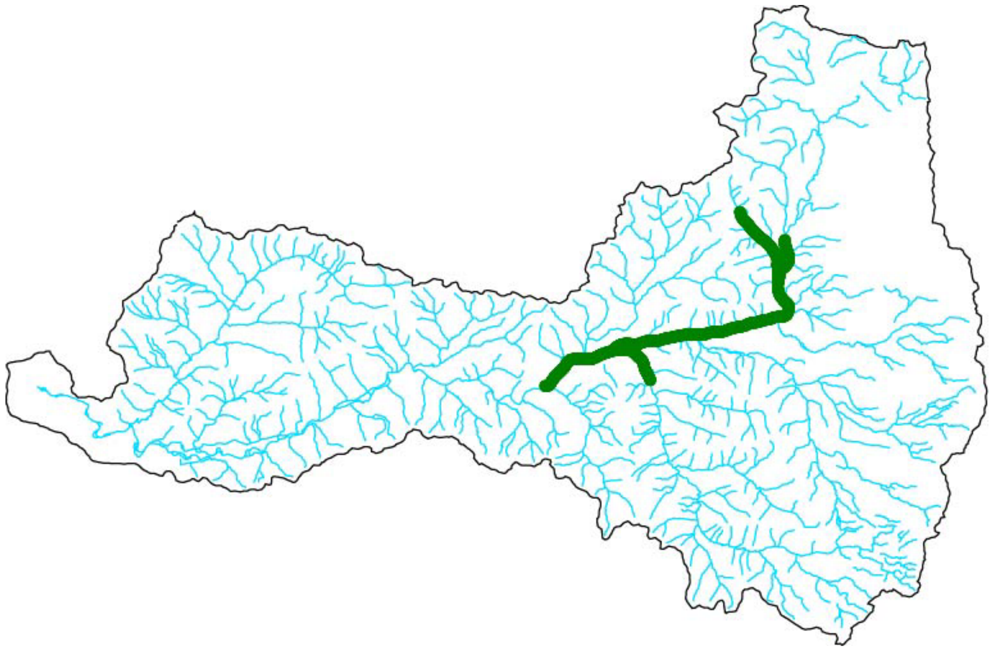
Aerial Survey of the Upper McKenzie River

Thermal Infrared and Color Videography



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Introduction

The Pacific Northwest Research Station and Oregon State University, in cooperation with the Environmental Protection Agency, have been pioneering the development of remote sensing technologies for stream temperature monitoring since 1994 (Karalus et al. 1996; Norton et al. 1996). Our research has shown that forward-looking infrared (FLIR) is a reliable, cost-effective, and accessible technology for monitoring and evaluating stream temperatures from the scale of watersheds to individual habitats. In 1999, the Pacific Northwest Research Station was contracted to map and assess temperatures in selected streams in the upper McKenzie River basin using FLIR.

Traditional methods for monitoring stream temperatures have relied on in-stream temperature monitors. These monitors provide temporally continuous data, but furnish no insight into spatial variability in water temperature. With the use of remote sensing, we have been able to quickly map stream temperatures across entire stream networks. 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 (habitat → reach → stream → watershed). 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; Torgersen et al. 1995; Torgersen et al. 1999).

This document summarizes the methods and initial results of the FLIR survey conducted in the McKenzie River basin on 3 September 1999. The results and analysis presented here are at the watershed scale. The data are structured in an ArcView GIS environment to facilitate further interpretation and analysis at multiple spatial scales.

Methods

Data Collection

The USDA Forest Service, McKenzie Ranger District contracted with Snowy Butte Helicopters of Medford, Oregon to collect thermal infrared and visible video imagery in the McKenzie River basin during the summer of 1999. Figure 1 illustrates the extent of the survey. The McKenzie River along with the South Fork McKenzie River and Deer Creek were surveyed on 3 September 1999. The survey covered a total of 61.2 km. Data collection was timed to capture maximum daily stream temperatures, which typically occur between 13:00 and 17:00. Table 1 summarizes the date, time, and survey distance for each stream.

Table 1. Date, time, and distance for streams surveyed in the upper McKenzie River basin, 3 September 1999.

Stream	Date	Time	Distance (km)
McKenzie River (Quartz Creek to Trail Bridge Res.)	9/3/99	16:23:37 – 16:30:29	45.5
South Fork McKenzie River (mouth to Cougar Dam)	9/3/99	16:24:43 – 16:25:37	7.0
Deer Creek	9/3/99	16:30:30 – 16:31:58	8.7

Data were collected using a FLIR Systems, Inc. FLIR and a Day TV digital video camera. The two sensors were aligned in a gyro-stabilized mount that attached to the underside of a Bell Jet Ranger helicopter. The helicopter was flown longitudinally over 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, flight altitude was selected so that the stream channel occupied 20% of the image frame. A minimum altitude of 300 m was set for maneuverability and safety. The McKenzie River was flown at an average altitude of 600 m above ground level. 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. This was the case in several locations on the McKenzie River, and the specific channel selected may be determined by comparing thermal imagery with digital topographic maps in ArcView GIS.

FLIR data were collected digitally and recorded directly from the sensor to an on-board computer at a rate of 1 image frame/second. 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). Each thermal image frame covers a ground area of about 144 x 216 m (400 x 600 pixel array) and has a spatial resolution of about 0.4 m/pixel. Image area and spatial resolution of individual pixels vary depending on the altitude of the aircraft.

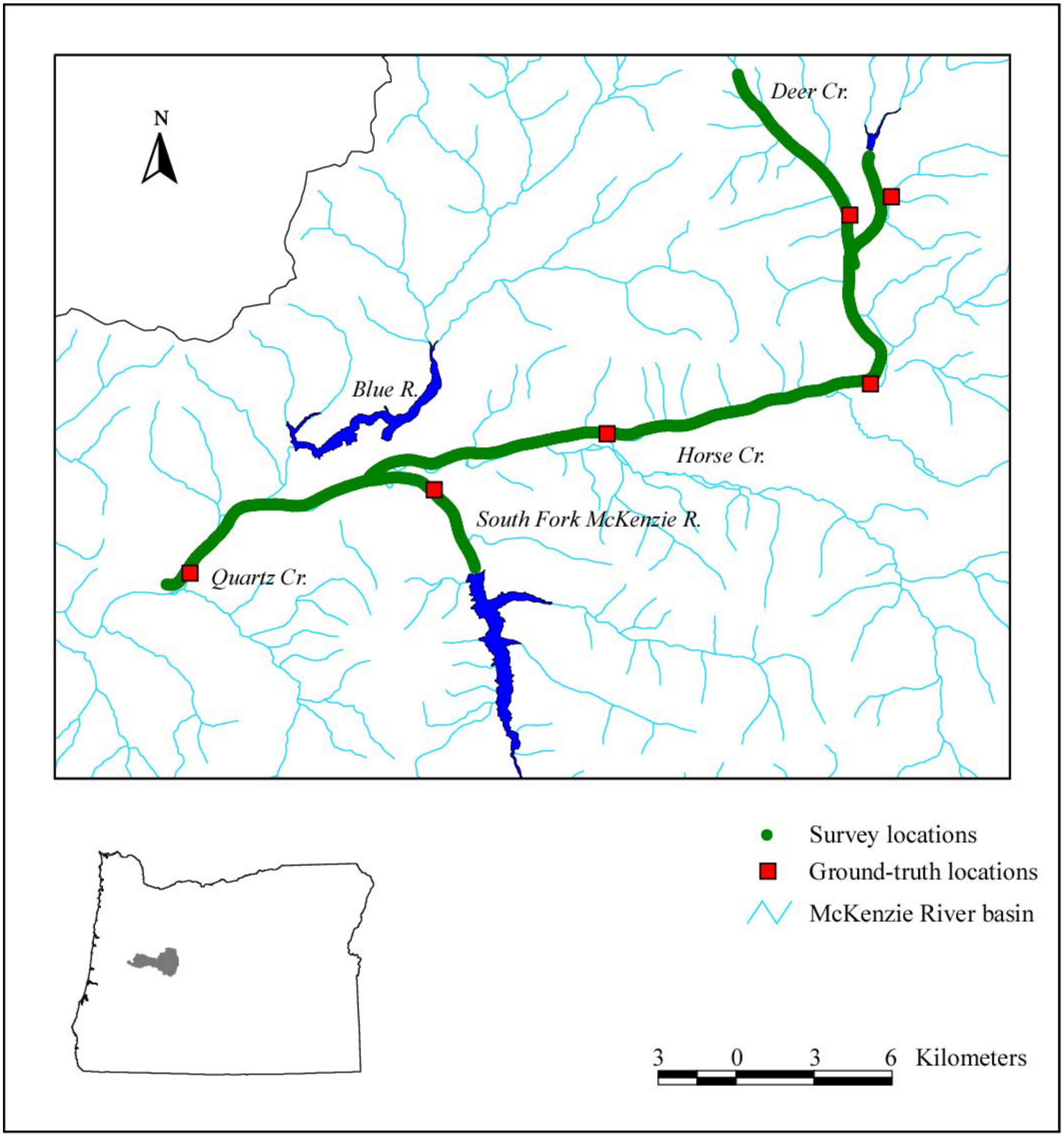

Figure 1. Map of the McKenzie River study area and streams surveyed with FLIR, 3 September 1999.

Day TV images were recorded to an on-board digital video recorder at a rate of 30 frames/second, and Greenwich Mean Time (GMT) provided by the GPS was encoded on the recorded video imagery. The Day TV sensor was aligned to present the same ground area as the thermal infrared sensor. The GMT time-code provides a means to correlate Day TV images with the FLIR images during post-processing.

Six in-stream temperature data loggers (Onset StowAways, accuracy ±0.2°C) were distributed in the basin prior to 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 their temperature information was downloaded to a computer. Meteorological conditions were collected before and after the flight at the Eugene airport and, depending on availability, from National Weather Service remote automated weather stations (RAWS) distributed throughout the survey area. Table 2 summarizes the meteorological conditions of the survey date.

Table 2. Meteorological conditions for 3 September 1999 at selected locations in the vicinity of survey area near Eugene, Oregon.

Location	Time	Temperature (°C)	Relative Humidity (%)	Sky Conditions	Winds (knots)
Eugene Airport	15:56	28.0	38	Clear	NW, 5
Vida	16:39	24.0	32	Clear	NW, 2
McKenzie Bridge	16:38	22.0	33	Clear	NE, 5

Data Processing

A computer program was used to scan the FLIR imagery and create a text file containing the image name and the time and location at which 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 locations of the in-stream recorders. The radiant temperatures were then compared to the kinetic temperatures from the in-stream data loggers.

The image points were associated with cumulative distance upstream (river km) using dynamic segmentation features of Arc/Info GIS software. The river km measures (rkm) were derived from 1:100,000 routed stream coverages 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 GRID's 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 sample temperature data. The GRID's were classified in one-degree increments from 1–20^{o}C and converted to tagged image file (TIF) format. Temperatures < 1^{o}C are black, temperatures between 20 and 55^{o}C are colored in shades of gray (darker tones are cooler and lighter tones are warmer), and temperatures > 55^{o}C are white.

Figure 2 illustrates a color-coded GRID displayed in the ArcView environment. This GRID shows the confluence of the South Fork McKenzie River with the McKenzie River. The legend on the left of the "Grid View" specifies the temperature range associated with each color. The other view window, "View1", shows the point coverage with the displayed GRID location highlighted in yellow. Each point in the "View1" view represents another image location.

Figure 3 illustrates the temperature GRID displayed in Figure 2 with its corresponding Day TV image. The McKenzie River and the South Fork McKenzie River are clearly visible in the image due to the high thermal contrast between streams of different temperatures and with the warmer terrain features. This is the standard format currently used to interpret and analyze the thermal image data.

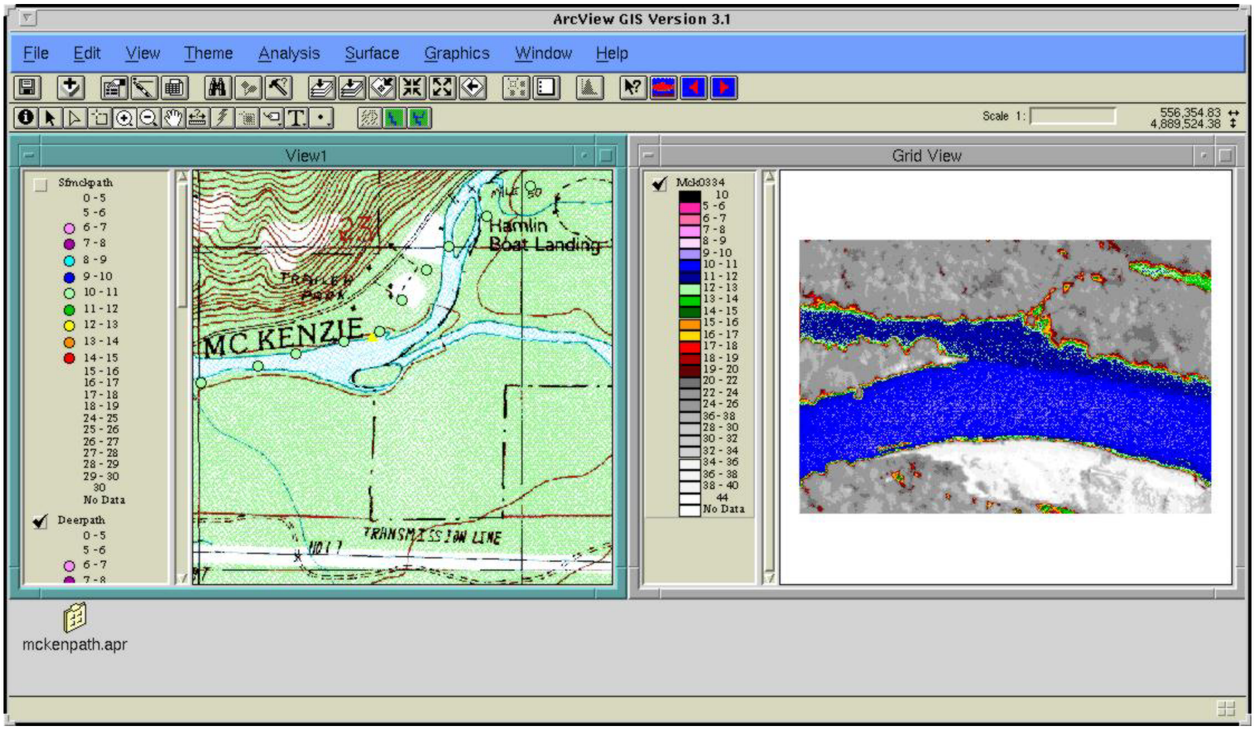

Figure 2. This is an image of an ArcView display showing a color-coded temperature GRID image in one window and the geographic location of the GRID in the other (note that the top of the image is in line with the flight direction not with the map). The map and GRID image depict the confluence of the South Fork McKenzie River with the McKenzie River.

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 values (i.e., water temperature) in the stream channel. Ten sample points were taken longitudinally in the center of the stream channel. Samples were taken from every 5th image to provide complete coverage without sampling the same water twice (there is 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 Deer Creek and in one location on the McKenzie River, the next image was sampled where the stream channel became clearly visible. For each sampled image, the minimum, maximum, median, and standard deviation of the values were recorded directly to the point coverage attribute file.

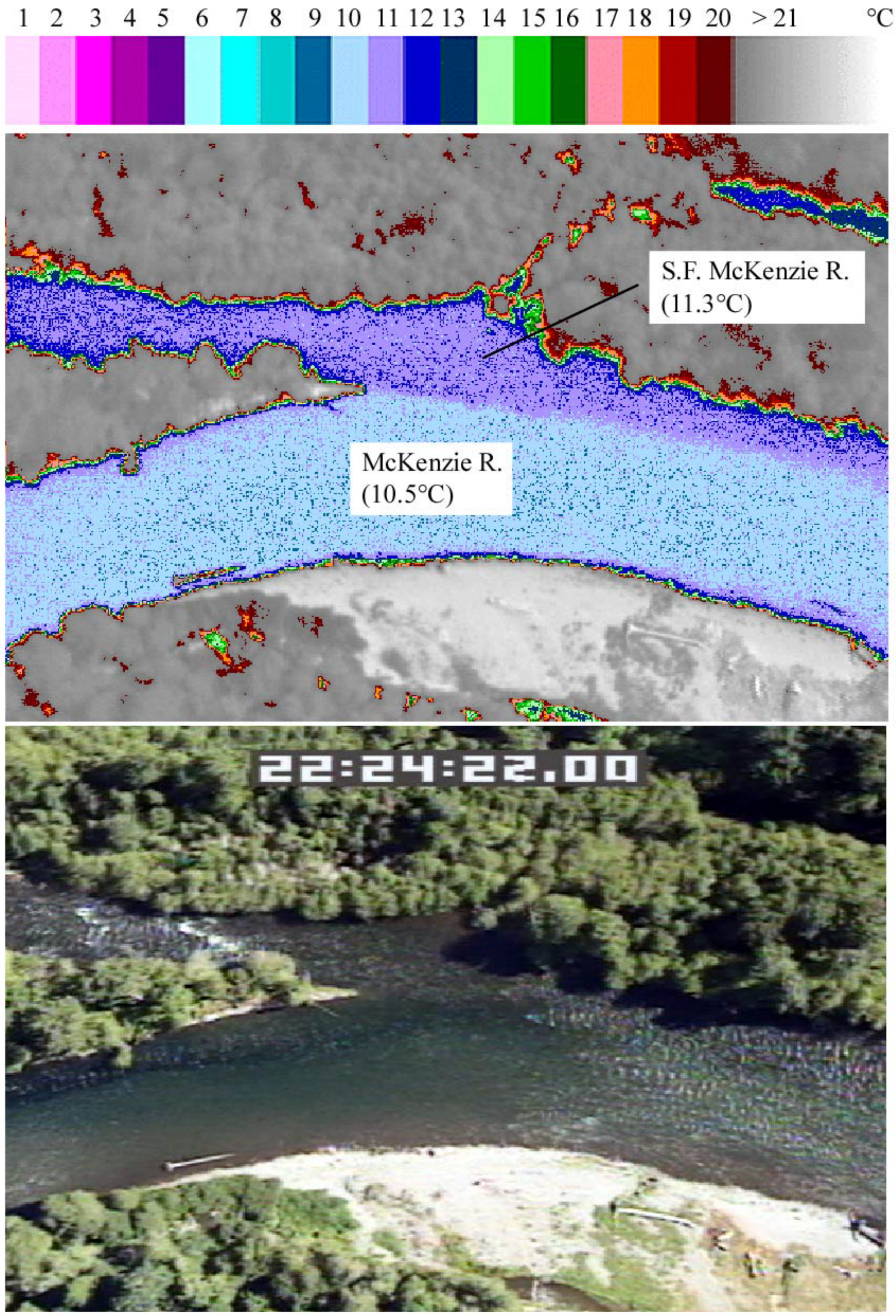

Figure 3. Temperature GRID (top) and corresponding Day TV image (bottom) showing the confluence of the South Fork McKenzie River with the McKenzie River. Water temperatures on the thermal image (see annotations) can be derived from the thermal scale where each color represents a one-degree range, e.g., light pink indicates water temperatures between 1 and 2°C. The number displayed at the top of the Day TV image is the approximate Greenwich Mean Time provided by the GPS when the image was acquired and serves as an independent reference to the thermal imagery.

The temperatures of tributaries and other detectable surface water inflows were also sampled from images. These inflows were sampled at their mouth using the same techniques employed for sampling the main stream channel. If possible, the surface inflows were identified on U.S.G.S. 1:24,000 base maps. The tributary name and median temperature were entered into the point coverage attribute file.

Day TV images were captured from digital video tape directly to a computer using stop-action image capture software and a FireWire connection to the digital video recorder. The images were captured to correspond to the thermal infrared images and provide complete coverage of the stream. The Day TV video images may be associated with the corresponding thermal image frame through their time-code link in the ArcView GIS environment.

Data Limitations

FLIR systems measure thermal infrared radiation emitted from the water surface. Because water is essentially opaque to thermal infrared wavelengths (8–14 microns), the sensor is only measuring water surface temperature. This not a significant source of error in water temperature measurement 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. Water levels and velocities in the McKenzie River basin at the time of survey were sufficient to provide adequate mixing in the water column necessary and ensure that surface measurements were representative of stream temperatures.

Detection of features using FLIR depends on thermal contrast between an object (in this case the stream) and its background. Although FLIR is very sensitive to temperature differences ($< 0.2^{o}$C), it is often difficult to distinguish the stream/land boundaries when water temperatures are equal to or greater than the temperature of the surrounding land cover. Decreased thermal contrast and canopy cover cause operational problems because it is difficult for the sensor operator to see and follow the stream channel. This caused some problems surveying the upper portion of Deer Creek where the apparent temperature of riparian vegetation and shadows were at or below water temperatures.

Results

Thermal Accuracy

Temperatures from in-stream data loggers were compared to radiant temperatures derived from the imagery for the McKenzie River basin (Table 3). The data were assessed at the time the image was acquired. The radiant values represent the median of 10 points sampled from the image at the data logger location. Radiant temperatures from thermal imagery of the McKenzie River, the South Fork McKenzie River, and Deer Creek were consistently within 0.3°C of in-stream temperatures recorded by data loggers. These results are slightly better than the average accuracy of ±0.4°C recorded during FLIR surveys throughout Oregon since 1994. Figure 4 shows the change in temperature that occurred at these locations during the course of the survey. Because the FLIR survey is a snapshot of the stream temperature profile, Figure 4 provides a context for comparing temperature recorded at the beginning and end of the flight. In addition, the figure illustrates the time at which the survey was conducted in relation to diurnal temperature patterns. Survey timing on 3 September 1999 coincided with maximum water temperature in the McKenzie River.

Table 3. Comparison of ground-truth water temperatures with radiant temperatures derived from thermal infrared images, 3 September 1999. Temperatures are reported in °C and river km (rkm) measures are cited for locations.

Location	File ID	Image frame	Time	Stream Temp. (T_s)	Radiant Temp. (T_r)	Difference ($T_r - T_s$)	ΔT_s during survey[a]
McKenzie R. Quartz Cr. (rkm 78.9)	68517	0029	16:24	11.4	11.1	-0.3	0.0
McKenzie Br. (rkm 99.7)	181257	0884	16:27	10.0	9.8	-0.2	0.0
Belknap Spr. (rkm 111.3)	177711	1273	16:29	8.7	8.4	-0.3	-0.1
Ollalie Camp. (rkm 121.4)	181258	1536	16:30	5.8	6.1	0.3	0.0
S.F. McKenzie R. (rkm 3.3)	68514	0428	16:25	10.4	10.6	0.2	-0.1
Dear Cr. (rkm 1.1)	2088	1666	16:30	12.6	12.6	0.0	-0.1

[a] Total survey duration was 8 minutes.

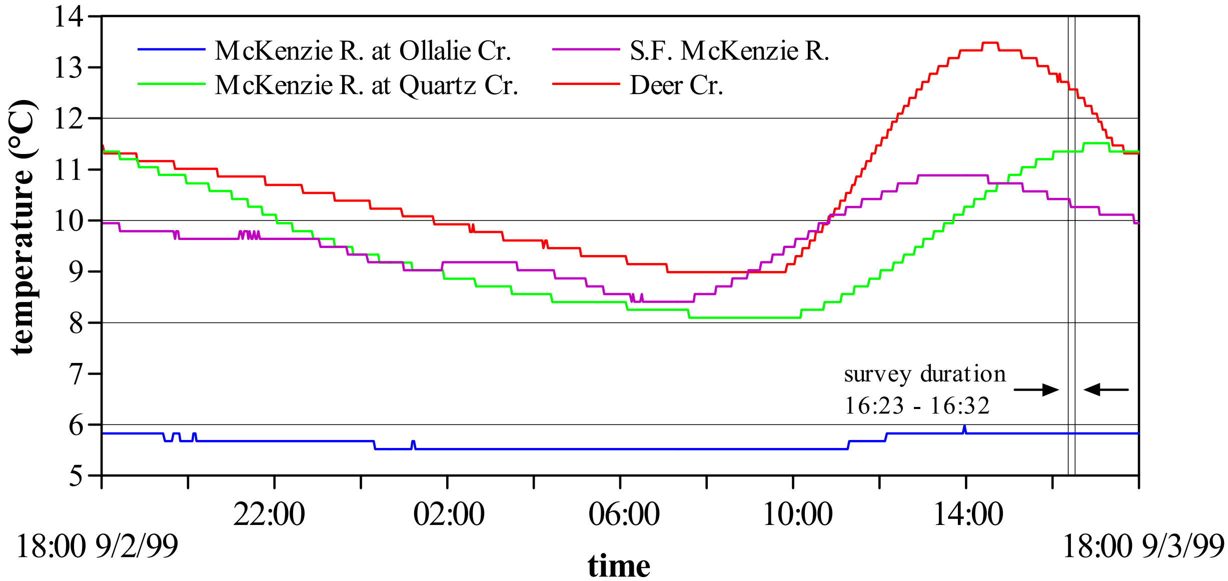

Figure 4. Diurnal temperature curves from in-stream data loggers during thermal surveys of the McKenzie River and its tributaries. Dashed vertical lines specify the timing and duration of the FLIR survey with respect to diurnal temperature fluctuations.

McKenzie River

Median temperatures were sampled on the McKenzie River from the confluence of Quartz Creek to Trail Bridge Reservoir (Figure 5). Longitudinal water temperature patterns and tributary inputs were assessed by plotting temperature versus distance upstream from the mouth of the McKenzie River (Figure 6). Tributary names were labeled and their temperatures were plotted for reference on the same axis as the McKenzie River. Only surface water inflows that could be positively identified in the imagery were included in analysis. Narrow tributaries in heavily forested reaches were obscured from aerial view and could not be sampled effectively. During the time of survey, Blue River and the South Fork McKenzie River were the two tributaries contributing the largest amount of flow to the McKenzie River. These streams were about 1°C warmer than the McKenzie River, but they had no apparent effect on thalweg water temperatures in the main stem. The smaller tributaries including Quartz Creek, Horse Creek, and Deer Creek contributed small amounts of relatively warm water to the main stem, but individually they had no clear thermal impact on McKenzie River temperatures. Ollalie Creek in the upper portion of the basin had a major cooling effect on main stem water temperature.

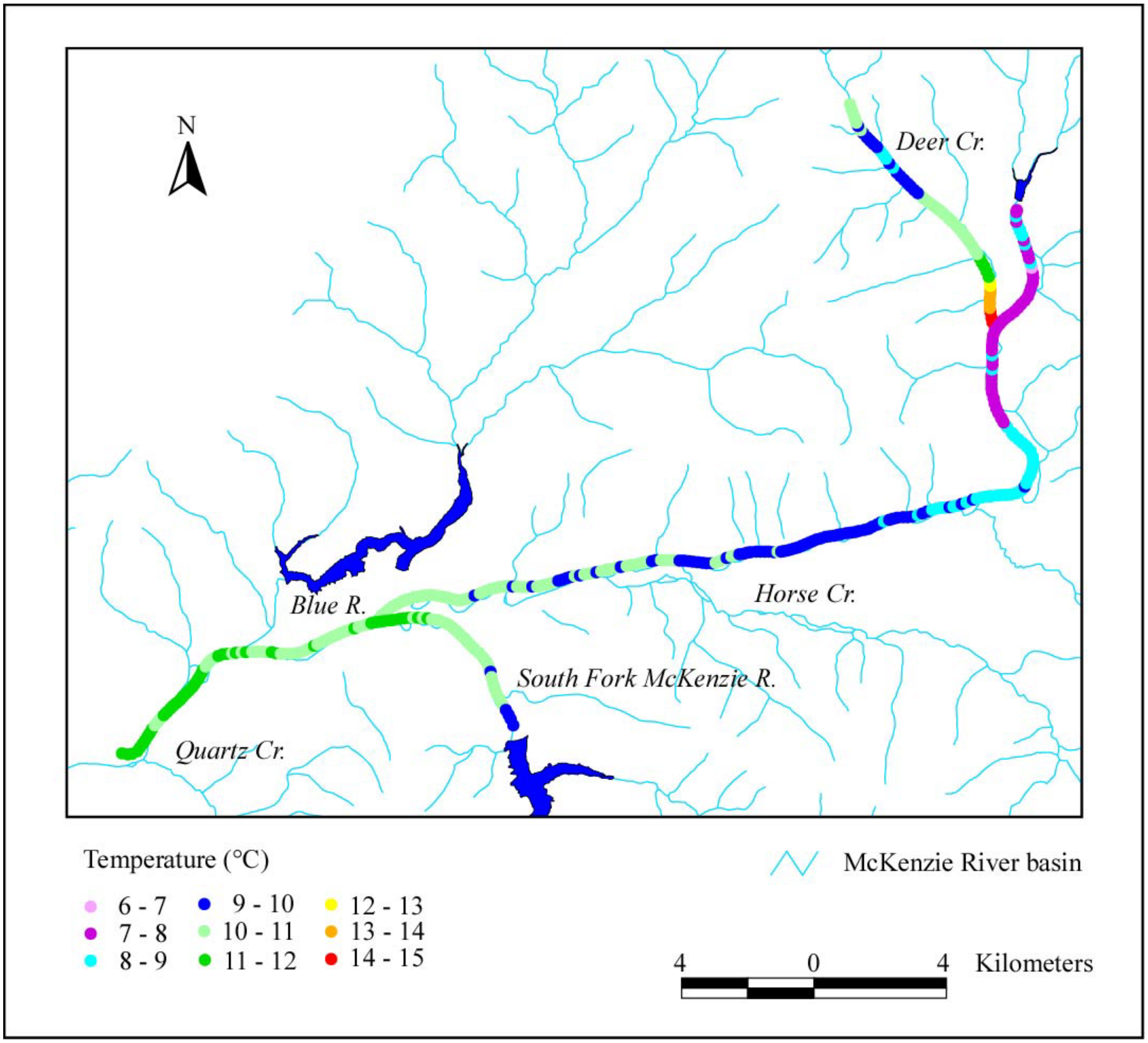

Figure 5. McKenzie River basin temperatures derived from FLIR imagery.

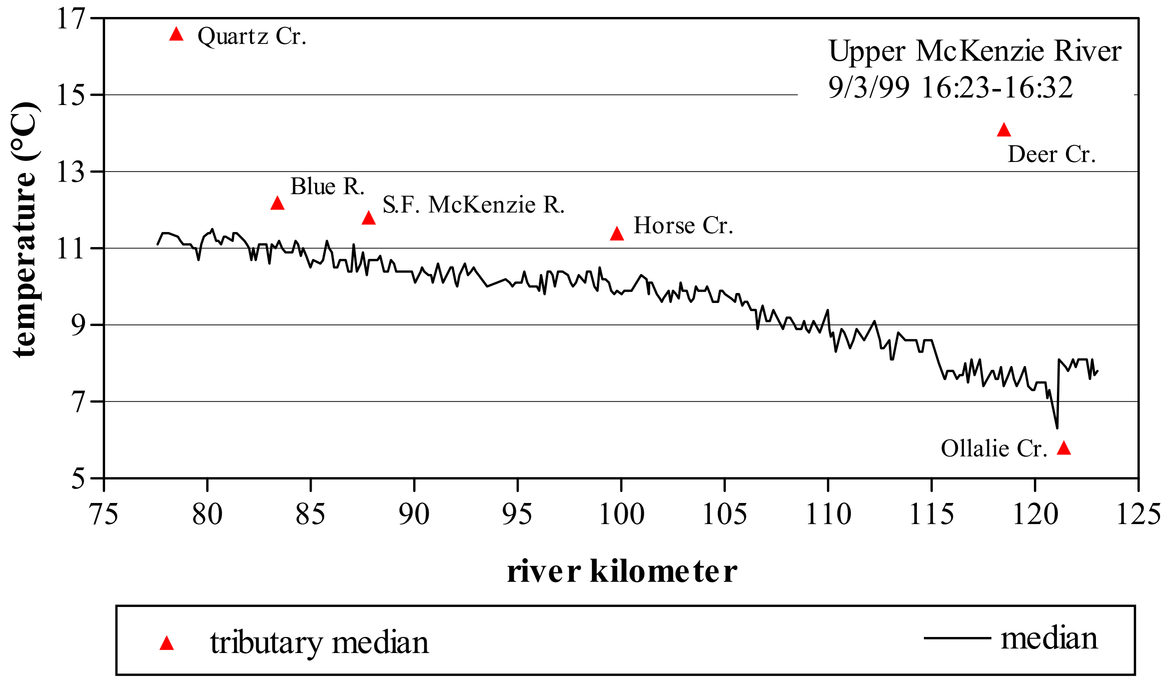

Figure 6. Median channel temperatures versus river km for the McKenzie River along with tributary locations and temperatures (3 September 1999).

Water temperature in the 46-km survey reach of the McKenzie River exhibited the usual downstream warming trend common to rivers surveyed with FLIR throughout the Pacific Northwest region (Figure 7). However, a detailed assessment of the stream revealed that the McKenzie River is unique in several aspects. The rate of temperature increase from the upper to the lower reaches of the survey route was unusually gradual (0.1°C/km), and reach-level variability in the longitudinal profile was surprisingly low compared to FLIR surveys of streams in western and eastern Oregon. Pronounced peaks and troughs in the longitudinal temperature profile that typically indicate strong tributary influences or differential heating among reaches were absent in the surveyed portion of the McKenzie River. However, the upper reaches of the McKenzie River between Belknap Springs and Trail Bridge Reservoir exhibited distinct reach-level warming and cooling patterns (Figure 8). In the longitudinal temperature profile, water released from Trail Bridge Reservoir starts out at 8°C and then rapidly cools with the inputs of Ollalie Creek, which at the time of survey was contributing significant flow to the McKenzie River. Diurnal temperature data from an in-stream data logger 50 m downstream of the Ollalie

Creek mouth varied less than 1°C over the 24-hour data collection period (Figure 4). Compressed diurnal temperature curves such as these are a clear indicator that Ollalie Creek is fed primarily by groundwater inputs.

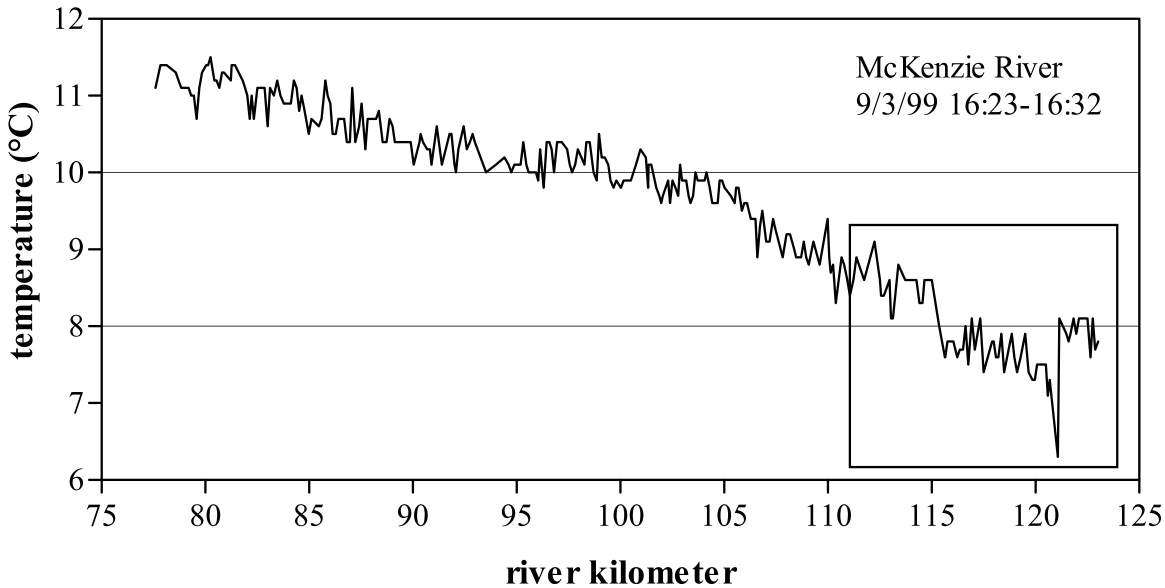

Figure 7. Median channel temperatures versus river km for the McKenzie River. Inset rectangle corresponds to the spatial extent of Figure 8.

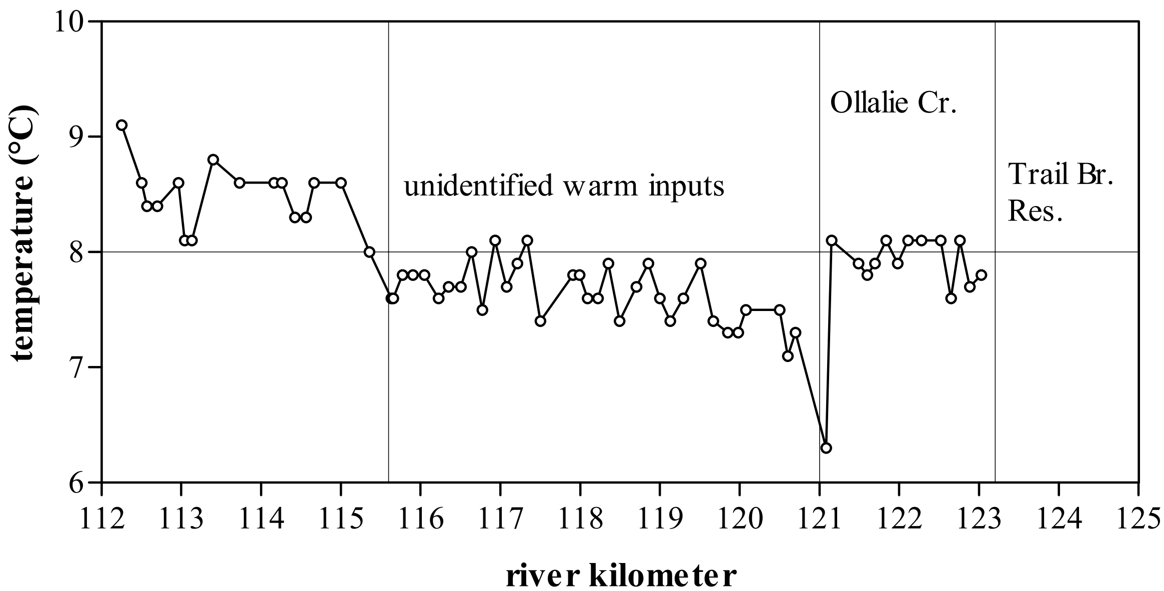

Figure 8. Median channel temperatures versus river km for the upper portion of the McKenzie River (Belknap Springs to Trail Bridge Reservoir).

From Ollalie Creek downstream, thalweg temperatures increase gradually until rkm 115, after which main stem temperatures jump upward by almost 1°C and continue to rise rapidly for the next 10 km downstream. The direct source of these increases in water temperature is not readily apparent; however, a plausible explanation could be that geothermal inputs are contributing a small warming influence on main stem temperatures. Cursory evaluation of known hot spring areas near the Deer Creek confluence and Belknap Springs revealed no individual warm inputs with sufficient flow to influence thalweg temperature (Figure 7). Any influences of warm springs on thalweg temperature are probably the result of cumulative effects from many small inputs as opposed to several large springs.

South Fork McKenzie River

Water temperature in the South Fork McKenzie River increased 1.5°C in 7 km from Cougar Reservoir to the confluence with the McKenzie River (Figure 9). The rate of increase for this stretch of river is 0.2°C/km, about twice that of the McKenzie River survey reach. Temperature increase as a function of distance in the South Fork McKenzie River is strictly linear with no significant peaks or troughs outside the accuracy (±0.4°C) of the FLIR sensor. Perhaps the most interesting aspect of the South Fork McKenzie River temperature patterns is that water was being released from Cougar Dam at 10°C, the same temperature as the main stem McKenzie River. This unanticipated difference actually made the South Fork McKenzie River a warm tributary compared to the main stem McKenzie River at the time of survey. Water released from dams is usually constant in temperature and this was the case with the South Fork McKenzie River. Daily fluctuations in water temperature in the South Fork McKenzie River (8.5–11°C) were lower than in the main stem McKenzie River (8–11.5°C). In addition to being relatively constant in temperature, water released from dams is usually colder than river water. However, data from in-stream data loggers placed in the South Fork (3 km upstream from the mouth) and in the McKenzie River (upstream of Quartz Creek) revealed that the South Fork McKenzie River was warmer than the McKenzie River for > 12 hours a day near the time of survey (Figure 4).

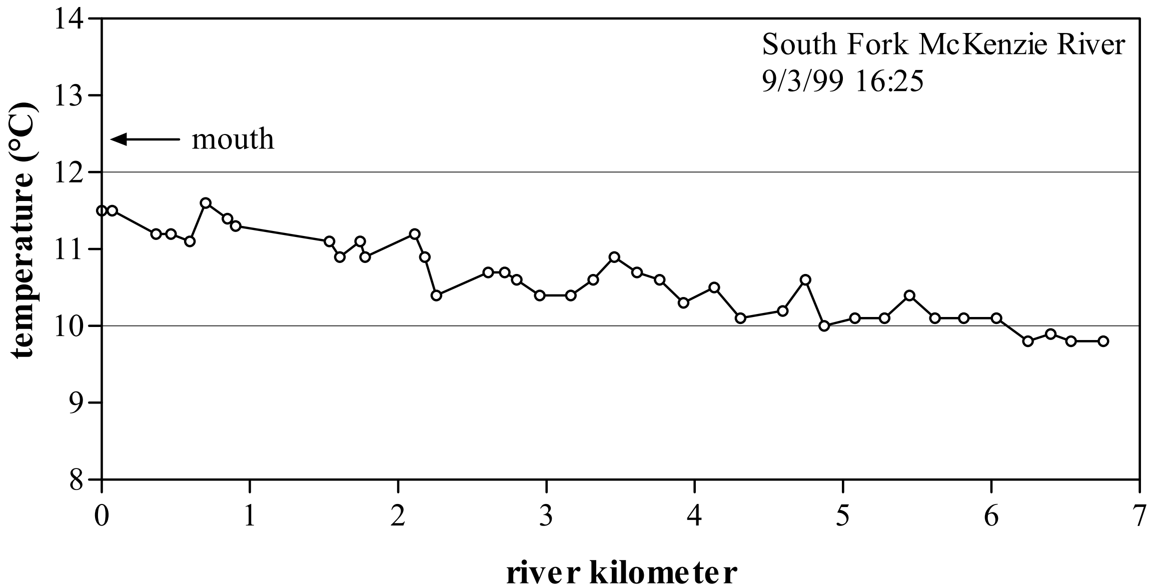

Figure 9. Median channel temperatures versus river km for the lower portion of the South Fork McKenzie River (mouth to the dam at Cougar Reservior).

Deer Creek

The warmest water temperatures in the surveyed portion of the McKenzie River basin were in Deer Creek. The longitudinal stream temperature profile in Deer Creek reached a maximum of 15°C just upstream of the confluence with the McKenzie River (Figure 5). The rate of water temperature increase as a function of distance was the most rapid in Deer Creek compared to the South Fork McKenzie River and the McKenzie River (Figure 10). Stream temperature in Deer Creek increased by 6°C in a downstream direction in the lower 7 km of the stream, a rate of 0.9°C/km. In the lowermost 3 km of the stream, water temperature increased downstream at a rate of 1.7°C/km. Reaches with the highest rate of temperature increase had wide, shallow channels and lacked riparian cover, which would normally limit insolation and prevent dramatic increases in water temperature. Water temperatures from rkm 7 to 3 increased gradually downstream at a rate of 0.4°C/km. Water temperature in Deer Creek reaches its minimum approximately 7 km from the mouth. Upstream from this point, water temperatures actually increase in an upstream direction. The cause of this temperature increase is not apparent in the imagery. However, it may be related to sampling difficulties caused by the stream being narrow and relatively obscured by overhead vegetation.

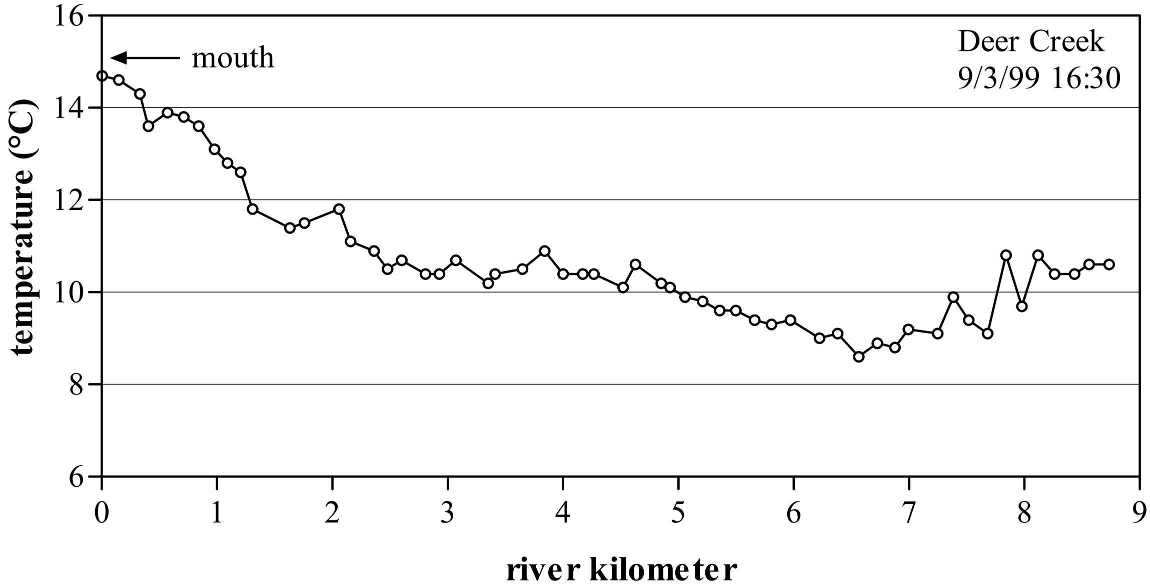

Figure 10. Median channel temperatures versus river km for Deer Creek in the upper McKenzie River basin.

From the Day TV imagery it is apparent that the lower portion of this basin recently experienced a major debris flow that widened the channel and scoured riparian vegetation from the banks. High water temperatures in the lower reaches of the stream may be related to this disturbance. In contrast, the upper portion of the basin has complex stream channel and riparian structure and contains unusually large accumulations of large woody debris. The effects of habitat complexity on water temperature could not be determined from the imagery. Further investigations of thermal heterogeneity in the upper portions of Deer Creek would be best conducted on the ground.

Tributary subbasins

Thermal inputs from tributary subbasins in the upper McKenzie River drainage were predominantly warm relative to main stem McKenzie River water temperatures (Figure 11). The largest single subbasins in the survey area, the South Fork McKenzie River, Blue River, Quartz Creek, and Deer Creek, were all contributing relatively warm water to the main stem McKenzie River at the time of the FLIR survey. However, none of these tributaries significantly affected main stem water temperatures because their respective flows were not sufficient in volume to change thalweg water temperature in the McKenzie River. The combined effects of multiple tributaries may influence basin temperatures as a whole. A more detailed analysis of tributary inputs and influences is beyond the scope of this report.

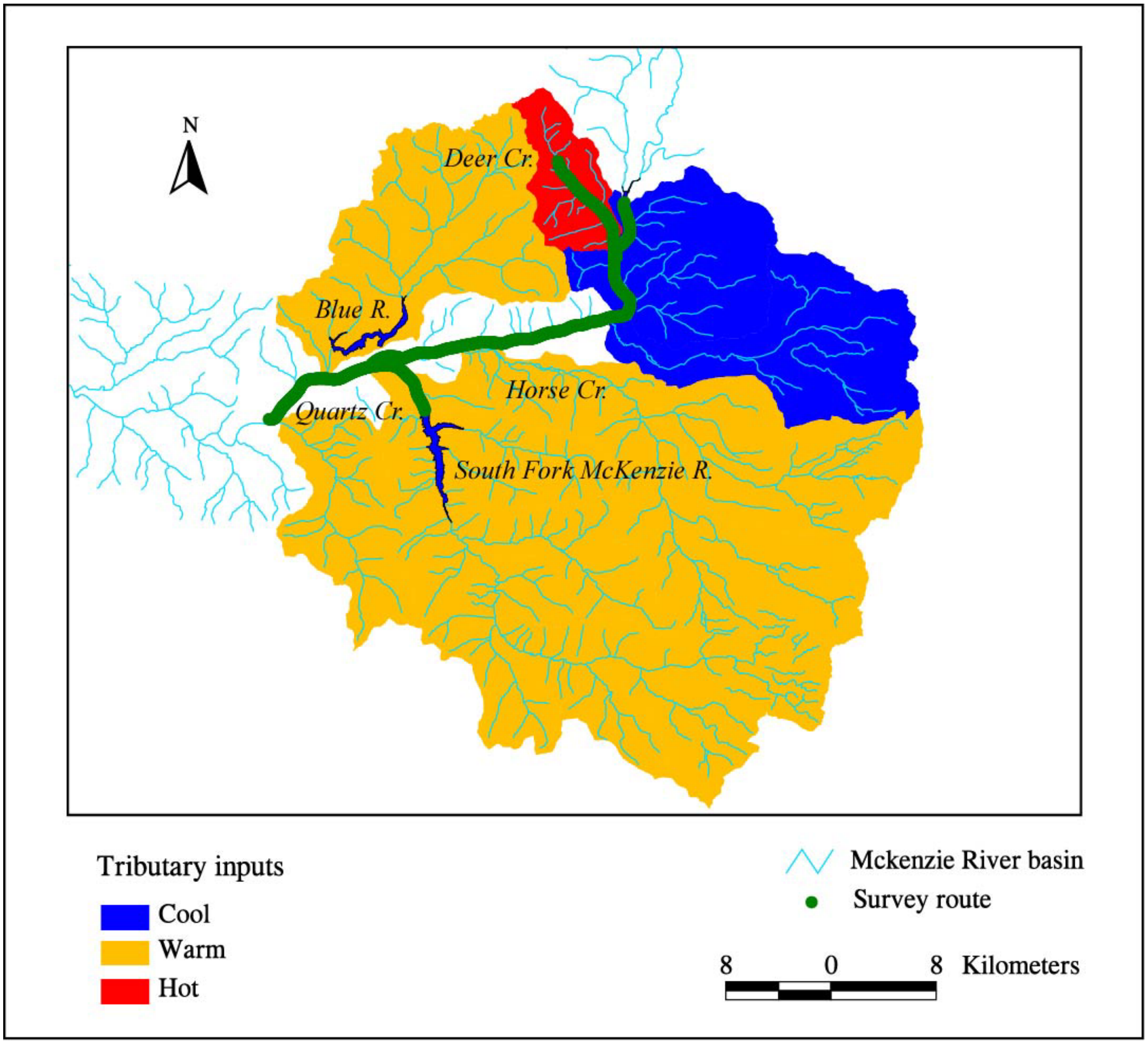

Figure 11. Thermal inputs from tributary subbasins in the upper McKenzie River drainage. Tributary inputs are classified as cool, warm, or hot relative to the main stem McKenzie River.

Cold-water inputs appear to play a much greater role than warm water inputs in regulating water temperature patterns in the upper McKenzie River. Ollalie Creek is the only tributary in the system that has a definite influence on thalweg water temperature and it is a cold tributary. This groundwater-fed stream is high volume and contributes water that is 2°C colder than the main stem McKenzie River. Ollalie Creek was the only major cold tributary in the system at the time of the survey. Therefore, it is apparent that groundwater inputs, cold springs, and other sub-surface processes are playing a relatively larger role than surface water processes in influencing the thermal regime of the upper McKenzie River.

Discussion

Thermal remote sensing has provided an accurate assessment of spatial patterns of water temperature in the upper McKenzie River basin. The analysis provided by this report has focused primarily large-scale patterns of water temperature. Additional, more detailed analyses will be necessary to develop a complete picture of thermal processes in the basin. The McKenzie River certainly has several features that make it unique and worthy of more detailed study. It is the aim of this report on water temperature patterns in the upper McKenzie River basin to 1) provide basic analysis, 2) highlight interesting features in the river system, and 3) recommend areas of potential study.

Longitudinal stream profiles of temperature typically have recognizable peaks and troughs that correspond to tributary influences or differential heating among reaches. The McKenzie River is unique in that it exhibits very little variation in the downstream warming trend in water temperature. This low level of spatial variability in the McKenzie River longitudinal thermal profile is remarkable considering the relatively warm weather conditions under which the survey was conducted and the diversity of warm and cold inputs to the system. This apparent lack of spatial heterogeneity in water temperature may be the result of the late summer survey date (3 September 1999). However, the best way to assess the seasonal context of the survey data is to identify when maximum summer water temperatures occur in various reaches throughout the basin. This will prove very important for interpreting patterns in the FLIR survey data and relating this information to management goals and objectives.

The McKenzie River system has the greatest range in thermal inputs of almost any other stream that has been surveyed with FLIR. Hot spring inputs contrast with cold springs, such as Ollalie Creek, to make the McKenzie River basin an interesting case study of thermal patterns. However, in spite of the presence of warm springs in the system, cold-water inputs far outweigh warm inputs in volume, and the McKenzie River and its tributaries are definitely cold streams in relation to other basins throughout Oregon. The McKenzie River may be the coldest stream that has been surveyed using this FLIR system. In our analysis of thalweg water temperatures in the main stem McKenzie River, we did not detect any major areas of cold-water upwelling. It is difficult to detect cold-water inputs in a cold river, especially if individual inputs are small and river flows are sufficient in volume to quickly mix with inputs from cold springs. Therefore, it will be necessary to make a more detailed assessment of small cold-water inputs in the system before any definitive statements can be made regarding their nature and distribution. However, from the relatively coarse analysis we have conducted, our conclusion is that diffuse, low-volume cold-water inputs throughout the system play a more important role than large cold-water inputs in regulating the thermal regime of the upper McKenzie River basin.

One of the great values of FLIR methodology is the synoptic aspect of the survey. In a very short time, long reaches of stream including tributary confluences may be assessed in a quantitative and precise manner. In interpreting the results and conclusions of this report, however, it is important to consider the temporal restrictions of the analysis. This is easily accomplished by reporting results and conclusions with a qualifier that relates water temperature patterns to the date, time, and duration of the FLIR survey. The analysis of FLIR data for this report has identified that 1) the upper McKenzie River is characterized by relatively homogeneous spatial patterns of water temperature and very gradual warming in a downstream direction, 2) cold inputs are more influential than warm inputs in the thermal regime of the upper McKenzie River and 3) groundwater/subsurface processes appear to be a very important factor influencing the thermal processes of this river system.

Follow-on

The FLIR imagery provides a snapshot of the stream temperature patterns at the time of the survey. This paper provides examples for viewing these patterns in relation to other spatial data sets. A complete explanation for these temperature patterns requires a better knowledge of the basin and the processes that may affect stream temperatures. This database provides a method to develop detailed maps and analyses of stream temperatures at multiple scales, dependent on the question of interest.

The following is a list of potential uses for these data in follow-on analysis:

1. The patterns provide a spatial context for analyses of seasonal temperature data from in-stream data loggers and for future deployment and distribution of in-stream monitoring stations. How does the temperature profile relate to seasonal temperature extremes? Are

local temperature minimums consistent throughout the summer and among years?

2. What is the temperature pattern within critical reach and sub-reach areas? Are there thermal refugia within these reaches that are used by coldwater fish species during the summer months?

3. What is the distribution and abundance of warm water inputs? The thermal classification of FLIR imagery is customized to identify cool patches in a warm landscape. In order to search out hot areas on land, additional classification schemes and methods would need to be developed (additional consulting would be necessary for this analysis). Hot spots are most easily detected with FLIR during winter as opposed to summer months.

4. The FLIR and Day TV images provided with the database can be aggregated to form image mosaics. These mosaics are powerful visual tools for planning fieldwork and for presentations.

5. The longitudinal temperature profiles provided in this report provide a spatially extensive, high resolution reference for water temperature status in the upper McKenzie River basin. Because stream temperature patterns can change as a result of landscape alteration or disturbance, the data provided with this report can be used in the future to assess the impacts of land-use practices and the effects of restoration efforts in the basin.

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