Applied Remote Sensing and Analysis

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Upper Grande Ronde River Basin Stream Temperature Model Expansion

Prepared for:

Columbia River Inter-Tribal Fish Commission

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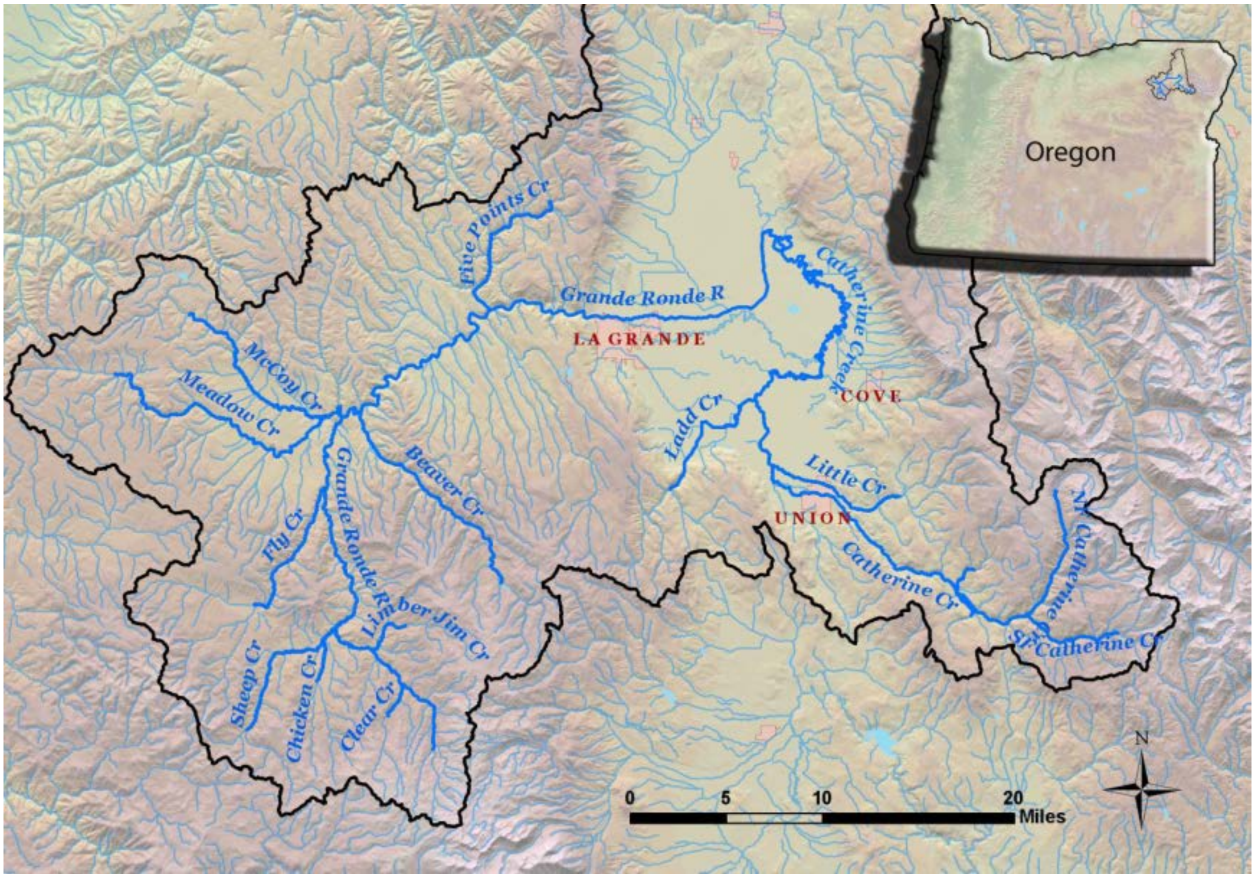
1. Overview and Scope

As part of a previous contract with The Columbia River Inter-Tribal Fish Commission (CRITFC), WSI completed stream temperature modeling of 17 streams in the Upper Grande Ronde River basin. Heat Source models were set up and calibrated for a 3-week time period spanning August 6–27, 2010 in order to assess critical summertime conditions. CRITFC has contracted with WSI to expand these 3-week models to cover the months of July, August, and September of 2010. This report summarizes the remote sensing and ground level data and describes the expanded stream temperature modeling results.

The goal of the project was to use previously collected high-resolution landscape and water quality data for use in the Heat Source stream temperature model. Stream temperature was simulated for the Grande Ronde River, Catherine Creek, and several of their tributaries for a period between July 10 and September 20, 2010. The simulation period is representative of low-flow and high stream temperature conditions, when salmonid habitat is at its most critical condition. Figure 1 shows the location of the study area within northeastern Oregon. Approximately 247 stream miles were simulated above the confluence of Catherine Creek and the Grande Ronde River. The streams of interest are either historic or current salmonid habitat.

Figure 1 – Streams of interest in the upper Grande Ronde River subbasin.



2. Data Summary

2.1 Remote Sensing Data

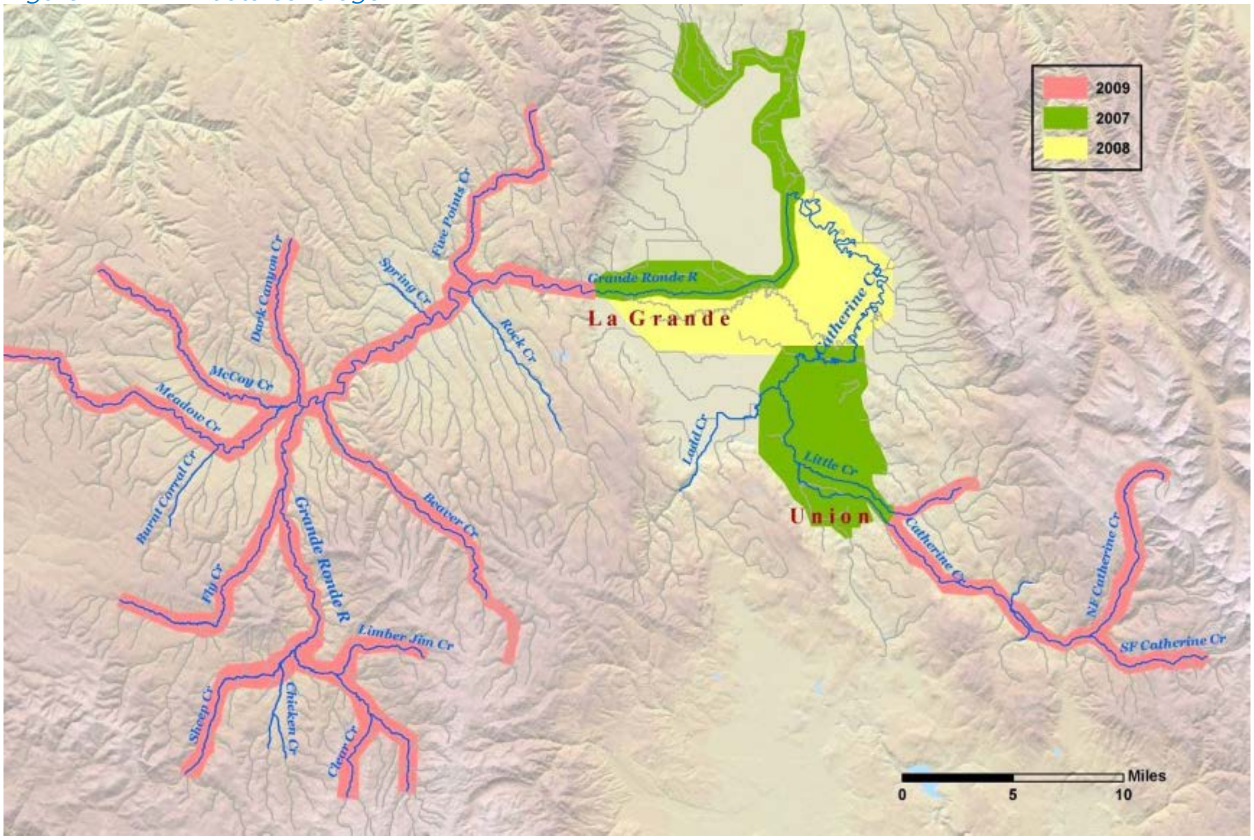
2.1.1 LiDAR

Light detection and ranging (LiDAR) data were collected by WSI in September 2009 in order to supplement two existing LiDAR datasets that were collected in 2007 and 2008 (Figure 2). Together, the three LiDAR datasets provide high resolution land cover and bare earth elevation data for stream temperature model input. Table 1 summarizes the LiDAR products and their applicability to Heat Source modeling.

Table 1 - LiDAR products and their applications for stream temperature modeling.

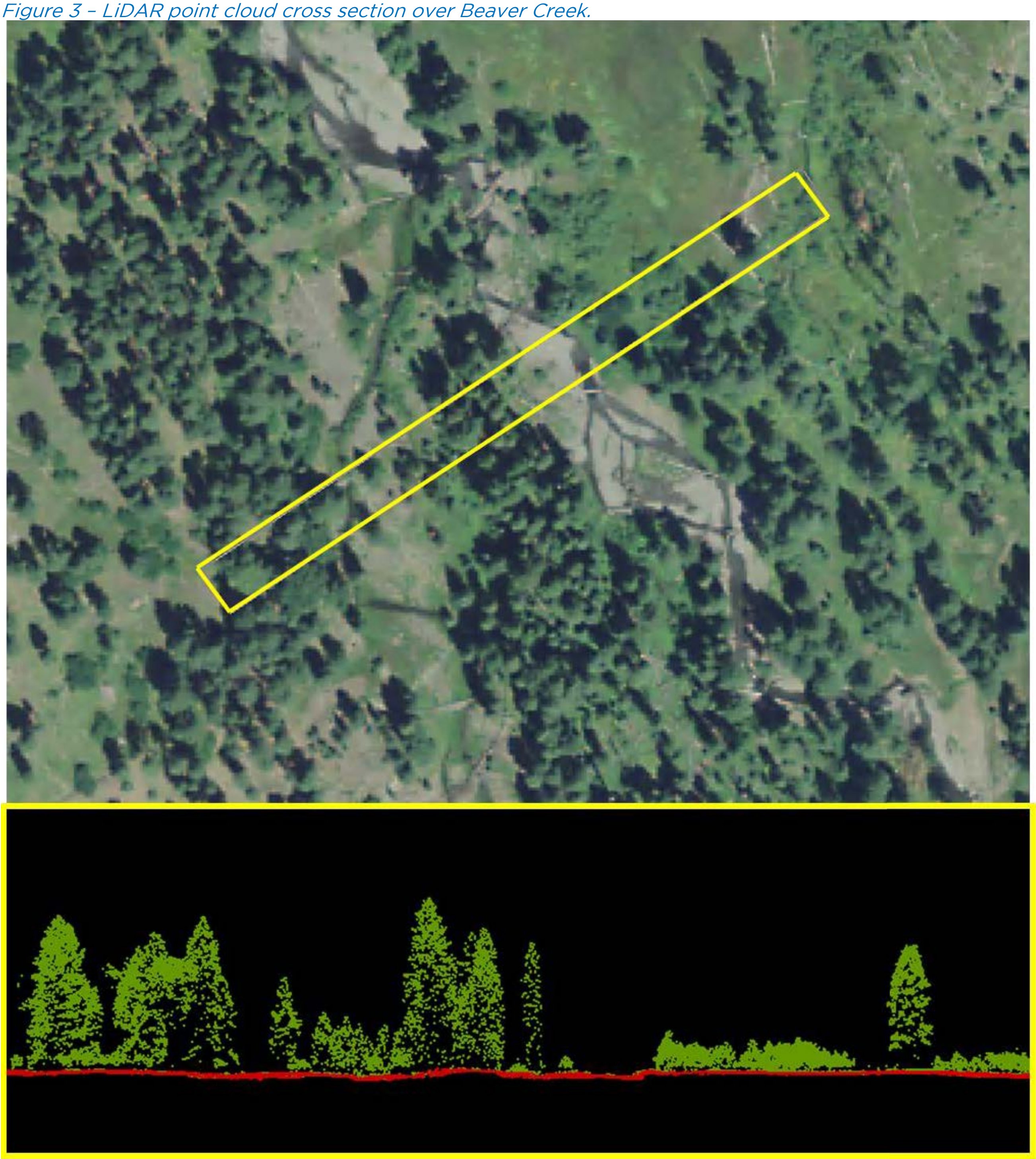
LiDAR Product	Applications
1-meter highest hit raster	Sampling near-stream land cover heights.
1-meter bare earth raster	Deriving high-resolution stream maps - including centerlines and banks. Sampling stream elevations and near-stream land surface elevations.
1-meter intensity images	Mapping stream centerlines and estimating wetted edges.

Figure 2 - LiDAR data coverage.



The LiDAR data consists of three-dimensional point clouds at approximately 8 points per square meter, with a relative accuracy of 5 centimeters. Each LiDAR data point is classified as either "ground" or "default". "Default" includes all non-ground features such as vegetation, buildings, and other human made structures. Figure 3 shows a cross section of LiDAR data over Beaver Creek. Default points are green, while the ground points are colored red.

Figure 3 – LiDAR point cloud cross section over Beaver Creek.



LiDAR point data can be associated with RGB values from orthophotographs in order to produce more realistic or true-color oblique imagery. The default points can also be “turned off” to reveal a bare earth surface model which is useful for studying ground surface features that are normally obscured by vegetation. Figure 4 shows a LiDAR point cloud with RGB extraction and the corresponding bare earth model for a section of Beaver Creek. Complex channel geometry within the floodplain is easily visible in the bare earth LiDAR model.

Figure 4 – LiDAR point cloud with RGB extraction (top) and bare earth digital terrain model (bottom).

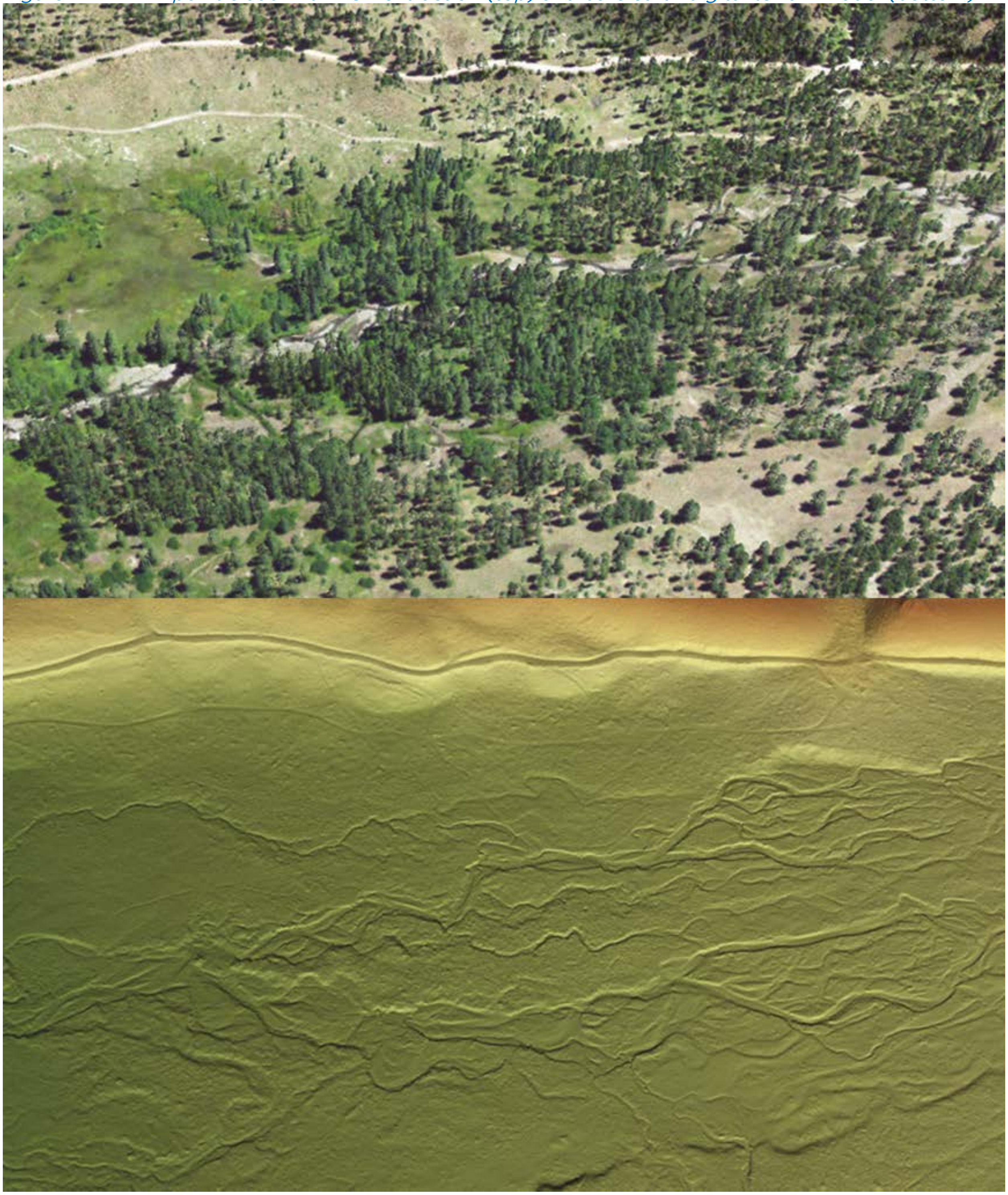
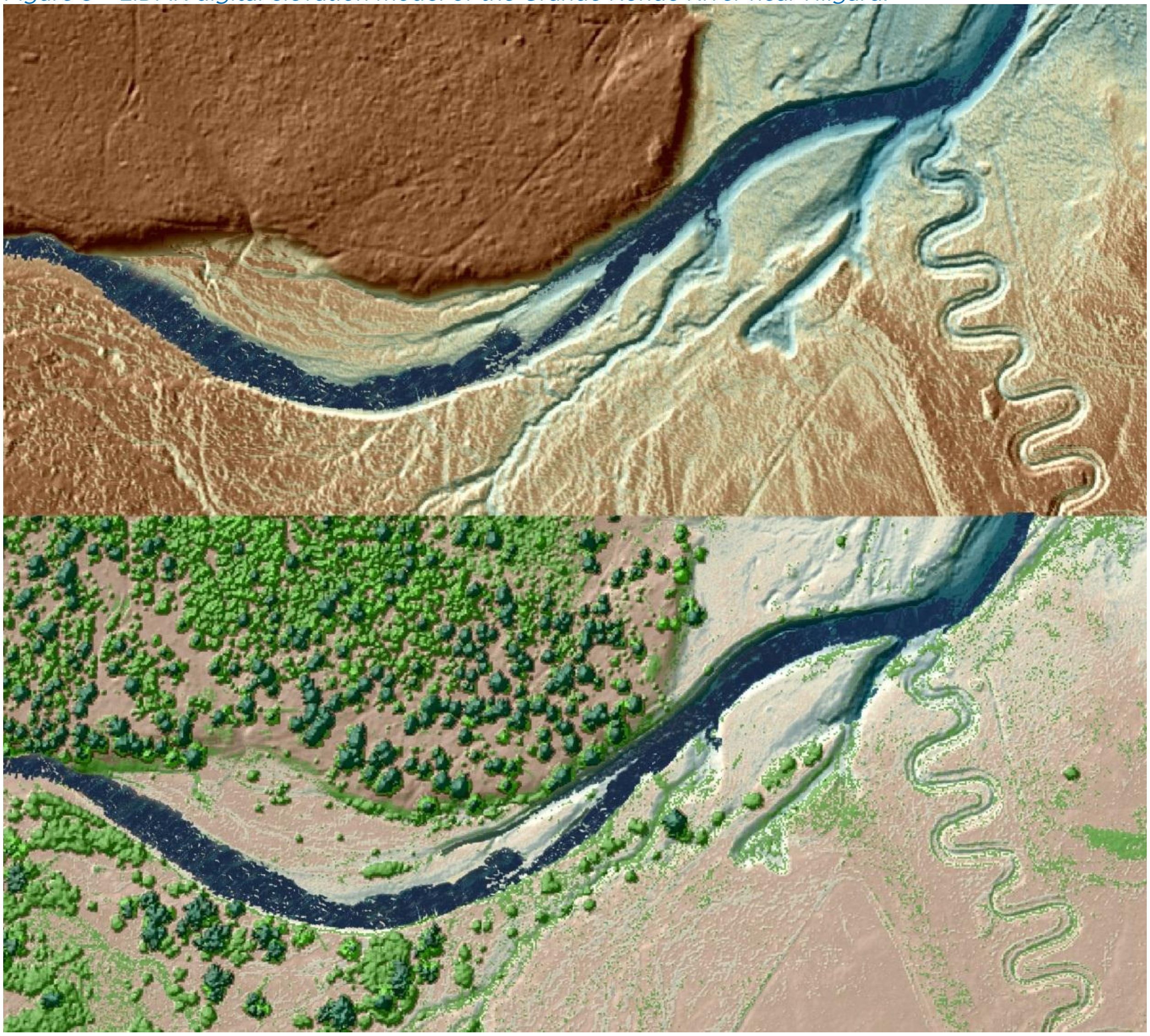


Figure 5 is another example of LiDAR digital elevation models (DEMs). The top image is the bare earth LiDAR model and the lower image is the highest hit LiDAR model. The DEM cell size is one meter. This type of raster data is commonly used within GIS applications such as ArcMap. For this project, the bare earth and highest hit rasters were used for stream mapping, tree height sampling, and other stream temperature model inputs.

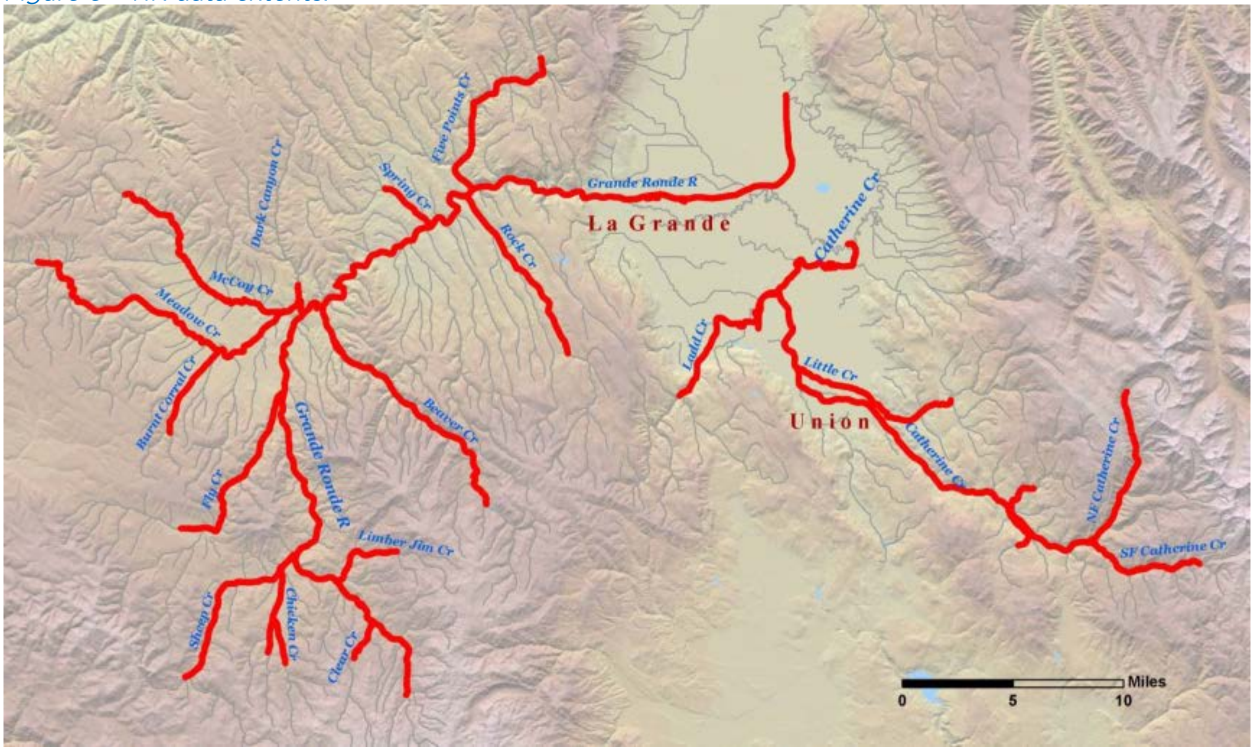
Figure 5 – LiDAR digital elevation model of the Grande Ronde River near Hilgard.



2.1.2 Thermal Infrared

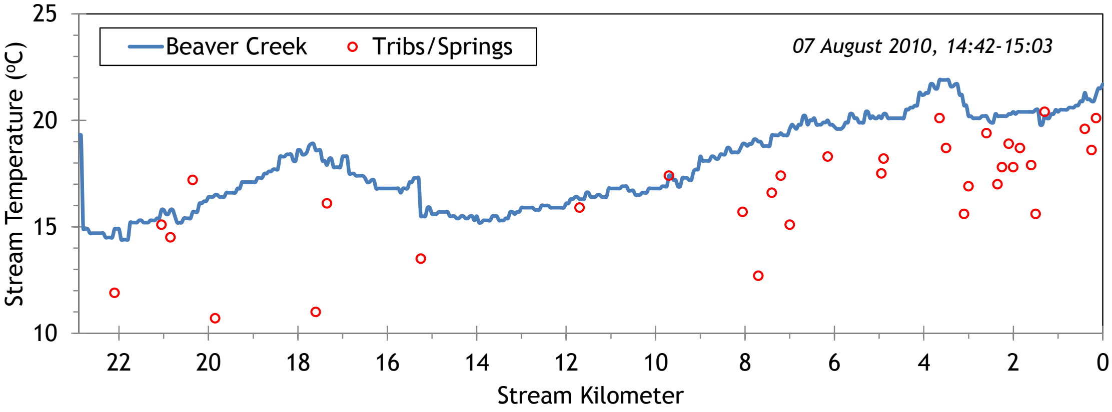
WSI collected thermal infrared (TIR) stream temperature data for approximately 226 river miles (364 kilometers) during August 2010 (Figure 6). The TIR data were collected during the warmest part of the afternoon in order to capture near-daily maximum stream temperatures, when aquatic life is most at risk. Additionally, the August data collection was intended to target the low-flow and high seasonal temperature window when salmonid habitat is most impaired. Coinciding with the TIR data collection window, CRITFC crews were collecting ground-level flow measurements and hourly stream temperature data.

Figure 6 - TIR data extents.



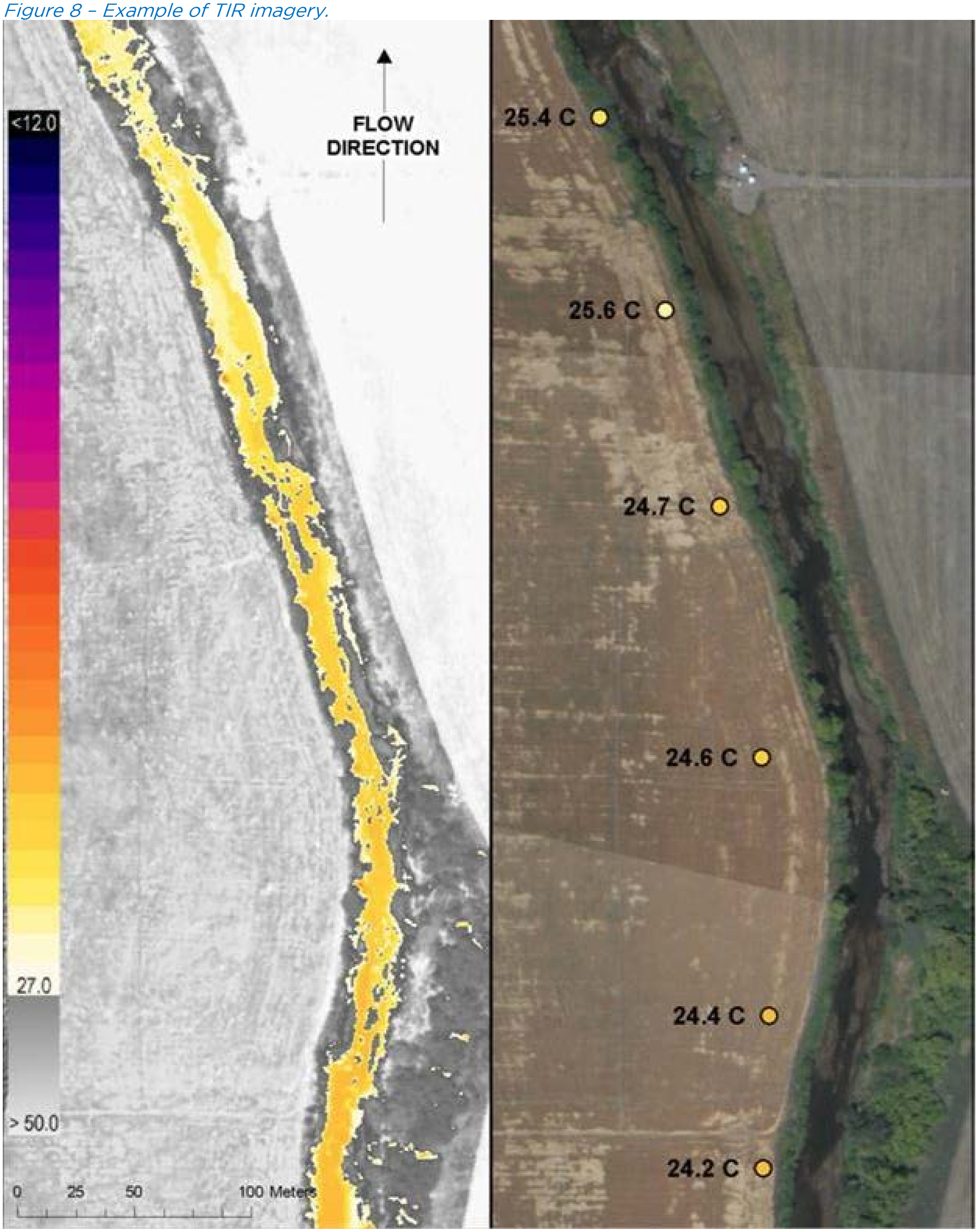
Following is an example of a TIR longitudinal temperature profile (Figure 7). In addition to the stream temperature profile, the temperatures of springs and tributaries are captured by the survey.

Figure 7 – Example of a TIR longitudinal stream temperature profile.



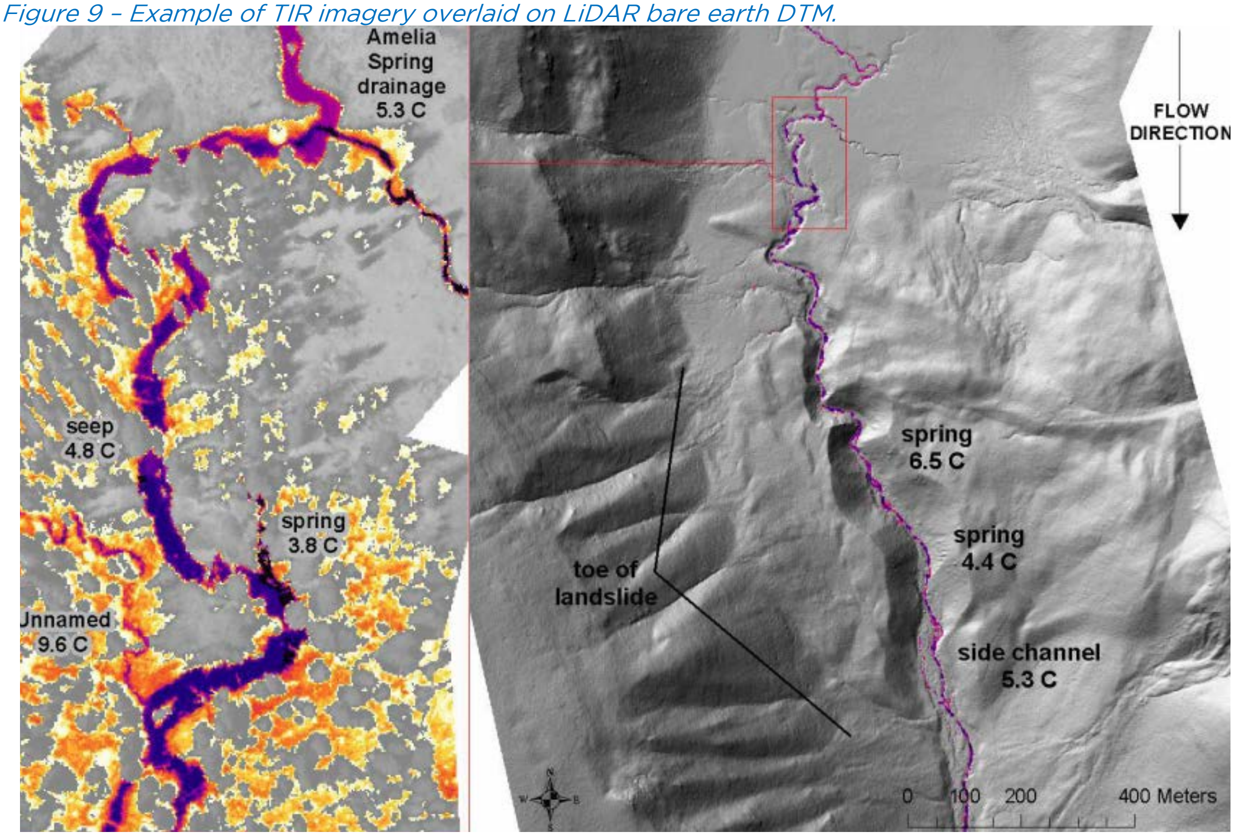
TIR surveys record only the surface temperatures and do not penetrate into the water column. Figure 8 shows an example of TIR imagery and the temperatures sampled from it. The points represent the position of the helicopter at the time the image was recorded.

Figure 8 – Example of TIR imagery.



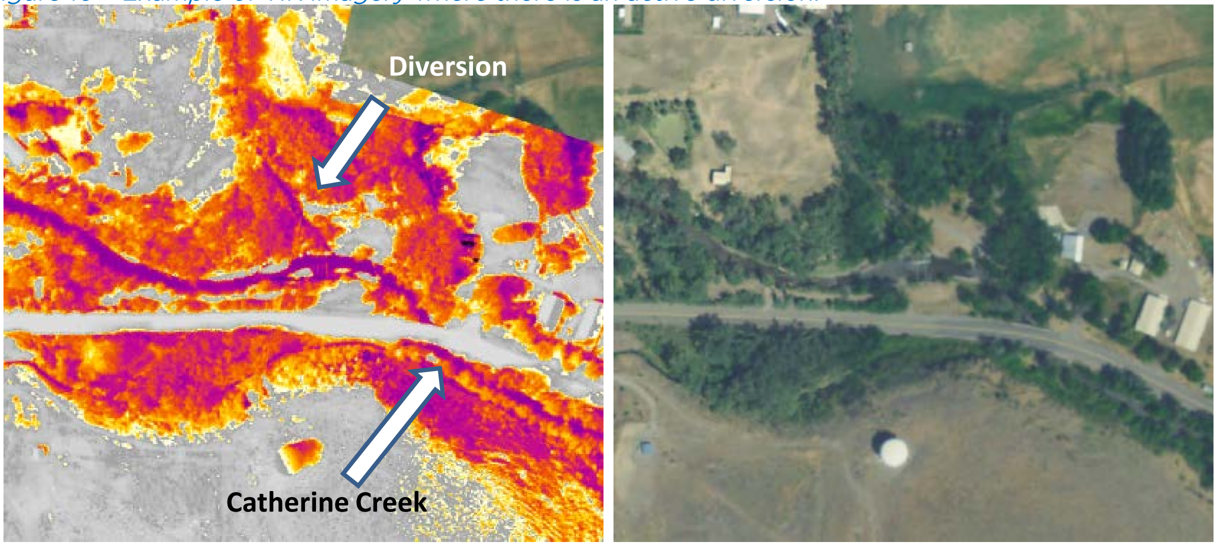
The TIR stream temperature imagery is useful for identifying features such as tributaries and springs (Figure 9). Temperatures can be sampled from those inflows and then mass balance calculations can be made to estimate their volumes. Significant inflows (ones that are large enough to accurately measure and are impacting stream temperature) are often included within the stream temperature models.

Figure 9 – Example of TIR imagery overlaid on LiDAR bare earth DTM.



The TIR imagery can also be used to identify diversion canals that were active at the time of the survey (Figure 10).

Figure 10 – Example of TIR imagery where there is an active diversion.

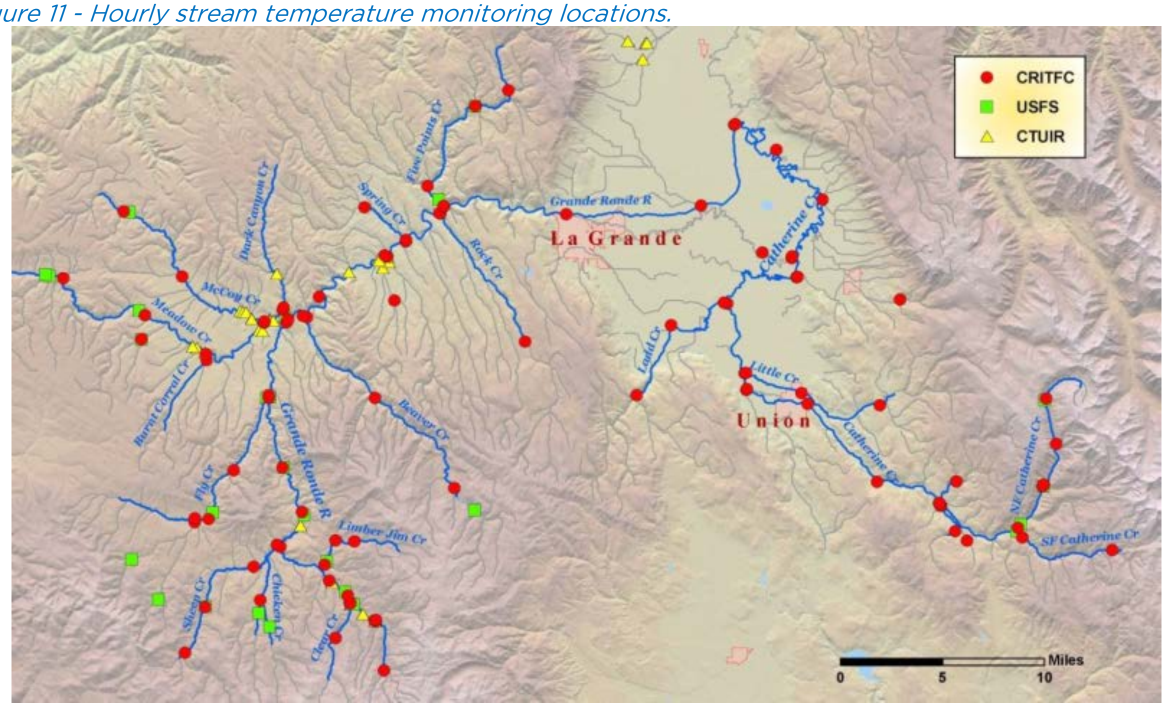


2.2 Ground Level Data

2.2.1 Hourly Temperature Data

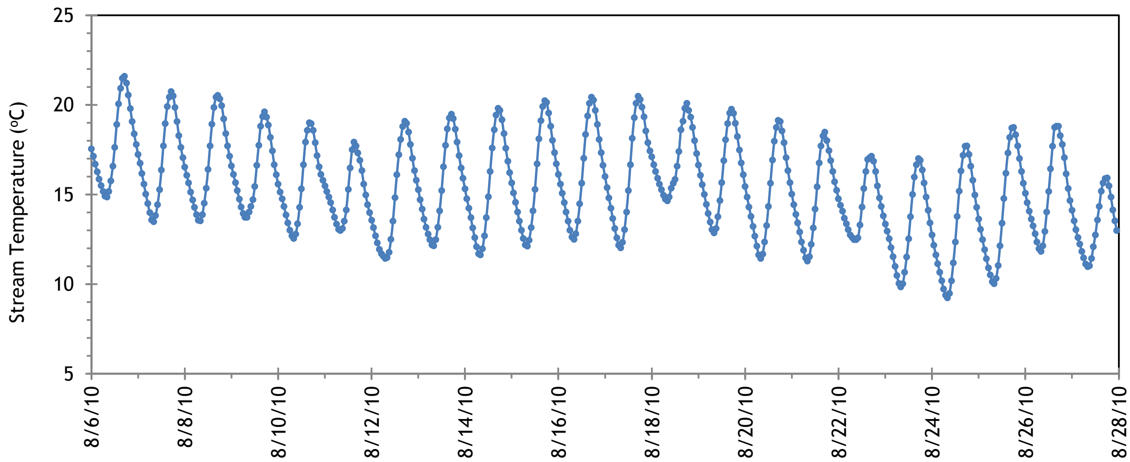
During the summer of 2010, CRITFC deployed thermistors throughout the study area in order to record hourly stream temperatures. The United States Forest Service (USFS) and Confederated Tribes of the Umatilla Indian Reservation (CTUIR) also provided hourly temperature data they had collected during that time. Figure 11 shows the hourly stream temperature monitoring locations.

Figure 11 - Hourly stream temperature monitoring locations.



Hourly stream temperature data were used to calibrate and verify the TIR data. Temperature data were also used for Heat Source input – to seed the uppermost boundary temperatures and for validating simulation results at various locations along the modeled streams. Figure 12 is an example of hourly temperature data.

Figure 12 – Example of hourly temperature data collected by CRITFC.



2.2.2 Seasonal Variation

A few stream temperature monitoring locations were selected in order to assess variability throughout the summertime period. The highest stream temperatures generally occurred in August. Figure 13 and Figure 14 display the stream temperature variability of sites along the Grande Ronde River and Catherine Creek.

Figure 13 – Grande Ronde River stream temperature variability during the summer of 2010.

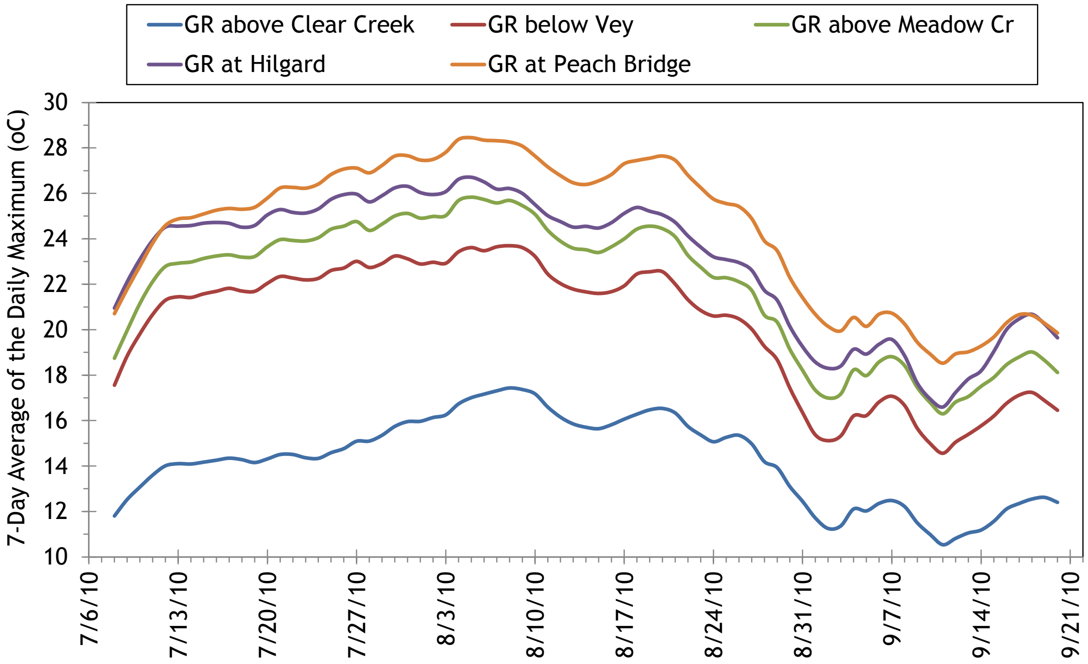
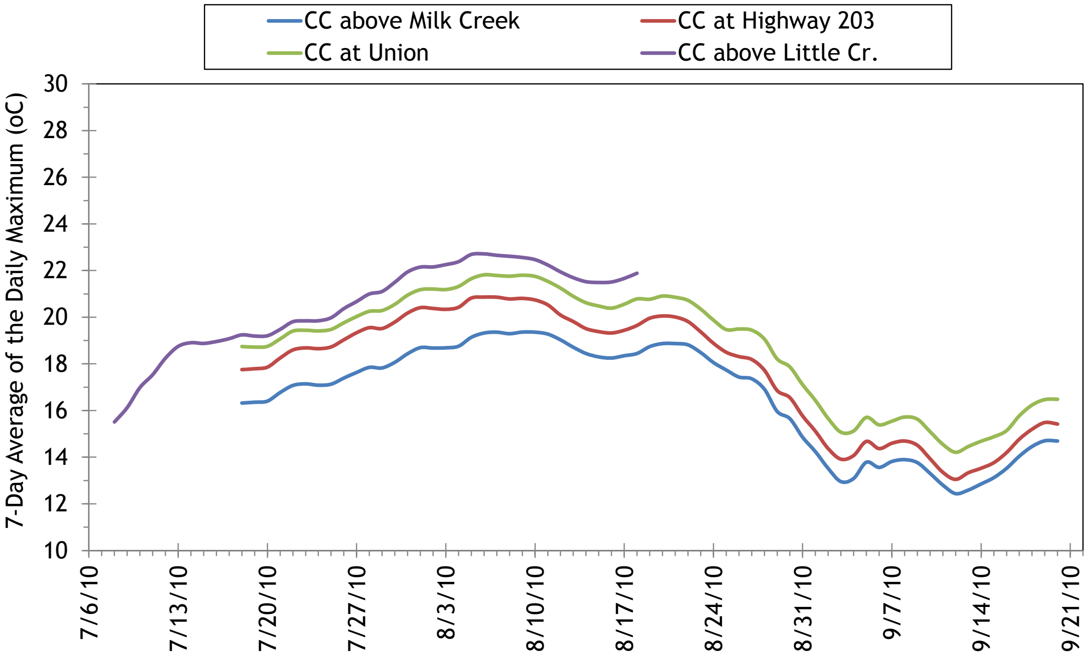


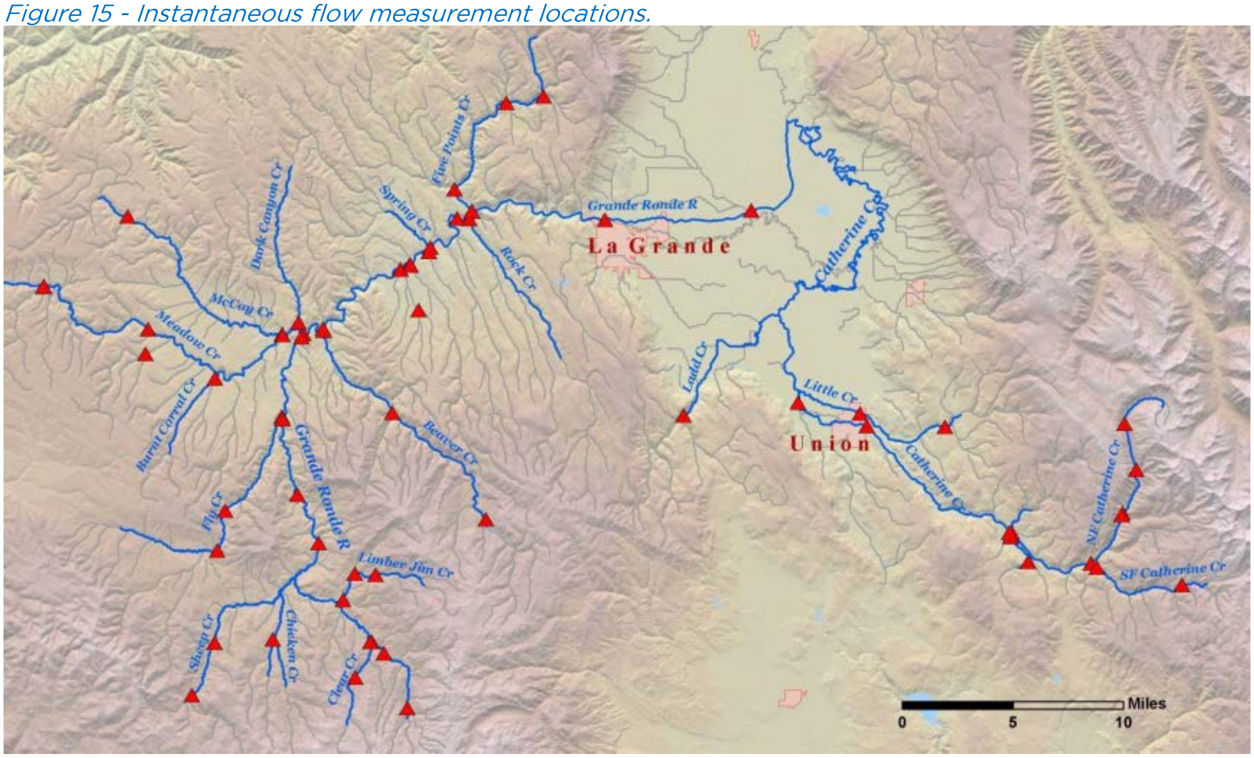
Figure 14 – Catherine Creek stream temperature variability during the summer of 2010.



2.2.3 Instantaneous Flow Data

CRITFC collected instantaneous ground-level flow data at various locations in August 2010 in order to coincide with the TIR flight window (Figure 15). Flow volume, velocity, depth and width were recorded at each location. The data were used to set up Heat Source hydraulics and to validate the simulation results.

Figure 15 - Instantaneous flow measurement locations.



The following data were recorded at each flow measurement site:

- Date and time
- Discharge volume
- Minimum, maximum and average velocity
- Minimum, maximum and average depth
- Wetted width
- Latitude and longitude

One measurement was taken at each site during the initial 3-week model simulation time period (August 6-27, 2010). The measurements were used to "seed" mass balance calculations of daily flow volume for streams where daily gage data were unavailable. The data were also used to validate the Heat Source simulated hydraulics.

2.2.4 Gaged Flow Data

Daily flow volumes were recorded at several USGS/OWRD gages within the study area (Figure 16). The daily average flows recorded at these locations were used to set up Heat Source hydraulics and validate the simulation results.

Figure 16 - Flow gage locations.

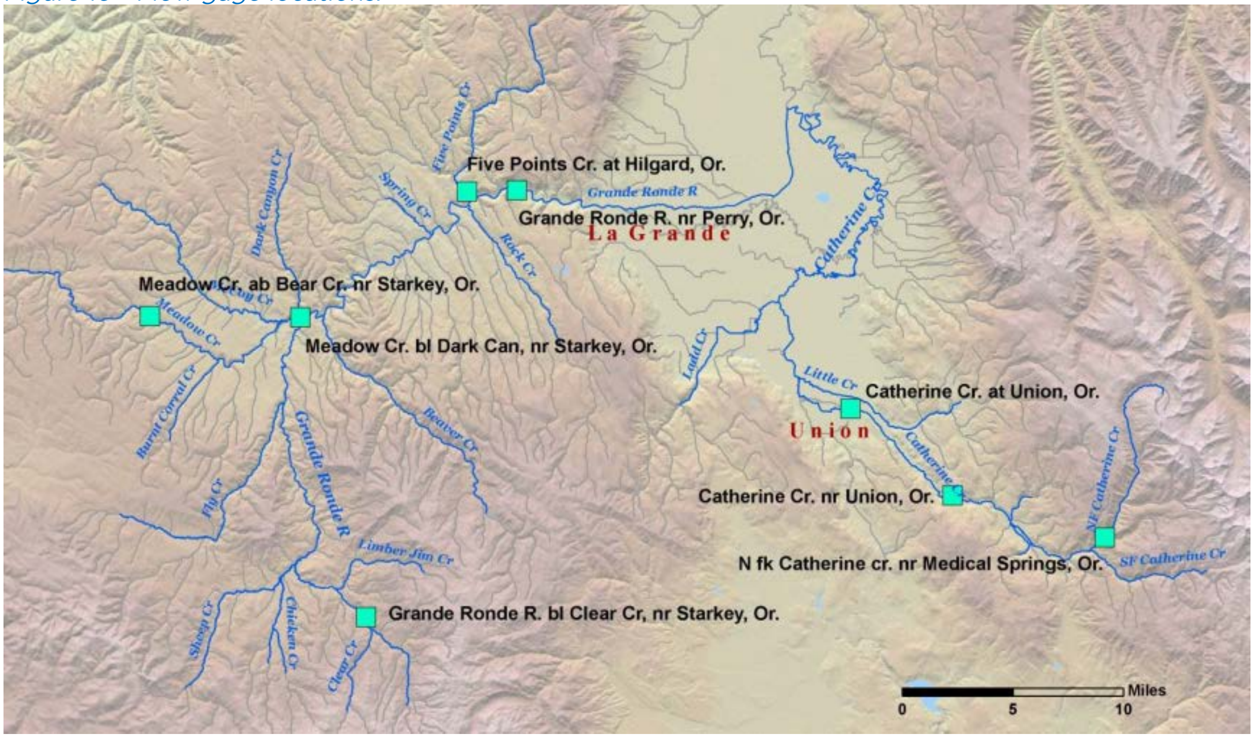


Table 2 lists the gages that were active from July 10 through September 20, 2010 within the study area. Data were downloaded from the Oregon Water Resources Department website. The original records were in 15-minute intervals and daily average values were calculated.

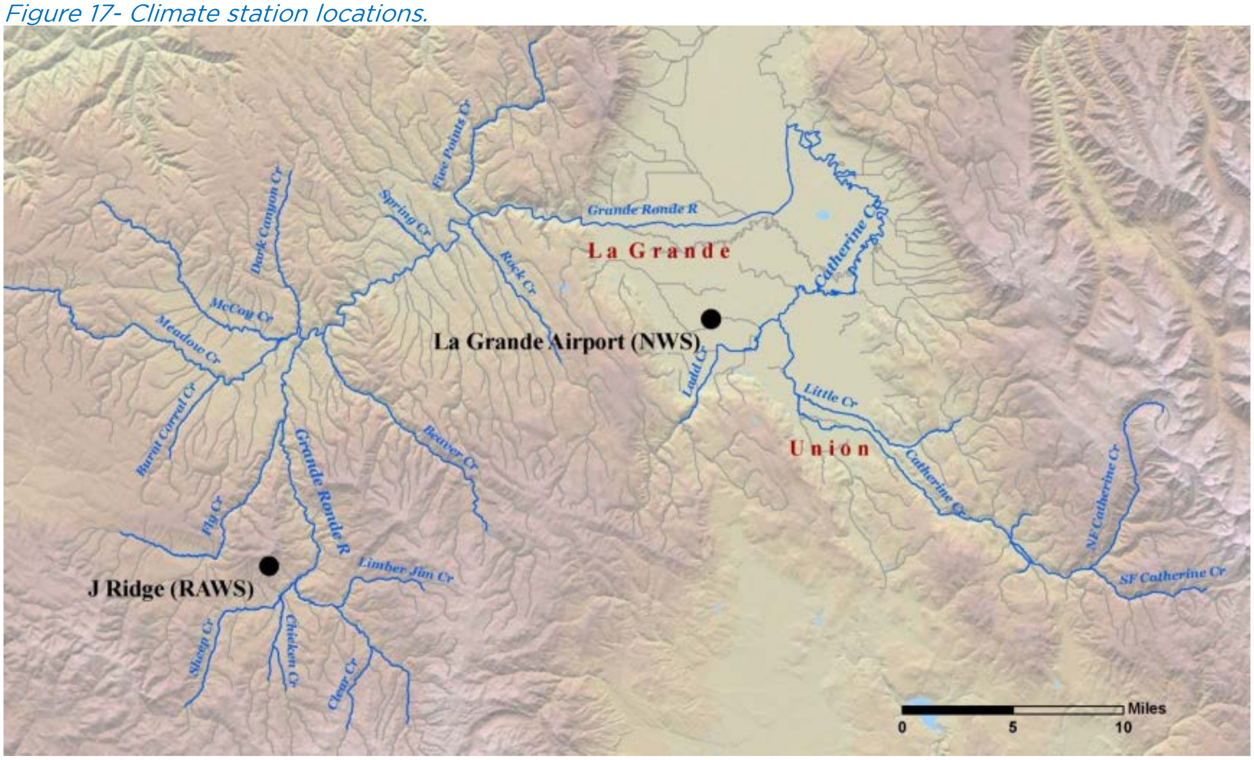
Table 2 – Stream flow gages within the study area.

ID #	Gage	Stream
13320300	Catherine Cr. at Union, OR	Catherine Creek
13320000	Catherine Cr. near Union, OR	Catherine Creek
13318920	Five Points Cr. at Hilgard, OR	Five Points Creek
13317850	Grande Ronde R. bl Clear Cr, nr Starkey, OR	Grande Ronde River
13318960	Grande Ronde R. nr Perry, OR	Grande Ronde River
13318060	Meadow Cr. above Bear Cr. nr Starkey, OR	Meadow Creek
13318210	Meadow Cr. below Dark Can, nr Starkey, OR	Meadow Creek
13319900	NF Catherine Cr. nr Medical Springs, OR	North Fork Catherine Creek

2.2.5 Climate Data

Hourly climate data were recorded by the National Weather Service at the La Grande airport. The U.S. Forest Service also recorded hourly climate data at the J Ridge remote automated weather station (RAWS) site in the upper Grande Ronde basin. Figure 17 shows the climate station locations. For most Heat Source models, data from the La Grande airport were used. Some upper basin models used the USFS RAWS climate data. Further details and assumptions are provided in the following sections for each simulated stream.

Figure 17- Climate station locations.



For all simulations, the cloud cover data recorded at the La Grande airport were used (Figure 18). Cloud cover was reported as eighths of sky and the data were translated into percentages for Heat Source input.

Figure 18 – Hourly cloud cover values recorded at La Grande airport.

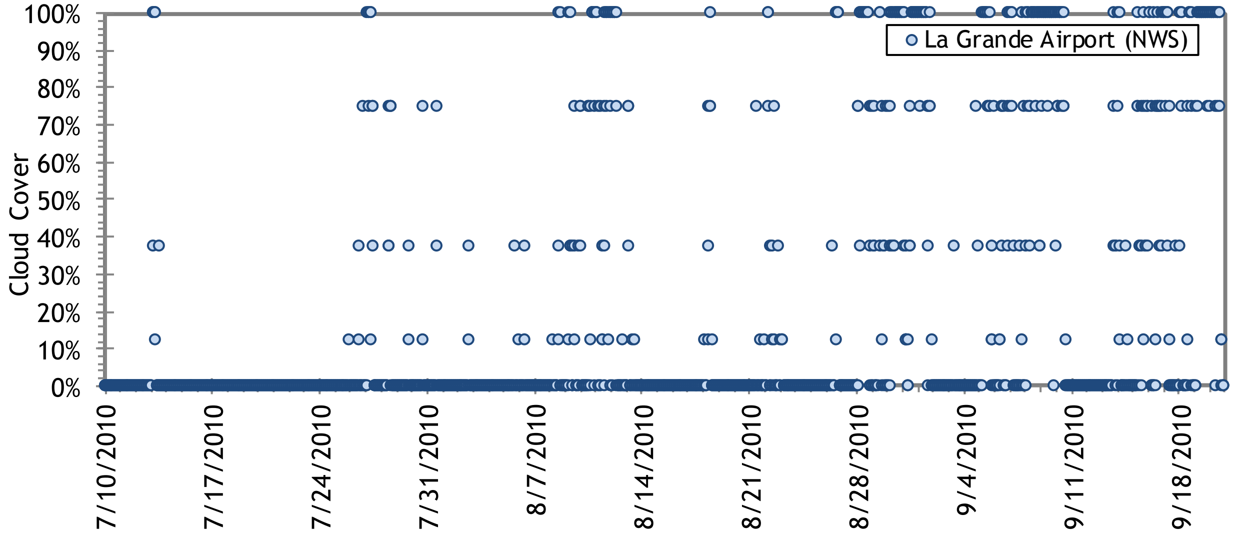
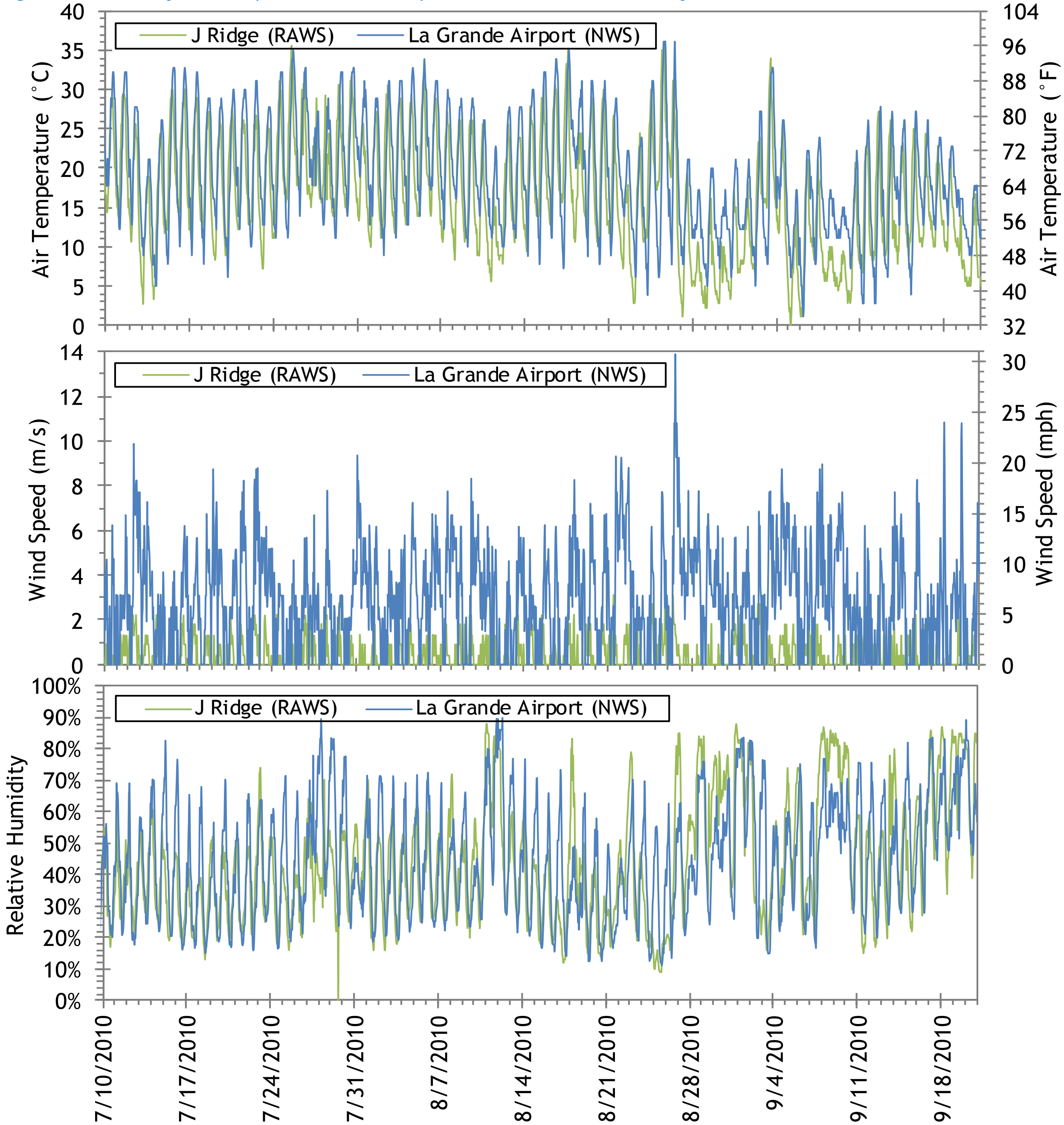


Figure 19 shows the recorded hourly air temperature, relative humidity and wind speed data recorded at the J Ridge (RAWS) and La Grande airport (NWS) weathers stations between August 6 and August 27, 2010. Wind speeds at the airport were higher than at J Ridge because the airport is located in a wide open valley bottom.

Figure 19 – Hourly air temperature, wind speed and relative humidity data.



3. GIS Data Sampling for Heat Source Input - TTools

Streams were mapped from the bare earth LiDAR data. Then TTools, a set of automated GIS sampling tools, was used to create an input database for the Heat Source model. Figure 20 is a map of where stream channels were mapped and TTools was run. Table 3 summarizes the streams and lengths that were mapped and sampled with TTools.

Figure 20 – TTools sampling extents

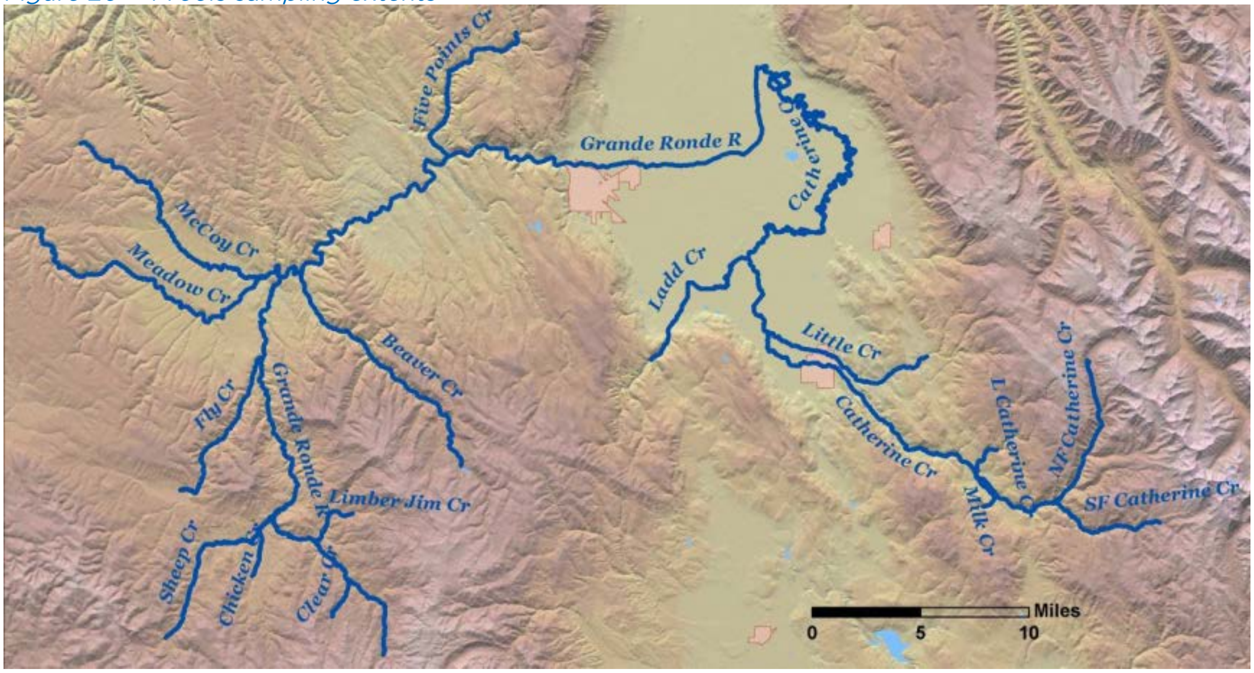


Table 3 – Streams where TTools sampling was completed.

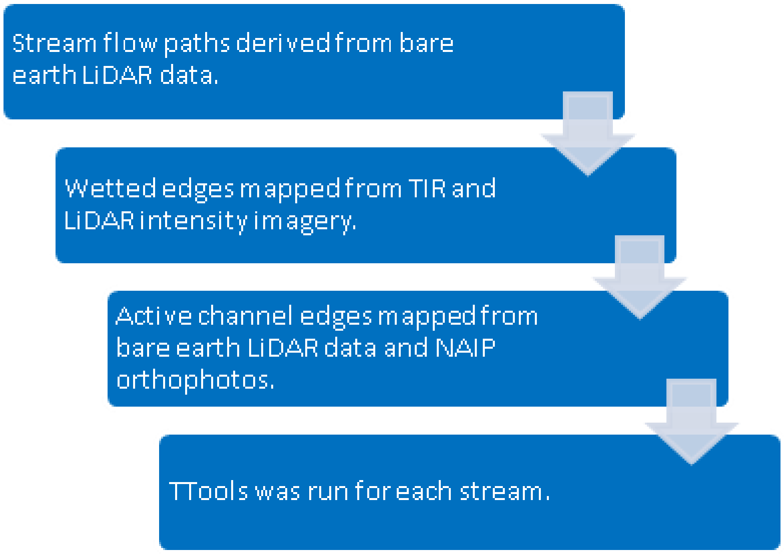
Watershed	Stream	Km	Miles
Catherine Creek	North Fork Catherine Creek	13.4	8.3
	South Fork Catherine Creek	10.4	6.5
	Milk Creek	3.4	2.1
	Little Catherine Creek	3.2	2.0
	Little Creek	16.5	10.3
	Ladd Creek	15.3	9.5
	Catherine Creek	88.7	55.1
Upper Grande Ronde River	Clear Creek	3.5	2.2
	Limber Jim Creek	5.9	3.7
	Chicken Creek	6.5	4.0
	Sheep Creek	22.2	13.8
	Fly Creek	15.5	9.6
	Meadow Creek	31.5	19.6
	McCoy Creek	23.9	14.9
	Beaver Creek	22.9	14.2
	Five Points Creek	16.4	10.2
	Grande Ronde River	98.1	61.0
	TOTAL:	**397.3**	**246.9**

Heat Source stream temperature modeling incorporates high-resolution LiDAR, TIR, and stream mapping. This section describes how stream channels were mapped from LiDAR data and how the various GIS data sources were sampled to create Heat Source input databases. Following is a brief overview of the methodology:

1. Stream flow paths were derived from 1-meter bare earth LiDAR rasters.
    a. Smoothing algorithms were applied.
    b. Results verified and manually corrected where needed.
2. Wetted edges were digitized.
3. Active channel edges were digitized.
4. TTools was used to segment the stream every 50 meters and sample the following:
    a. Stream elevation, gradient, and aspect
    b. Channel widths
    c. Topographic shade angles
    d. Near stream land cover heights
    e. TIR stream temperatures

Figure 21 summarizes the general workflow used to create, assemble, and sample GIS data for Heat Source model input. Once the TTools shapefile database was created for each stream, Heat Source models were set up and the calibration process was ready to commence.

Figure 21 – General workflow to prepare Heat Source model inputs.



3.1 Stream Mapping

Existing stream layers were outdated and had fairly coarse resolutions (1:24,000 or coarser). Since Heat Source relies on high resolution LiDAR inputs, new stream layers were mapped from the bare earth LiDAR data. Following are the steps used to create the high-resolution stream layers:

1. One-meter rasters of the bare earth LiDAR were mosaicked for each stream to be modeled.
2. The bare earth rasters were filled and flow direction and accumulation rasters were derived.
3. The flow accumulation raster was then converted to polylines using a minimum drainage area.
4. The stream of interest was isolated and all extraneous segments were deleted (Figure 22).
5. Smoothing algorithms were applied to remove "kinks" (Figure 23).
6. Smoothed stream polylines were verified against LiDAR, TIR, and aerial photography and manually corrected where necessary.

Figure 22 – Raw stream polyline.

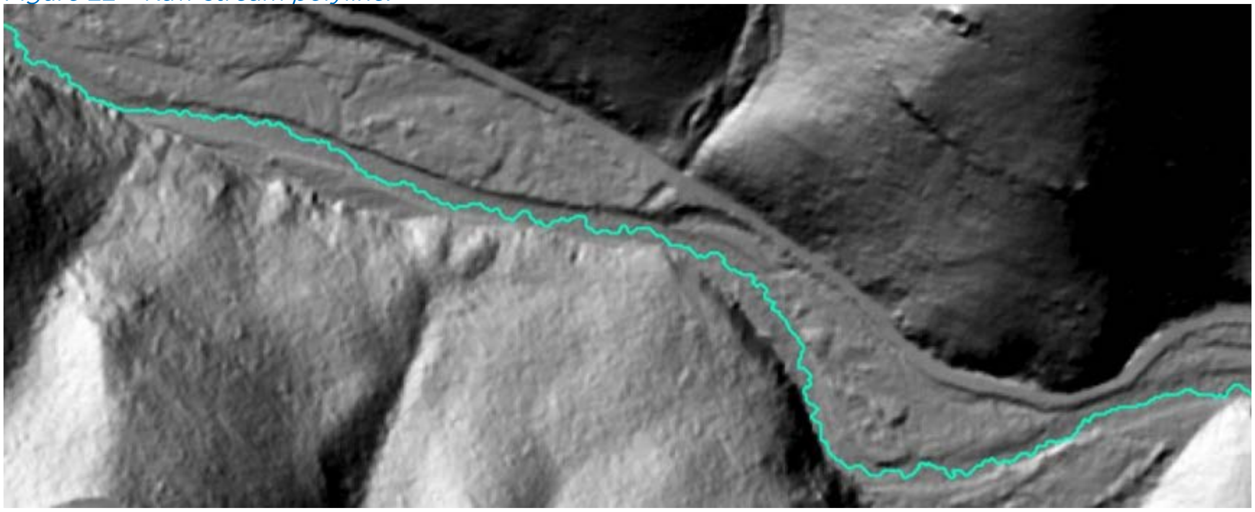
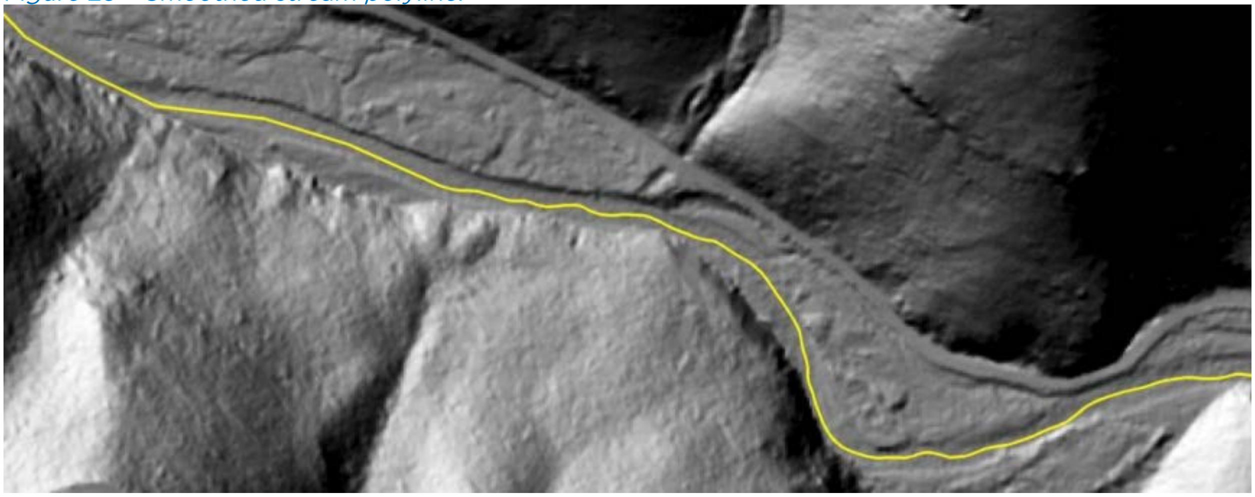


Figure 23 – Smoothed stream polyline.



3.2 Wetted Edge Mapping

Wetted widths are an important input parameter for the Heat Source model because accurate hydraulics are essential for a robust modeling effort. LiDAR intensity images and TIR imagery provided clear depictions of the stream surface in most cases. The right and left wetted edges were digitized from those sources. Then TTools was used to measure the wetted width at each 50-meter segment.

Figure 24 – Stream polyline overlaid on LiDAR intensity image.

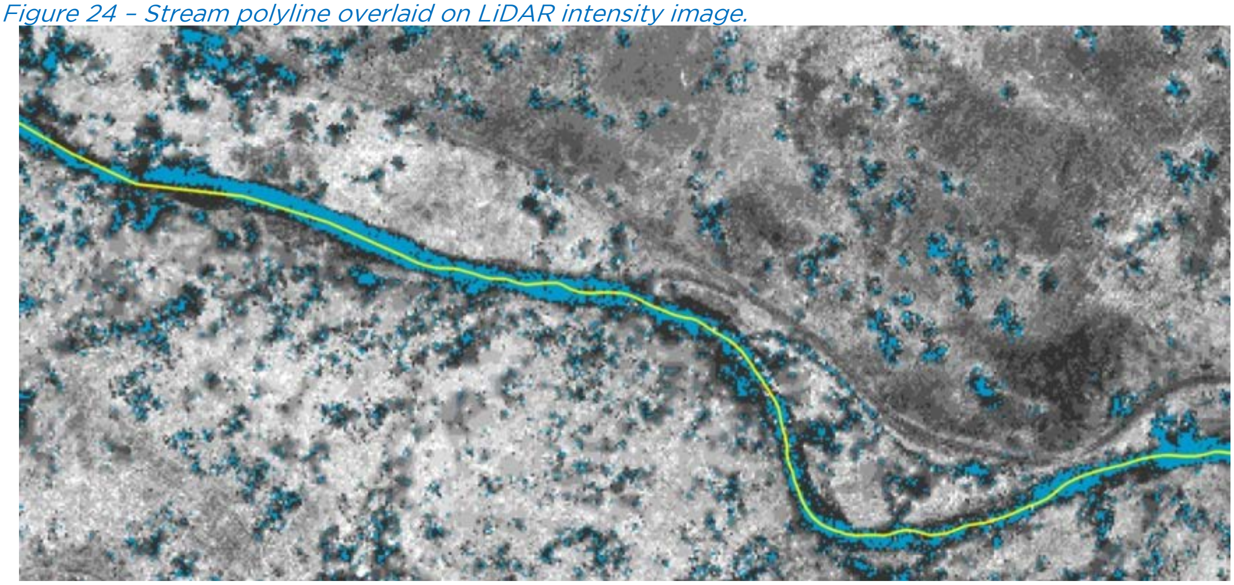
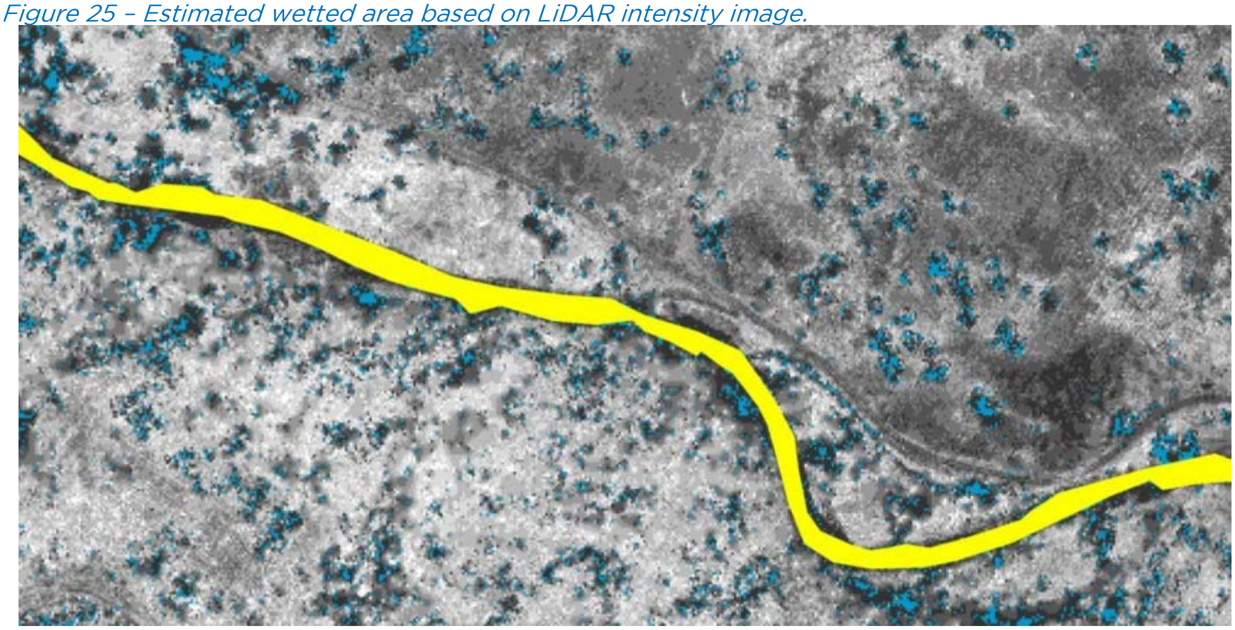


Figure 25 – Estimated wetted area based on LiDAR intensity image.



3.3 Active Channel Mapping

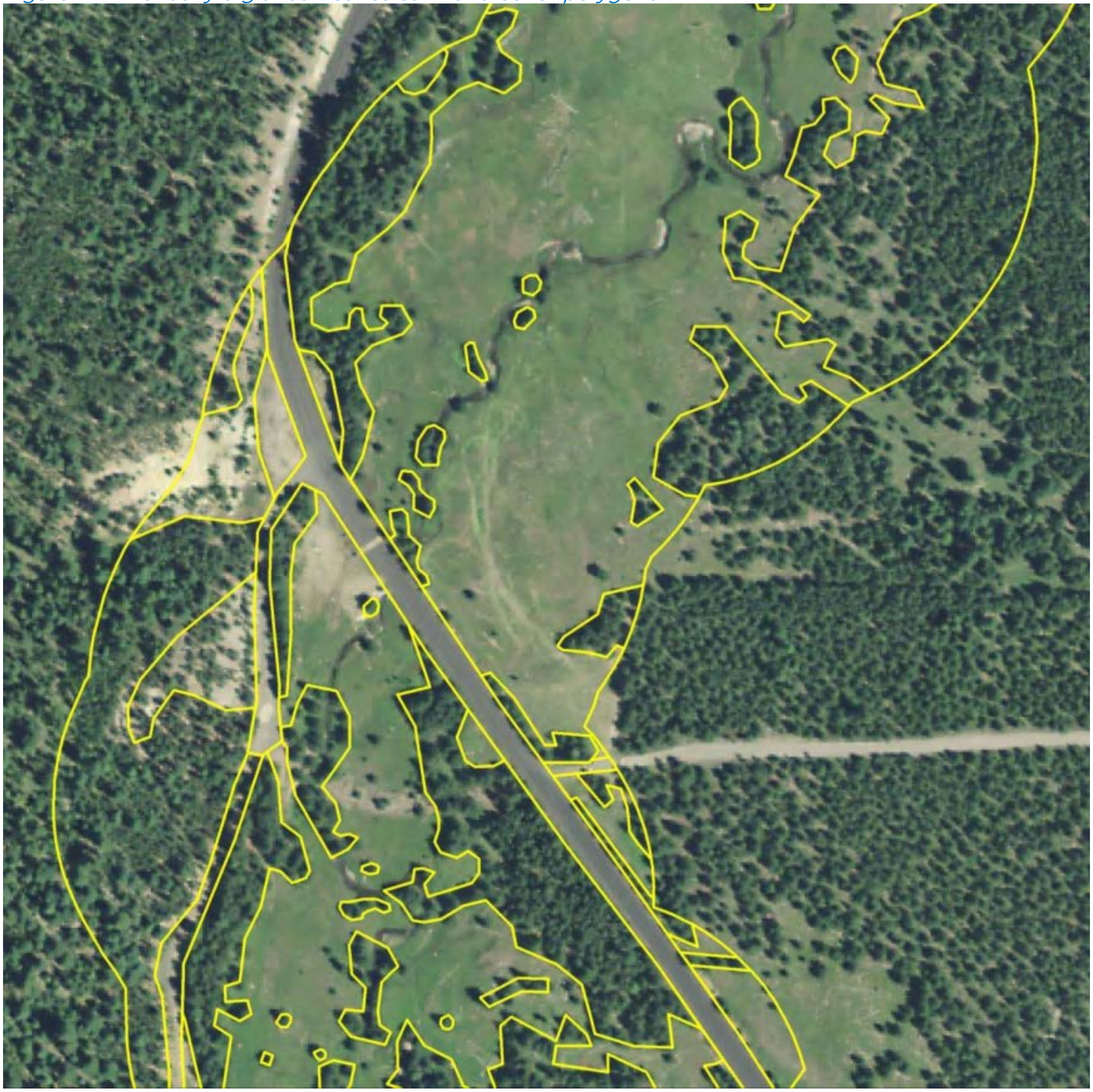
Active channel edges are an important consideration when applying potential vegetation for "what-if" model runs. In most cases, the active channel should remain free of vegetation during the potential vegetation scenarios. Active channel edges were digitized from the bare earth LiDAR data and aerial photography. TTools was used to sample the active channel widths at each 50-meter stream segment.

Figure 26 - Wetted channel edges (yellow) and active channel edges (red).

3.4 Near Stream Land Cover Mapping

Some streams had partial or no LiDAR data available. In those cases, the near stream land cover was manually digitized from aerial imagery (NAIP orthophotography). The stream was buffered 100 meters from each bank and that buffer was divided into polygons based on land cover type, height class, and density class (Figure 27). General height estimates were made based on nearby LiDAR data (see following sections for individual stream details).

Figure 27 – Manually digitized near stream land cover polygons.



3.5 Automated GIS Sampling – TTools

TTools is an ArcMap tool set that is designed to sample high-resolution GIS data and create an input database for Heat Source. Table 4 summarizes the TTools functions.

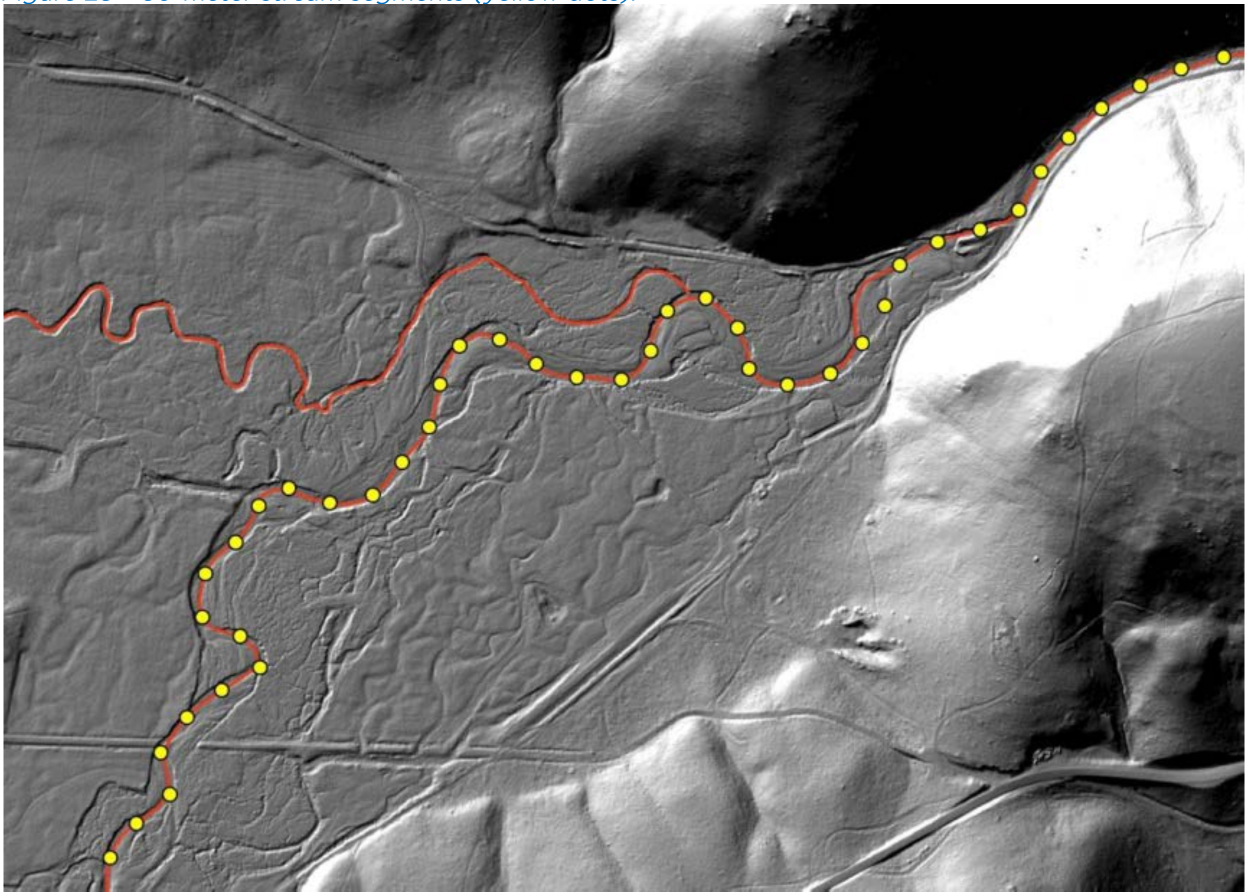
Table 4 – TTools steps and data sources.

Step	Description	Data Sources
1	Segments stream polyline every 50 meters and calculates aspect	Stream polyline
2	Measures channel width at each 50-meter node	Wetted and active channel edge polylines
3	Measures stream elevation and gradient	Bare earth LiDAR data
4	Measures topographic shade angles	10-meter DEM
5	Samples near stream land cover heights	Highest hit and bare earth LiDAR data / manually digitized polygons
6	Samples TIR temperature data	TIR point shapefile

3.5.1 TTools Step 1

In the first step of TTools, the stream polyline is segmented every 50 meters and a point shapefile is created that will house the data from all subsequent steps. Figure 28 shows an example of a stream polyline that has been segmented using TTools.

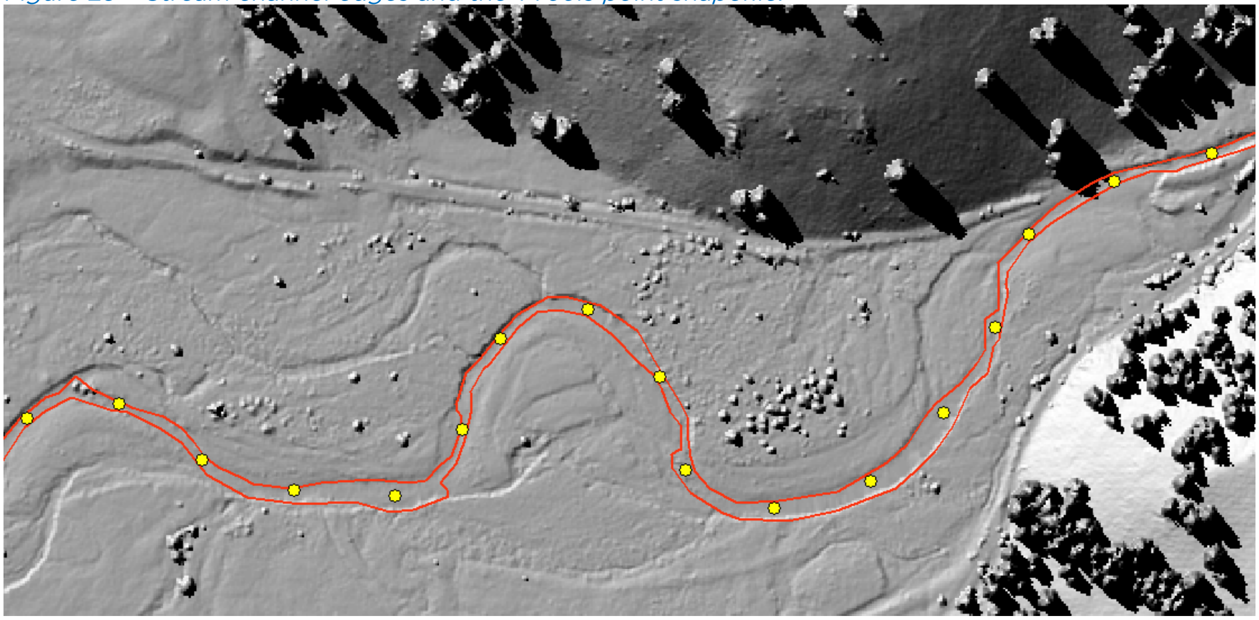
Figure 28 – 50-meter stream segments (yellow dots).



3.5.2 TTools Step 2

The second step of TTools is to sample the channel widths at each 50-meter node (Figure 29). The right and left banks or channel edges need to have been mapped and represented as individual polyline shapefiles. Channel widths are measured perpendicular to the stream flow. The user may use this step to sample wetted edges, active bank edges, floodplain widths, or various other widths relative to the stream.

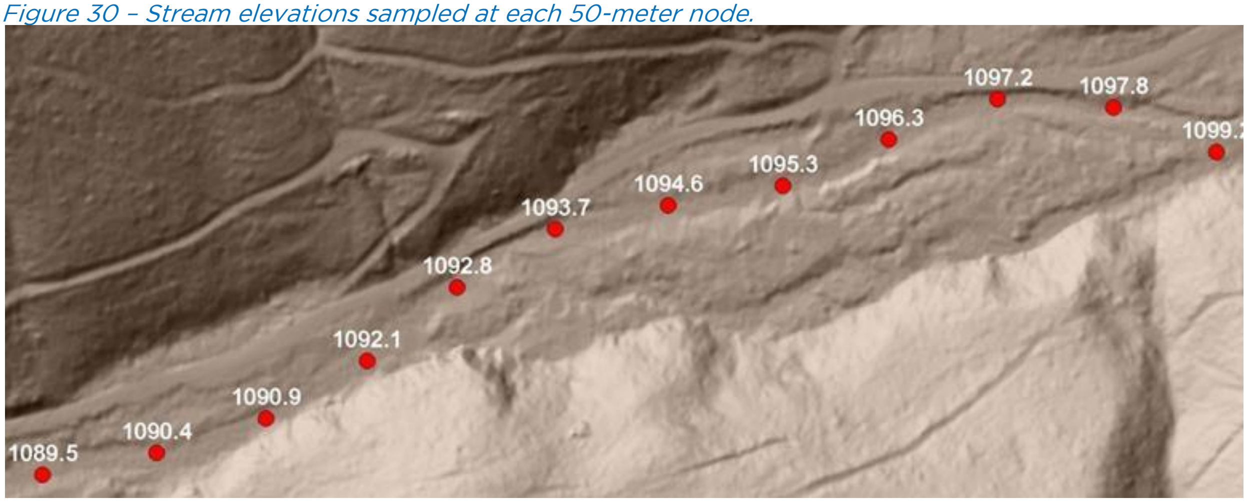
Figure 29 – Stream channel edges and the TTools point shapefile.



3.5.3 TTools Step 3

In the third step of TTools, stream elevation is sampled at each 50-meter node (Figure 30) and then the gradient is calculated as rise/run. Where LiDAR data is available, the elevations were sampled from the bare earth LiDAR data. Where LiDAR was not available, the 10-meter DEM was used.

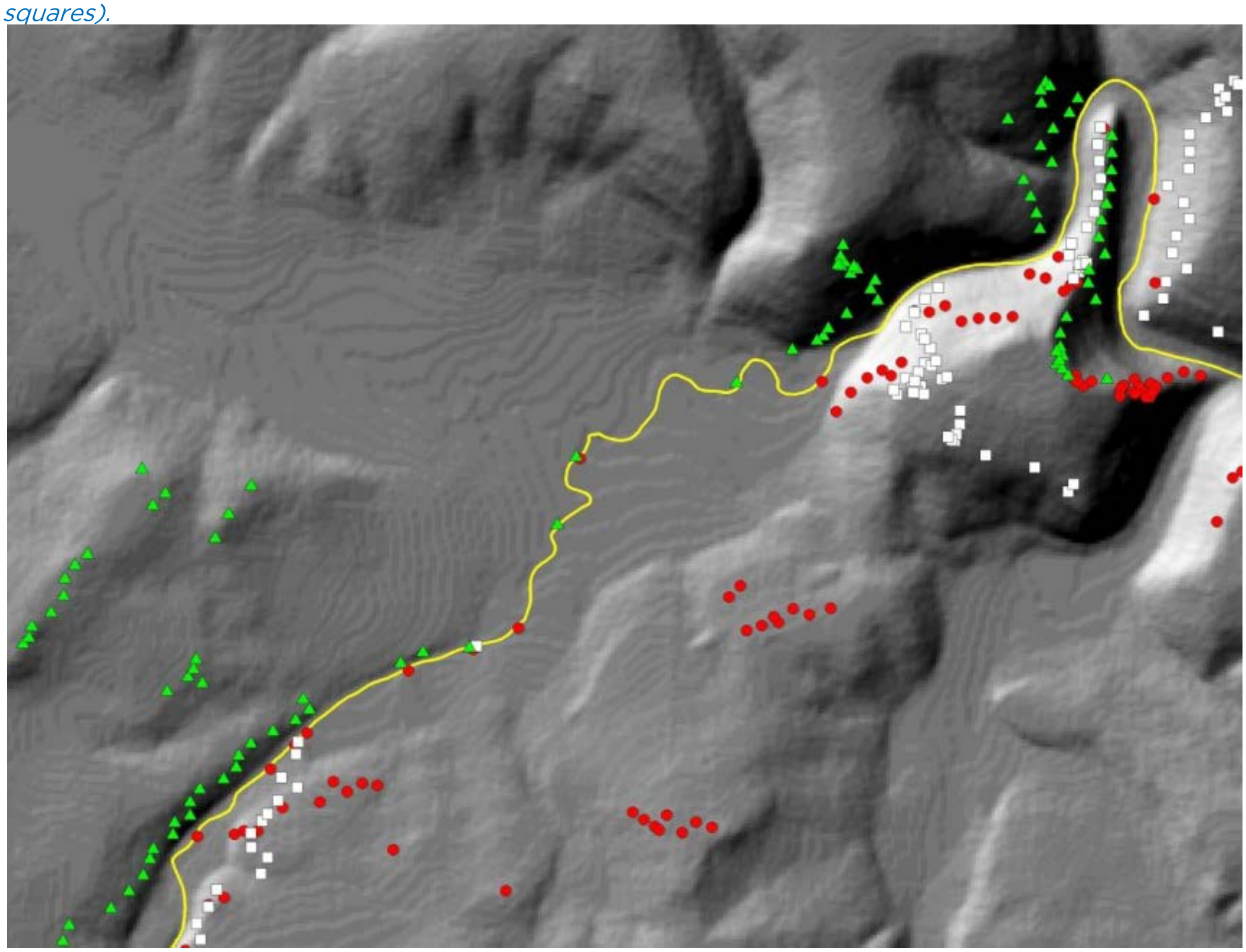
Figure 30 – Stream elevations sampled at each 50-meter node.



3.5.4 TTools Step 4

The maximum topographic angles to the east, south and west are sampled for each 50-meter node from the 10-meter DEM. The sampling routine looks up to 10 kilometers in each direction. Figure 31 shows the stream polyline (yellow) and the highest topographic shade producing features in each of the three directions. The TTools sampling routing is optimized to assess both near-field (<1 km) and far field (up to 10 km) topographic features. In many cases, the highest topographic shade feature is the bank where the stream has become down-cut or flows along cliffs.

Figure 31 – Topographic features to the west (green triangles), south (red circles) and east (white squares).



3.5.5 TTools Step 5

Near stream land cover heights are sampled at each 50-meter node using a dense radial sampling pattern. Where LiDAR is available, the bare earth elevation and the highest hit elevation are both sampled and the height is calculated as the difference between the two. Where near stream land cover was manually digitized, the unique land cover code is sampled and recorded in the database. The distance between samples was either 10 or 15 meters, depending upon stream size.

Figure 32 – Near stream land cover radial sampling pattern.

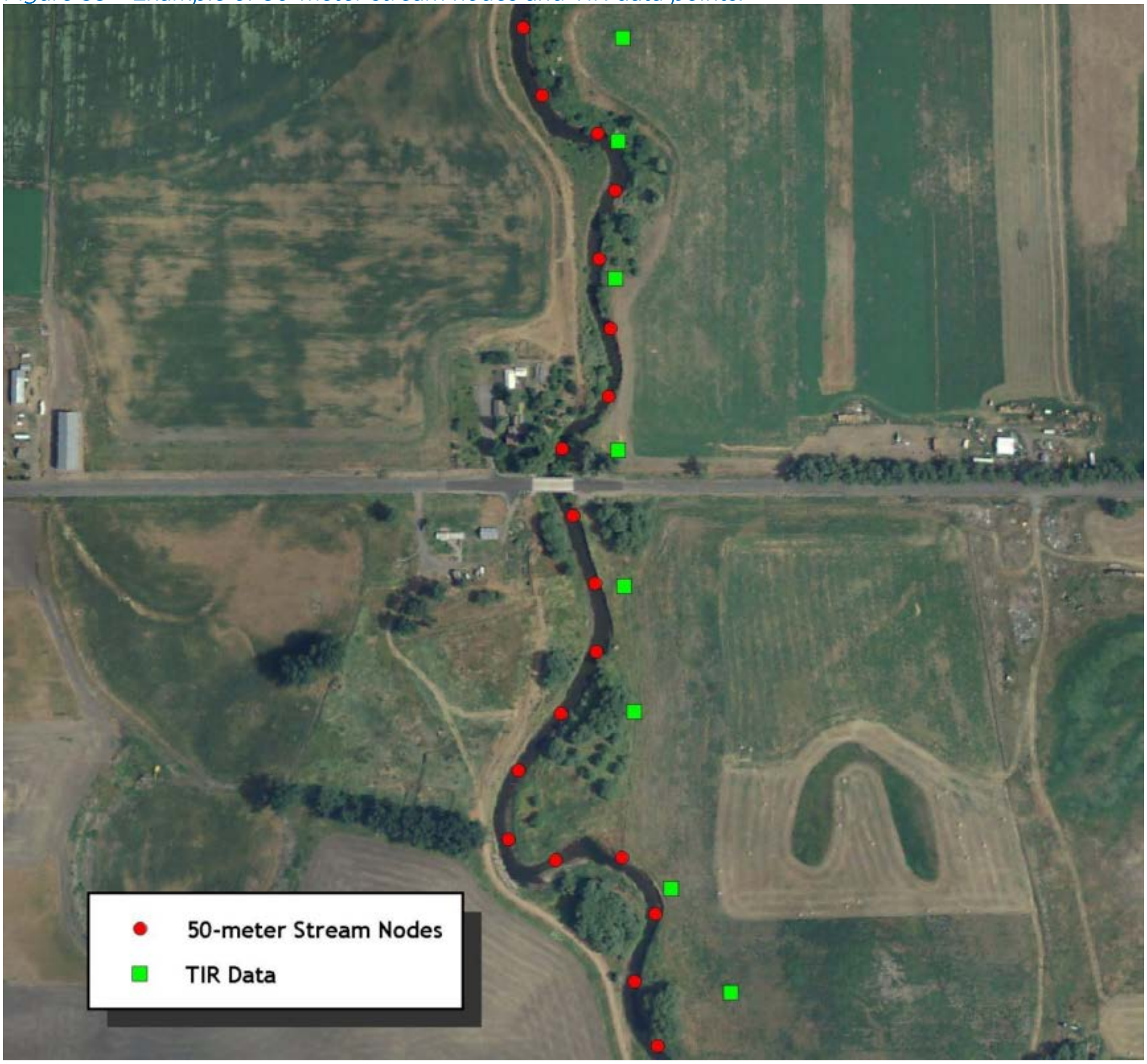
The radial sampling pattern produces extensive overlap between each 50-meter node which ensures dense sampling of the near stream area. While there is no direct canopy cover input in the Heat Source model, the extensive land cover sampling and complex solar flux algorithms indirectly account for the density of tree stands within each radial sampling area. For example, in the figure above, approximately 50% of the ground is visible within the sampling area and since the model calculates solar flux through each radial sampling location for every minute of the day, the overall canopy density is indirectly accounted for and varies for each 50-meter stream node.

Note that there is an input in Heat Source for "land cover density". This term is not the same as "canopy density" as it is classically used in the forest industry. Land cover density in Heat Source refers to the relative density of the vegetation that is being sampled. It can also be thought of as the amount of sky that is blocked by the trunk, branches, and leaves of a tree. In most Heat Source simulations of eastern and central Oregon, the land cover density value is set to 75%, which is representative of conifers in the region. Ground level solar pathfinder measurements have been used to successfully validate the Heat Source effective shade predictions using the 75% land cover density value.

3.5.6 TTools Step 6

One of the TIR deliverables was a point shapefile containing sampled stream temperatures. Step 6 of TTools associates the nearest TIR sample point with each 50-meter stream node. Figure 33 shows a section of Catherine Creek with the 50-meter nodes and the TIR data points. The TIR data points are typically more than 50-meters apart and a located according to the helicopter position at the time the TIR image frame was collected. TTools walks through each of the 50-meter stream nodes and locates the nearest TIR data point, then incorporates that data into the TTools shapefile database.

Figure 33 – Example of 50-meter stream nodes and TIR data points.

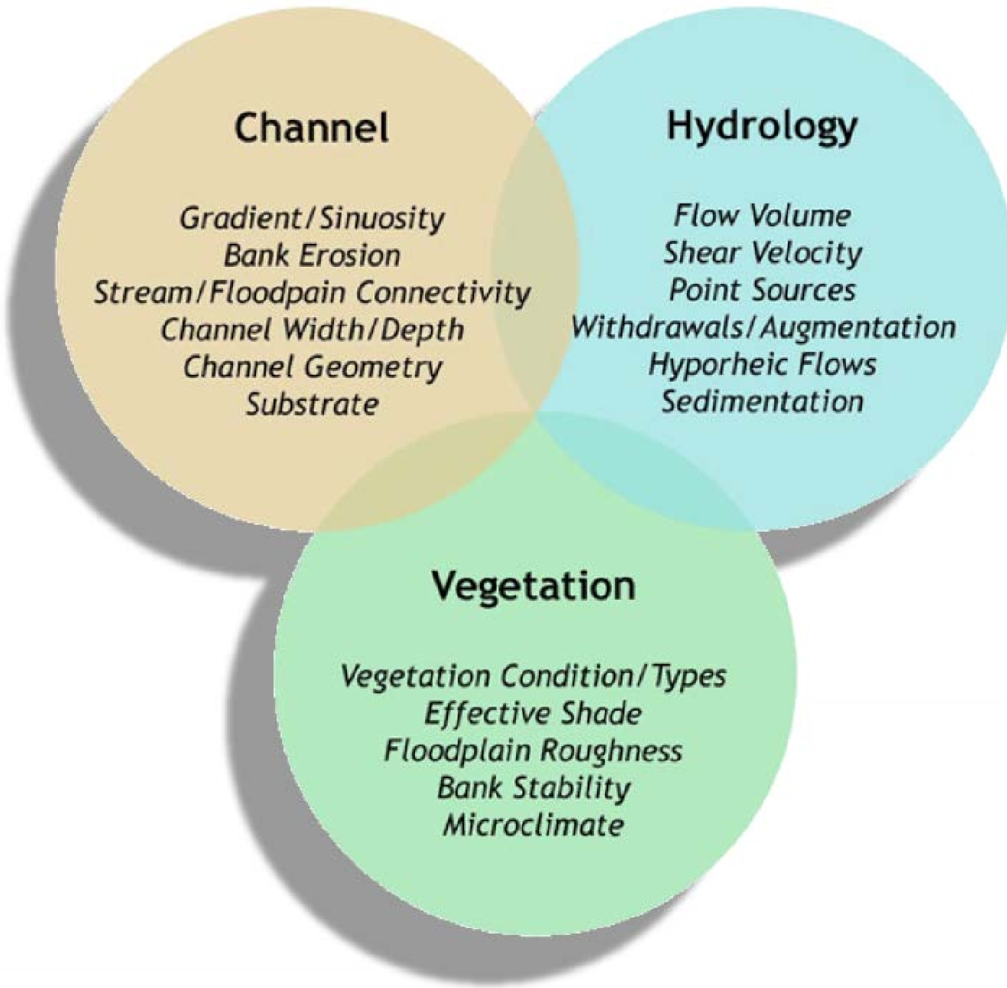


4. Heat Source Overview

Heat Source is a high-resolution stream temperature model that incorporates both remote sensing and ground level data. It has been used for stream temperature studies (including Total Maximum Daily Load development) throughout the Pacific Northwest since 1998. Some of the Heat Source characteristics are listed below:

- Input distance step = 50 meters.
- Output distance step = 100 meters.
- Time step = 1 minute.
- Hourly air temperature, relative humidity, wind speed and cloud cover inputs.
- Accommodates high-resolution LiDAR bare earth and highest hit data.
- Calibrated to TIR longitudinal profile and to hourly instream temperature measurements.
- Can be set up to simulate a connected stream network (i.e., outputs from tributaries can become inputs to receiving stream models).
- Strives to account for all factors that influence stream temperature (Figure 34).

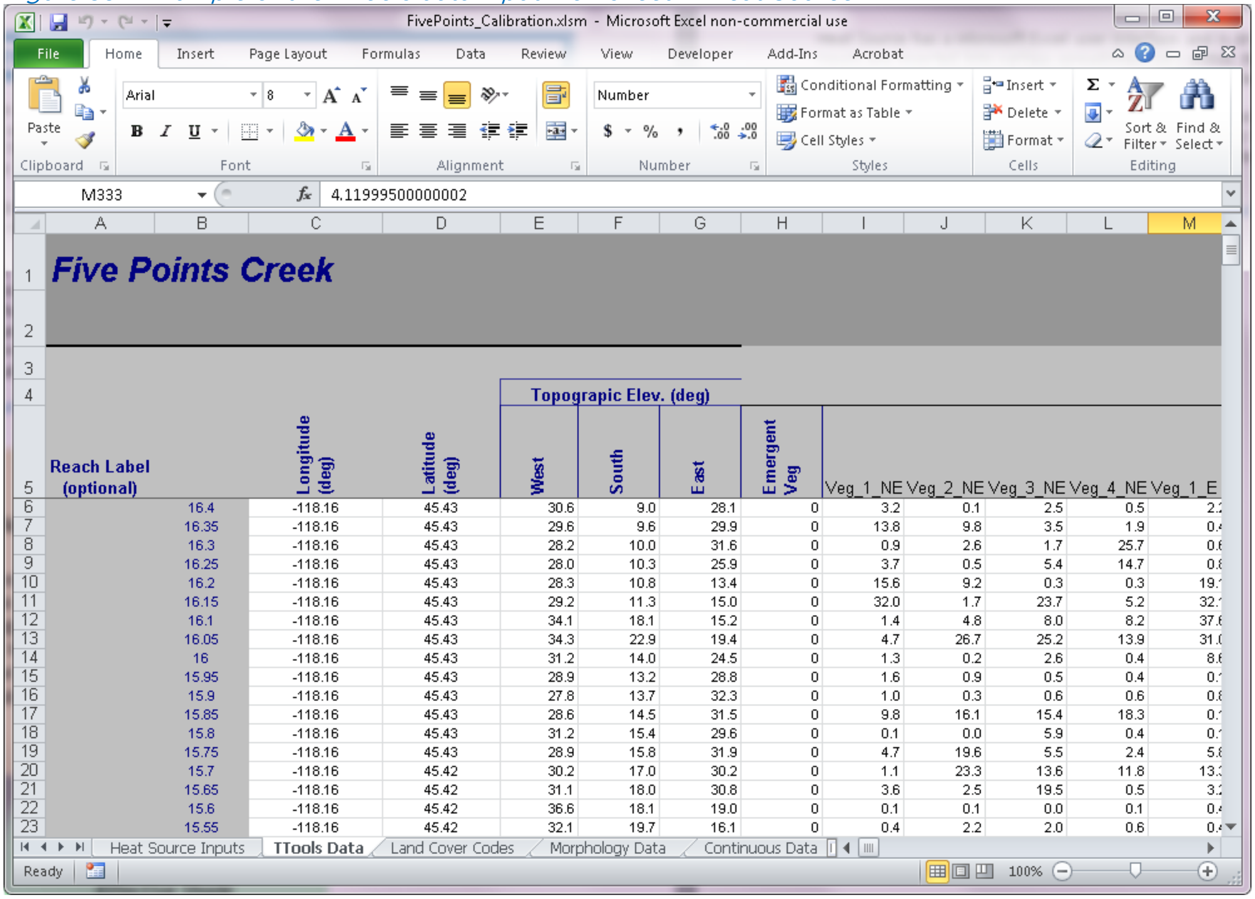
Figure 34 - Parameters included within the Heat Source methodology.



Heat Source has a Microsoft Excel user interface and is driven by Visual Basic, Python, and C+ code. Inputs are inserted into various spreadsheet tabs within the model. Outputs are written to text files that can then be accessed within the Excel interface to be plotted or listed within the spreadsheets.

The shapefile database created from TTools sampling contains much of the information required to set up a Heat Source model. Most of the data can be copied from the shapefile database and pasted directly into Heat Source's Excel interface. Figure 35 shows one of the input worksheets where TTools data are stored.

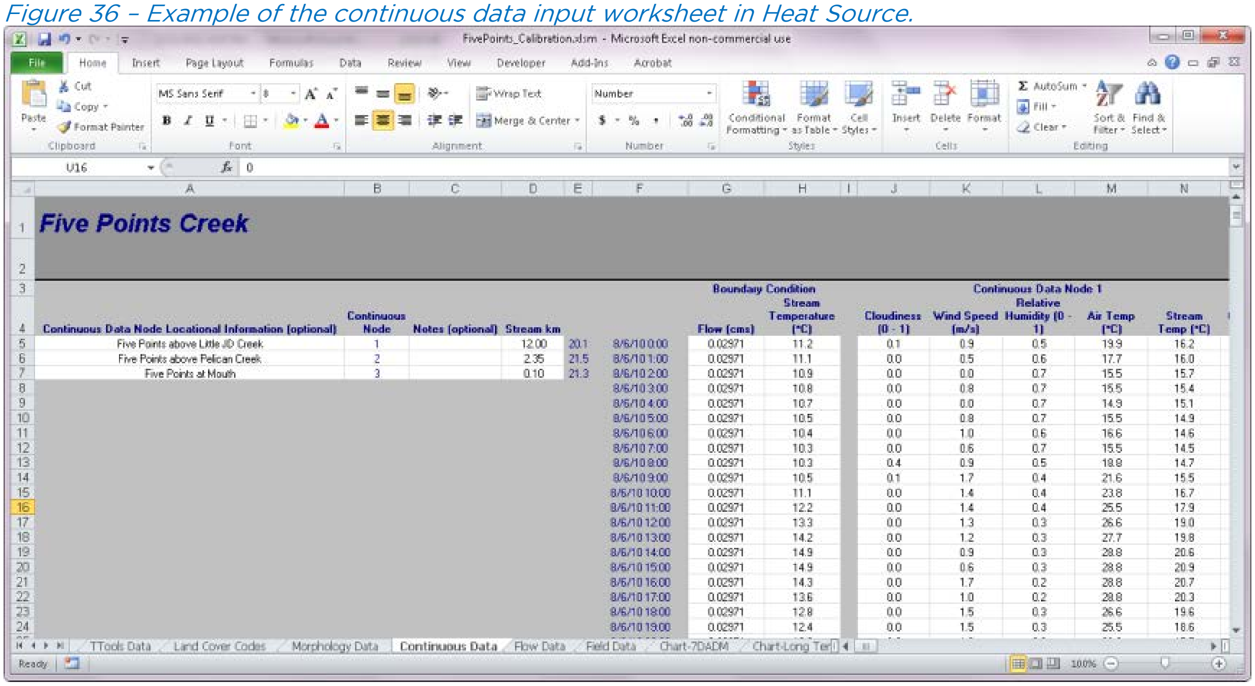
Figure 35 – Example of the TTools data input worksheet in Heat Source.



Row	Reach Label (optional)	Longitude (deg)	Latitude (deg)	Topograpic Elev. (deg) West	South	East	Emergent Veg	Veg_1_NE	Veg_2_NE	Veg_3_NE	Veg_4_NE	Veg_1_E
6	16.4	-118.16	45.43	30.6	9.0	28.1	0	3.2	0.1	2.5	0.5	2.
7	16.35	-118.16	45.43	29.6	9.6	29.9	0	13.8	9.8	3.5	1.9	0.
8	16.3	-118.16	45.43	28.2	10.0	31.6	0	0.9	2.6	1.7	25.7	0.
9	16.25	-118.16	45.43	28.0	10.3	25.9	0	3.7	0.5	5.4	14.7	0.
10	16.2	-118.16	45.43	28.3	10.8	13.4	0	15.6	9.2	0.3	0.3	19.
11	16.15	-118.16	45.43	29.2	11.3	15.0	0	32.0	1.7	23.7	5.2	32.
12	16.1	-118.16	45.43	34.1	18.1	15.2	0	1.4	4.8	8.0	8.2	37.
13	16.05	-118.16	45.43	34.3	22.9	19.4	0	4.7	26.7	25.2	13.9	31.
14	16	-118.16	45.43	31.2	14.0	24.5	0	1.3	0.2	2.6	0.4	8.
15	15.95	-118.16	45.43	28.9	13.2	28.8	0	1.6	0.9	0.5	0.4	0.
16	15.9	-118.16	45.43	27.8	13.7	32.3	0	1.0	0.3	0.6	0.6	0.
17	15.85	-118.16	45.43	28.6	14.5	31.5	0	9.8	16.1	15.4	18.3	0.
18	15.8	-118.16	45.43	31.2	15.4	29.6	0	0.1	0.0	5.9	0.4	0.
19	15.75	-118.16	45.43	28.9	15.8	31.9	0	4.7	19.6	5.5	2.4	5.
20	15.7	-118.16	45.42	30.2	17.0	30.2	0	1.1	23.3	13.6	11.8	13.
21	15.65	-118.16	45.42	31.1	18.0	30.8	0	3.6	2.5	19.5	0.5	3.
22	15.6	-118.16	45.42	36.6	18.1	19.0	0	0.1	0.1	0.0	0.1	0.
23	15.55	-118.16	45.42	32.1	19.7	16.1	0	0.4	2.2	2.0	0.6	0.

Heat Source uses hourly climate and stream temperature data as input. Figure 36 is an example of the continuous data input worksheet. Continuous data nodes are locations where hourly stream temperature was recorded.

Figure 36 – Example of the continuous data input worksheet in Heat Source.

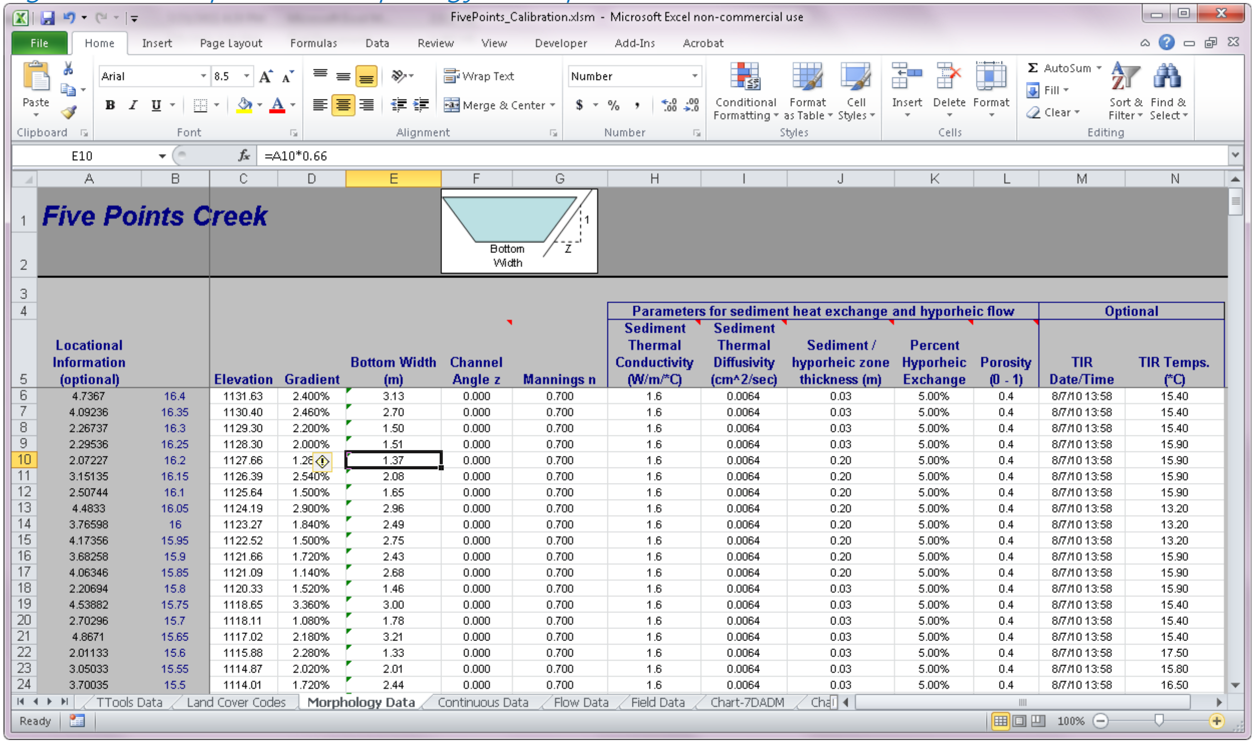


Five Points Creek

Continuous Data Node Locational Information (optional)	Continuous Node	Notes (optional)	Stream km			Boundary Condition: Flow (cms)	Boundary Condition: Stream Temperature (°C)	Continuous Data Node 1: Cloudiness (0 - 1)	Wind Speed (m/s)	Relative Humidity (0 - 1)	Air Temp (°C)	Stream Temp (°C)
Five Points above Little JD Creek	1		12.00	20.1	8/6/10 0:00	0.02971	11.2	0.1	0.9	0.5	19.9	16.2
Five Points above Pelican Creek	2		2.35	21.5	8/6/10 1:00	0.02971	11.1	0.0	0.5	0.6	17.7	16.0
Five Points at Mouth	3		0.10	21.3	8/6/10 2:00	0.02971	10.9	0.0	0.0	0.7	15.5	15.7
					8/6/10 3:00	0.02971	10.8	0.0	0.8	0.7	15.5	15.4
					8/6/10 4:00	0.02971	10.7	0.0	0.0	0.7	14.9	15.1
					8/6/10 5:00	0.02971	10.5	0.0	0.8	0.7	15.5	14.9
					8/6/10 6:00	0.02971	10.4	0.0	1.0	0.6	16.6	14.6
					8/6/10 7:00	0.02971	10.3	0.0	0.6	0.7	15.5	14.5
					8/6/10 8:00	0.02971	10.3	0.4	0.9	0.5	18.8	14.7
					8/6/10 9:00	0.02971	10.5	0.1	1.7	0.4	21.6	15.5
					8/6/10 10:00	0.02971	11.1	0.0	1.4	0.4	23.8	16.7
					8/6/10 11:00	0.02971	12.2	0.0	1.4	0.4	25.5	17.9
					8/6/10 12:00	0.02971	13.3	0.0	1.3	0.3	26.6	19.0
					8/6/10 13:00	0.02971	14.2	0.0	1.2	0.3	27.7	19.8
					8/6/10 14:00	0.02971	14.9	0.0	0.9	0.3	28.8	20.6
					8/6/10 15:00	0.02971	14.9	0.0	0.6	0.3	28.8	20.9
					8/6/10 16:00	0.02971	14.3	0.0	1.7	0.2	28.8	20.7
					8/6/10 17:00	0.02971	13.6	0.0	1.0	0.2	28.8	20.3
					8/6/10 18:00	0.02971	12.8	0.0	1.5	0.3	26.6	19.6
					8/6/10 19:00	0.02971	12.4	0.0	1.5	0.3	25.5	18.6

Typically, Heat Source uses a 50-meter input distance step. Figure 37 shows the morphology data input worksheet. Manning's n, sediment heat exchange, and hyporheic flow are some of the most commonly adjusted inputs during model calibration.

Figure 37 – Example of the morphology data input worksheet in Heat Source.

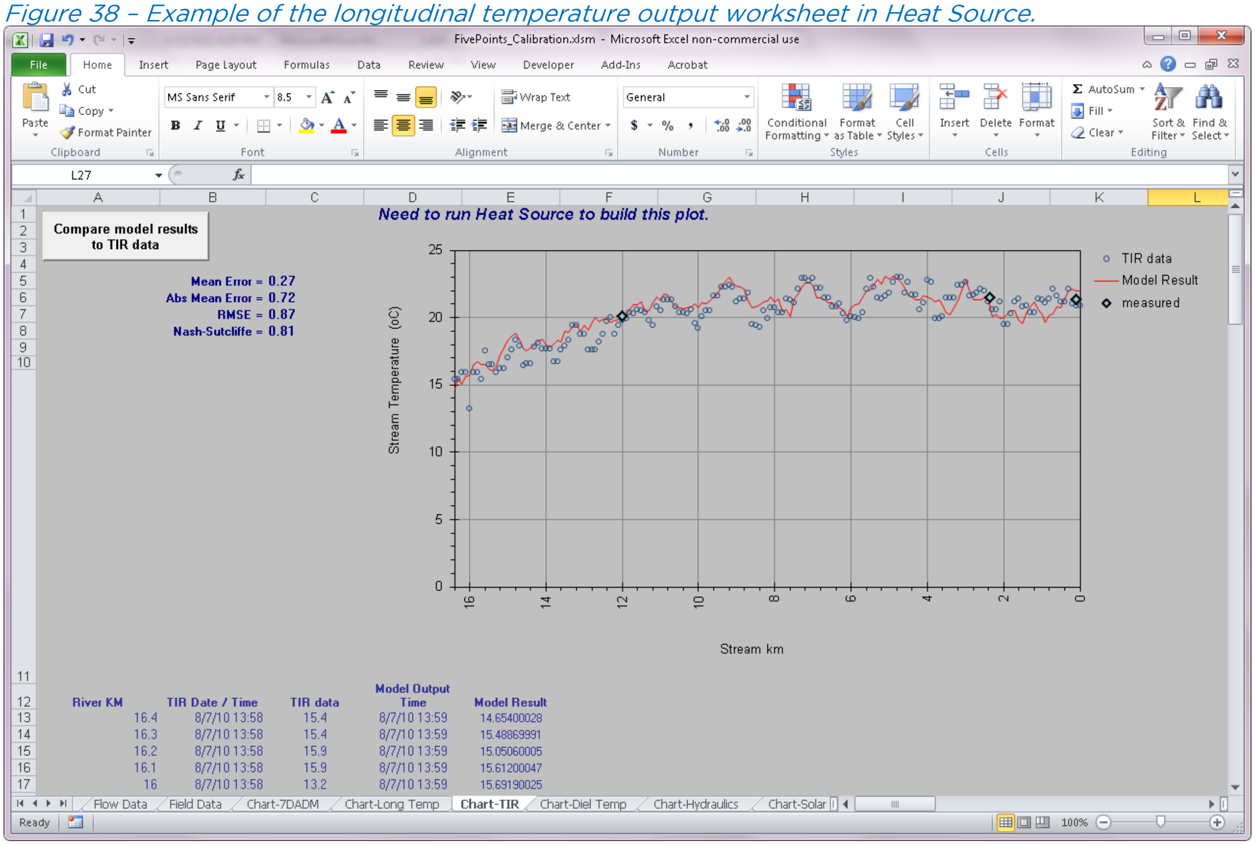


Five Points Creek

Locational Information (optional)		Elevation	Gradient	Bottom Width (m)	Channel Angle z	Mannings n	Sediment Thermal Conductivity (W/m/°C)	Sediment Thermal Diffusivity (cm^2/sec)	Sediment / hyporheic zone thickness (m)	Percent Hyporheic Exchange	Porosity (0 - 1)	TIR Date/Time	TIR Temps. (°C)
4.7367	16.4	1131.63	2.400%	3.13	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
4.09236	16.35	1130.40	2.460%	2.70	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
2.26737	16.3	1129.30	2.200%	1.50	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
2.29536	16.25	1128.30	2.000%	1.51	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.90
2.07227	16.2	1127.66	1.2[illegible]	1.37	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	15.90
3.15135	16.15	1126.39	2.540%	2.08	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	15.90
2.50744	16.1	1125.64	1.500%	1.65	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	15.90
4.4833	16.05	1124.19	2.900%	2.96	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	13.20
3.76598	16	1123.27	1.840%	2.49	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	13.20
4.17356	15.95	1122.52	1.500%	2.75	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	13.20
3.68258	15.9	1121.66	1.720%	2.43	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	15.90
4.06346	15.85	1121.09	1.140%	2.68	0.000	0.700	1.6	0.0064	0.20	5.00%	0.4	8/7/10 13:58	15.90
2.20694	15.8	1120.33	1.520%	1.46	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.90
4.53882	15.75	1118.65	3.360%	3.00	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
2.70296	15.7	1118.11	1.080%	1.78	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
4.8671	15.65	1117.02	2.180%	3.21	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.40
2.01133	15.6	1115.88	2.280%	1.33	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	17.50
3.05033	15.55	1114.87	2.020%	2.01	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	15.80
3.70035	15.5	1114.01	1.720%	2.44	0.000	0.700	1.6	0.0064	0.03	5.00%	0.4	8/7/10 13:58	16.50

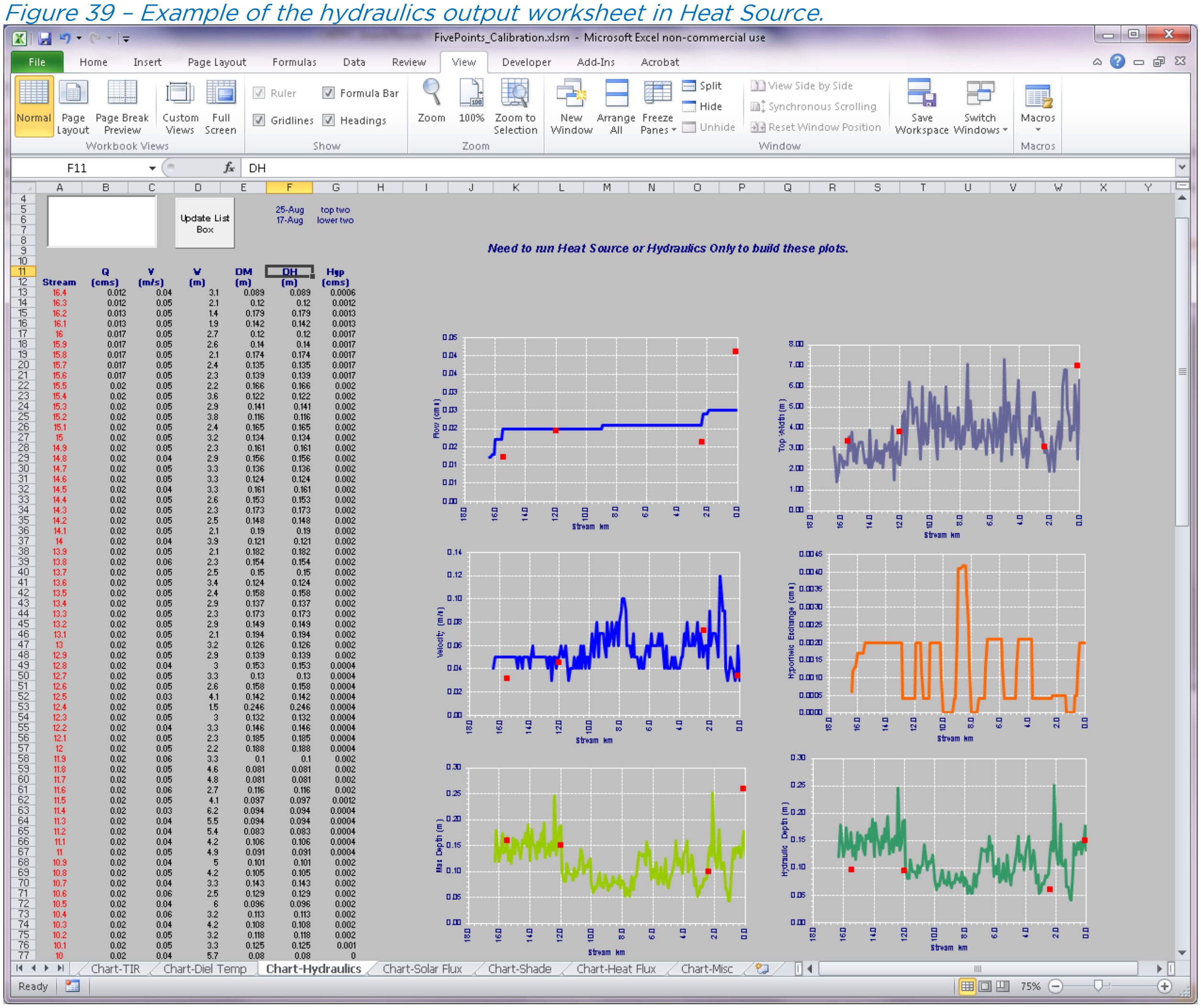
The Heat Source model contains several worksheets that use data from the output text files to display temporal and longitudinal data. Figure 38 shows the longitudinal temperature calibration worksheet. After the model is run, this chart is updated for the user to compare simulated and measured values. There are similar charts that compare the hourly simulated and measured data for each continuous monitoring location.

Figure 38 – Example of the longitudinal temperature output worksheet in Heat Source.



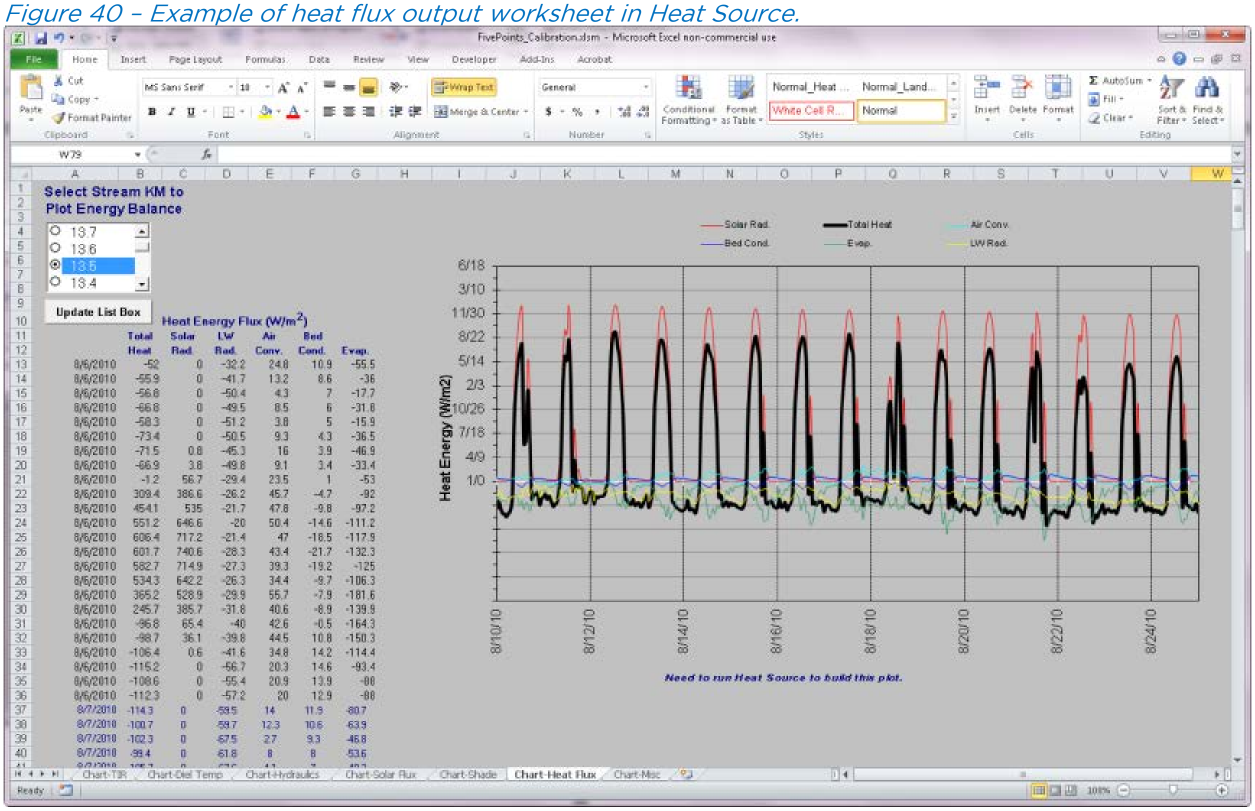
Model hydraulics is another important output worksheet in Heat Source (Figure 39). The simulation outputs can be plotted within this worksheet for model validation purposes. Any available ground level measurements can be included within these charts to compare simulated and measured values. The data can be plotted for each day of the simulation.

Figure 39 – Example of the hydraulics output worksheet in Heat Source.



Heat Source also records the hourly heat flux values for each 100-meter output node. There is a worksheet where the user can view various simulated heat flux values (Figure 40). These outputs are useful during calibration to make sure that the simulation is within reasonable boundaries for solar flux, bed conduction, evaporation, air convection, longwave radiation, etc.

Figure 40 – Example of heat flux output worksheet in Heat Source.



5. Model Set Up and Calibration

5.1 North Fork Catherine Creek

RGB-colored LiDAR point cloud - North Fork Catherine Creek looking upstream just above mouth (road visible alongside stream).

5.1.1 North Fork Catherine Creek TTools

The North Fork Catherine Creek has a moderate gradient, typically between 2% and 8%. Figure 41 shows the TTools-sampled stream elevations and calculated gradients for each 50-meter node.

Figure 41 – North Fork Catherine Creek elevation and gradient.

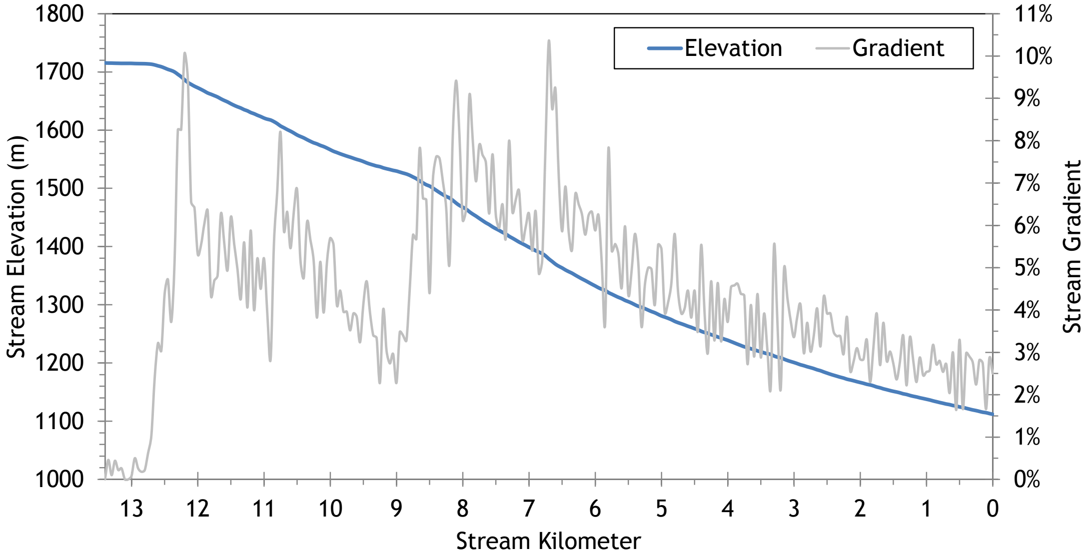
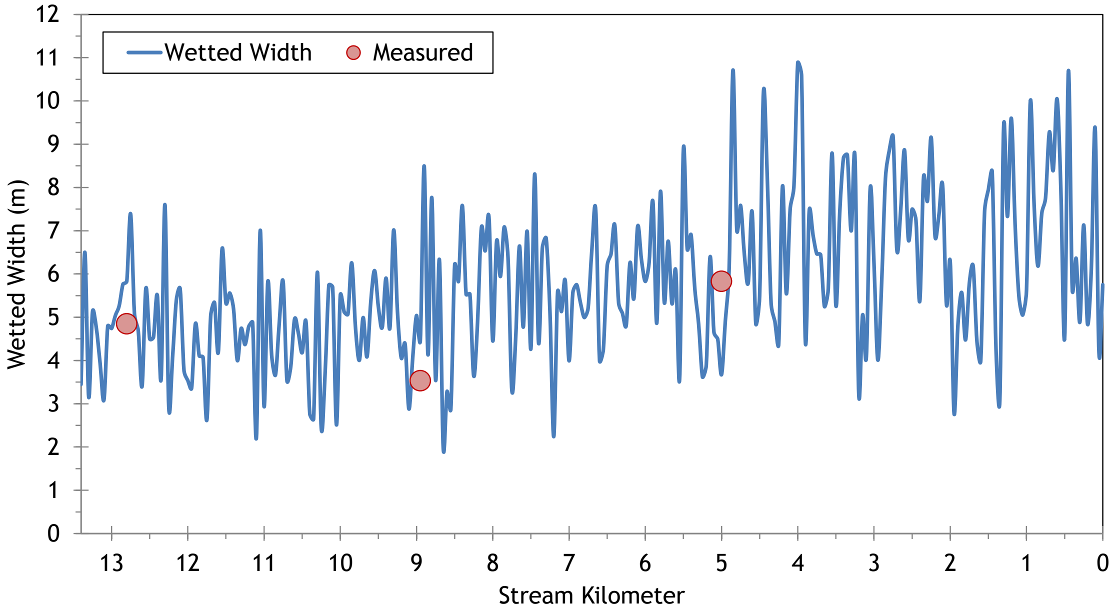


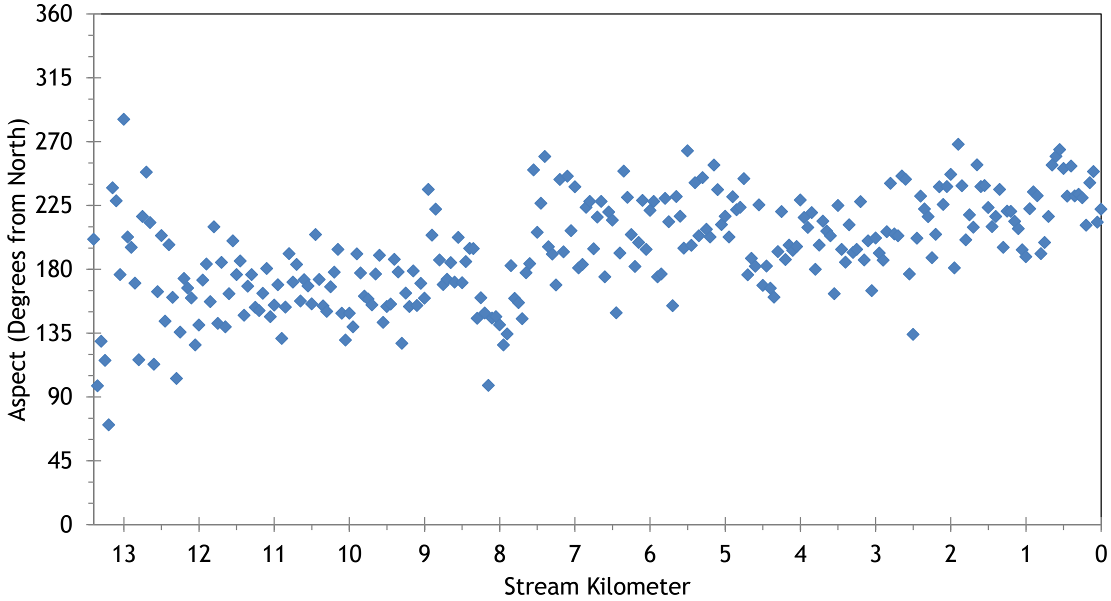
Figure 42 shows the TTools-sampled and measured wetted widths for the North Fork Catherine Creek which are used as estimates for the simulation time period. Generally, the stream was between 4 and 8 meters wide during August 2010.

Figure 42 – North Fork Catherine Creek wetted width.



The North Fork Catherine Creek generally flows from north to south. Figure 43 shows the TTools-sampled stream aspect for each 50-meter node. Aspect is an important Heat Source input parameter because it is used to calculate solar flux at the stream surface.

Figure 43 – North Fork Catherine Creek stream aspect.



The North Fork Catherine Creek flows through mountainous foothills and eastern and western topographic shade angles are typically over 20 degrees from the horizon (Figure 44). Since the stream flows down a predominately south-facing slope, the southern topographic shade angles are smaller.

Figure 44 – North Fork Catherine Creek topographic shade angles.

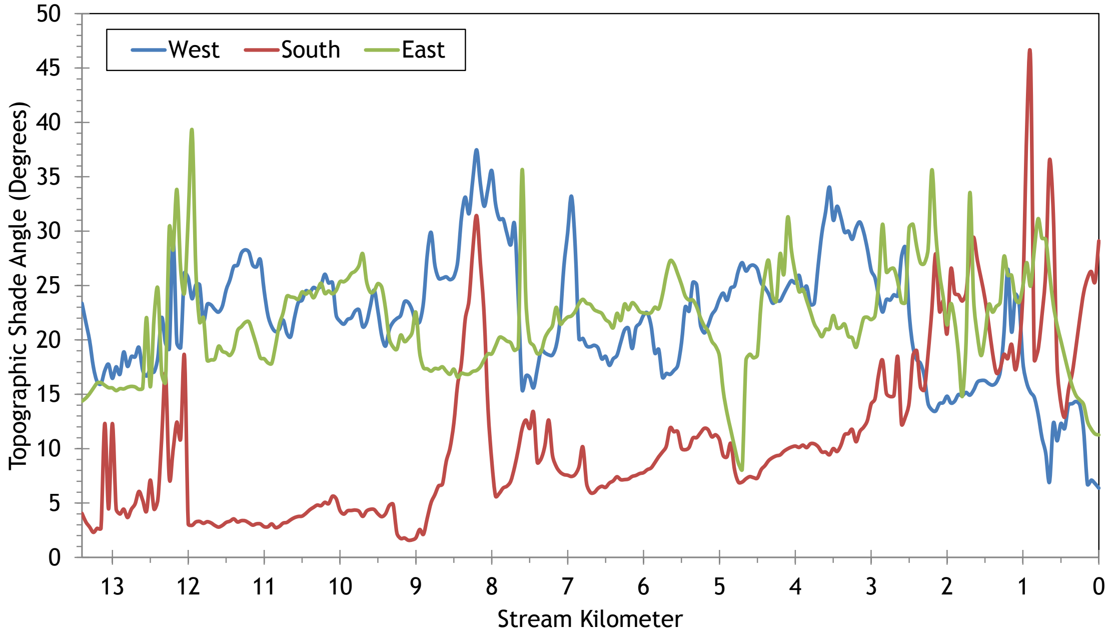
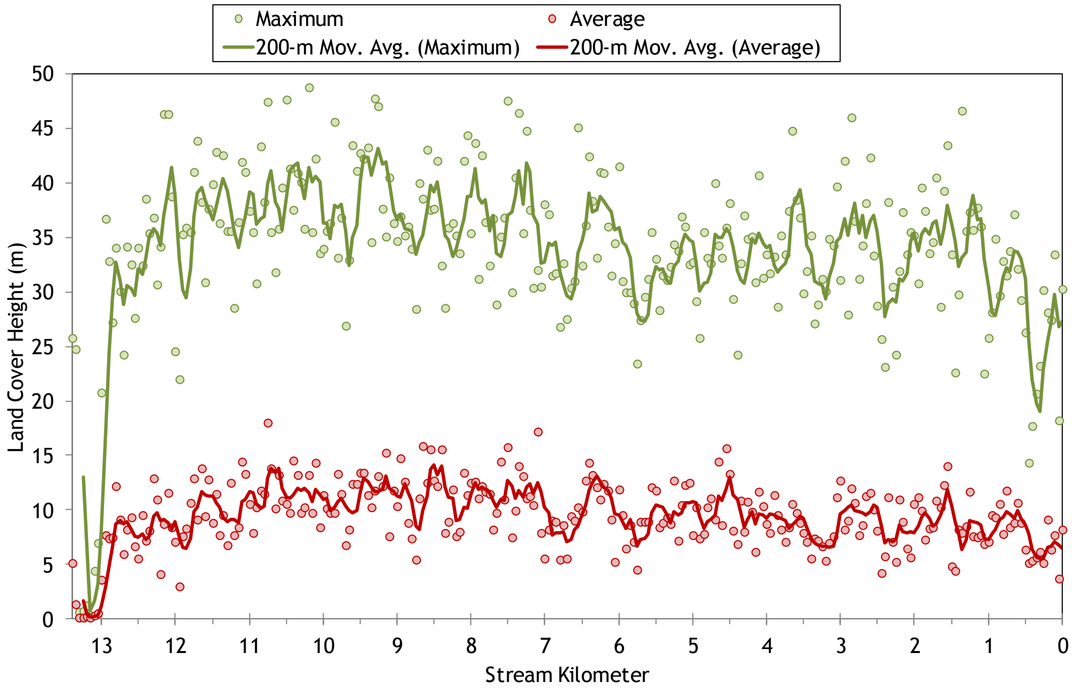


Figure 45 shows the land cover heights sampled along North Fork Catherine Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. The stream is well-forested throughout most of its length. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

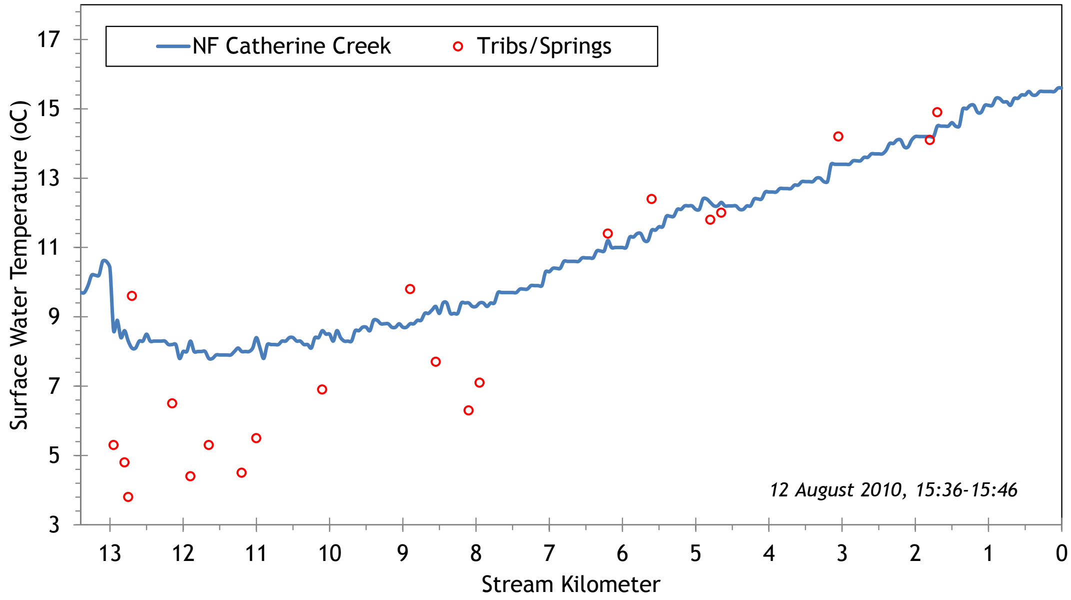
Figure 45 – North Fork Catherine Creek land cover heights sampled from highest hit LiDAR.



TTools was used to associate TIR temperatures with each 50-meter node (

Figure 46). Heat Source is calibrated to the TIR longitudinal temperature profile. The North Fork Catherine Creek was cool, relative to other streams in the watershed at the time of the survey (12 August 2010, 15:36-15:46).

Figure 46 – North Fork Catherine Creek TIR temperature profile.



5.1.2 North Fork Catherine Creek Heat Source Calibration

The North Fork Catherine Creek was simulated from just above Amelia Spring to the mouth (13.4 stream kilometers). The largest tributaries are the Middle Fork Catherine Creek, Buck Creek, and Lick Creek. There were four sites where hourly stream temperature data collection was attempted; however there were data quality issues at some locations. Figure 47 shows the simulation extent and continuous temperature monitoring locations.

Figure 47 – North Fork Catherine Creek simulation extent.

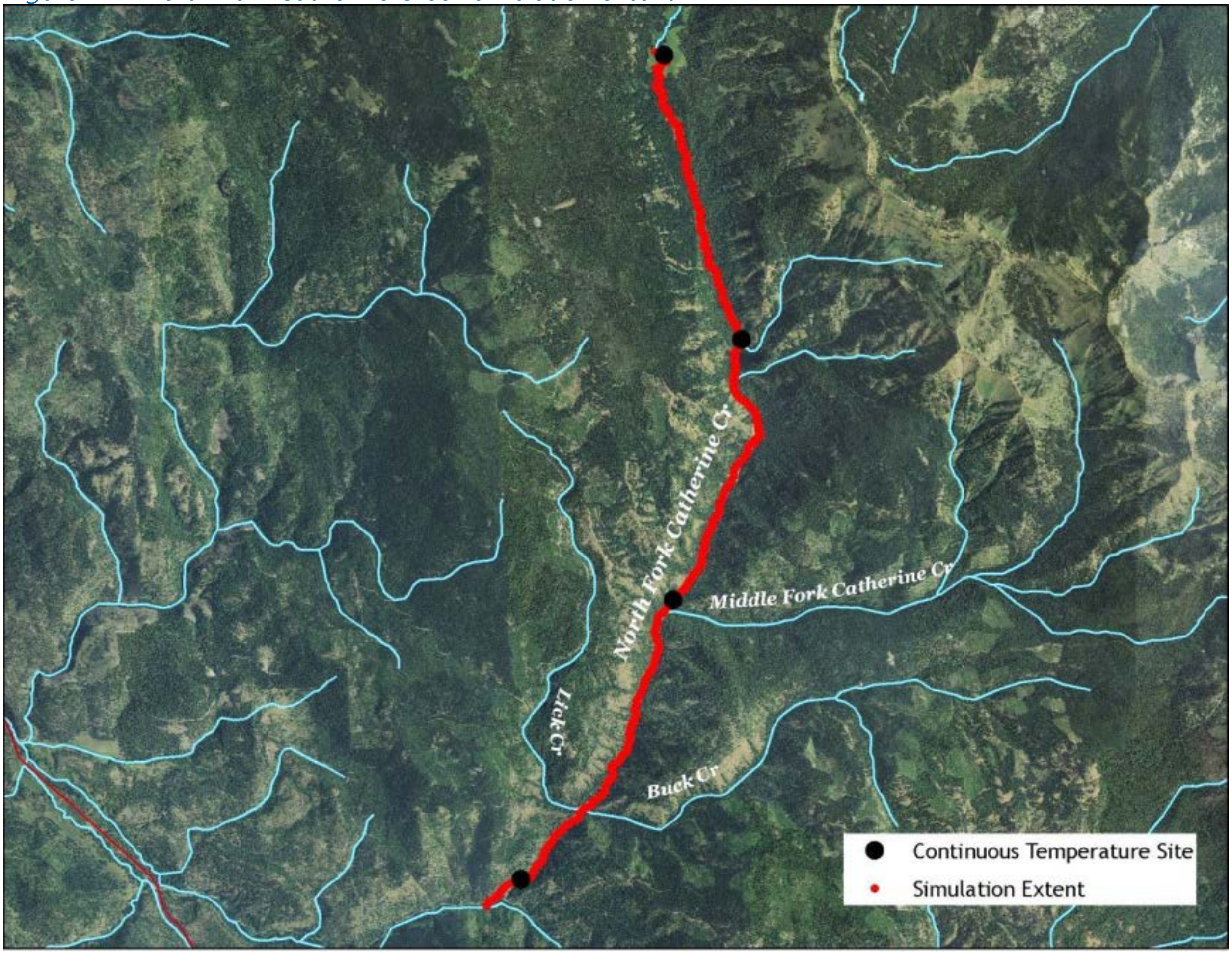


Table 5 – North Fork Catherine Creek general Heat Source parameters.

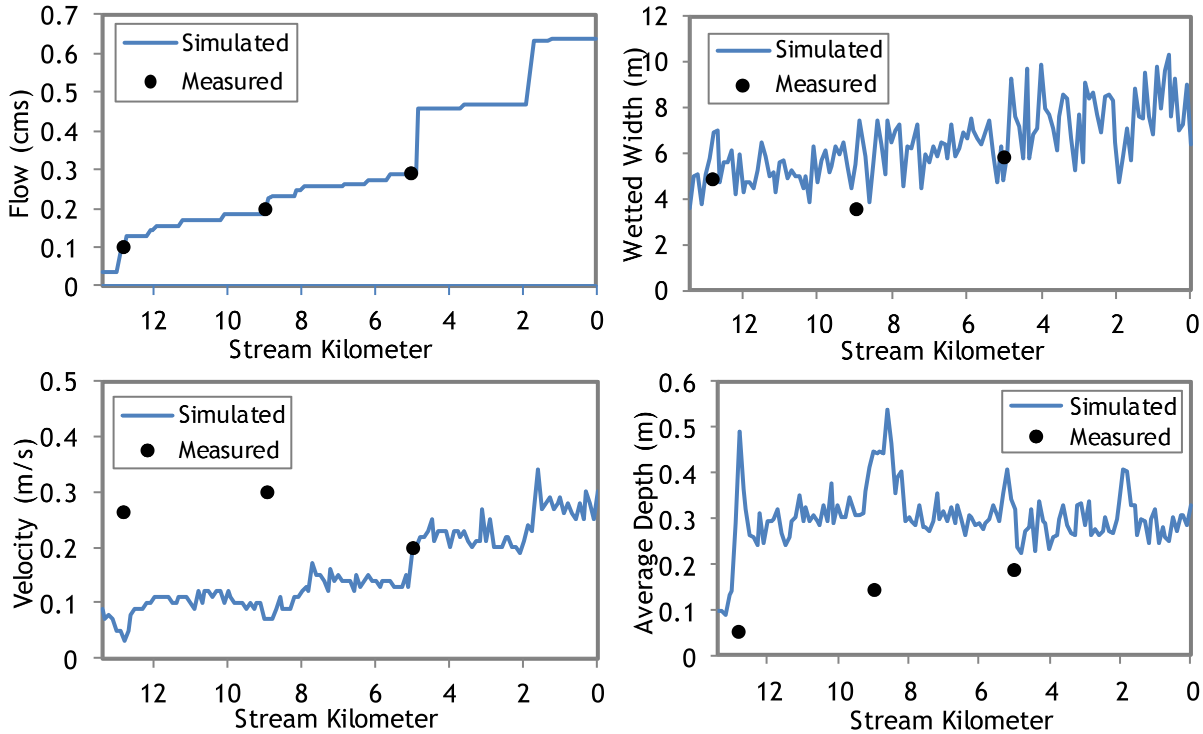
Stream:	North Fork Catherine Creek
Length:	13.4 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 12, 2010 15:36-15:46
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

Following is a list of assumptions that were used during Heat Source calibration:

- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Daily flow volumes vary based on extrapolation (back-calculation) from the gage data recorded on the North Fork Catherine Creek at Medical Springs (stream kilometer 1.6).
- There were no observed diversions or withdrawals on the stream.
- Small springs and seeps were assumed constant volumes and temperatures.
- Jim Creek, Buck Creek, Lick Creek, and Middle Fork Catherine Creek were included using daily variable flow volume and hourly temperatures (see Table 6).

Figure 48 shows the simulated and measured hydraulic values for the calibrated model. The simulated data was plotted for August 25, 2010 because that is the day most of the field measurements were collected. The simulated values vary daily based upon flow volume.

Figure 48 – North Fork Catherine Creek simulated and measured hydraulics values.



Site	Stream Km	Date
Upper NF Catherine Creek	12.8	8/25/2010
Above Jim Creek	8.95	8/25/2010
Above Middle Fork	5	8/19/2010
Gage	1.6	8/25/2010

Daily flow values used in the model were based upon data recorded at the gage near Medical Springs. Figure 49 compares the simulated and measured flow volumes at the gage for the entire simulation time period. The simulated daily flow values are identical to the gage values because those gage data were used as the starting point for the stream flow mass balance calculations. Tributary and spring inflows were estimated and applied within the model in order to meet the recorded gage values.

Figure 49 – North Fork Catherine Creek simulated and measured daily flow volumes at the gage near Medical Springs.

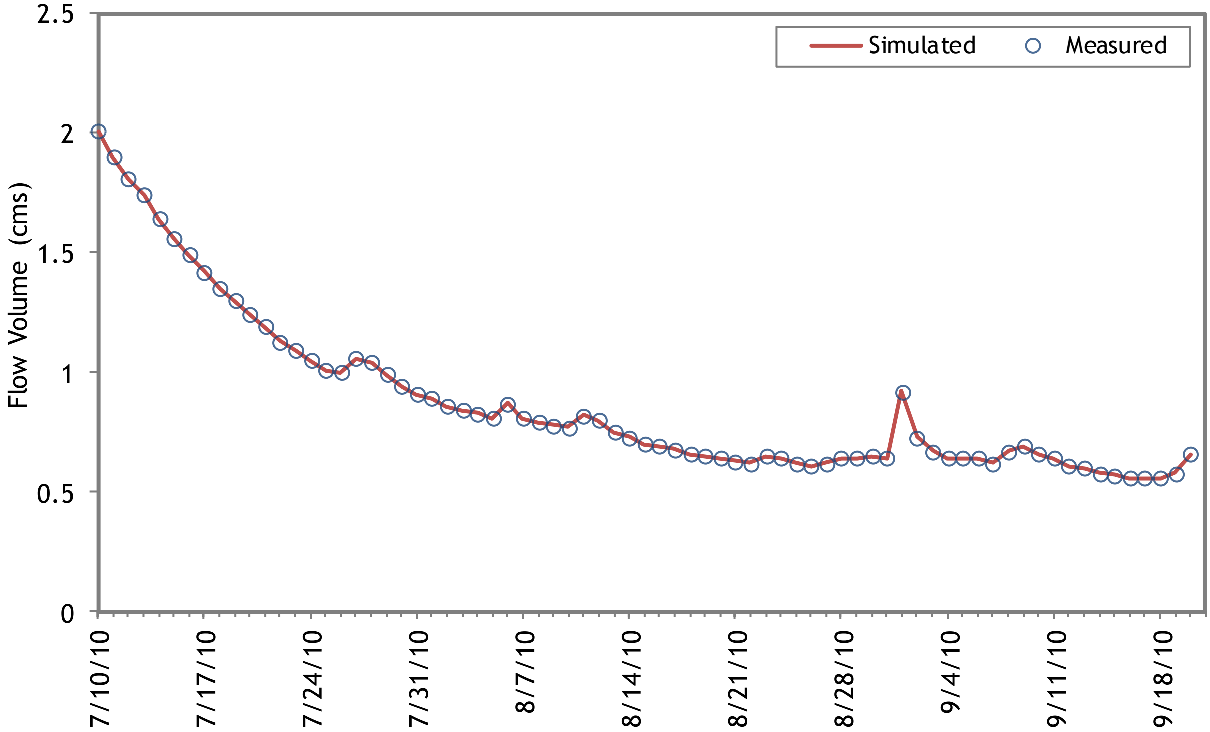


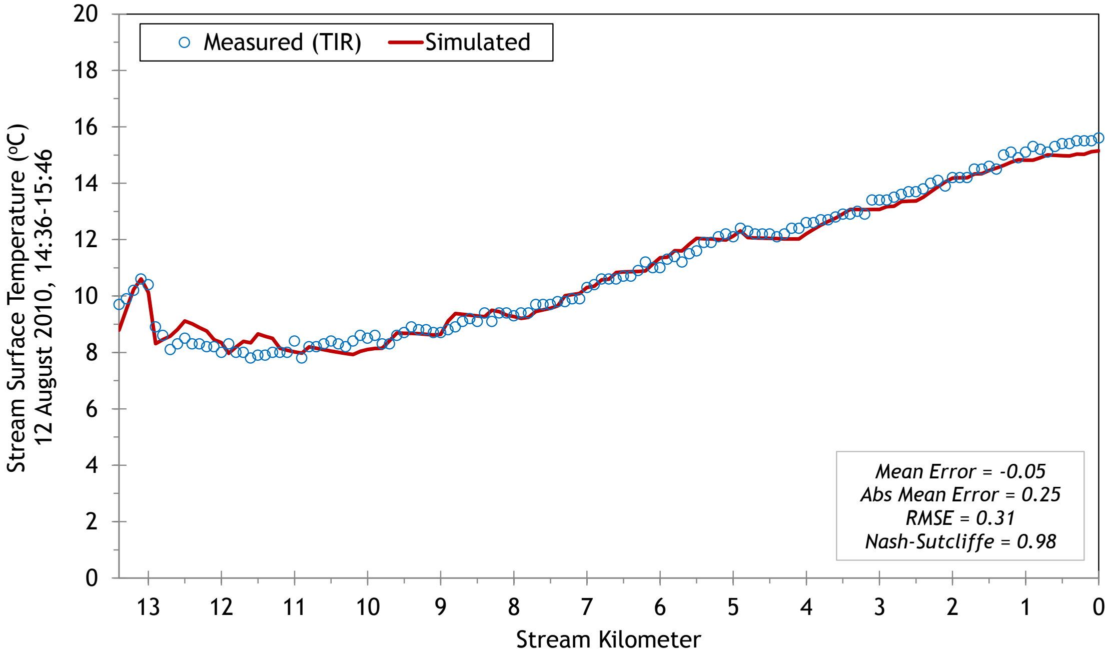
Table 6 summarizes the mass flow inputs that were included within the calibrated Heat Source model. They are features that were identified from the TIR imagery.

Table 6 – North Fork Catherine Creek mass inflow locations and assumptions.

Feature	Stream Km	Assumptions
Amelia Spring	12.95	0.05 cms at 5.3ºC (constant)
Seep	12.8	0.014 cms at 4.8ºC (constant)
Spring	12.75	0.014 cms at 3.8ºC (constant)
Unnamed Trib	12.7	0.014 cms at 9.6ºC (constant)
Spring	12.15	0.014 cms at 6.5ºC (constant)
Spring	11.9	0.014 cms at 4.4ºC (constant)
Spring	11.2	0.014 cms at 4.5ºC (constant)
Seep	10.1	0.014 cms at 6.9ºC (constant)
Jim Creek	8.9	Estimated daily flow (mass balance) and MF temperatures minus 2ºC.
Spring	8.1	0.014 cms at 8.1ºC (constant)
Spring	7.95	0.014 cms at 7.1ºC (constant)
Unnamed Trib	6.2	0.014 cms at variable temperature
Unnamed Trib	5.6	0.014 cms at variable temperature
Middle Fork Catherine Cr	4.8	Estimated daily flow (mass balance) and measured hourly temperatures.
Buck Creek	1.8	Estimated daily flow (mass balance) and MF temperatures minus 2.3ºC.
Lick Creek	1.7	Estimated daily flow (mass balance) and MF temperatures minus 3.1ºC.

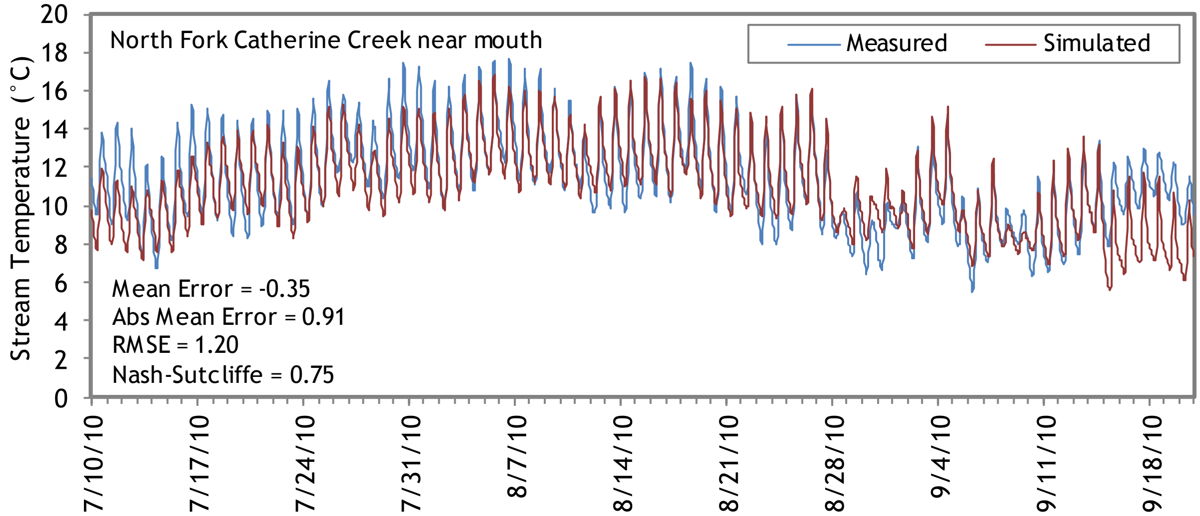
The North Fork Catherine Creek simulated and measured longitudinal temperatures are shown in Figure 50. Amelia Spring is responsible for the sudden temperature drop near stream kilometer 13. Then the stream gradually heats without any significant thermal fluctuations. The springs and seeps were small, while the tributaries were also relatively small and cool. The RMSE of the longitudinal temperature calibration is 0.31°C, which means the simulated instantaneous values match well to the measured TIR data.

Figure 50 – North Fork Catherine Creek longitudinal stream temperature calibration.



Besides the boundary condition (stream kilometer 13.4), there was one other hourly temperature monitoring site located near the mouth. Figure 63 shows the simulated and measured hourly stream temperatures near the mouth.

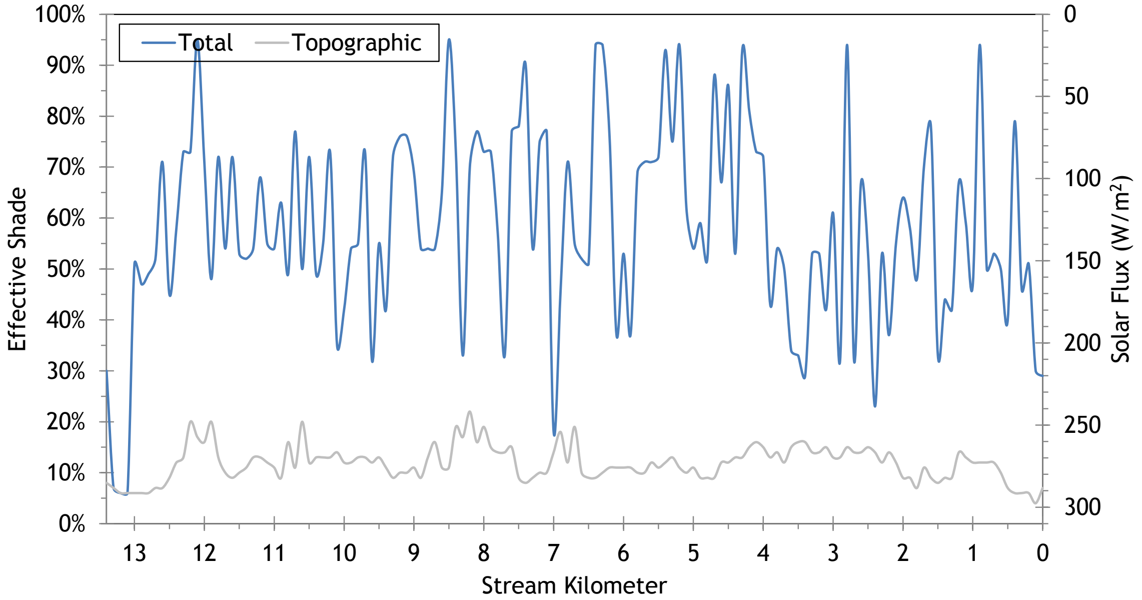
Figure 51 - North Fork Catherine Creek simulated and measured hourly temperatures.



Effective shade is one of the Heat Source simulation outputs (Figure 52). The North Fork Catherine Creek is well-forested and the stream is shaded through much of the day, resulting in effective shade values over 50% for most areas. See Appendix for effective shade maps.

Topographic shade was simulated by removing all land cover from within the model. Topographic shade was typically 10% or greater throughout the stream. The difference between the total effective shade and the topographic shade show in Figure 52 is the amount that can be attributed to land cover.

Figure 52 – North Fork Catherine Creek simulated effective shade.



LiDAR point cloud with RGB extraction – North Fork Catherine Creek upper reach.

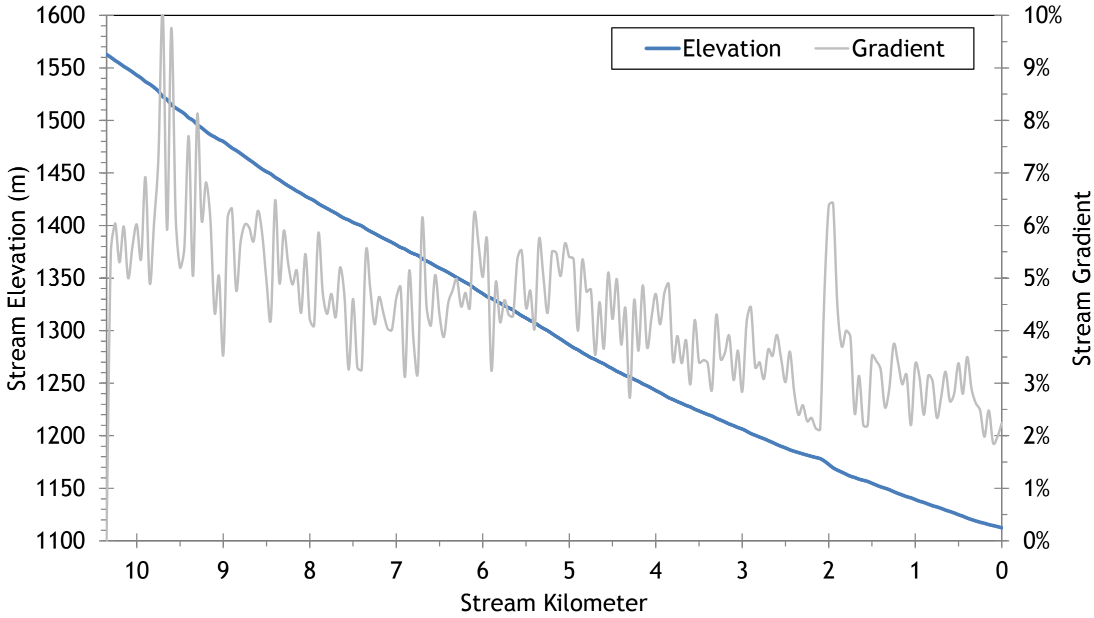
5.2 South Fork Catherine Creek

RGB-colored LiDAR point cloud - South Fork Catherine Creek looking upstream toward Corral Creek confluence.

5.2.1 South Fork Catherine Creek TTools Results

The South Fork Catherine Creek has a moderately steep gradient that ranges between 2% and 8% (Figure 53). It drops about 450 meters in elevation in the lower 10 stream kilometers.

Figure 53 – South Fork Catherine Creek elevation and gradient.



The South Fork Catherine Creek wetted widths were sampled at each 50-meter node (Figure 54). Ground level measurements are included in the chart for validation purposes. Generally, the stream is between 3 and 6 meters wide.

Figure 54 – South Fork Catherine Creek wetted width.

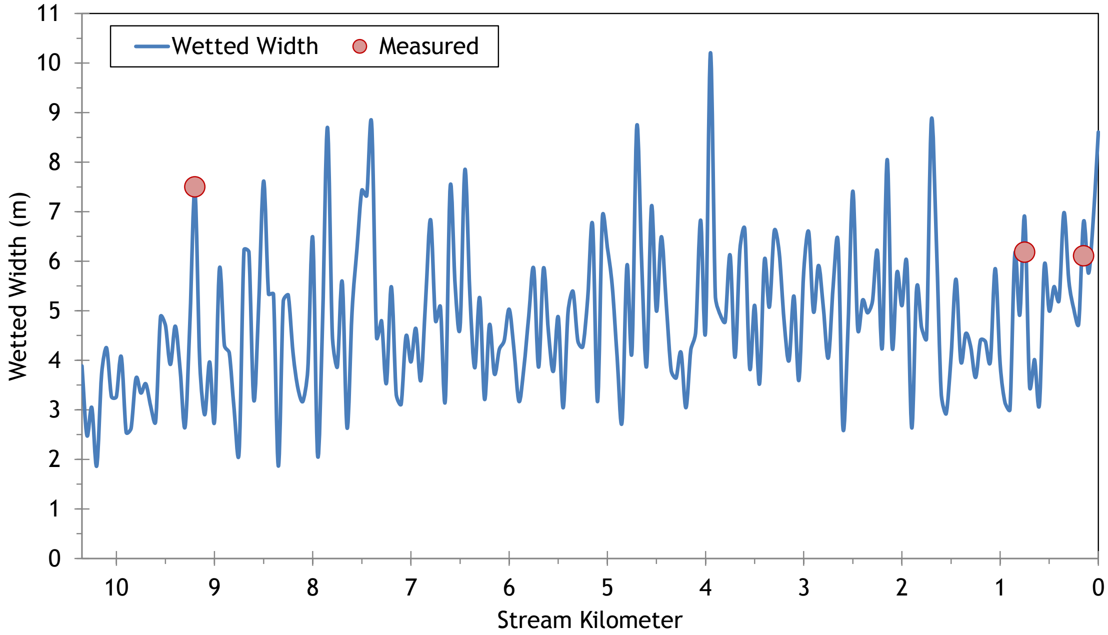
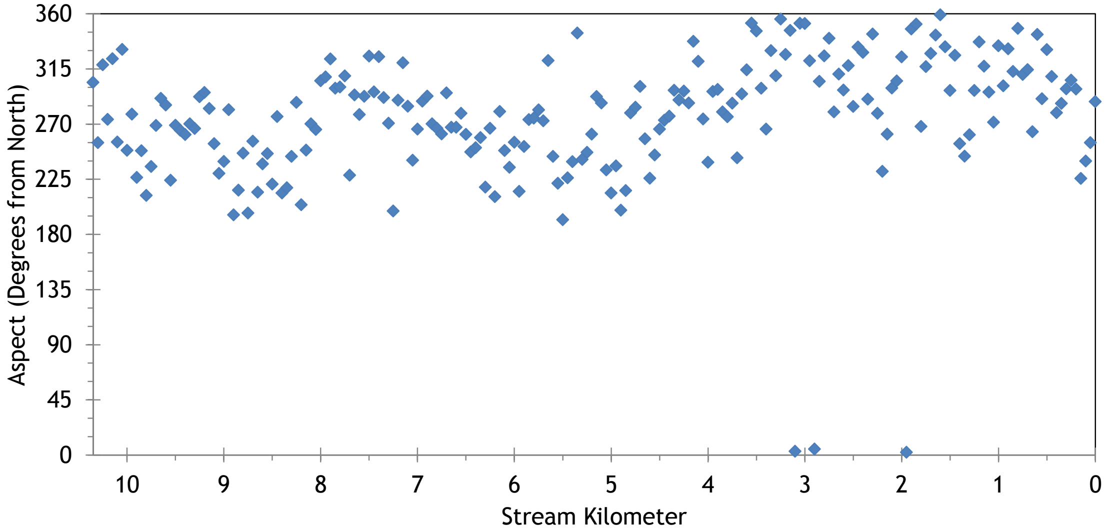


Figure 55 shows the stream aspect for each 50-meter reach of the South Fork Catherine Creek. The stream flows generally from east to west. Since it flows within a confined mountain valley, the stream meanders very little.

Figure 55 – South Fork Catherine Creek stream aspect.



Topographic shade angles of the South Fork Catherine Creek are shown in Figure 56. Since the stream flows east to west, the highest topographic shade angles are produced by hills or mountains to the south.

Figure 56 – South Fork Catherine Creek topographic shade angles.

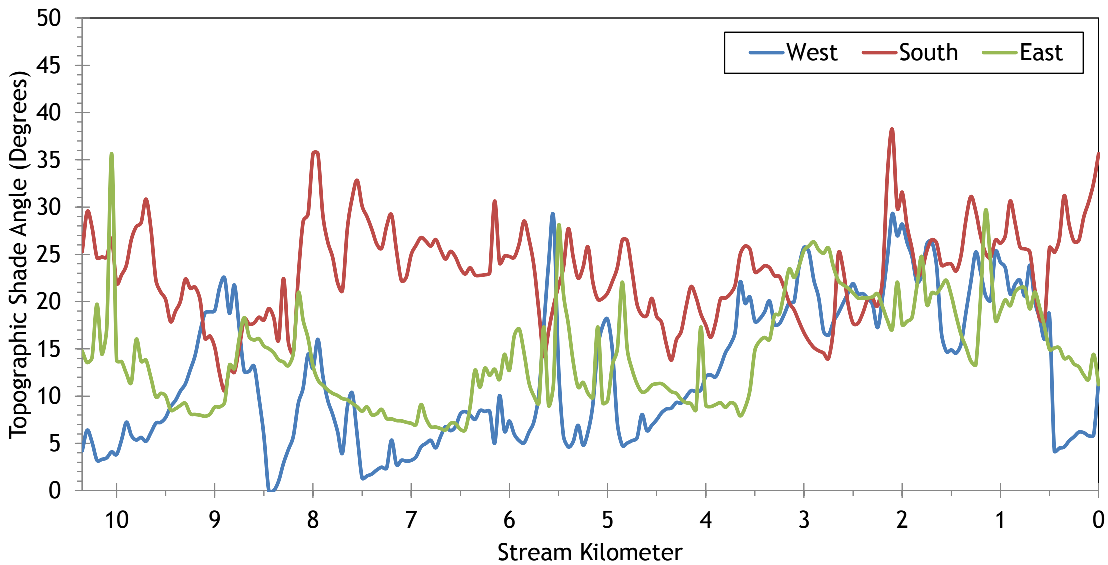
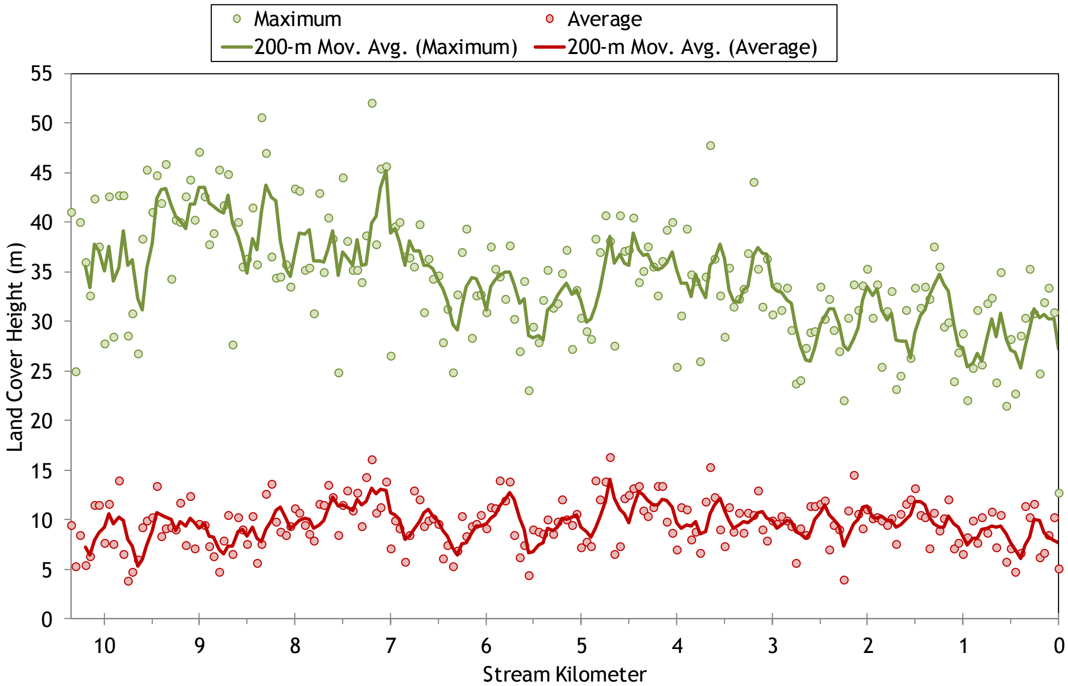


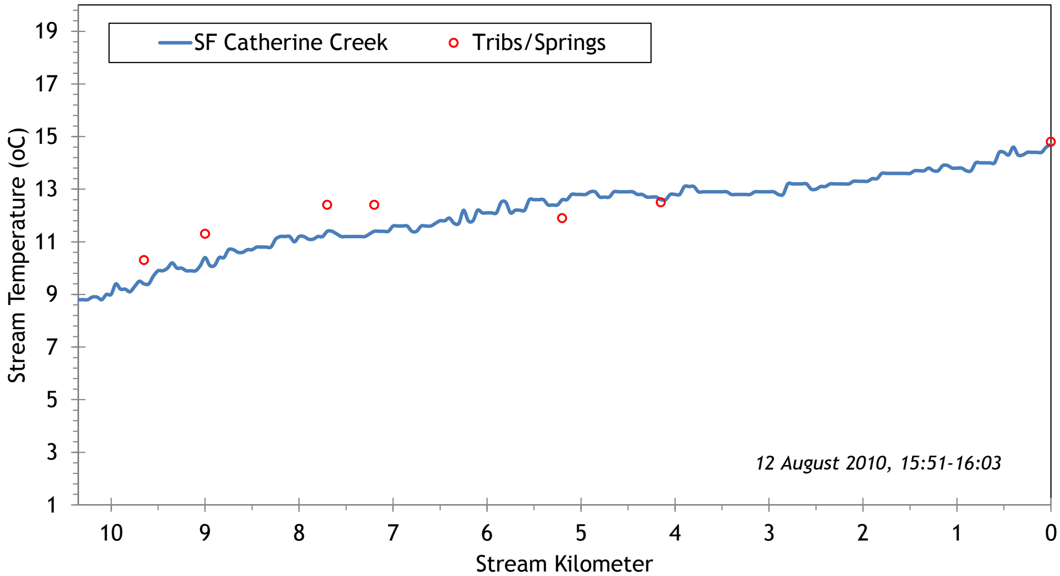
Figure 57 shows the land cover heights sampled along South Fork Catherine Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. The stream is flanked by mature conifers and riparian trees through most of its length. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 57 – South Fork Catherine Creek land cover heights sampled from highest hit LiDAR.



The South Fork Catherine Creek flows through predominantly forested mountain foothills, is well-shaded and remains relatively cool compared to other streams in the watershed (Figure 58). The stream barely reached 15°C at the mouth at the time of the TIR survey.

Figure 58 – South Fork Catherine Creek TIR stream temperature profile.



5.2.2 South Fork Catherine Creek Heat Source Calibration

The lower 10.4 kilometers of South Fork Catherine Creek were simulated (Figure 59). The stream originates in the Eagle Cap Wilderness area and flows westward until joining with the North Fork to form the Catherine Creek mainstem. The South Fork Catherine Creek is primarily forested and flows within a v-shaped mountain valley. There are several small tributaries as well.

Figure 59 – South Fork Catherine Creek simulation extent.

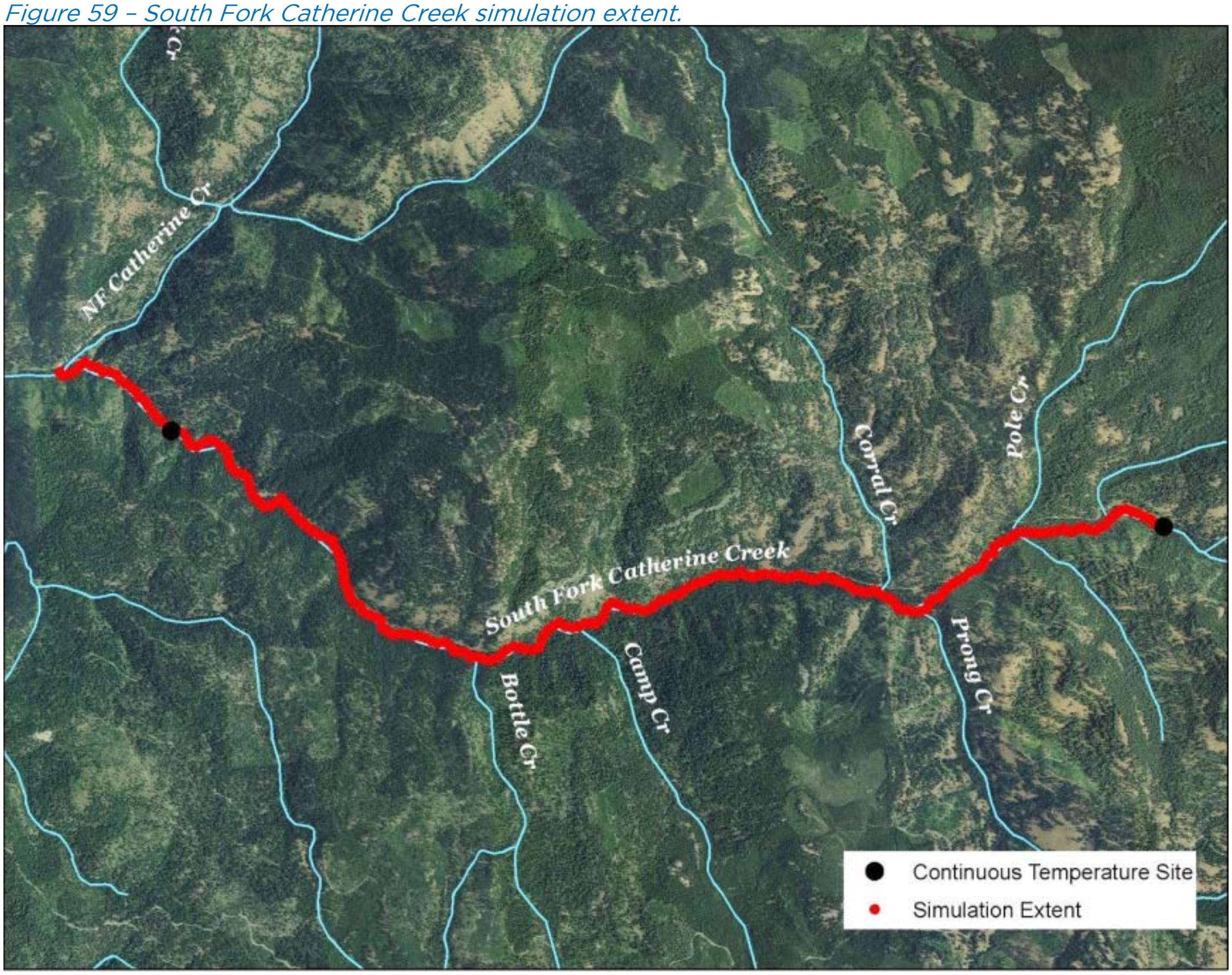


Table 7 – South Fork Catherine Creek general Heat Source parameters.

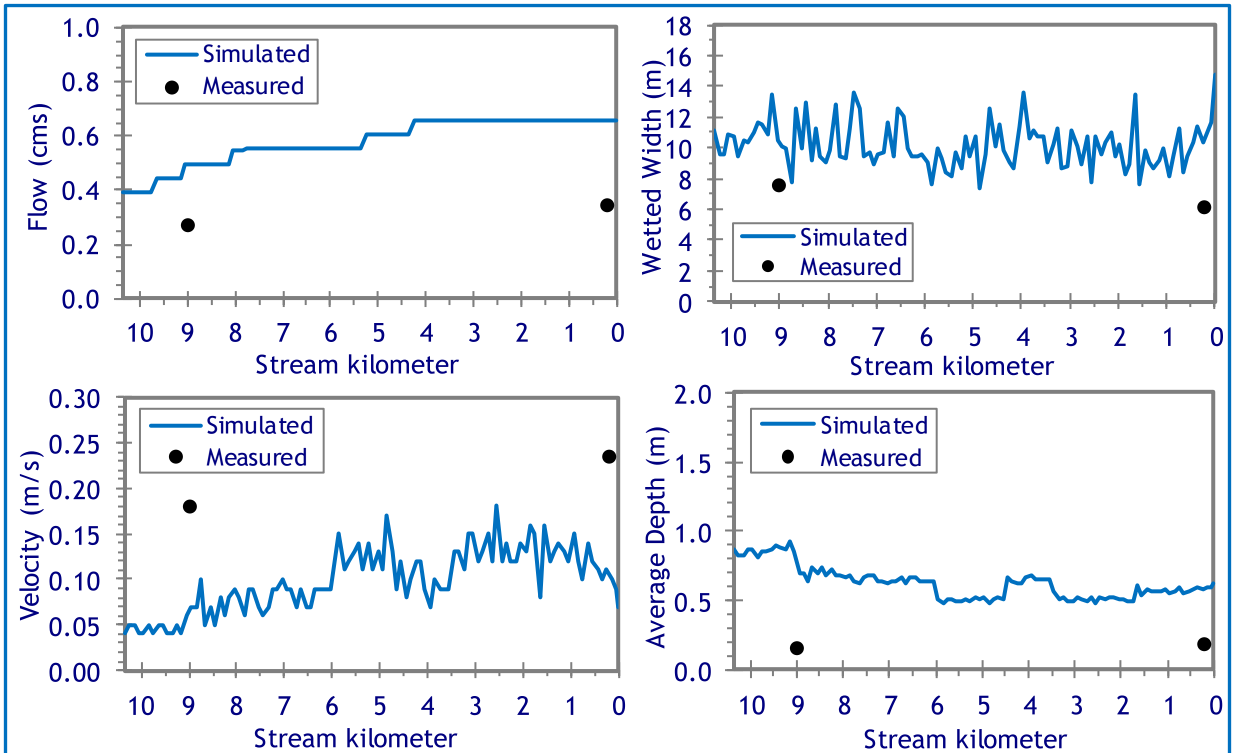
Stream:	South Fork Catherine Creek
Length:	10.4 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 12, 2010 15:51-16:03
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the South Fork Catherine Creek Heat Source model:

- The upstream monitoring site had no hourly temperature data available, so 5.5°C were subtracted from the values recorded at the mouth and used as the upstream boundary condition. This assumption adds unquantifiable uncertainty to the model. However, since the stream is well-forested and the longitudinal profile has little variability, this assumption is considered a "best estimate" of actual boundary temperatures.
- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Sand Pass, Pole, Prong, Camp and Butte Creek were all assumed to be contributing equal flow volumes.
- Wetted widths used in the final calibration are 130% of the raw TTools values, based on the ground level hydraulics data.
- USGS gages on the North Fork Catherine Creek and Mainstem of Catherine Creek were used to extrapolate daily flow volumes for South Fork Catherine Creek, Milk Creek, Little Catherine Creek and Scout Creek (a tributary to South Fork Catherine Creek). Relative contribution for each stream was determined based on CRITFC instantaneous measurements. Daily USGS gaged data were greater than CRITFC instantaneous values (see Figure 59).

Figure 60 shows the hydraulic input parameters for the South Fork Catherine Creek for August 19, 2010. The ground level data were measured on August 19, 2010 at two locations.

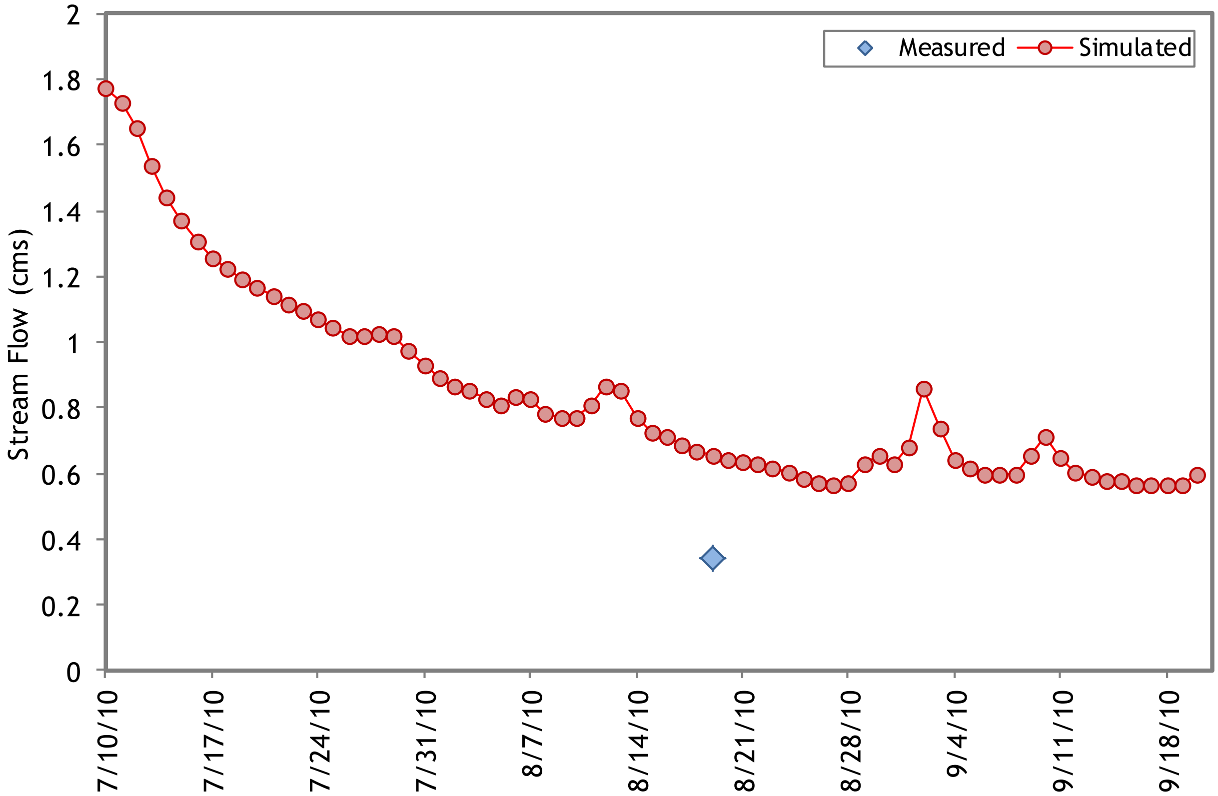
Figure 60 – South Fork Catherine Creek simulated and measured hydraulic values.



Site	Stream Km	Date
CRITFC Upper site	9.0	8/19/2010
Mouth	0.2	8/19/2010

Figure 61 shows the measured and simulated daily stream flow volume near the mouth of the South Fork Catherine Creek. Daily values for the simulation were extrapolated from USGS gage data on the North Fork and Mainstem Catherine Creek. Daily USGS gaged data were greater than CRITFC instantaneous values.

Figure 61 – South Fork Catherine Creek measured and simulated daily stream flow near the mouth.



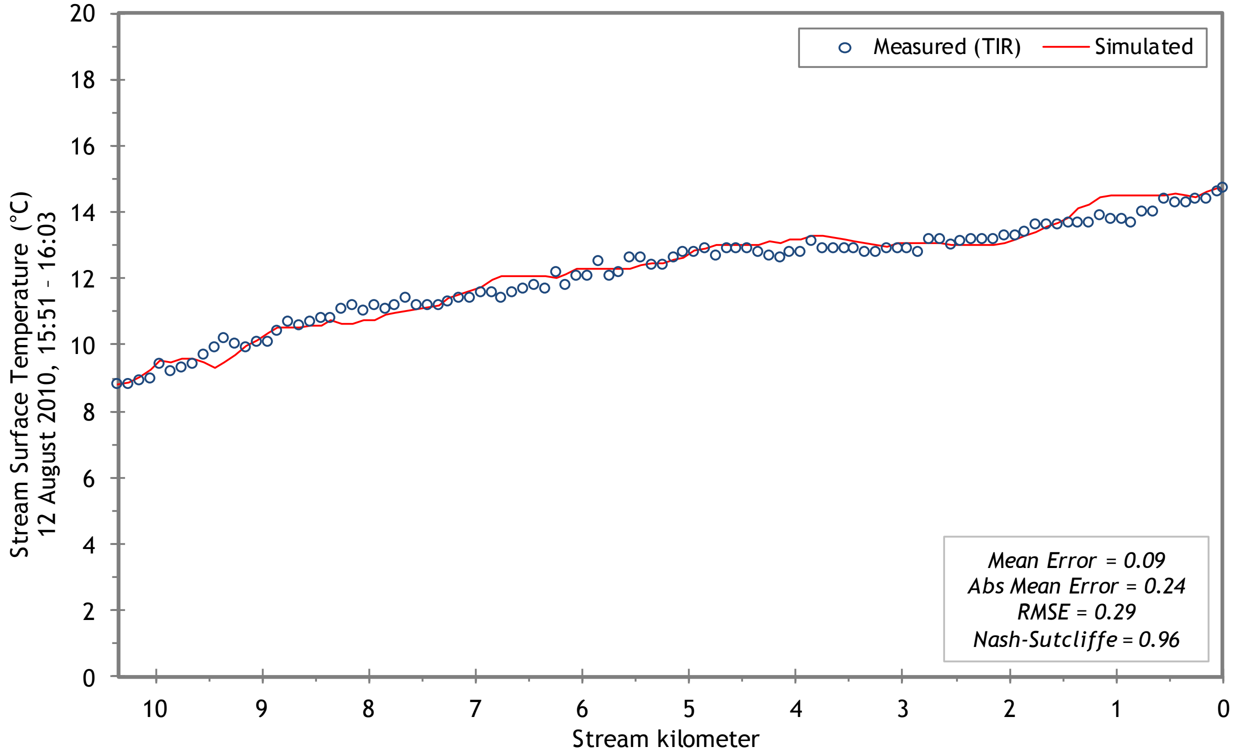
There were 5 tributaries observed in the TIR imagery. They were small enough that they did not have a measurable impact on the South Fork Catherine Creek temperatures; therefore mass balance flow estimates were not possible and simple conservative estimates were used. Hourly temperatures of the tributaries were assumed by adjusting hourly data recorded at the South Fork mouth based on temperature of the tributary observed in the TIR data.

Table 8 – South Fork Catherine Creek mass inflow locations and assumptions.

Feature	Stream Km	Assumptions
Sand Pass Creek	9.65	Daily flow estimated and hourly temperatures estimated by adjusting SF mouth data according to TIR imagery.
Pole Creek	9.05	Daily flow estimated and hourly temperatures estimated by adjusting SF mouth data according to TIR imagery.
Prong Creek	8.1	Daily flow estimated and hourly temperatures estimated by adjusting SF mouth data according to TIR imagery.
Camp Creek	5.25	Daily flow estimated and hourly temperatures estimated by adjusting SF mouth data according to TIR imagery.
Butte Creek	4.3	Daily flow estimated and hourly temperatures estimated by adjusting SF mouth data according to TIR imagery.

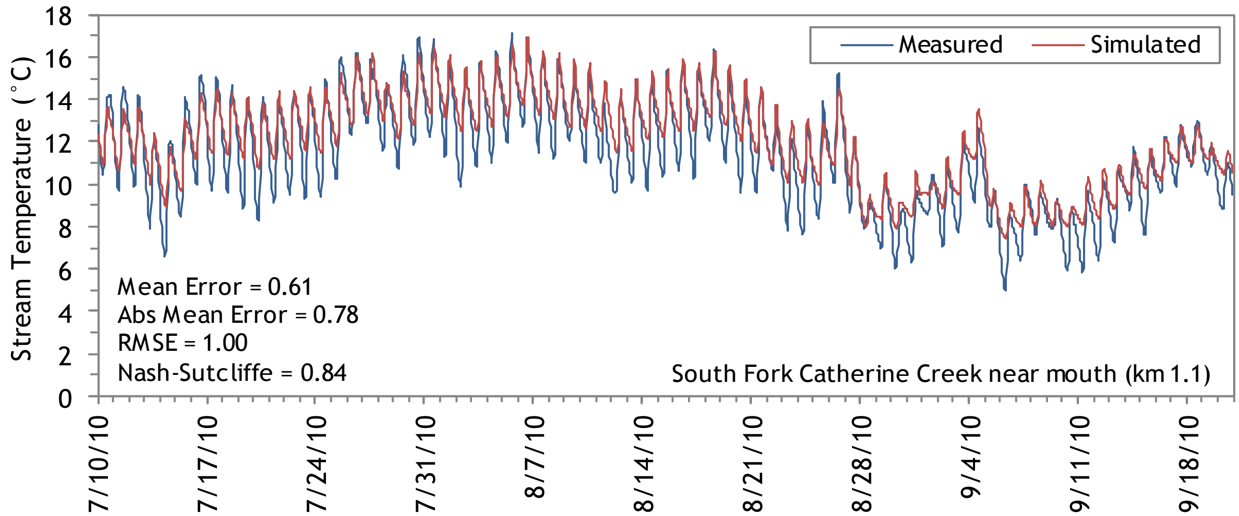
The South Fork Catherine Creek simulated and measured longitudinal temperatures are shown in Figure 62. The calibration statistics are also presented on the chart.

Figure 62 – South Fork Catherine Creek simulated and measured stream temperature.



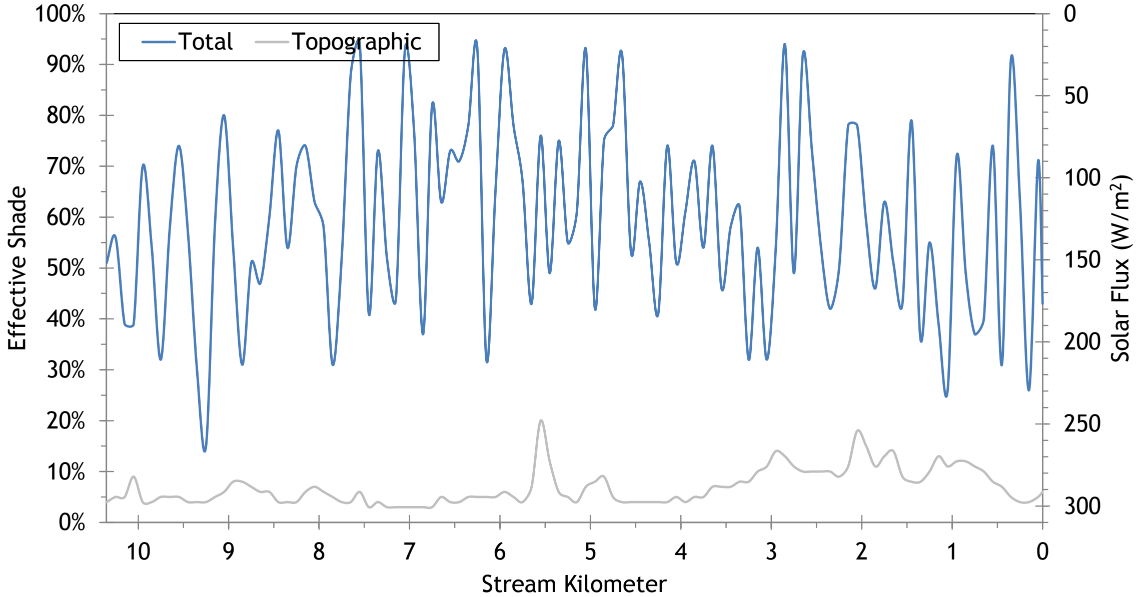
Besides the boundary condition (stream kilometer 10.4), there was one other hourly temperature monitoring site located near the mouth. Figure 63 shows the simulated and measured hourly stream temperatures near the mouth.

Figure 63 – South Fork Catherine Creek simulated and measured hourly temperatures.

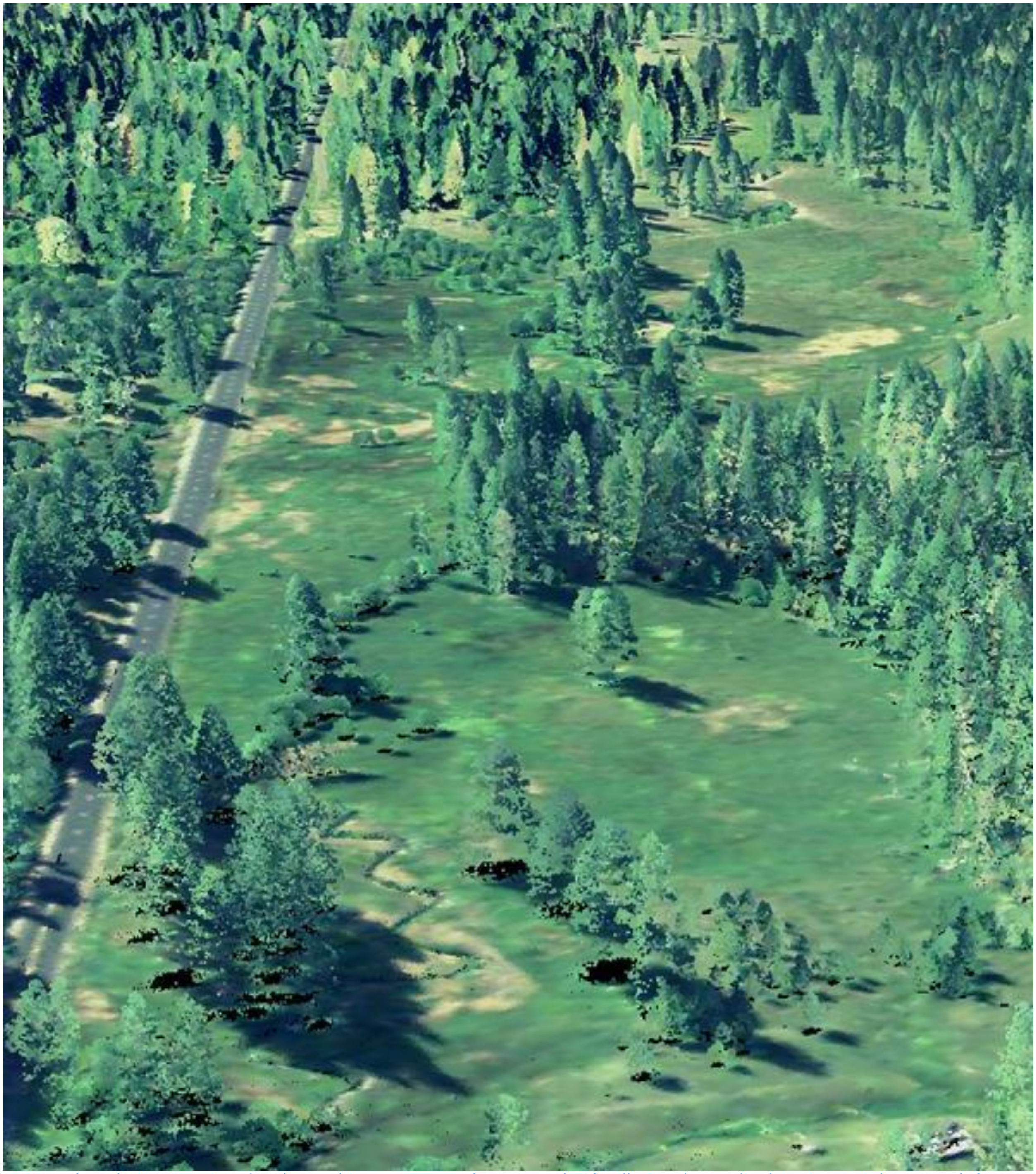


The simulated effective shade values for South Fork Catherine Creek are presented in Figure 64. The total effective shade is that which the stream experiences from both topography and vegetation. The topographic effective shade is the amount received by the stream in the absence of vegetation. The difference between the two is the amount of effective shade provided by the near stream land cover. Since the South Fork Catherine Creek is well forested, effective shade values are substantial for most of the stream. See Appendix for effective shade maps.

Figure 64 – South Fork Catherine Creek simulated effective shade.



5.3 Milk Creek

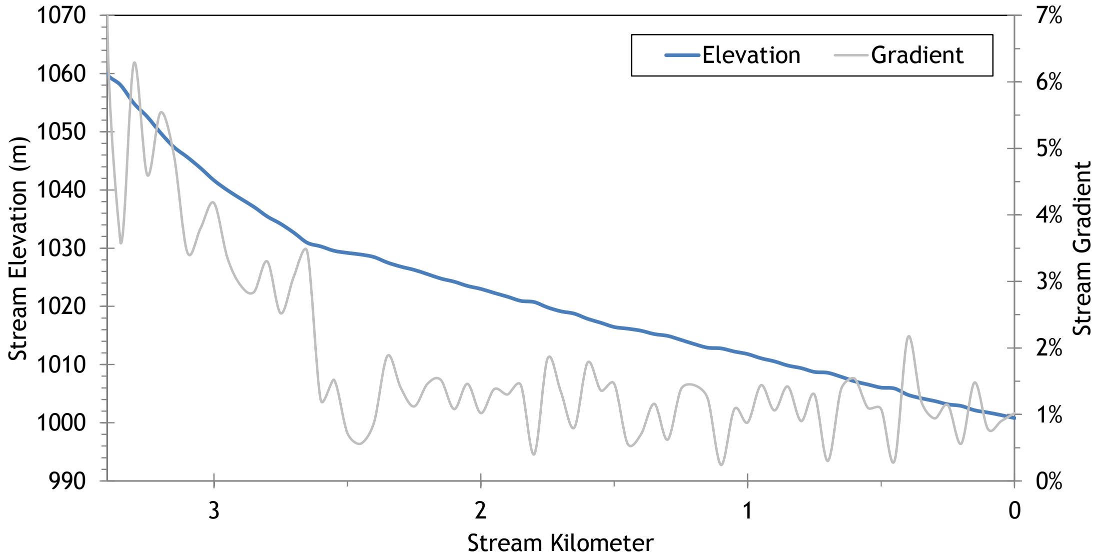


RGB-colored LiDAR point cloud - Looking upstream from mouth of Milk Creek (Medical Springs Highway on left).

5.3.1 Milk Creek TTools Results

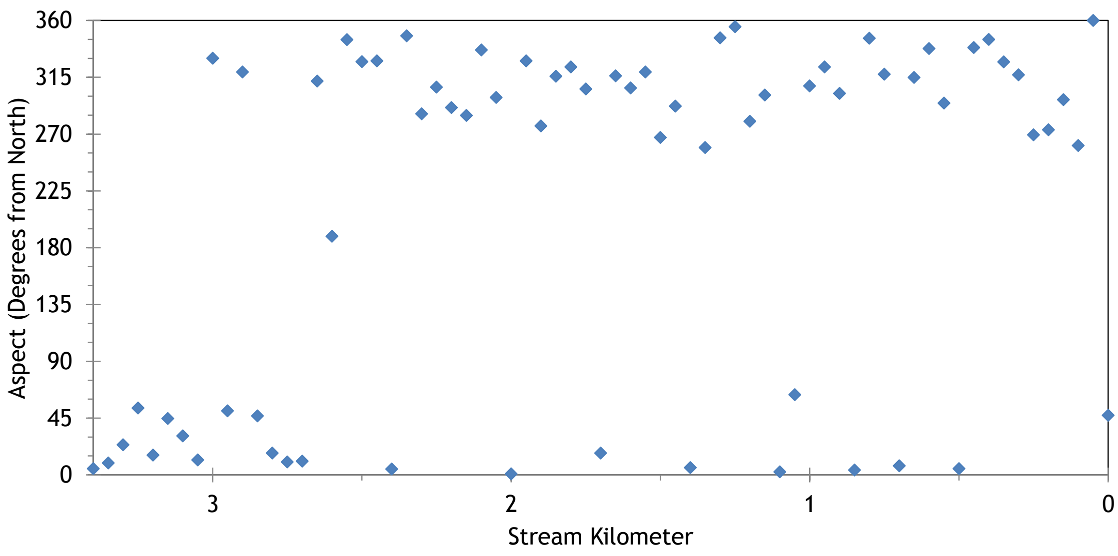
The lower 2.5 kilometers of Milk Creek flow through mostly open meadow and is low gradient. Figure 65 shows the elevation and gradient of the lower 3.4 kilometers where LiDAR data were available.

Figure 65 – Milk Creek stream elevation and gradient.



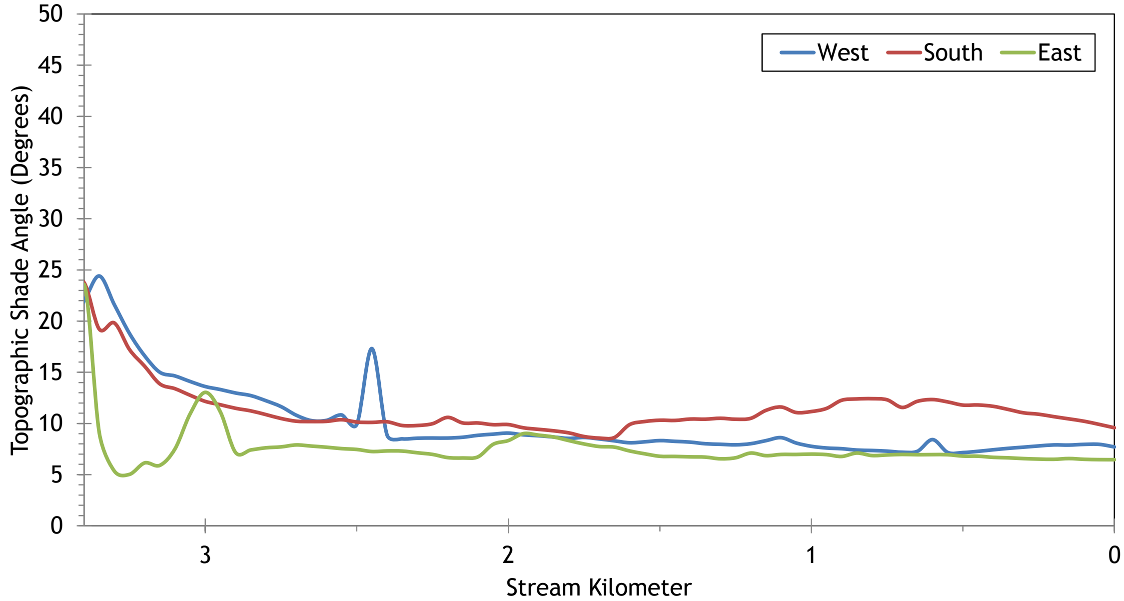
Milk creek generally flows in the northwesterly direction. Figure 66 displays the stream aspect for each 50 meter node of the lower 3.4 kilometers.

Figure 66 – Milk Creek stream aspect.



Topographic shade angles are around 10 degrees for Milk Creek (Figure 67). The highest topographic shade producing features are located to the south of the stream.

Figure 67 – Milk Creek topographic shade angles.



Milk Creek is a small stream so TIR stream temperature samples were sparser than for larger streams (Figure 68). Overall, Milk Creek was about 15-16°C during the TIR flight. These data are used for Heat Source calibration purposes.

Figure 68 – Milk Creek TIR stream temperature profile.

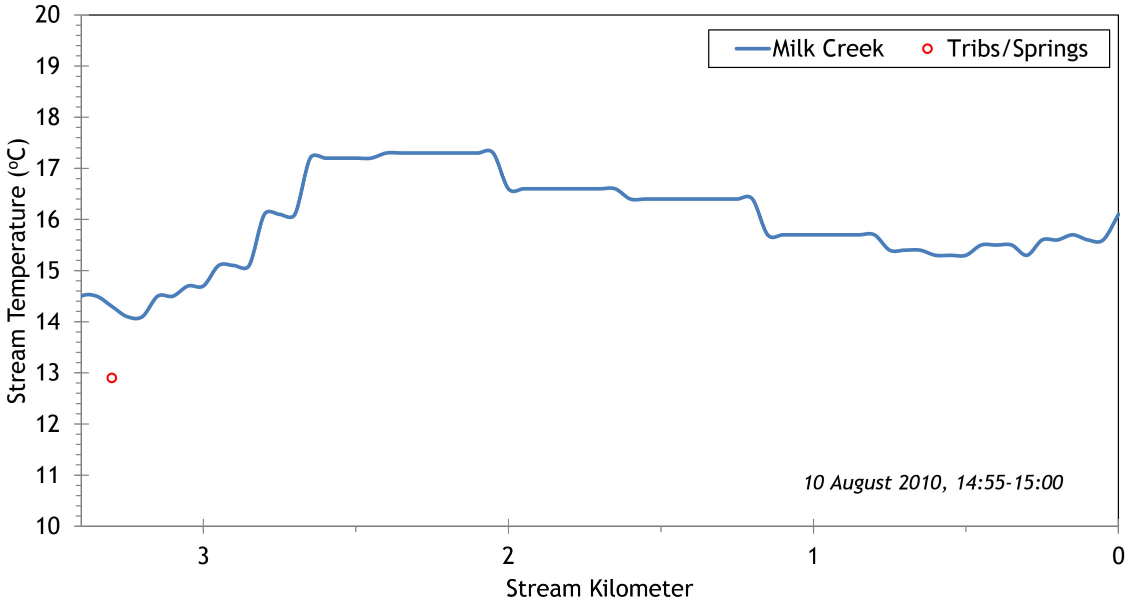
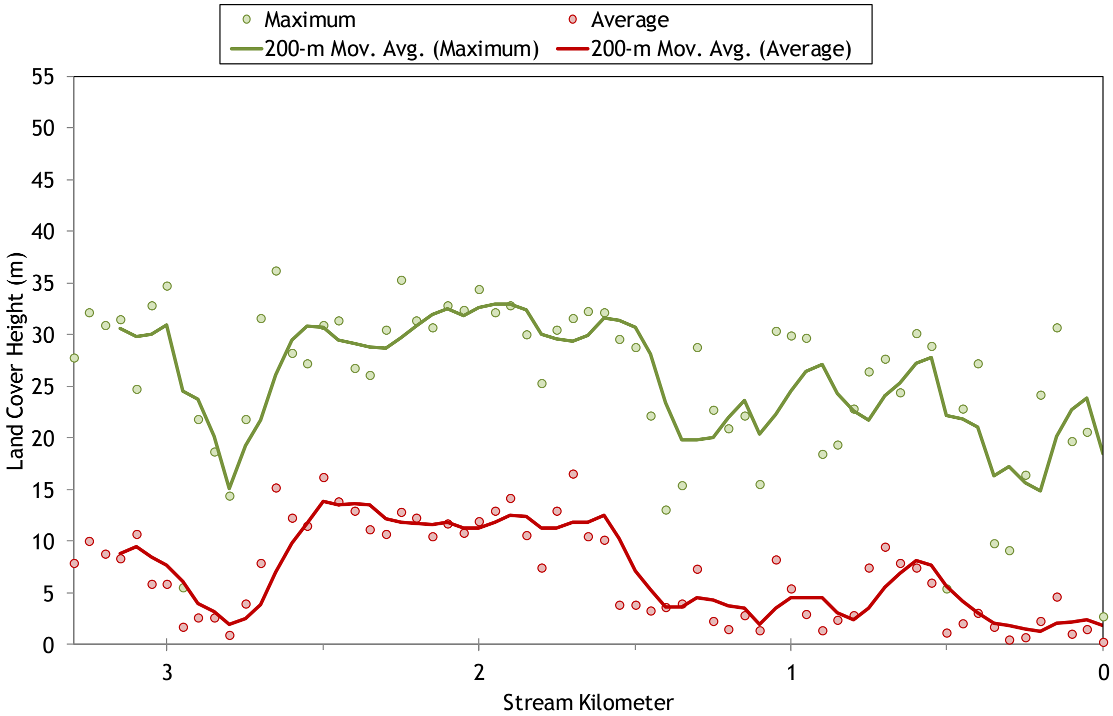


Figure 69 shows the land cover heights sampled along Milk Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. Average heights are small in the lower 1.5 kilometers because there are fewer trees and many of the radial samples are of meadow grasses. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 69 - Milk Creek land cover heights sampled from highest hit LiDAR.



5.3.2 Milk Creek Heat Source Calibration Results

The lower 3.3 kilometers for Milk Creek were simulated (Figure 70). There were two ground level monitoring sites which determined the simulation extent.

Figure 70 – Milk Creek simulation extent.

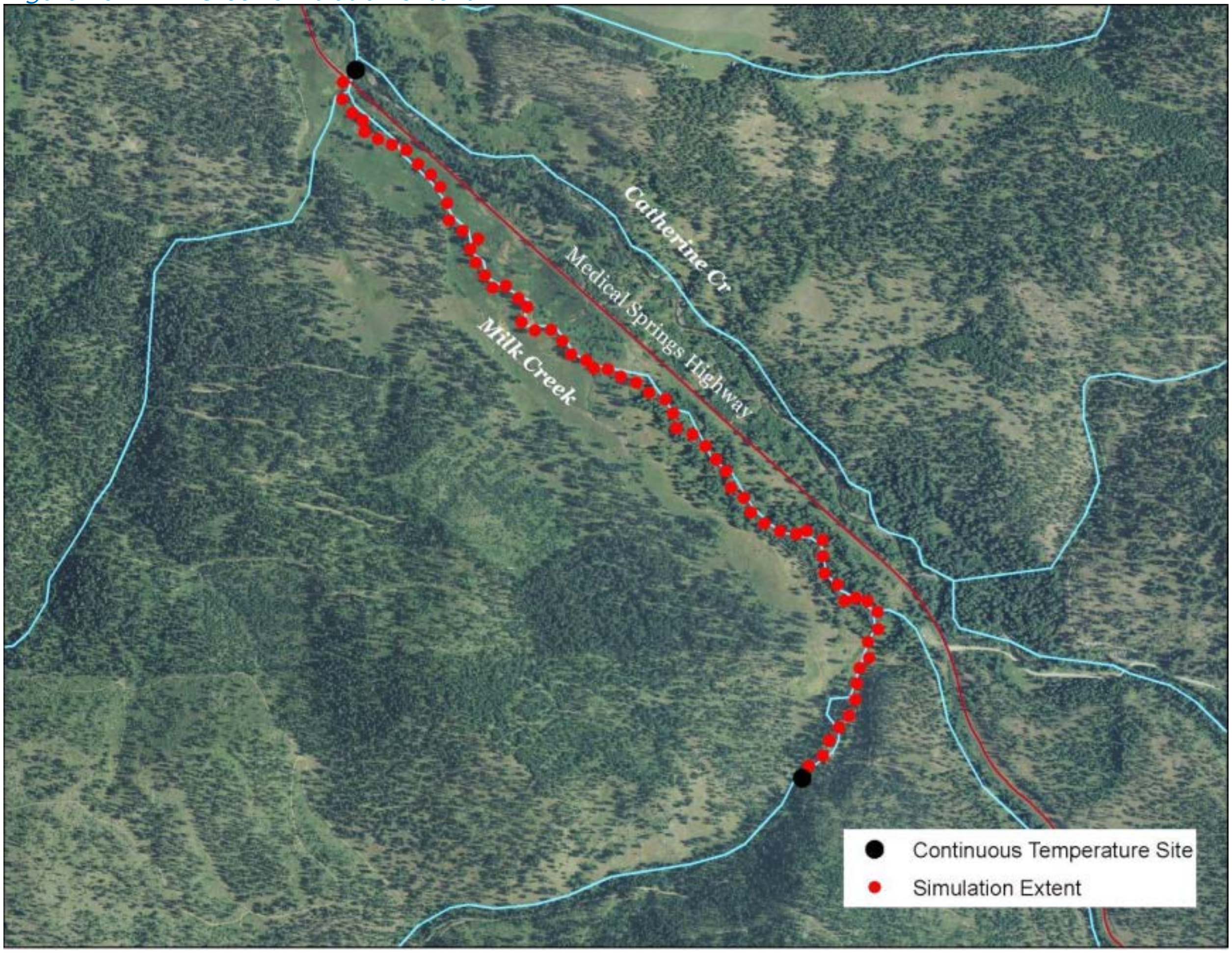


Table 9 – Milk Creek general Heat Source parameters.

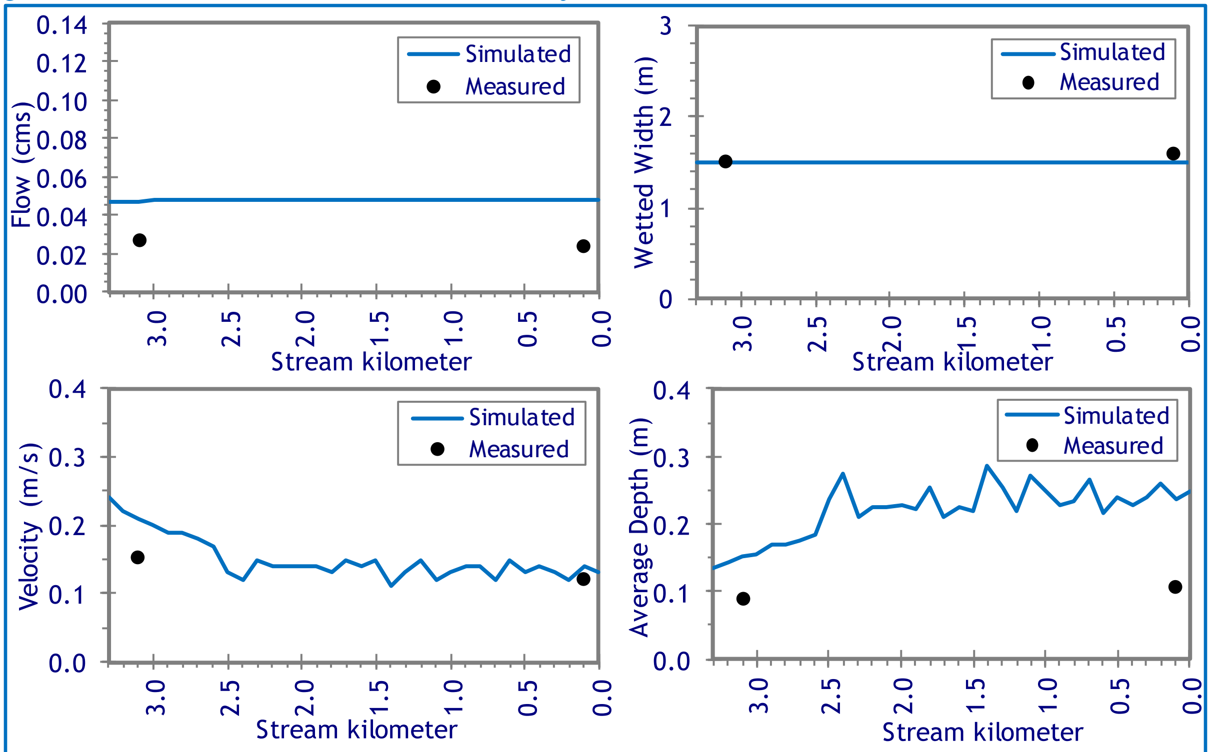
Stream:	Milk Creek
Length:	3.3 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 10, 2010 14:55-15:00
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	10 meters

The following assumptions were used when calibrating the Milk Creek Heat Source model:

- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Wetted widths used in the final calibration were 1.5 meters for the entire length. The stream was too small to digitize wetted edges from the remote sensing imagery, so this value was estimated based on the two field measurements.
- USGS gages on the North Fork Catherine Creek and Mainstem of Catherine Creek were used to extrapolate daily flow volumes for South Fork Catherine Creek, Milk Creek, Little Catherine Creek and Scout Creek (a tributary to South Fork Catherine Creek). Relative contribution for each stream was determined based on CRITFC instantaneous measurements. Daily USGS gaged data were greater than CRITFC instantaneous values (see Figure 71).
- Since the stream is so small, the land cover sampling distance step was reduced to 10 meters in order to capture the land cover nearest the stream.

Figure 71 shows the simulated and measured hydraulic parameters for Milk Creek. The simulated data are for August 19, 2010. The field measurements were collected on August 18th and 19th.

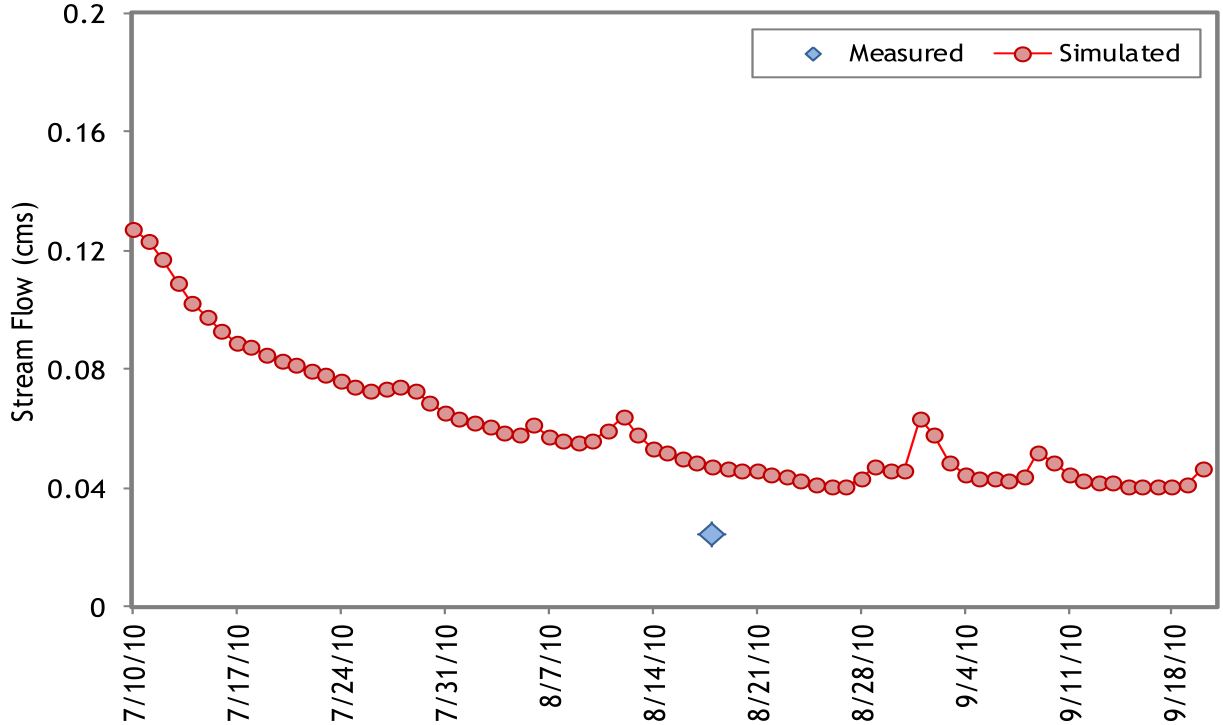
Figure 71 – Milk Creek simulated and measured hydraulic values for 8/19/2010.



Site	Stream Km	Date
Milk Creek upper site	3.1	8/19/2010
Milk Creek near Mouth	0.1	8/18/2010

The measured and simulated flow volumes at the mouth of Milk Creek are shown in Figure 72. The data were extrapolated/estimated from daily gage records in Catherine Creek. Since there were no tributary or spring inputs to Milk Creek, these are the flow volumes that were simulated throughout the length of the stream.

Figure 72 – Milk Creek measured and simulated daily stream flow at the mouth.



The simulated and measured longitudinal stream temperatures are shown in Figure 73. Due to the small size of Milk Creek, few TIR samples were obtained.

Figure 73 – Milk Creek simulated and measured longitudinal temperatures.

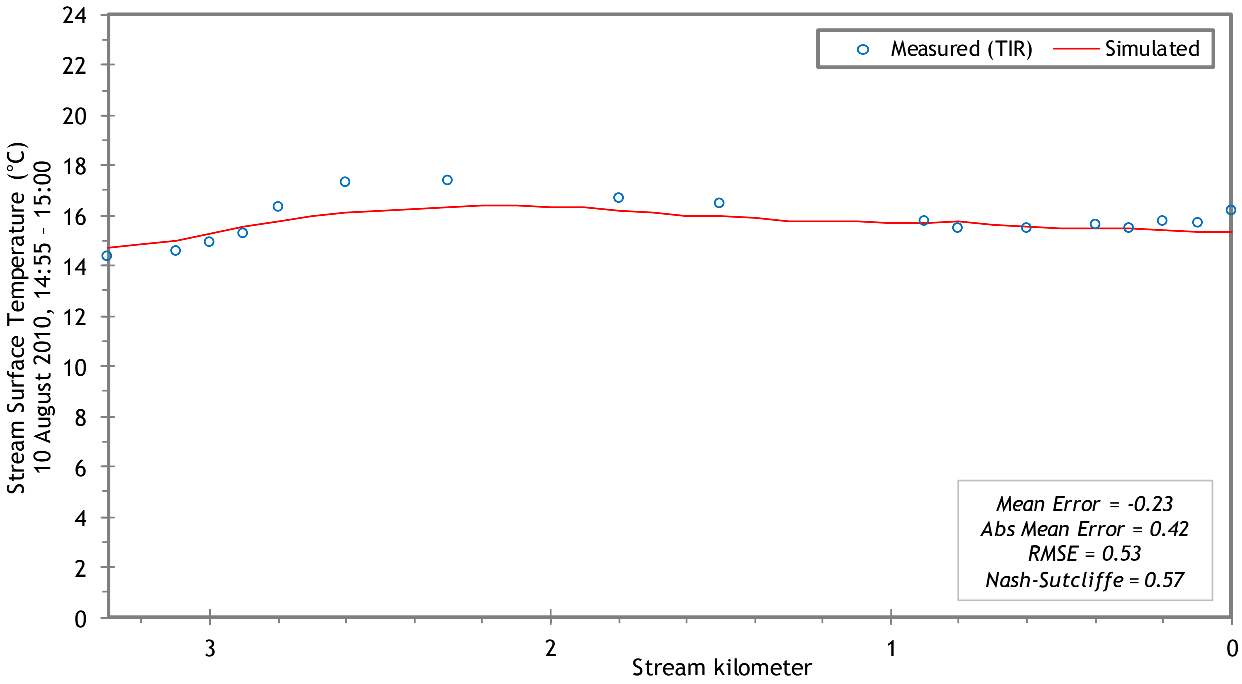
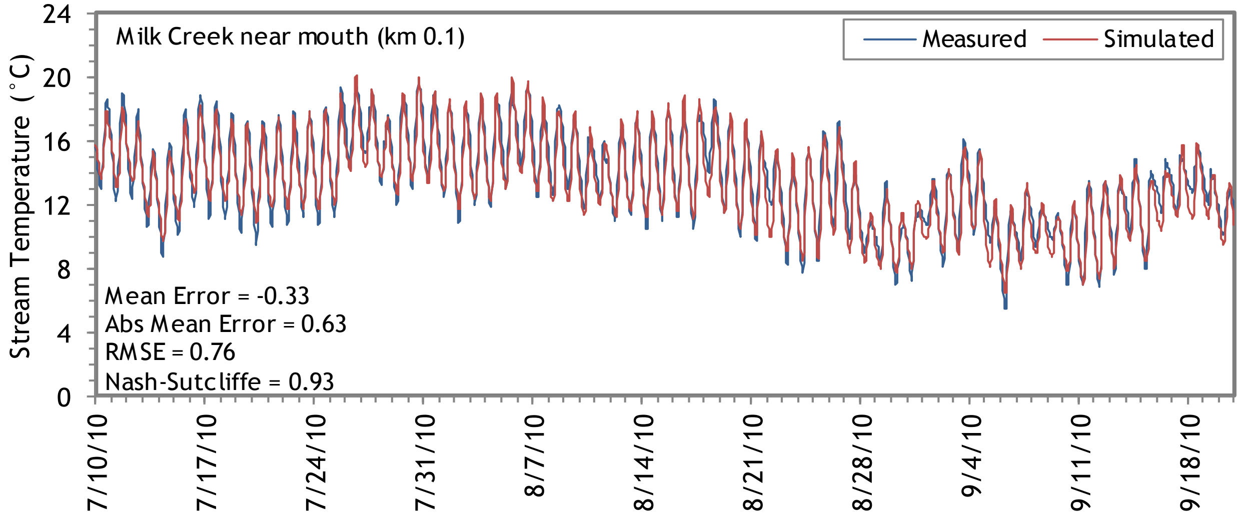


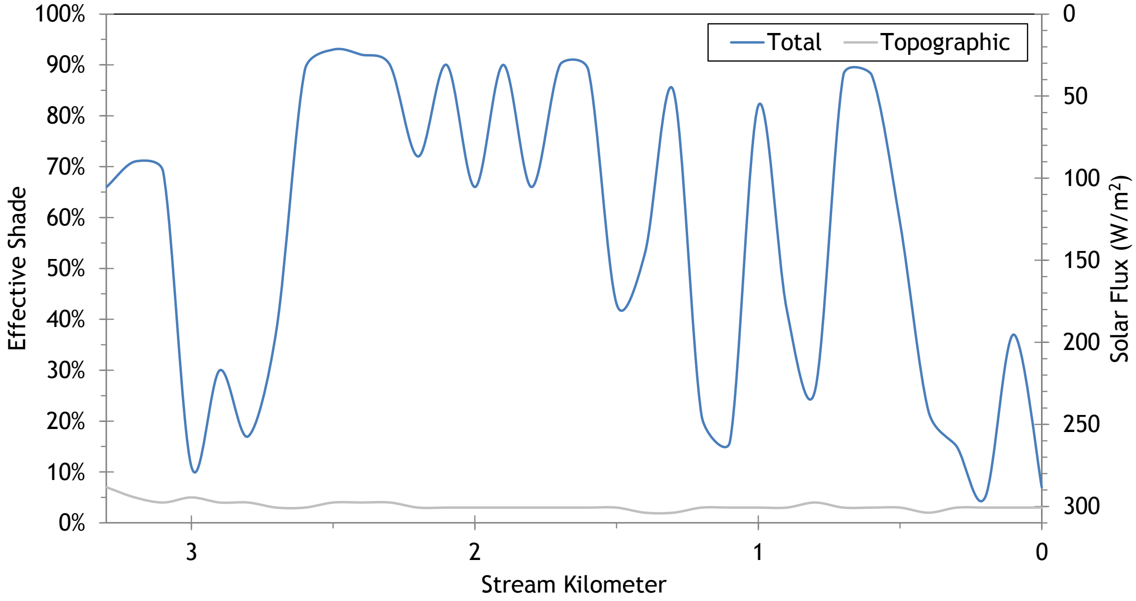
Figure 74 shows the simulated and measured hourly stream temperatures for Milk Creek.

Figure 74 – Milk Creek simulated and measured hourly temperatures.

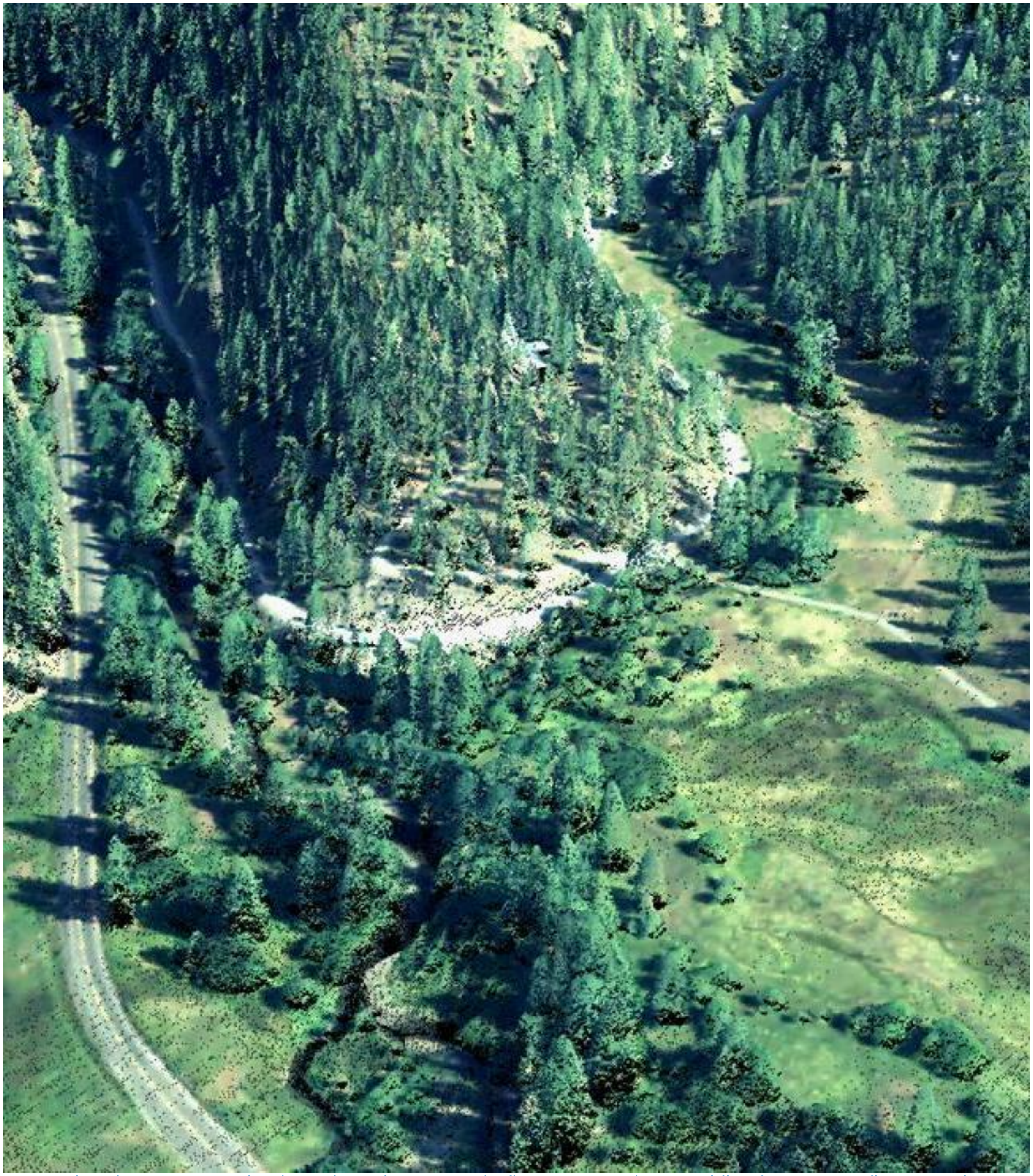


The simulated effective shade values of Milk Creek are presented in Figure 75. The total effective shade is variable because Milk Creek is flowing through a meadow with occasional stands of trees. There is fairly little topographic shade within the meadow. See Appendix for effective shade maps.

Figure 75 – Milk Creek simulated effective shade values.



5.4 Little Catherine Creek

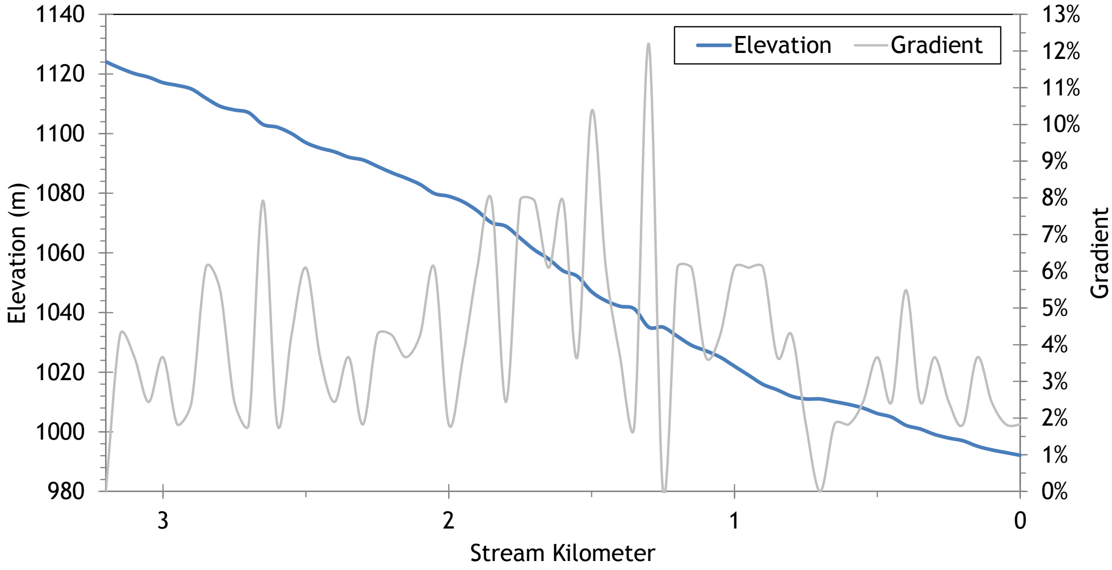


RGB-colored LiDAR point cloud - Little Catherine Creek (flowing top right to middle of image) confluence with Catherine Creek (flowing from bottom to top left of image).

5.4.1 Little Catherine Creek TTools Results

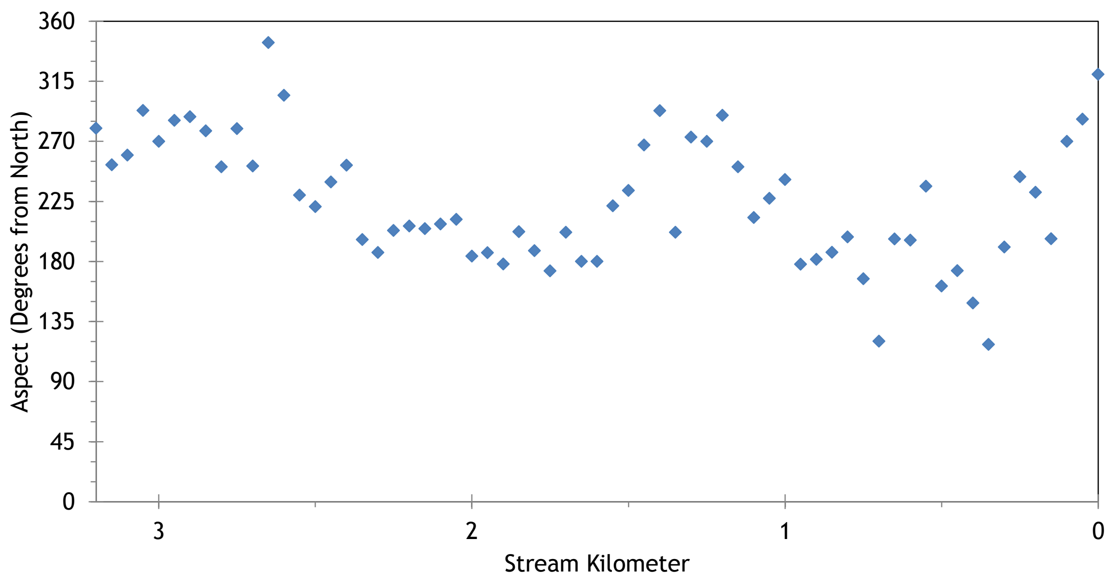
Little Catherine Creek did not have LiDAR coverage (except for a small reach near the mouth). Therefore, stream elevations and gradients were sampled from the 10-meter DEM. Figure 76 shows the elevations and gradients for Little Catherine Creek.

Figure 76 – Little Catherine Creek elevation and gradient.



Little Catherine Creek flows generally toward the southwest until it reaches Catherine Creek just upstream of the city of Union. Figure 77 shows the stream aspect for each 50-meter node of Little Catherine Creek.

Figure 77 – Little Catherine Creek stream aspect.



Topographic shade angles are relatively high on Little Catherine Creek, with some values over 30 degrees (Figure 78). This is due to the fact that the stream is flowing out of mountain foothills within a deep v-shaped valley.

Figure 78 – Little Catherine Creek topographic shade angles.

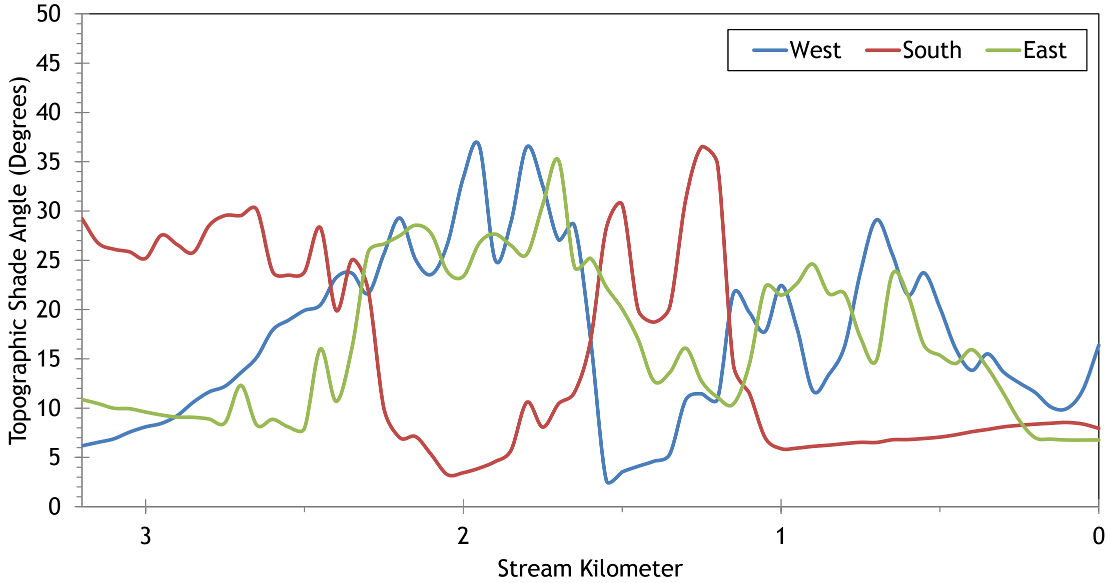
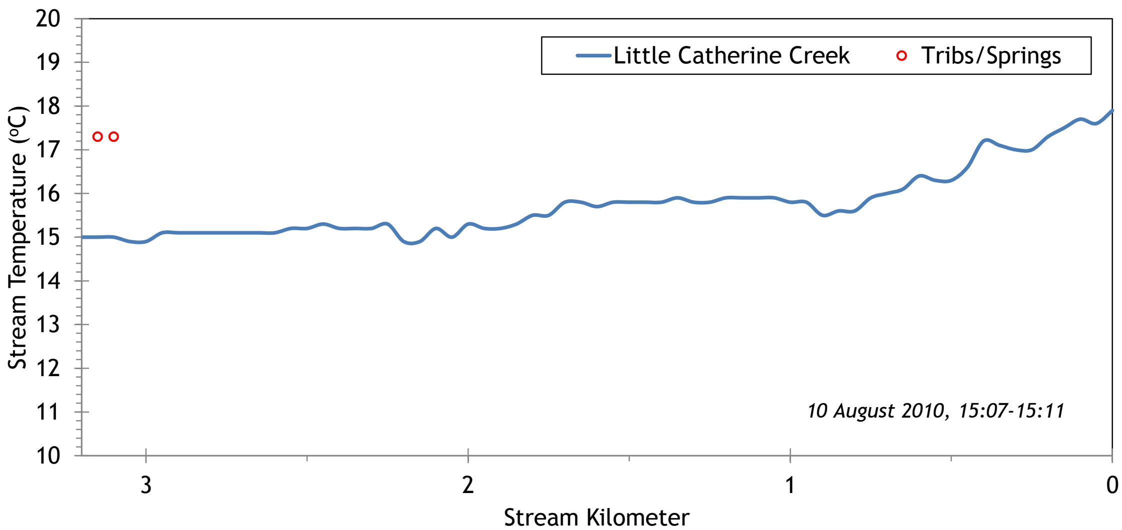


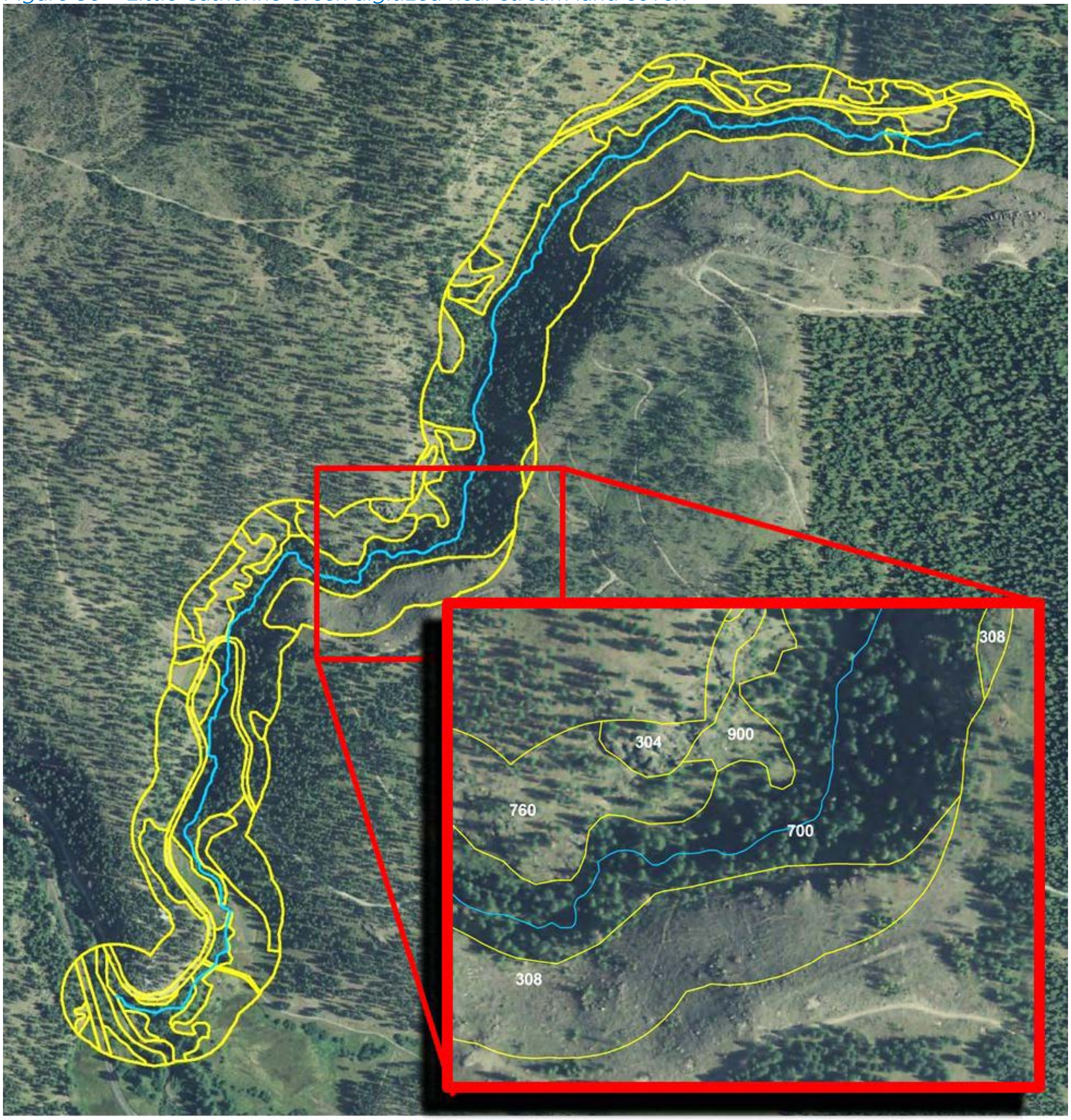
Figure 79 shows the TIR stream temperature profile of Little Catherine Creek. Stream temperature ranged from 15-18°C during the TIR flight.

Figure 79 – Little Catherine Creek TIR stream temperature profile.



Since there was no LiDAR available for Little Catherine Creek, the near stream land cover was digitized from the NAIP imagery within 100 meters of the stream. Figure 80 shows the near stream land cover polygons along Little Catherine Creek. Each polygon contains a code that signifies the land cover type, height class, and density class.

Figure 80 – Little Catherine Creek digitized near stream land cover.



5.4.2 Little Catherine Creek Effective Shade Simulation

Little Catherine Creek was simulated for effective shade only. There was insufficient ground-level flow and temperature for stream temperature modeling. Figure 81 shows the effective shade simulation extent.

Figure 81 – Little Catherine Creek simulation extent.

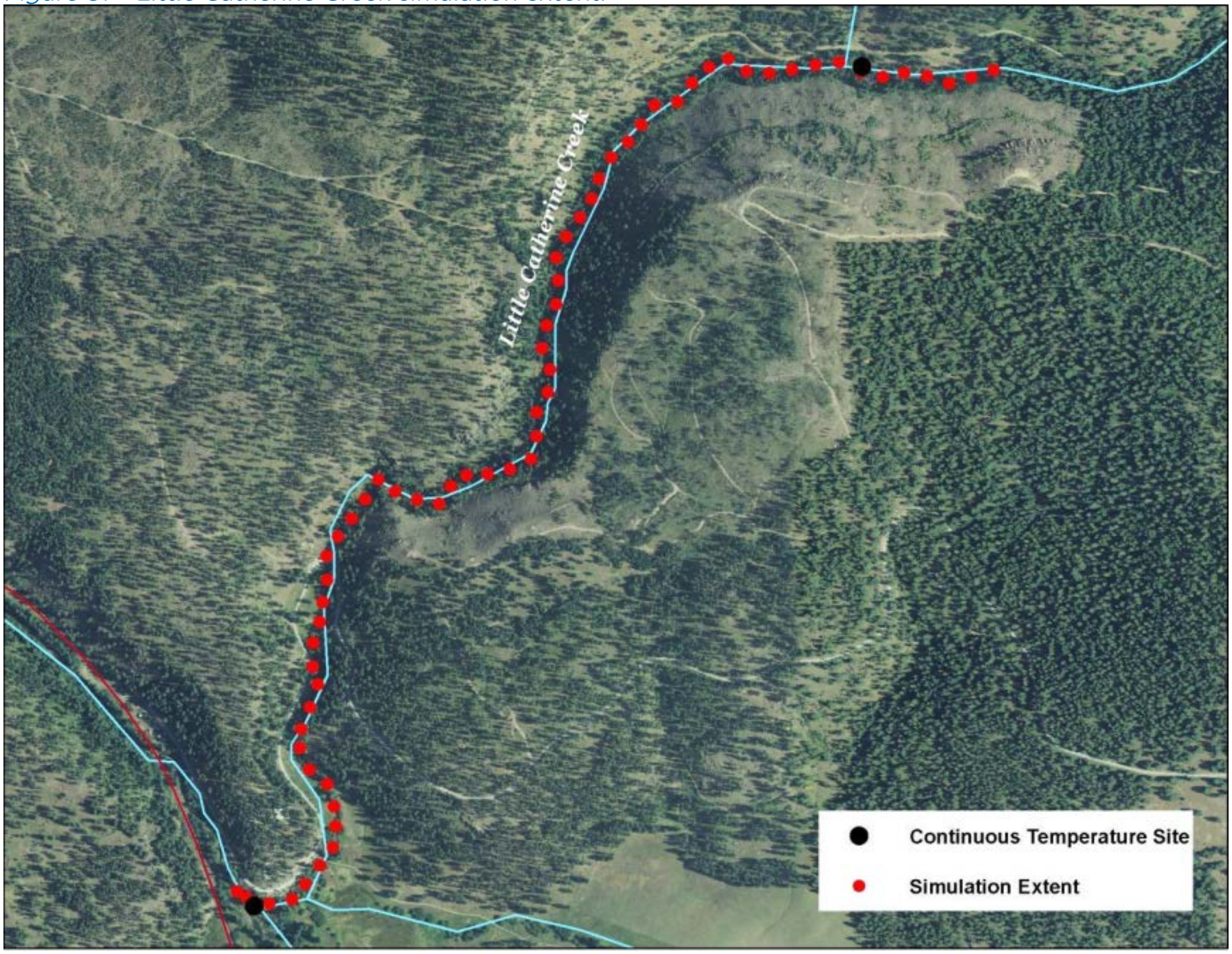


Table 10 – Little Catherine Creek general Heat Source parameters.

Stream:	Little Catherine Creek
Length:	3.2 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	NA
TIR Date and Time:	NA
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	10 meters

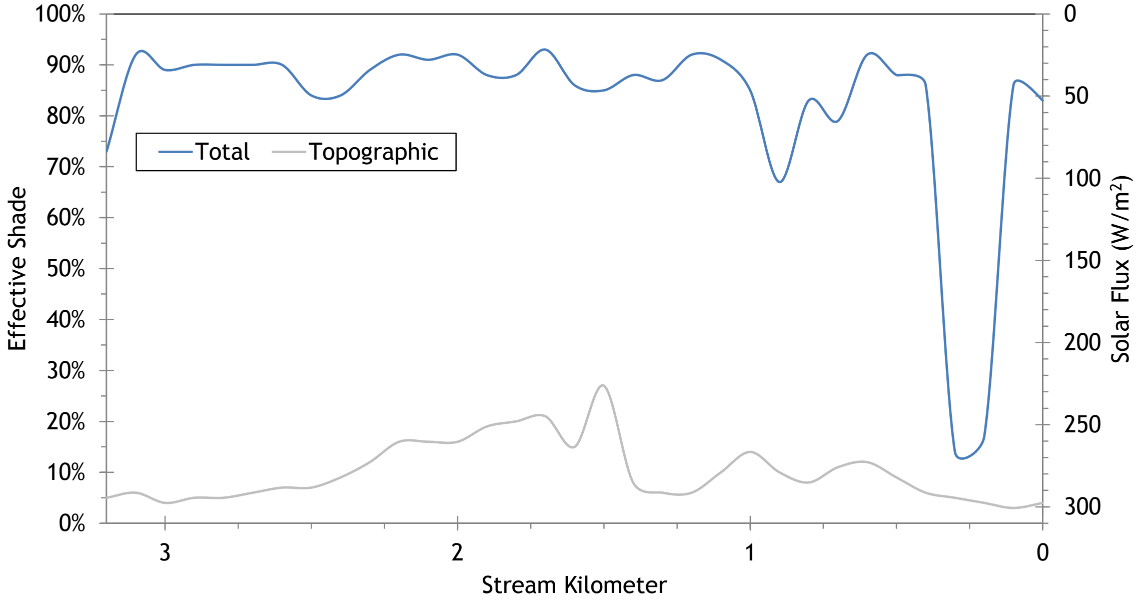
The near stream land cover codes used for Little Catherine Creek are shown in Table 11. The height values were derived from the tree heights sampled from the LiDAR data on the North Fork and South Fork Catherine Creek. The large conifer height value is the 75th percentile of all samples greater than 3 meters. The small conifer height is the 25th percentile of all samples greater than 3 meters. Density was estimated. Overhang was set at zero.

Table 11 – Little Catherine Creek land cover codes and descriptions.

Land Cover Name	Code	Height (m)	Density	Overhang (m)
Rock	304	0	0	0
Embankment	305	0	0	0
Clearcut	308	0	0	0
Road - paved	400	0	0	0
Road - unpaved	401	0	0	0
Large Conifer Forest	700	24.2	0.6	0
Small Conifer Forest	701	6.8	0.6	0
Large Conifer Forest	750	24.2	0.2	0
Small Conifer Forest	751	6.8	0.2	0
Conifer, small, sparse	760	3	0.1	0
shrubs	800	2	0.75	0
dry upland grass	900	0.5	0.9	0
floodplain grasses	901	0.5	0.9	0
active stream channel	3011	0	0	0

Figure 82 shows the simulated effective shade for Little Catherine Creek. The stream is well-forested throughout most of its length and thus well shaded by near stream land cover. Using manually digitized land cover for Heat Source inputs is less robust than using LiDAR and captures less of the natural variability. As a result, simulated effective shade also shows less variability and is more likely to be over-estimated. Ground level measurements could be used as validation if available. See Appendix for effective shade maps.

Figure 82 – Little Catherine Creek simulated effective shade.



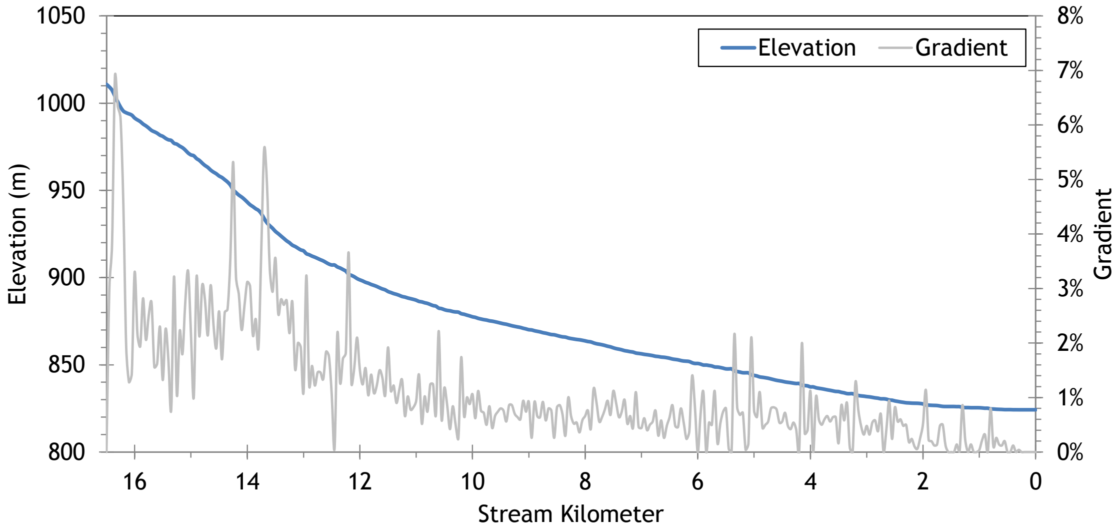
5.5 Little Creek

RGB-colored LiDAR point cloud - Little Creek looking downstream where it enters valley bottom.

5.5.1 Little Creek TTools Results

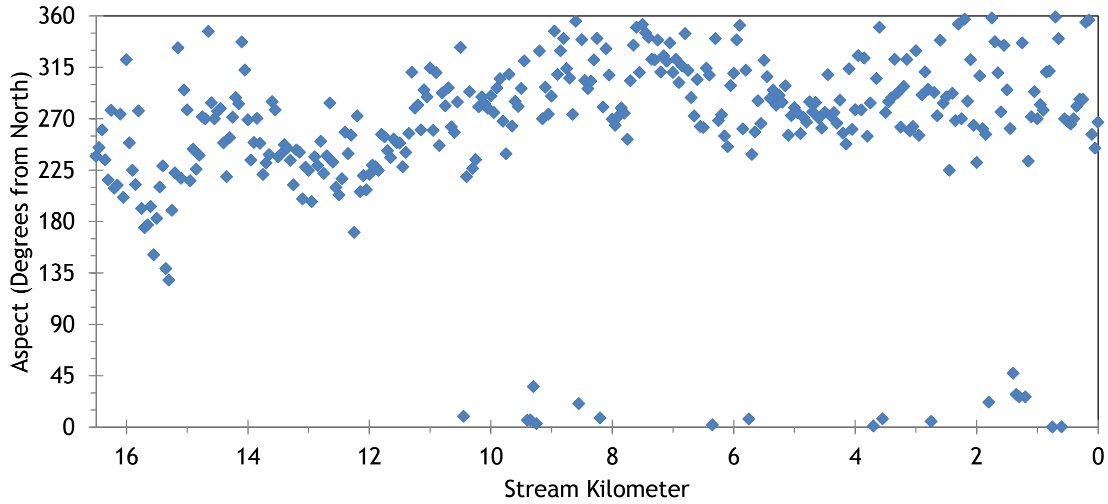
Figure 83 shows Little Creek elevations and gradients sampled from bare earth LiDAR data. The lower 10 stream kilometers are fairly low gradient because that reach flows through flat agricultural valley bottom.

Figure 83 – Little Creek elevation and gradient.



Little Creek flows mostly in the southwest-westerly direction before joining Catherine Creek below the city of Union. Figure 84 shows stream aspects for each 50-meter node.

Figure 84 – Little Creek stream aspect.



Topographic shade angles on Little Creek are highest above stream kilometer 10, where the terrain is hilly (Figure 85). The lower 10 stream kilometers have much lower topographic shade angles because the terrain is broad flat valley bottom.

Figure 85 – Little Creek topographic shade angles.

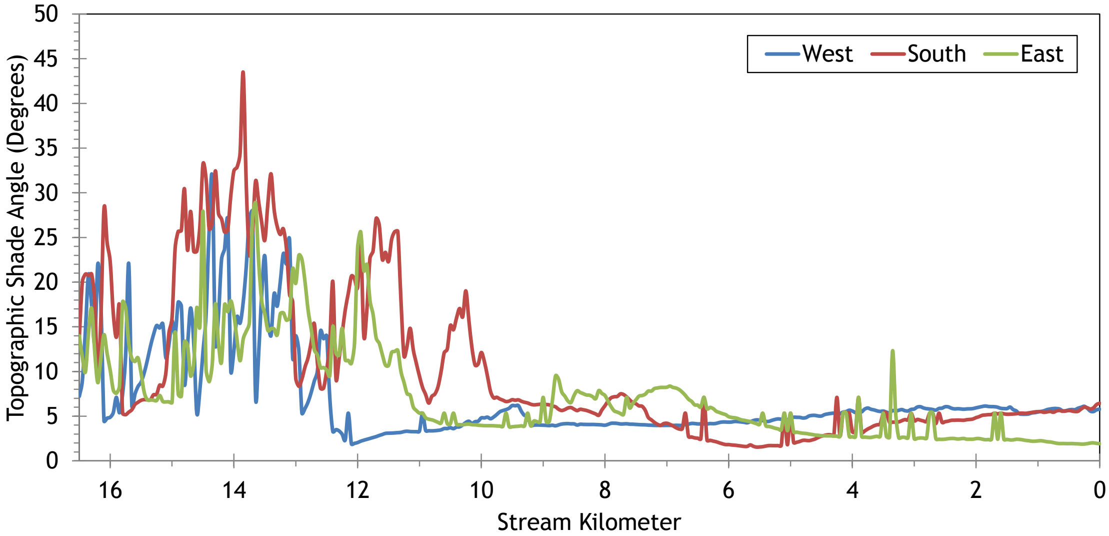
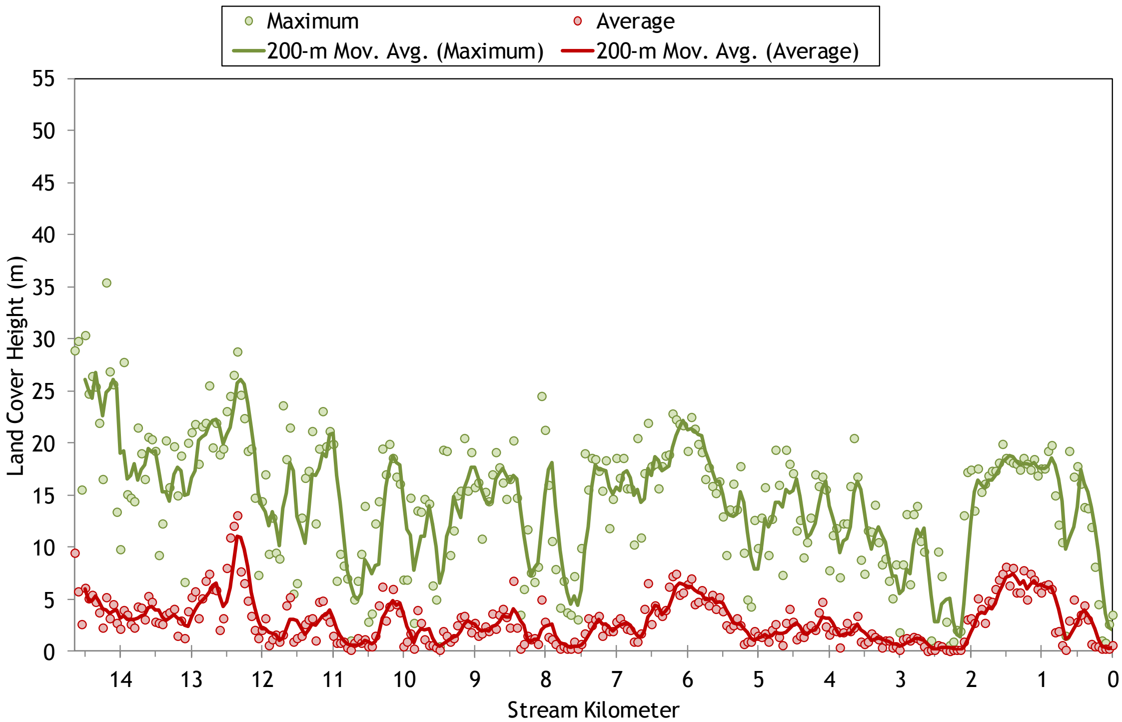


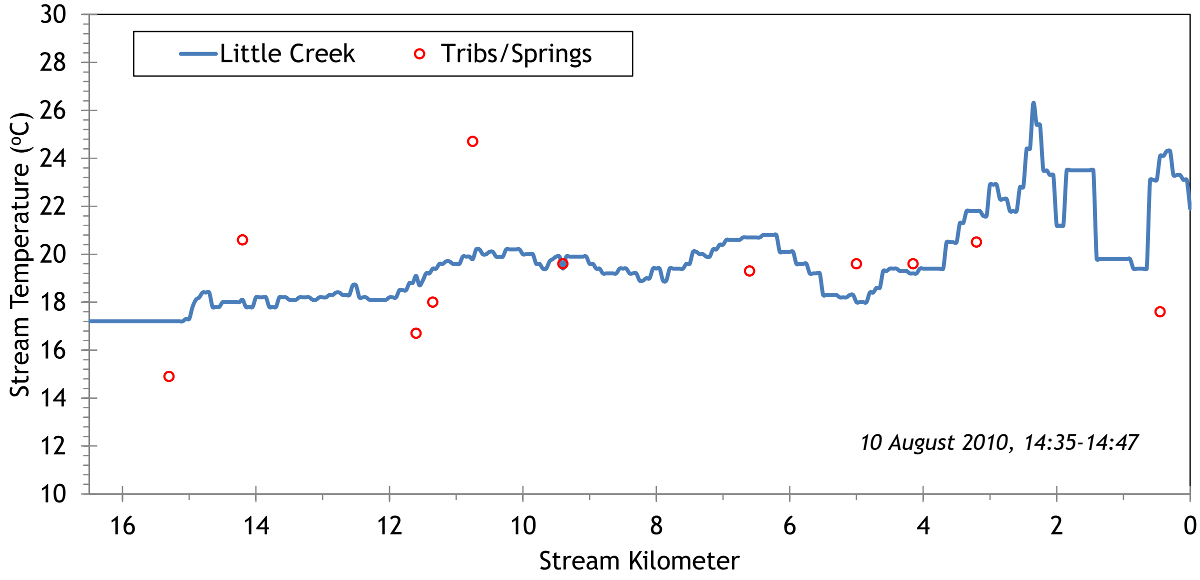
Figure 86 shows the land cover heights sampled along Little Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 86 – Little Creek land cover heights sampled from highest hit LiDAR.



Little Creek TIR stream temperatures are presented in Figure 87. Overall, stream temperatures were 18-24°C during the TIR flight. There are areas of potential thermal stratification in the lower 3 kilometers where the stream velocities were very slow due to the low gradients. TIR only records the surface water temperature.

Figure 87 – Little Creek TIR stream temperatures.



5.5.2 Little Creek Heat Source Calibration Results

Little Creek was simulated from High Valley Road to the mouth (14.7 kilometers). Figure 88 shows the simulation extent and temperature monitoring sites.

Figure 88 – Little Creek simulation extent.

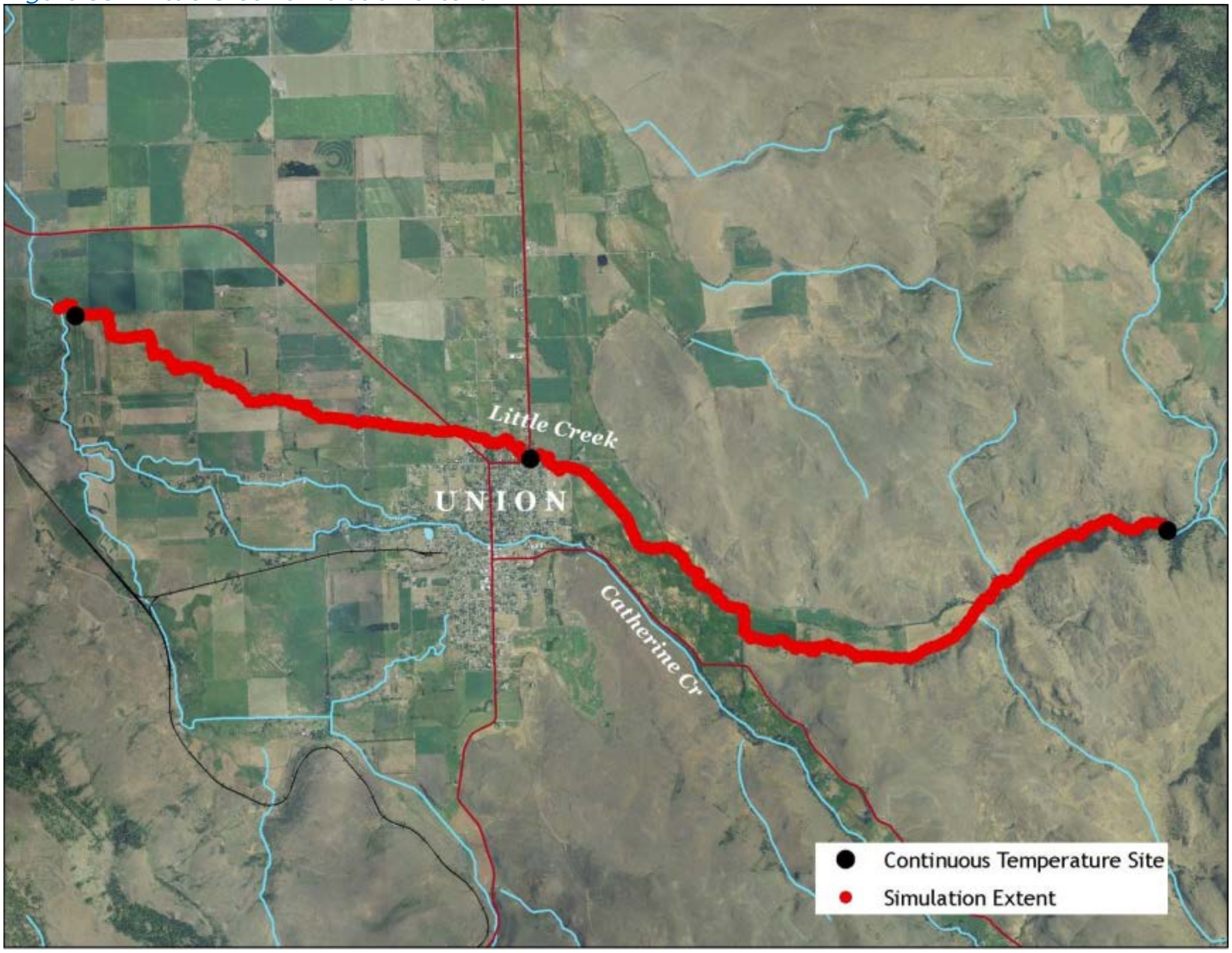


Table 12 – Little Creek general Heat Source parameters.

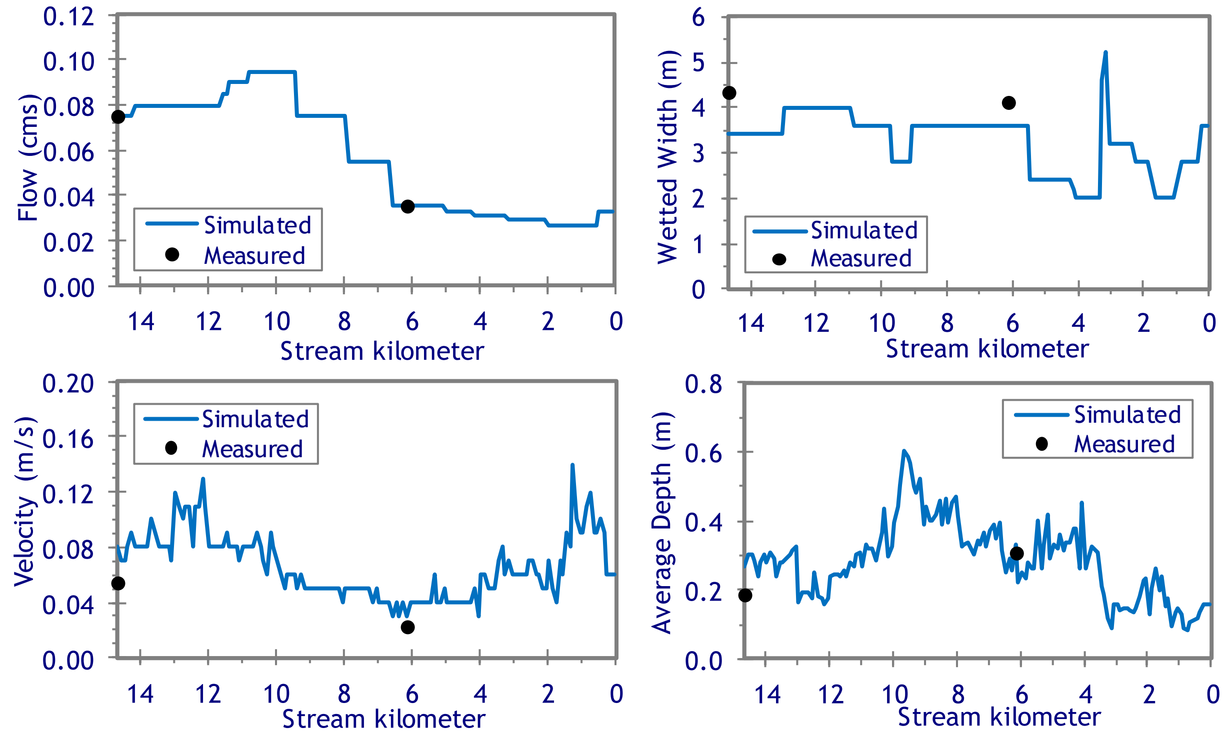
Stream:	Little Creek
Length:	14.65 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 10, 2010 14:34-14:46
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Little Creek Heat Source model:

- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- In many reaches, the stream was too small to digitize right and left banks. Therefore, wetted widths were estimated by taking several manual measurements from the TIR imagery.
- Since the flow of Little Creek was so small and highly regulated by irrigation withdrawals, a constant volume was used for the entire simulation time period (i.e., daily variability was not applied).
- There were 6 active diversion canals identified in the TIR imagery. The uppermost three were each assumed to withdraw 0.02 cms during the simulation time period while the lower three were assumed to withdraw 0.002 cms. No measured data were available for the canals.

The simulated and measured hydraulic values for Little Creek are presented in Figure 89. The simulated values are for August 19, 2010. There were two ground level measurement sites, including the upstream boundary at High Valley Road, where data were collected on August 18th and 19th.

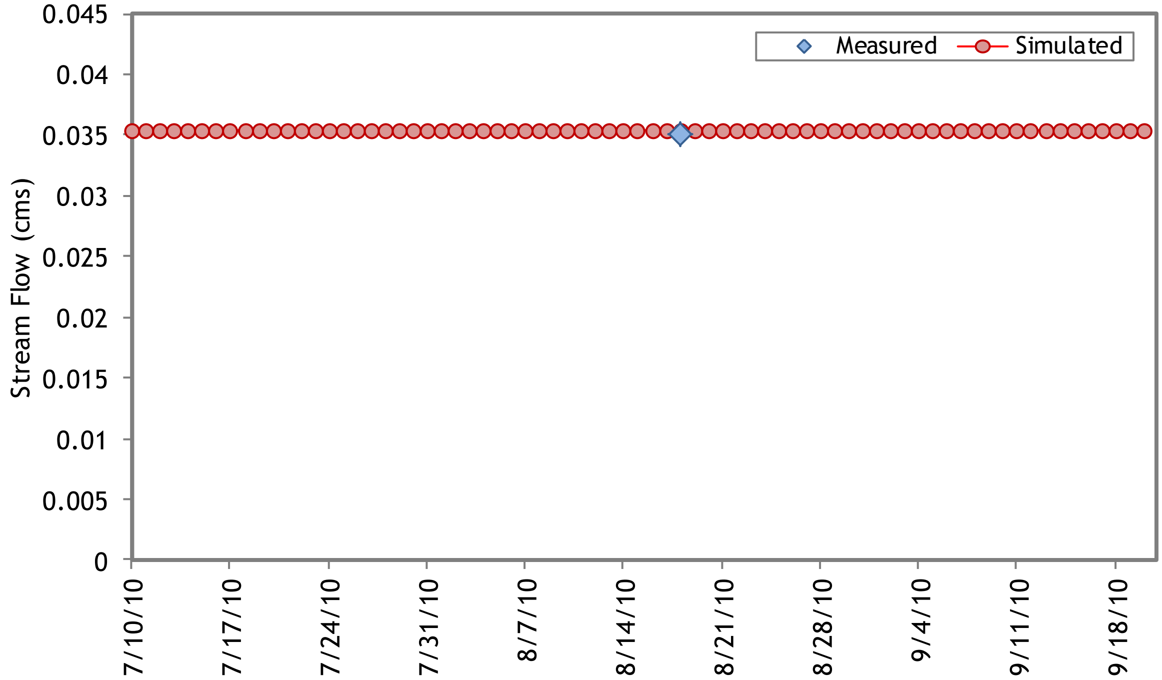
Figure 89 – Little Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Upper High Valley Road	14.65	8/19/2010
North end of Union	6.1	8/18/2010

As mentioned previously, Little Creek simulated flows do not have daily variability. The same values were used for each day of the simulation (Figure 90). This assumption was used because of the low flow volumes and un-monitored irrigation withdrawals. (Estimating daily variability for such a stream adds unquantifiable uncertainty and also tends to make the Heat Source model unstable.) The closest field measurement was 0.035 cms on August 18, 2010 at stream kilometer 6.1.

Figure 90 – Little Creek simulated flow volume at the mouth of Little Creek.



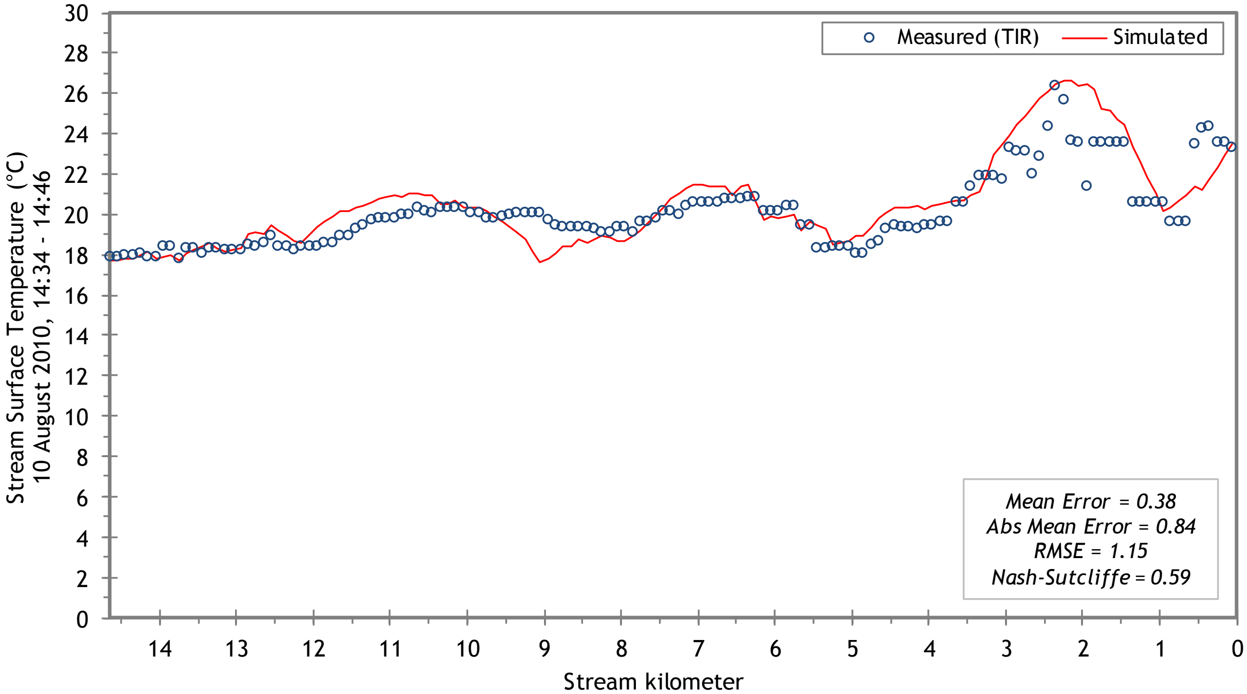
There was one unnamed tributary and several seeps identified within the TIR imagery. Those features were not large enough to compute a mass balance flow volume (i.e., did not produce a measurable thermal signature in Little Creek's longitudinal temperature profile), so volumes were estimated for each. Temperatures were measured from the TIR imagery. No daily variation was applied to these inputs because of their insignificant size relative to Little Creek.

Table 13 – Little Creek mass inflow features and assumptions.

Feature	Stream Km	Assumptions
Unnamed Tributary	14.2	0.005 cms at 19.6ºC (constant)
seep	11.6	0.005 cms at 16.4ºC (constant)
seep	11.35	0.005 cms at 17.8ºC (constant)
seep	10.75	0.005 cms at 24.4ºC (constant)
seep	0.45	0.005 cms at 17.4ºC (constant)

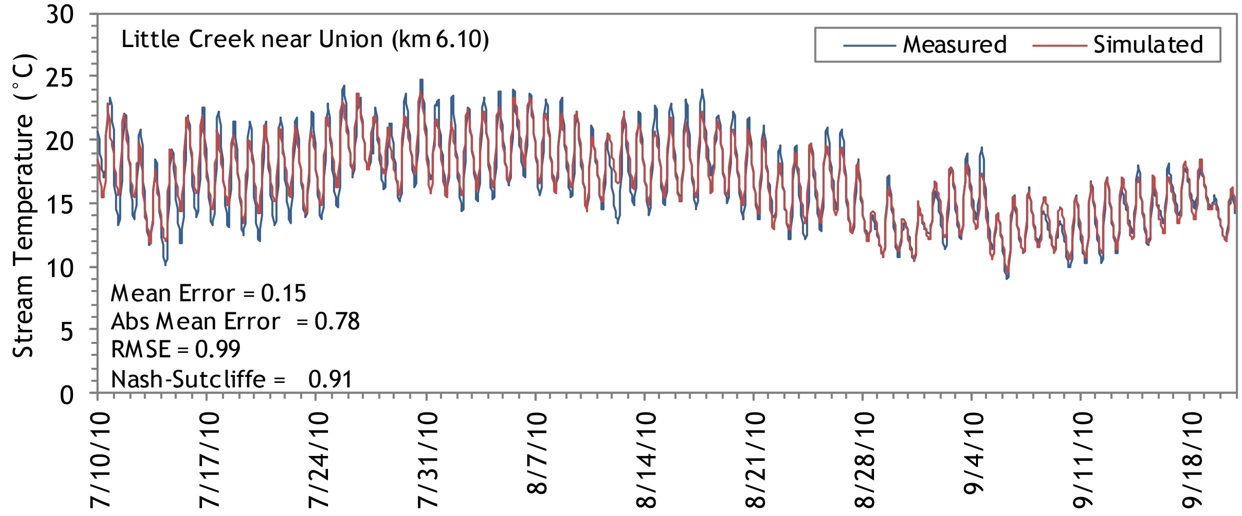
The simulated and measured longitudinal stream temperatures for Little Creek are shown in Figure 91. The lower 3 kilometers are uncertain because there is possible (but unverified) thermal stratification occurring.

Figure 91 – Little Creek simulated and measured longitudinal temperatures.



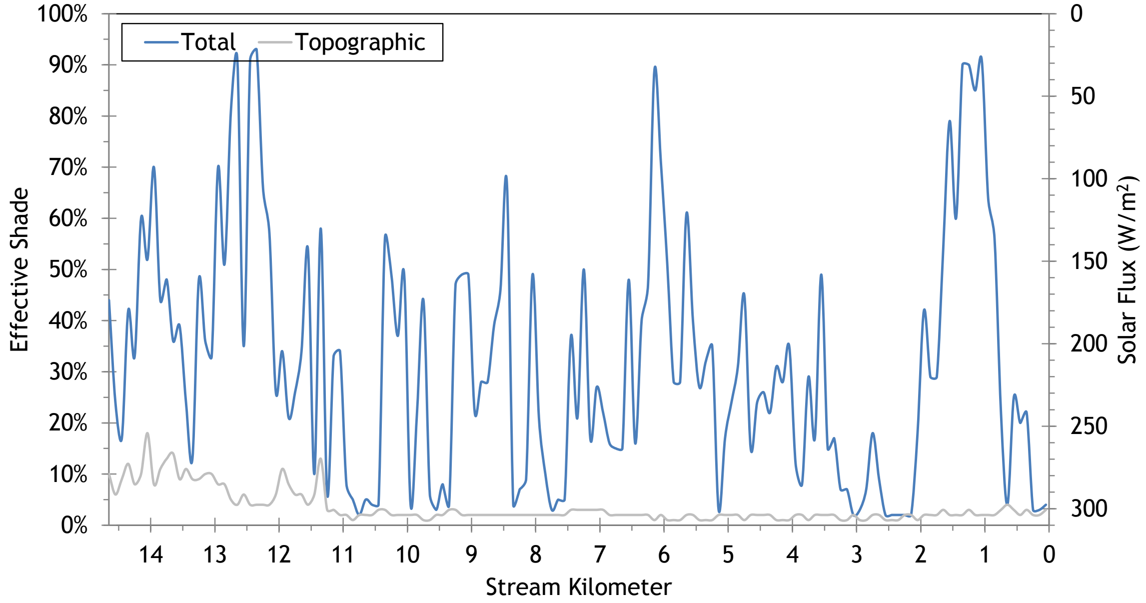
There was one site with valid hourly temperatures besides the upstream boundary condition. Figure 92 shows the simulated and measured hourly temperatures near the city of Union (stream kilometer 6.1).

Figure 92 – Little Creek simulated and measured hourly temperatures.



Simulated effective shade values for Little Creek are presented in Figure 93. The total effective shade is variable because much of the stream has intermittent riparian vegetation limited to a small strip along the banks. See Appendix for effective shade maps.

Figure 93 – Little Creek simulated effective shade.



5.6 Ladd Creek

RGB-colored LiDAR point cloud - Looking downstream Ladd Creek at the mouth.

5.6.1 Ladd Creek TTools Results

Ladd Creek did not have LiDAR data available, except for a small section near the mouth. The elevations and gradients were sampled from the 10-meter DEM (Figure 94). The lower 9 stream kilometers are extremely low-gradient as they flow through agricultural lands and are often channelized.

Figure 94 – Ladd Creek elevation and gradient.

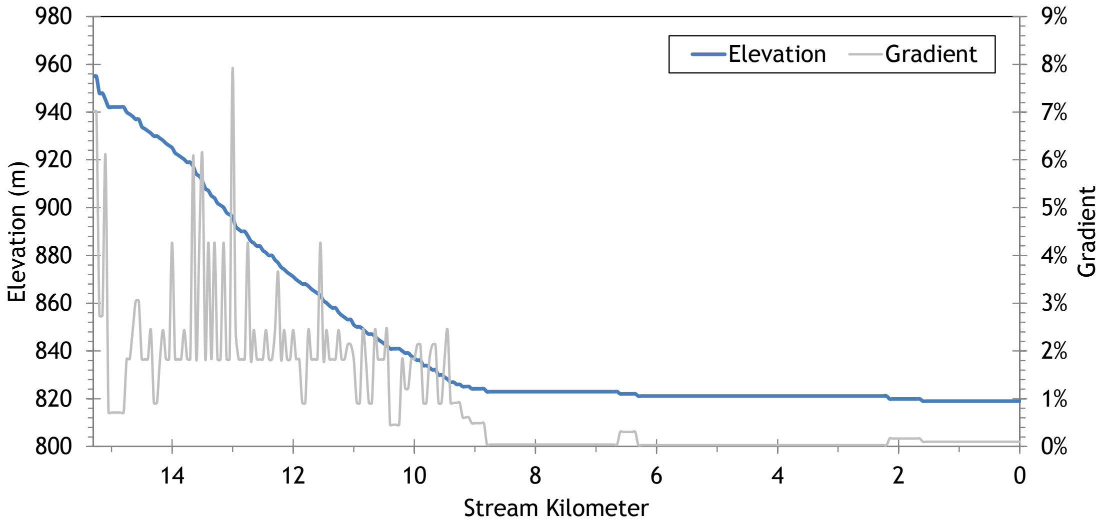
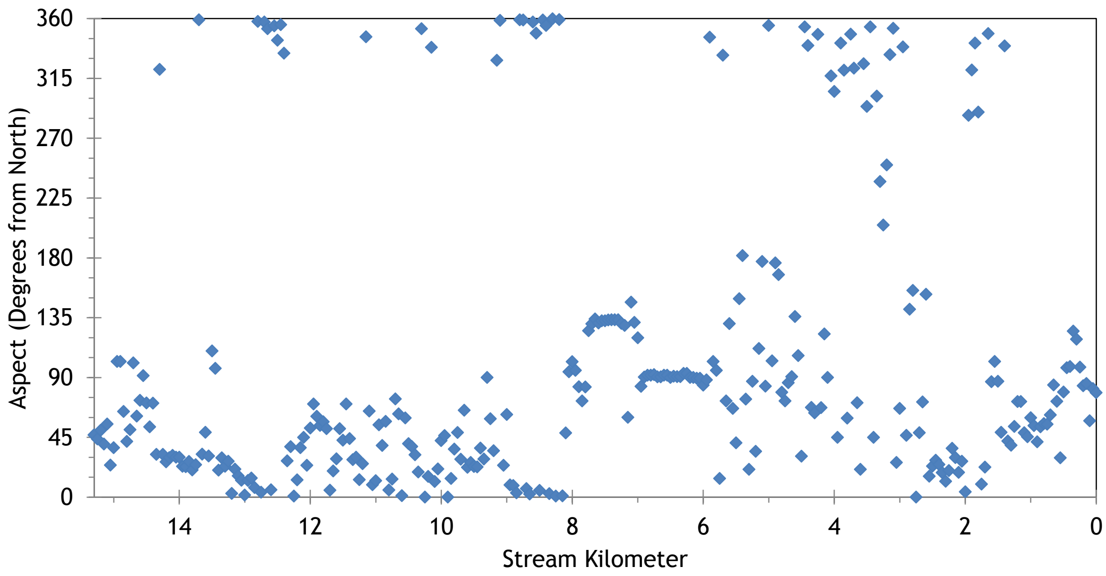


Figure 95 displays the stream aspect for each 50-meter segment of Ladd Creek. The stream flows mostly northeasterly and easterly until it merges with Catherine Creek.

Figure 95 – Ladd Creek stream aspect.



The lower 12 stream kilometers of Ladd Creek have little topographic shade because the stream is flowing through flat agricultural valley bottom (Figure 96). The upper 3 kilometers that were sampled are within more hilly terrain.

Figure 96 – Ladd Creek topographic shade angles.

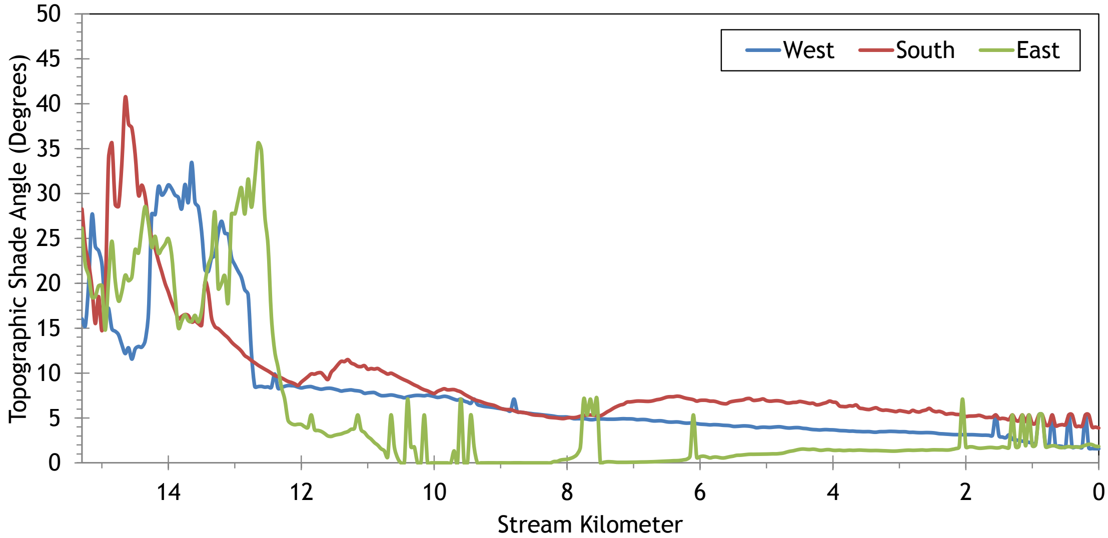
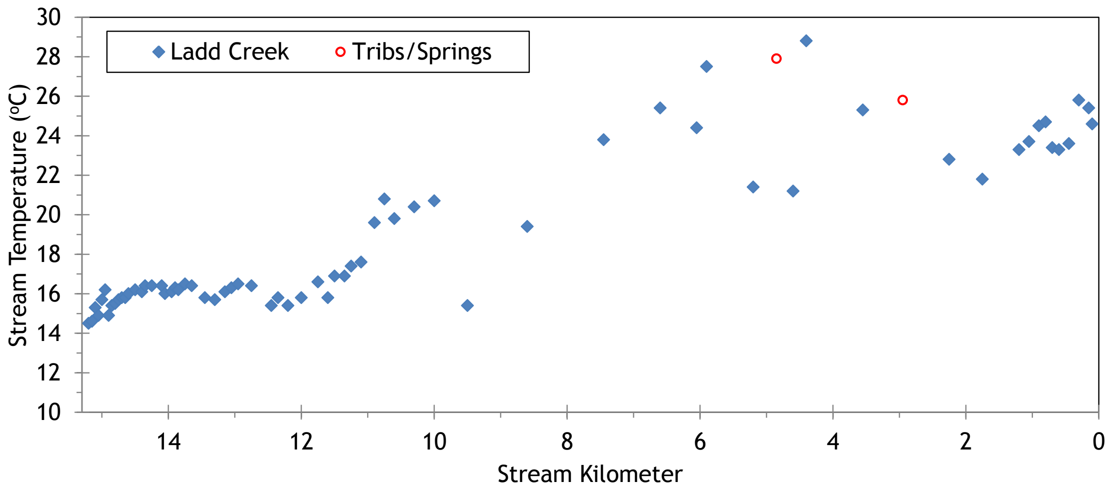


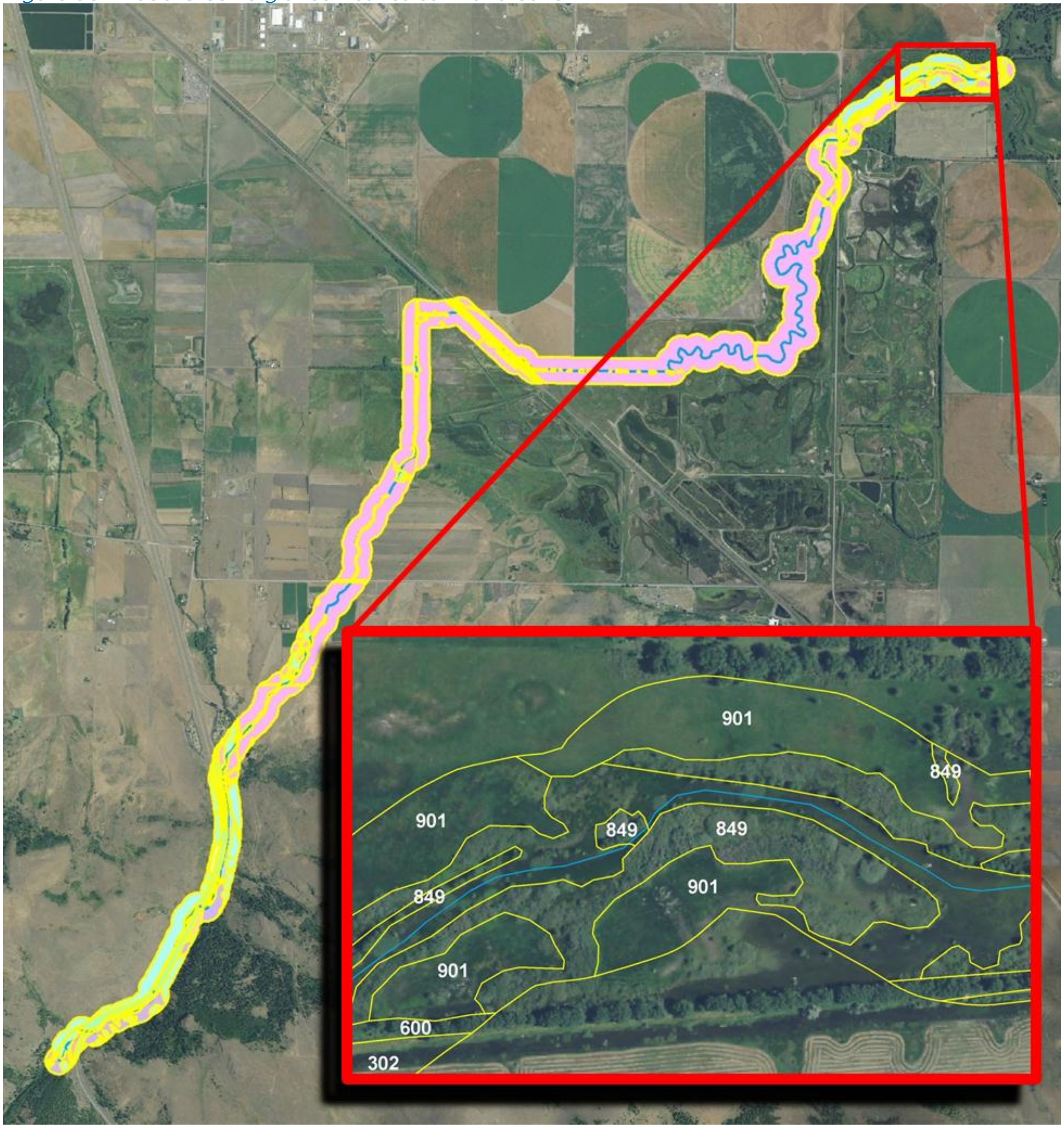
Figure 97 shows the TIR profile of Ladd Creek. The TIR temperature data is sparse throughout much of Ladd Creek and of limited value for multiple reasons. The stream flow was very low (~1 cfs) at the time of the survey. The stream is very small and difficult to sample in the TIR imagery. Much of the stream is channelized and flow volumes and paths are regulated for irrigation purposes. Many areas are very low gradient and likely to have been thermally stratified during the TIR flight.

Figure 97 – Ladd Creek TIR stream temperature profile.



LiDAR data was not available for Ladd Creek, so the near stream land cover was manually digitized from the NAIP orthophotos within 100 meters of the stream (Figure 98). Each polygon was coded to represent a specific land cover type, height class, and density class.

Figure 98 – Ladd Creek digitized near stream land cover.



5.6.2 Ladd Creek Effective Shade Simulation

Stream temperature was unable to be simulated for Ladd Creek because of its extreme low flow volume and a lack of sufficient ground level data. Effective shade was simulated for the extent shown in Figure 99.

Figure 99 – Ladd Creek simulation extent.

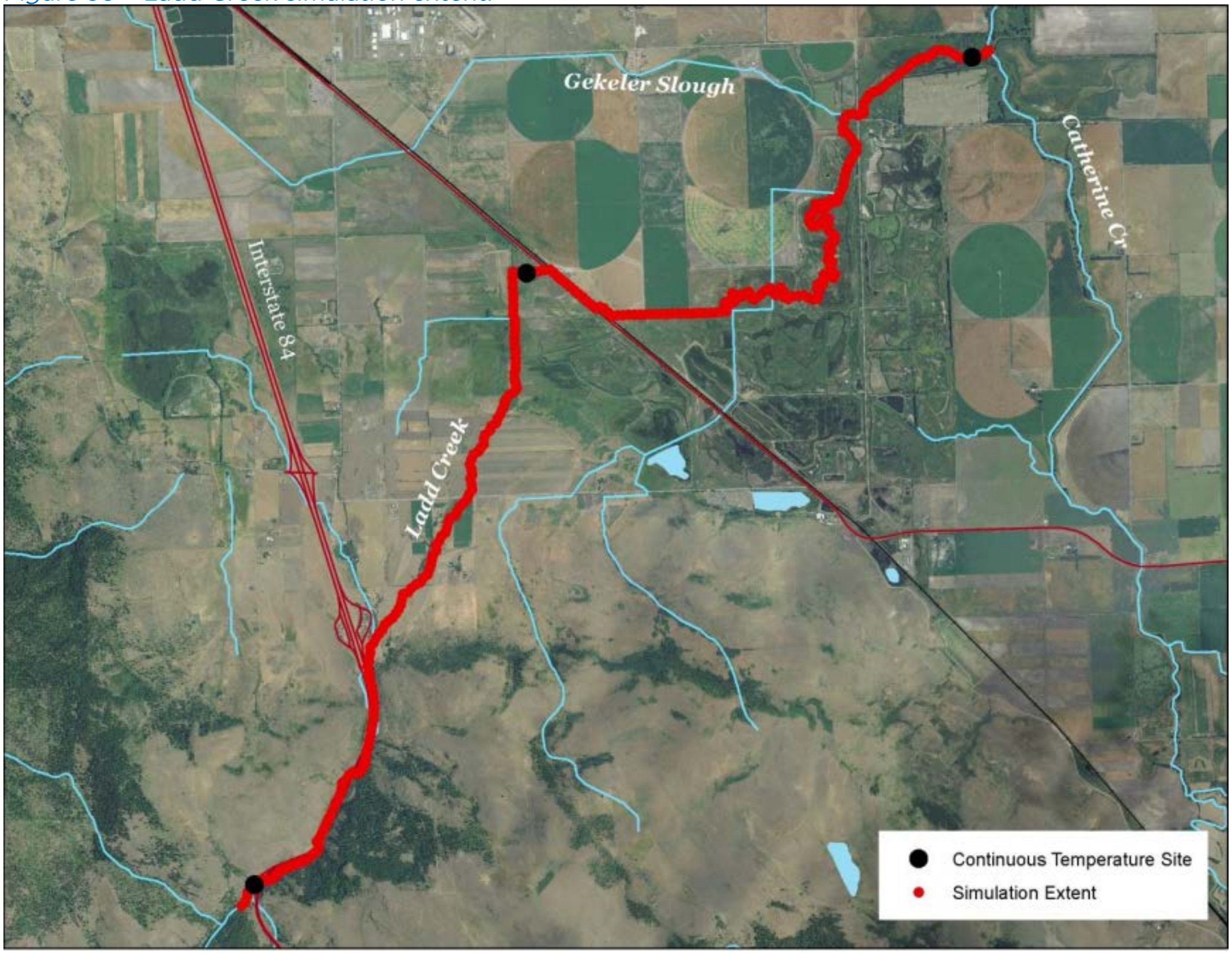


Table 14 – Ladd Creek general Heat Source parameters.

Stream:	Ladd Creek
Length:	15.3 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	NA
TIR Date and Time:	NA
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

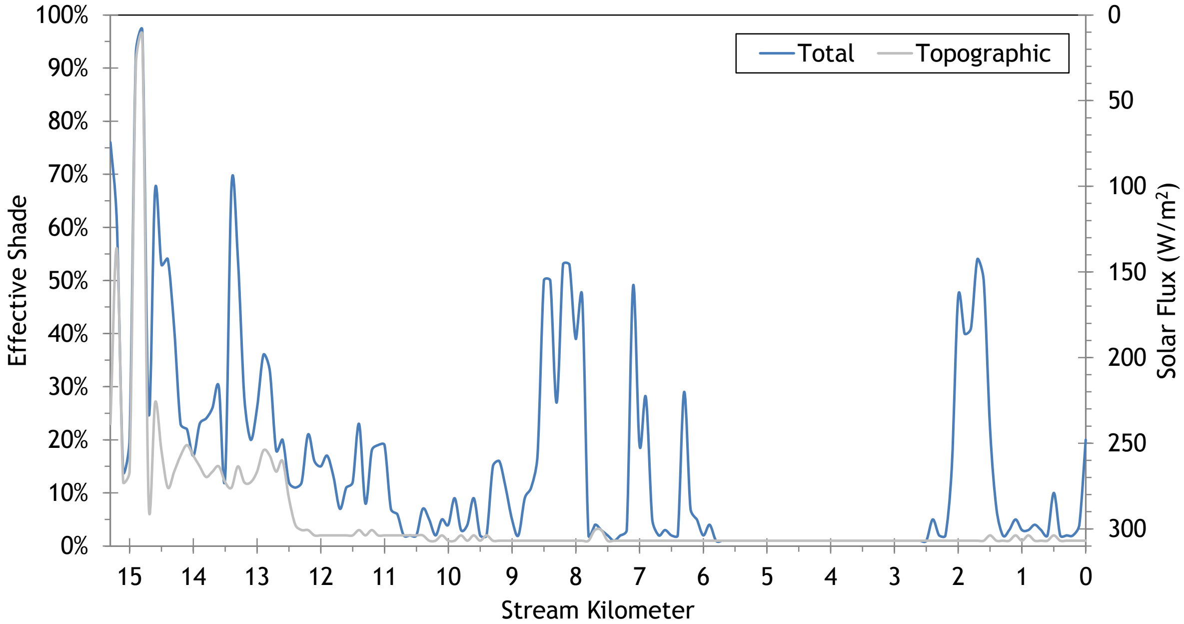
Table 15 shows the near stream land cover codes that were used in the manually digitized layer for Ladd Creek. Height values are based on the lower 66.5 kilometers of Catherine Creek, where LiDAR data were sampled. Values over 3 meters were evaluated for the 75th and 25th percentile. The large height class for Ladd Creek was 9.7 meters, which is equivalent to the 75th percentile of trees on lower Catherine Creek. The small height class used the 25th percentile of 4.4 meters. Values within the regions of Ladd Creek and lower Catherine Creek are smaller than in the upper watershed, primarily because the vegetation consists of smaller riparian shrubs and trees as opposed to large conifer stands.

Table 15 – Ladd Creek near stream land cover codes and descriptions.

Land Cover Name (optional)	Code	Height (m)	Density	Overhang (m)
water	301	0	0	0
pasture, field, cultivated, agriculture	302	0.5	0.9	0
rock	304	0	0	0
road (paved)	400	0	0	0
road (unpaved)	401	0	0	0
Road (unpaved)	403	0	0	0
mixed forest, large	500	9.7	0.75	0
mixed forest, small	501	4.4	0.75	0
deciduous, large	600	9.7	0.75	0
deciduous, small	601	4.4	0.75	0
conifer forest, large	700	9.7	0.75	0
conifer forest, small	701	4.4	0.75	0
conifer forest, large	750	4.4	0.25	0
conifer forest, small and sparse	760	4.4	0.1	0
riparian shrubs, large	849	4.5	0.75	0
shrubs	850	4.5	0.75	0
riparian shrubs, small	899	1	0.75	0
dry upland grasses	900	0.5	0.9	0
floodplain grasses	901	0.5	0.9	0
active channel	3011	0	0	0
building	3248	4	1	0

The simulated effective shade for Ladd Creek is shown in Figure 100. In the upper reaches, most of the effective shade is provided by topographic features. Below stream kilometer 12.5, the stream is flowing through the flat valley bottom and has relatively little streamside vegetation. See Appendix for effective shade maps.

Figure 100 – Ladd Creek simulated effective shade.



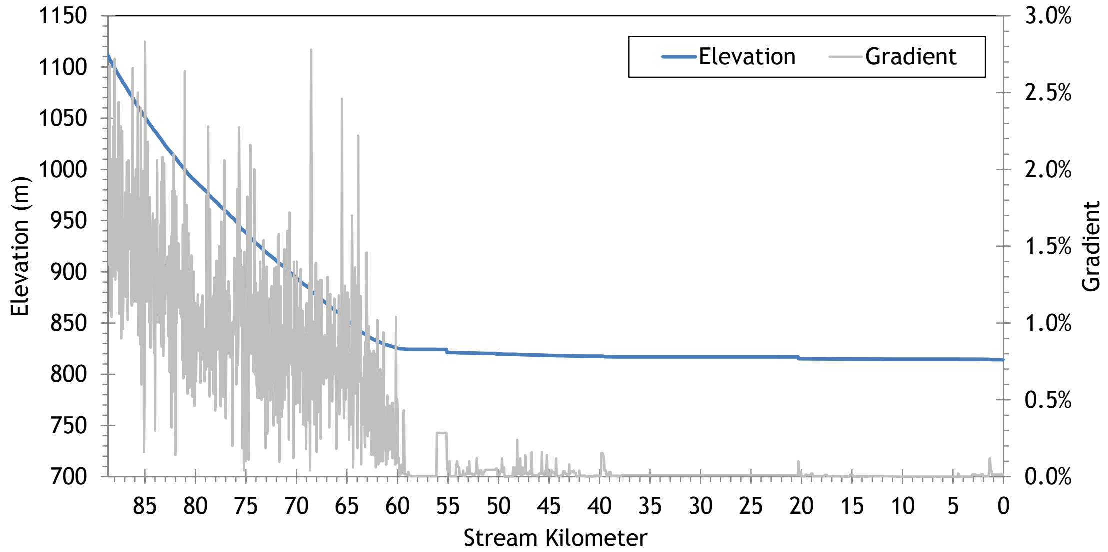
5.7 Catherine Creek

RGB-colored LiDAR point cloud - Catherine Creek in Union (looking upstream).

5.7.1 Catherine Creek TTools Results

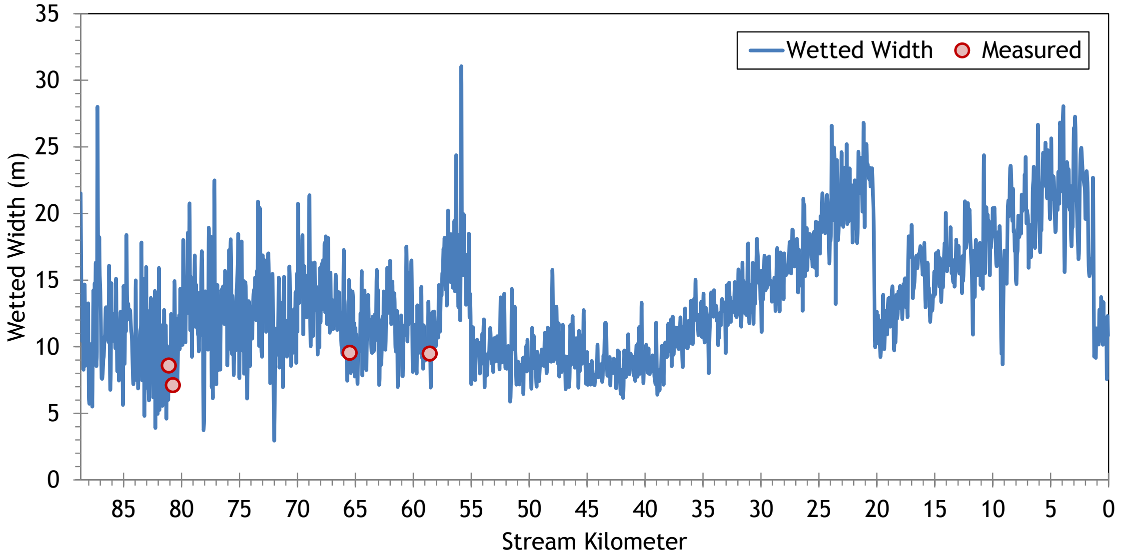
Catherine Creek elevations and gradients are shown in Figure 101. The upper reaches are flowing through mountain foothills, while the lower 60 stream kilometers run through flat agricultural valley bottom. In addition, the lower 60 stream kilometers have much higher sinuosity, thereby further decreasing the stream gradient.

Figure 101 – Catherine Creek elevation and gradient.



Wetted widths were digitized using the TIR, LiDAR intensity, and NAIP imagery. Figure 102 shows the sampled wetted widths along with the ground level measurements. These wetted widths were used as estimates for setting up the Heat Source model hydraulics.

Figure 102 – Catherine Creek wetted widths.



Overall, Catherine Creek flows northwesterly; however, there is huge variation in the lower 60 kilometers where the stream is very sinuous and has large meander bends (Figure 103).

Figure 103 – Catherine Creek stream aspect.

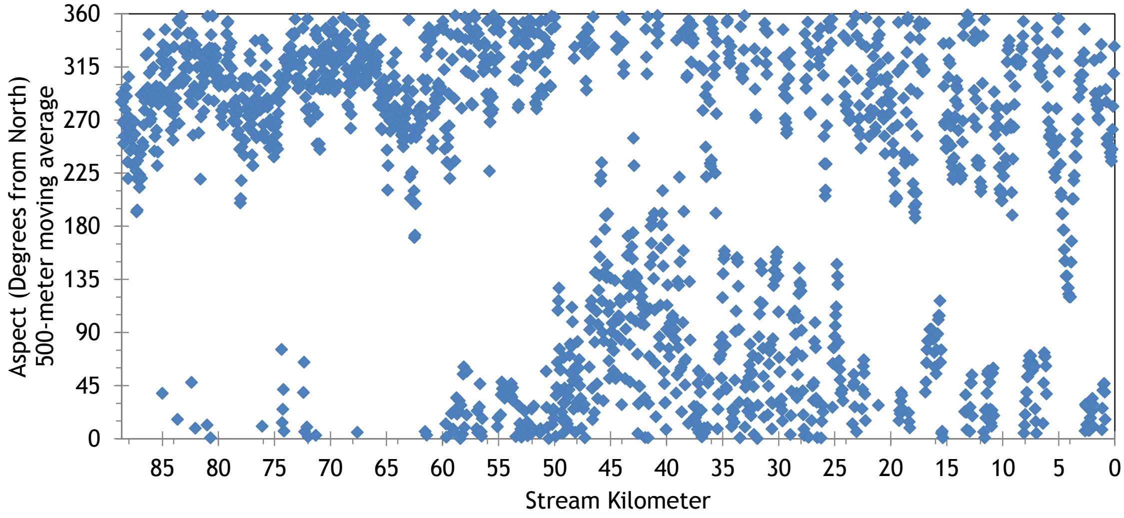


Figure 104 shows the topographic shade angles for Catherine Creek. The upper reaches have more topographic shade because the stream is flowing through a confined valley. The lower reaches have less topographic shade because they are within the Grande Ronde valley bottom.

Figure 104 – Catherine Creek topographic shade angles.

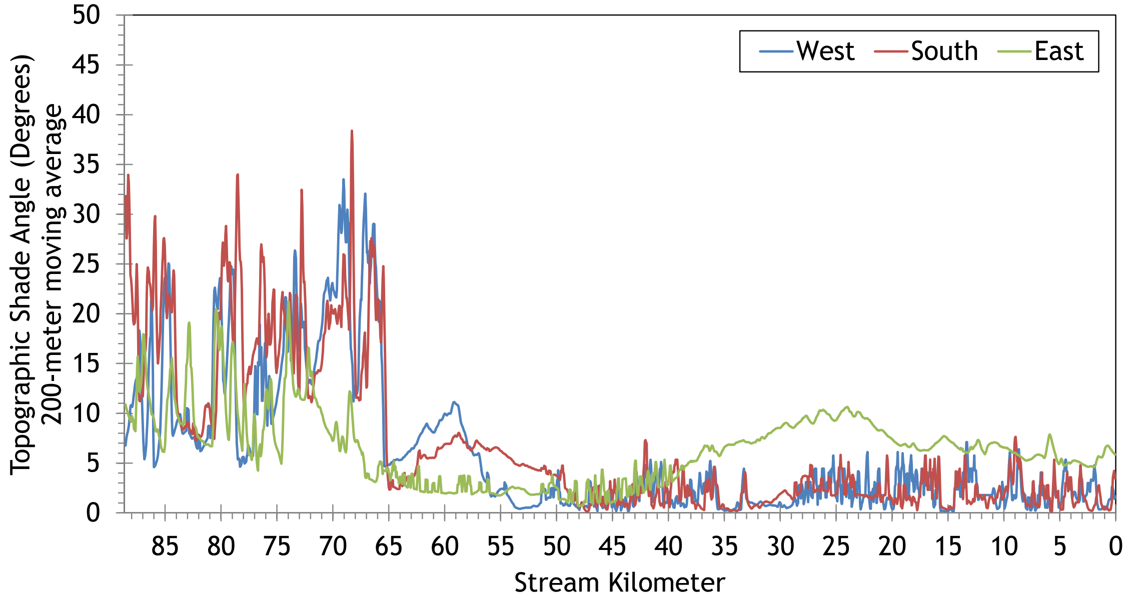
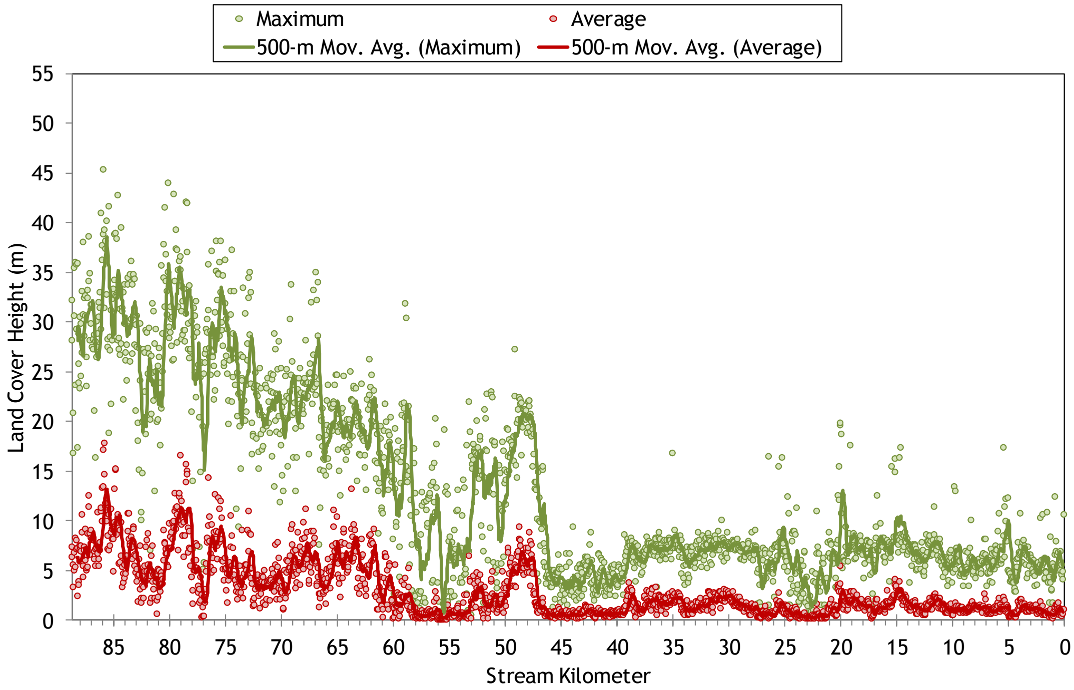


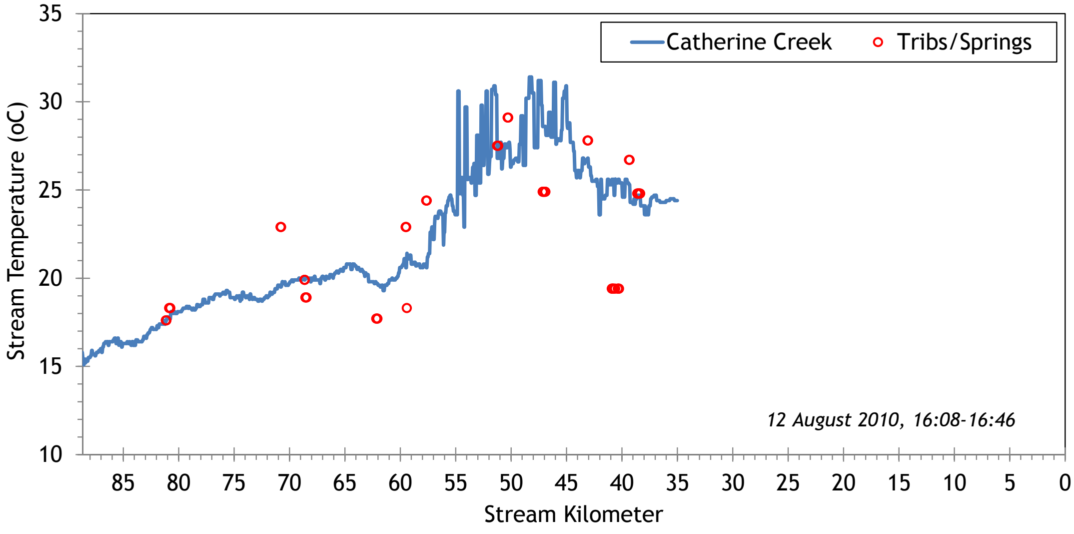
Figure 105 shows the land cover heights sampled along Catherine Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 105 – Catherine Creek land cover heights sampled from highest hit LiDAR.



TIR data were available for approximately the upper 50 stream kilometers of Catherine Creek (Figure 106). Between the forks and the city of Union (stream kilometer 60), stream temperatures were more stable because there was more volume within the river. At Union, most of the water had been diverted for irrigation use, leaving relatively little volume in the stream. At this point, the stream temperatures rise rapidly and become variable. There are most likely areas of thermal stratification in the lower section as well.

Figure 106 – Catherine Creek TIR stream temperature profile.



5.7.2 Catherine Creek Heat Source Calibration Results

Catherine Creek was simulated for temperature from the forks to the city of Union. The entire stream was simulated for effective shade.

Below Union, the flow is heavily regulated by irrigation withdrawals which use most of the water. The reach between Union and the mouth was unable to be simulated for temperature. In addition, there are many stratified reaches below Union, which cannot be simulated using Heat Source because it is a 2-D model.

Figure 107 – Catherine Creek simulation extent.

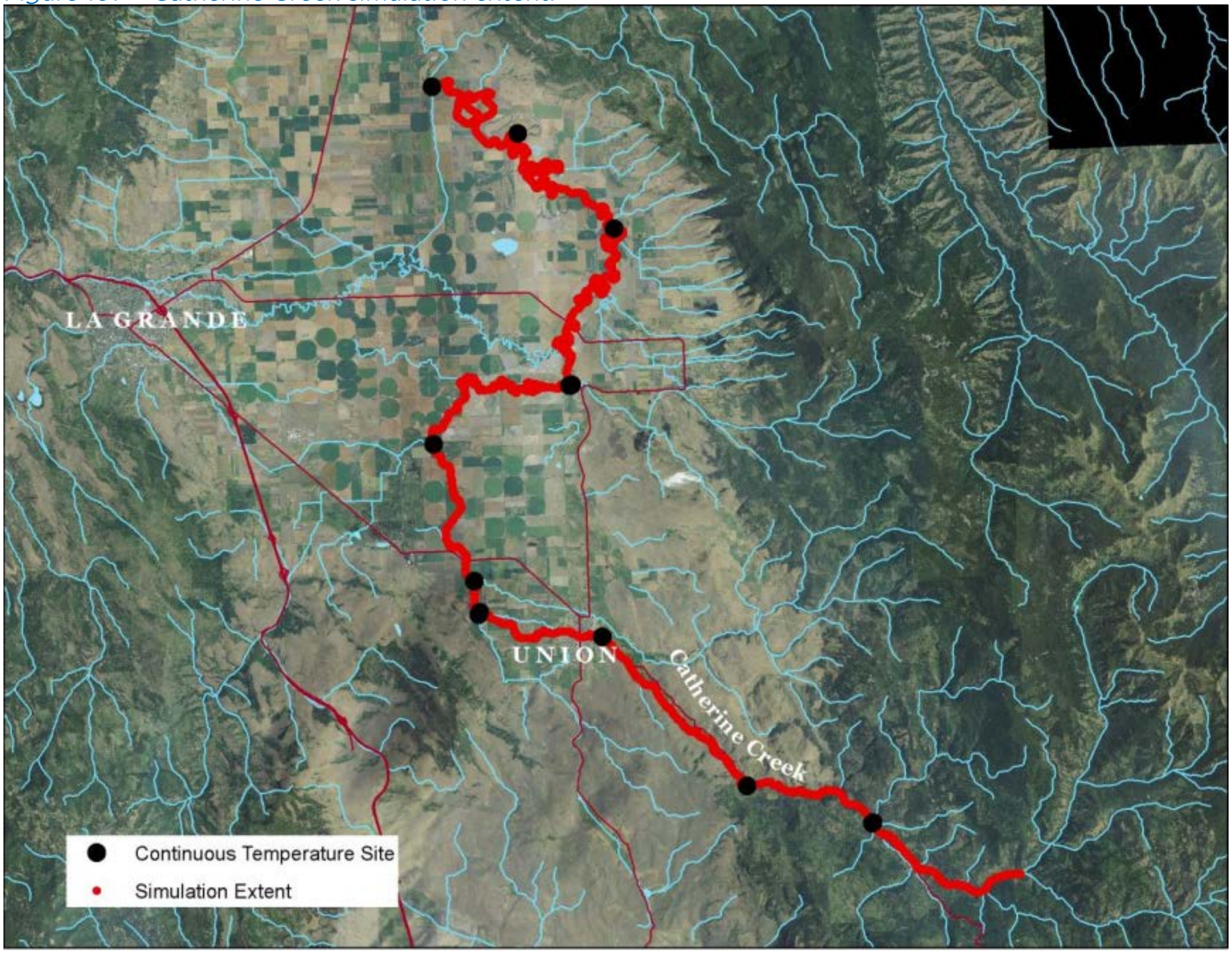


Table 16 – Catherine Creek general Heat Source parameters.

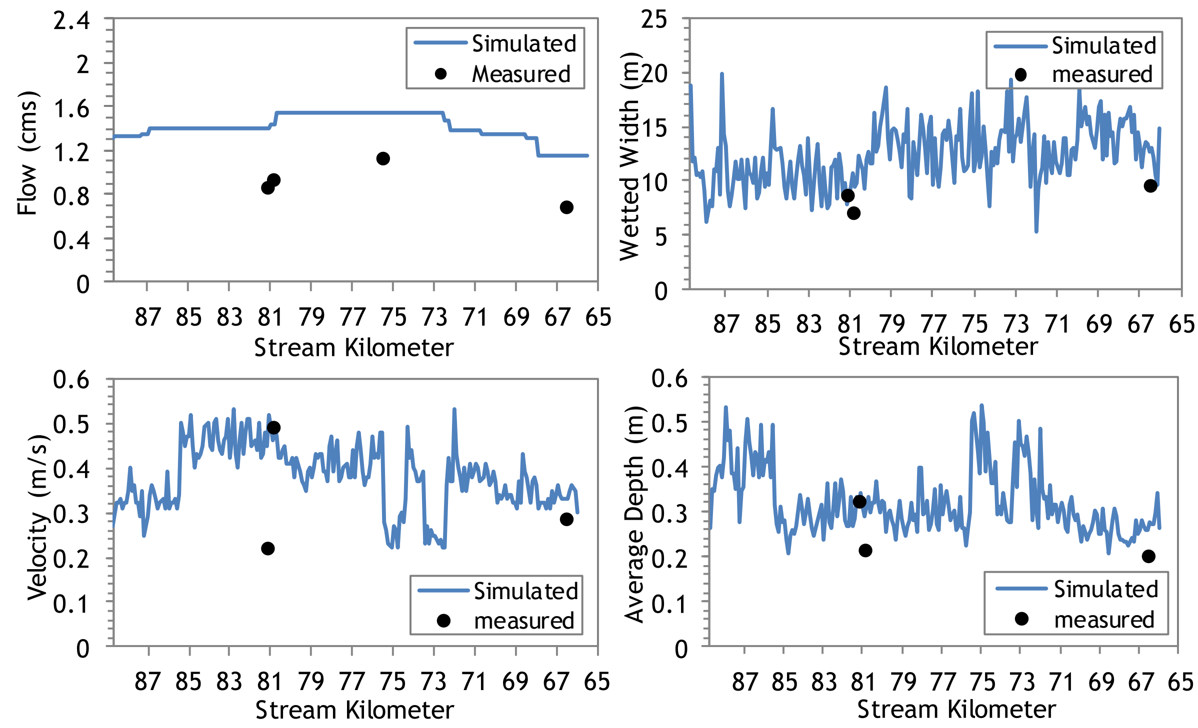
Stream:	Catherine Creek
Length:	88.7 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 12, 2010 16:08-16:46
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Catherine Creek Heat Source model:

- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- The upstream boundary condition is a mass balance of data from the mouths of the North and South Forks.
- USGS gages on the North Fork Catherine Creek and Mainstem of Catherine Creek were used to extrapolate daily flow volumes for South Fork Catherine Creek, Milk Creek, Little Catherine Creek and Scout Creek (a tributary to South Fork Catherine Creek). Relative contribution for each stream was determined based on CRITFC instantaneous measurements. Daily USGS gaged data were greater than CRITFC instantaneous values (see Figure 108).
- There is a large diversion in the city of Union where most of the water was being diverted for irrigation use. Below this point there were additional diversions, very low flow, and thermal stratification which prohibited stream temperature modeling; however, effective shade was simulated the entire length from the forks to the confluence with the Grande Ronde River.

Figure 108 shows the simulated and measured hydraulic values for the calibrated Heat Source model for August 18, 2010. The upstream boundary flow volume is a mass balance of the North and South Forks. The Catherine Creek simulated flow volumes are based on the daily values recorded at the gage above Union (stream kilometer 75.5).

Figure 108 – Catherine Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Catherine Creek above Milk Creek	81.1	8/18/2010
Catherine Creek above Little Catherine Cr.	80.8	8/18/2010
Gage near Union	75.5	8/18/2010
Catherine Creek East End of Union	66.5	8/18/2010

The simulated and daily gage flows for select locations are shown in Figure 109. The flow below the forks is a mass balance of the simulated flows at the mouths of the North and South Forks. The Catherine Creek simulated flows were then calibrated to target the values recorded at the gage near (upstream of) Union. Diversions on Catherine Creek were estimated as constant outflows, while inflows from tributaries vary daily based on mass balance calculations. Beginning on July 16th, 2010, estimated outflows become greater than inflows; hence, simulated flows below the forks become greater than gaged flows at Union (Figure 108). There is a large diversion that was occurring between the lower end of the simulation and the gage in Union. Very little water was left in the stream and those volumes fluctuated each day. The very low flows below Union, thermal stratification, and unmonitored diversions prohibited Heat Source temperature simulation of lower Catherine Creek (effective shade was still simulated for the entire stream).

Figure 109 – Catherine Creek simulated and measured daily flow volumes at select locations.

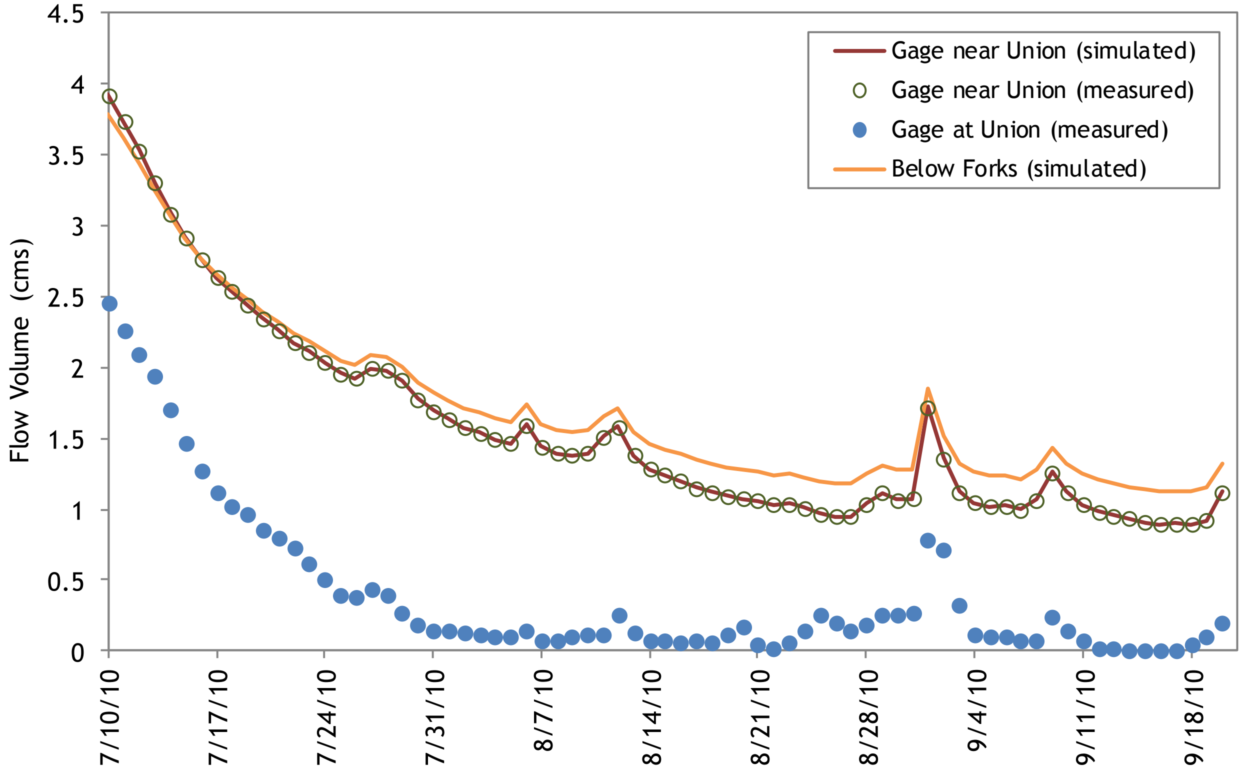


Table 17 summarizes the mass inflows and outflows included in the calibrated Heat Source model. Scout, Milk, and Little Catherine Creek flows were calculated based on the difference between the boundary condition and the gage above Union and vary daily.

Table 17 – Catherine Creek mass inflow and outflow features and assumptions.

Feature	Stream Km	Assumptions
Scout Creek	87.0	0.04-0.13 cms, used Little Catherine Creek at mouth hourly temperatures
Milk Creek	81.1	0.04-0.13 cms, measured hourly temperatures
Little Catherine Cr.	80.7	0.09-0.29 cms, measured hourly temperatures
Diversion (small)	72.5	-0.08 cms (constant)
Diversion (small)	72.2	-0.08 cms (constant)
Diversion	70.8	-0.04 cms (constant)
Hatchery / Ponds	68.5	-0.04 cms (constant)
Dam and Diversion	68.0	-0.16 cms (constant)

The simulated and measured longitudinal stream temperatures above Union are shown in Figure 110.

Figure 110 – Catherine Creek simulated and measured longitudinal temperatures.

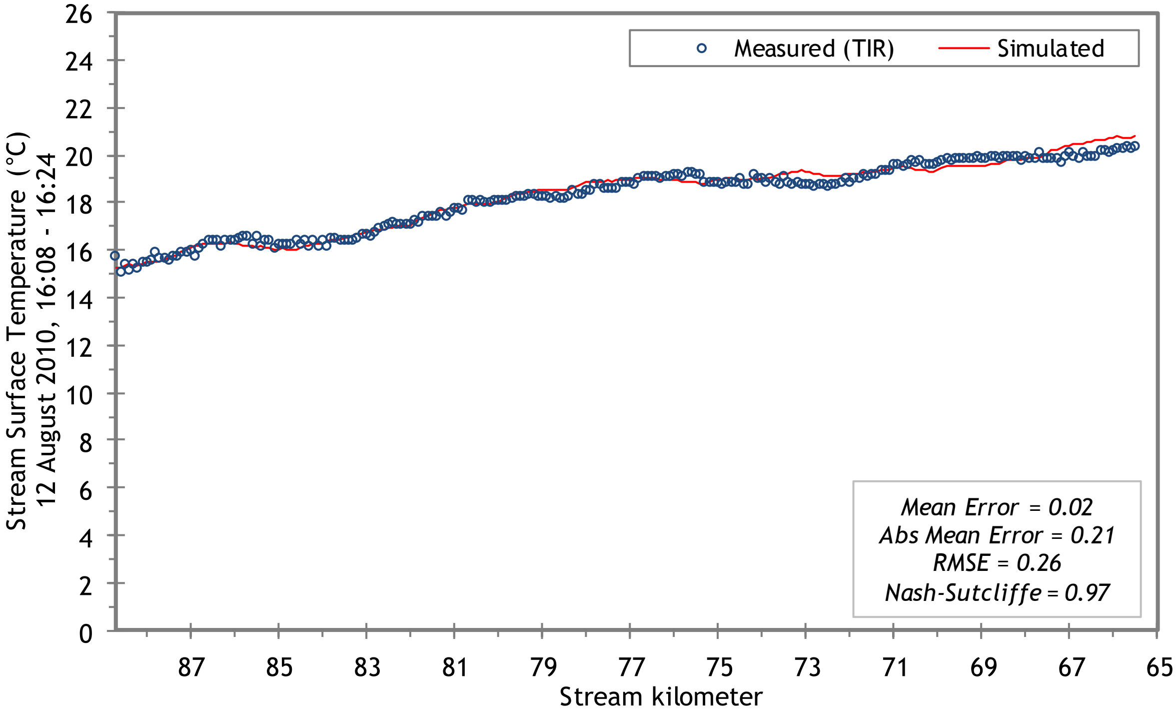
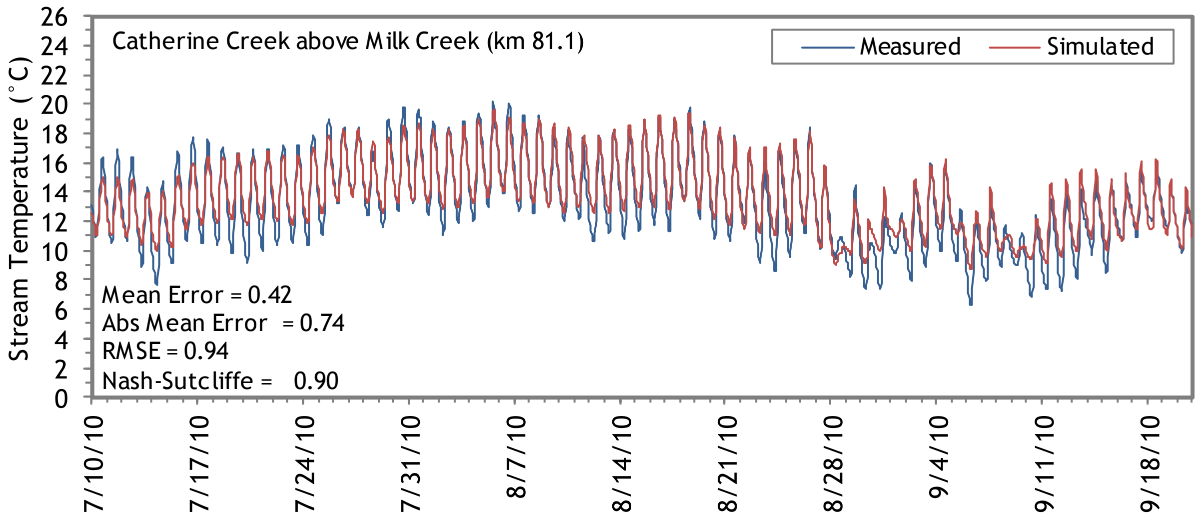
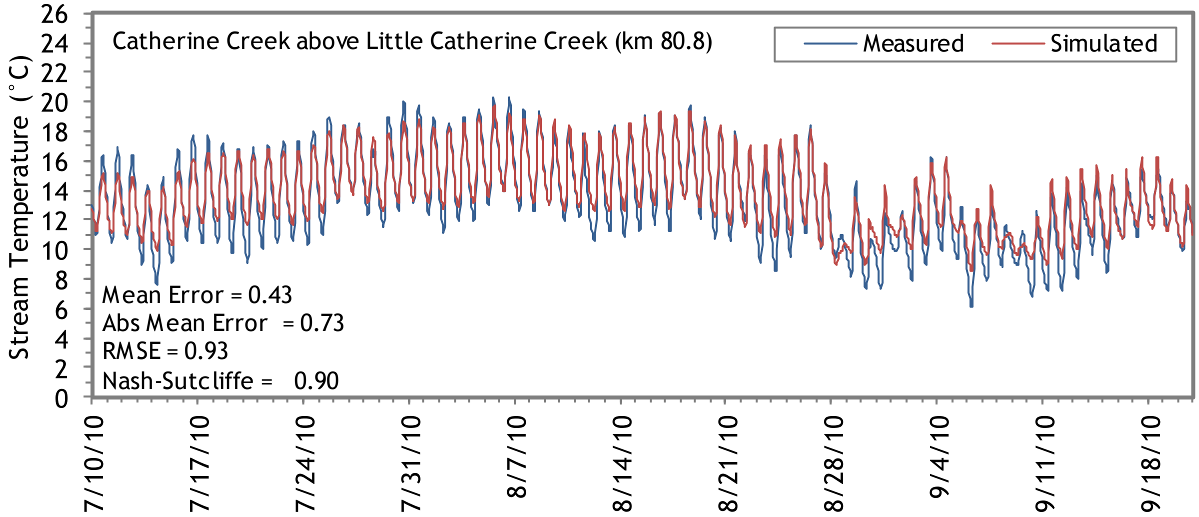
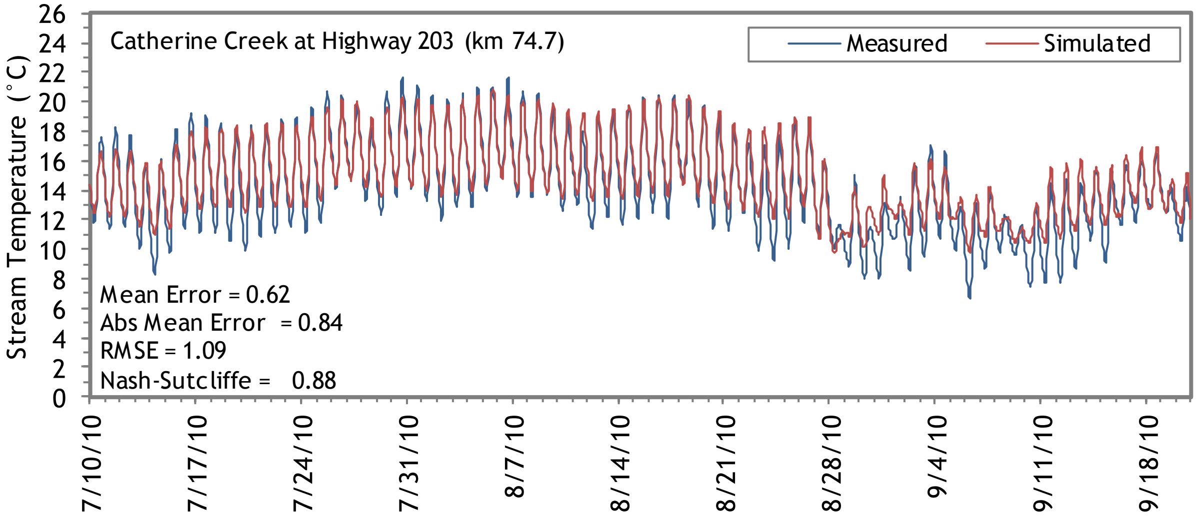


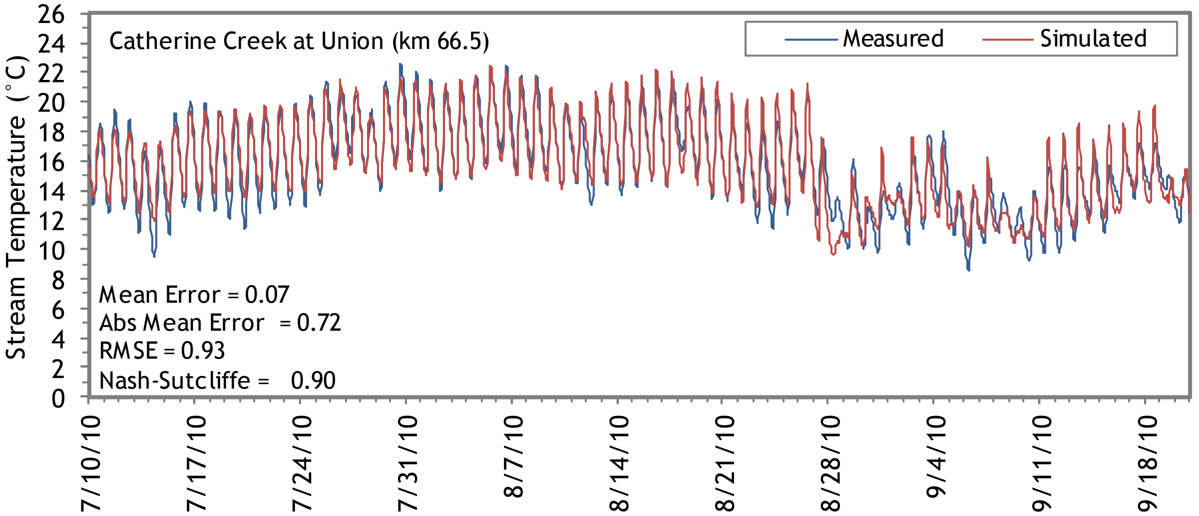
Figure 111 shows the simulated and measured hourly temperatures at 4 locations along the simulated reach between the forks and Union.

Figure 111 – Catherine Creek simulated and measured hourly stream temperatures.



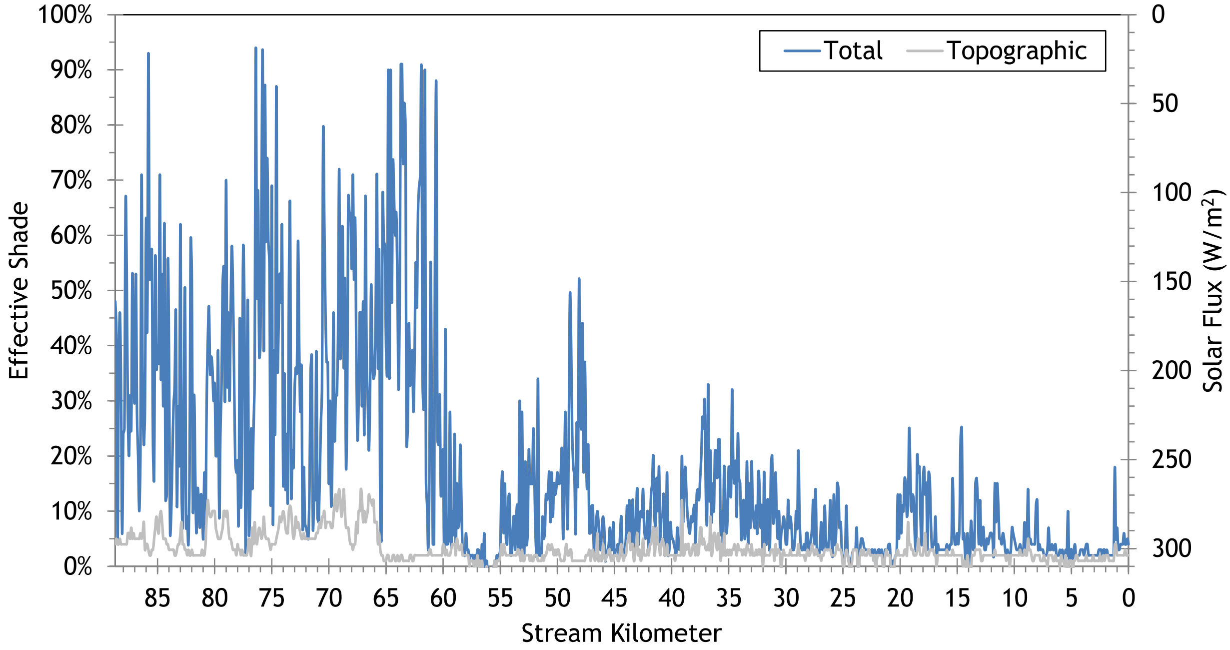

Catherine Creek above Little Catherine Creek (km 80.8)
Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.43
Abs Mean Error = 0.73
RMSE = 0.93
Nash-Sutcliffe = 0.90
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Catherine Creek at Highway 203 (km 74.7)
Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.62
Abs Mean Error = 0.84
RMSE = 1.09
Nash-Sutcliffe = 0.88
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Catherine Creek at Union (km 66.5)
Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.07
Abs Mean Error = 0.72
RMSE = 0.93
Nash-Sutcliffe = 0.90
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

The simulated effective shade values for Catherine Creek are presented in Figure 112. Above the city of Union (approximately kilometer 65) the stream is flowing through a more confined valley in the foothills and is well forested. Below Union, the land use is primarily agriculture and there is little stream side vegetation, so effective shade is lower. See Appendix for effective shade maps.

Figure 112 – Catherine Creek simulated effective shade values.



RGB-colored LiDAR point cloud - Catherine Creek downstream of Warm Creek.

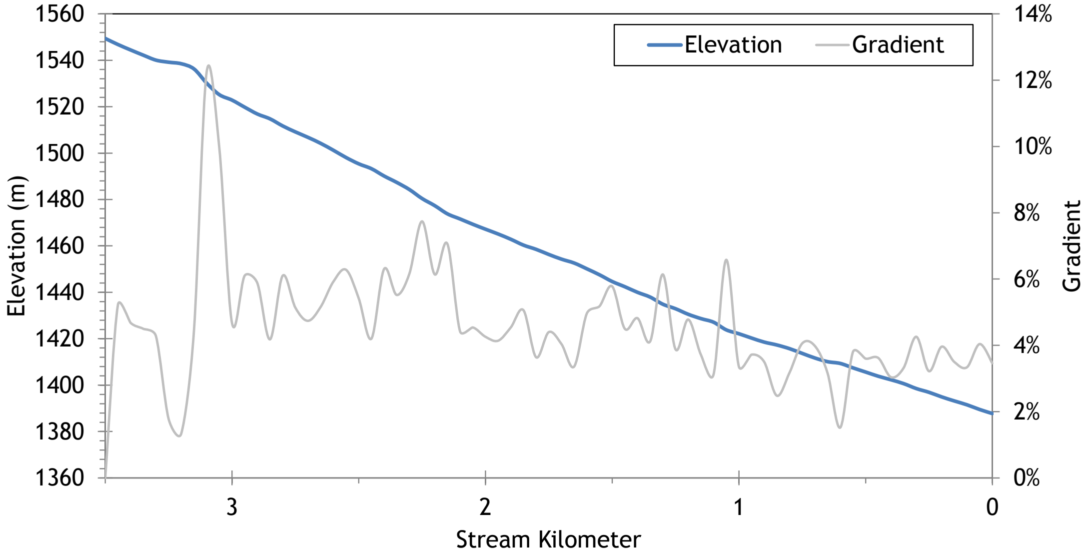
5.8 Clear Creek

RGB-colored LiDAR point cloud - Clear Creek looking upstream from near mouth.

5.8.1 Clear Creek TTools Results

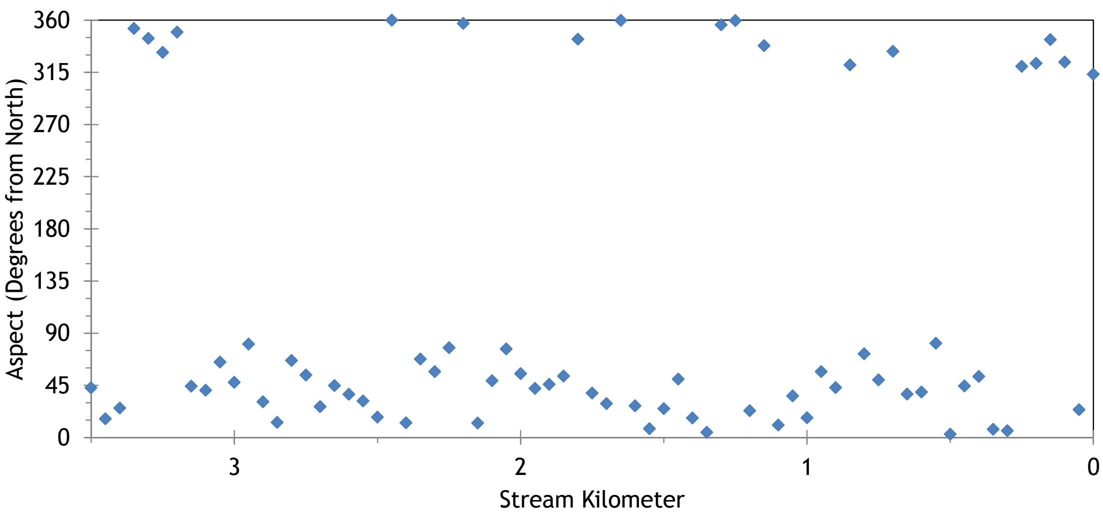
Clear Creek elevations and gradients were sampled from bare earth LiDAR data (Figure 113). The stream is located in the Blue Mountains area of the upper watershed and has a moderately steep gradient.

Figure 113 – Clear Creek elevation and gradient.



Clear Creek flows mostly toward the northeast until it reaches the Grande Ronde River (Figure 114).

Figure 114 – Clear Creek stream aspect.



Topographic shade angles for Clear Creek are shown in Figure 115. There is a significant amount of topographic shade provided by the surrounding mountains.

Figure 115 – Clear Creek topographic shade angles.

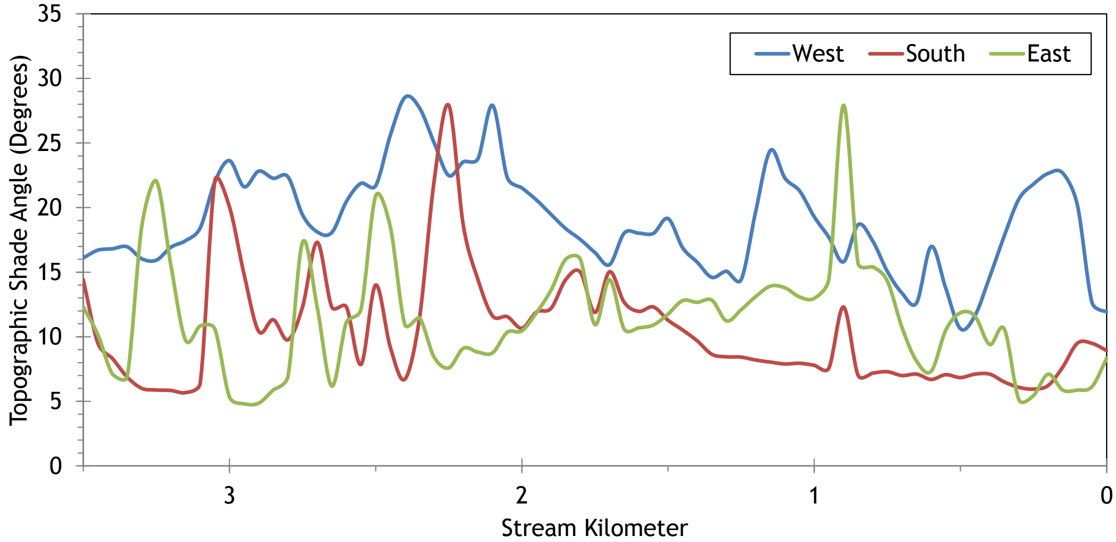
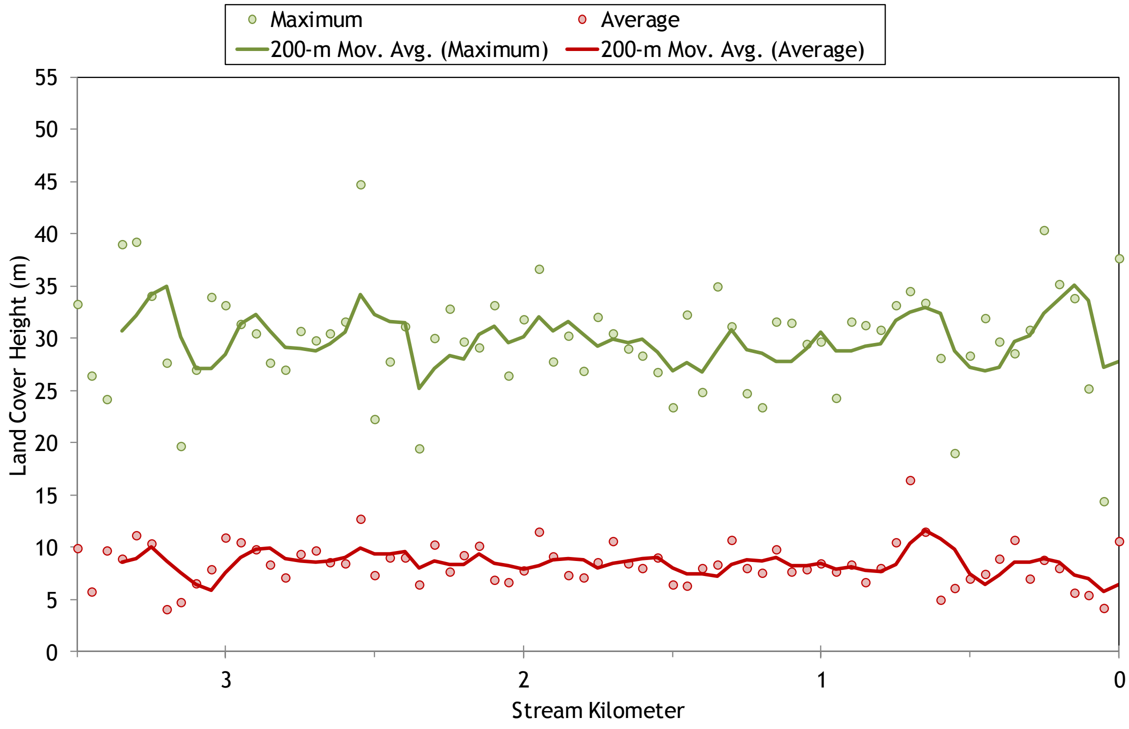


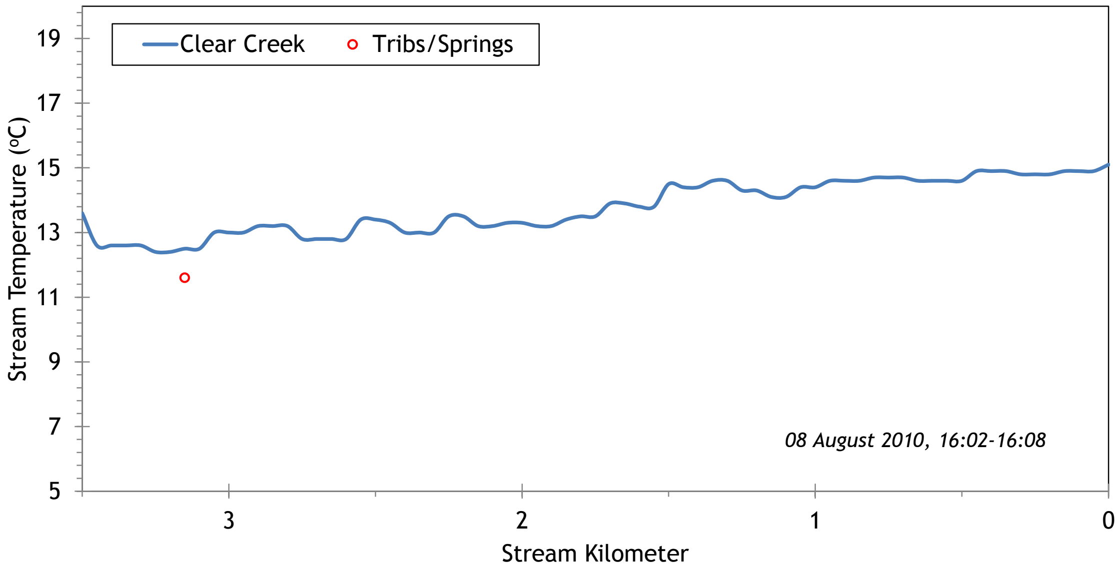
Figure 116 shows the land cover heights sampled along Clear Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 116 – Clear Creek land cover heights sampled from highest hit LiDAR.



The TIR stream temperature profile for Clear Creek is shown in Figure 117. Clear Creek is well-forested and remains fairly cool throughout the day.

Figure 117 – Clear Creek TIR stream temperature profile.



5.8.2 Clear Creek Heat Source Calibration Results

Stream temperature was simulated for the lower 3.5 kilometers of Clear Creek (Figure 118).

Figure 118 – Clear Creek simulation extent.

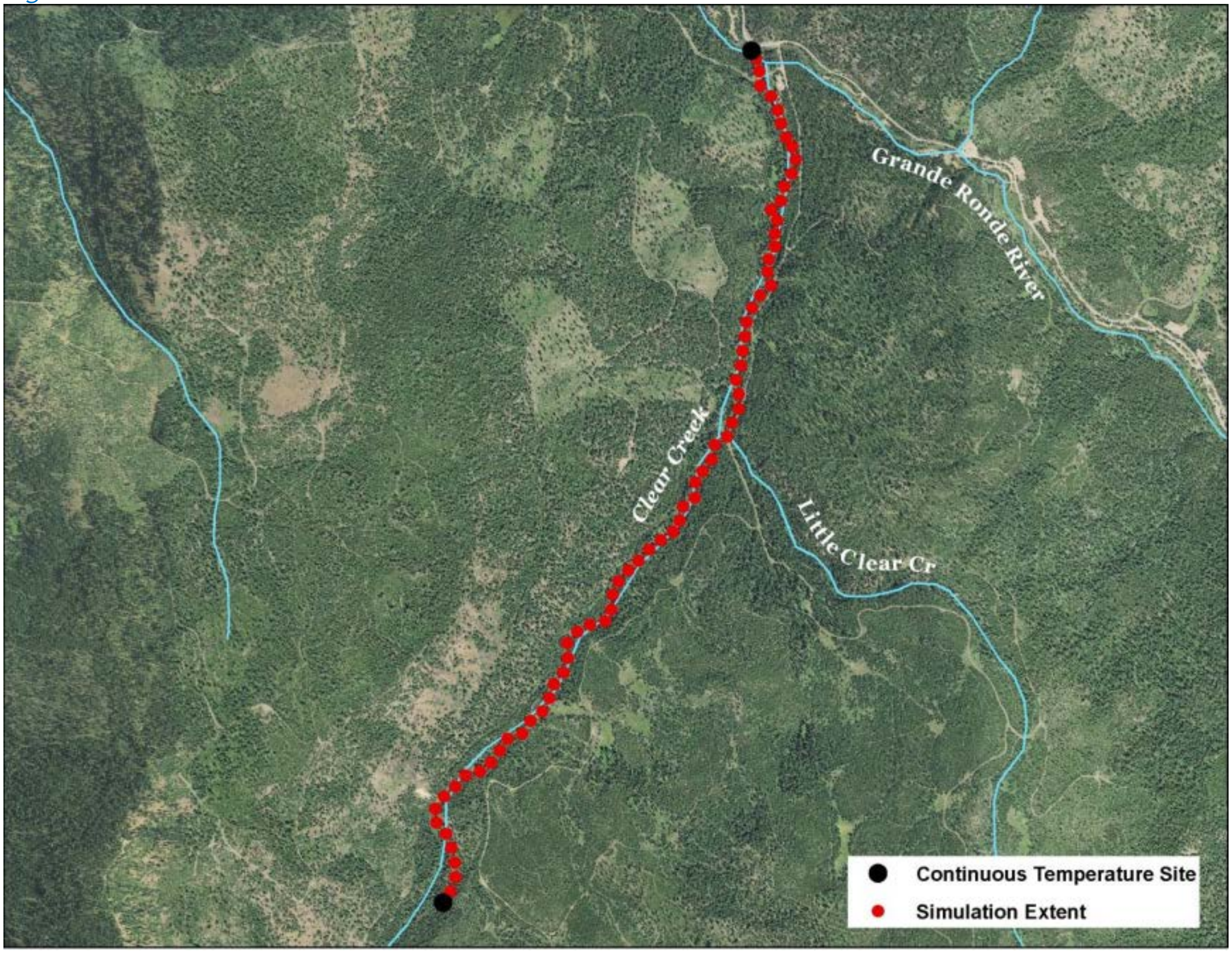


Table 18 – Clear Creek general Heat Source parameters.

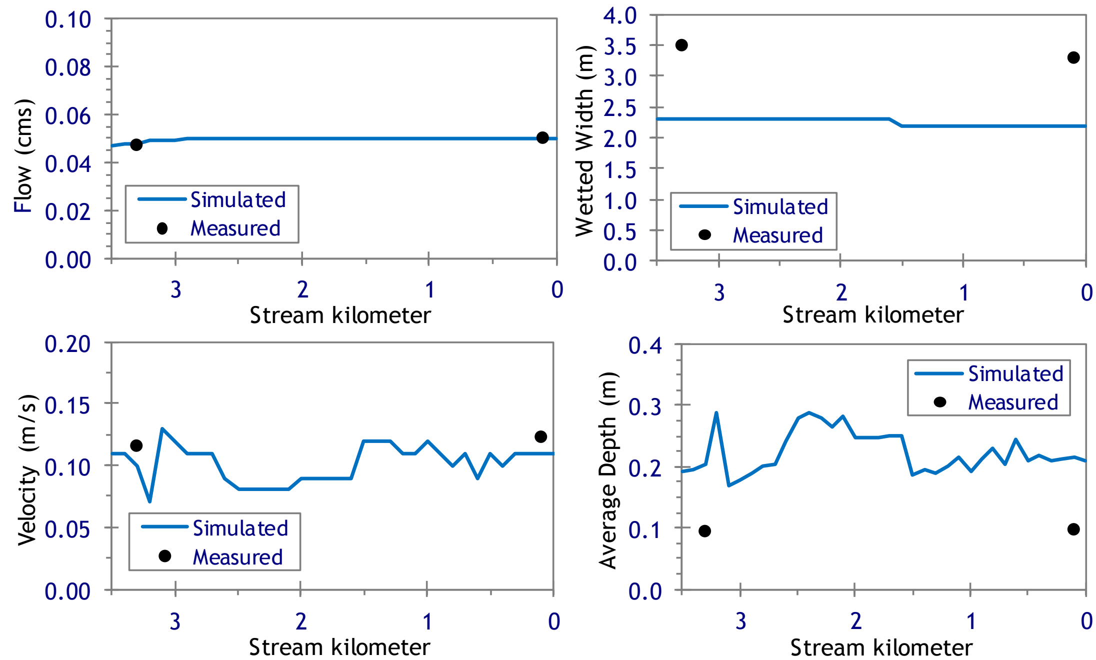
Stream:	Clear Creek
Length:	3.5 kilometers
Time Period:	July 10 – Sept 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 16:01-16:07
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Clear Creek Heat Source model:

- Hourly climate data were obtained from the J Ridge RAWS (USFS) site. Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Wetted widths were too small to be digitized from the remote sensing data and were therefore estimated based on the field measurements.
- Daily flow variability was extrapolated from Grande Ronde River gage data.
- There were no significant springs or tributaries observed in the TIR imagery, and therefore none were included within the model.

Figure 119 displays the simulated and measured hydraulic values for Clear Creek for August 19, 2010.

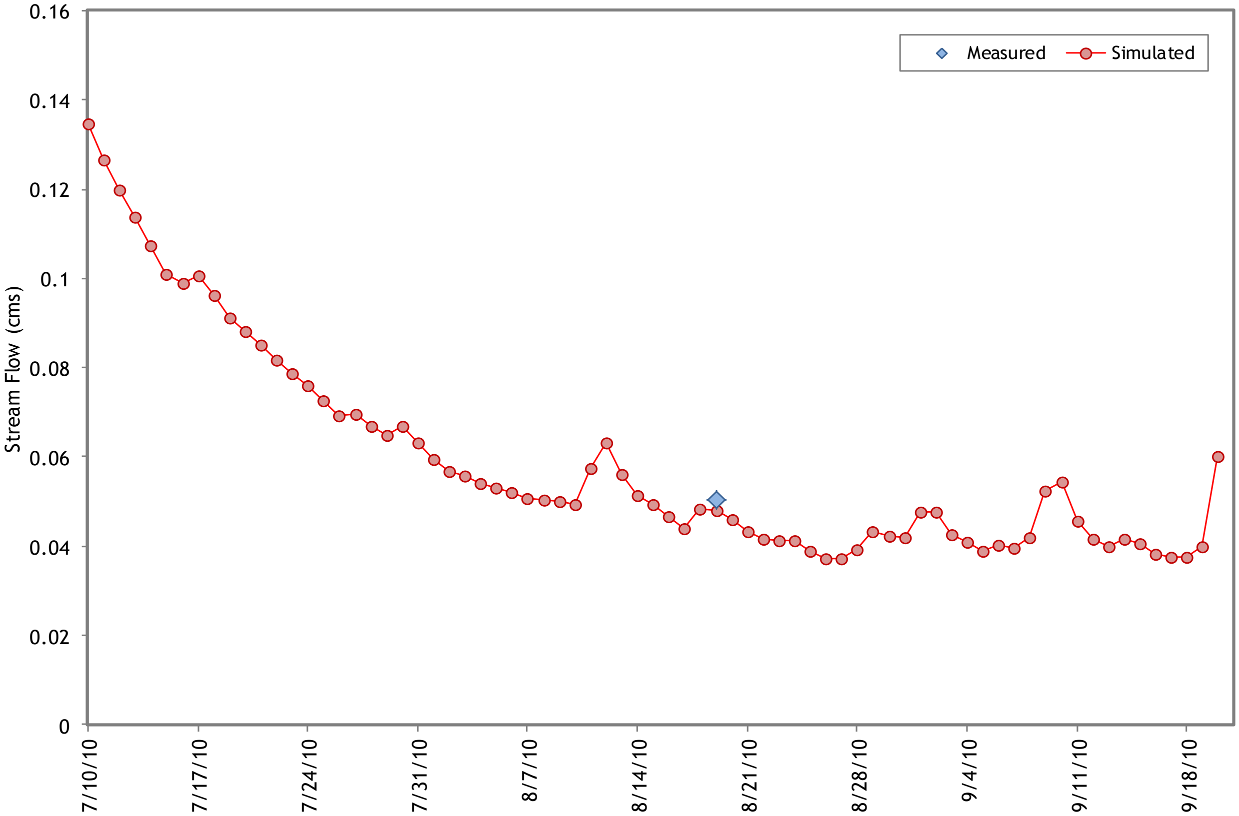
Figure 119 – Clear Creek simulated and measured hydraulics values for 8/19/2010.



Site	Stream Km	Date
Clear Creek Upper	3.3	8/19/2010
Clear Creek Mouth	0.1	8/19/2010

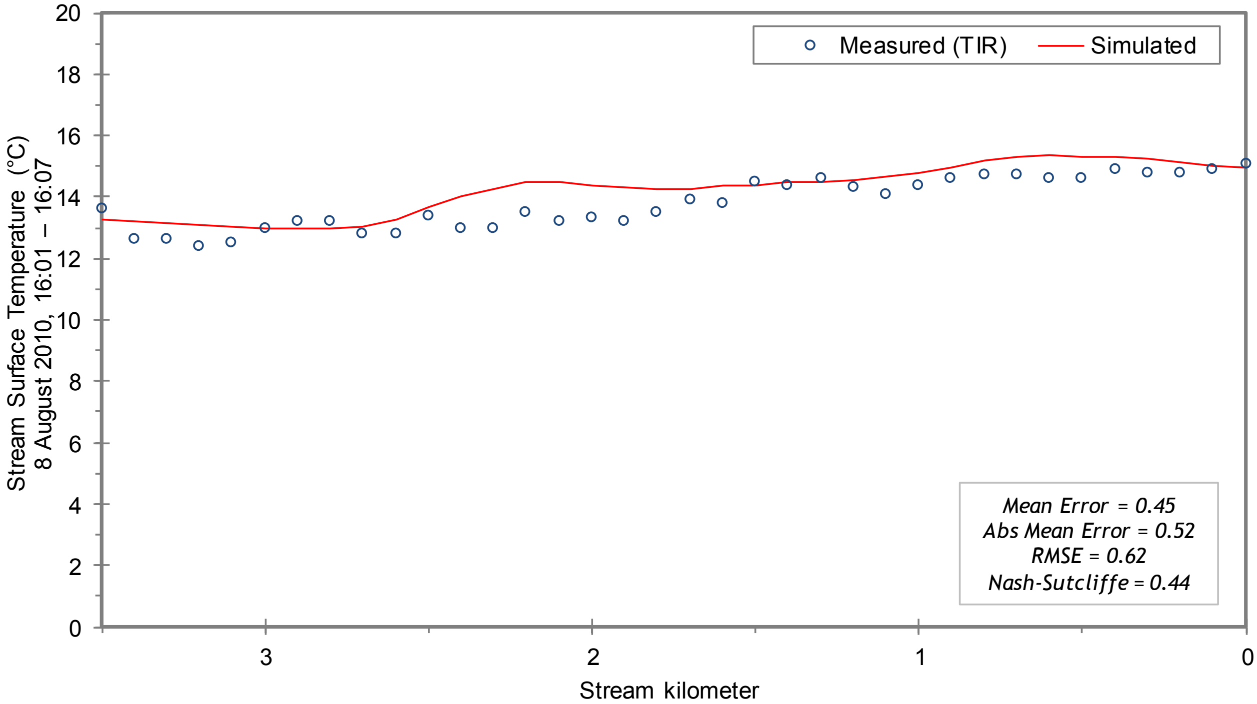
The simulated daily flow volumes at the mouth of Clear Creek are shown in Figure 120. The daily values were extrapolated from gage data recorded on the Grande Ronde River near Starkey, OR.

Figure 120 – Clear Creek measured and simulated daily flow volumes near the mouth.



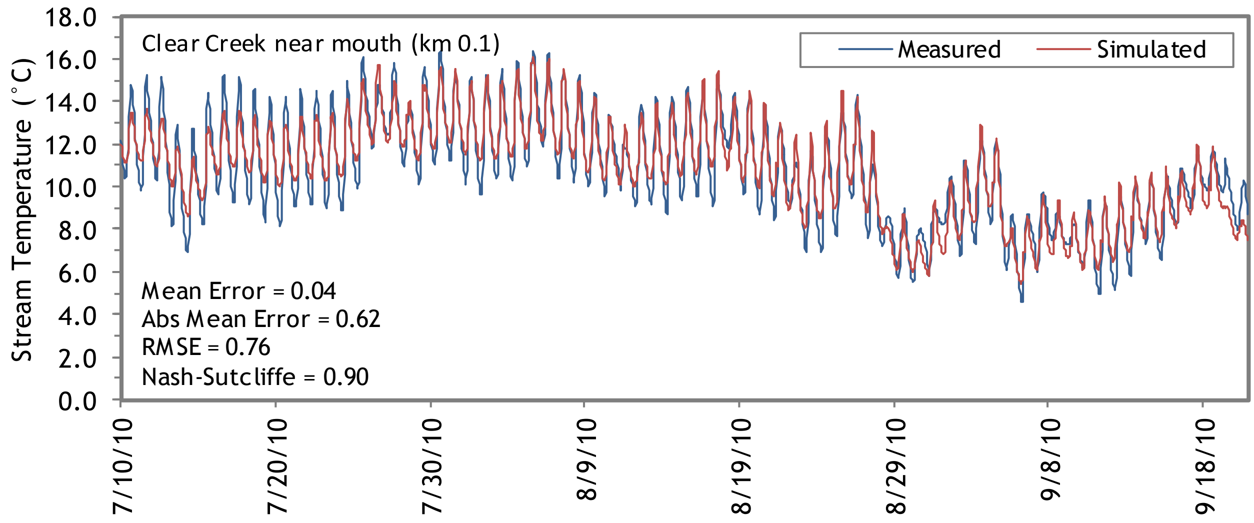
The simulated and measured longitudinal stream temperatures and calibration statistics are shown in
Figure 121. There was little thermal variability in the lower 3.5 stream kilometers.

Figure 121 – Clear Creek simulated and measured longitudinal temperatures.



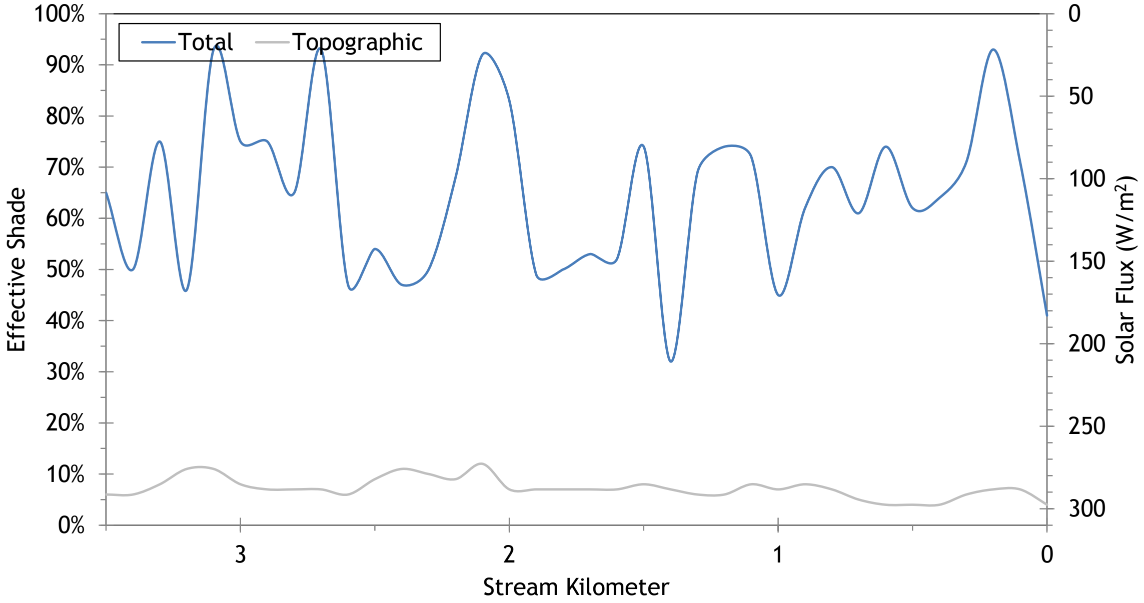
Clear Creek simulated and measured hourly temperatures are plotted in Figure 122.

Figure 122 – Clear Creek simulated and measured hourly temperatures.



The simulated effective shade values for Clear Creek are shown in Figure 123. There is less than 10% topographic shade along the simulated reach. The majority of the total effective shade is produced by near stream vegetation. See Appendix for effective shade maps.

Figure 123 – Clear Creek simulated effective shade.



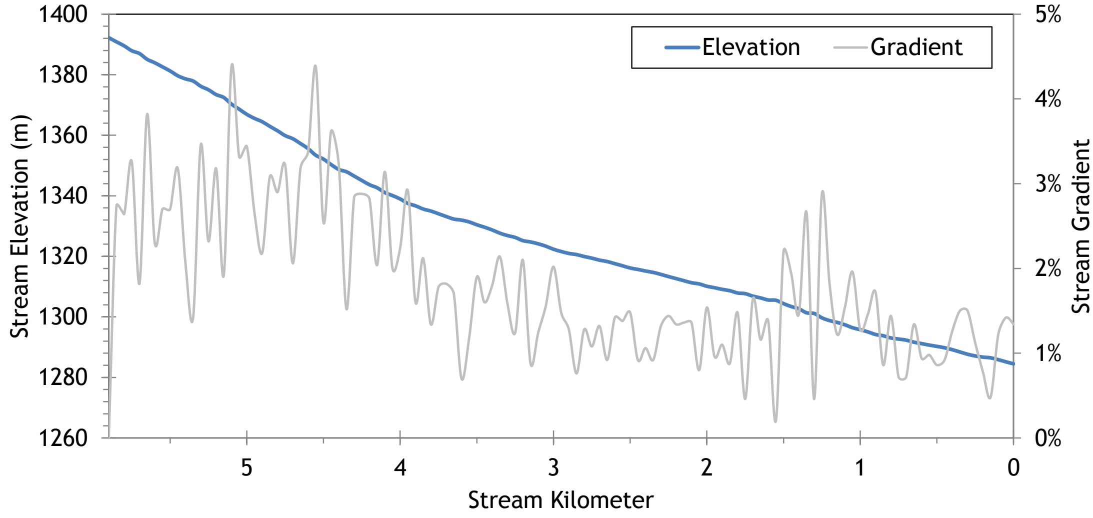
5.9 Limber Jim Creek

RGB-colored LiDAR point cloud - Limber Jim Creek looking downstream just below the North Fork.

5.9.1 Limber Jim Creek TTools Results

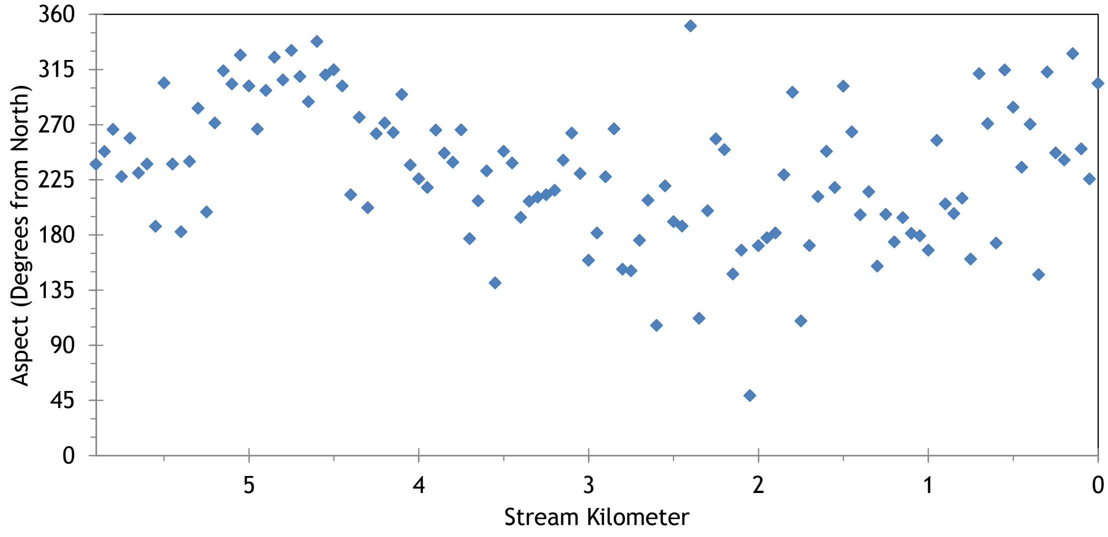
Limber Jim Creek elevations and gradients are shown in Figure 124. The values were sampled from the bare earth LiDAR data. The stream goes from a more constricted valley to a more flat valley bottom in the lower 3 kilometers, where it meanders more and has a lower gradient.

Figure 124 – Limber Jim Creek elevation and gradient.



Limber Jim Creek stream aspects are shown in Figure 125 for each 50-meter reach. Overall, the stream flows in the westerly direction before reaching the Grande Ronde River.

Figure 125 – Limber Jim Creek stream aspect.



Limber Jim Creek has a good amount of topographic shade features provided by the surrounding mountains (Figure 126). Values range between 5 and 25 degrees in general.

Figure 126 – Limber Jim Creek topographic shade angles.

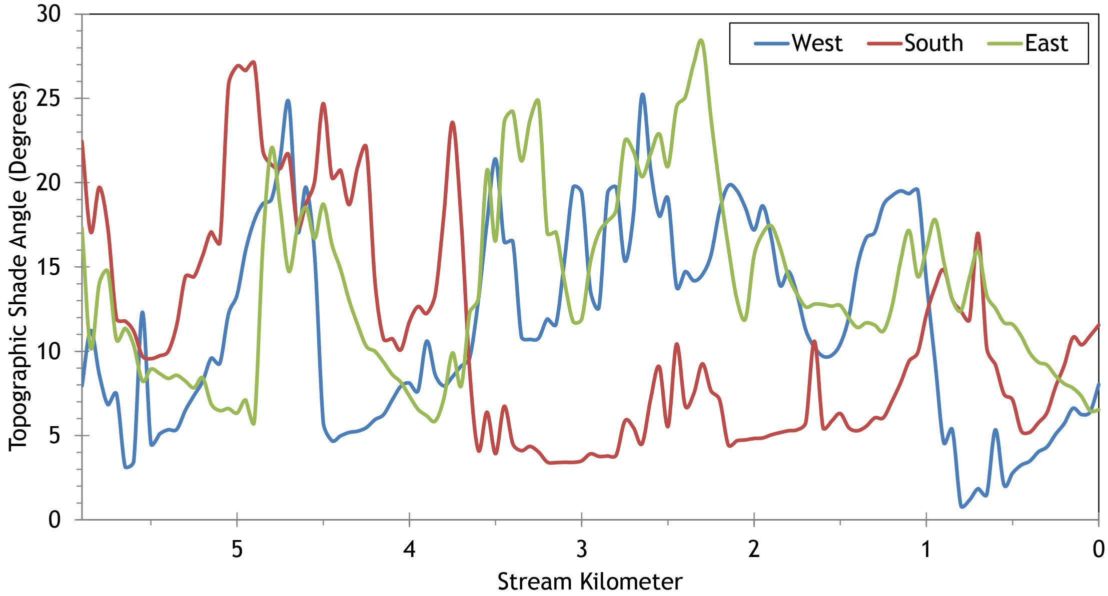
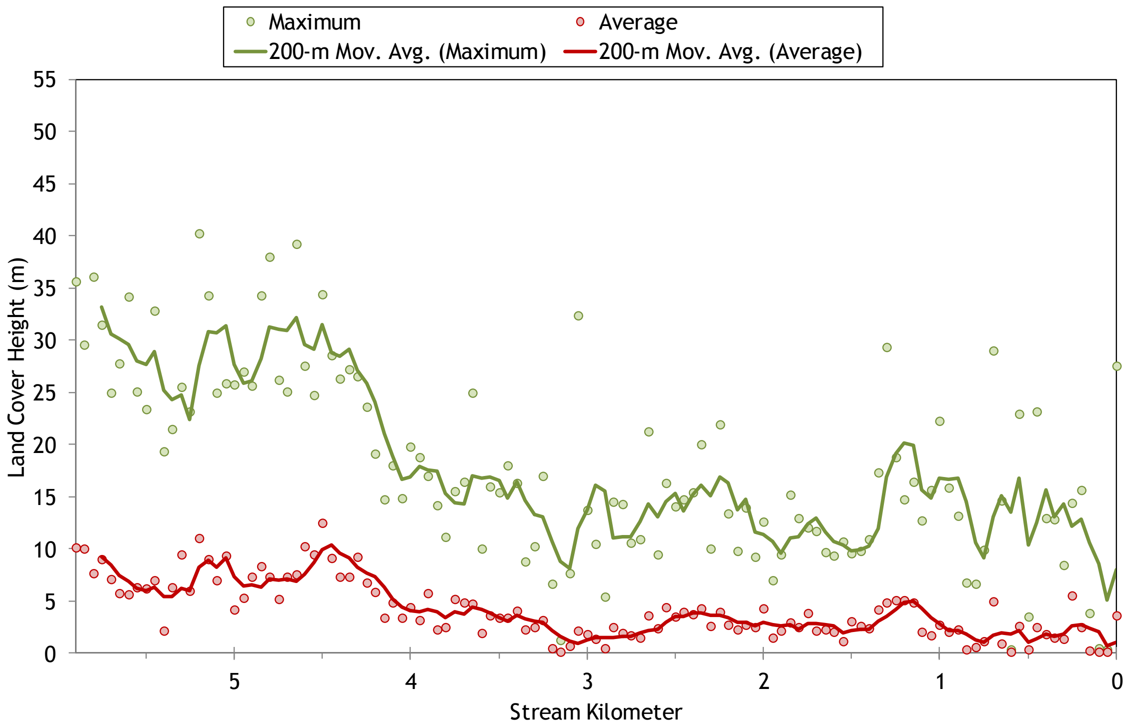


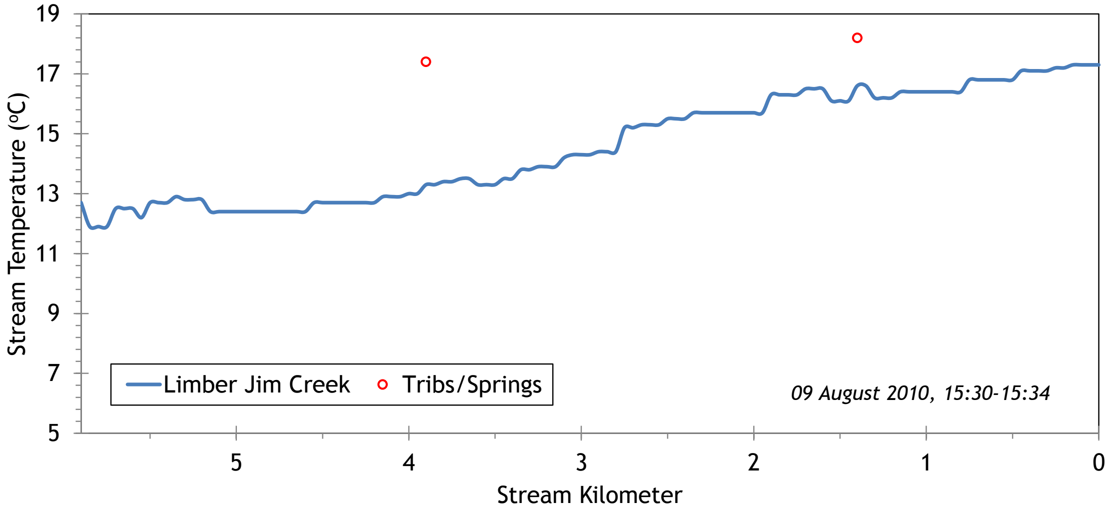
Figure 127 shows the land cover heights sampled along Limber Jim Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 127 – Limber Jim Creek land cover heights sampled from highest hit LiDAR.



Limber Jim Creek is a fairly cool mountain stream relative to others in the basin (Figure 128). The TIR stream temperature profile shows a steady increase within the lower 6.5 kilometers.

Figure 128 – Limber Jim TIR stream temperature profile.



5.9.2 Limber Jim Creek Heat Source Calibration Results

The lower 5.9 stream kilometers of Limber Jim Creek were simulated for temperature. Figure 129 shows the simulation extent and hourly temperature data sites.

Figure 129 – Limber Jim Creek simulation extent.

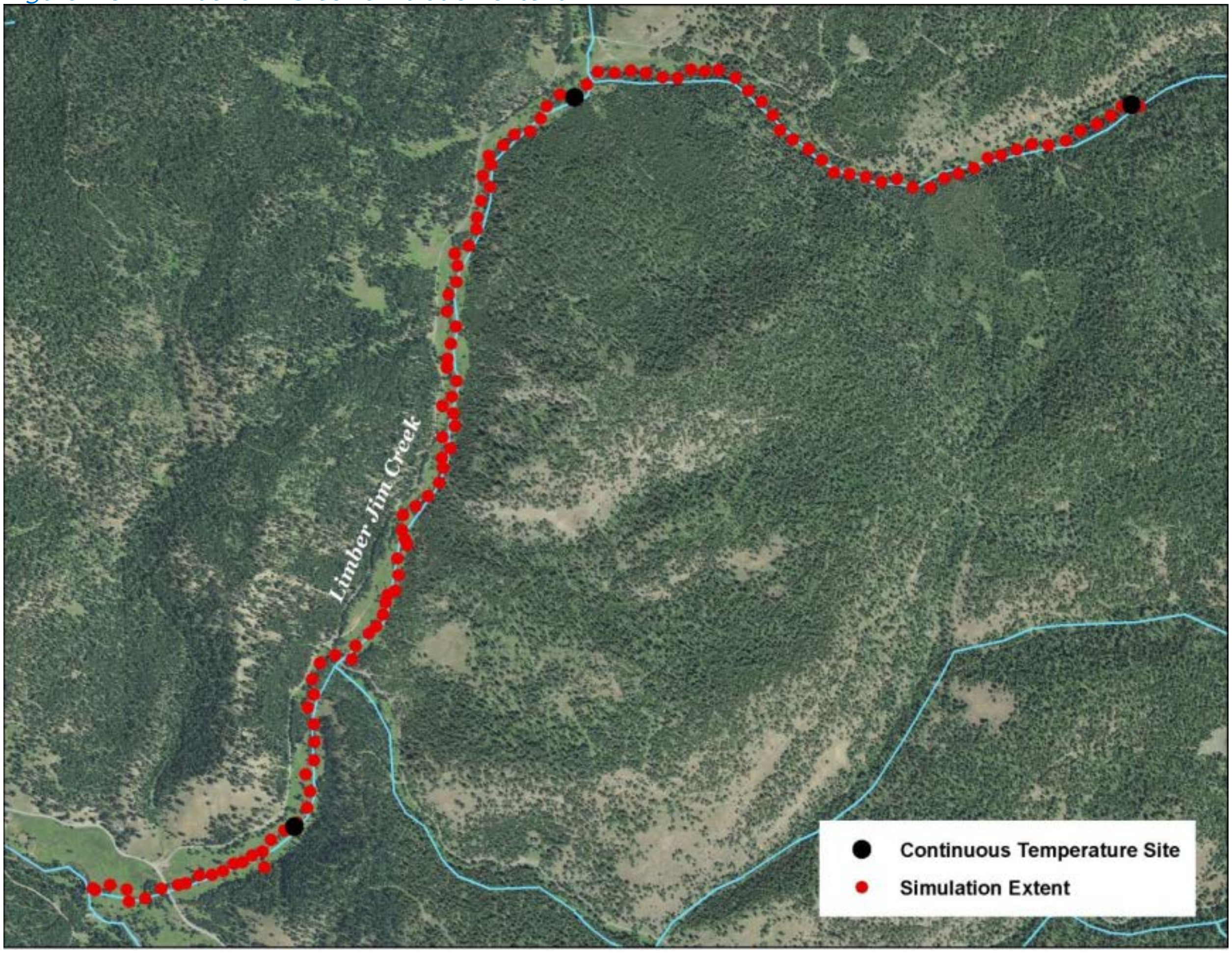


Table 19 – Limber Jim Creek general Heat Source parameters.

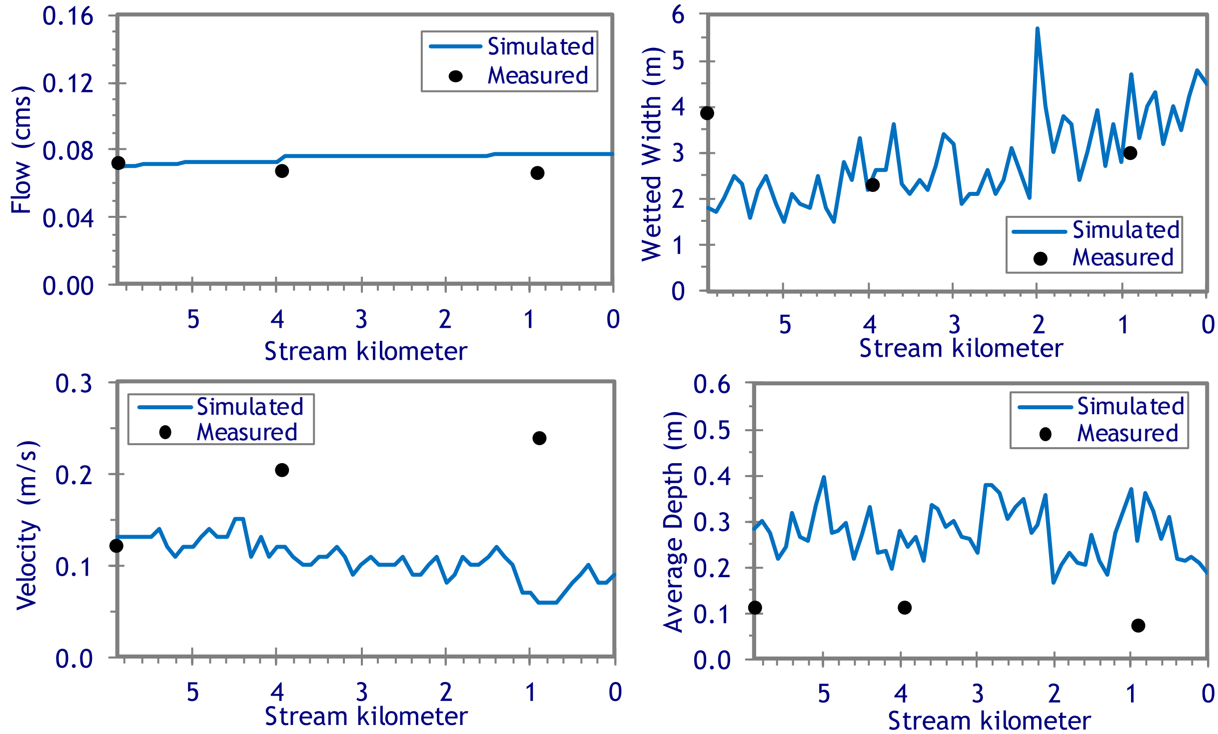
Stream:	Limber Jim Creek
Length:	5.9 kilometers
Time Period:	July 10 - September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 15:30-15:34
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	10 meters

The following assumptions were used when calibrating the Limber Jim Creek Heat Source model:

- Hourly climate data were obtained from the J Ridge RAWS (USFS) site. Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Wetted widths were digitized from the remote sensing imagery and then had to be reduced in some reaches in order to accommodate the stream hydraulics and measured data.
- Daily flow values were extrapolated from the Grande Ronde River gage data.

Figure 130 displays the simulated and measured hydraulic values for Limber Jim Creek for August 14, 2010. The ground-level data were collected at three locations, including the upstream boundary of the model extent.

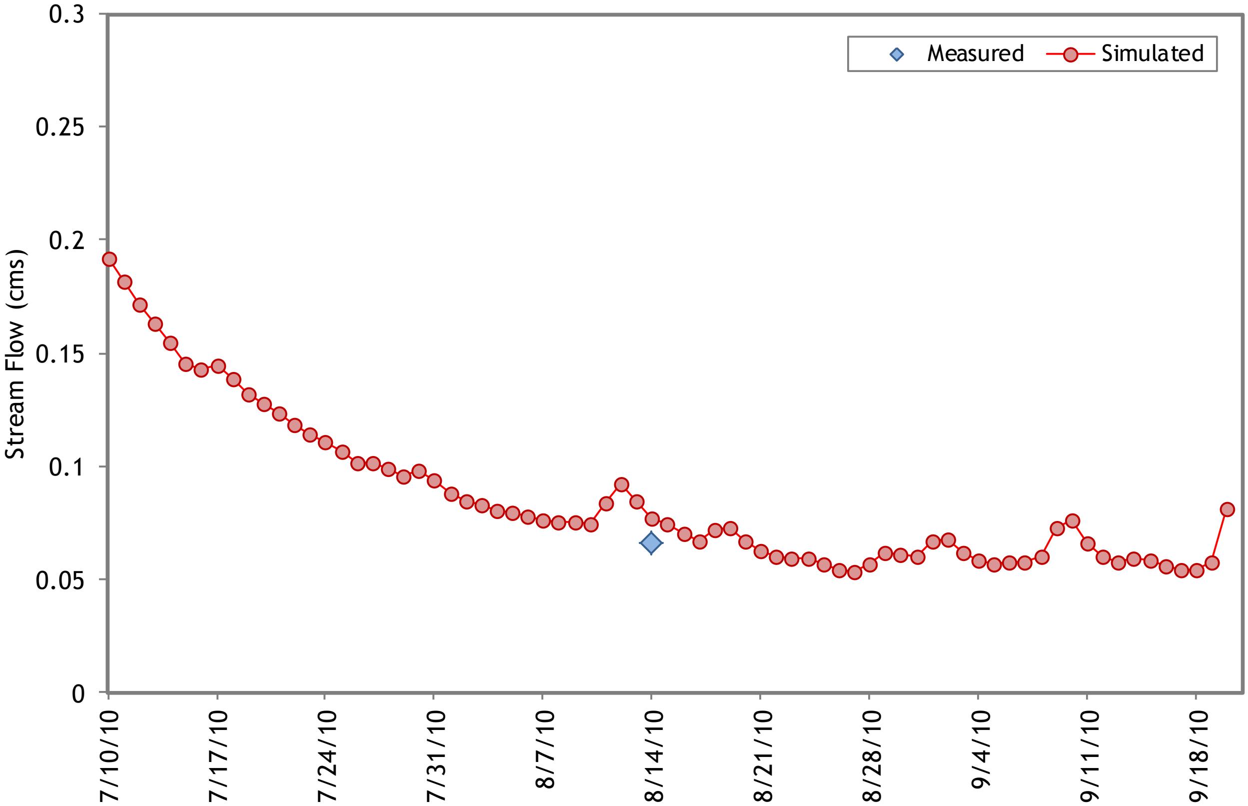
Figure 130 – Limber Jim Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Limber Jim Upper	5.9	8/14/2010
Limber Jim below North Fork	3.95	8/14/2010
Limber Jim Mouth	0.9	8/14/2010

Figure 131 displays the simulated daily flow volumes near the mouth of Limber Jim Creek. The values were extrapolated from gage data on the Grande Ronde River, assuming that each stream in the watershed exhibited similar degrees of daily variability.

Figure 131 – Limber Jim Creek simulated and measured flows near the mouth.



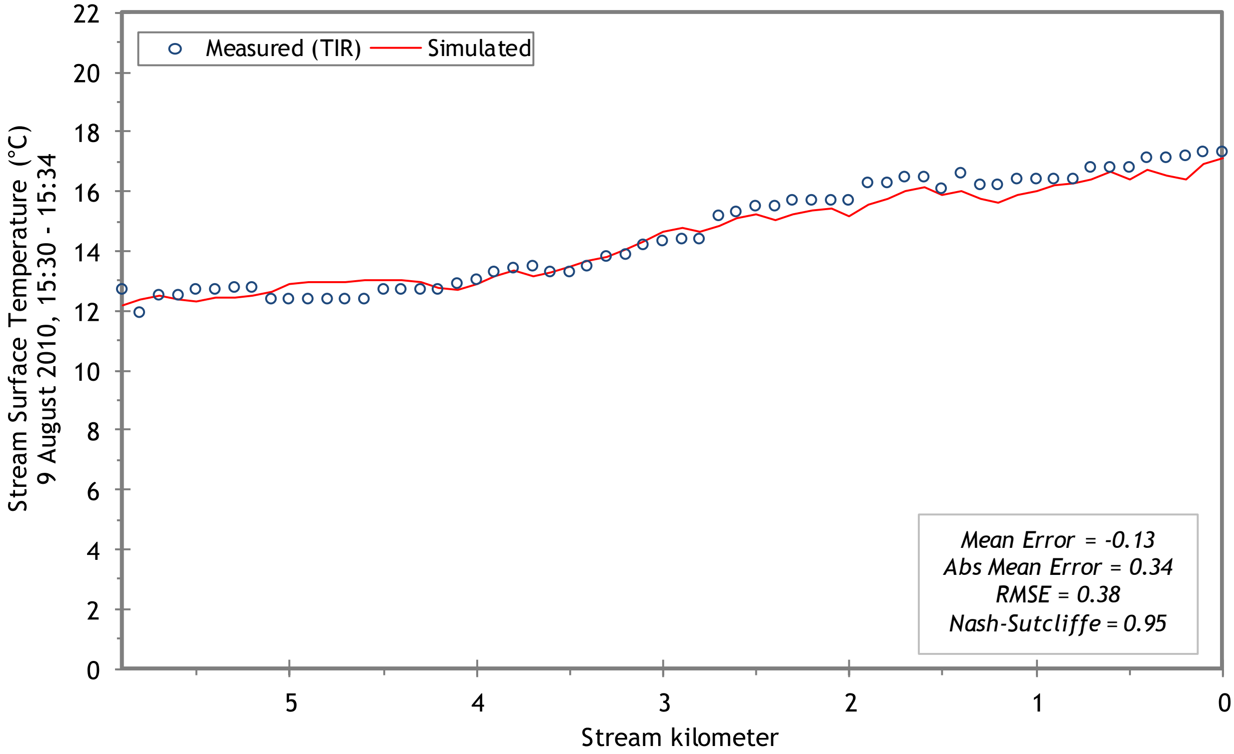
There were two tributaries observed in the TIR data (Table 20). Their daily flow volumes were estimated and daily variability was extrapolated from gage data on the Grande Ronde River. Overall, the tributaries were estimated to be much smaller than the mainstem Limber Jim Creek; therefore their flow estimates were small and temperatures were included as constants.

Table 20 – Limber Jim Creek mass inflow features and assumptions.

Feature	Stream Km	Assumptions
North Fork Limber Jim Cr.	3.9	0.004-0.009 cms at 17.4°C
South Fork Limber Jim Cr.	1.4	0.002-0.004 cms at 18.2°C

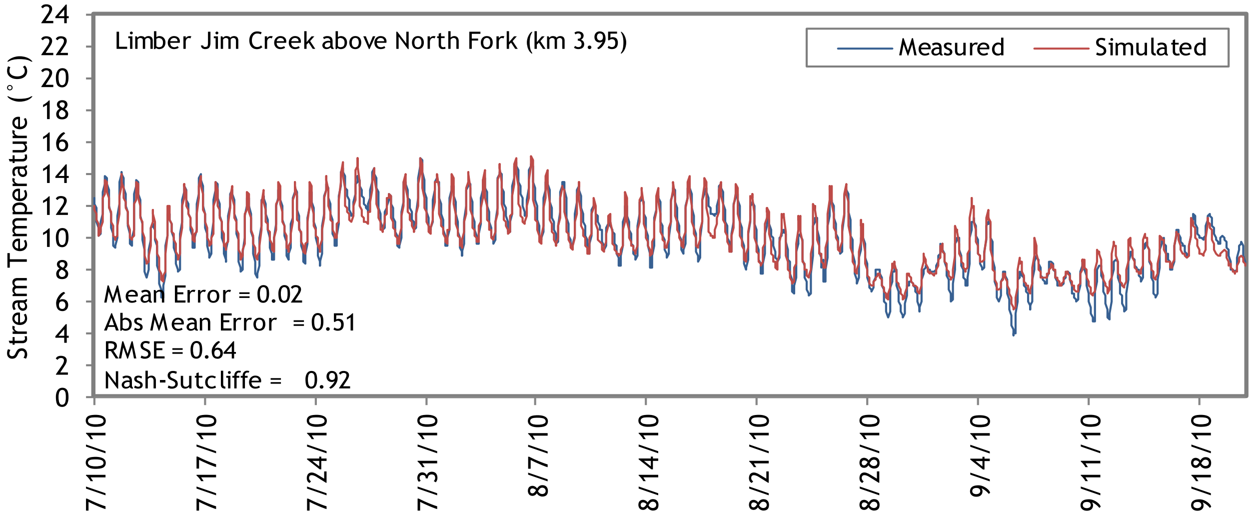
The simulated and measured longitudinal stream temperatures for Limber Jim Creek are shown in Figure 132. The stream gradually heated approximately 5°C in its lower six kilometers at the time that the TIR data were collected

Figure 132 – Limber Jim Creek simulated and measured longitudinal stream temperatures.



Simulated and measured hourly stream temperatures are presented in Figure 133. Calibration statistics are also shown in each plot.

Figure 133 – Limber Jim Creek simulated and measured hourly stream temperatures.



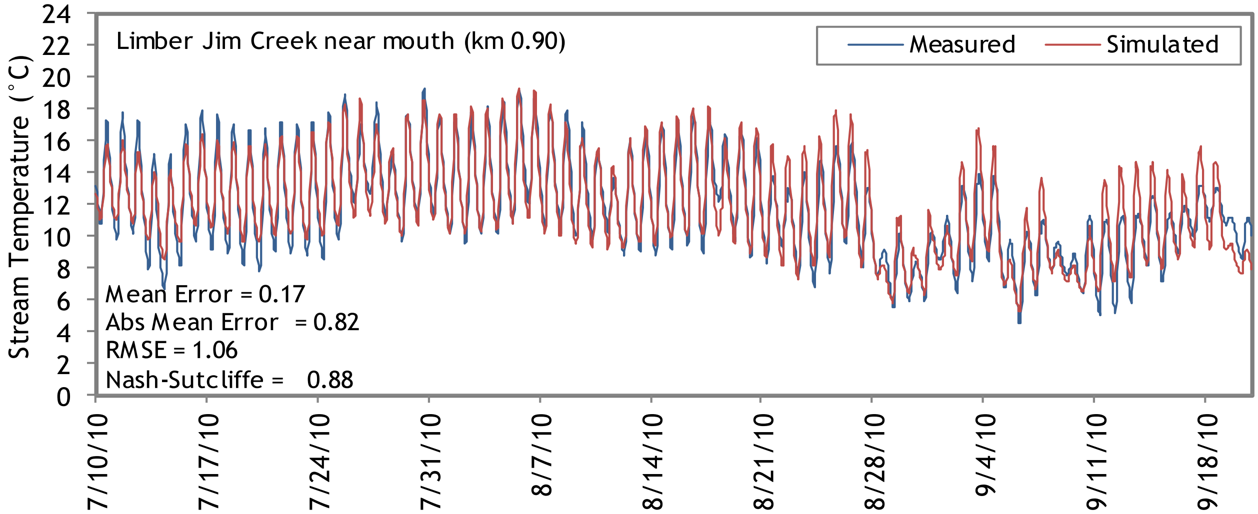
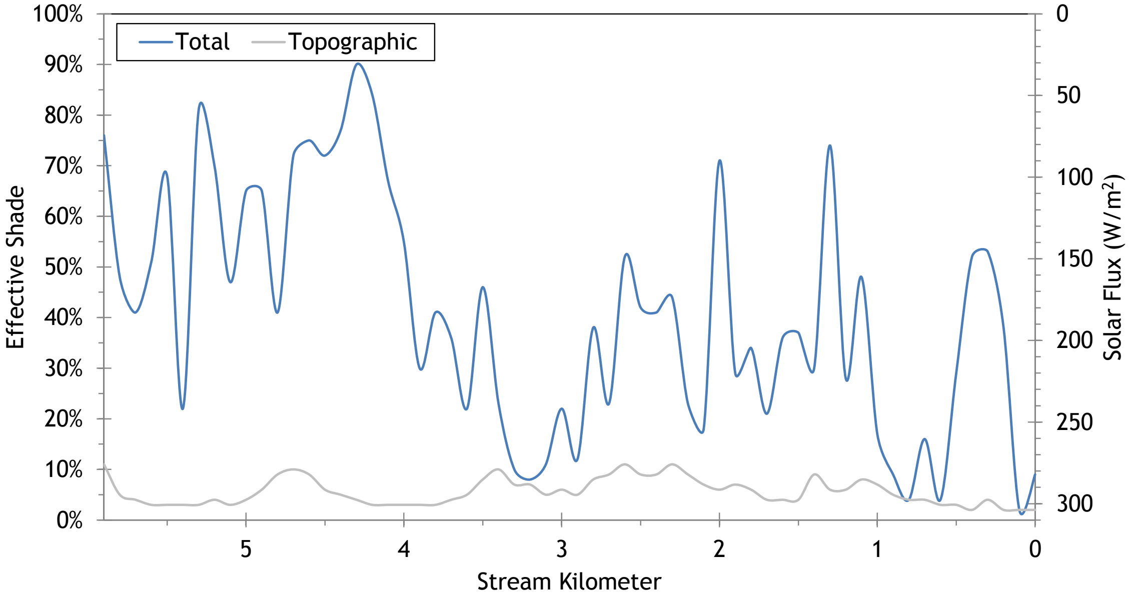


Figure 134 shows the simulated effective shade values for Limber Jim Creek. Between stream kilometer 4 and the mouth, there is less effective shade because the stream is flowing through a meadow-forest complex. Topographic shade is generally less than 10%. See Appendix for effective shade maps.

Figure 134 – Limber Jim Creek simulated effective shade.



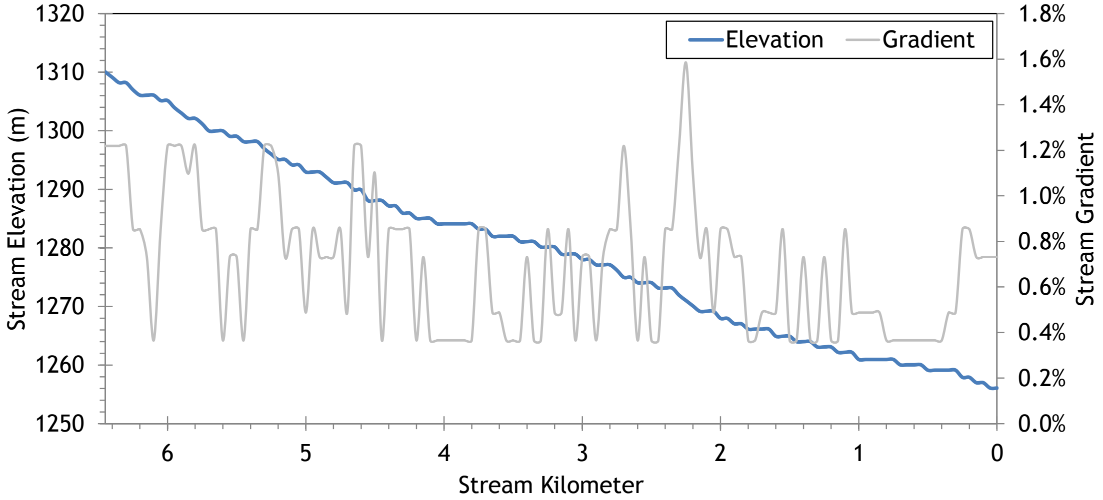
5.10 Chicken Creek

RGB-colored LiDAR point cloud - Chicken Creek (flowing from bottom of image) at confluence with Sheep Creek.

5.10.1 Chicken Creek TTools Results

Chicken Creek elevations and gradients are shown in Figure 135. The values were sampled from the 10-meter DEM because LiDAR data were only available for a short reach near the mouth. Of the sampled reach, gradients were usually less than 1%.

Figure 135 – Chicken Creek elevation and gradient.



Stream aspects for every 50 meters of Chicken Creek are shown in Figure 136. Chicken Creek generally flows northward until it reaches Sheep Creek; however there is significant small scale variation due to the meandering nature of the stream within the valley bottom.

Figure 136 – Chicken Creek stream aspect.

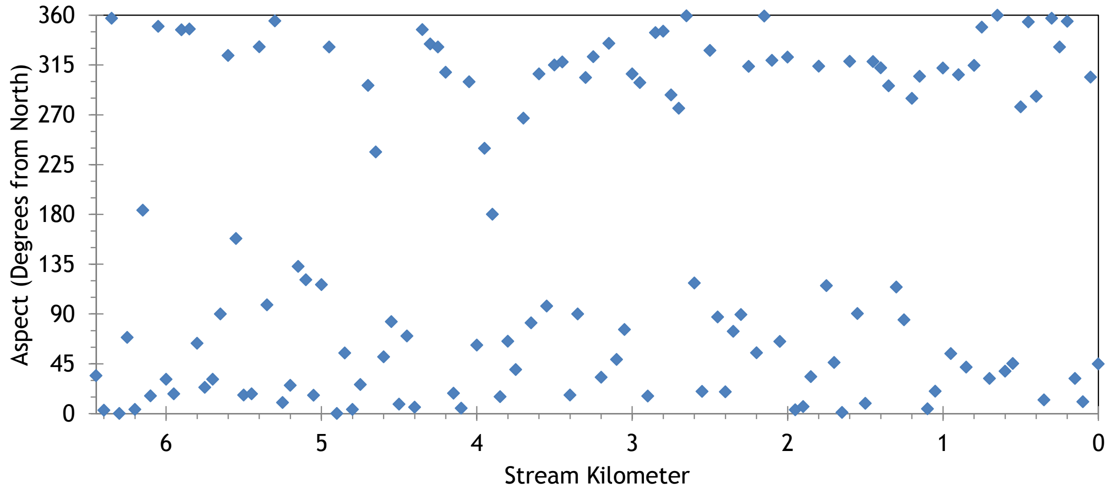
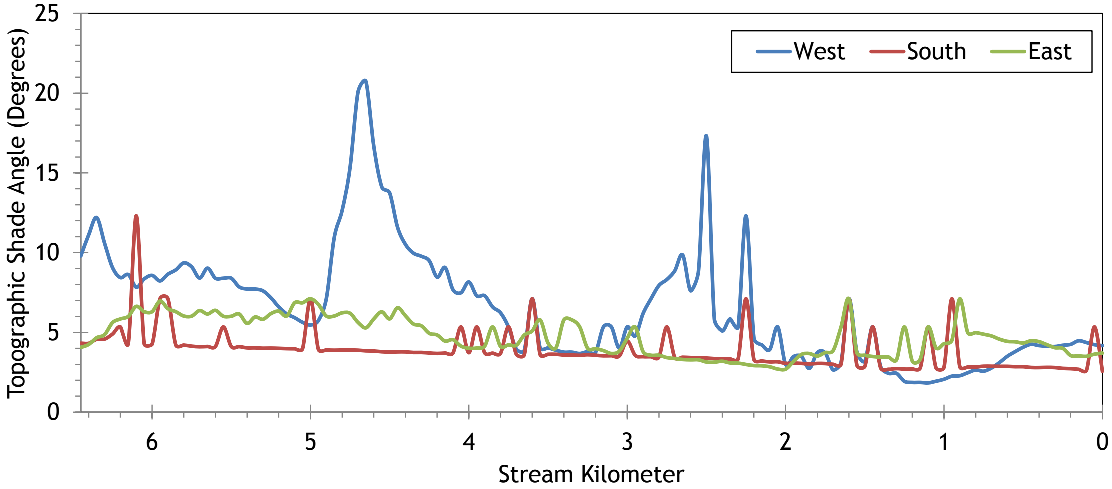


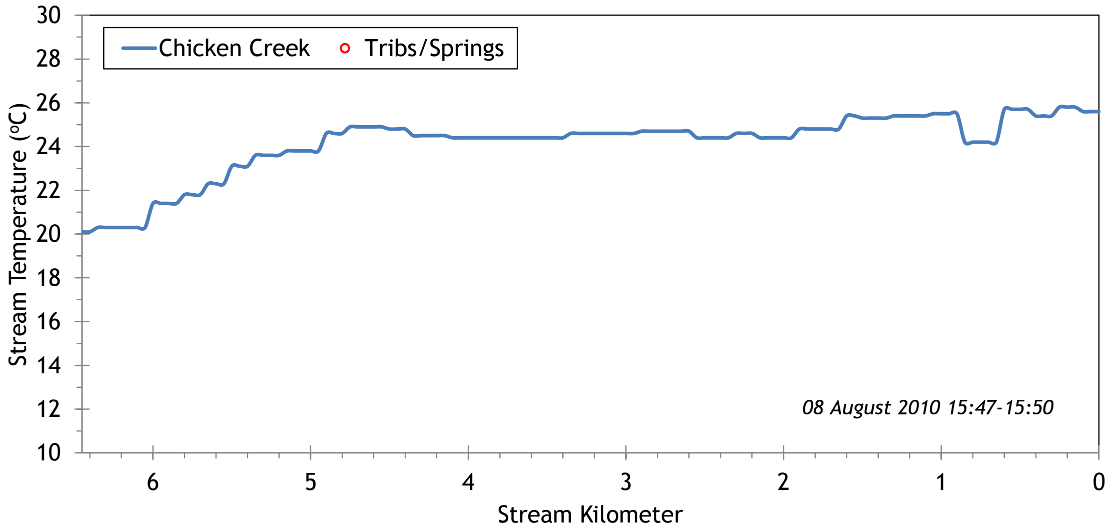
Figure 137 shows the topographic shade angles. Overall, topographic shade is minor because of the wide flat valley morphology through which this section of stream flows.

Figure 137 – Chicken Creek topographic shade angles.



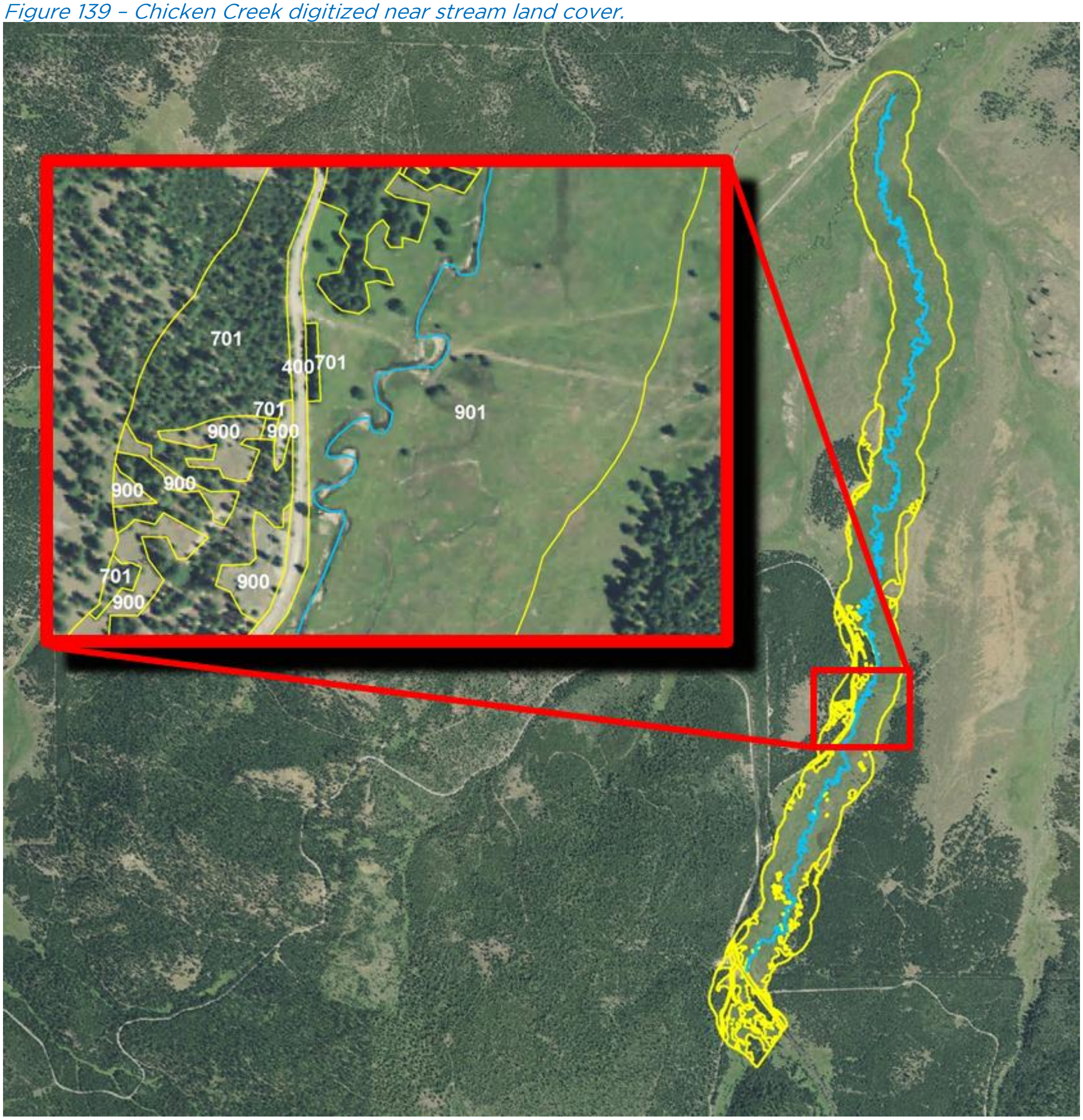
The Chicken Creek TIR stream temperature profile is shown in Figure 138. In this section of lower Chicken Creek, the temperatures were fairly warm and reached a maximum of about 25°C during the TIR flight.

Figure 138 – Chicken Creek TIR stream temperature profile.



LiDAR data were unavailable for Chicken Creek, so the near stream land cover was manually digitized within 100 meters of the stream using NAIP orthoimages (Figure 139). Most of the lower 6.5 kilometers of Chicken Creek flow through open grassy areas and has few trees.

Figure 139 – Chicken Creek digitized near stream land cover.



Chicken Creek land cover height estimates were derived from the LiDAR samples of Sheep Creek (Table 21). The 25th and 75th percentiles of values over 3 meters were calculated from the Sheep Creek TTools data. The 75th percentile was 14.1 meters, which was applied to tall tree classes for Chicken Creek. The 25th percentile was 6.3 meters, which was applied to the short tree classes for Chicken Creek.

Table 21 – Chicken Creek near stream land cover codes and descriptions.

Land Cover Name	Code	Height (m)	Density	Overhang (m)
Upland dry grasses	900	0.5	0.9	0.0
Lowland wet grasses	901	0.5	0.9	0.0
large conifer - dense	700	14.1	0.75	1.0
small conifer - dense	701	6.2	0.75	1.0
large conifer - sparse	750	14.1	0.25	1.0
small conifer - sparse	751	6.2	0.25	1.0
paved road	400	0	0	0
unpaved road	401	0	0	0
water	3011	0	0	0

5.10.2 Chicken Creek Heat Source Calibration Results

The lower 6.5 kilometers of Chicken Creek were simulated for temperature (Figure 140).

Figure 140 – Chicken Creek simulation extent.

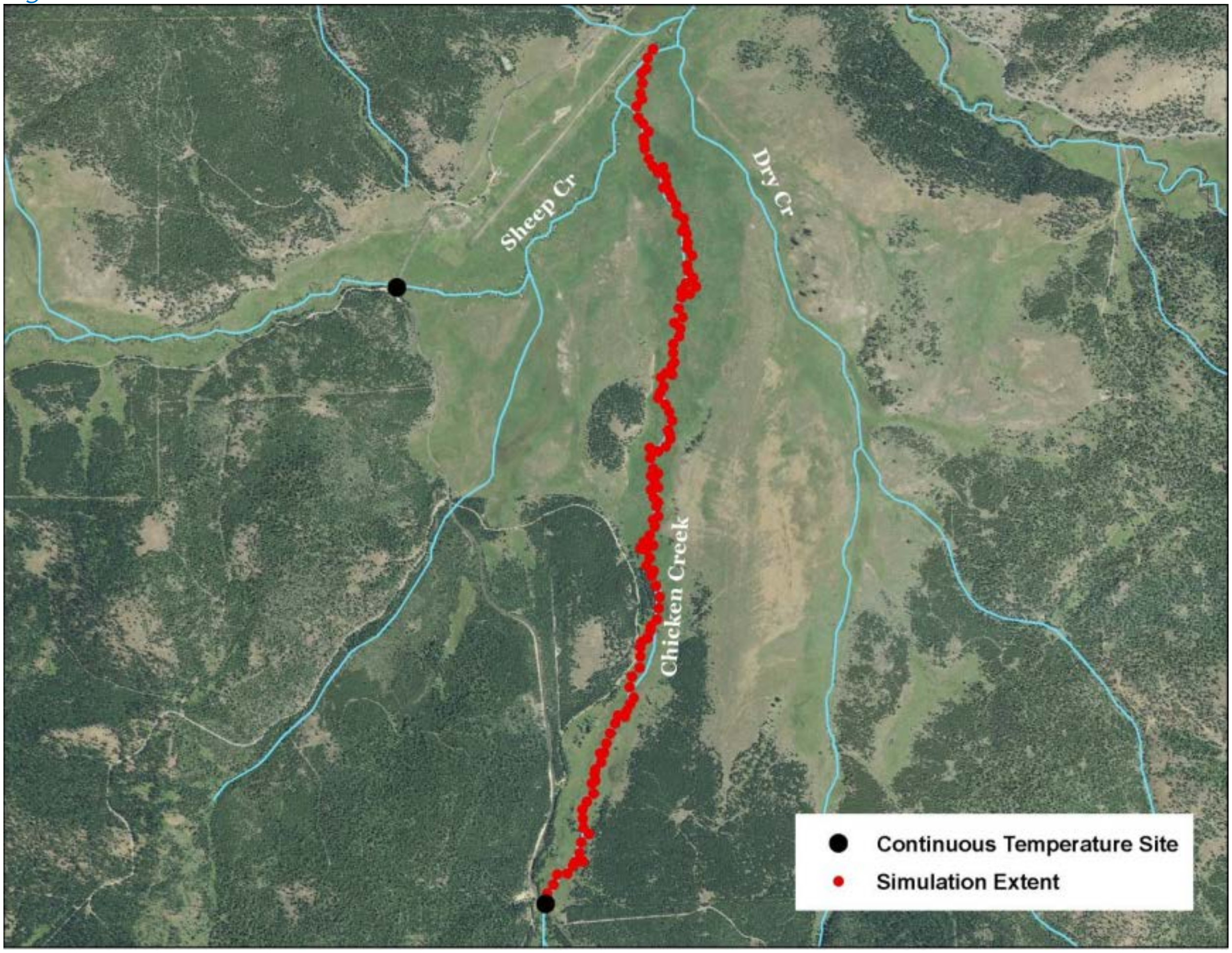


Table 22 – Chicken Creek general Heat Source parameters.

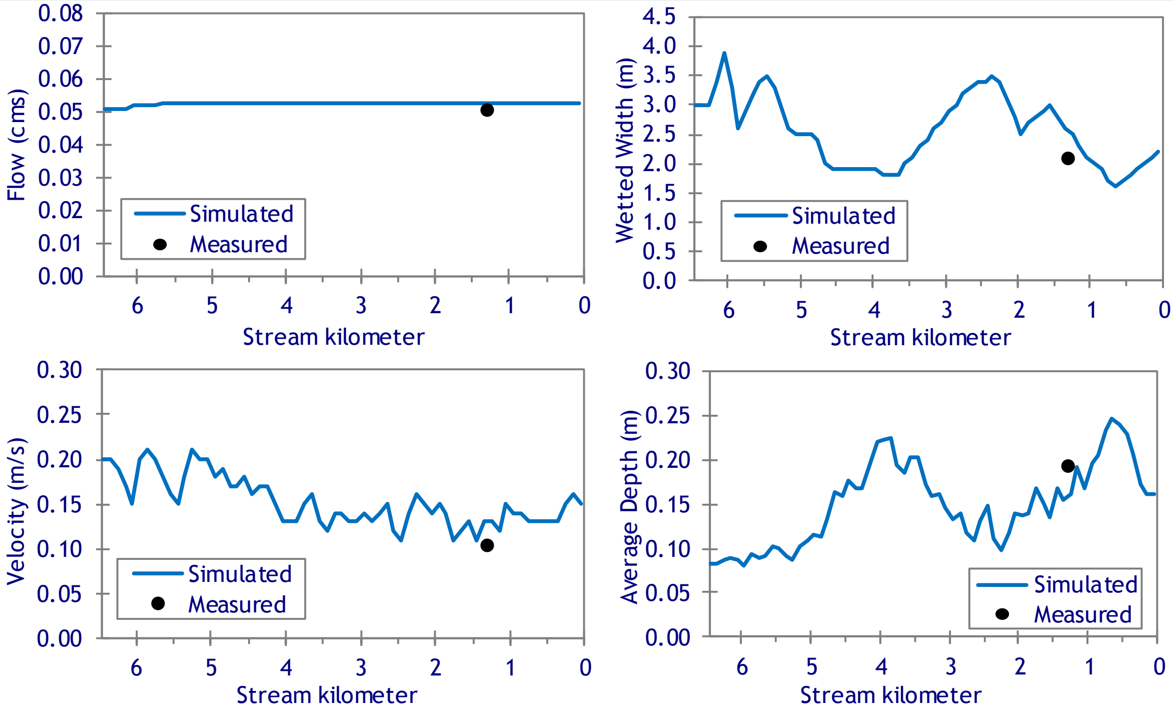
Stream:	Chicken Creek
Length:	6.5 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 15:30-15:34
Land Cover Data Source:	Manually Digitized
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Chicken Creek Heat Source model:

- Hourly climate data were obtained from the J Ridge RAWS (USFS) site. Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- The stream was too small to digitize the banks from the remote sensing imagery. Several measurements were made from the NAIP images and the in-between values were interpolated for each 50-meter model node.
- Daily flow variability was extrapolated from Grande Ronde River gage data.
- The only available hourly temperature data were for the upstream boundary condition, therefor there is no hourly calibration validation. This model is calibrated strictly to the TIR data, which increases the uncertainty associated with it.
- Since there was no LiDAR available, the near stream land cover was digitized within a 100-meter buffer of the stream. Height estimates were applied based on values observed in the LiDAR data along other streams in the vicinity.

Figure 141 shows the simulated hydraulic parameters for Chicken Creek for August 19, 2010.

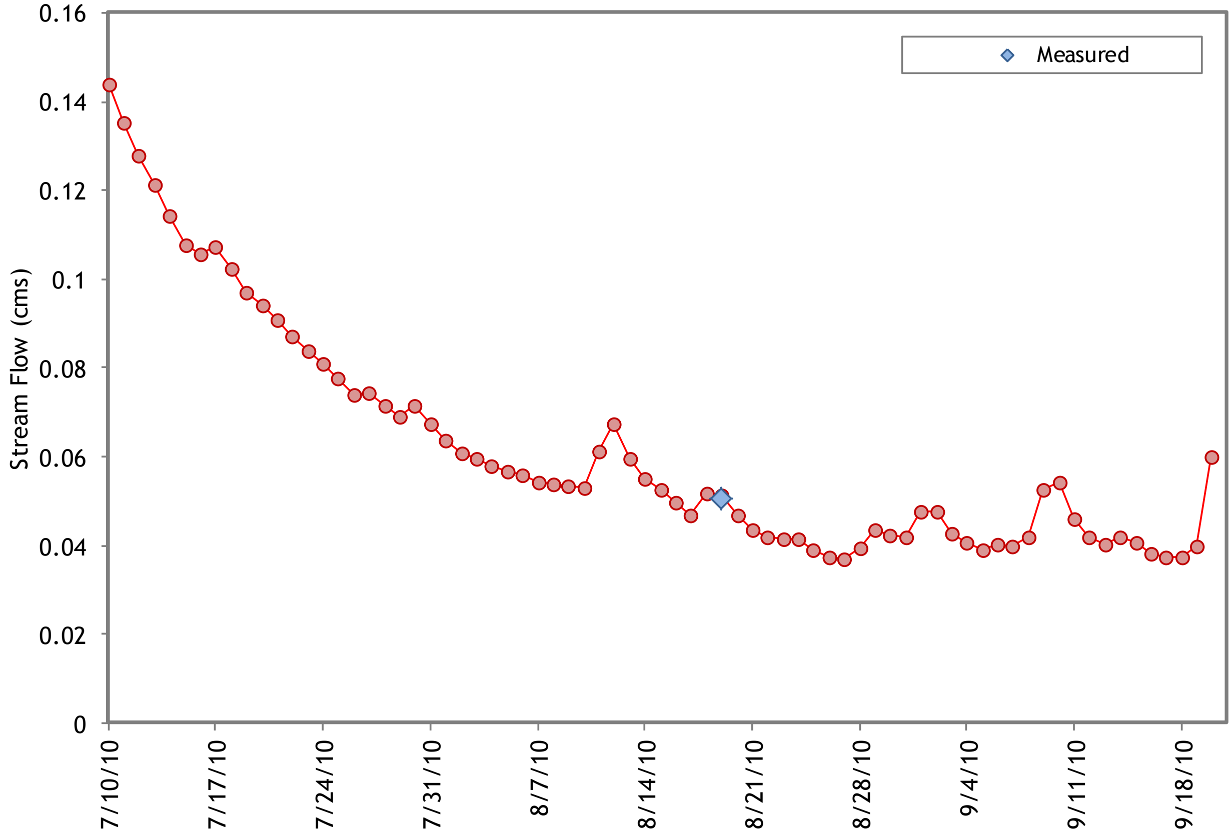
Figure 141 – Chicken Creek simulated hydraulic values.



Site	Stream Km	Date
Chicken Creek below forks	1.3	8/19/2010

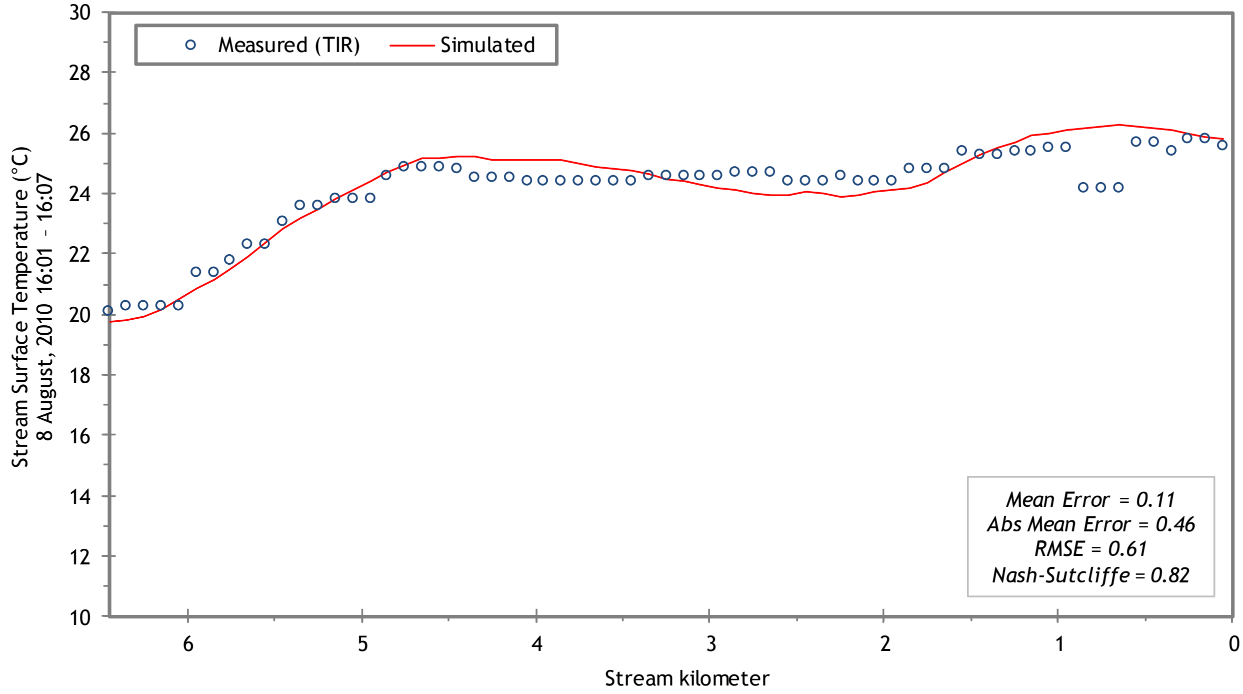
Figure 142 shows the simulated and measured flows near the mouth of Chicken Creek. Since there were no tributaries or diversions, this is also the flow for the entire simulation length. The values were extrapolated through back-calculations from Sheep Creek. The measured flow on August 19, 2010 below the forks was 0.05 cms (1.8 cfs).

Figure 142 – Chicken Creek measured and simulated flow volumes near the mouth.



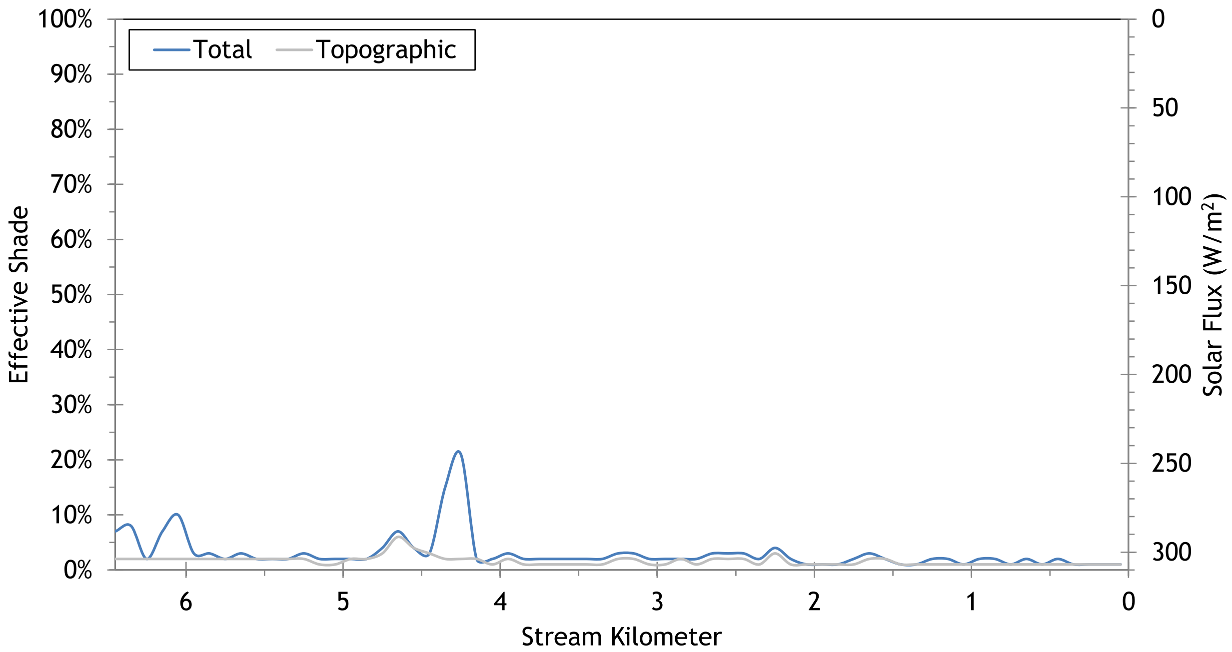
The simulated and measured longitudinal temperatures for Chicken Creek are presented in Figure 143. It appears that the stream heated more rapidly once it entered the open meadow, and then reached a maximum temperature of approximately 25°C.

Figure 143 – Chicken Creek simulated and measured longitudinal stream temperatures.



The lower 6.5 kilometers of Chicken Creek flow through mostly open meadow and hence there is very little effective shade (Figure 144). See Appendix for effective shade maps.

Figure 144 – Chicken Creek simulated effective shade.



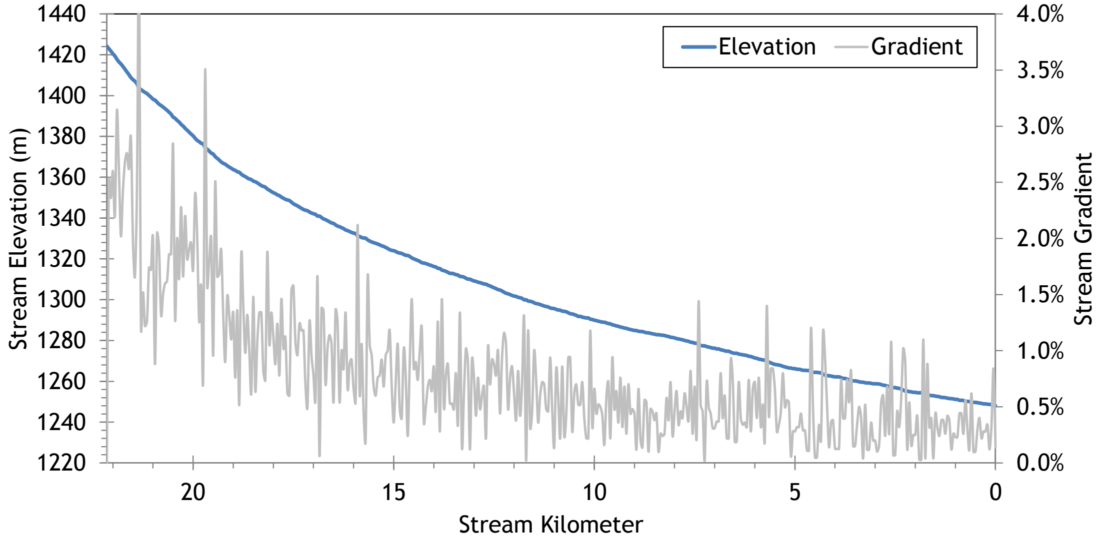
5.11 Sheep Creek

RGB-colored LiDAR point cloud - Sheep Creek downstream of East Sheep Creek (looking upstream).

5.11.1 Sheep Creek TTools Results

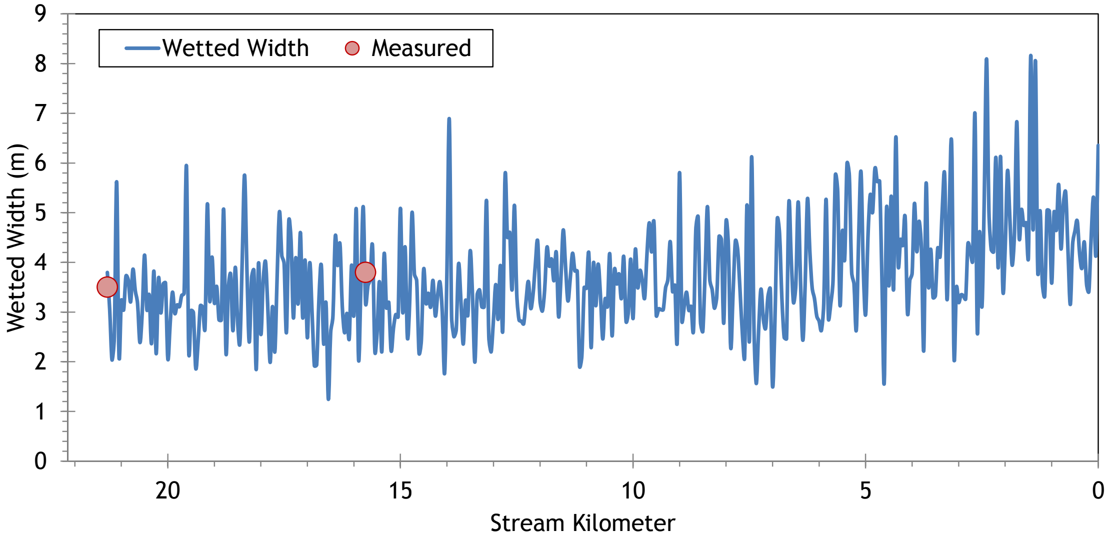
Sheep Creek elevations and gradients were sampled from the bare earth LiDAR data (Figure 145). The stream is steeper in the upper 7 kilometers, while the lower 15 kilometers meander more through a less confined valley.

Figure 145 – Sheep Creek elevation and gradient.



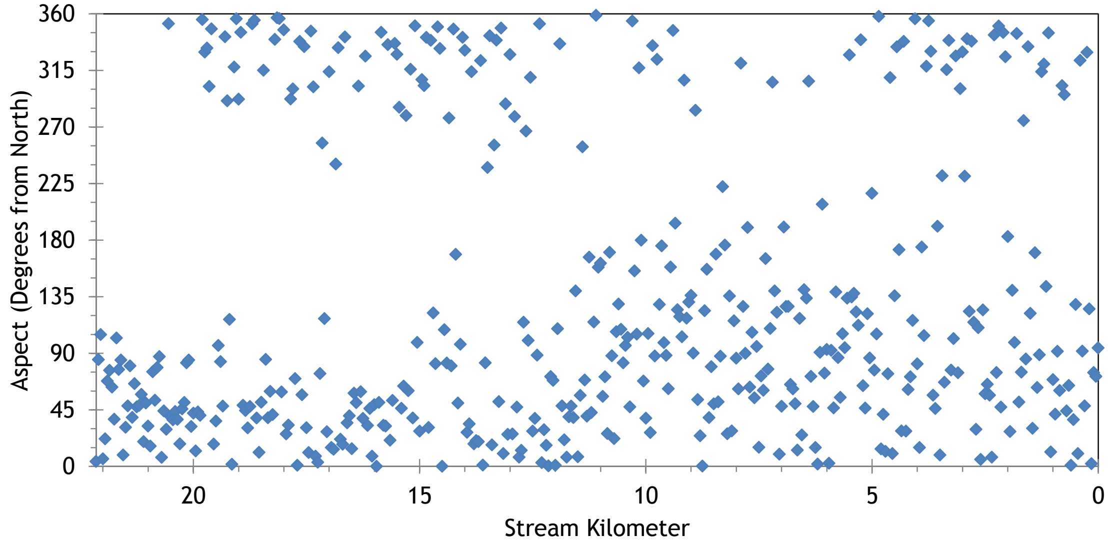
Sheep Creek wetted widths were digitized from the LiDAR intensity, TIR, and NAIP images. Figure 146 shows the sampled and measured values. Sheep Creek is a small stream, with wetted widths between about 3 and 5 meters on average during the simulation time period.

Figure 146 – Sheep Creek wetted widths.



The stream aspect for every 50 meters of Sheep Creek is presented in Figure 147. The stream is oriented northeasterly.

Figure 147 – Sheep Creek stream aspect.



Topographic shade angles for Sheep Creek are shown in Figure 148. There is a moderate amount of topographic shade produced by surrounding mountains.

Figure 148 – Sheep Creek topographic shade angles.

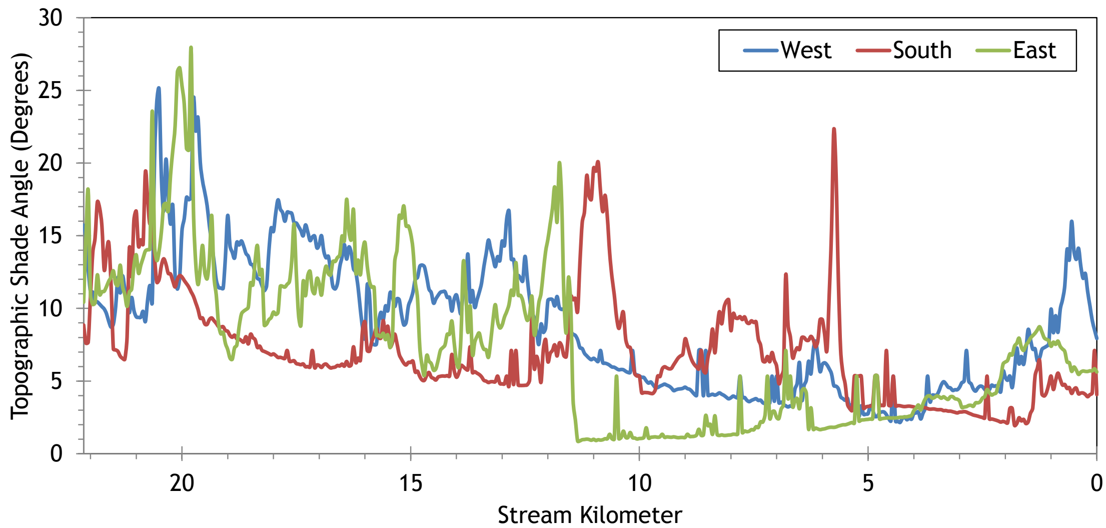
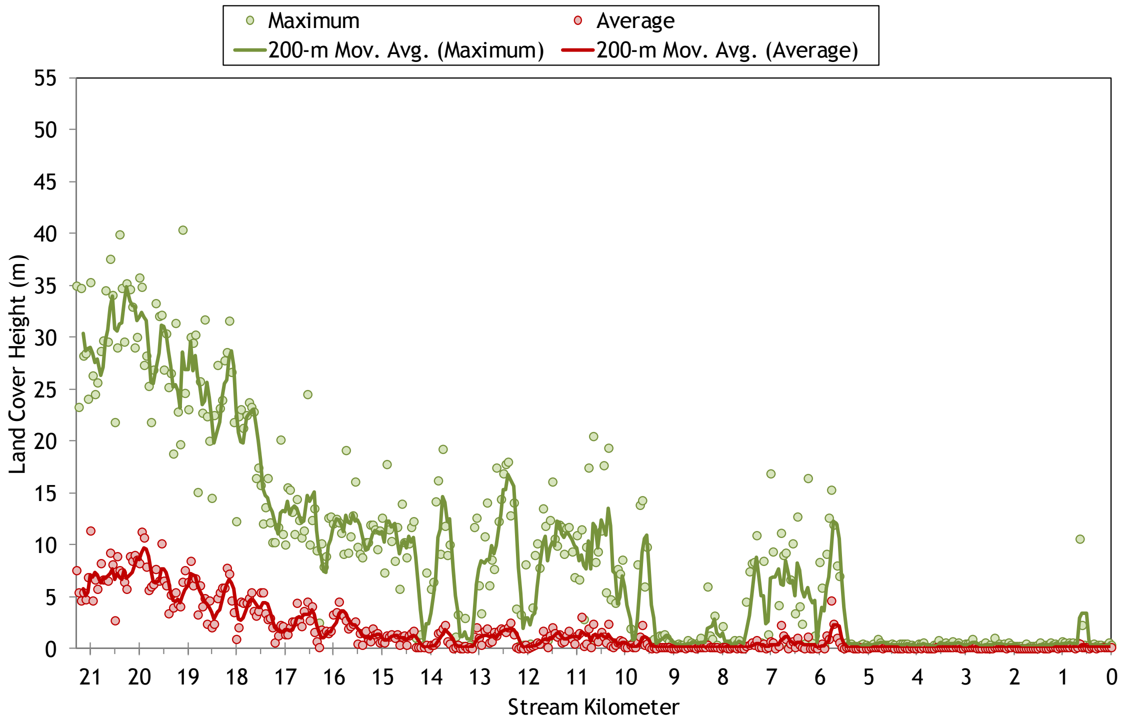


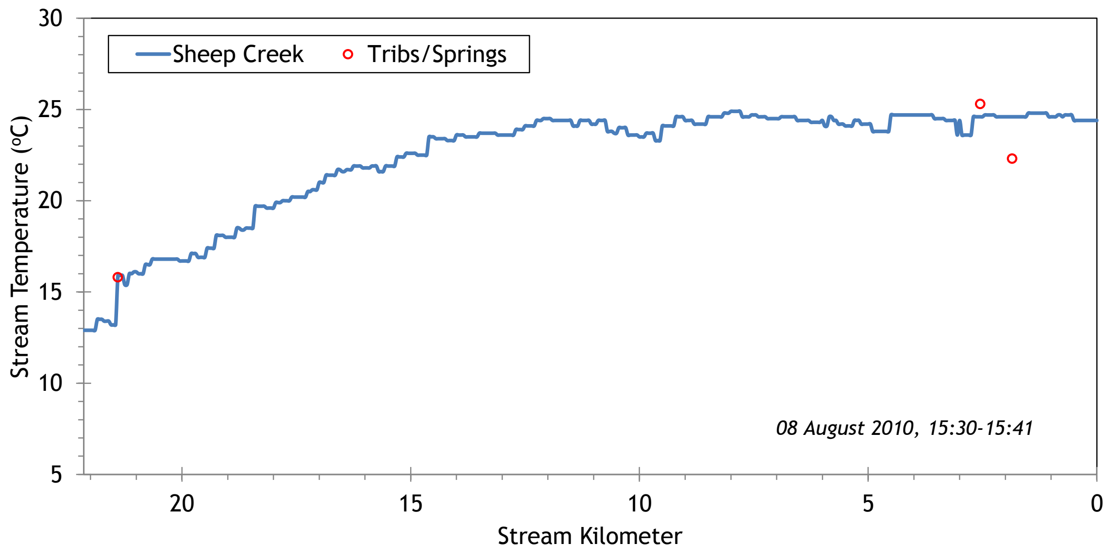
Figure 149 shows the land cover heights sampled along Sheep Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 149 – Sheep Creek land cover heights sampled from highest hit LiDAR.



The TIR stream temperature profile of Sheep Creek is presented in Figure 150. The stream gained about 10°C between kilometers 20 and 14, and then remained around 25°C until the mouth during the TIR flight.

Figure 150 – Sheep Creek TIR stream temperature profile.



5.11.2 Sheep Creek Heat Source Calibration Results

Sheep Creek stream temperatures were simulated from East Sheep Creek to the mouth (Figure 151).

Figure 151 – Sheep Creek simulation extent.

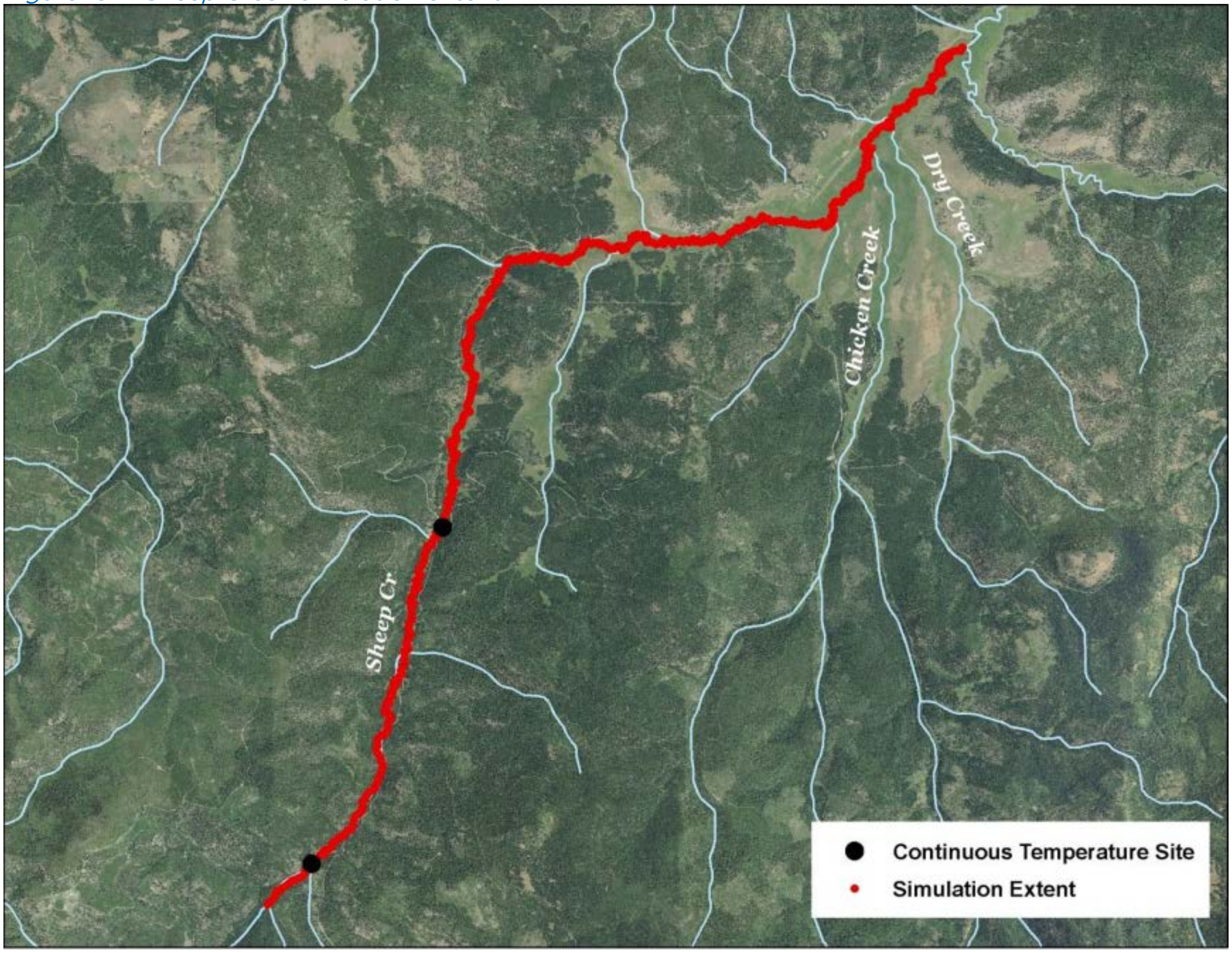


Table 23 – Sheep Creek general Heat Source parameters.

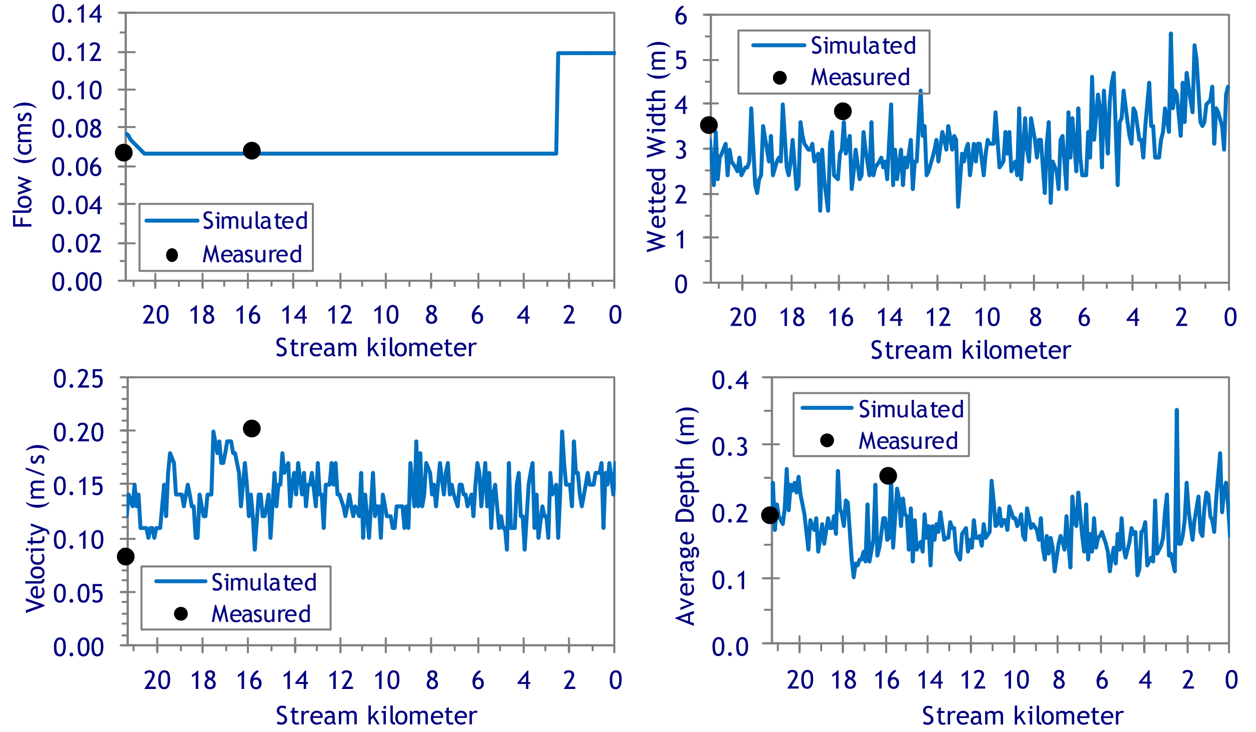
Stream:	Sheep Creek
Length:	21.3 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 15:29-15:40
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Sheep Creek Heat Source model:

- Hourly climate data were obtained from the J Ridge RAWS (USFS) site. Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Daily flow variability was extrapolated from Grande Ronde River gage data.

Figure 152 shows the simulated and measured hydraulic values for the calibrated Sheep Creek model. There were only two available ground level data points, one of which was at the upstream boundary of the model. The data were plotted for August 19, 2010 when the ground level measurements were taken.

Figure 152 – Sheep Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Sheep Creek below East Sheep Creek	21.3	8/19/2010
Sheep Creek Gage	15.75	8/19/2010

The simulated daily flow volumes at a point about 15.8 km from the mouth of Sheep Creek simulation extent are shown in Figure 153. Daily values were extrapolated based on gage data from the Grande Ronde River. No field measurements were recorded at the mouth of Sheep Creek; however measurements were taken in the upper reaches.

Figure 153 – Sheep Creek measured and simulated flow volumes at approximately 15.8 km from the mouth.

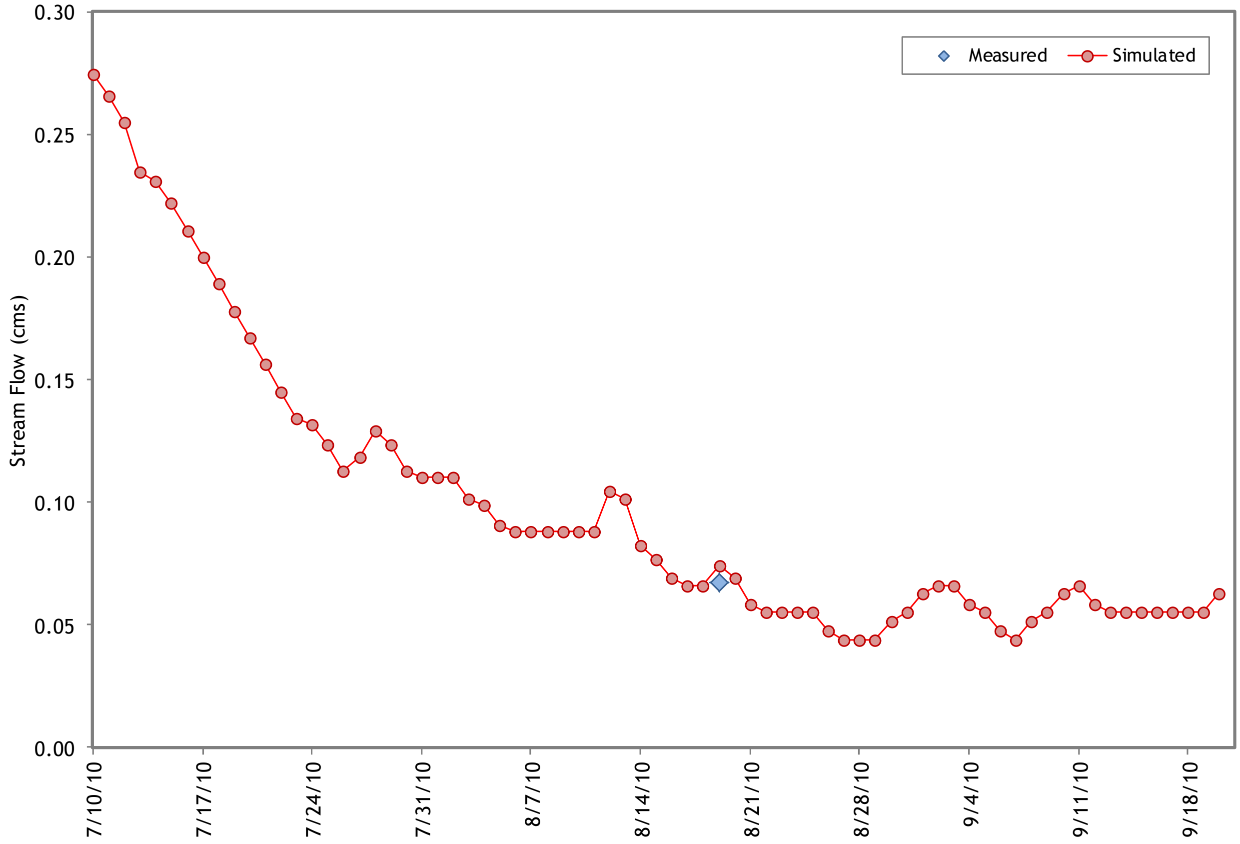


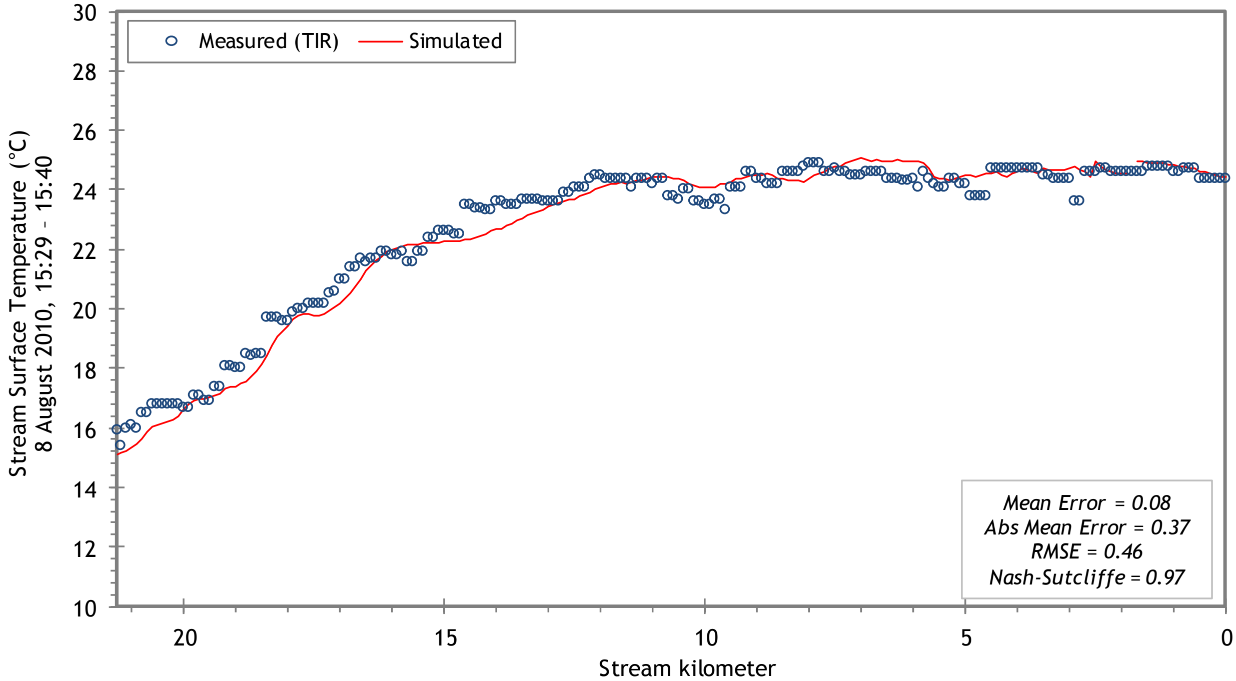
Table 24 summarizes the mass inflow input for the Sheep Creek model. There was only one significant tributary observed in the TIR data, which was Chicken Creek. There were no measured data available for Chicken Creek at the mouth, so the simulation outputs from the Chicken Creek model were used a s inputs to the Sheep Creek model.

Table 24 – Chicken Creek mass inflow feature and assumption.

Feature	Stream Km	Assumptions
Chicken Creek	2.5	Used simulation outputs from Chicken Creek model as inputs to Sheep Creek model.

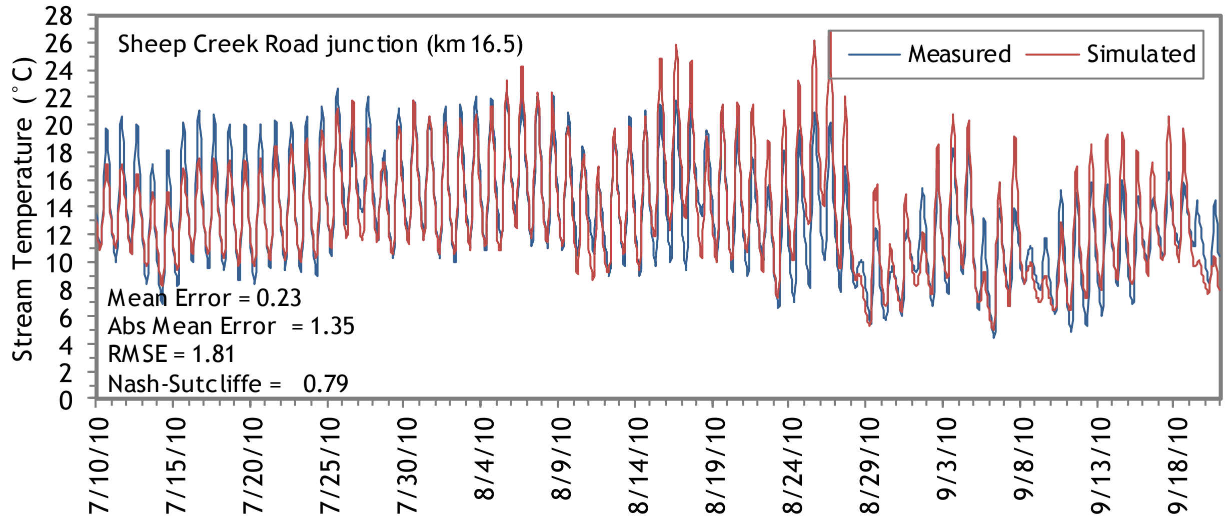
The simulated and measured longitudinal stream temperatures are shown in Figure 145. Validation statistics are also included within the plot.

Figure 154 – Sheep Creek simulated and measured longitudinal stream temperatures.



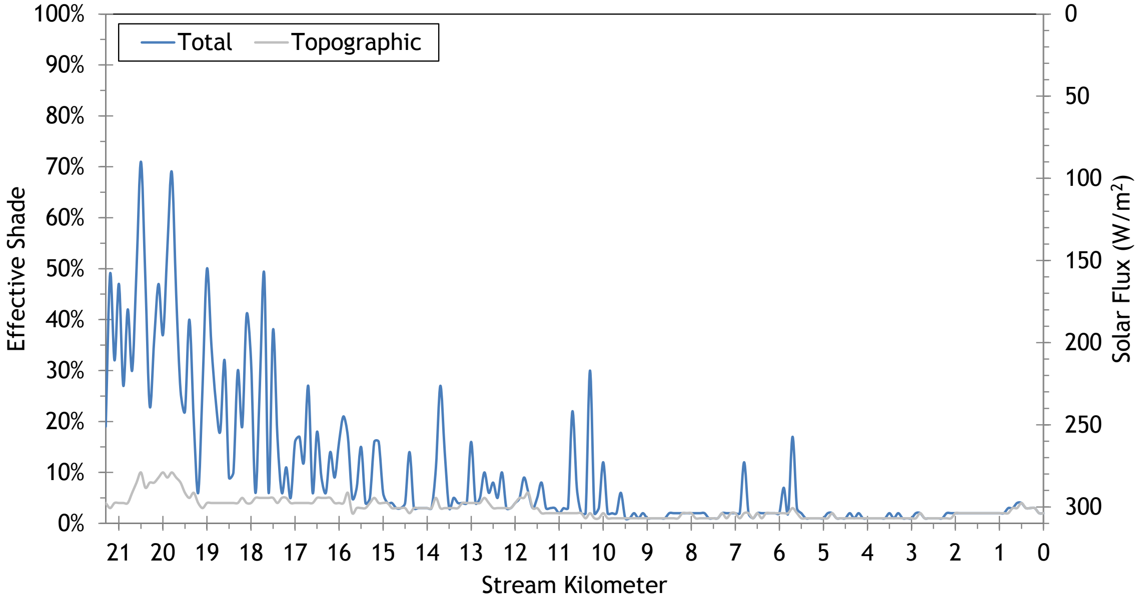
There was one site where measured hourly temperature data was available (stream kilometer 16.5). Figure 155 compares the measured and simulated hourly temperatures at that site. Validation statistics are also included in the figure.

Figure 155 – Sheep Creek simulated and measured hourly stream temperatures.



Simulated effective shade values are shown in Figure 156. Sheep Creek flows from more forested areas into wide open valley bottom meadows, so effective shade decreases in the lower reaches where there are very few trees. See Appendix for effective shade maps.

Figure 156 – Sheep Creek simulated effective shade.



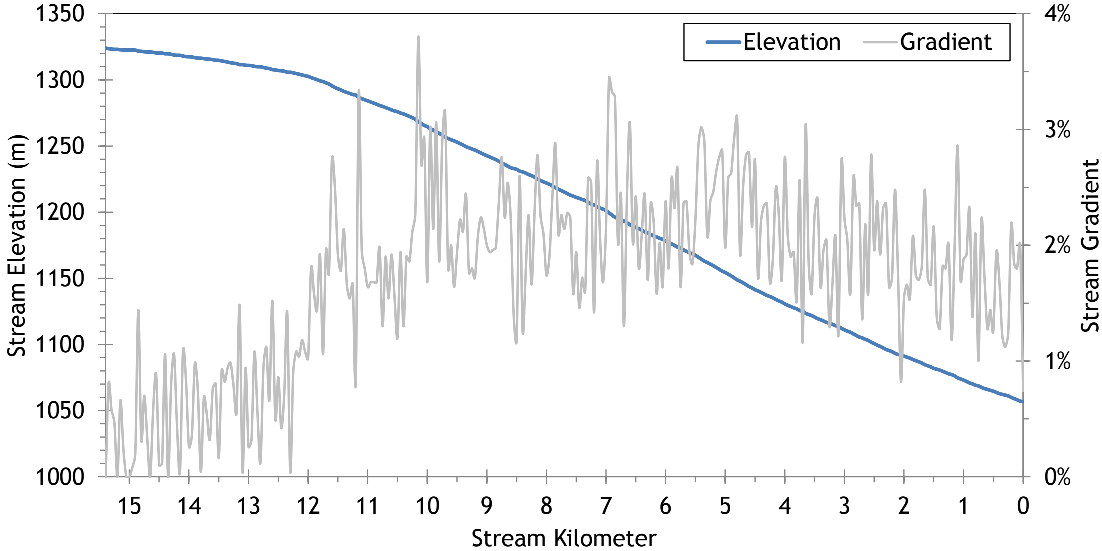
5.12 Fly Creek

RGB-colored LiDAR point cloud - Fly Creek just above mouth (looking upstream).

5.12.1 Fly Creek TTools Results

Fly Creek elevations and gradients are shown in Figure 157. The upper 4 kilometers flow through a low-gradient meadow. The gradients are higher in the lower 12 kilometers where the stream enters steeper and more confined valley terrain.

Figure 157 – Fly Creek elevation and gradient.



The wetted widths for Fly Creek were digitized from the LiDAR intensity, TIR, and NAIP imagery. Figure 158 shows the sampled and measured wetted widths. Overall, Fly Creek is a small stream with widths between about 3 and 5 meters.

Figure 158 – Fly Creek wetted widths.

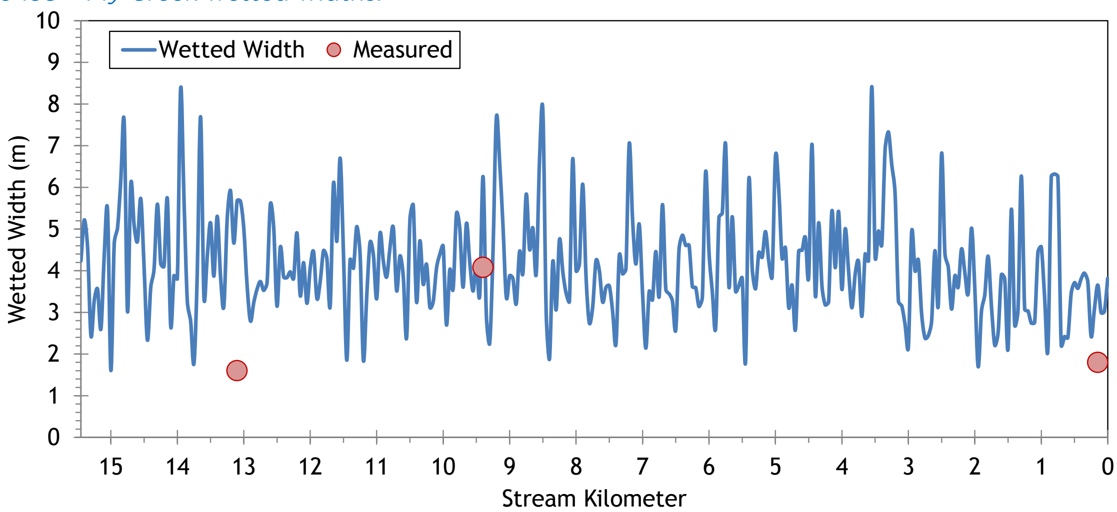
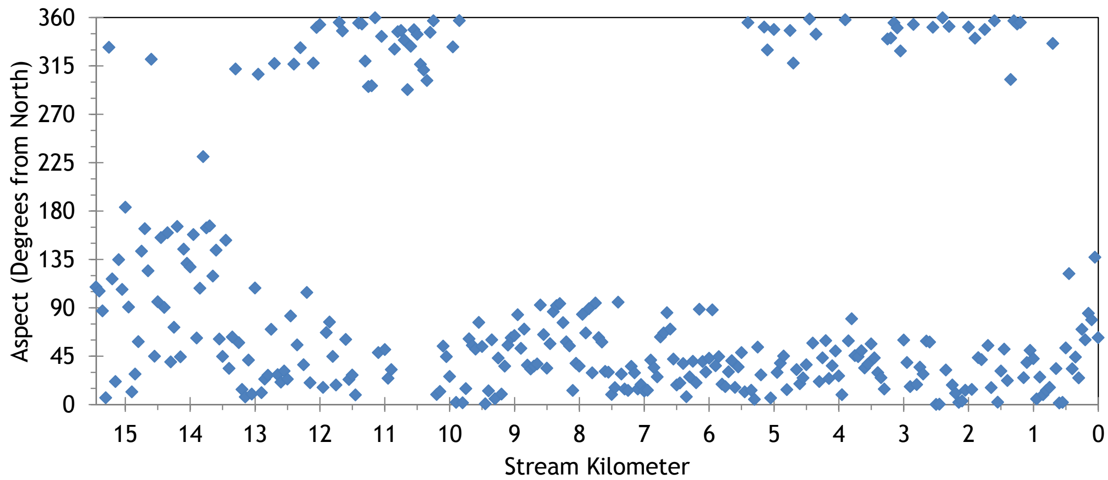


Figure 159 shows the stream aspect for every 50 meters of Fly Creek. The stream generally flows toward the northeast.

Figure 159 – Fly Creek stream aspect.



Fly Creek topographic shade angles are shown in Figure 160. The values for Fly Creek are relatively large, reaching up to 30 degrees in many locations.

Figure 160 – Fly Creek topographic shade angles.

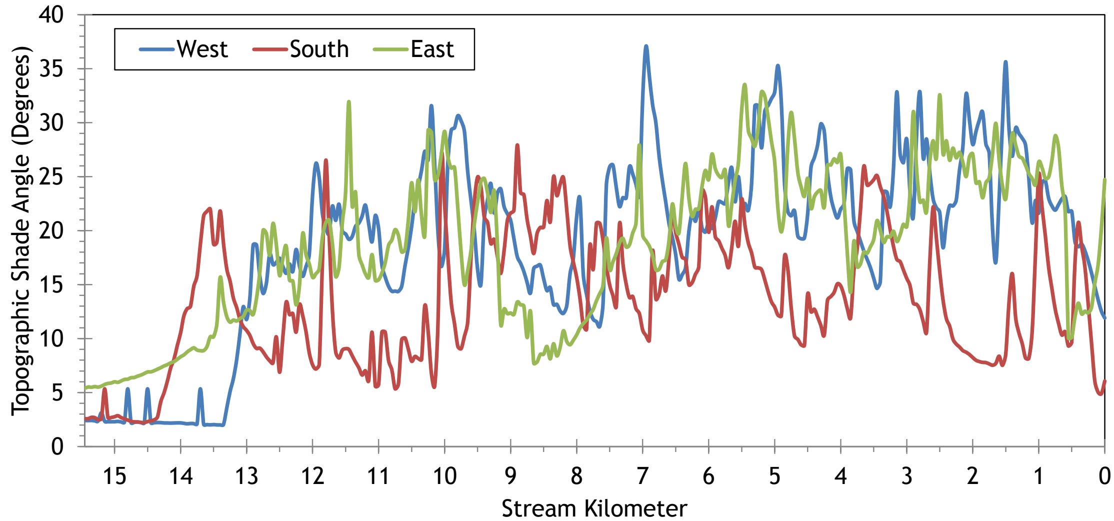
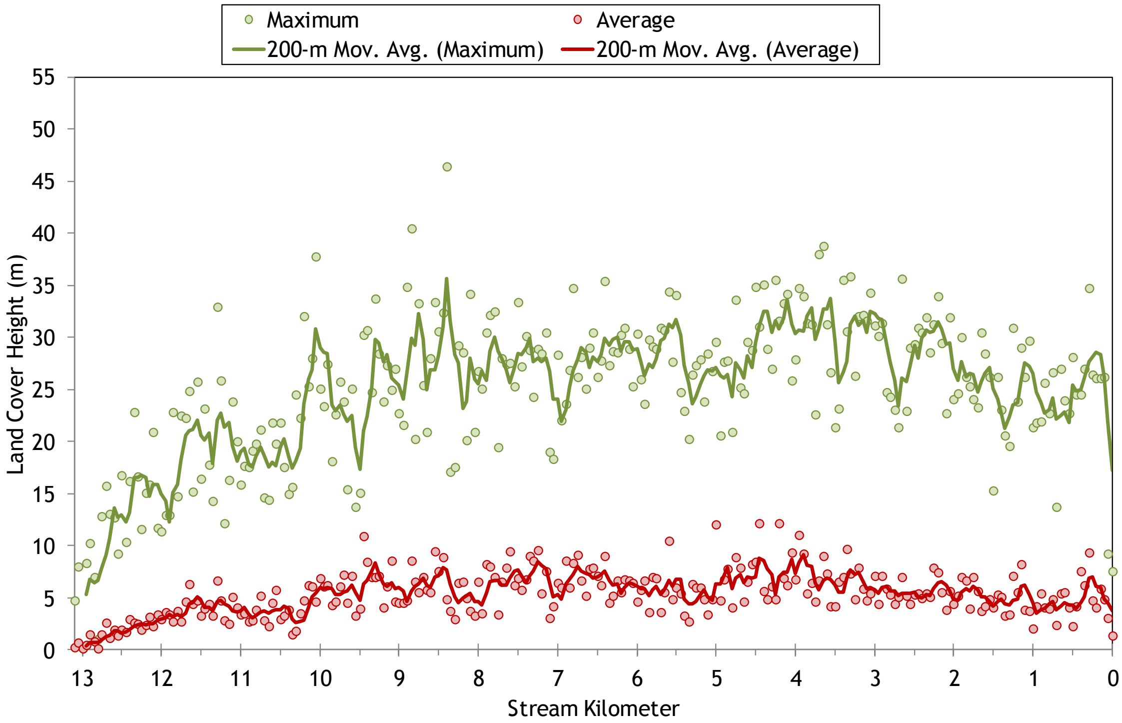


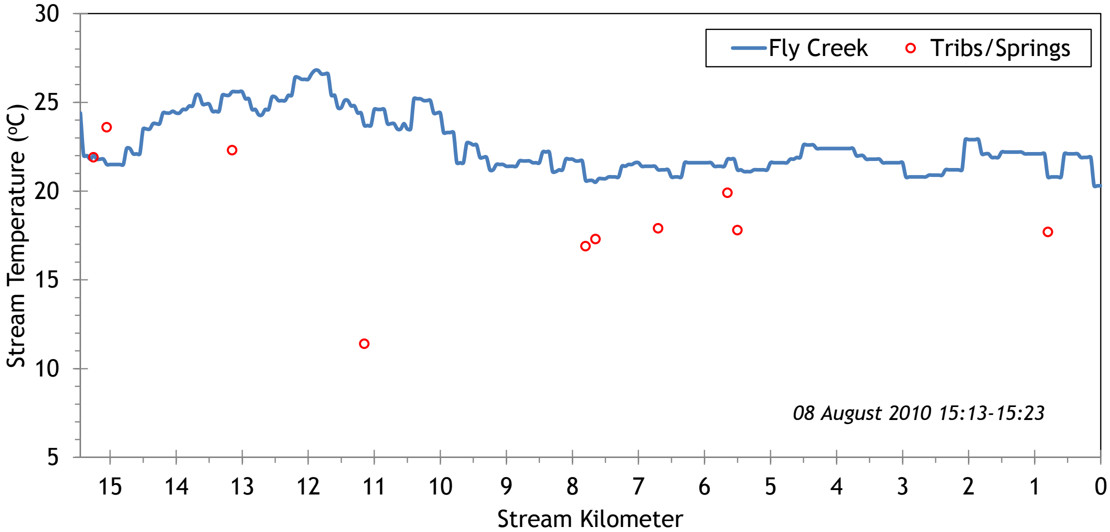
Figure 161 shows the land cover heights sampled along Fly Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 161 – Fly Creek land cover heights sampled from highest hit LiDAR.



The TIR stream temperature profile of Fly Creek is shown in Figure 162. Interestingly, the stream temperature drops slightly in the downstream direction. The upper reaches are lower gradient open meadow, so the temperatures become quite warm. Then the stream enters a steeper and more confined valley, where some of that heat is lost from the stream.

Figure 162 – Fly Creek TIR stream temperature profile.



5.12.2 Fly Creek Heat Source Calibration Results

Fly Creek was simulated from below Little Fly Creek to the mouth (Figure 163). The total simulation length was 13.1 kilometers.

Figure 163 – Fly Creek simulation extent.

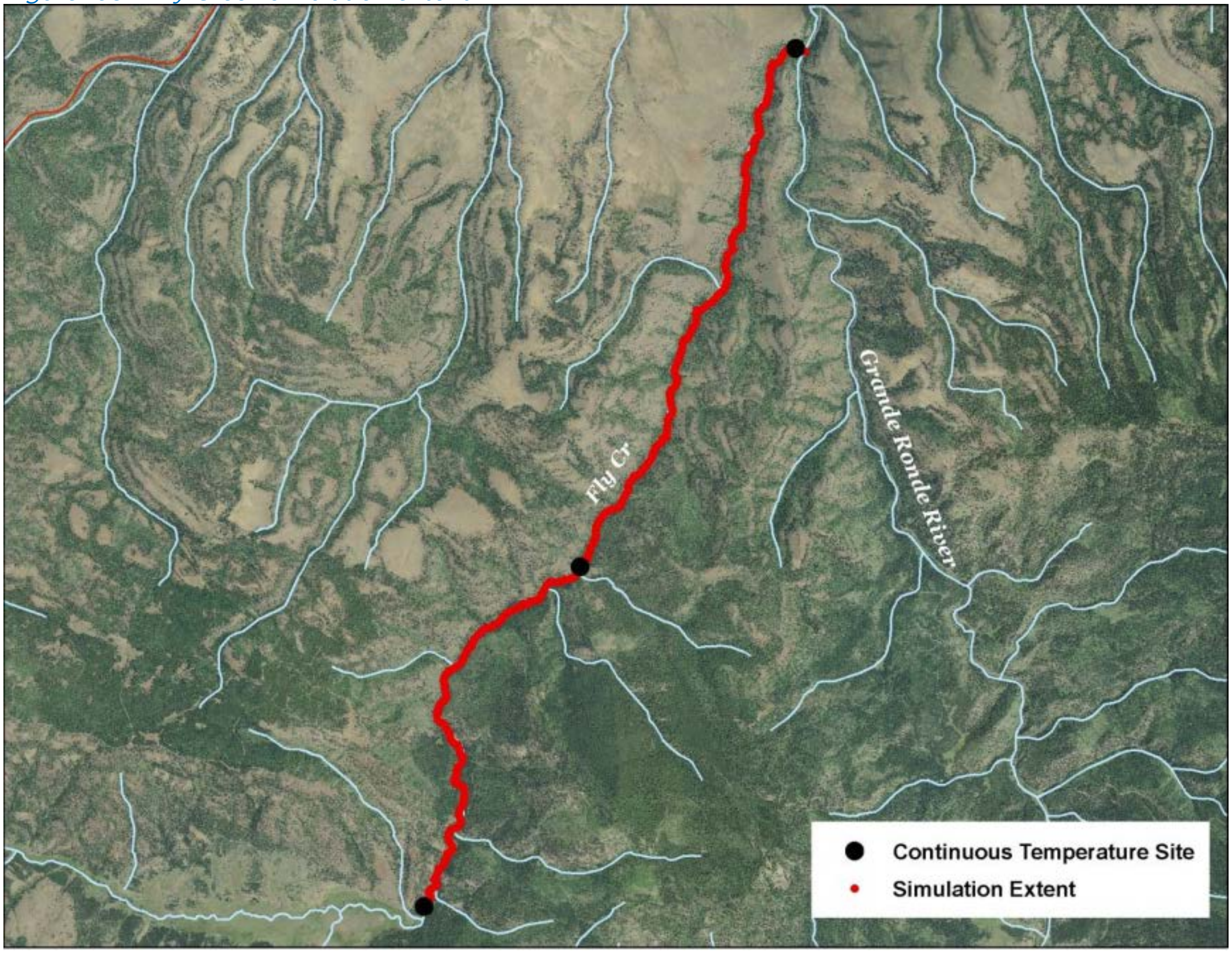


Table 25 – Fly Creek general Heat Source parameters.

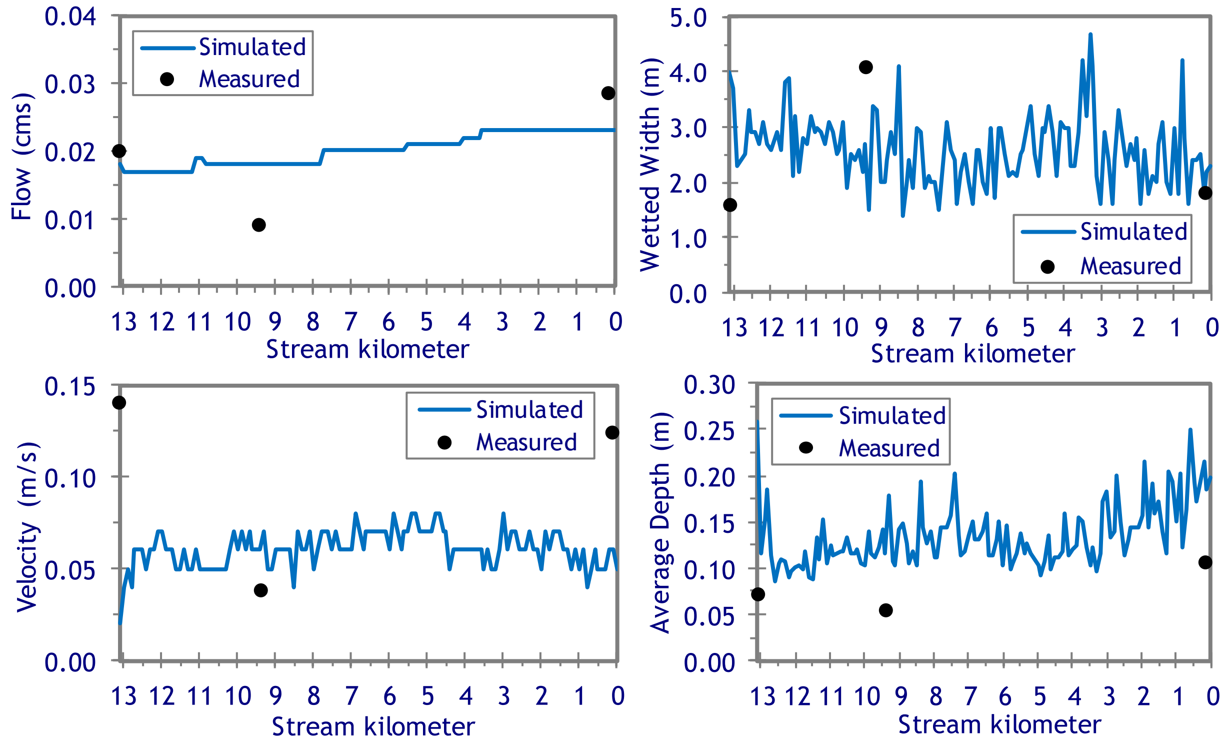
Stream:	Fly Creek
Length:	13.1 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 15:12-15:21
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Fly Creek Heat Source model:

- Hourly climate data were obtained from the J Ridge RAWS (USFS) site. Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Daily flow variability was extrapolated from Grande Ronde River gage data.
- The wetted widths were reduced 60%-70% from the raw TTools values in order to match the ground level measurements and calibrate the hydraulics.

Fly Creek's simulated and measured hydraulic values are shown in Figure 164. The simulated values are from August 18th, while the measured values' dates vary. There were three ground level measurement sites. The measurements at kilometer 9.4 were taken on August 26 and do not match the simulated values for August 18 as well.

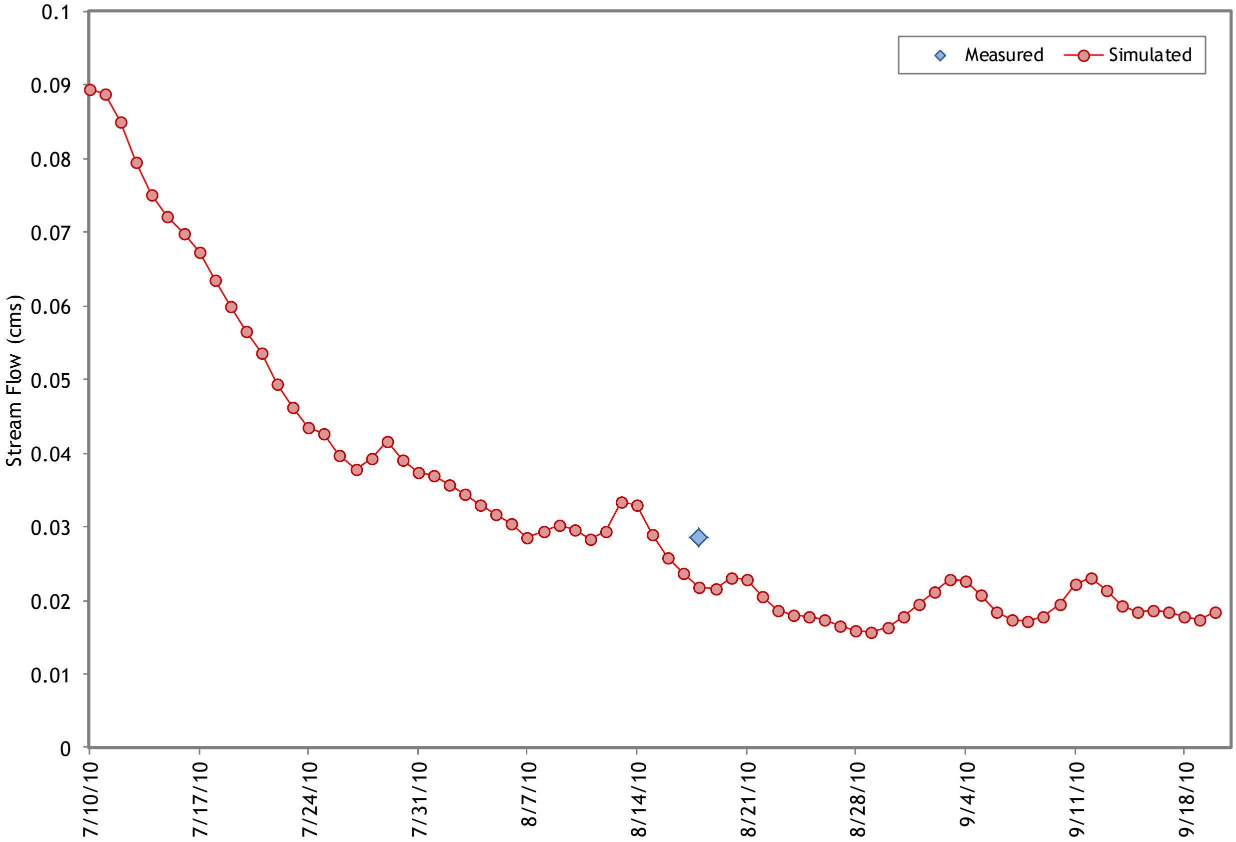
Figure 164 – Fly Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Fly Creek below Little Fly Creek	13.1	8/19/2010
Fly Creek Middle Section	9.4	8/26/2010
Fly Creek at Mouth	0.15	8/18/2010

The measured and simulated daily flows at the mouth of Fly Creek are shown in Figure 165. The daily values were extrapolated from gage data on the Grande Ronde River.

Figure 165 – Fly Creek measured and simulated flow volumes at the mouth.



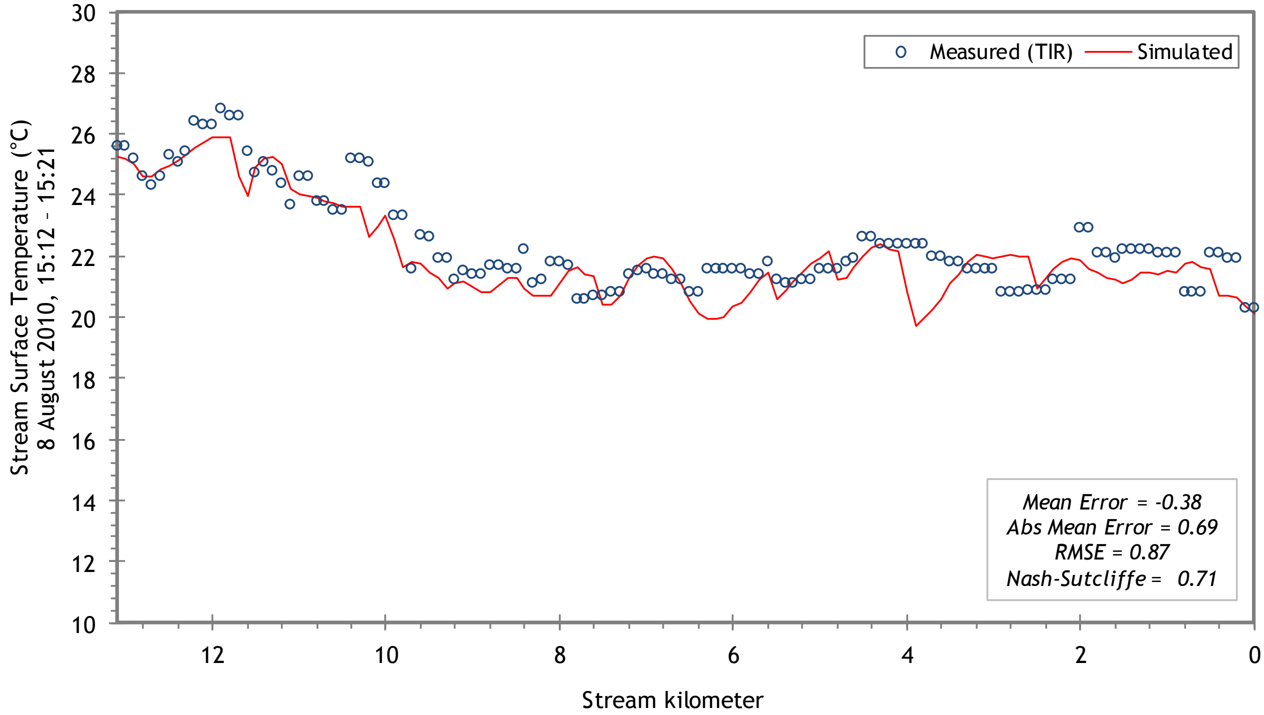
There were 2 springs and one tributary included within the Fly Creek model (Table 26). Their flow volumes were varied daily in order to mimic the variation assumed for the flows at the mouth of Fly Creek. Their temperatures were held at a constant value because of their insignificant volumes.

Table 26 – Fly Creek mass inflows and assumptions.

Feature	Stream Km	Assumptions
Spring	11.1	0.002-0.005 cms at constant 11.4ºC
Spring	7.7	0.002-0.005 cms at constant 16.9ºC
Unnamed Tributary	5.5	0.002-0.005 cms at constant 17.8ºC

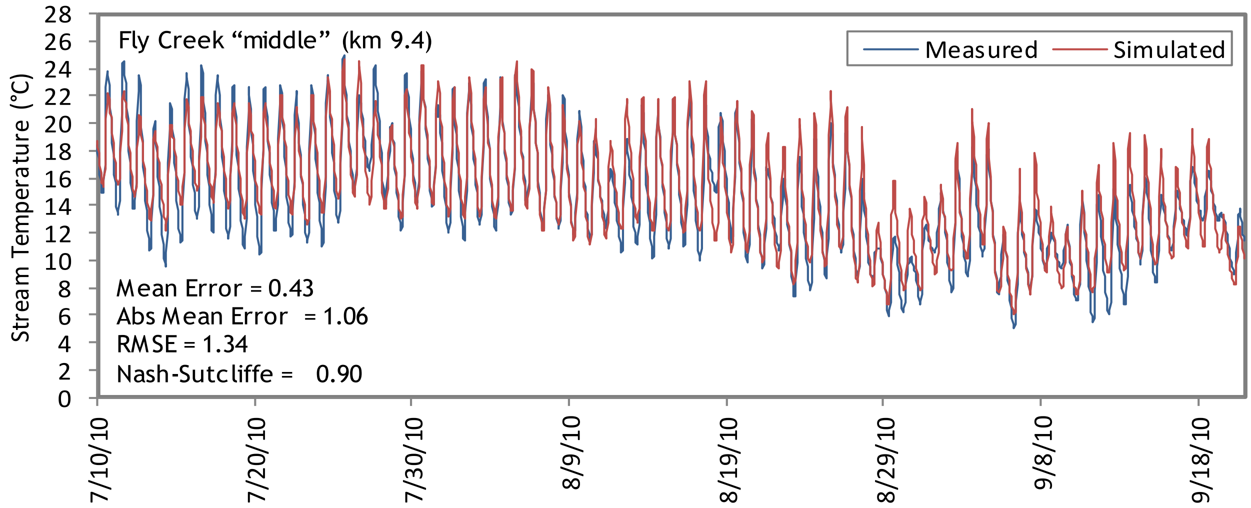
Figure 166 shows the simulated and measured longitudinal stream temperatures for Fly Creek. As previously mentioned, Fly Creek temperatures decline in the downstream direction because the stream is flowing from lower gradient meadows at the upper end into a more confined and steeper valley.

Figure 166 – Fly Creek simulated and measured longitudinal stream temperatures.



The simulated and measured hourly stream temperatures are presented in Figure 167.

Figure 167 – Fly Creek simulated and measured hourly stream temperatures.



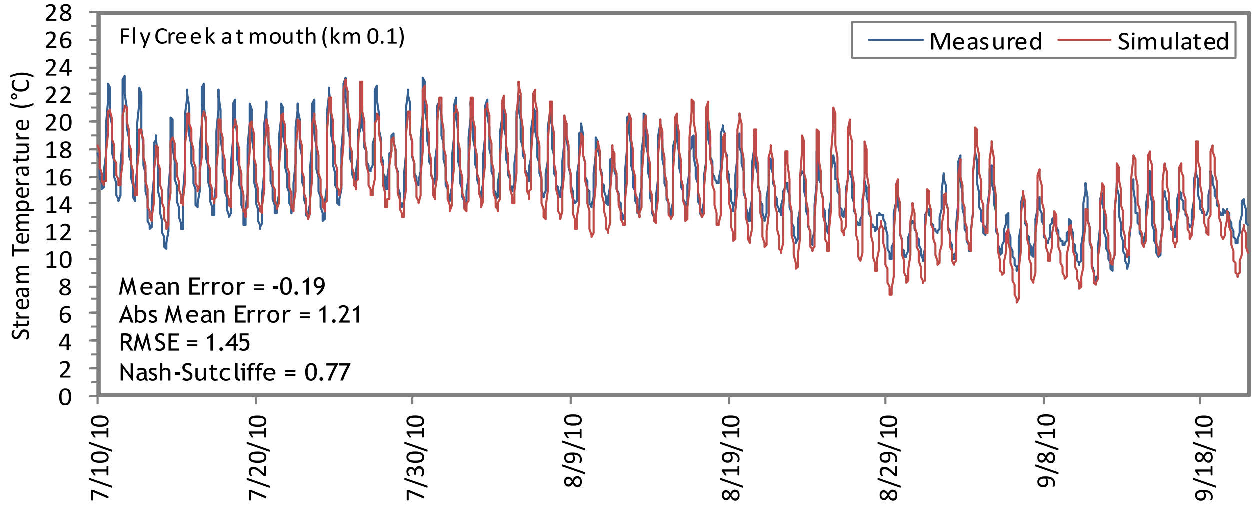
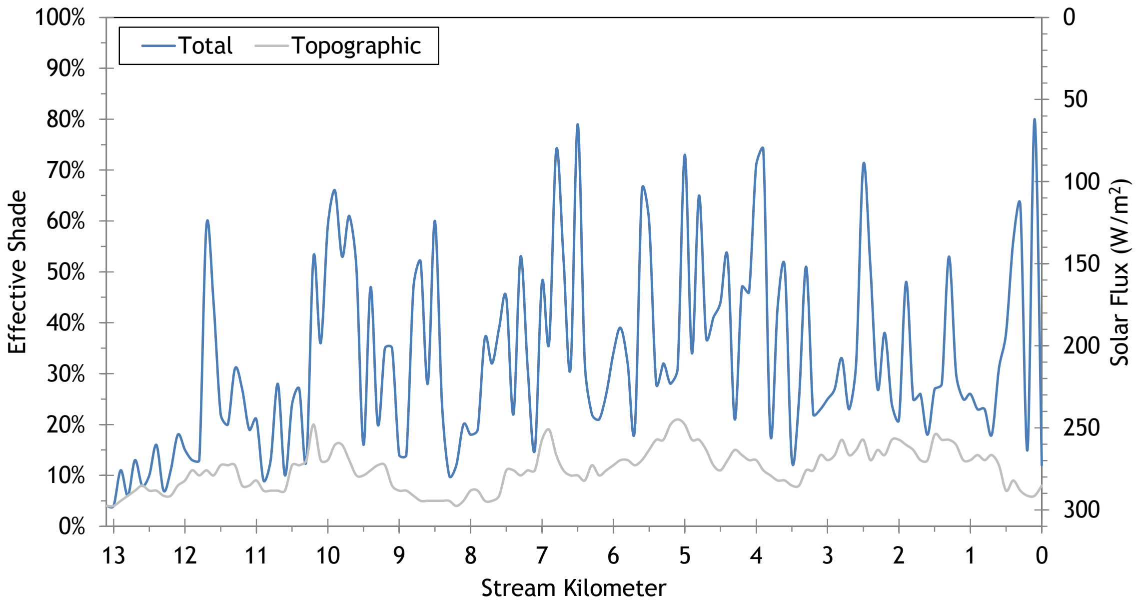


Figure 168 shows the simulated effective shade for Fly Creek. The upper few kilometers have less shade because the stream is flowing through a mixed meadow-forest complex. The lower 10 stream kilometers have more topographic shade and more total effective shade produced by the surrounding forest. See Appendix for effective shade maps.

Figure 168 – Fly Creek simulated effective shade.



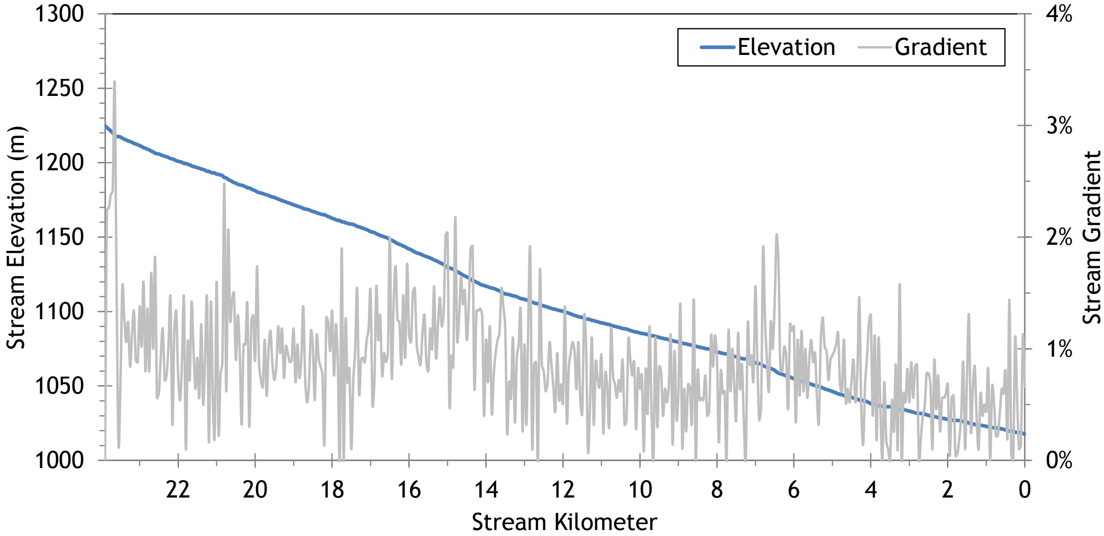
5.13 McCoy Creek

RGB-colored LiDAR point cloud - McCoy Creek just above mouth – the once channelized stream has been restored to its original channel.

5.13.1 McCoy Creek TTools Results

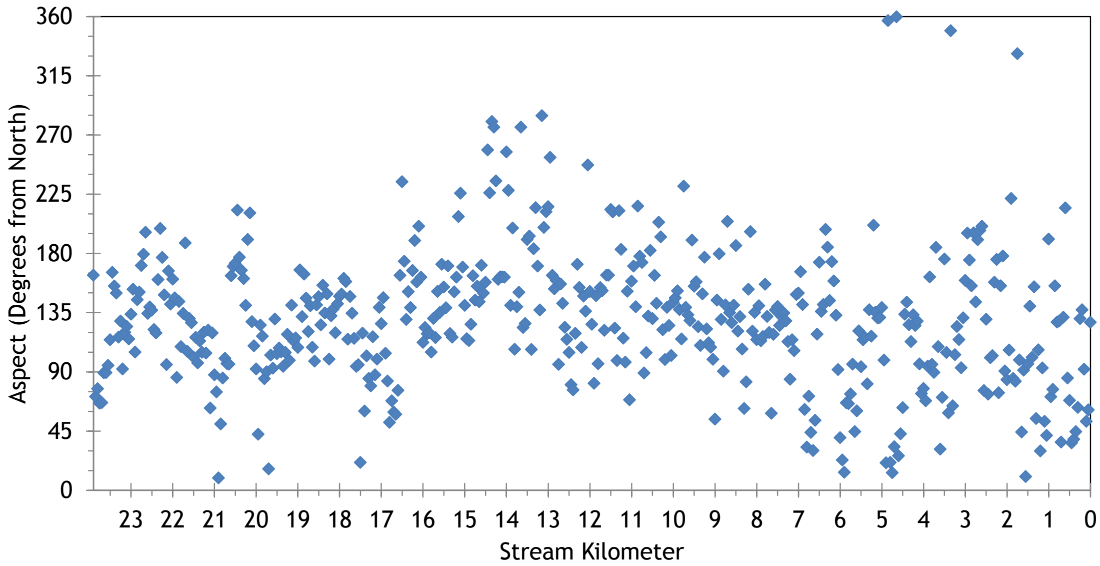
McCoy Creek elevations and gradients were sampled from the bare earth LiDAR data (Figure 169). The stream has a moderately low gradient due to the gradual elevation drop and meandering nature.

Figure 169 – McCoy Creek elevation and gradient.



McCoy Creek flows generally toward the southeast (Figure 170).

Figure 170 – McCoy Creek stream aspect.



Topographic shade is variable along McCoy Creek (Figure 171). As the stream enters more confined valleys, the topographic shade angles increase. In the lower 3.5 kilometers, the stream flows through a wide flat valley and has less topographic shade.

Figure 171 – McCoy Creek topographic shade angles.

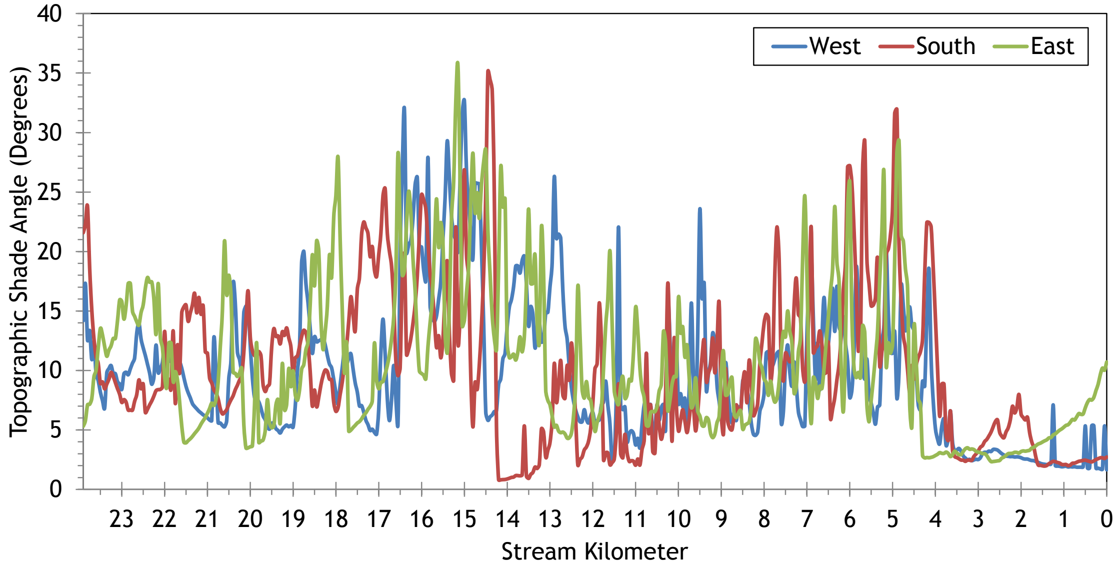


Figure 172 shows the land cover heights sampled along McCoy Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 172 – McCoy Creek land cover heights sampled from highest hit LiDAR.

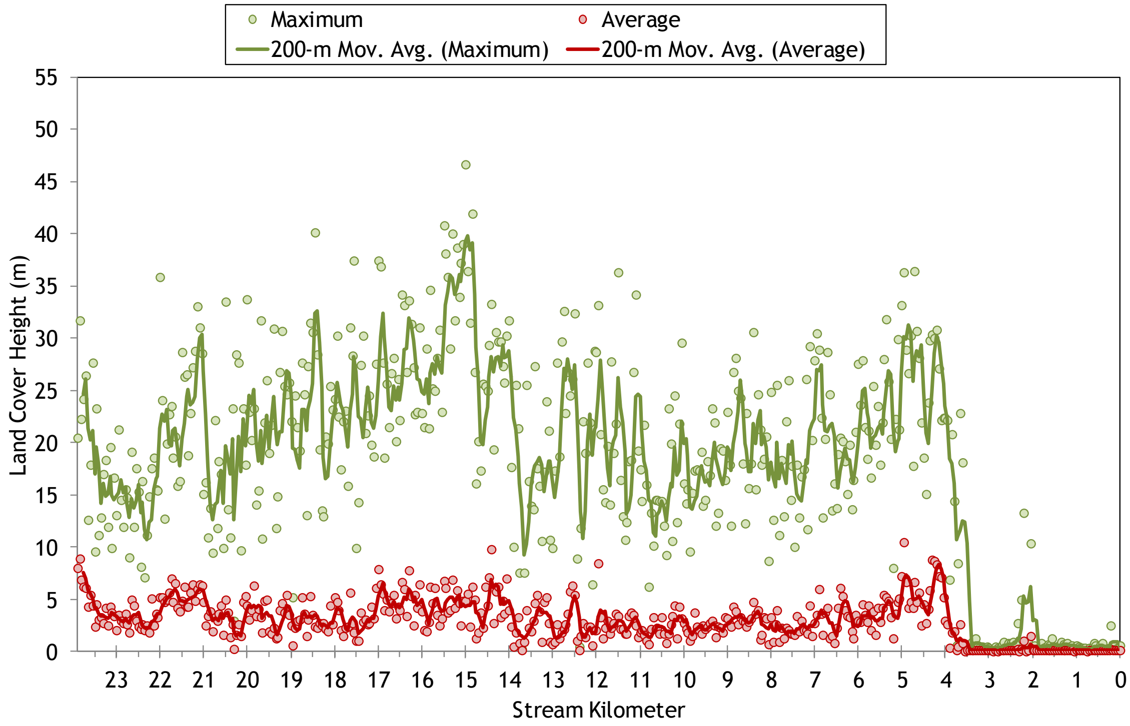
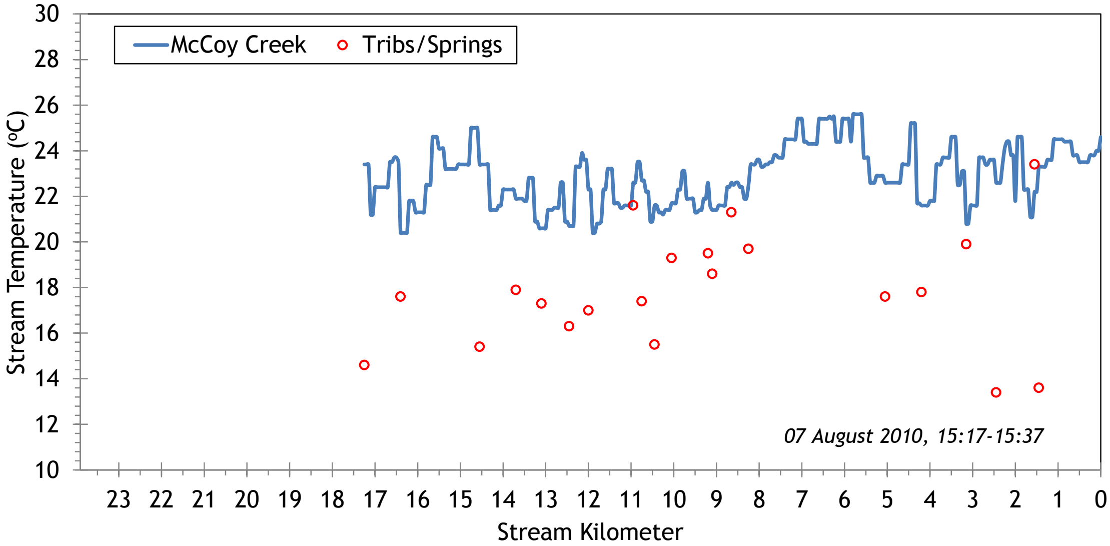


Figure 173 shows the TIR stream temperature profile of McCoy Creek. It is a fairly small stream with low summertime flows; therefore temperatures are fairly high and variable. The small flows (less than 1 cfs) are the main factor contributing to the highly variable stream temperatures.

Figure 173 – McCoy Creek TIR stream temperature profile.



5.13.2 McCoy Creek Heat Source Calibration Results

McCoy Creek effective shade was simulated for the lower 23.9 stream kilometers. The flow was too low in August 2010 to simulate temperature.

Figure 174 - McCoy Creek simulation extent.

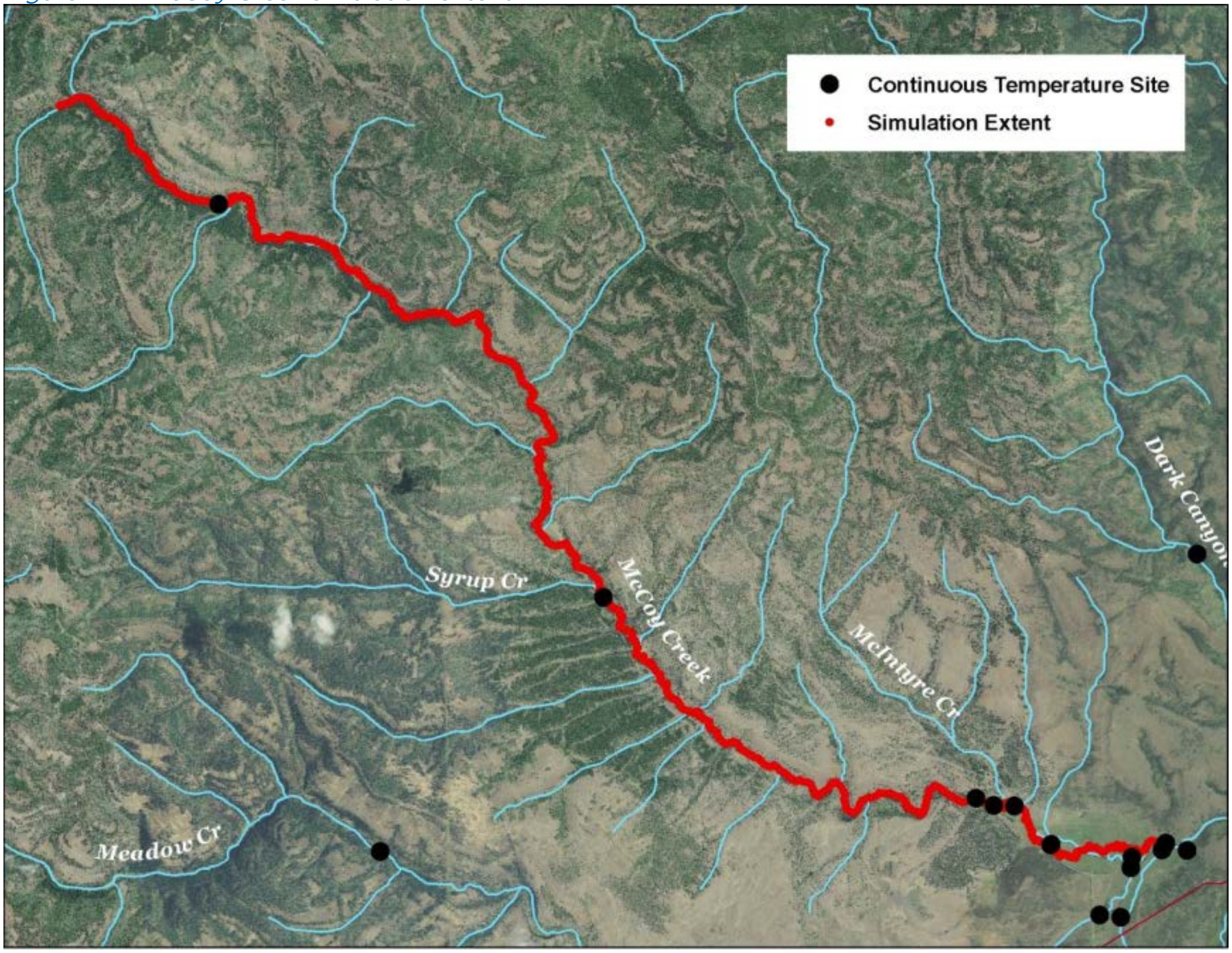


Table 27 – McCoy Creek general Heat Source parameters.

Stream:	McCoy Creek
Length:	23.9 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	NA
TIR Date and Time:	NA
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

Figure 175 shows the simulated effective shade values for McCoy Creek. There is moderate effective shade along most of the stream, and much of the total effective shade is often created by topographic features. The lower 4 kilometers are where the stream flows in open meadow and through the restoration area. See Appendix for effective shade maps.

Figure 175 – McCoy Creek simulated effective shade.

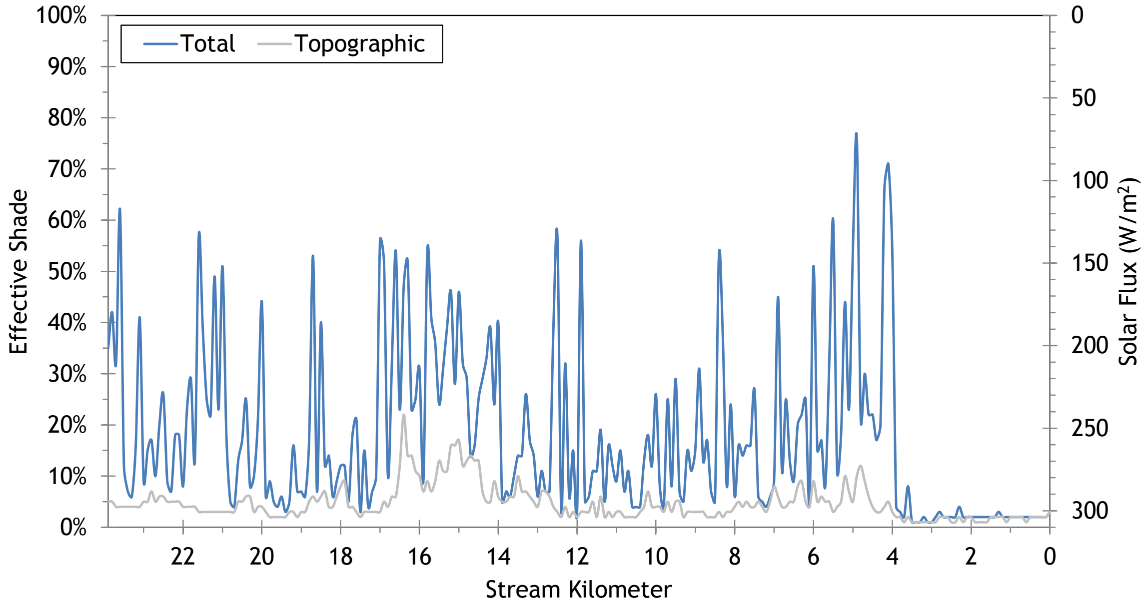
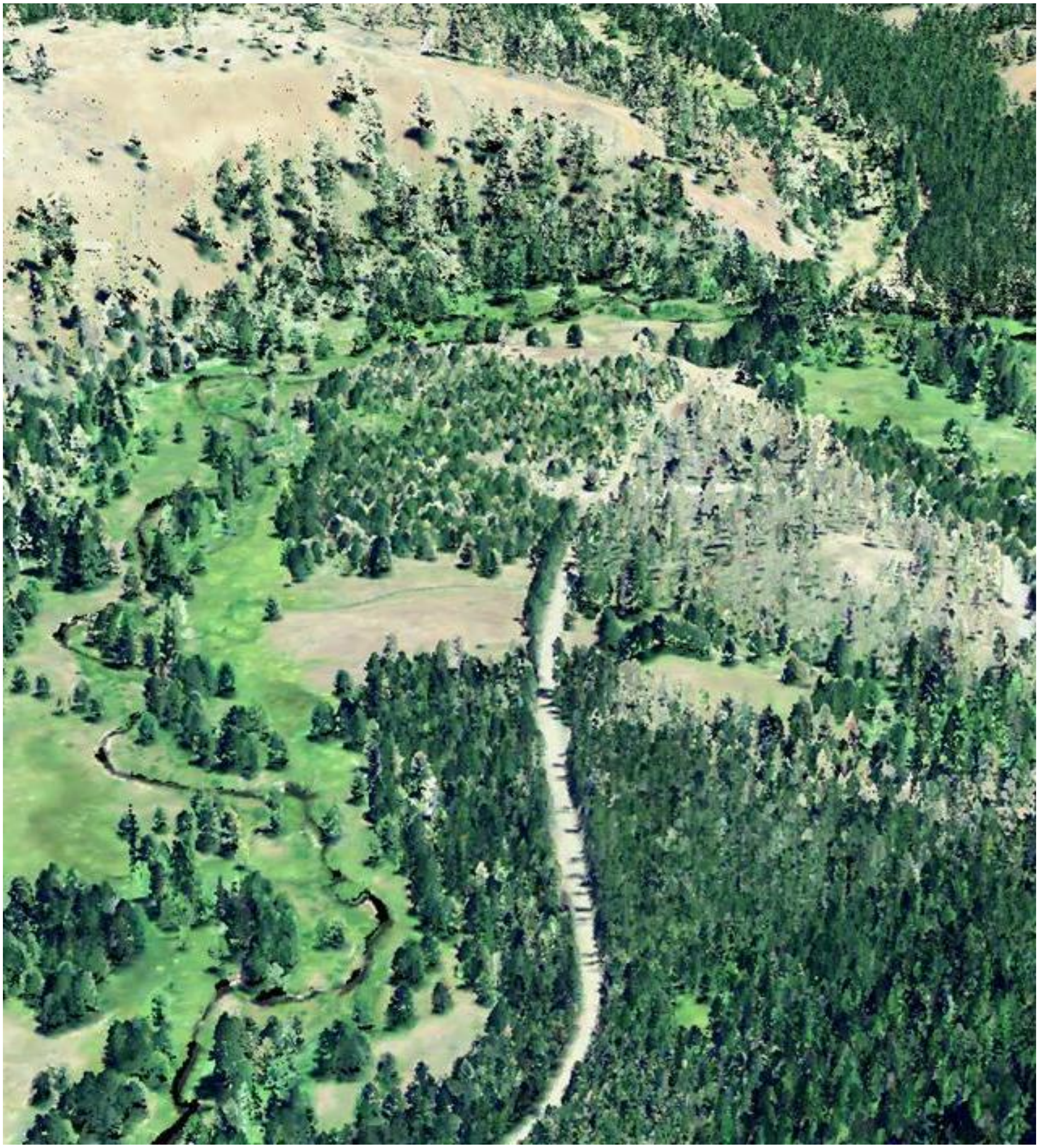


Figure 176 shows the typical terrain and vegetation along McCoy Creek. The stream often has a wide flat floodplain and intermittently is flanked by large trees. The image gives a better understanding of why effective shade is relatively low compared to other streams in the basin.

Figure 176 – McCoy Creek typical terrain and vegetation.

5.14 Meadow Creek

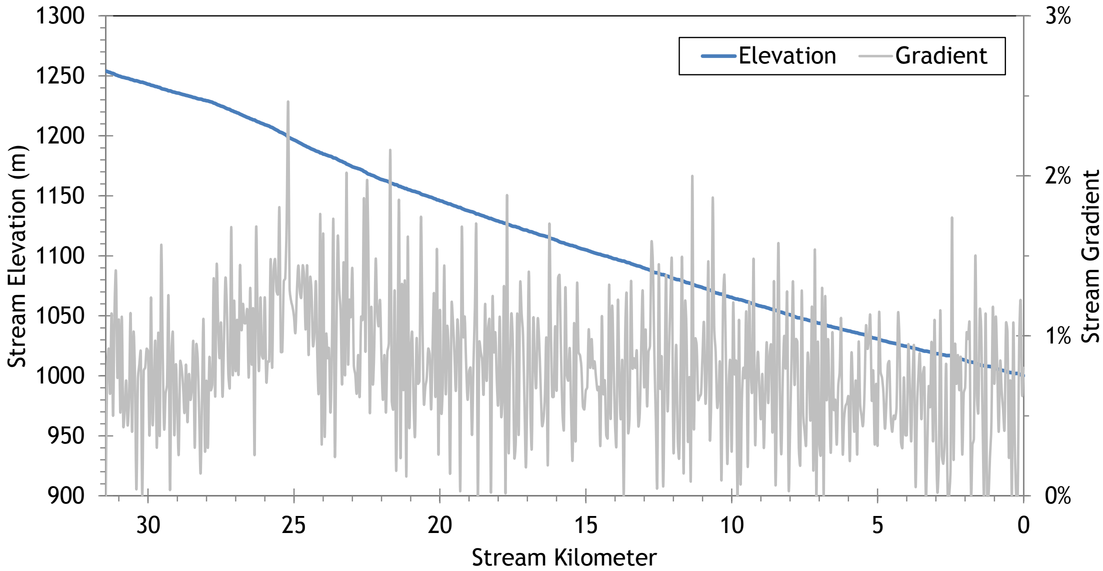


RGB-colored LiDAR point cloud - Meadow Creek looking downstream near Smith Creek.

5.14.1 Meadow Creek TTools Results

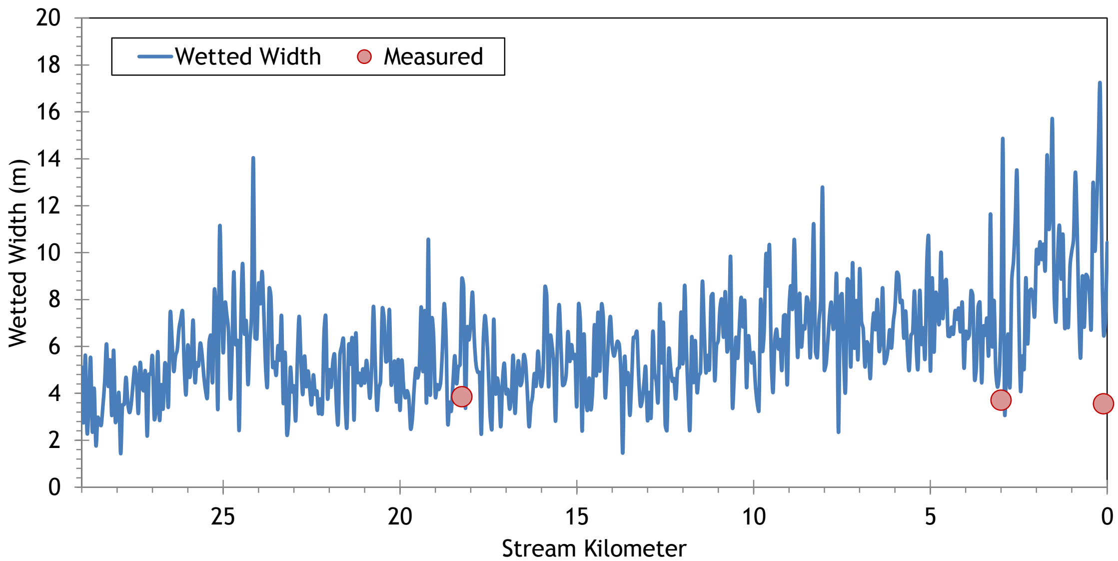
Meadow Creek elevations and gradients are shown in Figure 177. The stream has a fairly gradual descent, is moderately sinuous, and hence gradient is moderated throughout.

Figure 177 – Meadow Creek elevation and gradient.



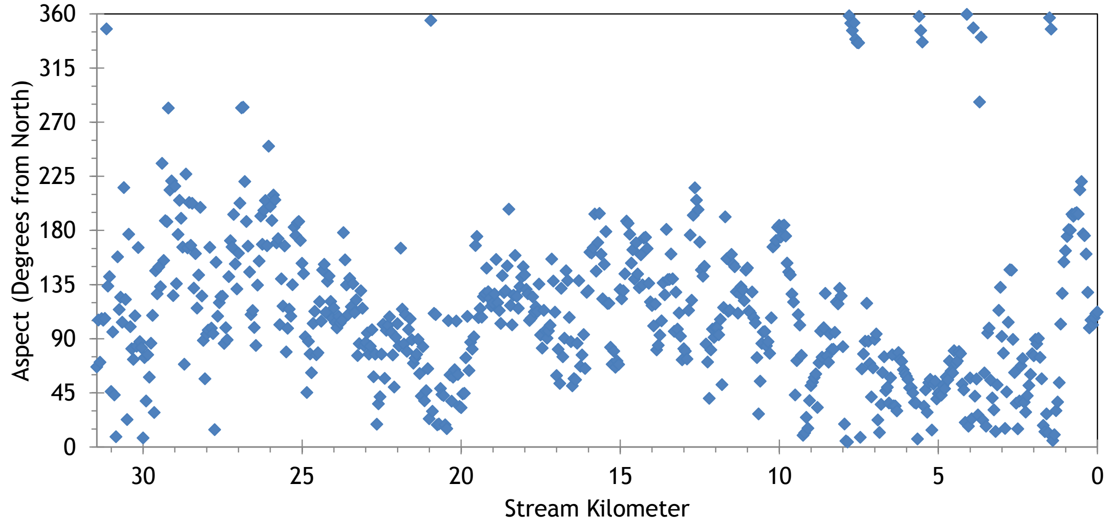
The wetted widths for Meadow Creek are shown in Figure 178. There is a slight increase in widths in the downstream direction, but overall the stream is relatively small.

Figure 178 – Meadow Creek wetted width.



Meadow Creek flows from west to east before joining the Grande Ronde River (Figure 179).

Figure 179 – Meadow Creek stream aspect.



The mountainous terrain surrounding Meadow Creek creates moderately high topographic shade angles (Figure 180). Values vary between about 5 and 30 degrees.

Figure 180 – Meadow Creek topographic shade angles.

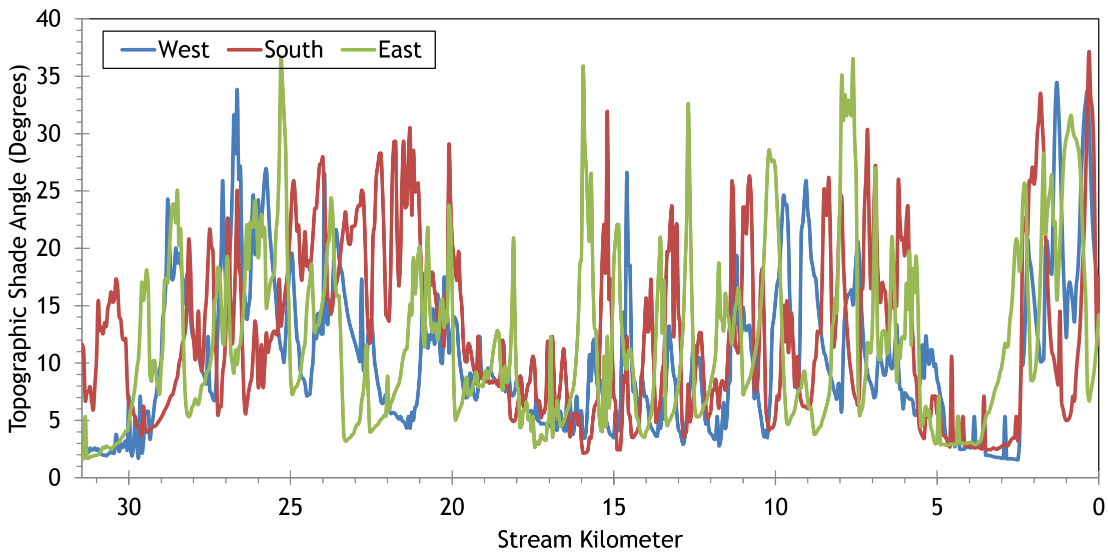
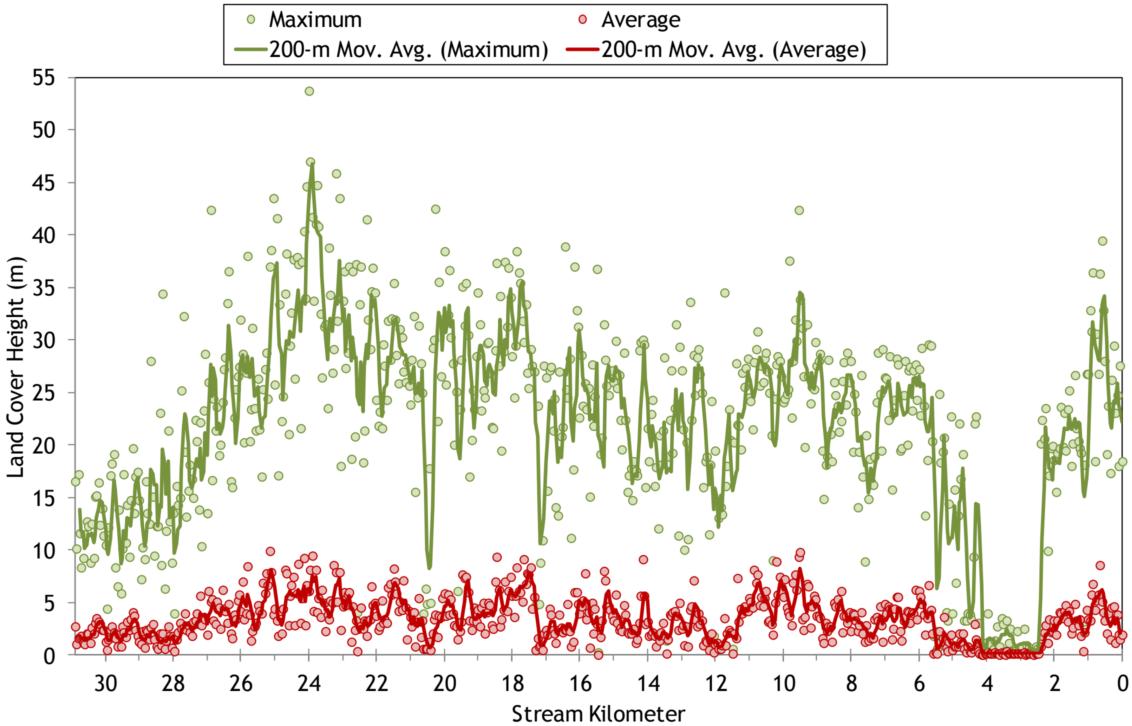


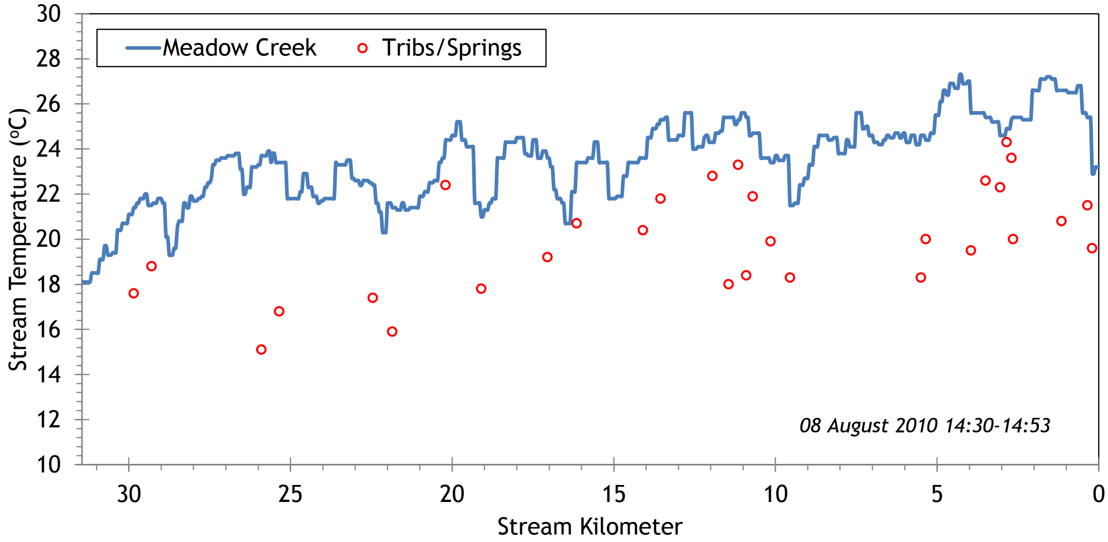
Figure 181 shows the land cover heights sampled along Meadow Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 181 – Meadow Creek land cover heights sampled from highest hit LiDAR.



The moderate gradients and low stream flows make the longitudinal thermal profile quite variable (Figure 182). Maximum stream temperatures were about 27°C during the TIR flight.

Figure 182 – Meadow Creek TIR stream temperature profile.



5.14.2 Meadow Creek Heat Source Calibration Results

Meadow Creek was simulated from Waucup Creek to the mouth (Figure 183). The total simulation length was 30.9 stream kilometers.

Figure 183 – Meadow Creek simulation extent.

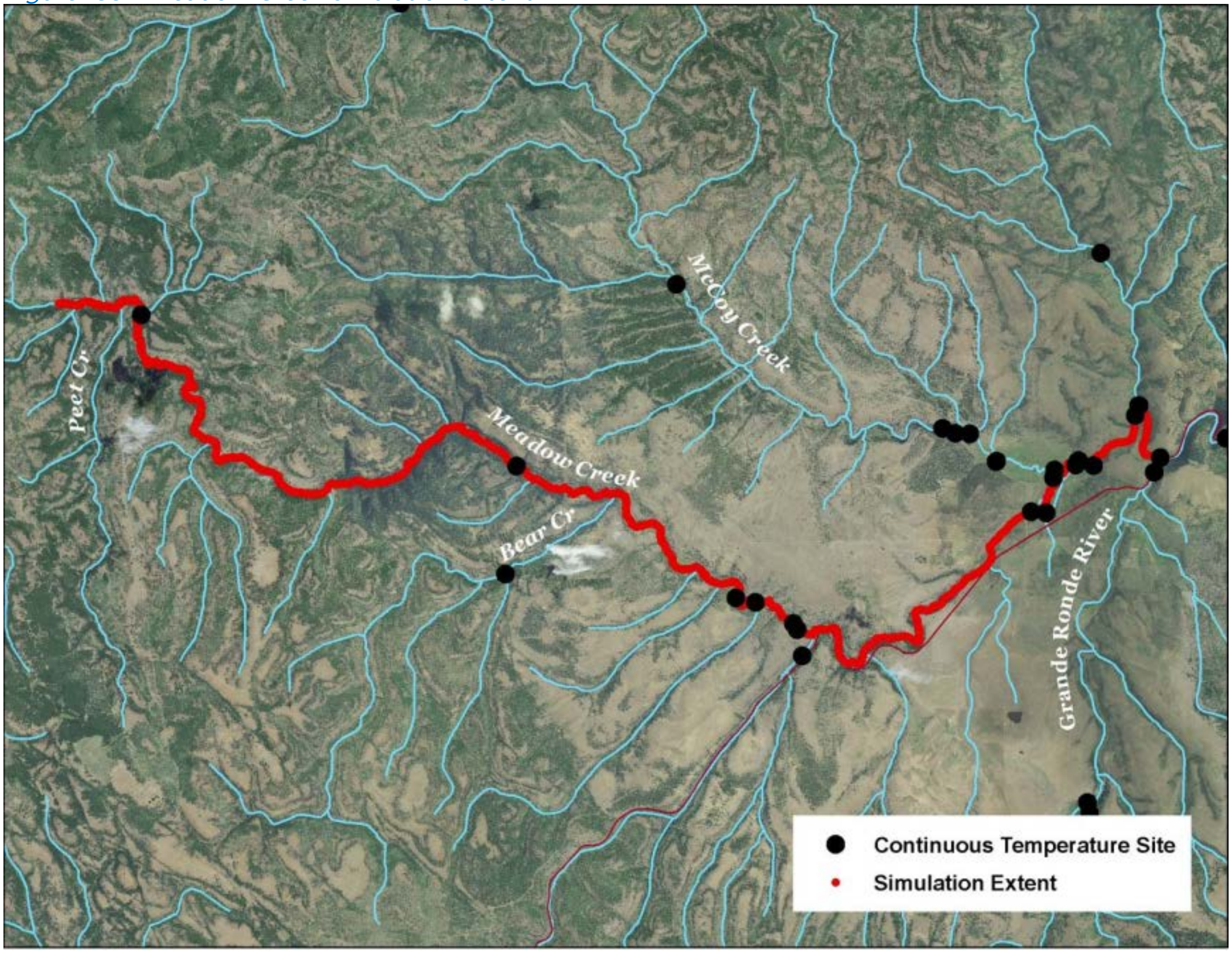


Table 28 – Meadow Creek general Heat Source parameters.

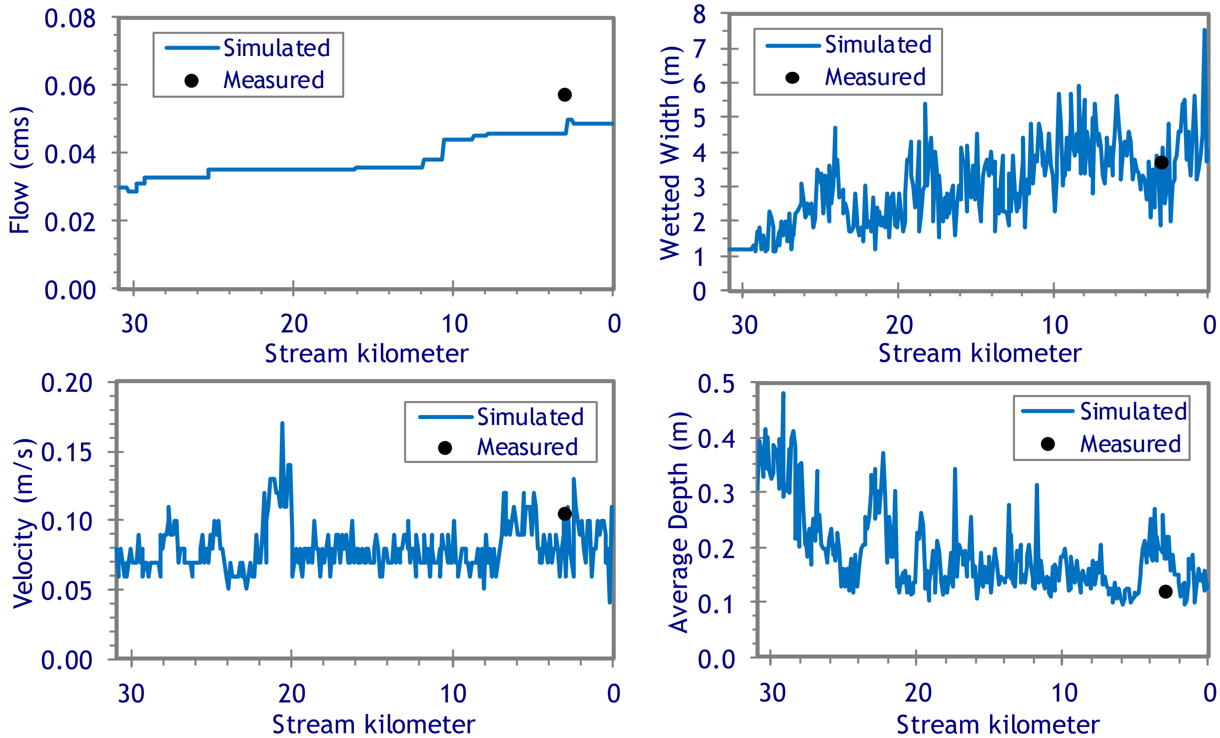
Stream:	Meadow Creek
Length:	30.9 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 8, 2010 14:30-14:53
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Meadow Creek Heat Source model:

- Hourly climate data were obtained from the La Grande Airport (NWS). Air temperature was adjusted using the adiabatic lapse rate of 1°C per 100 meters elevation.
- Daily flow variability was extrapolated from Meadow Creek above Bear Creek gage data.

Figure 184 summarized the simulated and measured hydraulic values used in the calibrated Meadow Creek model. The simulated data were plotted for August 23th, while the ground level measurements were collected on four different days.

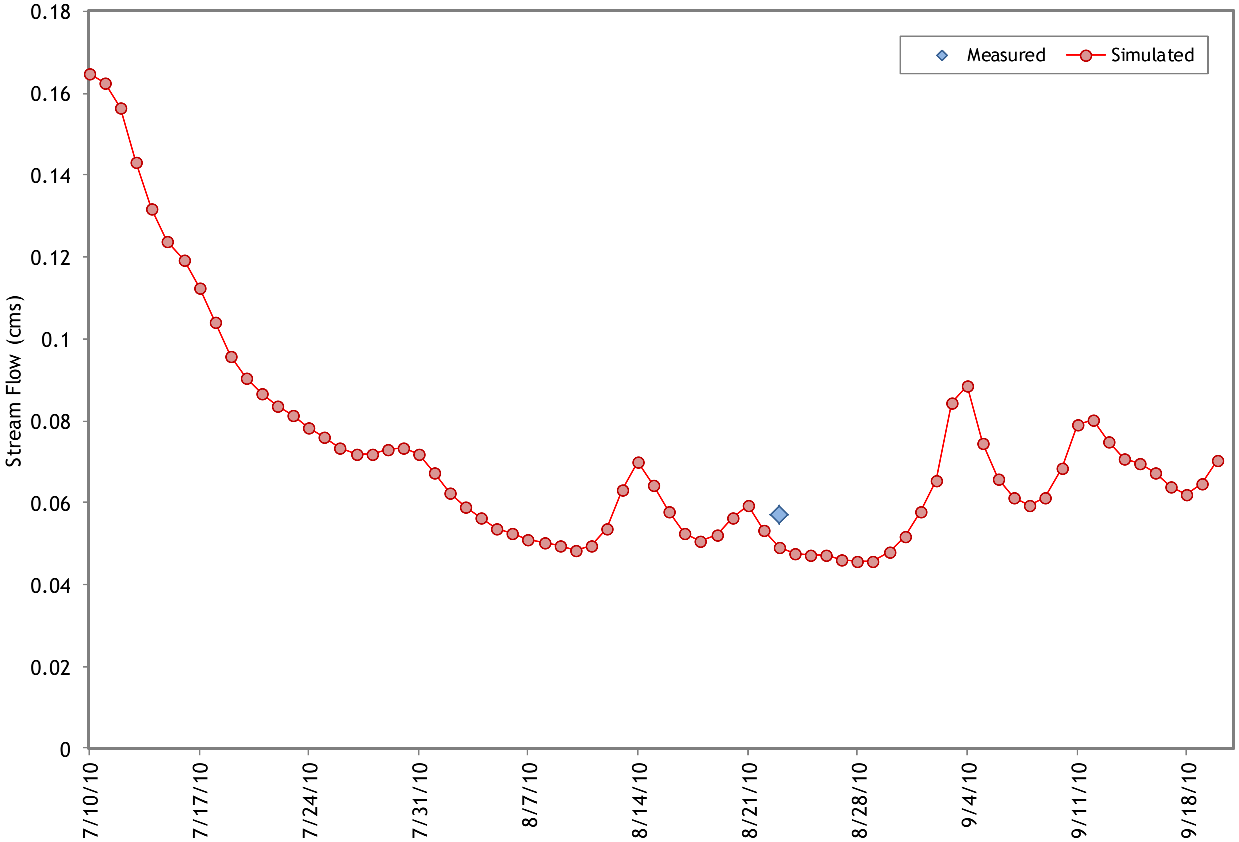
Figure 184 – Meadow Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Meadow Creek above Bear Creek	18.25	8/20/2010
Meadow Creek above McCoy Creek	3.0	8/23/2010
Meadow Creek at Mouth	0.1	8/18/2010

The measured and simulated daily flow values near the mouth of Meadow Creek are presented in Figure 185. The upstream initial boundary condition daily flow values were extrapolated from gage data recorded on a lower portion of Meadow Creek.

Figure 185 – Meadow Creek measured and simulated flows near the mouth.



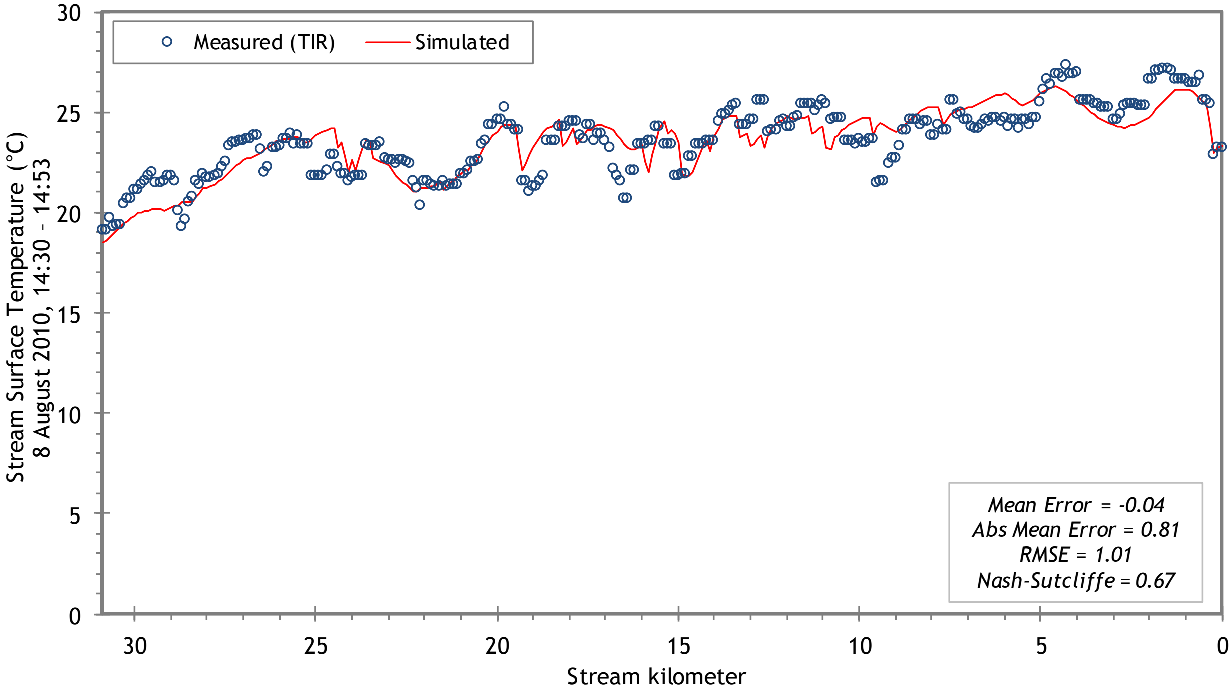
The tributaries included within the Meadow Creek Heat Source model are summarized in Table 29. Dark Canyon Creek had intermittent flow during August 2010 and was assumed dry during the simulation time period.

Table 29 – Meadow Creek mass inflow features and assumptions.

Feature	Stream Km	Assumptions
Peet Creek	29.8	0.006-0.01 cms, used Bear Cr temps
Smith Creek	29.3	0.006-0.01 cms, used Bear Cr temps
Cougar Canyon	25.3	0.006-0.01 cms, used Bear Cr temps
Bear Creek	16.15	0.0006-0.001 cms, measured hourly temps
Battle Creek	11.95	0.006-0.01 cms, used Bear Cr temps
Burnt Corral Creek	10.65	0.007-0.01 cms, measured hourly temps
McCoy Creek	2.9	0.004-0.007 cms, measured hourly temps

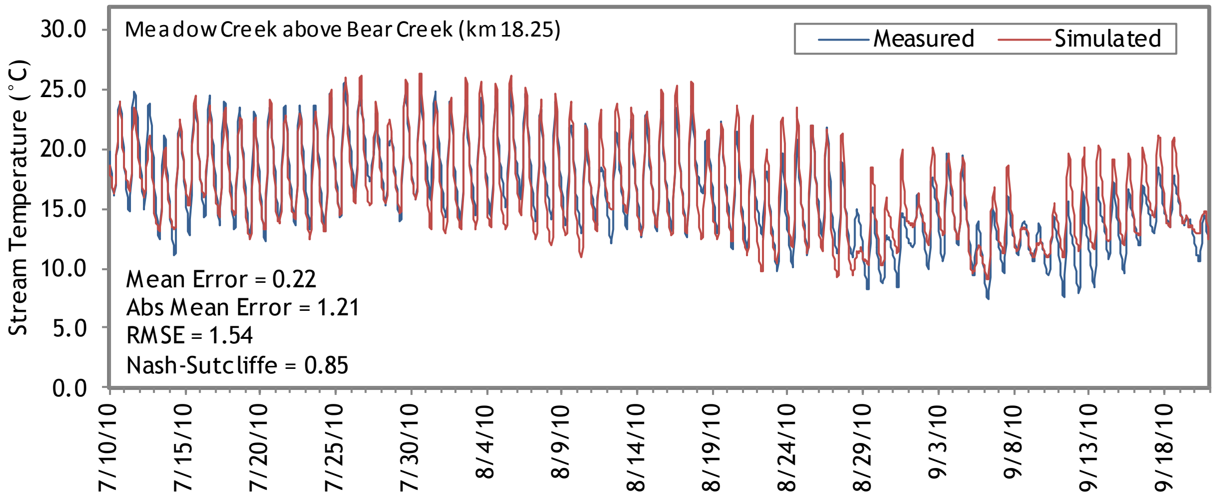
Meadow Creek simulated and measured longitudinal temperatures are shown in Figure 186. There is a great deal of variability over short distances because the stream flows were quite low during August 2010.

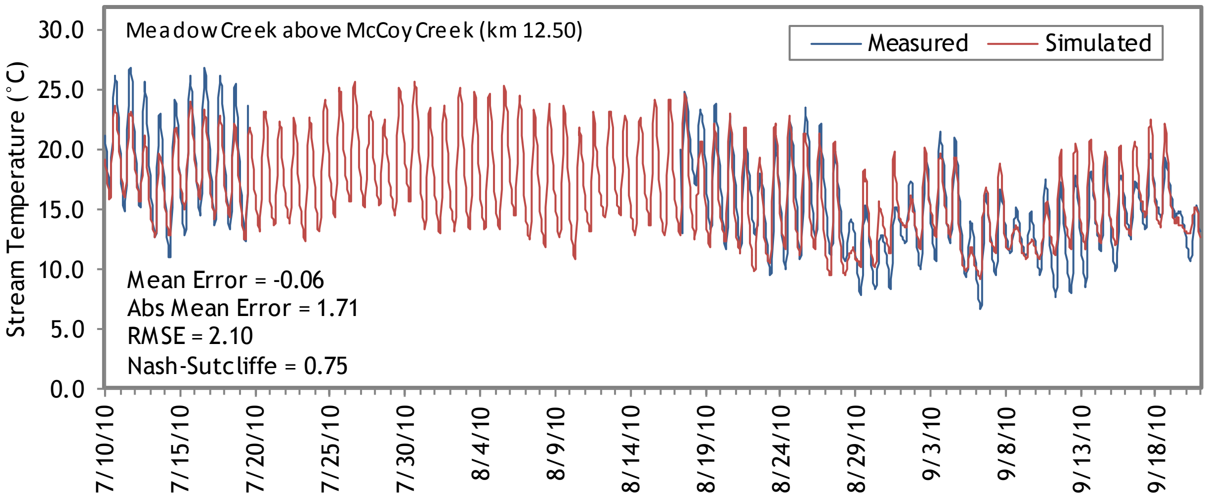
Figure 186 – Meadow Creek simulated and measured longitudinal stream temperatures.

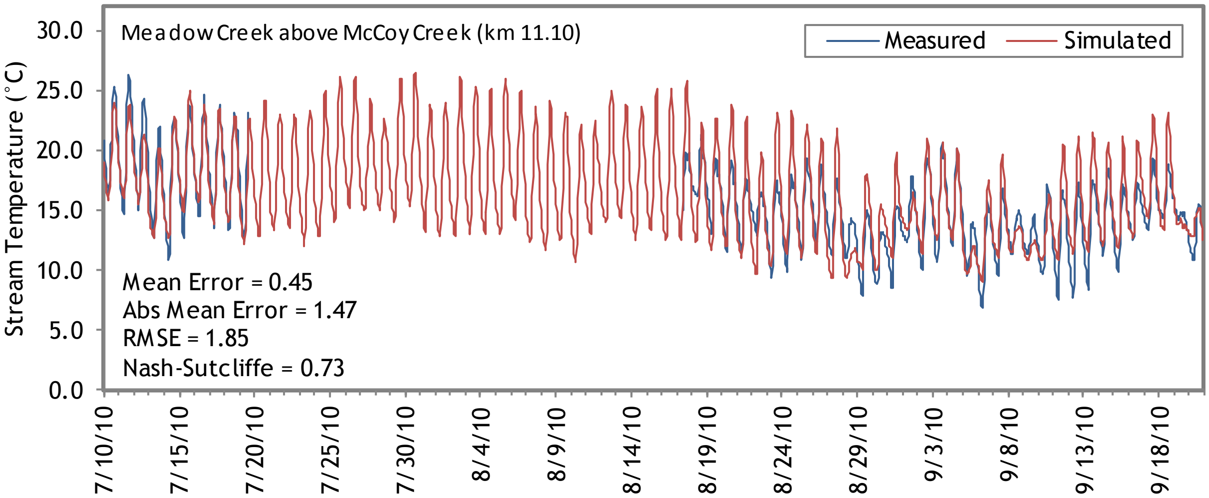


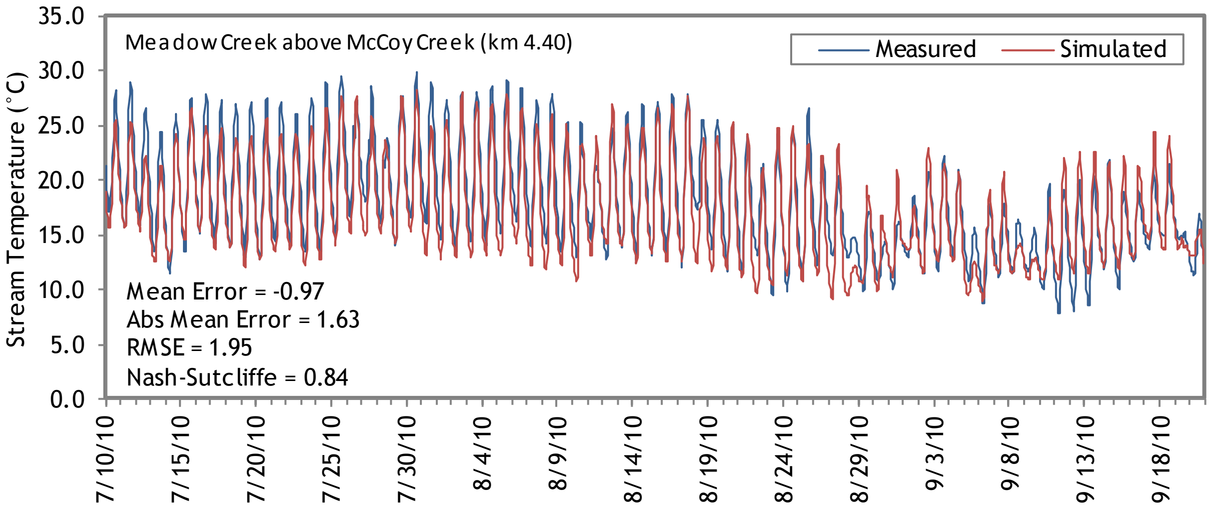
Simulated and measured hourly stream temperatures are compared in Figure 187. Meadow Creek had very low flow which makes the stream temperatures more variable over shorter distances. Calibration of the Heat Source model was more challenging than for other streams and the resulting calibration statistics reflect that.

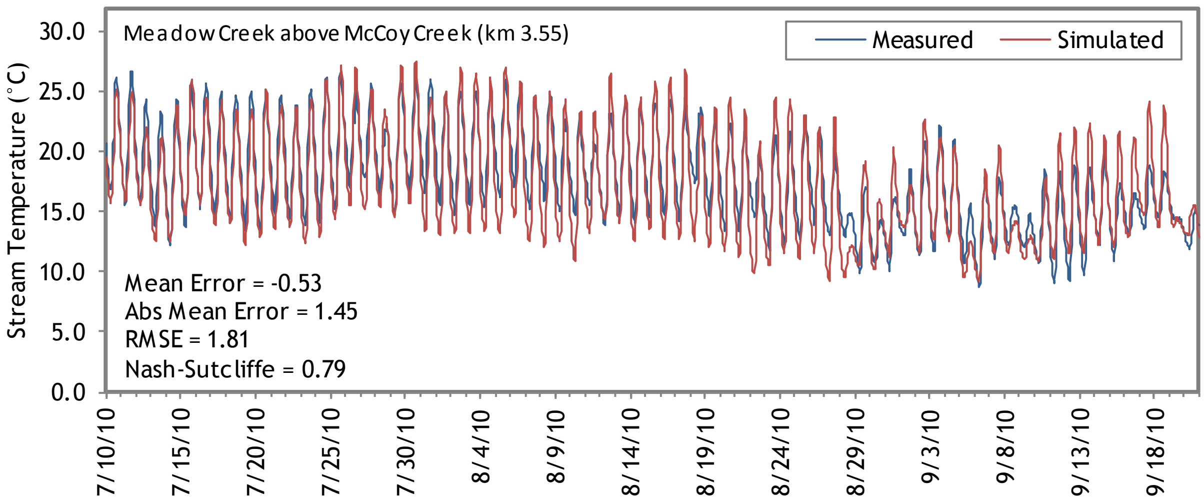
Figure 187 – Meadow Creek simulated and measured hourly stream temperatures.

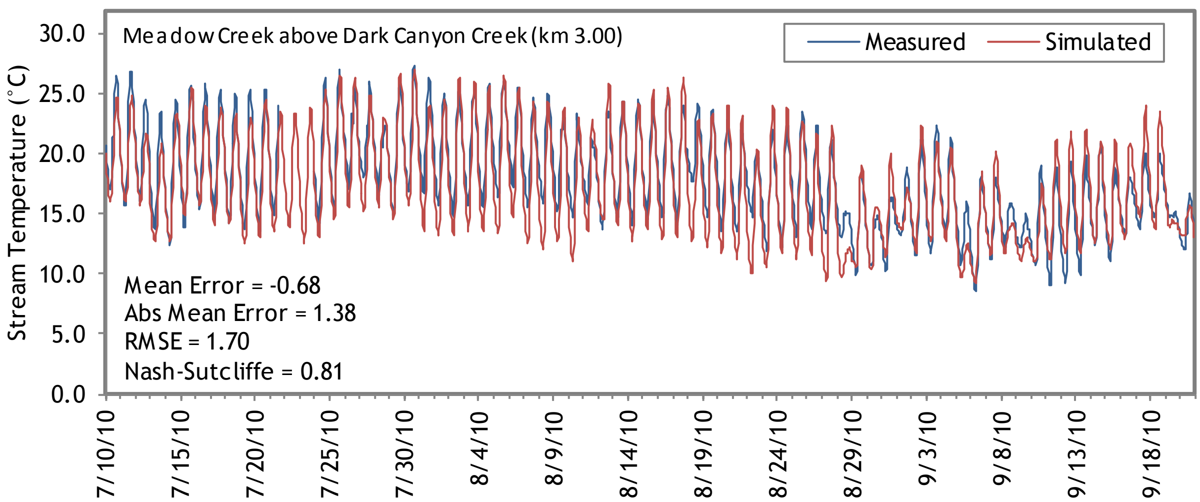


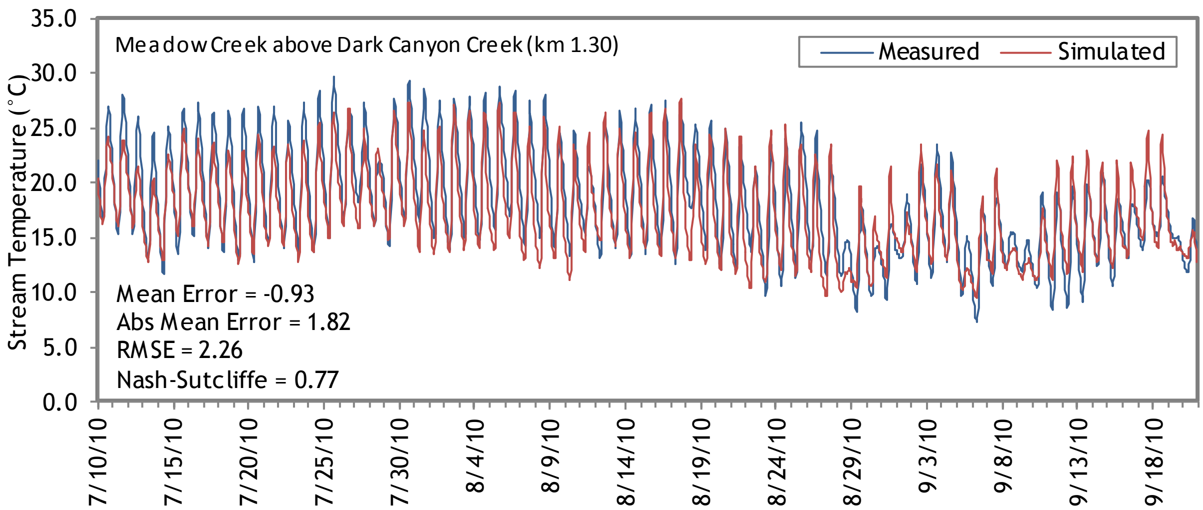

Meadow Creek above McCoy Creek (km 12.50)
Measured
Simulated
Mean Error = -0.06
Abs Mean Error = 1.71
RMSE = 2.10
Nash-Sutcliffe = 0.75
Stream Temperature (°C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10


Meadow Creek above McCoy Creek (km 11.10)
Measured
Simulated
Mean Error = 0.45
Abs Mean Error = 1.47
RMSE = 1.85
Nash-Sutcliffe = 0.73
Stream Temperature (°C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10


Meadow Creek above McCoy Creek (km 4.40)
Measured
Simulated
Mean Error = -0.97
Abs Mean Error = 1.63
RMSE = 1.95
Nash-Sutcliffe = 0.84
Stream Temperature (°C)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10


Meadow Creek above McCoy Creek (km 3.55)
Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.53
Abs Mean Error = 1.45
RMSE = 1.81
Nash-Sutcliffe = 0.79
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10


Meadow Creek above Dark Canyon Creek (km 3.00)
Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.68
Abs Mean Error = 1.38
RMSE = 1.70
Nash-Sutcliffe = 0.81


Meadow Creek above Dark Canyon Creek (km 1.30)
Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.93
Abs Mean Error = 1.82
RMSE = 2.26
Nash-Sutcliffe = 0.77

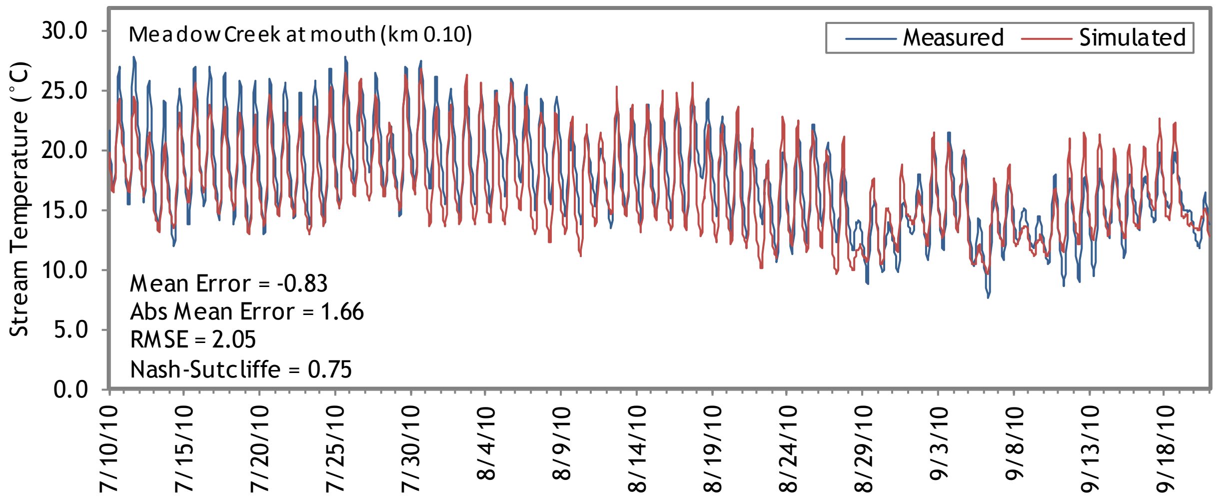
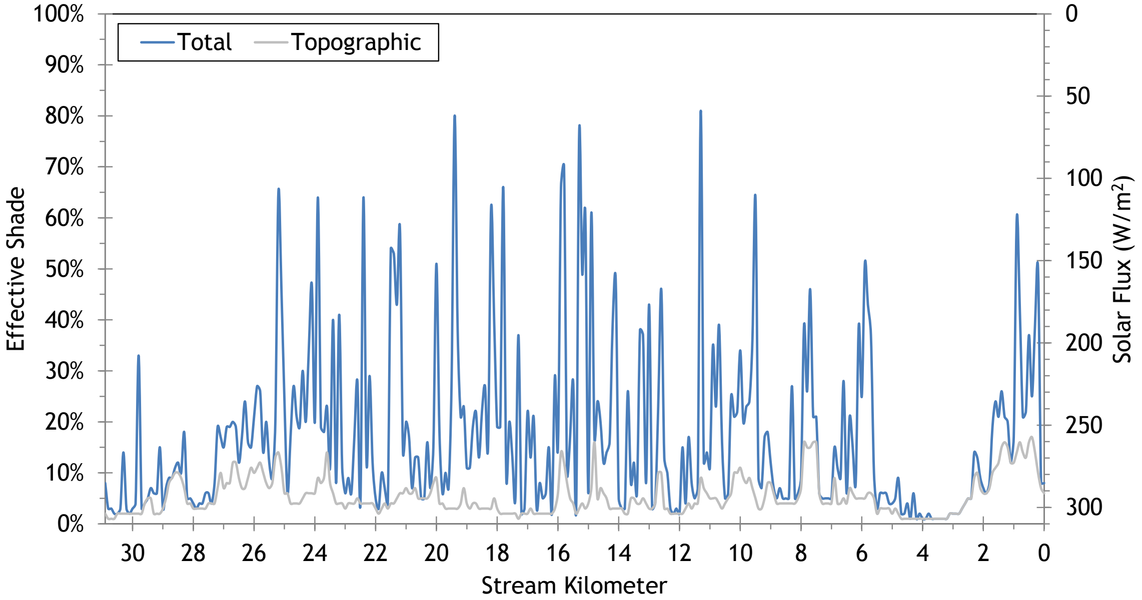
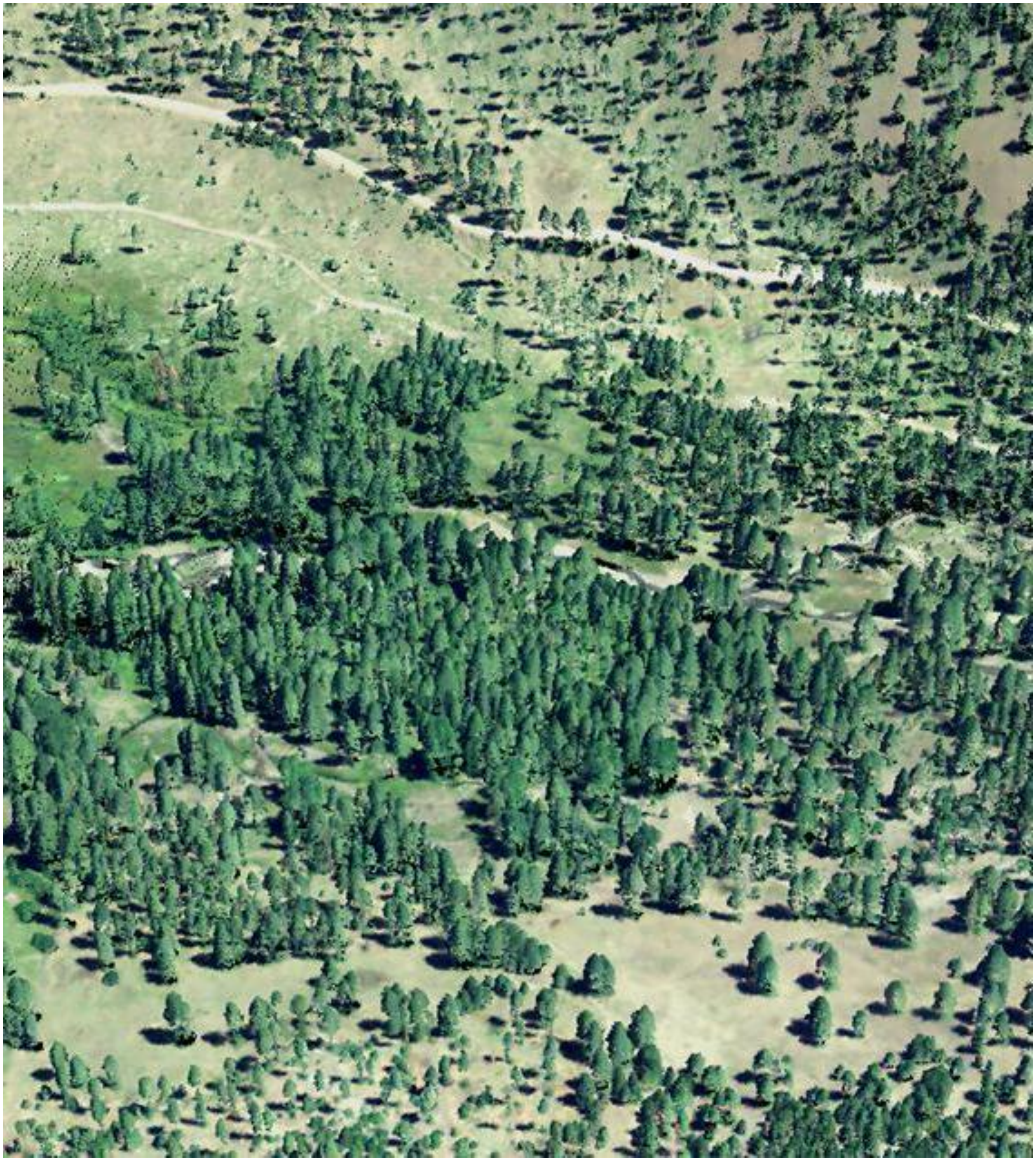

Meadow Creek at mouth (km 0.10)
Measured
Simulated
Stream Temperature (°C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Mean Error = -0.83
Abs Mean Error = 1.66
RMSE = 2.05
Nash-Sutcliffe = 0.75
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10

Figure 188 shows the simulated effective shade values for Meadow Creek. The total effective shade is somewhat moderate because of the meanders through meadows that are a mix of grass and trees. There is upwards of 10% effective shade produced by topography throughout much of the stream length. See Appendix for effective shade maps.

Figure 188 – Meadow Creek simulated effective shade.



5.15 Beaver Creek



RGB-colored LiDAR point cloud - Beaver Creek near Little Beaver Creek (stream flowing from right to left of image).

5.15.1 Beaver Creek TTools Results

Beaver Creek elevations and gradients were sampled from the bare earth LiDAR data (Figure 189). The reaches just below La Grande Reservoir (kilometer 22.9) are the steepest, and then gradients are generally between 1% and 4%.

Figure 189 – Beaver Creek elevation and gradient.

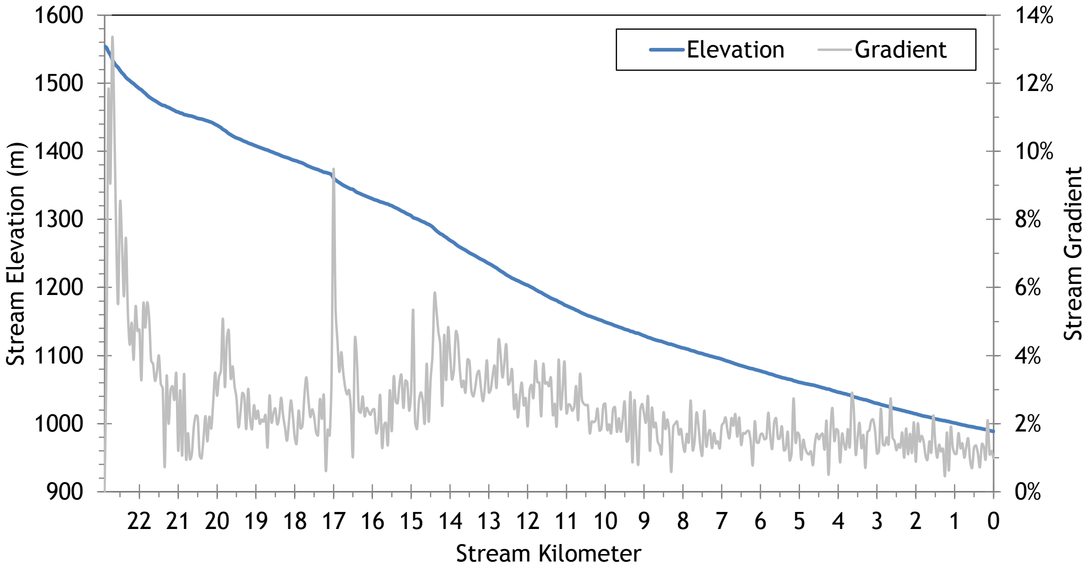
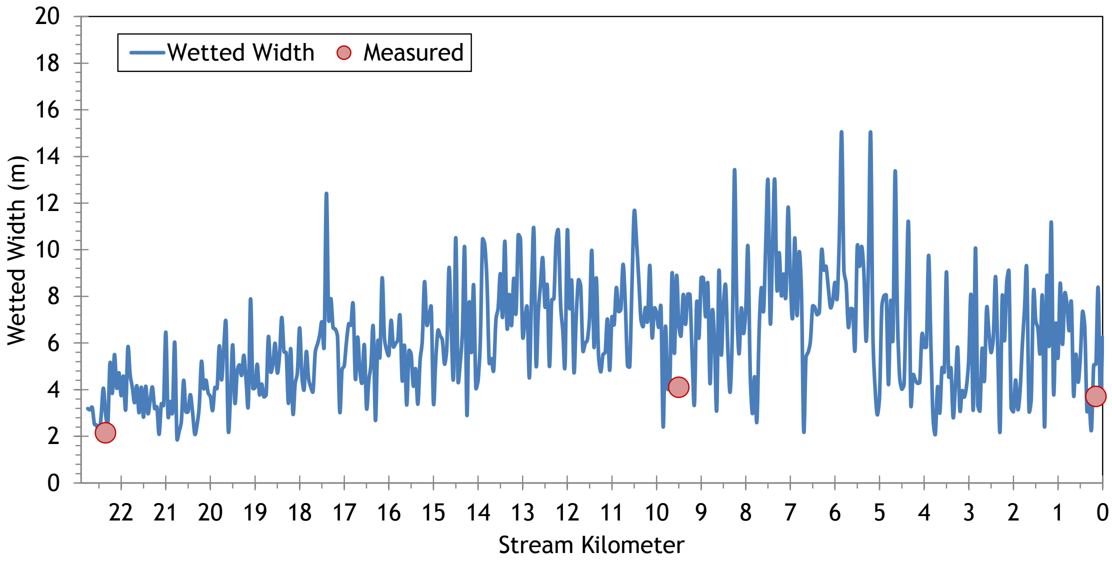


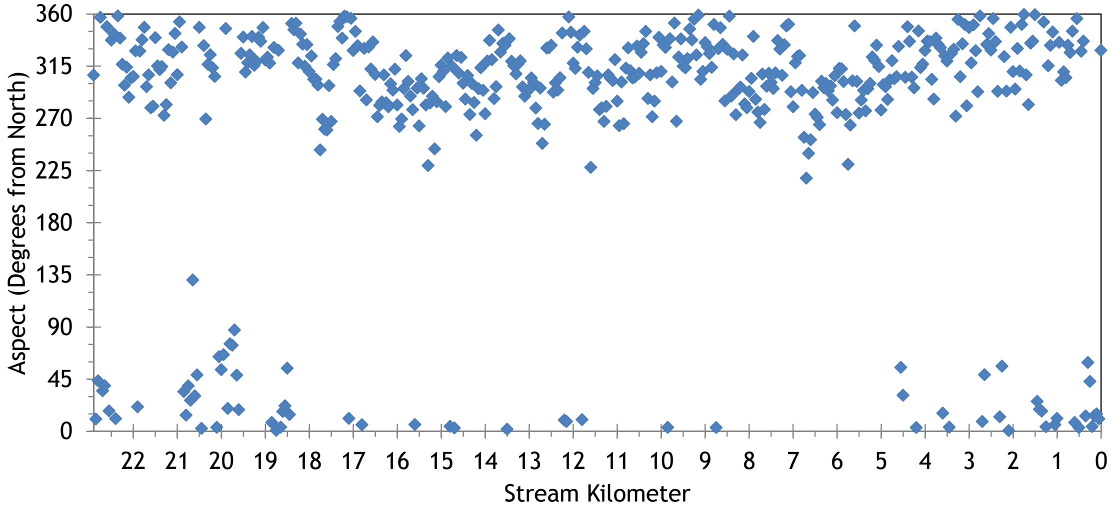
Figure 190 displays the measured and sampled wetted widths for Beaver Creek. The average width was about 6 meters during the simulation time period.

Figure 190 – Beaver Creek wetted widths.



Beaver Creek flows generally in the northwesterly direction (Figure 191).

Figure 191 – Beaver Creek stream aspect.



Topographic shade angles on Beaver Creek are somewhat higher than other streams in the watershed (Figure 192). Maximum values regularly exceed 30 degrees, while the minimums are generally above 10 degrees in most reaches.

Figure 192 – Beaver Creek topographic shade angles.

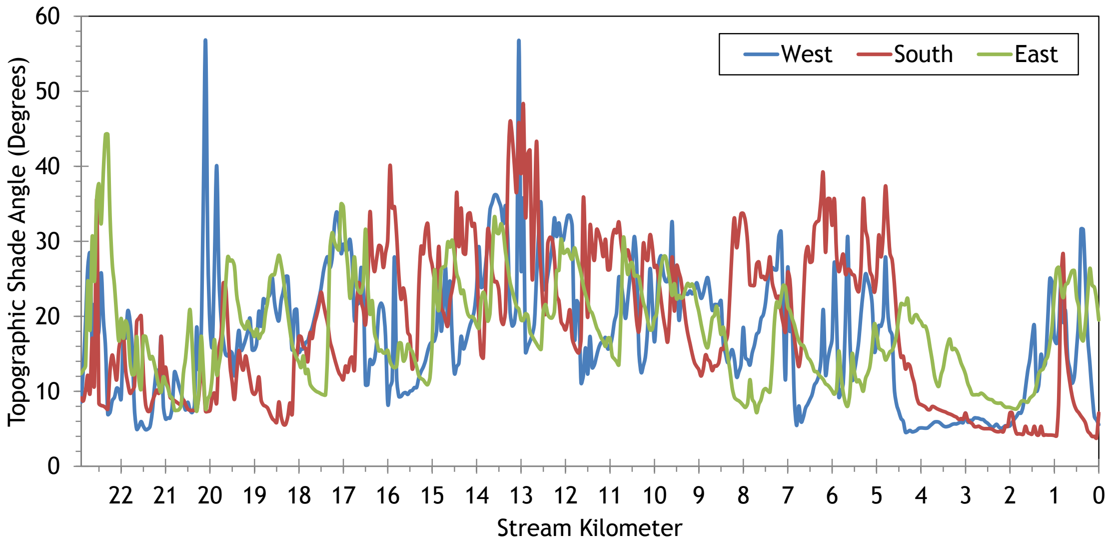


Figure 193 shows the land cover heights sampled along Beaver Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 193 – Beaver Creek land cover heights sampled from highest hit LiDAR.

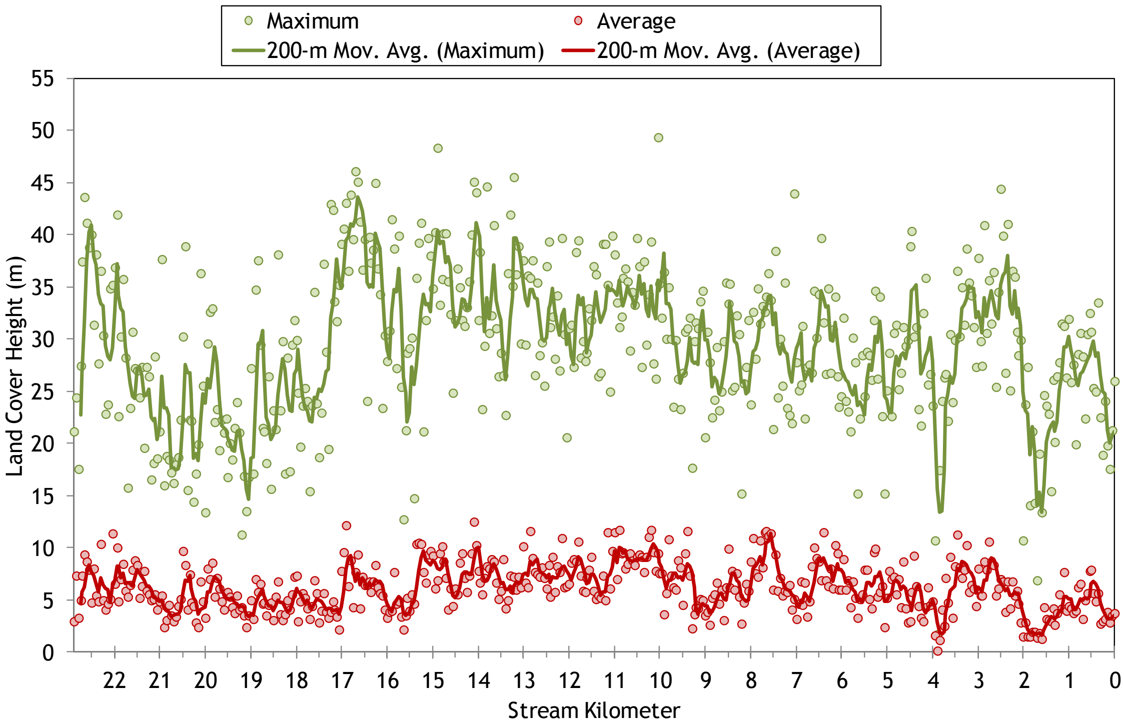
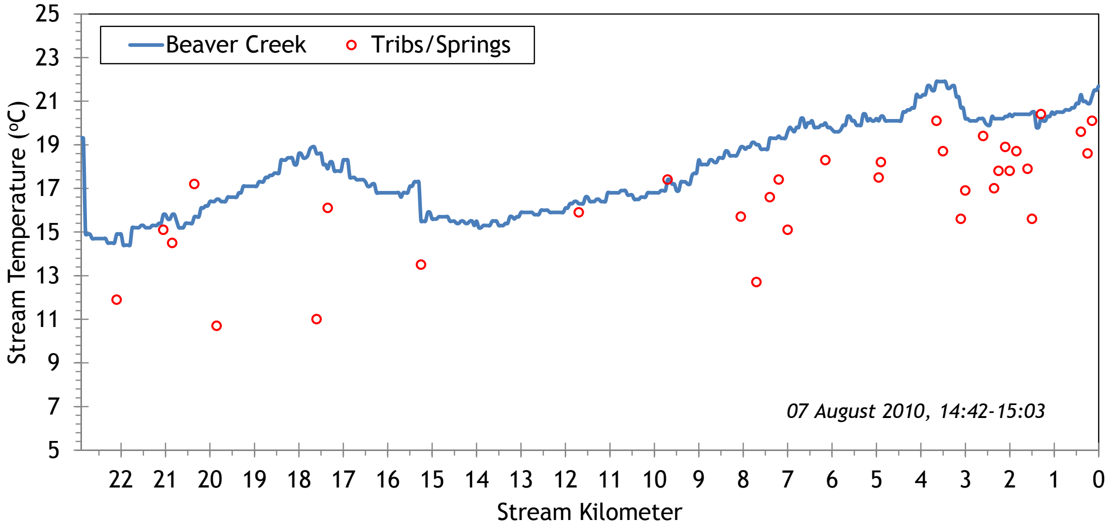


Figure 194 shows the TIR stream temperature profile of Beaver Creek. The stream was leaving the La Grande Reservoir at approximately 15°C at the time of the TIR flight.

Figure 194 – Beaver Creek TIR stream temperature profile.



5.15.2 Beaver Creek Heat Source Calibration Results

Beaver Creek was simulated from La Grande Reservoir to the mouth (Figure 195).

Figure 195 – Beaver Creek simulation extent.

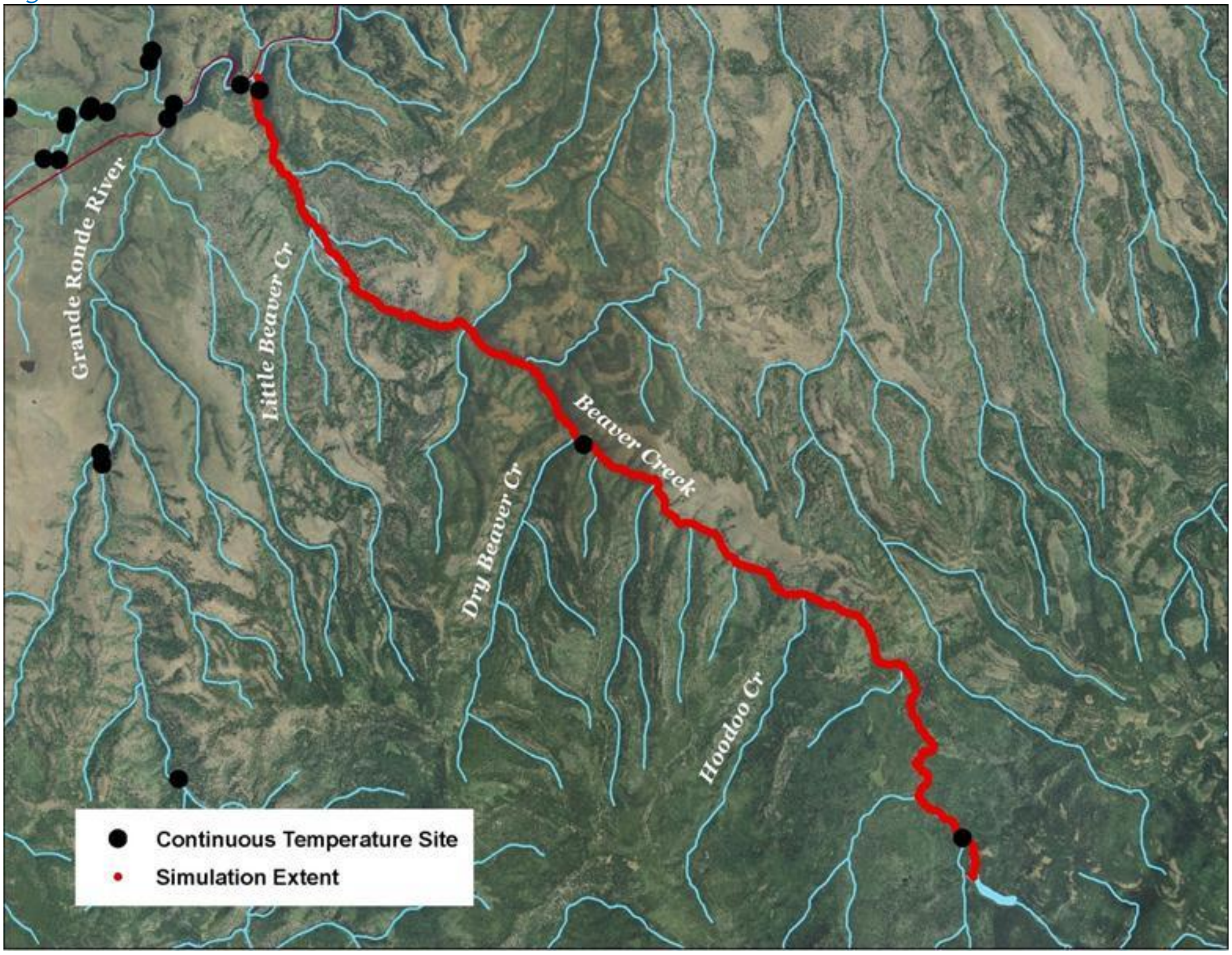


Table 30 – Beaver Creek general Heat Source parameters.

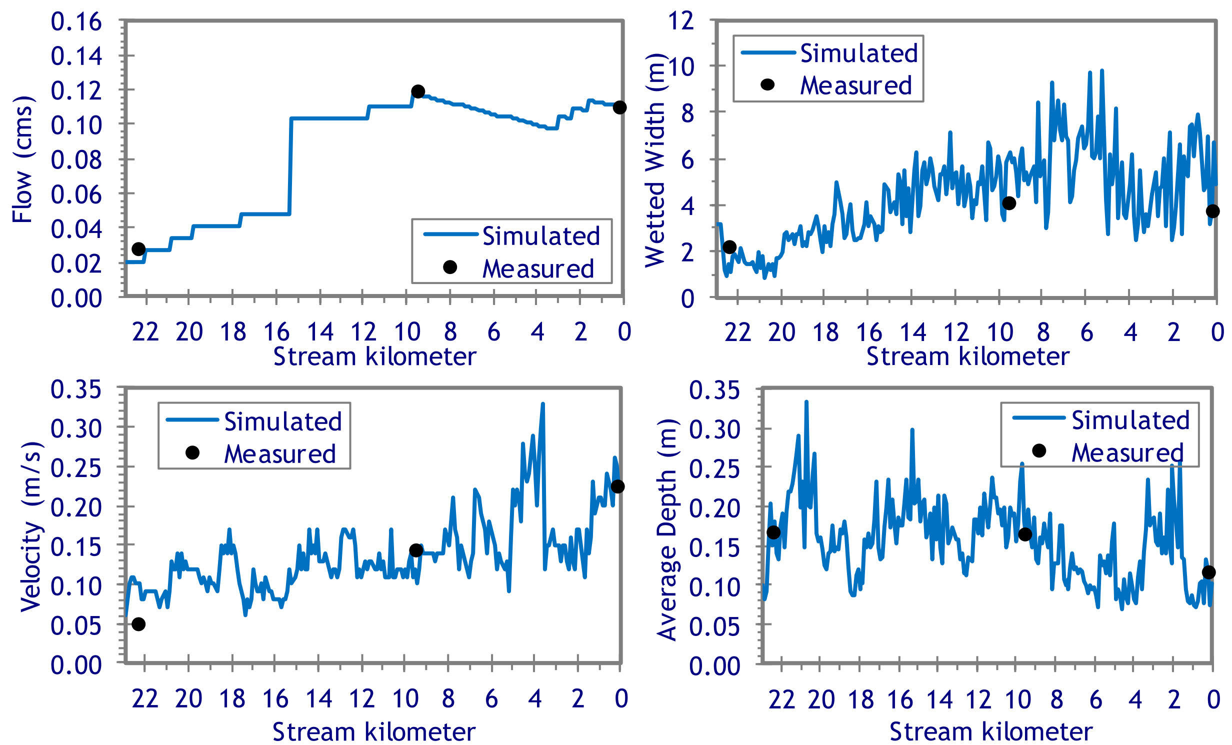
Stream:	Beaver Creek
Length:	22.9 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 7, 2010 14:42-15:03
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Beaver Creek Heat Source model:

- Hourly climate data are from the La Grande airport. Wind speeds were reduced 50% and air temperatures were adjusted using the adiabatic lapse rate.
- Wetted widths were roughly digitized from the TIR and LiDAR intensity images. The model reduced the value sampled by TTools by 35-60% in order to accommodate the other hydraulic values.

Figure 196 summarizes the simulated and measured hydraulic values from the calibrated model. The simulated values are from August 24th, while the measurements were taken on various days. There was an unverified losing reach between kilometer 9.5 and the mouth, based on measurements taken on August 24, 2010. The loss was accounted for in the simulation by gradually removing 1 cfs across the lower 9.5 kilometers.

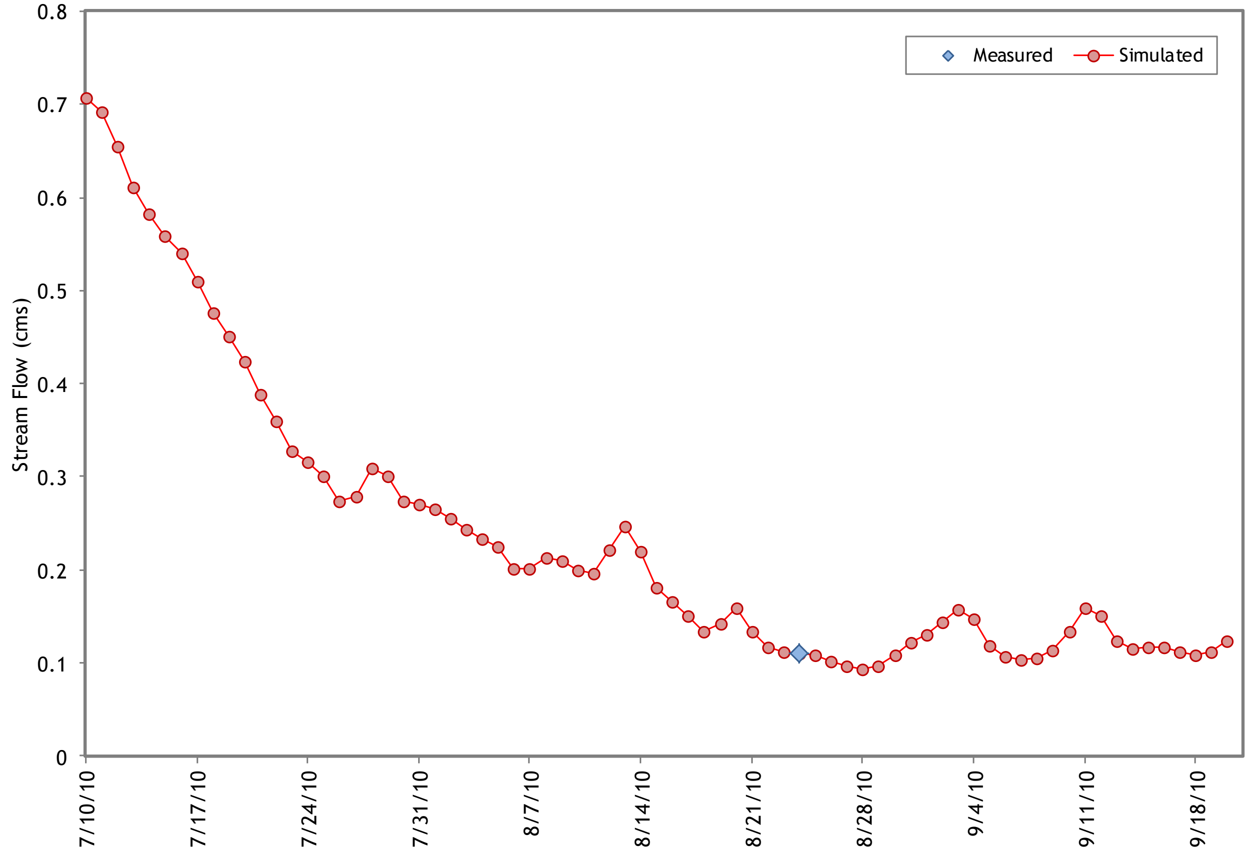
Figure 196 – Beaver Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Beaver Creek below Reservoir	22.35	8/19/2010
Beaver Creek below Dry Beaver	9.5	8/24/2010
Beaver Creek at Mouth	0.15	8/24/2010

The measured and simulated daily flow volumes at the mouth of Beaver Creek are shown in Figure 197. The daily values for the initial upstream boundary flow were extrapolated from gage measurements on the Grande Ronde River.

Figure 197 – Beaver Creek measured and simulated flows near the mouth.



The tributaries and springs included in the calibrated model are listed in Table 31. Hoodoo Creek was the largest tributary and created a significant thermal signature in the TIR imagery. The other tributaries were all assumed to be of equal (small) volume. Hourly temperature data were estimated by using the values recorded on Beaver Creek upstream of Dry Beaver Creek, minus the difference between the tributary (TIR temperature) and the Beaver Creek upstream of Dry Beaver Creek temperature.

Table 31 – Beaver Creek mass inflow features and assumptions.

Feature	Stream Km	Assumptions
Cove Creek	22.0	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
West Fork Beaver Cr.	20.85	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Unnamed Tributary	19.8	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Spring	17.6	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Hoodoo Creek	15.3	0.04-0.1 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Watermelon Creek	11.75	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Dry Beaver Creek	9.75	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Little Beaver Creek	3.0	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.
Unnamed Tributary	2.35	0.006-0.01 cms, hourly temps based on Beaver Cr. u/s Dry Beaver Cr. minus difference of TIR observation.

The simulated and measured longitudinal stream temperatures are shown in Figure 198.

Figure 198 – Beaver Creek simulated and measured longitudinal stream temperatures.

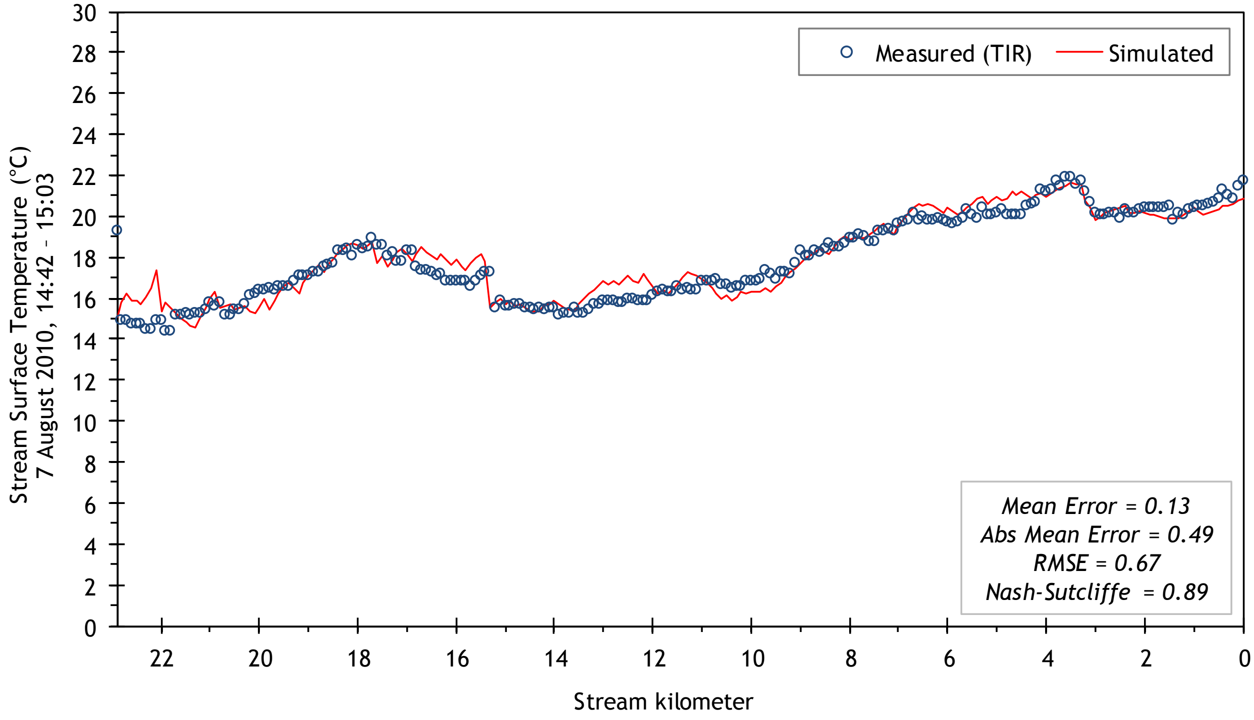
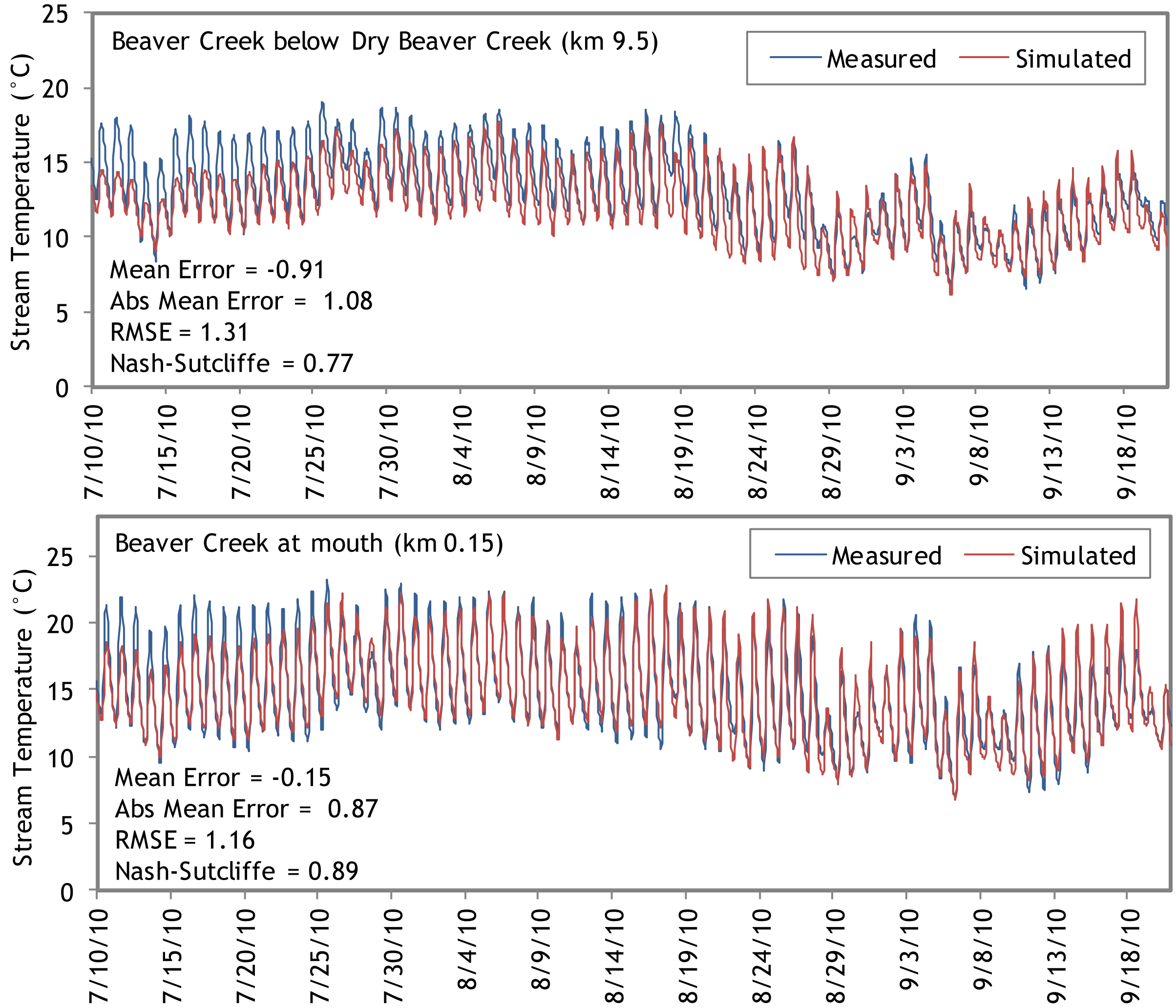


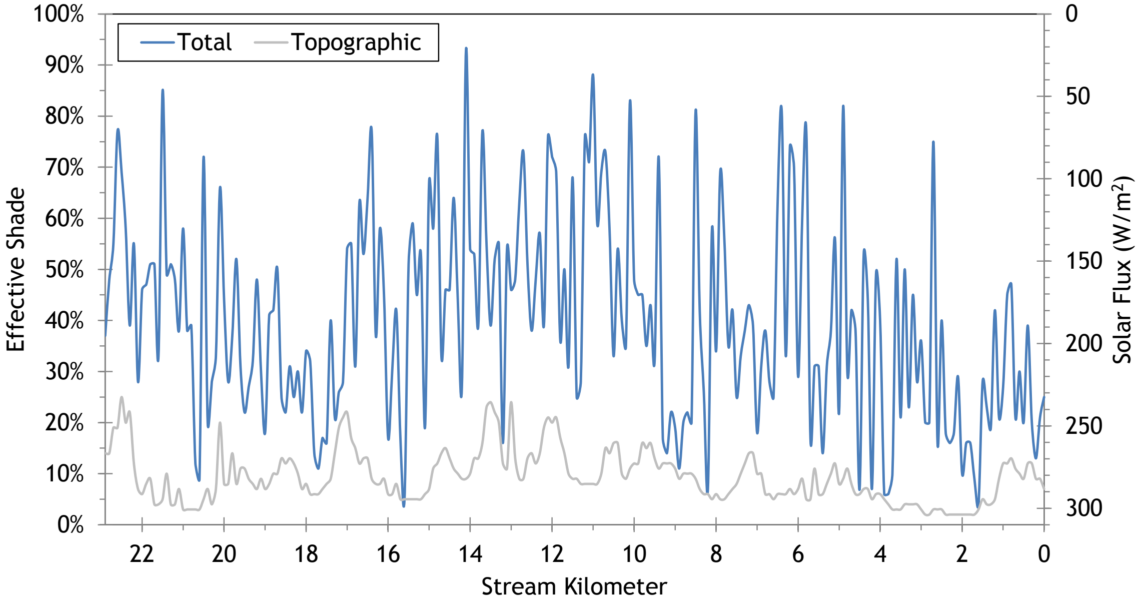
Figure 199 shows the simulated and measured hourly stream temperatures. Error statistics are also presented for each location.

Figure 199 – Beaver Creek simulated and measured hourly stream temperatures.



The simulated effective shade values for Beaver Creek are presented in Figure 200. A fair amount of topographic shade occurs along Beaver Creek - upwards of 20% effective shade is created by topographic features in many locations. Beaver Creek is not very densely forested because of the wide grassy floodplain that occurs in so many reaches. See Appendix for effective shade maps.

Figure 200 – Beaver Creek simulated effective shade.



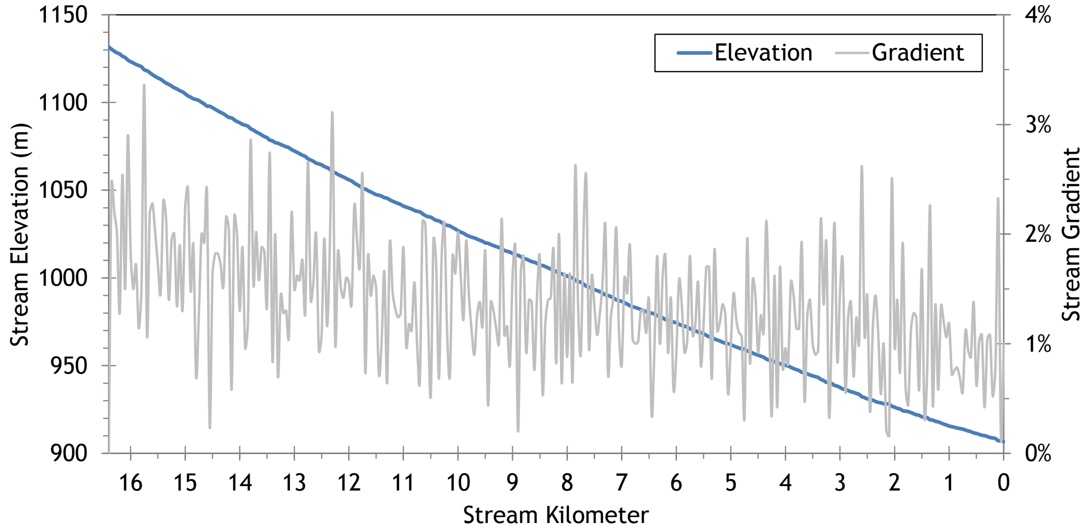
5.16 Five Points Creek

RGB-colored LiDAR point cloud - Five Points Creek below Little John Day Creek (looking downstream).

5.16.1 Five Points Creek TTools Results

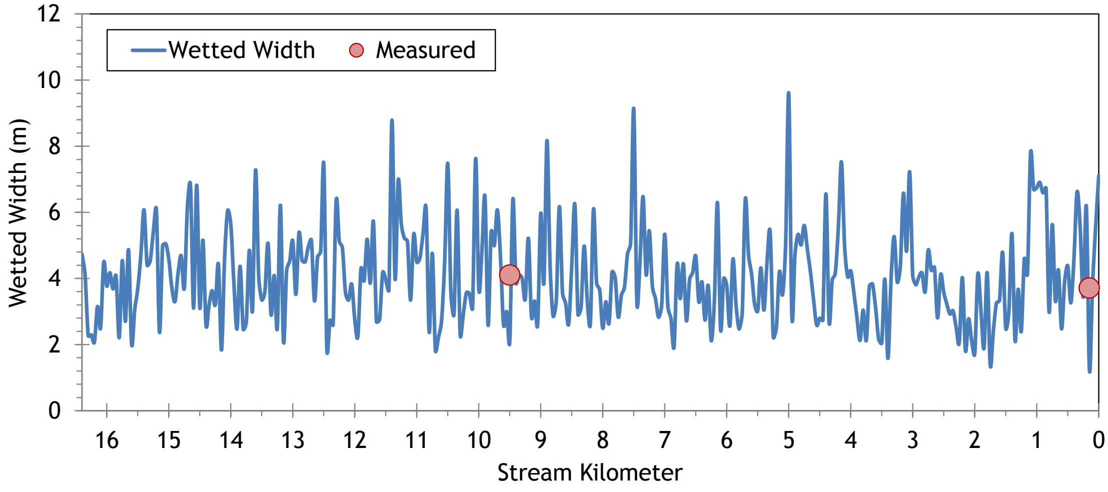
Figure 201 shows the sampled elevations and gradients for Five Points Creek. Gradients were generally between 1% and 2%. The stream flows through mostly confined valley in a mountainous terrain.

Figure 201 – Five Points Creek elevation and gradient.



Five Points Creek is also relatively small during the summertime. Figure 202 shows the measured and sampled wetted widths. The average width was about 4 meters for most of the stream.

Figure 202 – Five Points Creek wetted widths.



Five Points Creek flows from north to south before joining the Grande Ronde River (Figure 203).

Figure 203 – Five Points Creek stream aspect.

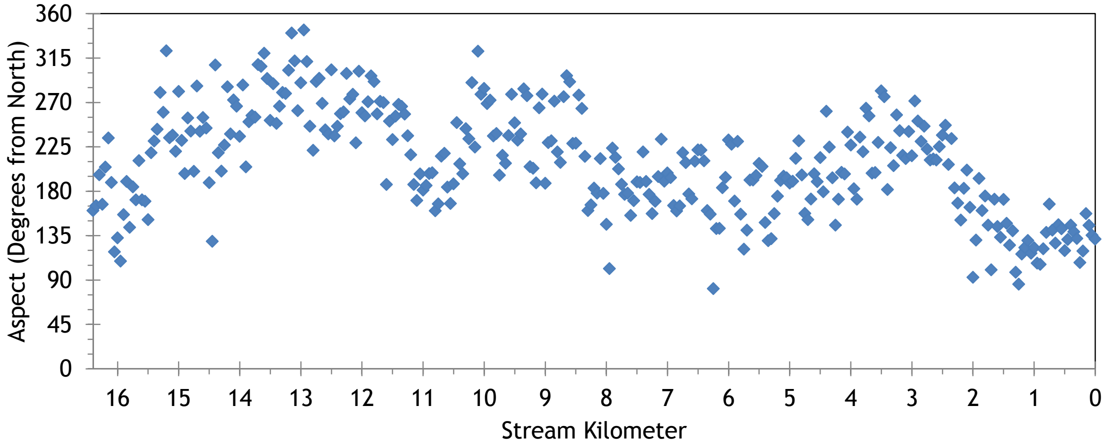


Figure 204 shows the topographic shade angles sampled for Five Points Creek. Overall, there is a significant amount of topographic shade.

Figure 204 – Five Points Creek topographic shade angles.

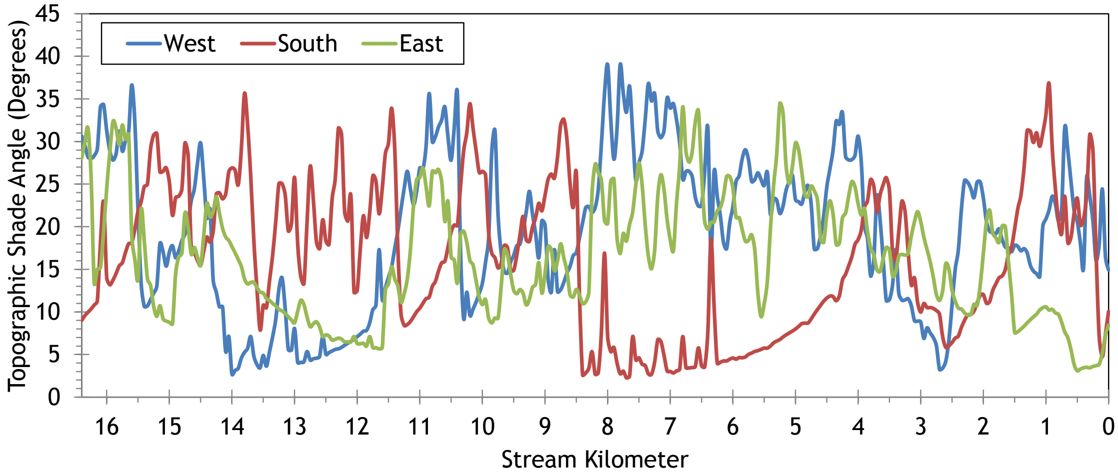
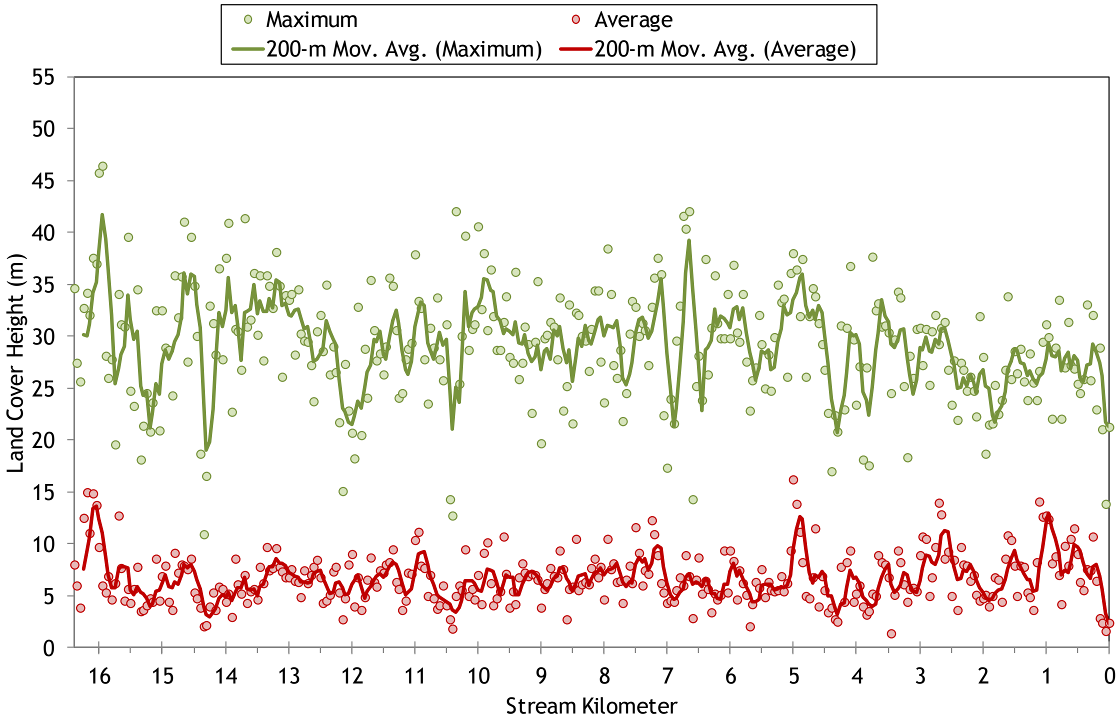


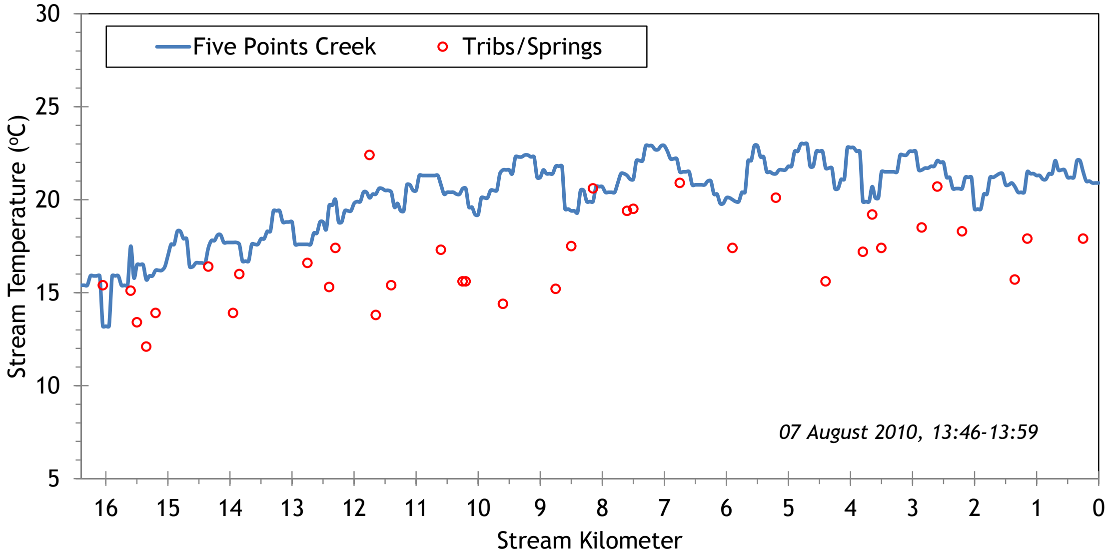
Figure 205 shows the land cover heights sampled along Five Points Creek. The maximum and average of the 28 radial samples were calculated for each 50-meter stream node. *(Note: Heat Source uses each of the 28 radial samples for each 50-meter node. The maximum and average are shown here for simplification purposes.)*

Figure 205 – Five Points Creek land cover heights sampled from highest hit LiDAR.



The TIR stream temperature profile of Five Points Creek is shown in Figure 206. The low flow volumes at the time of the flight are the primary reason for so much variability in the temperature profile. Smaller stream volumes are more sensitive to environmental factors that influence stream temperature.

Figure 206 – Five Points Creek TIR stream temperature profile.



5.16.2 Five Points Creek Heat Source Calibration Results

Five Points Creek flows from the north to the south and joins the Grande Ronde River. Figure 207 shows the simulation extent of the Heat Source model.

Figure 207 – Five Points Creek simulation extent.

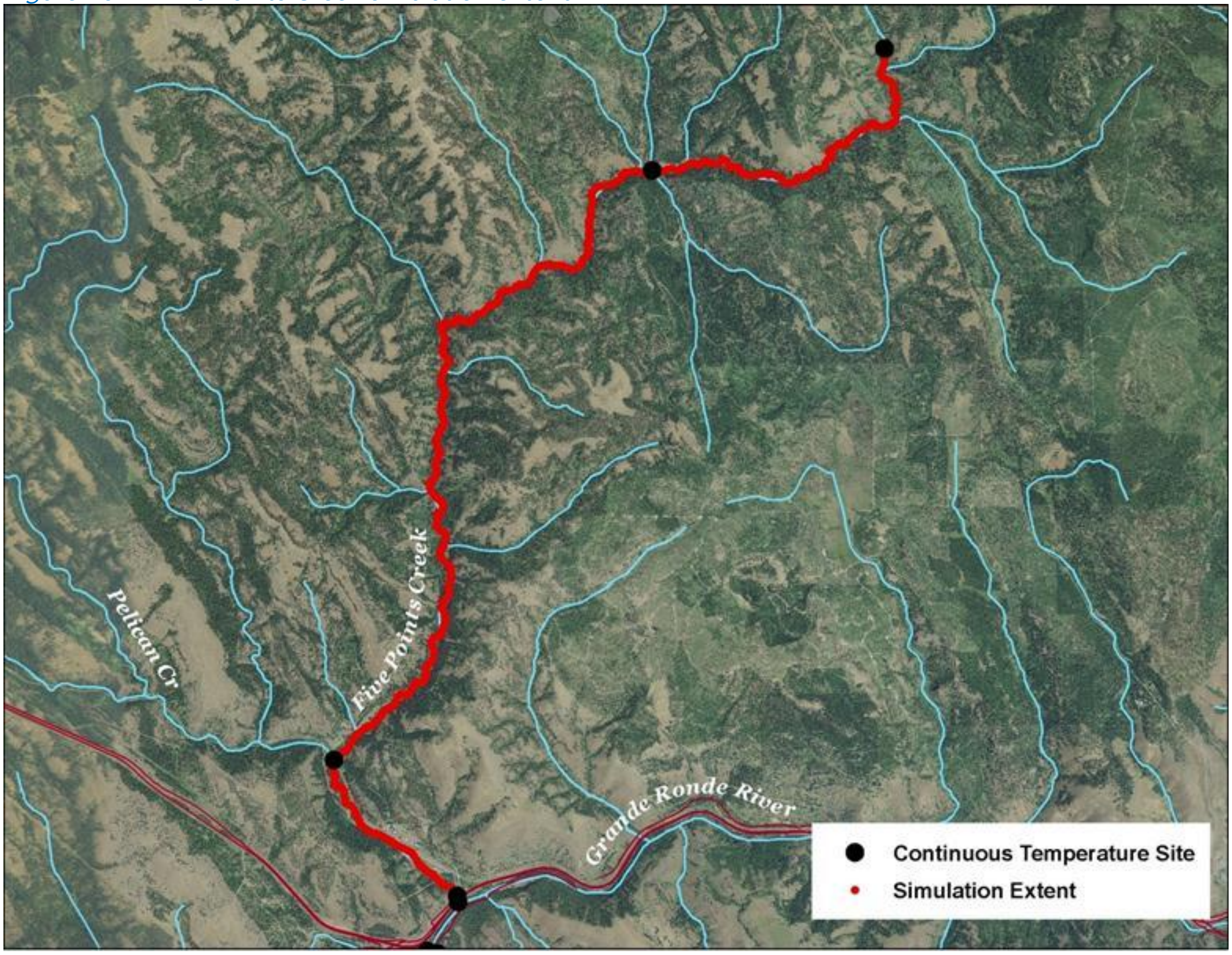


Table 32 – Five Points Creek general Heat Source parameters.

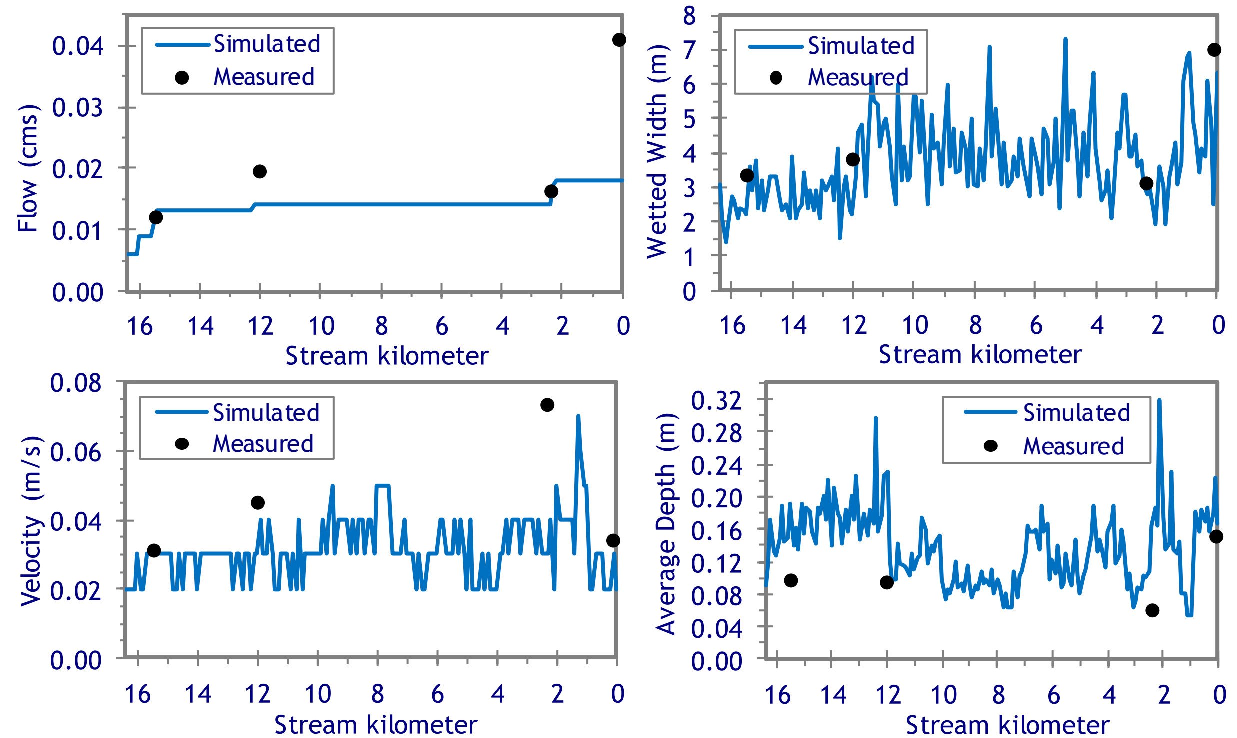
Stream:	Beaver Creek
Length:	22.9 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 7, 2010 14:42-15:03
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

The following assumptions were used when calibrating the Five Points Creek Heat Source model:

- Hourly climate data were obtained from the La Grande airport (NWS). Wind speeds were reduced to better represent forested mountain terrain. Air temperatures were adjusted using an adiabatic lapse rate of $1^{o}C$ per 100 meters elevation.
- Wetted widths were digitized from the TIR and LiDAR intensity images. The calibrated model used 45% of the TTools-sampled value in the upper 4.4 stream kilometers, while 85% of sampled wetted width was used in the lower 12 kilometers.

Figure 208 summarizes the simulated and measured hydraulic values for Five Points Creek. The simulated values are from August 25^{th}, while the measured values were obtained on various dates.

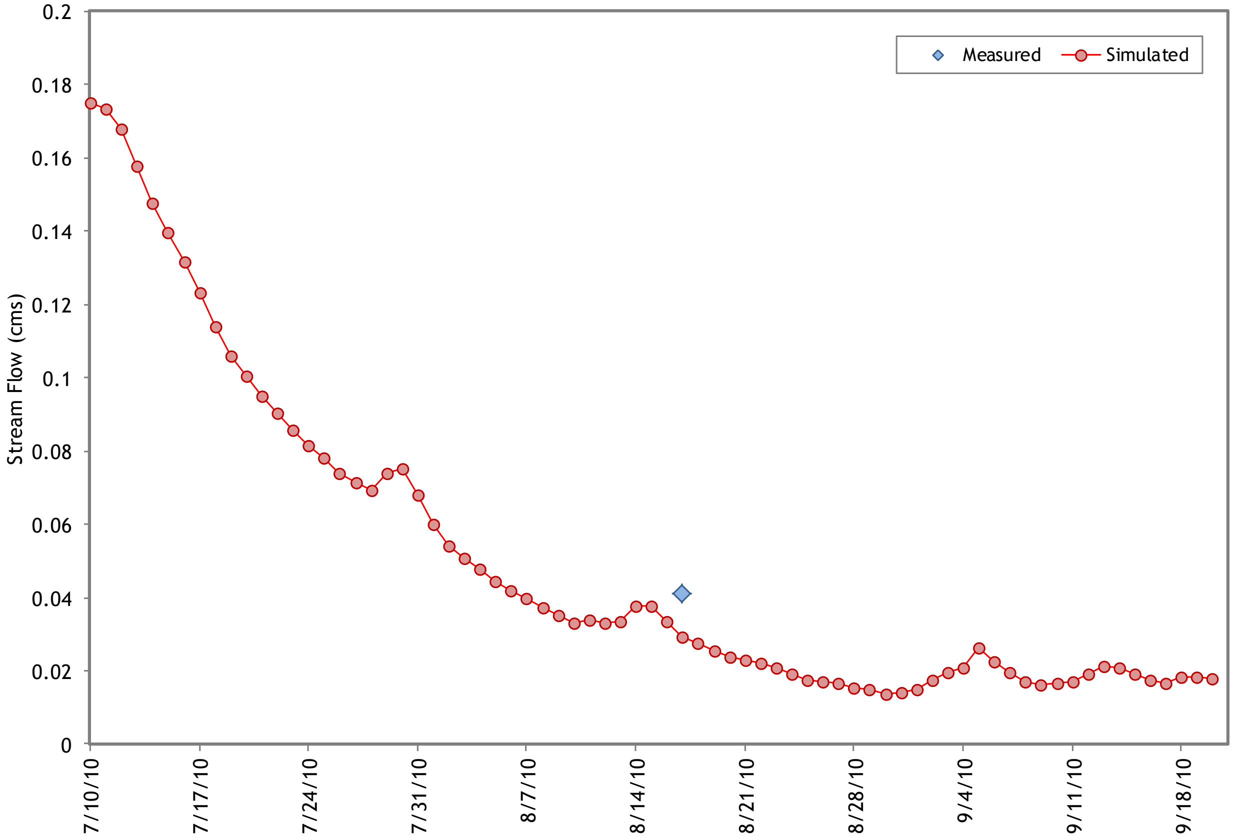
Figure 208 – Five Points Creek simulated and measured hydraulic values.



Site	Stream Km	Date
Five Points Creek Upper End	15.45	8/25/2010
Five Points Creek above Little JD Creek	12	8/25/2010
Five Points Creek above Pelican Creek	2.35	8/17/2010
Five Points Creek at Mouth	0.1	8/17/2010

The measured and simulated daily flows near the mouth of Five Points Creek are presented in Figure 209. Daily variability was extrapolated from data measured at the mouth of Five Points Creek.

Figure 209 – Five Points Creek measured and simulated flow near the mouth.



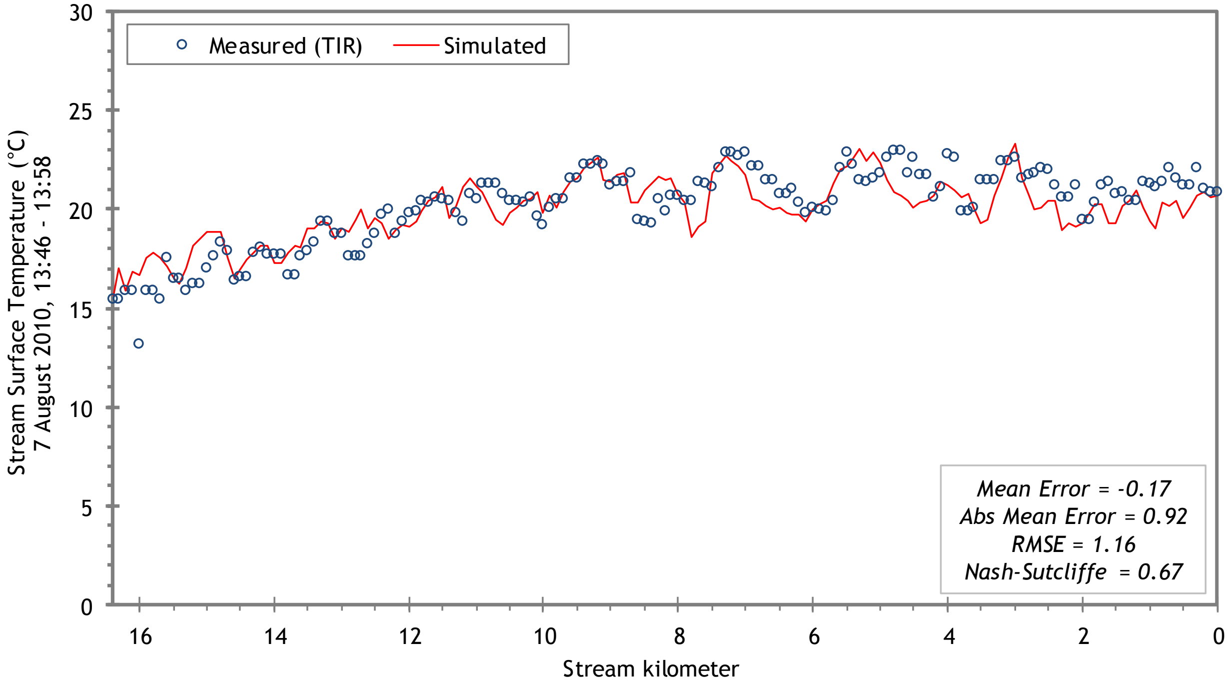
There were three active tributaries observed in the TIR imagery (Table 33). The flow volumes for each were estimated to be the same, while the TIR sampled temperatures were used for each.

Table 33 – Five Points Creek mass inflow features and assumptions.

Feature	Stream Km	Assumptions
Fiddlers Hell Creek	16.0	0.003-0.008 cms at constant 15.4ºC
Tie Creek	15.5	0.003-0.008 cms at constant 13.4ºC
Pelican Creek	2.3	0.003-0.008 cms at constant 18.3ºC

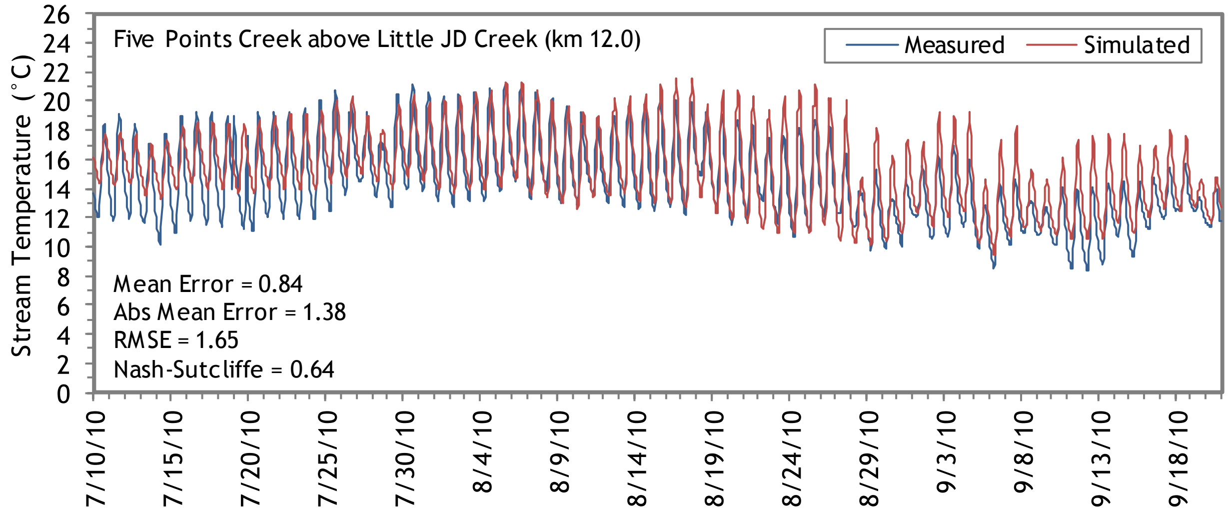
Figure 210 shows the simulated and measured longitudinal stream temperatures for Five Points Creek. There is a great deal of variability in the longitudinal temperatures mainly because of the low flow volume during the simulation time period.

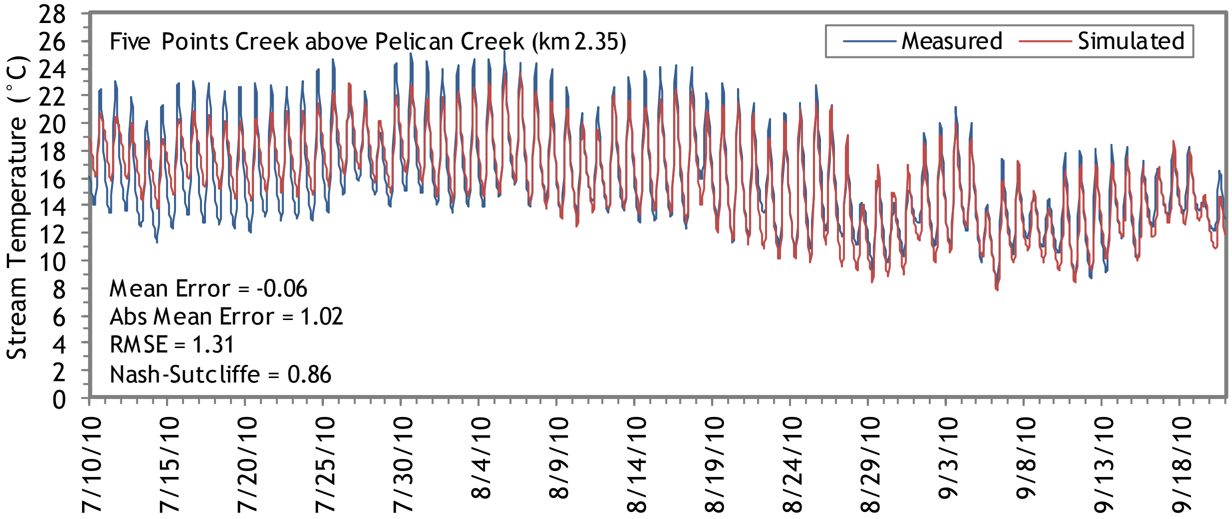
Figure 210 – Five Points Creek simulated and measured longitudinal stream temperatures.



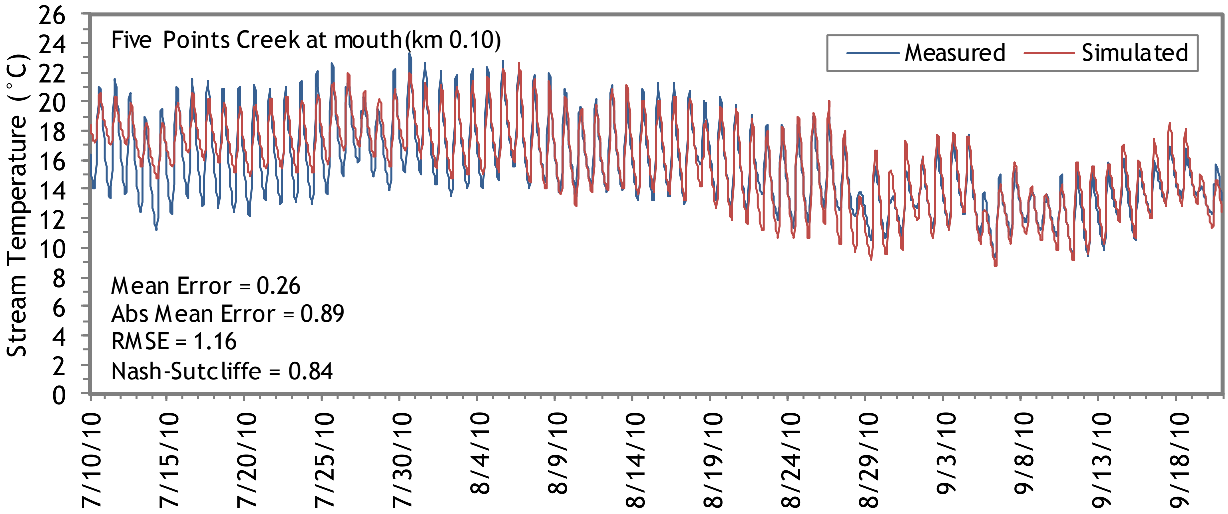
The simulated and measured hourly stream temperatures are presented in Figure 211. There were three locations where hourly stream temperatures were recorded.

Figure 211 – Five Points Creek simulated and measured hourly stream temperatures.





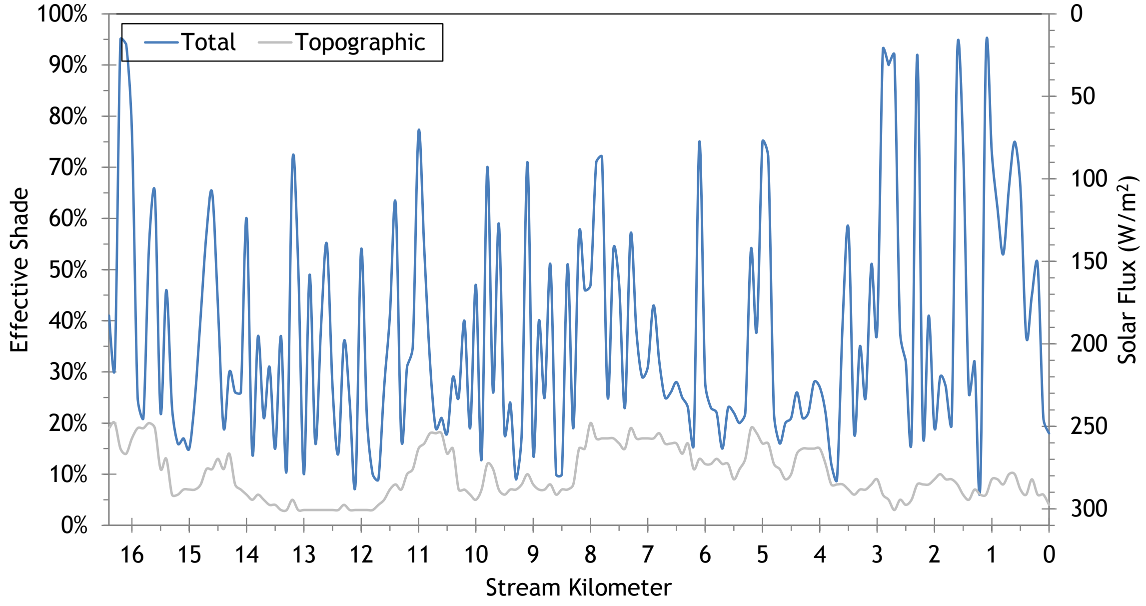
Five Points Creek above Pelican Creek (km 2.35)
Measured
Simulated
Mean Error = -0.06
Abs Mean Error = 1.02
RMSE = 1.31
Nash-Sutcliffe = 0.86
Stream Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10



Five Points Creek at mouth (km 0.10)
Measured
Simulated
Mean Error = 0.26
Abs Mean Error = 0.89
RMSE = 1.16
Nash-Sutcliffe = 0.84
Stream Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
7/10/10
7/15/10
7/20/10
7/25/10
7/30/10
8/4/10
8/9/10
8/14/10
8/19/10
8/24/10
8/29/10
9/3/10
9/8/10
9/13/10
9/18/10

Figure 212 shows the simulated effective shade values for Five Points Creek. There is a fair amount of topographic shade created by the mountainous terrain. See Appendix for effective shade maps.

Figure 212 – Five Points Creek simulated effective shade.



5.17 Grande Ronde River

RGB-colored LiDAR point cloud - Grande Ronde River alongside Interstate 84, below Five Points Creek (looking downstream).

5.17.1 Grande Ronde River TTools Results

The Grande Ronde River elevations and gradients were sampled from the bare earth LiDAR data (Figure 213). The upper reaches have a much higher gradient than the lower sections.

Figure 213 – Grande Ronde River elevation and gradient.

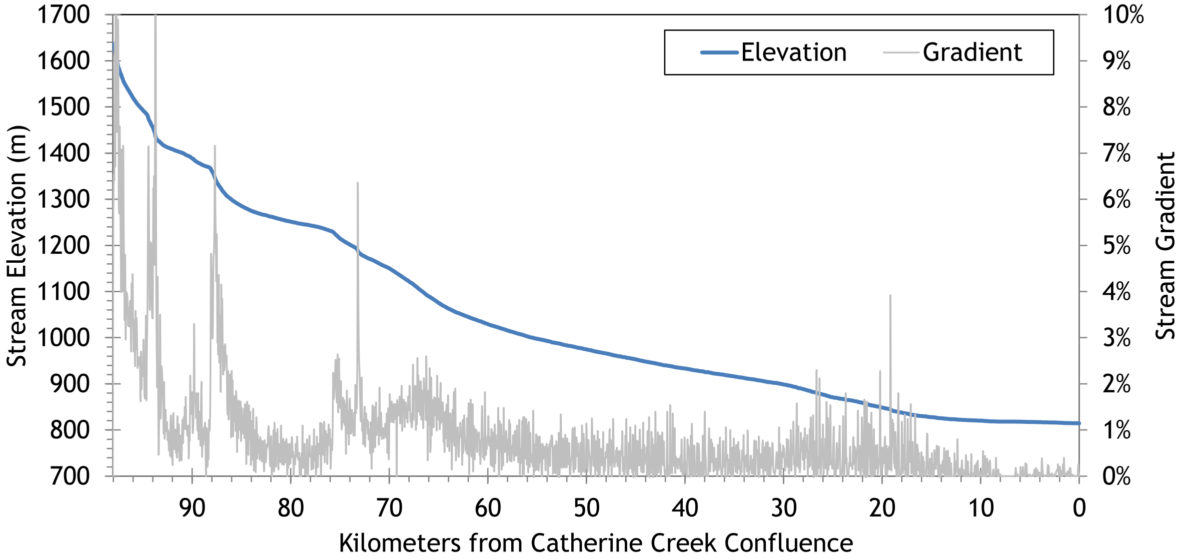


Figure 214 shows the sampled active and wetted channel widths along with the measured wetted widths. The Grande Ronde River generally gets wider as it flows downstream. Below stream kilometer 10, the channel is mostly diked and flows through a canal “State Ditch”.

Figure 214 – Grande Ronde River channel widths.

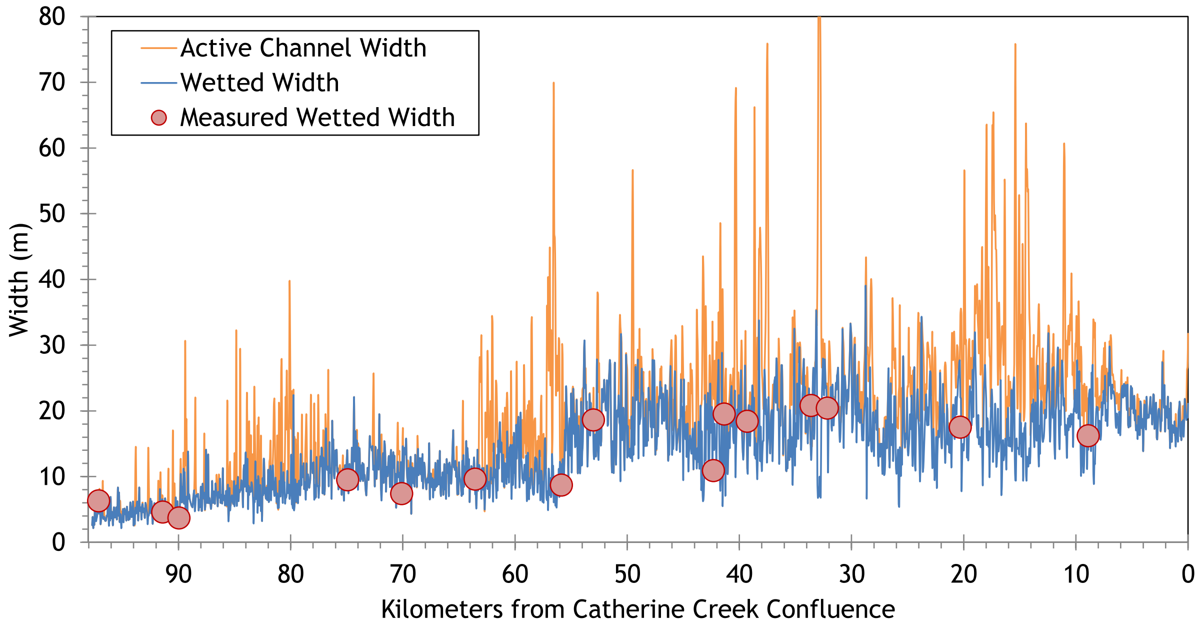
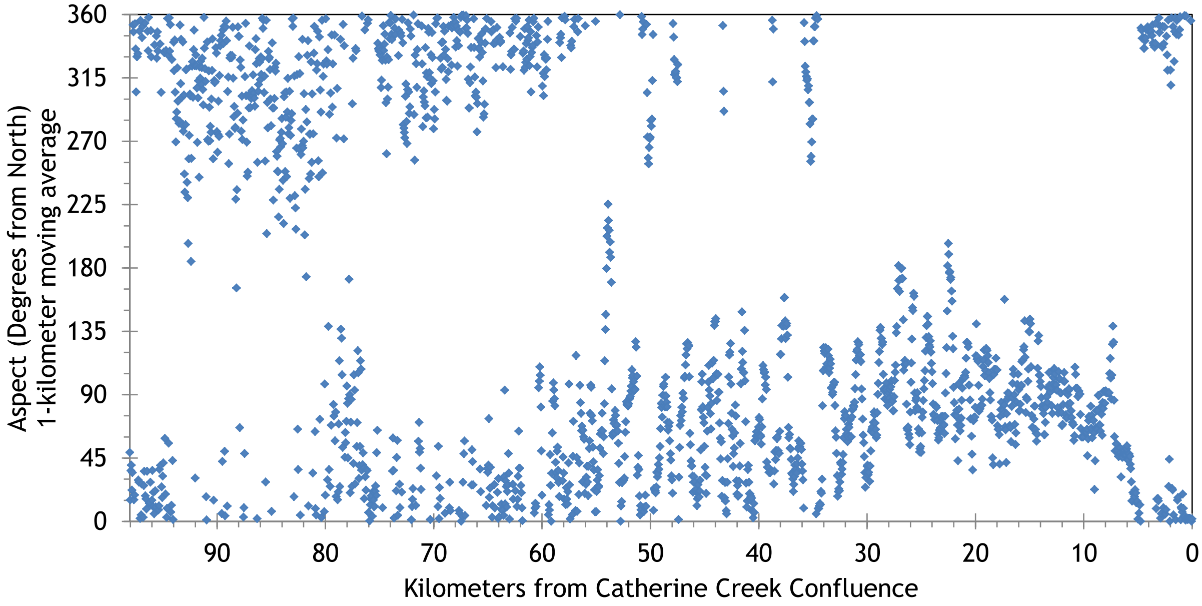


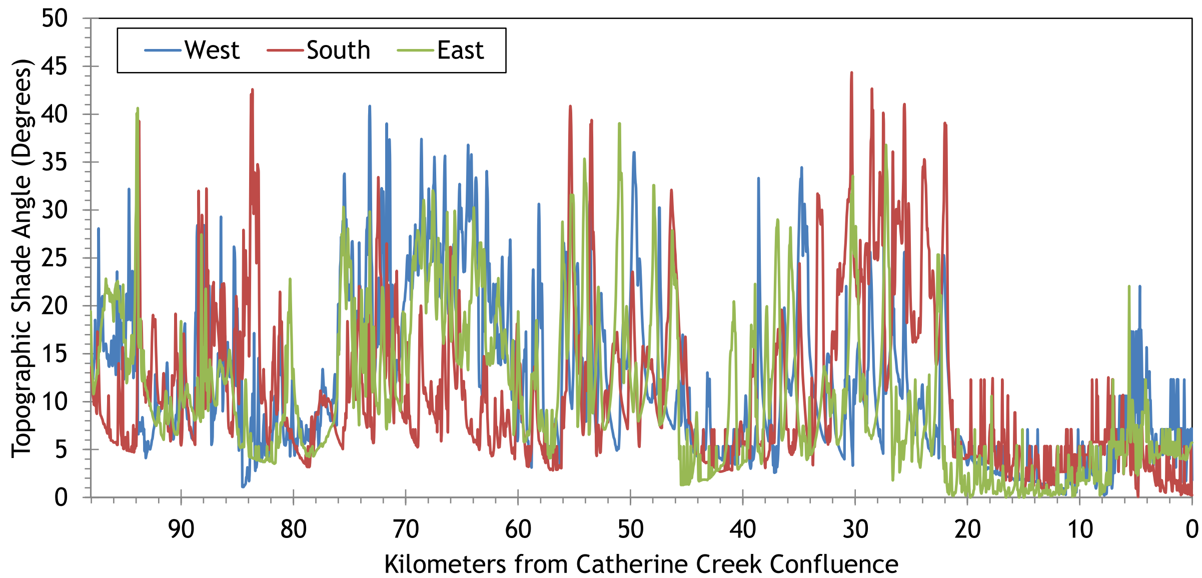
Figure 215 shows the stream aspect for each 50-meter segment of the Grande Ronde River. The river starts out flowing northerly, bends to the northeast between kilometers 60 and 30, then flows east through La Grande and the State Ditch.

Figure 215 – Grande Ronde River stream aspect.



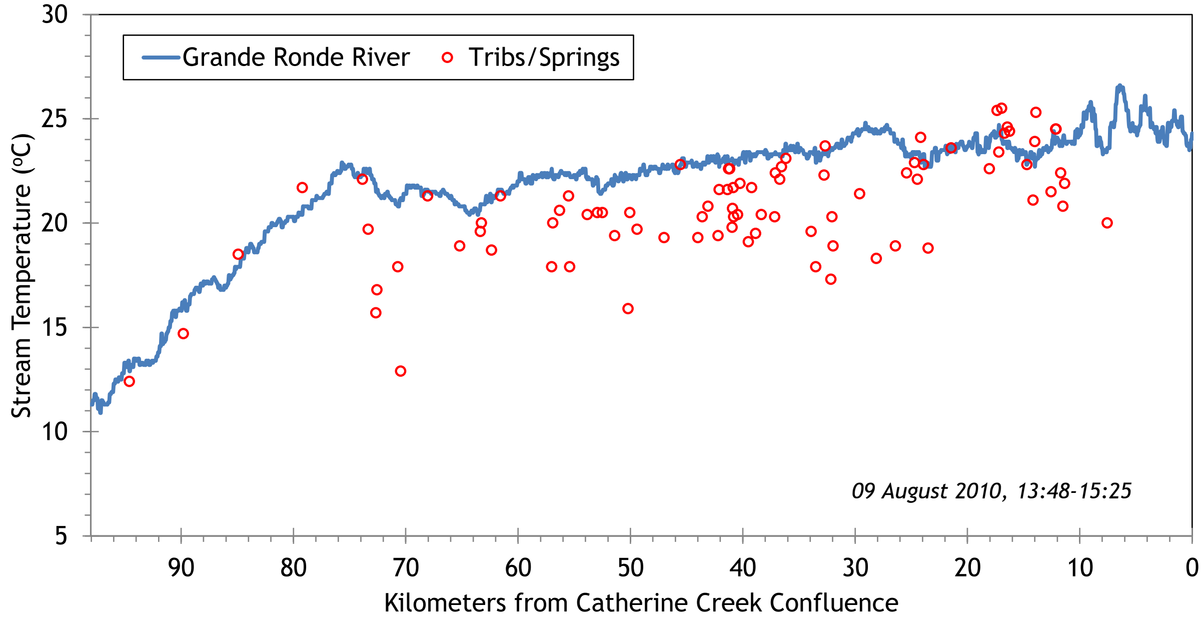
Topographic shade angles for the Grande Ronde River are shown in Figure 216. The upper river has a fair amount of topographic shade. The lower 20 kilometers are in the wide valley bottom and have much less topographic shade. In many of those lower 20 kilometers, the river banks are severely down-cut and it is the riverbanks that are producing the topographic shade.

Figure 216 – Grande Ronde River topographic shade angles.



The TIR stream temperature profile of the Grande Ronde River is shown in Figure 217. In the upper watershed, the stream is relatively cool, but heats steadily until approximately stream kilometer 75. Below that, stream temperatures hovered between 21 °C and 25°C during the TIR flight.

Figure 217 – Grande Ronde River TIR stream temperature profile.



RGB-colored LiDAR point cloud - Grande Ronde River at Vey Meadow (flowing from right to left of image).

5.17.2 Grande Ronde River Heat Source Calibration Results

The Grande Ronde River was simulated from just below Tanner Gulch to the Catherine Creek confluence (Figure 218).

Figure 218 – Grande Ronde River simulation extent.

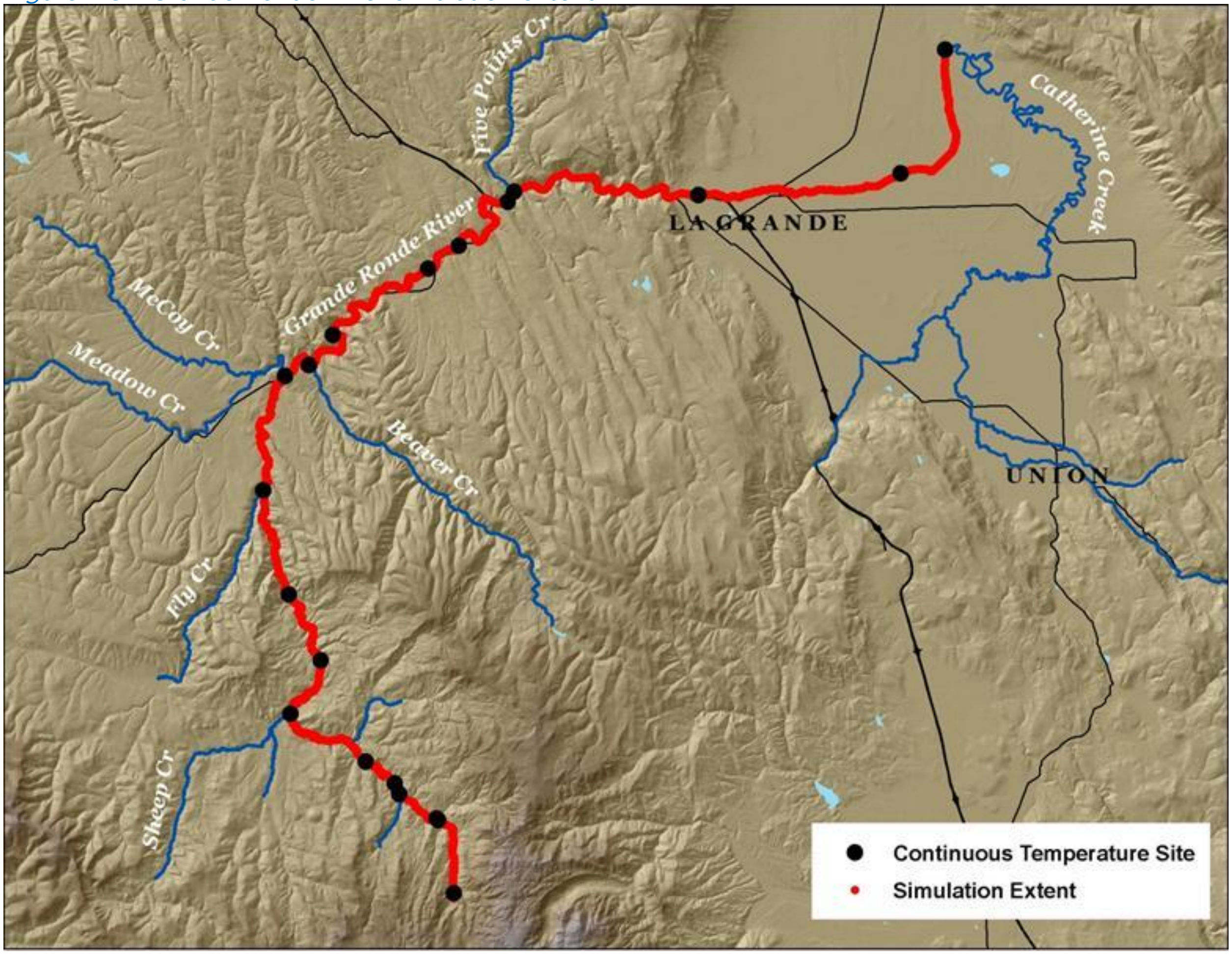


Table 34 – Grande Ronde River general Heat Source parameters.

Stream:	Grande Ronde River
Length:	97.2 kilometers
Time Period:	July 10 – September 20, 2010
Input Distance Step:	50 meters
Output Distance Step:	100 meters
Time Step:	1 minute
Flush Initial Condition:	7 days
TIR Date and Time:	August 9, 2010 13:48-15:25
Land Cover Data Source:	LiDAR
Land Cover Sampling Distance Step:	15 meters

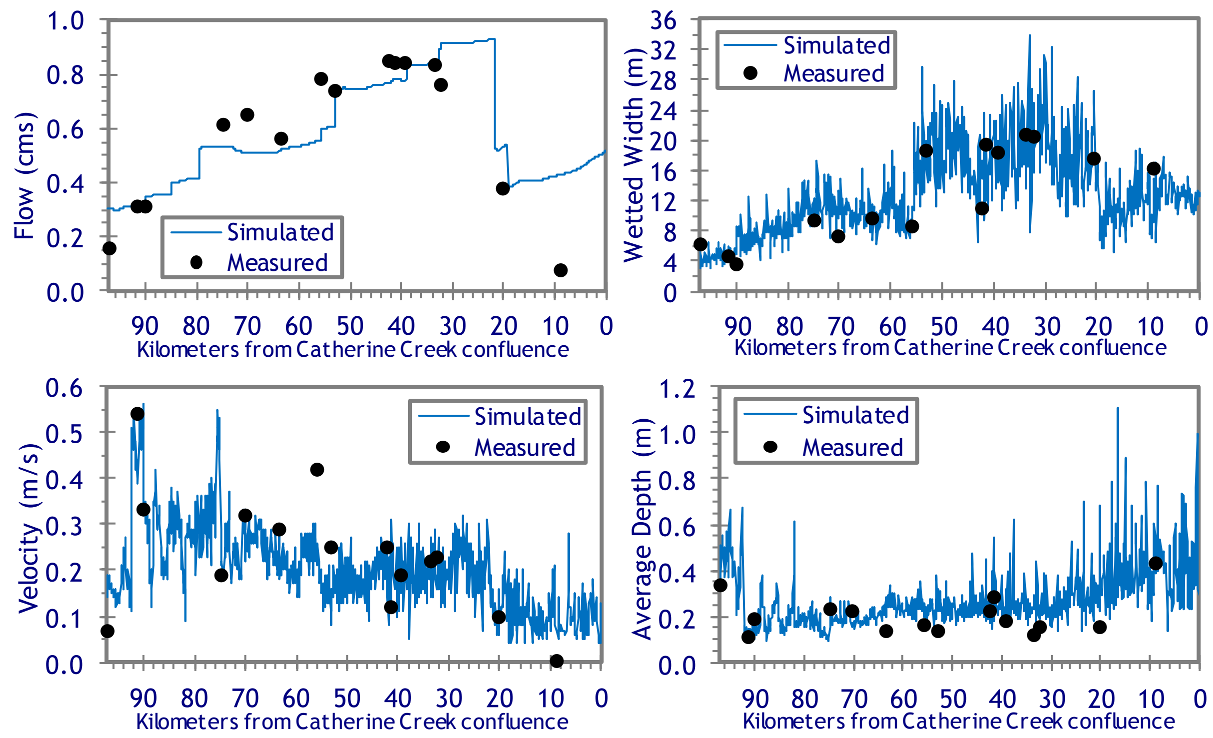
The following assumptions were used when calibrating the Grande Ronde River Heat Source model:

- Hourly climate data are from the La Grande airport. Wind speeds were reduced and air temperatures were adjusted for the adiabatic lapse rate of 1°C per 100 meters elevation.
- Wetted widths were digitized from the TIR and LiDAR intensity images.
- Most inflows observed in the TIR data were very small compared to the Grande Ronde River flow and did not produce measurable thermal influences. Therefore, only the larger inflows were included within the model, which includes but is not limited to the other simulated tributaries.
- There is significant withdrawal that occurs in La Grande. The withdrawals are not monitored and are likely to vary greatly during the simulation time period. Since the majority of water is consumed starting in the reaches through and below La Grande and the gradient is very low, the model exhibited instability below simulation kilometer 10. In addition, there is likely thermal stratification occurring in those low-gradient reaches below La Grande, which Heat Source is incapable of simulating. For these reasons, less water was removed at the diversions than was probably actually occurring.
- **Model results below simulation kilometer 21.75 should be considered as rough estimates only and should not be used for regulatory or planning purposes.**

RGB-colored LiDAR point cloud - Grande Ronde River above Meadow Creek (looking downstream).

Figure 219 shows the simulated and measured hydraulics values for the Grande Ronde River. Note that the measured data were collected on several different days, while the simulated values are plotted only for August 17, 2010.

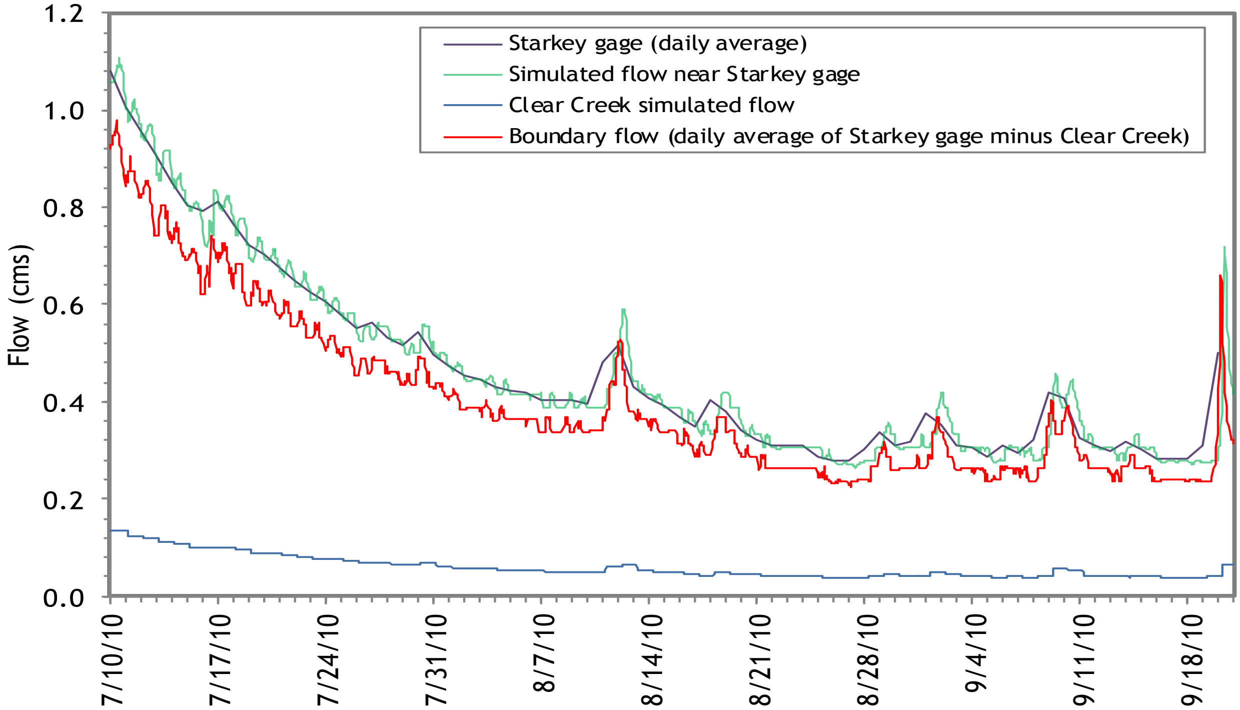
Figure 219 – Grande Ronde River simulated and measured hydraulic values.



Site	Simulation Km	Date
Below Tanner Gulch	97.1	8/20/2010
Reach U155154	91.4	8/19/2010
above Clear Creek	89.95	8/19/2010
below Vey	74.9	8/18/2010
Time and Half Bridge	70.1	8/11/2010
Above Fly Creek	63.55	8/18/2010
above Meadow Creek	55.85	8/11/2010
above Beaver Creek	53	8/18/2010
above Bear Creek	42.3	8/18/2010
above Jordan Creek	41.35	8/18/2010
above Spring Creek	39.3	8/18/2010
Hilgard Park	33.6	8/17/2010
above Five Points Creek	32.15	8/17/2010
at Second Street Bridge	20.3	8/17/2010
at Peach Road Bridge	8.9	8/17/2010

The simulated and measured flows at the gage near Starkey, Oregon, simulated Clear Creek discharge and boundary flow are shown in
Figure 220. The boundary flow is based on the daily average from the gage near Starkey minus the simulated flow from Clear Creek. This is because the gage near Starkey is approximately 1 km below the mouth of Clear Creek while the upper boundary of the Grande Ronde model is above Clear Creek.

Figure 220 – Grande Ronde River simulated and measured flows at the gage near Starkey and the upper boundary flow.



A mass balance of all inflows (Table 35) and model boundary flow was targeted towards the Grande Ronde Perry gage flow at river kilometer 28.6. Inflows were adjusted based on their relative contribution to the sum of all inflows in order to assure a flow balance for the extent of the modeling period. Figure 221 shows the results of this mass balance compared to upper and lower gage flows.

Figure 221 – Mass balance results and measured flow comparisons from a lower reach of the Grande Ronde River.

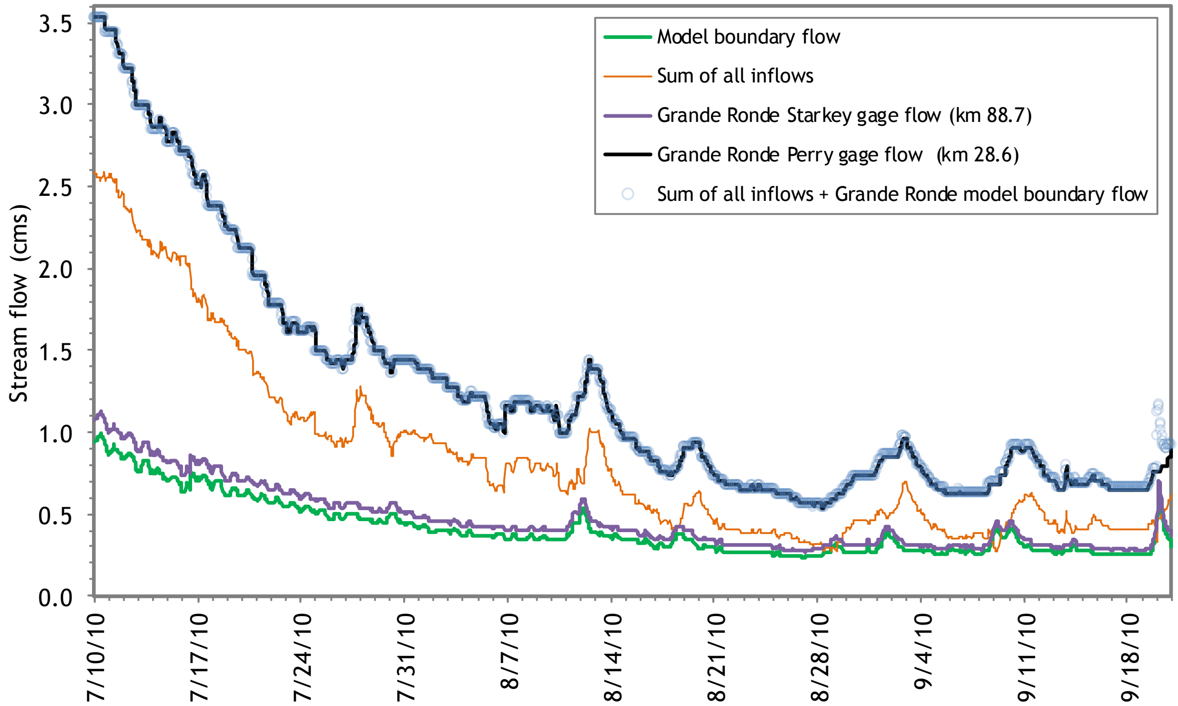


Table 1 summarizes the inflows and outflows included in the Grande Ronde River Heat Source model. All tributary flows had daily values estimated based on CRITFC measurements and patterns derived from Grande Ronde River gage data (see previous sections). Hourly stream temperatures were measured near the mouth of each tributary. The diversion rates were estimated as a constant percentage of the stream flow.

Table 35 – Grande Ronde River mass inflow and outflow features and assumptions.

Feature	Stream Km	Assumptions
Clear Creek	89.85	Simulated flow volume, measured hourly temperatures.
Limber Jim Creek	84.9	Simulated flow volume, measured hourly temperatures.
Sheep Creek	79.3	Simulated flow volume, measured hourly temperatures.
Fly Creek	63.35	Simulated flow volume, measured hourly temperatures.
Meadow Creek	55.55	Simulated flow volume, measured hourly temperatures.
Beaver Creek	52.95	Simulated flow volume, measured hourly temperatures.
Bear Creek	42.1	Simulated flow volume, measured hourly temperatures.
Spring Creek	38.95	Simulated flow volume, measured hourly temperatures.
Rock Creek	32.75	Simulated flow volume, measured hourly temperatures.
Five Points Creek	32.1	Simulated flow volume, measured hourly temperatures.
Dobbins Diversion	21.75	Estimated to be 60% of stream flow - based on 8/17/2010 CRITFC upstream and downstream flow measurements.
Diversion	19.2	Estimated to be 20% of stream flow (further reduction causes model instability)

The simulated and measured longitudinal stream temperatures are shown in Figure 222. The results below kilometer 21.75 should be considered for information purposes only because the diversions were not monitored and there is likely thermal stratification occurring.

Figure 222 – Grande Ronde River simulated and measured longitudinal stream temperatures.

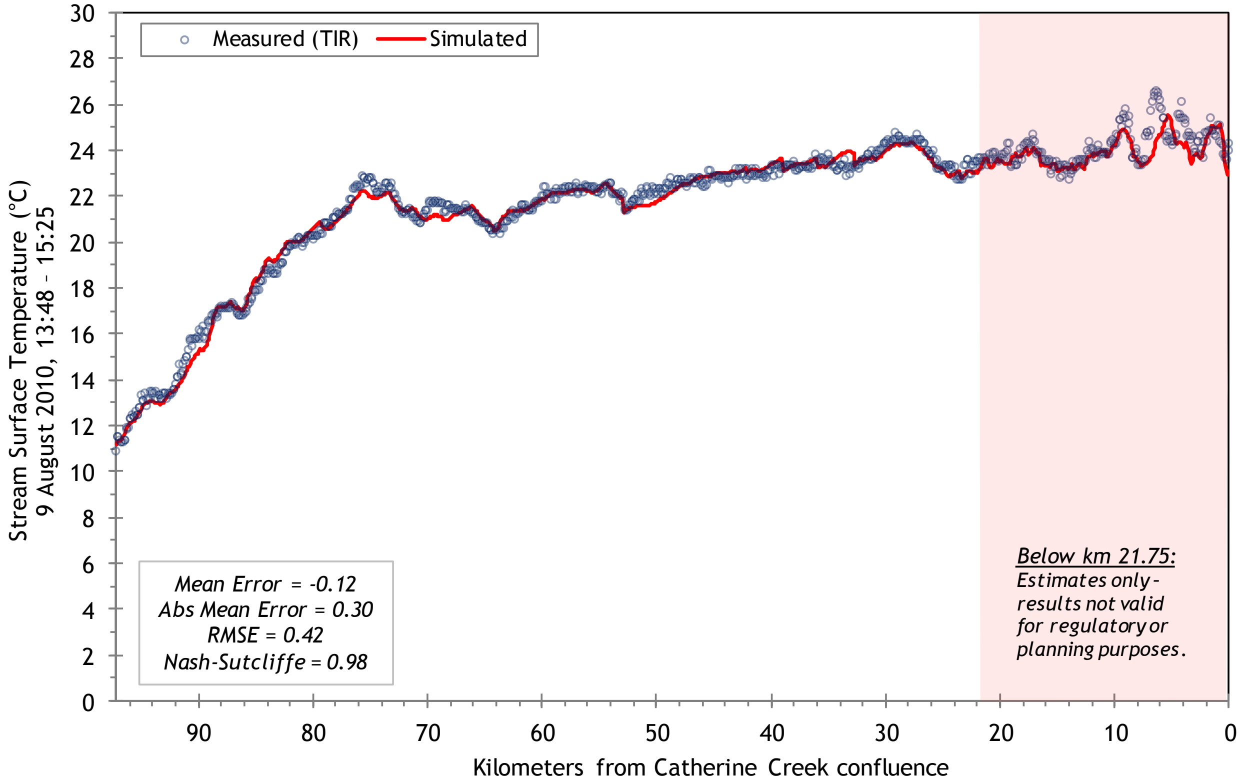
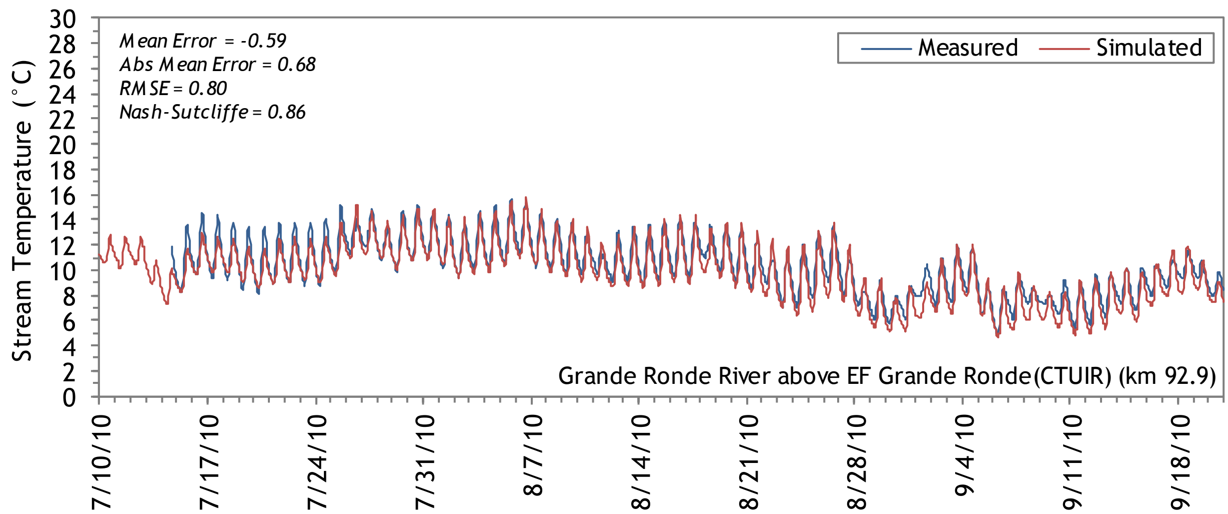
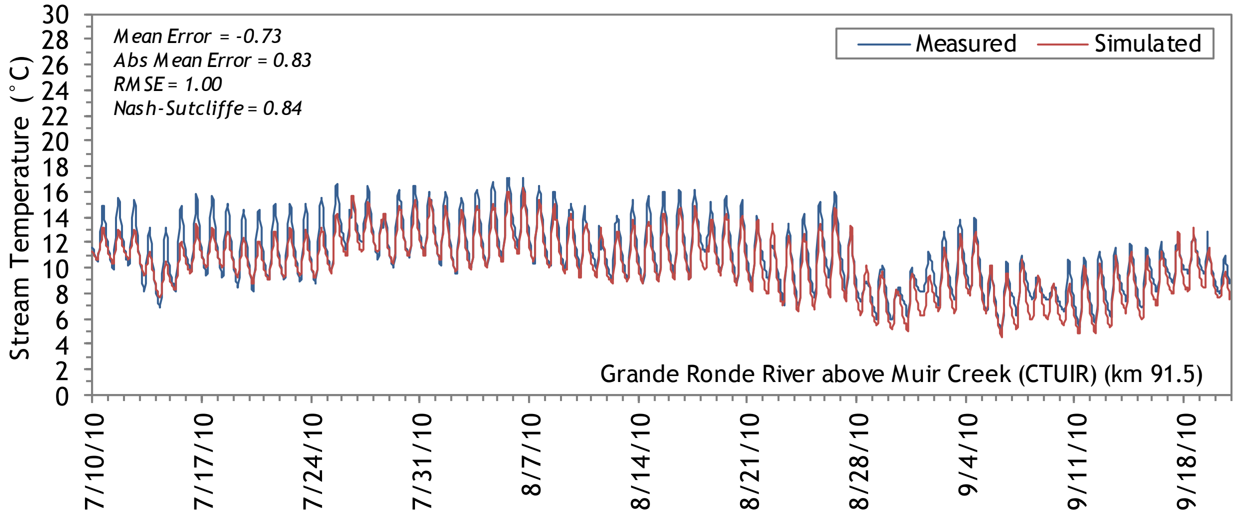
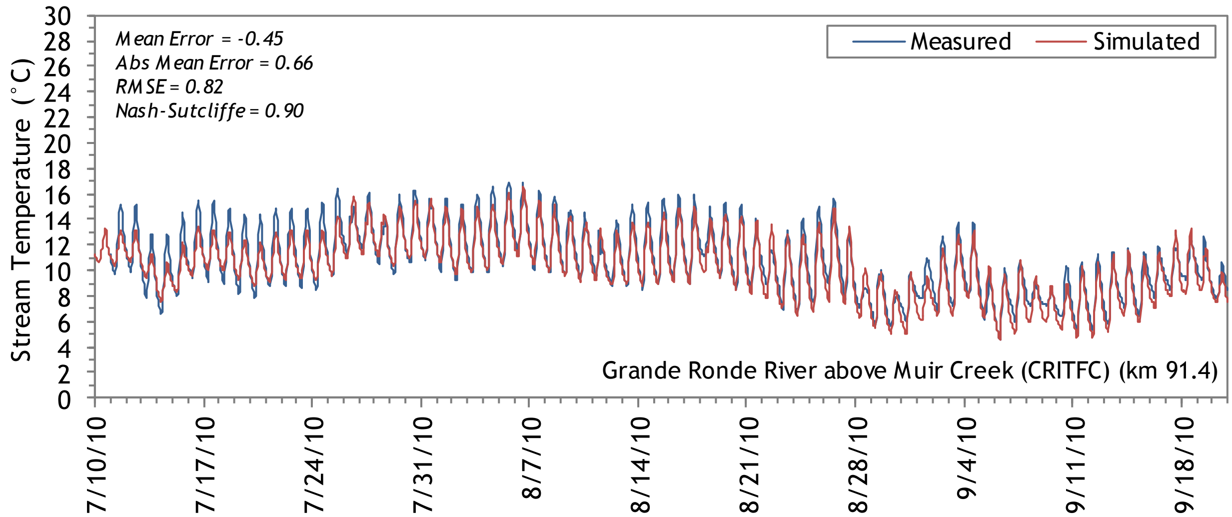


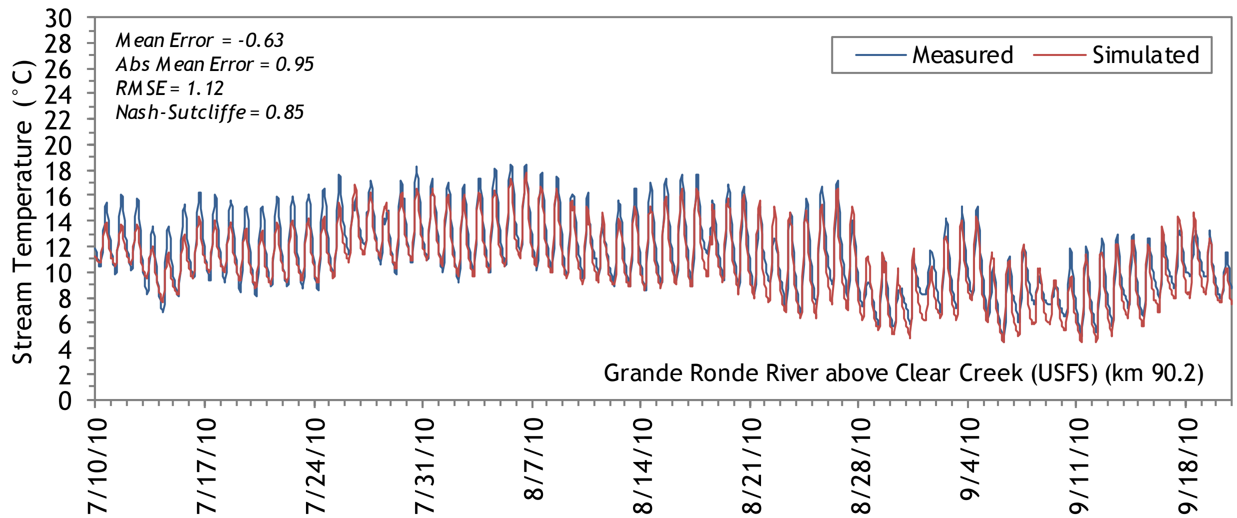
Figure 223 shows the simulated and measured hourly stream temperatures at locations along the Grande Ronde River where thermistors were deployed. Calibration statistics are included on each plot.

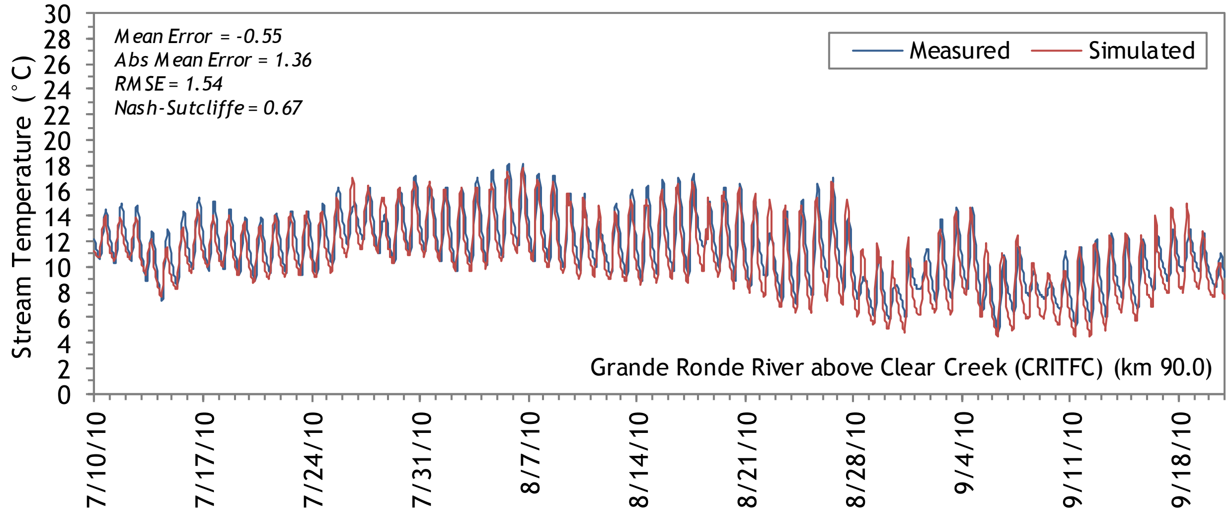
Figure 223 – Grande Ronde River simulated and measured hourly stream temperatures.

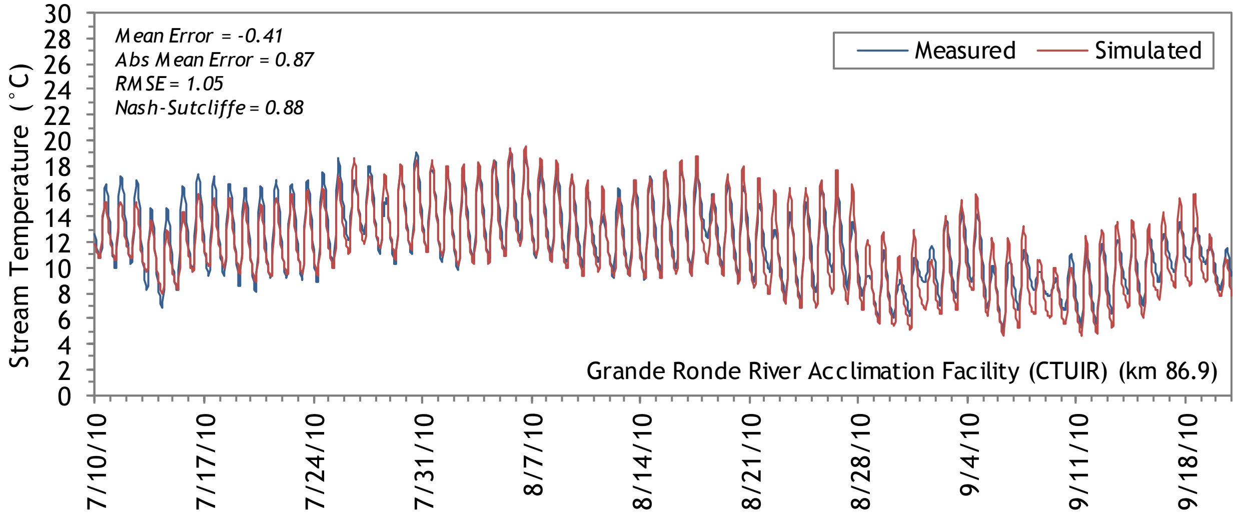


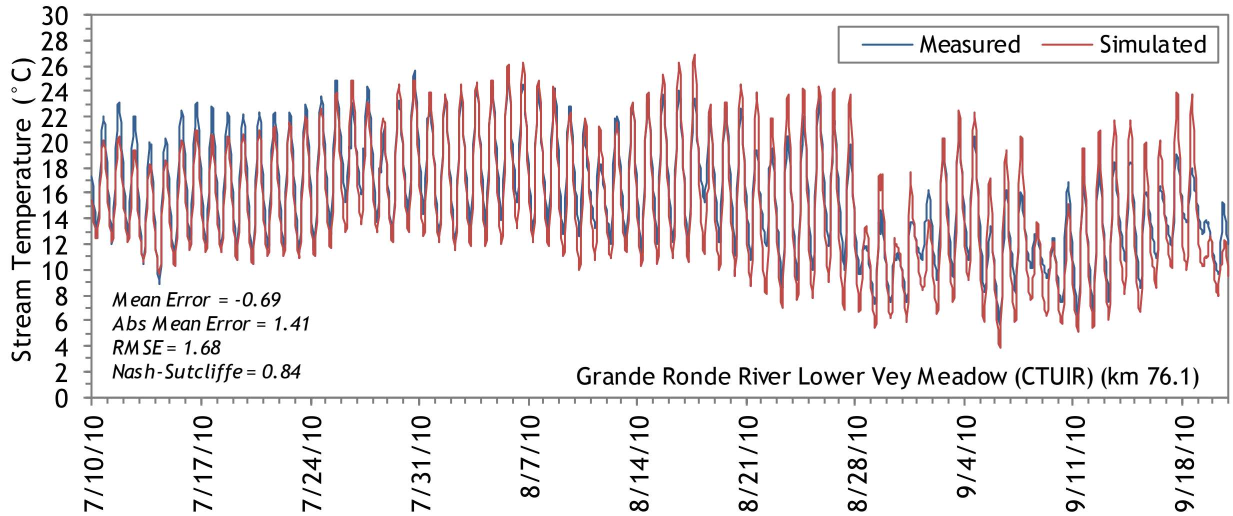

Mean Error = -0.73
Abs Mean Error = 0.83
RMSE = 1.00
Nash-Sutcliffe = 0.84
Measured
Simulated
Stream Temperature (°C)
Grande Ronde River above Muir Creek (CTUIR) (km 91.5)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

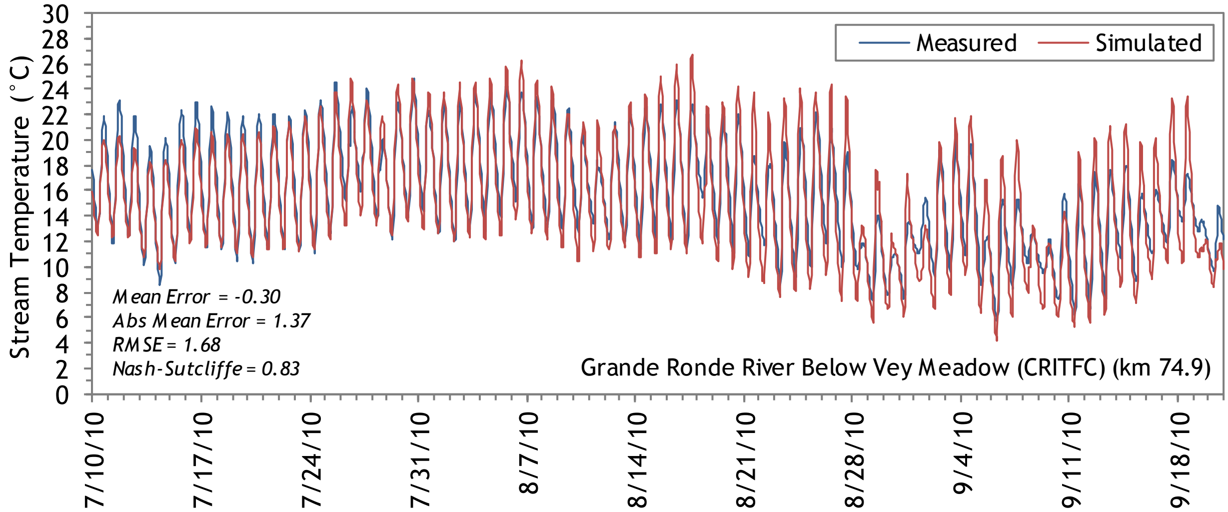

Mean Error = -0.45
Abs Mean Error = 0.66
RMSE = 0.82
Nash-Sutcliffe = 0.90
Measured
Simulated
Stream Temperature (°C)
Grande Ronde River above Muir Creek (CRITFC) (km 91.4)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

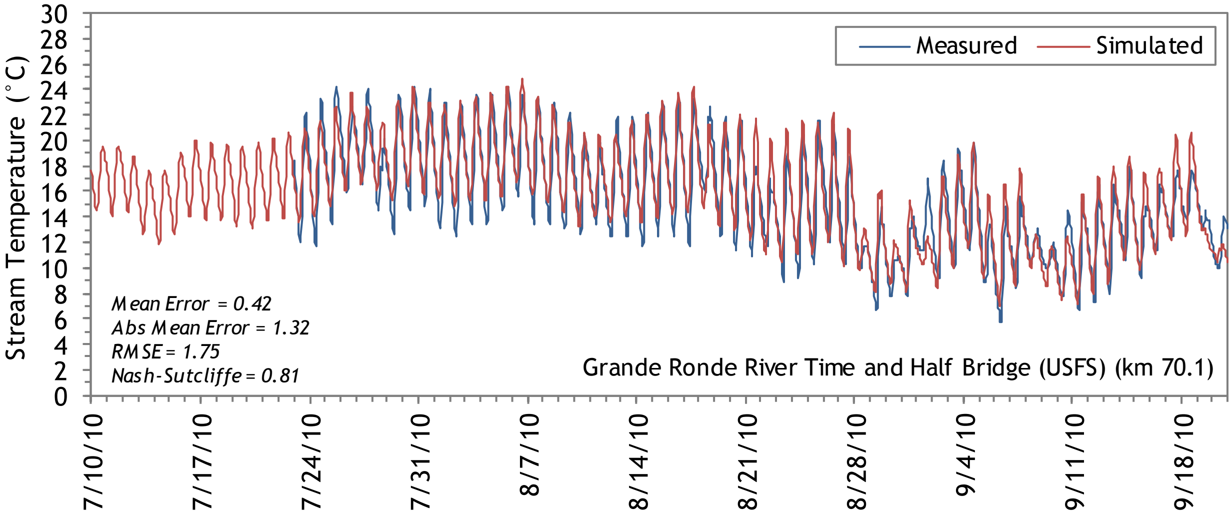

Mean Error = -0.63
Abs Mean Error = 0.95
RMSE = 1.12
Nash-Sutcliffe = 0.85
Measured
Simulated
Stream Temperature (°C)
Grande Ronde River above Clear Creek (USFS) (km 90.2)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

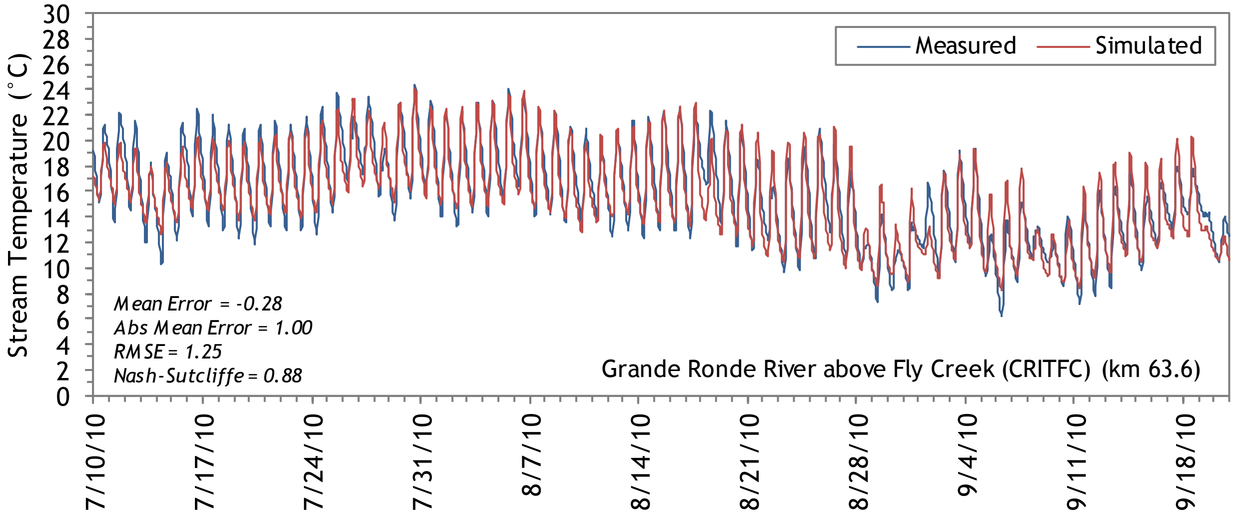

Mean Error = -0.55
Abs Mean Error = 1.36
RMSE = 1.54
Nash-Sutcliffe = 0.67
Measured
Simulated
Grande Ronde River above Clear Creek (CRITFC) (km 90.0)
Stream Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

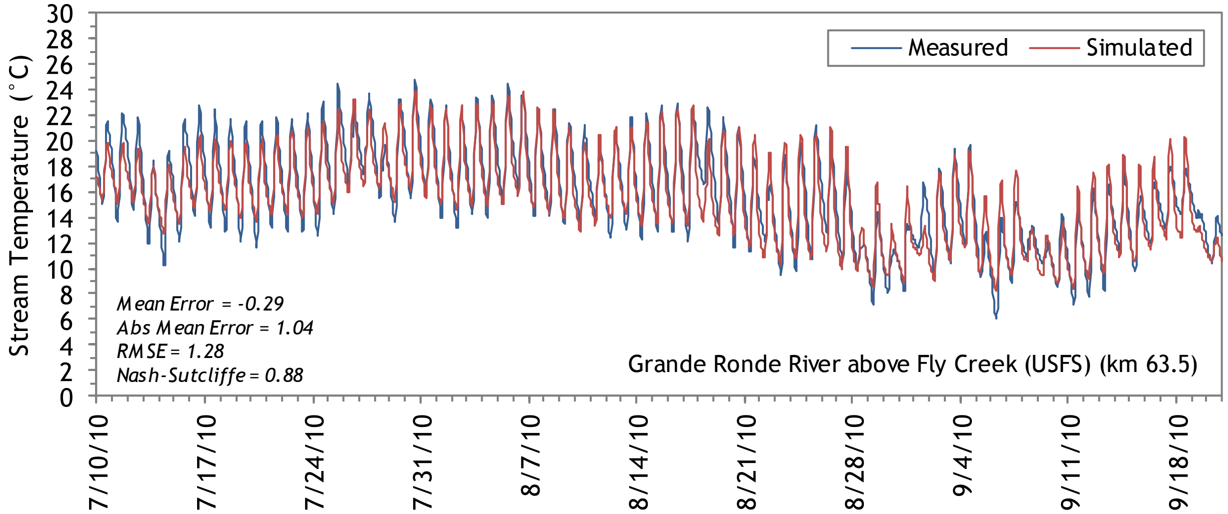

Mean Error = -0.41
Abs Mean Error = 0.87
RMSE = 1.05
Nash-Sutcliffe = 0.88
Measured
Simulated
Grande Ronde River Acclimation Facility (CTUIR) (km 86.9)
Stream Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

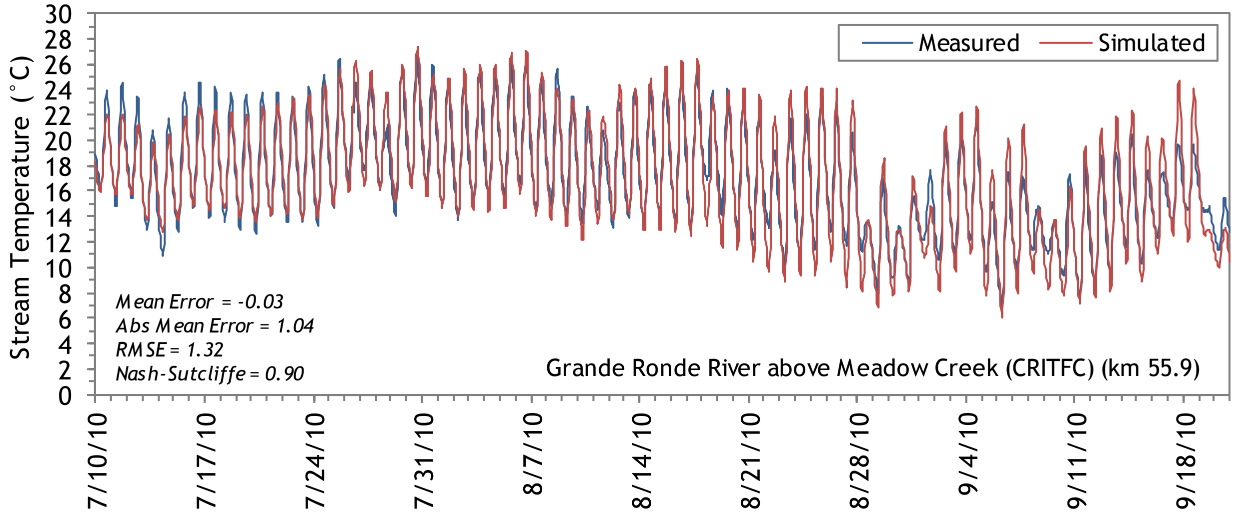

Measured
Simulated
Mean Error = -0.69
Abs Mean Error = 1.41
RMSE = 1.68
Nash-Sutcliffe = 0.84
Grande Ronde River Lower Vey Meadow (CTUIR) (km 76.1)
Stream Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

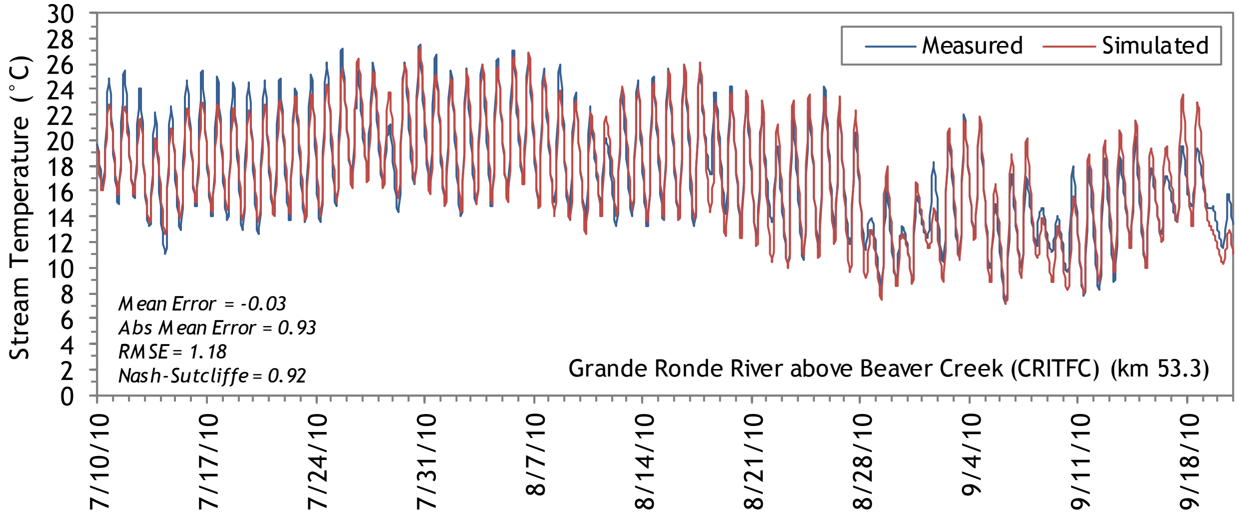

Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.30
Abs Mean Error = 1.37
RMSE = 1.68
Nash-Sutcliffe = 0.83
Grande Ronde River Below Vey Meadow (CRITFC) (km 74.9)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

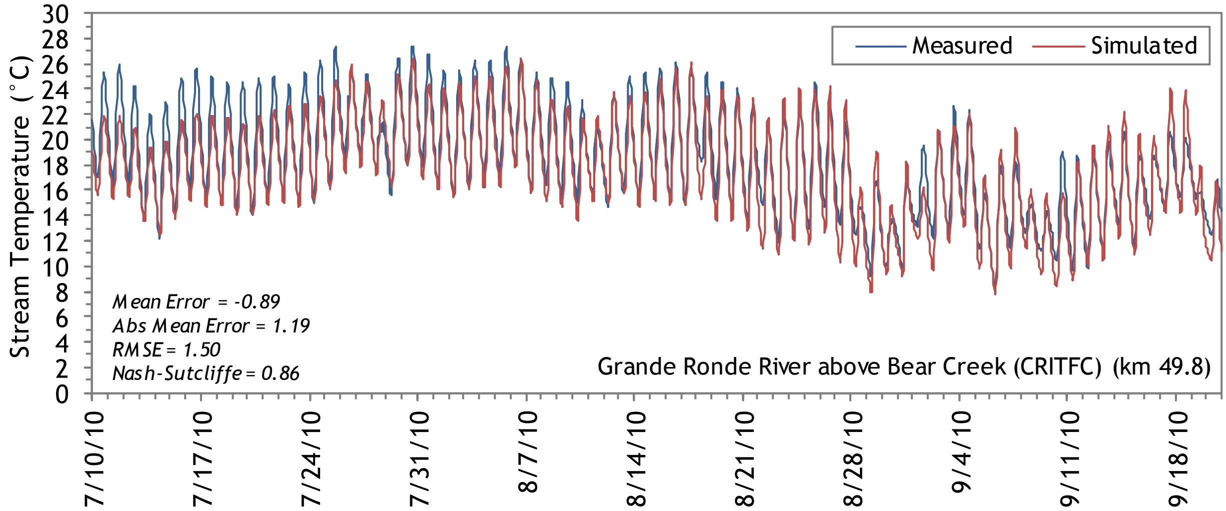

Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.42
Abs Mean Error = 1.32
RMSE = 1.75
Nash-Sutcliffe = 0.81
Grande Ronde River Time and Half Bridge (USFS) (km 70.1)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

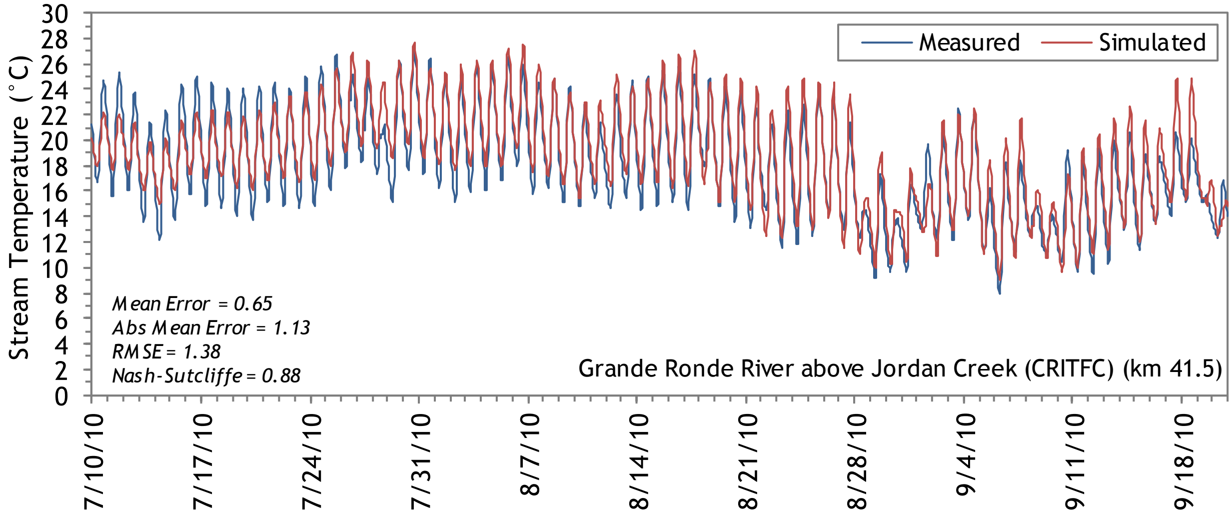

Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.28
Abs Mean Error = 1.00
RMSE = 1.25
Nash-Sutcliffe = 0.88
Grande Ronde River above Fly Creek (CRITFC) (km 63.6)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

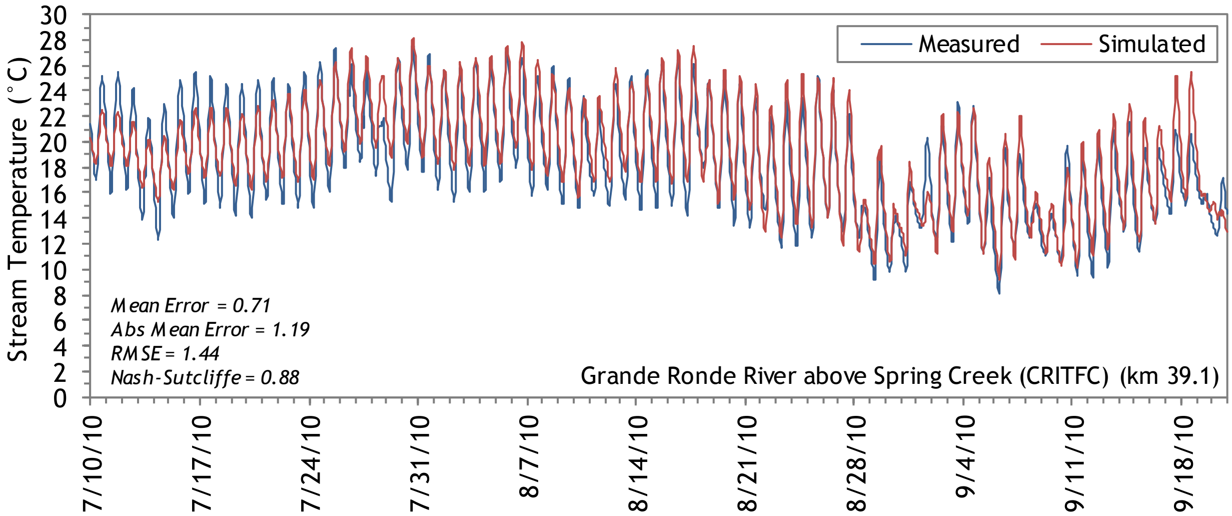

Stream Temperature (°C)
Measured
Simulated
Mean Error = -0.29
Abs Mean Error = 1.04
RMSE = 1.28
Nash-Sutcliffe = 0.88
Grande Ronde River above Fly Creek (USFS) (km 63.5)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

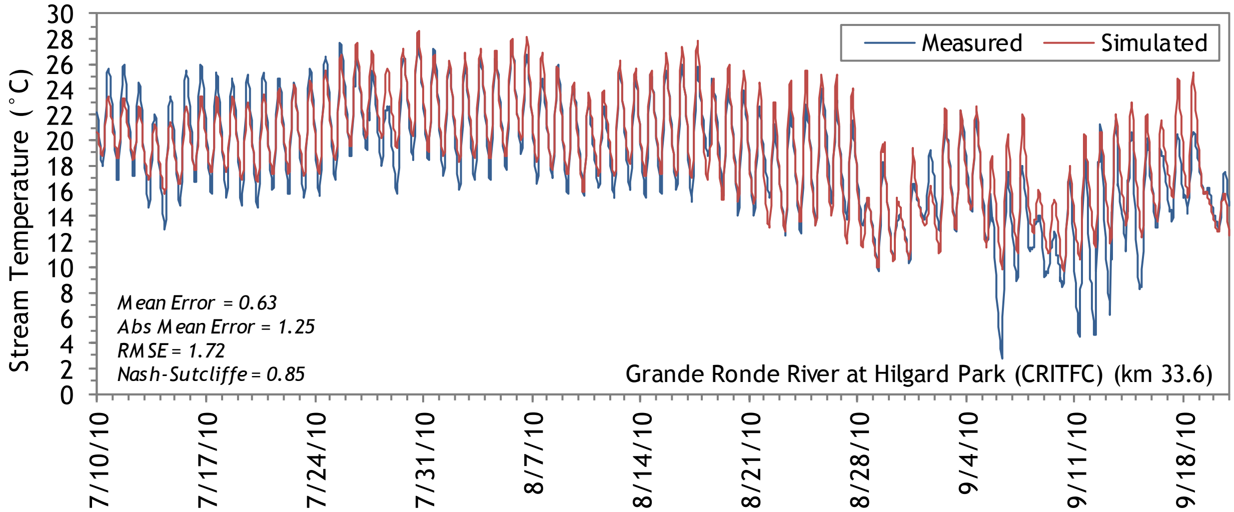

Stream Temperature (°C)
Measured
Simulated
Mean Error = -0.03
Abs Mean Error = 1.04
RMSE = 1.32
Nash-Sutcliffe = 0.90
Grande Ronde River above Meadow Creek (CRITFC) (km 55.9)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

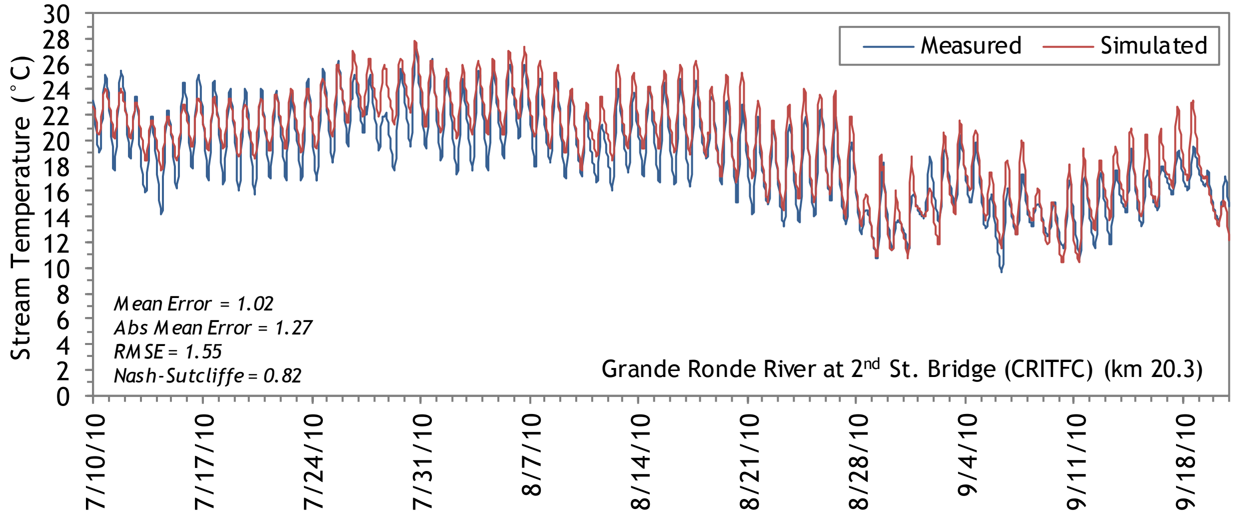

Stream Temperature (°C)
Measured
Simulated
Mean Error = -0.03
Abs Mean Error = 0.93
RMSE = 1.18
Nash-Sutcliffe = 0.92
Grande Ronde River above Beaver Creek (CRITFC) (km 53.3)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

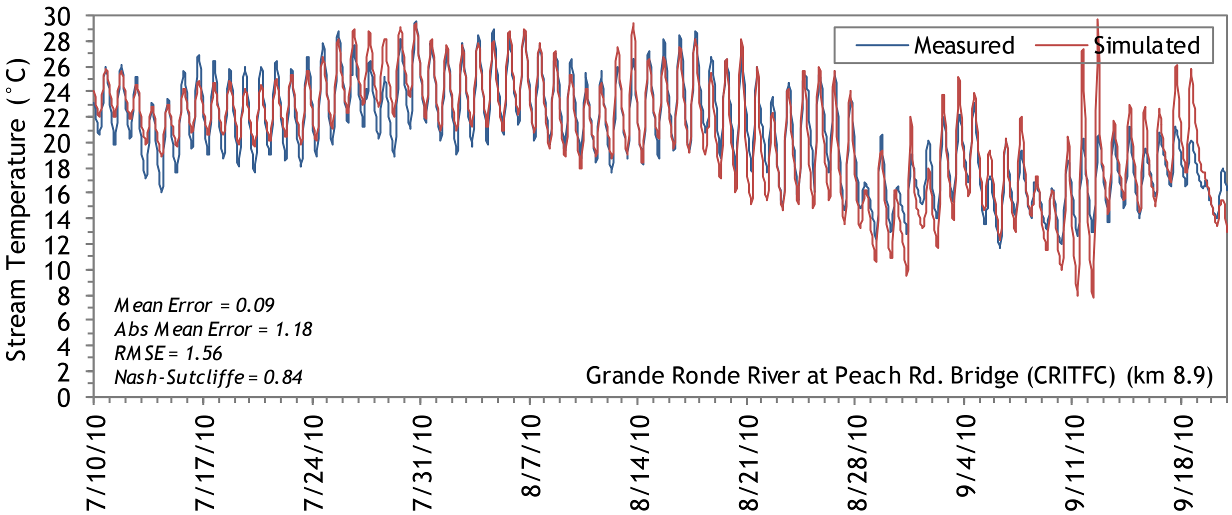

Measured
Simulated
Stream Temperature (°C)
Mean Error = -0.89
Abs Mean Error = 1.19
RMSE = 1.50
Nash-Sutcliffe = 0.86
Grande Ronde River above Bear Creek (CRITFC) (km 49.8)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.65
Abs Mean Error = 1.13
RMSE = 1.38
Nash-Sutcliffe = 0.88
Grande Ronde River above Jordan Creek (CRITFC) (km 41.5)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.71
Abs Mean Error = 1.19
RMSE = 1.44
Nash-Sutcliffe = 0.88
Grande Ronde River above Spring Creek (CRITFC) (km 39.1)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

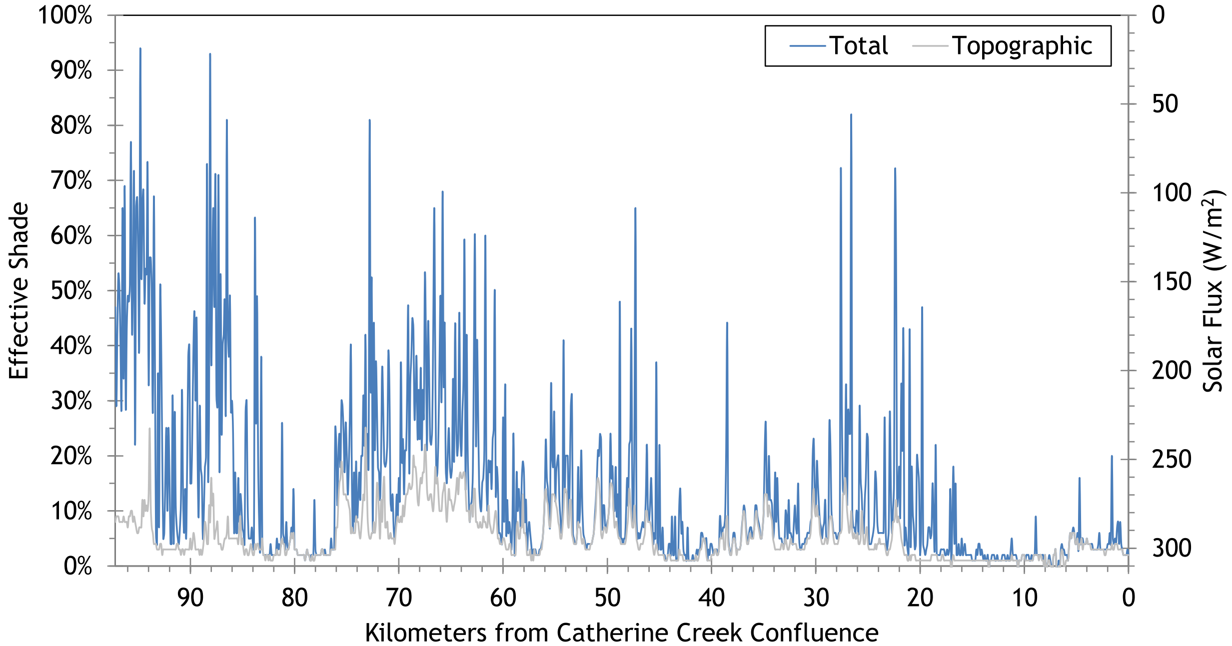

Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.63
Abs Mean Error = 1.25
RMSE = 1.72
Nash-Sutcliffe = 0.85
Grande Ronde River at Hilgard Park (CRITFC) (km 33.6)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Measured
Simulated
Stream Temperature (°C)
Mean Error = 1.02
Abs Mean Error = 1.27
RMSE = 1.55
Nash-Sutcliffe = 0.82
Grande Ronde River at 2nd St. Bridge (CRITFC) (km 20.3)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10


Measured
Simulated
Stream Temperature (°C)
Mean Error = 0.09
Abs Mean Error = 1.18
RMSE = 1.56
Nash-Sutcliffe = 0.84
Grande Ronde River at Peach Rd. Bridge (CRITFC) (km 8.9)
7/10/10
7/17/10
7/24/10
7/31/10
8/7/10
8/14/10
8/21/10
8/28/10
9/4/10
9/11/10
9/18/10

The simulated effective shade for the Grande Ronde River is presented in Figure 224. In many reaches, topography is producing the majority of effective shade. The Grande Ronde River is also wider than its tributaries and some reaches have less effective shade for that reason. Additionally, there is often a road or interstate highway alongside the river, which reduces the amount of near stream land cover. Below La Grande (approximately kilometer 22), there is less effective shade because the river is within the agricultural valley bottom where there are few large trees. See Appendix for effective shade maps.

Figure 224 – Grande Ronde River simulated effective shade.




RGB-colored LiDAR point cloud - Grande Ronde River below the city of La Grande (looking upstream).

Appendix A. Effective Shade Maps

Effective shade was simulated and mapped for the Grande Ronde River basin and the Catherine Creek basin. Simulated effective shade results are shown in figures 225-222.

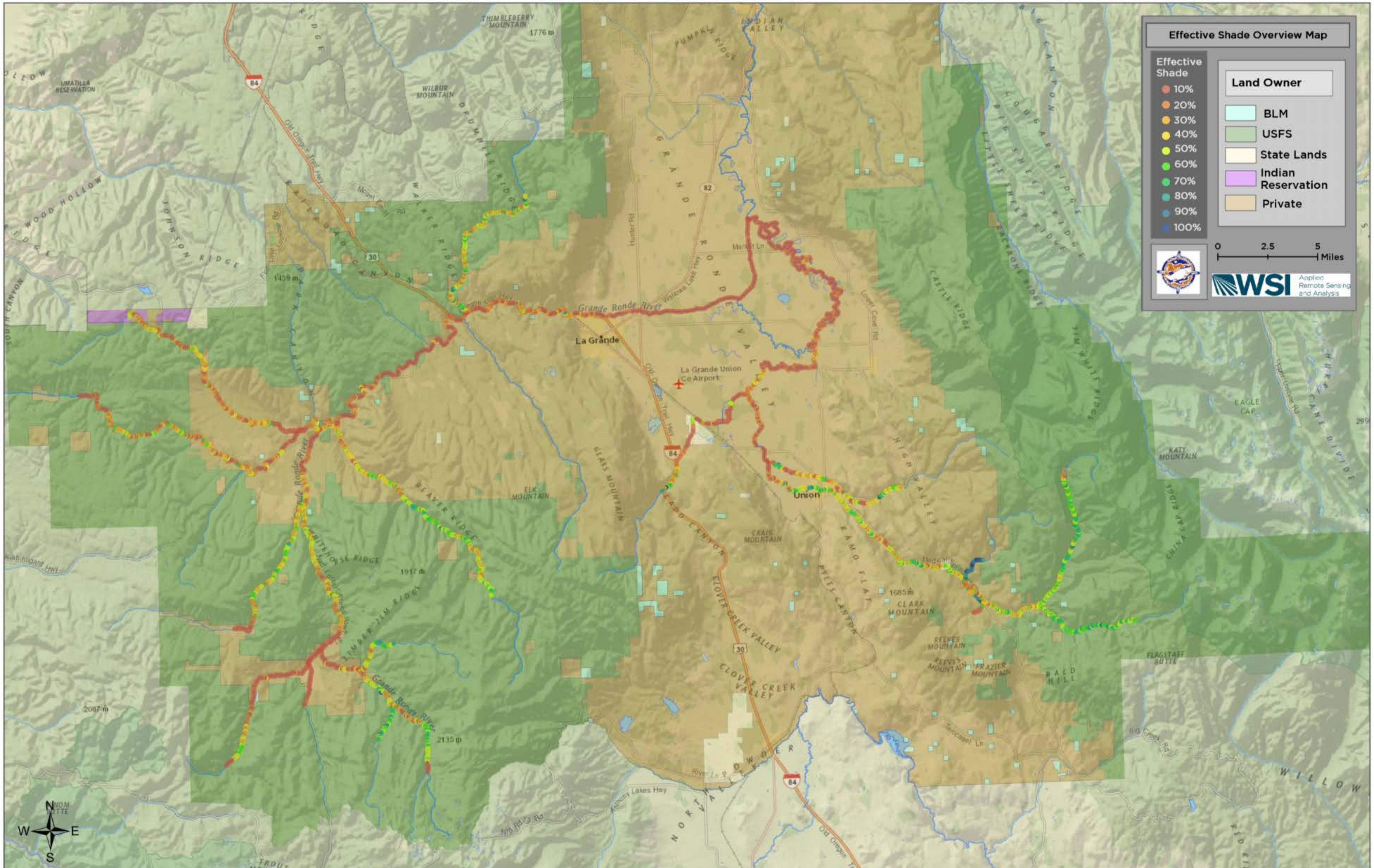


Figure 225 Effective shade overview map

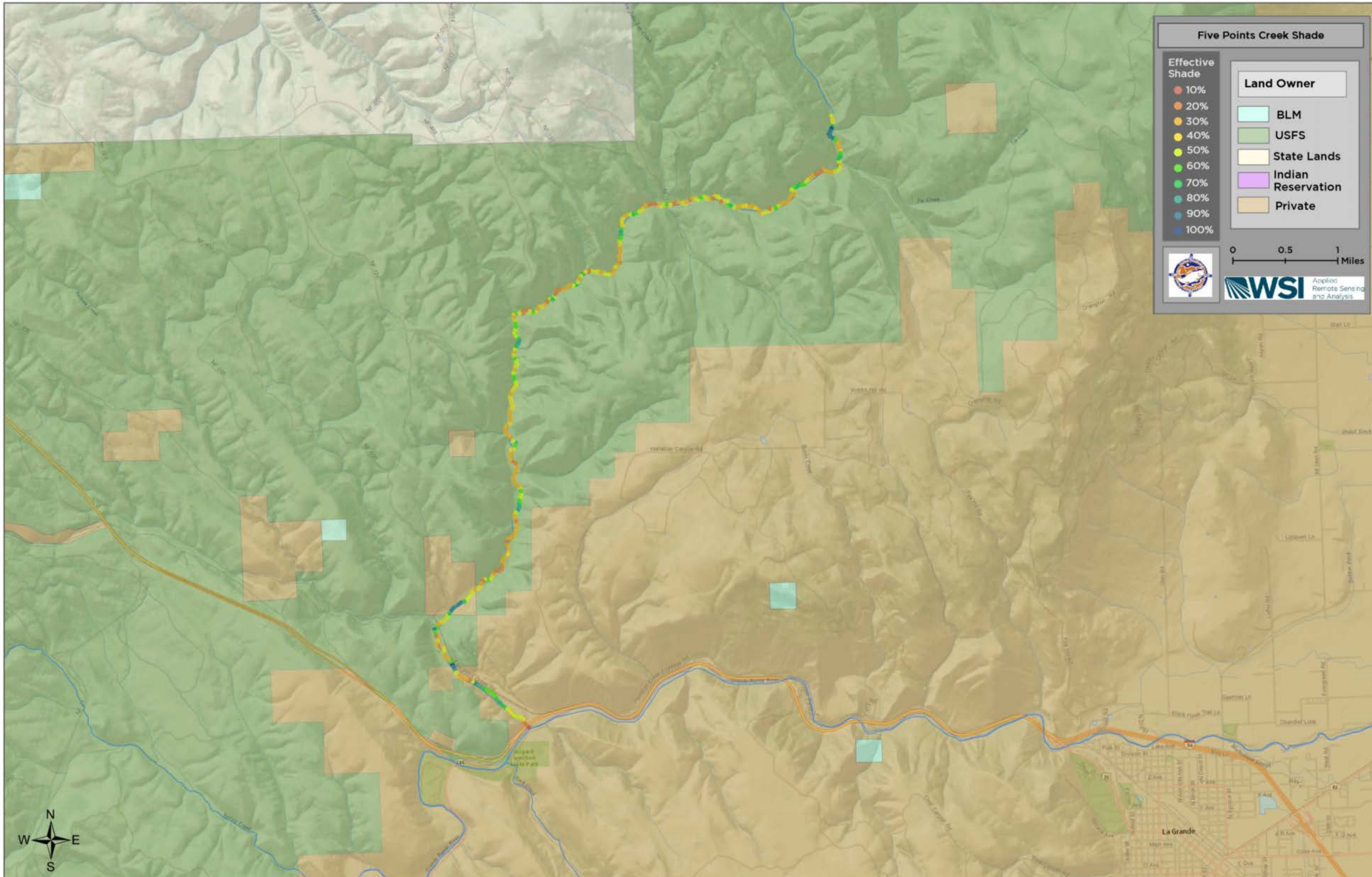


Figure 226 Effective Shade Five Points Creek

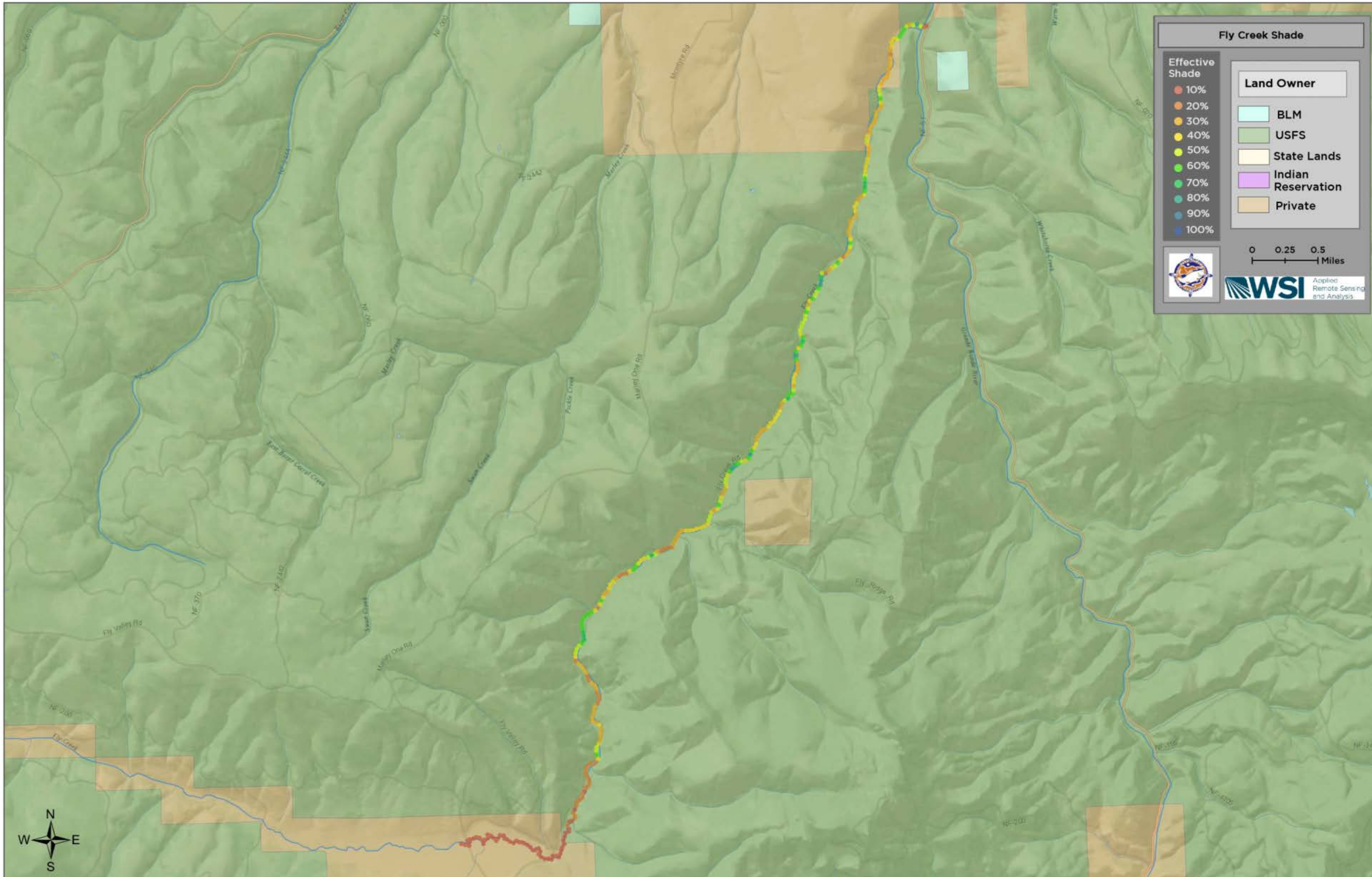


Figure 227 Fly Creek Effective Shade

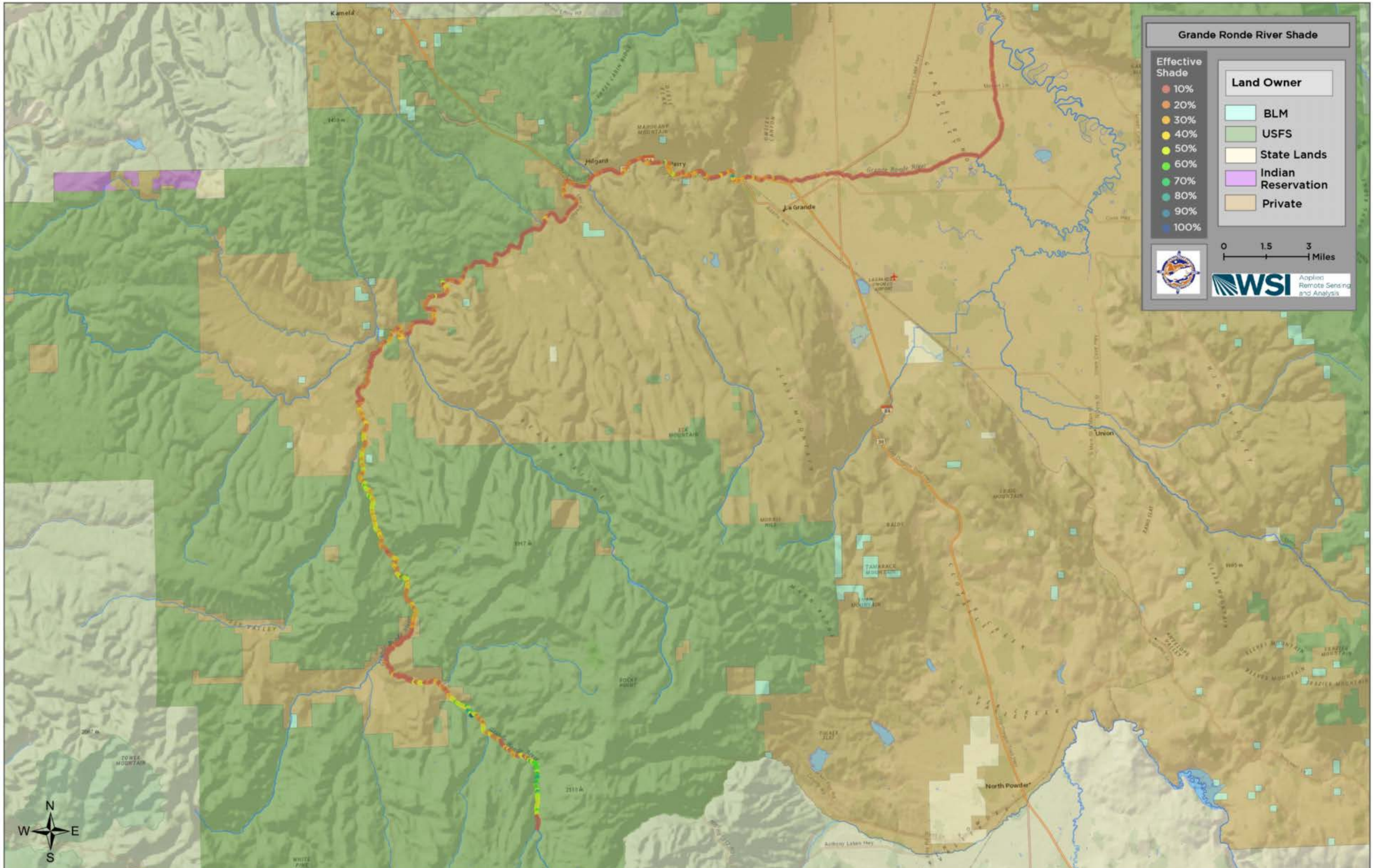


Figure 228 Grande Ronde River Effective Shade

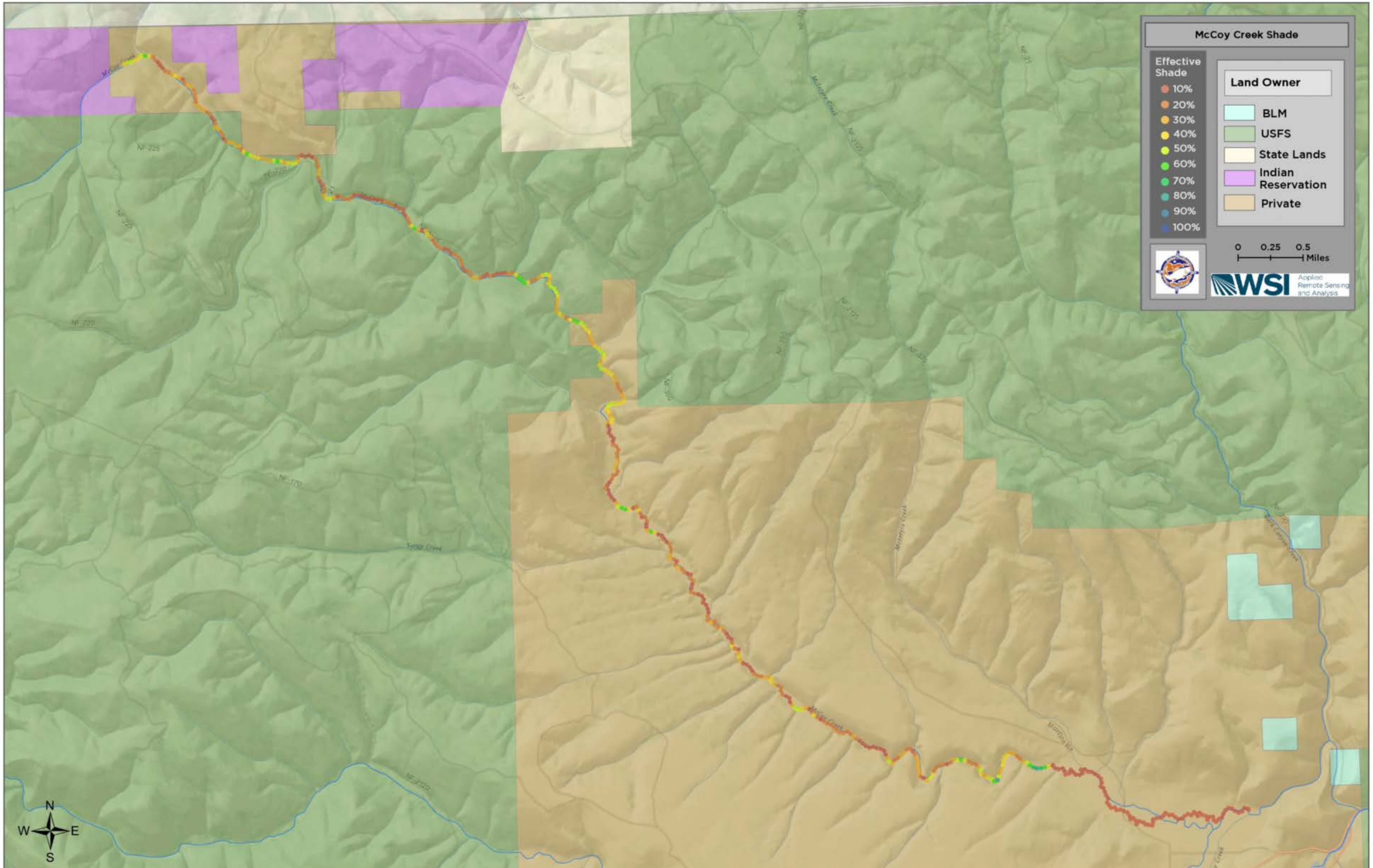


Figure 229 Mccoy Creek Effective Shade

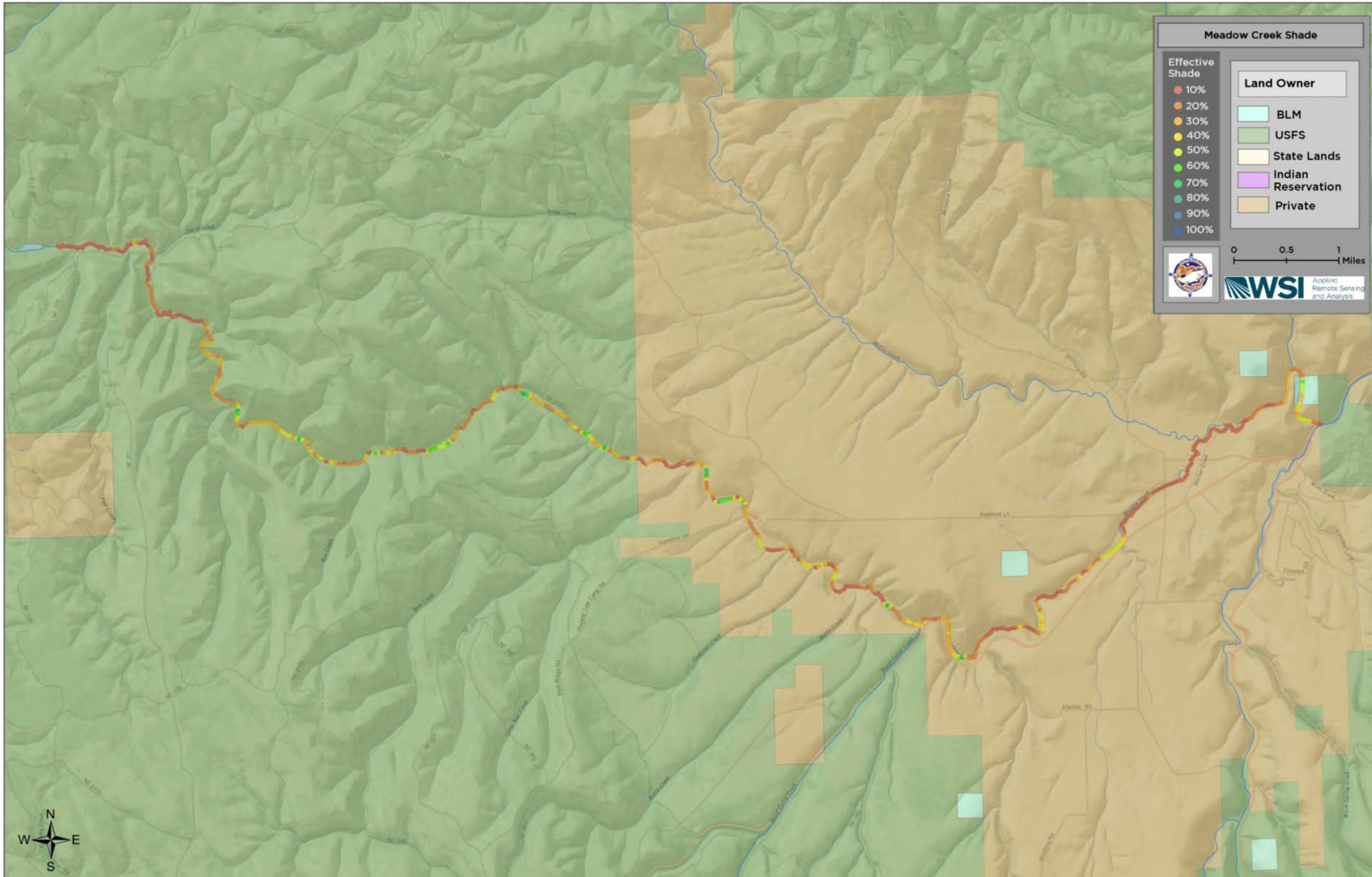


Figure 230 Meadow Creek Effective Shade

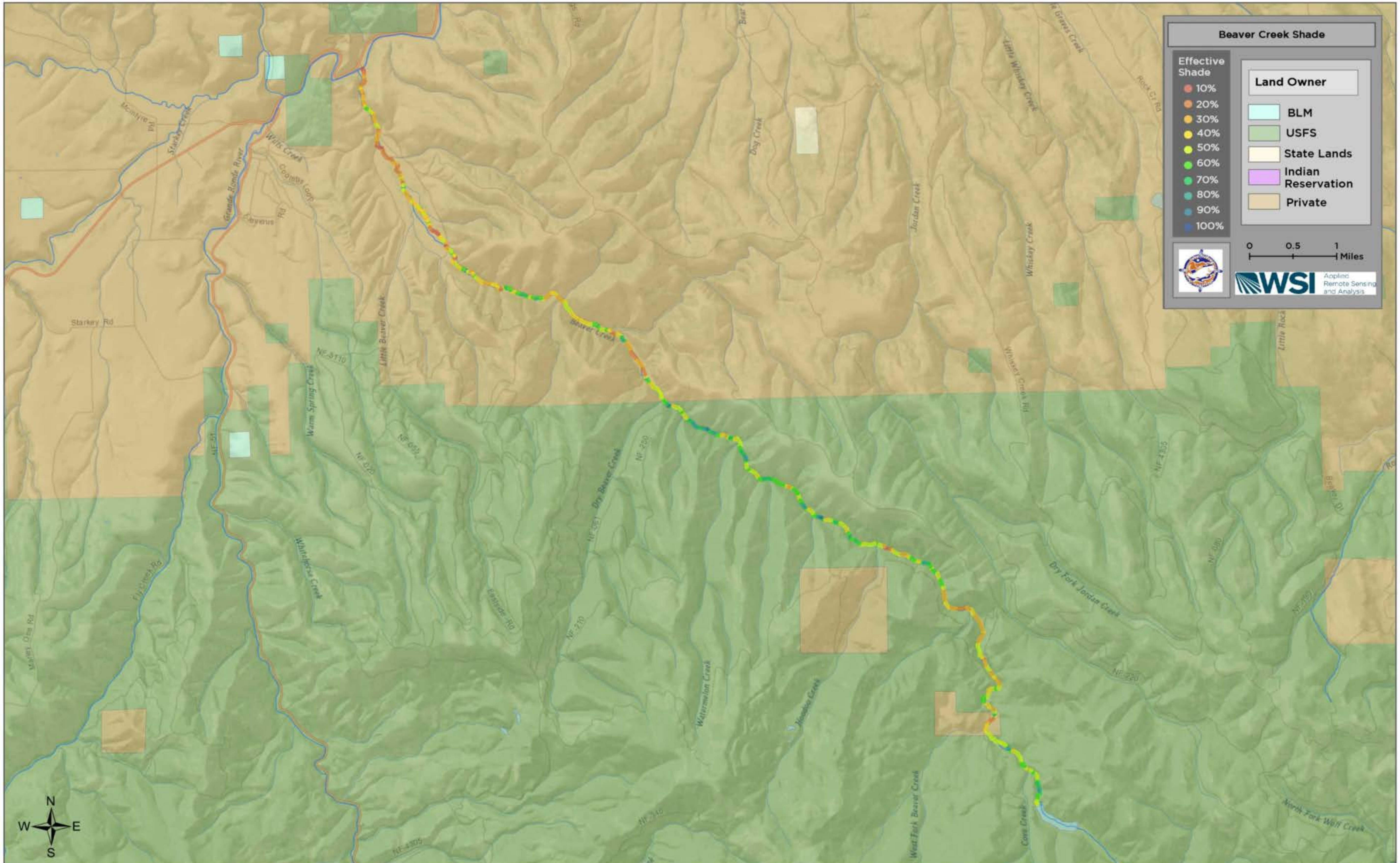


Figure 231 Beaver Creek Effective Shade

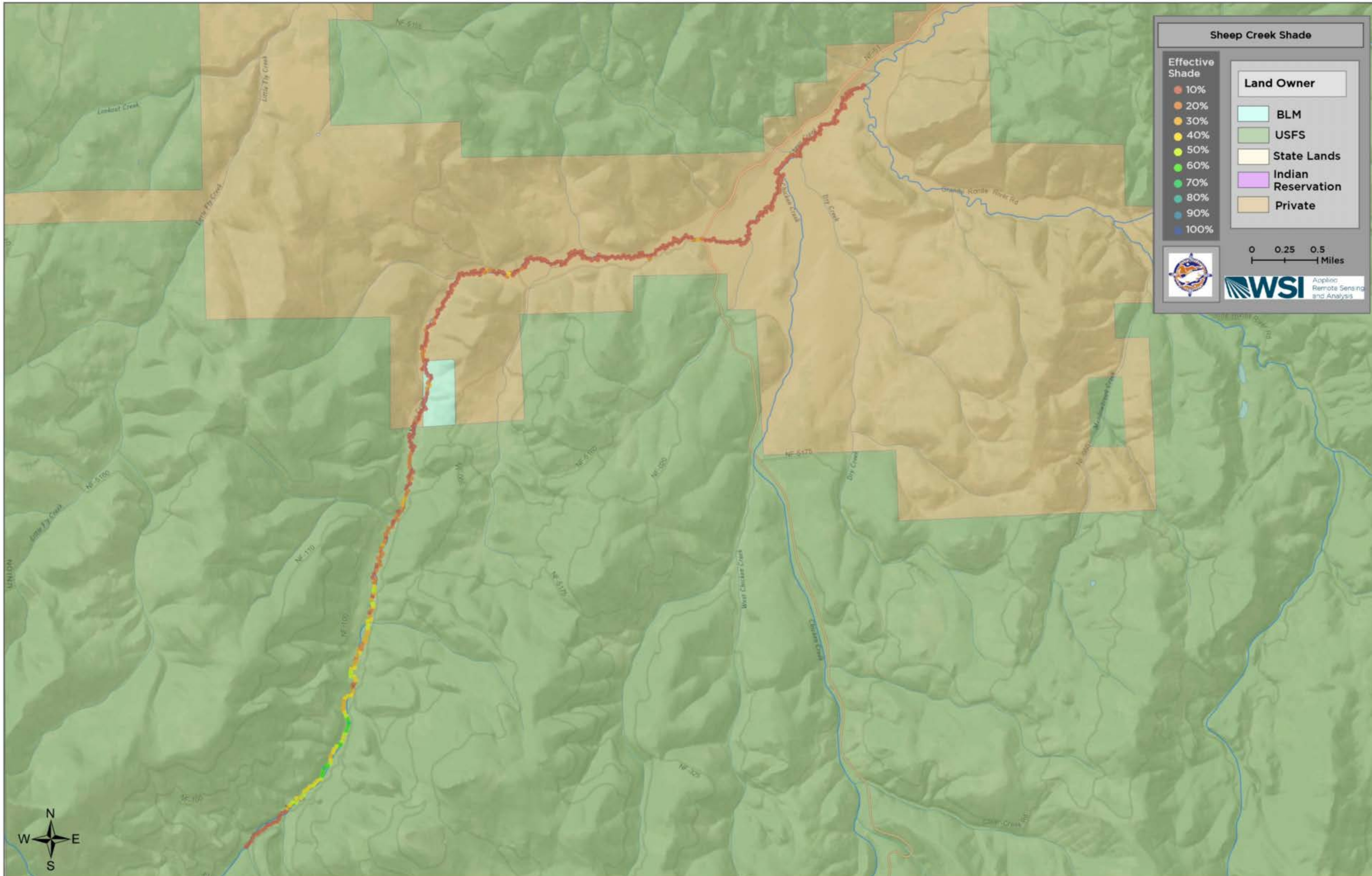


Figure 232 Sheep Creek Effective Shade

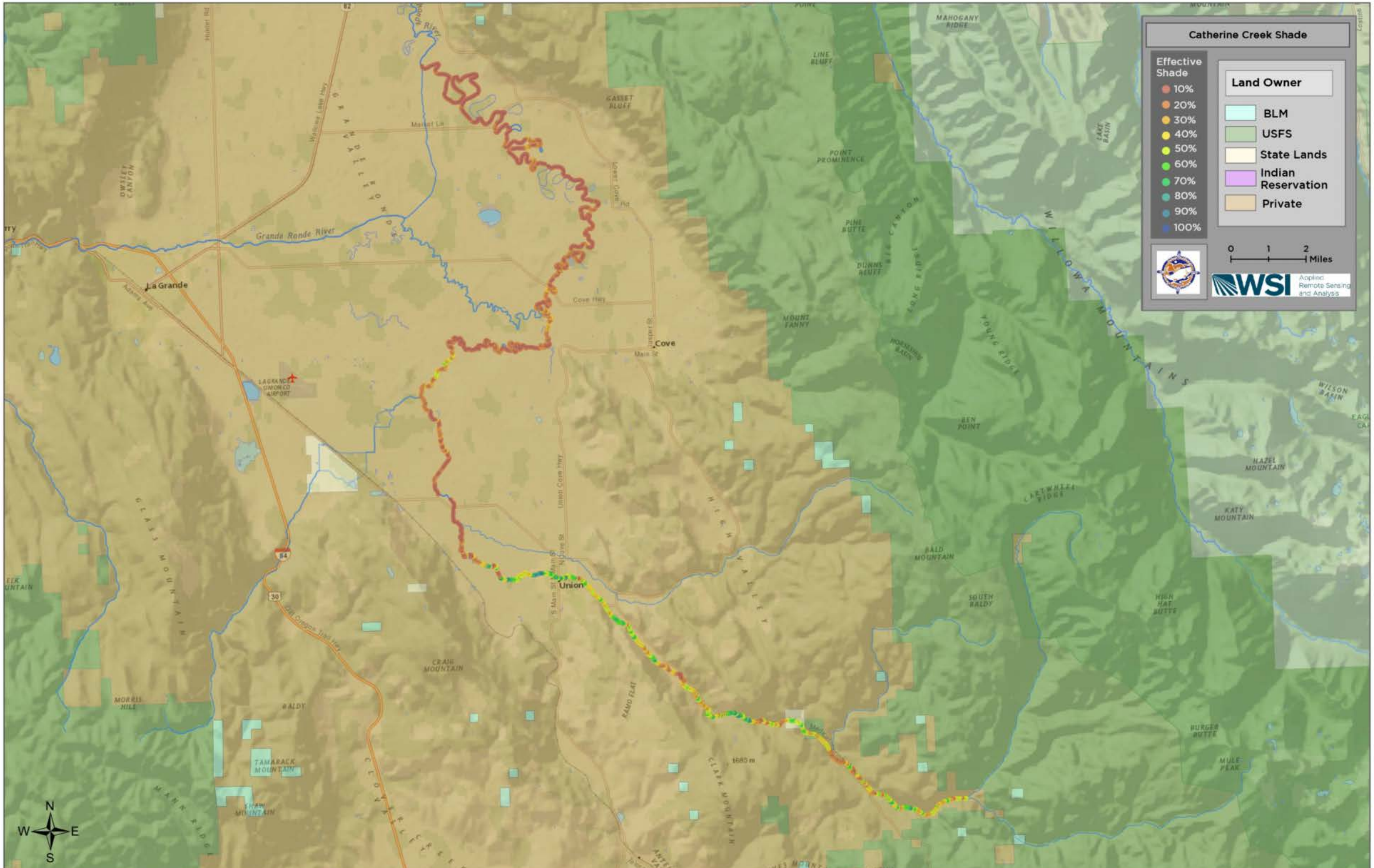


Figure 233 Catherine Creek Efective Shade

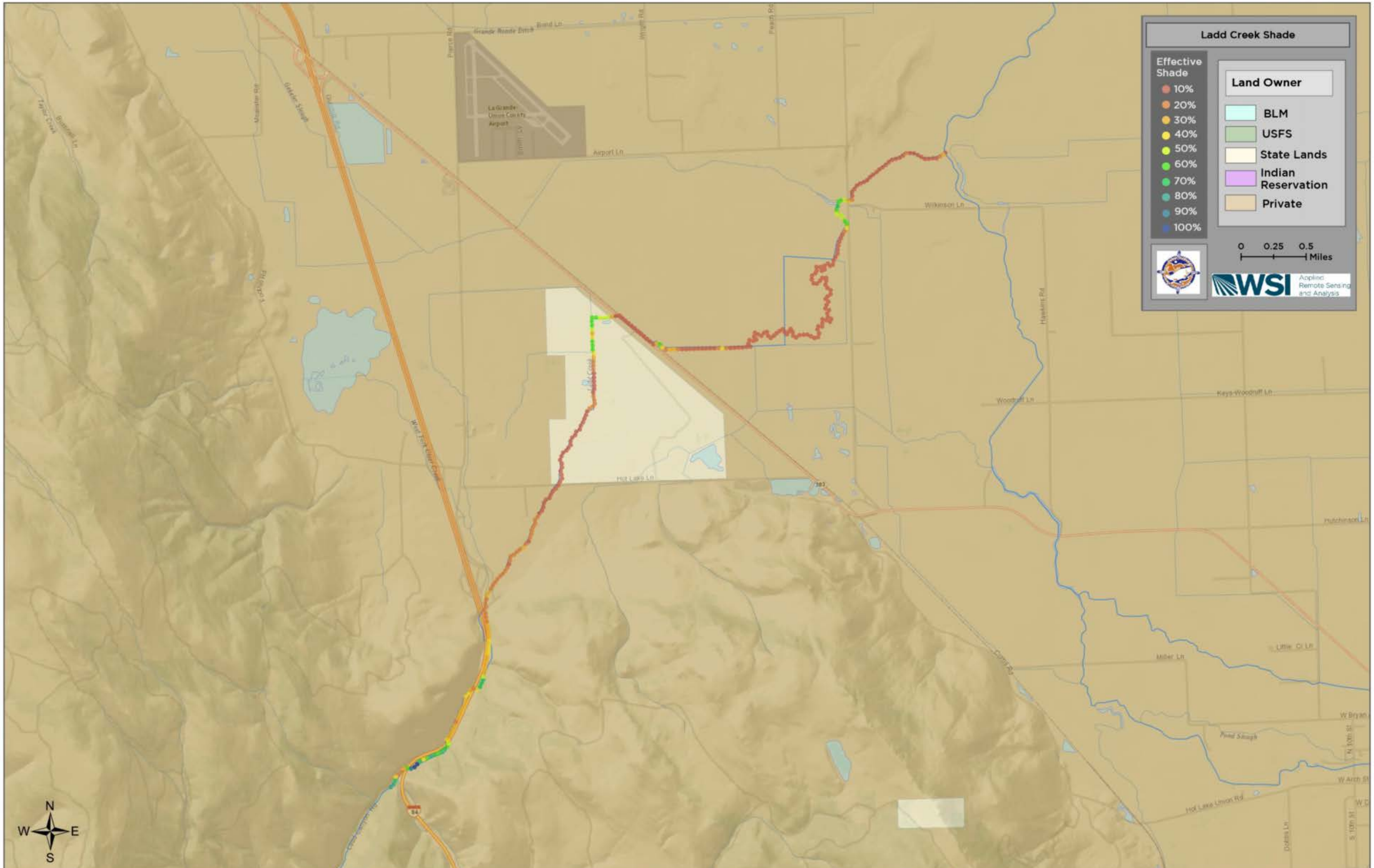


Figure 234 Ladd Creek Effective Shade

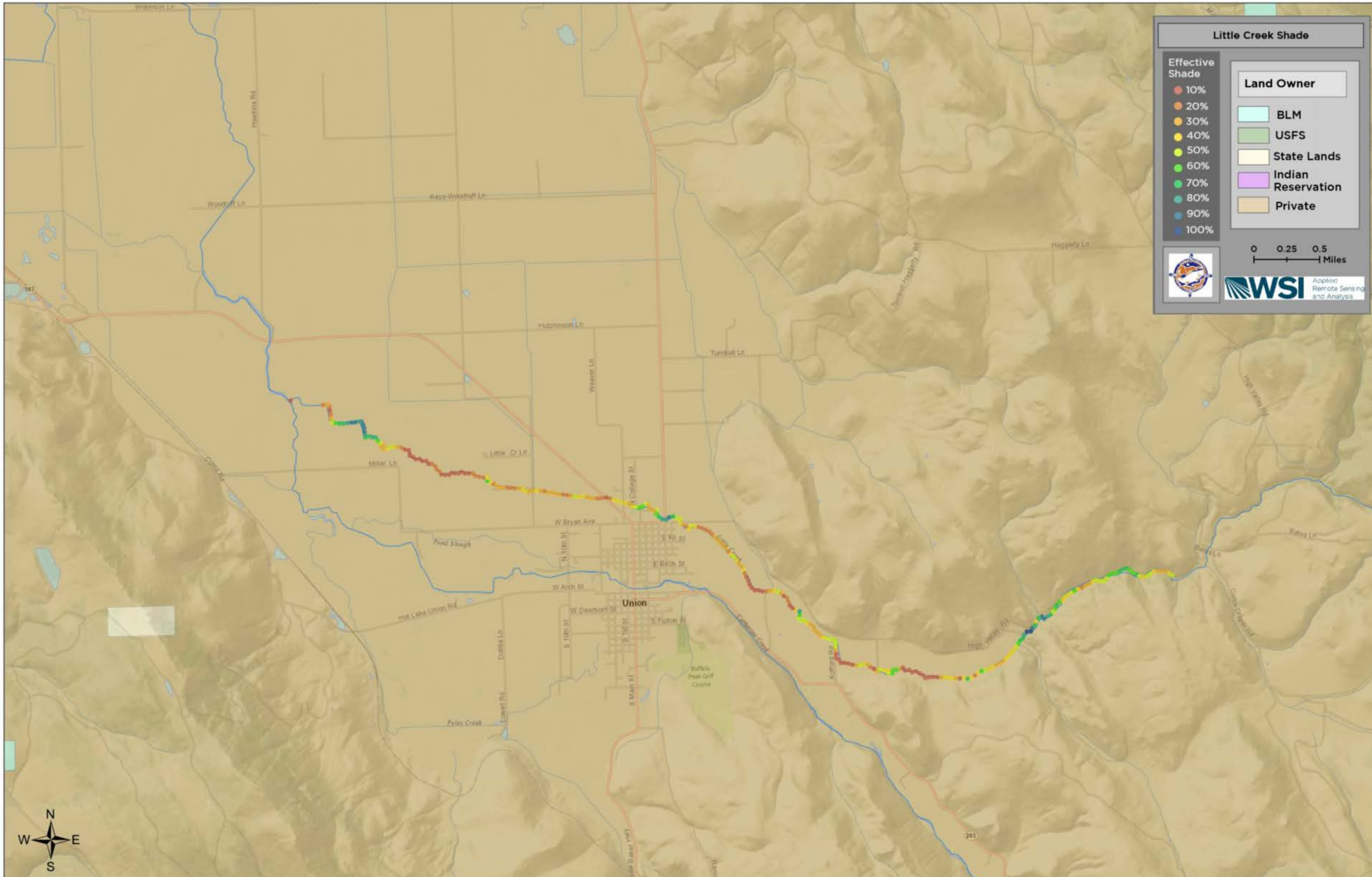


Figure 235 Little Creek Effective Shade

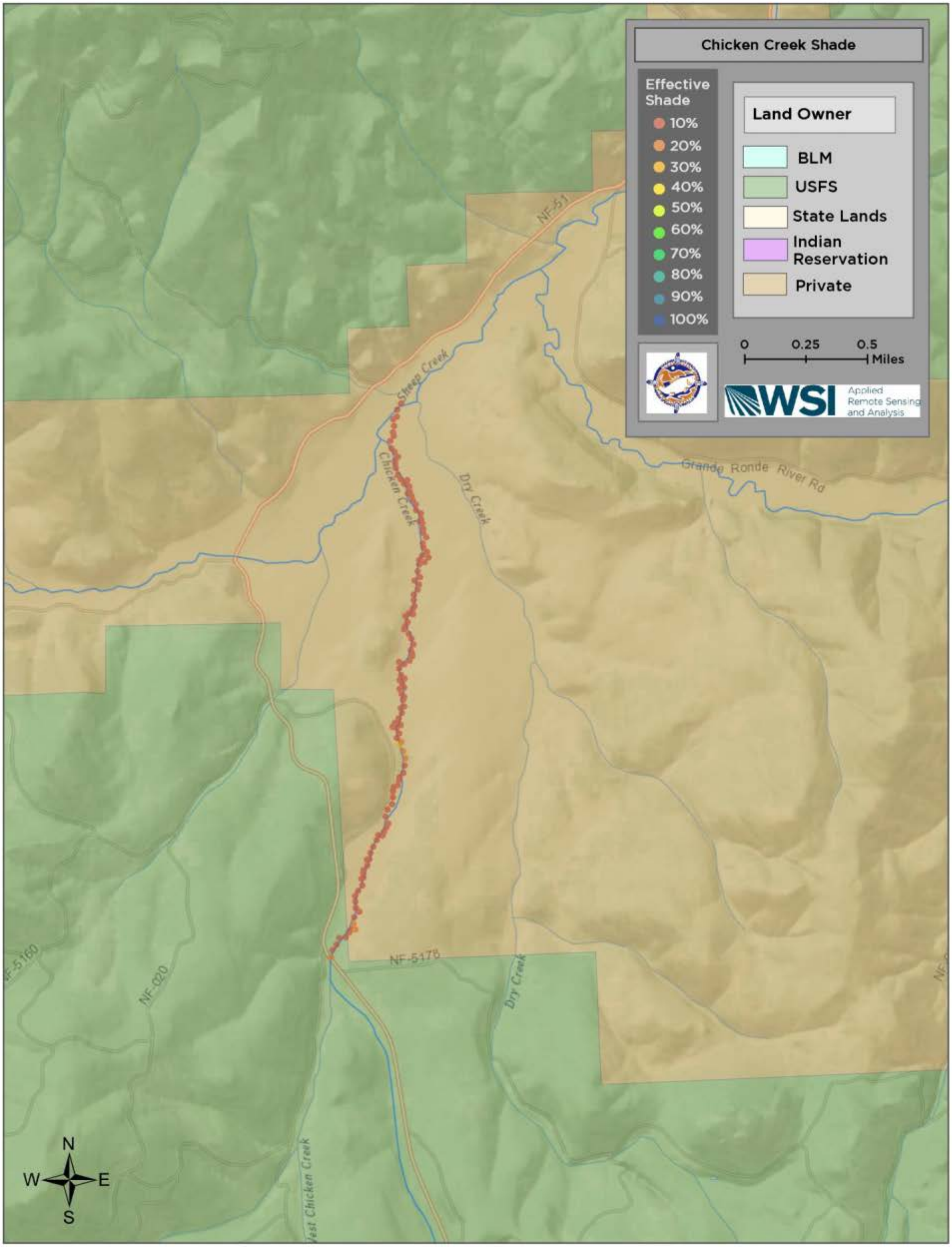


Figure 236 Chicken Creek Effective Shade

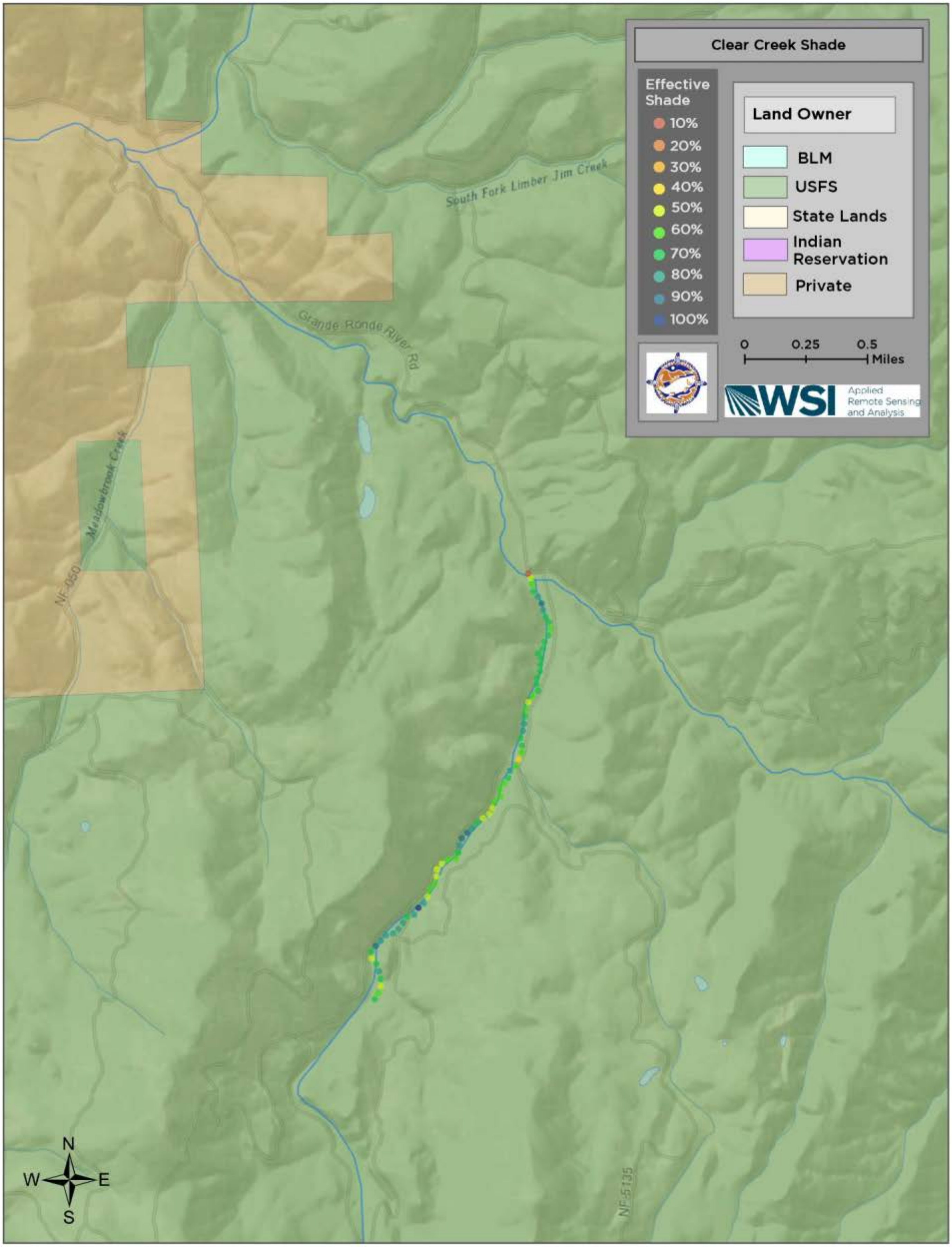


Figure 237 Clear Creek Effective Shade

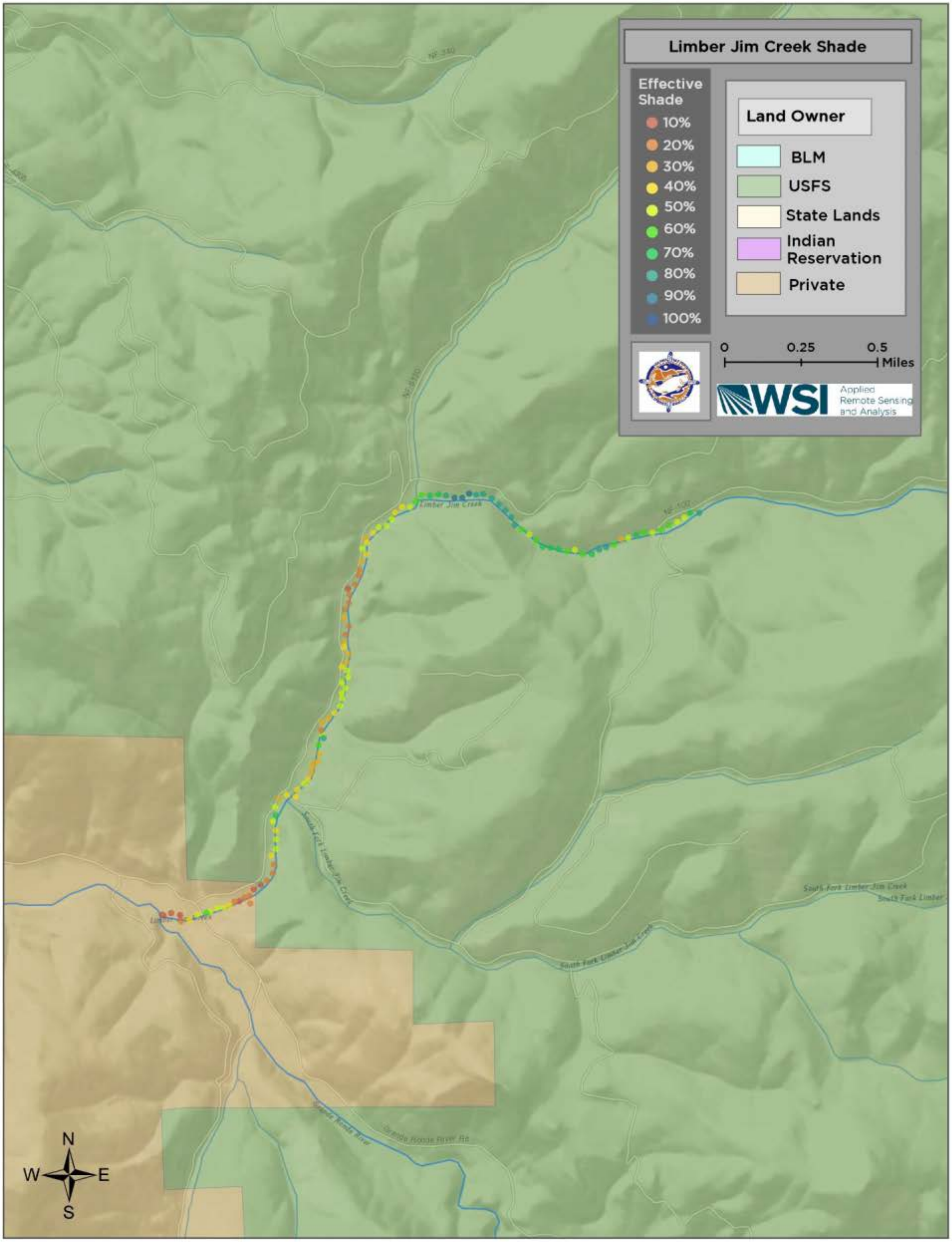


Figure 238 Limber Jim Creek Effective Shade

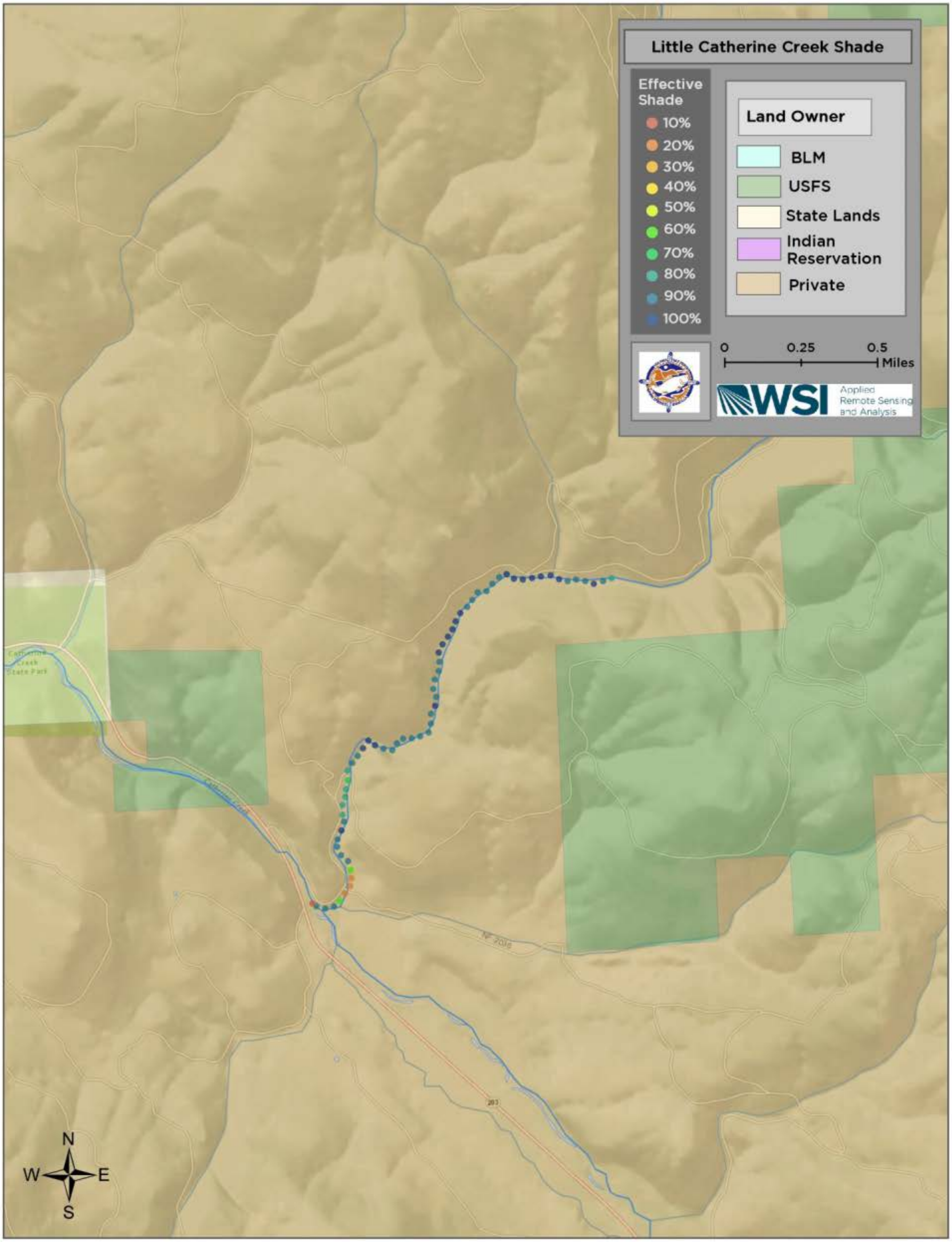


Figure 239 Little Catherine Creek Effective Shade

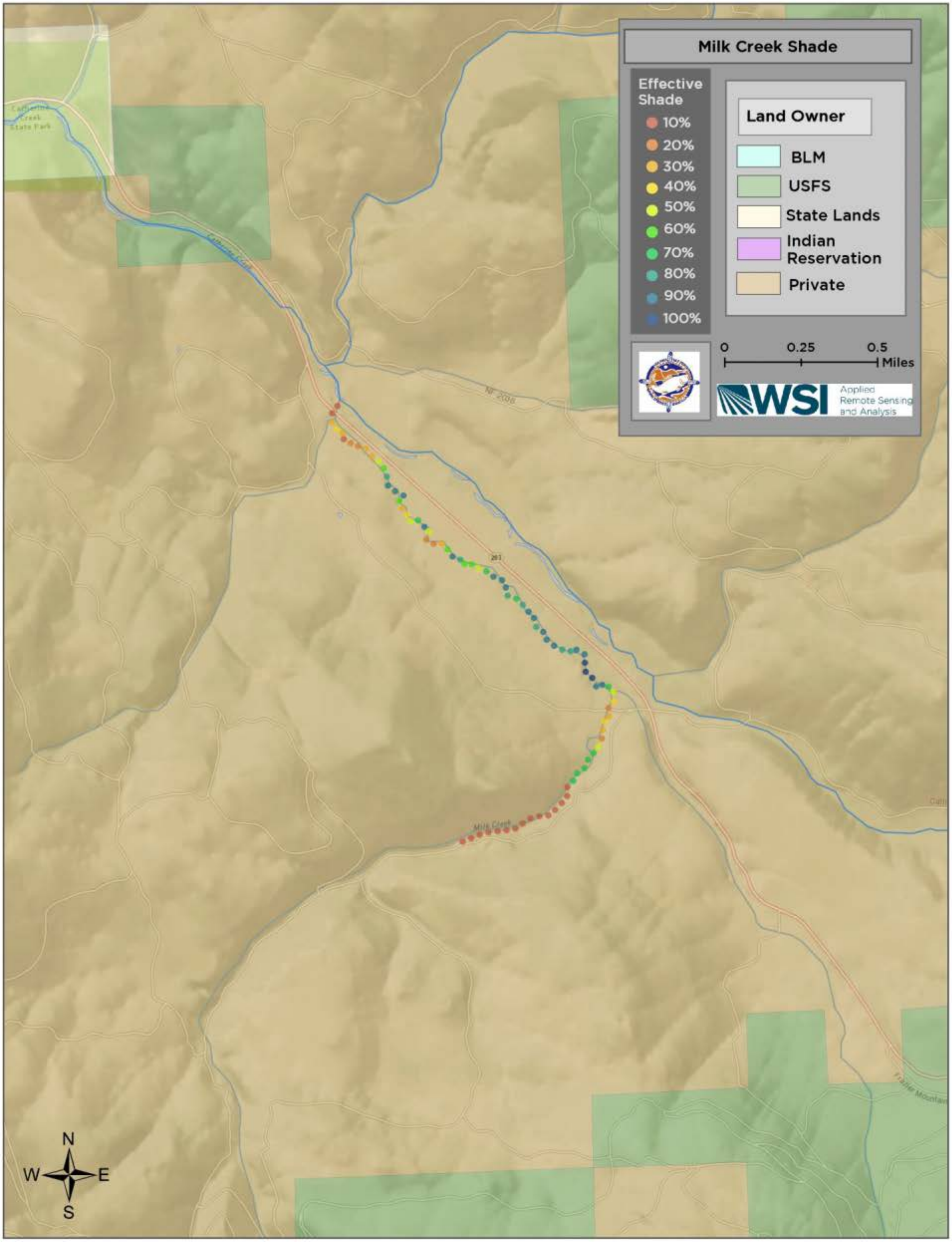


Figure 240 Milk Creek Effective Shade

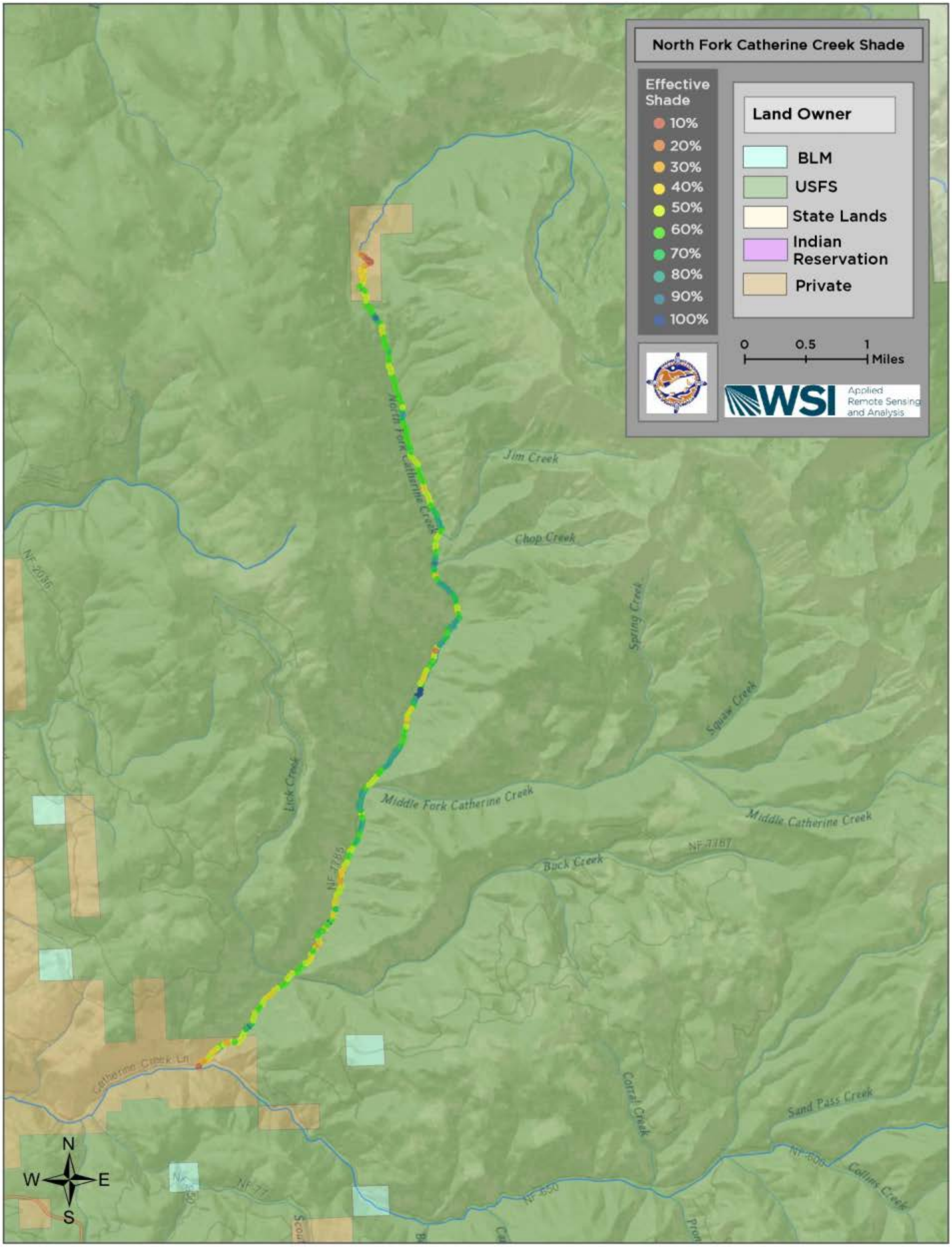


Figure 241 North Fork Catherine Creek Effective Shade

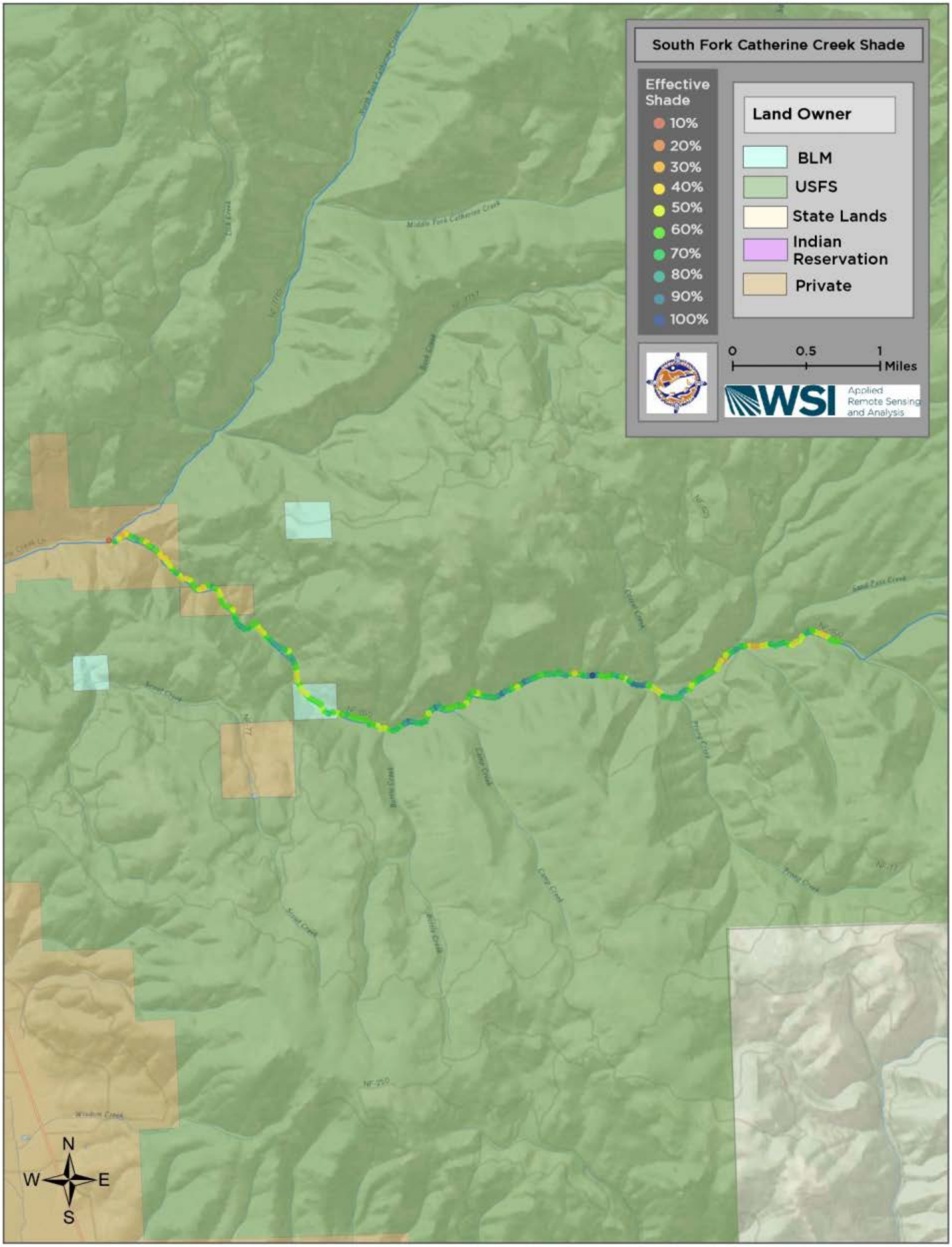


Figure 242 South Fork Catherine Creek Effective Shade

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Thank You

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