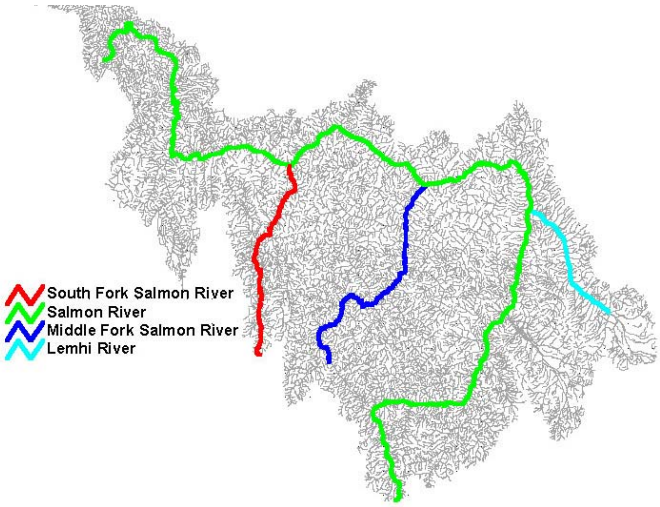
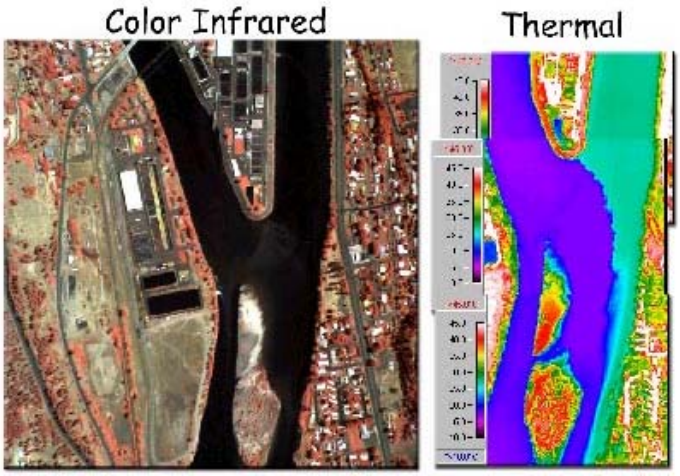


FIINAL REPORT

Paired Color Infrared and Thermal Infrared Imaging And Analysis for Selected Idaho Streams



Prepared for

IDAHO DEPARTMENT OF ENVIRONMENTAL QUALITY

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Mr. Don Essig
State of Idaho Department of Environmental Quality
Division of Water Quality
4741 N. Hilton
Boise, Idaho 83706

Aug 28,2002

Re: Paired Color Infrared and Thermal Infrared Imaging And Analysis for Selected Idaho Streams

Dear Don:

Once again we come to the conclusion of another river project. Each year the process becomes a little easier and more data is collected.

We appreciate all the help that you and your department provided us during this project. We are looking forward to working with you again in the future. Should you have any questions, please feel free to call me at 541-567-0252 or by email at tad@irz.com

Sincerely,

IRZ Consulting, LLC

_____
By Thaddeus Fickel

Table of Contents:

Introduction

Local and regional watershed issues have necessitated studies by various agencies to map river temperature and associated riparian habitat. Thermal infrared technology, otherwise known as FLIR (Forward Looking Infrared), has gained acceptance as a tool for quickly and accurately measuring the temperature of rivers and streams.

During the summer of 2001, IRZ Consulting was contracted by Idaho DEQ to provide an aerial thermal infrared survey of several rivers in the Salmon River basin. The purpose of the project was as follows:

- To provide baseline data to be used in the development of ongoing or potential Total Maximum Daily Load standards (TMDL).
- To characterize tributary influences on river temperature.
- To document diurnal fluctuations on individual rivers from a temporally constant perspective.
- To collect near-infrared imagery for correlation with FLIR images and riparian habitat visualization.

Project overview

This project consists of study areas in the central and southern portions of Idaho. Table 1 shows the names of the rivers, the dates, and miles of the rivers flown.

River	Date	Miles surveyed
Salmon River	Aug 8, 9, 11, 12 2001	400
Middle Fork Salmon River	Aug 10,11 2001	104
South Fork Salmon River	Aug 12 2001	36
Lemhi River	Aug 9 2001	51

Table 1 Rivers and date of Thermal Infrared Survey

Project Parameters

Units of measurement and projection information are in Table 3 below.

Time Zone	Mountain Daylight time
Geographic Projection	Idaho Transverse Mercator (see Table 14 in appendix)
Altitude measurements	Feet
River length units	Miles
Temperature units	Centigrade

Table 3 Project Information

To measure the coolest and warmest river diurnal temperatures, rivers were flown and image data was collected during two time windows each day. Morning flights were made between the hours of 0600 and 0800 local time. Afternoon flights were made between 1600 and 1800 local time. Historical data from in stream temperature recorders indicate that these time frames represent the daily minimum and maximum river temperatures for this time of year. The flight plan for each day was designed to maximize the time spent collecting data and minimize the time spent ferrying the helicopter between rivers. An overview of the project area can be seen in Figure 1. All flights were flown in a downstream fashion. After the morning flight the helicopter would return to base and the imagery would be downloaded and catalogued. In the evening the process would be repeated following the same flight path.

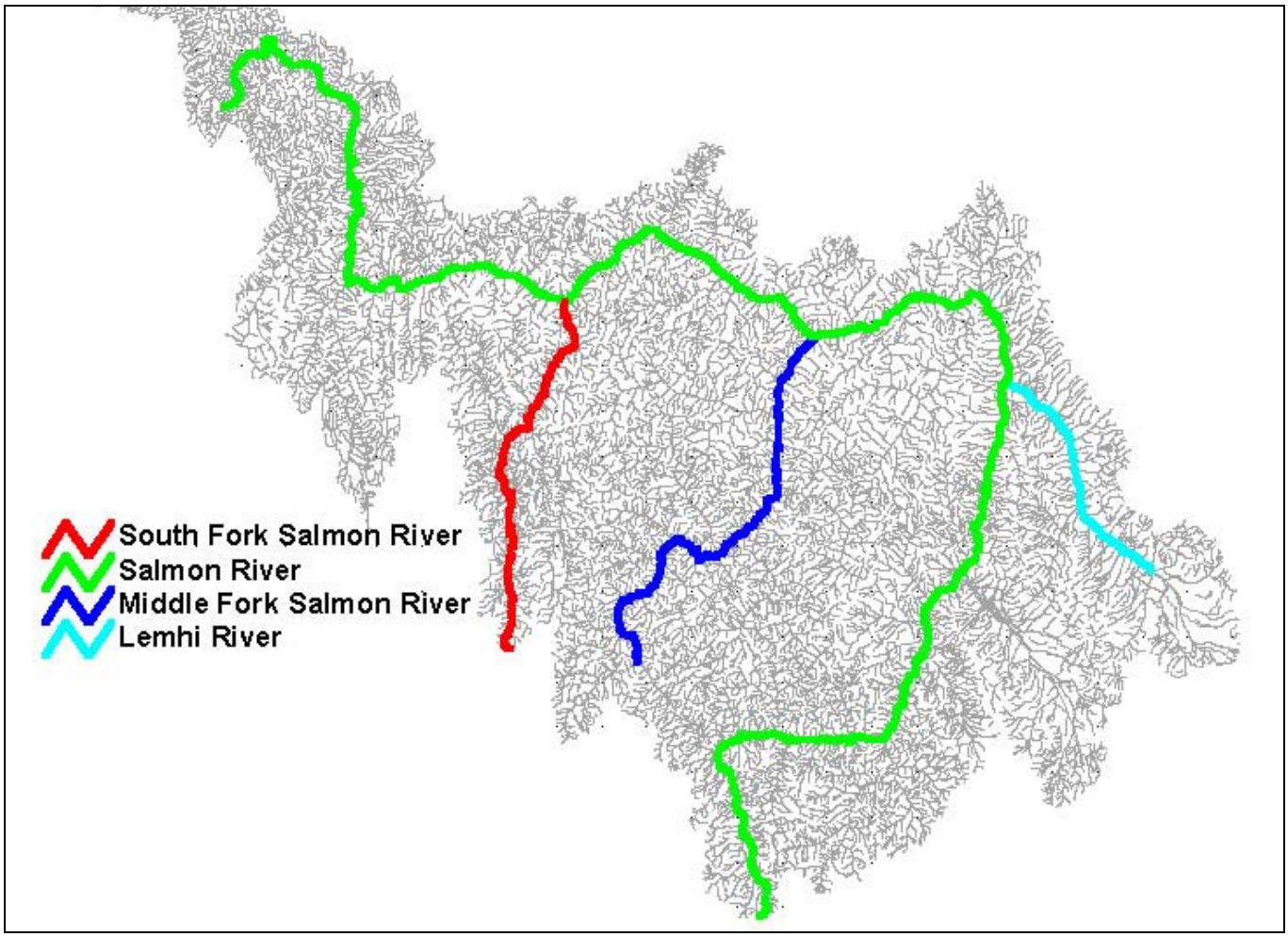


Figure 1 Project Overview

Methodology

FLIR

To measure and record river temperatures, a high-resolution thermal infrared camera was used to record imagery in the long wave region of the electromagnetic spectrum. The detector consists of a staring focal plane array with a 256 x 256 pixel density. The camera can differentiate temperatures as small as **0.07** degrees centigrade within an image or a collection of images and the accuracy of any measured temperatures are within 2 degrees centigrade of the absolute temperature.

The thermal infrared camera was mounted vertically in a custom designed gyro-stabilized, steer-able mount in an Enstrom helicopter. Images were saved onto a laptop computer at a rate of 1 second per image. The geographic coordinates of each image were recorded into a separate file using real time differential GPS.

Ground resolution (pixel size) of the images is determined by flight altitude. Pixel resolutions of the thermal images range from .5 meters on small streams to 1.5 meters on larger ones.

Digital Color-Infrared

To evaluate the riparian zone vegetation and to identify ground features (roads, cities, farms, etc.) a high-resolution digital near-infrared camera was used. This camera captures images using a portion of the visible spectrum *and* the near-infrared region (Figure 2). This camera has a higher pixel resolution than the thermal camera and thus provides better visual perception for identifying small objects. The near-infrared portion of the electromagnetic spectrum yields a better view of riparian zone vegetation. More red in an infrared image corresponds with more vigorous growth.

Pixel resolutions in the Color-Infrared images range from less than one meter on smaller rivers to 1.5 meters on larger ones.

Future uses of the color-infrared imagery could include geo-referencing the images for use estimating riparian vegetation density as a step to documenting stream shading.

Figure 2 Confluence of South Fork Salmon River with Salmon River.

Limitations

When measuring river temperature with FLIR imagery it is necessary to recognize that the camera is seeing and recording temperature exclusively at the surface of the water. Rivers with a turbulent flow will show very little thermal variability between surface and sub-surface temperature measurements. Some factors that might influence thermal mixing:

- Tributaries / Springs
- Irrigation return flows
- Industrial / Municipal influences

By studying the results of this type of a temperature survey informed decisions can be made regarding the placement of in-stream temperature monitors to supplement and enhance the FLIR data.

Data Processing

Over 52,000 thermal infrared images were analyzed in the offices of IRZ Consulting and temperature information (max, min, avg.) was extracted and input into a database. The temperature value from each image is the average of several points within that image. In images where there was a broad, clear view of the river, the temperature is averaged in a circle in the center of the river. Other places where the river is obscured by vegetation or is simply too small to draw a circle the temperature taken from a single point in the center of the river (Figure 3).

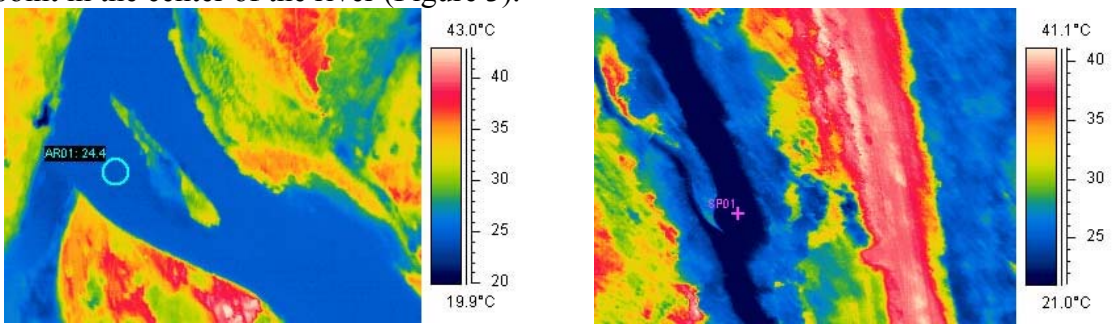


Figure 3 Line and point sampled FLIR imagery

Image Correlation

The color-infrared images are of much higher resolution than the FLIR images. The "footprint" of a color infrared image covers a much larger area than that of the FLIR coverage. To reduce the number of images that needed to be collected, the color infrared camera was turned 90 degrees to the direction of flight so that the river would be imaged with the cameras lateral axis spanning the widest part of the imager. In the office the resulting images were rotated back into place yielding an image with an aspect ratio in a "portrait" orientation.

Each color infrared image is associated with several thermal infrared images. Organization of the images is accomplished automatically in IRZ Consulting's **RiverView** image analysis database. Figure 4 below illustrates the relationship between the relative sizes of the images.

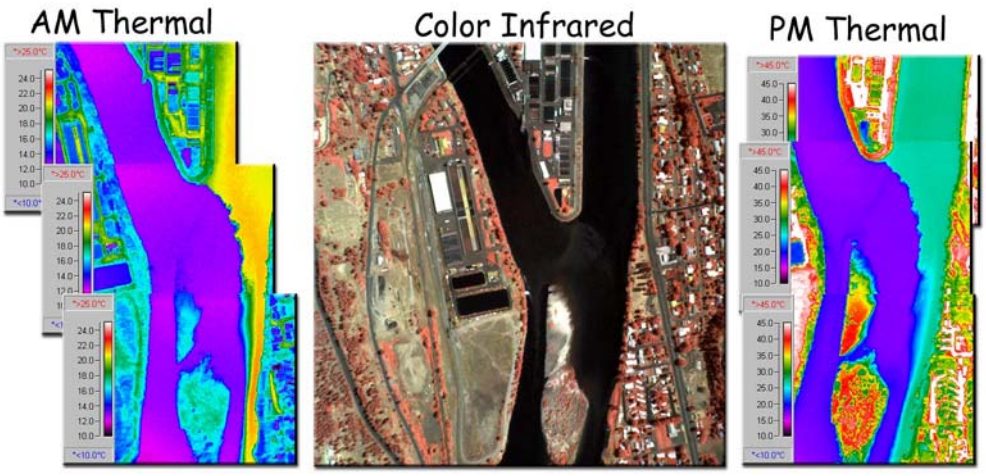


Figure 4 Image footprint comparison

Ground truthing

In stream temperature monitors at various locations throughout the study area provide ground truthing data. These devices are anchored in the stream in a fixed location and record temperatures at pre-determined intervals varying from between 15 minutes to an hour. The devices in the Middle Fork of the Salmon River were placed by Idaho DEQ and contain the most complete data. There were 5 sites on the lower Lemhi River and two sites on the lower Salmon near Riggins. No in stream data exists for the South Fork of the Salmon or the Upper Salmon. The locations of the temperature monitors are shown in

FLIR vs. In-river temperature monitors

The correlation between the FLIR imagery and the in stream temperature monitor data provides an important view of two very important aspects of river dynamics. Because the FLIR imagery measures temperature at the surface of the river, the in stream temperature monitors provide another view of the river. In stream temperature monitor data is enhanced by FLIR imagery because the FLIR fills in the blanks between in stream temperature monitor sites. As shown in Table 4, FLIR and in stream temperature monitor temperature values correlate better in some areas than in others. The high deviation values should be investigated and potentially recalibrated or relocated. It should be noted that FLIR data is an average temperature measured at the center of the streams, normally about a 2-meter wide strip of varying length from 50 meters to 200 meters long. In stream temperature monitors measure a single point at each site.

			Morning (C)			Afternoon (C)		
Site name	**Description**	**Mile**	**Data Logger**	**FLIR**	**Diff**	**Data Logger**	**FLIR**	**Diff**
Lemhi River	L-1 Diversion	0.8	15.5	15.9	**0.4**	21.8	23.2	**1.4**
Lemhi River	L-2 Diversion	1.4	15.5	15.7	**0.2**	20.4	22.9	**2.5**
Lemhi River	L-3 Diversion	3.5	15.4	15.9	**0.5**	21.7	22.7	**1**
Lemhi River	L-3A Diversion	5.15	15.2	15.6	**0.4**	20.5	21.9	**1.4**
Lemhi River	L-6 Diversion	7.4	15.5	15.6	**0.1**	20.7	22	**1.3**
Middle Fork Salmon	MF Salmon blw Indian Cr.	67.9	13.7	16.4	**2.7**	21.8	20.4	**-1.4**
Middle Fork Salmon	MF Salmon abv Sunflower	61.4	16.2	17.1	**0.9**	20.5	21.4	**0.9**
Middle Fork Salmon	MF Salmon abv Loon Cr.	45.9	17	18.7	**1.7**	20.5	22.2	**1.7**
Middle Fork Salmon	MF Salmon abv Camas Cr.	35.1	18.4	19.5	**1.1**	20.6	21.9	**1.3**
Middle Fork Salmon	MF Salmon @ Cliffside Camp	6.3	20.4	20.7	**0.3**	21.3	22	**0.7**
Middle Fork Salmon	MF Salmon just abv Bndry Cr.	94.5	13.3	14.5	**1.2**	17.3	18.2	**0.9**
Salmon River	Riggins	53.8	21.6	23.1	**1.5**	23.7	24.2	**0.5**
			Average difference		**0.917**			**1**

Table 4 Comparison of temperature between FLIR and in stream temperature monitor

Of note in the table above is the variability of the temperature at each station when comparing morning and evening FLIR images. Some possible explanations:

- Thermal stratification
- Location/placement of the in stream temperature monitor
- Surface effects on the water affecting the accuracy of the FLIR imagery*

* High wind causing localized ripples and clouds being mirrored can change the reflectivity of the water causing a false temperature reading of up to 1.5 degrees. On the days these images were collected winds were generally less than 5 knots and the skies were clear.

Project Analysis

Geographic Information System (GIS)

To view, analyze, and organize the temperature information for this project, ArcView 3.2 Geographic Information System (GIS) was employed. GIS is an excellent tool for gaining a basin-wide overview of temperature dynamics.

During the flights, real-time differentially corrected GPS location information was being continually recorded to an onboard laptop computer. The data was extracted in the office and matched up with the corresponding images by synchronizing the image file times with GPS time. Once the image times and the GPS times were linked a GIS theme could be created.

In the office the images were analyzed for temperature information. The mean temperature from center of each image (river) was transferred to ArcView and classified by color. Figure 5 and Figure 6 show an example of the type of broad scale comparisons that are possible for comparing temperatures at different times, or comparing two or more rivers at a similar point in time.

Figure 5 and Figure 6 shows the temperature variations of both morning and evening flights for the study area. All GIS themes are provided in the accompanying CD-ROMs. These graphs need to be studied in detail as they reveal a wealth of information about the watershed condition. Of interest are the temperatures in the tributaries where an inverse relationship exists between the temperature of the main river and the tributaries when comparing the morning and evening temperatures.

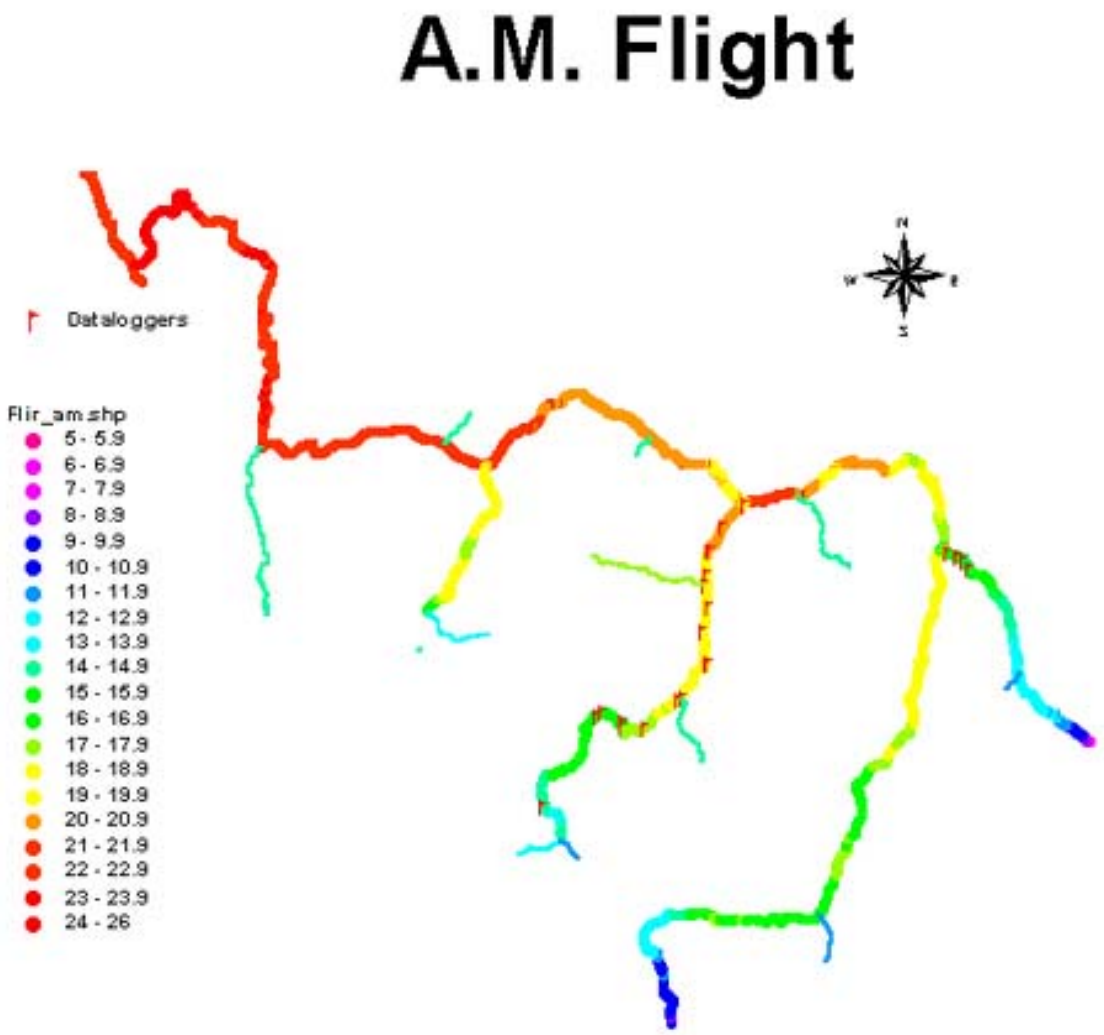


Figure 5 Stream temperatures from the morning flights

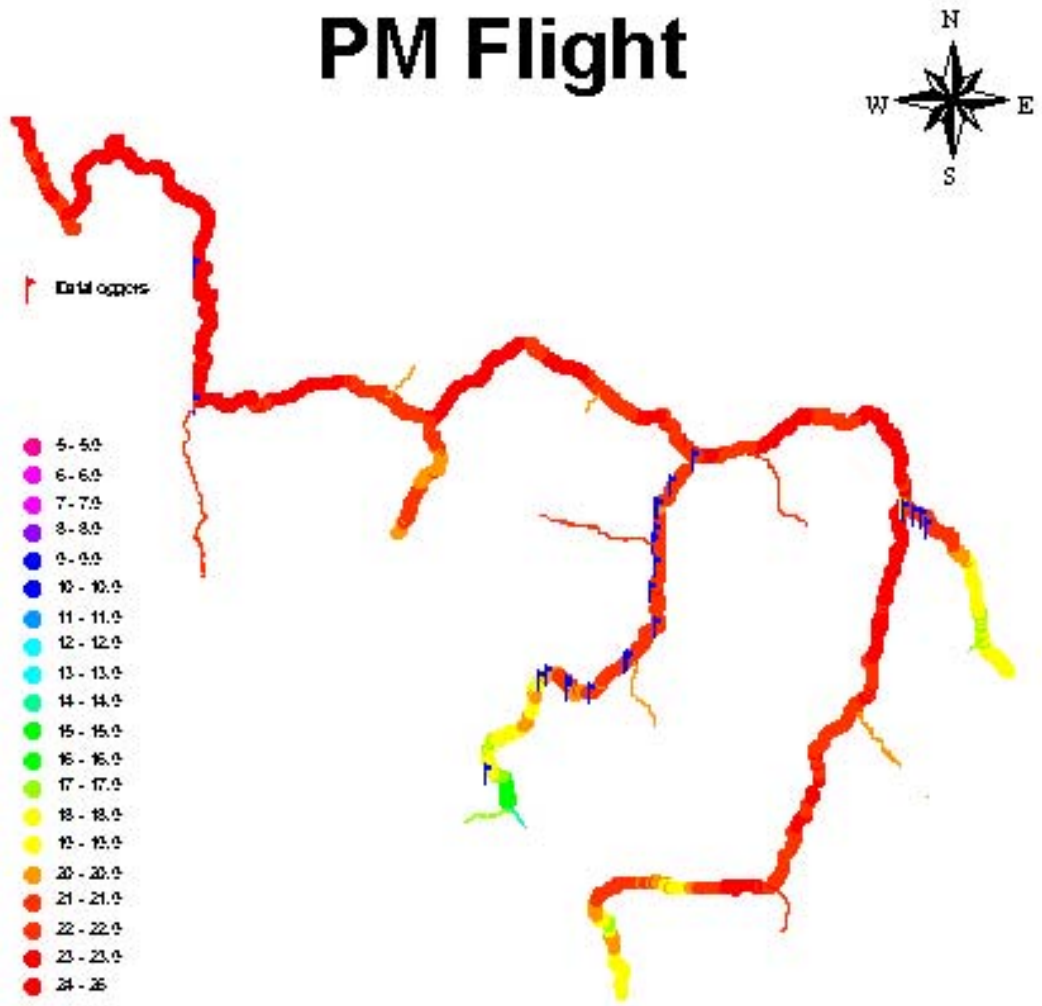


Figure 6 Stream temperatures from the evening flights

RiverView Image Analysis software

Purpose and Description

In gathering such a large volume of images the immediate question is how to organize them in a meaningful fashion? With multiple images of a particular stretch of a river it is necessary to compare the different images to arrive at a conclusion. To solve this problem, IRZ Consulting developed RiverView Image Analysis Software (Figure 7). Using this software the user can select and view any river in the study area, browse to different sections of a river or select river miles and see all associated images at once. It also allows you to zoom in and out, adjust color levels and print reports.

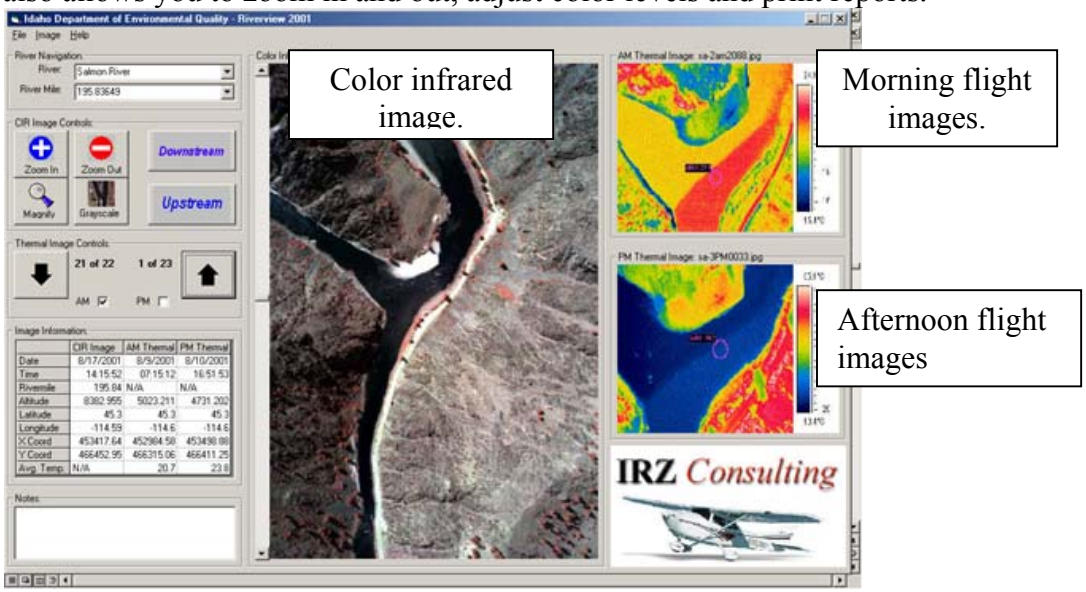


Figure 7 Riverview screen shot

Installation of RiverView™

1. From setup disk install d:\setup.exe (where d: is the letter of the CD-ROM drive).

RiverView Functions

Image Viewer

Project images can be accessed from the CD-ROM's included in this report or the images can be copied onto the users hard drive. To copy the images onto your hard drive:

- Place Images CD#1 into your CD drive on your computer
- Using My Computer or Windows Explorer, locate the folder called d:\Images (where d: is the drive designation for your CD drive).
- Copy that folder and all of its contents to a location specified on your computer.

Figure 8 RiverView screen shot

The first time the database is opened it will need to be instructed where to find the images. From the RiverView window, click on FILE, then click on OPEN IMAGE DATABASE and navigate to the *2001Images.mdb* file that was installed by default at c:\program files\RiverView. Click on TOOLS in the menu and IMAGE LOCATION. In the dialog box that appears select the location for accessing the images.

Viewing project images is as easy as selecting a river from the RIVERS drop down list in the upper left hand portion of the screen. When the images have been loaded you can navigate upstream or downstream with the buttons and/or the slider bar just to the left of the Color Infrared image. For each Color-Infrared image in the database there will be several FLIR images associated with it. The window in the upper right hand corner of the screen shows the FLIR images from the morning flight and the window in the lower right corner of the screen shows the FLIR images for the evening flight.

Printed Reports

To print a hard copy report of the images on the screen along with other pertinent information about the images (location, time, notes etc.) select FILE and PRINT. A dialog box will appear to edit printer settings if desired and the page will be sent to the default (or specified) printer.

Project Rivers

Salmon River

During the two hour window allotted for each flight the helicopter can only image about 150 miles. It was necessary to break the river up into 4 segments in order to image the entire river within the allotted time frame. There was some concern that upon ending a flight at 6:00 pm (for instance) that there would be significant temperature difference when we returned to resume the flight the following afternoon at 4:00. Table 6 below shows the start and ending segments of the river for each flight. The highest temperature difference was in the morning between the first and second flights (0.8 degrees), the rest of the flights had temperature differences between 0.1 C and 0.5 C.

Salmon River Segment	AM Start C°	AM End C°	PM Start C°	PM End C°
Mile 400 to Lemhi Confluence	8/8/01		8/8/01	
	12.2	18.9	20.4	24.0
Lemhi Confluence to Middle Fork Confluence	8/9/01		8/9/01	
	17.7	20.8	23.5	22.6
Middle Fork Confluence to Mile 103	8/11/01		8/10/01	
	20.6	22.8	22.8	24
Mile 103 to mouth	8/12/01		8/11/01	
	22.7	24.2	24.1	26.2

Table 6 Salmon River segments and daily FLIR fluctuations

Salmon River Tributaries

Only the tributaries with a Strahler number of at least 5 were measured. In many instances rivers less than 5 were to small in the FLIR imagery to get an accurate measurement. Table 7 below illustrates the relationship between some of the larger tributaries and the Salmon River.

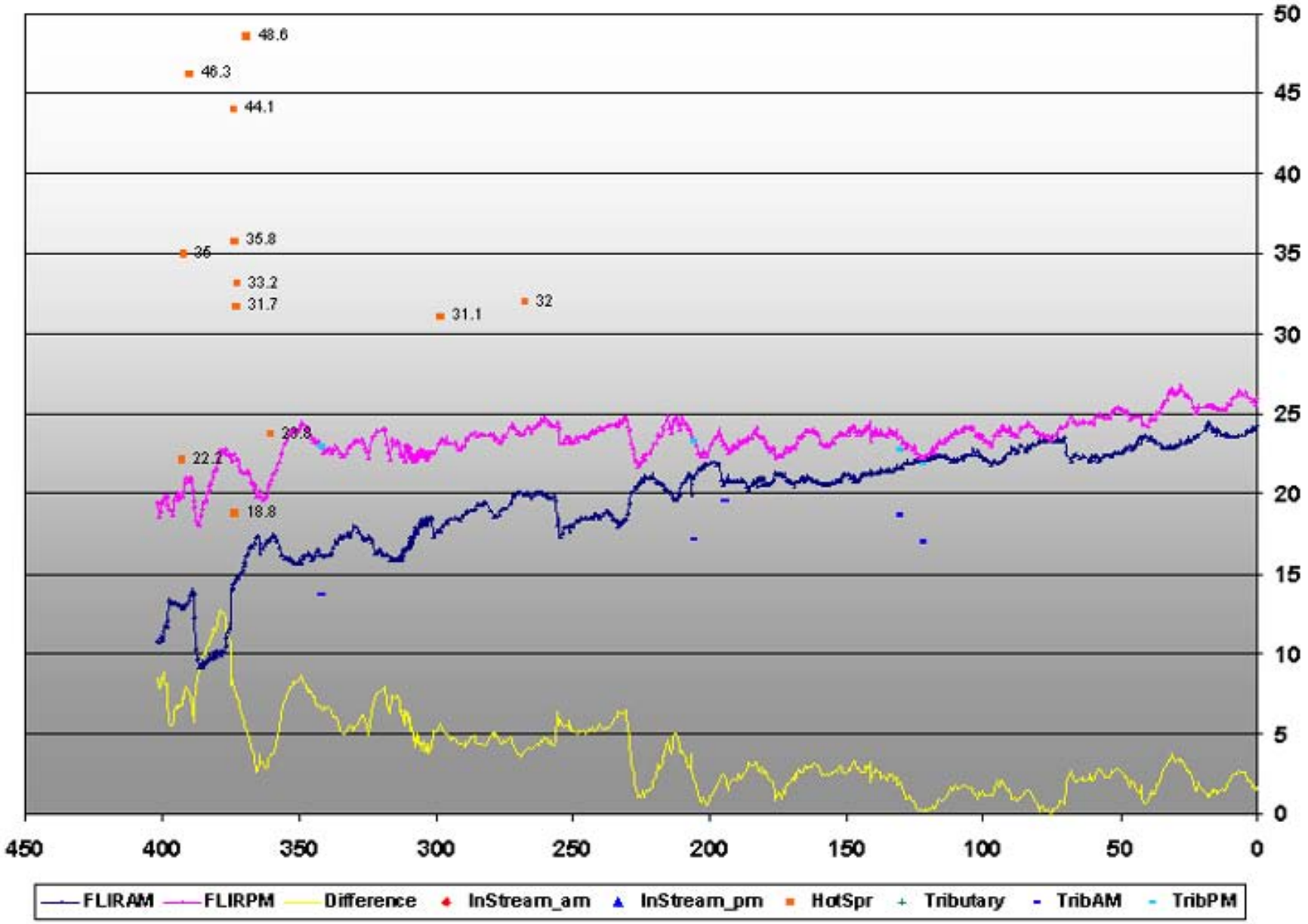
River Mile	Tributary Name	Trib AM	Salmon AM	Trib PM	Salmon PM
343	East Fork Salmon River	13.7	16.2	23.0	22.6
254	Lemhi River	18.5	18.5	23.0	23.6
207	Panther Creek	17.2	21.0	23.3	23.4
195.8	Middle Fork Salmon	19.6	20.4	*	21.3
172.8	Chamberlain Creek	16.1	20.7	21.6	22.4
132	South Fork Salmon	18.7	21.6	22.8	23.3
122.8	Sabe Creek	17.0	21.8	21.9	22.0
85.0	Little Salmon River	17.2	22.2	22.4	23.6

Table 7 Salmon River tributary temperature comparisons.

* FLIR images of the lower part of the Middle Fork of the Salmon River from the AM flight are missing.

Salmon River

Air Temp AM: 10-14 C. / PM: 28-32C



The upper reaches of the Salmon River showed some interesting thermal patterns. There are several hot springs as illustrated in the images below.

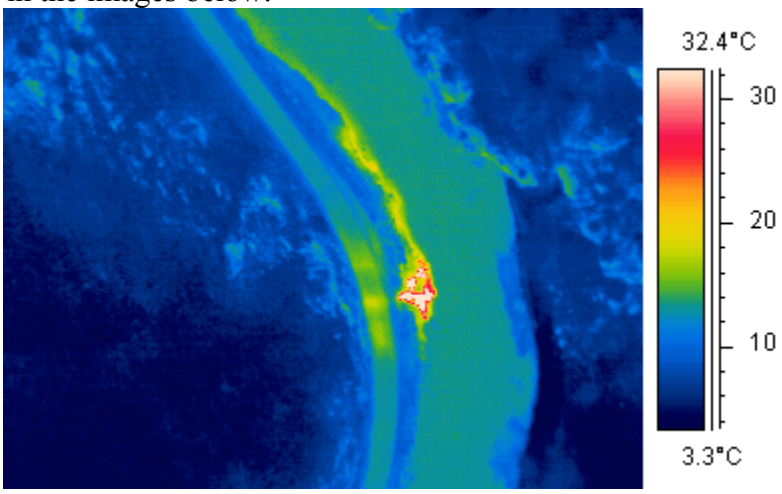


Figure 9 Mile 390, Hot springs is 44.8 degrees C.

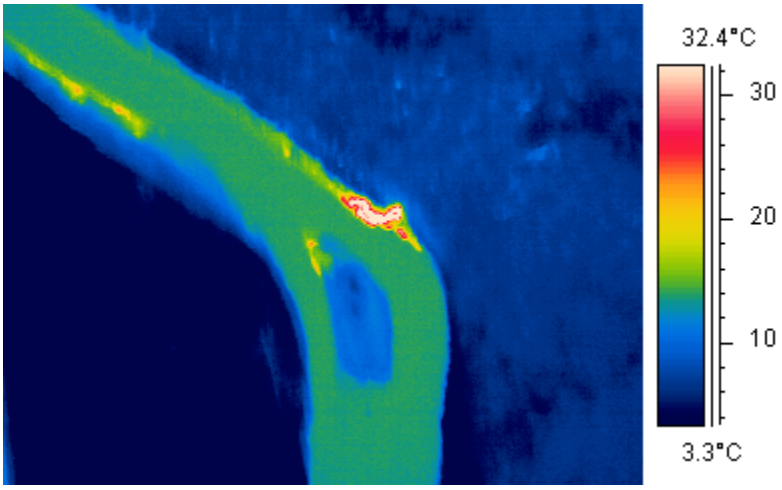


Figure 10 Mile 374, Hot springs is 43.9 degrees C.

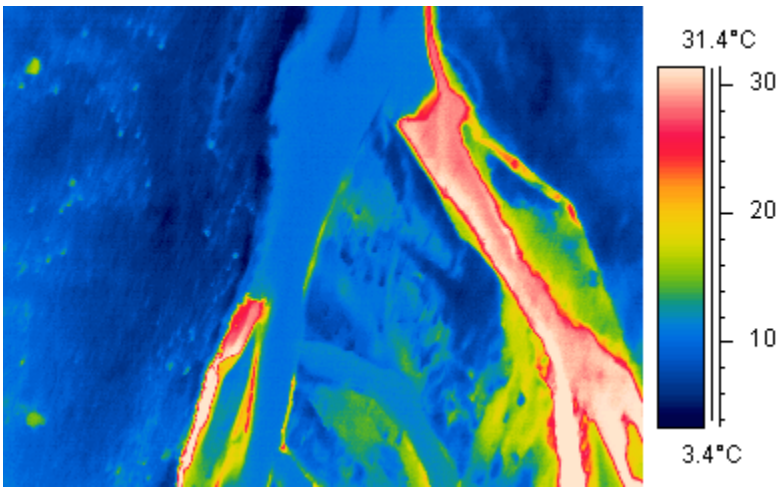


Figure 11 Mile 392, Hot springs is 32 degrees C.

Using the FLIR imagery we measured 13 hot springs entering the Salmon River. In many cases there were multiple springs in a single FLIR image and in those cases only a single measurement was made. Table 8 lists the measured hot springs and also gives a reference to the corresponding FLIR imagery. In all cases the detection of a hot spring was generally only possible during the morning flights when the ground and surrounding features are much cooler than the hot water. In the afternoon thermal heating of terrain features made it much more difficult to identify hot springs.

Flir Image name	Temp C.	Mile
Sa-1am0410.jpg	32	392
sa-1am0842.jpg	22.2	381
sa-1am0944.jpg	46.3	377
sa-1am1071.jpg	44.1	374.3
sa-1am1095.jpg	18.8	373.5
sa-1am1105.jpg	35.8	373.5
sa-1am1118.jpg	31.7	373.1
sa-1am1126.jpg	33.2	372.6
sa-1am1249.jpg	48.6	369.5
sa-1am1538.jpg	23.8	360.8
sa-1am3671.jpg	31.1	298.4
sa-1am4821.jpg	32	267.8

Table 8 Observed hot springs on the Salmon River.

Middle Fork Salmon River

On most of the project the FLIR images were taken in the morning and afternoon of the same day. Due to a technical problem we missed the morning flight and elected to continue on with the afternoon This threw off the schedule such that both the Middle Fork and the South Fork were imaged in reverse (i.e. PM one day and AM the following day). For the sake of consistency it may be better to maintain a pattern of morning and evening flights within the same calendar day, however in this case the data does not show any ill effects.

Middle Fork tributaries

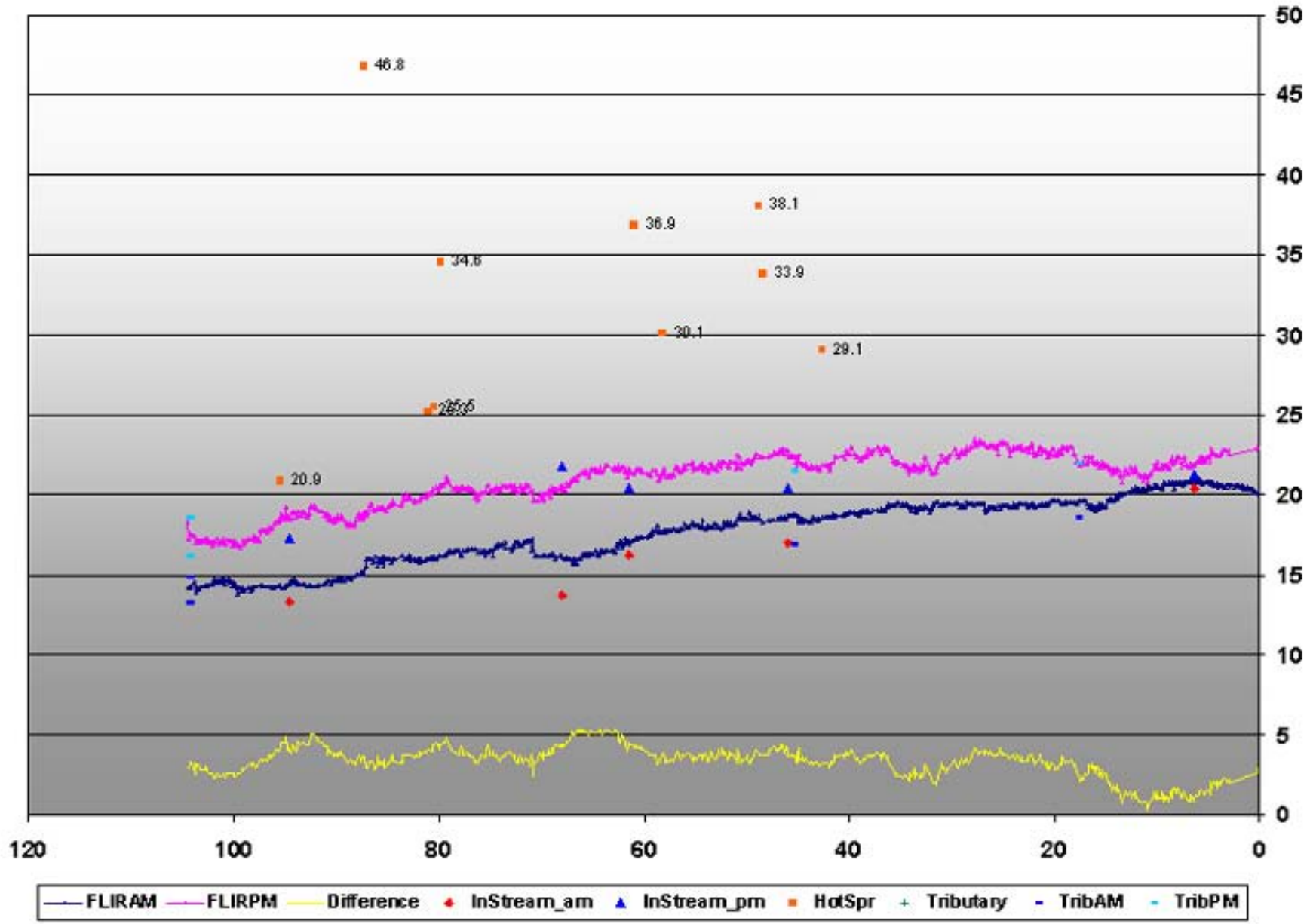
The Middle Fork of the Salmon River begins at the confluence of Marsh Creek and Bear Valley Creek. The Middle Fork has only two other tributaries that are 5th order or above. All measured tributaries on the Middle Fork are listed below in Table 9.

River Mile	Tributary	In Stream AM	In Stream PM	FLIR Trib AM	FLIR TribPM	RiverAM	RiverPM
45.5	Loon Creek	16.4	18.7	16.9	21.5	18.3	21.2
17.9	Big Creek	N/A	N/A	18.6	22.0	19.2	21.7
104.5	Bear Valley Creek	N/A	N/A	14.9	18.6	14.7	17.9
104.5	Marsh Creek	N/A	N/A	13.3	16.2	14.7	17.9

Table 9 Middle Fork tributaries temperature comparison.

Middle Fork Salmon River

Air Temp AM: 10-14 C. / PM: 28-32C



Middle Fork Hot Springs

The Middle fork was clearly the most active in terms of hot springs of all of the rivers in the project area. Of all the springs that we found, the hottest was actually on Bear Valley Creek (Figure 12) just a mile or so above the confluence with Marsh Creek which forms the headwaters of the Middle Fork. Other hot springs images follow in Figure 13 and Figure 14. All hot springs are listed in Table 10.

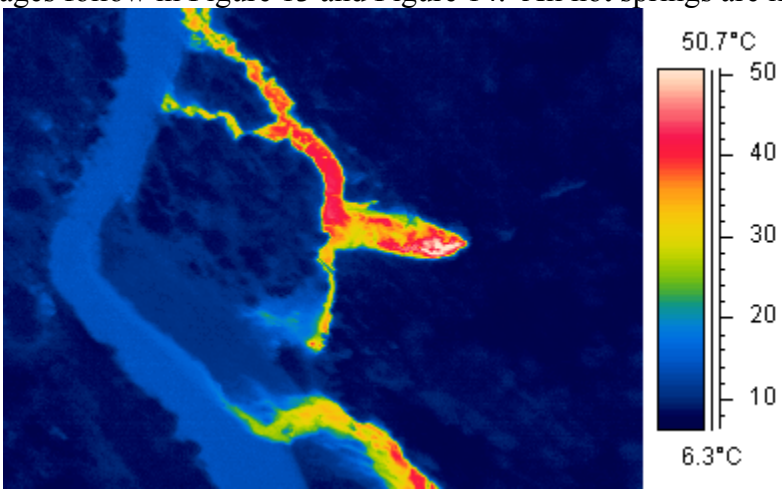


Figure 12 Bear Valley Creek, hot spring is 52 degrees C.

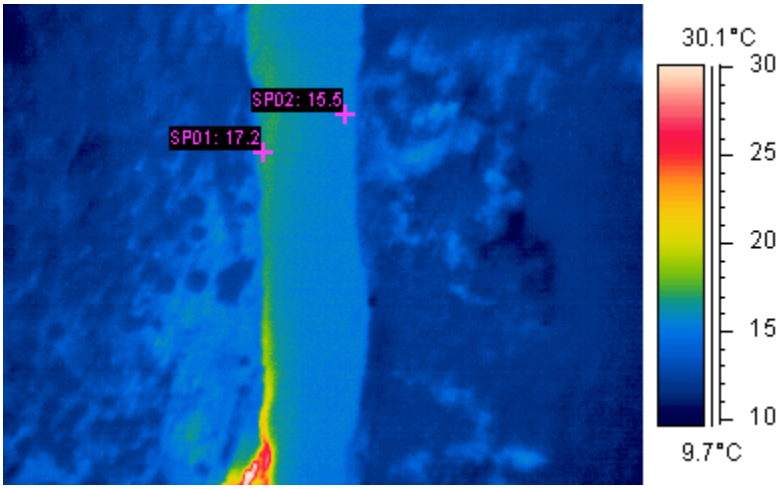


Figure 13 Hot springs at mile 87 showing an across channel temperature difference of 1.7 degrees.

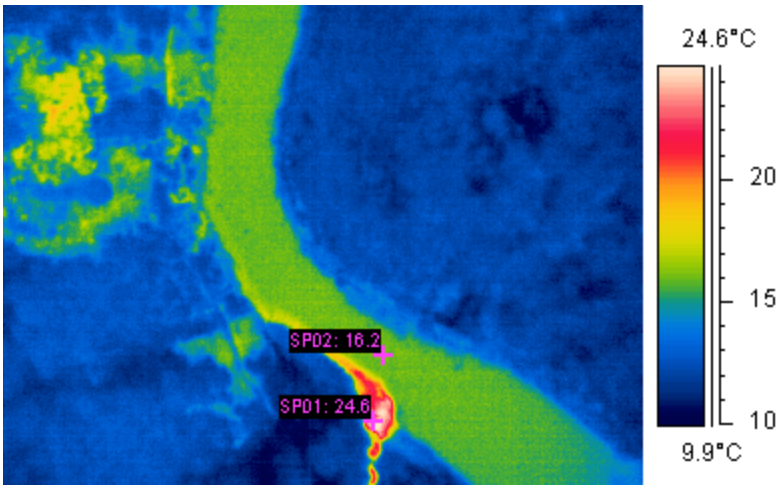


Figure 14 Hot springs at mile 81, 24.6 degrees C.

FLIR Image	TempC.	Mile
mf-am0359.jpg	20.9	95.5
mf-am0823.jpg	46.8	87.3
mf-am1015.jpg	25.3	81.1
mf-am1035.jpg	25.5	80.6
mf-am1055.jpg	34.6	79.9
mf-am1711.jpg	36.9	61.1
mf-am1795.jpg	30.1	58.3
mf-am2102.jpg	38.1	48.9
mf-am2114.jpg	33.9	48.4
mf-am2316.jpg	29.1	42.6

Table 10 All measured hot springs on the Middle Fork

South Fork Salmon River

The AM flight on the south fork took place on August 12. The PM flight was on August 11.

South Fork Tributaries

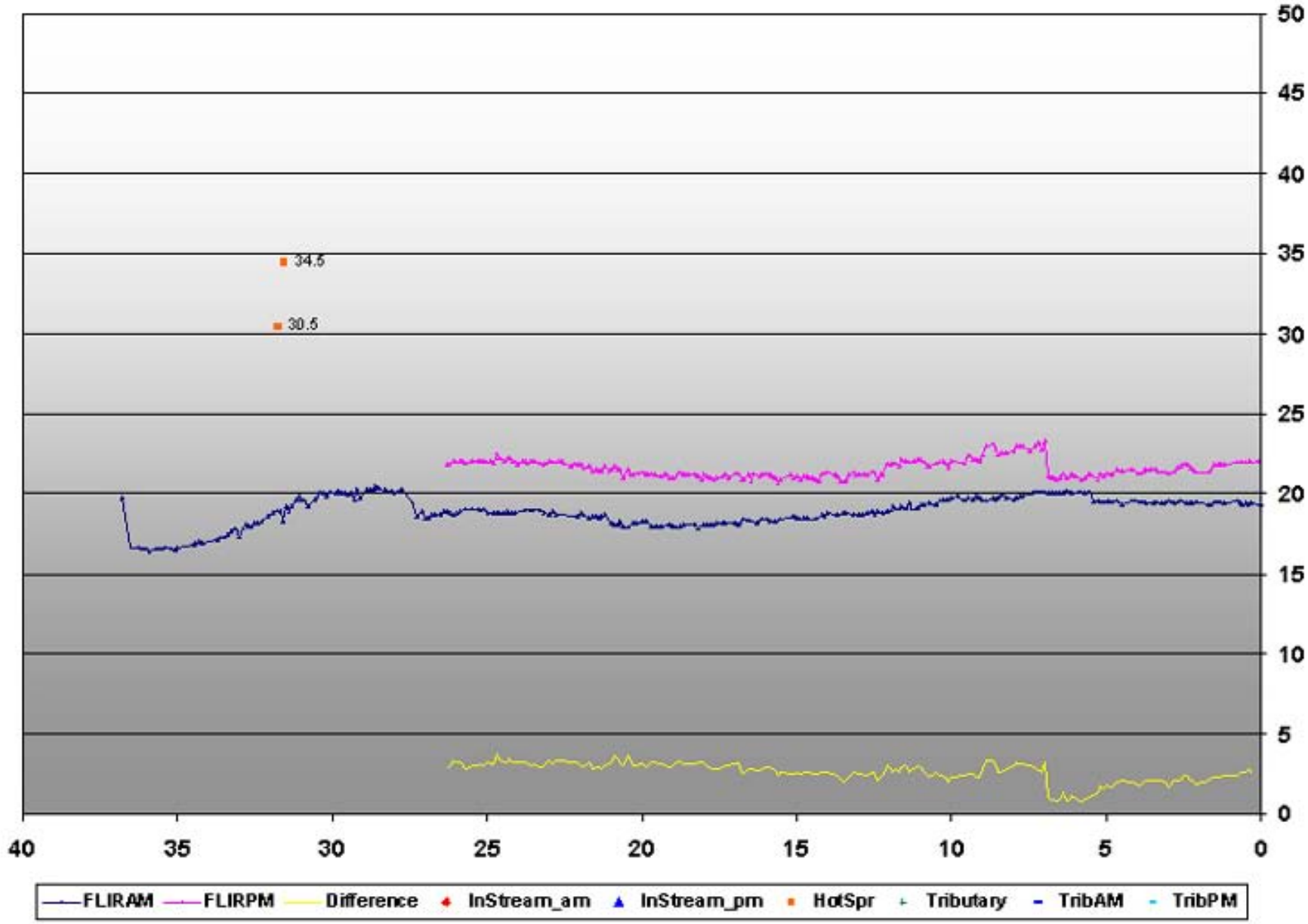
The only 5th order tributary on the South Fork of the Salmon River is at mile 36.4. Apparently this is the East Fork of the South Fork of the Salmon River (Table 11). The upper 8 miles of the South Fork were missed during the evening flight.

RiverMile	Tributary	Trib AM	Trib PM	River AM	
36.4	East fork of the south fork Salmon River	15.2	N/A	16.4	N/A

Table 11 South Fork Tributary temperature info.

South Fork Salmon River

Air Temp AM: 10-14 C. / PM: 28-32C



South Fork Hot Springs

Only two hot springs showed up on the South Fork. Illustrated below in Figure 15 and Figure 16

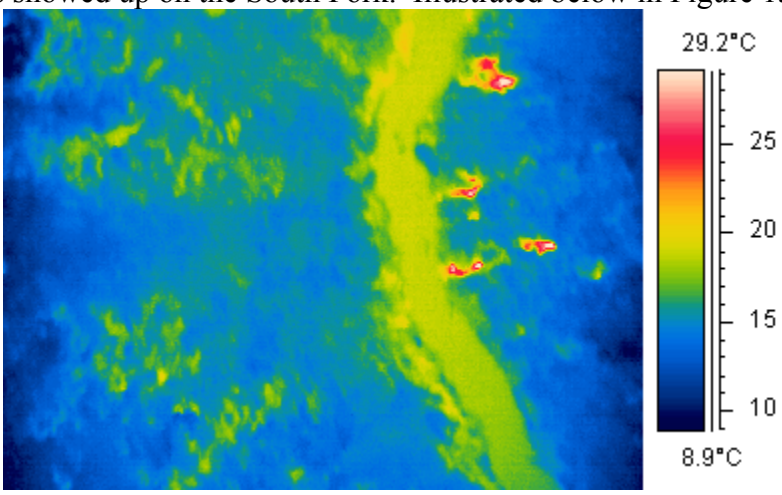


Figure 15 Hot Springs at mile 31.8 is 31.4 degrees C.

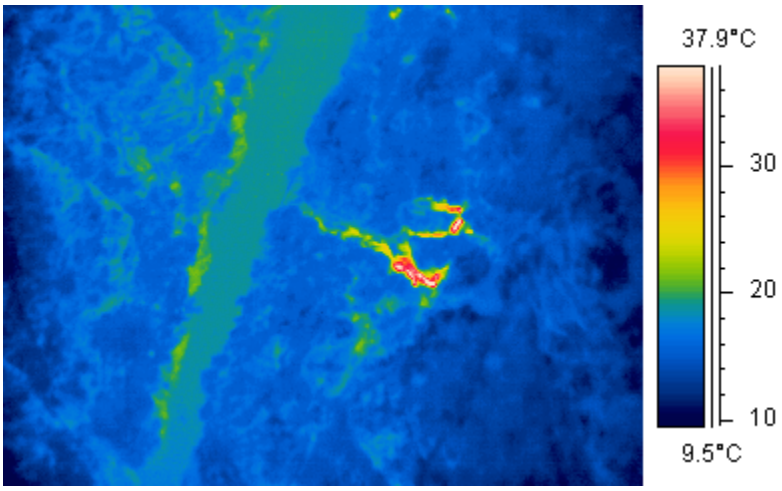


Figure 16 Mile 31.6, hot spring on the hillside is 42.3 degrees C.

FlirImageID	TempC.	Mile
sf-am0276.jpg	30.5	31.8
sf-am0282.jpg	34.5	31.6

Table 12 South Fork hot springs

Lemhi River

The Lemhi River was imaged on August 9, 2001. It is surrounded throughout virtually its entire length by various agricultural pursuits. In the headwaters it is extremely braided, small and difficult to follow. For this reason we eliminated approximately 8 miles from the upper portion of the Lemhi River from the PM flight.

Lemhi River Tributaries

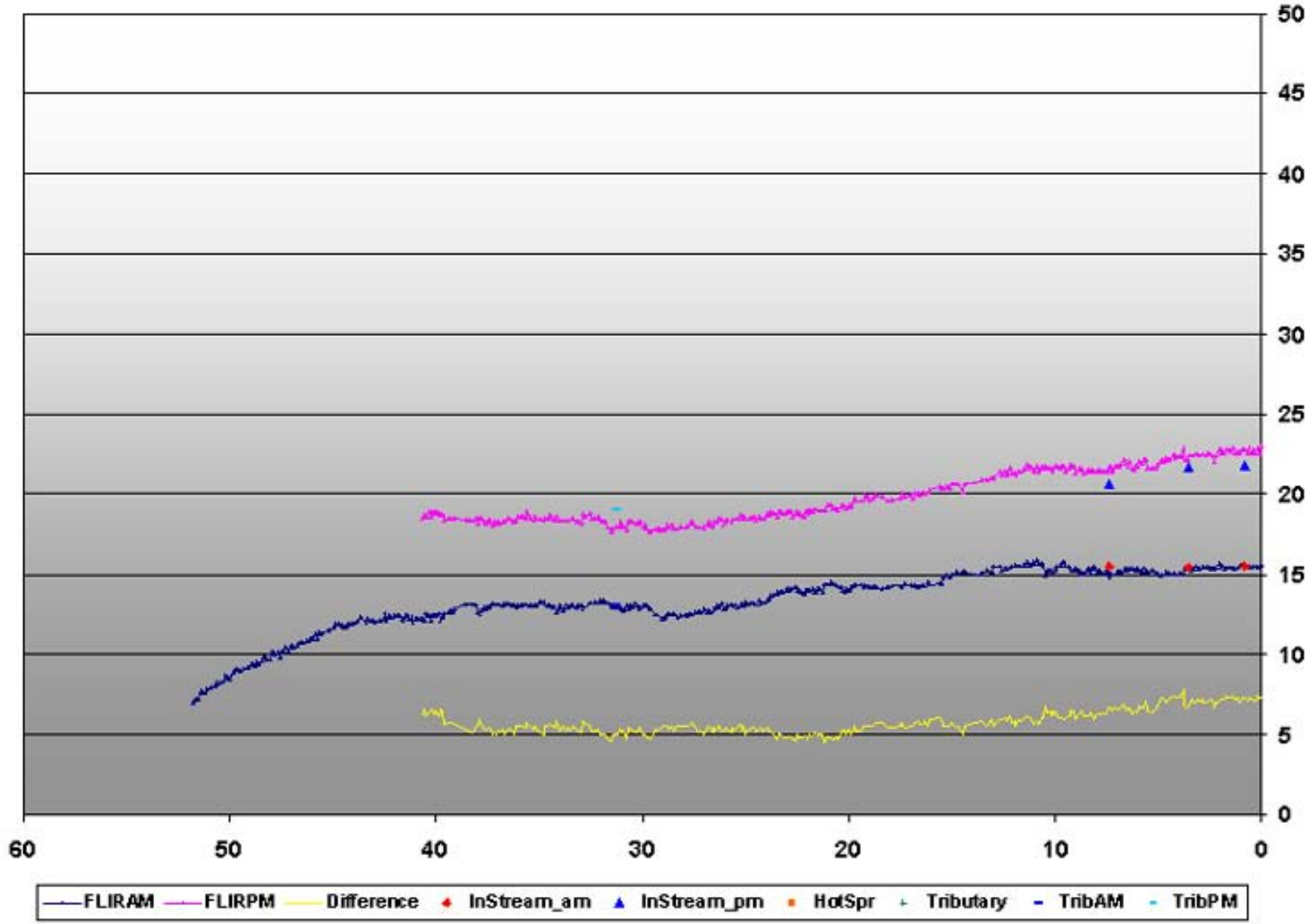
At mile 31.4, Hayden Creek is the only 5th order stream entering the Lemhi River (Table 13).

RiverMile	Tributary	Trib AM	Lemhi AM	Trib PM	Lemhi PM
31.4	Hayden Creek	13.1	12.9	19.1	17.6

Table 13 Lemhi River Tributary info at mile 31.4

Lemhi River

Air Temp AM: 10-14 C. / PM: 28-32C



Appendix

Projection parameters for the Idaho Transverse Projection

Projection Name	Units	Datum	Central Meridian	Latitude of Origin	Scale Factor	False Easting	False Northing
IDTM	Meters	Nad 27	-114	42.0	.9996	500000	10000

Table 14

Additional Data

Included on the CD-ROMS for this report are several GIS themes and additional files.

Themes

FinCIR.shp / Shapefile showing the locations of all CIR images.
FinFLIR.shp / Shapefile showing locations of all FLIR images and temperature data.
Tribs_am.shp and Tribs_pm.shp / Temperature information for all 5th order streams in the project area.
Dataloggers.shp / Location of the dataloggers and the temperature information for the time of the flight.
Legend.avl and tribs.avl / temperature classification legend.

Other Images

The folder called ProjectPics on the data CD contains various images of the helicopter and the some of the scenery that we saw while gathering data.