Aerial Survey of the Applegate River

Thermal Infrared and Color Videography
July 1999

Final Report to the

Applegate River Watershed Council
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Introduction

The Applegate Watershed Council contracted with Watershed Sciences, LLC to map and assess stream temperatures in selected streams in the Applegate River Basin during the summer of 1999 using Forward Looking Infrared (FLIR). This work was conducted as a follow-up to a FLIR survey that was conducted during the summer of 1998. Surveys conducted in 1998 were conducted during the latter part of August when stream temperatures has begun to cool. The 1999 surveys were conducted in late July to capture peak summer stream temperatures.

Traditional methods for monitoring stream temperatures have relied on instream temperature monitors. These monitors provide temporally continuous data, but furnish no insight into the spatial variability in temperatures. With the use of remote sensing, we have been able to map stream temperatures across entire stream networks for the time that is sampled. FLIR technology has proven to be a highly portable and cost-effective method to collect very detailed data over large areas in very little time. The combination of temporally and spatially continuous data provides very powerful tools for understanding the dynamics of stream temperature hierarchically across multiple scales (pools → reaches → streams → watersheds). Current research has identified cool versus warm streams within a watershed, cool reaches within a stream, and cool habitats within a reach (McIntosh et al., 1995; Torgerson et al., 1995; Torgerson et al., 1999).

This document summarizes the methods and results from the FLIR survey conducted in the Applegate River Basin on July 19 and 21, 1999 and compares these results to the 1998 surveys. The results and analysis presented here are at the watershed scale. The data is structured in an ArcView GIS environment to allow further analysis at finer scales.

Methods

Data Collection

The Applegate Watershed Council contracted with Watershed Sciences LLC of Corvallis, Oregon and Snowy Butte Helicopters of Medford, Oregon to collect thermal infrared and visible video imagery in the Applegate River basin during the summer of 1999. Figure 1 illustrates the extent of the survey. The Applegate River was surveyed on July 19, 1999 and the Little Applegate River and Williams Creek were surveyed on July 21, 1999. The survey covered a total of 128.1 river kilometers. Data collection was timed to capture maximum daily stream temperatures, which typically occur between 13:00 and 17:00 hours. Table 1 summarizes the date, time, and survey distance for each survey stream.

Figure 1 – Map of the Applegate River Study Area and streams surveyed with FLIR, 19 and 21 July 1999.

Data were collected using a FLIR and a Day TV video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. All streams were surveyed upstream starting from the mouth and flight altitude was selected based on the estimated average stream channel width. In general, the flight altitude was selected so that the stream channel occupied approximately 20% of the image frame. A minimum altitude of approximately 300 meters was used both for maneuverability and for safety reasons. The Applegate River was flown at an average altitude of 760 meters above ground level. All other streams were surveyed at an average altitude of 450 meters. If the stream split into two channels that could not be covered in the sensor's field of view, the survey was conducted over the larger of the two channels.

FLIR data were collected digitally and recorded directly from the sensor to an on-board computer at a rate of 1 image frame every 2 seconds. The FLIR detects emitted radiation at wavelengths from 8-14 microns and records the level of emitted radiation in the form of an image. Each image pixel contains a measured value that can be directly converted to a temperature. The raw FLIR images represent the full 12 bit dynamic range of the instrument and were tagged with time and position data provided by a Global Positioning System (GPS). For the Applegate River, each thermal image frame covers a ground area of approximately 200 x 300 meters and has a spatial resolution of < 0.5 meters/pixel. For all other streams each thermal image covers a ground area of approximately 100 x 150 meters and has a spatial resolution of about 0.25 meters/pixel.

Day TV images were recorded to an on-board digital videocassette recorder at a rate of 30 frames/second. GPS time and position were encoded on the recorded video. The Day TV sensor was aligned to present the same ground area as the thermal infrared sensor. The GPS time coding provides a means to correlate Day TV images with the FLIR images during post-processing.

Six in-stream temperature data loggers (Onset Stowaways) were distributed in the basin during the survey to ground truth (i.e. verify the accuracy) the radiant temperatures measured by the FLIR. The data loggers also provide a temporal context for interpreting the FLIR imagery. The ground truth locations are shown in Figure 1. The in-stream data loggers were removed shortly after the flight and the temperature information downloaded to a computer.

Table 1. Date, time, and distance for streams surveyed in the Applegate River Basin, 19 and 21 July 1999.

Stream	**Date**	**Time**	**Distance**
Applegate River (mouth to dam)	7/19/99	15:37 – 16:16	75.0 km
Williams Creek	7/21/99	15:13 – 15:21	11.3 km
West Fork Williams Creek	7/21/99	15:28 – 15:31	5.4 km
East Fork Williams Creek	7/21/99	15:23 – 15:25	4.1 km
Little Applegate River	7/21/99	14:26 – 14:45	32.3 km

The meteorological conditions were recorded before each flight. Table 2 summarizes the conditions for each day of the survey.

Table 2. Meteorological Conditions for 19 and 21 July 1999 at the Medford Airport, Oregon.

Day, Time	Temperature	Relative Humidity	Sky Conditions	Winds
7/19, 14:15:00	32.2°C	19%	Clear	Variable, 5 knots
7/21, 14:00:00	28.0°C	21%	Clear	Variable, 6 knots

Data Processing

A computer program was used to scan the FLIR imagery and create a text file containing the image name and time and location it was acquired. The text file was then converted to an ArcView GIS point coverage. The coverage provided the basis for assessing the extent of the survey and for integrating with other spatially explicit data layers in the GIS. This allowed us to identify the images associated with the ground truth locations. The data collection software was used to extract temperature values from these images at the location of the in-stream recorder. The radiant temperatures were then compared to the kinetic temperatures from the in-stream data loggers.

The image points were associated with a river kilometer using the dynamic segmentation features of Arc/Info GIS software. The river kilometers were derived from 1:100K "routed" stream covers from the Environmental Protection Agency (EPA). The route measures provide a spatial context for developing longitudinal temperature profiles of stream temperature.

In the laboratory, a computer algorithm was used to convert the raw thermal images (radiance values) to ARC/INFO GRIDS where each GRID cell contained a temperature value. During the conversion, the program recorded the minimum and maximum temperature value found in each image. An ArcView Extension was used to display the GRID associated with an image location selected in the point coverage. The GRID was color-coded to visually enhance temperature differences, enabling the user to extract temperature data. The GRIDS were classified in one-degree increments over the temperature range of 10 to 30°C. Temperatures < 10°C are black, temperatures between 30 and 55°C were colored in shades of gray (darker tones -> lighter tones), temperatures > 55°C are white.

Figure 2 illustrates a color coded GRID displayed in the ArcView environment. This GRID illustrates the confluence of the Applegate River and the Little Applegate River. The legend on the left of the "Grid View" specifies the temperature range associated with each color. The other view window, "Thermal Survey", shows the point coverage with the displayed GRID location highlighted in yellow. Each blue point in the "Thermal Survey" view represents another image location.

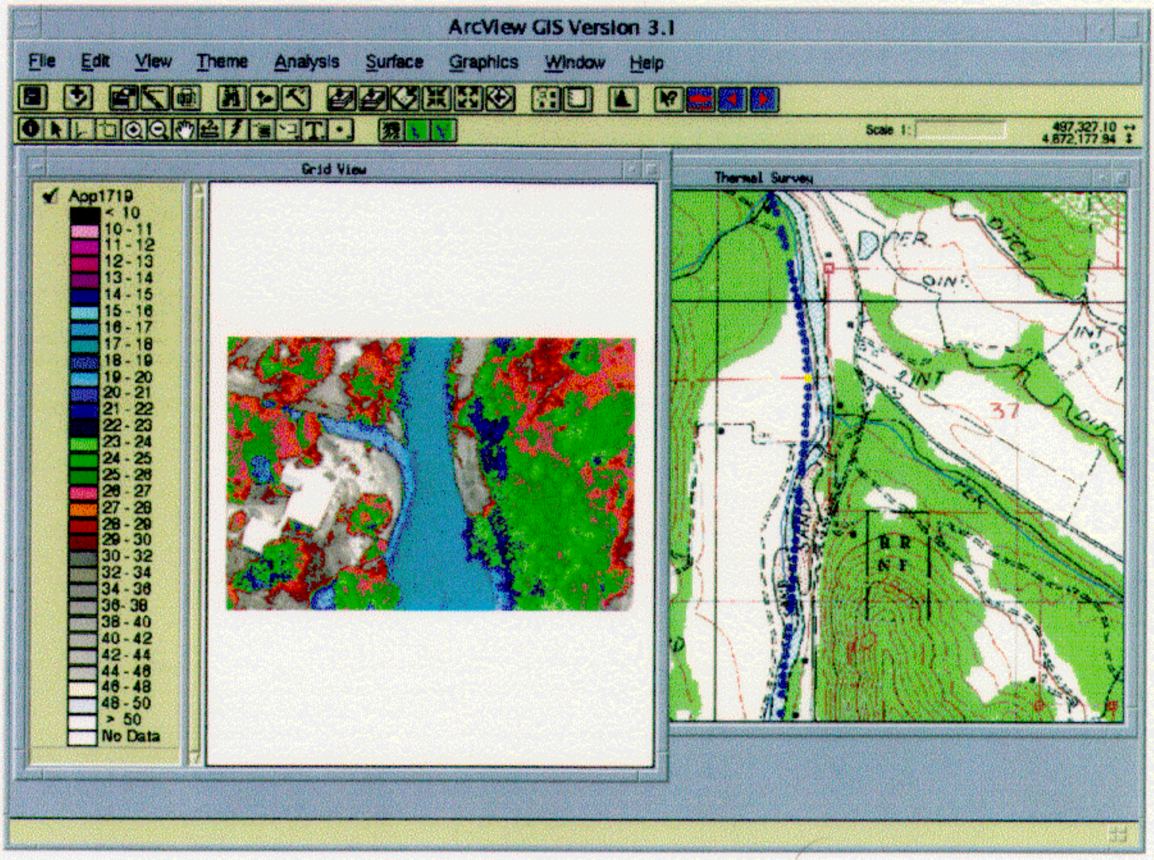


Figure 2 – ArcView display showing a color-coded temperature GRID in one window and the geographic location of the GRID in the other (note that the top of the image is in the flight direction and hence opposite the map).

Figure 3 illustrates the temperature GRID displayed in Figure 2 with its corresponding Day TV image. Prominent thermal features are identified in each image. The Applegate River and the Little Applegate River are clearly visible in the image due to the high thermal contrast with the warmer terrain features. This is the standard format currently used to interpret and analyze the thermal image data.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, an ArcView program was used to sample the GRID cell (temperature) values in the stream channel. Ten sample points were taken longitudinally in the center of the stream channel. Samples were taken on every 5th image to provide complete coverage without sampling the same water twice (there is approximately 40-60% overlap between images). Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled. In cases where the channel was obscured by vegetation, as was the situation on many of the tributaries, the next image where the stream channel was clearly

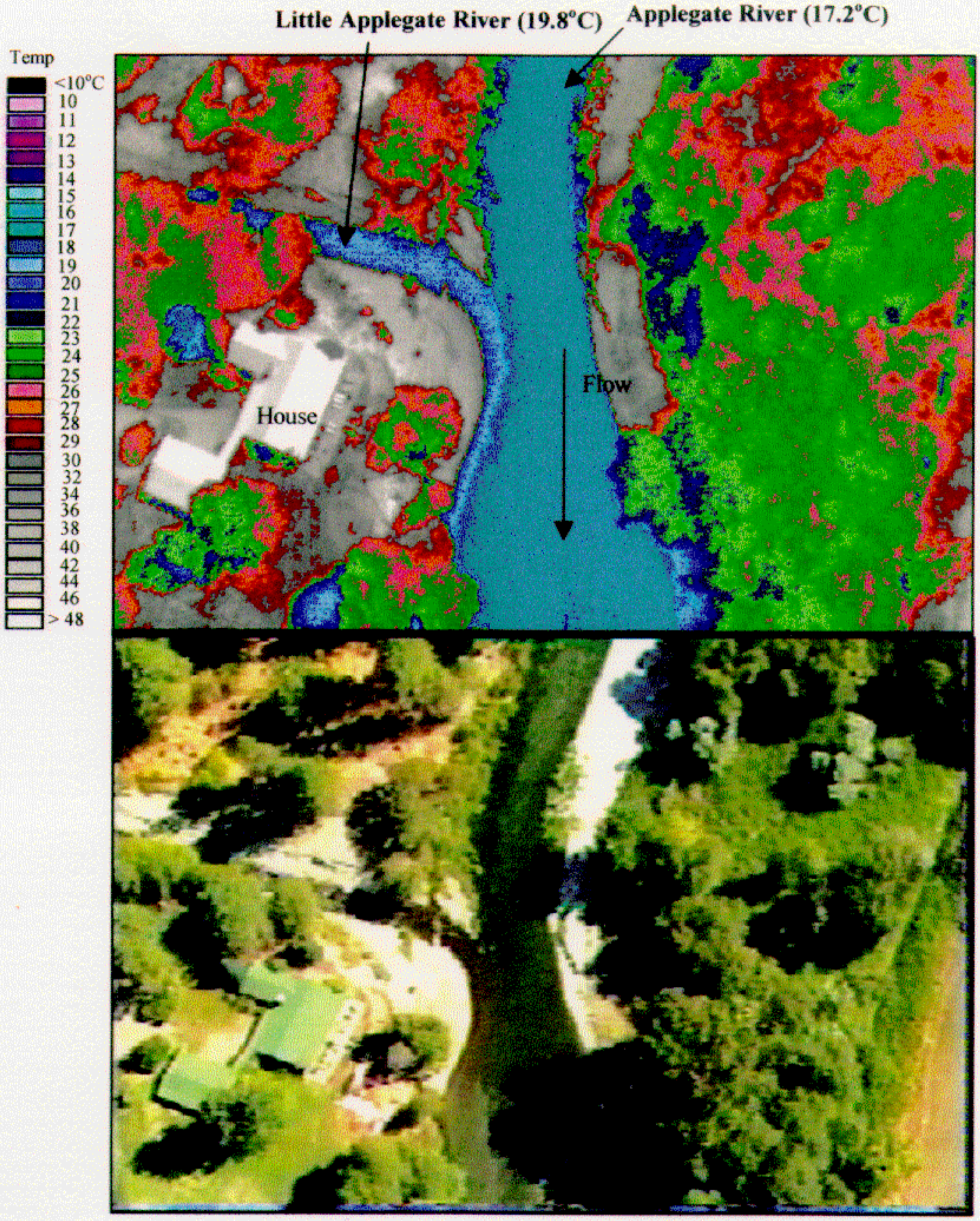


Figure 3 – Temperature Grid (top) and Corresponding Day TV image (bottom) showing the confluence of the Applegate and Little Applegate Rivers. Prominent thermal features are identified on the thermal image.

visible was sampled. For each sampled image, the sample minimum, maximum, median, and standard deviation was recorded directly to the point coverage attribute file.

The temperature of tributaries and other detectable surface inflows were also sampled from images. These inflows were sampled at their mouth using the same techniques described for sampling the main channel. If possible, the surface inflows were identified on the USGS 24K base maps. The inflow name and median temperature were then entered into the point coverage attribute file.

Day TV images corresponding to the FLIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the thermal infrared images and provide a complete coverage of the stream. The video images were "linked" to the corresponding thermal image frame in the ArcView GIS environment.

Data Limitations

FLIR systems measure thermal infrared energy emitted at the water surface. Since water is essentially opaque to thermal infrared wavelengths (8 - 12μm), the sensor is only measuring the water surface temperature. This is typically not an issue on streams where the water column is thoroughly mixed. Field measurements conducted on the Middle Fork of the John Day River, OR and on the Klamath River, CA confirmed that thermal stratification was insignificant or not present even in the deepest pools. This was not considered an issue on the streams sampled in the Applegate Basin. However, it is a consideration in the areas of very low flow and intermittent flow observed on Williams Creek.

Detection of features using FLIR depends on a thermal contrast between an object (in this case the stream) and its background. Although the FLIR is very sensitive to temperature differences (<0.2°C), it is often difficult to distinguish the stream boundaries when water temperatures are equal to or greater then the temperature of the surrounding land cover. Decreased thermal contrast along with canopy cover cause operational problems because it is difficult for the sensor operator to continuously detect the stream channel. This caused some problems surveying Williams Creeks where the apparent temperature of bank-side vegetation and shadows were at or below the in-stream water temperatures.

Results

Thermal Accuracy

Temperatures from the in-stream data loggers were compared to the radiant temperatures derived from the FLIR imagery for the Applegate watershed (Table 3). The data was assessed at the time the image was acquired. The radiant values represent

Table 3 – Comparison of in-stream temperatures and radiant temperatures derived from thermal infrared images, 19 and 21 July 1999.

Hobo Location	Image	Date, Time	In-Stream Temp.	Radiant Temp.	Δ °C
Applegate @ Cantrall Buckley State Park	0835	7/19, 16:04	20.61°C	20.9 °C	-0.29
Applegate @ Little Applegate (km 55)	0884	7/19, 16:06	20.95°C	21.1°C	-0.15
Applegate below Dam (km 74)	1170	7/19, 16:15	16.28°C	16.3°C	-0.02
Little Applegate near mouth (km 0.1)	0034	7/21, 14:26	19.65°C	19.5°C	0.15
Williams Ck near Mouth	0030	7/21, 15:23	21.40°C	21.3°C	0.10
Williams Ck near East Fork	0448	7/21, 15:33	17.20°C	17.6°C	0.40

the median of 10 points sampled from the image at the data logger location. All six locations used for ground-truthing indicated the FLIR imagery was accurate to +0.4°C of the measured in-stream temperatures.

Figures 4-6 compare the 24-hour temperature cycle at each ground-truthing site to the temperature calculated from the FLIR image for the corresponding site. These figures are useful for showing the relationship of the FLIR data to the daily maximums at each site. Since the FLIR survey represents a snapshot of the stream temperature profile for a given day, this analysis provides a context for the longitudinal temperature profile in relationship to the daily maximum streams temperatures for each stream. As each of the

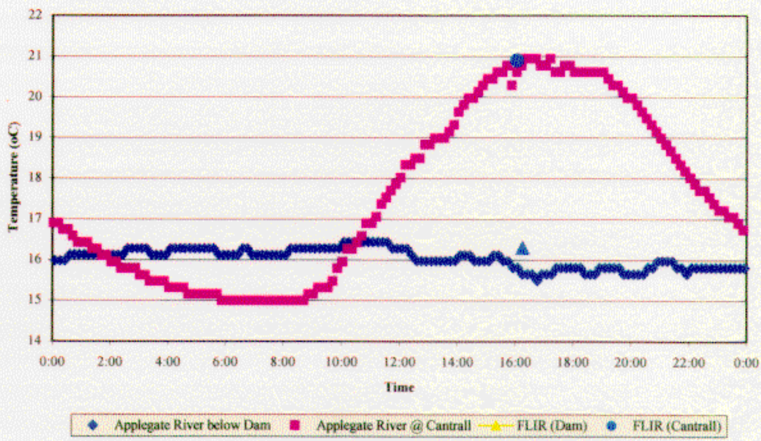


Figure 4 – Comparison of in-stream temperature measurements to FLIR temperature measurements on the Applegate River, July 19, 1999.

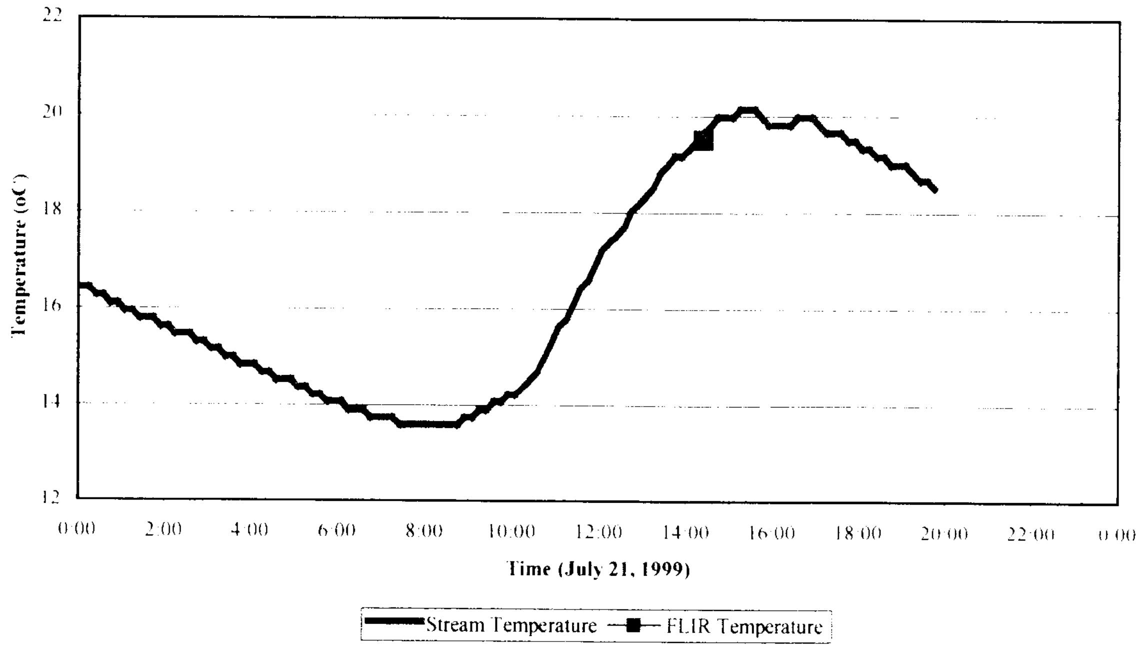


Figure 5 – Comparison of in-stream temperature measurements to FLIR temperature measurements on the Little Applegate River, July 21, 1999.

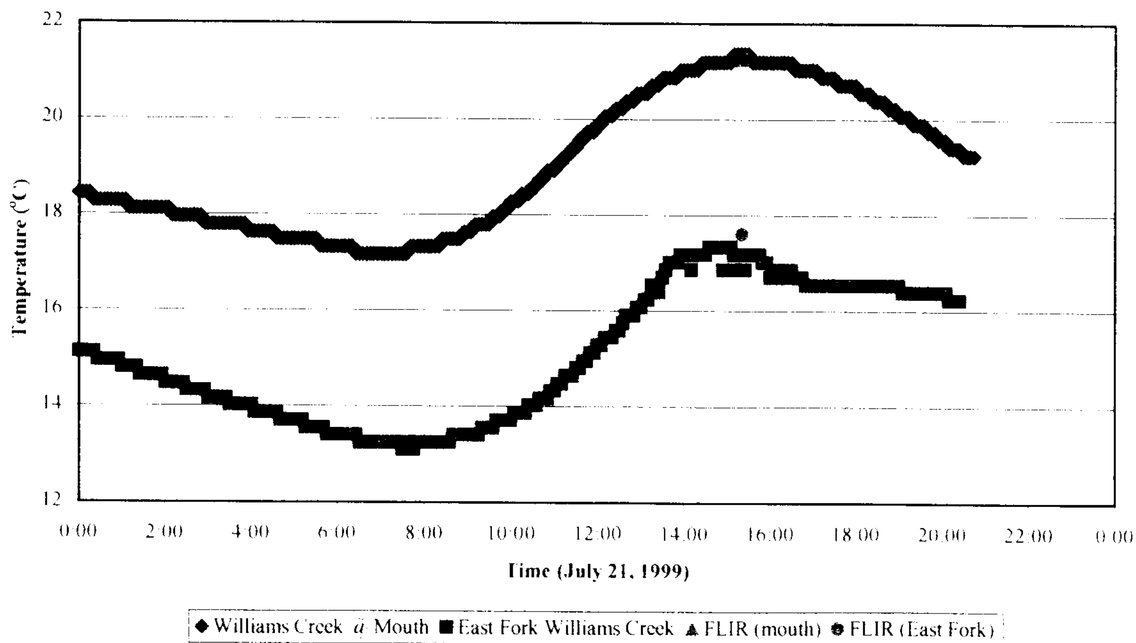


Figure 6. Comparison of in-stream temperature measurements to FLIR temperature measurements on Williams Creek, July 21, 1999.

figures illustrates we were at or near the daily maximum stream temperature for each of the surveyed streams.

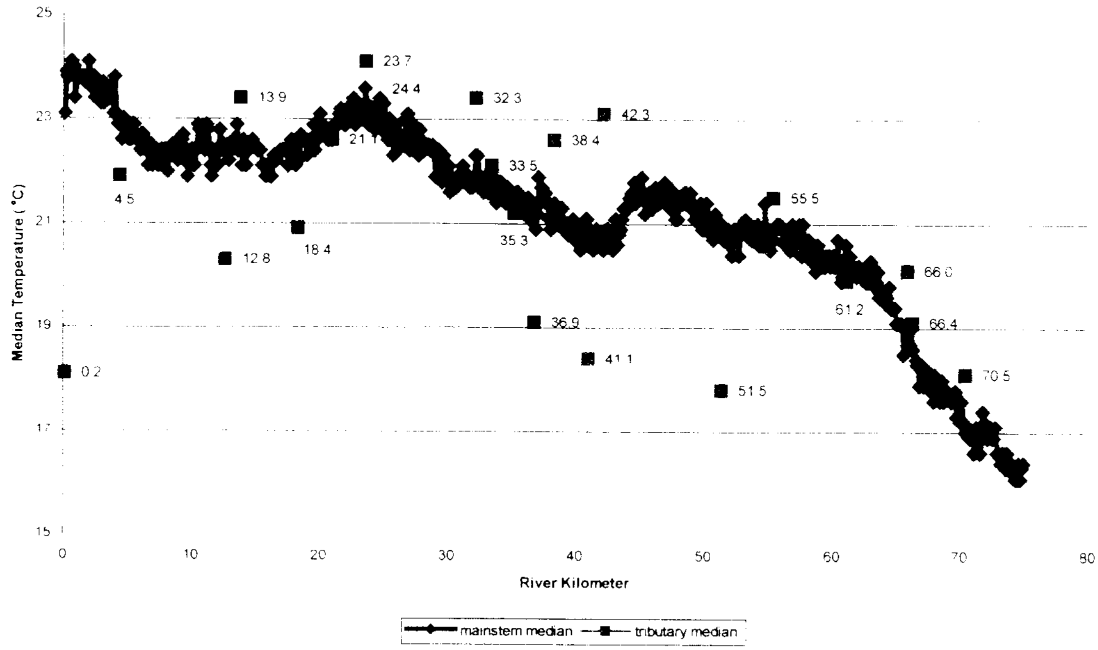
Applegate River

The median temperatures for each sample frame from the mouth of the Applegate River to the Applegate Dam were plotted versus river kilometer (Figure 7). The plot also includes the temperature of tributaries and side-channels that were visible in the imagery. Tributaries are labeled in Figure 7 by river kilometer with their name and temperature listed in the associated table. Only the surface water inflows that could be positively identified in the imagery were included. In some cases, tributaries and other surface water inputs were obscured by riparian vegetation or outside the sensor field of view and their image location could not be accurately determined.

Figure 7 shows how temperatures vary longitudinally along the river and the influence of tributaries. Temperatures at the dam outlet were 16.8°C and warmed rapidly to about 20°C at river kilometer 63, an increase of 0.3°C/km. From river kilometer 63 to river km 44.6 the median temperature increases at a much slower rate (0.08°C/km) to 21.8°C. At river km 44.6 stream temperatures drop over the next 1.3 km at a rate of 0.9°C/km to a local minimum of 20.6°C. There are no clear reasons for this decrease in temperature in the imagery, as no apparent cool water inputs are evident in the reach. From river kilometer 43 to 23.7, stream temperatures increase at a rate of 0.15°C/km to a local maximum of 23.6°C. At river kilometer 23.7 stream temperatures again decrease in a downstream direction at a rate of 0.23°C/km, reaching a local minimum of 21.9°C at river kilometer 16.3. For the next 9 kilometers stream temperatures remain relatively unchanged. At river kilometer 7 stream temperatures increase to the confluence of the Rogue River at a rate of 0.3°C to the maximum for the Applegate River of 24.1°C. At the confluence with the Rogue River the Applegate is 23.1°C and the Rogue is 18.1°C, a difference of 5.0°C.

While tributaries and other surface water inputs collectively contribute to the temperature pattern, they do not result in any dramatic changes in mainstem temperatures. This is primarily due to their relatively small flow compared to the flow of the main channel. Despite their relatively small contribution to the mainstem stream flow, the majority (7 of 13) of the mainstem tributaries were contributing warmer stream flows (range = +0.4°C to +2.5°C). The five streams that were contributing cooler inputs ranged from –0.2 to –3.2°C cooler then the Applegate River. This finding suggests that other factors such as solar energy, channel morphology, and ground water inputs are the driving temperature patterns at the watershed scale.

We plotted the 1998 and 1999 data from the FLIR surveys to compare the longitudinal profiles for different years and time of year (Figure 8). As the figure indicates, the longitudinal temperature profiles were similar between years with the absolute temperatures being different. We attribute this difference to the timing of the flights in the two summers. The 1999 flight captures summertime maximums, which typically occur in late July while the 1998 flight occurred later in the summer when daily



Tributary	River Km	Tributary Temp (°C)	Applegate Temp (°C)	Difference (trib-mainstem)	FLIR image
Rogue River	0.0	18.1	23.1	-5.0	App0013
Slate Creek	4.5	21.9	23.0	-1.1	App0076
Jackson Creek	12.8	20.3	22.4	-2.1	App0212
Side-channel	13.9	23.4	22.4	+1.0	App0230
Iron Creek	18.4	20.9	22.2	-1.3	App0296
Murphy Creek	21.1	22.6	22.6	0.0	App0332
Board Shanty Creek	23.7	24.1	23.3	+0.8	App0374
Wildcat Gulch	24.4	23.2	22.8	+0.4	App0384
Williams Creek	**32.3**	**23.4**	**21.9**	**+1.5**	**App0505**
Side-channel	33.5	22.1	21.7	+0.4	App0525
Side-channel	35.3	21.2	21.4	-0.2	App0555
Side-channel	36.9	19.1	21.3	-2.2	App0579
Thompson Creek	41.1	18.4	20.6	-2.2	App0647
Humbug Creek	**42.3**	**23.1**	**20.8**	**+2.3**	**App0666**
Forest Creek	51.5	17.8	21.0	-3.2	App0816
Little Applegate River	55.5	21.5	20.7	+0.8	App0884
Star Gulch	61.2	19.9	20.1	-0.2	App0980
Beaver Creek	**66.0**	**20.1**	**18.7**	**+1.4**	**App1052**
Side-channel	66.4	19.1	18.6	+0.5	App1060
Side-channel	70.5	18.1	17.0	+1.1	App1123

Figure 7 Median stream temperature versus river kilometer for the Applegate River. Tributaries and side channels are described in the table.

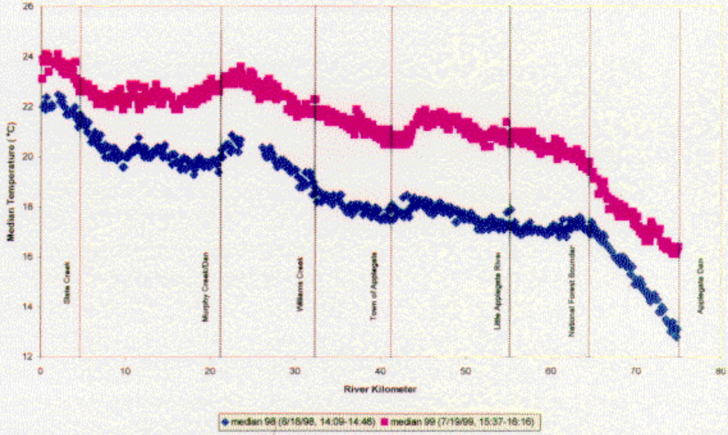
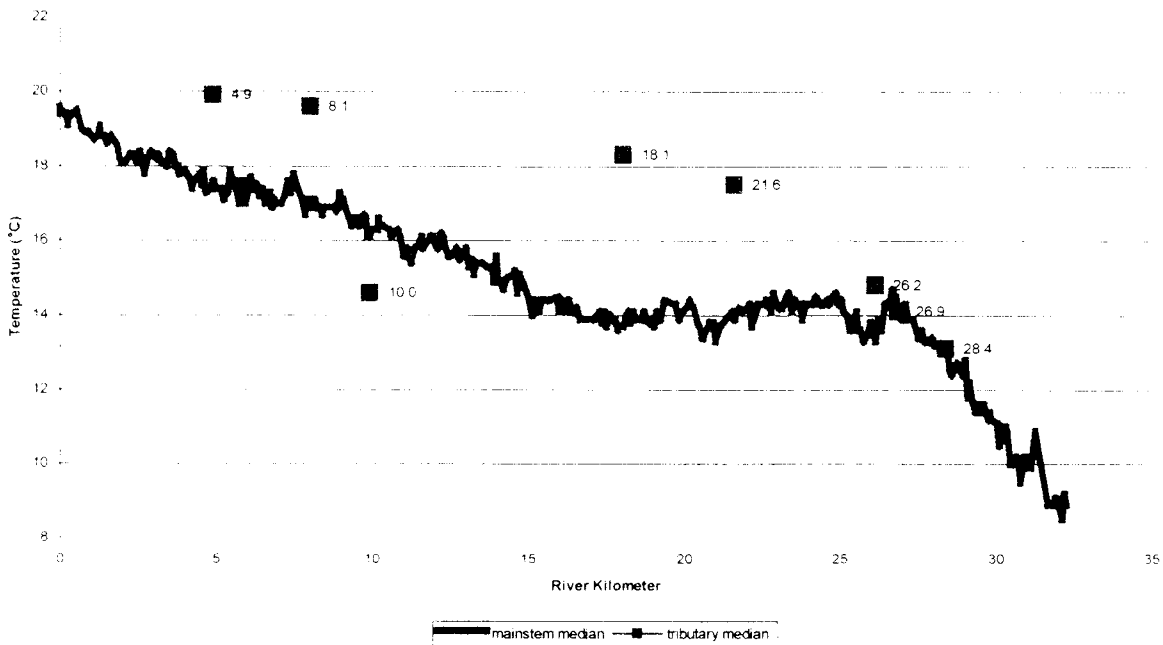


Figure 8 – Comparison of longitudinal temperature profiles for FLIR surveys in 1998 and 1999 in relationship to key landmarks.

maximums had begun to decrease. The Applegate Watershed Council now has a reliable benchmark of summertime maximum stream temperatures to assess improvements in temperature conditions with future flights at five to ten year intervals.

Little Applegate River

A longitudinal temperature profile was developed for the Little Applegate from the mouth to the headwaters, a distance of 32.3 km (Figure 9). Stream temperatures in the headwaters were comparable to groundwater temperatures (8-9°C) but rise rapidly to river km 26.5 at about 0.9°C/km. From river km 26.5 to 15.1 temperatures remain relatively constant at about 14°C. At river km 15.1 stream temperatures begin to increase steadily to the mouth at about 0.4°C/km, reaching a maximum for the survey of 19.6°C at the confluence with the Applegate River. We detected eight tributary inputs in the survey, with five contributing warmer flows (+0.2 to +3.6°C), one contributing cooler flows (-1.5°C) and two contributing flows at the same temperature as the Little Applegate River. While the tributary inputs contributed to the overall thermal environment, none seemed to affect the overall temperature profile.



Tributary	River Km	Tributary Temp (°C)	LApplegate Temp (°C)	Difference (trib-mainstem)	FLIR image
Sterling Creek	**4.9**	**19.9**	**17.6**	**+2.3**	**La0202**
Cantrall Gulch	**8.1**	**19.6**	**17.1**	**+2.5**	**La0307**
Yale Creek	10.0	14.6	16.1	-1.5	La0382
Rush Creek	18.1	18.3	18.1	+0.2	La0648
Second Chance Gulch	**21.6**	**17.5**	**13.9**	**+3.6**	**La0797**
Unknown Tributary	**26.2**	**14.8**	**13.3**	**+1.5**	**La0941**
Unknown Tributary	26.9	14.1	14.1	0.0	La0962
Unknown Tributary	28.4	13.1	13.2	-0.1	La1010

Figure 9 - Median stream temperature versus river kilometer for the Applegate River. Tributaries and side channels are described in the table.

We also compared the longitudinal temperature profile developed from the 1998 data to the 1999 data (Figure 10). Our comparison indicated there were no significant differences between the two surveys despite different seasonal and daily survey timing of the surveys. This suggests the longitudinal temperature pattern for the Little Applegate River is not as affected by variation in climate and/or stream discharge as the mainstem. It would be useful to compare stream discharges in the Little Applegate at the time of the two surveys to see if flow might have affected the results.

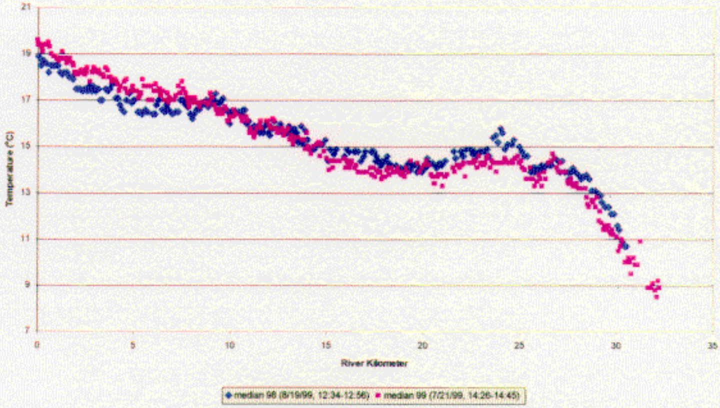
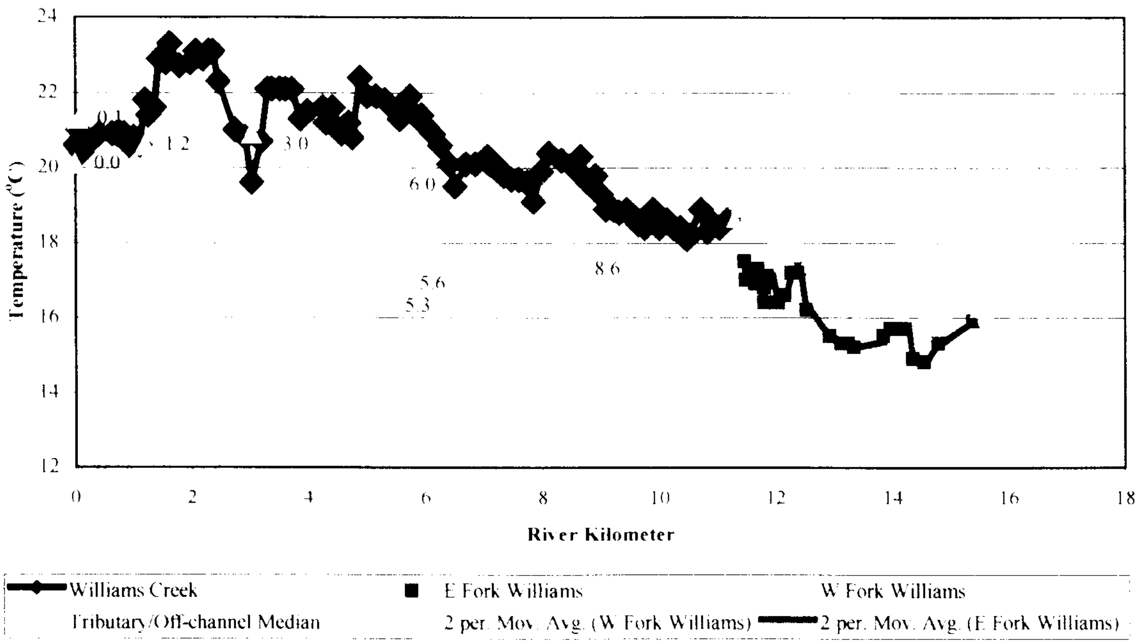


Figure 10 – Comparison of longitudinal temperature profiles for FLIR surveys in 1998 and 1999.

Williams Creek

FLIR data was collected and analyzed for Williams Creek (11.3 km) and the West (5.4 km) and East Fork (4.1 km) of Williams Creeks, a total distance of 20.8 km (Figure 11). The flights up the forks were a relatively short distance due to near complete canopy closure at the terminus of the survey. Stream temperatures were relatively warm (15-16°C) at the upper extent of the survey for both forks. Temperatures increase steadily in a downstream direction to the confluence with Williams Creek and continue to warm to river km 4.9, where temperatures drop by 1.6°C from one image to the next. There is no apparent reason for decrease in temperatures when reviewing the imagery, but the pattern is consistent with results from 1998. Temperatures resume warming steadily below this point until river km 3.3 where temperatures abruptly decrease again. From here to the confluence with the Applegate River stream temperatures appear to be strongly influenced by flow increases and decreases due to several major water diversions and returns such as Watts and Topping Diversion and the Bridgeport Ditch. We compared our results from 1999 to 1998 and found similar patterns between years for Williams Creek (Figure 12). The forks were not flown in 1998. In addition, as in the Little Applegate, absolute temperatures from year to year were similar in Williams Creek despite being collected a month apart.



Tributary	River Km	Tributary Temp (°C)	Williams Temp (°C)	Difference (trib-mainstem)	FLIR image
Applegate River	0.0	20.1	20.6	-0.5	Wil0026
Side-channel	0.05	21.3	21.0	+0.3	Wil0029
Bridgeport Ditch	1.2	20.6	21.8	-1.2	Wil0068
Watts & Topping Diversion	**3.0**	**20.9**	**19.6**	**+1.3**	**Wil0127**
Backwater/trib?	5.3	16.3	21.8	-5.5	Wil0199
Side-channel	5.6	16.9	21.3	-4.4	Wil0236
Side-channel	6.0	20.2	21.1	-0.9	Wil0252

Figure 11 – Median stream temperature versus river kilometer for Williams Creek, East Fork Williams Creek, and West Fork Williams Creek. Tributaries and side channels are described in the table.

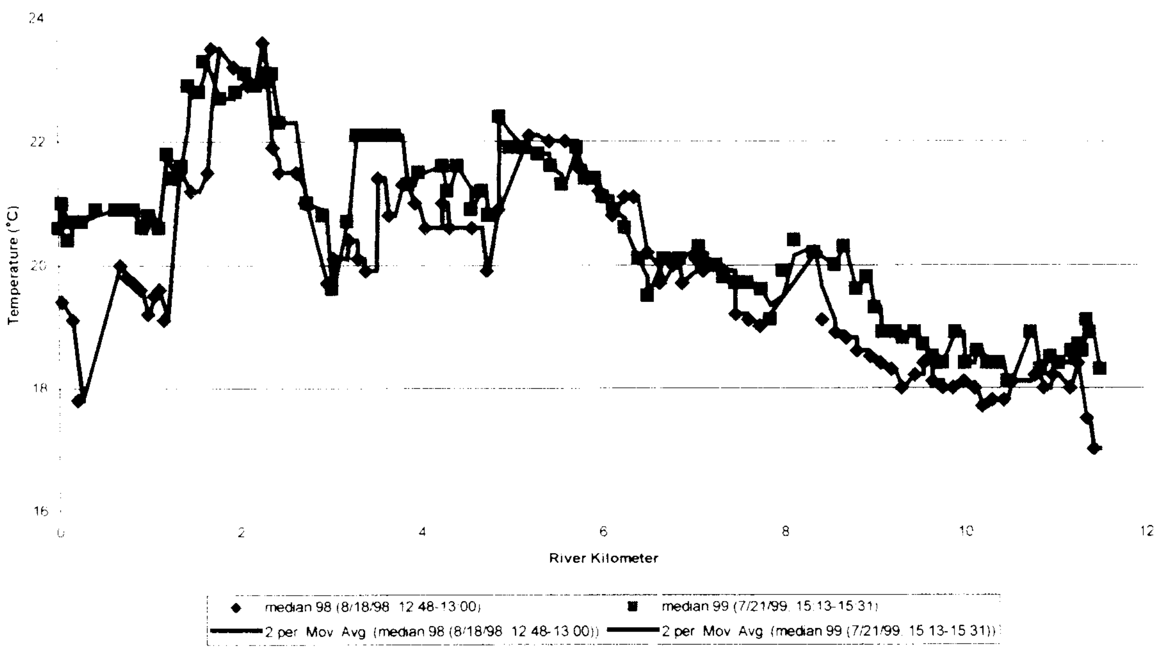


Figure 12. Comparison of longitudinal temperature profiles for Williams Creek from 1998 and 1999.

Discussion

During July 1999, FLIR imagery was collected on the Applegate River, Little Applegate River, and Williams Creek, a total of 128 km of streams in the Applegate River Basin. These surveys were repeated from a sub-sample of streams that were surveyed in August 1998. The resurveys were conducted to collect data during the period of maximum summertime stream temperatures, which typically occur from July 15 – August 15. The 1998 surveys were conducted in late August due to delays in the contracts to support the data collection and analysis. By late August stream temperatures had begun to cool, raising questions about whether the longitudinal temperature profiles that were developed in 1998 were representative of summer maximums.

Our analysis of the longitudinal stream temperature patterns in the Applegate River basin from the 1999 surveys were consistent with the patterns we observed in the 1998 surveys (McIntosh et al., 1999). Our resurvey of the Applegate River indicated that the pattern remained unchanged from 1998 to 1999, but the absolute difference in temperatures was about 2.8°C higher in 1999. This result is consistent with our expectation of higher daily maximum temperatures in later July versus late August. For the Little Applegate River and Williams Creek we also found little variation in longitudinal temperature patterns from 1998 to 1999. In contrast to the comparison of surveys for the Applegate River we found little to no difference in absolute temperatures for the Little Applegate River and Williams Creek. This suggests that stream temperature patterns in the Little Applegate and Williams Creek are more stable seasonally while the Applegate River is more variable. The variation in the Applegate River may be due to highly variable flow regimes from dam regulation and irrigation withdrawals along with greater exposure to incoming solar radiation due to inherent geomorphology and lower levels of shade from riparian vegetation along the mainstem river. Our analysis of the timing of flights in relationship to the daily temperature cycles indicates we collected the FLIR data at or very near the daily maximum temperatures for the surveyed stream.

Assessment of the stream temperature patterns in the Applegate River basin indicated that stream temperatures tended to increase in a downstream direction, but the pattern of this change varied among streams. Along the Applegate River, there were three reaches in which stream temperatures warmed relatively rapidly. The first was the reach from the Applegate Dam to the Forest Service Boundary. Stream temperatures in the reach are most likely controlled by releases from the Applegate Dam, where the discharge and temperature of the release can be regulated. Previous work indicated that maximum stream temperatures in this reach occur at night while minimum temperatures occur in late afternoon (McIntosh at al., 1999). This pattern is not consistent with the normal daily cycle of stream temperatures in unregulated streams. The second reach with significant warming is from Thompson to Murphy Creek. In this reach the river is in a wider valley, the channel is highly braided in many areas, and the levels of riparian shade are quite low. Irrigation withdrawals are also a likely influence in this reach but will require further field investigations to confirm. We suspect the rapid warming and apparent cooling above Murphy Creek may be due to the effect of the dam just above Murphy Creek. Streamflow is greatly reduced in this reach, creating stagnant flow and conditions where thermal stratification may occur. If thermal stratification is occurring in this reach the surface temperatures detected by the FLIR are probably not representative of the temperature of the entire water column. Surface temperatures under these conditions would tend to be warmer then the water column due to poor mixing and greater heating of the water surface from exposure to solar radiation. The third reach of thermal warming is from Slate Creek to the confluence with the Rogue River. A wide valley, highly braided stream channels, and low levels of riparian shade also characterize this reach.

In addition, our analysis attempted to show the influences of tributary inputs on stream temperature. Tributaries influenced the receiving streams locally, but did not seem to alter the prevailing temperature trend. Analysis of the imagery suggests that most tributaries to the Applegate River, with the exception of the Little Applegate River, do not have sufficient flow during the summer months to provide a detectable shift to the in-stream temperatures. These results were consistent with the 1998 survey (McIntosh et al., 1999). In Williams Creek, the downstream reaches are strongly influenced by irrigation withdrawals and returns. The amount of canopy on the upper reaches of these creeks made it difficult to determine the influence of tributaries and other surface water inflows on the temperature patterns. Colder inflows can lower the temperature of the stream the discharge into considerably. When streams cool where there are no tributaries, the cooling is likely to be the result of subsurface inputs.

In summary, our analysis of the FLIR data collected in 1998 and 1999 indicated that the *patterns* derived from longitudinal temperature profiles were consistent from year-to-year with variation in absolute temperatures. The consistency of these patterns provide the Applegate River Watershed Council with a reliable and replicable benchmark with which to prioritize further field-based stream temperature evaluations and prioritization of temperature restoration projects. We would suggest that the basic groundwork has been laid to integrate the Oregon Department of Environmental Qualities (ODEQ) TMDL process into watershed planning and restoration. In particular, water temperature modeling as conducted by ODEQ can provide a powerful tool to address the bio-physical parameters that are driving stream temperature patterns and suggest multiple pathways for remediation. In addition, the longitudinal temperature patterns provide a robust and rigorous template to construct a monitoring program from, in particular the deployment of instream temperature sensors. A instream monitoring network based on the FLIR data will allow continuous monitoring on an annual basis and suggest when another FLIR flight may be prudent, given the unknown lag in restoration and the remediation of high stream temperatures. Finally, it remains apparent that thermal conditions in the dam-influenced reach are strongly affected by dam operations. It is our recommendation that the Applegate River Watershed Council work with the U.S. Army Corps of Engineers to develop a dam operations plan that more closely mimics natural conditions if possible.

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Appendix I – Example Images

Applegate River

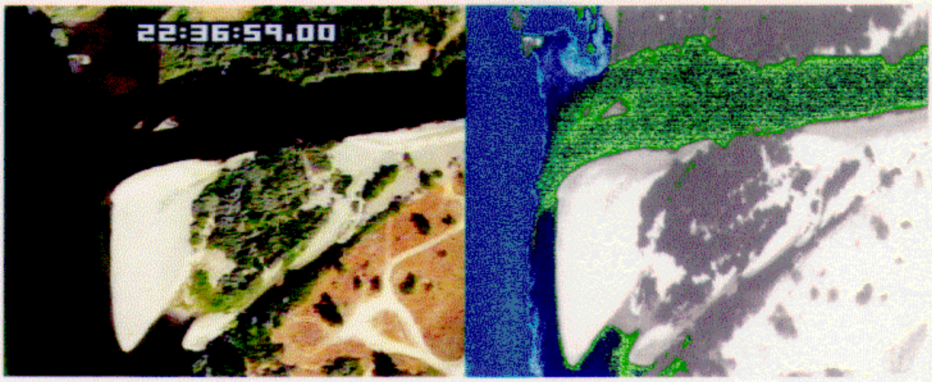

Figure I-1 - Day TV/FLIR Image Pair showing the mouth of the Applegate River. The Rogue River (18.2 deg C) is partially visible on the left side of the image and the Applegate River (23.0 deg C) flows from right to left in the image *(frame app0013).*

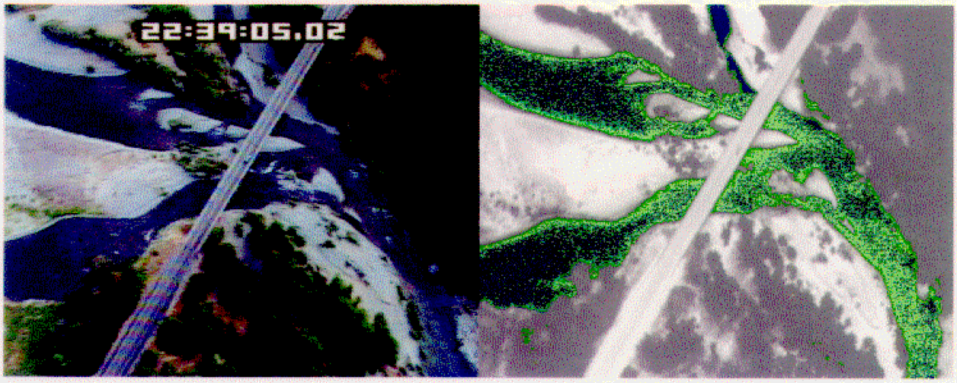

Figure I-2 - Day TV/FLIR Image Pair showing the confluence of the Applegate River (23.0 deg C) and Slate Creek (21.9 deg C). Tributaries are often visible in the thermal image. When the tributaries are identified, the surface water temperature is sampled using the same methods used to sample the mainstem. Tributaries and other off channel features are identified from base maps, the day video, and other features such as the bridge. *(frame app0076).*

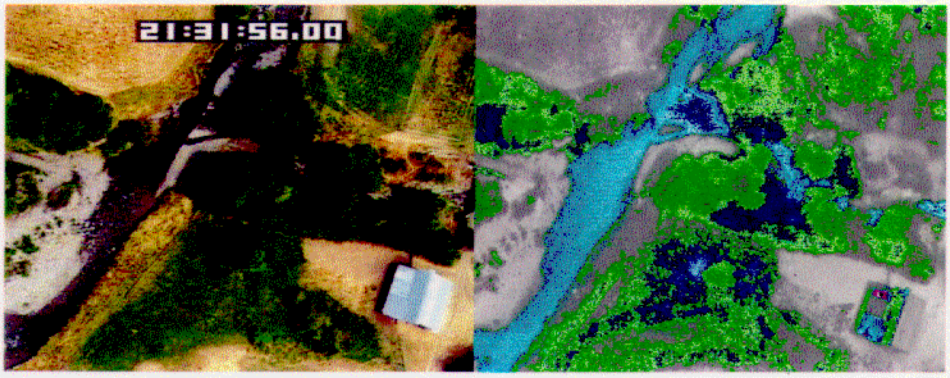

Figure I-5 - Day TV/Flir Image Pair showing the confluence of the Little Applegate River (16.1 deg C) and Yale Creek (14.6 deg C). *(frame: la0648).*

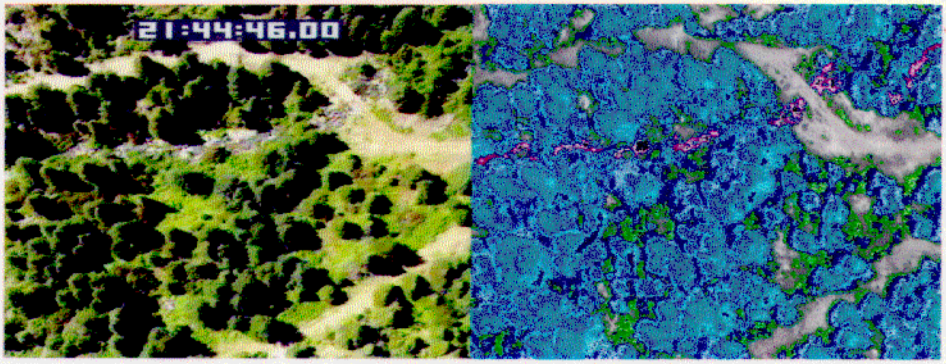

Figure I-6 - Day TV/Flir Image Pair showing the Little Applegate River. The river flows from right to left in the image. In headwater areas like this, the radiant temperatures of the terrain and vegetation are lower and the stream width is much smaller. This sometimes makes detecting the stream in these areas more difficult. *(frame: la1084)*

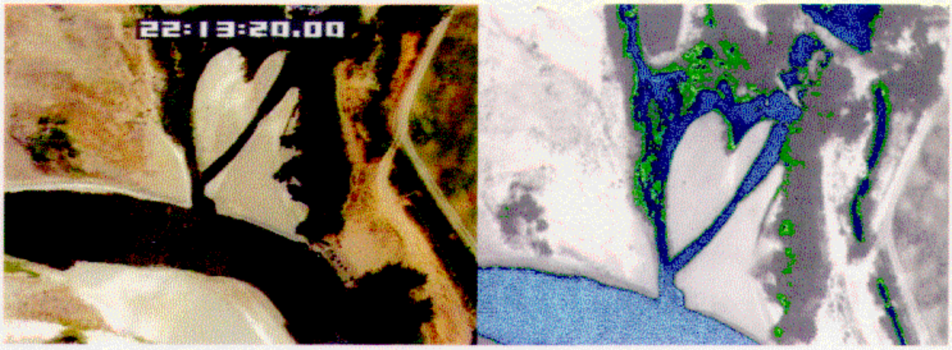

Figure I-7 - Day TV/FLIR Image pair showing the mouth of Williams Creek. The Applegate River flows in from the bottom left side of the image and Williams Creek flows in from the top of the image. Williams Creek is braided at this location and a irrigation canal is visible on the right side of the image. *(frame wil0026).*

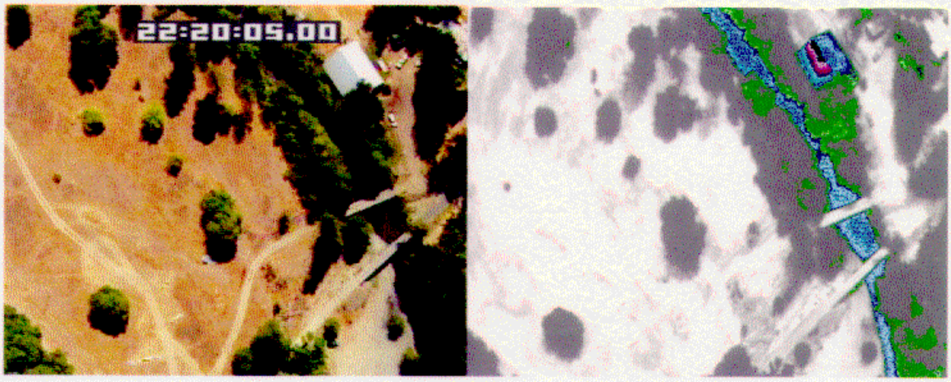

Figure I-8 - Day TV/FLIR Image pair showing a characteristic view of Williams Creek. Williams Creek flows from the top to the bottom of the image. There are two bridges clearly visible in the imagery. The very low apparent temperatures from the barn roof are typical of low emissivity objects. *(frame wil0343).*

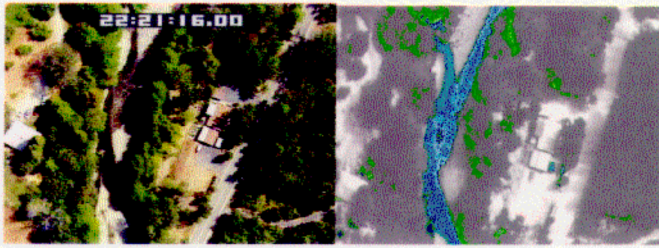

Figure I-9 - Day TV/FLIR image confluence of East Fork and West Fork Williams Creek. Williams Creek flows from the top to bottom of the image. The East Fork flows in from the left side of the image. A gravel bar at the confluence is detectable in both the day TV and thermal image. *(frame wil0413).*