Big Hole River Thermal Infrared (TIR) Temperature Analysis Interpretive Report

Revised Final Report

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EXECUTIVE SUMMARY

In the 1800s, fluvial Arctic grayling could be found throughout the streams and rivers of the upper Missouri River system from the Montana/Idaho border and the continental divide to Great Falls, Montana. Interrelated factors, such as habitat degradation, introduction of non-native salmonids, climate change, and exploitation by anglers have since threatened the existence of the Arctic grayling, reducing its population distribution to less than 5% of its native range. Currently, the population is limited to the Big Hole River in southwest Montana. One of the greatest perceived threats to the Arctic grayling and other cold water fisheries in the Big Hole River is the extreme low flows that often occur during the hot summer months. During these low flows, habitat is limited and water temperatures often increase to levels that cause heavy stress and death to threatened species[1].

This Thermal Infra-Red (TIR) study was conducted in 2008 to identify warming and cooling influences on the Big Hole River and to identify thermal refugia. The TIR analysis is one level of habitat assessment for cold water fisheries research specifically pertaining to fluvial Arctic grayling. This document is a summary of the TIR temperature monitoring methods and results.

The TIR data was collected during the historically hottest week of the year, on July 30th, in an attempt to study the river at a time when the threat to fisheries is greatest. Data was collected by plane in three formats: aerial, color infrared, and thermal infrared. Data collection and processing is detailed in sections below. To summarize, temperature data were correlated with temperatures measured by in-stream temperature loggers during the same time frame and was adjusted to account for cooler air temperatures at altitude.

Temperature data have been analyzed and formatted into several maps that display average temperatures throughout the study area and locations of thermal refugia, tributary inputs, irrigation returns, groundwater inflows, and other influences on stream temperature. The criteria used for selecting these temperature features are outlined in section 4.1.2. Temperature data is also available in tabular format.

An overview of the results and findings of this study are presented by the longitudinal temperature profile in section 5.1. The longitudinal temperature profile shows the TIR temperatures plotted versus the corresponding river mile, and the temperatures of several tributaries using data collected by in-stream temperature loggers located in the corresponding tributary. The profile indicates that in-stream temperatures ranged from a maximum of 21.81°C at river mile 105.6 to a minimum of 17.42°C at mile 79.1, as averaged within 100 ft circumference areas at points corresponding to TIR images extracted from the flight video. There were several areas with warming trends and cooling trends that appear to result from the lack or presence of riparian cover, warm and cool inputs such as tributaries and irrigation returns, and warm and cold water refugia.

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[1] Rens, Emily, and Patrick Byorth. "Fluvial Arctic Grayling." April 2007. Montana Fish, Wildlife, & Parks. 23 Sept. 2008. <http://www.fisheries.org/units/AFSmontana/ArcticGrayling.html>.

Section 5.2 of this report provides data for all of the discrete temperature features, with figures and details on the more noteworthy features.

This study outlines the overall temperature trends of the study area. Tributaries and groundwater inflows generally are colder than the Big Hole River. Although instances of groundwater inflow present the highest number of cold water inputs to the Big Hole, it is difficult to ascertain their overall impact without having field research and additional flow data. Groundwater upwelling within the main channel was not a common feature type identified with the TIR imagery. Several streams, especially in the most downstream 22 miles of the study area, offer significant cold water inputs and potential for high quality coldwater fish habitat. In the lower reaches of the Big Hole the smaller tributaries appear to cool the river as a cumulative effect of several smaller inputs. Water entering the Big Hole River from side channels and irrigation returns was generally warmer than the main stem of the river; however, side channels appear to contribute a great deal of habitat complexity and contain multiple coldwater refugia.

This TIR study noted 29 in-stream coldwater refugia with direct connections to the main stem of the Big Hole River and an additional 11 refugia located in side channels and other areas of the floodplain that also had surface water connections with the main stem. In-stream coldwater refugia, as identified in this study, may be due to deep pooling or due to groundwater upwelling. It is not possible from TIR data to ascertain their depths and overall habitat quality for fish, but this study identifies the coldwater habitat to allow further study.

It should be noted that stream temperatures reflect both watershed-scale and local-scale influences. Temperatures are subject to cumulative effects that extend beyond the reach scale. While this analysis provided a general source characterization and identified some temperature sources influencing temperature at a local scale, it was not designed to define cause-effect relationships between land management factors and the temperature of the Big Hole River at the watershed scale. However, by characterizing and identifying thermally significant inputs and areas of the Big Hole River, this study should provide useful data for determining areas of concern and areas of opportunity for increasing coldwater fish habitat in this watershed.

1. Introduction

The TIR method is an effective way to measure temperature trends over a spatial gradient. Color-infrared (CIR) imagery and color-normal video were also collected to provide context for the TIR images by showing the adjacent terrain and associated land use practices. The TIR imagery was correlated with temperature loggers installed in the river to ensure accuracy. The collected data were utilized for the following: to identify heat sources; to identify thermal refugia, tributary inputs, irrigation return flows, groundwater inputs, riparian vegetation, and dewatering; and for overall assessment of thermally suitable grayling habitat.

This document describes methods used in the TIR analysis, processing, and interpretation, and presents results for temperature trends and sources. Note: The terms "Forward-Looking Infra-Red" (FLIR) and "Thermal Infra-Red" (TIR) are used interchangeably in this report. Also, the term "cold water refuge" is used throughout this report to describe in-stream cold water refugia. Tributaries and other cold water inputs are identified in separate categories, distinct from instream cold water refugia.

2. Data Collection Methods

2.1. Flight Data Collection

On July 30, 2008, multispectral imagery of the Big Hole River near Wisdom, MT was acquired by Infrared Baron, LLC of Hermiston, OR. An additional flight on August 13 was made to capture an additional set of near-infrared images over the same area. The project area extent is illustrated in Figure 1.

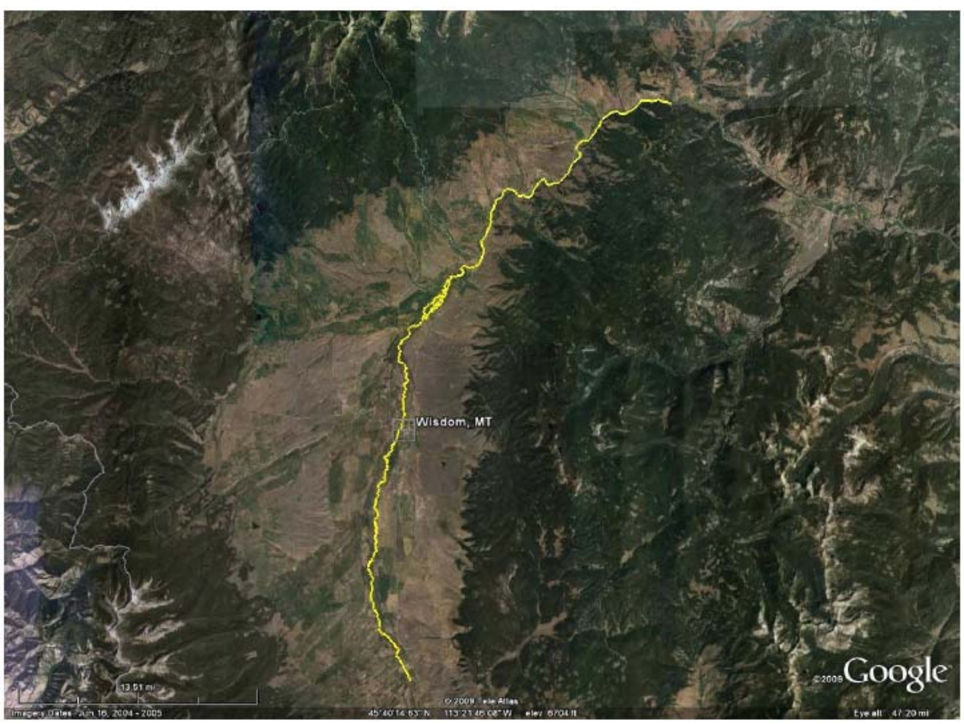

Figure 1. Project area overview.

The flight dates were chosen because they are during what is historically the hottest time of year. Climate data for the project area are presented in Figure 2.

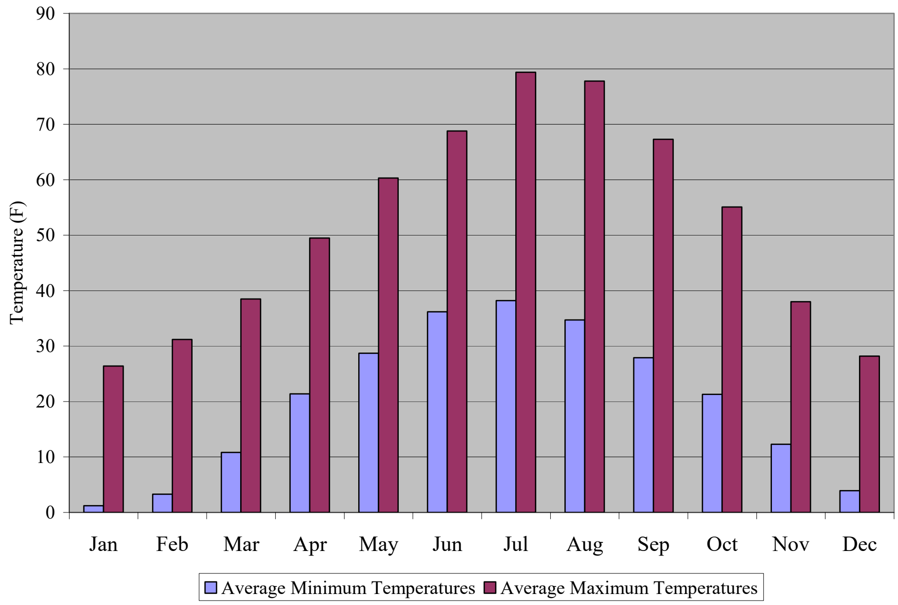

Figure 2. Average annual air temperature at Wisdom, Montana: 1923 to 2007. Source: Western Regional Climate Center

The first flight on July 30 captured color infrared, normal color and thermal infrared imagery simultaneously. All of this imagery was combined to display simultaneously on DVD. The thermal infrared imagery from this flight was also calibrated for air and in-stream water temperatures using temperature logger data, and output as a series of still images. A technical problem during data capture for the color infrared and normal color imagery necessitated a return to the project area on August 13 to recapture these images. The second set of RGB and CIR images were formatted into image mosaics for GIS overlay analysis.

2.2. EQUIPMENT

2.2.1. General Flight Equipment

2.2.1.1. Camera Platform

A Cessna 172 fixed wing aircraft was used for this project. The Cessna is an excellent platform for aerial TIR surveys because of its slow flight characteristics and low operating expense. The plane is equipped with a 5x9 inch camera port located beside the pilot's seat. The TIR camera was mounted in a vertical orientation.

2.2.1.2. Flight

Data recording began at Dickie Bridge on July 30, 2008 just after 2:00 P.M. and concluded at 4:00 P.M. upstream near Little Lake Creek road. Winds as recorded by the pilot were out of the west at 15 mph. Skies were generally clear and sunny. The flight was interrupted over the town of Wisdom for about 20 minutes waiting for some cumulus clouds to move.

2.2.2. TIR Data Collection

Thermal infrared imagery was recorded with a TIR model SC640 thermal infrared radiometer. Data was streamed into a laptop computer running TIR ThermaCam Researcher software. More information about the SC640 camera or ThermaCam Researcher can be found on the TIR website[2].

2.2.3. CIR Data Collection

Color infrared images were collected during the flight on August 13. The CIR camera has a much higher resolution than the TIR camera and therefore can be flown from a higher altitude. The higher altitude affords a wider field of view while still maintaining pixel resolutions of less than a meter. The CIR images put the watershed into context by showing the adjacent terrain and associated land use practices. An example of the CIR images is provided in Figure 3.

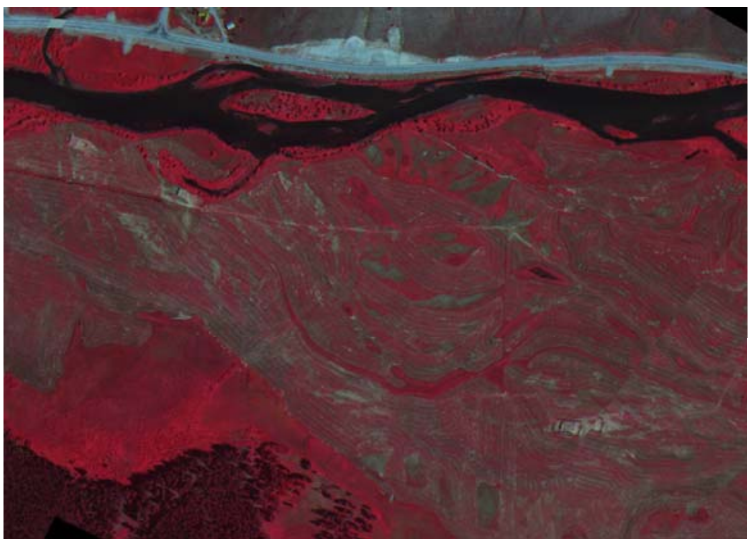

Figure 3. Sample CIR Image

2.2.4. Video Data Collection

Visual videography was recorded simultaneously with the TIR imagery. Video recording was done with an 8 mm VHS video recorder. The video is a normal color presentation of the TIR imagery. Video lends understanding of the TIR imagery, as the human eye is not accustomed to distinguishing features in thermal infrared. Video is synchronized with the TIR imagery and delivered in AVI format on DVD. The two TIR images in the video are identical, the only difference being the color scale. One color scale is better for riparian analysis and the other better for water analysis.

[2] http://flirthermography.com/cameras/camera/1101/

2.2.5. GPS

Global positioning data was streamed from a WAAS-enabled GPS receiver through a serial connection to a laptop computer. Figure 4 shows the path of the airplane's flight during the TIR study. The blue line represents the Big Hole River. The flight path has been provided to the client in an ArcGIS shapefile as described below in section 4.1.

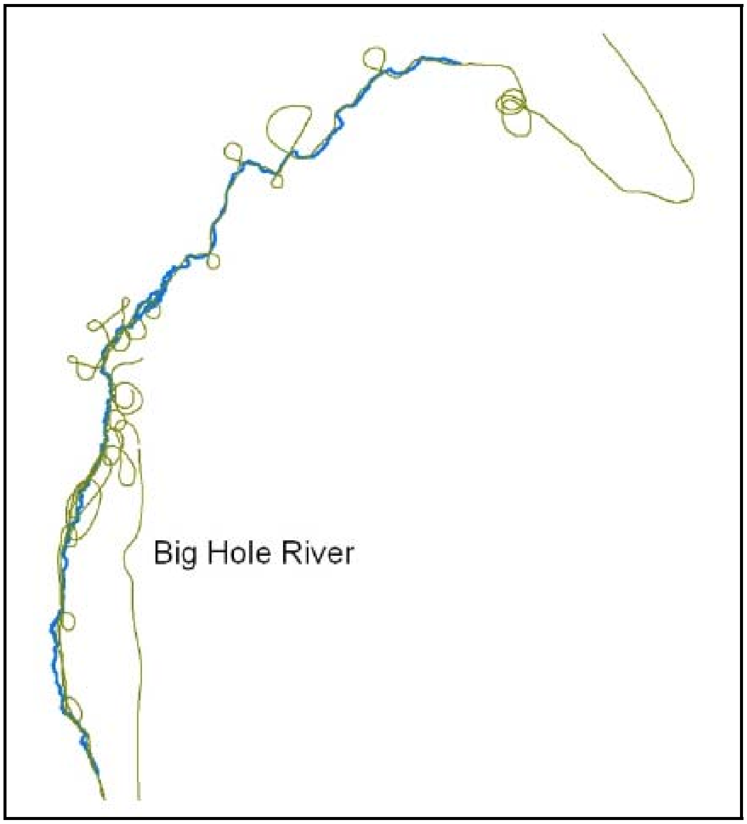

Figure 4. Flight Path of Airplane

2.2.6. In-stream Temperature Data Collection

During the summer and fall of 2008, Onset HOBO® temperature loggers were deployed in the Big Hole Watershed to monitor in-stream temperatures. Montana State University deployed 23 temperature loggers and Montana Fish, Wildlife, and Parks deployed an additional 17. Those agencies were responsible for the management of calibration and accuracy of temperature loggers. Temperature logger locations are mapped in Figure 5. Further data on the use of temperature logger data for this study is outlined below in sections 4.1.5 and 4.2.4.

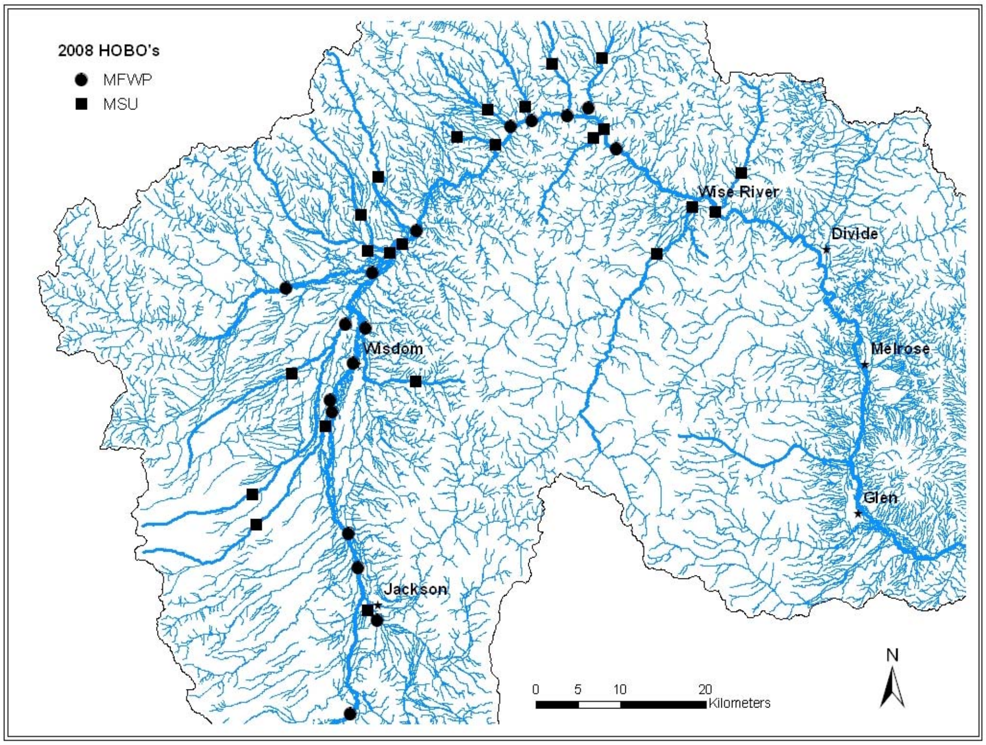

Figure 5. Locations of HOBO Temperature Loggers

3. DATA PROCESSING

3.1. TIR DATA PROCESSING

TIR data was recorded with a firewire connection at a rate of 7.5 frames per second to ThermaCam Researcher running on a laptop computer[3]. The data was saved in TIR Sequence (.seq) format, which is a proprietary file format for TIR cameras. In this format each pixel in every frame are addressable for temperature information. Of course it is not necessary to scrutinize and evaluate every single frame (27,000 frames per hour). While it does make for large file sizes, the extra frames make a smoother video presentation. For purposes of analysis 7 out of every 8 frames were dropped and individual images were created out of the original .seq file (i.e. approximately one frame per second). ThermaCam Researcher allows export of TIR data in numerous formats. Individual TIR images were exported to the formats (Table 1):

Extension	File Type	Description
CSV	Comma Separated Values	Tabular data; can be imported into other analysis programs, i.e. Matlab and ERDAS Imagine.
FFF	TIR Public Format	These images are for use with ThermaCam QuickView.
IMG	ERDAS Imagine	In post-processing, the CSV files were converted to ERDAS Imagine format.

Table 1. File formats used in processing TIR data.

[3] http://flirthermography.com/software/swf004.asp

3.1.1. ThermaCam QuickView

ThermaCam QuickView is a stand-alone TIR image viewer for viewing .fff files. QuickView allows for basic TIR image manipulation and analysis. QuickView is included on the project DVDs. It can also be downloaded from the TIR website[4].

3.1.2. Temperature Extraction Technique

Temperature data can be extracted from .csv, .fff, and .img formats. In deriving the temperature values used in the attribute fields of the shapefiles, we used the .fff files and tools native to ThermaCam Researcher to sample temperature values near the middle of the river. ThermaCam Researcher allows the user to find average temperatures within a given shape. For this study, a circle with 100 foot diameter was placed in the center of the river on each image and the average temperature was calculated. Next, the average temperature for each image was averaged with five to six of the adjoining images. The length of stream covered by the 5 or 6 images varied depending factors such as air speed, channel pattern, and image angle, but equals 5 seconds of flight time at an average of 90 miles per hour, or 0.025 mi (132 ft) on average.

The averaged temperatures were added to a table that was then imported into ArcView and spatially joined to the GPS data to produce a shapefile with the following attributes (Table 2):

Attribute	Description
Start_Lat	X coordinate
Start_Long	Y coordinate
Start_Alt	Altitude in meters MSL
GPSTime	Central Daylight time
TempC	Average temperature of the center of the river
Speed_kph	Aircraft speed
Heading	Aircraft heading

Table 2. Attribute data for TempCJoin.shp

3.1.3. TIR Image Mosaic

To produce the TIR image mosaics, .fff images were exported from ThermaCam Researcher to .csv (comma separated value) format. The .csv files were then imported into ERDAS Imagine as floating point decimal files (.img). The floating point decimal format retains the temperature values from the original image as pixel values. These images were then geo-referenced to a set of USGS Orthoquads obtained from the Montana Natural Resource Information System (NRIS)[5]. The TIR image mosaics have a pixel resolution of one meter. Figure 6 provides image examples.

[4] http://www.flirthermography.com/software/

[5] Montana Natural Resource Information System. Geographic Information Systems (GIS) Shapefiles. Cited 2009 April. Available from: http://nris.mt.gov/gis.

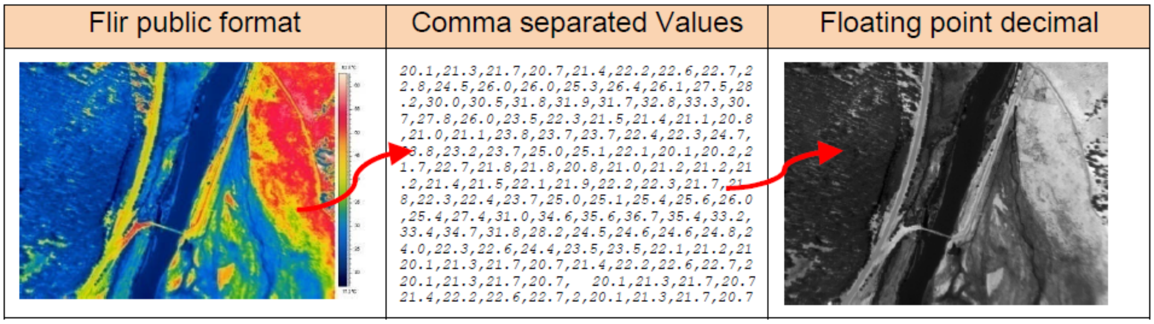

Figure 6. TIR image mosaic processing (.fff, .csv, .img)

3.1.4. TIR Temperature Accuracy

The TIR SC640 thermal camera used for this project is one of the most advanced thermal imaging radiometers available. It has a temperature resolution of 0.08°C and an absolute accuracy of 1.0°C; that is, the temperature read from the camera can be within 1°C of the absolute temperature of an object when all object parameters are accounted for, i.e. humidity, atmospheric temperature, object distance (elevation), and emissivity. When flying a river, these parameters are constantly in flux, and they have a direct, though minor, impact on the temperature readings from the original TIR images. Changes in altitude or atmospheric temperature can cause the temperature readings to fluctuate by as much as 1.0°C to 1.5°C.

The area upstream from Wisdom was flown twice, the first time at an altitude of 5000 AGL and the second time at 4000 AGL. A separate TIR calibration was done for each section to make the TIR temperatures as accurate as possible. The raw TIR temperature at those sites BELOW Wisdom Bridge differed from the calibrated ground temperatures by an average of 0.8 degrees. To correct for this, the object parameters of the TIR imagery were adjusted. The original and adjusted values are listed below:

Item	Value
Emissivity	.92
Distance	5000 feet
Humidity	50%
Atmospheric Temperature	20 C. Adjusted to 22.5 C.

Table 3. Flir object parameters downstream from Wisdom Bridge.

The raw TIR temperature at those sites ABOVE Wisdom Bridge differed from the calibrated ground temperatures by an average of 2.1 degrees. To correct for this, the object parameters of the TIR imagery were adjusted according to **Error! Reference source not found.** below.

Item	Value
Emissivity	.93
Distance	5000 feet Adjusted to 4000 feet
Humidity	50%
Atmospheric Temperature	20 C. Adjusted to 24.0 C.

Table 4. Flir object parameters upstream from Wisdom Bridge.

A note about object parameters.

Atmospheric conditions have an effect on the amount of infrared energy entering through the lens of the camera. In a laboratory setting these variables can be accurately measured. However, when flying 5000 feet above the earth in changing weather conditions it is impossible to completely account for these variables. By comparing the TIR temperatures with the datalogger temperatures we can adjust the object parameters to better match what was measured on the ground.

In **Error! Reference source not found.**4 above, we adjusted the object distance (flight altitude), and atmospheric temperature to more closely match the average datalogger temperature upstream of Wisdom.

3.1.5. Temperature Comparison Results

A key element of the project correlates in-stream temperatures as measured from the ground with the aerial TIR imagery. There were several in-stream temperature recording devices located throughout the project area placed by other agencies. For purposes of TIR calibration the following locations were sampled and hourly temperatures measurements from that location were compared with the nearest TIR image temperature.

Location	Flir Time	before time	before C.	after time	after C.	% time diff	temp diff	Cali-brated Temp	Raw FLIR Temp	diff
Dickie Bridge	14:06:28	14:00	19.555	15:00	20.317	0.11	0.76	19.6	20.9	1.3
Sportsman's Pool	14:16:57	14:00	19.318	15:00	19.888	0.28	0.57	19.5	19.8	0.3
Mud Creek Bridge	14:32:16	14:00	18.961	15:00	19.841	0.54	0.88	19.4	20.8	1.4
Christiansen	14:35:48	14:00	19.436	15:00	20.198	0.60	0.76	19.9	21	1.1
Pintlar Pool	14:38:19	14:00	19.674	15:00	20.698	0.64	1.02	20.3	20.1	-0.2
Wisdom	15:42:54	15:00	19.698	16:00	20.388	0.72	0.69	20.2	22.8	2.6
McDowell	15:48:50	15:00	19.888	16:00	20.46	0.81	0.57	20.4	22.1	1.7
Rock Creek Road	15:51:03	15:00	19.627	16:00	20.222	0.85	0.60	20.1	21.8	1.7
Peterson Bridge	15:57:56	15:00	18.081	16:00	18.937	0.97	0.86	18.9	21.5	2.6
Little Lake Creek	15:59:25	15:00	17.962	16:00	18.889	0.99	0.93	18.9	20.7	1.8

Datalogger and FLIR image temperature comparison and calibration. Note the variability in the Diff column upstream (avg 0.8 degrees) and downstream (avg 2.1 degrees) from Wisdom.

After calibration, the final temperature readings have a difference of less than 1.0°C from in stream temperature measurements. In prior projects, differences have averaged 0.4°C, which would be applicable here as well, as is consistent with thermal infrared surveys conducted on other streams since 1994 (Torgersen et. al. 2001).

3.2. CIR and RGB Image Processing

An MS4100 multi-spectral camera from GeoSpatial Systems[6] was used to collect 4-band imagery. The raw imagery consists of blue, green, red, and infrared bands. In post-processing, the individual images were separated into two sets of images; blue, green, and red bands were combined to produce normal color (RGB) images, while green, red, and near infrared were used to make color-infrared images (CIR), as shown below in Figure 7:

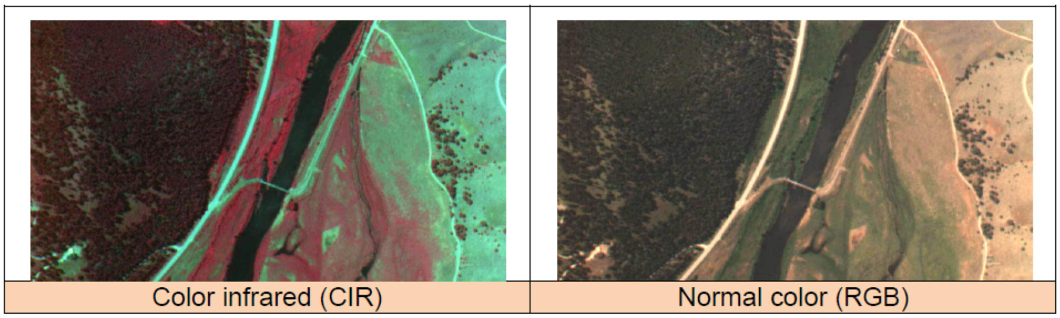

Figure 7. CIR and RGB image comparison.

These two image sets have the same extent and resolution. After separating the RGB from the CIR images, the CIR images were then geo-referenced to orthoquads from NRIS. The spatial models of the CIR images were then applied to the RGB images. The CIR and RGB image mosaics have a pixel resolution of approximately 0.75 meters.

3.3. GIS Data

All spatial data for the project were either collected in, or converted to, the following projection: State Plane Coordinate System, Montana, NAD 1983. Meters are the unit used. GIS files were created during the initial data processing, as noted above in section 3.1.2 of this report. Several more files were created for data analysis and are discussed further in section 4.1 below.

3.4. Video Processing

VideoSync™ is a DVD-based product unique to Infrared Baron, LLC. VideoSync combines TIR and other imagery on a single screen (Figure 8). It is useful for getting a quick view of a project area and guides the user to areas on the ground that require in-depth attention. VideoSync will play on computers with a DVD drive or on home DVD systems.

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[6] http://www.geospatialsystems.com

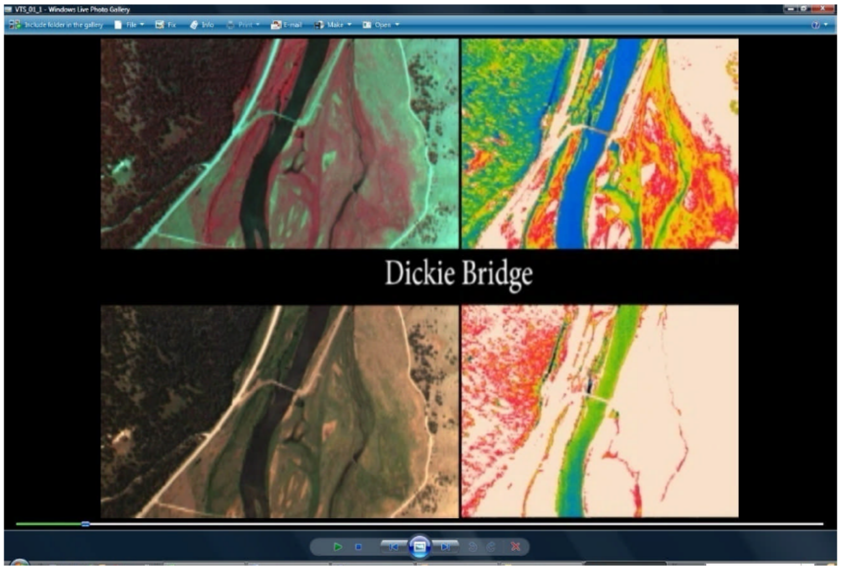


Figure 8. Screen shot of a VideoSync playing in Windows Media Player.

4. DATA ANALYSIS

4.1. GIS

Several GIS files were created in addition to those noted above in sections 2 and 3 to guide temperature source analysis and mapping of thermal refugia. All GIS files are being submitted with this report. Table 5 below compiles all GIS files created through this project. The creation of these files is described in the following sections.

Item	Description
FlightPath.shp	Data from GPS; delineates flight path on July 30, 2008
TempC_Join.shp	Original temperature join shapefile
TempC_JoinRiverMile02.shp	Temperature shapefile in which average temperatures are related to nearest horizontal point in river for display
FeaturePoint.shp	Delineates location of temperature features in river
FPFeatures.shp	Delineates location of temperature features in greater floodplain
DownstreamReachXY.shp	Delineates downstream end of each reach (as defined by UMT/FWP staff)
UpstreamReachXY.shp	Delineates upstream end of each reach (as defined by UMT/FWP staff)
LatLongTLoggers.shp	Delineates the location of each temperature logger which used a GCS, NAD 83 coordinate system.
UTMTLoggers.shp	Delineates the location of each temperature logger

	which used a UTM zone 12, NAD 83 coordinate system.
BigHoleRiver_Miles71to112.shp	Delineates river location between Dickie Bridge and Wisdom, per 2008 RGB, CIR, and TIR data
BigHoleRiver_Miles112to136.shp	Delineates river location upstream of Wisdom, per 2008 RGB, CIR, and TIR data

Table 5. GIS data created for this project.

4.1.1. Big Hole River Mile Shapefiles

The path of the Big Hole River was digitized at approximately 1:5000 to create more accurate shapefiles of the river, one for the region upstream of Wisdom and one for the region downstream of Wisdom. The river's location was defined by the aerial data (RGB, CIR, and TIR) collected during 2008. In some locations, the path of the river in these shapefiles differs from that in the topographic maps due to the coarser scale and greater age of the topographic map data, although the two datasets are in alignment in general.

The created river shapefiles were then divided into segments measuring one tenth of a mile. This was done to facilitate easier feature point referencing. Several different sources provided different locations for a starting river mile. The Montana Fish, Wildlife, and Parks website (http://fwp.mt.gov/default.html) has an interactive map feature with a river point layer. This interactive map was used to find Dickie Bridge and assign a river mile starting at that point (river mile 71). The Montana Fish, Wildlife, and Parks interactive map assigns river miles to a river layer which is built from topographic maps. As noted above, this is different from the way in which our river shapefile was created. For that reason, river miles do not line up exactly for the entirety of the river. At the upstream location where the river mile shapefile created for this project ends (just south of Nelson Lane), the river mile noted is approximately 134.0 miles. Alternatively, on the Montana Fish, Wildlife, and Parks interactive map, the same location shows a river mile of approximately 131.6. Therefore, the shapefile created for this project is approximately 2.4 miles longer than the river as shown on Montana Fish, Wildlife, and Parks maps. This should be taken into consideration when correlating the two data sources.

4.1.2. Input Feature Shapefiles

Other shapefiles were created based on thorough examination of the TIR data and supporting GIS data. Two point files were created in GIS, one containing water temperature features, such as coldwater refugia, in the Big Hole River (FeaturePoint.shp), and one containing temperature of inflow and outflow features in the greater floodplain (FPFeatures.shp). For both point files, the following criteria were used for noting points:

- Any input, refuge, pond or other temperature feature with a minimum 1.0°C temperature difference was noted. All differences less than 1.0°C were assumed to be within the error associated with the TIR data.

- An effort was made to note all irrigation returns, regardless of temperature differences.
- Temperature measurements were made in the following situations:
    - When water was visible in aerial or CIR data.
    - When a temperature change was visible in the river. In some locations it was difficult to discern whether the temperature change was due to a temperature feature or due to shading. These features were noted as "possible shading."
    - When the feature was distinct enough from the surrounding area (in TIR data) to accurately distinguish it from its surroundings.
    - As noted above in Section 3.2, the pixels in the TIR data represent approximately 0.75 meters². Therefore, in some cases, features were too small to accurately measure temperature.
    - Features which did not allow for accurate temperature measurement due to size or proximity to the edge of the image were included in the findings but noted as follows: "Temperature measurement not feasible."

Temperature difference was measured between the hottest or coldest reasonable point in a temperature feature, and that compared to an average temperature in the middle of the river. The program used to study temperature features (ThermaCam QuickView) allows users to create a box within which temperatures are averaged. For the purpose of this study, a box was created within the middle of the river in an area close to, but upstream of, the inflow or outflow feature. Maximum and minimum temperatures within this box were noted to ensure that extreme values were not being included in the average value. If the maximum and minimum temperatures did not appear to be extreme values, the average temperature was used for the river temperature. In the FPfeatures.shp file, the river temperature was taken from the nearest river location or from the temperature of the side channel if the floodplain feature was located in a side channel.

Two attribute fields within the temperature feature files can be used to reference the feature point. First, all points are related to the tenth of a mile within the river where they are located. Second, all points are related to the .fff, .img, or .jpg file which best displays the temperature feature. The attribute field "TimeSignature" contains a five digit number which relates to the file name. For .img files, the five digit number is displayed as 12345.img, while in .fff and .jpg files, the five digit number is displayed as 1_23_45. Both of these instances would represent that the image was taken at 1:23:45pm.

4.1.3. TempC_Join Shapefiles

The TempC_Join file, as described above in section 3.1.2, used temperature values from .fff files to determine average river temperatures. In each .fff file, an approximately 100-foot diameter circle was used to determine the average temperature. Associated .jpg files show the location of the circle used in each image. The TempC_Join file contains points which represent five to six of the average values from individual images joined and averaged. Therefore, there is one point in the TempC_Join file for every five to six .fff files. As noted above in section 3.1.2, the tabular data that these joins and averages created were related to GPS data to produce a shapefile. The resulting shapefile followed the path of the flight, not necessarily the path of the river, although the temperatures were from the river. A second shapefile was created to connect the TempC_Join data with the river mile shapefile. This file, TempC_JoinRiverMile02.shp, used the original points created for the TempC_Join.shp file and, because each point represented the average of the middle of five to six images in that location, each TempC_Join point was relocated to the point in the river directly horizontal from its original point in the TempC_Join file within the area represented by those files. Adjusting the shapefile to place the over the river does not affect the temperatures derived from TIR images, but gives a more accurate representation of the location of the stream temperature data.

4.1.4. Reach Location Shapefiles

The client had previously delineated 77 reaches throughout the study area. We received an MS Excel file with upstream and downstream latitudinal and longitudinal references. These were converted into shapefiles and were provided to the client with the rest of the project data.

4.1.5. Temperature Logger Location Shapefiles

As noted above in section 2.2.6, several in-stream temperature loggers collected data over the summer of 2008. We were provided with the raw data for the data collection season. Tabular data work is detailed below in section 4.2.4. The temperature loggers each held unique location information. This data was collected in two different coordinate systems. Approximately half of the loggers collected data in a GCS, NAD83 coordinate system; the others collected data in a UTM, NAD83 coordinate system. These locations were converted to ArcGIS shapefiles in the project coordinate system. These location shapefiles are listed in the table above and were provided to the client.

4.2. Tabular Data

4.2.1. Image File Locations

An Excel file (FFFLocations.xls) was created to organize all image file locations by time signature. As discussed above in section 4.1.2, the time signature is the unique attribute that links the location of image files (RGB, CIR, & TIR imagery) to a specific point in the flight. The FFFlocations.xls file relates time signatures to river miles. Using this file, one can find the appropriate images for any portion of the river they are studying, or vice versa, can find the river mile for any images they are studying.

4.2.2. Input Feature Files

As described above in section 4.1.2, two files were created to provide additional information about input features into the Big Hole River and its greater floodplain. These files are included in electronic format on CD, in Data Appendix B. The BigHoleTIR_Featurestxt.xls file contains three worksheets: Method, FPFeatures, and InputFeatures. The Method sheet contains the data outlined above in section 4.1.2 about how and why certain features were chosen. The FPFeatures and InputFeatures sheets contain detailed information about each feature. The sheets contain the following fields for cross-referencing features: Feature ID, Time Signature, Feature Type, Tributary

Name (included if applicable), Approximate River Mile, Feature Temperature, River Temperature, Temperature Difference, and Additional Notes. All temperatures are calculated in degrees Celsius. These sheets were joined with their respective shapefiles so all of this data is also available in each shapefile's attribute table. It should be noted that the attribute tables also include the field "FID," which is an automatic field created by ArcGIS. Because feature points were created in two rounds of TIR data study and then reorganized in order from the downstream end of the study area to the upstream end, the FID (which is assigned at the time the feature is created) can be significantly different from the Feature ID. The Feature ID should be used to identify specific features.

4.2.3. Flow Data

Tributary stream flow data was collected by the Department of Natural Resources and Conservation Water Management Bureau for several tributaries in the Big Hole watershed during 2008. We received data collected on a daily basis between 7/1/2008 and 10/1/2008. That dataset provided flow data collected on 7/30/2008, the date of the TIR flight, for the Big Hole River at Saginaw Bridge, Big Lake Creek at Twin Lakes, Steel Creek at the Forest Service boundary, and Steel Creek, Fish Trap Creek, Seymour Creek, and Deep Creek at their intersections with Highway 43. Additionally, data from the USGS National Water Information System was added to this data set for two locations along the Big Hole River, at Big Lake Creek and Mudd Creek. The resulting dataset included five locations for which there was both flow data and temperature data from the TIR study. These five locations are at the following approximate river miles: 117.0, 89.4, 81.4, 76.8, and 75.5. Respectively, these represent the Big Hole River at Big Lake Creek, the Big Hole River at Mudd Creek, and Fish Trap Creek, Seymour Creek, and Deep Creek at their intersections with Highway 43. Because of the distance between these five locations it is difficult to make conclusions about the impacts of tributaries on various sections of the river.

4.2.4. In-Stream Data Collection

As noted in multiple sections above, several in-stream temperature loggers were placed in the Big Hole River and its tributaries during the summer of 2008. We received raw data on all of the collected hourly data for those loggers placed either in the main stem of the river or near the mouths of tributaries. This data was reduced to data collected during the TIR study: 2:00pm, 3:00pm, and 4:00pm on 7/30/2008. A portion of this data was used to check the accuracy of the TIR study, as described above in section 3.1.5. The data collected in tributaries was added to the river temperature data to create a longitudinal temperature profile, as defined in section 5.1.

5. RESULTS

5.1. LONGITUDINAL TEMPERATURE PROFILE

To demonstrate temperature trends over the length of the river, the TIR temperatures for the Big Hole River were plotted versus the corresponding river mile. The temperature longitudinal profile is included on the following page in Figure 9. The points in the figure were created by associating each point in the TempC_JoinRiverMile02.shp shapefile (as described above in section 3.1.2) with the tenth of the river mile in which it was located. Each point shown in the Big Hole River line graphed below represents a temperature reading in the TempC_JoinRiverMil02.shp file. The region shown is the area of study, from river mile 133.8 down to river mile 71.0 at Dickie Bridge. The river is displayed in the figure below with the upstream end (river mile 133.8) on the left side of the graph, and the downstream end (river mile 71.0) on the right side of the graph. It should be noted that the TempC_JoinRiverMile02.shp file did not contain a point in each river mile tenth, while in some river mile tenths, it contained more than one point.

The figure below also contains temperatures of tributaries. The tributaries shown are those in which a temperature logger was placed by Montana State University (MSU) or Montana Fish, Wildlife, and Parks (FWP). The tributary temperatures graphed below were calculated by doing a linear interpolation of the temperatures calculated by the associated temperature logger at 2:00pm, 3:00pm, and 4:00pm on 7/30/2008. The TempC_Join file was used to determine the time at which the study flight flew closest to the tributary and associated temperature logger. Next, that time was used to determine what the approximate temperature of the tributary would have been, using the interpolated temperature logger data. These temperatures were then added to the longitudinal temperature profile at the river mile at which they enter the Big Hole River. It should be noted that on some tributaries the temperature logger was not placed exactly at the confluence, but within a close proximity to the mouth of the tributary. Interpolated tributary temperatures ranged from approximately 14.36°C (Bryant Creek) to 21.21°C (Steel Creek).

Temperatures on the Big Hole River averaged for the temperature profile ranged from a maximum of 21.81°C at river mile 105.6 near Wisdom, to a minimum of 17.92°C at mile 79.1. Overall, the Big Hole River has several areas with warming trends and cooling trends which appear to result from the lack or presence of riparian cover, warm and cool inputs such as tributaries and irrigation returns, and warm and cold water refugia. Stream temperatures reflect both watershed-scale and local-scale influences. Temperatures are subject to cumulative effects that extend beyond the reach scale. This analysis provides a general source characterization and identifies some temperature sources influencing temperature and habitat quality at a local scale.

The longitudinal temperature profile based on the TempC_JoinRiverMile02.shp shapefile is also illustrated in Map 1, Appendix A. Warm points downstream of Little Lake Creek below the data gap on Map 1 are assumed to be noise in the data associated with the equipment failure just below the stream confluence, rather than indicating a discrete warm water feature. The "sections" illustrated in the longitudinal temperature profile below are described in greater detail in section 5.2.

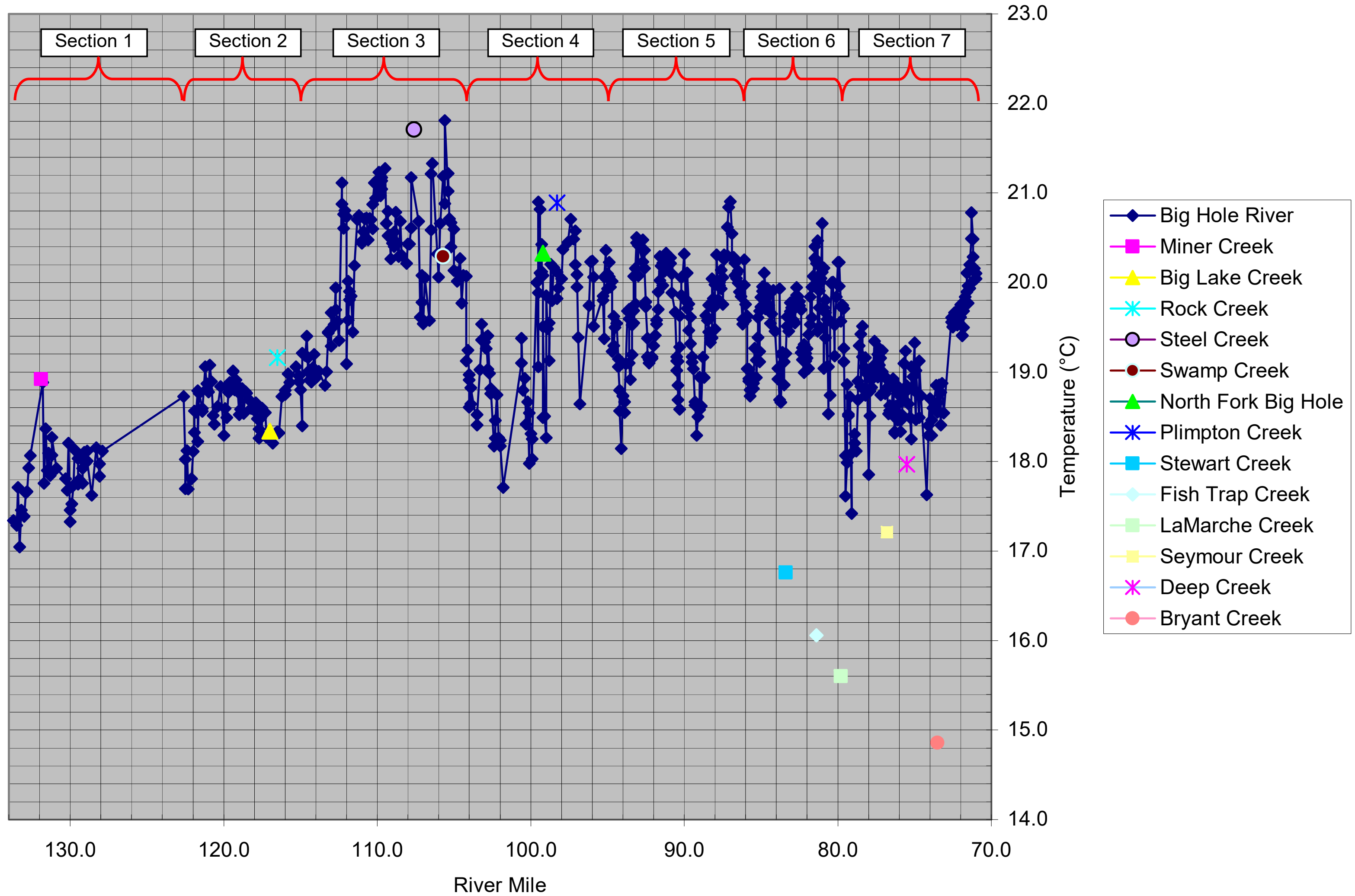


Figure 9. Longitudinal Temperature Profile for the Big Hole River

5.2. Results by Stream Reach

Seventy-seven reaches were delineated by investigators at MSU for fish habitat research between Miner Creek Road and Dickie Bridge. For the purpose of discussing and identifying trends, these reaches have been grouped into seven larger river sections. These sections were divided based on temperature and trend changes seen in the TempC_Join shapefile, aerial data, and overall TIR data. Sections are organized with section 1 being at the upstream end of the study area. It should be noted that the thermal infrared data begins at reach 12, near Little Lake Creek Road. Table 6 lists and describes these sections, and provides a list of the MSU study reaches included in each section.

Section #	MSU Reaches Included	River Miles Included	Length	Description
1	12 – 33	133.8 to 122.7	11.1 miles	Upstream end of study area; section stops just above confluence with significantly warmer side channel.
2	34 – 41	122.7 to 115	7.7 miles	River is fairly warm, although becomes significantly warmer below mile 115; several locations of additional study, i.e. USGS flow station at Big Lake Creek, multiple DNRC flow stations, several UMT/FWP temperature logger locations.
3	42 – 55	115 to 104.2	10.8 miles	Warmest section of river; significantly cooler below river mile 104.2.
4	56 – 62	104.2 to 95.1	9.1 miles	Valley begins to narrow; river becomes one channel.
5	63 – 69	95.1 to 86.3	8.8 miles	Valley continues to gradually narrow; variable temperatures.
6	70 – 72	86.3 to 79.8	6.5 miles	Several cold water inputs with little overall impact on water temperature.
7	73 – 77	79.8 to 71.0	8.8 miles	Several cold water inputs.

Table 6. Definition of river section breaks, including correlation with MSU/FWP reach breaks and river miles.

Results for each section of river are described below, beginning with a discussion about features that connect directly into the main stem of the Big Hole River. Overall trends are observed, followed by a table outlining and describing all of the noted features in the applicable section of river. See sections 4.1.2 and 4.2.2 of this report for more data on the methods used to create feature data. The more noteworthy features are described in greater detail with images from the TIR study included for illustrative purposes. All images are provided with a temperature scale of 15.0°C to 30.0°C for ease of comparison. Please note that because the TIR data collection flight was flown from the downstream end of the river to the upstream end of the river, the top of each image is the upstream end, and the bottom of each image is the downstream end. Consequently, one should not assume the tops of images are oriented to North.

Following discussion of the mainstem features, the same format is used to describe all of the features noted in the greater river floodplain: a discussion of overall trends, tabular data of all features in the floodplain, and examples of noteworthy features. In the tabular data provided in reference to floodplain features, the “River Mile” noted is the river mile located perpendicular to the floodplain feature. Note that because of the limited range of TIR imagery, this study of features within the floodplain may not be comprehensive. Additionally, due to complications with the TIR data, there are some small sections of the river for which TIR data is lacking. Should this data be determined to be necessary for the purposes of the study, further study may be conducted during the summer of 2009. The sections that were missed have been digitized into a GIS shapefile, which is included in the GIS data deliverables.

It is important to remember that thermal inputs to a stream are cumulative and often show trends over a watershed scale. For example, riparian condition may affect the equilibrium of temperature in downstream reaches. The results of each reach discuss sources of higher and lower temperature water that are specific to that reach, but are not indicative of temperature trends at the watershed scale. Temperature data were collected during the hottest time of day during the hottest time of year, and should be considered representative of the warmest conditions, not annual average temperatures, or temperatures necessarily affecting spring spawning conditions.

Maps listing in-stream and floodplain temperature features for each section are included in Appendix A. These maps also list MSU reaches to facilitate locating warm or cool water inputs for future study. These maps are based on the features shapefiles and projects in GIS, which contain feature temperatures and descriptions.

5.2.1. Section 1: Reaches 12 – 33

This section begins at the upstream end of the TIR study area. River temperatures generally become cooler as the river progresses downstream. Section 1 includes three instances of groundwater inflow, three in-stream cold water features (general refugia), fourteen irrigation returns, one confluence with a side channel, and one confluence with a tributary. The most significant feature of this section is that it lies directly upstream of the Big Hole River’s confluence with a large side channel that appears to warm temperatures downstream of this section, in river section 2. Individual features are discussed further below.

5.2.1.1. Main Stem Features

Table 7 lists temperature features in Section 1 which have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
12	181	35927	Groundwater Inflow		133.8	24.2	17.5	6.7	
13	180	35910	Refuge		133.1	13.3	17.8	-4.5	
14	179	35903	Irrigation Return		132.8	19.7	17.8	1.9	
16	178	35843	Side Channel		131.9	18.9	17.9	1.0	
	177	35830	Groundwater Inflow		131.5	15.5	17.8	-2.3	
17	176	35822	Refuge		131.3	12.7	18.5	-5.8	
	175	35819	Irrigation Return		131.2	19.0	17.9	1.1	
	174	35812	Groundwater Inflow		130.9	16.2	18.1	-1.9	
	173	35809	Refuge		130.8	16.9	17.9	-1.0	
18	172	35800	Tributary	South Branch Big Swamp Creek or Little Lake Creek	130.6	--	--	--	Feature not shown on FLIR data, but temperature change is visible (probable cold input). Temperature measurement not feasible.
19	171	35756	Irrigation Return		130.3	20.0	17.8	2.2	
20	170	35730	Irrigation Return		129.2	21.5	18.1	3.4	
21	169	35721	Irrigation Return		128.9	--	--	--	Temperature measurement not feasible
23	168	32341	Irrigation Return		127.9	--	--	--	Temperature measurement not feasible
	167	32330	Irrigation Return		127.5	17.7	17.3	0.4	
28	166	32226	Irrigation Return		125.2	--	--	--	Temperature measurement not feasible
30	165	32208	Irrigation Return		124.5	--	--	--	Temperature measurement not feasible
31	164	32202	Irrigation Return		124.3	17.3	17.4	-0.1	
32	163	32159	Irrigation Return		124.1	17.2	17.3	-0.1	

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
	162	32153	Irrigation Return		123.9	--	--	--	Temperature measurement not feasible
	161	32153	Irrigation Return		123.8	--	--	--	Temperature measurement not feasible
	160	32153	Irrigation Return		123.8	--	--	--	Temperature measurement not feasible

Table 7. Features with direct connection or proximity to the main stem of Big Hole River: Section 1.

This section contains several noteworthy features. A probable groundwater inflow at river mile 133.8, the uppermost end of the TIR study, has a temperature of 24.2°C, 6.7°C higher than the surrounding river temperature. Although it does appear to connect with the river, it does not appear to have a substantial impact on overall river temperatures, possibly due to a small flow volume. This feature is illustrated below in TIR imagery (Figure 10).

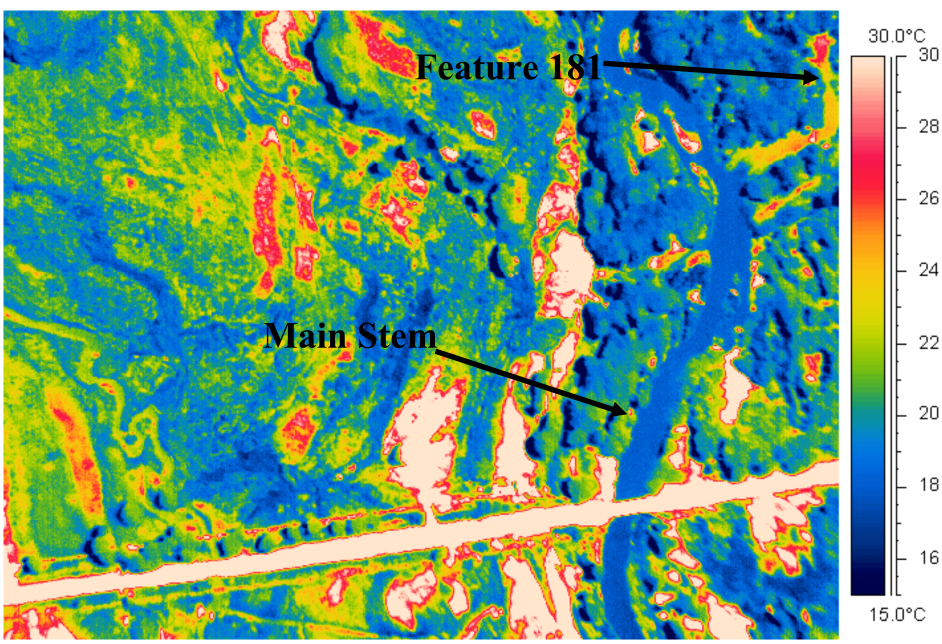


Figure 10. Warm groundwater inflow. Feature 181, Section 1.

Approximately 0.7 miles downstream of feature 181 is a cold water refuge (feature 180) with temperatures roughly 4.5°C lower than the nearby river temperature. It appears to be long and narrow and could provide excellent cold water fish habitat (Figure 11).

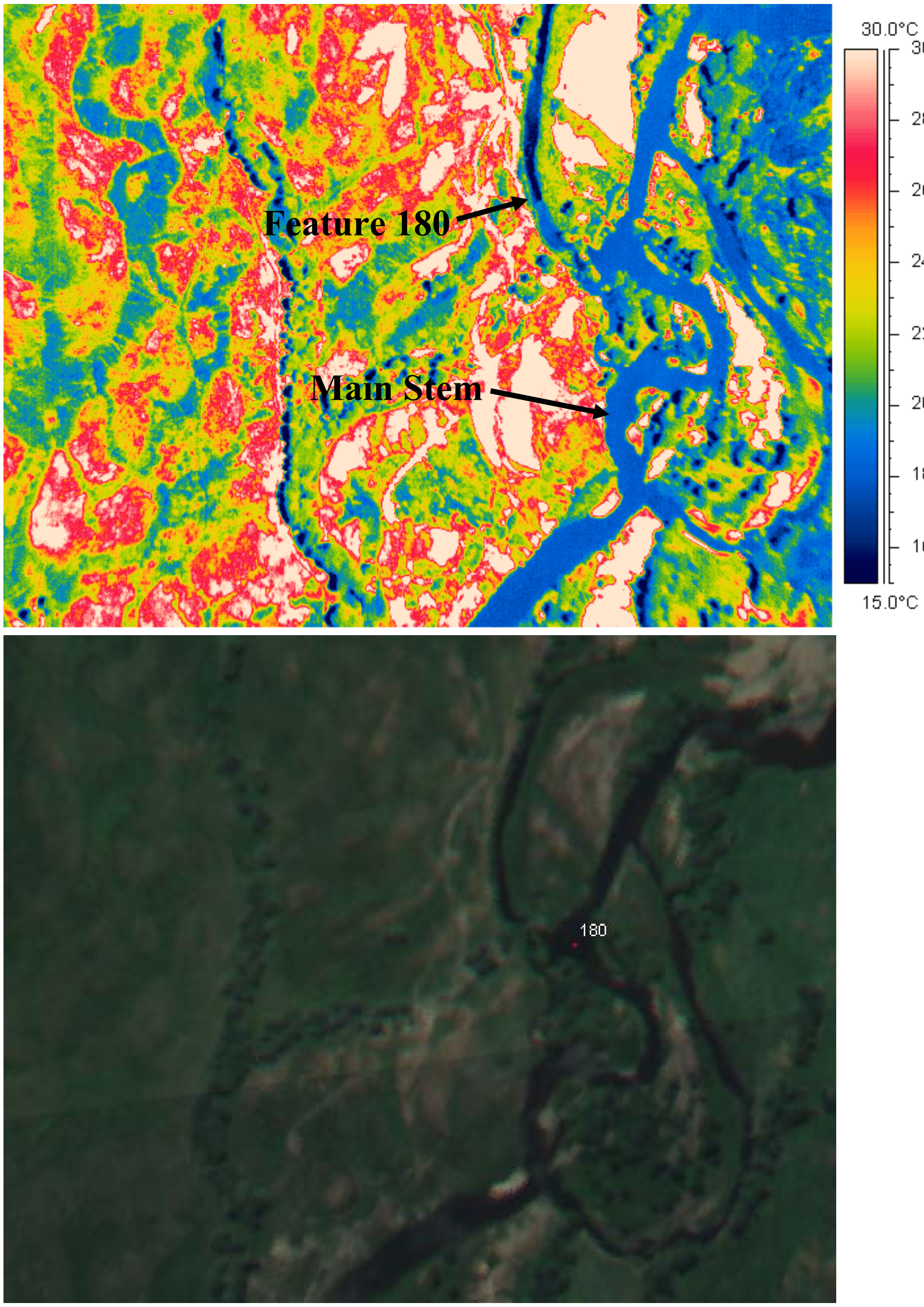


Figure 11. TIR and Aerial: Cold water refuge. Feature 180, Section 1.

Another cold water refuge (feature 176) exists in river mile 131.3, with temperatures approximately 5.8°C below nearby river temperatures (Figure 12).

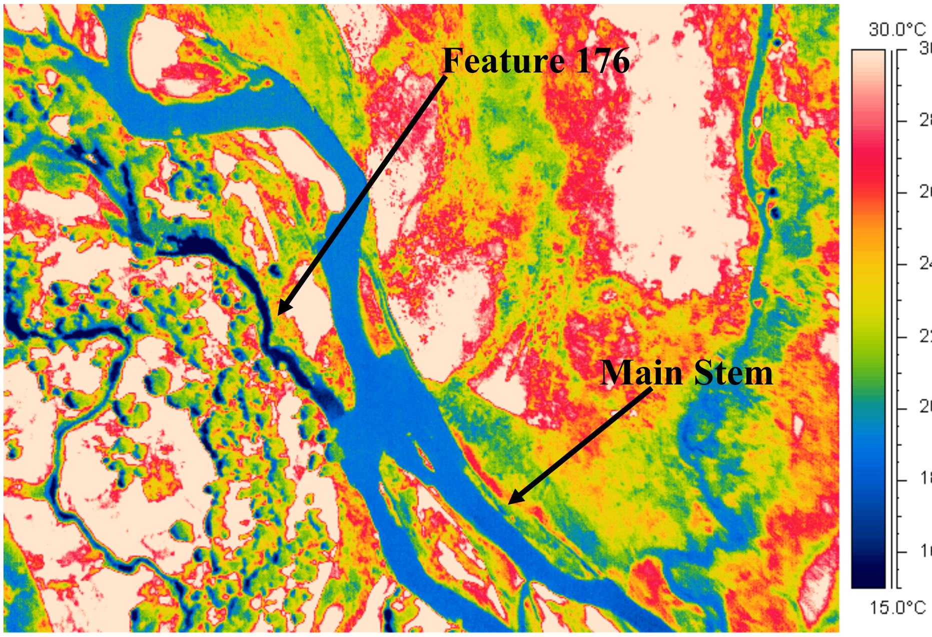


Figure 12. Cold water refuge. Feature 176, Section 1.

Finally, although there are several irrigation returns in this section of river, one is particularly interesting. Feature 171 is an irrigation return approximately 2.2°C warmer than the nearby river and appears to have a minor influence on river temperatures immediately downstream (Figure 13).

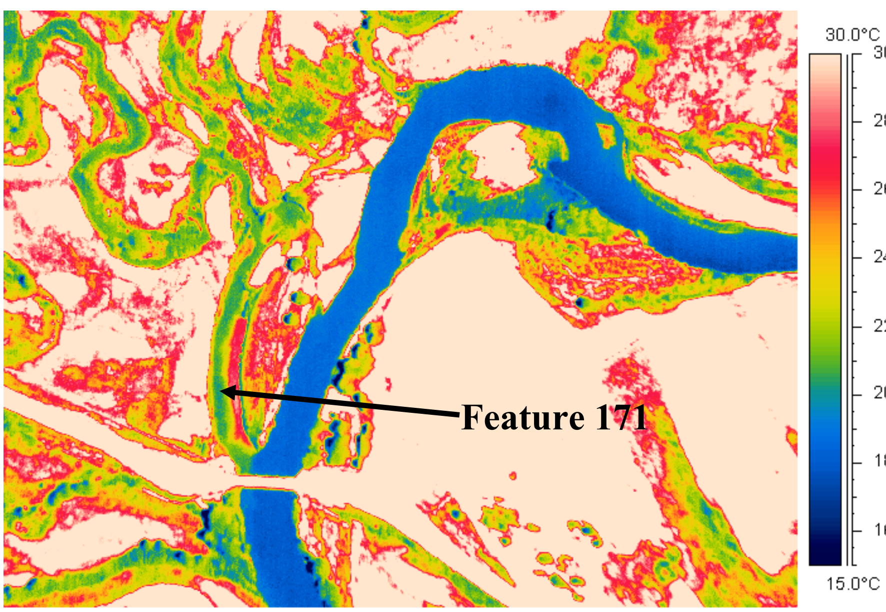


Figure 13. TIR and Aerial: Irrigation return. Feature 171, Section 1.

5.2.1.2. Floodplain Features

Table 8 lists temperature features in Section 1 that are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection
15	43	35845	Refuge in Side Channel		132.2	11.6	19.1	-7.5	Yes
24	42	35449	Warm Inflow		126.7	25.5	20.0	5.5	Yes
30	41	35353	Refuge in Side Channel		124.4	16.4	19.9	-3.5	Yes
31	40	35340	Refuge in Side Channel		123.9	16.8	20.1	-3.3	Yes
32	39	35337	Refuge in Side Channel		123.8	13.5	20.0	-6.5	Yes
33	38	35324	Refuge in Side Channel		123.1	14.0	20.0	-6.0	Yes
	37	35310	Pond		122.7	23.0	20.3	2.7	No

Table 8. Features located in the floodplain of the Big Hole River, Section 1.

This section of the Big Hole runs adjacent to a significant side channel with several refugia with potential for cold water fish habitat and a warm input that appears to be a warm or hot spring. This feature (floodplain feature 42) is located at a position perpendicular to river mile 126.7. The TIR imagery is somewhat difficult to decipher due to the range of temperatures present in the images at this location. The TIR image below shows a portion of the warm inflow and the adjacent side channel into which it eventually flows (Figure 14).

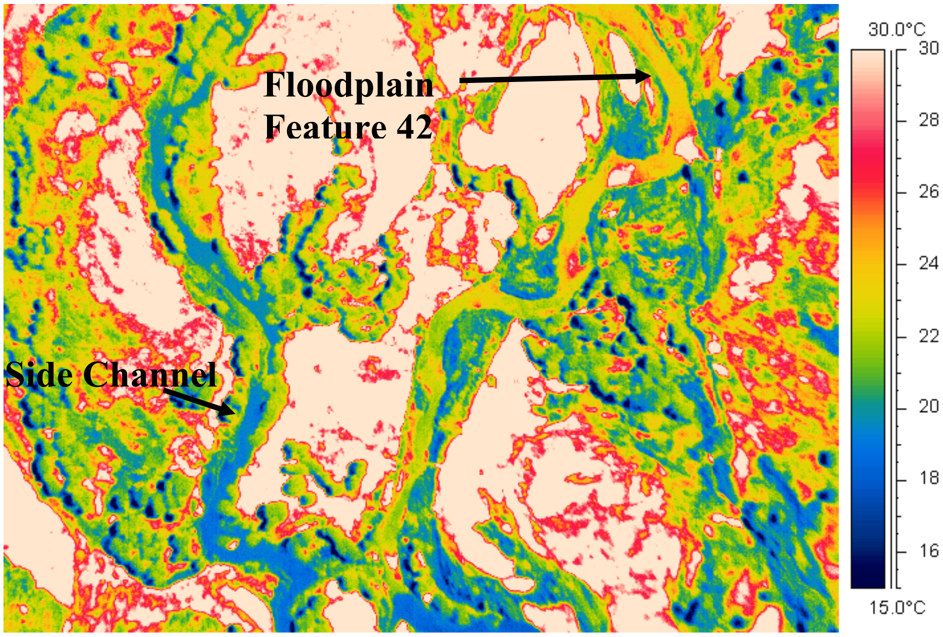


Figure 14. Warm water input. Floodplain feature 42, Section 1.

The following two images show three cold water refugia in the same side channel as that affected by floodplain feature 42, above. Floodplain features 40 and 39 have temperatures approximately 3.3°C and 6.5°C cooler than the adjacent side channel, respectively (Figure 15). Floodplain feature 38 is approximately 6.0°C cooler than the adjacent side channel (Figure 16). As noted above, this side channel could provide excellent cold water fish habitat with its multiple cold water refugia.

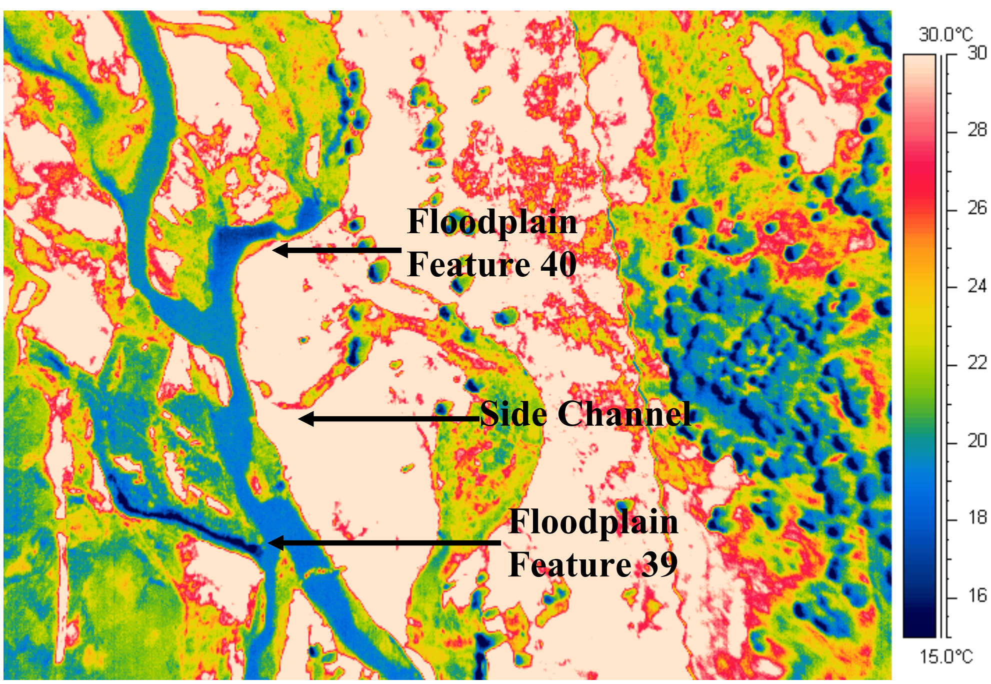


Figure 15. Cold water refugia. Floodplain features 40 and 39, Section 1.

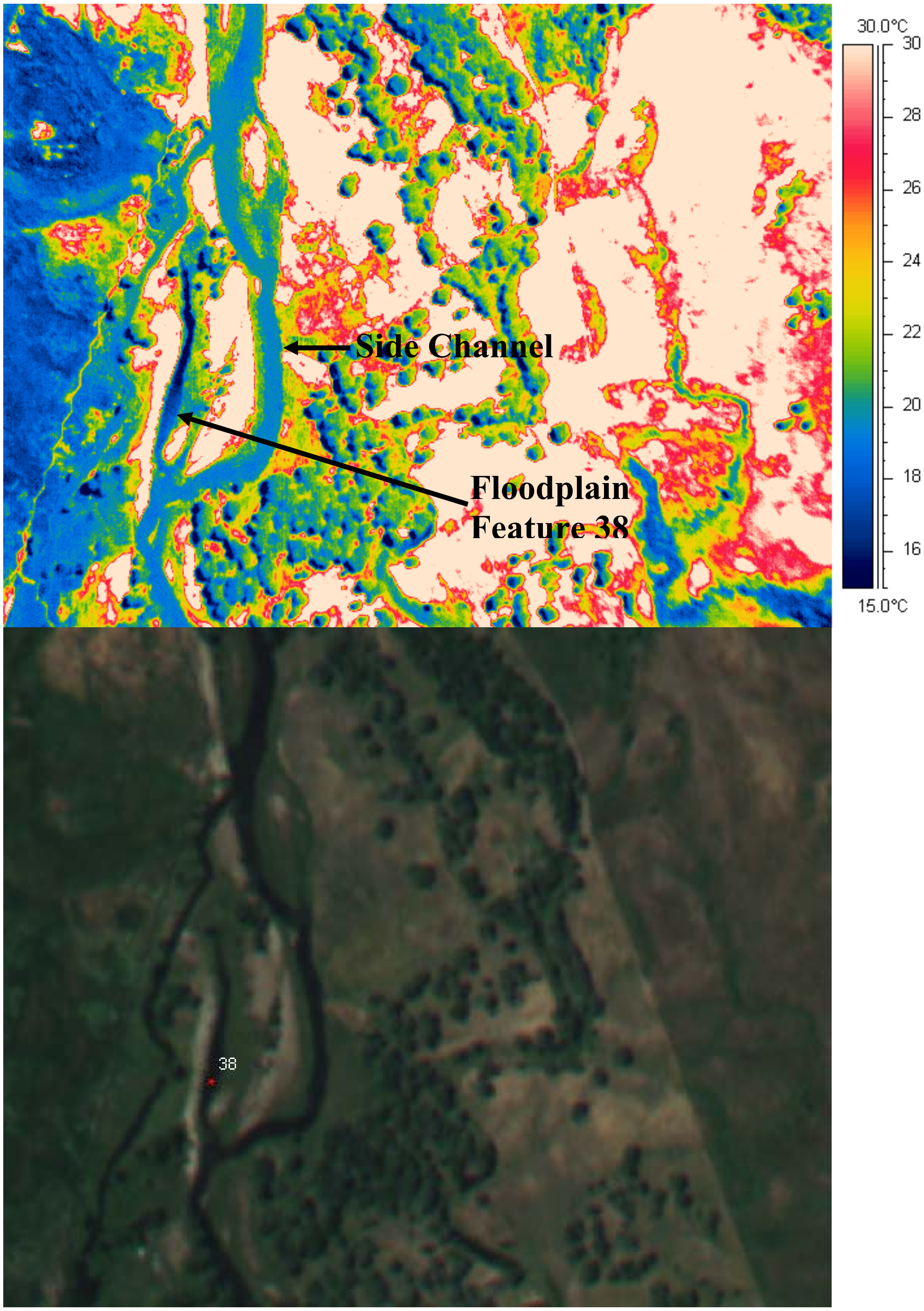


Figure 16. TIR and Aerial: Cold water refuge. Floodplain feature 38, Section 1.

5.2.2. Section 2: Reaches 34 – 41

While this section of the Big Hole does not contain the warmest temperatures found on the river, it is approximately 1.0°C warmer on average than the section upstream. This is potentially due in part to its confluence with a warmer side channel at the upstream end of the section. The river continues to warm gradually throughout this section, warming to approximately 18.9°C at its downstream end. This section of river is of additional interest because there are several locations of additional study in this area. For example, there is a USGS flow station at its confluence with Big Lake Creek, multiple DNRC flow stations throughout the section, and several UMT/FWP temperature logger locations. This allows for advanced study opportunities in this section. This section includes confluences with three side channels, twelve cold water refugia, seven instances of groundwater inflow, ten irrigation returns, and one backwater.

5.2.2.1. *Main Stem Features*

Table 9 lists temperature features in Section 2 which have a proximity to, or are directly on the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
34	159	35307	Side Channel		122.6	19.5	17.5	2.0	
35	158	35255	Refuge		122.2	--	--	--	Temperature measurement not feasible
	157	35248	Groundwater Inflow		121.9	--	--	--	Temperature measurement not feasible
36	156	35234	Irrigation Return		121.2	17.2	19	-1.8	
	155	35228	Refuge		121.1	17.1	18.6	-1.5	
	154	35228	Refuge		121.1	15.7	18.8	-3.1	
	153	35224	Refuge		120.9	14.3	18.9	-4.6	
	152	35224	Irrigation Return		120.9	16.6	18.9	-2.3	
37	151	35213	Groundwater Inflow		120.5	14.3	18.7	-4.4	
	150	35209	Side Channel		120.2	17.2	18.7	-1.5	
	149	35208	Irrigation Return		120.2	17.3	18.6	-1.3	
	148	35205	Refuge		120.1	17.1	18.7	-2.5	
	147	35204	Refuge		120.0	14.3	18.8	-4.5	
	146	35203	Groundwater Inflow		120.0	16.8	18.8	-2.0	
37	145	35200	Groundwater Inflow		119.8	13.4	18.8	-5.4	
	144	35156	Refuge		119.6	18.4	19.1	-0.7	
	143	35149	Irrigation Return		119.4	--	--	--	Temperature measurement not feasible
	142	35147	Refuge		119.3	14.4	18.9	-4.5	
	141	35147	Refuge		119.3	17.6	18.8	-1.2	
	140	35140	Refuge		119.1	16.7	18.7	-2.0	
38	139	35138	Irrigation Return		119.0	16.8	18.4	-1.6	
	138	35121	Irrigation Return		118.4	--	--	--	Temperature measurement not feasible
	137	35113	Groundwater Inflow		118.0	--	--	--	Temperature measurement not feasible
	136	35110	Refuge		118.0	17.2	19.1	-1.9	

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
39	135	34907	Refuge		116.9	16.5	18.3	-1.8	
	134	34858	Groundwater Inflow		116.5	20.4	18.4	2.0	
40	133	34855	Side Channel		116.2	19.5	18.9	0.6	
	132	34847	Groundwater Inflow		115.9	14.7	19.1	-4.4	
	131	34841	Irrigation Return		115.7	20.1	18.9	1.2	
	130	34841	Irrigation Return		115.6	21.6	18.6	3.0	
41	129	34831	Irrigation Return		115.3	20.5	18.8	1.7	
	128	34829	Irrigation Return		115.1	--	--	--	Temperature measurement not feasible
	127	34825	Backwater		115.0	20.4	18.9	1.5	

Table 9. Features with direct connection or proximity to the main stem, Section 2.

The first feature in this section at its upstream end is a side channel which joins the Big Hole from the east. The side channel (which is documented more extensively in the section above on the floodplain features of river section 1) has a temperature 2.0°C higher than the Big Hole River at its confluence. This temperature difference would not necessarily be noteworthy considering that there are other features in this section with temperature differences of 4.0°C to 5.0°C; however, it is noteworthy in this instance because the side channel appears to add significant flow to the Big Hole River. Further studies relating flows and temperatures may be interested in studying this side channel in greater detail.

As noted, this river section contains several cold water refugia with temperatures up to 4.6°C colder than the adjacent river. Below is an image of two such refugia: features 148 and 147. Feature 148 is the feature further upstream (therefore higher on the image) and has a temperature of 17.1°C compared to a river temperature of 18.7°C. Feature 147 has a temperature of 14.3°C, which is approximately 4.5°C cooler than the surrounding river water (Figure 17). As listed in Table 9, this section has several other features potentially offering coldwater habitat.

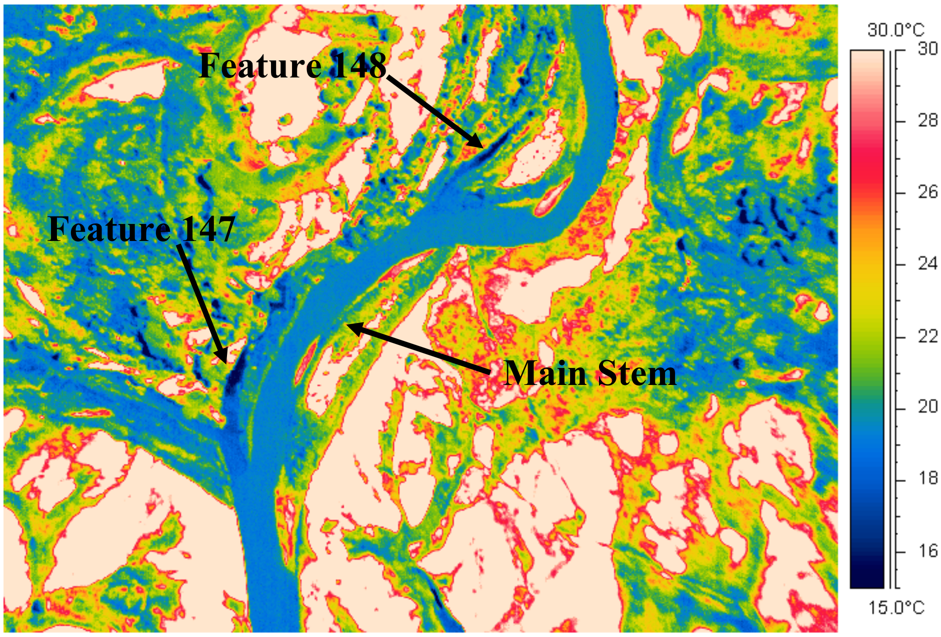


Figure 17. Cold water refugia. Features 148 and 147, Section 2.

5.2.2.2. Floodplain Features

Table 10 lists temperature features in Section 2 that have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection
35	36	35255	Refuge in Side Channel		122.2	18.2	19.8	-1.6	Yes
35	35	35250	Refuge in Side Channel		122.0	16.1	19.6	-3.5	Yes
	34	35250	Side Channel		122.0	17.7	19.6	-1.9	Yes
36	33	35244	Refuge in Side Channel		121.7	16.9	19.3	-2.4	Yes
	32	35238	Refuge in Side Channel		121.6	18.0	19.9	-1.9	Yes
	31	35230	Oxbow		121.1	22.1	20.0	2.1	No
37	30	35215	Oxbow		120.6	15.0	20.0	-5.0	No
38	29	35119	Oxbow		118.3	16.9	19.8	-2.9	No
40	28	34851	Refuge		116.2	18.7	20.1	-1.4	No

Table 10. Features located in the floodplain, Section 2.

This section has several cold water refugia in side channels that have surface water connections to the main stem of the Big Hole River. One such refuge is floodplain feature 32 which has significant areas of water between 2.0°C and 3.0°C colder than the temperature of the adjacent main stem and side channels (Figure 18).

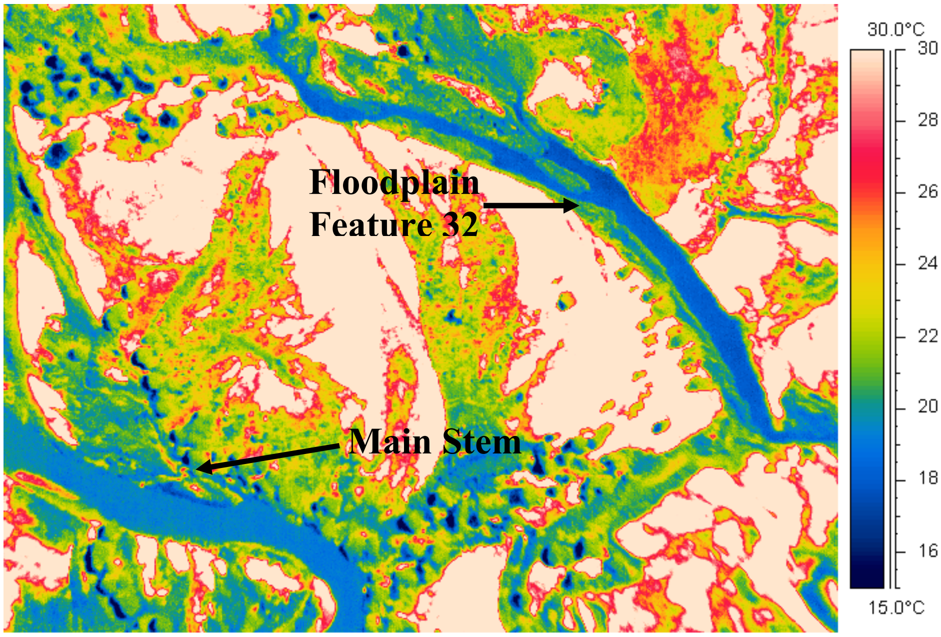


Figure 18. Cold water refuge. Floodplain feature 32, Section 2.

Floodplain feature 30 is an oxbow with close proximity to the main stem of the Big Hole River but no surface connection. However, it has temperatures approximately 5.0°C colder than the adjacent river temperature. While it is not currently connected through surface flow, it is an interesting feature of this study nonetheless (Figure 19).

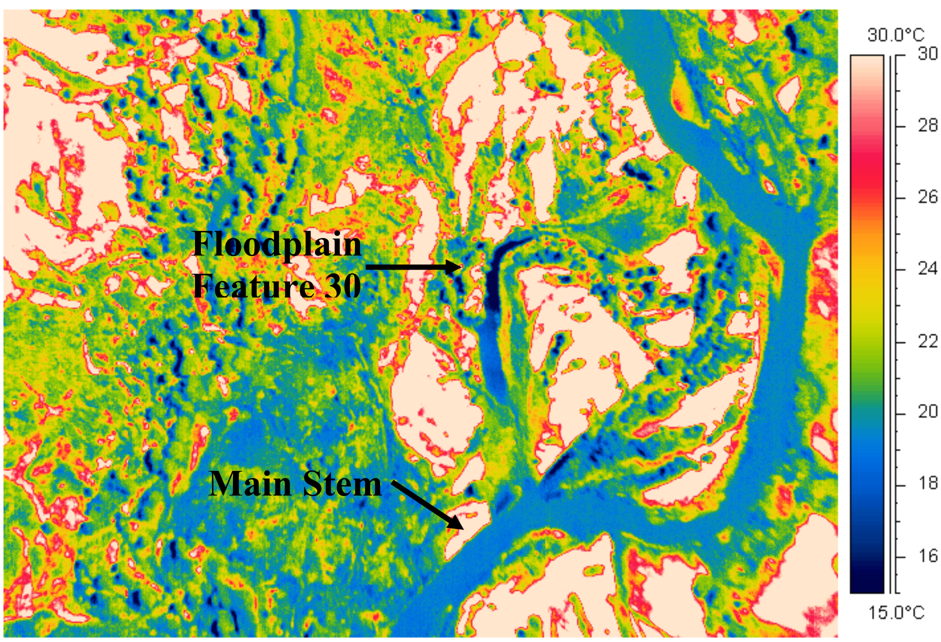


Figure 19. Oxbow. Floodplain feature 30, Section 2.

5.2.3. Section 3: Reaches 42 – 55

This section of river is the warmest of the seven sections, with river temperatures ranging from 19.2°C to 21.0°C and temperatures averaging 20.2°C throughout the section. From a preliminary study of aerial data, it appears that this river section also has the least amount of riparian cover. As visible below in the images of noteworthy features, the section includes many irrigation returns and warm inputs, although several cold water refugia and other inputs also exist. This section includes confluences with one side channel and two tributaries, eight cold water refugia, four instances of groundwater inflow, thirteen irrigation returns, and one backwater.

5.2.3.1. Main Stem Features

Table 11 lists temperature features in Section 3 which have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
42	126	34813	Side Channel		114.6	19.0	19.6	-0.6	
43	125	34806	Refuge		114.4	18.0	19.2	-1.2	
	124	34733	Groundwater Inflow		113.2	15.7	19.6	-3.9	
43	123	34728	Irrigation Return		112.9	17.2	19.8	-2.6	
	122	34317	Irrigation Return		112.9	20.9	19.5	1.4	
44	121	34314	Groundwater Inflow		112.7	16.1	19.5	-3.4	
	120	34310	Irrigation Return		112.6	20.8	19.7	1.1	
	119	34305	Backwater		112.5	19.2	19.6	-0.4	
	118	34301	Refuge		112.4	17.3	19.9	-2.6	
45	117	34252	Irrigation Return		112.0	--	--	--	Temperature measurement not feasible
46	116	31146	Refuge		111.6	16.0	20.4	-4.4	
	115	30916	Refuge		111.3	15.5	20.4	-4.9	
	114	30913	Irrigation Return		111.2	21.6	21.0	0.6	
	113	30906	Irrigation Return		111.0	--	--	--	Temperature measurement not feasible
	112	30901	Refuge		110.9	15.6	20.8	-5.2	
	111	30851	Irrigation Return		110.5	21.6	20.5	1.1	
	110	30851	Groundwater Inflow		110.5	19.0	20.6	-1.6	
	109	30844	Irrigation Return		110.3	20.8	20.8	0.0	
47	108	30834	Irrigation Return		109.7	21.8	20.8	1.0	

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
48	107	30642	Irrigation Return		109.1	21.8	20.1	1.7	
53	106	25552	Refuge		107.0	13.8	19.8	-6.0	
	105	25552	Refuge		106.9	17.0	20.0	-3.0	
	104	25552	Groundwater Inflow		106.9	17.8	20.0	-2.2	
	103	25540	Refuge		106.6	16.7	19.4	-2.7	
55	102	24730	Side Channel		105.4	21.8	20.7	1.1	
	101	24728	Irrigation Return		105.3	--	--	--	Temperature measurement not feasible
	100	24728	Irrigation Return		105.3	18.9	20.8	-1.9	
	99	24728	Side Channel		105.3	23.5	20.8	2.7	
	98	24710	Irrigation Return		104.8	22.3	19.8	2.5	

Table 11. Features with direct connection or proximity to the main stem, Section 3.

Figures 20 and 21 below offer good examples of the nature of this section; the surrounding area is generally quite wet with many groundwater and irrigation inputs into the river. Figure 20 shows features 115 and 114. Feature 115 is a cold water refuge with a temperature approximately 4.9°C colder than the adjacent river temperature. Feature 114 is an irrigation return with an approximate temperature 0.6°C warmer than the adjacent river temperature. The temperature for feature 114 was measured a small distance away from the river to ensure accurate measurement was made. Figure 21 shows feature 111, an irrigation return with a temperature approximately 1.1°C warmer than the adjacent river temperature. In both figures 20 and 21 there appears to be visible warming along the edges of the river. It is possible that this warming is occurring due to the lack of riparian vegetation; however, it would be necessary to do further studies to verify whether that is the case.

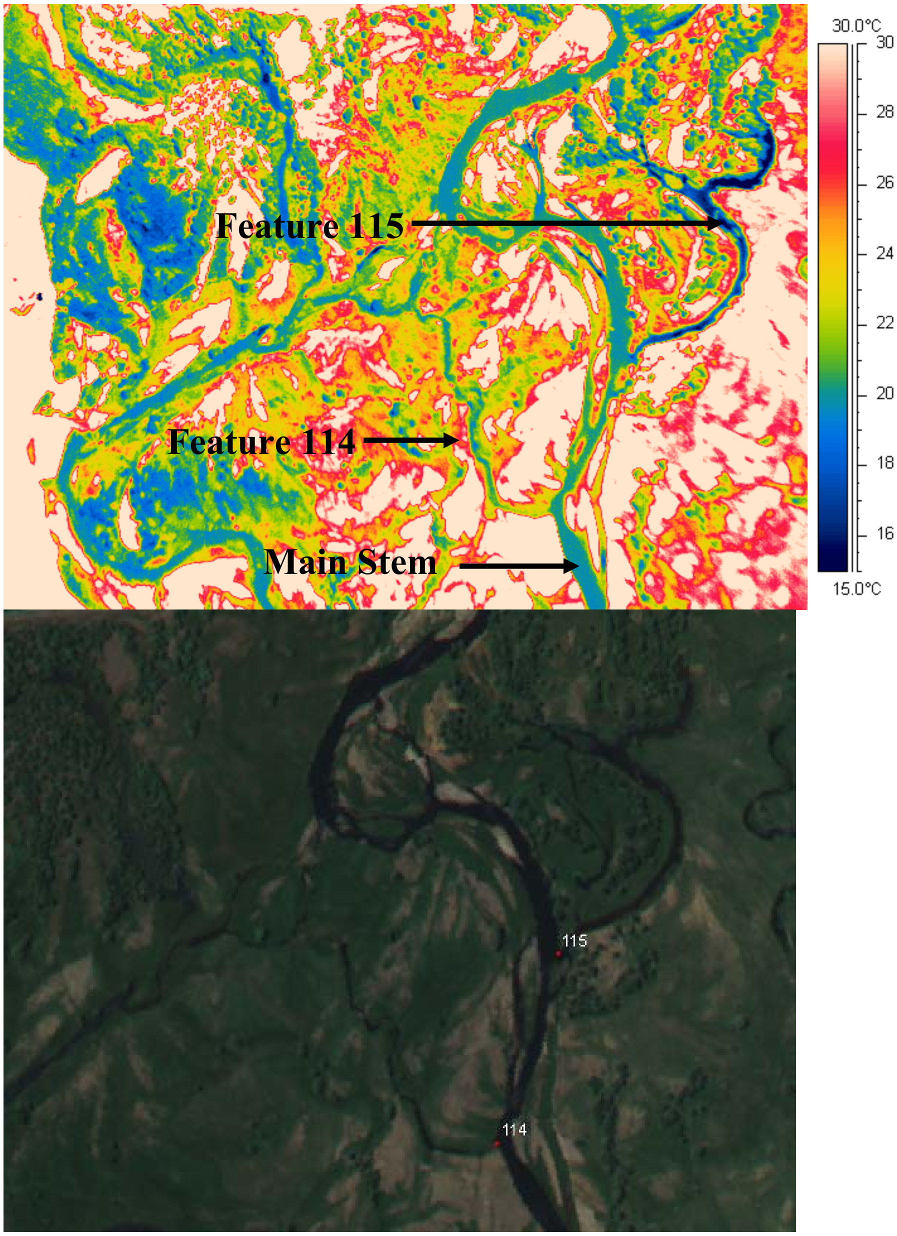


Figure 20. TIR and Aerial: Cold water refuge and irrigation return. Features 115 and 114, Section 3.

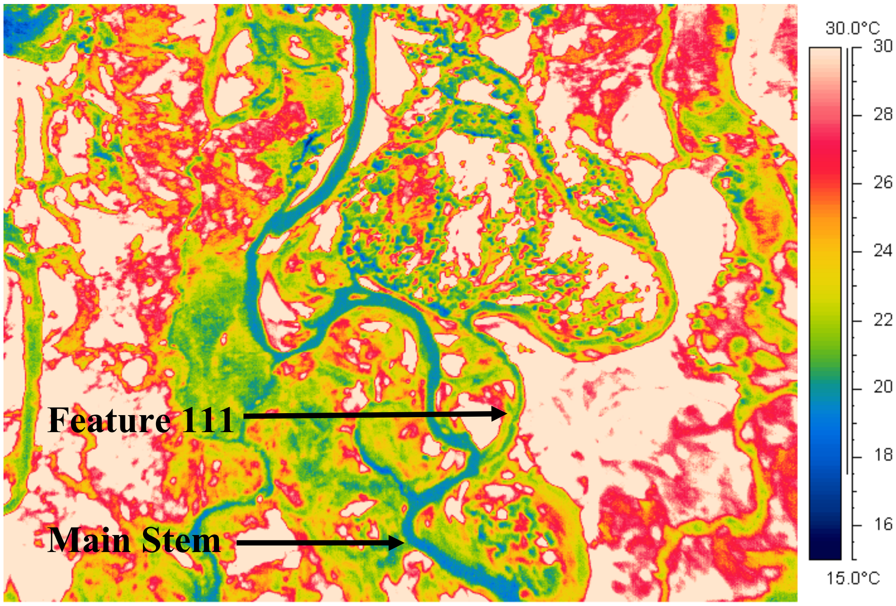


Figure 21. Irrigation return. Feature 111, Section 3.

The following image also shows several noteworthy features. The two side channels entering from the left side of the image appear to have a potentially significant impact on river temperatures. Flow data from these inputs would provide more information. The upper side channel input (feature 102) has a temperature approximately 1.1°C warmer than the adjacent river temperature and the lower side channel input (feature 99) has a temperature approximately 2.7°C warmer than the river. Figure 22 also includes two irrigation returns (features 101 and 100) with temperatures that appear to be either relatively similar to that of the adjacent river or somewhat cooler. Features 101 and 100 are also examples of features that could not be measured due to the size of the feature and resolution of the TIR data. While feature 100 is channelized enough to differentiate between the feature temperatures and the surrounding area, feature 101 is not. The feature's temperature could not be accurately measured due to an inability to accurately distinguish the feature from the surrounding ground temperatures in the TIR imagery, although it does appear to be a cooler feature.

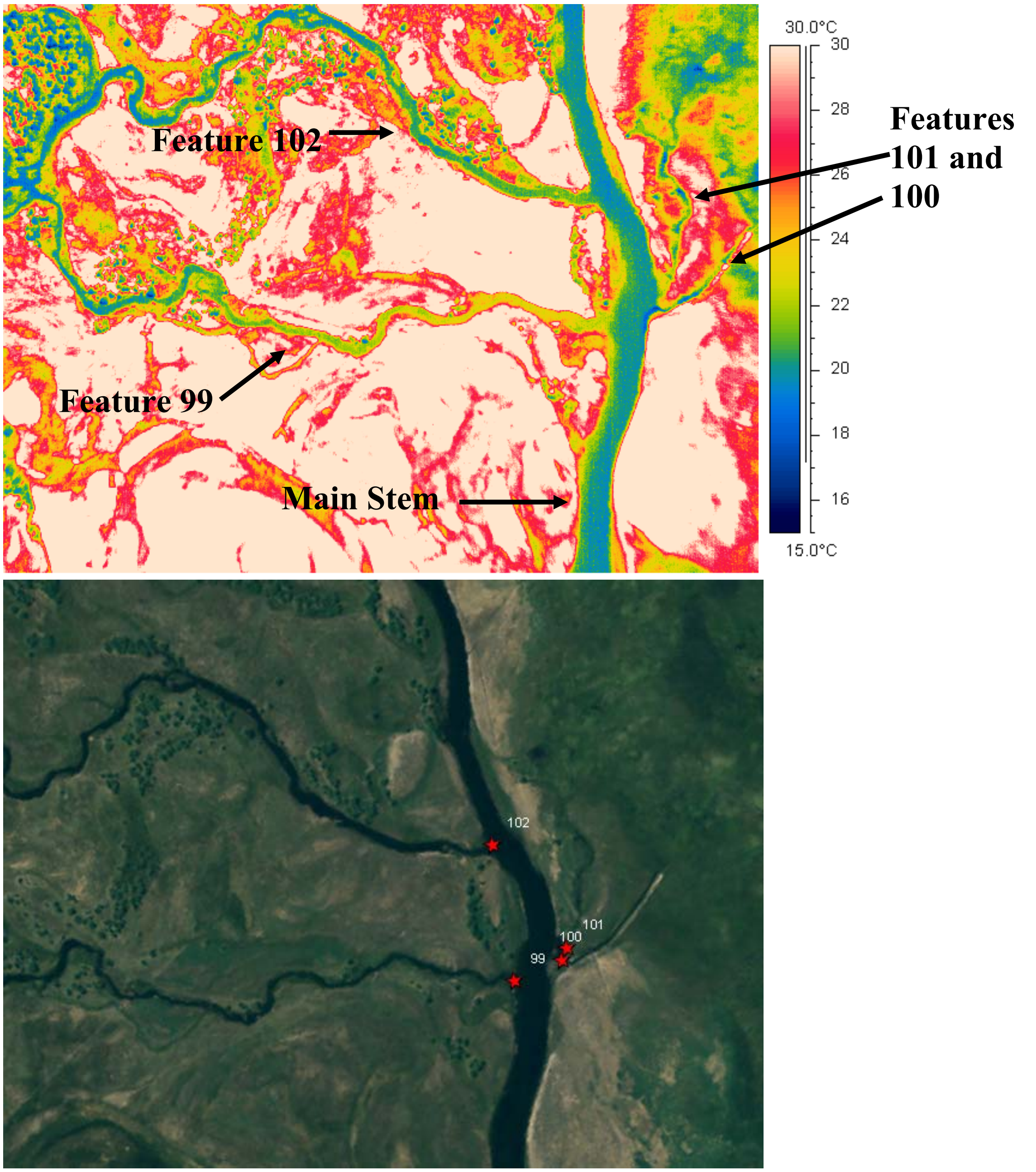


Figure 22. TIR and Aerial: Two side channels and two irrigation returns. Features 102 through 99, Section 3.

5.2.3.2. Floodplain Features

Table 12 lists temperature features in Section 3 that are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection	Notes
43	27	34758	Beaver Complex		114.1	16.8	19.1	-2.3	No	
	26	34737	Side Channel		113.4	21.5	19.0	2.5	Yes	
45	25	34255	Pond		112.2	20.6	19.3	1.3	No	
50	24	25625	Refuge in Side Channel		108.4	18.3	20.1	-1.8	Yes	
52	23	25615	Refuge in Side Channel		107.7	20.1	20.1	0.0	Yes	
53	22	25544	Oxbow		106.9	15.8	19.5	-3.7	Yes	
	21	24747	Irrigation Return into Side Channel		106.1	--	--	--	Yes	Temperature measurement not feasible
54	20	24744	Irrigation Return into Side Channel		105.8	--	--	--	Yes	Temperature measurement not feasible
	19	24744	Irrigation Return into Side Channel		105.7	--	--	--	Yes	Temperature measurement not feasible
	18	24744	Irrigation Return into Side Channel		105.7	--	--	--	Yes	Temperature measurement not feasible
	17	24744	Irrigation Return into Side Channel		105.7	--	--	--	Yes	Temperature measurement not feasible
	16	24744	Irrigation Return into Side Channel		105.7	--	--	--	Yes	Temperature measurement not feasible
55	15	24701	Groundwater Inflow		104.5	11.8	19.5	-7.7	No	

Table 12. Features located in the floodplain, Section 3.

The image below shows another example of the large numbers of irrigation returns in this section of the river. Visible in the image are five irrigation returns which join a side channel of the river. The returns are small and their temperatures could not be accurately measured. However, the figure is still illustrative of the sheer number of inputs in this area (Figure 23).

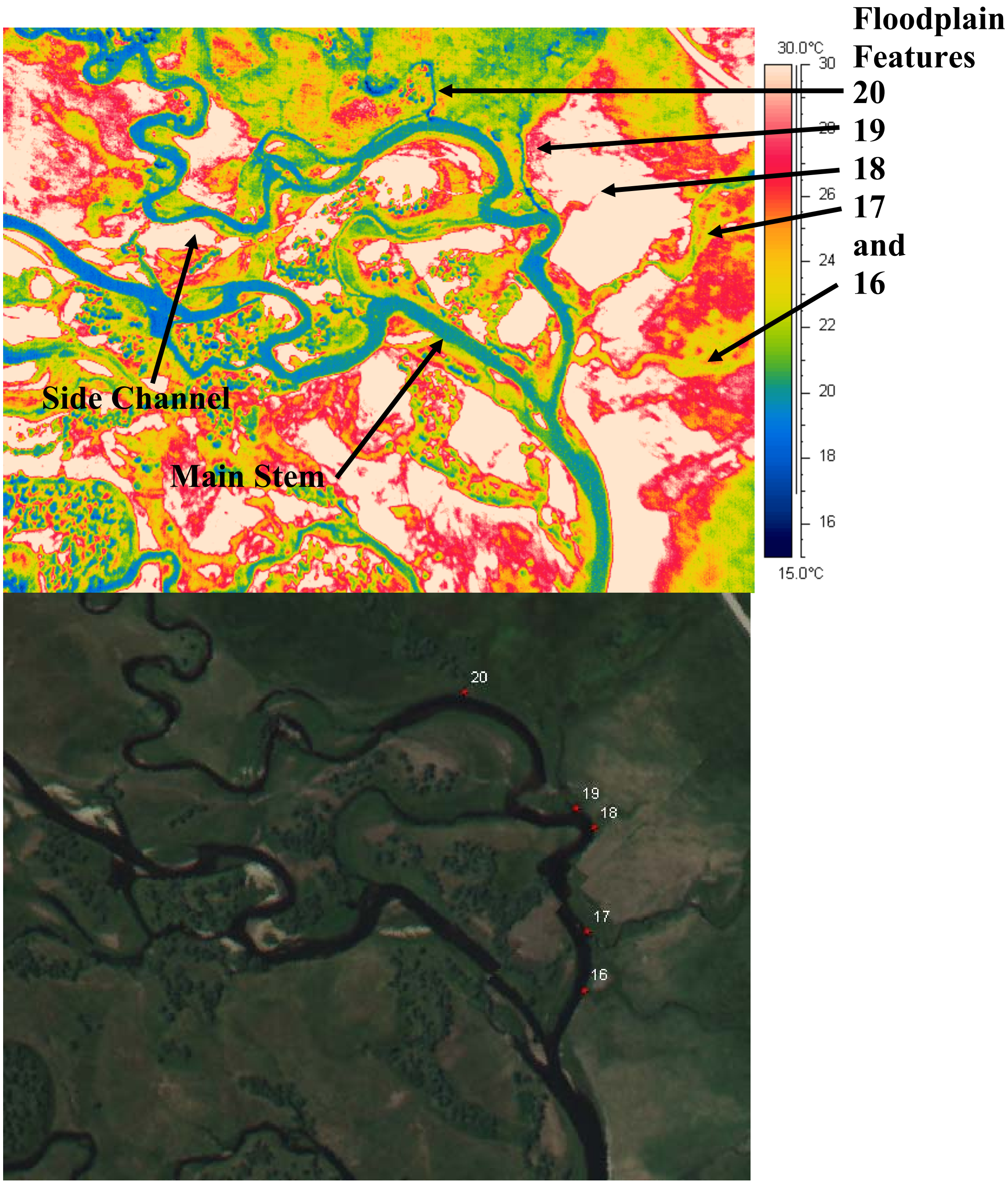


Figure 23. TIR and Aerial: Irrigation returns. Floodplain features 16 – 20, Section 3.

5.2.4. Section 4: Reaches 56 – 62

In this section the valley begins to narrow and the river becomes one channel. This section is significantly cooler than the section upstream of it, although it does begin to warm in its downstream end. The upstream portion of the segment decreases in temperature to an approximate low of 17.7°C before beginning to warm again to temperature highs between 20.5°C and 21.5°C, as averaged fro the longitudinal temperature mapping (see section 4.1.3). On this portion of the Big Hole River, the valley begins to narrow and the river becomes less braided, becoming one main channel around river mile 95.0. This section includes twelve irrigation returns, confluences with four side channels and four tributaries, one oxbow, and two instances of groundwater inflow. Many of the irrigation returns in this section are warmer than the river temperature.

5.2.4.1. Main Stem Features

Table 13 lists temperature features in Section 4 which have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
56	97	24652	Irrigation Return		104.1	19.6	19.0	0.6	
	96	24647	Irrigation Return		103.9	20.3	18.5	1.8	
	95	24452	Side Channel		103.3	19.0	19.0	0.0	
	94	24449	Tributary	North Fork	103.1	20.5	19.5	1.0	
	93	24430	Irrigation Return		102.8	22.4	19.0	3.4	
	92	24429	Irrigation Return		102.7	21.6	18.8	2.8	
	91	24424	Irrigation Return		102.5	19.9	18.3	1.6	
	90	24411	Irrigation Return		101.8	19.0	18.5	0.5	
57	89	24040	Oxbow		100.7	21.8	19.4	2.4	
58	88	24040	Irrigation Return		100.5	20.7	18.9	1.8	
59	87	24014	Side Channel		99.6	20.4	19.2	1.2	
	86	24001	Side Channel		99.2	19.8	21.0	-1.2	
59	85	23949	Irrigation Return		98.8	21.9	20.0	1.9	
60	84	23947	Tributary	Plimpton Creek	98.3	22.5	21.3	1.2	
	83	23936	Groundwater Inflow		98.2	--	--	--	Temperature measurement not feasible
	82	23928	Irrigation Return		97.9	23.3	21.3	2.0	
61	81	23917	Groundwater Inflow		97.7	22.2	20.3	1.9	
	80	23907	Irrigation Return		96.9	22.0	19.4	2.6	
	79	23857	Irrigation Return		96.8	17.5	19.0	-1.5	
	78	23857	Side Channel		96.5	20.5	19.0	1.5	
	77	23849	Tributary	Howell Creek	96.4	22.7	20.0	2.7	
62	76	23836	Irrigation Return		96.0	18.2	19.9	-1.7	
	75	23708	Tributary	Doolittle Creek	95.2	21.1	20	1.1	

Table 13. Features with direct connection or proximity to the main stem, Section 4.

The image below shows the confluence of the Big Hole River with Plimpton Creek. Plimpton Creek (Feature 84) enters the Big Hole with temperatures approximately 1.2°C warmer than the main stem of the river. As is visible, the river appears to warm significantly in this area. The channel also appears to get shallow after the braid, before the Plimpton Creek confluence, but more detailed research is required to understand the entire cause of its warming in this area (Figure 24).

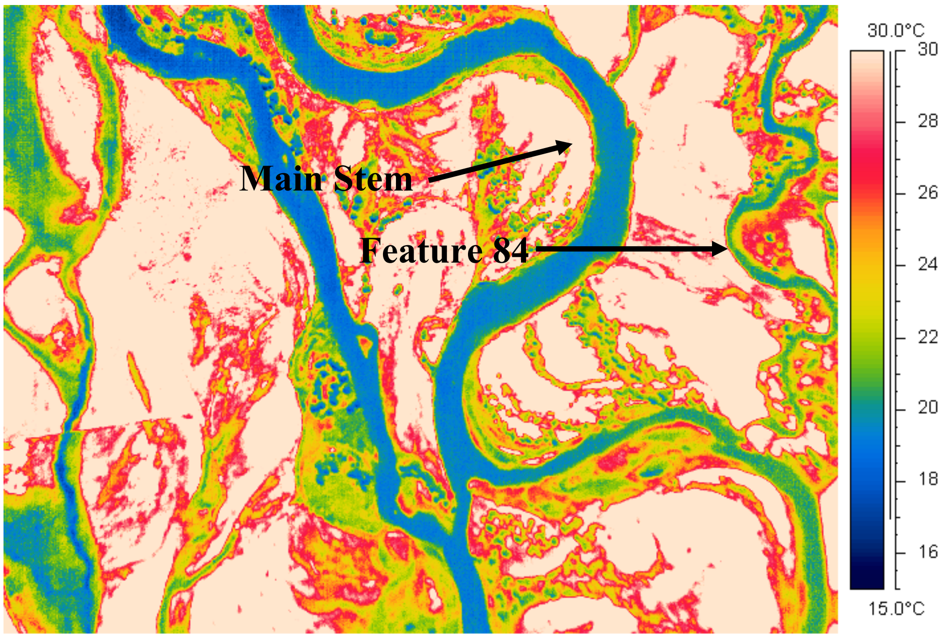


Figure 24. Plimpton Creek. Feature 84, Section 4.

The following three images are consecutive and show four features: two irrigation channels (features 80 and 79); one side channel (feature 78); and one tributary, Howell Creek (feature 77). The images are indicative of the variety of features in this section of the river. These inputs provide both opportunities and obstacles for cold water fisheries habitat in this section of the river. The three images below are arranged from upstream to downstream for ease of viewing.

Feature 80 is an irrigation return with temperatures approximately 2.6°C warmer than the adjacent river (Figure 25).

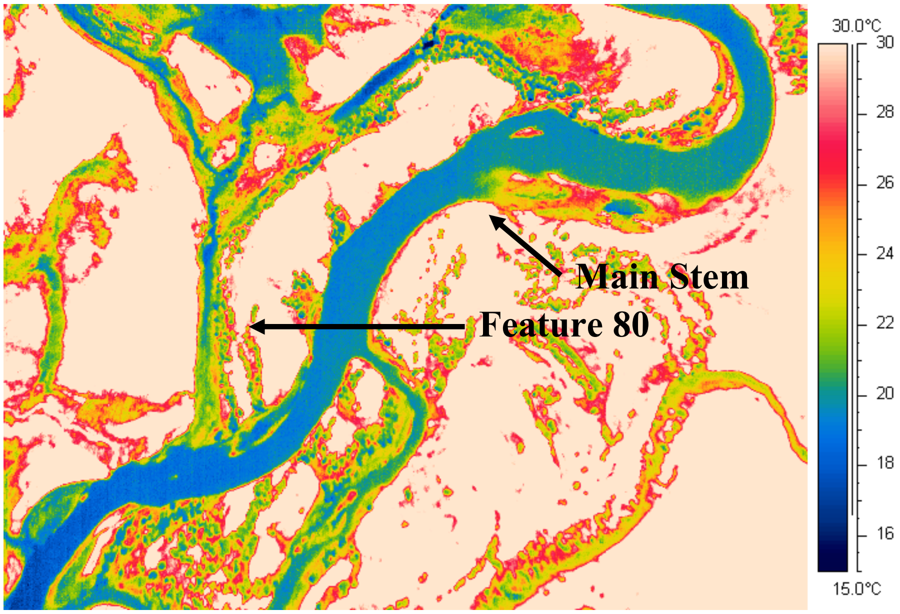


Figure 25. Irrigation return. Feature 80, Section 4.

Feature 79 is an irrigation return with temperatures approximately 1.5°C below those of the adjacent river. Feature 78, a side channel, enters the Big Hole with temperatures 1.5°C higher than the main stem of the river (Figure 26).

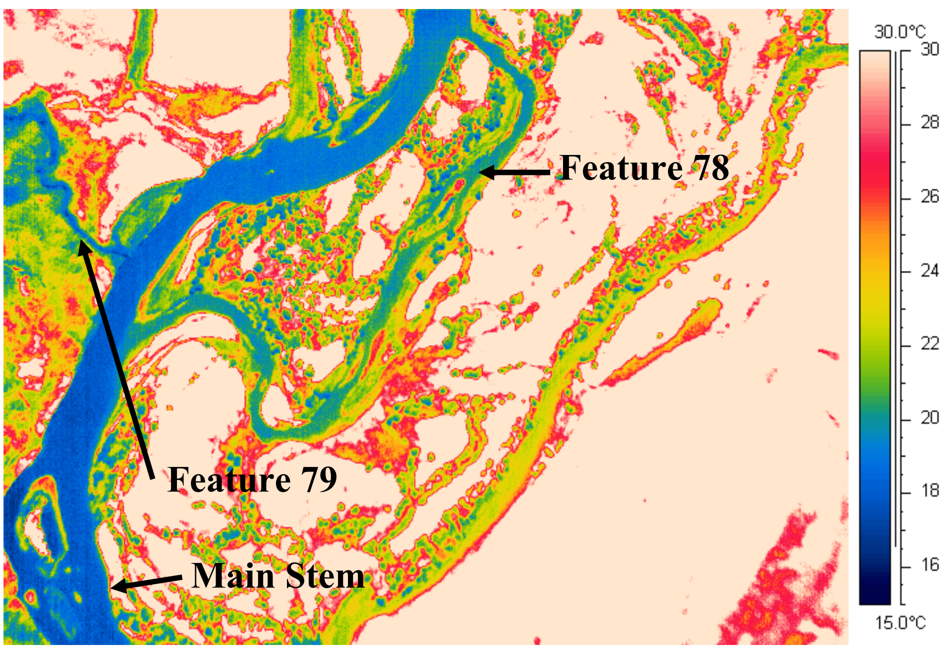


Figure 26. Irrigation return and side channel. Features 79 and 78, Section 4.

Feature 77, Howell Creek, is approximately 2.7°C warmer than the Big Hole at its confluence (Figure 27).

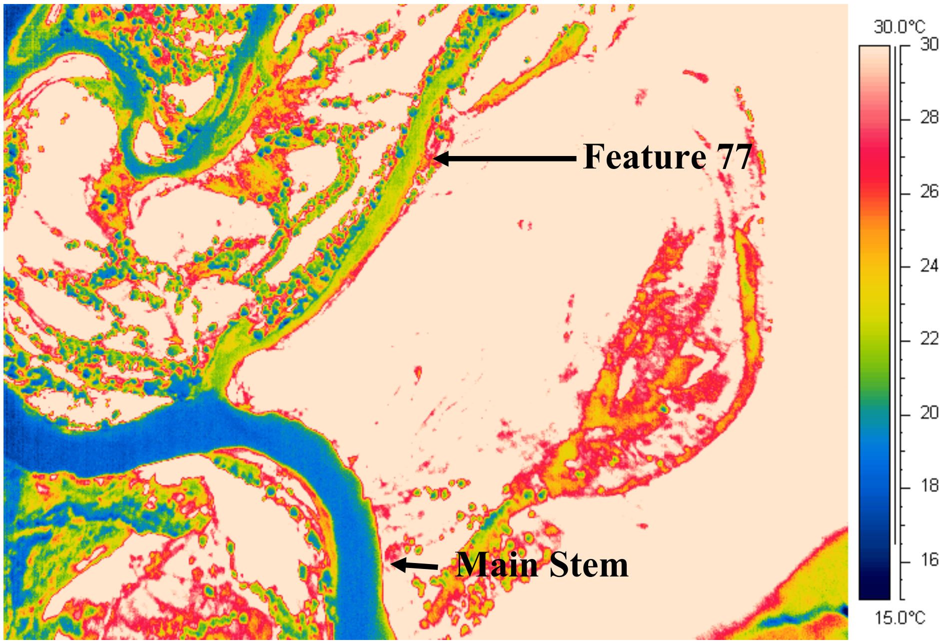


Figure 27. Tributary. Feature 77, Section 4.

Following is an aerial image that shows features 77 – 80 together (Figure 28).

Figure 28. Aerial: Features 77 – 80, Section 4.

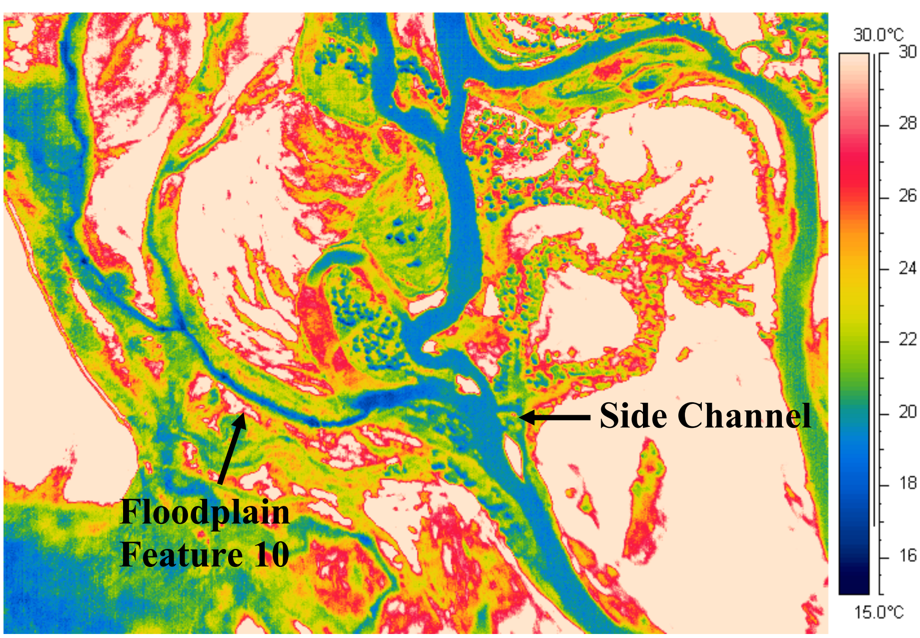
5.2.4.2. Floodplain Features

Table 14 lists temperature features in Section 4 that are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection	Notes
57	14	24213	Irrigation Return into Side Channel		101.2	--	--	--	Yes	Temperature measurement not feasible
	13	24214	Tributary	North Fork	101.2	19.1	18.1	1.0	Yes	
	12	24209	Irrigation Return into Side Channel		101.1	19.9	18.4	1.5	Yes	
58	11	24144	Irrigation Return into Side Channel		100.0	--	--	--	Yes	Temperature measurement not feasible
60	10	23936	Side Channel Inflow		98.1	17.1	19.8	-2.7	Yes	
61	9	23914	Impoundment		97.7	16.7	20.4	-3.7	No	
62	8	23709	Irrigation Return		95.3	--	--	--	No	Temperature measurement not feasible

Table 14. Features located in the floodplain, Section 4.

Floodplain feature 10 is the most noteworthy feature in this section's greater floodplain. In the TIR imagery it appears to be a fairly significant groundwater inflow or irrigation return into a side channel with temperatures approximately 2.7°C lower than those of the side channel into which it flows. However, on the aerial imagery, little is visible outside of the initial pool. The two images below highlight these differences (Figure 29). Field measurements would be needed to determine the magnitude of flow from this feature.



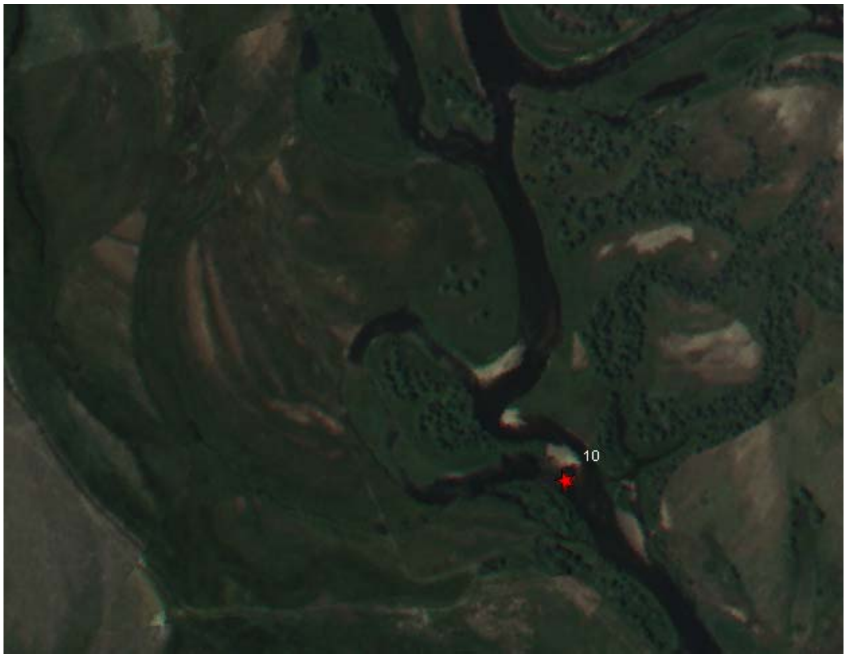


Figure 29. TIR and Aerial: Inflow into side channel. Floodplain feature 10, Section 4.

5.2.5. Section 5: Reaches 63 – 69

During this section of the Big Hole River, the valley continues to narrow gradually and there is little to no braiding. Temperatures are variable, with minimum and maximum averaged water temperatures of approximately 18.1°C to 20.6°C along the temperature profile. This section includes confluences with six tributaries, twelve irrigation returns, one refuge, and one instance of possible shading.

5.2.5.1. Main Stem Features

Table 15 lists temperature features in Section 5 which have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
63	74	23642	Tributary	Pintlar Creek	94.7	19.6	19.6	0.0	
65	73	23554	Irrigation Return		93.4	15.5	19.4	-3.9	
66	72	23508	Irrigation Return		92.3	--	--	--	Temperature measurement not feasible
67	71	23435	Tributary	Unnamed	91.5	24.2	19.7	4.5	
	70	23429	Tributary	York Gulch	91.4	--	--	--	Temperature measurement not feasible

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
	69	23359	Refuge		90.4	18.1	19.2	-1.1	
68	68	23205	Irrigation Return		89.8	--	--	--	Temperature measurement not feasible
	67	23200	Irrigation Return		89.8	--	--	--	Temperature measurement not feasible
	66	23200	Irrigation Return		89.7	--	--	--	Temperature measurement not feasible
	65	23150	Tributary	Mudd Creek	89.5	15.8	19.4	-3.6	
	64	23148	Tributary	Squaw Creek	89.3	17.6	19.0	-1.4	Side channel connected to FPFeature which is significantly cooler in places
69	63	23127	Possible Shading		88.6	22.9	19.7	3.2	
	62	22941	Irrigation Return		87.8	--	--	--	Temperature measurement not feasible
	61	22935	Irrigation Return		87.6	--	--	--	Temperature measurement not feasible
	60	22932	Irrigation Return		87.6	--	--	--	Temperature measurement not feasible
69	59	22932	Irrigation Return		87.5	--	--	--	Temperature measurement not feasible
	58	22932	Irrigation Return		87.4	--	--	--	Temperature measurement not feasible
	57	22533	Irrigation Return		87.3	--	--	--	Temperature measurement not feasible
	56	22523	Irrigation Return		86.9	--	--	--	Temperature measurement not feasible
	55	22516	Tributary	Toomey Creek	86.8	16.9	20.3	-3.4	

Table 15. Features with direct connection or proximity to the main stem, Section 5.

The figure below shows feature 73, a possible irrigation return with temperatures approximately 3.9°C lower than the adjacent river. It is difficult to determine from aerial and TIR imagery how far the irrigation return maintains low temperatures but this could be providing cold water fish habitat (Figure 30).

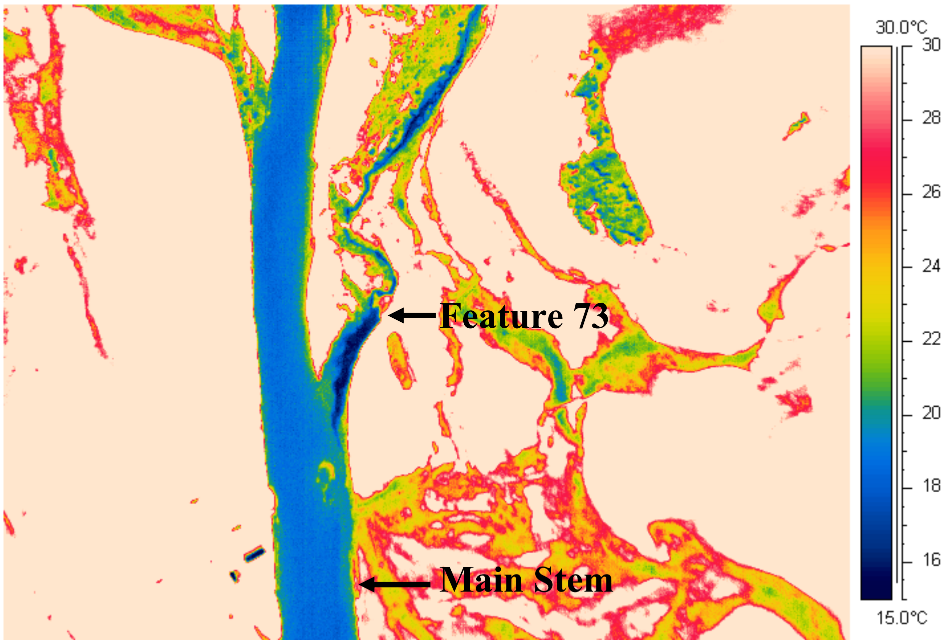


Figure 30. Irrigation return. Feature 73, Section 5.

Below is TIR imagery of two tributaries. Mudd Creek is an example of a feature for which the temperature was measured from the temperature change seen in the main channel (the arrow in the image below points to the location where the temperature was measured). The feature's temperature could not be measured higher upstream because thick riparian vegetation did not allow for an image that showed the surface of the water. From the measurement taken, Mudd Creek appears to be 3.6°C colder than the main stem. Squaw Creek appears to have temperatures 1.4°C colder than the adjacent main stem of the Big Hole. From the TIR imagery it is difficult to discern any substantial impact by these tributaries on river temperatures (Figure 31).

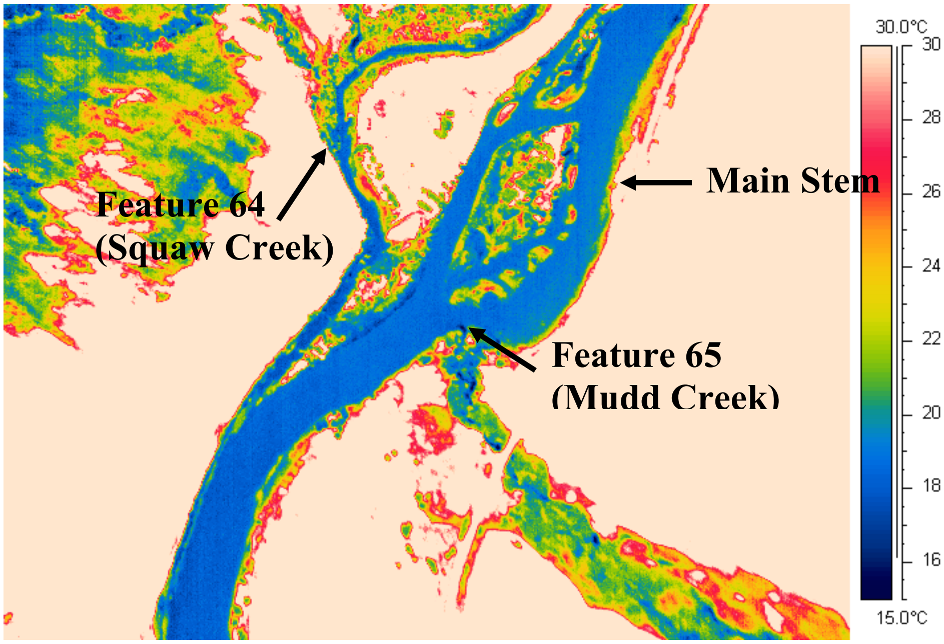


Figure 31. Tributaries. Features 65 and 64, Section 5.

5.2.5.2. Floodplain Features

Table 16 lists temperature features in Section 5 that are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection	Notes
67	7	23422	Oxbow		91.0	14.5	20.0	-5.5	Yes	
69	6	23129	Refuge		88.8	15.1	19.0	-3.9	No	
	5	22941	Pond		87.8	19.6	19.7	-0.1	No	
	4	22524	Oxbow		86.9	--	--		No	Temperature measurement not feasible

Table 16. Features located in the floodplain, Section 5.

As noted above, the valley begins to narrow and there is little to no braiding; therefore, this section, like those downstream, has few floodplain features entering into large side channels. However, between river miles 94 and 89 there are significant examples of historic river migration. The image below shows an example of a long collection of oxbows and historic channel features. It appears from aerial images that this oxbow, for example, is connected by surface flow to the Big Hole River; however, field research is needed to verify connection. This oxbow (floodplain feature 7) has estimated temperatures 5.5°C lower than the adjacent river. If connected to the Big Hole River, this series of features could offer excellent cold water fish habitat (Figure 32).

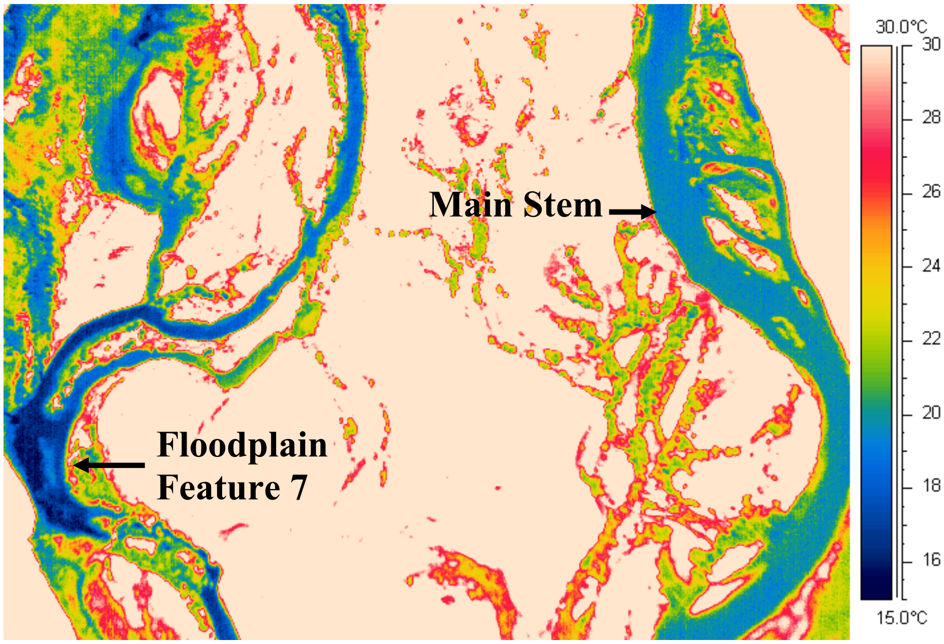


Figure 32. Oxbow. Floodplain feature 7, Section 5.

5.2.6. Section 6: Reaches 70 – 72

This section has several inputs with water temperatures significantly colder than the main stem river temperature. However, few inputs appear to have significant impact on the overall water temperature in the Big Hole River. The exception to this is Fish Trap Creek, which joins the Big Hole River at approximately river mile 81.4. Fish Trap Creek is also one of the few tributaries for which we have temperature data and flow data. This feature and questions of flow and impact are discussed in greater detail in section 5.2.6.1 below. Overall, river temperatures are variable in this section. They range from approximately 18.8°C to 20.5°C. This section includes six irrigation returns, five instances of groundwater inflow, four cold water refugia, confluences with two tributaries and one side channel, and four instances of possible shading.

5.2.6.1. Main Stem Features

Table 17 lists temperature features in Section 6 which have a proximity to, or are directly on the main stem of the Big Hole River. Features labeled with “Possible Shading” as a feature type may have a colder temperature signature because of heavy shading on the water surface at that point.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
70	54	22438	Irrigation or Ephemeral Stream		85.9	--	--	--	Temperature measurement not feasible
	53	22427	Groundwater		85.6	--	--	--	Temperature

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
			Inflow						measurement not feasible
71	52	22424	Refuge		85.5	16.9	18.8	-1.9	
	51	22416	Groundwater Inflow		85.4	--	--	--	Temperature measurement not feasible
	50	22339	Possible Shading		84.3	16.8	19.2	-2.4	
	49	22337	Possible Shading		84.2	17.4	18.9	-1.5	
	48	22302	Tributary	Stewart Creek	83.4	17.3	19.3	-2.0	
	47	22242	Groundwater Inflow		83.0	--	--	--	Temperature measurement not feasible
	46	22237	Groundwater Inflow		82.9	--	--	--	Temperature measurement not feasible
	45	22208	Refuge		82.3	14.9	19.3	-4.4	
	44	22208	Groundwater Inflow		82.2	16.9	19	-2.1	
	43	22200	Irrigation Return		82.1	--	--	--	Temperature measurement not feasible
	42	22200	Refuge		82.0	18.0	19.2	-1.2	
	41	22147	Irrigation Return		81.8	--	--	--	Temperature measurement not feasible
	40	22135	Side Channel		81.4	21.9	20.2	1.7	
72	39	22133	Tributary	Fishtrap Creek	81.4	15.2	20.5	-5.3	
	38	22105	Possible Shading		80.8	16.1	19.1	-3.0	
	37	21844	Irrigation Return		80.4	--	--	--	Temperature measurement not feasible
	36	21844	Irrigation Return		80.4	--	--	--	Temperature measurement not feasible
	35	21844	Irrigation Return		80.4	--	--	--	Temperature measurement not feasible
	34	21844	Refuge		80.3	15.7	20.1	-4.4	
	33	21840	Possible Shading		80.1	15.1	20.3	-5.2	

Table 17. Features with direct connection or proximity to the main stem, Section 6.

Stewart Creek provides a good example of the tributaries which flow into this section of the Big Hole, but appear to have little impact on the overall river temperature except very near the confluence, which provides a coldwater refuge. Stewart Creek (feature 48) has temperatures approximately 2.0°C lower than those in the adjacent main stem (Figure 33). Further flow research can better illuminate the impact of this and other tributaries on the overall river temperatures.

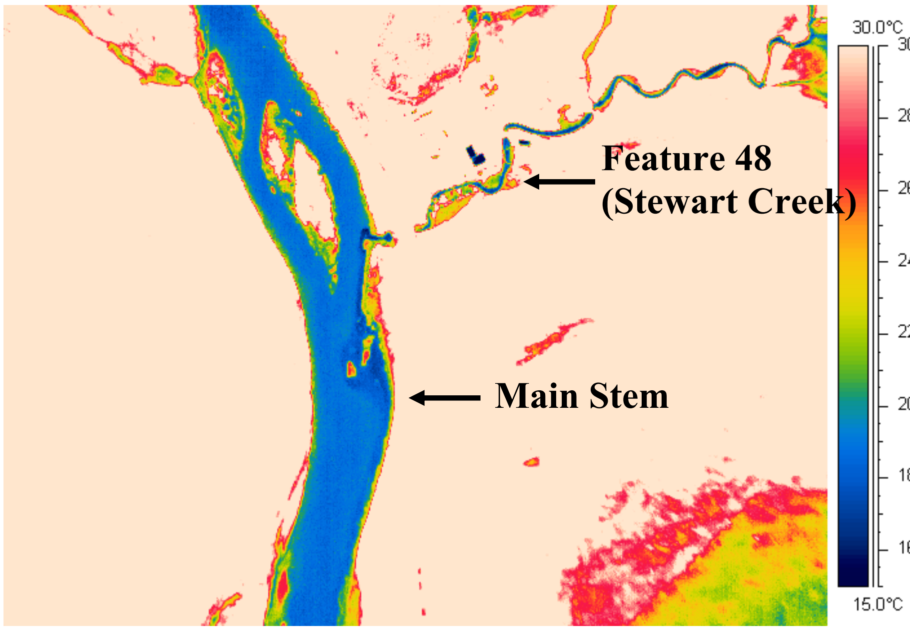


Figure 33. Tributary. Feature 48, Section 6.

The image below shows two features (45 and 44) and one floodplain feature (3). Feature 45 is a cold water refuge with water temperatures approximately 4.4°C colder than the main stem of the river. From TIR and aerial imagery it is difficult to discern whether this feature has an upstream connection with the Big Hole. Field data may better define this. Feature 44 is a groundwater inflow with temperatures approximately 2.1°C colder than the main stem. As it was not possible to capture the surface water temperature of feature 44, it serves as another example of temperature being measured from the temperature change visible in the main stem (arrow indicates temperature measurement location). Finally, floodplain feature 3 is an impoundment with temperatures approximately 5.6°C colder than the main stem of the river. It does not appear to have a surface water connection with the Big Hole, although flows could connect seasonally (Figure 34).

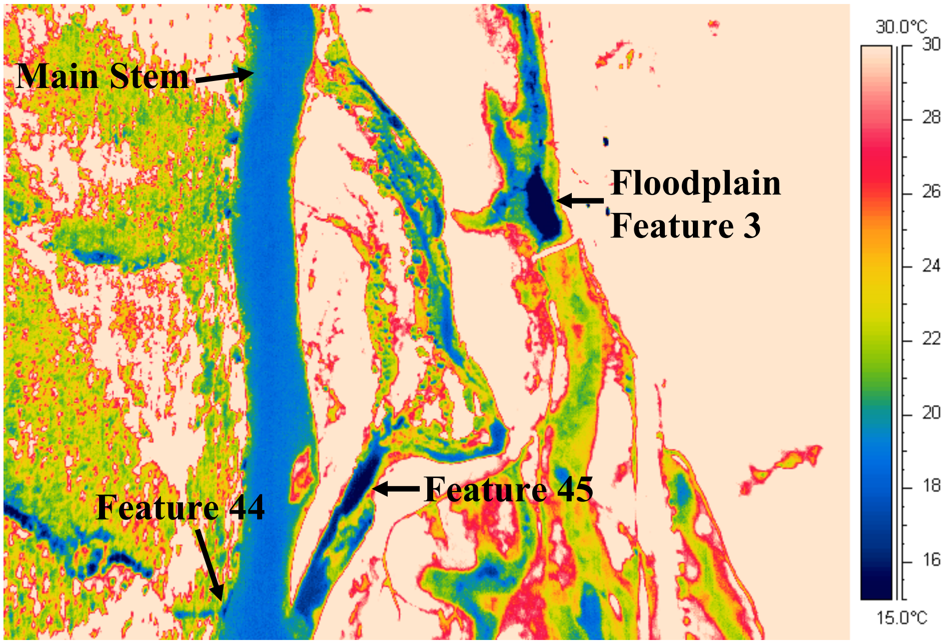


Figure 34. Cold water refuge, groundwater inflow, and impoundment. Features 45 and 44, and floodplain feature 3, Section 6.

The only tributary in this section which appears to have an impact on overall river temperatures in the Big Hole is Fish Trap Creek, which flows into the Big Hole at approximately river mile 81.4. As shown in the figure below, it appears that Fish Trap Creek has flow significant enough to cool the river, and it obviously provides coldwater habitat. Data provided by the DNRC Water Management Bureau shows that on 07/30/2008, Fish Trap Creek had a flow of 27.6 cfs (measured at its crossing with Hwy 43). Unfortunately, the nearest point for which we have flow data on the main stem of the Big Hole is approximately eight miles upstream at Mudd Creek. At this location, data from the USGS National Water Information System indicate that the Big Hole River flowed at a volume of 235.0 cfs on 07/30/2008. Without flow data for the Big Hole River at the confluence of Fish Trap Creek it is difficult to quantify the impact of Fish Trap Creek on temperatures in the Big Hole River; however, the change in temperature is notable in the TIR images.

The image below shows the confluence of Fish Trap Creek (feature 39) and the Big Hole River. At this point, Fish Trap Creek had temperatures measuring approximately 5.3°C colder than the main stem of the river. In the following image, a side channel (feature 40) is also visible which has an input temperature approximately 1.7°C higher than the main stem. The third feature visible in the image below is another tributary, Walker Creek. This tributary, floodplain feature 2, is listed below in table 18 (section 5.2.6.2). Due to riparian vegetation, it was not possible to measure a surface water temperature for Walker Creek. It is also possible that the feature shown here is a temperature change due to shading. It is not possible to determine the exact type of feature (Figure 35).

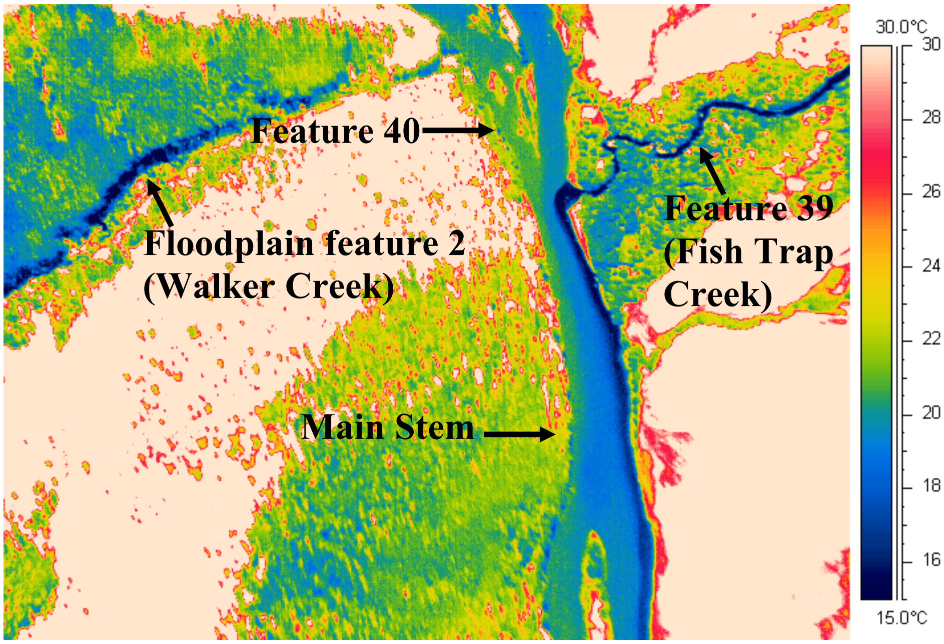


Figure 35. Tributaries and side channel. Features 40 and 39, and floodplain feature 2, Section 6.

5.2.6.2. Floodplain Features

Table 18 lists temperature features in Section 6 which are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes	Surface Water Connection
73	3	22222	Pond		82.4	14.0	19.6	-5.6		No
	2	22138	Possible Shading	Walker Creek	81.6	--	--	--	Temperature measurement not feasible	Yes

Table 18. Features located in the floodplain, Section 6.

Floodplain features 3 and 2 are discussed and shown above with figures 34 and 35, respectively.

5.2.7. Section 7: Reaches 73 – 77

This section includes several cold water inputs, with seventeen cold water inputs over 3.0°C colder than the adjacent main stem river temperature. Multiple tributaries, most notably Bryant Creek and La Marche Creek, appear to have flows high enough to lower overall river temperatures in this section. Further flow research may provide more in-depth knowledge of tributary impact in this river section. A temperature modeling study conducted by DEQ in 2006 (Flynn et. a. 2008) also noted the cooling influence of tributaries in this part of the Big Hole River. Overall, water temperatures in this section of the river are variable, as in other sections. Averaged water temperatures range from

17.6°C to 20.8°C along the temperature profile, with the majority of the Big Hole in this section having temperatures around 18.8°C. This section includes confluences with six tributaries, ten irrigation returns, one cold water refuge, nine instances of possible shading, five instances of groundwater inflow, and one instance which could be groundwater inflow or shading (field research necessary for final determination).

5.2.7.1. Main Stem Features

Table 19 lists temperature features in Section 7 that have a proximity to, or are directly on, the main stem of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
73	32	21815	Tributary	La Marche Creek	79.8	15.0	19.5	-4.5	
	31	21806	Irrigation Return		79.7	--	--	--	Temperature measurement not feasible
	30	21806	Irrigation Return		79.6	--	--	--	Temperature measurement not feasible
	29	21748	Tributary	Pony Creek	79.1	15.8	18.1	-2.3	
	28	21747	Irrigation Return		79.1	17.1	18.1	-1.0	
74	27	21710	Possible Shading		78.4	12.9	19.1	-6.2	
	26	21702	Possible Shading		78.1	14.2	19.1	-4.9	
75	25	21640	Possible Shading		77.6	14.9	19.1	-4.2	
	24	21639	Possible Shading		77.5	15.7	19.0	-3.3	
	23	21625	Possible Shading		77.2	14.8	19.0	-4.2	
	22	21619	Irrigation Return		77.1	19.0	18.8	0.2	
	21	21617	Groundwater Inflow		77.0	16.5	18.9	-2.4	
	20	21612	Tributary	Seymour Creek	76.8	16.7	18.9	-2.2	
	19	21612	Possible Shading		76.8	13.1	18.9	-5.8	
	18	21603	Groundwater Inflow or Shading		76.7	--	--	--	Temperature measurement not feasible
	17	21605	Irrigation Return		76.6	18.6	18.9	-0.3	
	16	21550	Possible Shading		76.4	12.5	19.1	-6.6	
	15	21543	Possible Shading		76.2	10.8	19	-8.2	
	14	21534	Possible Shading		75.9	15.1	18.4	-3.3	
75	13	21517	Irrigation Return		75.6	16.9	18.8	-1.9	
76	12	21517	Tributary	Deep Creek	75.5	18.0	18.9	-0.9	

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Notes
	11	21446	Groundwater Inflow		74.7	15.9	18.7	-2.8	
	10	21445	Irrigation Return		74.4	15.9	18.7	-2.8	
	9	21431	Irrigation Return		74.3	15.7	17.7	-2.0	
	8	21413	Tributary	Bear Creek	73.6	13.9	17.5	-3.6	
	7	21413	Tributary	Bryant Creek	73.6	13.5	18.5	-5.0	
77	6	20728	Groundwater Inflow		72.4	11.3	19.6	-8.3	
	5	20656	Irrigation Return		71.7	17.7	19.9	-2.2	
	4	20644	Irrigation Return		71.4	23.7	20.6	3.1	
	3	20640	Groundwater Inflow	Teddy Creek	71.3	--	--	--	Temperature measurement not feasible
	2	20636	Groundwater Inflow	Teddy Creek	71.2	14.4	19.9	-5.5	
	1	20632	Refuge		71.0	16.6	19.9	-3.3	

Table 19. Features with direct connection or proximity to the main stem, Section 7.

The first, and possibly most interesting, feature of Section 7 is La Marche Creek (feature 32). Currently, no flow data for La Marche Creek is available; however, TIR imagery indicates that its potential impact on overall stream temperatures may be significant. La Marche Creek measures approximately 15.0°C at its confluence with the Big Hole River, with the main stem measuring approximately 19.5°C, a difference of 4.5°C. As visible below, TIR imagery shows the entering cold water to maintain its influence for a distance downstream of the confluence (Figure 36).

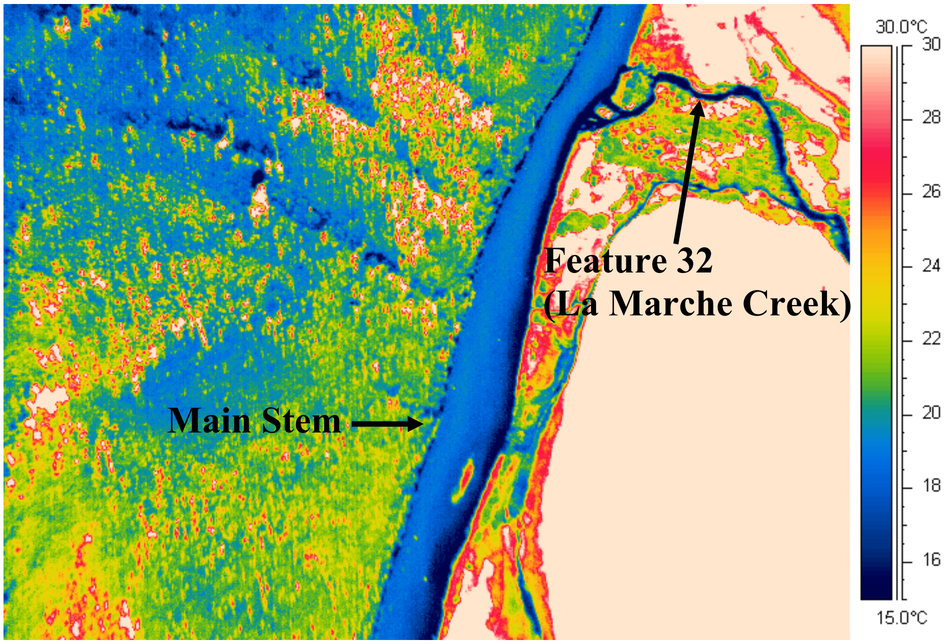


Figure 36. Tributary. Feature 32, Section 7.

The image below (Figure 37) shows examples of three different temperature variants in this section of the Big Hole. Feature 21 is a groundwater inflow or very small surface flow with temperatures approximately 2.4°C below the adjacent river temperatures. Feature 20, Seymour Creek, is a tributary with temperatures approximately 2.2°C below those found in the main stem. The available data from the DNRC Water Management Bureau indicates that on 7/30/2008 (the day of this TIR study), Seymour Creek had a flow of approximately 7.0 cfs. As noted in sections above, the nearest flow data for the Big Hole River is from approximately 12.6 miles upstream, at river mile 89.4 (Big Hole River at Mudd Creek). The flow data from the USGS National Water Information System from that site indicates that the Big Hole River was flowing at was 235 cfs on 7/30/2008. It is difficult to extrapolate flow data downstream without greater knowledge of the river; however, it is reasonable to deduce that Seymour Creek does not have a significant impact on overall river temperatures. The TIR imagery below appears to support that point.

Finally, the image below also includes feature 19, possible shading, visible along the viewer's left bank of the river (river right). This section of the Big Hole included several areas which were considerably cooler than temperatures measured from the center of the river, but which had no apparent inputs such as groundwater inflows, tributaries, etc. This feature, for example, shows temperatures approximately 5.8°C cooler than those measured in the center of the river. This edge effect appears to be due to shading by tree cover or higher banks and steeper sideslopes in this more confined region of the river. The 2006 DEQ study (Flynn 2008) also noted shading from landform in confined reaches of the river.

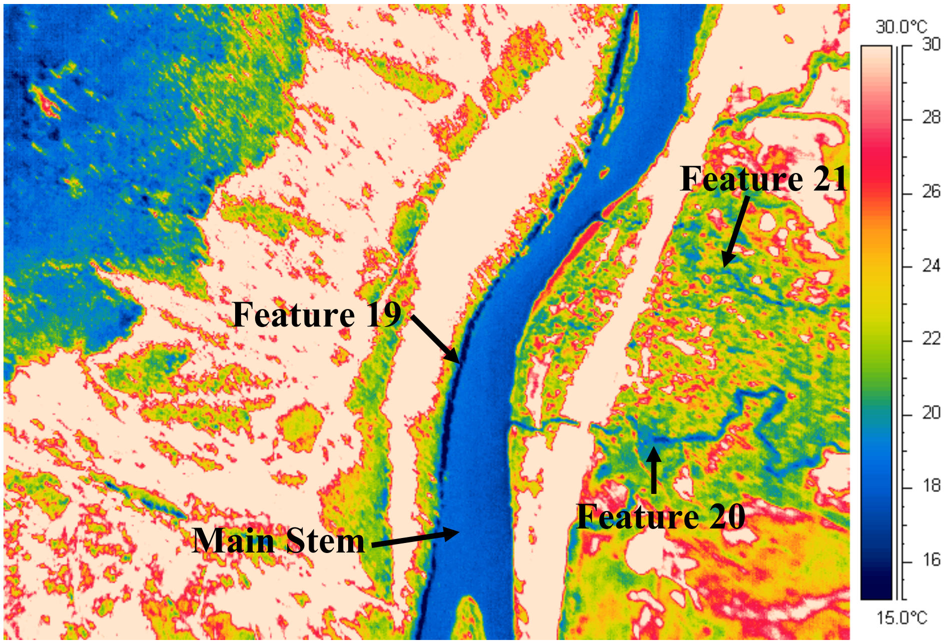


Figure 37. Groundwater inflow, tributary, possible shading. Features 21-19, Section 7.

The image below (Figure 38) shows two additional tributaries which have confluences with the Big Hole River in this section: Bear Creek and Bryant Creek. No flow data is available for either tributary, but could provide data of interest in the future as Bryant Creek especially shows potential as cold water fish habitat. Bear Creek joins the Big Hole with approximate temperatures 3.6°C colder than the main stem, Bryant Creek approximately 5.0°C colder. The figure below also includes floodplain feature 1, a pond with possible connection to Bryant Creek. The pond has temperatures approximately 6.2°C higher than those in the main stem.

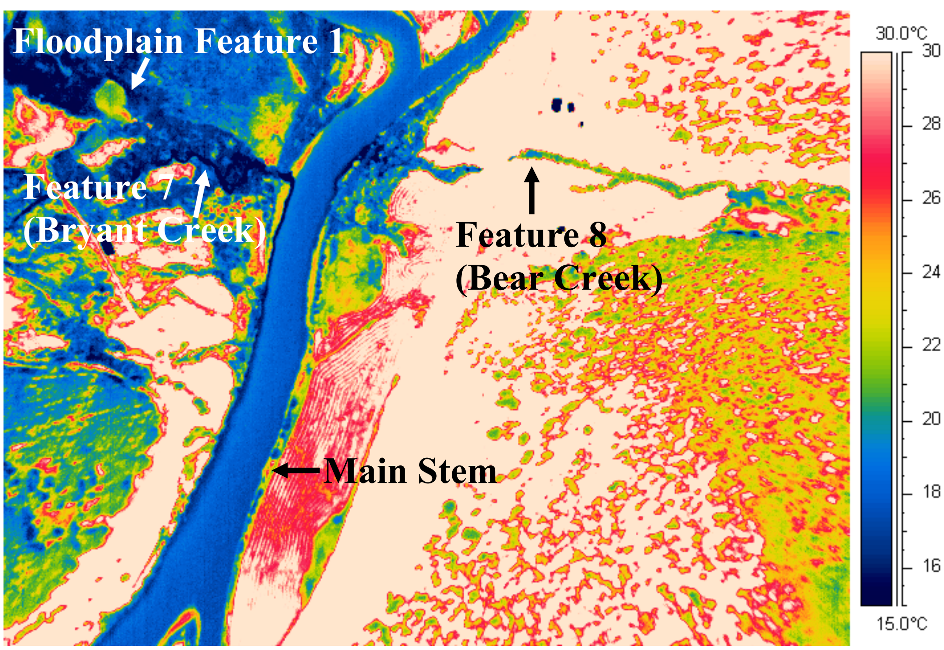


Figure 38. Tributaries. Features 8 and 7, Section 7.

5.2.7.2. Floodplain Features

Table 20 lists temperature features in Section 7 which are located in the greater floodplain of the Big Hole River.

Reach	Feature ID	Time Signature	Feature Type	Tributary Name (if applicable)	River Mile	Feature Temperature (°C)	River Temperature (°C)	Temperature Difference (°C)	Surface Water Connection
76	1	21413	Pond	Bryant Creek	73.6	24.7	18.5	6.2	No

Table 20. Features located in the floodplain, Section 7.

This floodplain feature is addressed above in figure 38, section 5.2.7.1.

6. DISCUSSION

As stated in the statement of work associated with this project, "uncertainty about the dynamics and magnitude of thermal loading, and conversely, the distribution of critical cold-water refuge habitats, limits our inference about the extent of thermal threats to grayling and our ability to identify and prioritize conservation and restoration opportunities in the Big Hole River." This TIR study was conducted in an effort to bring to light the cold and warm water temperature inputs and opportunities and concerns for cold water fish habitat. The previous five sections of this report discussed the methods and analyses conducted during this project. This section consists of a brief discussion of the features which have been described in greater detail above in section 5. This section also attempts to bring together some of the larger trends seen in this TIR study over the length of the study area with the goal of contributing to conservation efforts on the Big Hole River.

6.1. SUMMARY OF POTENTIAL THERMAL LOADING SOURCES

6.1.1. Tributaries and Groundwater Inflows

Tributaries and groundwater inflows generally are colder than the Big Hole River. Out of the approximately 27 instances of apparent groundwater inflow directly into the Big Hole (often as subsurface flow from tributaries), 15 are colder than the adjacent river temperature. It should be noted that 10 of the instances of groundwater inflow were not measurable for temperature due to the lack of visible measurable water. These were noted regardless, to offer locations for future research. Groundwater inflows range in temperature from 10.8°C to 25.5°C, offering a range in temperature between 8.3°C cooler and 6.7°C warmer than the adjacent main stem temperatures. The most noteworthy exception to the cooler groundwater/lateral flow inputs is feature 181, shown above in figure 10. Feature 181 has an approximate temperature of 24.2°C which, viewed in contrast to the adjacent river temperature of 17.5°C, makes it a significant feature of note. Only two other measurable groundwater inputs offered warmer temperatures (1.9°C and 2.0°C warmer).

Although instances of groundwater inflow present the highest number of cold water inputs to the Big Hole, it is difficult to ascertain their overall impact without having field research and additional flow data. Because they are often linked with tributary inflows, many can be categorized with tributary influences. Their primary contribution is additional coldwater refuge habitat for fish. Groundwater upwelling within the main channel was not a common feature type identified with the TIR imagery. Groundwater upwelling may be associated with several coldwater features in side channels and minor channels braided from side channels of the river.

Of the approximately 19 tributaries and ephemeral streams which enter directly into the Big Hole River, 11 contribute water colder than the main stem. Again, without flow data it is difficult to understand exactly how much of an influence these tributaries have on overall river temperatures. As noted above in sections 5.2.6.1 and 5.2.7.1, Fish Trap Creek and La Marche Creek appear to be the tributaries with the greatest impact on the overall river temperatures, based on the TIR data. However, several streams, especially in the most downstream 22 miles of the study area, offer significant cold water inputs and potential for high quality coldwater fish habitat. In the lower reaches of the Big Hole the smaller tributaries appear to cool the river as a cumulative effect of several smaller inputs.

6.1.2. Side Channels and Irrigation Returns

Water entering the Big Hole River from side channels and irrigation returns was generally warmer than the main stem of the river. Of the 46 irrigation returns that entered the Big Hole and have measurable temperatures, 17 were cooler than the adjacent river temperatures and 28 were warmer (one feature appeared to be the same temperature as the main stem). Temperature differences ranged from 3.9°C below the adjacent river temperature to 3.4°C above. Cooler irrigation returns may be partially attributed to deeper, narrower channels or groundwater influences. Warmer irrigation returns may be partially attributed to shallower and wider returns with little to no shading. In some areas of the river, most notably river section 3, it is possible that a lack of shading along the river's banks combines with a high number of warm irrigation returns to affect the warmest section of the river. Dewatering for irrigation also can lead to warmer general stream temperatures. More flow measurements and field research are necessary to verify the cause for this warming trend.

This assessment marked the confluence of 12 side channels rejoining the Big Hole River at various locations. Although four of these enter the river with temperatures approximately 1.5°C to 0°C cooler than the main stem, the other eight side channels contribute water that is warmer than the main stem of the river. Side channels appear to contribute a great deal of habitat complexity and contain multiple coldwater refugia.

6.1.3. Cold Water Refugia

As stated in the statement of work for this project, cold water refugia are considered to be critical to the survival and persistence of grayling in the Big Hole River watershed. Data from FWP states that the optimum spawning temperatures for grayling are approximately 10°C and optimum growth temperatures are between 10°C and 15°C. At just over 20°C, temperatures begin to exert stress on cold water fish. These temperature guidelines help relate the temperature features to grayling temperature requirements; however, the temperatures identified in this study are from the warmest time of year, and may not be applicable to grayling spawning conditions.

In-stream coldwater refugia, as identified in this study, may be due to deep pooling or due to groundwater upwelling. This TIR study noted 29 in-stream refugia with direct connections to the main stem of the Big Hole River and an additional 11 refugia located in side channels and other areas of the floodplain that also had surface water connections with the main stem. Due to the limited span of TIR imagery and the complexity of the Big Hole River Floodplain, not all floodplain features can be noted through this study, as discussed in section 5.2. The refugia with direct connection to the main stem have temperatures ranging from 6.0°C to 0.7°C below adjacent river temperatures. It is not possible from TIR data to ascertain their depths and overall habitat quality for fish, but this study identifies the coldwater habitat to allow further study.

The cold water refugia which directly connect to side channels of the Big Hole have temperature differences ranging from 7.5°C to 0.0°C below water temperature in the adjacent side channels. Individual floodplain feature temperatures are often cooler than nearby river temperatures and could provide excellent opportunities for cold water fish habitat. Mapping these coldwater refugia is the first step in pinpointing the quality grayling and other coldwater fish habitat in the Big Hole River. Additional field work can provide an assessment of overall habitat quality based on pool physical features.

Groundwater upwellings are also considered to be important habitat for grayling, but are not always apparent in TIR imagery if their influence is not significant enough to impact surface temperatures. Therefore, the possibility remains that some deeper areas with upwelling could be present but are not reflected by this study if the cooler temperatures remain at the bottom of the pools and the flow is too minor to noticeably influence stream temperature.

6.2. UNCERTAINTIES

Although the TIR flight was conducted in what is historically the hottest week of the year, the day of the flight was not the hottest day of 2008. Air temperatures were approximately 20.0°C with partly cloudy skies. These conditions were acceptable for the objectives of the survey. Analysis of the thermal accuracy of the TIR images compared to in stream sensors was within the specified tolerance, as outlined above in section 3.1.5.

There are several quality control factors involved in measuring temperature with a thermal infrared camera. For one, the camera must be internally calibrated for atmospheric conditions. These include:

- Lens temperature (essentially the temperature of the air at flight altitude)
- Atmospheric temperature (air temperature near the river)
- Background temperature (temperature of the sky above the airplane)
- Object distance (altitude AGL)

- Relative humidity

When all of these parameters are set correctly the camera should be accurate to within 2.0°C of absolute temperature. Although the absolute temperature is within 2°C, the temperature accuracy of a single image or within a collection of images is 0.1 °C (i.e., the camera can differentiate to with 0.1 °C). It is not feasible to measure all of the object parameters accurately continuously during the flight. For instance, the air temperature changes with changes in altitude and the elevation of the riverbed is not constant. All of these factors contribute to fluctuations in temperature measurement. The fluctuations are minor; for instance, a 50% change in humidity or object distance only result in temperature differences of about 1.0°C. The real value in aerial TIR imaging lies in being able to measure the relative temperature differences accurately along a river in a short period of time. The absolute accuracy of the TIR temperature measurements varies along the river and is dependent on things such as the object parameters, the absolute accuracy of the in-stream temperature loggers, the placement of the in-stream temperature loggers (deep v. shallow), etc. However, the temperatures measured within a single image have an approximate error of 0.01°C.

Temperature loggers in the water are subject to their own accuracy issues. Temperature loggers could have been buried in the mud or placed in the vicinity of a cool water input. According to the manufacturer, the temperature loggers themselves are also subject to a ±0.2 °C variation. However, since the data loggers are subject to fewer object parameter fluctuations than the TIR camera, temperature measurements from a data logger are generally considered more accurate than a TIR image. Therefore, in post processing, the temperatures of the data loggers at the time of the flight are compared to the TIR temperatures, as described in section 3.1.4.

Groundwater upwellings are not visible from the surface radiation captured in TIR and are not mapped if they do not have enough influence on stream temperature to create a noticeable change in surface temperature. Therefore, some coldwater refugia may not be visible in the TIR imagery. Water surface temperature is measured by the TIR camera based on surface radiation; therefore, shaded areas appear to be cooler than areas under direct solar radiation. The uncertainty associated with this phenomenon is addressed by checking cooler areas in color-normal video, infrared images, and field research to determine if shading from vegetation is causing certain areas to appear cooler in the TIR imagery.

As stated above, no streamflow measurements were collected for this study. The influence of the various features noted could vary frequently as irrigation use changes throughout the season. The role of irrigation and groundwater return should be studied further to quantify as much as possible the influence of groundwater inputs and irrigation on stream temperature in the upper watershed, in the area not included in the previous temperature modeling study (Flynn 2008).

Stream temperatures reflect watershed-scale as well as local scale influences. Temperatures are subject to cumulative effects that extend beyond the reach scale. While this analysis provided a general source characterization and identified some temperature sources influencing temperature at a local scale, it was not designed to define cause-effect relationships between land management factors and the temperature of the Big Hole River at the watershed scale. However, by characterizing and identifying thermally significant inputs and areas of the Big Hole River, this study should provide useful data for determining areas of concern and areas of opportunity for increasing cold water fish habitat in this watershed.

7. Citations

Flynn, K., D. Kron, and M. Granger. 2008. Modeling Streamflow and Water Temperature in the Big Hole River, Montana – 2006. TMDL Technical Report DMS-2008-03. Montana Department of Environmental Quality.

Magee, J. 2007. Big Hole Arctic Grayling 2006. Presentation to Big Hole Watershed Committee; 2007 April 18; Divide, MT. Available from: http://bhwc.org/BHAGapril182006-Magee.pdf.

Montana Department of Natural Resources. Unpublished flow data from tributaries in the Big Hole River watershed.

Montana Natural Resource Information System. Geographic Information Systems (GIS) Shapefiles. Cited 2009 April. Available from: http://nris.mt.gov/gis.

Rens, Emily, and Patrick Byorth. "Fluvial Arctic Grayling." April 2007. Montana Fish, Wildlife, & Parks. 23 Sept. 2008. <http://www.fisheries.org/units/AFSmontana/ArcticGrayling.html>.

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

United States Geological Survey. Real-Time Data for Montana_Streamflow. Cited 2009 April. Available from: http://waterdata.usgs.gov/MT/nwis/current/?type=flow.

Western Regional Climate Center. Historical Climate Information. Cited 2009 April. Available from: http://www.wrcc.dri.edu/CLIMATEDATA.html.