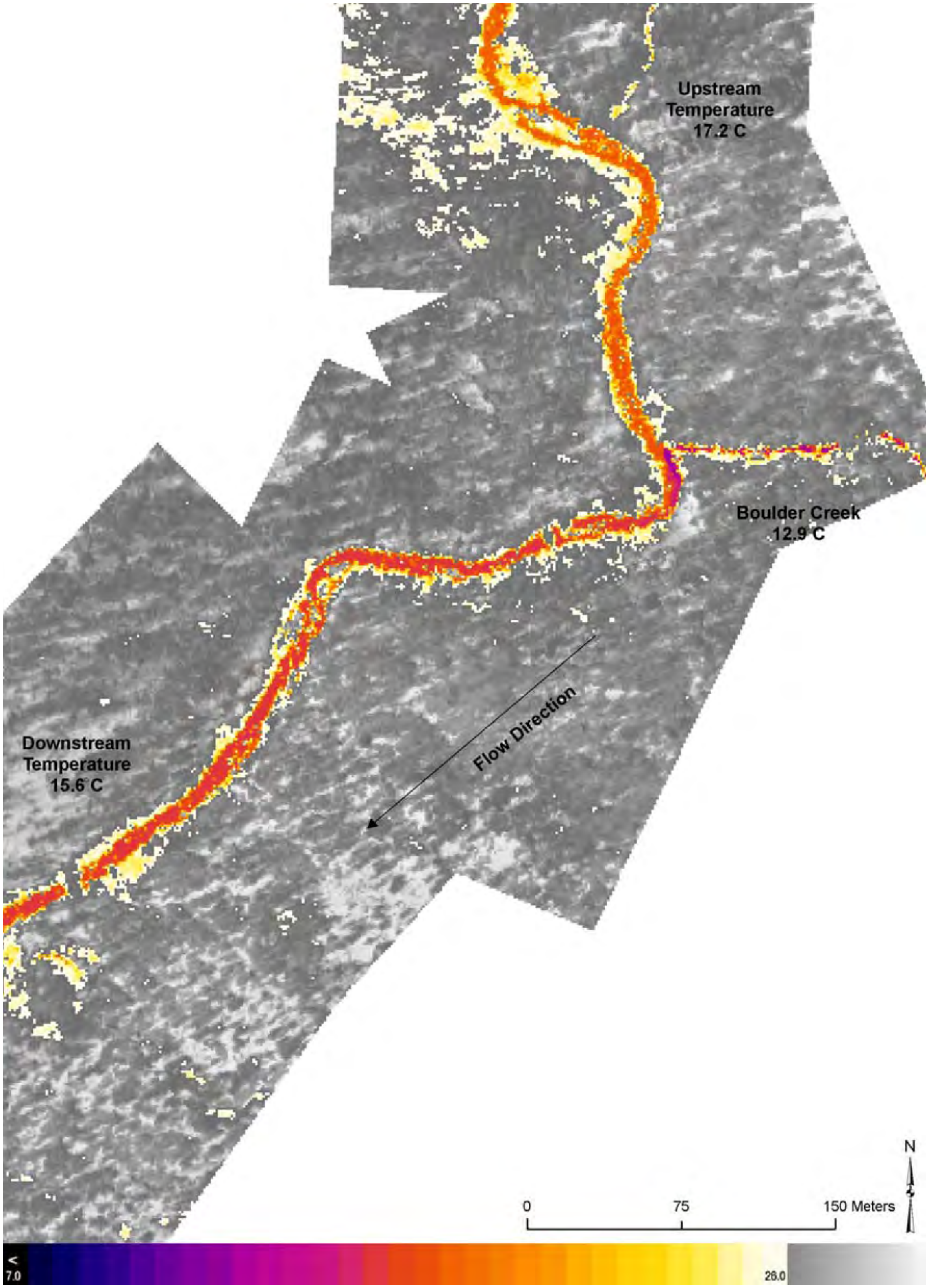
The cooler canyon waters continue until river mile 11.37 where a canal appears to divert a significant amount of water from the main channel (North Fork Sprague Image 1). After the diversion, the river emerges from the canyon into Bailey Flats where it continues warming until stabilizing around 24°C.

All of the sampled tributaries are cooling influences to the North Fork except for a small unnamed tributary at river mile 24.45.

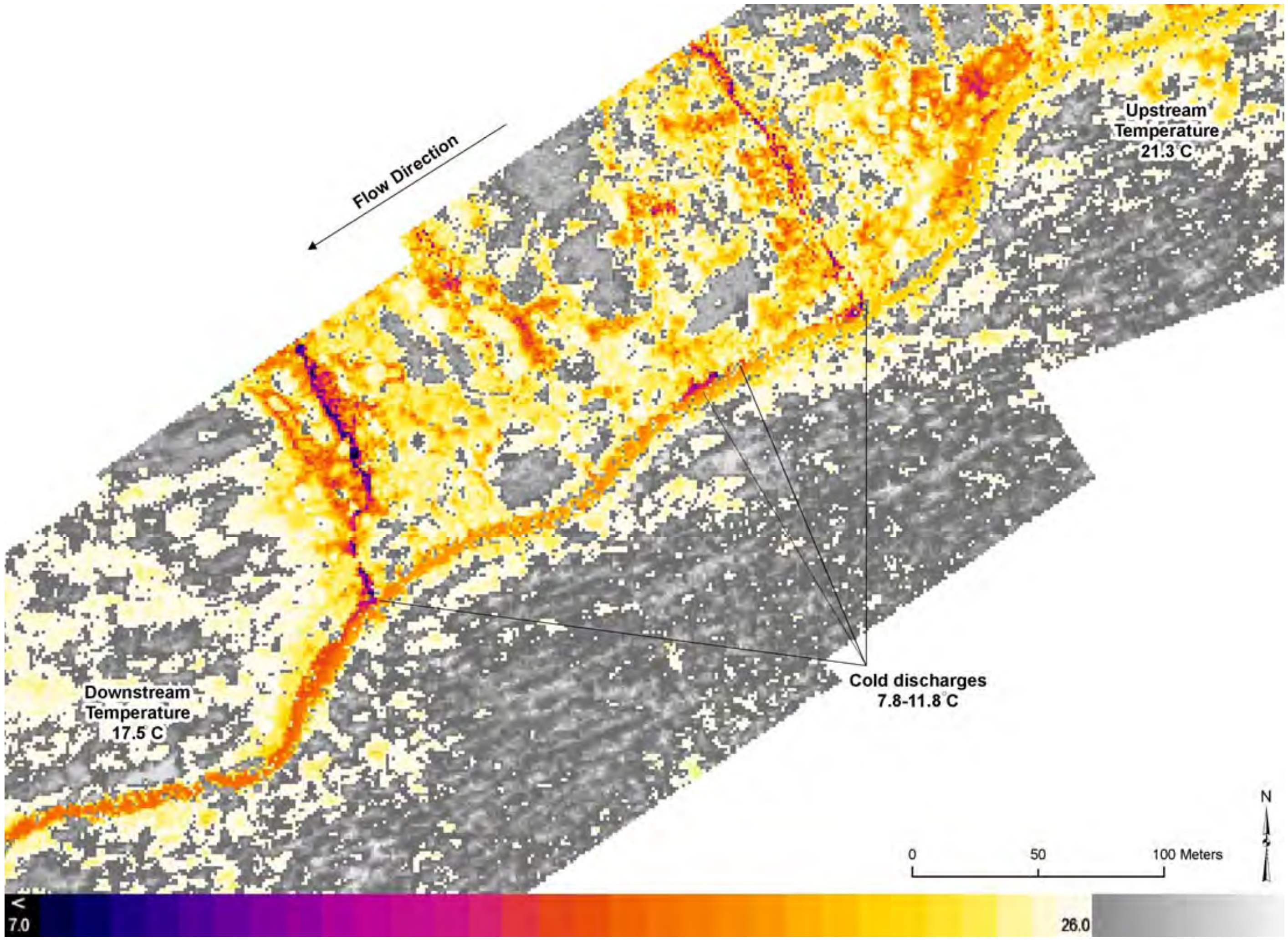
Sample Images



North Fork Sprague Image 1 – The image above shows the North Fork Sprague River between river miles 11.37 (16.3°C) and 10.37 (18.8°C). As illustrated in the longitudinal profile, stream temperatures in the North Fork increase rapidly downstream of the diversion.



North Fork Sprague Image 2. – The TIR image above shows the confluence of the North Fork Sprague River (17.2^{o}C) and Boulder Creek (12.9^{o}C) at river mile 14.94. The Boulder Creek inflow lowers water temperatures in the North Fork by ~1.5^{o}C.



North Fork Sprague Image 3– The image above shows a spring complex on the NF Sprague River at river mile 17.70. The series of cold water discharges contributes to dramatic decrease in bulk water temperatures in the North Fork.

South Fork Sprague River

Longitudinal Temperature Profile

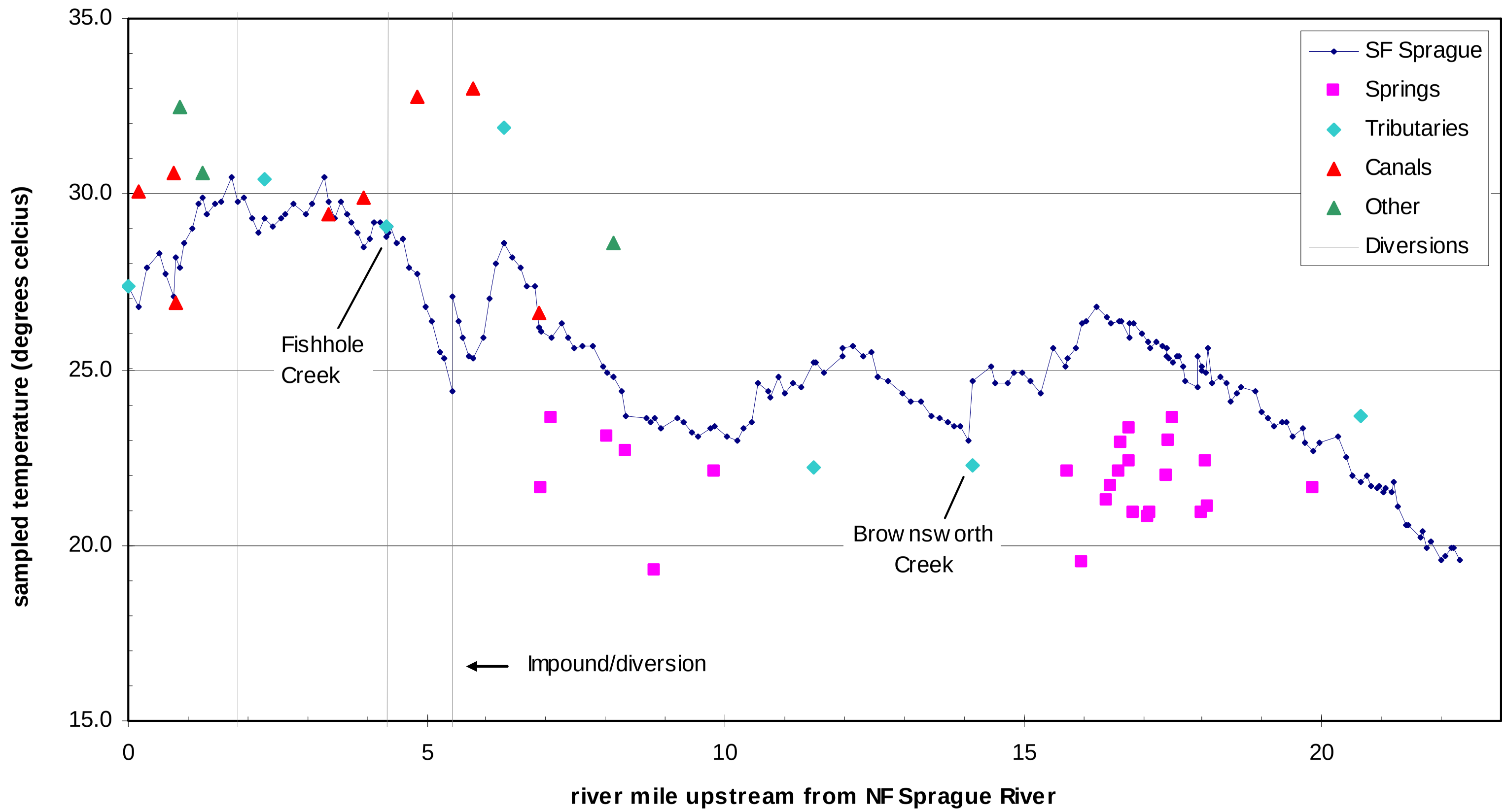


Figure 10 - Median channel temperatures plotted versus river mile for the South Fork Sprague River. The locations of detected surface inflows are illustrated on the profile and listed in Table 8.

Table 8 - Tributaries and other surface inflows sampled along the South Fork Sprague River with left or right bank designation (looking downstream).

Tributary	Kilometer	River Mile	Trib Temp (°C)	Mainstem Temp (°C)	Difference
NF Sprague (R)	0.00	0.00	27.4	27.4	0.0
Demming Creek (R)	3.69	2.29	30.4	29.3	1.1
Fishhole Creek (L)	6.97	4.33	29.1	28.8	0.3
side drainage (R)	10.16	6.31	31.9	28.6	3.3
Ish Tish Creek (L)	18.49	11.49	22.2	25.2	-3.0
Brownsworth Creek (R)	22.79	14.16	22.3	24.7	-2.4
Whitworth Creek (L)	33.23	20.65	23.7	21.8	1.9
Springs	**Kilometer**	**River Mile**	**Spring Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
cold field-no direct connect (L)	11.14	6.92	21.6	26.1	-4.5
seep (L)	11.42	7.09	23.6	25.9	-2.3
spring-hypopheric? (L)	12.93	8.03	23.1	24.9	-1.8
spring on side channel (L)	13.42	8.34	22.7	23.7	-1.0
marshy spring area (L)	14.18	8.81	19.3	23.6	-4.3
small spring (L)	15.79	9.81	22.1	23.4	-1.3
spring (L)	25.35	15.75	22.1	25.3	-3.2
spring (R)	25.71	15.97	19.5	26.3	-6.8
spring (L)	26.38	16.39	21.3	26.5	-5.2
spring (L)	26.53	16.48	21.7	26.3	-4.6
spring (L)	26.72	16.60	22.1	26.4	-4.3
spring (L)	26.79	16.65	22.9	26.4	-3.5
spring (L)	26.97	16.76	22.4	25.9	-3.5
spring (R)	27.00	16.78	23.3	26.3	-3.0
big spring (L)	27.14	16.86	20.9	26.3	-5.4
off channel spring (R)	27.49	17.08	20.8	25.8	-5.0
spring on lake (R)	27.56	17.12	20.9	25.6	-4.7
small springs along edge (L)	27.98	17.39	22.0	25.4	-3.4
seep (L)	28.04	17.42	23.0	25.3	-2.3
seep (L)	28.17	17.51	23.6	25.2	-1.6
spring (L)	28.96	18.00	20.9	25.0	-4.1
spring/shadow (L)	29.08	18.07	22.4	24.9	-2.5
spring (L)	29.13	18.10	21.1	25.6	-4.5
spring? (L)	31.95	19.85	21.6	22.7	-1.1
Canals	**Kilometer**	**River Mile**	**Canal Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
canal (R)	0.30	0.19	30.1	26.8	3.3
canal (R)	1.23	0.76	30.6	27.1	3.5
canal/Leonard Slough (R)	1.31	0.81	26.9	28.2	-1.3
canal (L)	5.42	3.37	29.4	29.8	-0.4
canal (L)	6.33	3.94	29.9	28.5	1.4
canal (L)	7.81	4.85	32.8	27.7	5.1
canal-in (R)	9.29	5.77	33.0	25.3	7.7
canal-in (L)	11.08	6.88	26.6	26.2	0.4
Diversions	**Kilometer**	**River Mile**	**Diversion Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
diversion (R)	2.94	1.83	29.9	29.8	0.1
diversion (R)	7.00	4.35	29.6	28.9	0.7
diversion (L)	8.73	5.43	29.5	24.4	5.1

Other features	Kilometer	River Mile	Temp (°C)	Mainstem Temp (°C)	Difference
marshy slough (L)	1.36	0.85	32.5	27.9	4.6
remnant channel/marsh (L)	2.00	1.24	30.6	29.9	0.7
remnant channel (R)	13.10	8.14	28.6	24.8	3.8

Observations

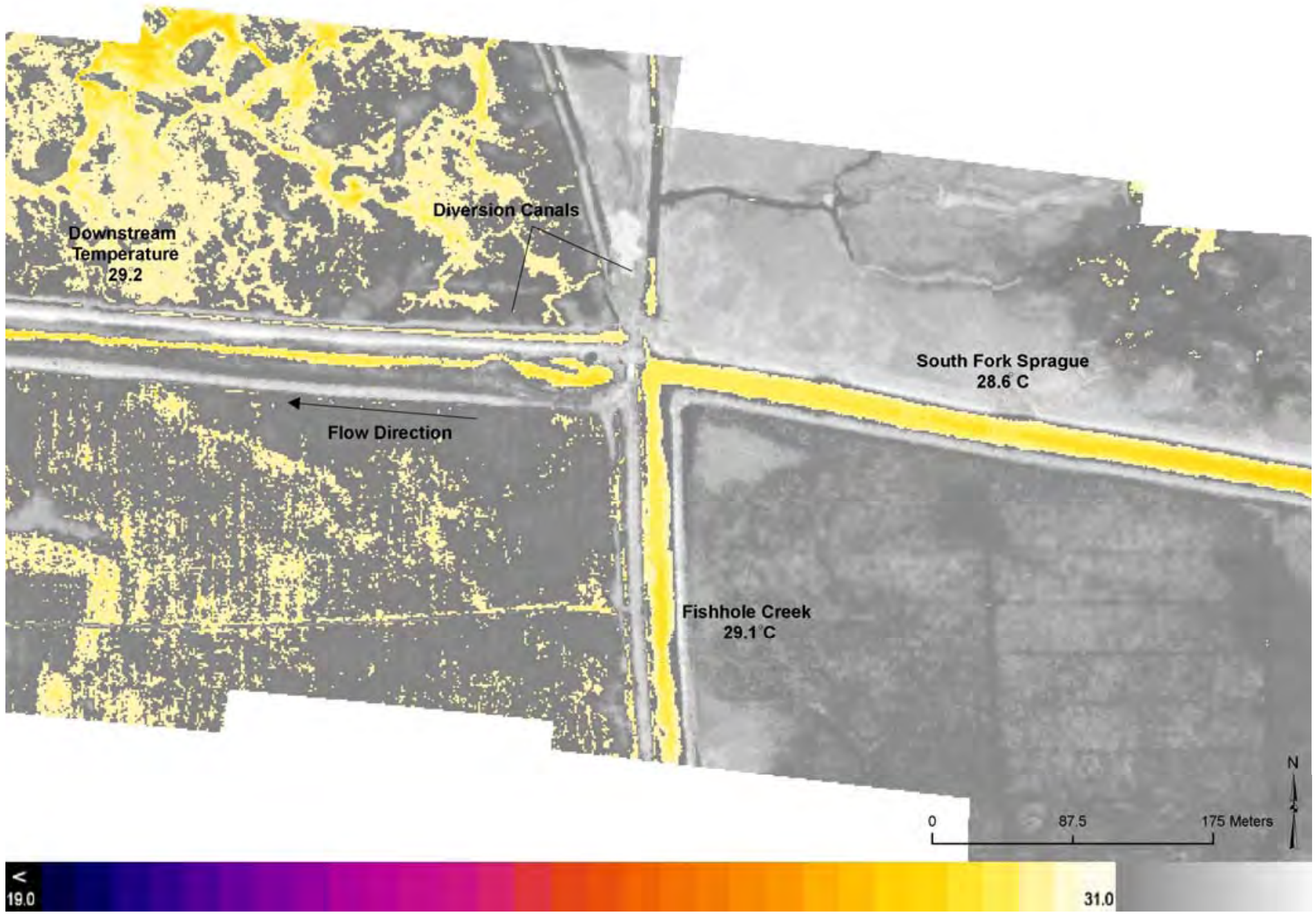
Approximately 22 miles of the South Fork Sprague River were surveyed on July 31, 2007 from the mouth at the Sprague River upstream to Buckboard Creek. Six tributaries, 24 springs and seeps, 8 canals, 3 diversions and 3 remnant channel features were sampled in the imagery.

Bulk water temperatures ranged from 19.6°C at the head of the survey at Buckboard Creek (RM 22.17) to 30.5°C in the lower four miles of stream below the diversion at Fishhole Creek (South Fork Sprague Image 1).

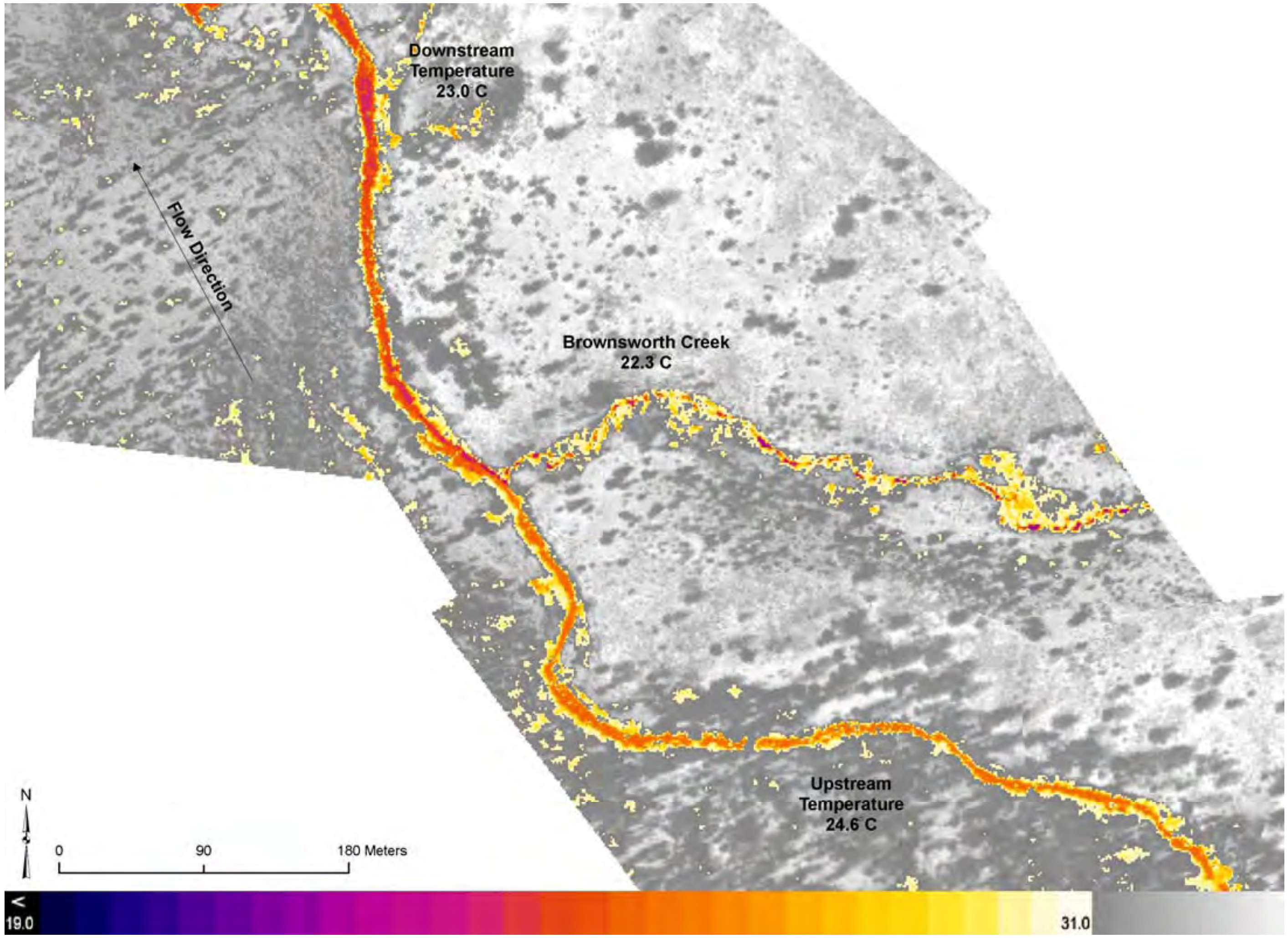
The river generally warms as it flows downstream from the headwaters until river mile 16.22, where multiple springs and possible subsurface flows have a cooling effect (South Fork Sprague Image 3). This transition also occurs as the valley changes from forested hillslopes to a steeper more confined canyon. The rate of warming increases below river mile 8.93 as the river exits the canyon into the flats.

Brownsworth Creek (RM 14.16) and Ish Tish Creek (RM 11.49) both contribute cooler water to the river, but only Brownsworth has a significant impact on the bulk water temperature (South Fork Sprague Image 2). The other sampled tributaries are warming influences to the South Fork, although only Whitworth seems to contribute a significant volume of water.

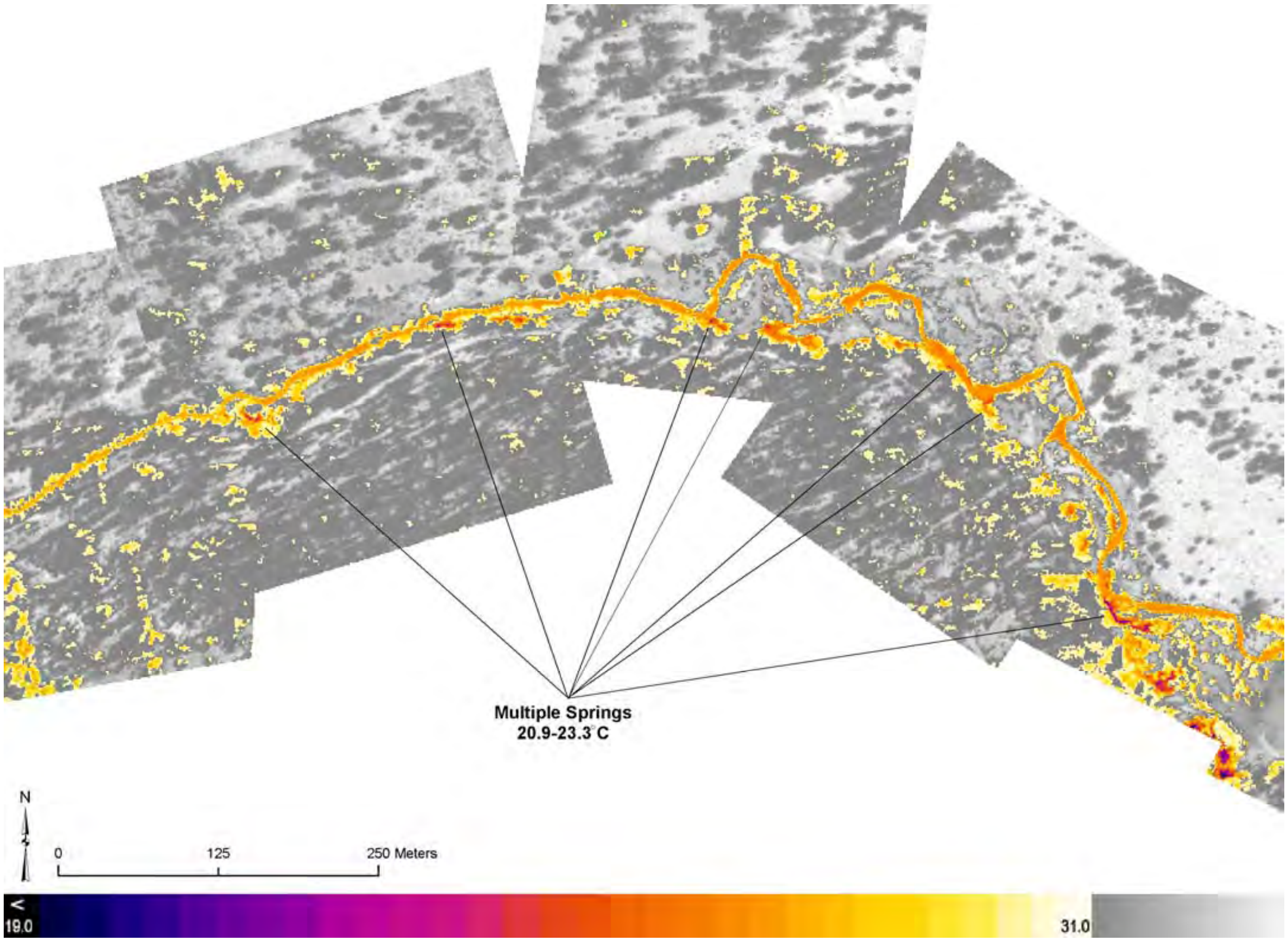
Sample Images



South Fork Sprague Image 1 – The TIR image above shows the confluence of the Fishhole Creek and the SF Sprague River at mile 4.33. Both streams are channelized through this reach with little spatial temperature variability.



South Fork Sprague Image 2 - The TIR image above shows the confluence of Brownsworth Creek (22.3°C) and the South Fork Sprague River (24.7°C) at mile 14.16. Brownsworth was a cooling source to the South Fork. The size of Brownsworth Creek combined with masking by riparian vegetation made it difficult to sample radiant temperatures.



South Fork Sprague Image 3 – The TIR image above shows an apparent spring complex along the left bank of the South Fork Sprague between river miles 16.39 and 16.86. The apparent spring discharges appear individually very small. However, a general cooling trend was observed in the longitudinal profile just downstream of this location suggesting a collective influence.

Sycan River

Longitudinal Temperature Profile

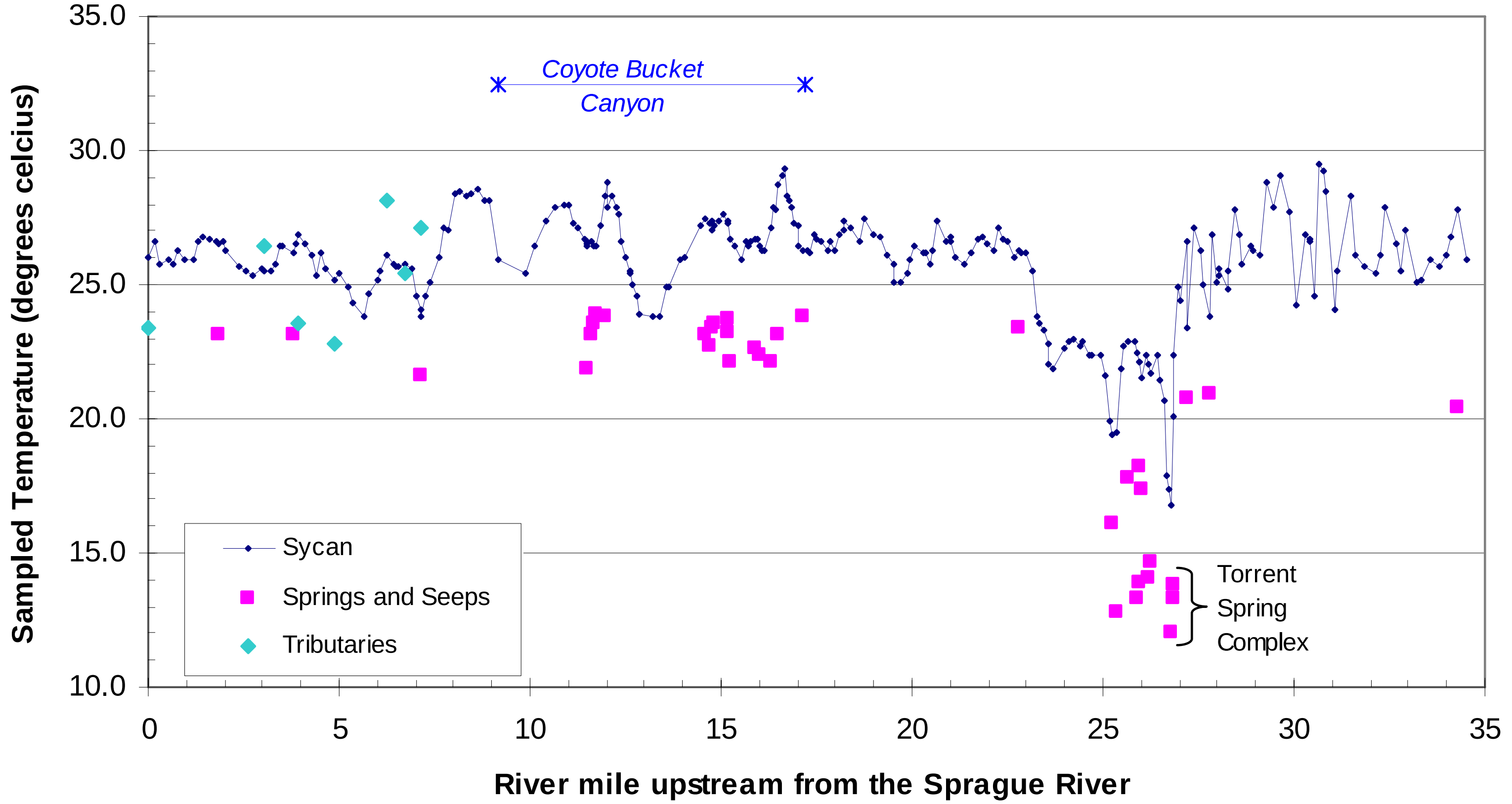


Figure 11 - Median channel temperatures plotted versus river mile for the Sycan River. The locations of detected surface inflows are illustrated on the profile and listed in Table 9.

Table 9 - Tributaries and other surface inflows sampled along the Sycan River with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Ttibutary Temp (C)	Mainstem Temp (C)	Difference
Sprague River	0.01	0.00	23.4	26.0	-2.6
Snake Creek (L)	4.85	3.01	26.4	25.5	0.9
unnamed trib (R)	6.36	3.95	23.6	26.9	-3.3
unnamed trib (R)	7.86	4.89	22.8	25.2	-2.4
very small trib (R)	10.06	6.25	28.2	26.1	2.1
unnamed trib (L)	10.84	6.73	25.4	25.8	-0.4
trib/seep (R)	11.48	7.14	27.1	24.1	3.0
Springs/Seeps	**Kilometer**	**River Mile**	**Spring Temp (C)**	**Mainstem Temp (C)**	**Difference**
small seep (R)	2.94	1.83	23.1	26.5	-3.4
spring (R)	6.12	3.80	23.1	26.2	-3.1
very small spring (L)	11.53	7.16	21.6	23.8	-2.2
cold spot (R)	18.48	11.48	21.9	26.4	-4.5
spring (R)	18.67	11.60	23.1	26.6	-3.5
cold seep (L)	18.80	11.68	23.6	26.4	-2.8
seep (R)	18.91	11.75	23.9	26.4	-2.5
seep (R)	19.21	11.94	23.8	28.3	-4.5
Seep (R)	19.38	12.04	24.6	27.9	-3.3
seep (R)	23.43	14.56	23.1	27.5	-4.4
seep (R)	23.63	14.68	22.7	27.3	-4.6
multiple seep (l/r)	23.72	14.74	23.4	27.0	-3.6
seeps (R)	23.89	14.84	23.6	27.2	-3.6
seep (R)	24.39	15.16	23.7	27.3	-3.6
seep (R)	24.47	15.20	23.2	27.4	-4.2
seep (R)	24.54	15.25	22.1	26.7	-4.6
spring (R)	25.54	15.87	22.6	26.7	-4.1
seep (R)	26.20	16.28	22.1	27.1	-5.0
seep (R)	26.53	16.49	23.1	28.7	-5.6
multiple small seeps (R)	27.62	17.16	23.8	26.3	-2.5
seep shadow (R)	36.66	22.78	23.4	26.3	-2.9
spring (R)	40.62	25.24	16.1	19.4	-3.3
Spring (R)	40.84	25.38	12.8	19.5	-6.7
small spring (L)	41.28	25.65	17.8	22.9	-5.1
spring (R)	41.64	25.88	13.3	22.5	-9.2
spring (R)	41.75	25.94	13.9	22.1	-8.2
head of spring complex (R)	41.80	25.97	18.2	22.1	-3.9
tiny springs (R)	41.85	26.01	17.4	21.5	-4.1
spring (R)	42.20	26.22	14.1	22.0	-7.9
Torrent Spring (R)	42.23	26.24	14.7	21.7	-7.0
spring (R)	43.15	26.81	12.0	16.8	-4.8
spring (R)	43.17	26.82	13.8	20.1	-6.3
spring (R)	43.22	26.86	13.3	22.4	-9.1
resurfacing ( )	43.81	27.22	20.8	23.4	-2.6
spring/upwelling? (L)	44.70	27.77	20.9	23.8	-2.9
spring (L)	55.21	34.31	20.4	27.8	-7.4

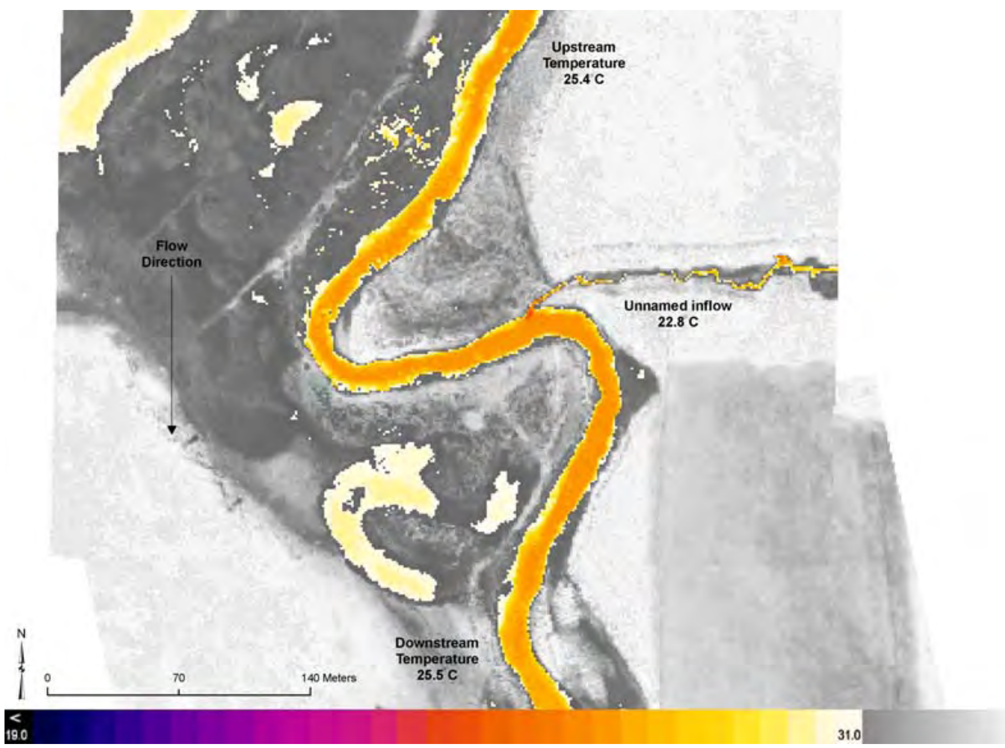
Observations

Approximately 34.5 miles of the Sycan River were surveyed on August 1, 2007 from the mouth at the Sprague River upstream to the Road 27 Crossing. Six tributaries and 36 springs and seeps were sampled in the imagery.

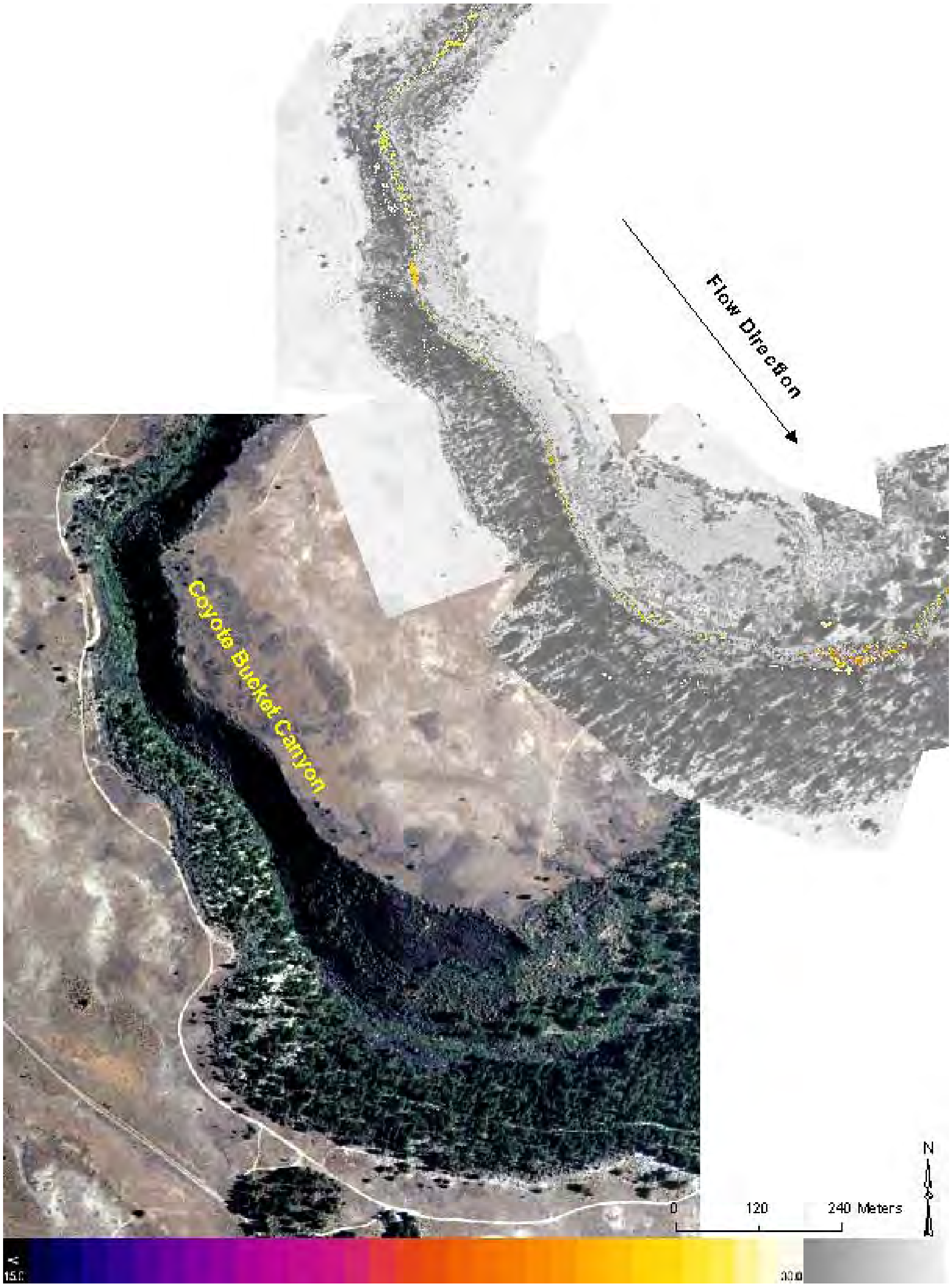
Bulk water temperatures ranged from 16.8°C at the Torrent Spring complex (RM 26.24) to 29.5°C found above the spring complex where flows are low (Sycan River Image 4). The low, slow flows are reflected in the temperature profile as increased variability. Similar variability can be seen along the reach within Coyote Bucket Canyon. Low to no flows at the downstream end of the canyon did not allow for reliable sampling between river miles 9-11 (Sycan River Image 2).

Of the six sampled tributaries, all were located below Coyote Bucket Canyon. None seemed to contribute significant volumes of water to the Sycan, but three of the unnamed tributaries did contribute colder water which may allow for small areas of thermal refugia in the warm summer months (Sycan River Image 1).

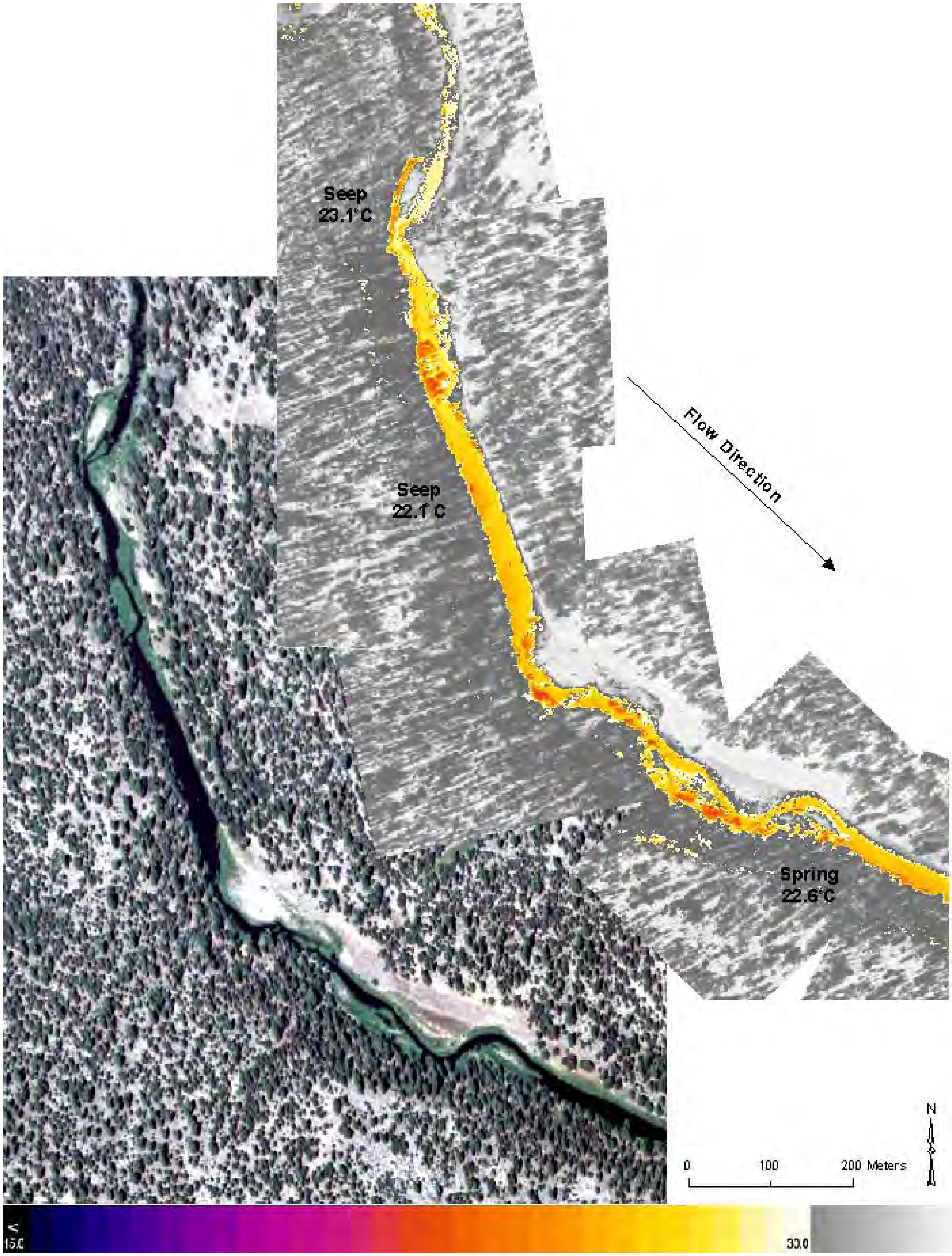
Sample Images



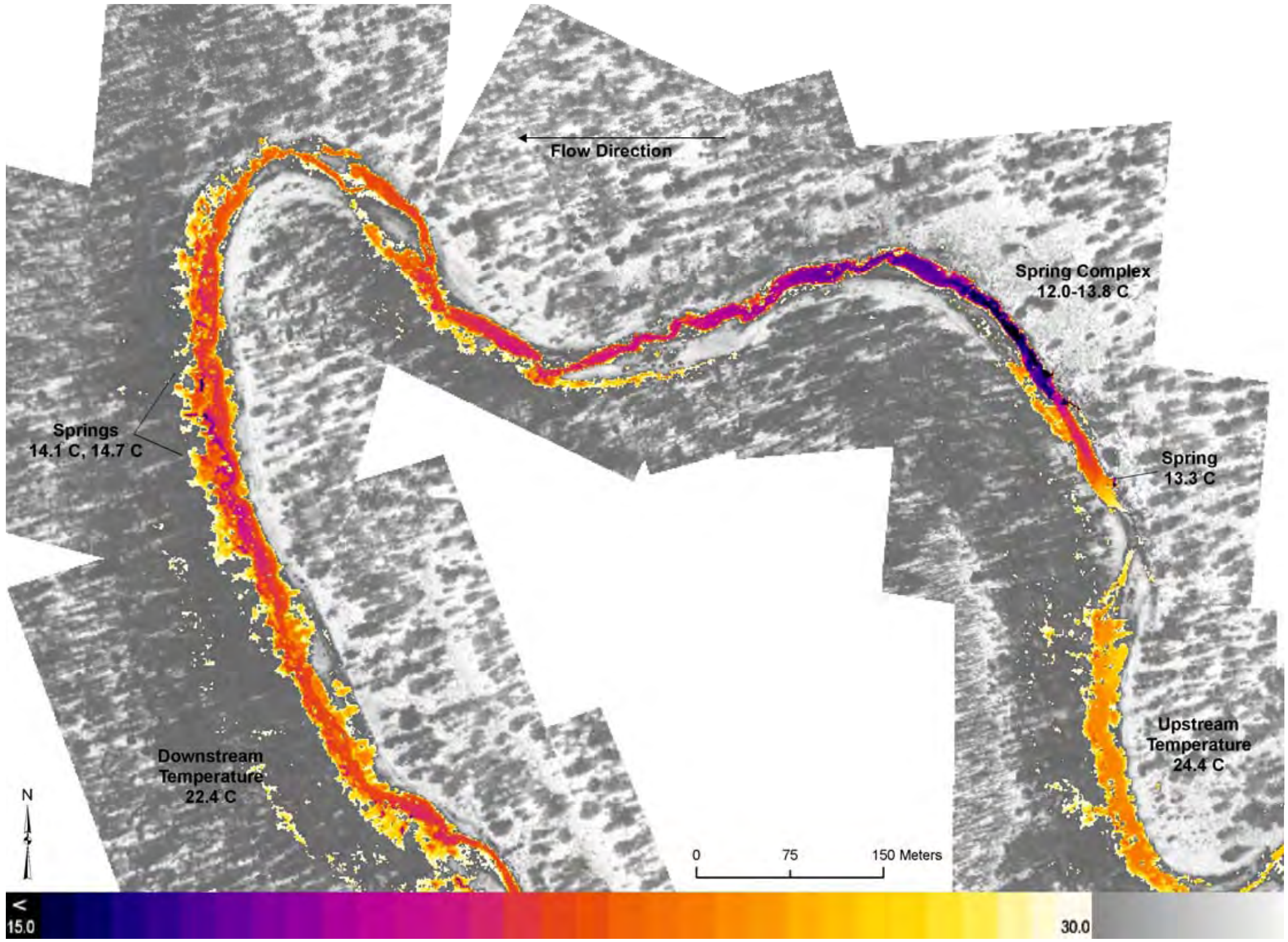
Sycan River Image 1 – The TIR image above illustrates the Sycan River at mile 4.9 showing a small, unnamed inflow along the right bank at river mile 4.9. Three small tributaries contributed cooler water to the Sycan and may represent localized areas of thermal refugia.



Sycan River Image 2 – The TIR/NAIP image pair above illustrates the Sycan River at mile 9.91 at the lower end of Coyote Bucket Canyon. The Sycan exhibited very little surface flow through this reach. Surface water temperatures were sampled intermittently where the surface water was clearly visible.



Sycan River Image 3 – The TIR/NAIP image pair above illustrates a complex of apparent springs/seeps along the right bank of the Sycan River at miles 15.87-16.49. The springs/seeps through this reach were difficult to interpret due to their small size and visible shadows along the right bank. However, the longitudinal temperature profile shows a temperature response in bulk water temperatures at this location.



Sycan River Image 4 – The TIR image above illustrates multiple springs in the Torrent Springs area (RM 26-27). The Sycan River was intermittent with large spatial variations in surface temperatures upstream of the springs.

Meryl Creek

Longitudinal Temperature Profile

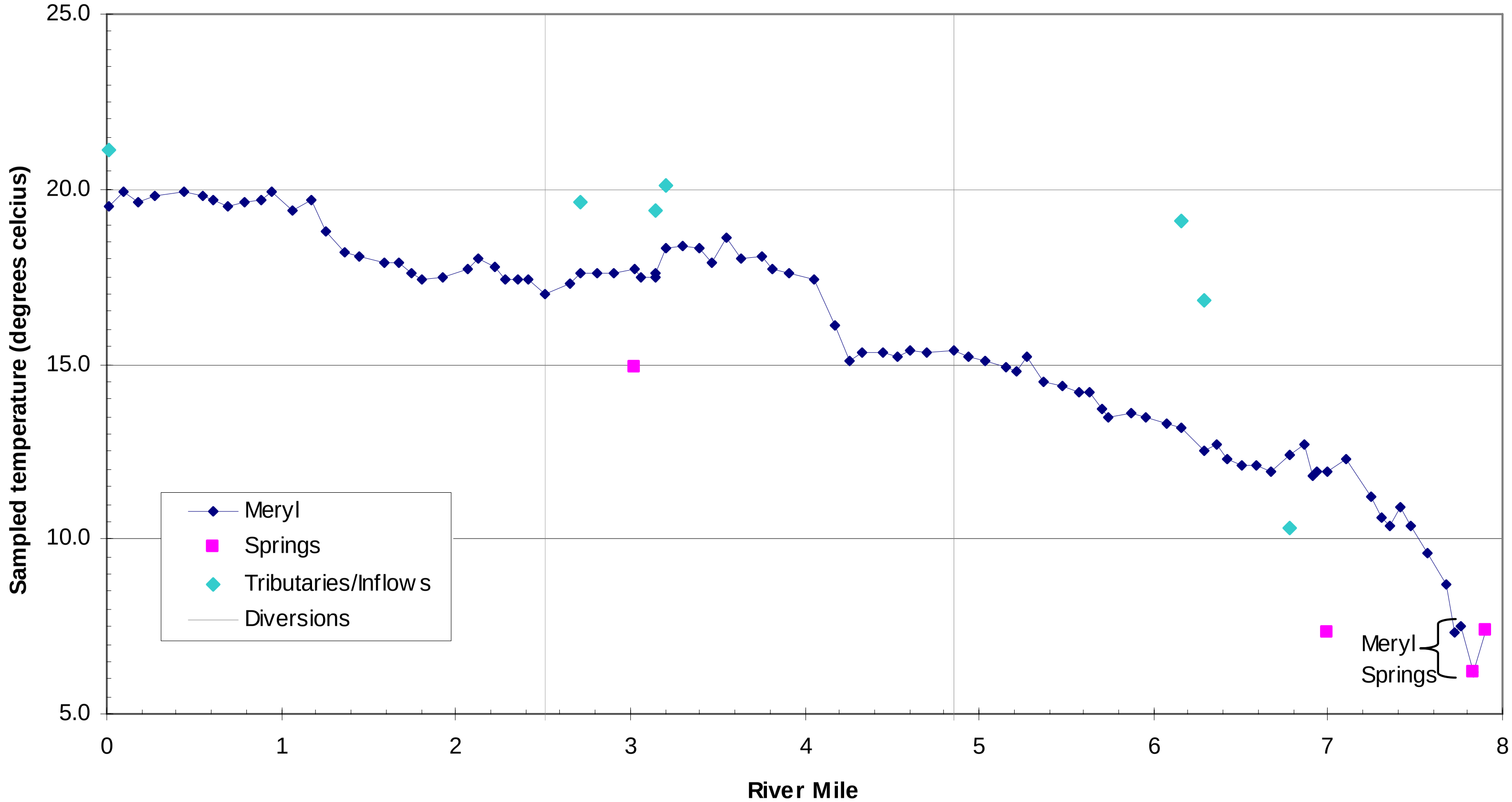


Figure 12 - Median channel temperatures plotted versus river mile for Meryl Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 10.

Table 10 - Tributaries and other surface inflows sampled along Meryl Creek with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Sprague River	0.02	0.01	21.1	19.5	1.6
unnamed (L)	4.37	2.71	19.6	17.6	2.0
Warm seep (R)	5.06	3.14	19.4	17.5	1.9
Long Creek (L)	5.15	3.20	20.1	18.3	1.8
Cain Creek (R)	9.91	6.16	19.1	13.2	5.9
side drainage (L)	10.13	6.29	16.8	12.5	4.3
unnamed drainage (L)	10.92	6.78	10.3	12.4	-2.1
Springs	**Kilometer**	**River Mile**	**Spring Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
spring? (L)	4.87	3.03	14.9	17.7	-2.8
major spring (L)	11.24	6.99	7.3	11.9	-4.6
Meryl Springs	12.60	7.83	6.2		0
Meryl Springs	12.73	7.91	7.4		0
Diversions	**Kilometer**	**River Mile**	**Diversion Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
Headgate	4.03	2.51	25.0	17.0	8.0
Diversion (L)	7.81	4.86	15.4	15.4	0

Observations

Approximately eight miles of Meryl Creek were surveyed from the mouth at the North Fork Sprague River upstream to Meryl Springs. The temperature profile shows a general warming trend from the headwaters to the mouth. Temperatures ranged from a low of 6.2°C at Meryl Springs to a high of 19.9°C near the mouth.

Six tributaries were sampled; five contributed warmer waters to the stream, while one unnamed drainage (RM 6.78) contributed cooler water.

Fivemile Creek

Longitudinal Temperature Profile

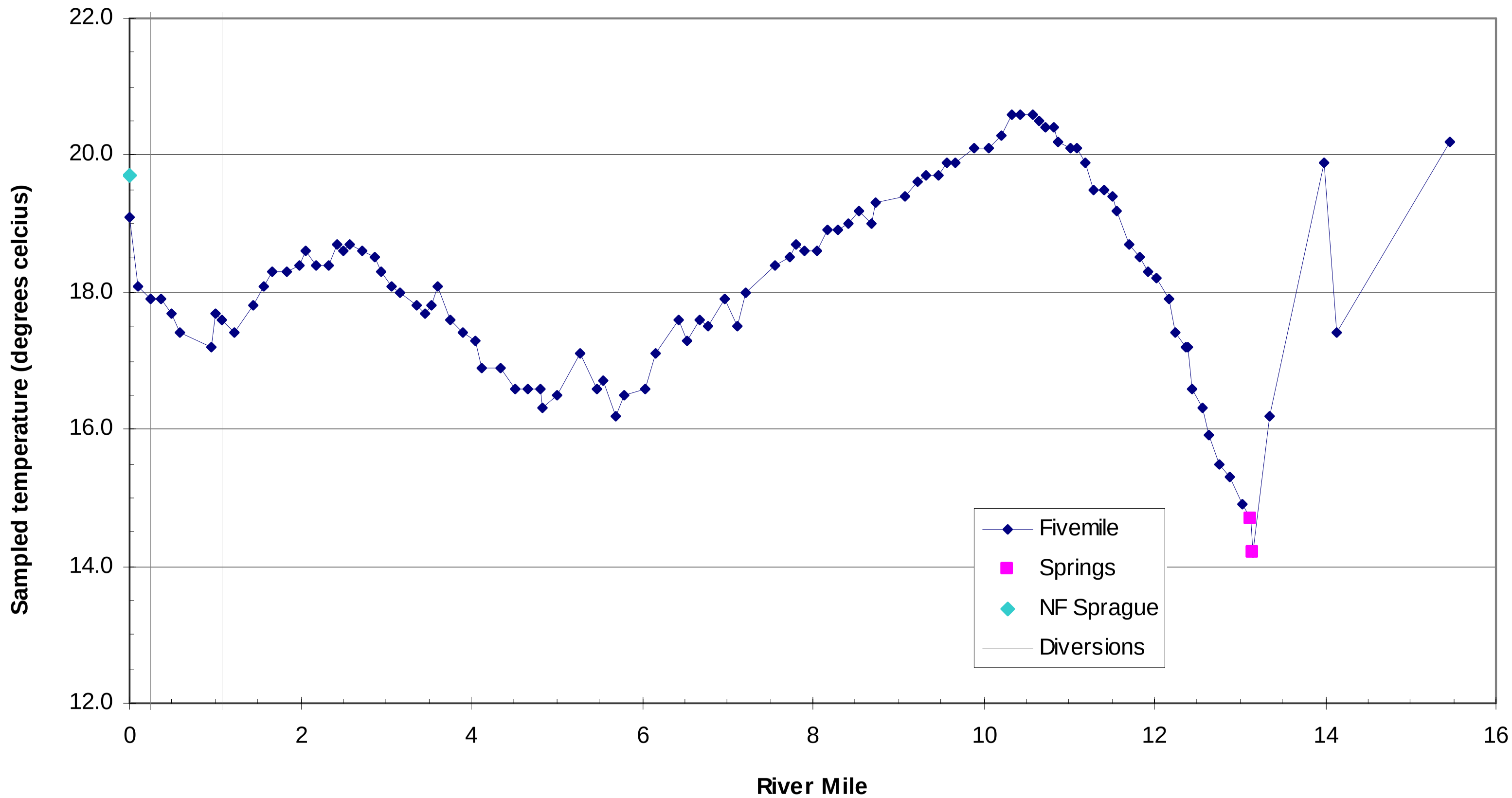


Figure 13 - Median channel temperatures plotted versus river mile for Fivemile Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 11.

Table 11 - Tributaries and other surface inflows sampled along Fivemile Creek with left or right bank designation (looking downstream).

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
NF Sprague	0.00	0.00	19.7	19.1	0.6
Springs	**Kilometer**	**River Mile**	**Spring Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
spring (R)	21.12	13.12	14.7	14.7	0.0
spring ( )	21.16	13.15	14.2	14.6	-0.4
Diversions	**Kilometer**	**River Mile**	**Diversion Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
Elder Ditch Diversion (R)	0.40	0.25	18.1	17.9	0.2
Elder Ditch Diversion #2 (R)	1.75	1.09	18.4	17.6	0.8

Observations

Approximately sixteen miles of Fivemile Creek were surveyed from the mouth at the North Fork Sprague River. Above the major spring complex at river mile 13.15, little to no water was visible for reliable sampling.

Temperatures ranged from a low of 14.6°C at the spring complex to a high of 20.6°C near river mile 10.58. At this point, the stream enters a narrower canyon and becomes more channelized. The increased variability between river miles 4-6 is likely due to a narrower channel, resulting in a less reliable sample.

Below river mile 4.53, the creek exits the canyon and warms by 2°C as it flows through agricultural lands on its final run to the North Fork Sprague.

Figure 14 – Five Mile Creek was mostly dry upstream of river mile 13.15. The image to the right was taken during the week of the TIR survey and shows a dry channel at the crossing of Forest Road 27.

Brownsworth Creek

Longitudinal Temperature Profile

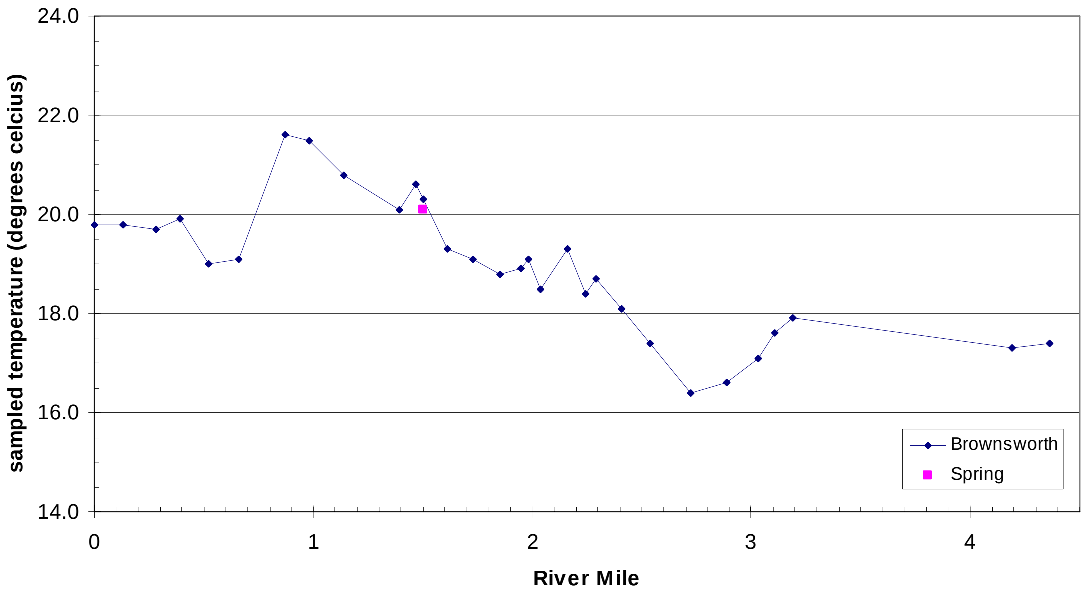


Figure 15 - Median channel temperatures plotted versus river mile for Brownsworth Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 12.

Table 12 - Tributaries and other surface inflows sampled along Brownsworth Creek with left or right bank designation (looking downstream).

Springs	Kilometer	River Mile	Spring Temp (°C)	Mainstem Temp (°C)	Difference
spring on hillslope (R)	2.41	1.50	20.1	20.3	-0.2

Observations

Approximately 4.5 miles of Brownsworth Creek were surveyed from the mouth at the South Fork Sprague River upstream to the Road 34 crossing. Due to the small size of the creek and very low water volume, caution must be used in interpreting the temperature profile. The overall trend shows warming as the stream flows downstream, and one small seep was seen on the hillside at river mile 1.50.

Whitworth Creek

Longitudinal Temperature Profile

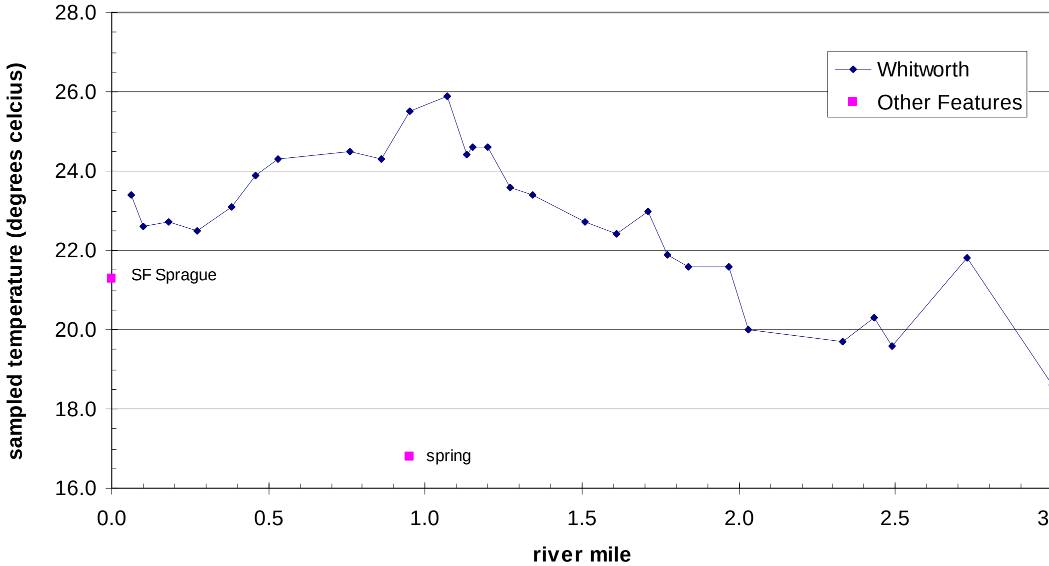


Figure 16 - Median channel temperatures plotted versus river mile for Whitworth Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 13.

Table 13 - Tributaries and other surface inflows sampled along Whitworth Creek with left or right bank designation (looking downstream).

Features	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
SF Sprague	0.09	0.00	21.3	23.4	-2.1
spring or shadow (L)	1.52	0.95	16.8	25.5	-8.7

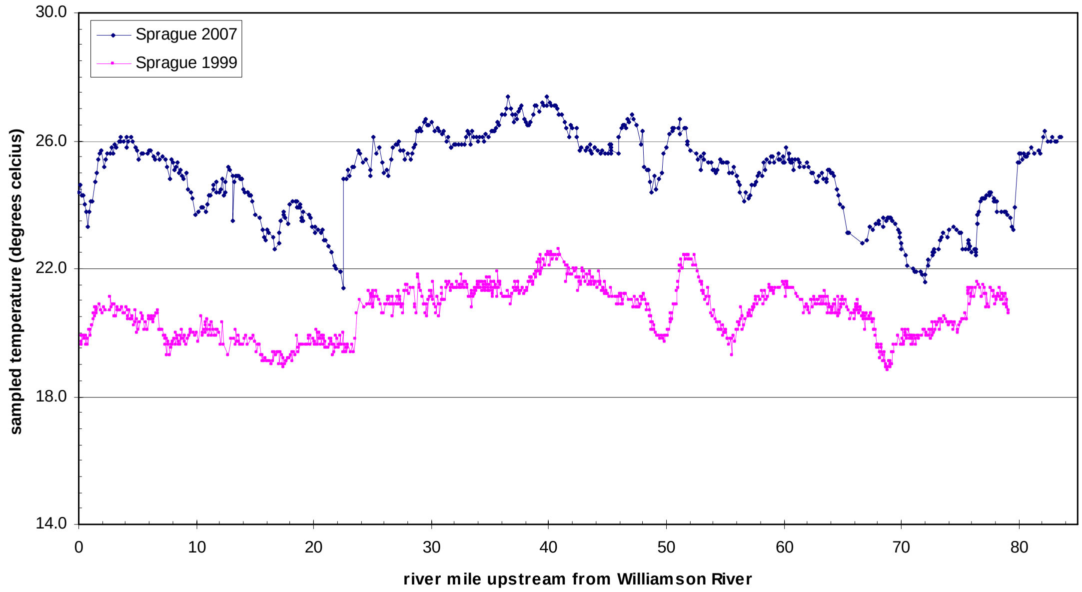
Observations

Approximately 3 miles of Whitworth Creek were surveyed upstream from the mouth at the South Fork Sprague River. Due to the small size of the creek and very low water volume, caution must be used in interpreting the temperature profile. The overall trend shows warming as the stream flows downstream, and one small spring was seen at river mile 0.95.

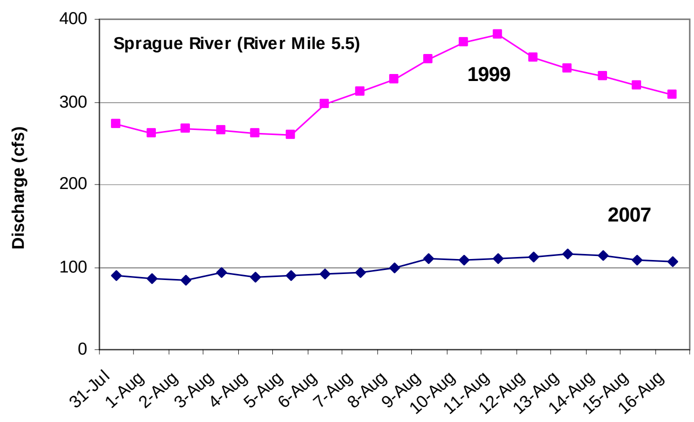
Profile Comparison (1999/2007)

An airborne TIR survey was conducted on many of the same stream reaches during the summer of 1999. The 1999 TIR survey was conducted within a few days of a large rain event and flows were uncharacteristically high. This section compares the longitudinal temperature profiles derived from the 1999 data and those generated from this study. The flow conditions from the USGS gauges on the Sprague River and North Fork Sprague River are included for each data set to provide additional context.

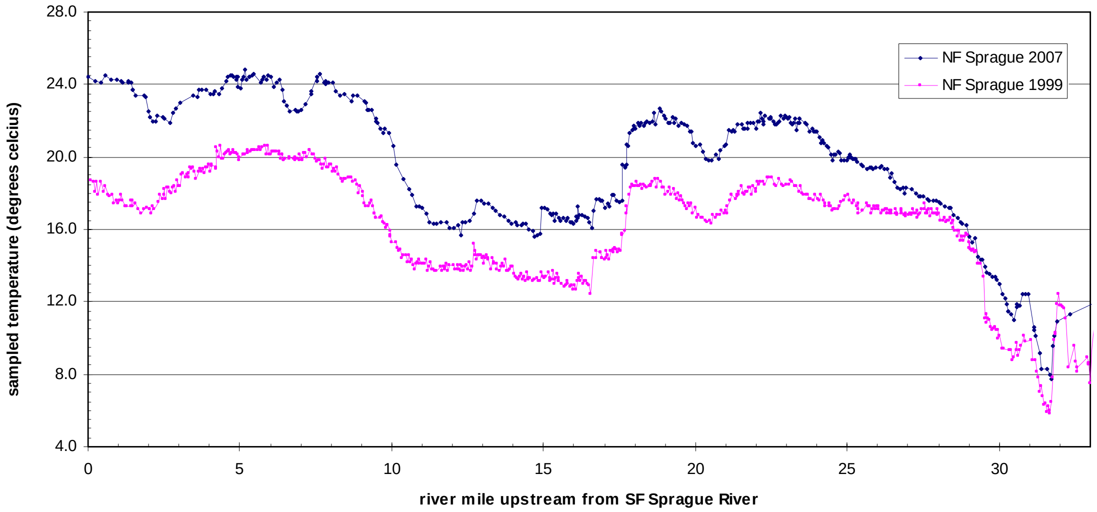
Sprague



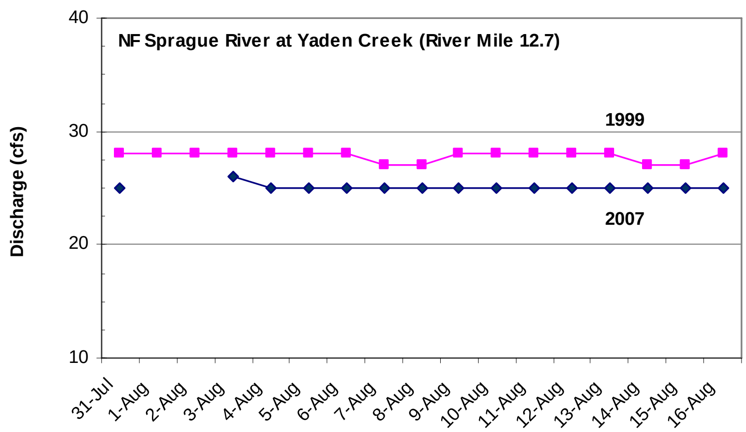
Date	Sprague River (Mile 5.5) Average Daily Discharge (cfs) 1999	2007
31-Jul	272	90
1-Aug	262	86
2-Aug	267	85
3-Aug	265	93
4-Aug	262	88
5-Aug	259	89
6-Aug	297	92
7-Aug	313	93
8-Aug	327	99
9-Aug	351	110
10-Aug	372	108
11-Aug	381	111
12-Aug	353	113
13-Aug	341	115
14-Aug	331	114
15-Aug	320	109
16-Aug	309	107



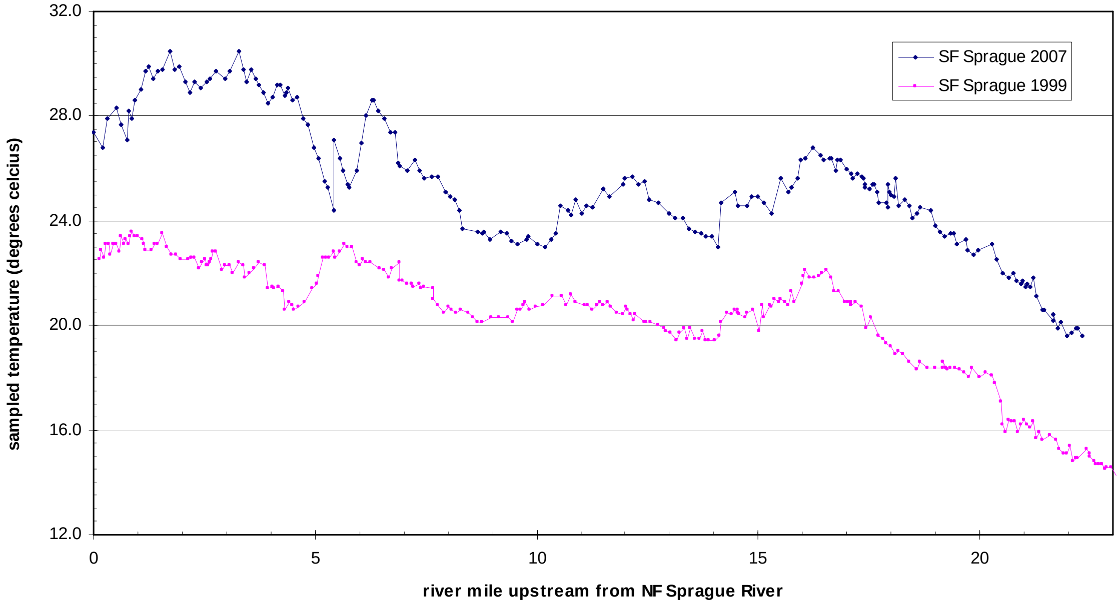
NF Sprague



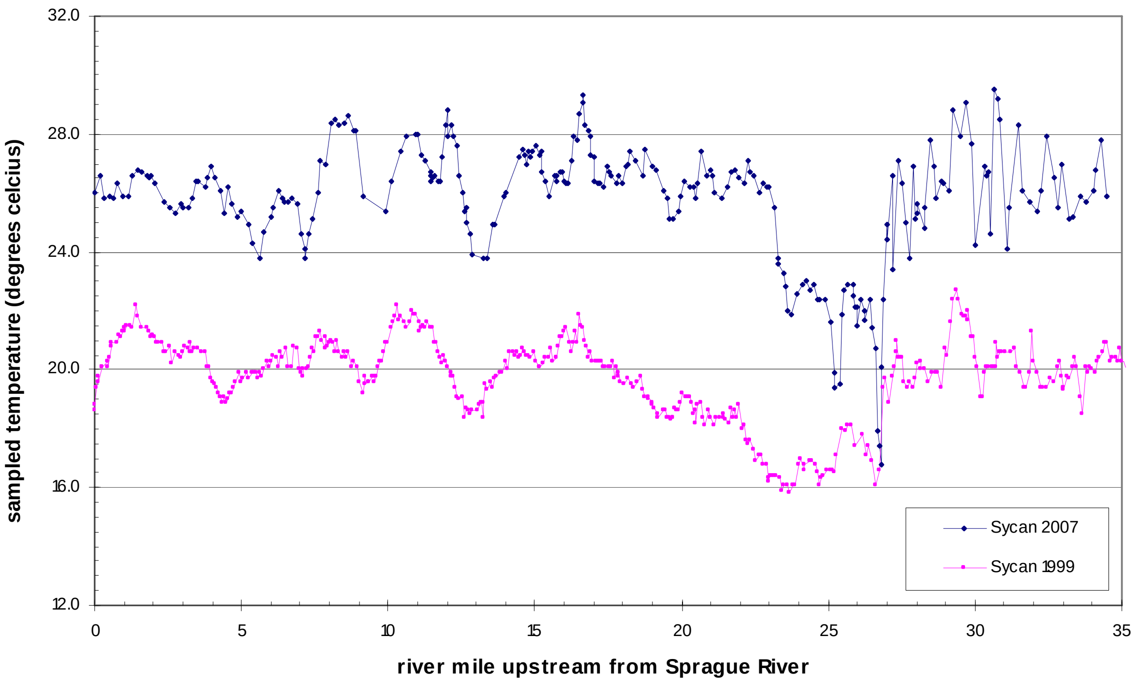
Date	NFSprague @ Yaden Creek Average Daily Discharge (cfs)	
	1999	2007
31-Jul	28	25
1-Aug	28	n/a
2-Aug	28	n/a
3-Aug	28	26
4-Aug	28	25
5-Aug	28	25
6-Aug	28	25
7-Aug	27	25
8-Aug	27	25
9-Aug	28	25
10-Aug	28	25
11-Aug	28	25
12-Aug	28	25
13-Aug	28	25
14-Aug	27	25
15-Aug	27	25
16-Aug	28	25



South Fork Sprague



Sycan River



Deliverables

The TIR imagery is provided in two forms: 1) individual un-rectified frames and 2) a continuous geo-rectified mosaic at 1.2 m resolution. The mosaic allows for easy viewing of the continuum of temperatures along the stream gradient, but also shows edge match differences and geometric transformation effects. The un-rectified frames are useful for viewing images at their native resolutions (~0.5-0.8 m) and are often better for detecting smaller thermal features. A GIS point layer is included which provides an index of image locations, the results of temperature sampling, and interpretations made during the analysis.

Deliverables are provided on DVD:

Geo-Corrected Images are stored as: **UTM Zone 10, NAD83, Units = Meters.**

1. <u>Thermal_Mosaics</u> - Continuous image mosaic of the geo-rectified TIR image frames at 1.2 meter resolution in ESRI Grid Format. GRID cell value = radiant temperature * 10.

2. Unrectified_Images
    a. <u>Thermal_Unrectified</u> - Calibrated TIR images in Erdas Imagine *img format. Cell value = radiant temperature * 10. Radiant temperatures are calibrated for the emissive characteristics of water and may not be accurate for terrestrial features. These images retain the native resolution of the sensor. GCP files are included for rectification purposes.

3. <u>Thermal_Surveys</u> - Point layers showing image locations, sampled temperatures, and image interpretations.

4. <u>Longprofiles</u> - Excel spreadsheet containing the longitudinal temperature profiles.

5. <u>Hydrography</u> – Relevant hydrography shapefiles

6. <u>Report</u> – A copy of this report