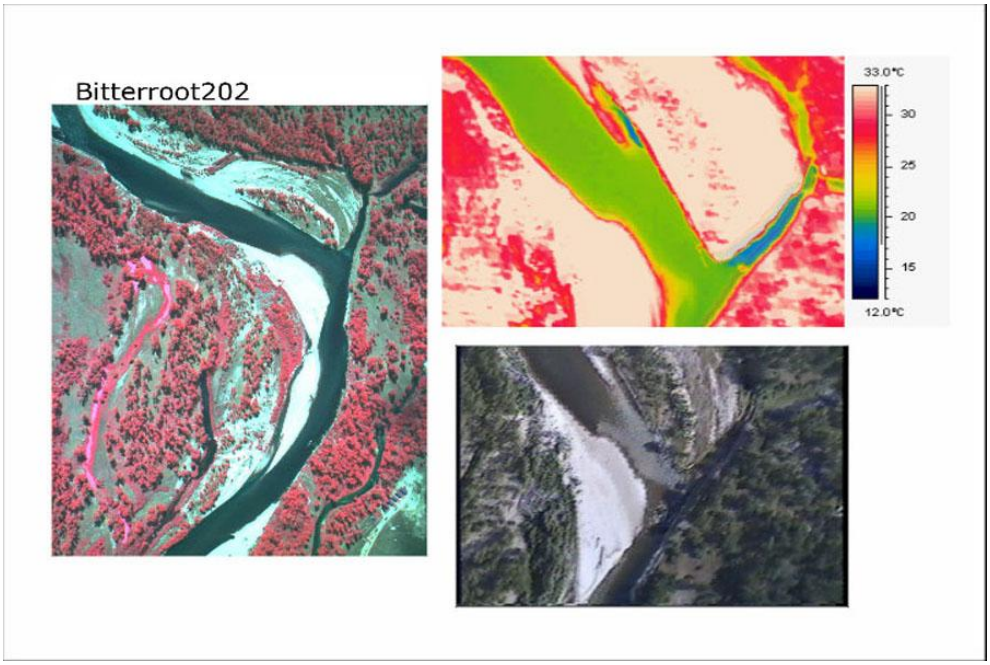
# ATTACHMENT A - BITTERROOT RIVER FLIR TEMPERATURE ANALYSIS INTERPRETIVE REPORT

# Bitterroot River FLIR Temperature Analysis

# Interpretive Report

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**INTERPRETIVE REPORT**
**BITTERROOT RIVER FLIR TEMPERATURE ANALYSIS**

## Introduction

Temperature and heat source mapping was conducted in 2004 using Forward-Looking Infra-Red (FLIR) technology to facilitate source assessment for the temperature-listed streams in the Bitterroot River TPA. The FLIR analysis was conducted to support Total Maximum Daily Load (TMDL) development for temperature-listed streams in the Bitterroot River TPA. This document is a summary of the FLIR temperature monitoring methods and results. The FLIR 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 FLIR images by showing the adjacent terrain and associated land use practices. The aerial imagery was used with field data collected during the same timeframe and temperature loggers installed in the temperature-listed streams. The combined data were utilized to identify heat sources, to assess the effects of thermal refugia, tributary inputs, irrigation return flows and groundwater inputs on temperature, and for overall assessment of streamside conditions. This document describes methods used in the FLIR analysis and interpretation followed by the analysis results for temperature trends and sources.

## Methods

*Data Collection*
During the summer of 2004, Infrared Image Solutions, Inc. of Hermiston, OR was contracted to collect multi-spectral imagery on the Bitterroot River and selected tributaries near Missoula, Montana (Figure 1).


**Figure 1. Project area overview.**

The purpose of the project was to collect continuous temperature measurements along the entire project area and to identify areas of cool water inputs to the stream. A morning flight and an evening flight were conducted on each stream to document diurnal fluctuations. Project data consists of digital imagery in thermal infrared (FLIR), color-infrared (CIR) and normal color videography.

*Equipment*

### FLIR ThermaCam S60

FLIR imagery was collected with a FLIR ThermaCam S60. The S60 images were fed via firewire connection to a laptop computer at a rate of 7.5 frames per second. The ThermaCam S60 camera has a built in normal color video camera. The normal color video was recorded to standard VHS video simultaneously with the FLIR imagery.
Pertinent specifications are listed below in **Error! Reference source not found.**.

**Table 1. Summary of S60 specifications.**

| ThermaCam S60 Specifications | |
|---|---|
| Spectral Range | 7.5 to 13 µm |
| Thermal Sensitivity | 0.06 C. at 30 C. |
| Detector Type | Focal plane array (FPA) uncooled microbolometer 320 x 240 pixels |
| Accuracy (% of reading) | ±2 °C or ±2% |

### Redlake MS4100

CIR imagery was collected with a RedLake MS4100. The MS4100 is a multi-spectral camera that can capture images in normal color (RGB) or color infrared (green, red and near-infrared). For this project the camera was configured for CIR imagery. Pertinent specifications are listed below in Table 2.

**Table 2. Summary of MS100 specifications.**

| RedLake MS4100 Specifications | |
|---|---|
| Pixel array | 1920 x 1080 |
| Bit depth | 24 bit |
| Sensor type | 3 CCD, interline |
| Max frame rate | 10 frames per second |

*Data Collection*

FLIR Data Collection

FLIR imagery was collected on a morning flight and an afternoon flight. Because of equipment problems and weather delays we were not able to collect the data for each flight on the same day. An evening flight was conducted on August 2, 2004 between 16:09 and 19:16 MDT. A morning flight occurred on August 4, 2004 between 7:00 and 9:58 MDT. Flights were conducted from a helicopter flying between 1000 and 2500 feet above the ground. Visual videography was recorded simultaneously with the FLIR imagery. Weather conditions for the flights are detailed in Table 3 below.

**Table 3. Atmospheric conditions.**

| | PM Flight | AM Flight |
|---|---|---|
| Flight Date | August 2, 2004 | August 4, 2004 |
| Flight Time | 4:00 - 7:15 MDT | 7:00 – 10:00 MDT |
| Air temperature (Missoula airport) | 29 C. | 12 C. |

This date was chosen because it is during what is historically the hottest 2-week period of the year in the Bitterroot valley. Figure 2 shows the historic temperatures in the Bitterroot watershed and the temperature trends for 2004.

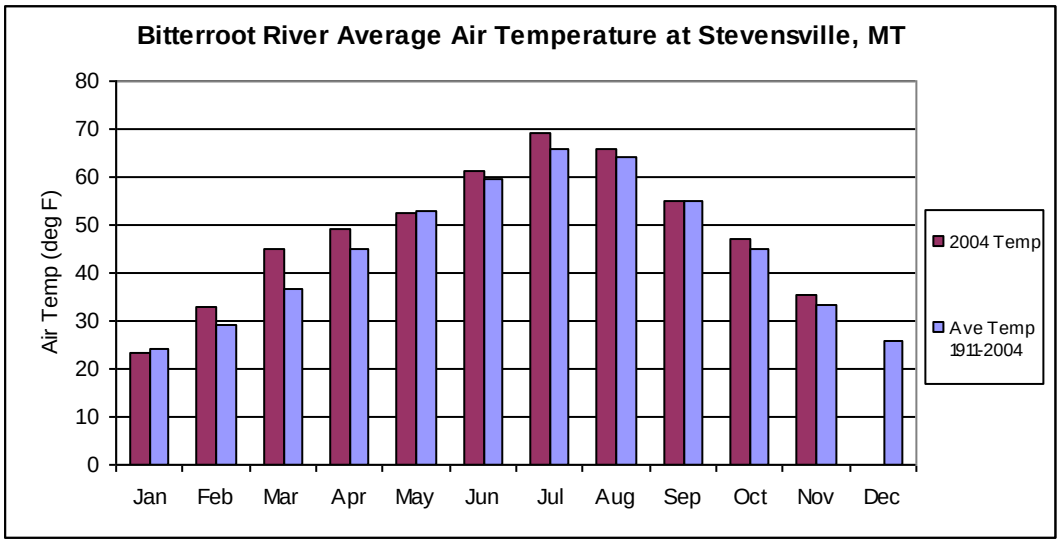


**Figure 2. Average annual air temperature at Stevensville, Montana. Source: Western Regional Climate Center.**

As illustrated in Figure 2, temperatures in 2004 were consistent with historic averages.

## Video Data Collection

Visual videography was recorded simultaneously with the FLIR imagery. Video recording was done with an 8 mm VHS video recorder. The video is a normal color presentation of the FLIR imagery. Video lends understanding of the FLIR imagery, as the human eye is not accustomed to distinguishing features in thermal infrared. Video is synchronized with the FLIR imagery and delivered in MPG format (Figure 3).

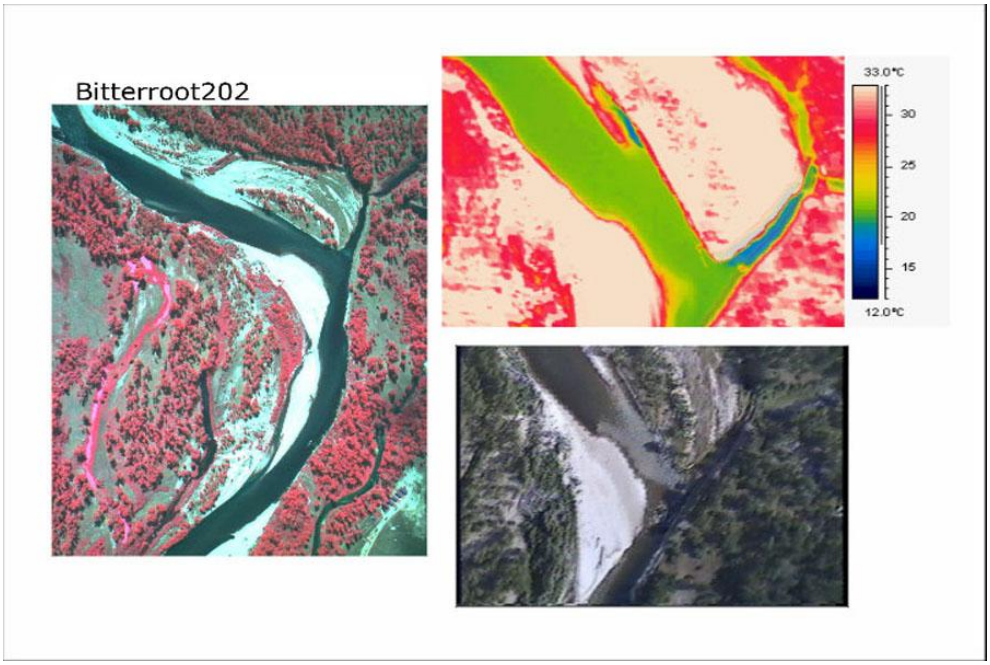


**Figure 3. Simulated frame capture of synchronized video, CIR and FLIR images on the Bitterroot River.**

* Note: In all of the FLIR images, downstream is toward the bottom of the page.

CIR Data Collection

Color-infrared images were collected from a fixed-wing airplane on August 2nd and 4th, 2004. The CIR camera has a much higher resolution than the FLIR 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 (Figure 3 and 4).

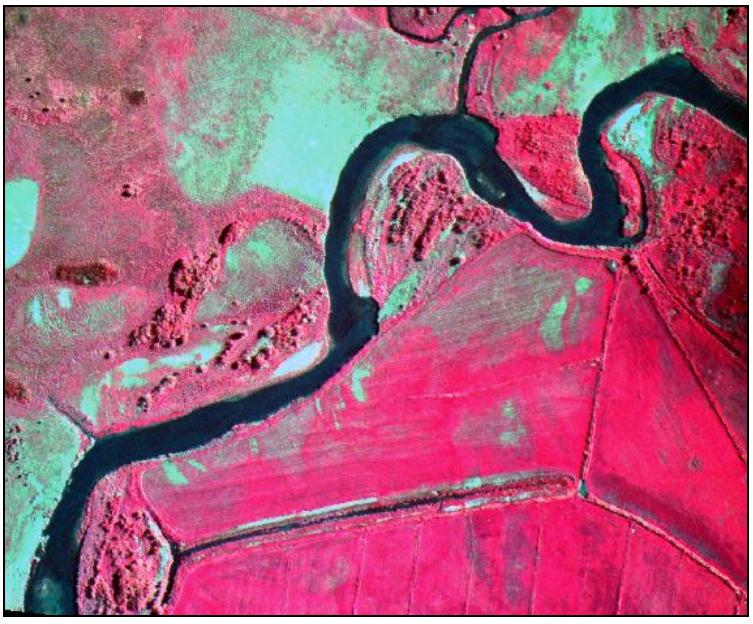

**Figure 4. CIR Image on the Bitterroot.**

CIR images were captured at a rate of 1 image every 5 seconds. This rate yielded an endlap of approximately 60%. A shapefile of the CIR image locations was created to facilitate comparison of FLIR and CIR images. Additionally, the CIRs were geo-referenced and put in mosaic at a 2 meter resolution to facilitate comparison of temperature trends and land use practices over a greater area.

Instream Temperature Data Collection

In-stream temperature loggers were deployed at 44 locations within the Bitterroot River Watershed prior to the aerial surveys (Figure 5). Temperature readings from the streams were recorded at half hour intervals (15 minute intervals on Lolo Creek) from July through September 2004. Figure 5 also illustrates the flight path and extent of the surveys, which began south of Missoula, Montana and progressed south past Sula, Montana to the headwaters of the East Fork of the Bitterroot River.

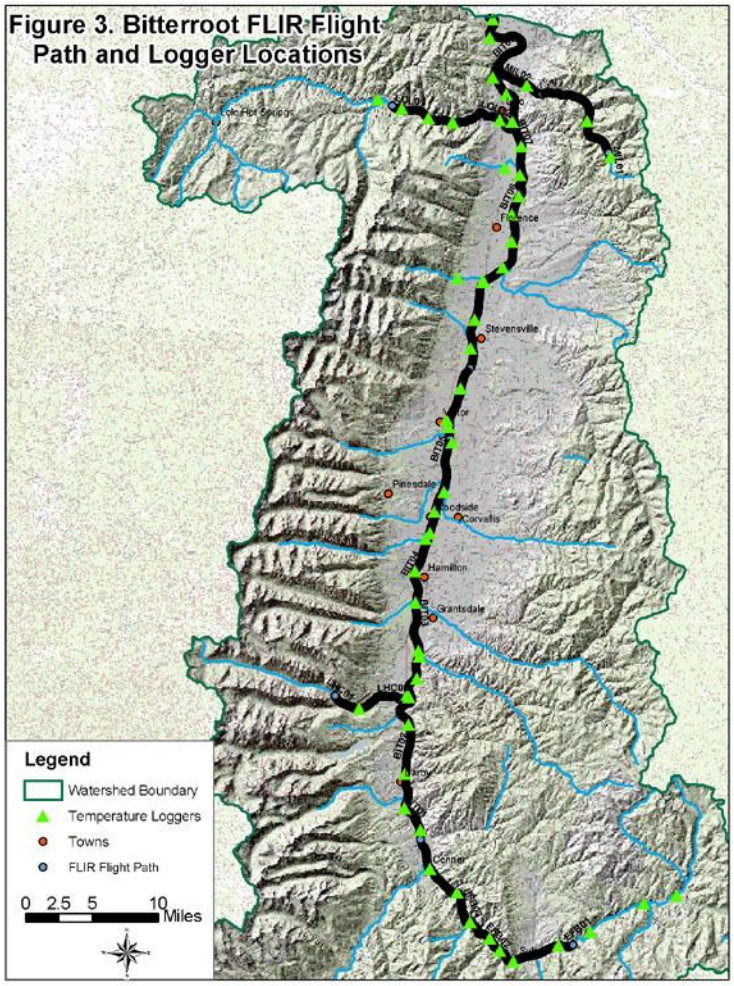


**Figure 5. Bitterroot River FLIR path and temperature logger locations**

The in-stream sensors were used to ground truth the radiant temperatures measured by the FLIR sensors. Temperature logger locations are given in Table 3.

**Table 3. Temperature logger locations**

| Stream | DEQ Site ID | Serial # | Reach/Site Description |
|---|---|---|---|
| | BCK1 | 530231 | BIT04 – RM 53.4 |
| | BLOD2 | 530243 | BIT04 – RM 50.9 |
| | BLOD3 | 530244 | BIT04 – RM 48.9 |
| | CLG2 | 530258 | BIT06 – RM 17.7 |
| | CLG3 | 530257 | BIT07 – RM 14.9 |
| | CLG4 | 530210 | BIT07 – RM 12.8 |
| | CLG5 | 530211 | BIT07 – RM 10.3 |
| | CLG6 | 530259 | BIT07 – RM 8.6 |
| | COMO 1 | 530215 | BIT03 – RM 67.6 |
| | COMO 2 | 530209 | BIT03 – RM 65.8 |
| | COMO 3 | 530212 | BIT03 – RM 63.3 |
| | COMO 4 | 530208 | BIT03 – RM 59.1 |
| | HAN1 | 530218 | BIT01 – RM 80.6 |
| | HAN3 | 530207 | BIT02 – RM 75.4 |
| | HAN4 | 530219 | BIT02 – RM 71.1 |
| | KEL1 | 530240 | BIT08 – RM 0.1 |
| | STEVI2 | 530247 | BIT06 – RM 29.1 |
| | STEVI3 | 530248 | BIT06 – RM 27.2 |
| | STEVI5 | 530250 | BIT06 – RM 21.7 |
| | VXING1 | 530251 | BIT05 – RM 42.0 |
| | VXING2 | 530253 | BIT05 – RM 39.0 |
| Bitterroot | WTP1 | 530230 | BIT04 – RM 56.2 |
| Blodgett | BLOD1B | 530242 | BIT04 (Blodgett Creek mouth) RM 52.8 |
| | EFK10 | 530228 | EFB03 – RM 1.3 |
| | EFK4 | 530225 | EFB01 – RM 17.0 |
| | EFK5 | 530222 | EFB02 – RM 12.9 |
| | EFK6 | 530220 | EFB02 – RM 11.3 |
| | EFK7 | 530223 | EFB02 – RM 9.9 |
| | EFK8 | 530221 | EFB03 – RM 7.4 |
| East Fork | EFK9 | 530227 | EFB03 – RM 4.3 |
| Lost Horse Creek | LOST HORSE 1 | 530213 | LHC02 – RM 0.1 |
| | LST1 | 530234 | LHC02 – RM 4.8 |
| Miller Creek | Mil1 | 530236 | MIL02 – RM 3.6 |
| | Mil3 | 530238 | MIL01 – RM 10.2 |
| | NA | 578042 | At Mormon Creek bridge – RM 5.6 |
| | NA | 578043 | At Hwy 93 bridge – RM 1.4 |
| | NA | 578044 | Below South Fork – RM 10.1 |
| Lolo Creek | NA | 578045 | At TD Antiques – RM 7.8 |

*Data Processing*

FLIR Processing

FLIR images were analyzed to extract temperature data from the center portion of the images. The final result is an ArcView point shapefile with field categories including river mile, time and temperature.

Approximately 1 out of every 15 frames (1 frame every two seconds) was sampled by averaging the temperatures in the center of the river (5). At times the area sampled was along a line, while at other times points sampled were within a circle. When the stream was very small a point was used.

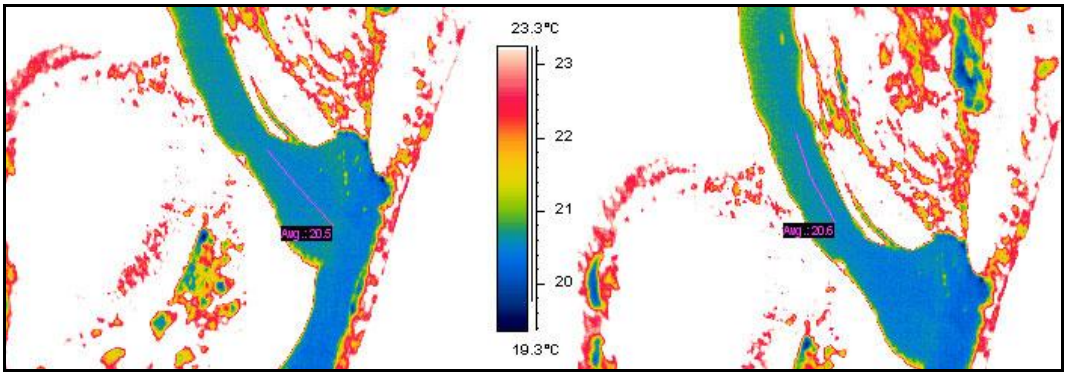


**Figure 5. Temperature sampling method. The image on the right was captured two seconds after the image on the left as the helicopter was moving upstream. Temperature data for each image is averaged along the magenta line in the center of each image.**

Tabular data from the FLIR image analysis was utilized to create an ArcView GIS shapefile.

Throughout this report, FLIR images are included to illustrate certain features. The temperature scales accompanying these images vary from image to image. This is to emphasize, with best contrast possible, the feature that is being discussed.

CIR Processing

CIR processing consisted of sorting all images into subfolders by river name and applying a universal histogram stretch to give the images a consistent contrast, brightness, and color balance.

Using ERDAS imagine software, the CIR images were first geo-referenced and then stitched together to form a mosaic. The images for the mosaic were sub sampled to 2-meter pixel resolution to reduce file size. The image mosaics comprise approximately 5 river miles each. A GIS shapefile was included to show the location of the georeferenced higher resolution individual CIRs as well.

Temperature Data Processing

Temperature loggers were downloaded by MDEQ. Temperature logger data was analyzed using an Excel macro (Tempture), which summarizes temperature metrics pertinent to coldwater fisheries. Raw temperature data and summary temperature metrics were provided by DEQ to Watershed Consulting for FLIR calibration and data analysis.

*Thermal Accuracy*

Temperatures from the in-stream temperature loggers were compared to radiant temperatures from the FLIR imagery for each survey (Table 4). The data were assessed at the time the flight was taken and the imagery acquired.

**Table 4. Comparison of logger temperatures with radiant temperatures.**

| Site ID | River Mile | Logger Temp PM | FLIR Temp PM | Difference PM | Logger Temp PM | FLIR Temp PM | Difference AM |
|---|---|---|---|---|---|---|---|
| | 0.1 | 20.7 | 21.0 | -0.3 | 17.9 | 17.9 | 0.0 |
| | 8.6 | 20.9 | 21.1 | -0.2 | 18.1 | 17.7 | 0.4 |
| | 10.3 | 20.7 | 21.1 | -0.4 | 18.1 | 17.8 | 0.3 |
| | 12.8 | 21.2 | 21.0 | 0.2 | 17.7 | 17.7 | 0.0 |
| | 14.9 | 20.4 | 21.0 | -0.6 | 18.1 | 17.8 | 0.3 |
| | 17.7 | 20.8 | 20.9 | -0.1 | 18.0 | 17.9 | 0.1 |
| | 21.7 | 20.9 | 20.7 | 0.2 | 17.6 | 18.1 | -0.5 |
| | 27.2 | 20.2 | 20.1 | 0.1 | 17.5 | 17.6 | -0.1 |
| | 29.1 | 20.1 | 20.4 | -0.3 | 17.1 | 17.5 | -0.4 |
| | 39 | 20.2 | 20.1 | 0.1 | 15.1 | 17.6 | -2.5 |
| | 42 | 20.2 | 20.7 | -0.5 | 16.8 | 17.0 | -0.2 |
| | 48.9 | 20.7 | 21.1 | -0.4 | 16.7 | 16.7 | 0.0 |
| | 50.9 | 19.9 | 21.2 | -1.3 | 16.6 | 16.6 | 0.0 |
| | 52.8 | 19.8 | 20.1 | -0.3 | 16.3 | 16.1 | 0.2 |
| | 53.4 | 19.6 | 20.0 | -0.4 | 15.8 | 16.0 | -0.2 |
| | 56.2 | 19.3 | 19.7 | -0.4 | 15.4 | NA | NA |
| | 59.1 | 19.4 | 19.2 | 0.2 | 15.6 | NA | NA |
| | 63.3 | 18.7 | 18.6 | 0.1 | 15.6 | NA | NA |
| | 65.8 | 19.2 | 19.2 | 0.0 | 14.6 | NA | NA |
| | 67.6 | 18.2 | 18.1 | 0.1 | 15.4 | NA | NA |
| | 71.1 | 17.8 | 17.9 | -0.1 | 15.2 | NA | NA |
| | 75.4 | 17.2 | 17.0 | 0.2 | 14.8 | 14.4 | 0.4 |
| Bitterroot | 80.6 | 16.2 | 16.4 | -0.2 | 14.1 | 13.4 | 0.7 |
| | 1.3 | 17.8 | 18.4 | -0.6 | 15.2 | 14.9 | 0.3 |
| | 4.3 | 17.5 | 18.3 | -0.8 | 14.7 | 14.5 | 0.2 |
| | 7.4 | 17.5 | 18.0 | -0.5 | 14.3 | 13.4 | 0.9 |
| | 9.9 | 16.9 | 17.4 | -0.5 | 13.7 | 12.9 | 0.8 |
| | 11.3 | 16.7 | 18.4 | -1.7 | 13.7 | 12.4 | 1.3 |
| | 12.9 | 16.5 | 17.1 | -0.6 | 14.1 | 12.4 | 1.7 |
| East Fork | 17 | 16.3 | 16.7 | -0.4 | 13.6 | 12.1 | 1.5 |
| Lost | 0.1 | 19.3 | 19.6 | -0.3 | 16.5 | 16.4 | 0.1 |
| Horse | 4.8 | 17.5 | 17.4 | 0.1 | 13.2 | 14.7 | -1.5 |
| | 3.6 | 21.8 | 22.2 | -0.4 | 13.5 | 13.9 | -0.4 |
| Miller | 10.2 | 19.0 | 18.9 | 0.1 | 9.9 | 9.5 | 0.4 |
| | 1.4 | 19.7 | 20.8 | -1.1 | 15.5 | 15.4 | 0.1 |
| | 5.6 | 19.8 | 21.2 | -1.4 | 14.5 | 14.4 | 0.1 |
| | 7.8 | 19.8 | 21.1 | -1.3 | 14.3 | 14.1 | 0.2 |
| Lolo | 10.1 | 19.5 | 20.6 | -1.1 | 14.1 | 13.7 | 0.4 |

The differences ranged from 2.5°C to 0.0°C. The average difference of 0.5°C for all the points is consistent with thermal infrared surveys conducted on other streams since 1994 (Torgersen et.al 2001).

GIS Processing

ArcView GIS is used to present the data in a meaningful and organized format for viewing, analyzing and sharing. Shapefiles were created to show the location of the CIR and FLIR images and the instream temperature loggers.

ArcGIS 8.3 was used to create shapefiles to identify and locate side-channels, oxbows, cold-water refugia, impoundments, tributary inflows, irrigation returns, and diversions. Digitizing occurred with the aid of the FLIR images, CIR images and DOQs to accurately locate features. The Bitterroot River is characterized through much of its length by a braided channel with a number of meander bends. Because of the large number of side channels on the Bitterroot and its tributaries, only those features that show a clear temperature difference from the main stem (in either the AM or the PM) in the FLIR images were digitized. Features were identified as a side channel if they appeared to originate from and connect to the river. Side channels do not necessarily have surface flow for their entire length, but are connected to the river on at least one end as surface water. There is a column included in the attribute table of the side channel shapefile that indicates whether or not there was surface water connectivity at the time of the flight.

Because of the braided nature of the Bitterroot River, the FLIR imagery was occasionally unable to capture all of the channels within the view of the camera lens. In these instances, only those channels which are included in the FLIR imagery are included in the analysis and digitizing.

Flights were conducted in the morning and the evening to compare temperatures throughout the day. (The image quality for Miller Creek in the morning was poor and no temperature differences were seen). In general the digitized features show greater temperature fluctuation throughout the day than the main stem. Coldwater refugia, as used in this analysis, indicates a noticeable change in temperature in the stream. It is not necessarily a 2°C difference.

## Results

*Longitudinal Temperature Profile*

The FLIR temperatures for the Bitterroot River were plotted versus the corresponding river mile (Figure 6). This figure shows the temperatures during the evening flight. The plot also contains temperatures of 16 tributaries. The tributary temperatures are from FLIR temperatures at the downstream end of each named tributary (just above confluence with the Ruby). There were a few tributaries for which FLIR temperatures could not be clearly determined, which are not included in Figure 4. The downstream end of the study segment (river mile 0) is on the left side of the graph, therefore trends downstream of a tributary are to the left of the data point for that tributary.

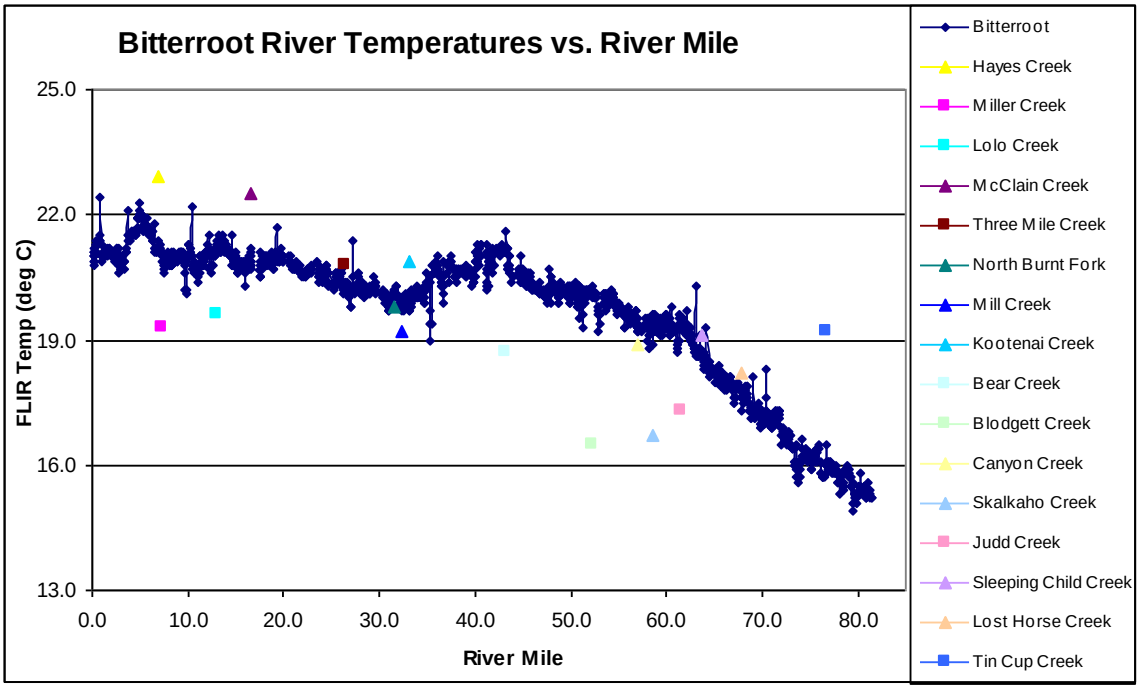


**Figure 6. Channel temperatures plotted by river mile for Bitterroot River**

A map illustrating temperature trends along the lower Bitterroot River and major tributaries is included in Appendix A (Maps 1-3). This map is based on GIS data derived from FLIR temperature data, as described above under FLIR Processing.

*Results by Stream Reach*

The following sections are organized by stream divided into reaches. The reaches were delineated based on major tributaries or diversions. The first figure for each stream is a longitudinal profile. Next is a table for each stream reach illustrating the features identified in the FLIR coverage on the Bitterroot. Also included is the average temperature of each of the features. This is not a comprehensive list of features due to the fact that some of the features were located outside the area covered by the FLIR flight, i.e. some areas of the river and adjacent riparian area were not captured in the flight.

Number and location of irrigation diversions are included for each reach, but there is no way to quantify the irrigation withdrawals for each diversion at the time of the FLIR flight. Some diversions were dry at the time of the flight, but may be used at other times.
Thermal inputs to a stream are cumulative and often show trends over a watershed scale. The results by 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.

## Bitterroot

Temperatures on the main Bitterroot ranged from a maximum of 22.4°C and a minimum of 14.9°C on the afternoon of August 2, 2004. Average afternoon temperature was 19.7°C. During the morning flight, the maximum temperature was 19.0°C and the minimum temperature was 12.0°C. The average morning temperature was 16.6°C. In general the temperature trends

were similar at both flight times, with the morning temperatures around 3°C cooler overall (Figure 7, also Map1-3 Appendix A).

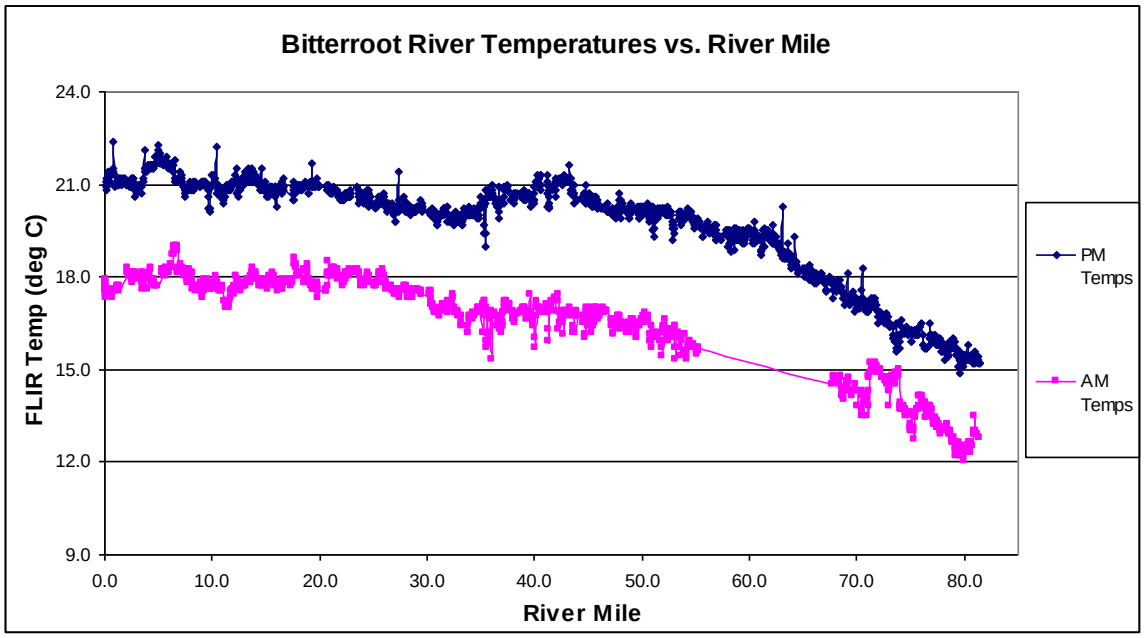


**Figure 7. Afternoon and morning channel temperatures plotted by river mile for Bitterroot River**

Because of the similarities in temperature trends in the Bitterroot, only the afternoon flight will be discussed in detail for the remainder of this section. The exception to this is where temperatures dramatically differed from the trend of being approximately 3°C cooler in the morning.

Overall the Bitterroot River showed a warming trend from the upstream end to the mouth in both the morning and afternoon flights. The Bitterroot River was broken into 8 reaches determined by tributary locations and irrigation returns or diversions (length was also taken into account).

Bitterroot 01 (River Mile 76.6-81.5)

Total length for Bitterroot 01 was approximately 4.9 miles. Bitterroot 01 had an afternoon temperature of 15.2°C at the upstream end (river mile 81.5) and 15.8°C at the downstream end (river mile 76.6) (Appendix A, Map 1). While an overall warming trend was observed (the stream warmed 0.6°C over 4.9 miles), the longitudinal profile shows locally cooler areas within this reach. The stream temperature fluctuated between 15.2°C and 15.6°C for the first mile and a half. The coolest water temperature (14.9°C) recorded during the Bitterroot River survey was observed on this reach at river mile 79.5. The imagery did not reveal any significant surface water inputs at this point. There were two side channels seen in the 79.5-79.6 area, however, neither side channel showed cold temperatures relative to the stream. Stream temperatures fluctuated and slowly rose from mile 79.5 to the end of the reach. The high temperature for the reach of 16.5°C was seen at river mile 76.7. Side channels were the only features identified on Bitterroot 01 (Table 5 and Appendix A, Map 4).

**Table 5. Bitterroot 01 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Side Channel | 81.2 | 14.4 | 15.3 | -0.9 | NA | 13.0 | NA |
| Side Channel | 80.9 | 18.3 | 15.3 | 3.0 | 10.6 | 13.0 | -2.4 |
| Side Channel | 79.6 | 17.4 | 15.3 | 2.1 | 12.5 | 12.3 | 0.2 |
| Side Channel | 79.5 | 17.2 | 15.3 | 1.9 | 11.8 | 12.6 | -0.8 |
| Side Channel | 79.1 | 17.0 | 14.9 | 3.7 | 12.8 | 12.7 | 0.1 |
| Side Channel | 78.9 | 16.1 | 15.8 | 0.3 | 12.0 | 12.8 | -0.8 |
| Side Channel | 78.0 | 16.2 | 15.9 | 0.3 | NA | 13.0 | NA |

In general the temperatures on the side channels on this reach of the Bitterroot were warmer than the main stem in the afternoon. The average side channel temperature was 16.7°C during the afternoon flight, while the average stream temperature on this reach was 15.6°C during the same time period. The only exception to this trend was the side channel at river mile 81.2 which was almost one degree Celsius cooler than the Bitterroot River at the same point.

Bitterroot 02 (River Mile 67.8-76.5)

Total length of reach Bitterroot 02 was approximately 8.7 miles. The upstream end of this reach is near the town of Darby, Montana. The temperature at the upstream end of this reach on the afternoon of August 2, 2004 was 15.7°C, while the temperature at the downstream end was 17.8°C (Appendix A, Map 1). This was an overall increase in stream temperature of 2.1°C from the upstream end to the downstream end of the reach. The high temperature in this reach was 18.3°C at river mile 70.5. Neither the CIR nor FLIR imagery revealed any significant surface water inputs directly at this point. However, an impoundment just upstream of this point had a temperature of 20.1°C. This feature may contribute warm water to the stream. The low temperature was 15.6°C at river mile 73.7. The imagery did not reveal any significant surface water inputs at this point. There were tributaries, impoundments and a side channel identified on this reach (Table 6 and Appendix A, Map 4).

**Table 6. Bitterroot 02 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Tin Cup Creek | 76.6 | 19.2 | 15.9 | 3.3 | NA | 13.6 | NA |
| Impoundment | 75.5 | 21.6 | 16.2 | 5.4 | NA | 13.5 | NA |
| Side Channel | 74.1 | 19.7 | 16.3 | 3.4 | NA | 13.8 | NA |
| Impoundment | 70.8 | 20.1 | 17.2 | 2.9 | NA | 13.9 | NA |
| Lick Creek | 69.6 | NA | 17.3 | NA | NA | 14.1 | NA |

There were no morning FLIR images, and thus no feature temperature information available on this and the subsequent reaches due to technical difficulties during the flight. All of the features identified on this reach of the Bitterroot on the afternoon of August 2, 2004 were warmer than

the main stem. The two impoundments had an average temperature that was 4.2°C warmer than the stream temperature adjacent to them. Both the side channel and Tin Cup Creek were over 3°C warmer than the Bitterroot. These warm features likely contribute to the temperature increase seen on this reach.

Bitterroot 03 (River Mile 58.7-67.7)

Total length of Bitterroot 03 was approximately 9.0 miles. The temperature was 17.9°C at the upstream end and 19.5°C at the downstream end (Appendix A, Map 2). The stream temperature increased by 1.6°C in nine miles on this reach. The high temperature of 20.3°C was seen at mile 63.1. Table 7 shows the features identified on Bitterroot 03 (Appendix A, Map 5).

**Table 7. Bitterroot 03 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Lost Horse Creek | 67.8 | 18.2 | 17.5 | 0.7 | NA | NA | NA |
| Side Channel | 67.5 | 19.2 | 17.8 | 1.4 | NA | NA | NA |
| Side Channel | 64.5 | 20.0 | 18.3 | 1.7 | NA | NA | NA |
| Sleeping Child Creek | 63.7 | 19.1 | 18.7 | 0.4 | NA | NA | NA |
| Side Channel | 61.7 | 16.4 | 19.4 | -3.0 | NA | NA | NA |
| Judd Creek | 61.6 | 17.3 | 19.3 | -2.0 | NA | NA | NA |
| Side Channel | 60.2 | 18.1 | 19.4 | -1.3 | NA | NA | NA |
| Impoundment | 60.0 | 19.3 | 19.5 | -0.2 | NA | NA | NA |
| Roaring Lion Creek | 58.8 | NA | 19.4 | NA | NA | NA | NA |

The features identified on the upstream end of this reach were warmer than the main stem, while the downstream features were cooler than the Bitterroot on this reach. It is interesting to note that at the same area the features alternate from being warmer to being cooler, the temperature trend on the Bitterroot also changes. As the Bitterroot thermograph shows, the steady increase in temperature seen from the upstream end of the Bitterroot down to this point levels off near river mile 62 (Figure 7). Just downstream of this point a cold side channel and tributary enter the Bitterroot (Figure 8).

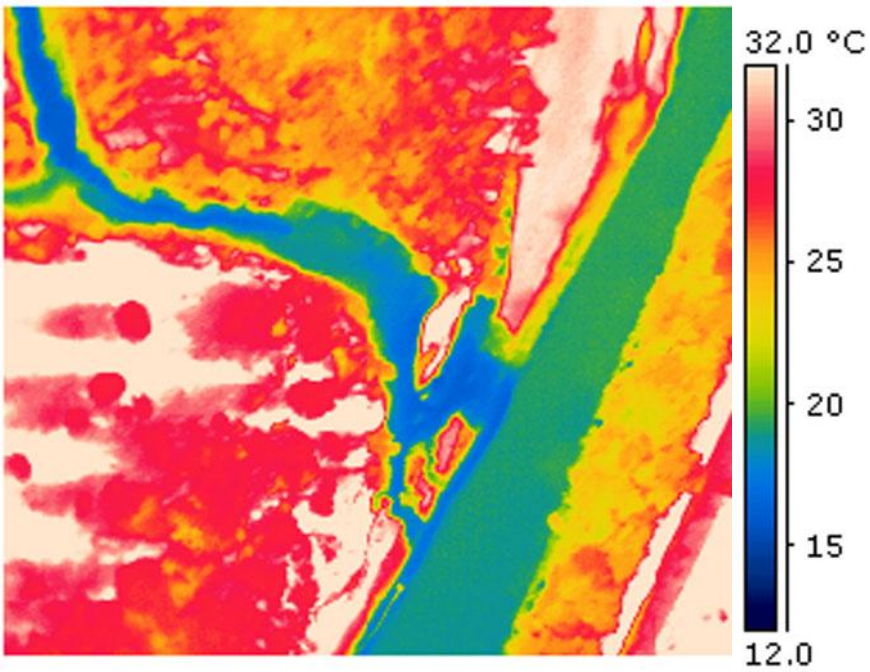


**Figure 8. Cold side channel entering the Bitterroot at mile61.7.**

The stream temperature is 19.7°C just upstream of this feature. This cool side channel and Judd Creek then enter and the Bitterroot stream temperature drops to 18.7°C. It is likely that the water from Judd Creek and a side channel at river mile 61.7 are the source of thermal cooling seen on the longitudinal profile at this point on the Bitterroot.

Bitterroot 04 (River Mile 48.9-58.6)

Total length of Bitterroot 04 was approximately 9.7 miles. The temperature at the upstream end was 19.4°C and 20.2°C at the downstream end (Appendix A, Map 2). This is a relatively small temperature increase of 0.8°C over ten miles. The change was stable with few local fluctuations in temperature. The many features identified in this reach were both warmer and cooler than the Bitterroot (Table 8 and Appendix A, Map 5).

**Table 8. Bitterroot 04 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Skalkaho Creek | 58.6 | 16.7 | 19.5 | -2.8 | NA | NA | NA |
| Side Channel | 58.1 | 17.1 | 19.2 | -2.1 | NA | NA | NA |
| Canyon Creek | 56.8 | 18.9 | 19.6 | -0.7 | NA | NA | NA |
| Impoundment | 55.0 | NA | 19.8 | NA | 17.5 | 15.7 | 1.7 |
| Side Channel | 54.8 | 21.7 | 19.9 | 1.8 | 12.0 | 15.7 | -3.7 |
| Side Channel | 54.6 | 23.0 | 19.9 | 3.1 | 16.6 | 15.7 | 0.9 |
| Side Channel | 54.3 | 22.9 | 20.1 | 2.8 | 14.4 | 15.6 | -2.8 |
| Side Channel | 54.1 | 15.7 | 19.9 | -4.2 | NA | 15.8 | NA |
| Blodgett Creek | 52.2 | 16.5 | 20.1 | -3.6 | 10.5 | 16.5 | -6.0 |
| Side Channel | 52.0 | 19.1 | 20.1 | -1.0 | 15.6 | 16.0 | -0.4 |
| Side Channel | 51.9 | 21.5 | 20.1 | 0.4 | 13.9 | 15.5 | -1.6 |
| Impoundment | 50.8 | 22.8 | 20.2 | 2.6 | NA | 15.9 | NA |
| Side Channel | 50.5 | 20.5 | 20.1 | 0.4 | 14.0 | 16.6 | -2.6 |

Blodgett Creek was the most significant contributor of cold water on this reach with temperatures 3.6°C cooler than the Bitterroot in the evening and 6°C cooler in the morning. Skalkaho and Canyon Creek also contributed cooler water into the Bitterroot. At river mile 56.2 the river flows past the sewage treatment ponds of the town of Hamilton. The stream temperature shows a slight increase in temperature (0.3°C) just after the ponds. Side channels on Bitterroot 04 were both warmer and cooler than the main channel (Figures 9 and 10).

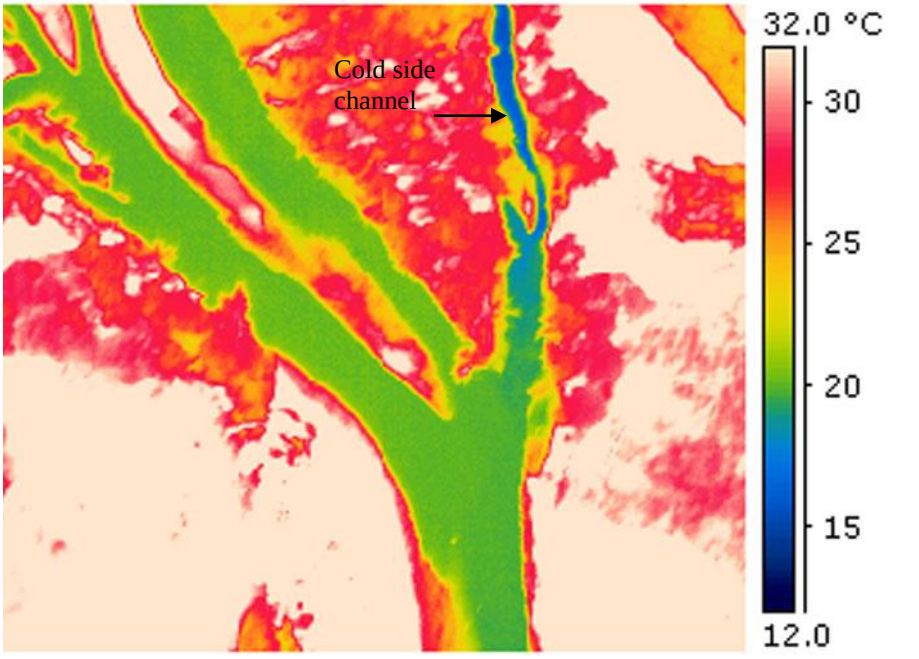


**Figure 9. Cold water side channel at river mile 54.1.**

This side channel was 4.2°C cooler than the Bitterroot; however, it did not alter the overall stream temperature.

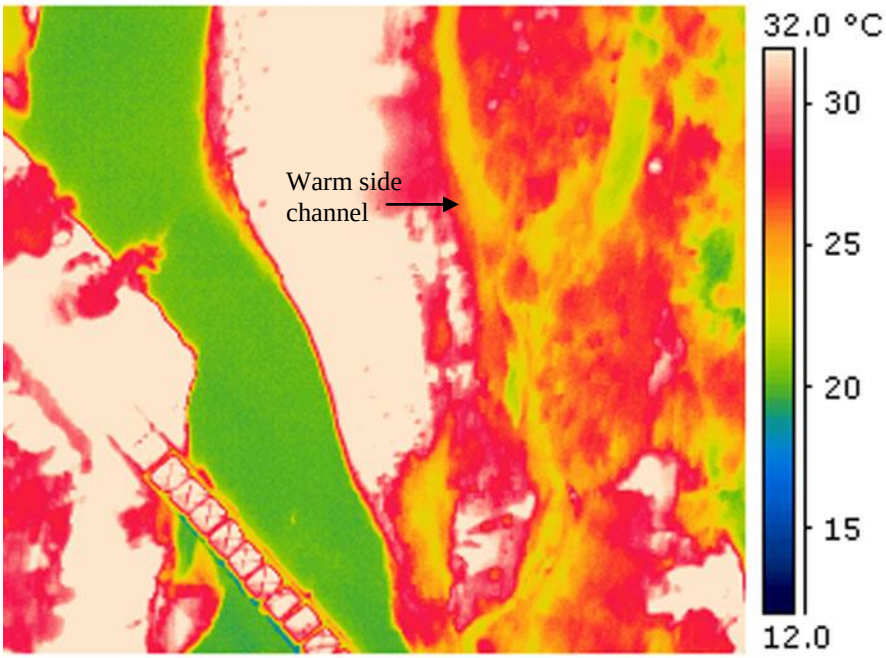


**Figure 10. Warm water side channel at river mile 54.6.**

This feature did not increase the overall temperature on the Bitterroot, thought the temperature of the side channel was 3.1°C warmer than the main channel. The blend of warm and cool water influences on this reach are probable contributors to overall temperatures that were relatively steady.

Bitterroot 05 (River Mile 33.1-48.8)

Total stream length of Bitterroot 05 was approximately 15.7 miles. The temperature at the upstream end of this reach was 19.9°C (Appendix A, Map 2). The downstream temperature was 20.0°C. Overall this is an insignificant increase over 15.6 miles, however, there was a large amount local thermal spatial variability within this reach. From the upstream end of this reach, the temperature increases to a high of 21.6°C at river mile 43.2. The Bitterroot then passes through the town of Victor, Montana and shows a cooling trend between river miles 43-33. The low temperature on the reach was 19.0°C at river mile 35.4. Around river mile 34 the Bitterroot passes the sewage disposal ponds for the town of Stevensville with no impact on stream temperatures. The features identified on Bitterroot 05 are primarily cooler then the main stem (Table 9 and Appendix A, Map 6).

**Table 9. Bitterroot 05 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Side Channel | 46.7 | 16.5 | 20.2 | -3.7 | 10.5 | 16.9 | -6.4 |
| Side Channel | 46.5 | 21.6 | 20.2 | 1.4 | 15.6 | 16.8 | -1.2 |
| Side Channel | 45.3 | 18.5 | 20.5 | -2.0 | 10.5 | 16.8 | -6.3 |
| Side Channel | 44.8 | 18.1 | 20.6 | -2.5 | NA | 16.5 | NA |
| Bear Creek | 43.2 | 18.7 | 21.3 | -2.6 | 12.0 | 16.8 | -4.8 |
| Tributary | 42.7 | 20.1 | 21.1 | -1.0 | 10.9 | 16.3 | -5.4 |
| Tributary | 42.3 | 17.9 | 21.1 | -3.2 | NA | 16.3 | NA |
| Side Channel | 41.7 | 23.1 | 20.9 | 2.2 | 15.9 | 17.0 | -1.1 |
| Side Channel | 40.5 | 19.9 | 21.0 | -1.1 | 15.2 | 16.8 | -1.6 |
| Side Channel | 39.7 | 17.6 | 20.4 | -2.8 | 13.9 | 17.0 | -3.1 |
| Side Channel | 38.0 | 17.6 | 20.6 | -3.0 | 14.0 | 16.8 | -2.8 |
| Side Channel | 36.5 | 19.6 | 20.3 | -0.7 | 11.5 | 16.7 | -5.2 |
| Willoughby Creek | 35.8 | NA | 20.7 | NA | 11.5 | 15.8 | -4.3 |
| Cold Water Refuge | 35.5 | 18.2 | 20.4 | -2.2 | 10.0 | 17.2 | -7.2 |
| Side Channel | 35.4 | 19.8 | 20.0 | -0.2 | 12.9 | 16.9 | -4.0 |
| Side Channel | 34.8 | 18.7 | 20.1 | -1.4 | 11.1 | 16.9 | -5.8 |
| Return | 34.4 | 16.7 | 20.0 | -3.3 | 9.8 | 16.8 | 7.0 |
| Side Channel | 33.8 | 17.4 | 20.0 | -2.6 | NA | 16.2 | NA |
| Side Channel | 33.2 | 17.7 | 20.0 | -2.3 | 10.8 | 16.7 | -5.9 |

All of the tributaries on this reach were cooler than the Bitterroot. This coldest spot identified, according to FLIR imagery, was located just downstream of the inflow of Willoughby Creek and a cold water refugia at river mile 35.5. Although Willoughby Creek was outside the scope of the FLIR imagery it is likely the source of the cool water seen in Figure 11.

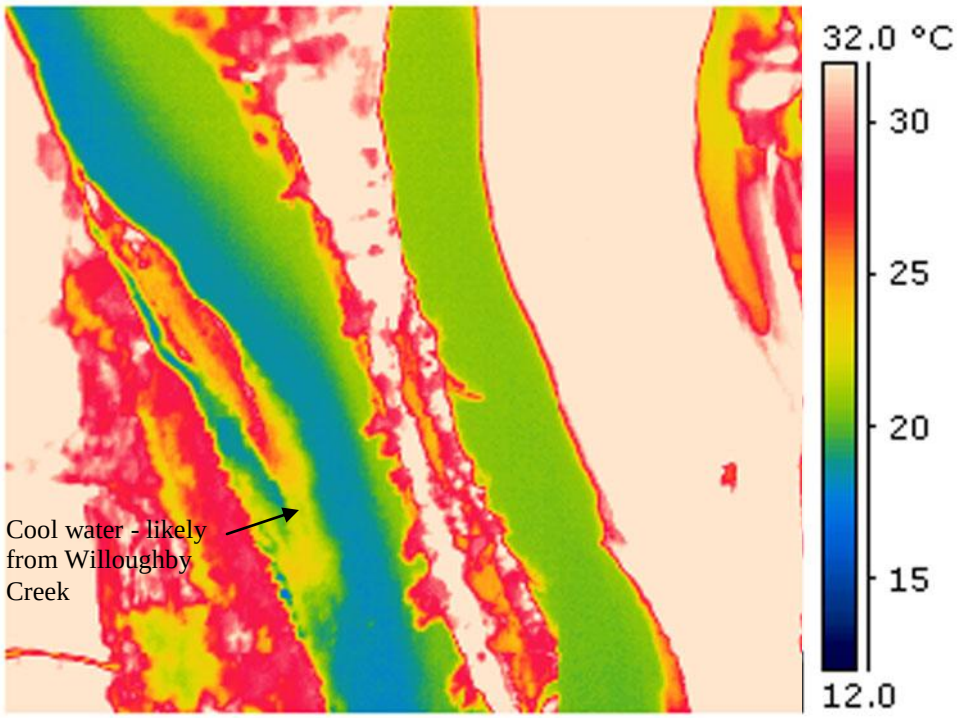


**Figure 11. Cool water at river mile 35.5.**

Overall the many cool inflows likely contribute to the cooling trend seen on almost ten miles of this reach. This cooling trend was unique on the Bitterroot the day the images were collected.

Bitterroot 06 (River Mile 16.5-33.0)

Total length of Bitterroot 06 was approximately 16.5 miles. The temperature at the upstream end of this reach was 19.8°C, while the downstream temperature was 20.7°C (Appendix A, Map 3). The overall increase of just under one degree Celsius accurately reflects the gradual temperature increase seen on this section of the Bitterroot longitudinal profile (Figure 7). The features identified on this reach showed varied temperatures relative to the Bitterroot (Table 10 and Appendix A, Map 6).

**Table 10. Bitterroot 06 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Kootenai Creek | 33.1 | 20.9 | 20.0 | 0.9 | 13.0 | 16.7 | -3.7 |
| Mill Creek | 32.4 | 19.2 | 19.8 | -0.6 | 15.0 | 17.3 | -2.3 |
| North Burnt Fork | 31.5 | 19.8 | 20.0 | -0.2 | 13.6 | 17.0 | -3.4 |
| Return | 30.5 | 23.2 | 20.0 | 3.2 | 15.6 | 17.1 | -1.5 |
| Side Channel | 28.9 | 26.3 | 20.2 | 6.1 | 14.6 | 17.6 | 3.0 |
| Bass Creek | 28.9 | NA | 20.1 | NA | 14.9 | 17.6 | -5.6 |
| Side Channel | 28.3 | 26.1 | 20.2 | 5.9 | 14.5 | 17.4 | -2.9 |
| Impoundment | 28.2 | 26.1 | 20.2 | 5.9 | 15.5 | 17.5 | -2.0 |
| Side Channel | 28.1 | 22.1 | 20.1 | 2.0 | 16.9 | 17.7 | -0.8 |
| Side Channel | 27.4 | 19.7 | 20.2 | -0.5 | 15.2 | 17.5 | -2.3 |
| Side Channel | 27.3 | 25.2 | 20.2 | 5.0 | 17.3 | 17.5 | -0.2 |
| Three Mile Creek | 26.4 | 20.8 | 20.2 | 0.6 | 15.2 | 17.6 | -2.4 |
| Side Channel | 26.3 | 23.9 | 20.2 | 3.7 | 16.6 | 17.7 | -1.1 |
| Side Channel | 25.4 | 17.1 | 20.4 | -3.3 | 11.5 | 17.8 | -6.3 |
| Side Channel | 25.4 | 22.8 | 20.5 | 2.3 | 16.3 | 17.8 | -1.5 |
| Side Channel | 24.5 | 19.7 | 20.6 | -0.9 | NA | 18.0 | NA |
| Cold Water Refuge | 24.3 | 18.5 | 20.6 | -2.1 | 14.1 | 17.8 | -3.7 |
| Cold Water Refuge | 22.8 | 16.8 | 20.6 | -3.8 | 14.9 | 18.1 | -3.2 |
| Side Channel | 21.4 | 22.5 | 20.8 | 1.7 | 15.7 | 18.3 | -2.6 |
| Side Channel | 19.0 | 16.1 | 21.0 | -4.9 | 10.0 | 18.1 | -8.1 |
| Side Channel | 16.7 | 18.2 | 20.1 | -1.9 | 13.4 | 17.7 | -4.3 |

On other reaches of the Bitterroot, tributaries have been a source of thermal cooling. However, on this reach the tributaries visible in the afternoon FLIR imagery were on average 0.2°C warmer than the main stem. Bass Creek was not visible in the afternoon FLIR imagery, however there was no noticeable temperature change downstream of the inflow and logger data does not suggest significantly cooler water on Bass Creek. There were 12 side channels identified on Bitterroot 06. They were on average 1.3°C warmer than the Bitterroot. Figure 12 illustrates one of the warm side channels.

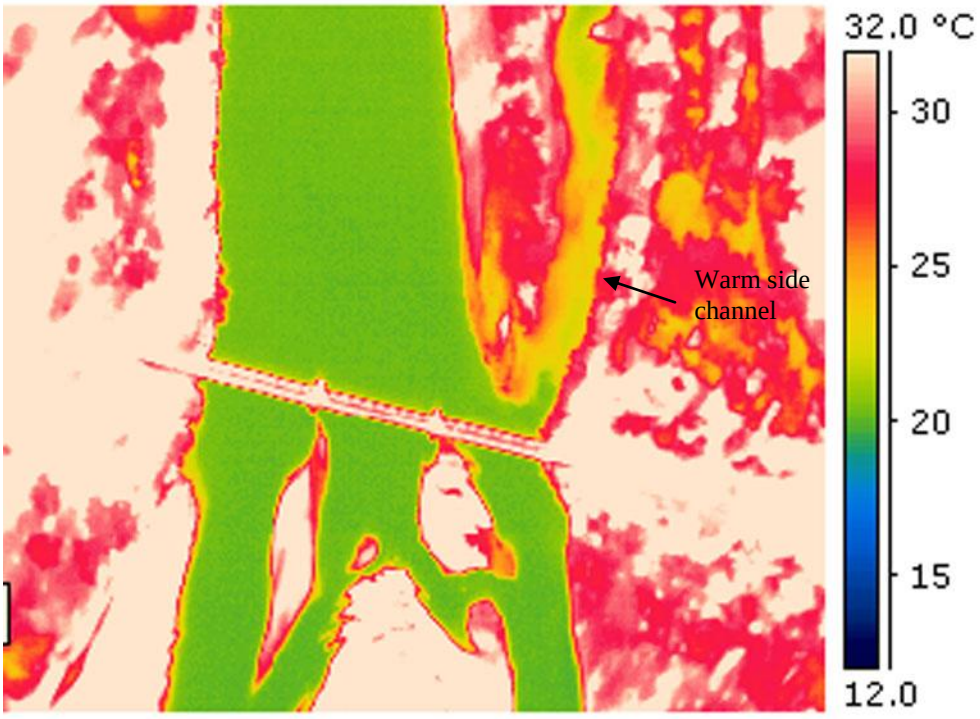


**Figure 12. Warm side channel at river mile 28.3.**

This side channel, although almost 6°C warmer than the main stem, did not have a visible impact on the Bitterroot temperature. Looking at the thermograph, a one degree temperature spike is visible at mile 27.3. There is a side channel at the same location that was 5.0°C warmer than the Bitterroot. The side channel does not appear to have connectivity at the upstream end. Consequently, the source of the dramatic, yet brief, warming of the Bitterroot it is not exactly clear from the imagery. Overall the combination of both warm and cool features result in the relatively stable stream temperatures on Bitterroot 06.

Bitterroot 07 (River Mile 7.4-16.4)

Total length of Bitterroot 07 was approximately 9.0 miles. The upstream temperature was 20.7°C, while the downstream temperature was 20.9°C (Appendix A, Map 3). This was an overall temperature increase of only 0.2°C over nine miles; however, there was some local temperature fluctuations within Bitterroot 07. The greatest temperature fluctuation was seen from river mile 10.4 to 9.8 where temperatures ranged from a high of 22.2°C to a low of 20.1°C. The features identified in this area partially explain the temperature fluctuations (Table 11 and Appendix A, Map 7)

**Table 11. Bitterroot 07 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| McClain Creek | 16.5 | 22.5 | 20.8 | 1.7 | 15.7 | 17.7 | -2.0 |
| Side Channel | 15.9 | 18.1 | 20.7 | -2.6 | 9.3 | 17.8 | -8.5 |
| Side Channel | 14.2 | 19.1 | 21.1 | -2.0 | 11.1 | 18.0 | -6.9 |
| Side Channel | 13.4 | 20.2 | 21.3 | -1.1 | 13.1 | 17.8 | -4.7 |
| Lolo Creek | 13.2 | 19.6 | 21.4 | -1.8 | 12.7 | 17.7 | -5.0 |
| Side Channel | 12.5 | 19.3 | 21.0 | -1.7 | 10.9 | 17.8 | -6.9 |
| Side Channel | 12.3 | 22.4 | 21.1 | 1.3 | 15.1 | 18.0 | -2.9 |
| Side Channel | 12.2 | 15.6 | 21.2 | -5.6 | 13.5 | 17.6 | -4.1 |
| Side Channel | 11.6 | 15.5 | 20.8 | -5.3 | 9.3 | 17.1 | -7.8 |
| Cold Water Refuge | 10.9 | 18.9 | 20.6 | -1.7 | 14.1 | 17.5 | -3.4 |
| Side Channel | 10.8 | 22.4 | 20.6 | 1.8 | 16.3 | 17.5 | -1.2 |
| Impoundment | 10.7 | 24.1 | 20.7 | 3.4 | 18.7 | 17.6 | 1.1 |
| Side Channel | 9.8 | 25.9 | 20.9 | 5.0 | 14.8 | 17.8 | -3.0 |
| Side Channel | 9.1 | 24.1 | 21.0 | 3.1 | 16.8 | 17.4 | -0.6 |
| Side Channel | 7.7 | 18.2 | 20.9 | -2.7 | 13.5 | 17.9 | -4.4 |

A warming trend is visible in the longitudinal profile after McClain Creek (with approximately 1.7°C warmer water) enters the Bitterroot (Figure 5). Similarly, Lolo Creek is a source of thermal cooling when it enters the Bitterroot at river mile 13.2. The high temperature at mile 10.4 could be influenced by the warm impoundment and side channels seen just upstream. The temperature drop to 20.1°C at river mile 9.8 is not explained by the imagery, as no surface water inflows were detected that would contribute to the temperature decrease. Although out of range of the FLIR imagery, there are two sloughs (Doyle's and Plummer's) in this area that may also impact Bitterroot temperatures. Overall the features identified on Bitterroot 07 had variable temperatures with warm and cool water influences.

Bitterroot 08 (River Mile 0.0-7.3)

Total length of Bitterroot 08 was approximately 7.3 miles. The upstream temperature was 20.9°C and the temperature at the mouth was 21.0°C (Appendix A, Map 3). This miniscule temperature increase overall does not reflect the local temperature variation seen on this reach. The features located on this reach are identified in Table 12 (Appendix A, Map 7).

**Table 12. Bitterroot 08 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Bitterroot PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Bitterroot AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Miller Creek | 7.3 | 19.3 | 21.0 | -1.7 | 11.5 | 18.3 | -6.8 |
| Side Channel | 7.1 | 24.1 | 21.0 | 3.1 | 17.5 | 18.2 | -0.7 |
| Hayes Creek | 7.0 | 22.9 | 21.2 | 1.7 | 17.3 | 18.3 | -1.0 |
| Diversion | 6.1 | 20.9 | 21.5 | -0.6 | 16.5 | 18.1 | -1.6 |
| Impoundment | 5.6 | 25.7 | 21.8 | 3.9 | 19.2 | 18.1 | 1.1 |
| Side Channel | 5.4 | 23.9 | 21.7 | 2.2 | 18.0 | 18.2 | -0.2 |
| Side Channel | 5.1 | 22.6 | 21.9 | 0.7 | 15.2 | 17.8 | -2.6 |
| Side Channel | 4.1 | 17.4 | 21.5 | -4.1 | 9.4 | 17.9 | -8.5 |
| Cold Water Refuge | 4.0 | 19.1 | 21.5 | -2.4 | 9.4 | 17.6 | -8.2 |
| Impoundment | 3.6 | 22.1 | 21.5 | 0.6 | 18.0 | 18.0 | 0 |
| Side Channel | 3.5 | 19.5 | 21.1 | -1.6 | 9.8 | 17.8 | -8.0 |
| Side Channel | 3.2 | 17.6 | 20.9 | -3.3 | NA | 18.0 | NA |
| Impoundment | 2.7 | 24.5 | 20.8 | 3.7 | 18.6 | 17.8 | 0.8 |
| Return | 2.7 | 24.5 | 21.1 | 3.4 | 18.6 | 17.8 | 0.8 |
| Side Channel | 2.1 | 24.1 | 21.0 | 3.1 | 15.0 | 18.1 | -3.1 |
| Side Channel | 0.8 | 23.6 | 21.4 | 2.2 | 14.9 | 17.5 | -2.6 |

The longitudinal profile shows a warming trend from 7.4 -4.9 where there is a 1.4°C increase in stream temperature. The temperature then decreases to the reach minimum of 20.7°C at mile 3.0. There are three side cannels with cooler water in this area. In addition, the cold water refuge seen in Figures 13 and 14 is located at river mile 4.0.

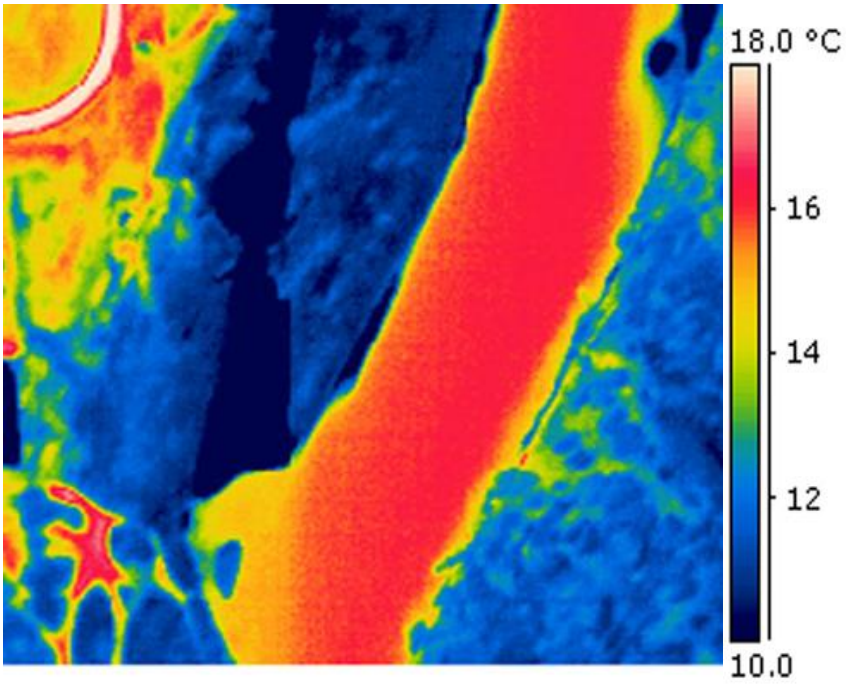

**Figure 13. Morning FLIR image of cold water refugia at river mile 4.0.**

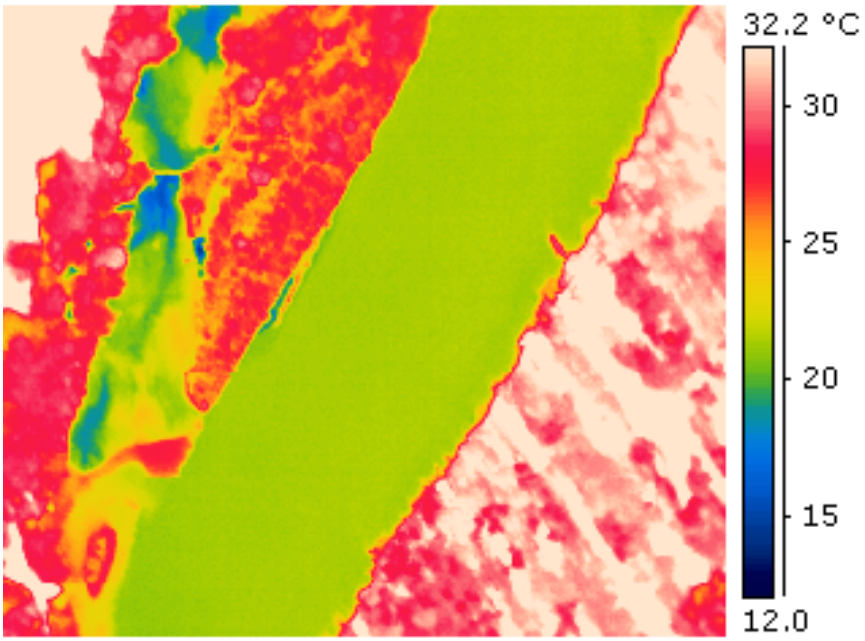


**Figure 14. Afternoon FLIR image of cold water refuge at river mile 4.0.**

The figures above show the same feature in the morning and afternoon to illustrate the differences in temperature variation throughout the day. The warmest temperature (22.4°C) recorded during the Bitterroot River survey was observed in this reach at river mile 0.8.

## Miller Creek

The median water temperatures for each sampled image of Miller Creek were plotted versus river mile (Figure 15). The morning and afternoon temperatures showed the same basic trend, and the morning temperatures were approximately 6°C cooler than the afternoon temperatures. However, there was less variability on the steady warming trend in the morning flight. Furthermore, the drop in temperature seen at the mouth of Miller Creek occurred father upstream in the morning. The afternoon temperatures on Miller Creek will be the primary focus of the following discussion.

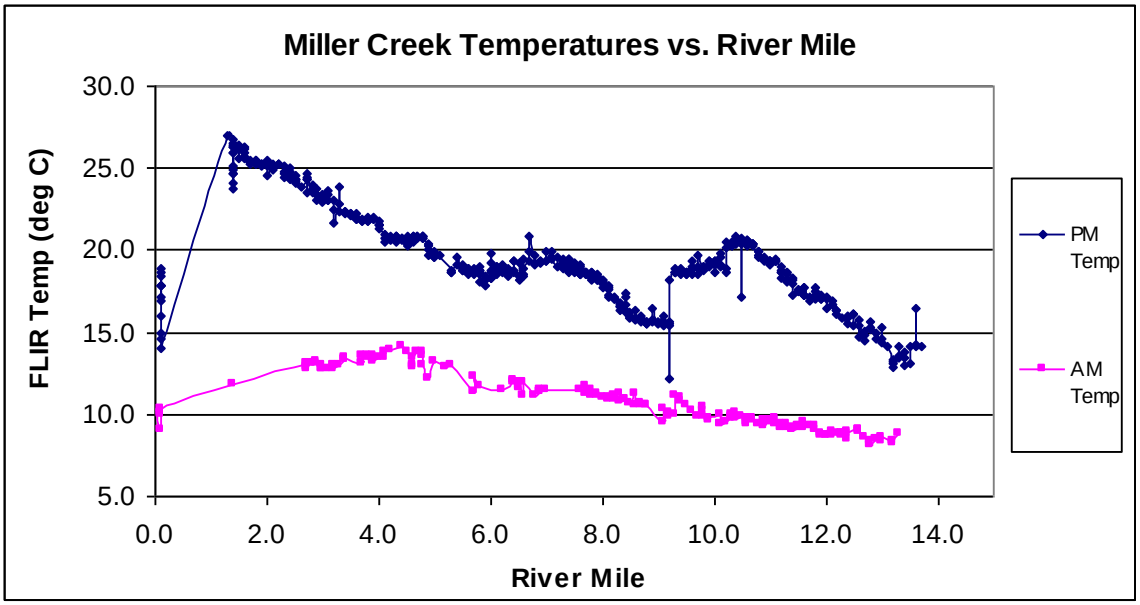


**Figure 15. Afternoon and morning channel temperatures plotted vs river mile for Miller Creek.**

Afternoon temperatures on Miller Creek ranged from 27.0 to 12.2°C (Appendix A, Map 3). This was a large temperature fluctuation (14.8°C) relative to the fluctuations seen on other streams included in this survey. The mean temperature was 19.5°C. Miller Creek showed a basic warming trend from the upstream to the downstream end, however, there was a greater temperature range seen on Miller Creek than on any other stream included in this survey. Miller Creek was broken into two reaches.

Miller Creek 01 (River Mile 8.5-13.7)

The section of Miller Creek 01 covered in this FLIR assessment is approximately 5.2 miles long. The stream temperature at the upstream end was 14.2°C and 16.2°C at the downstream end of this reach. A steady warming trend was observed between river miles 13.7 and 10.5 with temperatures increasing 7.5°C in approximately 3 miles. The irrigation return and two tributaries identified in this section of stream contributed water that was warmer than Miller Creek on this section, and were likely sources of warming (Table 13 and Appendix A, Map 9).

**Table 13. Miller Creek 01 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Miller Creek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Miller Creek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Return | 13.3 | 22.8 | 13.1 | 9.7 | NA | 8.8 | NA |
| Diversion | 13.2 | 25.8 | 12.9 | 12.9 | NA | 8.3 | NA |
| Tributary | 12.6 | 22.8 | 14.7 | 8.1 | 6.2 | 9.0 | -2.8 |
| Park Creek | 11.7 | 21.5 | 17.0 | 4.5 | NA | 9.3 | NA |
| Little Park Creek | 9.3 | 12.7 | 18.6 | -5.9 | 5.5 | 11.1 | -5.6 |

The longitudinal profile for Miller Creek reveals some spikes in temperature on this reach (Figure 17). The source of the spikes at river miles 13.6 and 10.5 are not apparent from the imagery. It is interesting that the -3°C spike at mile 10.5 is associated with the change from warming to a cooling trend on Miller Creek. A cooling trend was observed from miles 10.5 to

9.2. Little Park Creek (mile 9.3) contributed water that was almost 6°C cooler than Miller Creek. This inflow resulted in another spike in the temperature profile (from 18.2 to 12.2°C). The temperature increases to 15.4°C at river mile 9.1and is stable to the end of the reach.

Miller Creek 02 (River Mile 0.0-8.4)

This reach of Miller Creek is approximately 8.4 miles long. The temperature at the upstream end (river mile 8.4) of Miller 02 was 16.2°C. Temperature at downstream end (river mile 0.1) was 17.8°C. This was an overall temperature increase on 1.6°C. Overall Miller Creek showed a steady increasing trend on this reach (Figure 10). Miller Creek increased to 27.0°C at mile 1.3. A significant gap in the data occurs in the following segment where the pilot was unable to locate the channel. At this point Miller Creek has a non distinct channel and it was impossible to tell where to take a temperature. Based on CIR and DOQ images, Miller Creek appears to spread out into a marshy area. The final FLIR readings in this reach are significantly cooler. Both the AM and PM flights showed this drop in temperature at the downstream end of Miller Creek. It is likely that there is groundwater influences here contributing cooler water. The features identifies on Miller 01 were both warmer and cooler than the main channel (Figure 14 and Appendix A, Map 9).

**Table 14. Miller Creek 02 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Miller Creek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Miller Creek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Bear Run Creek | 8.4 | 16.7 | 16.2 | 0.5 | 7.7 | 10.9 | -3.2 |
| Tributary | 8.0 | 25.7 | 17.8 | 7.9 | NA | 11.0 | NA |
| Side Channel | 3.9 | 23.8 | 22.0 | 3.8 | 11.2 | 13.4 | -2.2 |
| Diversion | 2.7 | 26.9 | 24.2 | 2.7 | NA | 12.9 | NA |
| Impoundment | 0.1 | 17.3 | 18.3 | -1.0 | NA | NA | NA |

The quality of the morning flight FLIR images was poor on Miller Creek. It was almost impossible to differentiate between the channel and surrounding areas, therefore, most of the AM feature temperatures were recorded as "NA". The tributary seen at river mile 8.0 was 7.9°C warmer that Miller Creek on the afternoon of 8/2/04 (Figure 16). The CIR images suggest that there is some water in this tributary at the time of the flight; however, it is not possible to quantify the amount.

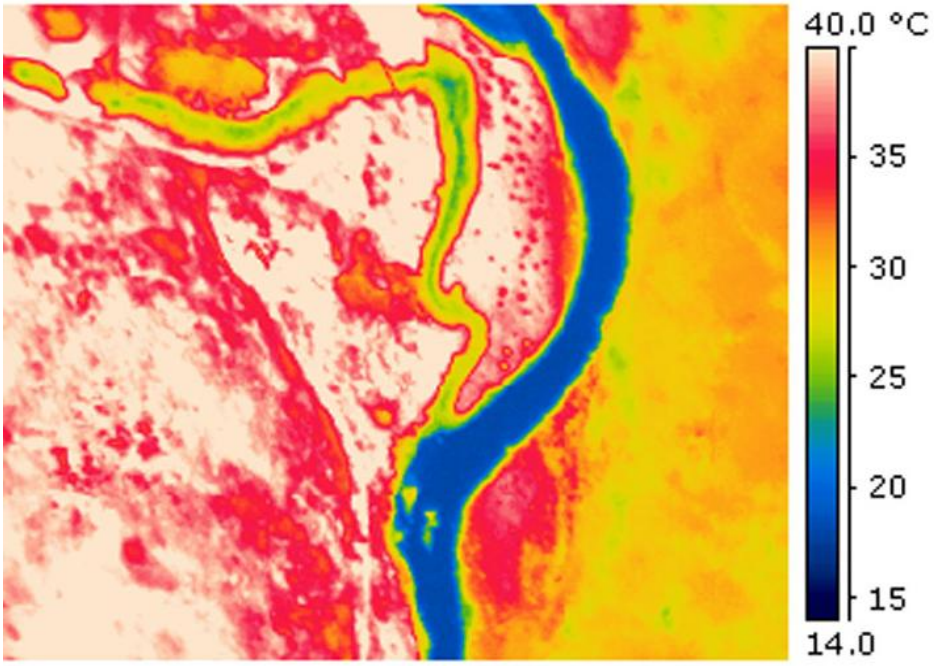


**Figure 16. Warm water tributary on Miler Creek, river mile 8.0.**

This warm feature does not appear to significantly increase the rate of temperature seen on this reach of Miller Creek.

## Lolo Creek

The median water temperatures for each sampled image of Lolo Creek were plotted versus river mile (Figure 17). The morning and afternoon surveys show similar temperature trends with the morning stream temperatures 6-7°C cooler than the afternoon temperatures. The following discussion will focus primarily on the afternoon FLIR temperatures.

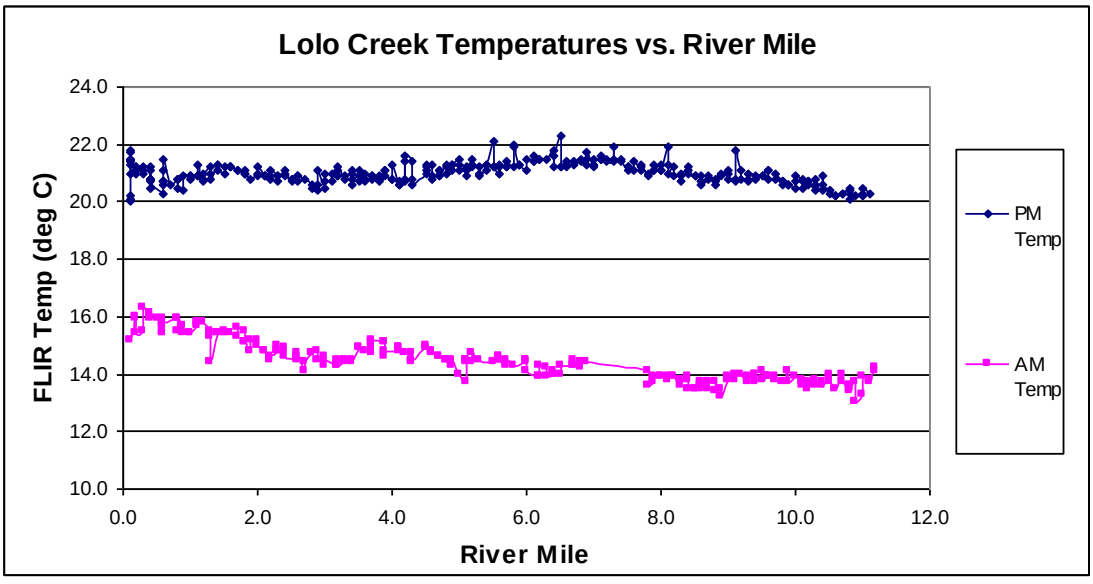


**Figure 17. Afternoon and morning channel temperatures plotted vs. river mile for Lolo Creek.**

As seen in Figure 17, the temperatures on Lolo Creek were relatively stable. The high afternoon stream temperature was 22.3°C while the low temperature was 20.0°C (Appendix A, Map 3). Lolo Creek was broken out into two reaches.

Lolo Creek 01 (River Mile 5.0–11.0)

Length of Lolo 01 is 6.0 miles. The temperature at the upstream end of this reach was 20.3°C, while the downstream temperature was 21.5°C. A slight warming trend was seen on this reach with areas of local temperature fluctuations. The majority of the features identified on this reach were warmer than Lolo Creek (Table 15 and Appendix A, Map 8).

**Table 15. Lolo Creek 01 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Lolo Creek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Lolo Creek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Impoundment | 10.6 | 25.2 | 20.2 | 5.0 | 13.5 | 13.9 | -0.4 |
| Return | 10.6 | 18.2 | 20.2 | -2.0 | 13.5 | 13.9 | -0.4 |
| Side Channel | 10.4 | 21.2 | 20.6 | 0.6 | 13.5 | 13.6 | -0.1 |
| Side Channel | 10.0 | 23.5 | 20.6 | 2.9 | 14.3 | 13.9 | 0.4 |
| Side Channel | 9.6 | 20.9 | 20.9 | 0.0 | 13.6 | 13.9 | -0.3 |
| Tributary | 9.4 | 18.5 | 20.9 | -2.4 | 9.5 | 14.0 | -4.5 |
| Return | 9.2 | 21.4 | 20.8 | 0.6 | 10.9 | 14.0 | -3.1 |
| Impoundment | 8.8 | 28.5 | 20.7 | 7.8 | 15.0 | 13.7 | 1.3 |
| Side Channel | 8.3 | 23.1 | 20.9 | 2.2 | 15.2 | 13.9 | 1.3 |
| Side Channel | 7.4 | 21.2 | 21.4 | -0.2 | NA | NA | NA |
| Impoundment | 7.0 | 23.5 | 21.4 | 2.1 | NA | 14.4 | NA |
| Side Channel | 6.2 | 18.2 | 21.5 | -3.3 | 11.1 | 14.3 | -3.2 |
| Side Channel | 6.1 | 22.3 | 21.5 | 0.8 | 14.5 | 13.9 | 0.6 |
| Impoundment | 5.1 | NA | 21.1 | NA | 15.0 | 14.3 | 0.7 |

At river mile 10.6 an impoundment, which was notably (5°C) warmer than Lolo Creek, was identified (Figure 18). This image was interesting because it illustrates a potential weakness in FLIR analysis. The images only record surface temperatures. It is clear that although the surface water was warmer than Lolo Creek, the water entering Lolo Creek (labeled an irrigation return) was cooler. The return water was clearly being released from the bottom of the reservoir and thus has cooler temperatures.

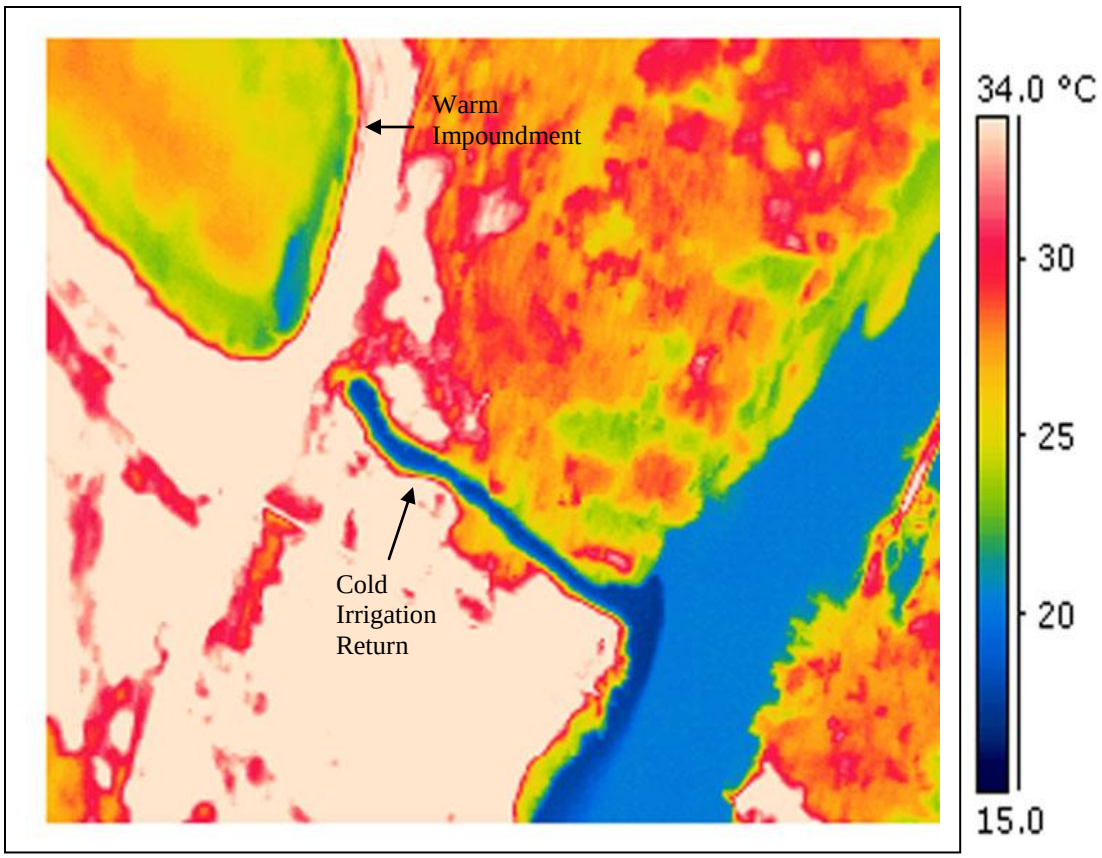


**Figure 18. Cold irrigation return and warm impoundment at river mile 10.6.**

This cooler water did not impact the overall temperatures of Lolo Creek. There were several small spikes in temperature seen in the longitudinal profile for this reach (Figure 15). The first stream temperature spike occurred at river mile 9.1 where the temperature increased by one degree Celsius and then dropped one degree Celsius. It is possible that the return at river mile 9.2 caused this temporary temperature increase. Additional temperature spikes can be seen on this reach (river mile 8.1, 6.5, 5.8, and 5.5). A review of the imagery did not reveal any point source inputs at any of these locations.

Lolo Creek 02 (River Mile 0.0-4.9)

Length of Lolo 02 is approximately 4.9 miles long. The temperature at the upstream end of this reach was 20.8°C, while the downstream temperature was 20.2°C. Overall the temperatures on this reach were relatively stable (Figure 15 and Appendix A, Map 3). There were three cold water refuges identified on this reach (Table 16 and Appendix A, Map 8).

**Table 16. Lolo Creek 02 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | LoloCreek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | LoloCreek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Diversion | 4.9 | 21.1 | 21.4 | -0.3 | 11.9 | 14.4 | -2.5 |
| Cold Water Refuge | 3.4 | 16.6 | 20.8 | -4.2 | 10.0 | 14.4 | -4.4 |
| Cold Water Refuge | 2.4 | 17.9 | 20.9 | -3.0 | 12.5 | 14.7 | -2.2 |
| Cold Water Refuge | 1.8 | 15.9 | 21.0 | -5.1 | 12.8 | 15.2 | -2.4 |
| Side Channel | 1.1 | 24.2 | 21.3 | 2.9 | 16.1 | 15.7 | 0.4 |
| Side Channel | 0.7 | 21.3 | 20.7 | 0.6 | 13.4 | 15.8 | -2.4 |
| Side Channel | 0.2 | 23.1 | 21.2 | 1.9 | 12.1 | 15.8 | -3.7 |

The cold water refuges were on average 4.1°C cooler than Lolo Creek. None of these features appear to affect the overall temperature on Lolo Creek. The largest temperature fluctuations on Lolo 02 occurred near the mouth. The side channels identified on the downstream end of this reach were all warmer than Lolo Creek. They may have contributed to the warmer temperature spikes seem on lower Lolo Creek, however there were also temperature drops towards the mouth. Because it is impossible to quantify the amount of water in the many side channels at the mouth of Lolo Creek, it is difficult to isolate the source of the temperature fluctuations seen here.

## Lost Horse Creek

Lost Horse Creek shows a general warming trend as you move downstream. The upstream temperature (river mile 7.4) was 16.1°C. The downstream temperature (river mile 0.1) was 21.6°C for a total temperature gain of 5.5°C. The longitudinal profile (Figure 19 and Appendix A, Map 1) showed that Lost Horse Creek had many significant temperature fluctuations in short distances, particularly at the downstream end. The morning and afternoon temperatures were similar, however the temperature spikes were not consistent in the two times. Despite these inconsistencies, the following section will focus on the afternoon temperatures.

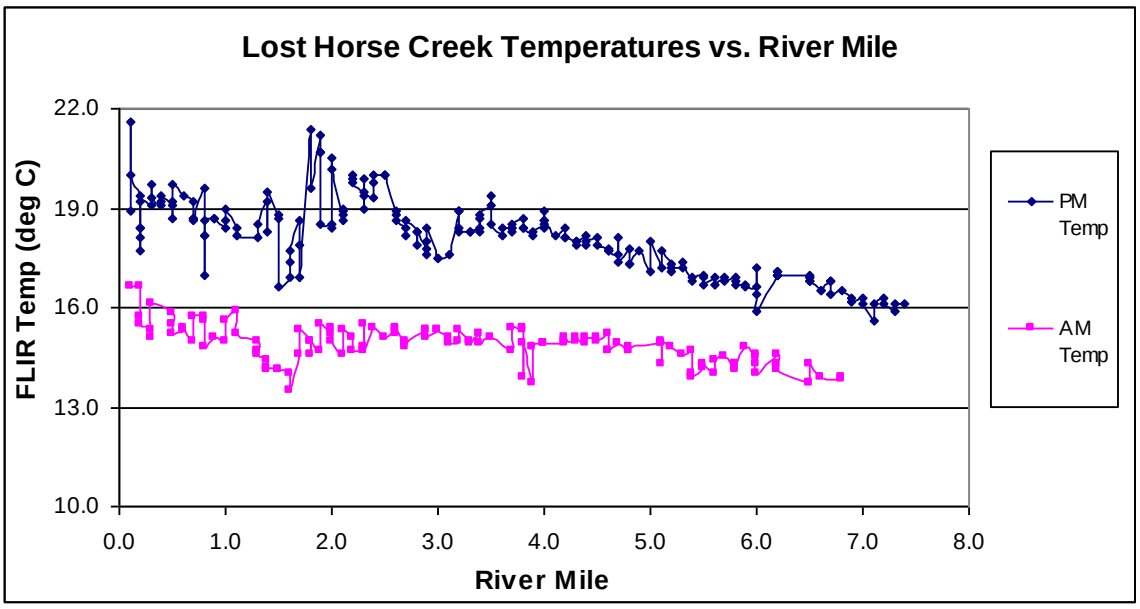

**Figure 19. Afternoon and morning channel temperatures plotted vs. river mile for Lost Horse Creek.**

Lost Horse Creek was broken in to two reaches.

Lost Horse Creek 01 (River Mile 5.4-7.4)

The total length of Lost Horse Creek 01 included in this assessment is approximately 2.0 miles. Overall the temperature in this reach increased slightly from 16.1°C at the upstream end to 16.8°C at the downstream end. The high temperature for this reach in the afternoon was 17.2°C at river mile 6.0. The low temperature was located at river mile 7.1 with 15.6°C. This is at the far upstream end of the area covered during the FLIR flight. The low temperature was only slightly cooler (0.5-0.3°C) than the temperatures in the surrounding stream. Looking at the CIR images, it appears that shade may play a role in the cooler temperatures at this location on Lost Horse Creek. In addition, there was a cold water refugia identified at river mile 7.2 that was 3.0°C cooler than the surrounding stream which may have contributed to the cool temperatures (Table17 and Appendix A, Map 4). This feature appears to be a pool and is perhaps shade influenced.

**Table 17. Lost Horse Creek 01 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Lost Horse Creek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Lost Horse Creek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Cold Water Refuge | 7.2 | 13.1 | 16.1 | -3.0 | NA | NA | NA |
| Side Channel | 6.0 | 13.7 | 16.8 | -3.1 | 7.9 | 14.4 | -11.9 |
| Side Channel | 5.6 | 16.9 | 16.8 | 0.1 | 11.1 | 14.4 | -5.4 |
| Impoundment | 5.4 | 16.9 | 16.9 | 0 | 12.0 | 14.1 | -2.1 |

A side channel located at river mile 6.0 was also 3°C cooler than the main stem of Lost Horse Creek at the same location (Figure 20).

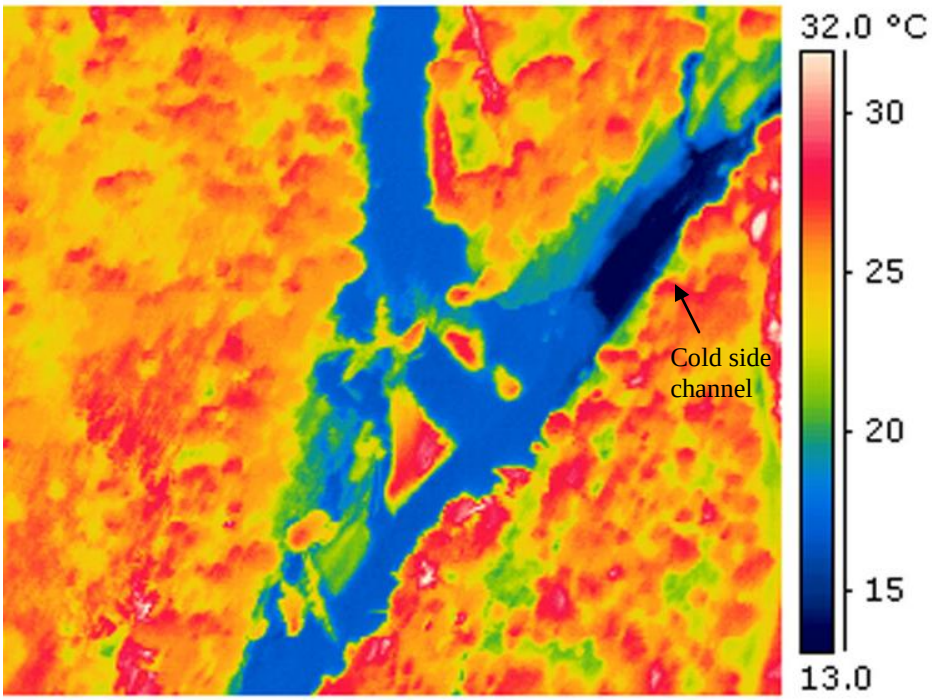


**Figure 20. Cold side channel at river mile 6.0.**

It is not clear from the imagery if the side channel is connected at the upstream end. No surface water coming into the stream is visible at this location. The cooler side channel could be shade or perhaps groundwater influenced. The cold side channel did not impact downstream temperatures.

Lost Horse Creek 02 (River Mile 0.0-5.3)

Lost Horse 02 includes approximately 5.3 miles of stream. The upstream temperature on this reach was 17.4°C. The downstream temperature was 21.6°C. This was a 4.2°C temperature increase over 5.2 miles. The temperature on this section of stream was far from constant. The stream showed a basic warming trend from river mile 5.3 to river mile 3.2 where the temperature was 18.9°C. At this point the stream temperature dropped 1.3°C. A cool side channel may have influenced this drop in temperature (Table 18 and Appendix A, Map 4).

**Table 18. Lost Horse Creek 02 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | Lost Horse Creek PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | Lost Horse Creek AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Diversion | 5.3 | 17.1 | 16.9 | 0.2 | 12.4 | 14.3 | -1.9 |
| Side Channel | 3.3 | 18.0 | 18.4 | -0.4 | 12.3 | 15.0 | -2.7 |
| Side Channel | 3.1 | 19.5 | 17.7 | 1.8 | 11.9 | 15.0 | -3.1 |
| Side Channel | 3.0 | 13.9 | 17.9 | -4.0 | 9.3 | 15.3 | -6.0 |
| Side Channel | 1.5 | 13.5 | 18.8 | -5.3 | 9.1 | 14.1 | -5.0 |
| Side Channel | 0.5 | 17.9 | 19.0 | -1.1 | 12.6 | 15.3 | -2.7 |

For the next mile the stream temperatures increased until around river mile 2.1. From this point to the mouth Lost Horse Creek temperatures fluctuated from 21.4 to 16.6°C. The two features identified on this section were warm side channels, which do not explain the great temperature variability. Perhaps there are sub surface influences that are not visible from the imagery.

## East Fork Bitterroot

The median water temperatures for each sampled image of East Fork of Bitterroot were plotted versus river mile (Figure 21). Temperature trends were similar during the morning and afternoon flights. The afternoon temperatures were 4-5 °C warmer than the morning temperatures. Afternoon temperatures will be the focus of the following section.

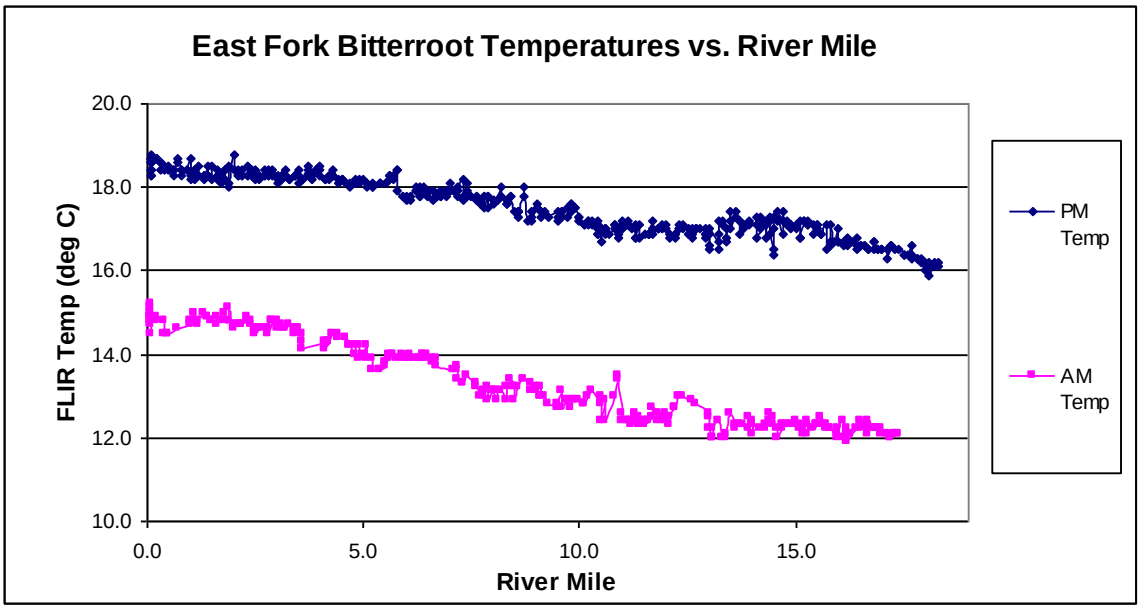


**Figure 21. Afternoon and morning channel temperatures plotted by river mile for East Fork Bitterroot River.**

The temperature at the upstream end of East Fork of Bitterroot was 16.2°C and the temperature at the mouth was 18.6°C (Appendix A, Map 1). This is an overall increase in stream temperature of 2.9°C over 18 miles. The maximum temperature on East Fork of Bitterroot was 18.8°C and the minimum stream temperature was 15.9°C. The East Fork was divided into three reaches.

East Fork Bitterroot 01 (River Mile 14.3-18.3)

The section of East Fork Bitterroot 01 covered in this FLIR assessment is approximately 4.0 miles long. The low temperature seen on the East Fork during this survey was on this reach at river mile 18.1. East Fork 01 showed a slight but steady warming trend through most of the reach. There were two side channels and one tributary (Tolan Creek) identified on this reach. All of these features were colder than the main channel (Table 19 and Appendix A, Map 10).

**Table 19. East Fork Bitterroot 01 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | East Fork PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | East Fork AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Tolan Creek | 17.2 | 15.2 | 16.5 | -1.3 | 11.6 | 12.0 | -0.4 |
| Cold Water Refuge | 16.6 | 13.2 | 16.6 | -3.4 | 12.4 | 12.3 | 0.1 |
| Side Channel | 15.8 | 16.1 | 16.7 | -0.6 | 12.9 | 12.2 | 0.7 |
| Side Channel | 14.5 | 15.6 | 17.1 | -1.5 | 13.8 | 12.4 | 1.4 |
| Reimel Creek | 14.3 | 17.3 | 17.2 | 0.1 | 14.3 | 12.3 | 2.0 |

Additionally, there was one cold water refuge identified on this reach with a temperature 3.4°C cooler that the East Fork. This feature did not impact the stream temperature. The warming trend on this reach continued to river mile 14.7. At this point the stream temperature dropped one degree to 16.4 at river mile 14.5. This is also the location of a side channel with a temperature 1.5°C cooler than the East Fork. Cooler water from the side channel likely influences the drop in stream temperature seen at this point.

East Fork Bitterroot 02 (River Mile 7.5-14.2)

This reach of the East Fork was approximately 6.7 miles long. The temperature at the upstream end of this reach was 17.3°C, while the temperature at the downstream end was 17.8°C. Stream temperatures fluctuated between 15.6 and 17.5 °C for the first mile of this reach. The source of this fluctuation was likely the tributaries and side channels seen within the first mile (Table 20 and Appendix A, Map 10).

**Table 20. East Fork Bitterroot 02 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | East Fork PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | East Fork AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Tributary | 13.5 | 15.9 | 17.2 | -1.3 | 14.0 | 12.4 | 1.6 |
| Side Channel | 13.5 | 16.5 | 17.2 | -0.7 | 12.5 | 12.4 | 0.1 |
| Camp Creek | 13.3 | 14.2 | 17.1 | -2.9 | 12.0 | 12.0 | 0 |
| Cameron Creek | 13.1 | NA | 16.8 | NA | 12.0 | 12.0 | 0 |
| Side Channel | 12.0 | 16.9 | 17.0 | -0.1 | 13.2 | 12.5 | 0.7 |
| Cold Water Refuge | 10.4 | 13.5 | 17.1 | -3.6 | NA | 13.0 | NA |

From river mile 13-10 the temperature stabilized around 17°C. The cold water refugia at river mile 10.4 had no impact on the over stream temperature. From river mile 10 to the end of the reach there was a steady warming trend on the East Fork.

East Fork Bitterroot 03 (River Mile 0.1-7.4)

This reach of the East Fork is approximately 7.4 miles long. The temperature at the upstream end of this reach was 17.9°C, while the temperature at the downstream end was 18.6°C. The East Fork continued with the steady warming trend seen in East Fork 02 until mile 4.5. Temperatures then stabilized and remained at 18.2-18.5°C to the mouth. The features identified did not have any dramatic impact on temperatures on East Fork 03 (Table 21 and Appendix A, Map 10).

**Table 21. East Fork Bitterroot 03 features and temperatures.**

| Feature Type | River Mile | PM Feature Temp °C | East Fork PM Temp °C | PM Temp Difference °C | AM Feature Temp °C | East Fork AM Temp °C | AM Temp Difference °C |
|---|---|---|---|---|---|---|---|
| Laird Creek | 7.4 | 18.1 | 17.9 | 0.2 | 13.4 | 13.5 | -0.1 |
| Impoundment | 5.6 | 21.5 | 18.2 | 3.3 | 16.0 | 13.9 | 2.1 |
| Impoundment | 4.9 | 22.4 | 18.2 | 4.2 | 14.5 | 14.0 | 0.5 |
| Impoundment | 4.3 | 21.5 | 18.3 | 3.2 | 15.6 | 14.5 | 1.1 |
| Impoundment | 3.4 | 17.5 | 18.3 | -0.8 | 12.9 | 14.5 | -1.6 |
| Diversion | 1.8 | 18.5 | 18.2 | 0.3 | 14.8 | 14.9 | -0.1 |
| Side Channel | 0.6 | 14.1 | 18.4 | -4.3 | NA | 14.6 | NA |
| Side Channel | 0.1 | 15.5 | 18.6 | -3.1 | 13.4 | 14.8 | -1.4 |

The only inflow was Laird Creek with only a slightly higher temperature than the East Fork. The impoundments identified on this reach were on average 2.5°C warmer, but may not be contributing water. There were two side channels located from the imagery (Figure 22).

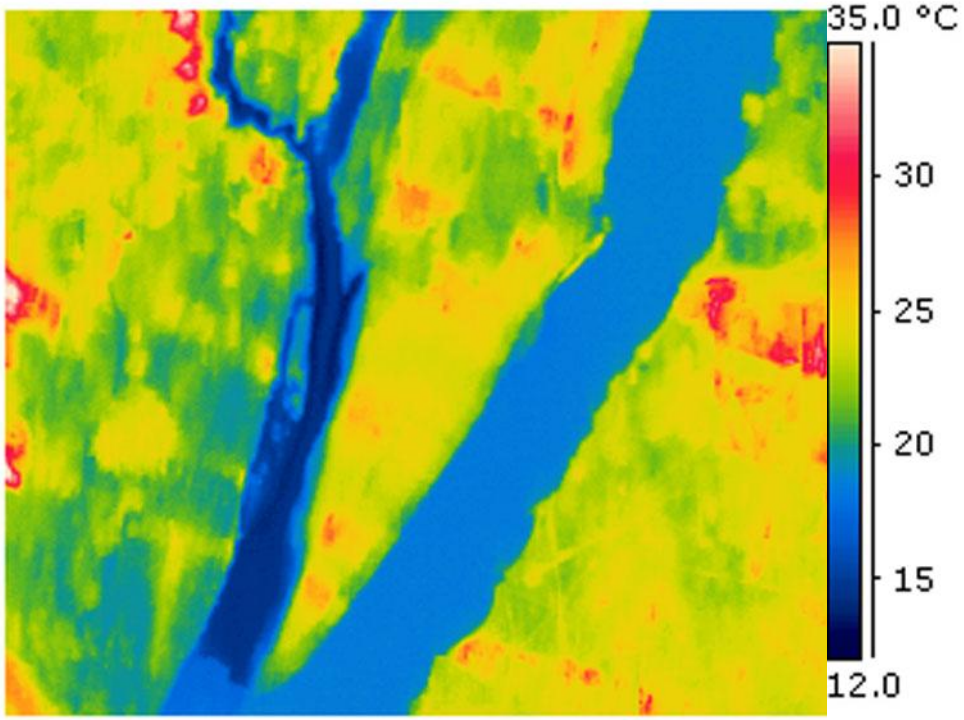


**Figure 22. Cold side channel at river mile 0.6.**

This side channel was 4.3°C cooler than the East Fork but did not impact the overall temperature downstream of its cold entry into the main channel.

## Discussion

### Summary of Potential Thermal Loading Sources

*Tributaries and Irrigation Returns*

Tributaries and returns are the features identified that are contributing water to the channel and would thus likely have a large influence on temperatures.

Tributaries were a source of thermal cooling on the Bitterroot and tributaries overall (Table 22).

**Table 22. Summary of temperature differences of tributaries compared to main channels.**

| Stream | n | Tributary – Main Channel (Afternoon Ave Temp °C ) | n | Tributary – Main Channel (Morning Ave Temp °C) |
|---|---|---|---|---|
| Bitterroot | 18 | -0.6 | 13 | -4.1 |
| Miller Creek | 5 | 3.0 | 3 | -3.8 |
| Lolo Creek | 1 | -2.4 | 1 | -4.5 |
| Lost Horse Creek | 0 | NA | 0 | NA |
| East Fork | 5 | -1.0 | 6 | 0.5 |

The average temperature of tributaries on the Bitterroot was 0.6°C cooler in the afternoon and 4.1°C cooler in the morning. The other streams follow this trend. The exception is Miller Creek with an average tributary temperature of 3°C warmer than the main channel. Looking at the data one tributary at mile 8 is almost 8°C warmer than Miller Creek. The CIR imagery does not make it clear that there is actually water in this tributary, therefore this high number could be the temperature of the dry channel. No flow data are available to determine what proportion of flow there tributaries contribute. In general tributaries were cooler and likely contributed to cooling trends.

Irrigation returns, when present, were usually a source of thermal warming on the Bitterroot and tributaries (Table 23).

**Table 23. Irrigation return summaries**

| Stream | n | Afternoon Ave Temp °C | n | Morning Ave Temp °C |
|---|---|---|---|---|
| Bitterroot | 3 | 1.1 | 3 | 2.1 |
| Miller Creek | 1 | 9.7 | 0 | NA |
| Lolo Creek | 2 | -0.7 | 2 | -1.8 |
| Lost Horse Creek | 0 | NA | 0 | NA |
| East Fork | 0 | NA | 0 | NA |

The Bitterroot and Miller Creek both had irrigation returns with temperatures higher than the main channels. Lolo Creek had cooler water entering from irrigation returns. All of these streams had a small number of irrigation returns identified. The other streams had no irrigation returns identified from the imagery. It is likely that there are additional irrigation returns on all if the streams, however they were impossible to accurately identify with this analysis. On the Bitterroot, for instance, the CIR imagery was useful in identifying irrigation returns, however the scope of these images often did not extend far enough out to capture all of the side channels, well enough the irrigation returns.

*Side Channels, Impoundments, and Cold Water Refugia*

Water stored on the floodplain in side channels and impoundments had wide-ranging temperature. Connectivity of these side features varies, but some may have an influence on

stream temperature. Due to the limited scope of the images, in many locations the full extent of side channels could not be viewed. It is possible that irrigation returns, tributaries and springs could contribute water to some of the features labeled as side channels. For this reason, it seems that side channels may have a significant influence on temperature changes. The variability seen in side channels is summarized in Table 24.

**Table 24. Side channel summaries**

| Stream | n | Afternoon Ave Temp °C | n | Morning Ave Temp °C |
|---|---|---|---|---|
| Bitterroot | 63 | 0.0 | 50 | -3.2 |
| Miller Creek | 1 | 3.8 | 1 | -2.2 |
| Lolo Creek | 10 | 0.8 | 9 | -0.8 |
| Lost Horse Creek | 7 | -0.7 | 7 | -5.3 |
| East Fork | 6 | -1.7 | 5 | 0.3 |

On the main Bitterroot, the average side channel temperature was not different from the main channel. This should not suggest that there was no temperature differences, but rather that the combination of warm and cool water was balanced out and that other cumulative factors affect stream temperature. Miller and Lolo Creek had side channels with average temperatures that were warmer in the morning and cooler in the afternoon, while Lost Horse showed the opposite pattern. The influence of side channels on temperature is likely significant, particularly on the Bitterroot, however it was not easy to quantify in this assessment. Ground water influences to and connectivity of side channels should be studied further to determine if these features are a consideration for water quality management.

Impoundments were generally warmer than the streams, as seen in Table 25.

**Table 25. Impoundment summaries**

| Stream | n | Afternoon Ave Temp °C | n | Morning Ave Temp °C |
|---|---|---|---|---|
| Bitterroot | 9 | 3.1 | 6 | 0.5 |
| Miller Creek | 1 | -1.0 | 0 | NA |
| Lolo Creek | 3 | 5.0 | 3 | 0.5 |
| Lost Horse Creek | 1 | 0 | 1 | -2.1 |
| East Fork | 0 | NA | 0 | NA |

Miller Creek was the exception to this rule. Connectivity of impoundments should be studied further to determine if these features are a consideration for water quality management.

Cold water refuges were found on all of the streams except Miller Creek (Table 26).

**Table 26. Cold water refuges summaries**

| Stream | n | Afternoon Ave Temp °C | n | Morning Ave Temp °C |
|---|---|---|---|---|
| Bitterroot | 5 | -2.4 | 5 | -5.1 |
| Miller Creek | 0 | NA | 0 | NA |
| Lolo Creek | 3 | -4.1 | 3 | -3.0 |
| Lost Horse Creek | 1 | -3.0 | 0 | NA |
| East Fork | 2 | -3.5 | 1 | -0.1 |

The degree of their influence on overall stream temperatures was not clear from this assessment.

***Uncertainties***

One uncertainty seen in this assessment is that the FLIR temperatures only reflect the temperature at the top of the waters surface. As illustrated in Figure 18, deeper water could greatly increase the potential for error in assessing true temperature.

The limited scope of the images is another weakness of this study. Because the FLIR methods dictate a limited image scope, any features located outside the main channel were excluded. This was particularly a problem on the main Bitterroot, which is characterized by multiple braided channels. Often the pilot would have to choose the main channel while missing other channels, which at times had dramatically different temperatures. As explained above, many of the side channels on the Bitterroot may have groundwater, spring or even irrigation returns entering them outside the visible scope of the imagery. For this reason the side channels had greater than expected impact on overall temperatures.

Analysis of the thermal accuracy of the FLIR images compared to in-stream sensors was well within the specified tolerance of plus or minus 5°C.

Groundwater upwellings are not visible from the surface radiation captured in FLIR, 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 FLIR imagery.

The influence of diversions and irrigation return flows could not be quantified at a cumulative level because the scope of this study did not include measuring flow for every diversion and return. Additionally, the influence of the diversions and returns would 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 dewatering for irrigation on stream temperature. Water commissioners in the Bitterroot area may have information about flow of irrigation diversions for the time of the flight, but irrigation returns generally are not measured.

Stream temperature reflects watershed-scale as well as local scale influences. It is 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 temperature of the Bitterroot at the watershed scale.

## Citations

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.

Western Regional Climate Center. Historical climate information accessed in December 2004 at http://www.wrcc.dri.edu/CLIMATEDATA.html