APPENDIX G
FORWARD LOOKING INFRARED REPORTS

Forward Looking Infrared Methods Report
Forward Looking Infrared Results Report
- Map 1 Lower Ruby River FLIR Temperatures
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- Map 3 Lower Ruby FLIR Remote Assessment Map Reaches LR01-LR04
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FLIR METHODS REPORT

Introduction

During the summer of 2004, Infrared Image Solutions, Inc. of Hermiston, OR was contracted to collect multi-spectral imagery on portions of the Ruby River in Montana. 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. Project data consists of digital imagery in thermal infrared (FLIR), color-infrared (CIR) and normal color videography.

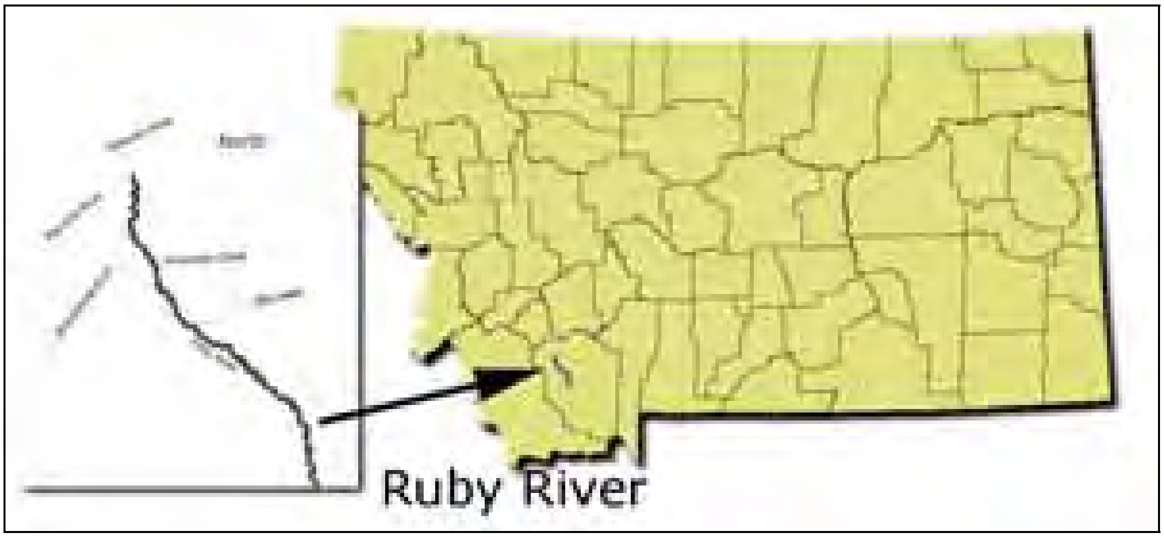


Figure 1: Project area overview.

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 Table 1. A link to the manufacturer's website with full specifications is included at the end of the document.

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.

Table 2: Summary of MS 4100 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

Methodology

FLIR imagery was collected on the afternoon of August 3 from a helicopter flying between 1000 and 1500 feet above the ground. Visual videography was recorded simultaneously with the FLIR imagery The project was scheduled for a time window between 4:00 pm and 6:00 pm. Because of afternoon thunderstorm activity on August 3 the flight was delayed by 45 minutes. Even with the delay the flight was concluded by approximately 5:30 pm. The flight began at the town of Twin Bridges and proceeded upstream to Ruby Reservoir.Weather conditions for the flight are detailed in Table 3 below.

Table 3: Atmospheric conditions.

Flight Date	August 3, 2004
Flight Time	4:45 - 5:30 MDT
Air temperature/Altitude	18.8 C.
Ground Temperature	20 C.
Relative Humidity	50%

Data

FLIR

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

FLIR Processing

Approximately 1 out of every 15 frames (1 frame every two seconds) was sampled by averaging the temperatures along a line in the center of the river (Figure 2).

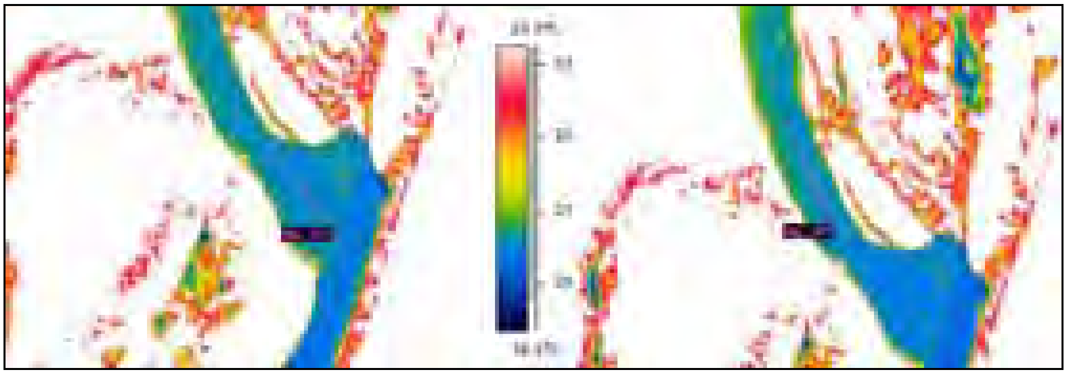


Figure 2: Temperature sampling method. The image on the right was captured two seconds after the image on the left as the helicopter was moving upstream. Temperature data for each image is averaged along the magenta line in the center of each image.

Tabular data from the FLIR image analysis was input into a GIS to create an ArcView shapefile. Figure 3 is a screen capture of the FLIR shapefile. The magenta dots are spaced at intervals one tenth of a mile apart. The temperature attribute in the theme table for each point represents the *average* temperature of all of the images within one tenth of a mile from that point, typically 6-8 images.

Figure 3: Detail of GIS coverage showing stream layer and FLIR data.

Video

Simultaneous 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 AVI format on DVD (Figure 4). The two FLIR images in the video are identical, the only difference being the color scale.

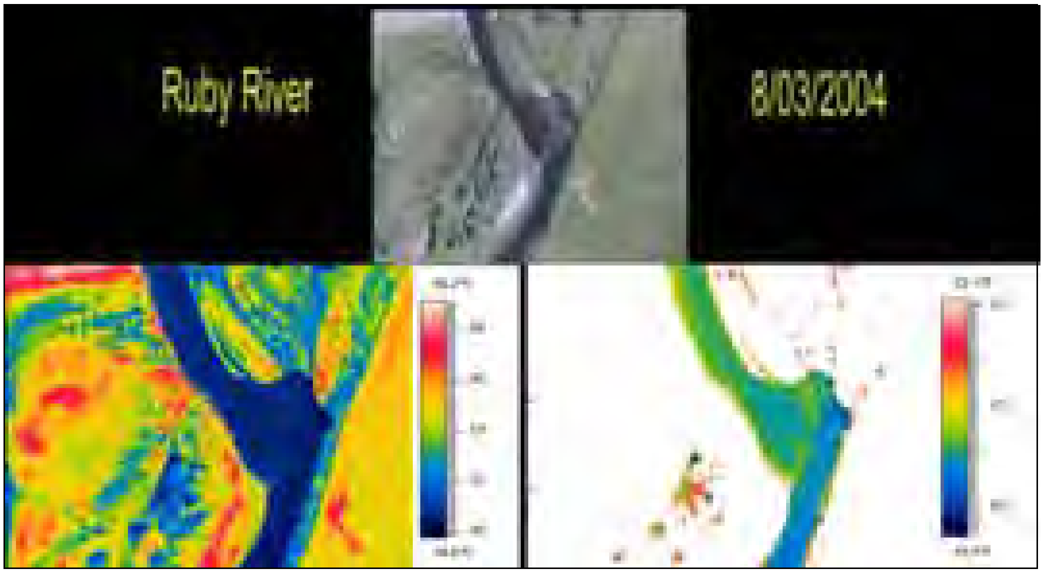


Figure 4: Simulated frame capture of synchronized video of the same portion of the Ruby River as seen in Figure 2 above.

CIR

Color-infrared images were collected from a fixed-wing airplane on August 30, 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 5). 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 is included in the data disk with this report.

Figure 5: CIR image of the same area as in Figure 2 and Figure 4.

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 look. On the day of the flight the skies had produced a scattered layer of cumulonimbus clouds that were building at the beginning of the flight. During the flight there were two locations that had shadows over the river. Because the clouds were building a decision was made to continue the flight and try to pick up those areas on the return flight. The area never did clear up sufficiently to make another try at the shady areas before the sun got too low in the sky. To mitigate this, images with shadows over the river were enhanced with an additional histogram stretch so that ground features would still be legible. Using ERDAS imagine, the CIR images were first geo-referenced then mosaicked. The images for the mosaic were sub sampled to 2-meter pixel resolution to reduce file size.

GIS

Nearly 4 gigabytes of raw data was collected for this project, mostly consisting of FLIR and CIR images. After processing the data the project size increased to 13.5 gigabytes. ArcView GIS is used to present the data in a meaningful and organized format for viewing, analyzing and sharing. The following table contains a short description of the GIS files.

File name	Description
Cirlocations.shp	Point theme representing the location and image ID of the CIR images.
Flow_2004loggers.shp	Point theme showing locations of all ground temperature loggers on the Ruby River.
Rubyflir_3.shp	FLIR image point theme. Points are one tenth of a mile apart and the temperature values are averaged at each point. Those points nearest in proximity to a ground datalogger contain data that represents the ground measured water temperature at the time of the flight.

Equipment

Detailed product specifications for the equipment used for the Ruby River Project may be found at the following locations on web:

- ThermaCam S60 http://www.flirthermography.com/english/cameras/camera/1026/
- Redlake MS 4100 http://redlake.com/spectral/mega_MS4100.html

Infrared Links

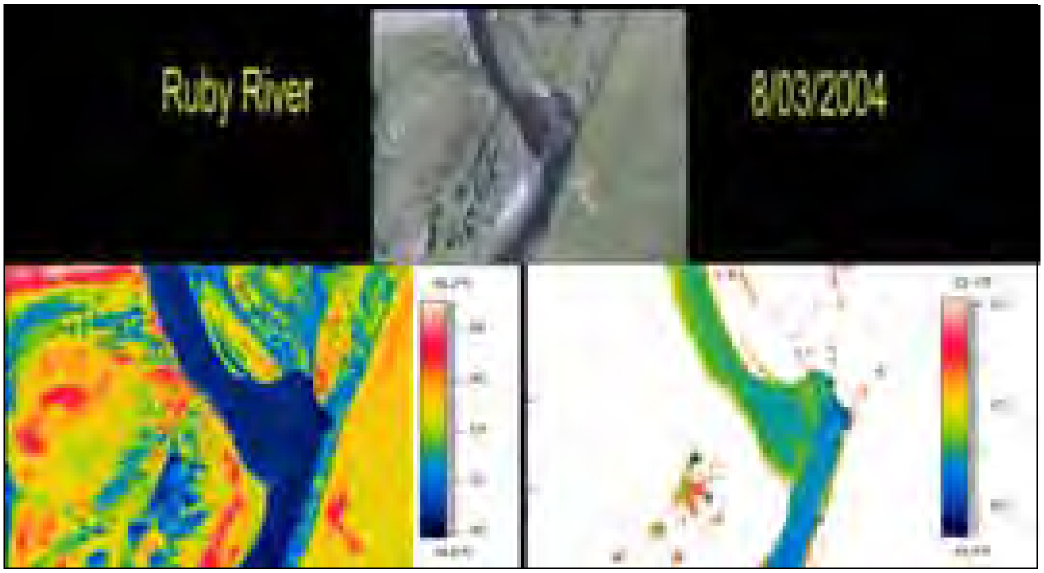
The following links contain additional information about thermal infrared technology and equipment.

- http://www.flirthermography.com/english/about/
- http://rst.gsfc.nasa.gov/Sect9/Sect9_1.html

Forward Looking Infrared Results Report

Ruby River FLIR Temperature Analysis

Interpretive Report



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INTERPRETIVE REPORT
RUBY 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 Ruby River TPA. The FLIR analysis was conducted to support Total Maximum Daily Load (TMDL) development for temperature-listed streams in the Ruby 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. Monitoring associated with the FLIR flight was also used to calibrate an SNTEMP temperature model run for the same assessment time period. Results of the modeling will provide additional information about the influence of streamflow and probable groundwater contributions to stream temperature. Temperature modeling results are presented in a separate document.

Methods

Data Collection
During the summer of 2004, Infrared Image Solutions, Inc. (IRIS) of Hermiston, OR was contracted to collect multi-spectral imagery on portions of the Ruby River in Montana. Project data consists of digital imagery in thermal infrared (FLIR), color-infrared (CIR) and normal color videography.

Equipment
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.
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). A complete description of camera specifications is given in Forward Looking Infrared Methods Report in this Appendix.

FLIR Data Collection

IRIS conducted flights to collect FLIR imagery of the Ruby River Watershed during a helicopter flight on August 3, 2004 between 14:44 and 17:30 MDT. This date was chosen because it is during what is historically one of the hottest 2-week periods of the year. Figure 1 shows the historic temperatures in the Ruby watershed and the temperature trends for 2004.

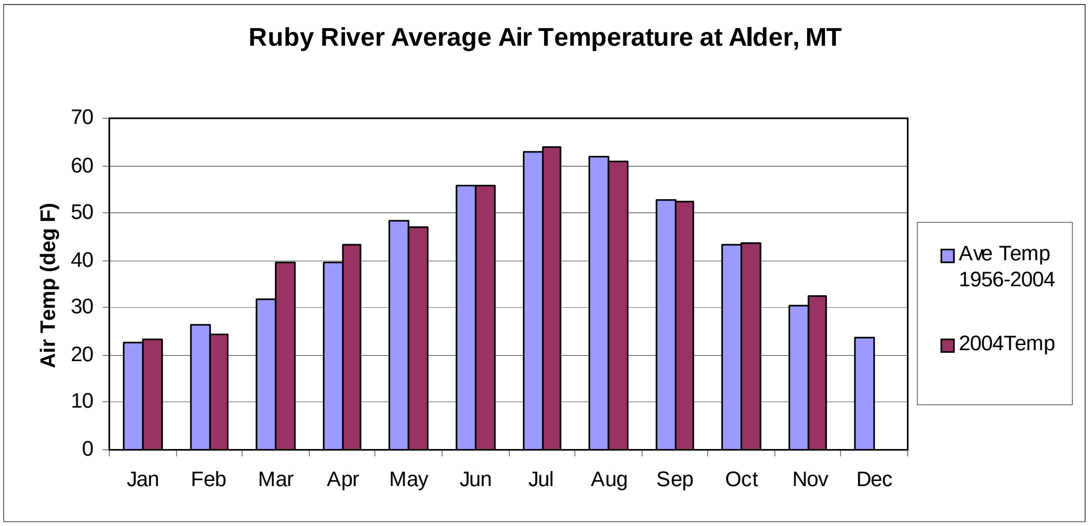


Figure 1. Average annual air temperature at Alder, Montana. Source: Western Regional Climate Center.

As illustrated in Figure 1, temperatures in 2004 were consistent with historic averages. However, thunderstorm activity in the watershed on the day of the FLIR flight cooled air temperatures on the date of the flight. More detail about this consideration is provided below.

Imagery was collected on the afternoon of August 3 from a helicopter flying between 1000 and 1500 feet above the ground. Weather conditions for the flight are detailed in Table 1 below.

Table 1. Weather conditions on flight date for Twin Bridges, MT.

Flight Date	August 3, 2004
Flight Time	4:45 - 5:30 MDT
Air temperature/Altitude	18.8 C.
Ground Temperature	20 C.
Relative Humidity	50%

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 AVI format on DVD (Figure 2).

The two FLIR 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.

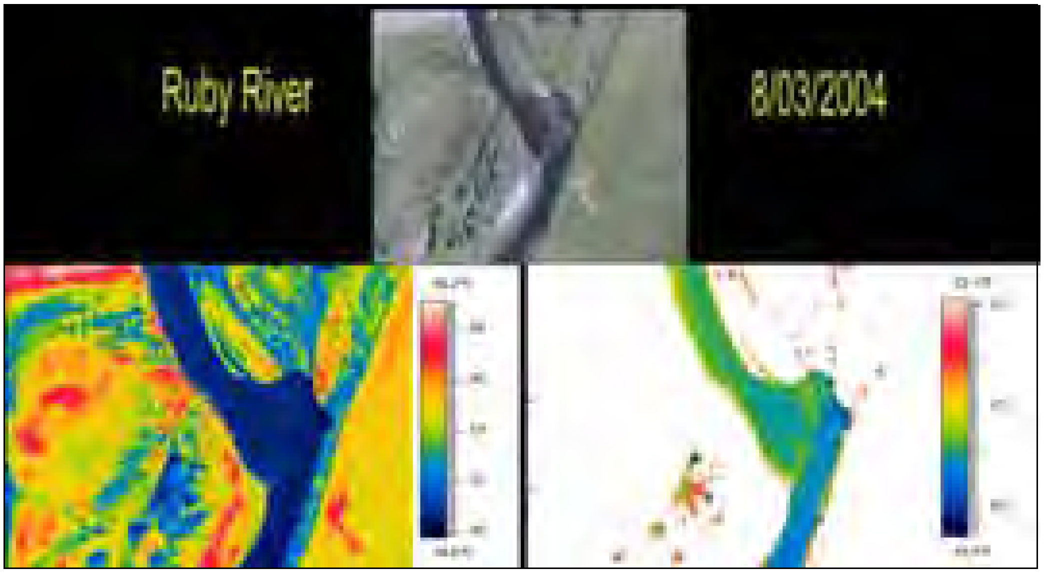


Figure 2. Simulated frame capture of synchronized video of the same portion of the Ruby River as seen in FLIR images below.

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

<u>CIR Data Collection</u>

Color-infrared images were collected from a fixed-wing airplane on August 30, 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).

Figure 3. CIR image of the area shown in Figure 2.

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 georeferenced 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 31 locations within the Ruby River Watershed prior to the aerial surveys (Figure 4). The temperature loggers were ONSET Optic Stowaway (Part # WTA32-05+37), manufactured by Onset Computer Corporation. They are accurate to hundredths of a degree. The stowaway did not require calibration and accuracy was determined by comparing recorded logger temperatures against an NIST thermometer according to manufacturers recommendation. Figure 4 also illustrates the flight path and extent of the surveys, which began near the town of Twin Bridges, MT and progressed south to the Ruby Reservoir.

Figure 4. Lower Ruby 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 2.

Table 2. Temperature logger locations

Site ID	Site Description
LR01	At USGS gage DS of dam
LR02	Below major diversions below dam
LR03	Above Clear Creek outflow
LR04	Ruby Springs Lodge
LR05	Above Alder Creek inflow
LR06	Above California Creek inflow
LR07	Below Bivens Creek inflow

Site ID	Site Description
LR08	Clear Ck above inflow to Ruby
LR09	Above Silver Sprig inflow
LR10	DS of Silver Spring inflow
LR11	DS of Ramshorn Ck inflow
LR12	Fay ranches
LR13	Above return from west bench ditch
LR14	Morse Land - above diversion
LR14	2nd logger in pool
LR15	Morse Land - above Mill Ck inflow
LR16	Below Mill Ck inflow
LR17	Seyler Lane- above Mouth of Ruby
M01	Headwaters- near forks
M02	Lower end conifer forest area- above first diversion
M03	Above diversion
M04	Below other diversion
M05	Above Sheridan
M06	Lower canopy cover - in alluvial valley
M07	100 ft US of Middle Road
M08	At springs area- Below inflow/GW return
M09	Above Confluence with Ruby
T01	Ramshorn Ck above confluence
T02	Silver Spring above confluence
T04	Indian Ck/Leonard slough above confluence
T05	Inflow –Irrigation return

Field Data Collection

Field data collected to calibrate and ground-truth temperature modeling included stream canopy density measurements using a spherical densiometer, channel widths and depths, and stream flow. These data have been submitted to MDEQ. Field Monitoring was conducted at the same locations as the temperature logger sites. These locations are included Figure 4 and Table 2 above.

Canopy density over the stream was estimated using a concave spherical densiometer held at waist height on six transects per reach. Transects were spaced at 200 feet intervals upstream from the cross section location. Measurements were taken at four points across the stream, standing one foot from each bank facing the banks, and standing in the middle of the stream channel facing upstream and downstream. The average of the measurements taken at the four points was used as the canopy density for that transect, and all transects were averaged for the reach.

Ten channel bankfull widths were measured in all assessment reaches. The average width was derived from the 10 measurements. Stream flow was measured using a Price AA meter with Aquacalc5000 digimeter, following USGS standard protocols.

Data Processing

<u>FLIR Processing</u>

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 along a line in the center of the river (Figure 5).

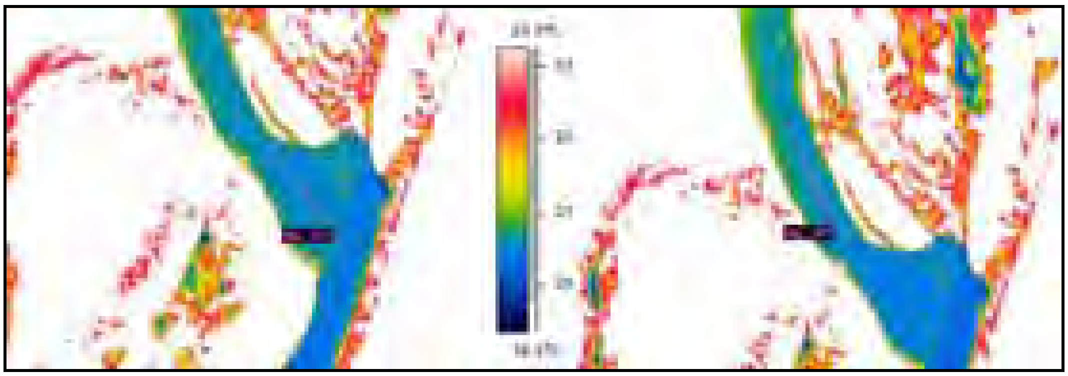


Figure 5. Temperature sampling method. The image on the right was captured two seconds after the image on the left as the helicopter was moving upstream. Temperature data for each image is averaged along the magenta line in the center of each image.

Tabular data from the FLIR image analysis was utilized to create an ArcView GIS shapefile. Figure 6 is a screen capture of the FLIR shapefile. The magenta dots are spaced at intervals one tenth of a mile apart. The temperature attribute in the theme table for each point represents the *average* temperature of all of the images within one tenth of a mile from that point, typically 6-8 images.

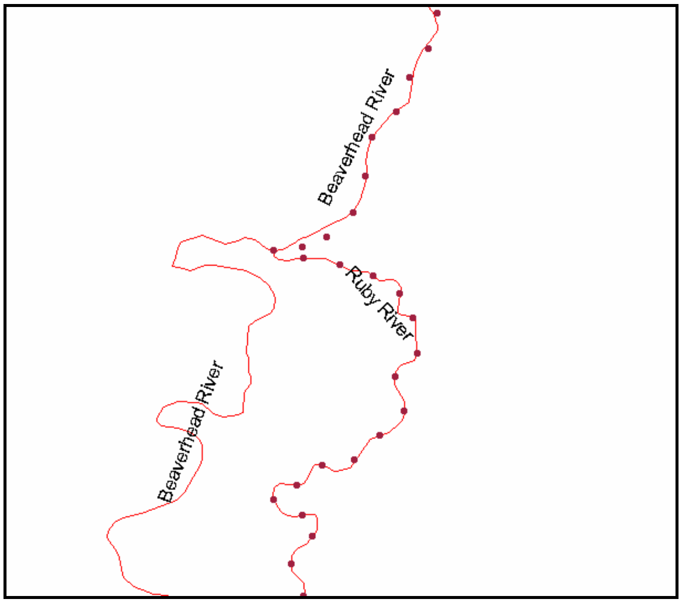


Figure 6. Detail of GIS coverage showing stream layer and FLIR data

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. On the day of the flight, the skies had produced a scattered layer of cumulonimbus clouds that were building at the beginning of the flight. During the flight there were two locations with shadows over the river. Because the clouds were building a decision was made to continue the flight and attempt to pick up those areas on the return flight. The clouded area did not clear up sufficiently that day to re-fly the shady areas before the sun dropped too low in the sky. To mitigate this, images with shadows over the river were enhanced with an additional histogram stretch so that ground features would still be legible.

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. 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 data and temperature macro analysis 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. The data were assessed at the time the flight was taken and the imagery acquired.

Table 3. Comparison of logger temperatures with radiant temperatures.

Site ID	River Mile	Logger Temp	FLIR Temp	Difference
RBYLR01	44.4	17.9	18.4	-0.5
RBYLR02	41.6	17.6	17.4	0.2
RBYLR03	37.4	17.8	16.9	0.9
RBYLR04	35.2	16.4	15.7	0.7
RBYLR05	31.2	16.3	16.5	-0.2
RBYLR07	27.6	16.2	16.5	-0.3
RBYLR09	21.2	16.3	15.4	0.9
RBYLR10	21.0	16.2	15.4	0.8
RBYLR11	18.9	17.3	16.6	0.7
RBYLR12	16.8	17.4	17.1	0.3
RBYLR13	13.5	18.1	18.1	0.0
RBYLR14	11.8	18.3	18.3	0.0
RBYLR15	8.3	18.2	18.6	-0.4
RBYLR16	7.1	18.7	18.5	0.2
RBYLR17	2.0	19.4	19.6	-0.2

The differences ranged from 0.9°C to 0.0°C. The average difference of 0.4°C for all the points is consistent with thermal infrared surveys conducted on other streams since 1994 (Torgersen et.al 2001).

GIS Processing

Nearly 4 gigabytes of raw data was collected for this project, mostly consisting of FLIR and CIR images. ArcView GIS was 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, diversions and areas with no riparian buffer. The Ruby River was characterized through much of its length by a number of meander bends and small oxbow ponds. These areas were labeled during the analysis as either a side channel or an oxbow. 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. If the feature was visible in the imagery, but did not appear to have current surface exchange with the mainstem, it was labeled an oxbow.

Coldwater refugia, as used in this analysis, indicates a noticeable change in temperature in the stream. It is not necessarily a 2°C difference, and is within the accuracy range of the camera used to collect FLIR images (Table 4).

Table 4. Specifications for the camera used in the FLIR flight.

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%

Absence of riparian buffer was assessed using CIR imagery and DOQs. In addition sites in which field data was collected were used to verify the presence or absence of riparian buffer as seen in the CIR and DOQ imagery.

Results

Longitudinal Temperature Profile

The FLIR temperatures for the Ruby River were plotted versus the corresponding river mile (Figure 7). The plot also contains temperatures of tributaries. The tributary temperatures are from loggers at the downstream end of each tributary (just above confluence with the Ruby). The six side channels included in Figure 7 are all of the tributaries in which temperature logger data was collected. 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 datapoint for that tributary. FLIR flights were not conducted on side channels. An average of the three temperatures logged during the flight time was used to determine the tributary temperature.

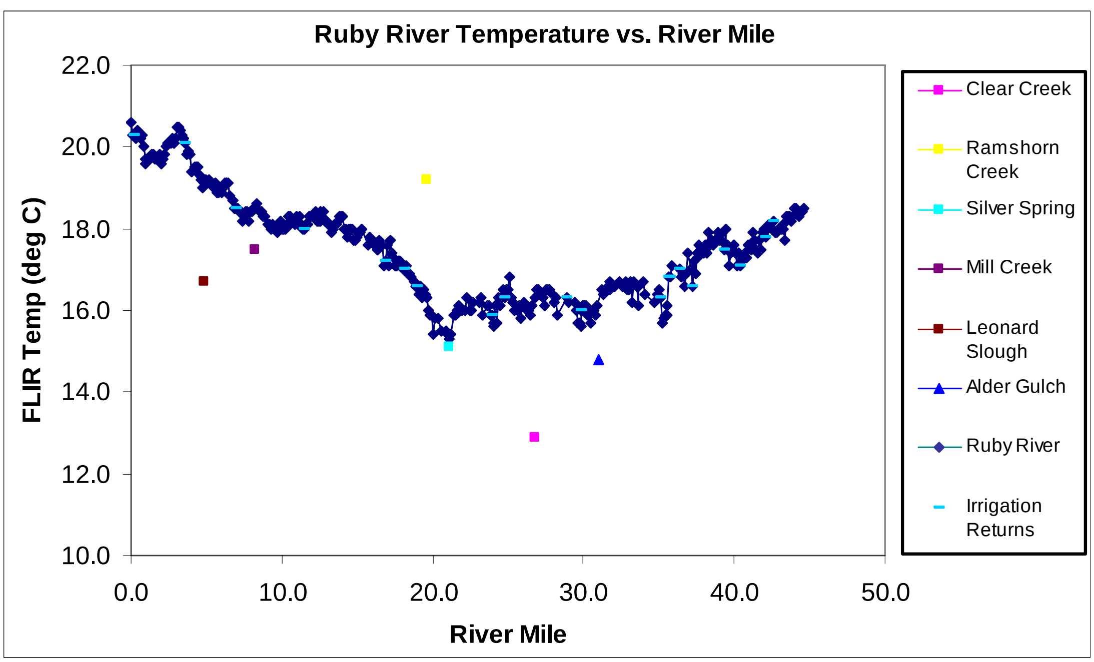


Figure 7. Channel temperatures plotted by river mile for Lower Ruby River

A map illustrating temperature trends along the lower Ruby River is included in Map 1. This map is based on GIS data derived from FLIR temperature data averaged for every 0.1 mile, as described above under FLIR Processing.

Temperatures on the Ruby River ranged from a maximum of 20.6°C at the mouth (river mile 0.0) to a minimum of 15.3°C at river mile 22.9. The average temperature was 17.6°C. Overall the Ruby River shows a warming trend from the Ruby Reservoir (RM 44.6) downstream to the confluence with the Beaverhead River. The following data presents many potential influences on Ruby River temperatures. The river was broken into 22 reaches determined by tributary locations and irrigation returns or diversions (length was also taken into account) (Map 2). A quantification of features based on reach breaks is housed at MDEQ and available upon request. Maps 3 through 7 include digitized features by reach. Stream temperature reflects watershed-scale as well as local scale influences. It is subject to cumulative effects that extend beyond the reach scale. This analysis provides a general source characterization and identifies some temperature sources influencing temperature at a local scale.

Results by Stream Reach

The following sections are delineated by reaches grouped together based on temperature trends. Reaches are grouped into larger segments for this discussion for reporting clarity and to reveal larger trends. The first table for each section of stream illustrates the features identified in the FLIR coverage that potentially contributed water (hence potential temperature change) to the Ruby. 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. Some areas of the river and adjacent riparian area were not captured in the flight. The sections that were missed were digitized into a GIS shapefile and submitted to Montana DEQ. Contact MDEQ to acquire for a complete list of features based on CIR and DOQ analysis (including those without temperature data).

Another table for each section includes information about adjacent oxbows and impoundments which were captured by the FLIR flight and which may contribute water to the stream but are not located directly on the stream. The third table of each section below includes additional data for each section of stream including reach length, number of diversions and length of stream with no riparian buffer. The number of diversions has been summarized 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. There were a total of 28 diversions seen on the Lower Ruby. The number of diversions in each reach is included in the third table for each stream segment as supporting information. Contact MDEQ for the database with this detailed information.

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. However, we did not find any relationship between increased temperature of a segment to the riparian buffer of the upstream segments in this assessment. It was expected that a lack of riparian buffer would have a slight effect on stream temperature. A great influence on temperature is not expected because the Ruby River is a willow-dominated system, and never has canopy cover greater than 35%. Further assessment of temperature trends in relation to riparian cover and stream flow will be addressed through SNTEMP modeling. 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.

Miles 44.6-39.2

This stretch of river includes the upstream-most reaches, including reaches LR1, LR2 and LR3 (Map 2). The temperature directly below the Ruby Reservoir, at river mile 44.6, was 18.5°C. The stream temperature decreased for the next four miles to 17.1°C at river mile 40.4. The decrease was generally gradual with each temperature reading (taken every one tenth of a mile) 0.1 or 0.2 °C cooler than the upstream temperature measurement. An exception to this general cooling trend was seen at mile 43.5, where the temperature was 18.3 and the next reading (mile 43.3) was 17.7. The temperature then increased to 18.1 (mile 43.3) and continued with the general cooling trend.

There is a spring located near river mile 41 on reach LR3. The water from this spring appears to flow into a canal that enters the river downstream of this section. There are several surface irrigation returns on this stretch of river contributing water with temperatures from 15.7 to 17.9°C. Irrigation returns, side channels, and irrigation returns are generally cooler than the main Ruby River, indicated by a negative number in the last column in Table 5. The lower temperature of side channels may reflect groundwater inputs. The cooler side channels likely contribute to the cooling trend seen on this section of the Ruby.

Table 5. Tributary, diversion intake and side channel temperatures for Lower Ruby reaches LR1-LR3.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Temperature Difference °C
Side Channel	43.4	17.7	17.7	0.0
Side Channel	43.3	16.7	18.1	-1.4
Irrigation Return	42.6	16.9	18.2	-1.3
Irrigation Return	42.1	17.9	17.8	0.1
Irrigation Return	40.4	15.7	17.1	-1.4
Cold Water Refuge	39.5	12.5	17.6	-5.1

The average temperatures in the impoundment and oxbow found in this section are also cooler than the Ruby (Table 6).

Table 6. Impoundment and oxbow temperatures for Lower Ruby reaches LR1-LR3.

Off-channel Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Impoundment	40.4	15.2	17.1	-1.9
Oxbow	40.2	16.5	17.1	-0.6

These features do not appear to dramatically alter the stream temperature within this reach, and there is no noticeable change in FLIR temperature with any of them. However, they are likely contributors to the general cooling trend seen on this section of the Ruby. The Ruby River shows a slight warming trend from river mile 40.3 to 39.4, where the temperature was 18°C. The cold water refuge listed in Table 5 (mile 39.5) appears to be associated with a surface water irrigation return flow (Figure 8).

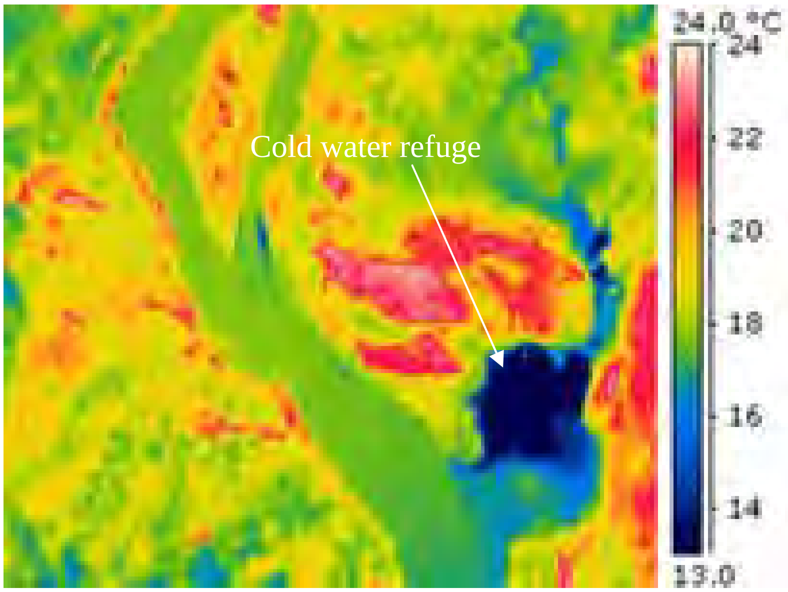


Figure 8. FLIR image of cold water refuge found at river mile 39.5

The average temperature of this feature was 12.7°C, which is over 5°C cooler than the stream at this point. This feature contributed colder water locally to the Ruby River, but did not impact the overall temperature of the Ruby River in this section.

Table 7 summarizes data reflecting the overall cooling trend on this section of river. Also included is information on riparian buffer, for its possible influence on stream temperature. FLIR results do not show any noticeable influence of riparian buffer on stream temperature for this segment.

Table 7. Summary of features for Lower Ruby reaches LR1-LR3.

Reach ID	Average Temp °C	Upstream-Downstream Temp Change	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR01	18.41	-0.2	1466.6	145.8	5.0	0
LR02	18.06	-0.2	3012.3	664.9	11.0	3
LR03	17.54	0.1	5464.1	1762.9	16.1	2

*** Note:** In this and all sections, the percent no buffer was found by taking the no buffer length divided by reach length times two. This is due to the fact that no buffer was recorded on both sides of stream, hence total possible length is twice reach length.

Reaches LR01 and LR02 were both 0.2°C cooler at the bottom than at the top of the reach, even though LR02 has twice as much streambank lacking riparian buffer as LR01. LR03 displayed a slight increase in temperature and had the lowest percent riparian buffer, but that trend is not necessarily indicative of a cause-effect relationship.

39.3-35.1 (Reaches LR4-LR5)

From river mile 39.4-35.1 the temperature in the Ruby shows a general decreasing trend. Temperature decreased to 15.7°C at river mile 35.2. Upstream of mile 35.7 the river temperature is around 17°C. An irrigation return comes in just below this point and a cold water refuge was identified at this inflow with a temperature almost 5°C cooler than the Ruby at the irrigation return confluence (Figure 9, Table 8). This cold water input can be seen as the dark blue water entering from the upper left side of figure 9. Although not seen in this image, this cold water appears to lower the temperature of the Ruby locally by 1°C.

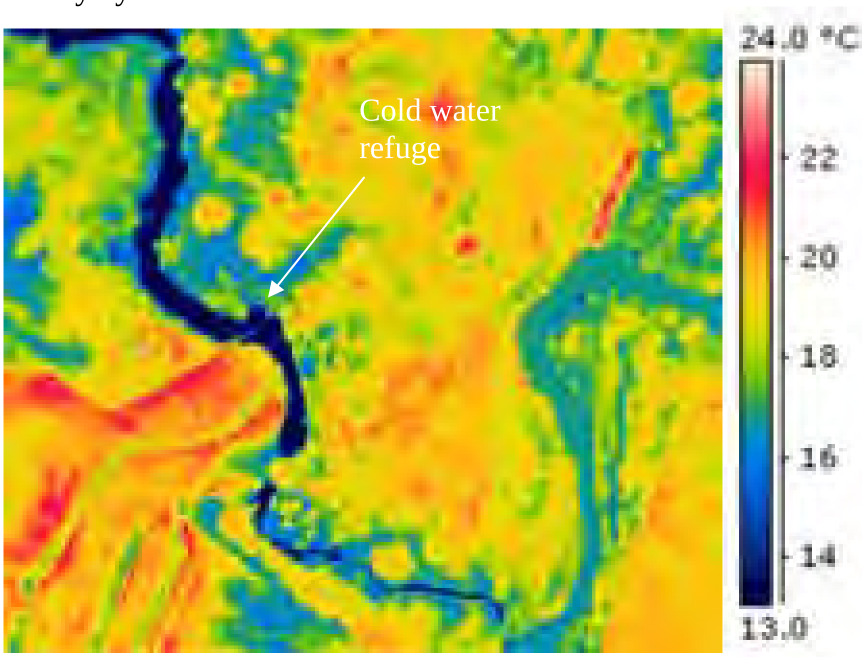


Figure 9. FLIR image of cold water refuge (entering from top left) found at river mile 37.2.

Table 8 shows that almost all of the inflows in this stretch of river are cooler than the Ruby River.

Table 8. Tributary, diversion intake and side channel temperatures for Lower Ruby reaches LR4 and LR5.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Irrigation Return	39.3	17.5	17.5	0.0
Cold Water Refuge	38.2	14.3	17.4	-3.1
Cold Water Refuge	37.6	13.3	17.3	-4.0
Side Channel	37.5	17.0	17.4	-0.4
Cold Water Refuge	37.2	12.0	16.6	-4.6

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Irrigation Return	37.2	12.5	16.6	-4.1
Irrigation Return	36.4	16.6	17	-0.4
Cold Water Refuge	35.8	14.8	16.8	-2.0
Irrigation Return	35.8	14.8	16.8	-2.0
Irrigation Return	35.7	16.2	16.8	-0.6
Irrigation Return	35.1	17.9	16.3	1.6

In addition there are likely cold water inputs from groundwater in this section of river. This is where Alder Creek historically entered the Ruby. The temperature in LR05, which is the reach at the base of Alder Gulch, was 0.8°C cooler at the bottom of the reach than at the top. The channel of Alder Creek was altered by mining alterations and re-channeled to flow north. Although not visible in the imagery, the cooling suggests that sub-surface water exchanges through the flood plain probably mitigate other sources of heat gain in this reach.

Table 9 summarizes data reflecting a cooling trend seen in this section of river. Again there are significant lengths of stream with no buffer, however they are not reflected in stream temperatures for this segment. The effects of diversions also are not reflected in stream temperature of this segment.

Table 9. Summary of features for Lower Ruby reaches LR4 and LR5.

Reach ID	Average Temp °C	Change in Temp	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR04	17.56	0.1	3359.4	1724.0	25.7	3
LR05	16.60	-0.8	4205.7	1723.5	20.5	3

One of the diversions in this section of stream (mile 37.4) is where Clear Creek is diverted from the Ruby.

35.0-21.1 (Reaches LR6-LR10)

Stream temperatures on the Ruby fluctuate between 15.3°C and 16.8°C from river mile 35.1 to 21.1. The temperature reaches a low of 15.3°C at river mile 21.1. There are numerous inputs to this section of stream (Table 10). They contribute primarily cold water, with an average temperature that is 1.3°C cooler than the Ruby in the same area.

Table 10. Tributary, irrigation return and side channel temperatures for Lower Ruby reaches LR6-LR10.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Cold Water Refuge	33.0	13.1	16.5	-3.4
Side Channel	31.3	16.3	16.4	-0.1
Side Channel	30.9	15.9	16.1	-0.2
Side Channel	30.4	16.2	16	0.2
Alder Gulch	30.0	14.8	16.2	-1.4
Cold Water Refuge	29.9	14.4	16	-1.6
Irrigation Return	29.9	14.0	16	-2.0
Side Channel	29.8	16.0	15.6	0.4

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Side Channel	29.4	15.8	16.2	-0.4
Irrigation Return	28.9	15.2	16.3	-1.1
Bivens Creek	27.7	16.2	16.5	-0.3
Cold Water Refuge	27.4	13.0	16.1	-3.1
Cold Water Refuge	26.8	13.1	16.3	-3.2
Clear Creek	26.8	13.1	16.3	-3.2
Side Channel	26.6	16.0	16.1	-0.1
Cold Water Refuge	26.1	11.2	16.2	-5.0
Cold Water Refuge	26.0	14.5	16.2	-1.7
Side Channel	25.3	16.6	16.2	0.4
Irrigation Return	24.8	15.5	16.3	-0.8
Side Channel	24.8	16.5	16.3	0.2
Side Channel	24.4	14.5	16.3	-1.8
Cold Water Refuge	24.3	13.2	15.7	-2.5
Irrigation Return	23.9	15.6	15.9	-0.3
Cold Water Refuge	23.2	13.5	16.3	-2.8
Side Channel	21.4	16.6	15.9	0.7
Cold Water Refuge	21.1	14.1	15.3	-1.2
Silver Spring	21.1	14.1	15.3	-1.2

Tributaries also contribute to the areas of cooling seen on this section of the Ruby. Alder Creek enters at river mile 30.9 and the instream temperature drops from 16.7°C to 15.7°C. As mentioned earlier, there may be groundwater influences as well, primarily upstream of this segment. Clear Creek enters at river mile 26.8 and causes the stream temperature to drop slightly (16.5 to15.9 °C). Silver Spring (river mile 21.1) is another source of thermal cooling in this section of river. It results the river dropping to 15.3, its lowest temperature below the dam. A temperature logger in Silver Spring recorded the temperature at 15.1°C at the time of the flight. There were nine cold water refugia detected in this section of stream. They were, on average, 2.7°C cooler than the surrounding stream.

In addition to many cool water inputs, there are multiple features without surface connectivity to the Ruby. Table 11 shows that the many off stream features are warmer than the Ruby in this section. The average temperature of these features was 1°C warmer than the river. The exact influence of groundwater from oxbows and impoundments on temperature is impossible to quantify in this study. However, both connected and disconnected surface water that can be seen in the FLIR images could explain the warming/cooling pattern in this section of the Ruby River.

Table 11. Impoundment and oxbow temperatures for Lower Ruby reaches LR6-LR10.

Off-channel Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Oxbow	33.1	13.5	16.7	-3.2
Oxbow	32.9	16.7	16.5	0.2
Oxbow	30.9	16.9	16.1	0.8
Impoundment	30.7	13.3	16	-2.7

Off-channel Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Impoundment	29.7	14.6	15.7	-1.1
Oxbow	27.6	18.1	16.5	1.6
Impoundment	26.8	20.0	16.3	3.7
Oxbow	24.7	17.4	16.5	0.9
Oxbow	24.6	18.8	16.3	2.5
Oxbow	24.2	17.7	16.1	1.6
Oxbow	23.1	19.5	16.2	3.3
Oxbow	22.6	20.1	16	4.1

Figure 10 shows cold water from Clear Creek entering the Ruby on river left (average temperature is 3.2°C cooler than the Ruby). At the same point on the river (mile 26.8) there is an impoundment which potentially contributes warm water (average temperature 3.7°C warmer than the Ruby). This impoundment had water in it the day of the flight but it does not seem to contribute warm water. Directly downstream of this point the overall temperature cools due to the coldwater input on the left bank.

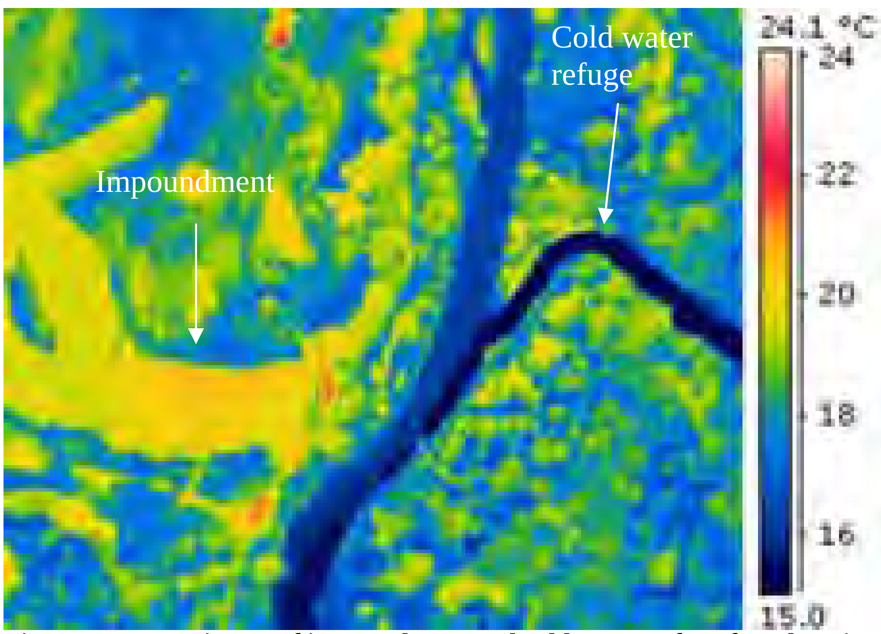


Figure 10. FLIR image of impoundment and cold water refuge found at river mile 26.8.

Table 12 summarizes the temperature fluctuations seen in this section of the Ruby.

Table 12. Summary of features for Lower Ruby reaches LR6-LR10.

Reach ID	Average Temp °C	Change in Temp	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR06	16.52	-0.9	7394.0	5563.8	37.6	1
LR07	15.94	0	3640.4	1092.7	15.0	0
LR08	16.33	0.1	4758.2	2791.8	29.3	2
LR09	16.19	0.3	4959.4	1321.6	13.3	0
LR10	15.98	-0.2	6308.7	1514.3	12.0	2

<u>21.0-15.2 (Reaches LR11-LR13)</u>

From river mile 21.0 to 15.2 the stream temperature generally shows a warming trend to a maximum temperature of 17.9°C at river mile 15.2. Table 12 illustrates that many of the inputs on this stretch of river are warm water. At mile 19.6 Ramshorn Creek enters and contributes warmer water, increasing the rate of gradual warming on the Ruby. Another likely significant contributor to the warming trend seen on this section of river is an irrigation return at mile 18.1 that is 4.1°C warmer that the Ruby at that point (Table 13).

Table 13. Tributary, irrigation return and side channel temperatures for Lower Ruby reaches LR11-LR13.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Ramshorn Creek	19.6	19.2	16.3	2.9
Side Channel	19.2	17.1	16.6	0.5
Irrigation Return	19.0	16.1	16.6	-0.5
Irrigation Return	18.1	21.1	17.0	4.1
Side Channel	17.9	17.0	17.1	-0.1
Side Channel	17.9	18.9	17.1	1.8
Side Channel	17.3	17.5	17.4	0.1
Side Channel	17.2	17.5	17.7	-0.2
Irrigation Return	16.9	16.5	17.2	-0.7
Side Channel	16.7	17.2	17.6	-0.4
Side Channel	16.6	17.4	17.6	-0.2

Groundwater dynamics may also influence the increasing temperature of the Ruby in this section. Upstream of reach LR11, the Ruby sits in a broad alluvial valley in which groundwater connectivity likely contributes to the cooling trend. Around reach LR11, a large fan deposit from the northern Ruby Range pinches off the wide alluvial valley. This feature likely restricts the groundwater connectivity, which results in increasing stream temperatures.

Table 14 summarizes the warming trend seen on this section of river.

Table 14. Summary of features for Lower Ruby reaches LR11-LR13.

Reach ID	Average Temp °C	Change in Temp	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR11	15.65	-0.9	3064.4	856.2	14.0	0
LR12	16.65	0.7	2837.0	233.5	4.1	2
LR13	17.42	0.7	5419.5	1028.0	9.5	2

<u>15.3-8.4 (Reaches LR14-LR17)</u>

For the next five miles the stream temperatures on the Ruby are relatively stable, with only a 0.4°C fluctuation (18.0-18.4°C) (Table 15).

Table 15. Tributary, irrigation return and side channel temperatures for Lower Ruby reaches LR14-LR17.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Side Channel	13.7	18.6	18.2	0.4
Irrigation Return	11.5	17.9	18	-0.1
Side Channel	11.3	18.2	18.1	0.1
Side Channel	10.5	18.0	18.3	-0.3

There are many warm oxbows on this reach of river (Table 16). The oxbows do not appear to increase instream temperatures within this reach.

Table 16. Impoundment and oxbow temperatures for Lower Ruby reaches LR14-LR17.

Off-channel Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Impoundment	15.1	20.1	17.9	2.2
Oxbow	11.9	22.4	18.3	4.1
Oxbow	11.7	20.9	18.1	2.8
Oxbow	11.6	21.3	18.1	3.2
Oxbow	11.2	22.8	18.3	4.5
Oxbow	11.0	23.5	18.3	5.2
Oxbow	10.9	21.2	18.1	3.1
Oxbow	10.3	23.5	18.1	5.4

Water inputs are primarily warm on this section of stream. There is an oxbow with an average temperature 5°C warmer than the main Ruby (Table 16, Image11). This oxbow, although significantly warmer than the Ruby, (average temperature 23.5°C) shows no detectable influence on the overall temperature. The oxbow most likely does not contribute significant surface flow to the River.

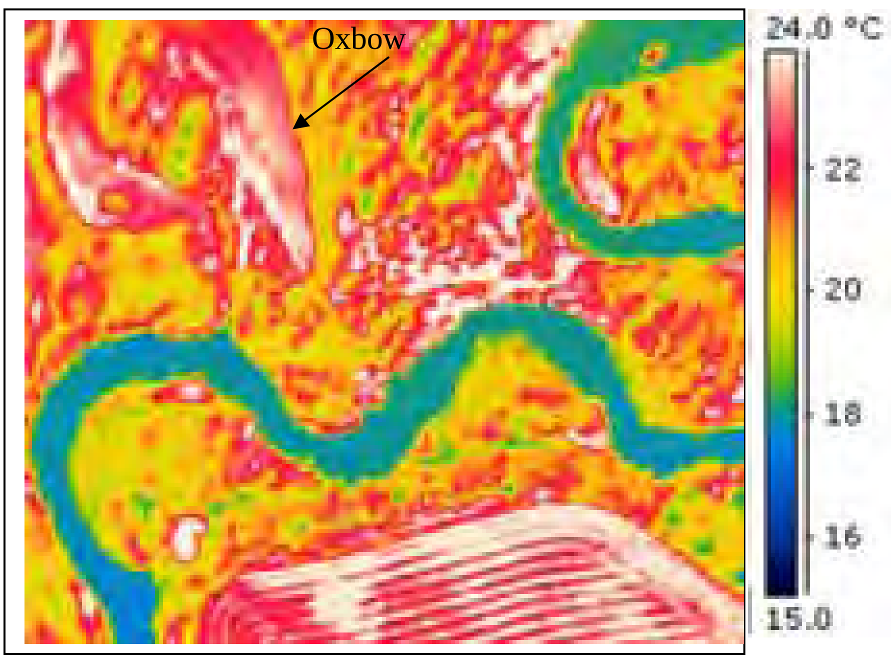


Figure 11. FLIR image of oxbow found at river mile 10.3.

Table 17 shows the stable temperatures seen in reaches 14-17. There were dramatic differences in the percentage of stream with no buffer among reaches. The influence of riparian vegetation on stream temperature will be assessed through temperature modeling.

Table 17. Summary of features for Lower Ruby reaches LR14-LR17.

Reach ID	Average Temp °C	Change in Temp	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR14	18.07	0.6	6970.4	5577.2	40.0	0
LR15	18.16	0.3	2823.2	282.5	5.0	1
LR16	18.16	-0.3	2465.5	259.9	5.3	1
LR17	18.17	-0.3	4297.7	1332.8	15.5	1

8.3-0.0 (Reaches LR18 - LR22)

The temperature in the Ruby River increases from river mile 8.7 to the mouth where the stream reaches its maximum temperature of 20.6°C. Table 18 shows that there were both warm and cold water inputs in this section. Overall the average input was 0.6°C warmer than the Ruby, which is consistent with the overall warming trend seen on this section.

Table 18. Tributary, irrigation return and side channel temperatures for Lower Ruby reaches LR18-LR22.

Connected Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Mill Creek	8.3	18.7	18.6	0.1
Irrigation Return	7.0	17.0	18.5	-1.5
Cold Water Refuge	5.3	18.5	19.1	-0.6
Cold Water Refuge	5.1	18.7	19.1	-0.4
Leonard Slough	4.9	17.4	19.2	-1.8
Cold Water Refuge	4.0	17.8	17.4	0.4
Irrigation Return	3.6	23.0	20.1	2.9
Side Channel	3.6	25.0	20.1	4.9
Side Channel	1.6	23.0	19.7	3.3
Side Channel	0.8	19.7	20	-0.3
Irrigation Return	0.2	20.4	20.3	0.1

There are three cold water refugia which do not appear to influence local stream temperatures. Mill Creek flows in at almost the same temperature as the Ruby. Leonard Slough, which is formed from Wisconsin Creek and Indian Creek just upstream of confluence with the Ruby, contributes colder water (1.8°C cooler), but a significant impact on the overall temperature of the Ruby River was not detectable through this analysis.

The two oxbows with temperature data on this section of stream are both warmer than the Ruby (Table 19). It is not possible to determine the impact of the warm oxbows on the warming Ruby River.

Table 19. Impoundment and oxbow temperatures for Lower Ruby reaches LR18-LR22.

Off-channel Feature Type	River Mile	Input Temp °C	Ruby Temp °C	Difference
Oxbow	3.7	22.1	19.8	2.3
Oxbow	7.8	22.5	18.2	4.3

The average reach temperatures seen in Table 19 summarize the overall warming trend in this downstream end of the Ruby.

Table 20. Summary of features for Lower Ruby reaches LR18-LR22.

Reach ID	Average Temp °C	Change in Temp	Reach Length (m)	No Buffer (m)	% No Buffer	Number of Diversions
LR18	18.39	0	2526.6	523.5	10.4	1
LR19	18.97	0.7	4135.7	1318.5	15.9	1
LR20	19.40	0.7	2429.7	217.6	4.5	0
LR21	20.10	-0.2	3513.0	672.4	9.6	1
LR22	19.94	0.8	3019.1	215.1	3.6	2

Discussion

Summary of Potential Thermal Loading Sources

Tributaries and Irrigation Returns

Tributaries and irrigation returns are generally colder than the Ruby River, and therefore are not considered a likely source of thermal impairment. The cooler irrigation returns can be partially attributed to the fact that many irrigation ditches are relatively deep, narrow channels. Groundwater influences may also impact cooler irrigation return and tributary temperatures. An exception to the cooler water input trend is seen in the segment between river mile 21.0 to15.2, where Ramshorn Creek (which is mostly irrigation return water at the confluence) and a separate irrigation return contribute warm water that appears to have some effect on stream temperature. The lowest segment of the Ruby River also appears to increase in temperature partly due to warmer irrigation returns and tributaries. Most of the water entering the Ruby from Mill Creek and much of the water in the lower part of Indian Creek are irrigation return water, but these inflows are similar or slightly lower in temperature compared to the Ruby River. Groundwater inputs likely contribute a significant portion of the flow to these tributaries, although the exact proportion of groundwater to surface water return is not known.

Stream temperature and flow of the tributaries are compared to flow of the Ruby River in Table 21. Most tributaries contribute colder water to the Ruby, and of the seven tributaries and returns contributing colder water, 4 contribute at least 10% of the flow to the river at the inflows. The primary warm-water input is from Ramshorn Creek, which is primarily irrigation return water by the time it reaches the Ruby River.

Table 21. Estimated contribution of tributary flows to Ruby River temperature.

Logger ID-Location	Flow (cfs)	Ruby Flow (cfs) US of Confluence	Estimated % Tributary Contrib to Flow (Surface)	Tributary Temperature Difference from Ruby (°C)
ALDCK-Alder Creek above confluence	11.5	47	24.47	-1.4
BIVENS-Bivens Creek above confluence	1.2	68.9	1.74	-0.3
CALCK-California Creek above confluence	0.9	68.9	1.31	-1.2
LR08-Clear Creek above inflow to Ruby	7.86	57.1	13.77	-3.2
M9-Above confluence w/Ruby	4.1	52.3	7.84	0.1
T1-Ramshorn Creek above confluence	0.9	108	0.83	2.9
T2-Silver Spring above confluence	15.6	93.2	16.74	-1.2
T3-Logger not placed- int. inflow return from W. bench	6	77.6	7.73	-5.1
T4-Indian Ck/Leonard slough above confluence	11.4	53.4	21.35	-1.8

Side Channels, Oxbows, and Impoundments
Water stored on the floodplain in oxbows and impoundments was generally warmer than the Ruby River. Connectivity of these side features varies, but they may have an influence on stream temperature. The influence of oxbows is not evident locally, but may contribute to warming trends over a larger general area. Connectivity of oxbows and impoundments should be studied further to determine if these features are a consideration for water quality management.

Uncertainties
Although the FLIR flight was conducted in what is historically the hottest time of the year, the day of the flight was not the hottest day of 2004. Air temperatures were around 20°C with partly cloudy skies. These conditions were acceptable for the objectives of the survey. Analysis of the thermal accuracy of the FLIR images compared to in-stream sensors was well within the specified tolerance of plus or minus 2°C.

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 helicopter)

- Object distance (altitude AGL)
- Relative humidity

When all of these parameters are set correctly the camera should be accurate to within two degrees C of absolute temperature. Although the absolute temperature is within 2°C, the temperature accuracy of a single image or within collection of images is 0.1 °C. (i.e., the camera can differentiate to with 0.1 °C.). It is not feasible to accurately measure all of the object parameters continuously during the flight. For instance, the air temperature changes with changes in altitude, the elevation of the riverbed is not constant and in the case of the Ruby River there were thunderstorms and recent rainfall in the area causing a change in relative humidity. 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 °C.

Temperature loggers in the water are subject 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 plus or minus 2 °C. However, since the dataloggers are subject to fewer object parameter fluctuations than the FLIR camera temperature measurements from a datalogger are generally considered more accurate than a FLIR image. Therefore, in post processing the temperatures of the dataloggers at the time of the flight are compared to the FLIR temperatures. The FLIR temperature is measured from the center of the river on the video image taken in closest proximity to each datalogger. If FLIR images are a few tenths higher or lower on average than the dataloggers the object parameters of the FLIR images are adjusted to account for the differences. The same adjustment is made for each image in the collection. The humidity is setting is the hardest parameter to account for during the flight and is generally adjusted. After addressing all of these considerations the FLIR temperatures are considered as accurate as possible.

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. One temperature logger was placed deep in a pool at the same site as a logger placed in a riffle. The logger placed in the pool recorded temperatures an average of 0.1°C warmer than the logger in the riffle, which is contrary to expectations. Gradients from near the water surface to the deepest points in the river vary at different locations.

Water surface temperature is measured by the FLIR 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 and infrared images to determine if shading from vegetation is causing certain areas to appear cooler in the FLIR imagery.

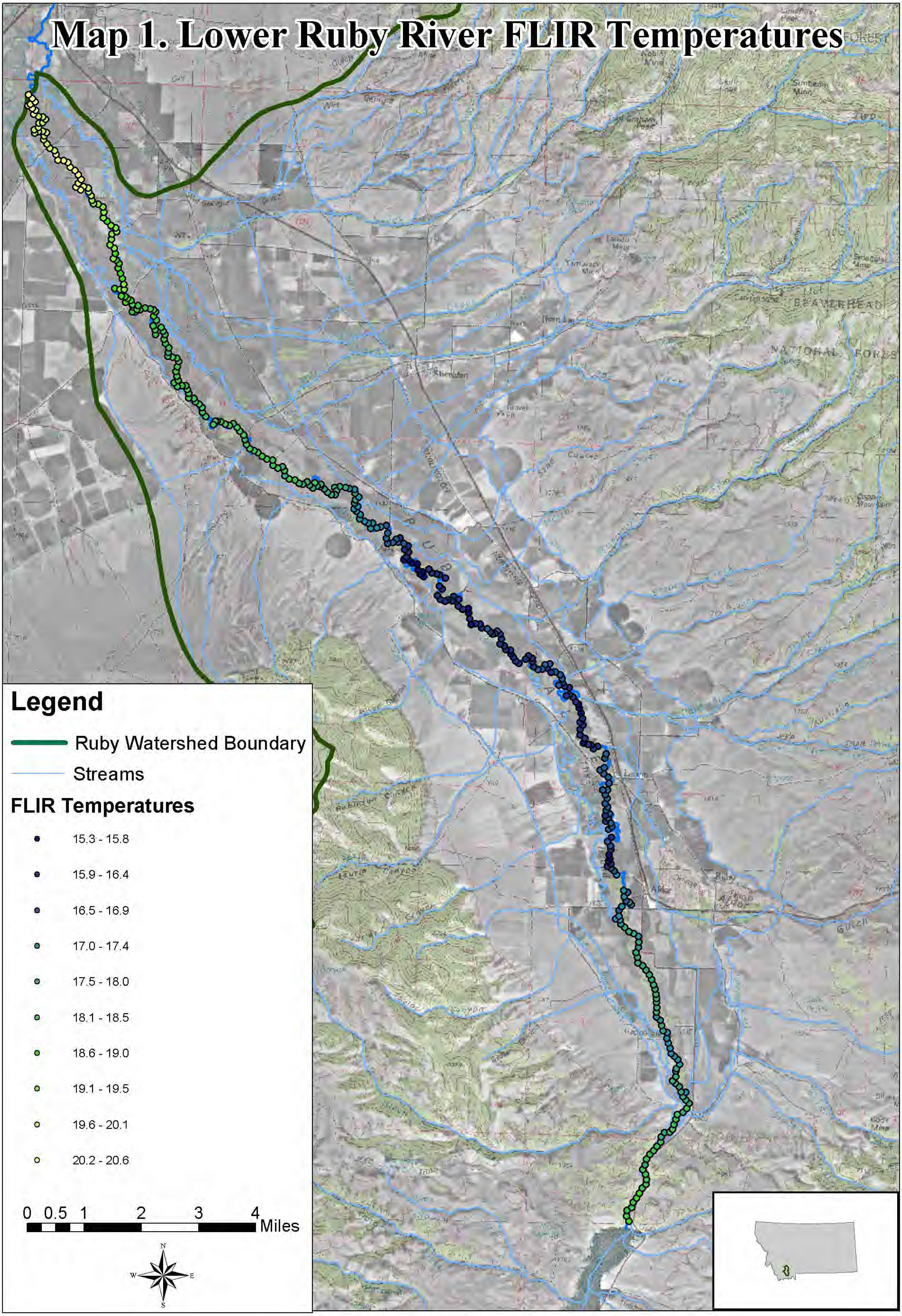
The influence of diversions and irrigation return flows could not be quantified at a cumulative level because the scope of this study did not include measuring flow for every diversion and return. No diversion flows were measured, and only tributaries and a few major irrigation returns were measured. 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.

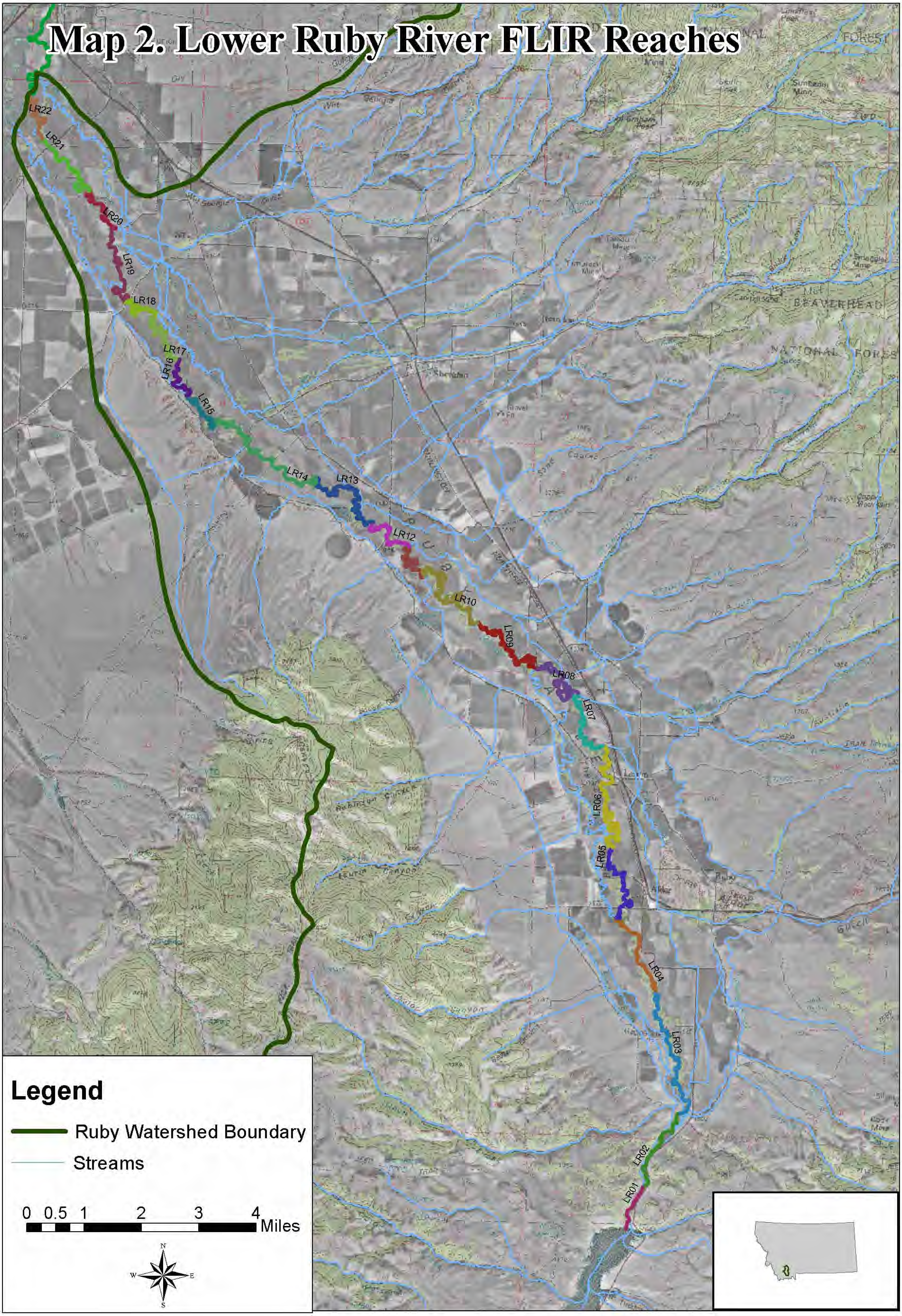
Stream temperature reflects watershed-scale as well as local scale influences. It is subject to cumulative effects that extend beyond the reach scale. While this analysis provided a general source characterization and identified some temperature sources influencing temperature at a local scale, it was not designed to define cause-effect relationships between land management factors and temperature of the lower Ruby River at the watershed scale. Temperature modeling using the SNTEMP model will be conducted to define the influence of riparian canopy cover and changes to stream flow on water temperature for the entire lower Ruby River and Mill Creek. This FLIR analysis will be used in conjunction with temperature modeling to define source of thermal impairment for temperature TMDL development.

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.

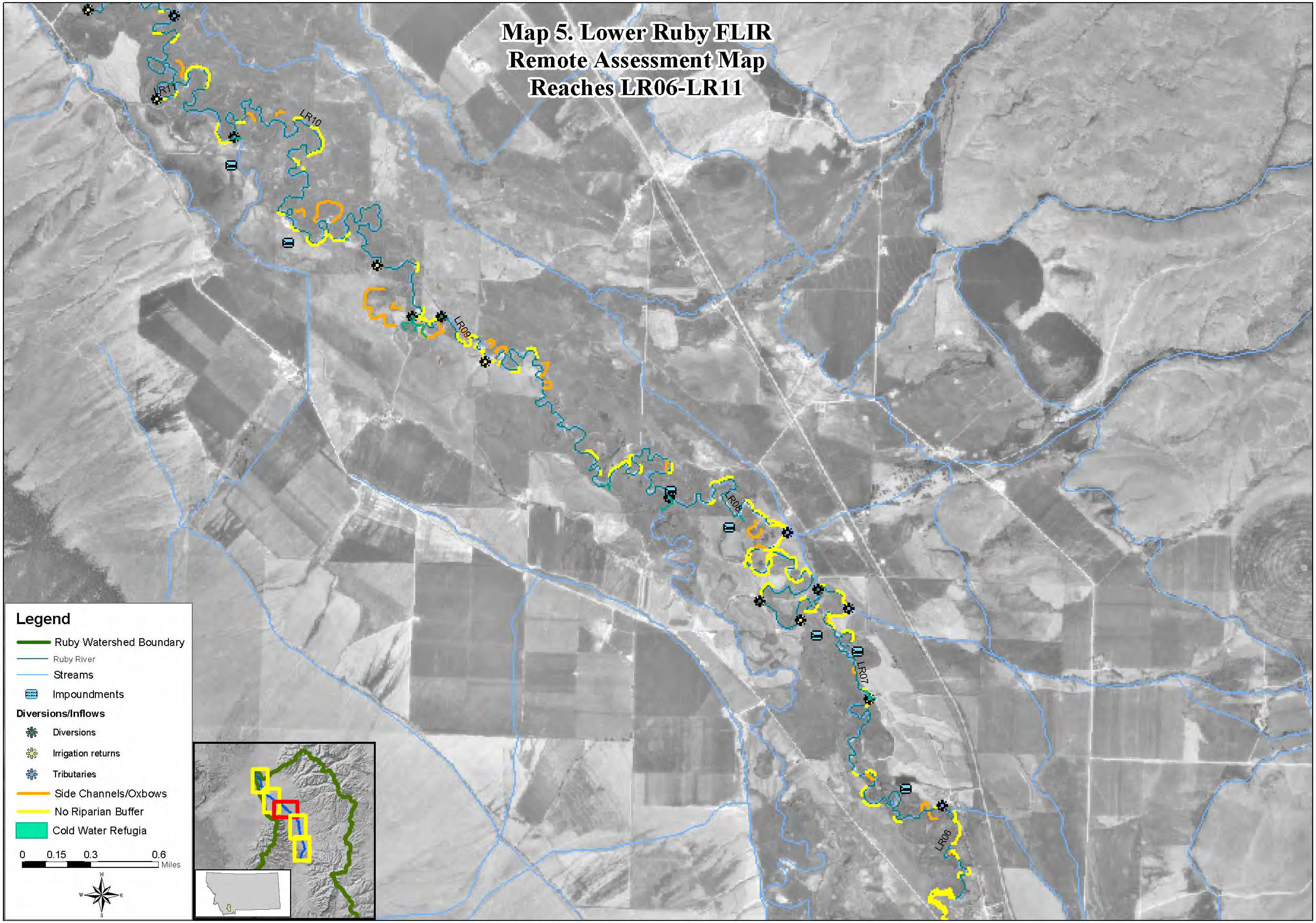
Western Regional Climate Center. Historical climate information accessed in December 2004 at http://www.wrcc.dri.edu/CLIMATEDATA.html.


Map 1. Lower Ruby River FLIR Temperatures
Legend
Ruby Watershed Boundary
Streams
FLIR Temperatures
15.3 - 15.8
15.9 - 16.4
16.5 - 16.9
17.0 - 17.4
17.5 - 18.0
18.1 - 18.5
18.6 - 19.0
19.1 - 19.5
19.6 - 20.1
20.2 - 20.6
0 0.5 1 2 3 4
Miles
N
W
E
S
Sheridan
Laurin
Alder
Ruby
BEAVERHEAD
NATIONAL FOREST


Map 2. Lower Ruby River FLIR Reaches
LR22
LR21
LR20
LR19
LR18
LR17
LR16
LR15
LR14
LR13
LR12
LR10
LR09
LR08
LR07
LR06
LR05
LR04
LR03
LR02
LR01
Legend
Ruby Watershed Boundary
Streams
0 0.5 1 2 3 4 Miles
N
W
E
S


Map 3. Lower Ruby FLIR
Remote Assessment Map
Reaches LR01-LR04
LR05
LR04
LR03
LR02
LR01
Legend
Ruby Watershed Boundary
Ruby River
Streams
Impoundments
Diversions/Inflows
Diversions
Irrigation returns
Tributaries
Side Channels/Oxbows
No Riparian Buffer
Cold Water Refugia
0 0.25 0.5 1 Miles
N
S
E
W

Map 4. Lower Ruby FLIR
Remote Assessment Map
Reaches LR03-LR06
LR06
LR05
LR04
LR03
Legend
Ruby Watershed Boundary
Ruby River
Streams
Impoundments
Diversions/Inflows
Diversions
Irrigation returns
Tributaries
Side Channels/Oxbows
No Riparian Buffer
Cold Water Refugia
0
0.25
0.5
1
Miles
N
S
E
W



Map 5. Lower Ruby FLIR
Remote Assessment Map
Reaches LR06-LR11
LR11
LR10
LR09
LR08
LR07
LR06
Legend
Ruby Watershed Boundary
Ruby River
Streams
Impoundments
Diversions/Inflows
Diversions
Irrigation returns
Tributaries
Side Channels/Oxbows
No Riparian Buffer
Cold Water Refugia
0 0.15 0.3 0.6
Miles


Map 6. Lower Ruby FLIR
Remote Assessment Map
Reaches LR11-LR15
LR15
LR14
LR13
LR12
LR11
Legend
Ruby Watershed Boundary
Ruby River
Streams
Impoundments
Diversions/Inflows
Diversions
Irrigation returns
Tributaries
Side Channels/Oxbows
No Riparian Buffer
Cold Water Refugia
0
0.25
0.5
1
Miles
N
S
E
W


Map 7. Lower Ruby FLIR
Remote Assessment Map
Reaches LR14-LR22
LR22
LR21
LR20
LR19
LR18
LR17
LR16
LR15
LR14
Legend
Ruby Watershed Boundary
Ruby River
Streams
Impoundments
Diversions/Inflows
Diversions
Irrigation returns
Tributaries
Side Channels/Oxbows
No Riparian Buffer
Cold Water Refugia
0
0.25
0.5
1
Miles
N
S
E
W