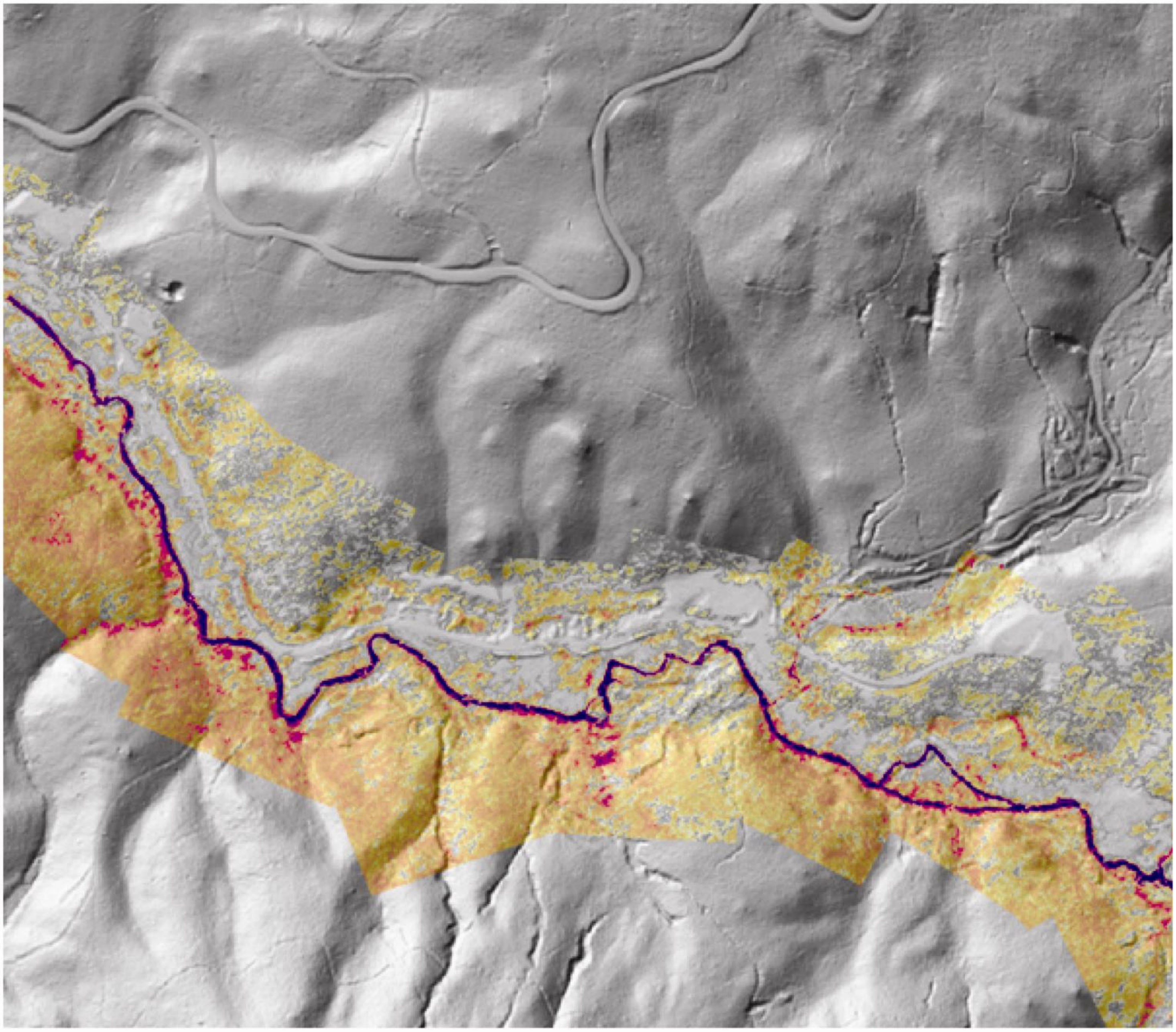
AIRBORNE THERMAL INFRARED REMOTE SENSING

UPPER GRANDE RONDE RIVER BASIN • OREGON

(SURVEY DATE - 8/7-12/2010 • REPORT DATE - 12/13/2010)



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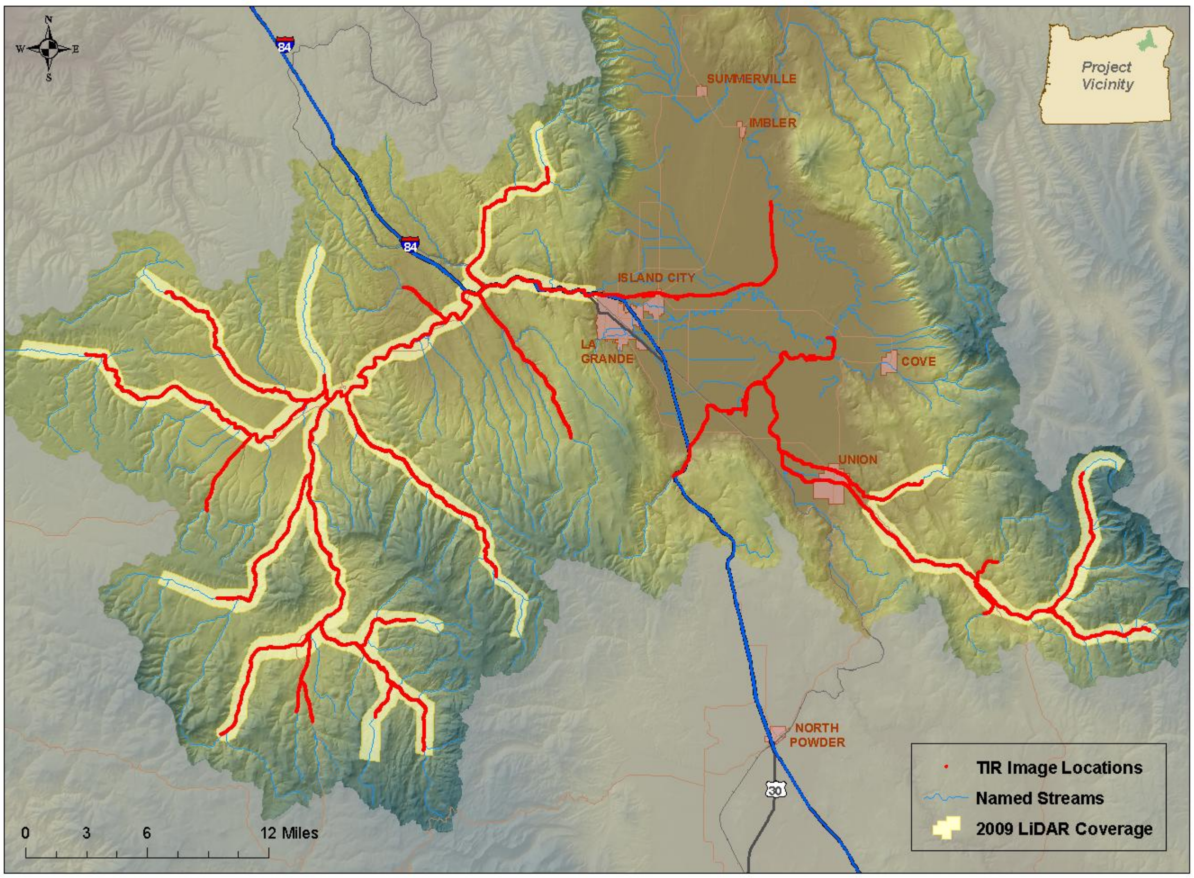
UPPER GRANDE RONDE RIVER AND TRIBUTARIES

CATHERINE CREEK AND TRIBUTARIES

1. Overview

In 2010, the Columbia River Inter-Tribal Fish Commission contracted with Watershed Sciences, Inc. to provide thermal infrared (TIR) imagery for approximately 226 river miles in the Upper Grande Ronde River Basin, Oregon, including 60 miles of the Grande Ronde River and 31 miles of Catherine Creek. The thermal imagery acquisition was an extension of the Upper Grande Ronde LiDAR project flown in September 2009[1] and a pre-cursor to the stream temperature modeling effort which will occur in 2011 (*Figure 1)*. The extents of the 22 stream segments covered in the project area are listed by survey date in Table 1.

Figure 1. A TIR survey in the Upper Grande Ronde River Basin was conducted August 7-12, 2010.



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, TIR data also illustrates reach-scale thermal responses to changes in morphology, vegetation, and land-use.

[1] Reference Report: “LiDAR Data Collection Phase, Grande Ronde River Basin.” December 23, 2009. Prepared by Watershed Sciences, Inc. for the Columbia River Inter-Tribal Fish Commission.

The specific objectives of the TIR image acquisition were:

- Spatially characterize surface temperatures and stream flow conditions for 226 miles of stream in the Upper Grande Ronde River basin (*Figure 1*).
- Develop a longitudinal temperature profile which illustrates basin scale stream temperature patterns.
- Identify and map cool water sources and thermal refugia along current and potential Spring Chinook spawning reaches.
- 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.

Table 1. Stream segments obtained with TIR in the Upper Grande Ronde River Basin.

Stream Name	Miles Flown	Location
August 7, 2010		
Beaver Creek	13.5	Mouth to La Grande Reservoir
Dark Canyon	0.7	Mouth to Unnamed Tributary
Five Points Creek	9.5	Mouth to Fiddlers Hell Creek
McCoy Creek	11.4	Mouth to the Rock Spring drainage
Spring Creek	2.9	Mouth to South Fork Spring Creek
Rock Creek	9.1	Mouth to unnamed bridge
August 8, 2010		
Burnt Corral Creek	4.5	Mouth to East Burnt Corral Creek
Chicken Creek	4.5	Mouth upstream 4.5 river miles
Clear Creek	2.0	Mouth upstream 2.0 river miles
Fly Creek	9.6	Mouth to Fly Valley
Meadow Creek	18.2	Mouth to Waucup Creek
Sheep Creek	9.1	Mouth to East Fork Sheep Creek
West Chicken Creek	1.6	Mouth to Unnamed Tributary
August 9, 2010		
Grande Ronde River	58.3	State Ditch to Tanner Gulch
Limber Jim Creek	3.9	Mouth to Deadwood Gulch
August 10, 2010		
Ladd Creek	9.2	Mouth to Ladd Canyon Pond Creek
Little Creek	8.7	Mouth to Bates Lane
Little Catherine Creek	1.9	Mouth upstream 1.9 river miles
Milk Creek	2.2	Mouth upstream 2.2 river miles
August 12, 2010		
Catherine Creek	31.3	Mouth the North/South Fork confluence
North Fork Catherine Creek	8.0	Mouth to Catherine Creek Meadow
South Fork Catherine Creek	6.0	Mouth to Collins Creek
TOTAL MILES:	**226.1**	

2. Acquisition

2.1 Airborne Survey - 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.

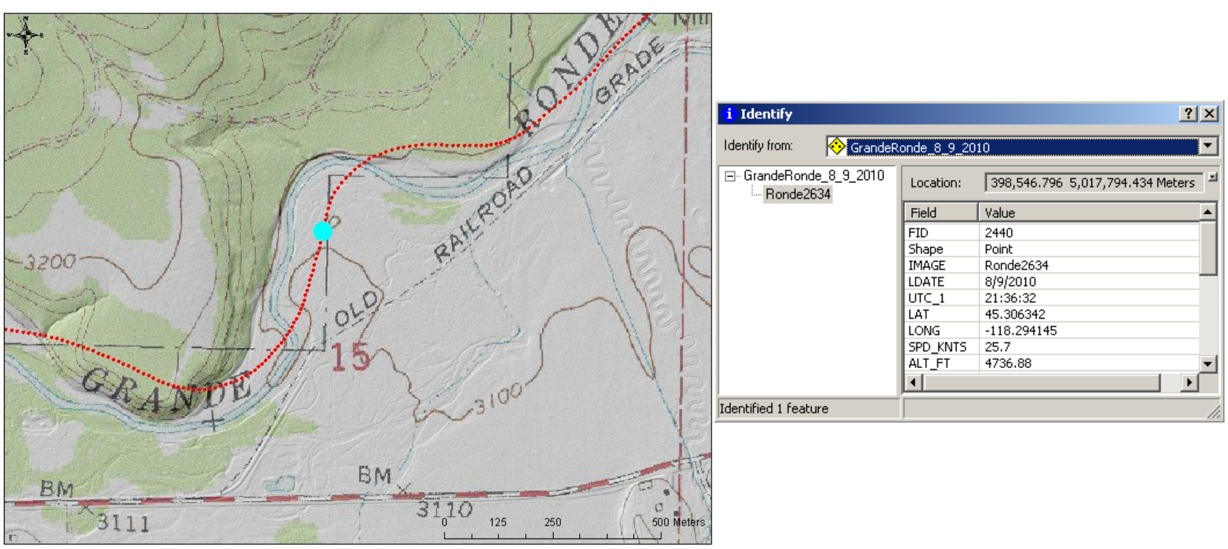
Figure 2. Bell Jet Ranger equipped with a thermal infrared radiometer and high resolution digital camera. The sensors are contained in a composite fiber enclosure attached to the underside of the helicopter which is flown longitudinally along the stream channel.

Table 2. Summary of TIR sensor specifications

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

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*).

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.



2.2 Image Collection

The aircraft was flown longitudinally along the stream corridor in order to have the stream 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 second resulting in 40-70% vertical overlap between images.

Flight altitudes were selected in order to optimize resolution while providing an image ground footprint wide enough to capture the active channel. Catherine Creek had a planned flight altitude of 1800 ft (549 m) resulting in a ground sample distance of 0.6 m (1.97.0 ft). A planned flight altitude of 1500 ft (457 m) was selected for the Grande Ronde River and the North and South Forks of Catherine Creek which resulted in a native pixel ground sample distance of 0.5 m (1.64 ft). All other streams had planned flight altitudes of 1300 ft (396 m) which would result in ground sample distances of 0.4 m (1.31 ft). However, due to terrain variations, wind conditions, and stream size, altitudes can vary throughout the flight duration. Little Catherine Creek and Milk Creek were flown lower than planned due to their small size. They were flown at ~1000 ft (305 m) elevation resulting in a ground pixel distance of 0.3 m (0.98 ft). Table 3 summarizes the flight acquisition parameters.

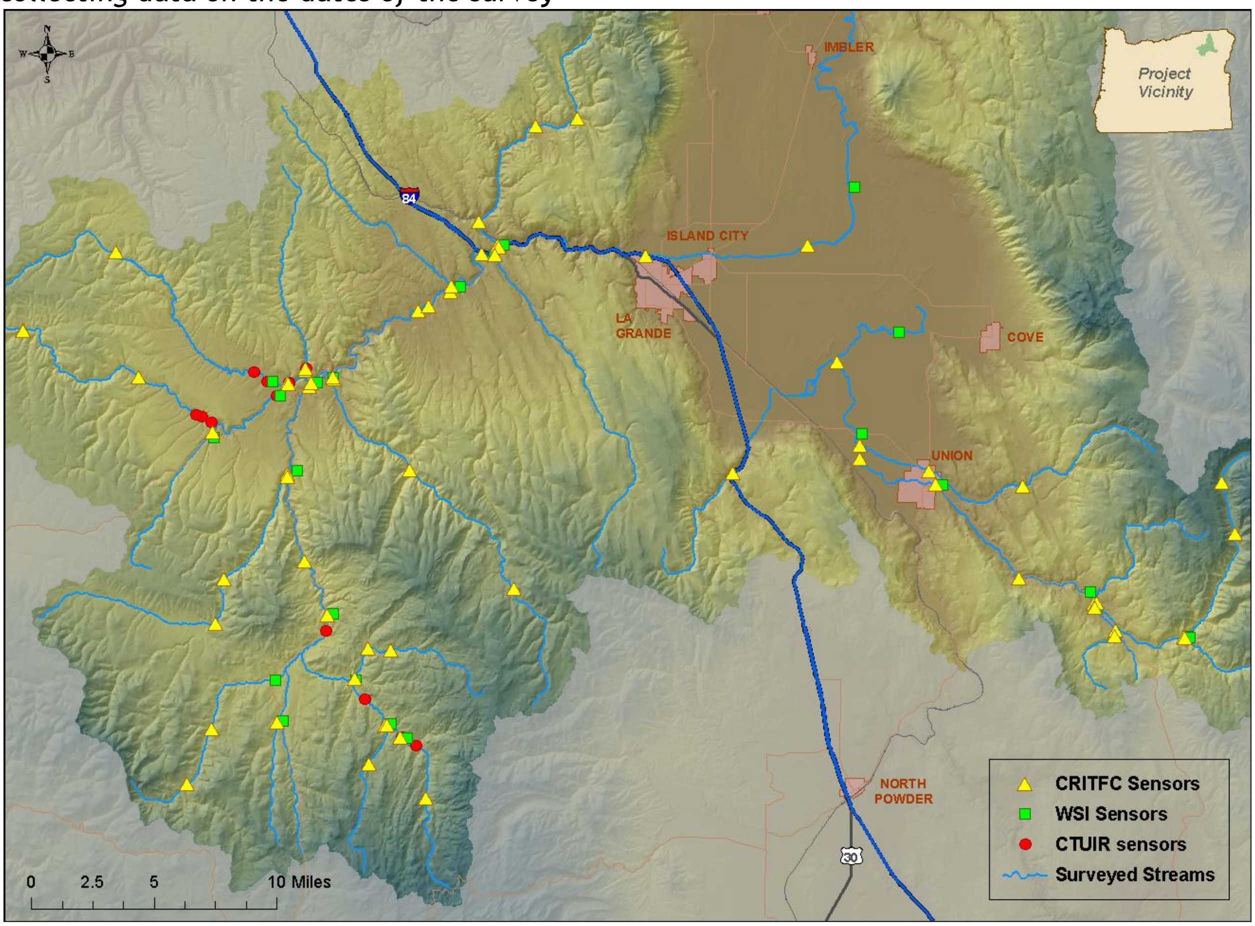
Table 3. Summary of Thermal Image Acquisition Parameters

Catherine Creek	
Flight Above Ground Level (AGL):	1800 ft (549 m)
Image Footprint Width:	1164 ft (355 m)
Pixel Resolution:	1.97 ft (0.60 m)
Grande Ronde River, North and South Fork Catherine Creek	
Flight Above Ground Level (AGL):	1500 ft (457 m)
Image Footprint Width:	969 ft (296 m)
Pixel Resolution:	1.64 ft (0.50 m)
Beaver, Burnt Corral, Chicken, Clear, Dark Canyon, Five Points, Fly, Ladd, Limber Jim, Little, McCoy, Meadow, Rock, Sheep, Spring, West Chicken	
Flight Above Ground Level (AGL):	1300 ft (396 m)
Image Footprint Width:	774 ft (236 m)
Pixel Resolution:	1.31 ft (0.40 m)
Little Catherine Creek and Milk Creek	
Flight Above Ground Level (AGL):	1000 ft (305 m)
Image Footprint Width:	581 ft (177 m)
Pixel Resolution:	0.98 ft (0.30 m)

2.3 Ground Control

Watershed Sciences, Inc. deployed 23 in-stream sensors (Hobo Pros) during the time frame of the flight for calibrating and verifying the thermal accuracy of the TIR imagery. The Hobo Pro data loggers were set to record temperatures at 10-minute intervals and suspended in the water column in areas with good vertical mixing. CRITFC provided data for 64 sensors active during the survey, collecting water temperatures at 30 minute intervals. Confederated Tribes of the Umatilla Indian Reservation (CTUIR) provided data for 14 sensors in the study area. The sensors collected data every hour. All data logger locations are illustrated in Figure 4.

Figure 4. Location of sensors deployed by Watershed Sciences, CRITFC, and CTUIR actively collecting data on the dates of the survey



2.4 Weather and Flow Conditions

Weather conditions on the date of the survey were fair with warm temperatures, low humidity and mostly clear skies. Table 4 summarizes the weather conditions observed at the La Grande Airport (KLGD) on the dates of the survey[2]. No data was collected on August 11, 2010 due to low clouds and cool temperatures. 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.

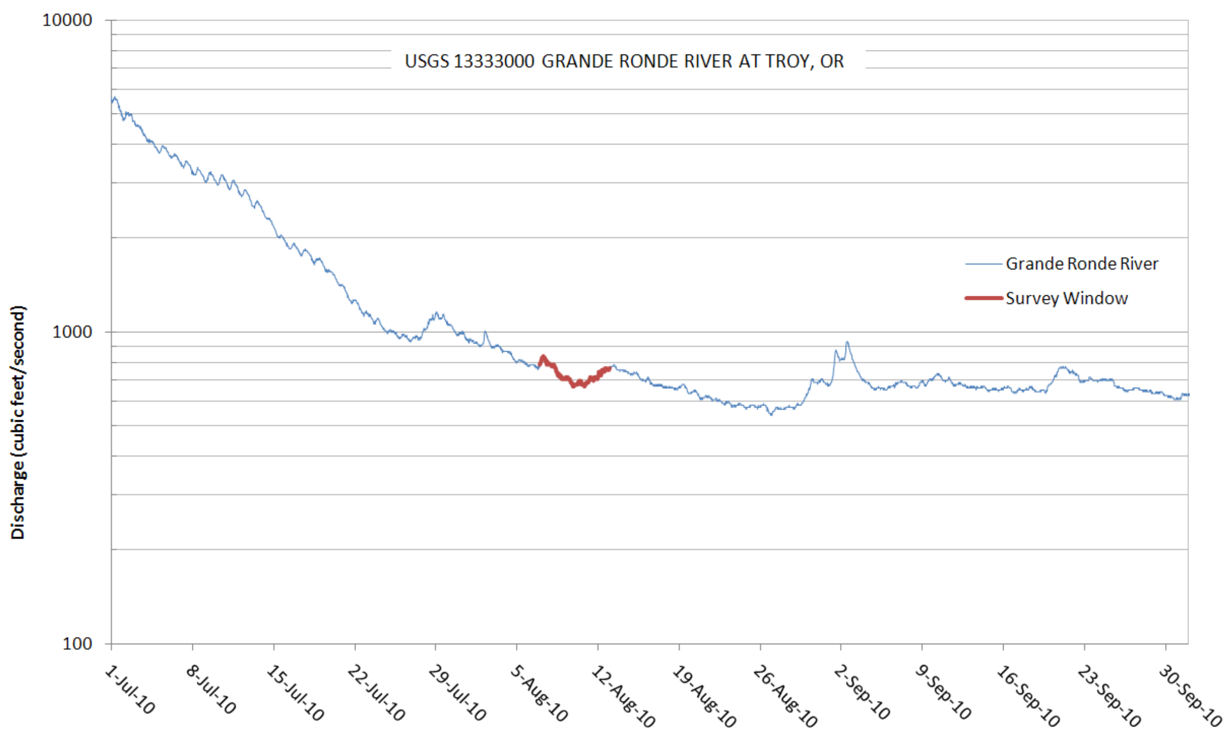
Table 4. Weather conditions measured at the Stanley Airport on August 6, 2010.

Time (PDT)	Temperature (°F)	% Humidity	Wind Direction	Wind Speed (MPH)	Conditions
August 7, 2010 (Beaver, Five Points, McCoy, Rock, Spring)					
11:55 AM	80.6	28	WSW	8.1	Clear
12:55 PM	84.2	23	NW	15	Clear
1:55 PM	86	22	North	9.2	Clear
2:55 PM	84.2	25	NW	15	Clear
3:55 PM	84.2	25	NNW	17.3	Clear
4:55 PM	84.2	25	NW	11.5	Clear
August 8, 2010 (Burnt Corral, Chicken, Clear, Dark Canyon, Fly, Meadow, Sheep, W. Chicken)					
11:55 AM	75.2	36	NE	3.5	Clear
12:55 PM	78.8	32	Calm	Calm	Clear
1:55 PM	82.4	30	NNW	6.9	Partly Cloudy
2:55 PM	82.4	28	NW	9.2	Scattered Clouds
3:55 PM	82.4	30	NE	8.1	Overcast
4:55 PM	84.2	29	NNE	9.2	Overcast
August 9, 2010 (Upper Grande Ronde, Limber Jim)					
11:55 AM	77	32	Calm	Calm	Clear
12:55 PM	80.6	26	South	6.9	Clear
1:55 PM	82.4	26	Calm	Calm	Scattered Clouds
2:55 PM	84.2	23	NW	18.4	Mostly Cloudy
3:55 PM	84.2	23	NNW	9.2	Partly Cloudy
4:55 PM	82.4	23	North	8.1	Scattered Clouds
August 10, 2010 (Ladd, Little, Little Catherine, Milk)					
11:55 AM	73.4	31	NNW	9.2	Clear
12:55 PM	75.2	27	NE	3.5	Clear
1:55 PM	78.8	26	ENE	8.1	Mostly Cloudy
2:55 PM	78.8	26	North	4.6	Mostly Cloudy
3:55 PM	78.8	26	NW	5.8	Partly Cloudy
4:55 PM	75.2	31	NW	11.5	Clear
August 12, 2010 (Catherine, North and South Forks Catherine)					
11:55 AM	68	60	Calm	Calm	Clear
12:55 PM	75.2	44	NE	3.5	Clear
1:55 PM	78.8	32	East	6.9	Clear
2:55 PM	80.6	26	East	4.6	Clear
3:55 PM	82.4	26	East	6.9	Clear
4:55 PM	80.6	28	Calm	Calm	Partly Cloudy

[2] Source: http://www.wunderground.com

No active USGS flow gages were found for the Upper Grande Ronde River or the tributaries in the survey area; however, one active USGS gage was found 35 miles downstream of the survey on the Lower Grande Ronde River at Troy, OR[3]. The gage shows flows were near the lowest point for the summer; however, it is unclear how the gage at this location translates to the upstream reaches of the river (*Figure 5*). Local flow data from the streams of interest will be needed to further assess the discharge rates.

Figure 5. Discharge measured along the Salmon River at the time of the survey



[3] Source: USGS NWIS Site Information for USA: http://waterdata.usgs.gov/nwis/inventory?

3. Thermal Image Characteristics

3.1 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. Stratification can usually be easily detected in the imagery.

3.2 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%). In general, apparent stream temperature changes of < 0.5°C are not considered significant unless associated with a surface inflow (e.g. tributary). However, certain conditions may cause variations in the accuracy of the imagery.

3.2.1 Surface Conditions

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°C (Torgersen et al. 2001[4]). The occurrence of reflections as an artifact (or noise) in the TIR images is a consideration during image interpretation and analysis.

3.2.2 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.

3.2.3 Feature Size and Resolution

A small stream width logically translates to fewer pure stream pixels 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 variability and inaccuracies in the measured radiant temperatures as more 'mixed pixels' are sampled. This is a consideration especially when sampling the radiant temperatures at tributary mouths and surface springs.

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[4] 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.

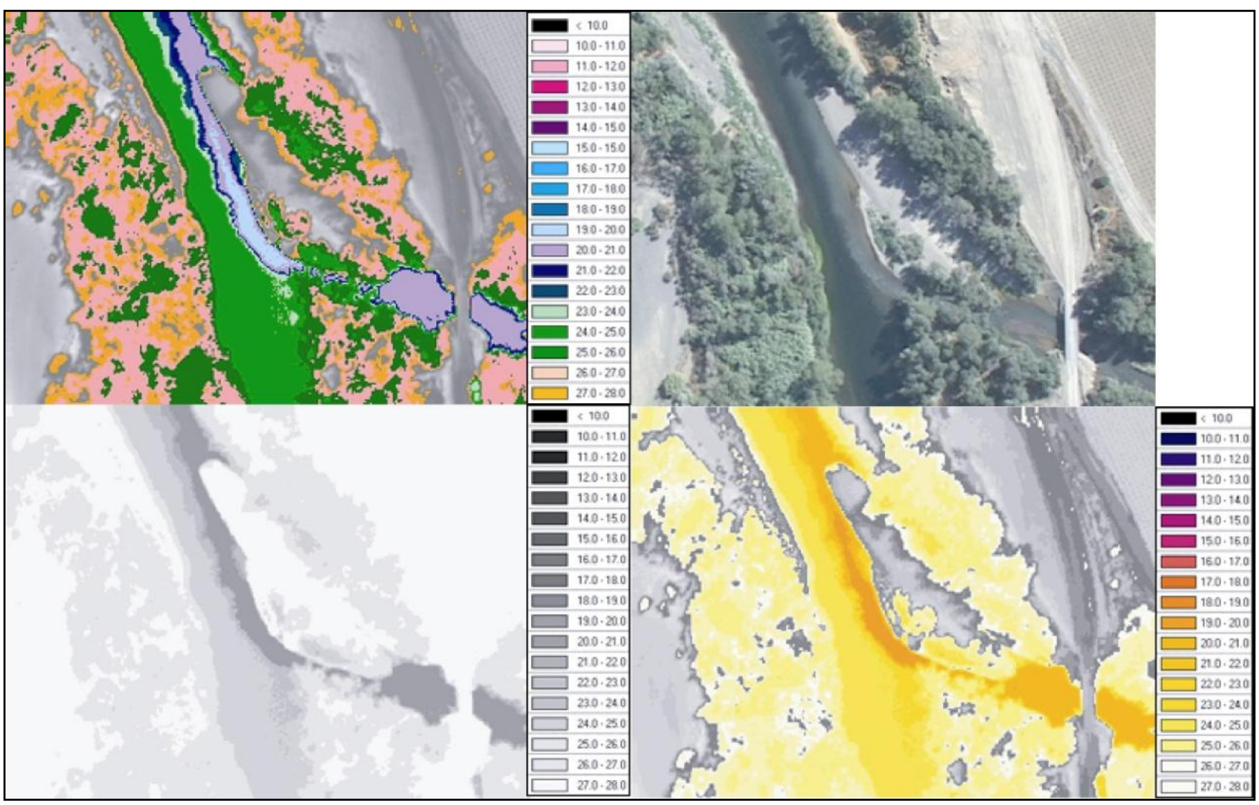
3.3 Image Uniformity

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 edges of the image frame. During the flight, every effort is made to keep the stream in the center of the image frame. The uniformity differences within frames and slight differences from frame-to-frame are often most apparent in the continuous mosaics.

3.4 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 (*Figure 6*).

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



4. Data Processing

4.1 Sensor Calibration

Prior to the season, the response characteristics of the TIR sensor are measured in a laboratory environment. The response curves relate the raw digital numbers recorded by the sensor to emitted radiance from a 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 are adjusted based on the kinetic temperatures recorded at each ground truth location. This adjustment is performed to correct for path length attenuation and the emissivity of natural water. The in-stream data are assessed at the time the image is acquired, with radiant values representing the median of ten points sampled from the image at the data logger location.

4.2 Geo-referencing

During the survey, the images are tagged with a GPS position and heading at the time they are acquired. 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. However, 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 of the sensor and the time of capture.

4.3 Geo-rectification

Individual TIR frames are manually geo-rectified by finding a minimum of six common ground control points (GCPs) between the image frames and imagery available for the area. The images are then warped using a 1st order polynomial transformation. The 2009 1-meter NAIP imagery was used as a base for the rectification for the Grande Ronde.

4.4 Interpretation and Sampling

Once calibrated, the images are integrated into a GIS in which an analyst interprets and samples stream temperatures. Sampling consists 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 (e.g. surface springs, tributaries) are also sampled at their mouths. During sampling, the analyst provides interpretations of the spatial variations in surface temperatures observed in the images.

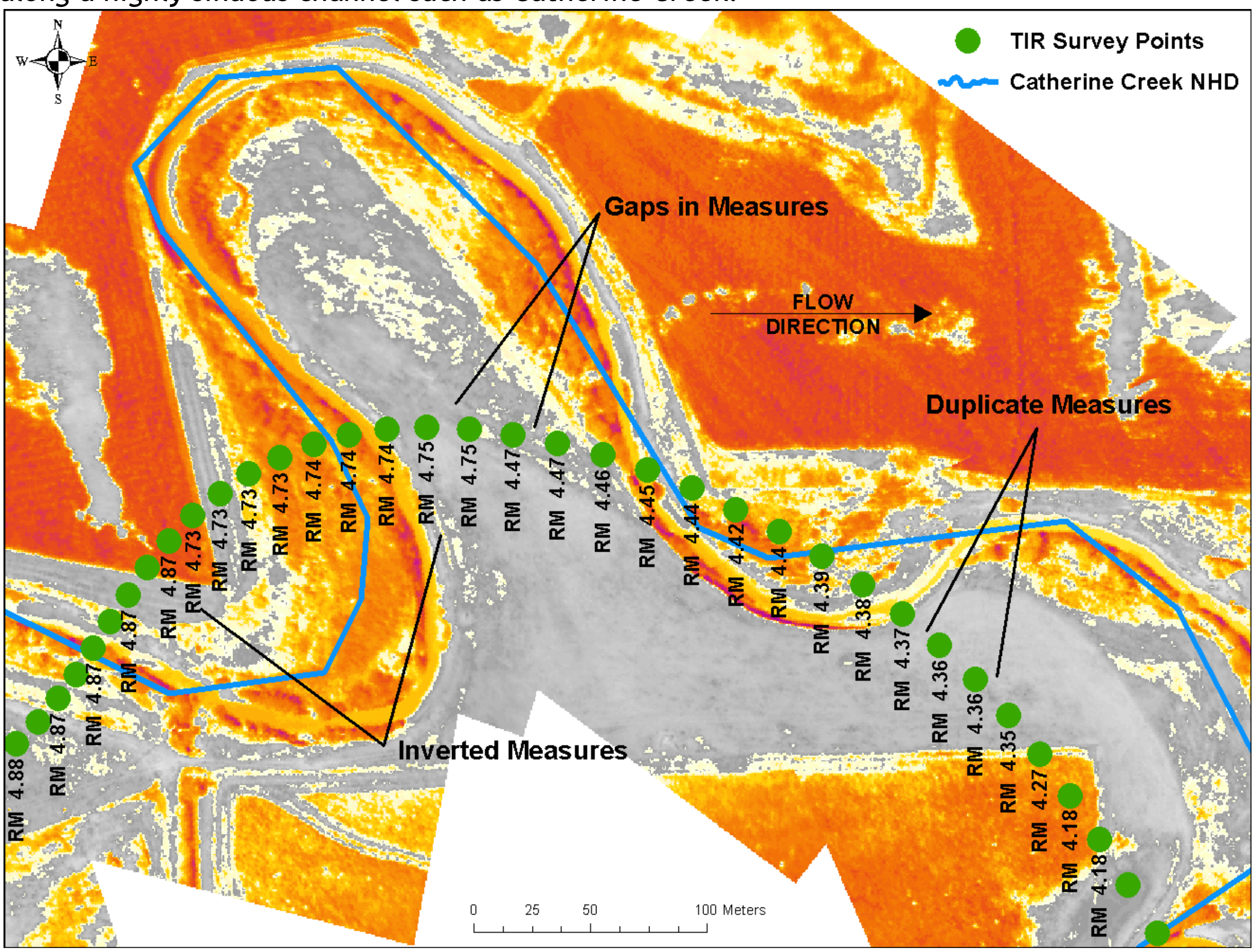
4.5 Temperature Profiles

In order to provide further spatial reference, the image index shapefile is assigned an approximate river mile based on a routed stream layer. The median temperature for each sampled image frame is 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 are only sampled along what appears to be the main flow channel in the river.

River miles in this report are only approximate and based on the USGS National Hydrography Dataset (NHD) flowlines for the Upper Grande Ronde Basin. Changes in channel morphology over time and the inherent difficulty of measuring a straight flight line against a sinuous river channel add to the difficulty. River measures of tributaries and inflows should be used with discretion outside the scope of this report (*Figure 7)*. A slight modification was made to the Ladd Creek NHD line in order to better measure the natural channel versus the canal.

Figure 7. The image below illustrates discrepancies which occur in measuring river miles along a highly sinuous channel such as Catherine Creek.



5. Thermal Accuracy

Watershed Sciences used data from the CRITFC and Confederated Tribes of the Umatilla Indian Reservation (CTUIR) in-stream data loggers, as well as 23 additional Hobo Pro sensor placements, to calibrate and validate the thermal imagery (*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 sorted by collection date. 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°C with few exceptions. If necessary, data logger temperatures were interpolated based on the 30-minute and 1-hour temperature readings. Results that fell well outside the accuracy limits are highlighted in yellow and discussed in further detail below.

McCoy Creek – The uppermost CRITFC data logger on McCoy Creek recorded temperatures 1.7°C cooler than the radiant temperatures derived from the TIR imagery. The reason for this difference was not immediately apparent from the imagery. However with the confluence of Ensign Creek just above the data logger, the data logger could have been placed in an area of locally cool water that did not mix to the surface and therefore was not detected in the TIR images. Of the three CTUIR data loggers in McCoy Creek, the MCCOY7 sensor showed water temperatures being coldest in the middle of the afternoon raising suspicions of its internal clock settings. The CTUIR sensor at the bridge crossing (RM 0.89) was inconsistent with both the derived radiant temperatures and WSI data logger readings at the same location. It is unclear why the other CTUIR data logger (RM 1.67) did not validate the TIR image calibration.

Grande Ronde River – The 60 mile reach of the Upper Grande Ronde was calibrated with WSI sensors only. The 15 CRITFC sensors and 4 CTUIR sensors were strictly used for validation purposes. Though four sensors along the Grande Ronde showed discrepancies of greater than ±1.0°C, in every case the sensors immediately upstream and downstream calibrated well indicating a possible data logger issue.

Ladd Creek – Of the three data loggers in or near the stream, two gave suspect readings for the time and date of the survey. In-stream temperatures for the 'CC_above_Ladd_Creek' sensor seemed extremely low (17.7°C) given the temperatures and water levels seen in Catherine Creek. The sensor went offline at the end of the day on the 10th and was found dewatered on August 18th making stream temperature readings from this data logger suspect. The sensor at the mouth of Ladd Creek ('Ladd_Cr_mouth') showed a -2.8°C discrepancy between the in-stream sensor and the radiant temperatures. There appears to be a constriction or a culvert at this location in the channel. If the sensor was below the constriction, it is possible that it was measuring cooler water off the bottom of the upstream wetland and did not represent surface water temperatures. A good measurement was obtained at the uppermost sensor so the calibration was based on this location.

Little Creek - The CRITFC data logger reading at the mouth of the Little Creek is suspect given that the imagery shows Little Creek as a warming source to Catherine Creek. The two data loggers upstream and the nearest downstream data logger on Catherine Creek were consistent with the radiant temperatures.

Meadow Creek – Four of the five CTUIR data loggers used for validation purposes in Meadow Creek (MEADOW2, MEADOW5, MEADOW6, and BATTLE1) had temperature readings that appear to be out of sync with the time of day with the coolest temperatures occurring near noon and the warmest temperatures occurring in the middle of the night. Without further information, they cannot be considered accurate.

Table 5. Comparison of radiant temperatures derived from the TIR images and kinetic temperatures from the in-stream monitor. Data shown in blue were not used in the imagery calibrations, but as independent verification of the results.

Stream	Site	Logger_id	Owner	River Mile	TIR_Image	UTC Time	In-Stream Temp	Radiant Temp	Δ°C
8/7/2010									
Beaver Creek									
Grande Ronde R.	GR_above_Beaver_Cr	2395849	WSI	0.00	beaver1881	14:42	24.4	24.3	0.1
Beaver Creek	Beaver_Cr_mouth	2395829	CRITFC	0.11	beaver1907	14:42	21.2	21.3	-0.1
Beaver Creek	Beaver_Cr_above_Dry_Beaver	2395827	CRITFC	5.57	beaver2400	14:52	17.2	16.9	0.3
Beaver Creek	Beaver_Cr_upper	2395858	CRITFC	13.16	beaver2980	15:02	15.1	14.8	0.3
Dark Canyon Creek									
Dark Canyon Creek	Dark_Canyon_Cr_mouth	DC1	CTUIR	0.05	GrandeRonde3167	15:16	21.3	21.0	0.3
Five Points Creek									
Five Points Creek	Five_Points_Cr_mouth	2395854	CRITFC	0.06	fivepts0033	13:46	21.2	21.0	0.2
Five Points Creek	Five_Points_Cr_mouth	1026260	WSI	0.06	fivepts0033	13:46	21.1	21.0	0.1
Five Points Creek	Five_Points_Cr_above_Pelican	2395833	CRITFC	1.42	fivepts0172	13:49	20.0	20.6	-0.6
Five Points Creek	Five_Points_Cr_above_Little_JD	2395799	CRITFC	6.87	fivepts0575	13:55	20.1	19.6	0.4
Five Points Creek	Five_Points_Cr_upper	2395811	CRITFC	8.74	fivepts0714	13:58	16.7	16.5	0.2
McCoy Creek									
Meadow Cr	Mouth	1026261	WSI	d/s	mccoy3020	15:12	24.0	23.8	0.2
Dark Canyon Creek	Dark_Canyon_Cr_mouth	DC1	CTUIR	d/s	mccoy3167	15:16	21.3	21.0	0.3
McCoy Creek	McCoy_Cr_mouth	2395804	CRITFC	0.04	mccoy3246	15:17	24.1	23.9	0.2
McCoy Creek	McCoythermo7	MCCOY7	CTUIR	0.04	mccoy3243	15:18	15.6	23.8	**-8.2**
McCoy Creek	at bridge	1026267	WSI	0.89	mccoy3330	15:18	23.2	22.6	0.6
McCoy Creek	McCoythermo6	MCCOY6	CTUIR	0.89	mccoy3330	15:18	24.7	22.6	**2.1**
McCoy Creek	McCoythermo1	MCCOY1	CTUIR	1.67	mccoy3400	15:19	23.2	21.8	**1.4**
McCoy Creek	McCoy_Cr_below_Ensign_Cr	2395841	CRITFC	11.37	mccoy4338	15:37	14.1	16.1	**-1.7**
Rock Creek									
Grand Ronde R.	U/S Rock Creek	2386980	WSI	u/s	rock0842	14:06	24.1	24.4	-0.3
Rock Creek	Rock_Cr_mouth	2395853	CRITFC	0.19	rock0860	14:08	26.0	25.6	0.4
Spring Creek									
Grande Ronde	GRR at Spring Creek	2386979	WSI	0.00	spring1472	14:28	24.6	25.0	-0.4
Spring Creek	Spring_Cr_mouth	2395846	CRITFC	0.07	spring1480	14:28	21.5	21.1	0.4

Stream	Site	Logger_id	Owner	River Mile	TIR_Image	UTC Time	In-Stream Temp	Radiant Temp	Δ°C
8/8/2010									
Burnt Corral Creek									
Burnt Corral	Burnt_Corral_Cr_mouth	2395869	CRITFC	0.27	burntcorr1498	15:00	21.3	20.6	0.7
Burnt Corral	Burnt_Corral	1026266	WSI	0.61	burntcorr1519	15:01	19.9	20.2	-0.3
Chicken Creek									
Chicken Creek	Chicken_Cr_below_W_Chicken	2395866	CRITFC	2.33	chicken3630	15:49	19.8	20.1	-0.3
Chicken Creek	Chicken_Cr_below_W_Chicken	1026259	WSI	2.33	chicken3630	15:49	20.0	20.1	-0.1
Clear Creek									
Clear Creek	Clear_Cr_mouth	2395843	CRITFC	0.00	clear4003	16:01	15.2	15.3	-0.1
Clear Creek	Clear Creek lower	CLC1	CTUIR	0.05	clear4009	16:01	15.5	14.9	0.6
Clear Creek	Clear_Cr_upper	2395860	CRITFC	1.84	clear4236	16:07	13.2	13.0	0.2
Fly Creek									
Grande Ronde R.	GR d/s Fly Cr.	1026262	WSI	0.00	fly1974	15:12	22.5	22.3	0.2
Fly Creek	Fly_Cr_mouth	2395805	CRITFC	0.08	fly1993	15:12	20.1	20.4	-0.3
Fly Creek	Fly_Cr_Canyon	2395828	CRITFC	5.44	fly2355	15:18	21.5	21.9	-0.4
Fly Creek	Fly_Cr_below_Little_Fly_Cr	2395865	CRITFC	7.56	fly2532	15:21	25.5	25.1	0.4
Meadow Creek									
Grande Ronde R.	Up Stream Meadow	2395845	CRITFC	u/s	meadow0014	14:29	24.6	24.7	-0.1
Meadow Creek	at mouth	1026261	WSI	0.01	meadow0014	14:29	23.9	23.7	0.2
Meadow Creek	Meadow_Cr_mouth	2395826	CRITFC	0.03	meadow0019	14:30	23.2	23.0	0.2
Meadow Creek	Meadow_Cr_above_Dark_Cyn	2395839	CRITFC	0.67	meadow0076	14:30	26.9	26.6	0.3
Meadow Creek	Meadows2 Lower	MEADOW2	CTUIR	1.81	meadow0143	14:32	15.7	24.6	**-8.9**
Meadow Creek	Meadow_Cr_above_McCoy_Cr	2395825	CRITFC	1.82	meadow0144	14:32	24.7	24.4	0.3
Meadow Creek	Meadow1 Upper	MEADOW1	CTUIR	2.61	meadow0199	14:33	27.3	26.6	0.7
Meadow Creek	Meadow Ck Habberstad2 Lower	MEADOW6	CTUIR	6.65	meadow0474	14:37	8.7	25.4	**-16.7**
Meadow Creek	Battle Creek	BATTLE1	CTUIR	7.09	meadow0508	14:38	7.6	22.8	**-15.2**
Meadow Creek	Meadow Ck Habberstad1 Upper	MEADOW5	CTUIR	7.26	meadow0534	14:38	6.9	24.0	**-17.1**
Meadow Creek	Meadow_Cr_above_Bear_Cr	2395800	CRITFC	10.82	meadow0810	14:43	24.0	23.4	0.6
Meadow Creek	Meadow_Cr_above_Waucup_Cr	2395864	CRITFC	17.94	meadow1439	14:53	18.4	18.6	-0.2
Sheep Creek									
Sheep Creek	at Vey Ranch	2386978	WSI	2.04	sheep2857	15:32	24.6	24.6	0.0
Sheep Creek	Sheep_Cr_Rd_junction	2395819	CRITFC	6.10	sheep3177	15:37	22.1	21.9	0.2
Sheep Creek	Sheep_Cr_below_E_Sheep_Cr	2395852	CRITFC	8.71	sheep3368	15:40	15.2	15.2	0.0

Stream	Site	Logger_id	Owner	River Mile	TIR_Image	UTC Time	In-Stream Temp	Radiant Temp	Δ°C
8/9/2010									
Grande Ronde									
Grande Ronde	State Ditch/Market Lane Bridge	1026260	WSI	36.40	GrandeRonde0197	13:50	23.6	24.3	-0.7
Grande Ronde	GR_Peach_Rd_bridge	2395823	CRITFC	40.15	GrandeRonde0490	13:55	24.7	24.9	-0.3
Grande Ronde	GR_at_2nd_St_Bridge	9760482	CRITFC	47.31	GrandeRonde1188	14:10	22.4	23.6	**-1.2**
Grande Ronde	GR_above_Five_Points_Cr	2395842	CRITFC	54.49	GrandeRonde1995	14:25	24.3	23.6	0.7
Grande Ronde	Milgard Jct. State Park	2386980	WSI	55.10	GrandeRonde2064	14:27	23.4	23.1	0.3
Grande Ronde	GR_Hilgard Park	2395862	CRITFC	55.39	GrandeRonde2103	14:27	23.5	23.6	-0.1
Grande Ronde	downstream of Spring Creek	2386979	WSI	58.60	GrandeRonde2397	14:32	24.1	23.0	**1.1**
Grande Ronde	GR_above_Spring_Cr	2395815	CRITFC	58.80	GrandeRonde2420	14:32	23.7	23.0	0.7
Grande Ronde	GR_above_Jordan_Cr	9760475	CRITFC	60.11	GrandeRonde2538	14:34	23.0	23.2	-0.2
Grande Ronde	GR_above_Bear Creek	9760479	CRITFC	60.63	GrandeRonde2595	14:35	23.3	23.2	0.1
Grande Ronde	GR_above_Beaver_Cr	2395849	CRITFC	67.02	GrandeRonde3189	14:47	22.1	22.2	-0.1
Grande Ronde	upstream of Beaver Creek	1026265	WSI	67.21	GrandeRonde3210	14:47	22.2	22.0	0.2
Grande Ronde	GR_above_Meadow_Cr	2395845	CRITFC	68.71	GrandeRonde3354	14:50	22.2	22.3	-0.1
Grande Ronde	downstream of Fly Creek	1026262	WSI	72.87	GrandeRonde3804	14:58	20.9	21.1	-0.2
Grande Ronde	GR_above_Fly_Cr	2395851	CRITFC	73.24	GrandeRonde3834	14:58	20.6	20.4	0.2
Grande Ronde	GR_at_Time_and_Half_Bridge	2395830	CRITFC	77.09	GrandeRonde4121	15:03	18.9	21.4	**-2.5**
Grande Ronde	near GR Guard Station	9783696	WSI	79.99	GrandeRonde4291	15:06	22.8	22.8	0.0
Grande Ronde	GR_below_Vey	2395867	CRITFC	80.05	GrandeRonde4296	15:06	22.0	22.8	-0.8
Grande Ronde	Grande Ronde River lower Vey	GR4	CTUIR	80.74	granderonde4347	15:07	22.4	22.5	-0.1
Grande Ronde	Acclimation Facility	GR5	CTUIR	86.61	granderonde4738	15:14	17.0	17.2	-0.2
Grande Ronde	GR_above_Clear_Cr	2395820	CRITFC	88.38	GrandeRonde4939	15:19	15.8	15.8	0.0
Grande Ronde	Grande Ronde River Mid	GR6	CTUIR	89.16	granderonde4997	15:20	14.7	14.4	0.3
Grande Ronde	GR_Reach_U155154	9760488	CRITFC	89.16	GrandeRonde4997	15:20	14.5	14.4	0.1
Grande Ronde	along Reach U155154	1187769	WSI	89.20	GrandeRonde5000	15:20	14.4	14.8	-0.4
Grande Ronde	Grand Ronde River upper	GR8	CTUIR	89.96	granderonde5059	15:21	13.3	13.2	0.1
Grande Ronde	GR_below_Tanner_Gulch	2395822	CRITFC	92.42	GrandeRonde5240	15:24	11.3	10.9	0.4
Limber Jim Creek									
Limber Jim Creek	first bridge crossing	9793695	WSI	0.11	limberjim5328	15:30	17.4	17.2	0.2
Limber Jim Creek	Limber_Jim_Cr_mouth	2395810	CRITFC	0.38	limberjim5346	15:31	16.5	16.5	0.0
Limber Jim Creek	Limber_Jim_Cr_below_NF	2395836	CRITFC	1.78	limberjim5446	15:32	13.1	12.9	0.2
Limber Jim Creek	Limber_Jim_Cr_upper	2395824	CRITFC	2.82	limberjim5526	15:34	12.4	12.5	-0.1

Stream	Site	Logger_id	Owner	River Mile	TIR_Image	UTC Time	In-Stream Temp	Radiant Temp	Δ°C
8/10/2010									
Ladd Creek									
Catherine Cr.	CC_above_Ladd Cr	9760490	CRITFC	0.00	ladd0492	14:11	17.7	24.2	**-6.5**
Ladd Creek	Ladd_Cr_mouth	9760485	CRITFC	0.03	ladd0492	14:10	20.7	23.5	**-2.8**
Ladd Creek	Ladd_Cr_upper	2395806	CRITFC	8.23	ladd1361	14:28	15.2	15.3	-0.1
Little Catherine Creek									
Catherine Creek	d/s of Little Catherine	1026261	WSI	d/s	Catherine2662	15:03	19.0	18.9	0.1
Little Catherine	Little_CC_mouth	2395812	CRITFC	0.11	Catherine2759	15:06	17.4	17.3	0.1
Little Creek									
Catherine Creek	d/s of Little Creek	9783697	WSI	d/s	little1430	14:34	23.3	22.9	0.4
Little Creek	Little_Cr_mouth	2395848	CRITFC	0.02	little1473	14:34	19.7	23.2	**-3.5**
Little Creek	Little_Cr_N_Union	9760489	CRITFC	3.38	little1721	14:38	20.1	20.1	0.0
Little Creek	Little_Cr_High_Valley_Rd	9760492	CRITFC	8.29	little2154	14:46	18.3	18.5	-0.3
Milk Creek									
Catherine Creek	downstream of mouth	1026261	WSI	d/s	milk2279	14:53	19.1	18.5	0.6
Catherine Creek	CC above Little CC	9760476	CRITFC	0.00	milk2332	14:54	18.1	18.1	0.0
Catherine Creek	CC above Milk Cr	9760474	CRITFC	0.00	milk2349	14:55	17.9	17.7	0.2
Milk Creek	Milk_Cr_mouth	2395838	CRITFC	0.06	milk2353	14:55	16.1	16.5	-0.4
Milk Creek	below_unnamed	2395837	CRITFC	1.41	milk2550	14:59	16.7	16.4	0.3
Milk Creek	Milk_Cr_upper	2395855	CRITFC	1.66	milk2569	15:00	14.7	14.6	0.1

Stream	Site	Logger_id	Owner	River Mile	TIR_Image	UTC Time	In-Stream Temp	Radiant Temp	Δ°C
8/12/2010									
Catherine Creek									
Catherine Creek	CC_above_Little_Cr	2395807	CRITFC	13.40	Catherine2564	16:28	20.7	20.6	0.1
Catherine Creek	CC_E_Union	9760477	CRITFC	17.49	Catherine2297	16:24	20.1	20.3	-0.2
Catherine Creek	CC_Hwy_203	9760478	CRITFC	22.97	Catherine1933	16:18	18.9	18.9	0.0
Catherine Creek	CC_above_Little_CC	9760476	CRITFC	26.73	Catherine1663	16:13	17.9	17.7	0.2
Catherine Creek	CC_above_Milk_Cr	9760474	CRITFC	26.90	Catherine1650	16:13	17.8	17.6	0.2
N.F. Catherine	NF_Mouth	1026266	WSI	31.31	Catherine1332	16:08	15.6	15.5	0.1
S.F. Catherine	SF_Mouth	2386978	WSI	31.37	Catherine1329	16:08	14.3	14.4	-0.1
North Fork Catherine Creek									
N.F. Catherine	Near Mouth	1026266	WSI	0.10	Catherine0083	15:36	15.6	15.6	0.0
N.F. Catherine	NF_CC_mouth	2395796	CRITFC	0.13	Catherine0090	15:36	15.5	15.6	-0.1
N.F. Catherine	NF_CC_upper	2395859	CRITFC	7.45	Catherine0614	15:45	8.7	8.5	0.2
South Fork Catherine Creek									
SF Catherine	mouth	2386978	WSI	0.10	Catherine0693	15:51	14.4	14.4	0.0
SF Catherine	SF_CC_mouth	2395844	CRITFC	0.08	Catherine0693	16:08	14.2	14.4	-0.2

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6. Study Area Results

Median channel temperatures were plotted versus river mile for the streams in the survey area. Tributaries, springs, and seeps sampled during the analysis are included on the longitudinal profiles to provide additional context for interpreting spatial temperature patterns. Significant features such as braids, impoundments, diversions and dam outflows were plotted where relevant.

Due to the nature of the project, the focus of the survey was to capture thermal conditions during peak temperatures. 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. It is important to reiterate that temperature changes of less than ± 0.5°C in the absence of a point source should be interpreted with caution until verified in the field due to the inherent nature of the thermal imagery.

Springs and seeps are generally differentiated by size and temperature; a feature is considered a spring when it has a defined source and is distinctly cooler than the surrounding waters. Features are called seeps when they are less defined spatially and in temperature; they most commonly occur on the edges of the river banks. If there was any doubt about the source of a feature, they were noted with a '?' in the sampled shapefile. These locations should be verified in the field to confirm the presence of groundwater.

The Upper Grande Ronde River and its tributaries are discussed first, followed by Catherine Creek and its tributaries, with the major focus being on the longer streams in the study area. The sample images contained in this report are not meant to be comprehensive, but to provide examples of river features and interpretations. Color ramps in the sample images are unique for each stream.

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UPPER GRANDE RONDE RIVER AND TRIBUTARIES

8/9/2010
Upper Grande Ronde River
Limber Jim Creek

8/7/2010
Beaver Creek
Dark Canyon Creek
Five Points Creek
McCoy Creek
Rock Creek
Spring Creek

8/8/2010
Burnt Corral Creek
Chicken Creek/West Chicken Creek
Clear Creek
Fly Creek
Meadow Creek
Sheep Creek

6.1 Upper Grande Ronde River

6.1.1 Longitudinal Temperature Profile

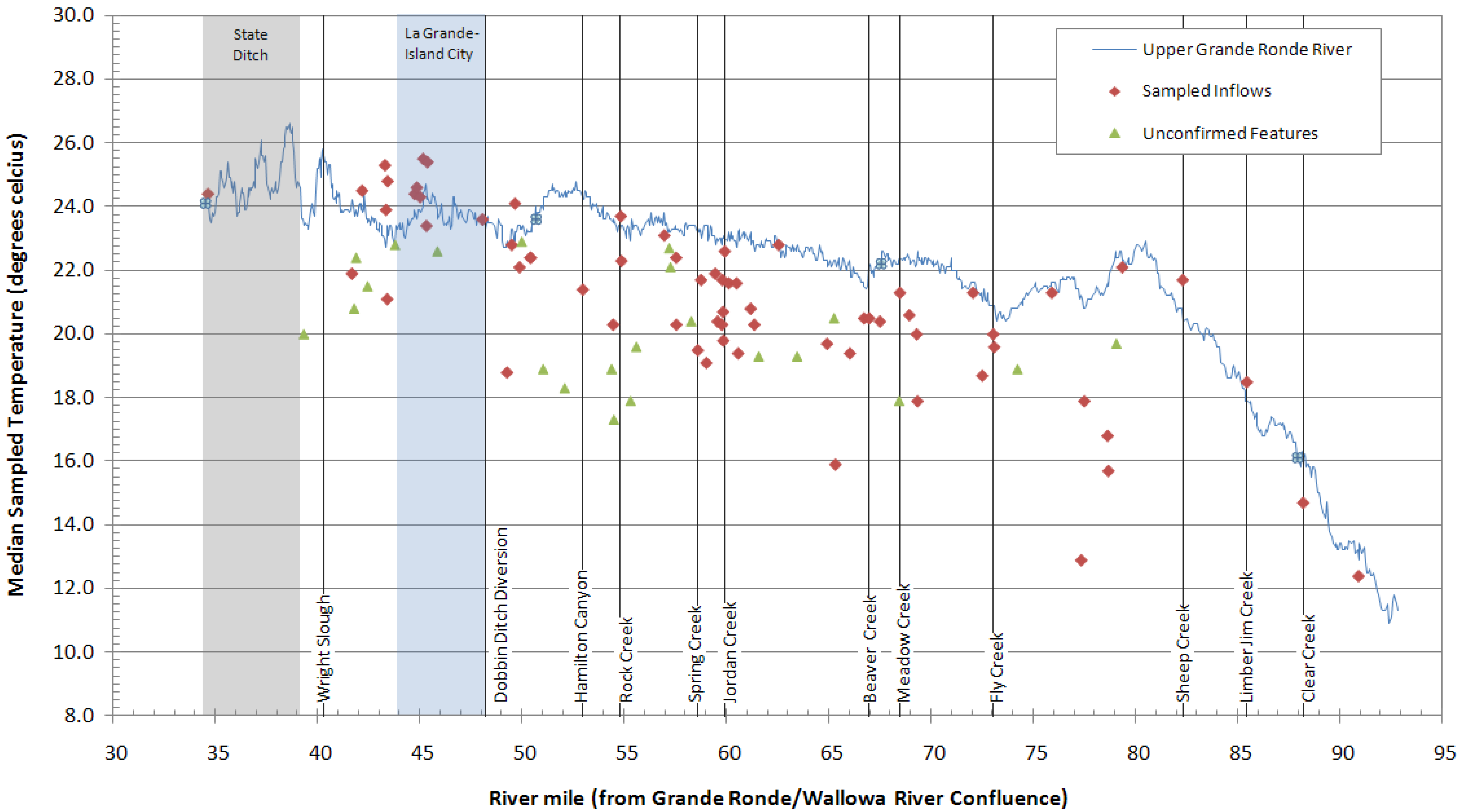


Figure 8. Median sampled temperatures versus river mile for the Upper Grande Ronde River from State Ditch upstream to Tanner Gulch. The locations of detected surface inflows are illustrated on the profile and listed in Table 6. All mileages are referenced from the confluence with the Wallowa River.

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

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Grande Ronde River (R)	55.70	34.61	24.4	24.3	0.1
seep/shadow (R)	67.04	41.66	21.9	23.9	-2.0
pond (L)	67.85	42.16	24.5	24.1	0.4
gravel pit pond (R)	69.65	43.28	25.3	23.0	2.3
gravel pit pond (R)	69.74	43.33	23.9	22.7	1.2
seep (R)	69.83	43.39	21.1	23.3	-2.2
gravel pit pond (R)	69.86	43.41	24.8	23.4	1.4
gravel pit pond (R)	71.98	44.73	24.4	23.7	0.7
gravel pit pond (R)	72.17	44.84	24.6	23.6	1.0
gravel pit pond (R)	72.42	45.00	24.3	23.9	0.4
gravel pit pond (L)	72.66	45.15	25.5	24.0	1.5
hyporheic flow (R)	72.92	45.31	23.4	24.7	-1.3
gravel pit pond (L)	73.00	45.36	25.4	24.2	1.2
Dobbin Ditch overflow? (L)	77.33	48.05	23.6	23.5	0.1
spring (R)	79.27	49.26	18.8	22.8	-4.0
Unnamed (R)	79.65	49.49	22.8	23.3	-0.5
Unnamed (L)	79.90	49.65	24.1	22.9	1.2
hyporheic flow (R)	80.26	49.87	22.1	23.4	-1.3
Wilson Canyon (R)	81.10	50.39	22.4	23.2	-0.8
Robbs Creek (L)	81.16	50.43	22.4	23.2	-0.8
Hamilton Cyn/Cottonwood Sp (L)	85.24	52.97	21.4	24.3	-2.9
Five Points Creek (L)	87.64	54.46	20.3	23.5	-3.2
Rock Creek (R)	88.25	54.83	23.7	23.3	0.4
hyporheic flow (R)	88.29	54.86	22.3	23.4	-1.1
Unnamed (R)	91.66	56.96	23.1	23.8	-0.7
Whiskey Creek (R)	92.61	57.54	22.4	23.4	-1.0
wet meadow (R)	92.62	57.55	20.3	23.3	-3.0
Spring Creek (L)	94.31	58.60	19.5	23.2	-3.7
Unnamed (R)	94.57	58.76	21.7	23.3	-1.6
hyporheic flow (R)	94.98	59.02	19.1	23.4	-4.3
hyporheic flow (R)	95.68	59.45	21.9	23.1	-1.2
Unnamed (L)	95.87	59.57	20.4	23.0	-2.6
seep (L)	96.20	59.78	20.3	22.8	-2.5
seep (L)	96.25	59.81	21.7	23.0	-1.3
seep (R)	96.30	59.84	20.7	23.0	-2.3
seep (L)	96.32	59.85	19.8	23.1	-3.3
Jordan Creek (R)	96.43	59.92	22.6	23.0	-0.4
seep (R)	96.74	60.11	21.6	23.2	-1.6
side channel (R)	97.34	60.48	21.6	22.7	-1.1
Unnamed (R)	97.45	60.56	19.4	23.2	-3.8
hyporheic flow (L)	98.45	61.17	20.8	23.2	-2.4
spring (R)	98.73	61.35	20.3	22.8	-2.5
side channel (L)	100.64	62.54	22.8	22.8	0.0
side channel (R)	104.46	64.91	19.7	22.3	-2.6
spring (L)	105.13	65.32	15.9	22.3	-6.4
side channel (R)	106.26	66.03	19.4	22.3	-2.9
side channel (R)	107.37	66.72	20.5	21.5	-1.0
Beaver Creek (R)	107.78	66.97	20.5	22.1	-1.6

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
hyporheic flow (R)	108.64	67.50	20.4	22.1	-1.7
Meadow Creek (L)	110.21	68.48	21.3	22.4	-1.1
hyporheic flow (R)	110.95	68.94	20.6	22.4	-1.8
Winter Canyon (R)	111.53	69.30	20.0	22.2	-2.2
side channel (R)	111.59	69.34	17.9	22.6	-4.7
hyporheic flow (L)	115.98	72.06	21.3	21.6	-0.3
spring (R)	116.69	72.51	18.7	21.0	-2.3
Fly Creek 1 (L)	117.57	73.05	20.0	20.9	-0.9
seep (L)	117.64	73.10	19.6	20.9	-1.3
Unnamed (L)	122.18	75.92	21.3	21.6	-0.3
spring (L)	124.51	77.36	12.9	21.2	-8.3
seep (L)	124.74	77.51	17.9	20.8	-2.9
Unnamed (R)	126.58	78.65	16.8	21.6	-4.8
seep (L)	126.63	78.69	15.7	21.5	-5.8
Unnamed (L)	127.73	79.37	22.1	22.3	-0.2
Sheep Creek (L)	132.50	82.33	21.7	20.4	1.3
Limber Jim Creek (R)	137.55	85.47	18.5	17.9	0.6
Clear Creek (L)	141.99	88.23	14.7	16.1	-1.4
Unnamed (R)	146.35	90.94	12.4	12.9	-0.5
Unconfirmed Features					
Tributaries	**Kilometer**	**River Mile**	**Tributary Temp (˚C)**	**Mainstem Temp (˚C)**	**Difference**
irrigation drain? (R)	63.27	39.31	20.0	23.6	-3.6
seep south of sandbar? (R)	67.23	41.77	20.8	24.0	-3.2
seep? (R)	67.39	41.87	22.4	23.9	-1.5
seep? (R)	68.28	42.43	21.5	23.6	-2.1
spring? (R)	70.46	43.78	22.8	22.8	0.0
hyporheic flow? (R)	73.79	45.85	22.6	23.9	-1.3
seep from Bear Cyn? (L)	80.43	49.98	22.9	23.3	-0.4
wet meadow? (R)	82.13	51.03	18.9	24.0	-5.1
seep/shadow? (R)	83.81	52.08	18.3	24.4	-6.1
seep? (L)	87.52	54.38	18.9	23.6	-4.7
spring? (R)	87.69	54.49	17.3	23.6	-6.3
spring? (R)	89.01	55.31	17.9	22.9	-5.0
seep? (R)	89.47	55.59	19.6	23.4	-3.8
hyporheic/riffle? (R)	92.05	57.20	22.7	23.3	-0.6
seep? (R)	92.15	57.26	22.1	23.2	-1.1
vegetation? (R)	93.79	58.28	20.4	23.4	-3.0
spring? (R)	99.07	61.56	19.3	22.8	-3.5
seep/shadow? (R)	102.10	63.44	19.3	22.7	-3.4
seep? (R)	105.00	65.25	20.5	22.3	-1.8
seep/shadow? (R)	110.15	68.44	17.9	22.3	-4.4
seep/shadow? (L)	119.46	74.23	18.9	20.8	-1.9
seep/shadow? (R)	127.26	79.08	19.7	22.4	-2.7

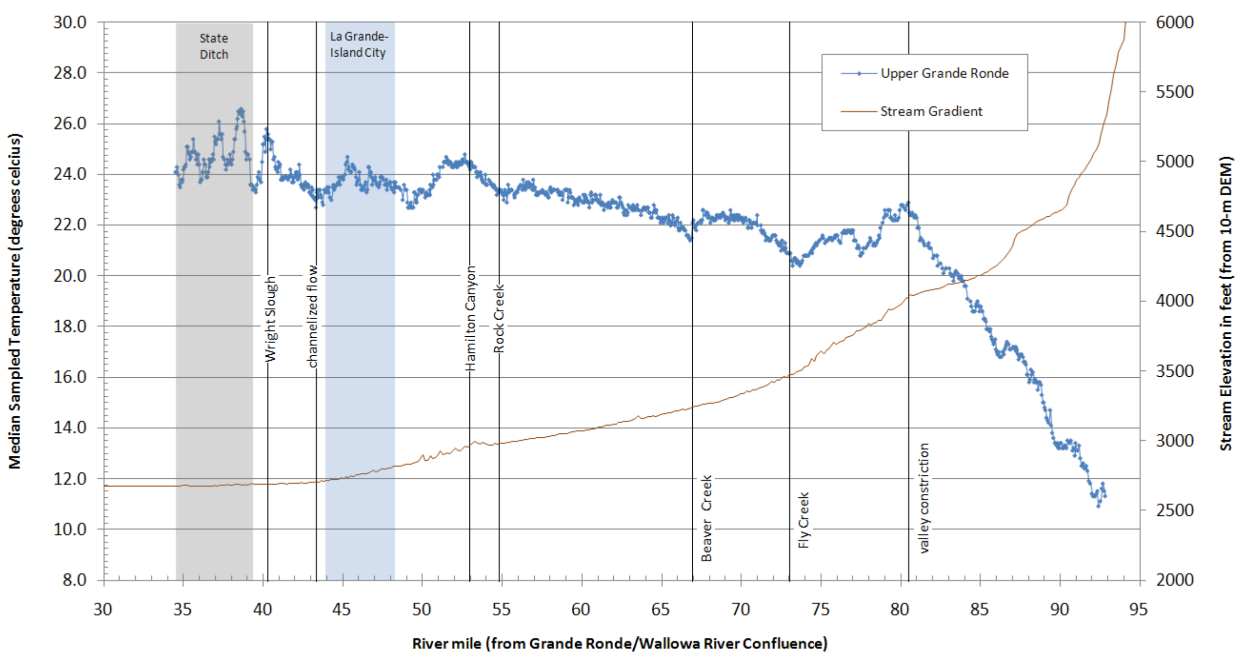
6.1.2 Observations

Approximately 60 miles of the Upper Grande Ronde River were surveyed on August 12, 2010 from the Alicel Lane Bridge (RM 34.52) following State Canal upstream to Tanner Gulch (RM 92.84). Bulk water temperatures ranged from 10.9˚C→26.6˚C, with the coolest temperatures occurring high in the drainage and the warmest temperatures seen along State Canal (*Figure 8*). Twenty-seven tributaries, 24 groundwater features (seeps, springs, and hyporheic flow), 9 ponds, 6 side channels, and 1 wet meadow were sampled in the imagery. Twenty-two other features were sampled but could not be confirmed as true hydrologic features from the available imagery. These locations should be verified in the field.

From Tanner Gulch (RM 92.84) downstream to river mile 80.51, bulk water temperatures showed a steep increase from 10.9→22.9˚C. Neither Sheep Creek (RM 82.33), Limber Jim Creek (RM 85.47), nor Clear Creek (RM 88.23) appeared to have any significant impact on the overall bulk water temperatures along this reach.

Near river mile 80.51, the Upper Grande Ronde enters a narrow canyon with steep intersecting drainages. The river stays confined downstream to river mile 73.69 and bulk water temperatures drop from 22.9→20.4˚C. This section of stream also has a slightly steeper gradient than the reaches upstream and downstream (*Figure 9*). Valley transitions, such as a narrowing of the canyon and changes in gradient typically result in increased subsurface exchange (*Figure 10*). Point source springs and seeps, such as those at river miles 77.36, 77.51, and 78.69, are evidence of groundwater influences. An unnamed tributary (RM 78.65) also contributes significantly colder water to the mainstem along this reach.

Figure 9. A comparison of stream gradient to bulk water temperatures for the Upper Grande Ronde River. Stream elevations were obtained from the 10-m digital elevation model for the area.



From Fly Creek (RM 73.05) downstream to Hamilton Canyon (52.97), bulk water temperatures gradually increase from 20.4→24.8°C. Localized cooling can be seen near the confluence with Beaver Creek and the confluence of Rock Creek.

At Hamilton Canyon, very little surface water inflow can be seen in the imagery, but the appearance of Cottonwood Spring on the Hilgard, OR 7.5-minute quadrangle map indicates that there is groundwater activity in the lower reaches of the canyon. This is likely responsible for the 2°C decrease in bulk water temperatures seen downstream of the Canyon (RM 52.97→RM 49.11)

Below river mile 49.11, the river emerges from the upper canyon, flows through La Grande and Island City and continues into the agricultural land of the Grande Ronde Valley. River temperatures show an expected warming trend through the urban areas until an unexplained 2.0°C decrease from river mile 45.31→43.33. There are several large gravel pit ponds along this reach which may be contributing to subsurface exchange with the mainstem of the river.

At river mile 43.33, the river gradient plateaus and the river becomes channelized as it flows through the State Ditch. Bulk water temperatures would be expected to increase in this type of slow, channelized flow condition, as is seen from river mile 43.33 to Wright Slough (RM 40.28). However, downstream of Wright Slough to the Alicel Lane Bridge, a good deal of variation is seen in the bulk water temperatures. This variation is likely a result of low flows and stratified flow causing differential heating in low mixing zones (*Figure 11*).

Figure 10. The LiDAR image below shows the median sampled temperatures near river mile 80.51. An inflection is seen in the temperature profile at this location indicating probable increased groundwater activity. The valley severely constricts here and the stream gradient steepens likely causing the drop in bulk water temperatures. The three unnamed tributaries shown in the image did not contribute surface water to the mainstem but may be contributing to the increased subsurface exchange.

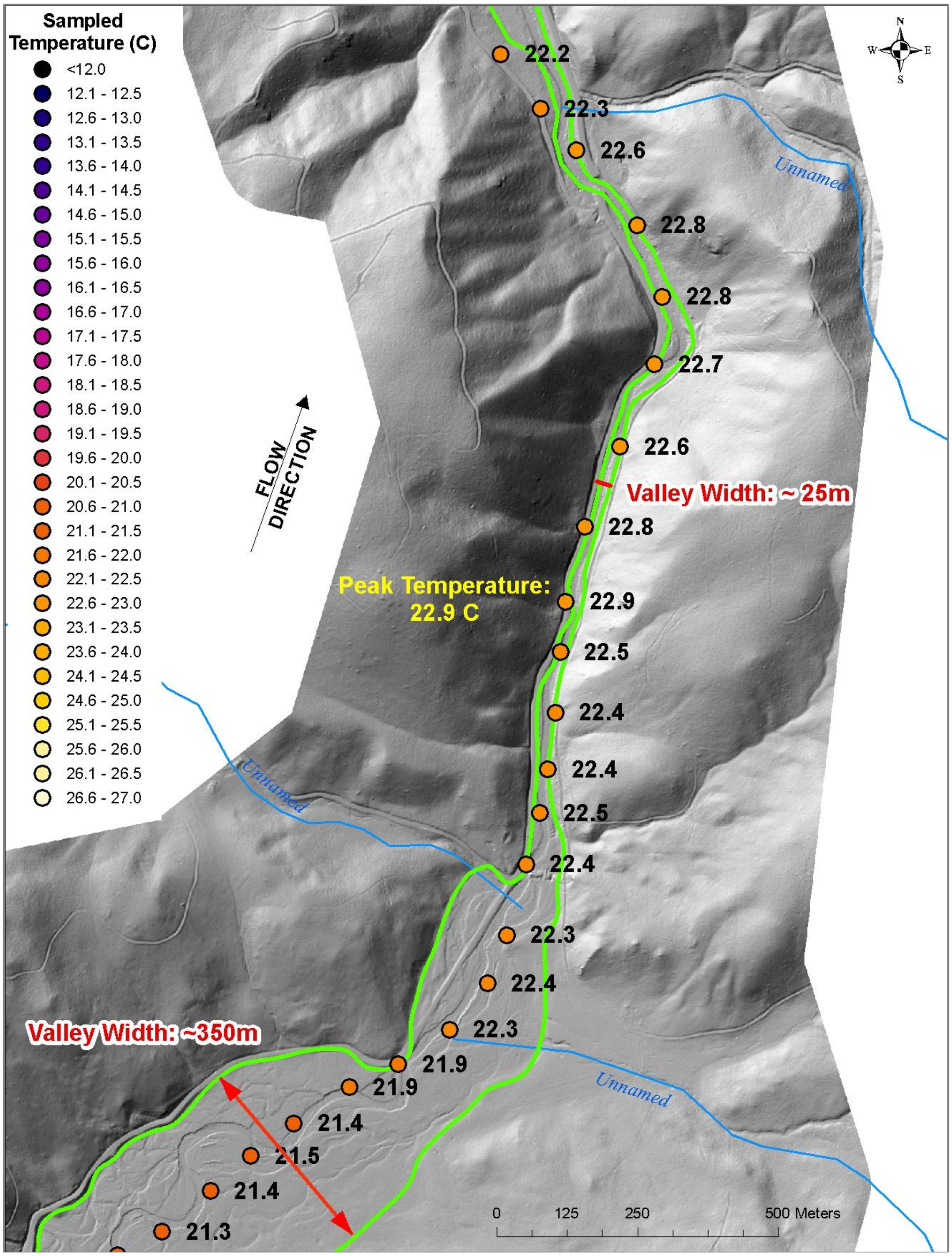
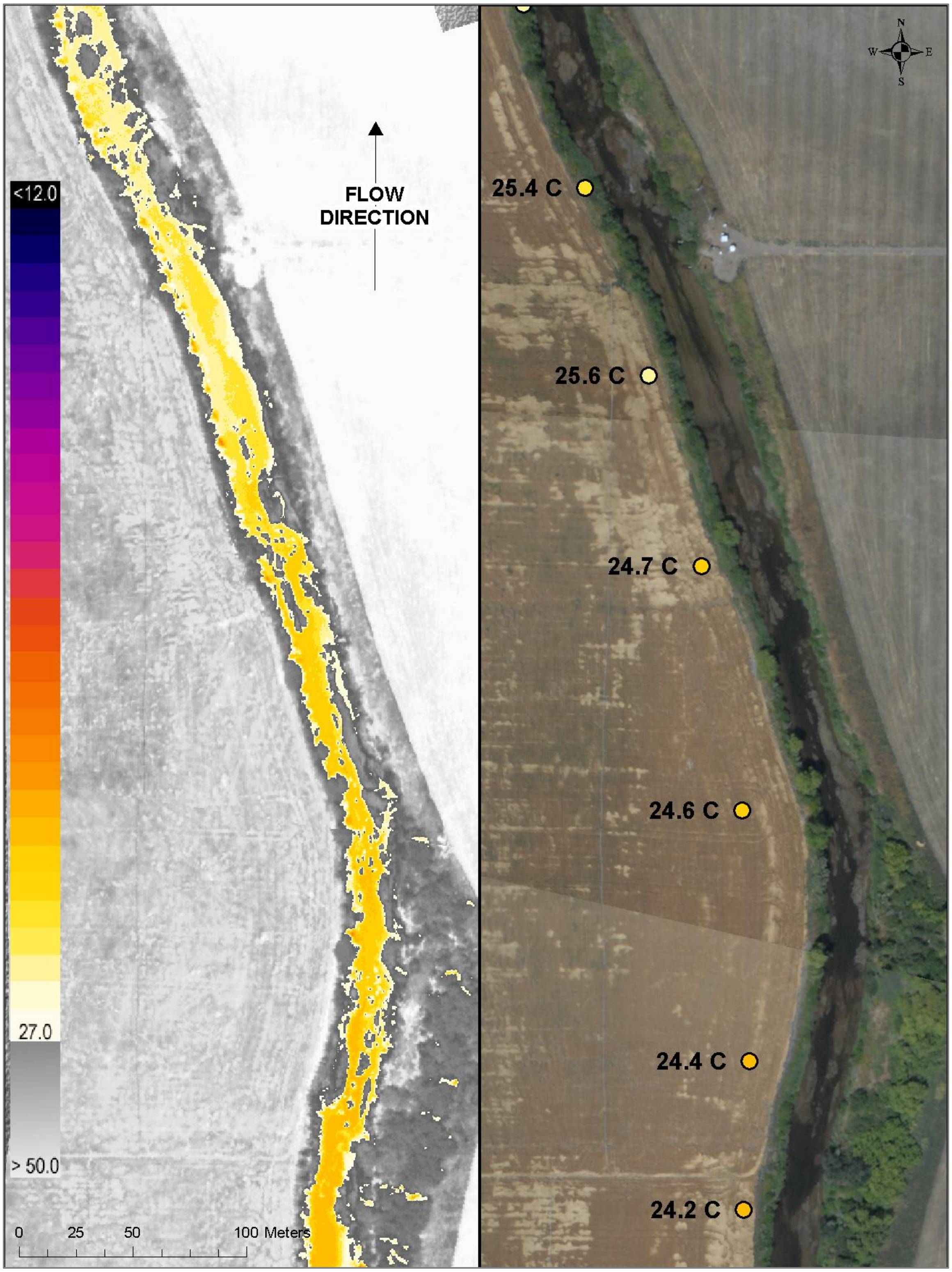
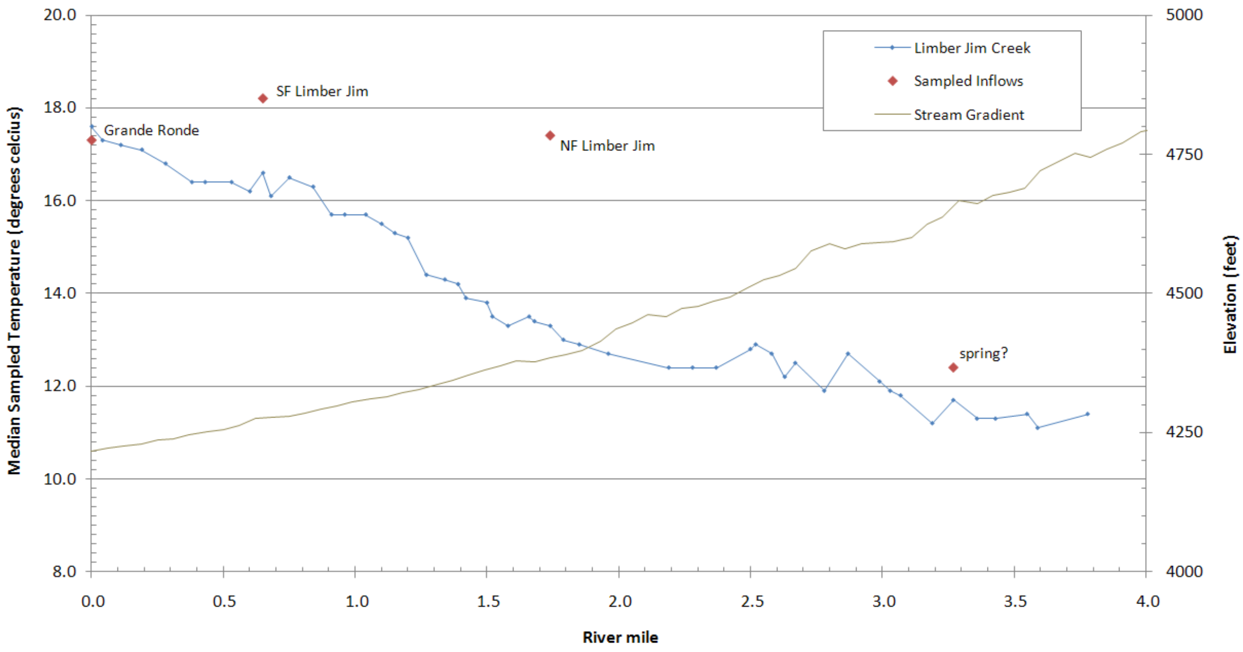


Figure 11. The TIR/natural color image pair below shows the Upper Grande Ronde River along State Ditch (RM 37.50). Along this reach of river, bulk water temperatures vary widely due to the low water conditions and possible stratified flow. The deeper pools are typically 1-2°C cooler than the shallow runs.



6.2 Limber Jim Creek

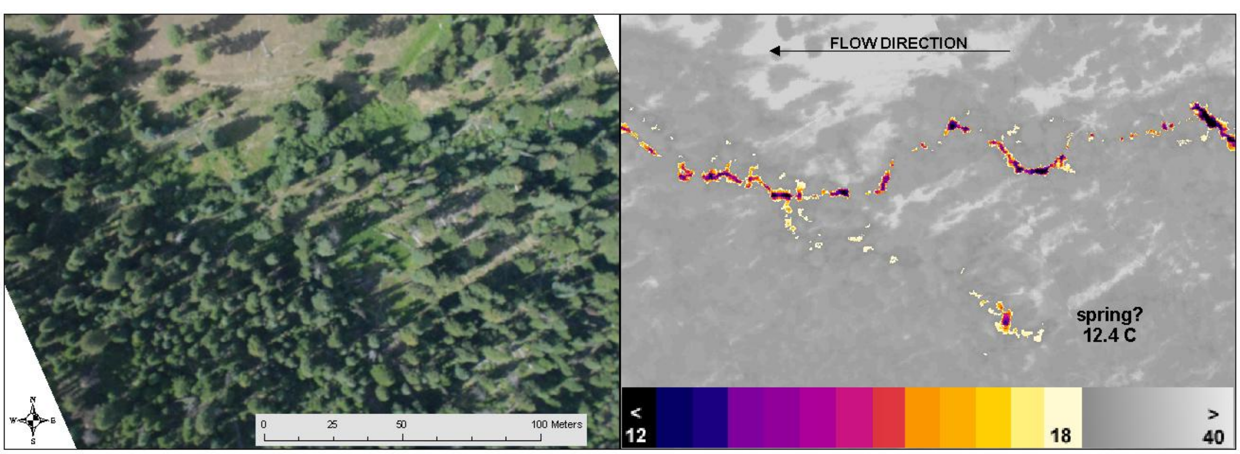
6.2.1 *Longitudinal Temperature Profile*



6.2.2 *Observations*

Just under 4 miles of Limber Jim Creek were surveyed on August 9, 2010 from the mouth upstream to Deadwood Gulch. A typical downstream warming profile was seen from 11.1°C to 17.6°C. Two tributaries, South Fork Limber Jim Creek (18.2°C) and North Fork Limber Jim Creek (17.4°C), and one possible spring at river mile 3.27 (12.4°C) (*Figure 12*) were sampled. All were too small to have a significant impact on bulk water temperatures. No obvious correlation was seen between the thermal profile and the stream gradient.

Figure 12. The natural color/TIR image pair below shows the possible spring at river mile 3.27. All three inflows to Limber Jim Creek were too small to have any impact on the bulk water temperatures.



6.3 Beaver Creek

6.3.1 Longitudinal Temperature Profile

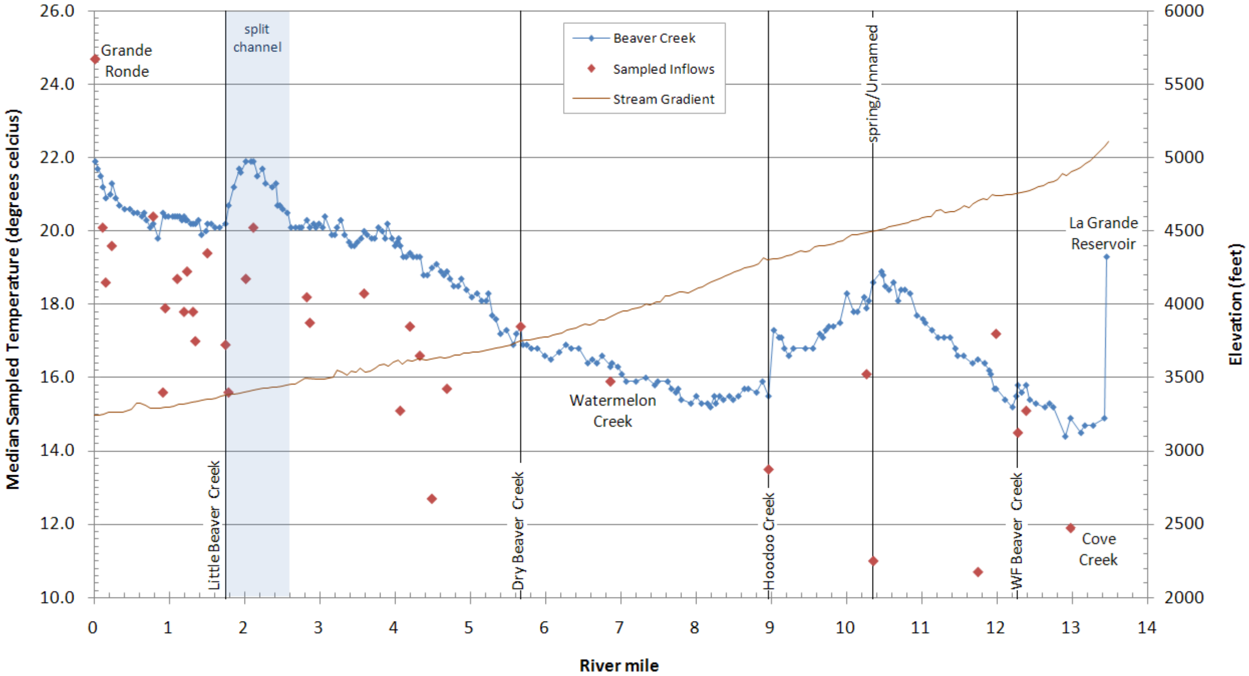


Table 7. Tributaries and other surface inflows sampled along Beaver Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Grande Ronde R.	0.03	0.02	24.7	21.9	2.8
side channel (L)	0.19	0.12	20.1	21.2	-1.1
seep (R)	0.26	0.16	18.6	20.9	-2.3
side channel (L)	0.39	0.24	19.6	21.3	-1.7
pond (L)	1.27	0.79	20.4	20.2	0.2
spring (L)	1.48	0.92	15.6	20.5	-4.9
seep (L)	1.53	0.95	17.9	20.4	-2.5
Unnamed (L)	1.79	1.11	18.7	20.4	-1.7
seep/shadow? (L)	1.92	1.20	17.8	20.4	-2.6
hyporheic flow (L)	2.00	1.24	18.9	20.3	-1.4
seep/shadow? (L)	2.13	1.32	17.8	20.2	-2.4
Unnamed (R)	2.18	1.35	17.0	20.2	-3.2
hyporheic seep (R)	2.44	1.51	19.4	20.2	-0.8
Little Beaver (L)	2.82	1.75	16.9	20.2	-3.3
hyporheic flow (L)	2.88	1.79	15.6	20.7	-5.1
seep (R)	3.25	2.02	18.7	21.9	-3.2
seep (R)	3.42	2.12	20.1	21.9	-1.8
hyporheic seep (R)	4.56	2.83	18.2	20.3	-2.1
hyporheic flow (L)	4.62	2.87	17.5	20.1	-2.6
seep? (R)	5.78	3.59	18.3	20.0	-1.7
hyporheic seep (L)	6.55	4.07	15.1	19.6	-4.5
seep (L)	6.75	4.20	17.4	19.4	-2.0

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
side channel (L)	6.97	4.33	16.6	19.3	-2.7
seep (L)	7.22	4.49	12.7	19.0	-6.3
side channel (L)	7.54	4.69	15.7	18.9	-3.2
Dry Beaver Creek (L)	9.12	5.67	17.4	17.4	0.0
Watermelon Creek (L)	11.04	6.86	15.9	16.3	-0.4
Hoodoo Creek (L)	14.42	8.96	13.5	15.5	-2.0
seep (R)	16.51	10.26	16.1	17.9	-1.8
Unnamed/spring (L)	16.66	10.35	11.0	18.6	-7.6
Unnamed (R)	18.89	11.74	10.7	16.5	-5.8
side channel (R)	19.28	11.98	17.2	15.7	1.5
WF Beaver (L)	19.75	12.27	14.5	15.8	-1.3
side channel (R)	19.93	12.38	15.1	15.8	-0.7
Cove Creek (L)	20.87	12.97	11.9	14.9	-3.0

6.3.2 Observations

Beaver Creek was surveyed on August 7, 2010 from the mouth at the confluence with the Upper Grande Ronde River upstream to the La Grande reservoir. Over the 13.5 miles of the survey, bulk water temperatures ranged from 14.4˚C at the confluence of Cove Creek to 21.9˚C at the mouth. Ten tributaries, 17 seeps and springs, 6 side channels, and 1 pond were sampled in the imagery.

Water exits the La Grande Reservoir at 14.9˚C and immediately begins to warm for the three miles downstream of the dam; however, localized cooling can be seen at the confluences of Cove Creek (11.9˚C) and West Fork Beaver Creek (14.5˚C).

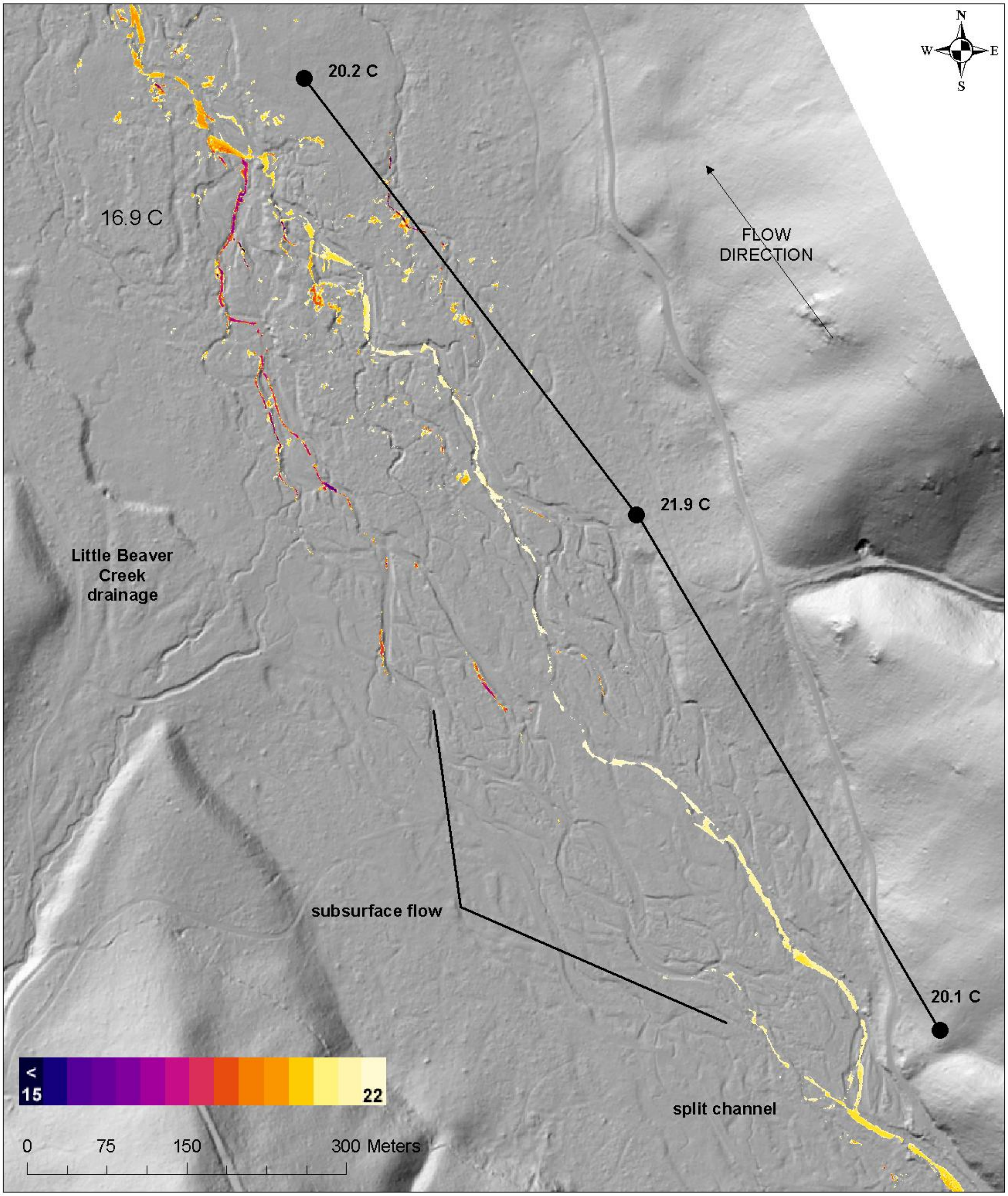
At river mile 10.35, a cold spring (11.0˚C) flowing out of an Unnamed canyon begins a cooling trend that continues downstream to river mile 8.19. Temperatures drop from 18.9˚C to 15.2˚C along this reach. Hoodoo Creek (13.5˚C) also has a further cooling impact along the reach dropping bulk water temperatures from 17.3˚C→15.5˚C.

Diurnal warming again takes control downstream of river mile 8.19 as temperatures rise from 15.2˚C to 20.2˚C over a 4-mile reach (RM 8.19→3.90). Watermelon Creek and Dry Beaver Creek do not appear have an impact on bulk water temperatures along this reach.

Below a constriction in the canyon at river mile 3.90, temperatures plateau near 20.0˚C. This plateau continues for a short distance until the stream splits into two channels at river mile 2.57. The left channel appears to go subsurface for a short distance before reemerging in the Little Beaver Creek channel at 16.9˚C. The right channel warms rapidly with lower flow. The channels rejoin at the Little Beaver Creek confluence (RM 1.75) at 20.2˚C (*Figure 13*).

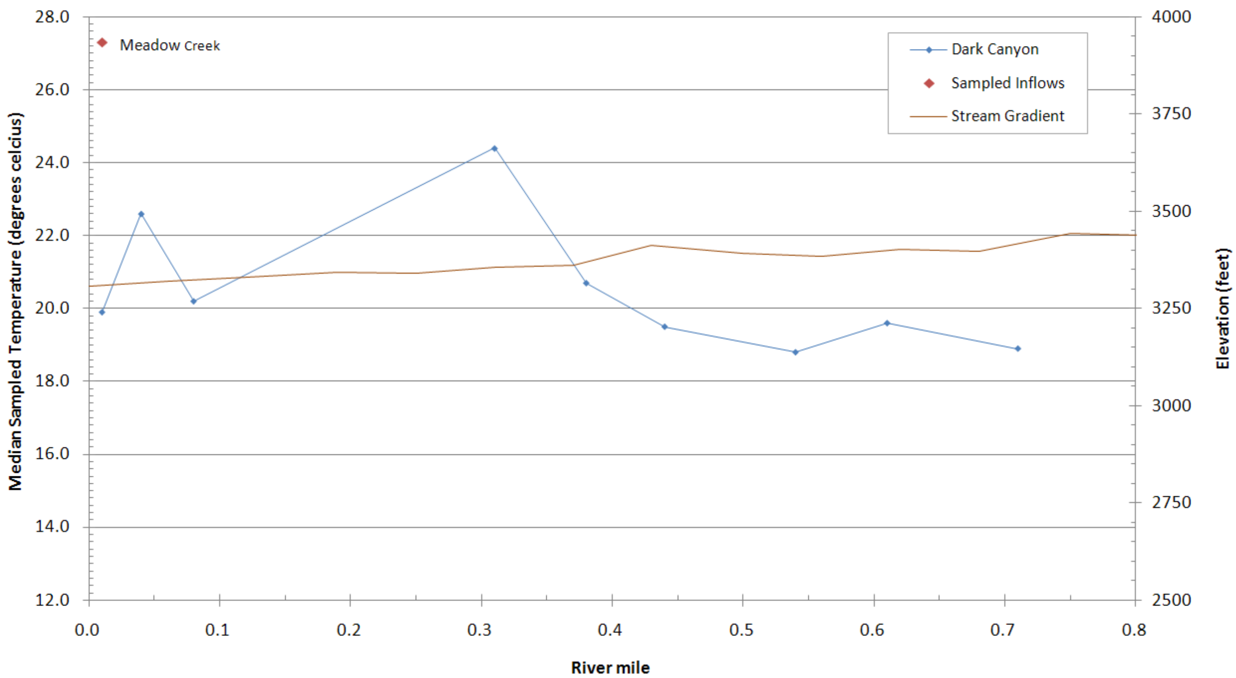
Below Little Beaver Creek, temperatures gradually warm to the profile maximum (21.9˚C) at the confluence with the Upper Grande Ronde River (24.7˚C), where Beaver Creek is a cooling influence.

Figure 13. The TIR/LiDAR image below shows the split channel between river miles 1.75-2.57. The left channel goes subsurface before reappearing at 16.9°C. The right channel warms rapidly with the decreased flows. Only the surface water temperatures are displayed in the thermal mosaic. A slight offset can be seen between the thermal imagery and the LiDAR, as the TIR images were rectified to the NAIP imagery, not the LiDAR.



6.4 Dark Canyon

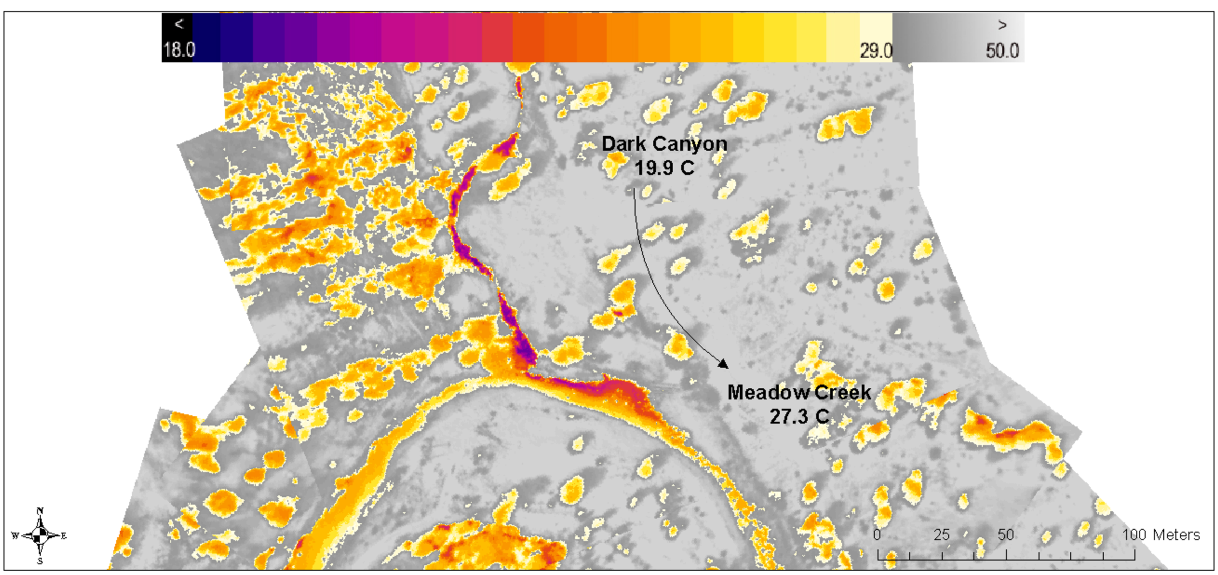
6.4.1 Longitudinal Temperature Profile



6.4.2 Observations

Less than one mile of Dark Canyon Creek was surveyed on August 7, 2010. There was little visible water for accurate sampling or trend detection. No inflows were seen along the surveyed reach. Dark Canyon acts as a cooling source to Meadow Creek (*Figure 14*).

Figure 14. The TIR image below shows the confluence of Dark Canyon and Meadow Creek. Dark Canyon is a cooling source for Meadow Creek. The TIR image is displayed with the Meadow Creek color ramp.



6.5 Five Points Creek

6.5.1 Longitudinal Temperature Profile

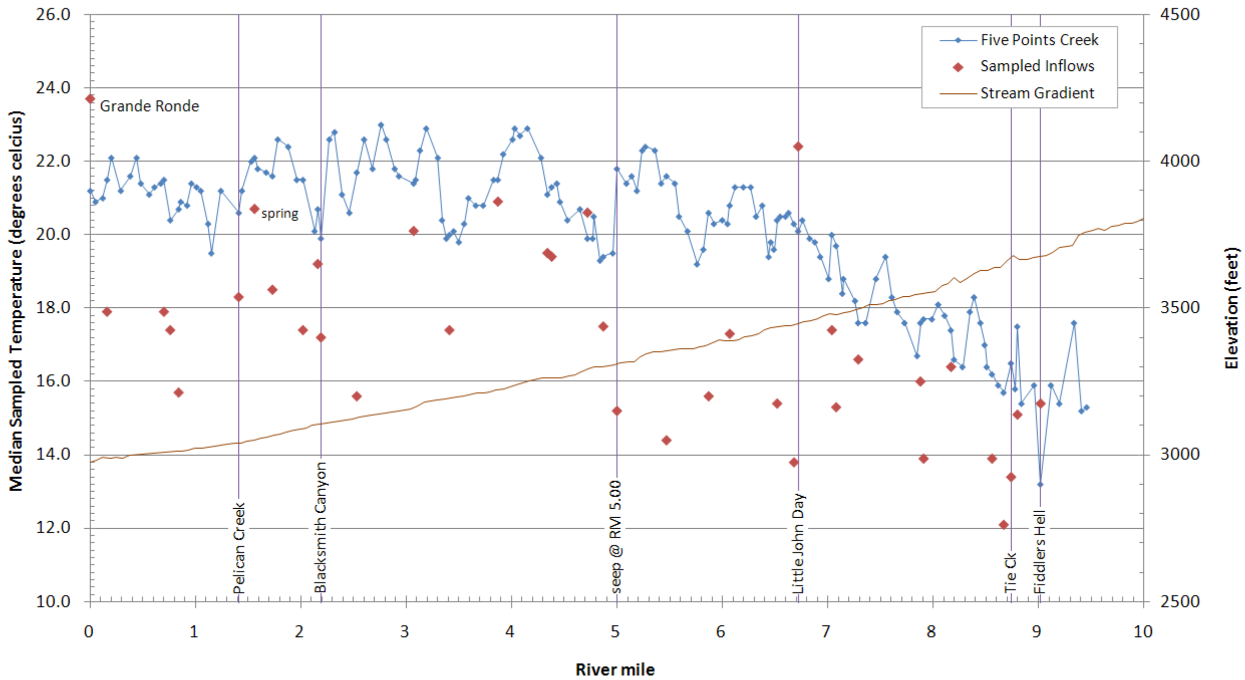


Table 8. Tributaries and other surface inflows sampled along Five Points Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Grande Ronde ( )	0.00	0.00	23.7	21.2	2.5
seep (R)	0.25	0.16	17.9	21.5	-3.6
seep/shadow (R)	1.13	0.70	17.9	21.5	-3.6
seep/shadow (R)	1.22	0.76	17.4	20.4	-3.0
spring in channel (R)	1.36	0.84	15.7	20.7	-5.0
Pelican Creek (R)	2.27	1.41	18.3	20.6	-2.3
Unnamed (L)	2.51	1.56	20.7	22.1	-1.4
seep (L)	2.78	1.73	18.5	21.6	-3.1
seep/shadow (R)	3.26	2.02	17.4	21.5	-4.1
hyporheic seep (R)	3.48	2.16	19.2	20.7	-1.5
Blacksmith Canyon (L)	3.53	2.19	17.2	19.9	-2.7
seep (L)	4.06	2.53	15.6	21.7	-6.1
seep (L)	4.94	3.07	20.1	21.4	-1.3
seep (L)	5.48	3.41	17.4	20.0	-2.6
seep (L)	6.22	3.87	20.9	21.5	-0.6
seep (L)	6.98	4.34	19.5	21.1	-1.6
Unnamed (L)	7.05	4.38	19.4	21.3	-1.9
side channel (L)	7.59	4.72	20.6	19.9	0.7
seep/shadow (L)	7.84	4.87	17.5	19.4	-1.9
seep (L)	8.05	5.00	15.2	21.8	-6.6
Unnamed (L)	8.81	5.47	14.4	21.6	-7.2
side channel (L)	9.44	5.87	15.6	20.6	-5.0
seep (L)	9.77	6.07	17.3	20.8	-3.5

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
seeps (L)	10.50	6.52	15.4	20.4	-5.0
side channel (L)	10.75	6.68	13.8	20.3	-6.5
side channel (R)	10.82	6.72	22.4	20.1	2.3
side channel (R)	11.33	7.04	17.4	20.0	-2.6
side channel (L)	11.39	7.08	15.3	19.7	-4.4
hyporheic seep (L)	11.73	7.29	16.6	17.6	-1.0
side channel (L)	12.68	7.88	16.0	17.6	-1.6
side channel (L)	12.73	7.91	13.9	17.7	-3.8
hyporheic seep (L)	13.14	8.17	16.4	17.4	-1.0
seep (L)	13.77	8.56	13.9	16.2	-2.3
spring (L)	13.95	8.67	12.1	15.7	-3.6
Tie Creek (L)	14.07	8.74	13.4	16.5	-3.1
spring/side channel (R)	14.17	8.80	15.1	17.5	-2.4
Fiddlers Hell (L)	14.51	9.02	15.4	13.2	2.2

6.5.2 Observations

Five Points Creek was surveyed on August 7, 2010 from the mouth at Hilgard Junction for 9.5 miles upstream to just beyond Fiddlers Hell Creek. Bulk water temperatures ranged from 13.2˚C at Fiddlers Hell to 23.0˚C at river mile 2.76. Seven tributaries, 8 side channels, and 21 seeps and springs were sampled in the imagery.

The longitudinal profile was highly variable due to numerous groundwater contributions seen throughout the survey which result in strong localized cooling troughs. However, the overall shape indicates a typical pattern of warming in the upper 5.5 miles followed by a plateau between 20.0˚C and 22.0˚C. The stream is shallow and rocky throughout its length and the strong groundwater returns indicate a gaining/losing stream system with a shallow water table.

Notable cooling sources include Fiddlers Hell (15.4˚C), the seep at river mile 5.00 (15.2˚C), Blacksmith Canyon (17.2˚C) and the spring at river mile 0.84 (15.7˚C). Five Points Creek (21.2˚C) was a cooling source to the Upper Grande Ronde River (23.7˚C).

6.6 McCoy Creek

6.6.1 Longitudinal Temperature Profile

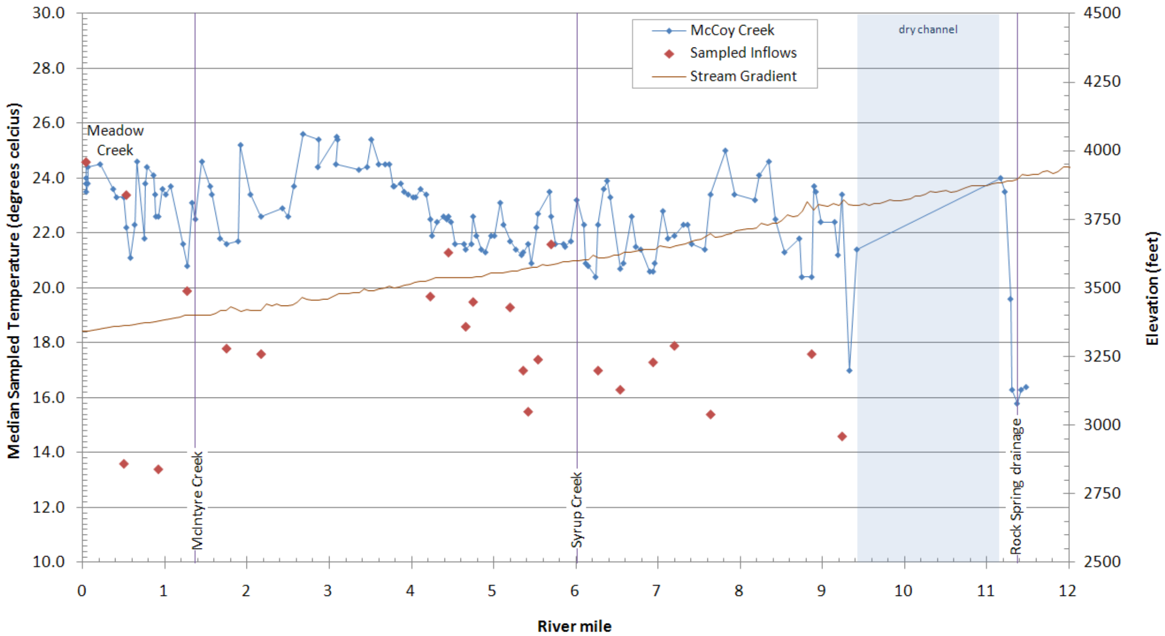


Table 9. Tributaries and other surface inflows sampled along McCoy Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Meadow Creek ( )	0.07	0.04	24.6	24.6	0.0
spring in pond (L)	0.81	0.50	13.6	23.3	-9.7
old channel (L)	0.85	0.53	23.4	22.2	1.2
spring off channel (L)	1.48	0.92	13.4	22.6	-9.2
pond (R)	2.04	1.27	19.9	20.8	-0.9
seep/shadow? (R)	2.82	1.75	17.8	21.6	-3.8
spring? (R)	3.49	2.17	17.6	22.6	-5.0
seep? (R)	6.80	4.23	19.7	22.5	-2.8
Unnamed (R)	7.17	4.45	21.3	22.6	-1.3
seep (R)	7.50	4.66	18.6	21.4	-2.8
seep? (R)	7.64	4.75	19.5	22.6	-3.1
seep/side channel (R)	8.36	5.20	19.3	21.7	-2.4
spring (L)	8.63	5.36	17.0	21.3	-4.3
spring (L)	8.72	5.42	15.5	21.6	-6.1
hyporheic flow (L)	8.91	5.54	17.4	22.7	-5.3
seep/shadow (R)	9.18	5.70	21.6	22.6	-1.0
spring? (R)	10.09	6.27	17.0	22.3	-5.3
spring? (R)	10.53	6.54	16.3	20.7	-4.4
seep/shadow (L)	11.16	6.94	17.3	20.6	-3.3
seep/shadow (R)	11.59	7.20	17.9	21.9	-4.0
Unnamed (L)	12.29	7.64	15.4	23.4	-8.0
spring? (R)	14.27	8.87	17.6	20.4	-2.8
spring/shadow (R)	14.87	9.24	14.6	23.4	-8.8

6.6.2 Observations

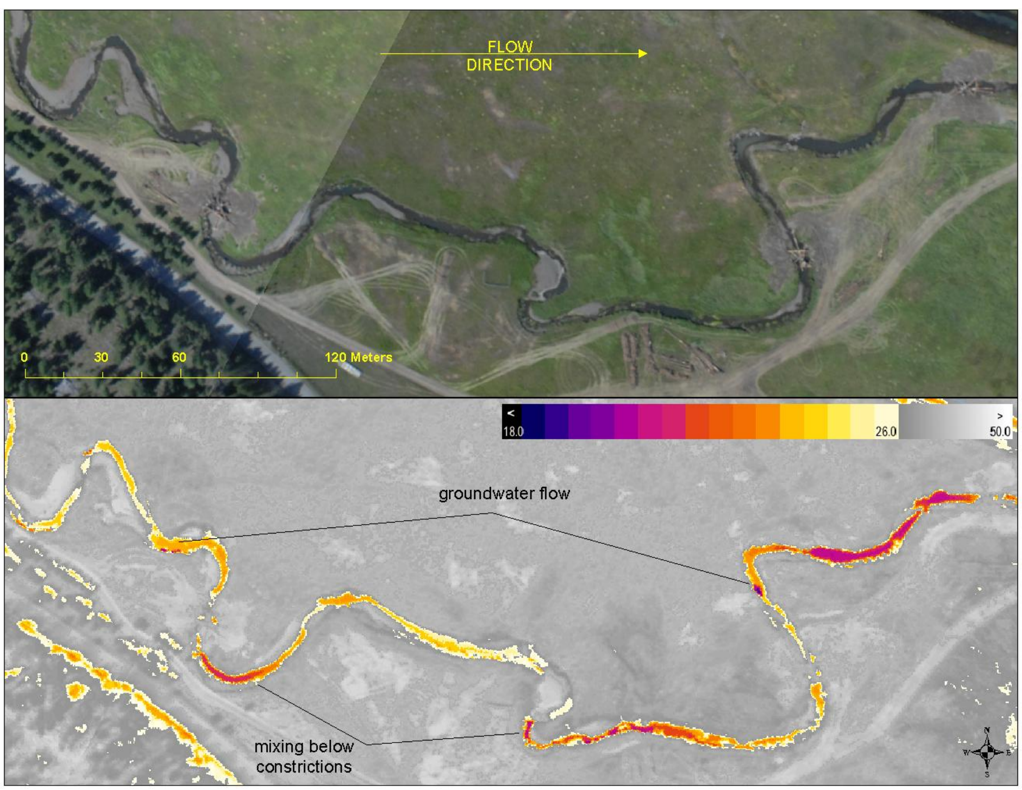
McCoy Creek was surveyed on August 7, 2010 from Meadow Creek upstream to the Rock Spring drainage (RM 11.37). Two unnamed tributaries, 18 seeps and springs, and two pond features were sampled in the imagery.

The minimum survey temperature occurred at the confluence with the Rock Spring drainage (15.8˚C). Immediately following, the stream channel went dry between river miles 9.42-11.16. The stream re-emerges at river mile 9.42 at 21.4˚C. Temperatures are highly variable until river mile 4.66, but center around 22.0˚C. There were many cold features sampled along the reach, but due to heavy shadows, many could not be confirmed as certain groundwater inflows.

Downstream of river mile 4.66, a warming trend is seen for almost two miles with temperatures rising from 21.4˚C→25.6˚C. Temperatures peaked at river mile 2.68 in a very narrow section of canyon.

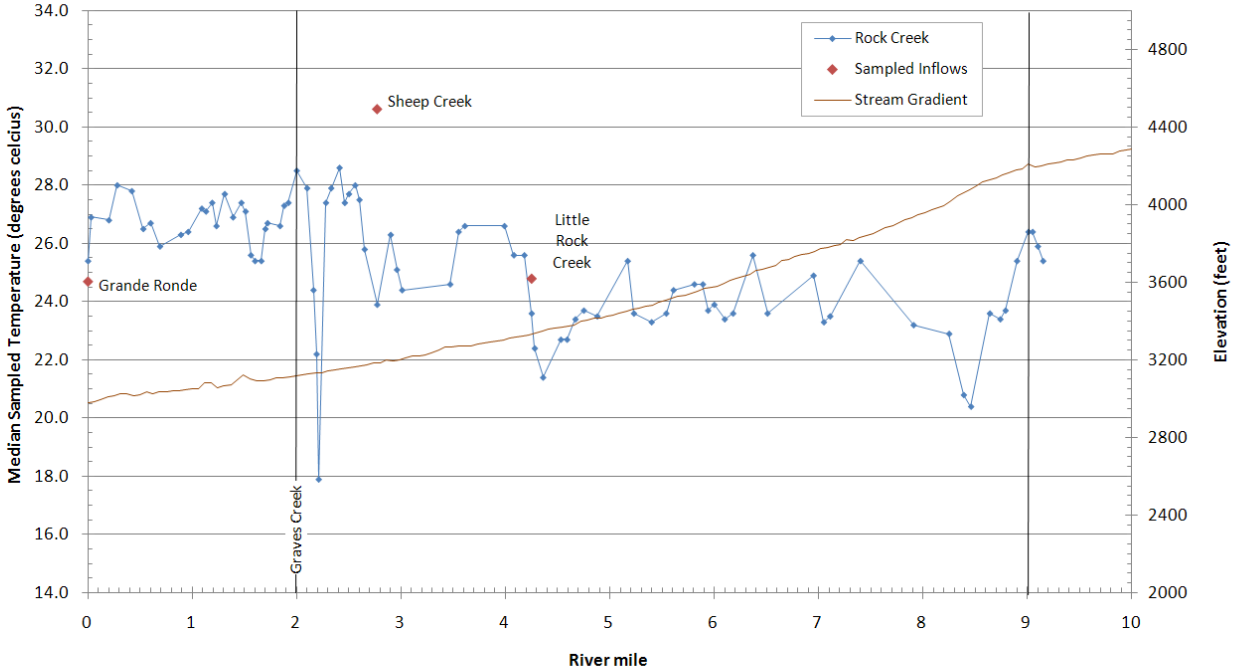
Below river mile 2.68, the canyon opens into a wide valley where a major channel restoration effort is underway. Along this reach, the TIR imagery shows a high degree of localized spatial variability in stream surface temperatures. The imagery suggests that there areas of shallow sub-surface upwelling particularly around woody debris check dams and below channel constrictions. The imagery also suggests that there might be some degree of surface stratification between these mixing zones (*Figure 15*).

Figure 15. The TIR/natural color image pair below shows the spatial variability in surface temperatures through the restoration area of the lower meadow of McCoy Creek.



6.7 Rock Creek

6.7.1 Longitudinal Temperature Profile



6.7.2 Observations

Rock Creek was surveyed on August 7, 2010 from the Upper Grande Ronde River 9 miles upstream to an unnamed bridge. Two tributaries were sampled: Sheep Creek at river mile 2.77 (30.6°C) and Little Rock Creek (RM 4.25, 24.8°C). The stream was very shallow and rocky throughout the surveyed area, which leads to increased variability due to mixed pixel sampling. Heavy shadows also obscured the stream in areas, making sampling and interpretation of the imagery less certain.

At the upstream end of the survey, temperatures immediately begin to cool as the stream exits an open meadow area and flows into a narrow forested canyon. Temperatures drop from 26.4°C→20.4°C over a 1/2 -mile reach (RM 8.95→8.46). Downstream of this point, the canyon widens slightly and temperatures rebound and plateau (with a good deal of variability) to near 24.0°C.

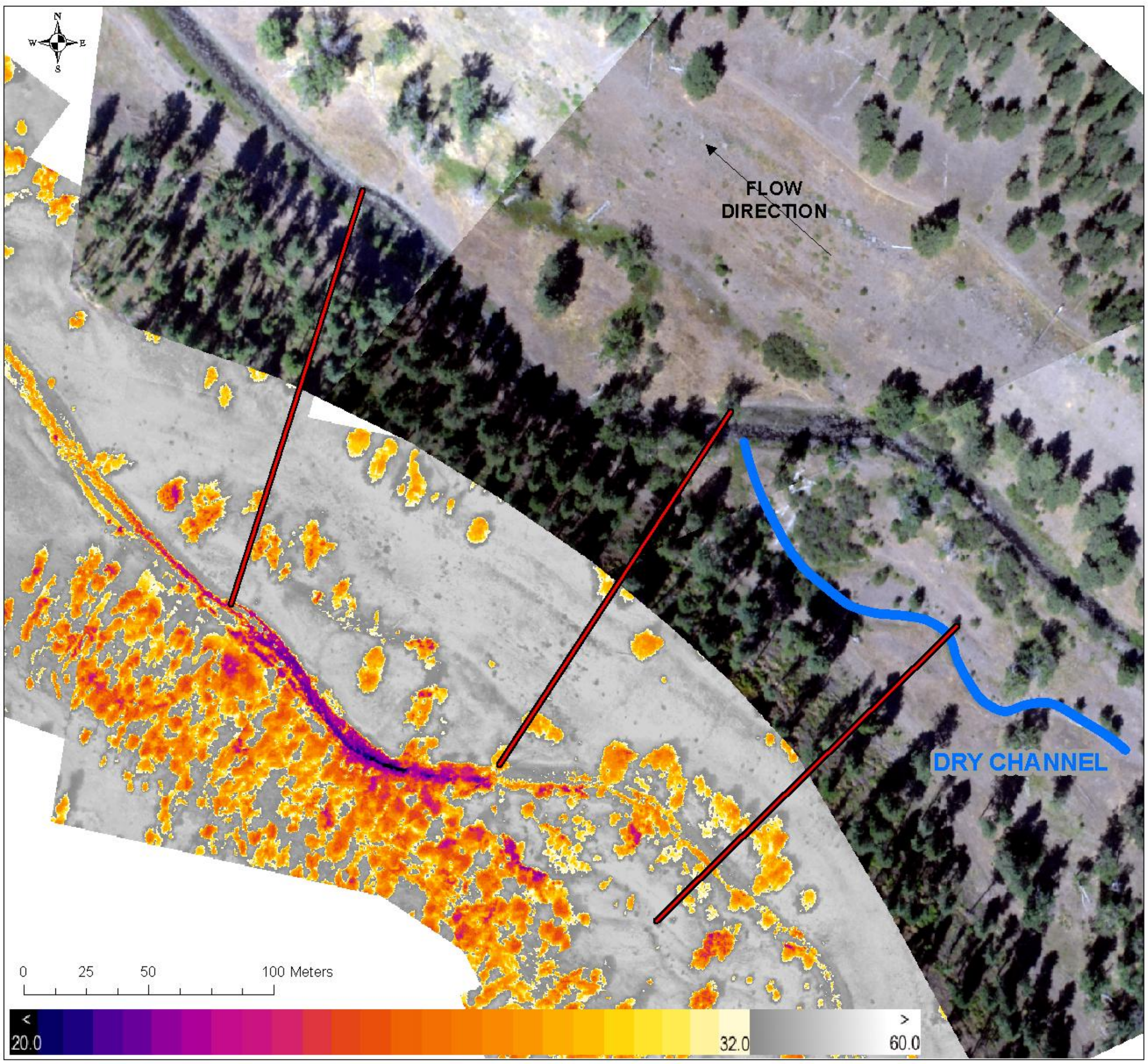
Just upstream of Little Rock Creek, temperatures again drop sharply from 25.4°C→21.4°C in less than one mile (RM 5.17→4.36). There is no apparent change in the canyon characteristics or vegetation regime along this reach, but the temperature decrease suggests increased groundwater interaction.

Temperatures warm rapidly from river mile 4.36→3.99 as Rock Creek merges with Little Rock Creek, though Little Rock Creek contains no water upstream of the immediate confluence. Sheep Creek (30.6°C) is a warming influence raising bulk water temperatures by over 4.0°C (23.9°C→28.0°C).

A third cooling spike occurs downstream of river mile 2.41 with sudden appearance of cooler water in the channel (28.6°C→17.9°C). A similar thermal signature is seen when streams go subsurface for a distance and re-emerge after mixing with a shallow groundwater table, as seen at the Beaver Creek/Little Beaver Creek confluence. In this case, the main channel does not dewater; however there is a dry side channel immediately upstream which is possibly providing a subsurface flow route allowing for hyporheic interaction (*Figure 16*).

Though not contributing surface water to the system, the Graves Creek drainage (RM 2.00) is likely a contributing factor to the cooling seen below river mile 2.00 (28.5°C→25.4°C). The lower 1 mile of stream shows temperatures fluctuating near 27.0°C, with Rock Creek acting as a warming source to the Upper Grande Ronde (24.7°C) at the confluence.

Figure 16. The TIR/natural color image pair below shows the groundwater feature at river mile 2.41. The natural color image is unscaled.



6.8 Spring Creek

6.8.1 Longitudinal Temperature Profile

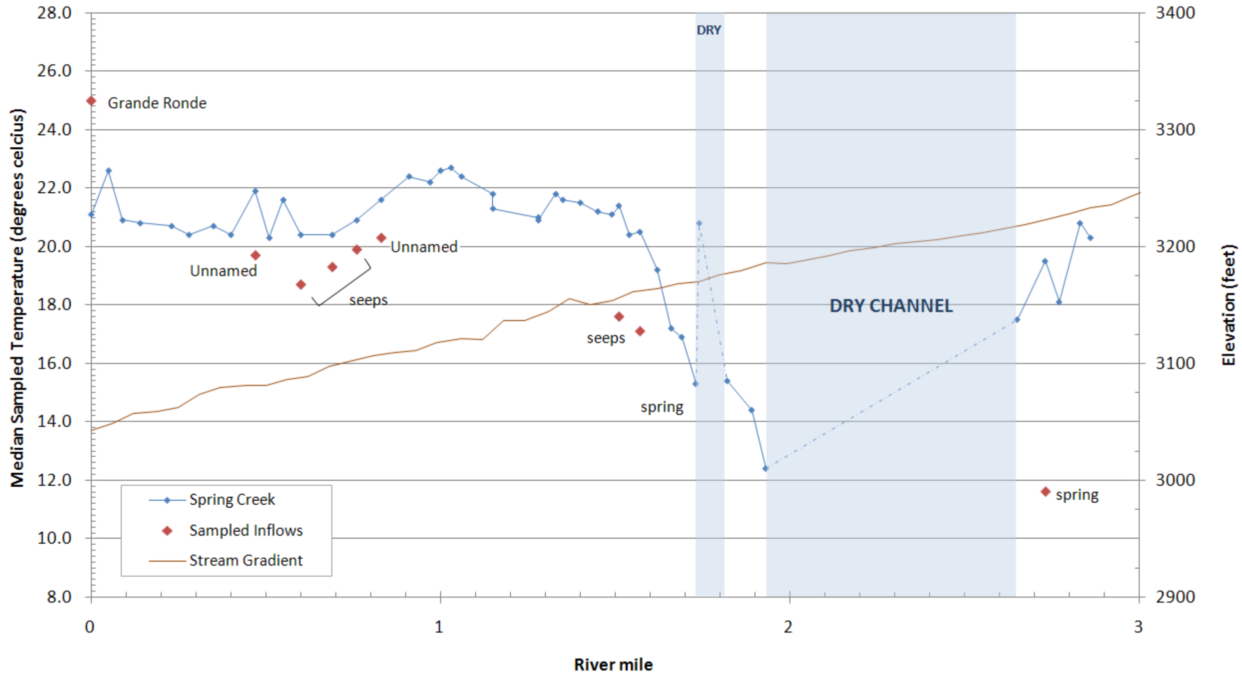


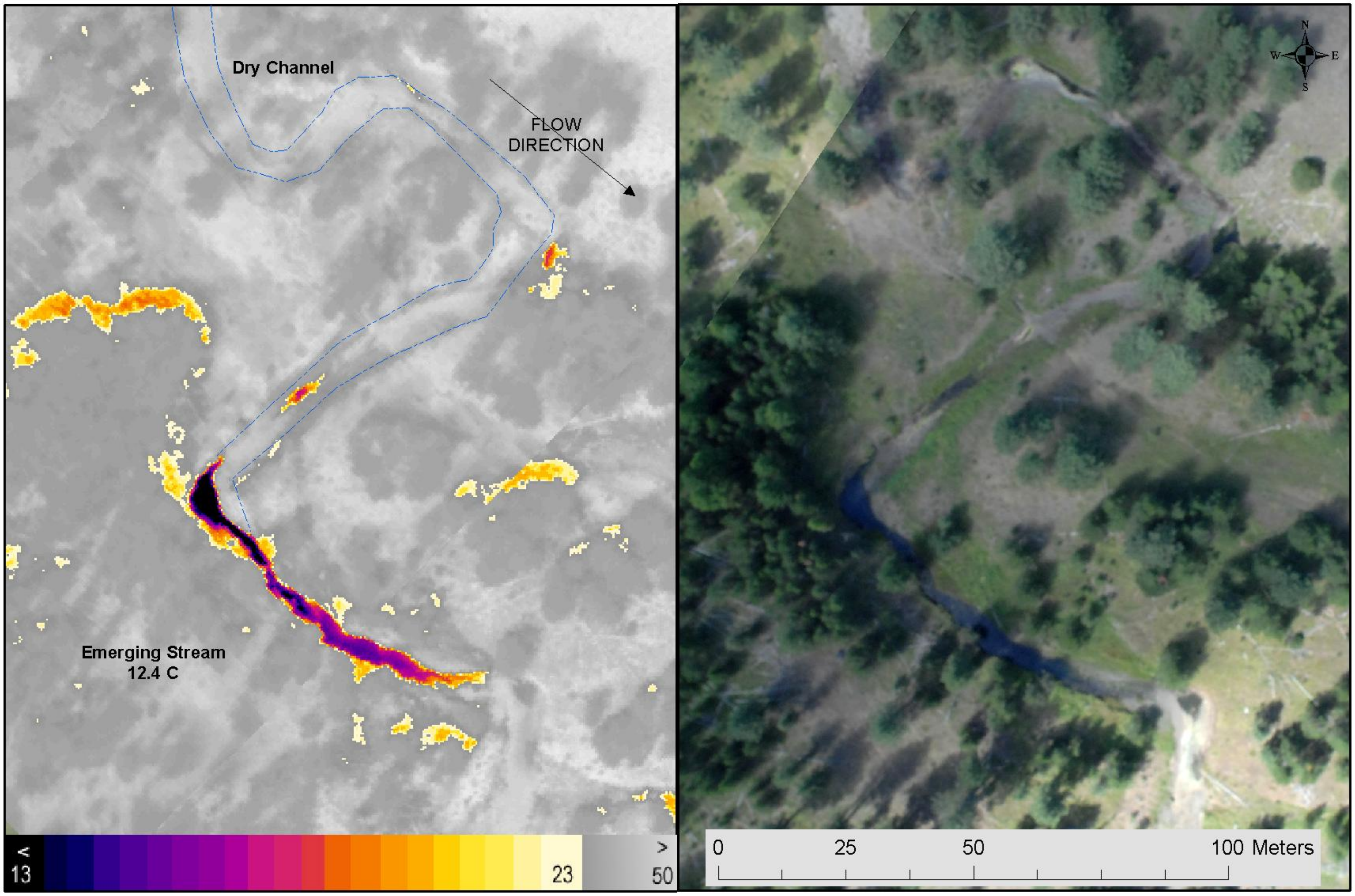
Table 10. Tributaries and other surface inflows sampled along Spring Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Grande Ronde R. ( )	0.00	0.00	25.0	21.1	3.9
Unnamed? (R)	0.75	0.47	19.7	21.9	-2.2
seep/side channel (R)	0.97	0.60	18.7	20.4	-1.7
seep (R)	1.10	0.69	19.3	20.4	-1.1
seep/shadow? (R)	1.22	0.76	19.9	20.9	-1.0
Unnamed/shadow? (R)	1.34	0.83	20.3	21.6	-1.3
seep (R)	2.43	1.51	17.6	21.4	-3.8
seeps (R)	2.53	1.57	17.1	20.5	-3.4
spring (R)	4.39	2.73	11.6	19.5	-7.9

6.8.2 Observations

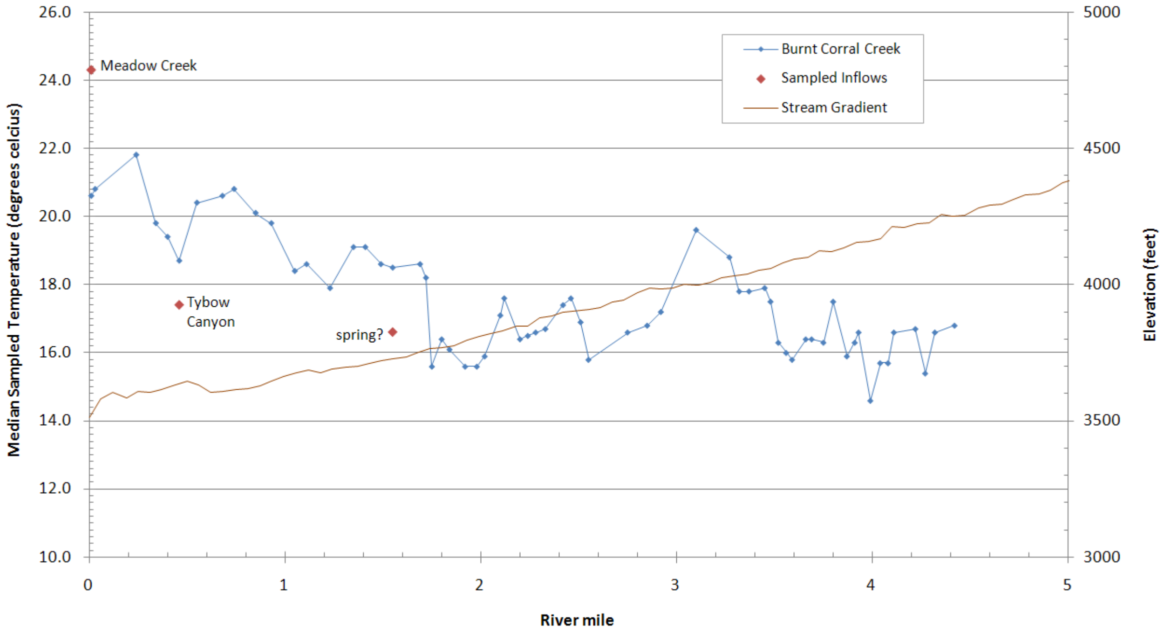
Three miles of Spring Creek were surveyed on August 7, 2010. The upper reach of the survey shows temperatures between 17.5˚C and 20.8˚C before the stream goes subsurface at river mile 2.65. At river mile 1.93, the stream emerges with the signature of a spring at 12.1˚C (*Figure 17*). This gaining/losing stream pattern continues downstream to river mile 1.73. Below river mile 1.73, flows stabilize and warm until river mile 1.51. Downstream of river mile 1.51, the stream enters a narrower section of canyon and temperatures begin to plateau near 22.0˚C with further cooling seen below river mile 0.91.

Figure 17. The TIR/Natural Color image pair below shows the emerging stream at river mile 1.93. When stream flows go subsurface, mix with the hyporheic or shallow groundwater zone and re-emerge, the resulting thermal return is similar to a spring.



6.9 Burnt Corral Creek

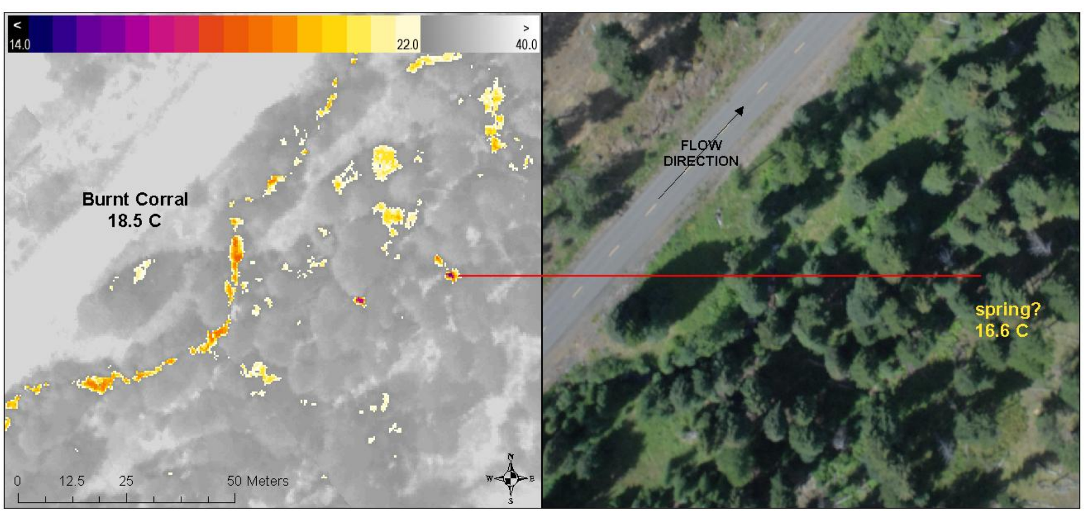
6.9.1 Longitudinal Temperature Profile



6.9.2 Observations

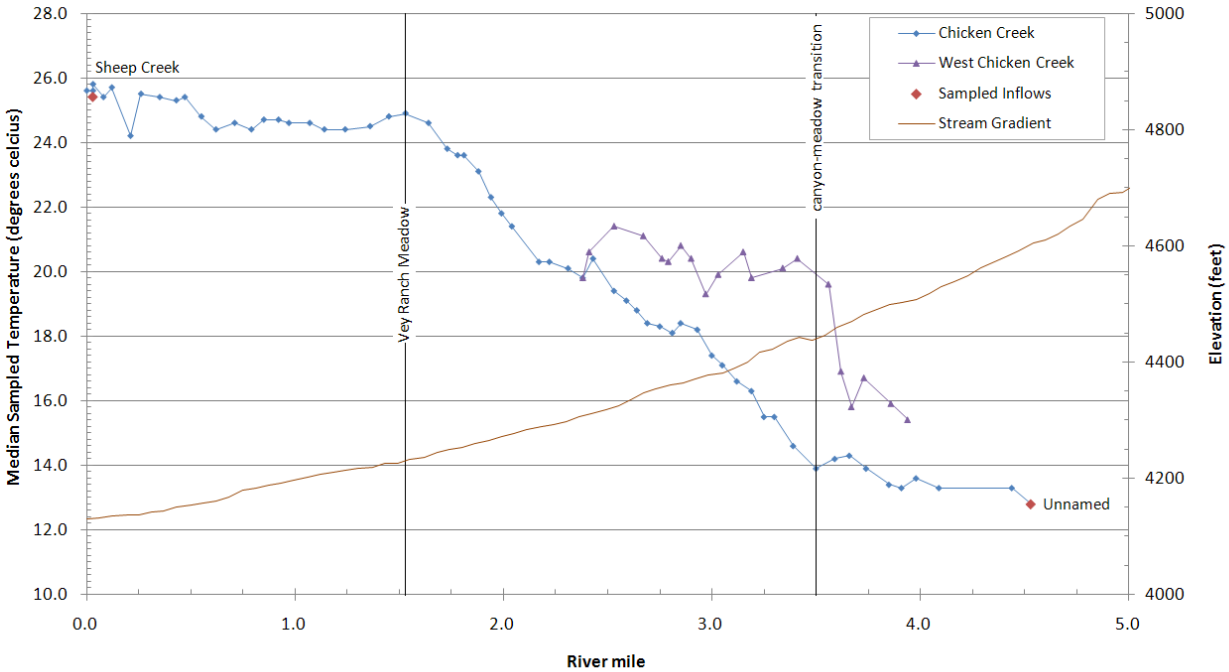
Approximately 4.5 miles of Burnt Corral Creek were surveyed on August 8, 2010 from the mouth upstream to East Burnt Corral Creek. The creek was very narrow with heavy streamside vegetation making sampling difficult. The visible pools that could be sampled resulted in a highly variable longitudinal profile. Only two inflows were sampled: Tybow Canyon (17.4°C) and a possible spring at river mile 1.55 (16.6°C) (*Figure 18*). It is difficult to interpret any thermal trends due to the variability seen in the profile.

Figure 18. The TIR/natural color image pair below shows the potential small spring at river mile 1.55. Even with high resolution color imagery, it was difficult to discern features in such a narrow, heavily vegetated stream.



6.10 Chicken Creek/West Chicken Creek

6.10.1 Longitudinal Temperature Profile



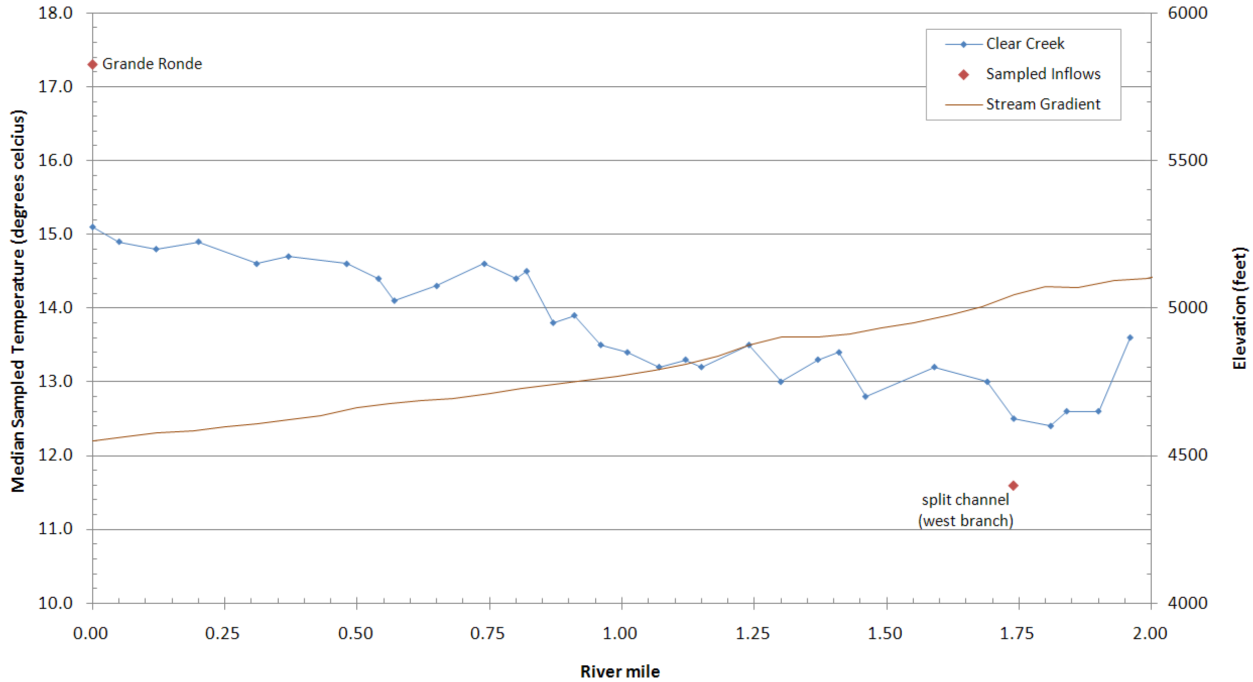
6.10.2 Observations

Just under five miles of Chicken Creek and 1.5 miles of West Chicken Creek were surveyed on August 8, 2010. One unnamed inflow (12.8˚C) was sampled to Chicken Creek at the head of the survey. Chicken Creek shows subsurface influences above river mile 3.50 with temperatures staying depressed between 12.8˚C and 14.3˚C. Downstream of river mile 3.50, the canyon widens slightly and the creek enters a more open meadow regime. Temperatures warm rapidly for 2 miles to river mile 1.53 (14.0˚C→24.9˚C). As Chicken Creek enters the broad Vey Ranch meadow, temperatures again stabilize near 25.0˚C as there is likely groundwater interaction between Sheep Creek, Dry Creek, and Chicken Creek.

West Chicken Creek sampled warmer than Chicken Creek, though the narrowness of the creek and the short distance of the survey preclude drawing any significant conclusions from the longitudinal profile.

6.11 Clear Creek

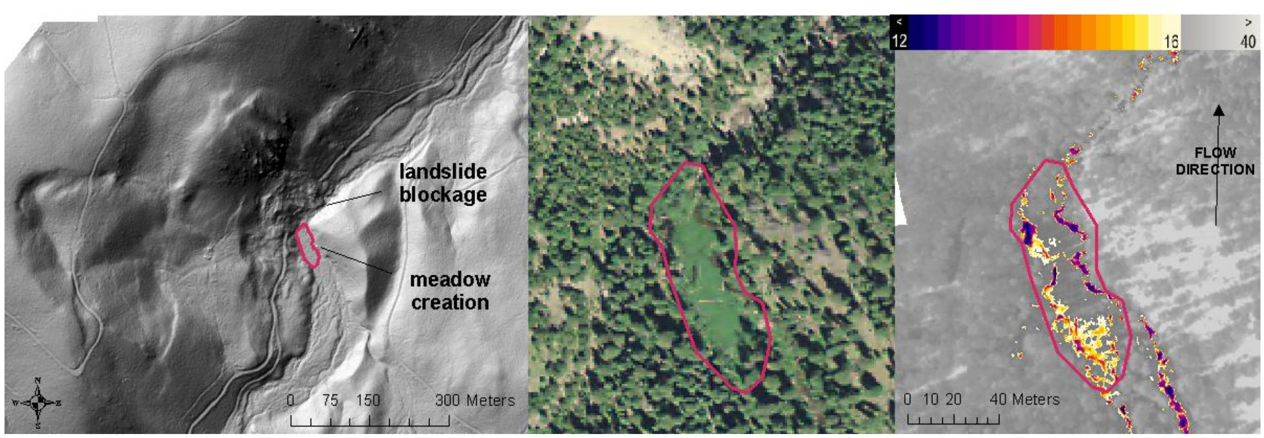
6.11.1 Longitudinal Temperature Profile



6.11.2 Observations

Two miles of Clear Creek were sampled on August 8, 2010. Temperatures ranged from 12.4˚C→15.1˚C. The divided channel seen at the upper end of the survey was the only sampled feature (11.6˚C). The meadow at that location was likely created by water pooling upstream of the landslide seen in the LiDAR imagery (*Figure 19*). Further investigation of aerial photos would be needed to determine the age of the landslide.

Figure 19. The bare-earth LiDAR/NAIP/TIR image below shows the landslide and meadow complex at river mile 1.74.



6.12 Fly Creek

6.12.1 Longitudinal Temperature Profile

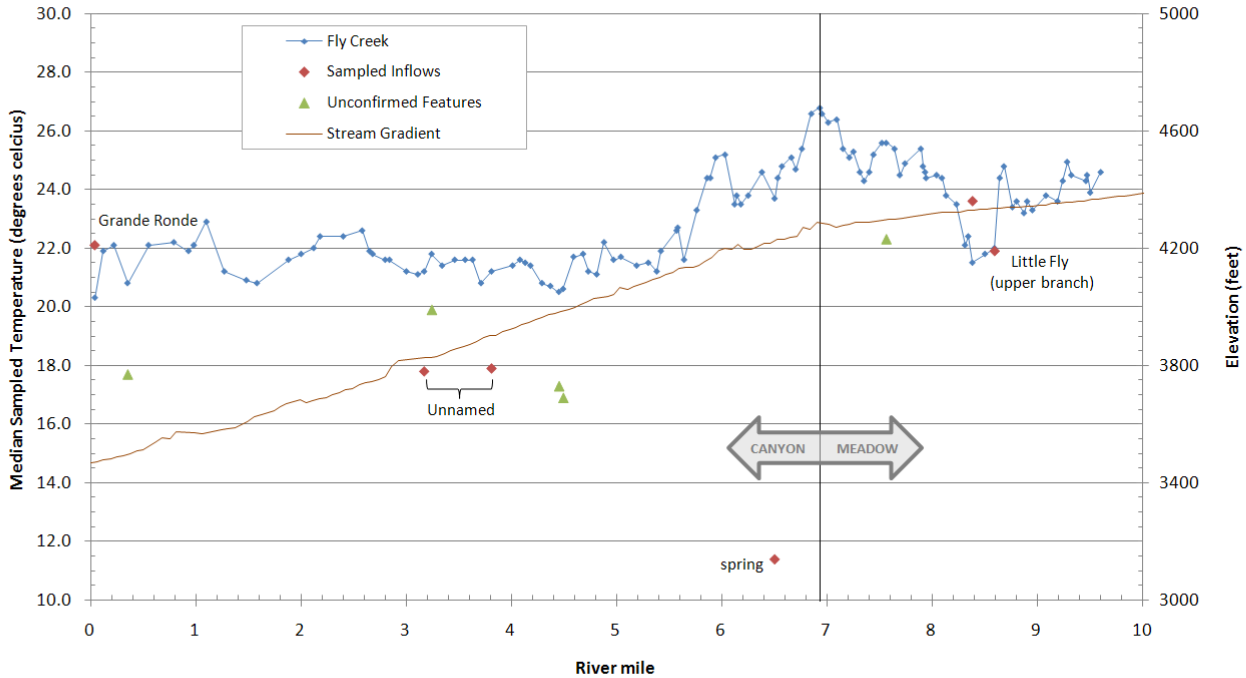


Table 11. Tributaries and other surface inflows sampled along Fly Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Grande Ronde ( )	0.06	0.04	22.1	20.3	1.8
Unnamed (R)	5.10	3.17	17.8	21.2	-3.4
Unnamed (L)	6.13	3.81	17.9	21.2	-3.3
spring (L)	10.45	6.50	11.4	23.7	-12.3
Little Fly Ck-lower (R)	13.48	8.38	23.6	21.5	2.1
Little Fly Ck-upper (R)	13.83	8.59	21.9	22.0	-0.1
Unconfirmed Features					
Tributaries	**Kilometer**	**River Mile**	**Tributary Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
seep? (R)	0.56	0.35	17.7	20.8	-3.1
seep? (L)	5.22	3.24	19.9	21.8	-1.9
seep? (R)	7.16	4.45	17.3	20.5	-3.2
spring? (R)	7.22	4.49	16.9	20.6	-3.7
seep? (L)	12.17	7.56	22.3	25.6	-3.3

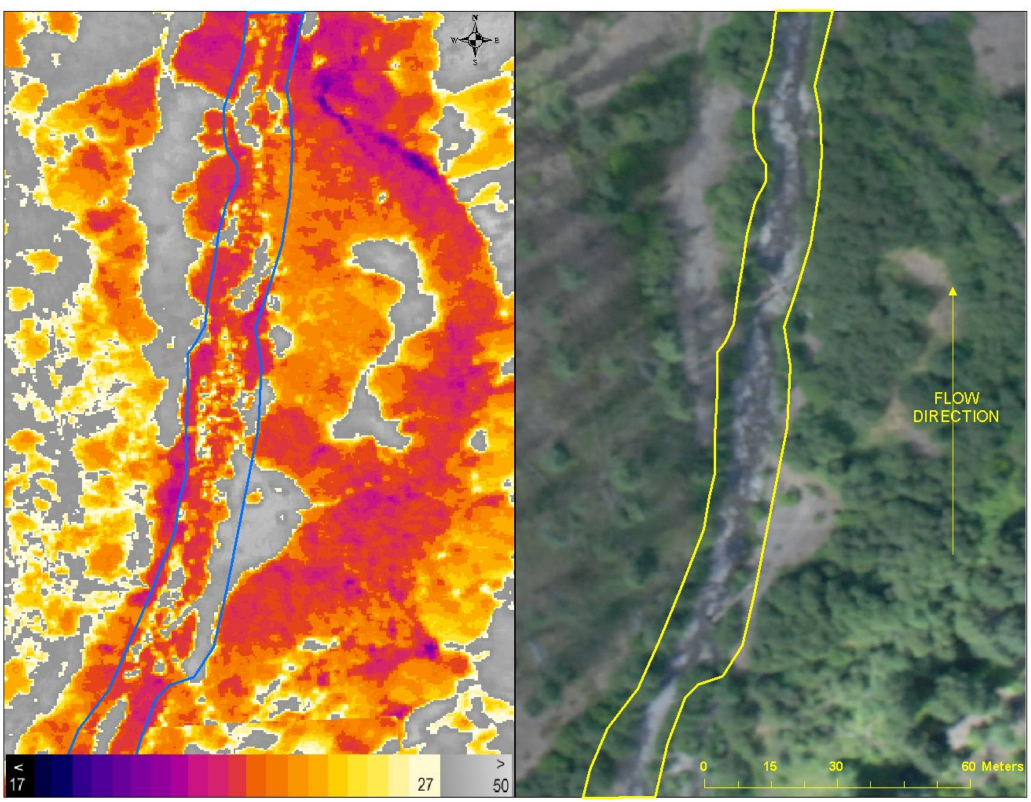
6.12.2 Observations

Approximately ten miles of Fly Creek were surveyed on August 8, 2010 from the mouth at the Grande Ronde River upstream to Fly Valley. The thermal imagery was difficult to sample given that the stream was very shallow in the lower reaches with many visible rocks which leads to mixed pixel sampling and increased variability. In addition, the vegetation had radiant temperatures which were colder than the stream temperature making it difficult to distinguish springs and seeps (*Figure 20*). The cooler temperatures from the vegetation were characteristic of rapid terrestrial cooling due to cloud cover. Five definite inflows were sampled as well as 5 features that could not be confirmed with the available imagery.

The longitudinal profile was interesting in that the stream cools as it flows downstream. From river mile 9.60 downstream to 6.93, the stream flows through Fly Valley, a heavily grazed open meadow with no streamside vegetation. Temperatures sampled near 24.0°C until the confluence with Little Fly Creek, which was a cooling source that lowered temperatures from 24.4°C→21.6°C. Downstream of Little Fly Creek, bulk water temperatures warmed to the survey maximum of 26.8°C at river mile 6.93.

At river mile 6.93, the canyon constricts severely, steepens, and becomes more forested. This increased vegetative cover as well as subsurface influence due to the change in valley width and stream gradient likely contributes to the cooling seem downstream until river mile 4.45 (26.8°C→20.5°C). Below this point, temperatures plateau near 21.5°C in the final reach to the mouth.

Figure 20. The TIR/natural color image pair below shows the difficulty in locating the stream when terrestrial vegetation displays cooler radiant temperatures than the stream.



6.13 Meadow Creek

6.13.1 Longitudinal Temperature Profile

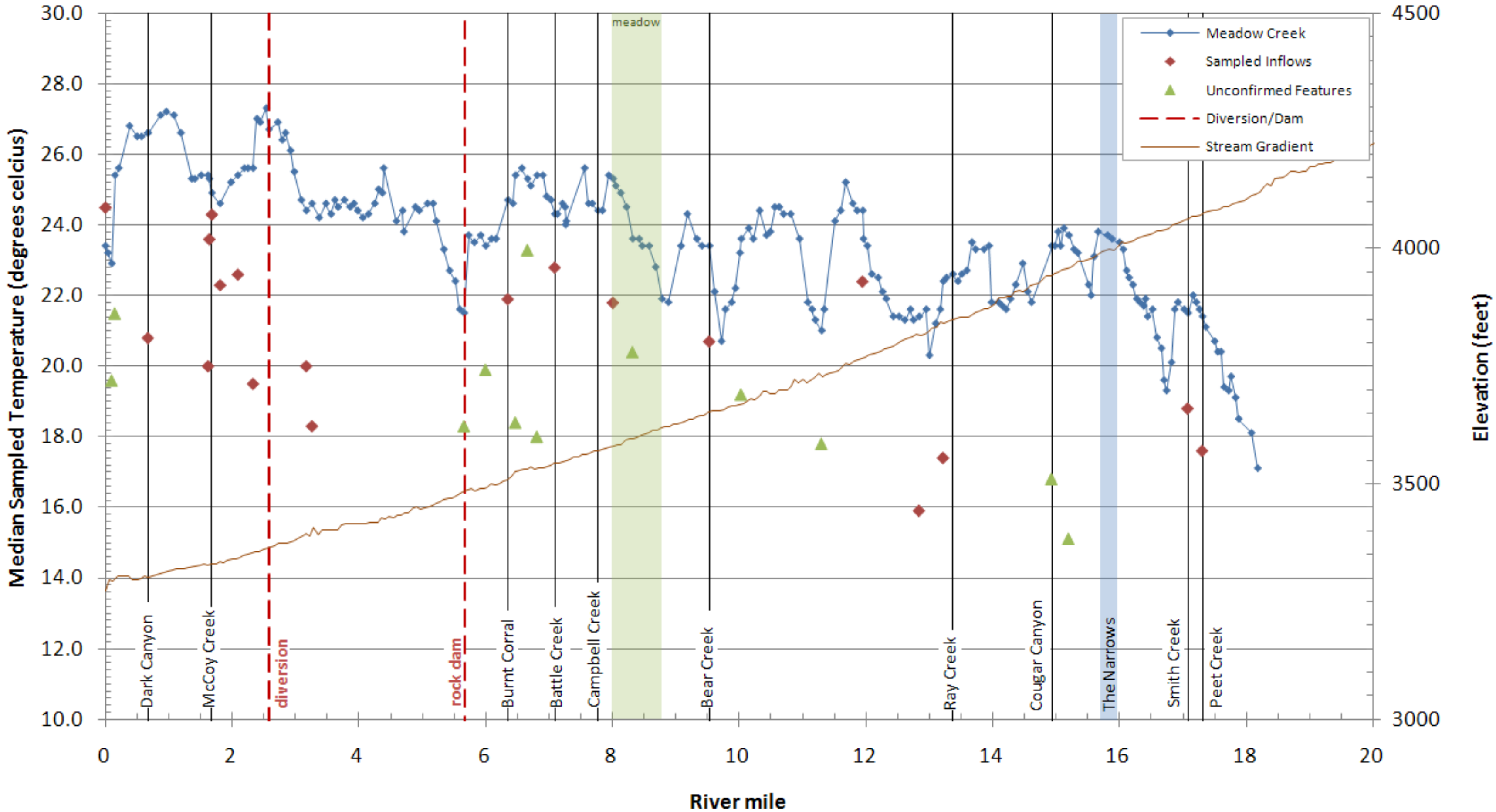


Figure 21. Median sampled temperatures versus river mile for Meadow Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 12.

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

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Grande Ronde ( )	0.00	0.00	24.5	23.4	1.1
Dark Canyon (L)	1.07	0.67	20.8	26.6	-5.8
Starkey Creek (R)	2.61	1.62	20.0	25.4	-5.4
hyporheic seep (R)	2.64	1.64	23.6	25.3	-1.7
McCoy Creek (L)	2.71	1.68	24.3	24.9	-0.6
drain (R)	2.91	1.81	22.3	24.6	-2.3
Old McCoy (L)	3.36	2.09	22.6	25.4	-2.8
Starkey Creek seep (R)	3.74	2.33	19.5	25.6	-6.1
seeps in pool (R)	5.11	3.17	20.0	24.4	-4.4
seep (L)	5.24	3.26	18.3	24.6	-6.3
Burnt Corral (R)	10.21	6.35	21.9	24.7	-2.8
Battle Creek (R)	11.41	7.09	22.8	24.3	-1.5
side channel (L)	12.89	8.01	21.8	25.3	-3.5
Bear Creek (R)	15.33	9.53	20.7	23.4	-2.7
seep (L)	19.23	11.95	22.4	24.4	-2.0
side channel (R)	20.67	12.84	15.9	21.4	-5.5
seep/side channel (R)	21.27	13.22	17.4	22.4	-5.0
Smith Creek (L)	27.48	17.08	18.8	21.5	-2.7
Peet Creek (R)	27.86	17.31	17.6	21.4	-3.8
Unconfirmed Features					
Tributaries	**Kilometer**	**River Mile**	**Tributary Temp (˚C)**	**Mainstem Temp (˚C)**	**Difference**
seep/shadow? (R)	0.16	0.10	19.6	22.9	-3.3
seep/shadow? (R)	0.24	0.15	21.5	25.4	-3.9
seep/shadow? (R)	9.10	5.66	18.3	21.5	-3.2
seep? (L)	9.66	6.00	19.9	23.4	-3.5
side channel/seep? (R)	10.41	6.47	18.4	25.4	-7.0
seep/veg? (R)	10.73	6.66	23.3	25.3	-2.0
veg/shadow? (R)	10.95	6.81	18.0	25.4	-7.4
seep/veg? (R)	13.39	8.32	20.4	23.6	-3.2
seep/rock outcrop? (R)	16.14	10.03	19.2	23.6	-4.4
seep/shadow? (R)	18.18	11.30	17.8	21.0	-3.2
Cougar Cyn/shadow? (R)	24.02	14.93	16.8	23.4	-6.6
seep/shadow? (R)	24.46	15.20	15.1	23.7	-8.6

6.13.2 Observations

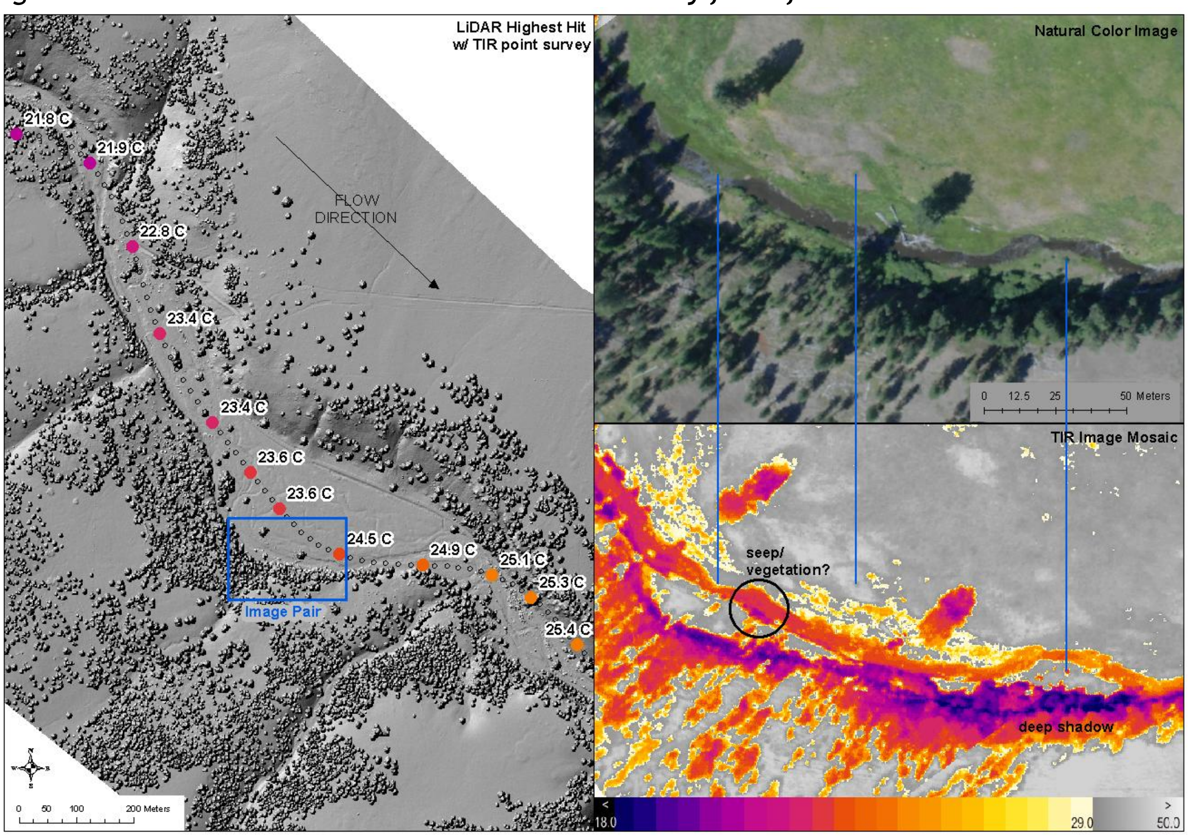
Eighteen miles of Meadow Creek were surveyed on August 8, 2010 from the mouth at the Grande Ronde River upstream to Waucup Creek. Bulk water temperatures were highly variable but ranged from 17.1˚C at the upper end of the survey to 27.3˚C at the diversion at river mile 2.58 (*Figure 21*). Nine tributaries, 6 seeps, 2 side channel/drains and 1 diversion were seen in the imagery. Twelve additional locations appeared as cold features in the thermal imagery, but could not be validated with the natural color photos due to deep shadows. These features should be confirmed in the field before further analyses are conducted.

A rapid warming (17.1°C→23.8°C) was seen from the head of the survey downstream through The Narrows with the exception of one cold pool at river mile 16.74. Downstream of the Narrows (RM15.66) to river mile 2.98, the creek stays confined to the canyon, flowing through alternating forest and meadow conditions. Temperatures fluctuate between 20.3°C→25.6°C with large variations over short distances.

It is difficult to determine any extended trends along this reach with so much local variability; however, general conclusions can be drawn to explain the localized variations. Bulk water temperatures tend to warm in open meadow conditions (e.g. RM 7.94→RM 8.78) (*Figure 22*). Temperatures tend to show a decrease downstream of narrow spots in the canyon (e.g. RM 11.69→RM 11.27). Manifestations of groundwater influence can commonly be seen in these reaches as evidenced by seeps and springs. The sharp temperature drop at river mile 5.66 is likely due to cold water seeping under the rock dam at Camp Elkanah.

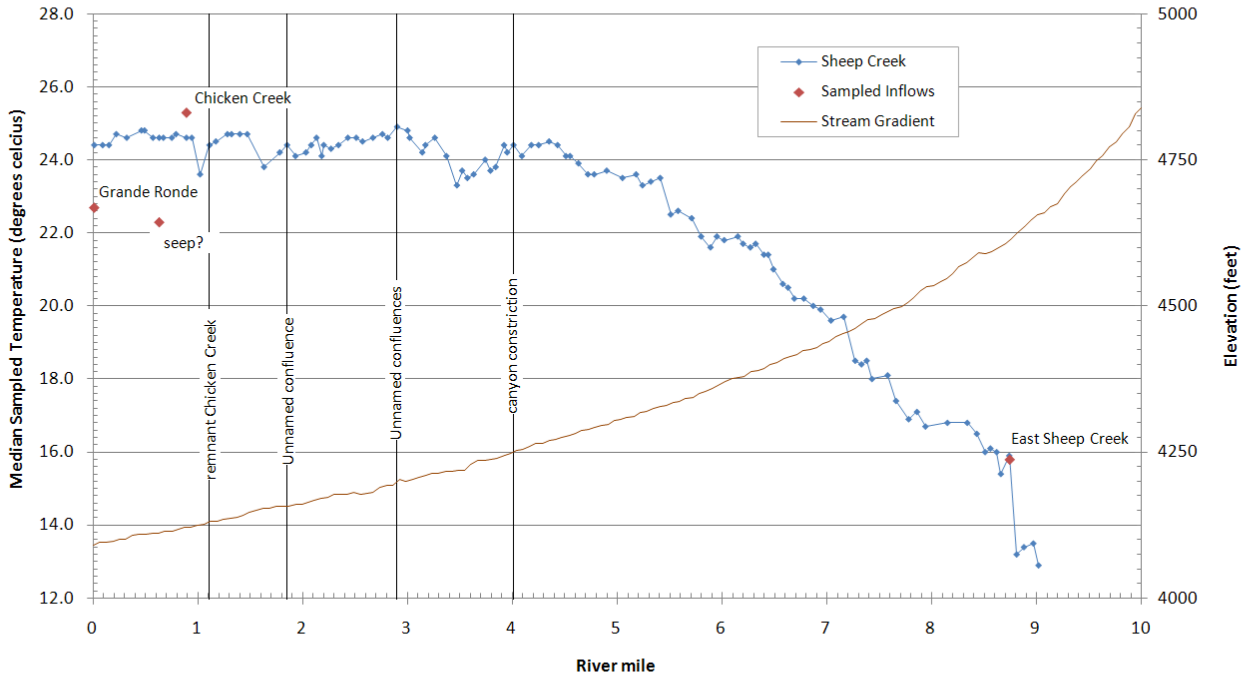
Below river mile 2.98, the canyon opens into a wide valley and temperatures warm for a short distance until the Starkey/McCoy Creek drainages create a cooling environment. Below the McCoy Creek confluence, temperatures again warm until the confluence of Dark Canyon which keeps temperatures depressed for the final reach to the Upper Grande Ronde.

Figure 22. The highest hit LiDAR image below illustrates the warming trend seen along the open reach below Meadow Cow Camp (RM 7.94→RM 8.78). The natural color/TIR mosaic inset on the right shows one example of heavy shadows showing cold thermal returns which should not be confused with cold inflows. If there was any uncertainty about the existence of a seep or spring, it was sampled in the imagery and designated with a '?' as with the signature in the circle. The blue tie lines are strictly for reference.



6.14 Sheep Creek

6.14.1 Longitudinal Temperature Profile



6.14.2 Observations

Nine miles of Sheep Creek were surveyed on August 8, 2010 from the mouth upstream to East Sheep Creek (RM 8.74). East Sheep Creek (15.8°C), Chicken Creek (25.3°C), and a potential seep at river mile 0.63 (22.3°C) were the only sampled inflows. Nine other drainages, Dry Creek, Warm Mineral Spring, and 7 unnamed streams, were shown in the NHD layer, but none had visible surface water that allowed for adequate sampling.

East Sheep Creek had a warming effect on Sheep Creek raising the bulk water temperatures from 13.2°C→15.9°C. Temperatures steadily increased downstream of East Sheep Creek to river mile 4.35 in a typical diurnal warming pattern where the rate of warming slows as the stream gradient becomes less steep. Temperatures plateau near 24.5°C for the lower 4 miles of river.

Localized cooling is seen immediately below river mile 4.01, likely due to a slight constriction in the canyon at this location (24.4°C→23.3°C). A gradual decrease in bulk water temperatures can be seen downstream of the Unnamed confluences near river mile 2.90 (24.9°C→24.1°C) and further cooling below the Unnamed confluence at river mile 1.85 (24.4°C→23.6°C). The cooling spike seen just above the Chicken Creek confluence at river mile 1.11 is likely due to remaining subsurface influences where the former Chicken Creek confluence was located (24.4°→23.6°C).

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CATHERINE CREEK AND TRIBUTARIES

8/12/2010
Catherine Creek
North Fork Catherine Creek
South Fork Catherine Creek

8/10/2010
Ladd Creek
Little Creek
Little Catherine Creek
Milk Creek

6.15 Catherine Creek

6.15.1 Longitudinal Temperature Profile

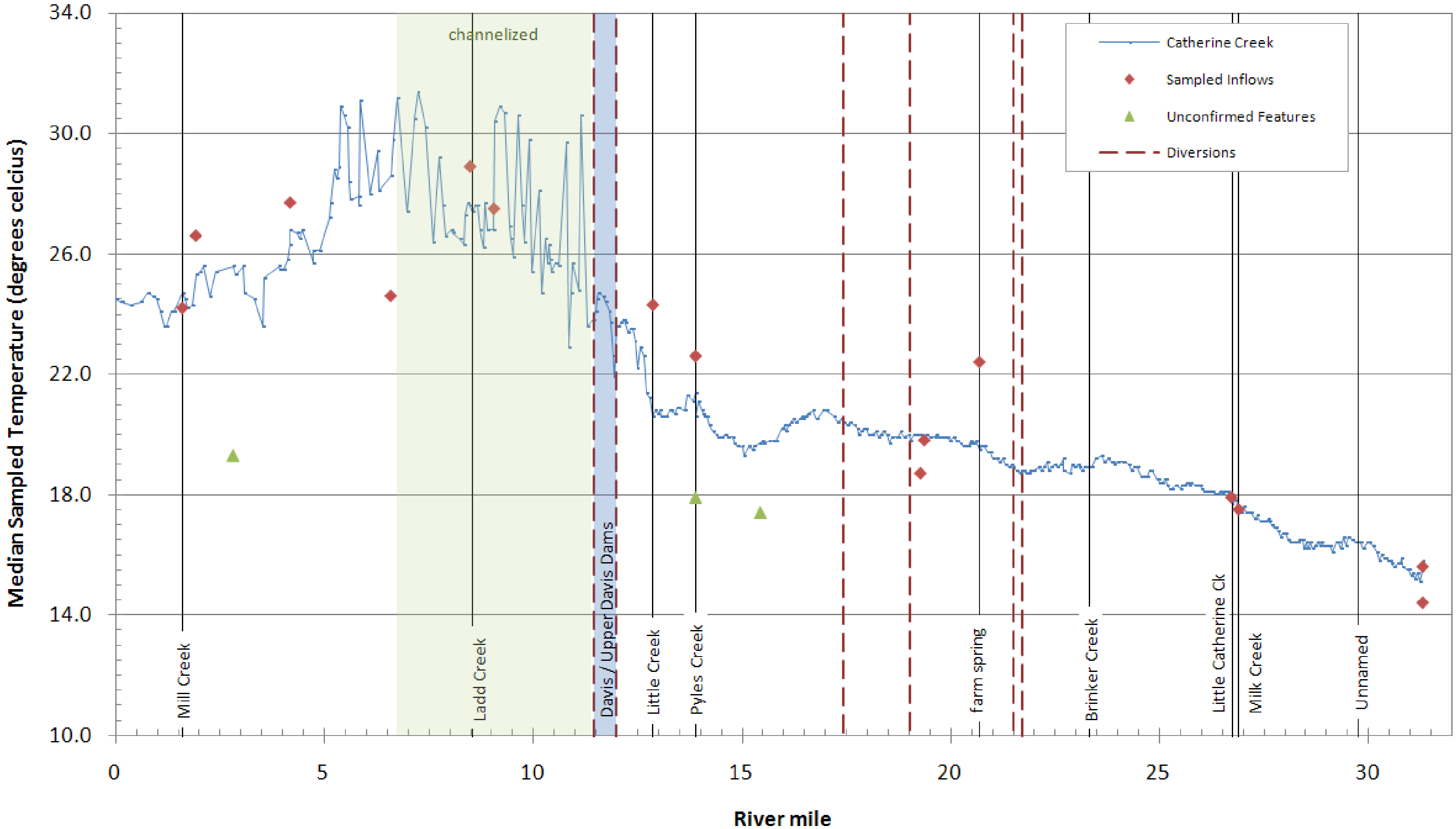


Figure 23. Median channel temperatures plotted versus river mile for Catherine Creek. The locations of detected surface inflows are illustrated on the profile and listed in Table 13.

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

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Mill Creek (R)	2.57	1.60	24.2	24.7	-0.5
slough (L)	3.09	1.92	26.6	25.3	1.3
slough (L)	6.73	4.18	27.7	26.8	0.9
McAlister Slough (L)	10.60	6.59	24.6	28.6	-4.0
canal (R)	13.67	8.49	28.9	27.6	1.3
flooded canal (R)	14.58	9.06	27.5	26.8	0.7
Little Creek (R)	20.71	12.87	24.3	20.6	3.7
Pyles Creek (L)	22.35	13.89	22.6	20.6	2.0
pond 1 (R)	31.02	19.28	18.7	20.0	-1.3
pond 2 (R)	31.17	19.37	19.8	19.9	-0.1
Seep to pond on farm (R)	33.30	20.69	22.4	19.5	2.9
Little Catherine Creek (R)	43.01	26.73	17.9	17.7	0.2
Milk Creek (L)	43.30	26.90	17.5	17.6	-0.1
South Fork Catherine (L)	50.40	31.31	14.4	15.8	-1.4
North Fork Catherine (R)	50.40	31.31	15.6	15.8	-0.2
Unconfirmed Features					
Tributaries	**Kilometer**	**River Mile**	**Tributary Temp (°C)**	**Mainstem Temp (°C)**	**Difference**
steep bank/seep? (R)	4.53	2.82	19.3	25.6	-6.3
steep bank/seep? (L)	22.33	13.88	17.9	21.4	-3.5
seep/shadows? (R)	24.83	15.43	17.4	19.7	-2.3
Dams/Diversion	**Kilometer**	**River Mile**			
Davis Dam/Diversion	18.41	11.44			
Upper Davis Dam	19.24	11.95			
diversion	19.30	11.99			
diversion	28.04	17.43			
diversion	30.63	19.03			
diversion-small	34.60	21.50			
diversion-small	34.93	21.70			

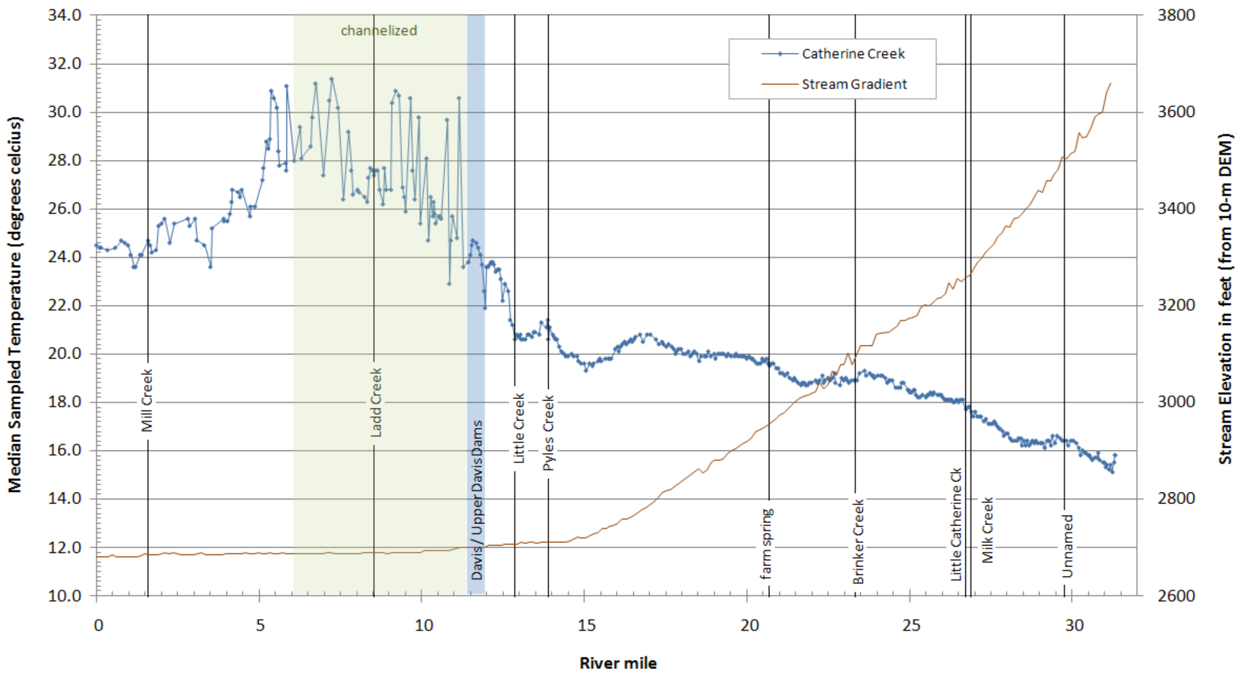
6.15.2 Observations

Approximately 31 miles of Catherine Creek were surveyed on August 12, 2010 from the mouth at the Old Grande Ronde River upstream to the confluence of North and South Fork Catherine Creek. Seven tributaries, 1 seep, 5 ponds/sloughs, and 2 canals were sampled in the imagery (*Figure 23*). Six active diversions and 2 dams were seen in the imagery. Bulk water temperatures ranged from 15.2°C near the North and South Fork confluence (RM 31.31) to 31.4°C at river mile 7.23 along the low water reach below Ladd Creek.

Temperatures show a gradual increase from the Forks (RM 31.31) downstream to river mile 16.93 (15.2°C→20.8°C). Localized cooling can be seen at 3 different locations: downstream of the unnamed stream at river mile 29.75, Brinker Creek (RM 23.32), and the farm spring (RM 20.69). None of these features have a visible surface water contribution to Catherine Creek, but subsurface interaction is suggested by the plateaus seen in the longitudinal profile. The slight inflection seen at the confluences of Little Catherine Creek and Milk Creek indicates a decrease in the rate of warming which also suggests groundwater interaction.

At river mile 16.93, bulk water temperatures decrease 1.5˚C (20.8→19.3˚C) over 1.88 miles. It is unclear what is causing this decrease in temperatures as the stream flows through Union, Oregon. There appear to be no significant inflows or outflows, no changes in stream gradient, morphology or vegetation type along this reach (*Figure 24*).

Figure 24. A comparison of stream gradient to bulk water temperatures for Catherine Creek. Stream elevations were obtained from the 10-m digital elevation model for the area.



As the stream gradient flattens, temperatures begin to increase downstream of river mile 15.05. A short cooling reach is seen downstream of Pyles Creek (RM 13.89) though it appears to be contributing warmer surface water (22.6˚C). A significant point source warming (24.3˚C) is seen at the confluence with Little Creek at river mile 12.87.

When Catherine Creek reaches Upper Davis Dam (RM 11.95) and Davis Dam (RM 11.44), a significant amount of flow is diverted out of the main channel. The low flows seen below the dams result in highly variable temperatures and potentially stratified water conditions. The river is also highly channelized for 4.80 miles below the dam. The Ladd Creek confluence appears to have a significant impact on bulk water temperatures, though it was not contributing enough surface water for accurate sampling (*Figure 25*).

Near river mile 6.64, the river resumes a more natural meandering flow, and water levels begin to rebound below river mile 5.38. In this more natural flow regime, a 6.4˚C temperature decrease is seen in the lower 5 miles of the river (*Figure 26*).

Of the six diversions seen along Catherine Creek, the increase in the warming rate downstream of the diversions at river mile 21.50 and 21.70 and the Davis Dams indicates that these diversions do have an impact on the temperature profile of the stream. The diversions at river miles 19.03 and 17.43 have a less quantifiable effect.

Figure 25. The TIR/natural color image pair below shows the confluence of Ladd Creek and Catherine Creek (RM 8.54). Despite the low flow of Ladd Creek and the highly variable temperatures along the reach due to low water, Ladd Creek does appear to have a cooling effect on the temperatures of Catherine Creek. The black and red graphic lines are strictly for reference.

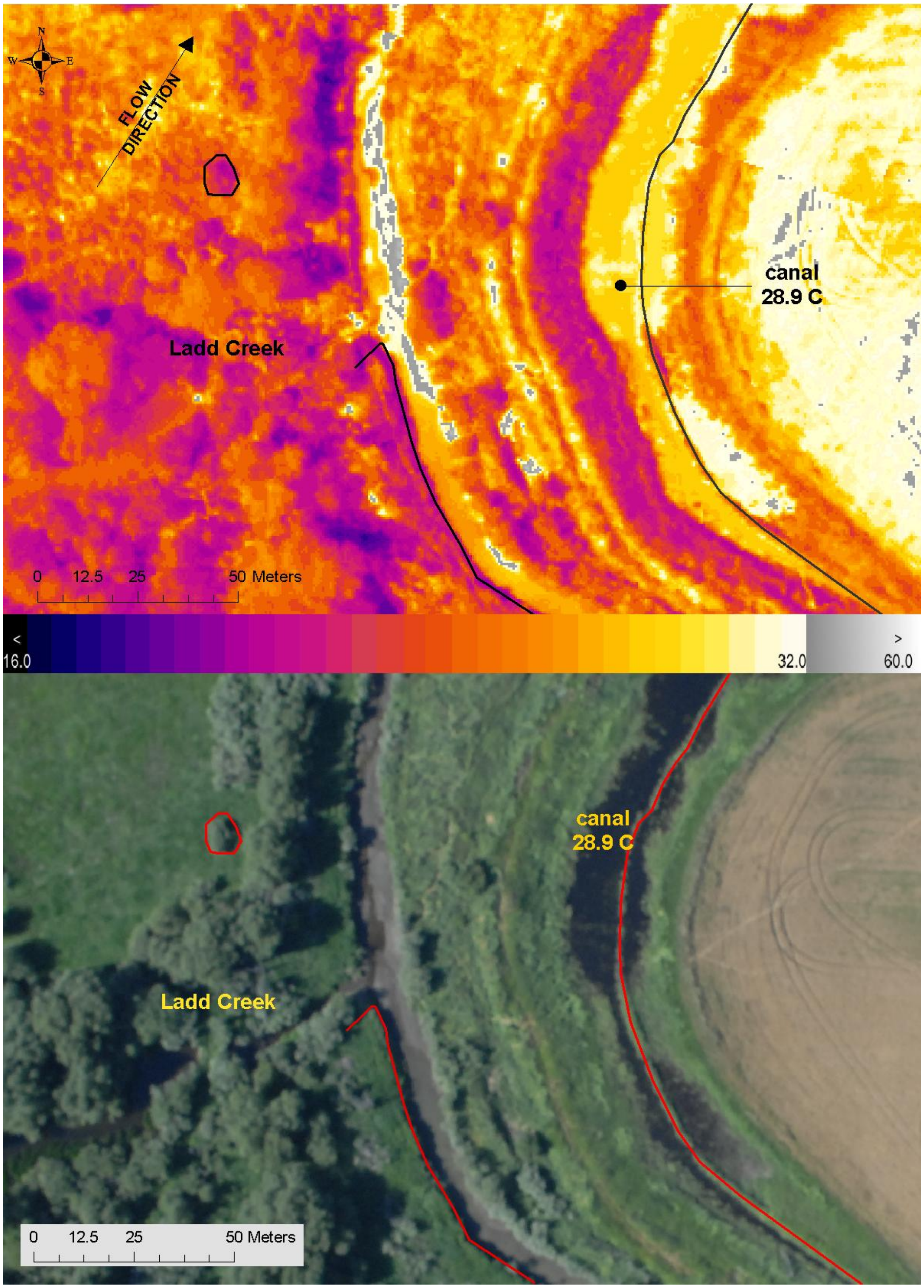
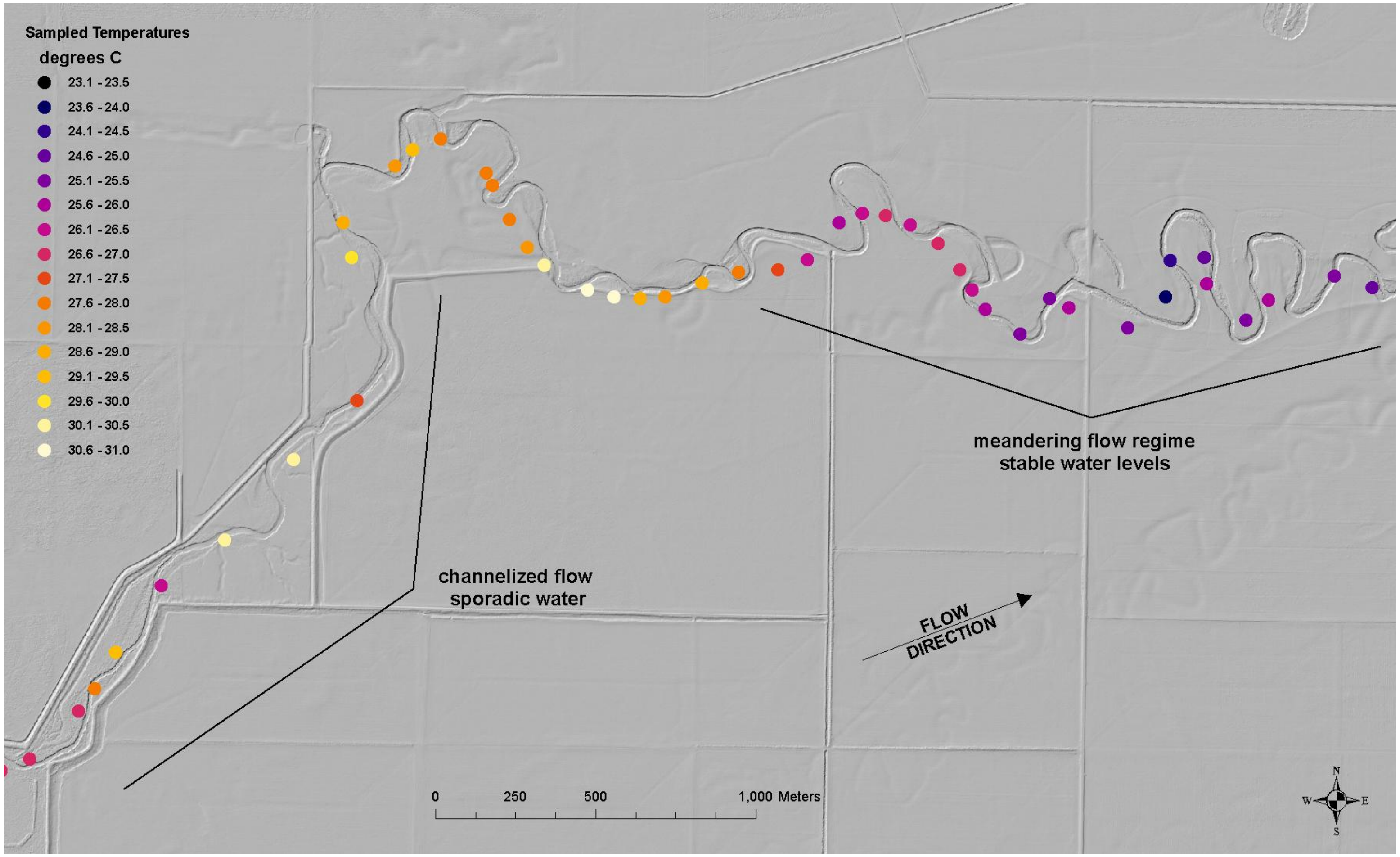


Figure 26. The LiDAR bare earth hillshade below shows the transition between the confined, channelized river and the sinuous meandering channel near river mile 6.64. Along this reach, water levels begin to rebound and a 6.4°C temperature decrease is seen in the lower 5 miles of the river as the river returns to a more natural flow regime. The point color ramp is exaggerated for this image.



6.16 North Fork Catherine Creek

6.16.1 Longitudinal Temperature Profile

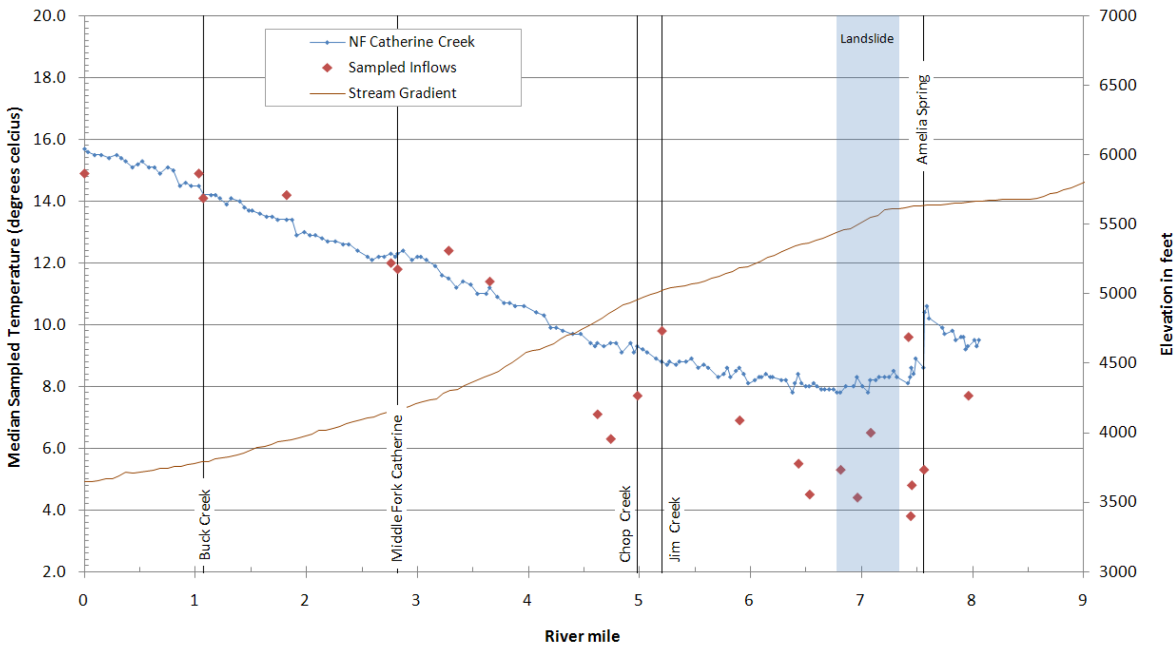


Table 14. Tributaries and other surface inflows sampled along North Fork Catherine Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (˚C)	Mainstem Temp (˚C)	Difference
Catherine Creek	0.00	0.00	14.9	15.7	-0.8
Lick Ck (R)	1.66	1.03	14.9	14.5	0.4
Buck Creek (L)	1.72	1.07	14.1	14.2	-0.1
side channel (L)	2.93	1.82	14.2	13.4	0.8
hyporheic flow? (L)	4.43	2.76	12.0	12.3	-0.3
Middle Fork (L)	4.55	2.82	11.8	12.3	-0.5
Unnamed (R)	5.28	3.28	12.4	11.5	0.9
Unnamed (R)	5.87	3.65	11.4	11.2	0.2
spring (L)	7.44	4.62	7.1	9.4	-2.3
spring (L)	7.63	4.74	6.3	9.4	-3.1
Chop Creek (L)	8.01	4.98	7.7	9.3	-1.6
Jim Creek (L)	8.37	5.20	9.8	8.8	1.0
seep (R)	9.49	5.90	6.9	8.6	-1.7
seep (L)	10.35	6.43	5.5	8.4	-2.9
spring (L)	10.50	6.53	4.5	8.0	-3.5
side channel (R)	10.96	6.81	5.3	7.8	-2.5
spring (L)	11.19	6.96	4.4	8.3	-3.9
spring (L)	11.40	7.08	6.5	8.2	-1.7
Unnamed (R)	11.93	7.42	9.6	8.1	1.5
spring (L)	11.97	7.44	3.8	8.3	-4.5
seep (R)	11.99	7.45	4.8	8.6	-3.8
Amelia Spring (L)	12.16	7.56	5.3	8.6	-3.3
Unnamed (R)	12.82	7.96	7.7	9.3	-1.6

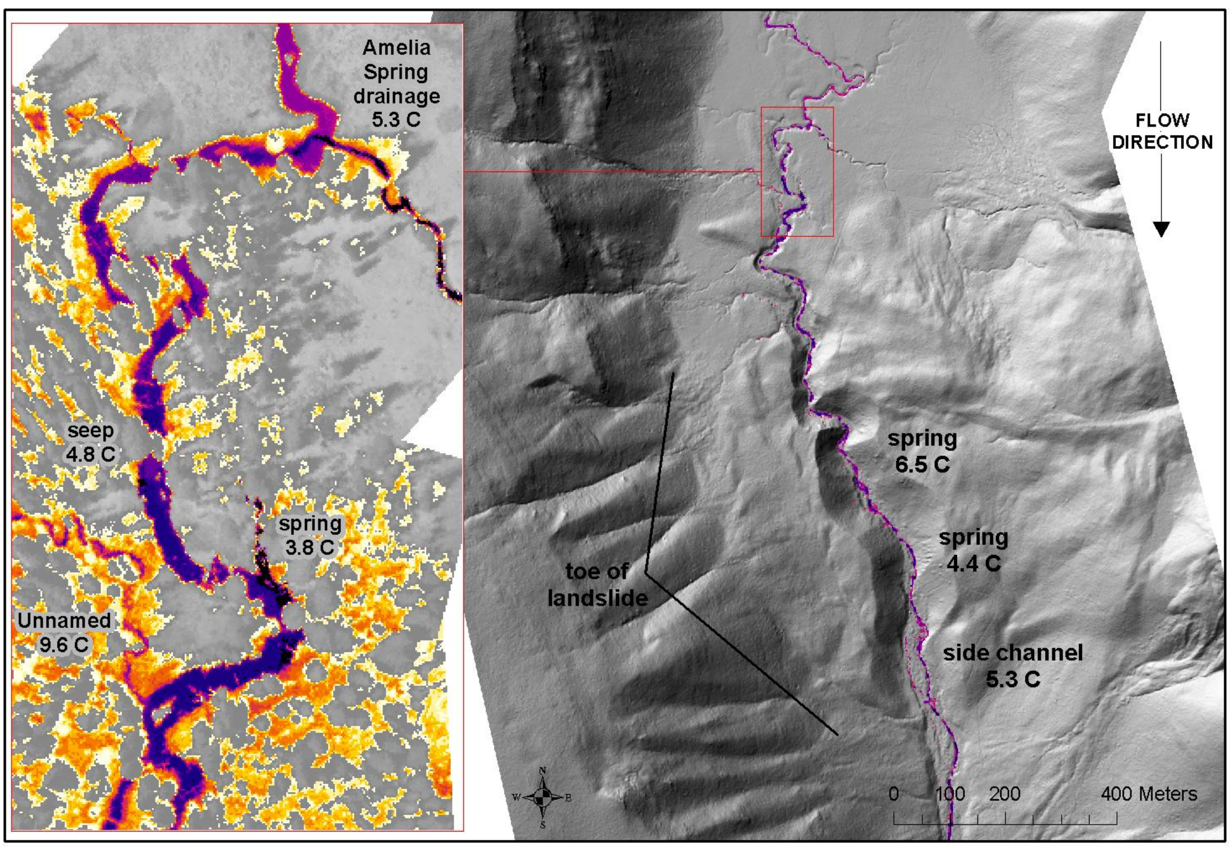
6.16.2 Observations

Approximately eight miles of North Fork Catherine Creek were surveyed on August 12, 2010 from the mouth at Catherine Creek upstream to Catherine Creek meadow. Temperatures ranged from 7.8°C upstream to 15.7°C at the mouth. Ten tributaries, 10 springs/seeps, and 2 side channels were sampled in the imagery.

In the upper mile of the survey, the Amelia Spring drainage (RM 7.56) lowers bulk water temperatures 2.0°C from 10.6°C→8.6°C. Temperatures stay depressed for approximately one mile as the stream flows out of the meadow and cuts through the toe of an inactive mature landslide between river miles 6.79-7.34. Several springs are seen along this reach which indicates increased groundwater activity (*Figure 27*).

In the lower 6.5 miles of the survey, the bulk water temperatures show a steady warming trend from the meadow downstream to the mouth. Most of the inflows are small and have minimal downstream influence on the stream temperatures. There are no obvious correlations between the stream gradient and temperature profile.

Figure 27. The TIR/bare earth LiDAR image shows the landslide at river mile 5.0.



6.17 South Fork Catherine Creek

6.17.1 Longitudinal Temperature Profile

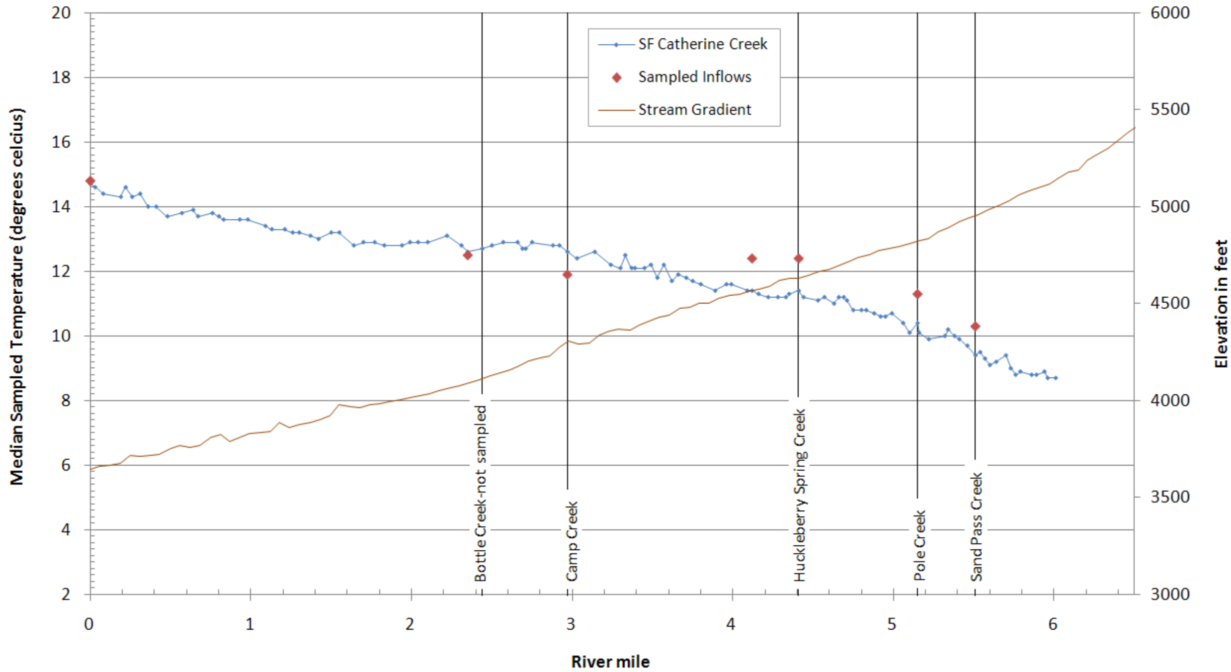


Table 15. Tributaries and other surface inflows sampled along South Fork Catherine Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Catherine Creek	0.00	0.00	14.8	14.7	0.1
side channel (R) ( )	3.77	2.35	12.5	12.6	-0.1
Camp Creek (L)	4.78	2.97	11.9	12.6	-0.7
side channel (R) ( )	6.63	4.12	12.4	11.4	1.0
Huckleberry Spring Creek (L)	7.09	4.41	12.4	11.4	1.0
Pole Creek (R)	8.29	5.15	11.3	10.4	0.9
Sand Pass Creek (R)	8.87	5.51	10.3	9.4	0.9

6.17.2 Observations

Six miles of South Fork Catherine Creek were surveyed on August 12, 2010. Four named streams and two side channels were sampled as inflows in the imagery. Temperatures ranged from 8.7°C upstream to 14.7°C at the mouth at Catherine Creek. Temperatures showed a gradual increase downstream as expected on a warm summer day. A plateau near 12.9°C was seen in the bulk water temperatures below Camp Creek (RM 1.64-2.97) indicating subsurface interactions. No definitive correlations were seen between water temperatures and stream gradient.

6.18 Ladd Creek

6.18.1 Longitudinal Temperature Profile

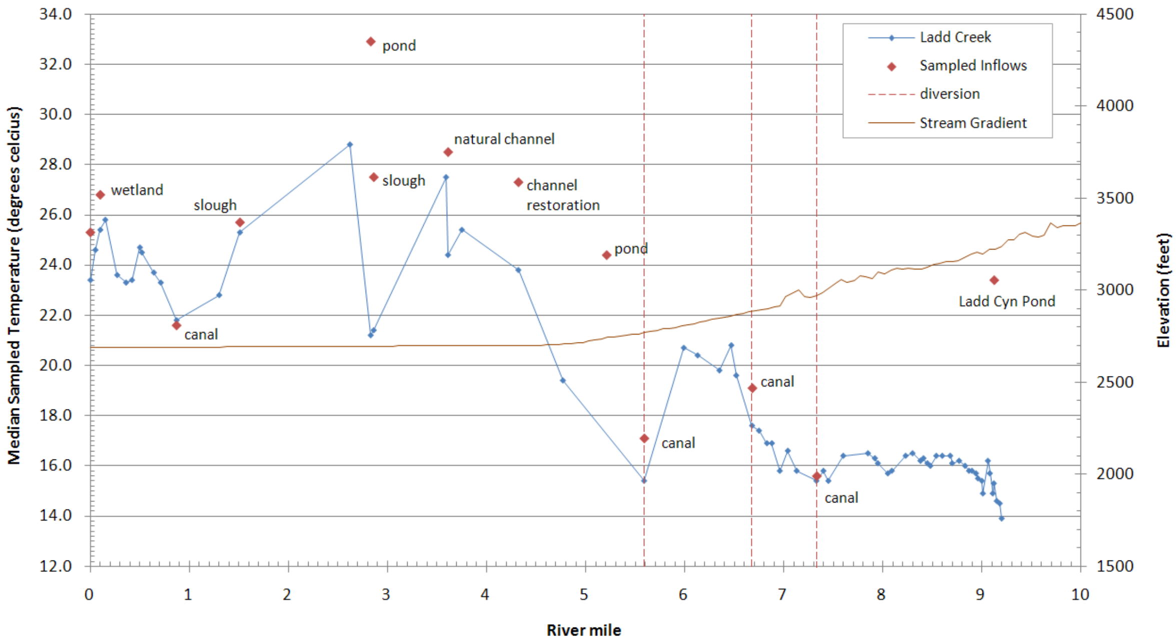


Table 16. Tributaries and other surface inflows sampled along Ladd Creek with left or right bank designation (looking downstream)

Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Catherine Creek	0.00	0.00	25.3	23.4	1.9
adjacent wetland (R)	0.15	0.10	26.8	25.4	1.4
canal (R)	1.40	0.87	21.6	21.8	-0.2
slough (R)	2.43	1.51	25.7	25.3	0.4
pond (R)	4.55	2.83	32.9	21.2	11.7
slough (L)	4.60	2.86	27.5	21.4	6.1
natural channel (R)	5.81	3.61	28.5	24.4	4.1
channel restoration (R)	6.94	4.32	27.3	23.8	3.5
pond (L)	8.38	5.21	24.4	no water	--
Canal/diversion (R)	8.99	5.59	17.1	15.4	1.7
Canal/diversion (R)	10.74	6.68	19.1	17.6	1.5
Canal/diversion (L)	11.79	7.33	15.6	15.4	0.2
Ladd Canyon Pond (R)	14.68	9.12	23.4	15.3	8.1

6.18.2 Observations

Nine miles of Ladd Creek were surveyed on August 10, 2010 from the mouth at Catherine Creek upstream to Ladd Canyon Pond Creek. Twelve features including 3 diversions were sampled in the imagery. Temperatures ranged from 13.9°C upstream to 28.8°C at river mile 2.62. Below the diversion at river mile 5.59, there are few areas of visible surface water. Water levels are low and in the lower reaches, the channel is heavily laden with aquatic vegetation. These conditions result in highly variable and mixed pixel sampling.

6.19 Little Creek

6.19.1 Longitudinal Temperature Profile

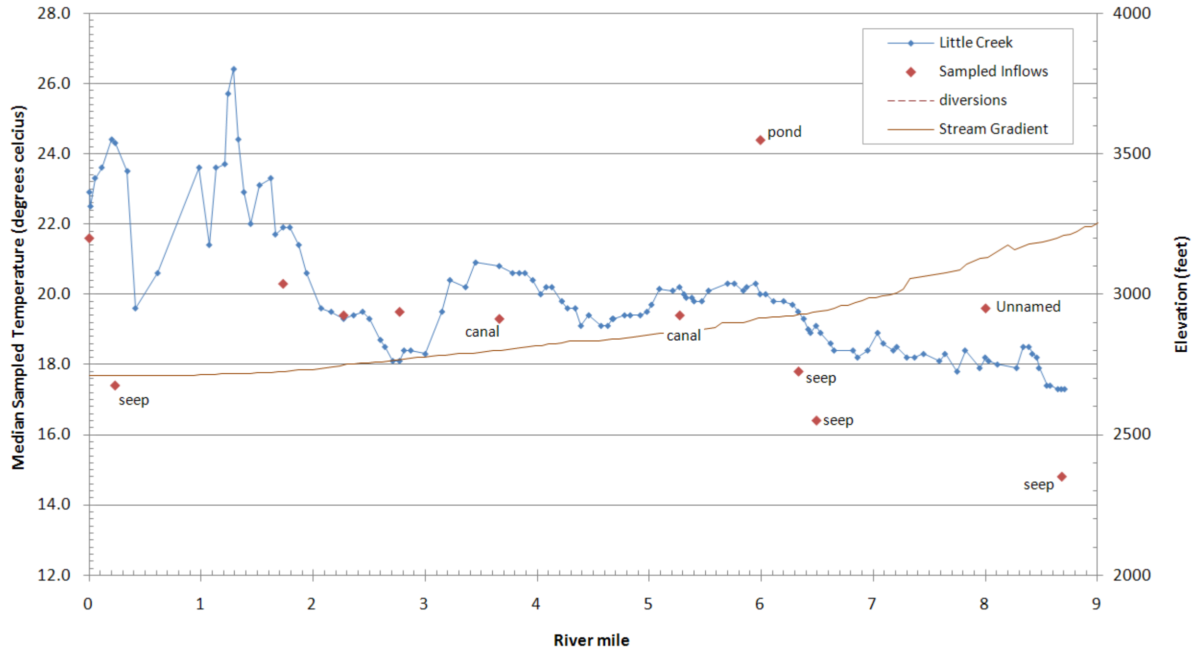


Table 17. Tributaries and other surface inflows sampled along Little Creek with left or right bank designation (looking downstream)

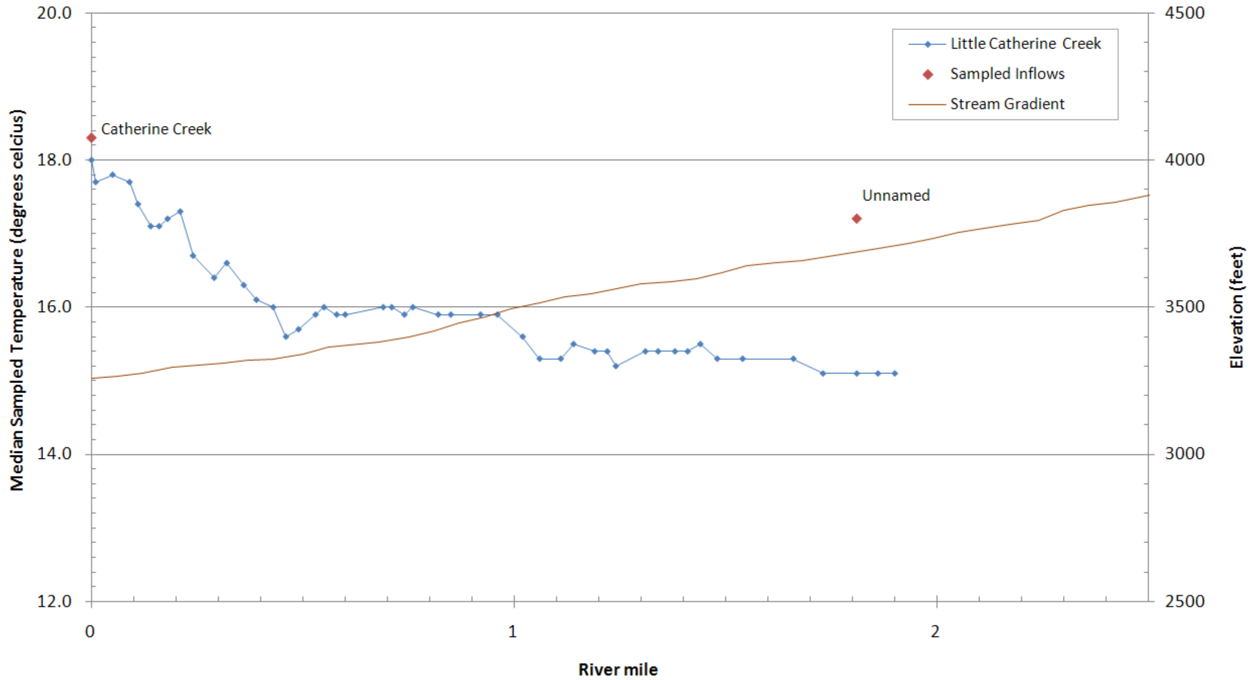
Tributaries	Kilometer	River Mile	Tributary Temp (°C)	Mainstem Temp (°C)	Difference
Catherine Creek	0.00	0.00	21.6	22.9	-1.3
irrigation seep? (R)	0.37	0.23	17.4	24.3	-6.9
canal (L)	2.78	1.73	20.3	21.9	-1.6
canal (L)	3.65	2.27	19.4	19.3	0.1
canal (R)	4.45	2.77	19.5	18.1	1.4
canal (L)	5.88	3.66	19.3	20.8	-1.5
canal (L)	8.48	5.27	19.4	20.2	-0.8
pond (L)	9.64	5.99	24.4	20.0	4.4
seep (L)	10.19	6.33	17.8	19.5	-1.7
seep (L)	10.45	6.49	16.4	19.1	-2.7
Unnamed (L)	12.87	8.00	19.6	18.2	1.4
seep (L)	13.97	8.68	14.8	17.3	-2.5

6.19.2 Observations

Nine miles of Little Creek were surveyed on August 10, 2010. Eleven features including 5 diversions were sampled in the imagery. Temperatures ranged from 17.3°C upstream to 26.4°C at river mile 1.29. The thermal plateau from river mile 6.65→8.28 and the cooling reaches at river miles 2.77→3.45 and 4.39→5.70 indicate subsurface influences are keeping temperatures depressed. As expected, temperatures rise downstream of each diversion as the volume of water in the main channel decreases.

6.20 Little Catherine Creek

6.20.1 Longitudinal Temperature Profile

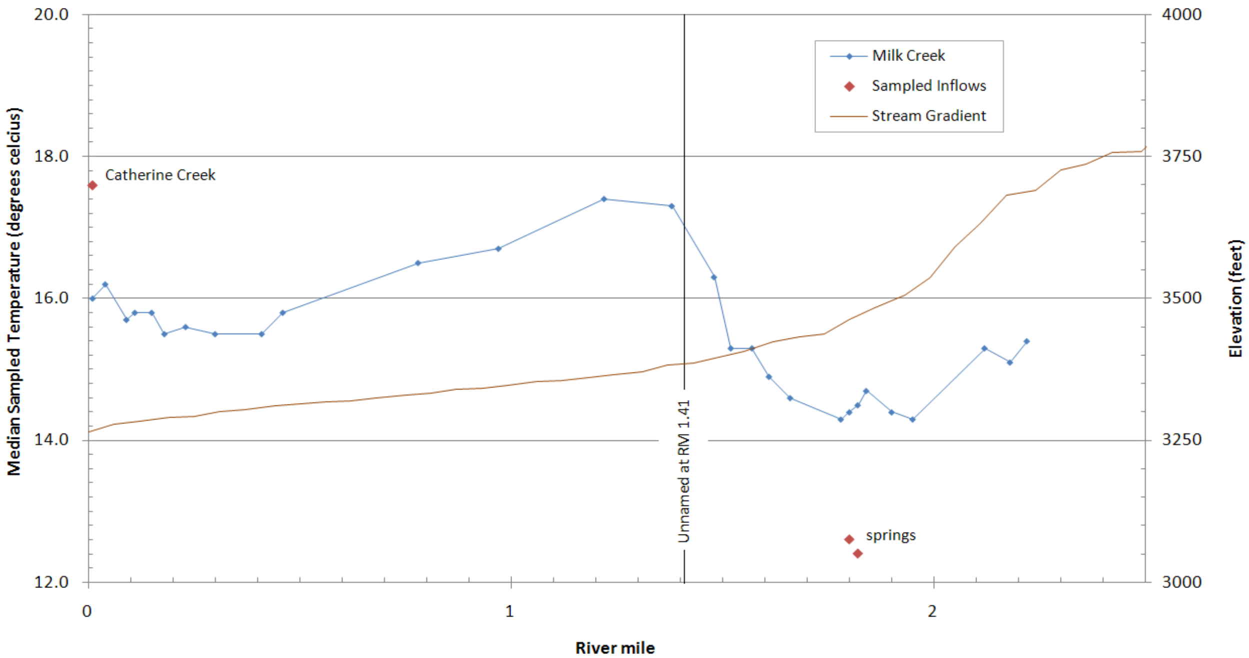


6.20.2 Observations

Just under two miles of Little Catherine Creek were surveyed on August 10, 2010. Temperatures ranged from 15.1°C upstream to 18.0°C at the confluence with Catherine Creek. Temperatures stay stable above river mile 0.46, between 15.1°C and 16.0°C. Below river mile 0.46, a warming is seen as the stream exits the canyon in the final run to Catherine Creek. One unnamed inflow was sampled at river mile 1.81 (17.2°C). No significant correlations were seen between bulk water temperatures and stream gradient.

6.21 Milk Creek

6.21.1 *Longitudinal Temperature Profile*



6.21.2 Observations

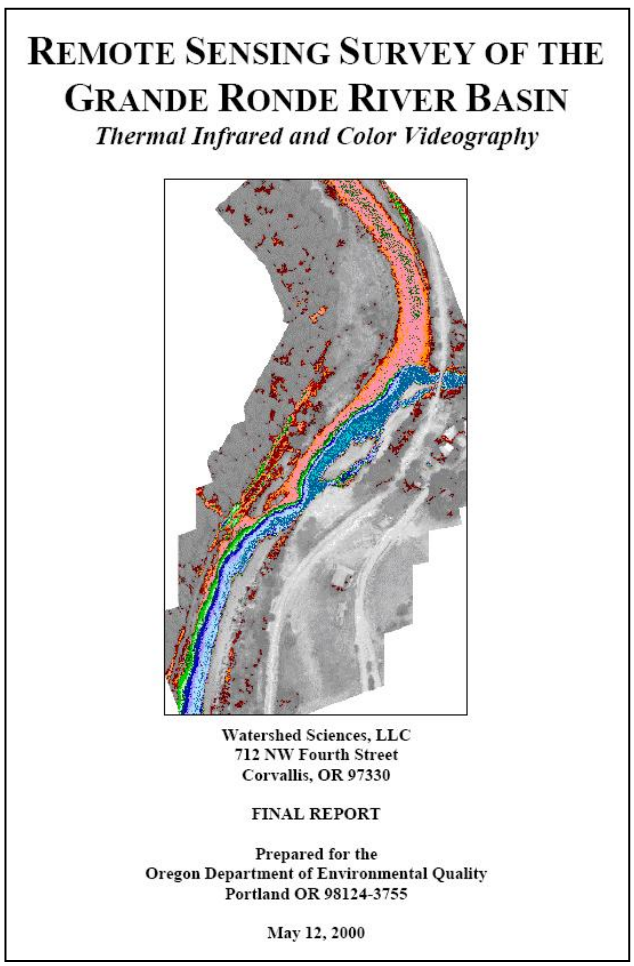
Two miles of Milk Creek were surveyed on August 10, 2010. Temperatures ranged from 14.3˚C at the spring complex (RM 1.80) to 17.4˚C at river mile 1.22. The two springs, sampled at 12.4˚C and 12.6˚C, occur as the stream exits the canyon and the stream gradient begins to flatten. With such a small stream, it is difficult to infer trends over such a short distance; however, there appears to be subsurface influences lowering the bulk water temperatures below the Unnamed tributary at river mile 1.41.

7. 1999/2010 Thermal Comparison

Watershed Sciences performed a similar thermal analysis in the Upper Grande Ronde Basin in August 1999[5] for the Oregon Department of Environmental Quality. Ten of the streams in the 2010 study area were surveyed including the Upper Grande Ronde River, Beaver Creek, Fly Creek, Limber Jim Creek, McCoy Creek, Meadow Creek, Sheep Creek, Catherine Creek, North Fork and South Fork Catherine Creek.

Air temperatures were 3-5°F warmer during the time frame of the 1999 flights (Appendix 1). No discharge data was found in the vicinity of the survey for the 1999 flight; however, the downstream flow gage at Troy, Oregon showed higher flow rates in 1999 (Appendix 2). As mentioned, it is unclear how well the gage, located 35 miles downstream, reflects the Upper Grande Ronde flow rates. Local discharge data would be needed to do a thorough data comparison.

Slight shifts may be visible in the profiles due to the difference in methodologies in calculating the river mile measures. Profiles were matched to the extent possible in the case of a distinct inflow or river marker such as a bridge.



REMOTE SENSING SURVEY OF THE GRANDE RONDE RIVER BASIN

Thermal Infrared and Color Videography

Watershed Sciences, LLC
712 NW Fourth Street
Corvallis, OR 97330

FINAL REPORT

Prepared for the
Oregon Department of Environmental Quality
Portland OR 98124-3755

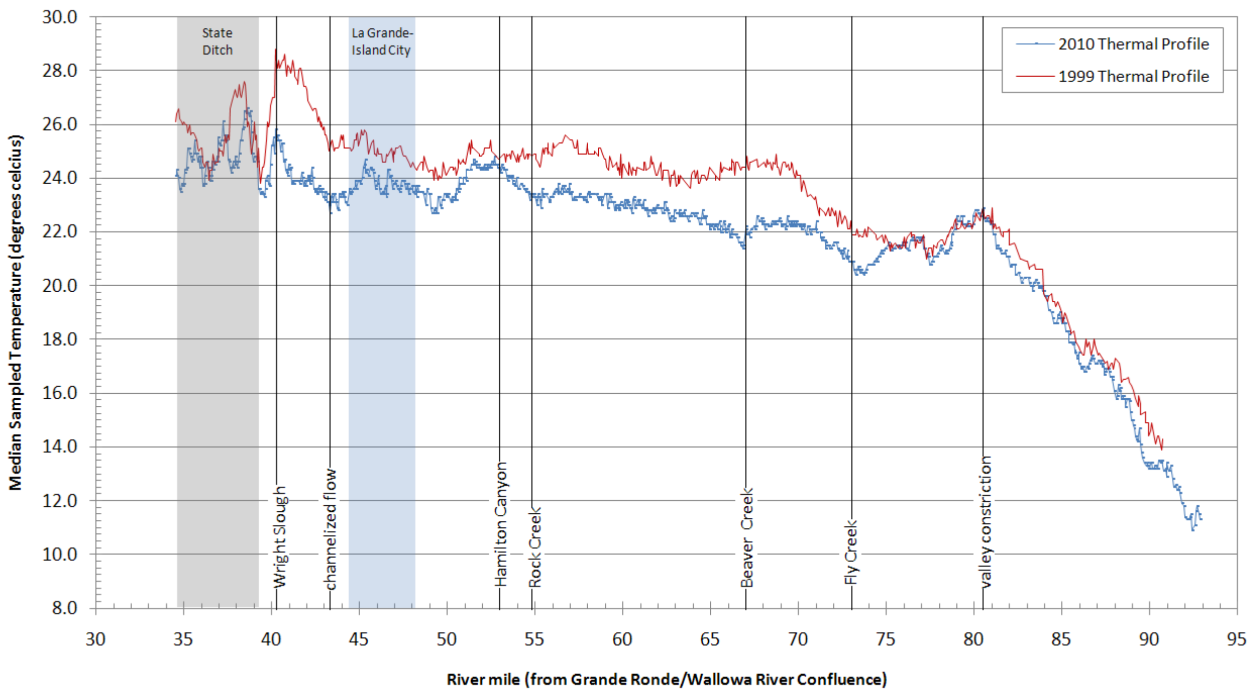
May 12, 2000

[5] Reference Report: "Remote Sensing Survey of the Grande Ronde River Basin: Thermal Infrared and Color Videography." Prepared by Watershed Sciences, LLC for the Oregon Department of Environmental Quality. May 12, 2000.

7.1 Upper Grande Ronde River

A comparison of the 1999/2010 longitudinal profiles for the Upper Grande Ronde River is shown in Figure 28. The overall shape of the profiles is very similar with temperature increases and decreases seen in the same locations. In the upper canyon upstream of river mile 75.0, temperatures are nearly identical; however, below river mile 75.0, the profiles diverge with 1999 sampled water temperatures being on average 2.0°C warmer. Air temperatures in 1999 averaged near 90°F, 5-10°F warmer than the 2010 survey, which likely accounts for the warmer temperatures.

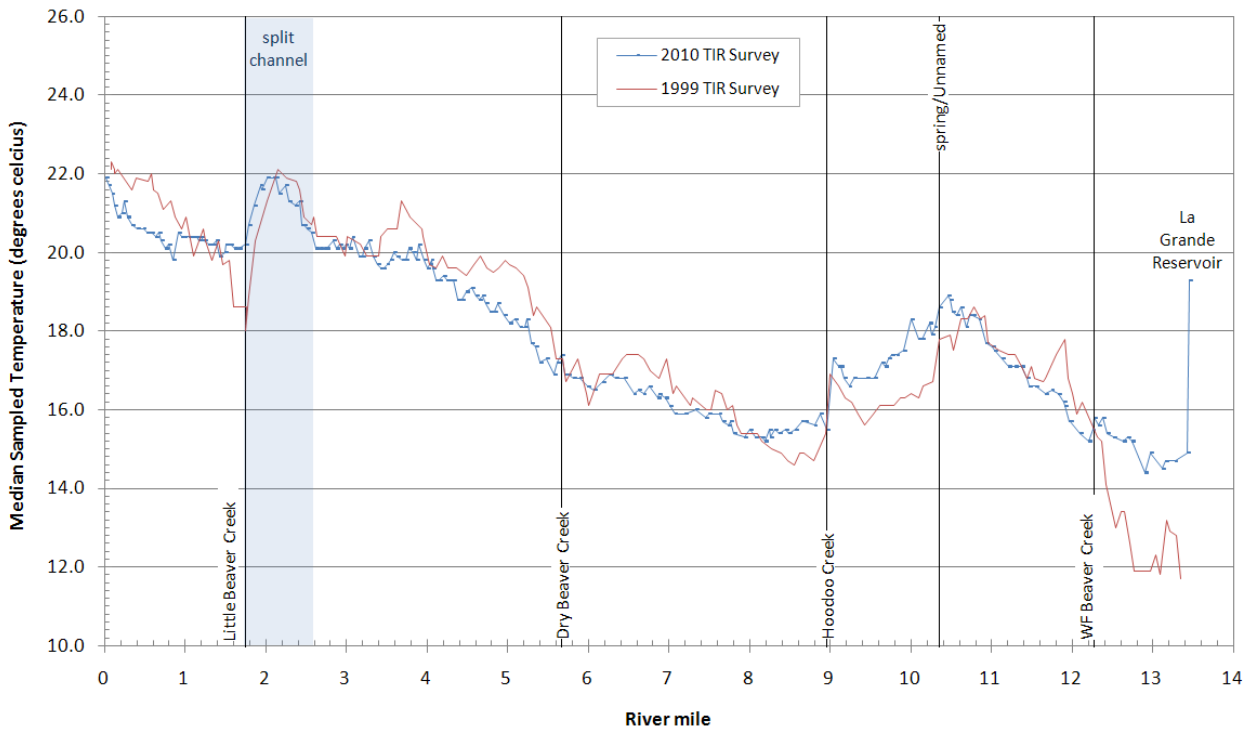
Figure 28. Comparison of the 1999 and 2010 thermal longitudinal profiles for the Upper Grande Ronde River



7.2 Beaver Creek

The 1999/2010 comparison shows similar profiles with a strong cooling trend below the spring at river mile 10.35, cooling at Hoodoo Creek, and the split channel response seen upstream of Little Beaver Creek. There was more variability in the 1999 survey and stronger cooling responses possibly indicating lower water levels (*Figure 29*). Further investigation of historic dam releases from the reservoir would confirm any difference in flow levels.

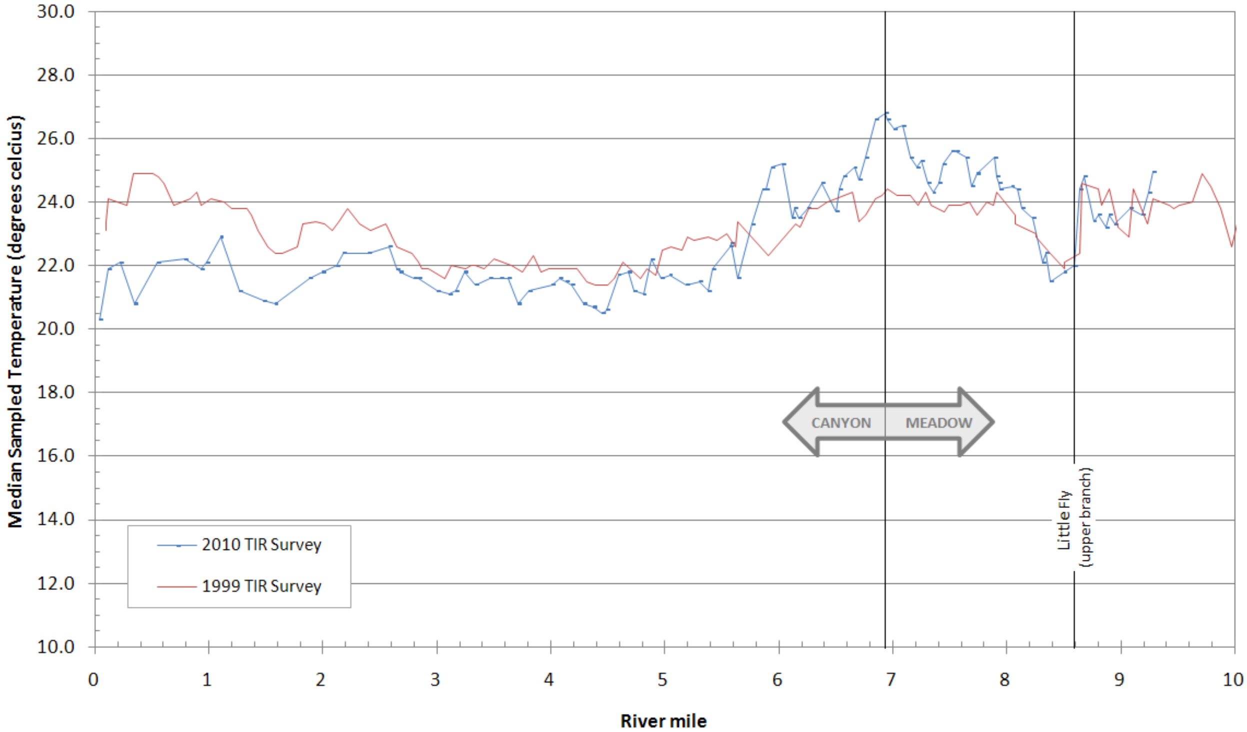
Figure 29. A comparison of the 1999 and 2010 thermal longitudinal profiles for Beaver Creek



7.3 Fly Creek

The 1999/2010 longitudinal profiles for Fly Creek are similar in shape; however, the 2010 profile had slightly lower temperatures downstream and higher temperatures near the meadow/canyon transition. The lower temperatures in the canyon would be expected given the slightly cooler air temperatures in 2010. It is unclear why the 2010 water temperatures are higher near the valley constriction (*Figure 30*). Further investigations of flow rates and grazing activity would be needed to fully analyze the profile differences.

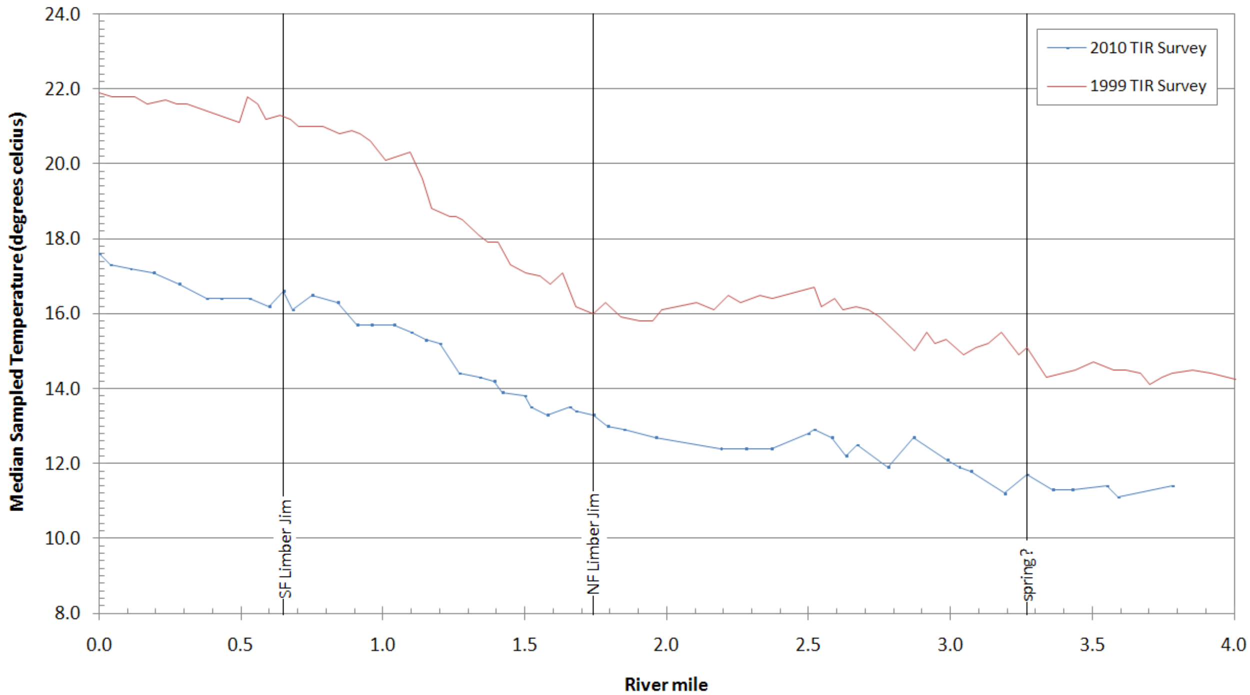
Figure 30. A comparison of the 1999 and 2010 thermal longitudinal profiles for Fly Creek



7.4 Limber Jim Creek

While the thermal profiles for Limber Jim Creek have similar shapes in 1999 and 2010, the thermal profile in 1999 was almost 4°C warmer than the 2010 profile (*Figure 31*). Air temperatures were slightly warmer in 1999, but not by enough to warrant such a large temperature difference. Further analysis would be needed to determine the cause of such a large temperature shift.

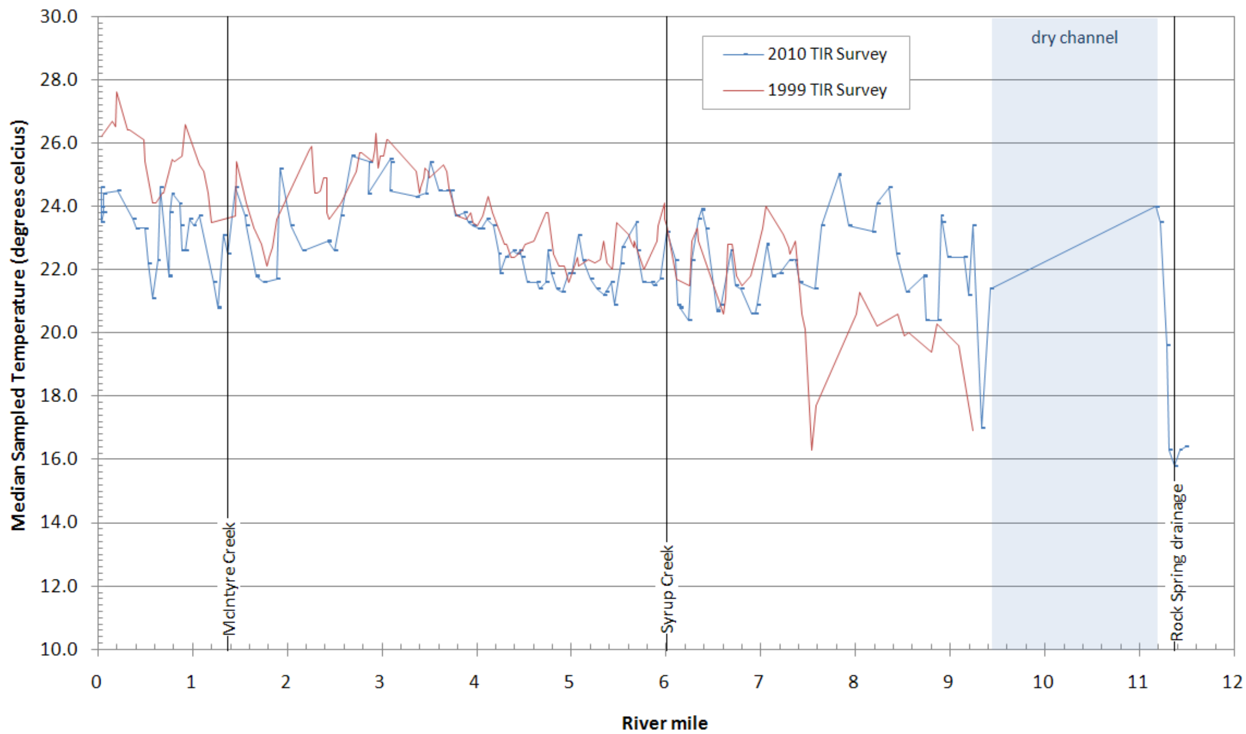
Figure 31. A comparison of the 1999 and 2010 thermal longitudinal profiles for Limber Jim Creek



7.5 McCoy Creek

While the longitudinal profiles for Meadow Creek are similar from 1999 to 2010, the extreme variability in temperatures makes it difficult to draw any conclusive results in the upper reaches (Figure 32). It does appear that temperatures have decreased (-2.0°C) in the reach below McIntyre Creek where the channel has been restored to its natural flow regime. Further analysis would be needed to confirm the significance of the temperature decrease, correcting for differences in daily air temperatures and flow rates.

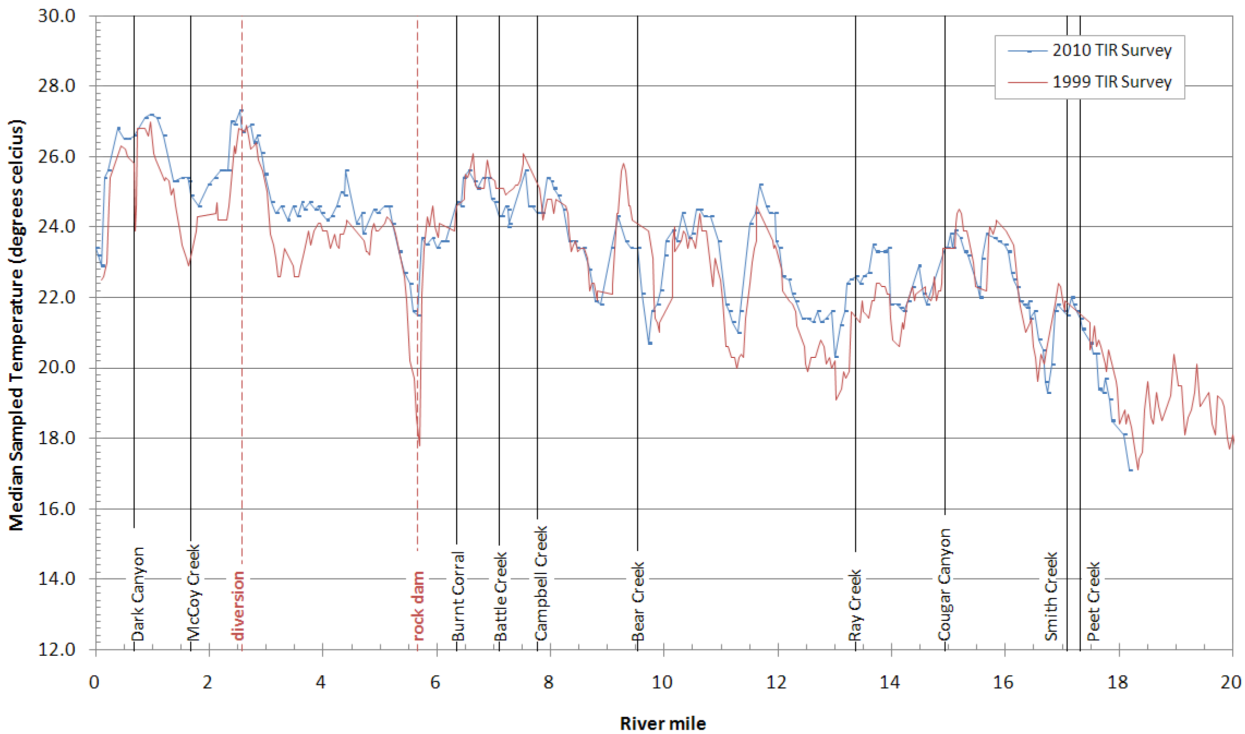
Figure 32. A comparison of the 1999 and 2010 thermal longitudinal profiles for McCoy Creek



7.6 Meadow Creek

The thermal longitudinal profile for the 1999 and 2010 Meadow Creek surveys are nearly identical (*Figure 33*). The cooling and warming responses are slightly greater in the 1999 survey indicating lower water levels.

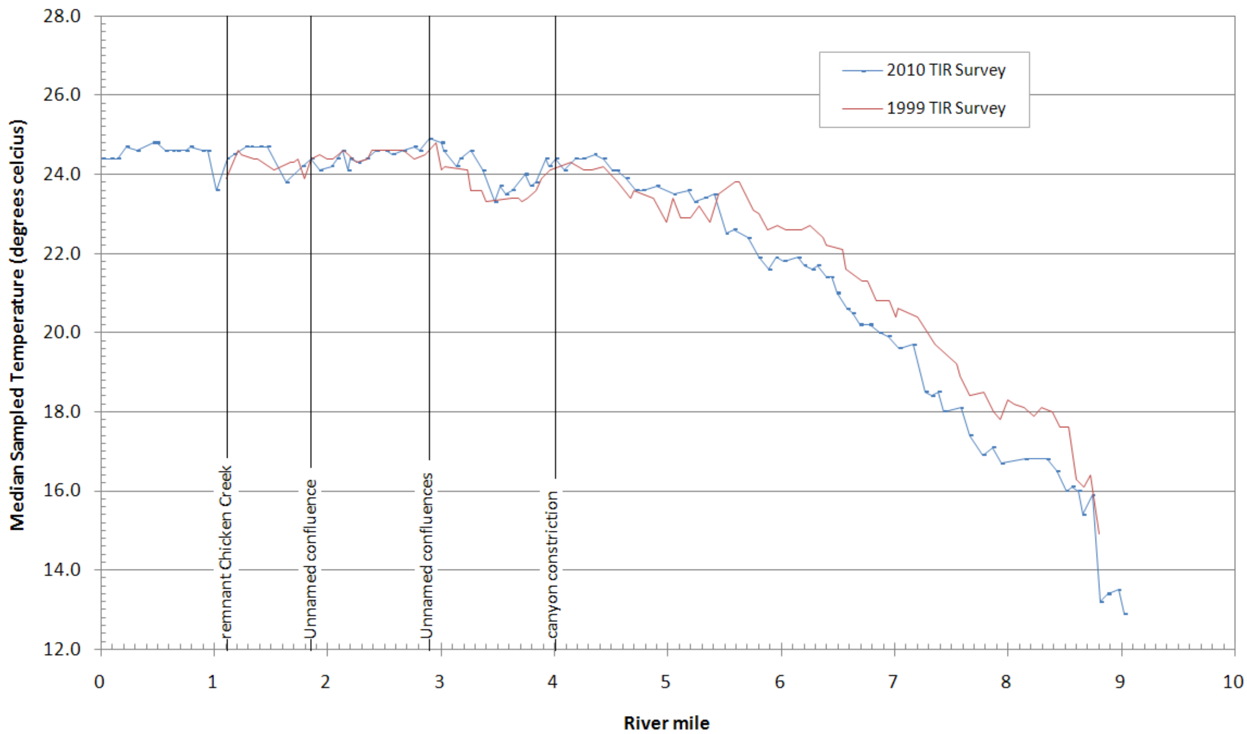
Figure 33. A comparison of the 1999 and 2010 thermal longitudinal profiles for Meadow Creek



7.7 Sheep Creek

The longitudinal temperature profiles for Sheep Creek for 1999/2010 were almost identical though the 1999 survey began at Chicken Creek (*Figure 34*). The bulk water temperatures in the upper 5 miles of stream were approximately 1˚C warmer in 1999, likely due to air temperatures being approximately 5˚F warmer than in 2010 (Appendix A).

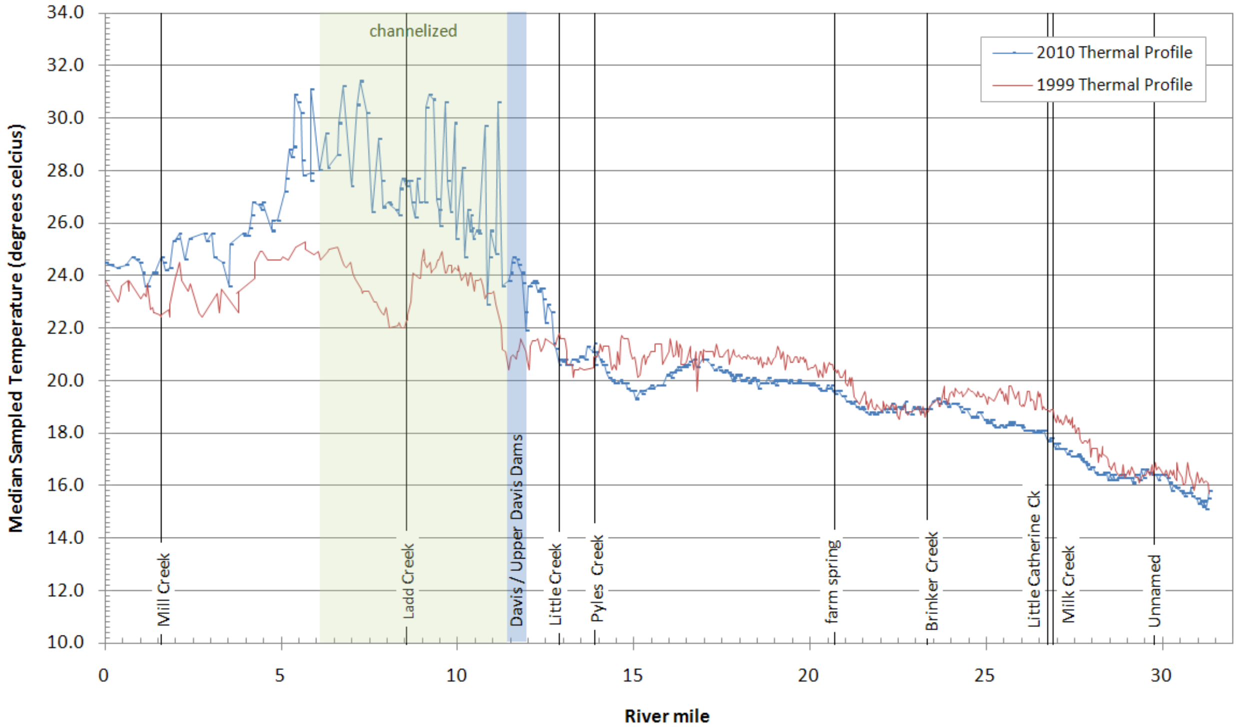
Figure 34. A comparison of the 1999 and 2010 thermal longitudinal profiles for Sheep Creek



7.8 Catherine Creek

The thermal profile comparison for Catherine Creek (*Figure 35*) shows slightly higher water temperatures in 1999 upstream of the dams and significantly lower, more stable temperatures downstream of the dams. This suggests that flows were higher downstream of the dam in 1999. With the more stable temperatures in 1999, the impact of Ladd Creek as a cooling point source is more obvious.

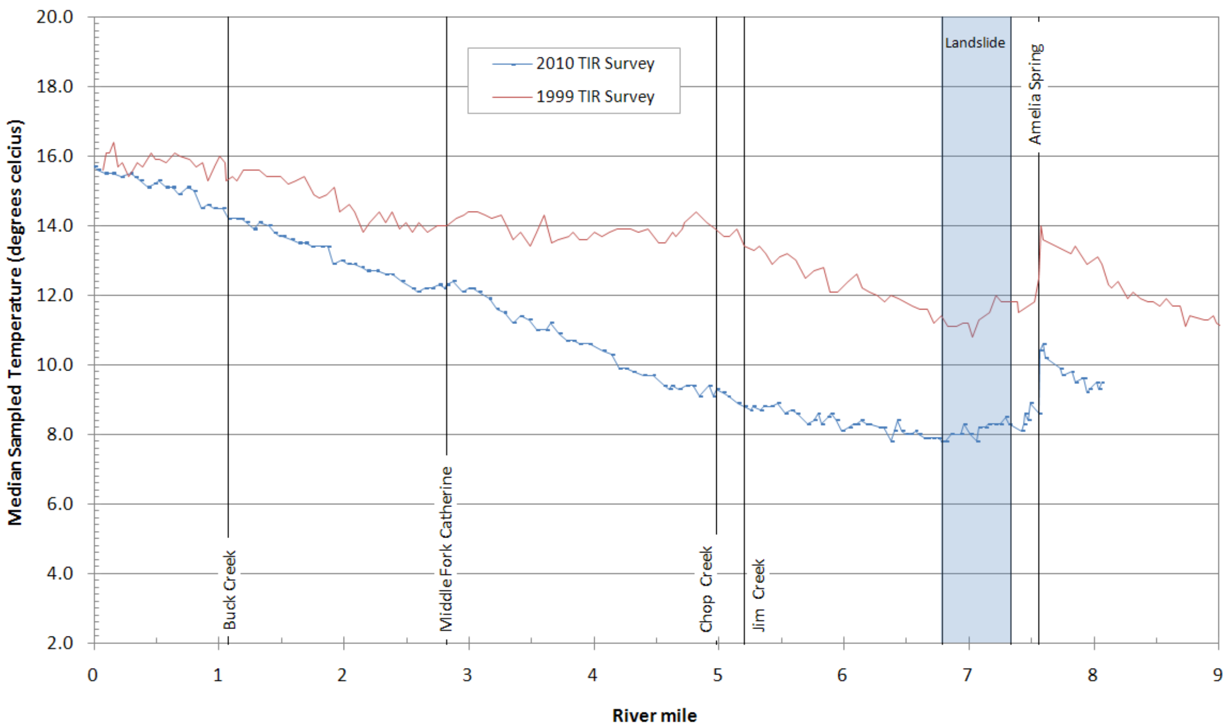
Figure 35. A comparison of the 1999 and 2010 thermal longitudinal profiles for Catherine Creek



7.9 North Fork Catherine Creek

The 1999/2010 profile comparison (*Figure 36*) shows higher water temperatures in 1999 (+0-4°C), but a slower rate of warming. Air temperatures were similar on the dates of the survey for the North Fork so it is unclear what is causing the difference in the profiles. Lower flow rates would likely result in warmer temperatures; however a steeper rate of warming would then be expected, which is not what is reflected in the profile.

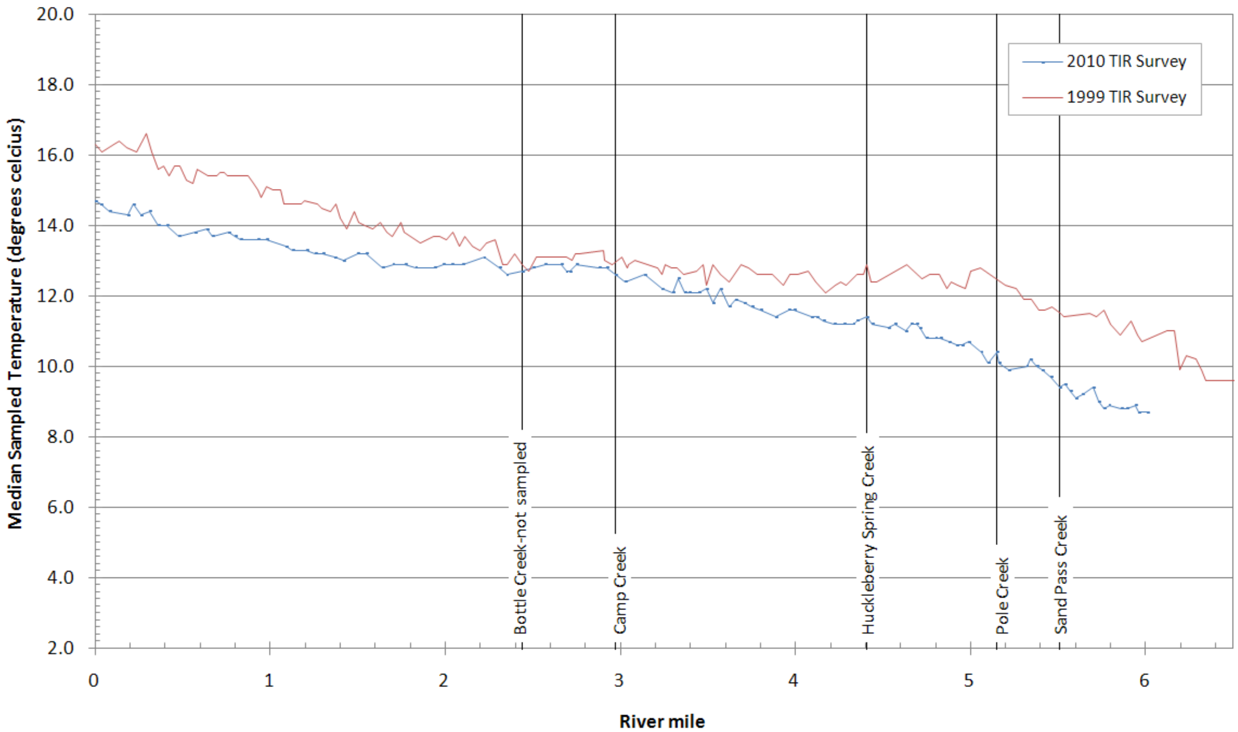
Figure 36. A comparison of the 1999 and 2010 thermal longitudinal profiles for North Fork Catherine Creek



7.10 South Fork Catherine Creek

Water temperatures in 1999 in South Fork Catherine Creek sampled approximately 2°C warmer than in 2010 (*Figure 37*). The temperature plateau seen below Camp Creek is present in the 1999 profile which reaffirms a constant source of groundwater influence along that reach.

Figure 37. A comparison of the 1999 and 2010 thermal longitudinal profiles for South Fork Catherine Creek



8. Projection, Datum and Units

Geo-corrected mosaics, surveys, and shapefiles are delivered in the following projection:

Projection:	UTM Zone 11
Horizontal Datum:	NAD83
Units:	meters

9. Deliverables

The TIR imagery is provided in two forms: individual un-rectified frames and continuous geo-rectified mosaics at varying resolutions: 0.3, 0.4, 0.5, and 0.6 meters (*See Table 3*).

The mosaics allow for easy viewing of the continuum of temperatures along the stream gradient, but also show edge match differences and geometric transformation effects. The un-rectified frames are useful for viewing images at their native resolutions and are often better for detecting smaller thermal features. Radiant temperatures are calibrated for the emissive characteristics of water and may not be accurate for terrestrial features.

Vector Data:	• *Thermal Surveys*. Sampled TIR point shapefiles by stream, showing image locations, sampled temperatures, and image interpretations. • *Natural Color Photo Indices*. Point shapefiles for photo points. • *Hydrography*. NHD Flowline shapefiles.
Raster Data:	• *Thermal Mosaics*. Continuous mosaics of the geo-rectified TIR image frames at varying resolutions in ERDAS Imagine (*.img) format. (Cell value = radiant temperature * 10) • *Thermal Singles Unrectified*. Calibrated TIR images in Erdas Imagine (*.img) format. (Cell value = radiant temperature * 10) • *Natural Color Unrectified*. Unrectified Natural color images in JPEG format
Spreadsheets:	*Long Profiles*. Excel spreadsheets by survey date containing the longitudinal temperature profiles for each stream
Data Project:	*ArcMap project* (*.mxd) containing the thermal surveys and thermal mosaics displayed with the corresponding colorramps.
Data Report:	Full report containing introduction, methodology, accuracy, and analysis

Appendix 1 – Daily air temperatures in La Grande, Oregon

2010			1999		
Date	Time (PDT)	Temperature (˚F)	Date	Time (PDT)	Temperature (˚F)
McCoy, Beaver					
8/7/2010	11:55 AM	80.6	8/26/1999	11:55 AM	77.0
	12:55 PM	84.2		12:55 PM	82.4
	1:55 PM	86.0		1:55 PM	86.0
	2:55 PM	84.2		2:55 PM	87.8
	3:55 PM	84.2		3:55 PM	87.8
	4:55 PM	84.2		4:55 PM	89.6
Meadow, Fly, Sheep					
8/8/2010	11:55 AM	75.2	8/26/1999	11:55 AM	77.0
	12:55 PM	78.8		12:55 PM	82.4
	1:55 PM	82.4		1:55 PM	86.0
	2:55 PM	82.4		2:55 PM	87.8
	3:55 PM	82.4		3:55 PM	87.8
	4:55 PM	84.2		4:55 PM	89.6
Upper Grande Ronde					
8/9/2010	11:55 AM	77.0	8/20/1999	11:55 AM	78.8
	12:55 PM	80.6		12:55 PM	84.2
	1:55 PM	82.4		1:55 PM	87.8
	2:55 PM	84.2		2:55 PM	89.6
	3:55 PM	84.2		3:55 PM	91.4
	4:55 PM	82.4		4:55 PM	91.4
Limber Jim					
8/9/2010	11:55 AM	77.0	8/26/1999	11:55 AM	77.0
	12:55 PM	80.6		12:55 PM	82.4
	1:55 PM	82.4		1:55 PM	86.0
	2:55 PM	84.2		2:55 PM	87.8
	3:55 PM	84.2		3:55 PM	87.8
	4:55 PM	82.4		4:55 PM	89.6
Catherine, North and South Forks Catherine					
8/12/2010	11:55 AM	68.0	8/21/1999	11:55 AM	78.8
	12:55 PM	75.2		12:55 PM	80.6
	1:55 PM	78.8		1:55 PM	80.6
	2:55 PM	80.6		2:55 PM	82.4
	3:55 PM	82.4		3:55 PM	80.6
	4:55 PM	80.6		4:55 PM	82.4
Not Flown in 1999: Rock, Five Points, Spring, Burnt Corral, Dark Canyon, Chicken, West Chicken, Clear, Ladd, Little, Milk, Little Catherine					

Source: Weather Underground http://www.wunderground.com

Appendix 2 – Mean discharge rates for the Grande Ronde River at Troy, Oregon (USGS 13333000)

Surveyed Stream	2010		1999	
	Date	Mean Discharge (ft3/s)	Date	Mean Discharge (ft3/s)
McCoy, Beaver	8/7/2010	804	8/26/1999	833
Meadow, Fly, Sheep	8/8/2010	745	8/26/1999	833
Upper Grande Ronde	8/9/2010	699	8/20/1999	948
Limber Jim	8/9/2010	699	8/26/1999	833
Catherine, North and South Forks Catherine	8/12/2010	751	8/21/1999	927
Not Flown in 1999: Rock, Five Points, Spring, Burnt Corral, Dark Canyon, Chicken, West Chicken, Clear, Ladd, Little, Milk, Little Catherine				

Source: USGS National Water Information System http://waterdata.usgs.gov/nwis