Aerial Surveys in the Sandy River Basin

Thermal Infrared and Color Videography

November 14, 2001

Report to:

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Final Report

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Introduction

Thermal infrared remote sensing has been demonstrated as a reliable, cost-effective, and accessible technology for monitoring and evaluating stream temperatures from the scale of watersheds to individual habitats (Karalus et al., 1996; Torgersen et. al. 1999; Torgersen et. al. 2001). In 2001, Oregon Department of Environmental Quality (ODEQ) contracted with Watershed Sciences, LLC to map and assess stream temperatures in the Sandy River basin using thermal infrared (TIR) remote sensing.

This report presents longitudinal temperature profiles for each stream surveyed as well as a discussion of the thermal features observed in basin. TIR and associated color video images are included in the report in order to illustrate significant thermal features. An ArcView GIS[1] database provided with this report includes all of the images collected during the survey and is structured to allow analysis at finer scales. Appendix A presents a collection of selected TIR and visible band images from the surveys.

Methods

Data Collection

Data were collected using a TIR sensor and a visible band color video camera co-located in a gyro-stabilized mount that attached to the underside of a helicopter. The helicopter was flown longitudinally along the stream channel with the sensors in a vertical (or near vertical) position. Figure 1 illustrates the extent of the TIR surveys and Table 1 summarizes the dates and times of each survey.

The Sandy River basin TIR surveys were conducted from August 8-9, 2001. Data collection was timed to capture maximum daily stream temperatures, which typically occur between 2:00 PM and 5:00 PM. Flight altitudes were selected based on the stream width and flood plain characteristics. The Sandy River was surveyed at an altitude of 1800 ft above ground level for approximately the first 5 stream miles.

Table 1 - Time, date and distance for the Sandy River Surveys.

Stream	Date	Local Time (PM)	Extent
Bull Run R.	8 Aug 01	13:54 – 14:36	Mouth to Bull Run Lake
SF Bull Run R.	8 Aug 01	14:44 – 14:59	Mouth to Headwaters
Sandy R.	8 Aug 01	15:11 – 16:24	Mouth to Headwaters
Little Sandy R.	9 Aug 01	14:02 – 14:31	Mouth to Headwaters
Salmon R.	9 Aug 01	14:38 – 15:50	Mouth to Headwaters
SF Salmon R.	9 Aug 01	14:58 – 15:08	Mouth to Headwaters
Zig Zag R.	9 Aug 01	15:57 – 16:19	Mouth to Headwaters

[1] Geographic Information System

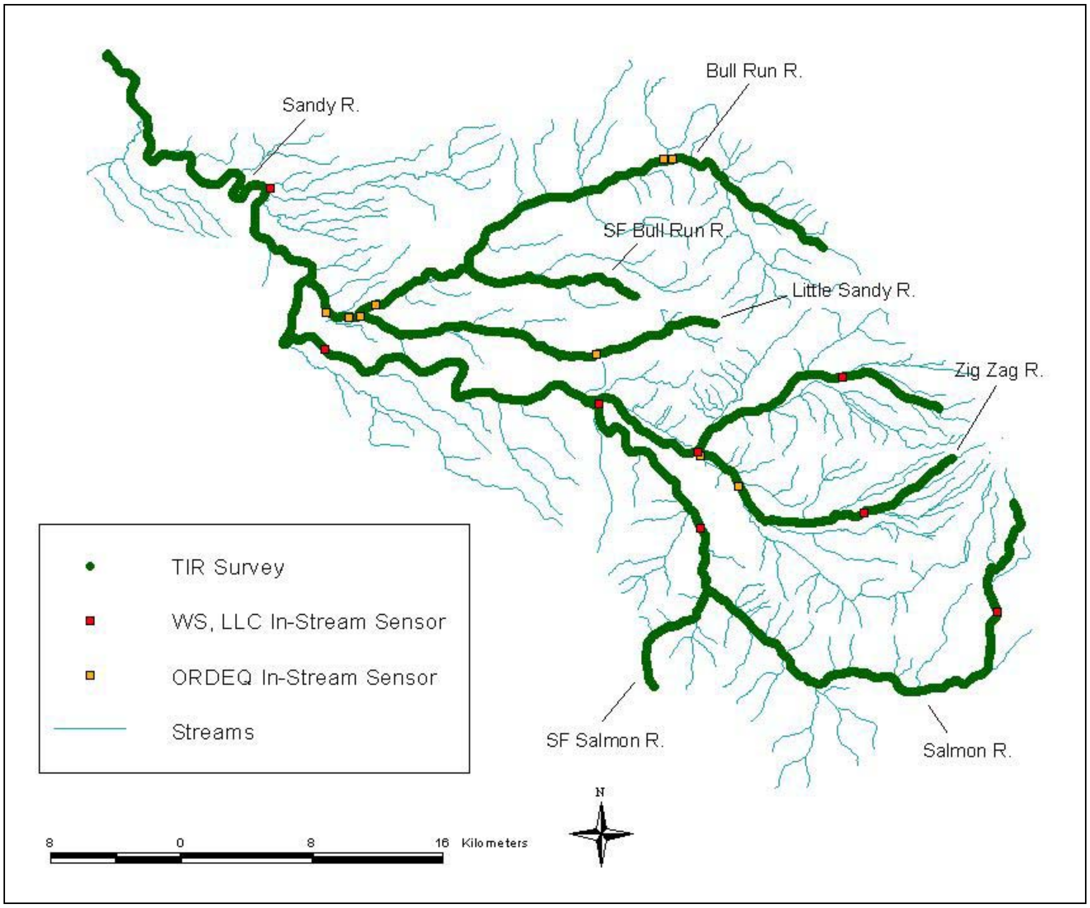


Figure 1 – Map of the Sandy River basin showing streams surveyed using TIR and visible band color video. The map also shows the location of in-stream sensors used to verify the accuracy of the radiant temperatures.

TIR images were collected digitally and recorded directly from the sensor to an on-board computer. The TIR detects emitted radiation at wavelengths from 8-12 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 TIR 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). Visible band color 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 color video camera was aligned to present the same ground area as the TIR sensor.

Watershed Sciences distributed eight in-stream temperature data loggers (Onset Stowaways) in the basin prior to the survey in order to ground truth (i.e. verify the accuracy of) the radiant temperatures measured by the TIR sensor. The advertised accuracy of the Onset Stowaway's is ±0.2°C. These locations were supplemented by data provided by ODEQ from 9 additional in-stream temperature loggers. Figure 1 shows the location of the Watershed Sciences and ODEQ in-stream data loggers used to ground truth the imagery. Meteorological conditions were recorded using a field station located at the Troutdale, OR airport (Table 2).

Table 2 – Meteorological conditions recorded at the Troutdale for the date and time of the TIR surveys conducted in the Sandy River Basin.

Date Time	***Temperature (*F)***	***Temperature (*C)***	***RH (%)***
8/8/01 1:30 PM	85.8	29.9	36.2
8/8/01 2:00 PM	83.0	28.3	41.2
8/8/01 2:30 PM	85.1	29.5	38.2
8/8/01 3:00 PM	86.6	30.3	36.7
8/8/01 3:30 PM	88.7	31.5	35.2
8/8/01 4:00 PM	89.5	31.9	33.3
8/8/01 4:30 PM	90.2	32.3	33.7
8/8/01 5:00 PM	90.2	32.3	34.2
8/9/01 1:30 PM	94.0	34.4	29.4
8/9/01 2:00 PM	94.0	34.4	27.1
8/9/01 2:30 PM	94.7	34.9	23.9
8/9/01 3:00 PM	96.3	35.7	22.5
8/9/01 3:30 PM	97.0	36.1	20.4
8/9/01 4:00 PM	97.8	36.6	22.1
8/9/01 4:30 PM	98.6	37.0	19.9
8/9/01 5:00 PM	97.8	36.6	20.4

Data Processing

A computer program was used to create an ArcView GIS point coverage containing the image name, time, and location it was acquired. 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 WS, LLC 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.

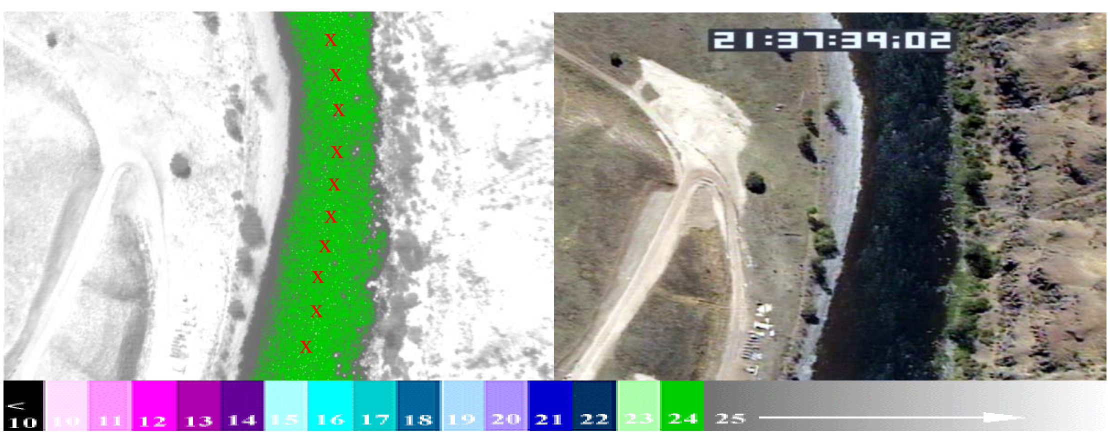
The image points were associated with a river kilometer within the GIS environment. The river kilometers were derived from 1:100K "routed" stream covers from the Environmental Protection Agency (EPA). The route measures provide a spatial context for developing longitudinal temperature profiles of stream 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. A GIS program 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.

Once in the GRID format, the images were analyzed to derive the minimum, maximum, and median stream temperatures. To derive these measures, a computer 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. Figure 2 provides an example of how temperatures are sampled. The red "x's" on the psuedo-color TIR image show typical sample locations. Samples were taken to provide complete coverage without sampling the same water twice. Where there were multiple channels, only the main channel (as determined by width and continuity) was sampled.   Side channels that had water temperatures different than the main channel were sampled as tributaries. For each sampled image, the sample minimum, maximum, median, and standard deviation was recorded directly to the point coverage attribute file. The median value is the most useful measure of stream temperatures because it minimizes the effect of extreme values.

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.

Visible band images corresponding to the TIR images were extracted from the database using a computer-based frame grabber. The images were captured to correspond to the TIR 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.



TIR/visible band color image

Figure 2 – Image pair showing typical temperature sampling locations. Temperatures are presented in ^{o}C.

Data Limitations

TIR sensors measure thermal infrared energy emitted at the water surface. Since water is essentially opaque to thermal infrared wavelengths, the sensor is only measuring water surface temperature. TIR data accurately represents bulk water temperatures in reaches where the water column is thoroughly mixed, the. However, thermal stratification can form in reaches that have little or no mixing. In the Sandy Basin, thermal stratification was observed in the larger reservoirs and directly upstream of impoundments. Areas of potential thermal stratification were noted in the survey database.

The TIR sensor cannot see through canopy. Vegetation occasionally masked the stream and tributaries during the Sandy River basin surveys. This was observed mostly in the middle reaches to upper reaches of the survey streams. Even in heavily canopied areas, the streams were intermittently visible through breaks in the canopy allowing the development of a continuous longitudinal profile. The major issue of the vegetation masking in these areas was identifying small tributaries and other thermal features in the riparian zone.

Results

Thermal Accuracy

Temperatures from the in-stream data loggers were compared to radiant temperatures derived from the imagery for each survey (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 Sandy River streams were all within 1.0°C and on average within ±0.4°C of in-stream temperatures recorded by data loggers. The differences between radiant and in-stream temperatures were consistent with the average accuracy of ±0.4°C recorded during TIR surveys throughout the Pacific Northwest since 1994.

Table 3 – Comparison of ground-truth water temperatures with radiant temperatures derived from the TIR images, 8-9 August 2001. Temperatures are reported in ^{o}C and river miles (rm) are cited for locations.

Location	River Mile	Image Frame	Time (pm)	Stream Temp. (Ts)	Radiant Temp. (Tr)	Difference (Ts-Tr)
Bull Run R.	1.5	Br0112	13:58	19.4	18.9	0.5
Bull Run R.	2.4	Br0148	14:00	17.7	17.1	0.6
Bull Run R.	3.8	Br0205	14:01	17.7	17.7	0.0
Bull Run R.	17.2	Br0766	14:21	14.3	14.5	-0.2
Bull Run R.	17.6	Br0783	14:20	14.2	15.2	-1.0
Gordon Cr. Mouth	12.6	San0566	15:30	18.6	18.7	-0.1
Sandy R.	23.7	San0927	15:42	17.1	17.3	-0.2
Zig Zag R. mouth	42.4	San1658	16:07	15.6	16.2	-0.6
Sandy R.	49.8	San1987	16:17	15.1	14.5	0.6
Little Sandy R.	0	Lsan0032	14:02	16.8	17.1	-0.3
Little Sandy R.	10.1	Lsan0551	14:20	14.4	13.5	0.9
Salmon R.	.3	Sfsa0047	14:39	17.9	18.5	-0.7
Salmon R.	8.0	Sfsa0440	14:53	16.1	16.1	0.0
Salmon R.	5.0	Sfsa0875	15:40	11.3	10.7	0.6
Zig Zag R.	.1	Zz0016	15:58	16.0	16.5	0.2
Zig Zag R.	2.1	Zz0113	16:00	12.7	12.9	-0.2
Zig Zag R.	8.1	Zz0453	16:12	10.6	10.4	-0.5

Longitudinal Temperature Profiles

Bull Run River

A longitudinal temperature profile was developed for the Bull Run River (Figure 3). The figure identifies the location and temperature of tributary and spring inflows. Tributaries and side channels are labeled in Figure 3 by river mile with their name and temperature listed in the associated table (Table 4).

The locations of the two Bull Run Reservoirs are identified in the figure. As the profile suggests, the reservoirs were thermally stratified. The reservoirs surface was sampled to provide continuity in the profile. However, it should be noted that the reservoir surfaces do not represent the deeper layers.

A total of 14 tributaries were detected and sampled. Of the 13 tributaries, six contributed water that was cooler than the Bull Run River. At the time of the survey, all tributaries sampled contributed inflow that was less than 16.6^{o}C. Further, a general

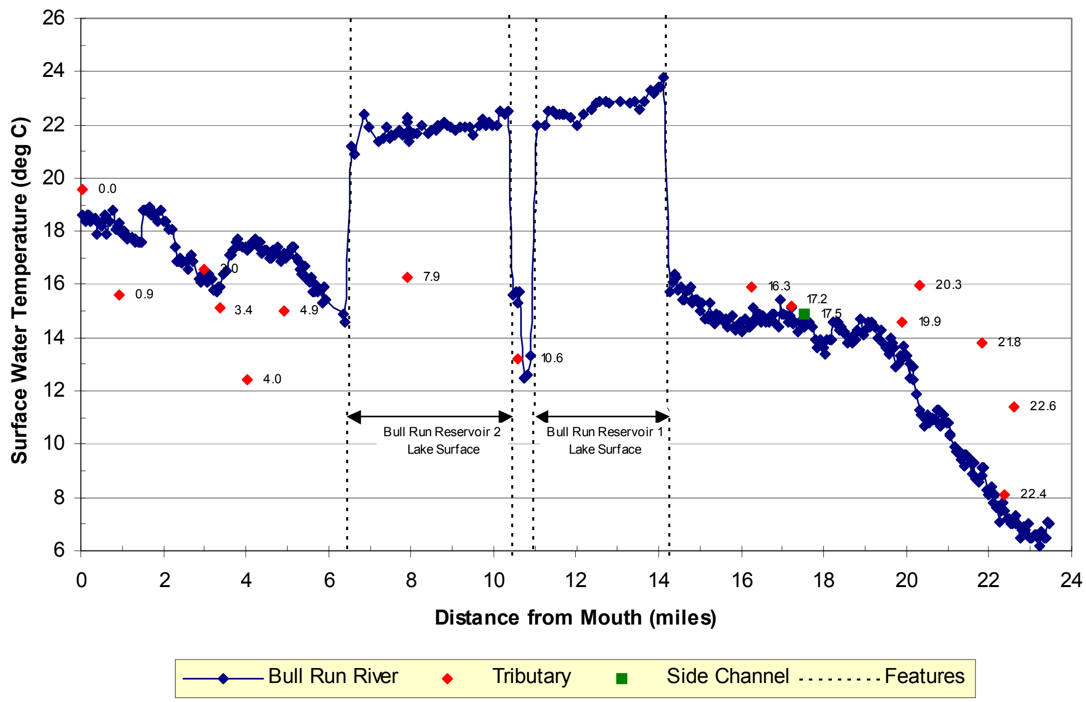


Figure 3 - Longitudinal Profile for the Bull Run River (8/08/01; 13:54 – 14:36).

Table 4 - Tributary and side channel temperatures for the Bull Run River, OR. River miles correspond to data labels shown in Figure 3.

Tributary Name	Image	Mile	Tributary	Bull Run	Difference
Sandy River (LB)	br0046	0.0	19.6	18.6	1.0
Deer Creek (RB)	br0088	0.9	15.6	18.3	-2.7
Little Sandy River (LB)	br0169	3.0	16.6	16.4	0.2
No Name (LB)	br0188	3.4	15.1	15.9	-0.8
Spring (LB)	br0214	4.0	12.4	17.3	-4.9
No Name (LB)	br0252	4.9	15.0	17.2	-2.2
SF Bull Run (LB)	br0405	7.9	16.3	22.1	-5.8
No Name (LB)	br0509	10.6	13.2	15.3	-2.1
No Name (LB)	br0720	16.3	15.9	14.5	1.4
Falls Creek (RB)	br0767	17.2	15.2	15.1	0.1
No Name (LB)	br0884	19.9	14.6	13.2	1.4
Blazed Creek (LB)	br0905	20.3	16.0	11.3	4.7
No name (LB)	br0984	21.8	13.8	9.1	4.7
No name (RB)	br1021	22.4	8.1	7.5	0.6
No Name (RB)	br1035	22.6	11.4	7.2	4.2
--- Side Channels ---					
Side Channel (LB)	br0780	17.5	14.9	14.4	0.5

pattern observed from the profile was that tributaries downstream of Bull Run Reservoir #1 contributed water that was cooler than the Bull Run River while tributaries upstream of Bull Run Reservoir #2 contributed inflow that was warmer than the main stem.

Vegetation masking made it difficult to detect the river as the survey approached Bull Run Lake. Review of the imagery suggests that there is no flow directly downstream of the Lake. The TIR imagery was sampled to the point (river mile 23.4) where the river was visible and could be reliably sampled. Stream temperatures in this reach were less than 8°C. The Bull Run River warms steadily between river mile 23.4 and river mile 19.0. The river continues to warm at a slower rate between river mile 19.0 and the beginning of the Bull Run Reservoir #2 at river mile 14.4.

South Fork Bull Run River

A longitudinal temperature profile was developed for 6.7 miles of the South Fork (SF) Bull Run River (Figure 4). Stream temperatures were relatively consistent (approximately 13.5°C) between river miles 6.2 and 3.2. Main stem temperatures increased consistently between river mile 3.2 and the mouth at Bull Run Reservoir #2. Two tributaries (Cedar Creek and Fox Creek) were detected during the survey. Cedar Creek showed stream temperatures consistent with the main stem while Fox Creek contributed slightly cooler water.

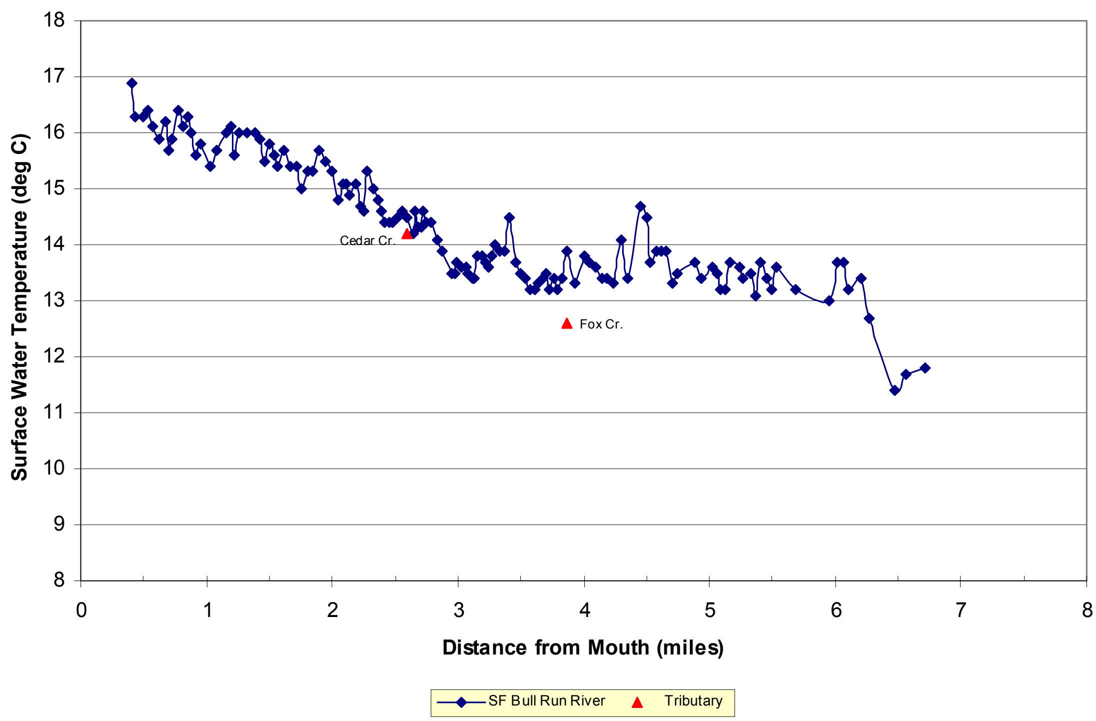


Figure 4 - Longitudinal temperature profile of the South Fork Bull Run River (8/08/01; 14:44 – 14:59).

Sandy River

A longitudinal temperature profile was developed for the Sandy River (Figure 5) from its confluence with the Columbia River to the headwaters on the west slope of Mt. Hood (Figure 6). Figure 6 identifies the location and temperature of tributary and spring inflows. Tributaries and side channels are labeled in Figure 6 by river mile with their name and temperature listed in the associated table (Table 5).

A total of 22 tributaries were detected and sampled during the Sandy River survey. In general, the tributary temperatures were either cooler or equal to main stem temperatures. No tributaries were detected that contributed water significantly warmer than the main stem. Twelve side-channels and off-channel features were also sampled. The side channels detected in the lower 12 river miles were generally warmer than main stem temperatures. However, they did not have a detectable influence on main stem water temperatures.

As might be expected due to the proximity of the snowfields, cool water temperatures ($\approx 8^{o}C$) were measured near the headwaters on Mt. Hood. From this point, the Sandy River warms steadily in a downstream direction for the first 10 miles reaching approximately $17^{o}C$ near the confluence of the ZigZag River at river mile 42. Over the next 18 miles, bulk stream temperatures remain relatively consistent varying less than $\pm 1^{o}C$ over this reach. At river mile 24.4, stream temperatures begin to increase again with a $4^{o}C$ increase between river miles 24.4 to river mile 19.4 at the confluence of the Bull Run River. The stream shows a slight cooling at river mile 19.4 due at least in part to the influence of the Bull Run River and Walker Creek further downstream. The stream temperatures then remain relatively constant ($20.5^{o}C$) to approximately river mile 5.0. A slight increase of $1.5^{o}C$ is observed in the lower five miles of the river.

Little Sandy River

A longitudinal temperature profile was developed for the Little Sandy River from its mouth to headwaters (Figure 7). As with the Sandy River, tributaries and side-channels are identified on Figure 7 by river mile with their name and temperatures listed in Table 6.

The Little Sandy River was small in size and partially masked by canopy from the Little Sandy Dam to the confluence with the Bull Run River. This made it difficult to detect and sample some of the mapped tributaries in the lower reaches. Several cold areas were noted along the right bank near river mile 7.8, which were sampled as springs. The level of canopy and shadowing made positive identification of these springs difficult. However, there was an observed drop in main stem temperatures along this reach. Finally, the survey covered the left headwater stream (looking upstream) for the final 1.0 miles of the survey. However, the1:100k EPA GIS stream layer shows the right fork as Little Sandy Creek.

Figure 5 - Ground level color photograph of the Sandy River looking upstream at river mile 23.7 (dcs0078).

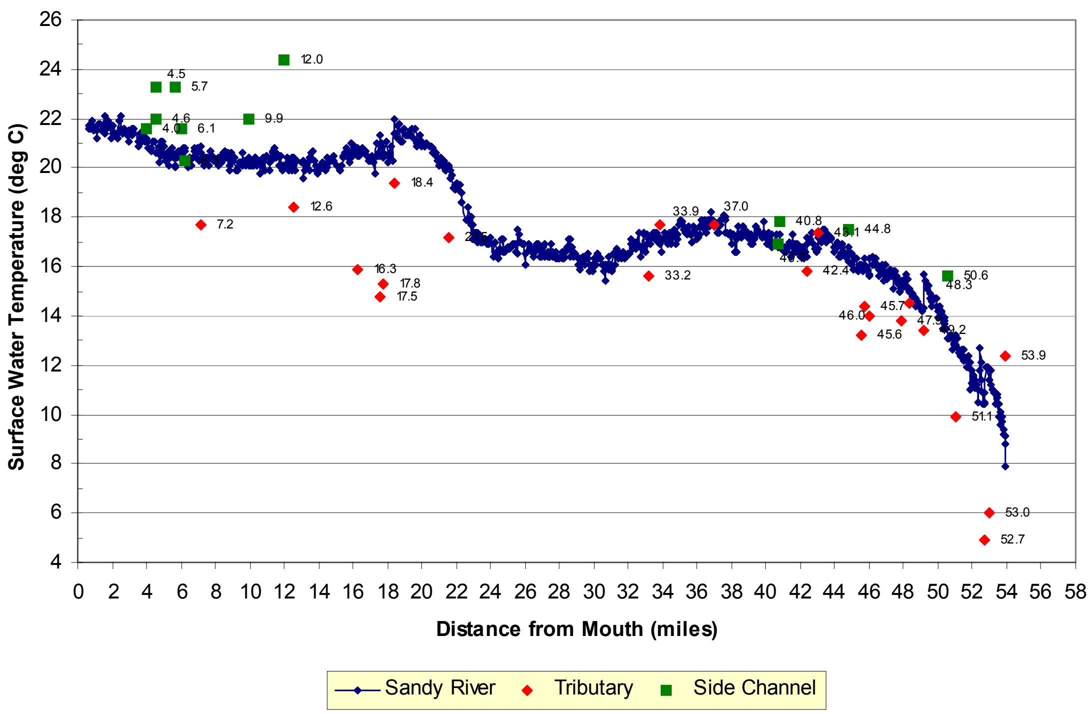


Figure 6 - Longitudinal temperature profile of the Sandy River, OR (8/09/01; 14:38 – 15:50 pm).

Table 5 - Tributary and side channel temperatures for the Sandy River, OR. The *mile* field corresponds to data labels in Figure 6. A question mark (?) indicates some uncertainty in the interpretation of the image or source of the inflow.

Name	Image	Km	Mile	Tributary	Sandy	Difference
------- Tributaries -----						
Smith Creek (RB)	san0335	11.6	7.2	17.7	20.9	-3.2
Buck Creek (RB)	san0566	20.3	12.6	18.4	20.4	-2.0
Spring? (RB)	san0681	26.3	16.3	15.9	20.5	-4.6
Unnamed Trib (RB)	san0723	28.2	17.5	14.8	20.5	-5.7
Walker Creek (RB)	san0733	28.6	17.8	15.3	20.4	-5.1
Bull Run (RB)	san0752	29.6	18.4	19.4	22.0	-2.6
Cedar Creek (LB)	san0847	34.7	21.5	17.2	20.0	-2.8
Alder Creek (LB)	san1297	53.4	33.2	15.6	17.2	-1.6
Wildcat Creek (LB)	san1320	54.5	33.9	17.7	16.9	0.8
Salmon River (LB)	san1447	59.6	37.0	17.7	17.6	0.1
Zig Zag River (LB)	san1653	68.2	42.4	15.8	16.9	-1.1
Clear Creek (RB)	san1701	69.3	43.1	17.4	17.2	0.2
Horseshoe Creek (LB)	san1805	73.3	45.6	13.2	16.1	-2.9
No Name (LB)	san1812	73.6	45.7	14.4	16.3	-1.9
Lost Creek (LB)	san1827	74.1	46.0	14.0	16.3	-2.3
Clear Creek (RB)	san1908	77.1	47.9	13.8	15.4	-1.6
No Name (LB)	san1923	77.8	48.3	14.5	15.0	-0.5
Muddy Creek (RB)	san1963	79.2	49.2	13.4	15.7	-2.3
No Name (LB)	san2040	82.2	51.1	9.9	13.2	-3.3
Rushing Water Creek (LB)	san2115	84.9	52.7	4.9	10.9	-6.0
No Name (LB)	san2123	85.2	53.0	6.0	11.4	-5.4
No Name (LB)	san2174	86.8	53.9	12.4	7.9	4.5
----- Side Channels -----						
Side Channel (LB)	san0193	6.5	4.0	21.6	21.2	0.4
Side Channel (RB)	san0212	7.3	4.5	23.3	20.6	2.7
Side Channel (LB)	san0217	7.4	4.6	22.0	20.6	1.4
Off Channnel (LB)	san0263	9.1	5.7	23.3	20.1	3.2
Side Channel (RB)	san0285	9.8	6.1	21.6	20.4	1.2
Side Channel (LB)	san0294	10.1	6.3	20.3	20.7	-0.4
Side Channel (RB)	san0453	16.0	9.9	22.0	20.3	1.7
Off Channel (RB)	san0541	19.3	12.0	24.4	20.1	4.3
Side Channel (LB)	san1591	65.6	40.7	16.9	16.8	0.1
Side Channel (RB)	san1593	65.7	40.8	17.8	16.8	1.0
Side Channel (RB)	san1777	72.2	44.8	17.5	16.8	0.7
Side Channel (LB)	san2018	81.4	50.6	15.6	13.1	2.5

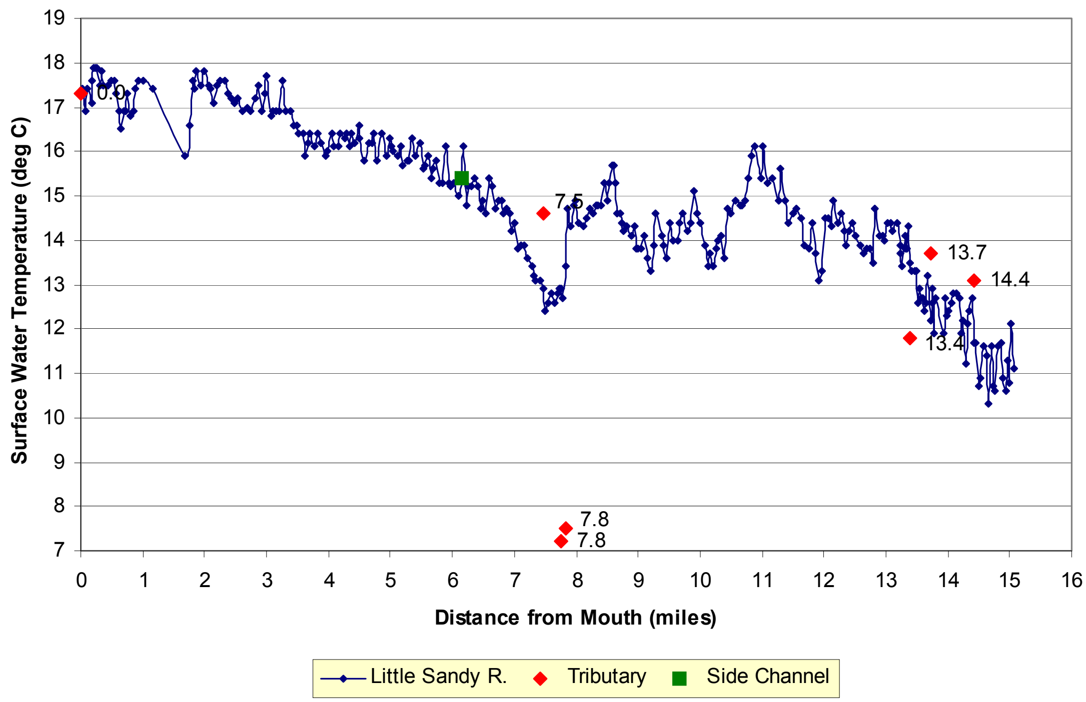


Figure 7 - Longitudinal temperature profile for the Little Sandy River, OR (8/09/01; 14:02 – 14:31).

Table 6 - Tributary and side channel temperatures for the Zig Zag River, OR. River miles correspond to data labels shown in Figure **.

Tributary Name	Image	Mile	Tributary	L. Sandy R.	Difference
Bull Run ( )	lsan0030	0.0	17.3	17.3	0.0
No Name (RB)	lsan0391	7.5	14.6	12.9	-1.7
Spring? (RB)	lsan0410	7.8	7.2	12.9	5.7
Spring? (RB)	lsan0415	7.8	7.5	13.4	5.9
Spring? (LB)	lsan0735	13.4	11.8	13.5	1.7
Little Sandy Creek (LB)	lsan0761	13.7	13.7	12.2	-1.5
No Name (RB)	lsan0805	14.4	13.1	11.7	-1.4
Side Channels					
Side Channel (LB)	lsan0318	6.1	15.4	15.4	0.0

Salmon River

A longitudinal temperature profile was developed for the Salmon River (Figure 8) from its confluence with the Sandy River to the headwaters on Mt. Hood (Figure 9). Figure 9 identifies the location and temperature of tributary and spring inflows. Tributaries and side channels are labeled by river mile with their name and temperature listed in the associated table (Table 7).

A total of 37 tributaries were detected and sampled during the analysis of the Salmon River. Of these tributaries, 24 contributed water that was cooler than the main stem. In addition, eight apparent springs were detected and sampled. The springs varied in size and appeared contribute cooler water to the Salmon River. However, the canopy and associated shadows precluded positive identification of these sources. Further review and ground verification can be used to validate these springs. Two off channel features were detected including a spring brook at river mile 3.7.

Stream temperatures are cool in the headwaters and generally warm in the downstream direction. Temperatures rise steadily between river miles 32.1 and 24.5. A slight decrease in temperatures is observed at river mile 28.7 due to the influence of an unnamed tributary. Stream temperatures remain relatively constant to river mile 16.7 with temperature variations within ±1.0^{o}C. A temperature drop of 2.0^{o}C was observed at river mile 16.8 at the confluence of Linney Creek. Stream temperatures then increase at a relatively consistent rate to the confluence with the Sandy River. Both cold and warm water tributaries were observed through this reach, but do not cause any dramatic shifts in the longitudinal temperature profile.

The South Fork (SF) Salmon River was surveyed as part of the Salmon River Survey. The south fork was surveyed from the mouth upstream until water could no longer be detected with the TIR sensor. Figure 10 illustrates the longitudinal temperature profile developed for the SF Salmon River. There were two tributaries detected during the survey including an apparent spring inflow approximately 0.1 miles upstream of the mouth. The SF Salmon River has canopy closure through some reaches, which somewhat limited the ability to sample tributaries and other riparian features.

Figure 8 - Ground level color photograph of the Salmon River at river mile 8.0 (frame: 0076).

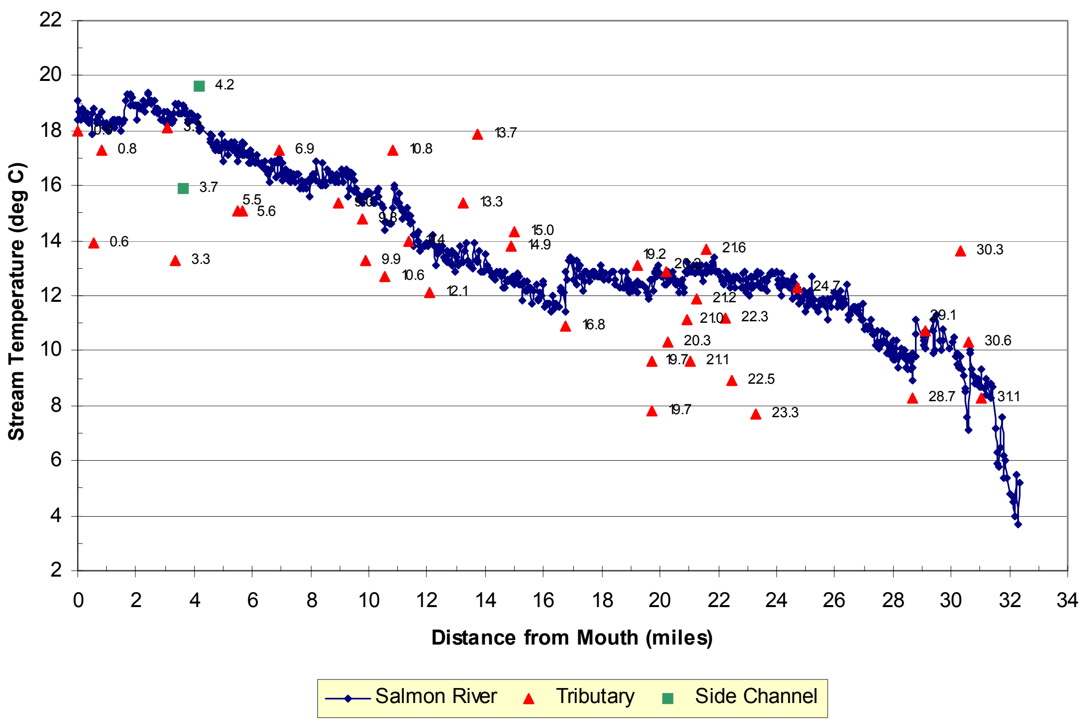


Figure 9 - Longitudinal temperature profile of the Salmon River (8/09/01; 14:38 – 15:50 pm).

Table 7 - Tributary and side channel temperatures for the Salmon River, OR. A question mark (?) in the name indicates some uncertainty in the interpretation of the image or source of the inflow.

Tributary	Image	Km	Mile	Tributary	Salmon R.	Difference
Sandy River ( )	sfsa0027	0.0	0.0	18.0	18.4	-0.4
No Name (RB)	sfsa0062	0.9	0.6	13.9	18.8	-4.9
Boulder Creek (LB)	sfsa0075	1.3	0.8	17.3	18.7	-1.4
No Name (RB)	sfsa0185	5.0	3.1	18.1	18.4	-0.3
Spring? (LB)	sfsa0199	5.4	3.3	13.3	19.0	-5.7
No Name (LB)	sfsa0303	8.8	5.5	15.1	17.1	-2.0
No Name (LB)	sfsa0313	9.1	5.6	15.1	17.6	-2.5
No Name (RB)	sfsa0384	11.2	6.9	17.3	17.0	0.3
No Name (RB)	sfsa0488	14.4	9.0	15.4	16.1	-0.7
No Name (LB)	sfsa0531	15.7	9.8	14.8	15.4	-0.6
No Name (LB)	sfsa0536	15.9	9.9	13.3	15.6	-2.3
No Name (LB)	sfsa0575	17.0	10.6	12.7	14.7	-2.0
SF Salmon (LB)	nfsa0012	17.4	10.8	17.3	15.2	2.1
Spring? (LB)	nfsa0045	18.3	11.4	14.0	14.8	-0.8
No Name (RB)	nfsa0085	19.5	12.1	12.1	13.9	-1.8
Copper Creek (LB)	nfsa0145	21.3	13.3	15.4	13.2	2.2
No Name (RB)	nfsa0172	22.1	13.7	17.9	13.2	4.7
Kingel Creek (RB)	nfsa0234	24.0	14.9	13.8	12.6	1.2
Iron Creek (LB)	nfsa0239	24.2	15.0	14.3	12.4	1.9
Linney Creek (LB)	nfsa0331	27.0	16.8	10.9	12.9	-2.0
No Name (RB)	nfsa0457	30.9	19.2	13.1	12.1	1.0
Spring? (LB)	nfsa0482	31.7	19.7	7.8	12.6	-4.8
Spring? (LB)	nfsa0484	31.7	19.7	9.6	12.6	-3.0
No Name (RB)	nfsa0512	32.6	20.2	12.9	12.4	0.5
Fir Tree Creek (RB)	nfsa0514	32.6	20.3	10.3	12.9	-2.6
Spring (LB)	nfsa0548	33.7	21.0	11.1	13.2	-2.1
Spring? (LB)	nfsa0552	33.9	21.1	9.6	12.9	-3.3
No Name (LB)	nfsa0560	34.2	21.2	11.9	13.1	-1.2
Mud Creek (RB)	nfsa0581	34.8	21.6	13.7	13.1	0.6
Spring? (RB)	nfsa0612	35.8	22.3	11.2	12.9	-1.7
Spring? (LB)	nfsa0622	36.1	22.5	8.9	12.6	-3.7
Spring (RB)	nfsa0666	37.5	23.3	7.7	12.7	-5.0
Ghost Creek (LB)	nfsa0733	39.8	24.7	12.3	12.3	0.0
No Name (RB)	nfsa0964	46.2	28.7	8.3	9.9	-1.6
West Fork Salmon (RB)	nfsa0982	46.8	29.1	10.7	10.7	0.0
No Name (LB)	nfsa1070	48.8	30.3	13.6	9.8	3.8
No Name (LB)	nfsa1082	49.2	30.6	10.3	7.1	3.2
No Name (RB)	nfsa1106	50.0	31.1	8.3	8.7	-0.4
------- Side Channels -------						
Spring Brook (LB)	sfsa0215	5.87	3.65	15.9	18.9	-3.0
Side Channel (RB)	sfsa0245	6.73	4.18	19.6	18.1	1.5

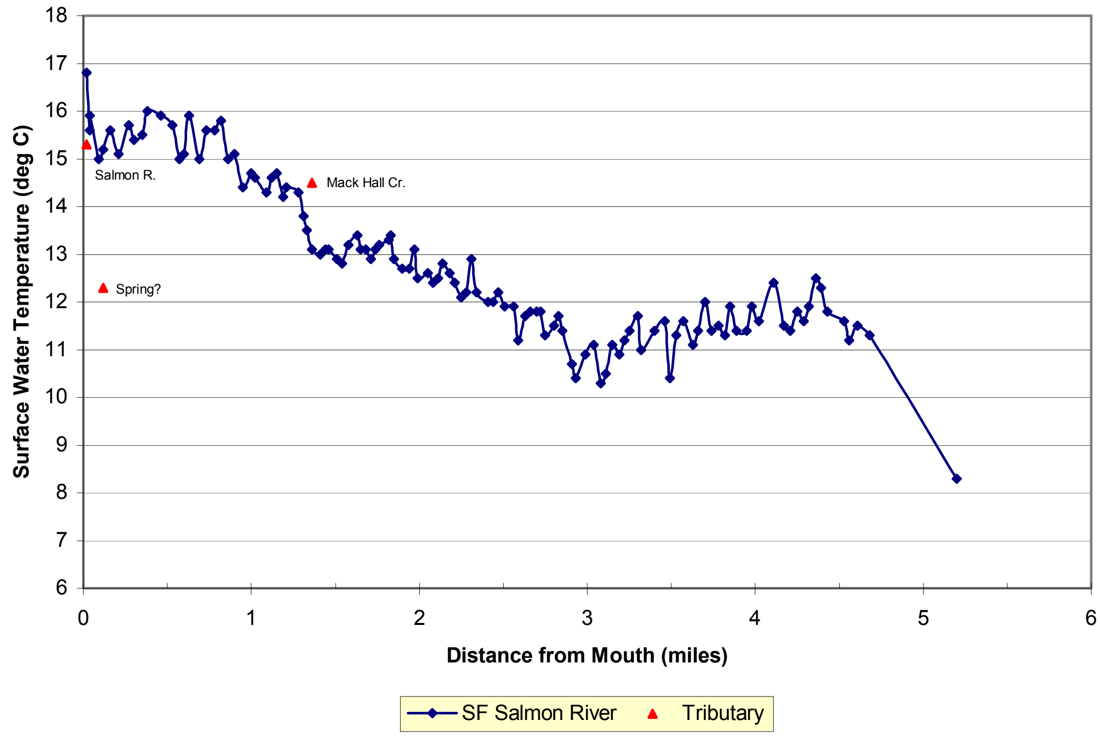


Figure 10 - Longitudinal temperature profile of the South Fork Salmon River OR (8/09/01; 14:58 – 15:08).

Zig Zag River

The Zig Zag River was surveyed from its mouth (Figure 11) to headwaters on Mt. Hood. Figure 12 illustrates the longitudinal temperature profile developed from sampling the TIR images. As with previous streams, tributaries and other surface water inflows are labeled on the longitudinal temperature profile by river mile while the name and temperatures are included in the associated table (Table 8).

A total of 20 tributary inflows were detected and sampled during the processing of the Zig Zag River. Of the 20, sixteen contributed water that was cooler than the main stem and all tributaries detected upstream of river mile 8.0 were cooler than the main stem. The influence of two unnamed tributaries at river miles 10.3 and 10.5 lowered main stem temperatures by approximately 2^{o}C. At river mile 8.3, the Little Zig Zag River enters the Zig Zag River and is approximately 6.8^{0}C cooler drops main stem temperatures by 4.0^{o}C. Stream temperatures rise at a relatively consistent rate (0.9^{o}C/mile) downstream of river mile 8.0. Still Creek at river mile 2.1 is a source of thermal loading and caused an observed 1.0^{o}C jump in the main stem temperatures.

Figure 11 - Ground level photograph looking downstream at the confluence of the Zig Zag River (left) and the Sandy River (right).

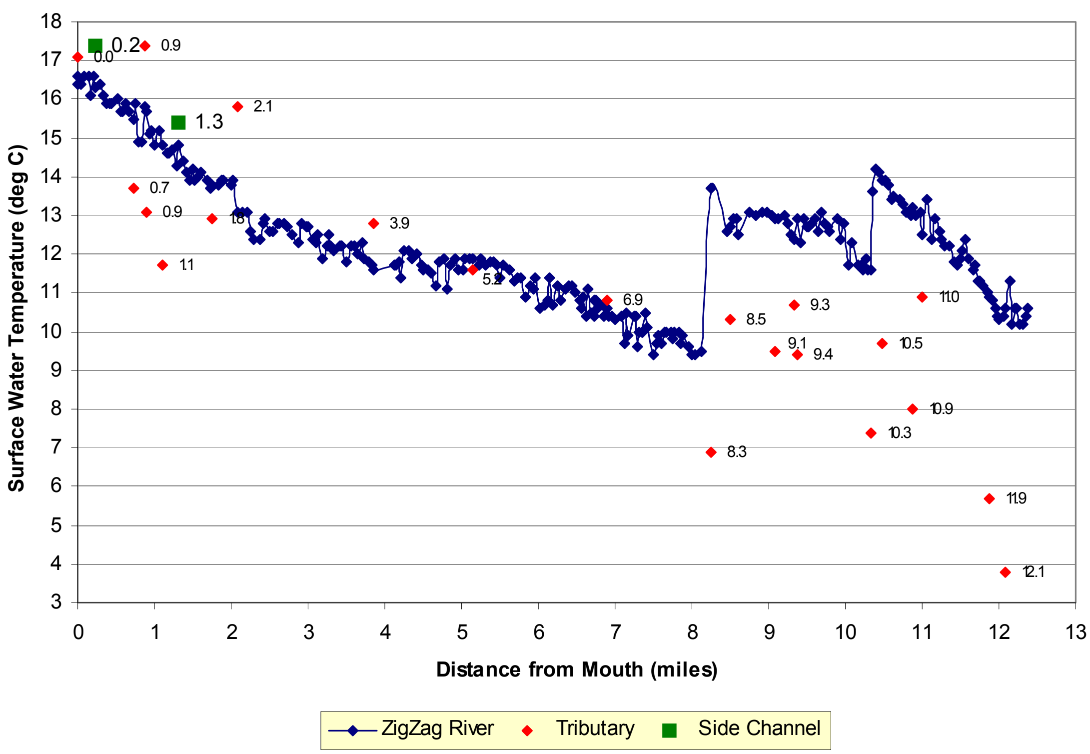


Figure 12 - Longitudinal Temperature Profile for the Zig Zag River, OR (8/9/01; 15:57 – 16:19).

Table 8 - Tributary and side channel temperatures for the Zig Zag River, OR. River miles correspond to data labels shown in Figure 12. A question mark (?) in the name indicates some uncertainty in the interpretation of the image or source of the inflow.

Tributary Name	Image	km	Mile	Tributary	ZigZag	Difference
--- Tributary ---						
Sandy River (RB)	zz0008	0.0	0.0	17.1	16.6	0.5
Spring? (RB)	zz0044	1.2	0.7	13.7	15.5	-1.8
No Name (RB)	zz0051	1.4	0.9	17.4	15.8	1.6
Spring (LB)	zz0053	1.4	0.9	13.1	15.7	-2.6
Spring (LB)	zz0065	1.8	1.1	11.7	14.8	-3.1
No Name (RB)	zz0095	2.8	1.8	12.9	13.8	-0.9
Still Creek (LB)	zz0112	3.4	2.1	15.8	13.1	2.7
Camp Creek (LB)	zz0198	6.2	3.9	12.8	11.6	1.2
Devil Canyon (RB)	zz0284	8.3	5.2	11.6	11.9	-0.3
Lady Creek (RB)	zz0377	11.1	6.9	10.8	10.6	0.2
Little Zig Zag R. (LB)	zz0464	13.3	8.3	6.9	13.7	-6.8
No Name (LB)	zz0478	13.7	8.5	10.3	12.7	-2.4
Spring (LB)	zz0506	14.6	9.1	9.5	12.9	-3.4
Spring (RB)	zz0518	15.0	9.3	10.7	12.4	-1.7
Spring (LB)	zz0520	15.1	9.4	9.4	12.9	-3.5
No Name (LB)	zz0564	16.6	10.3	7.4	11.6	-4.2
No Name (R B)	zz0572	16.9	10.5	9.7	13.9	-4.2
Spring (RB)	zz0590	17.5	10.9	8.0	13.2	-5.2
Spring? (RB)	zz0595	17.7	11.0	10.9	12.5	-1.6
Spring (RB)	zz0638	19.1	11.9	5.7	10.9	-5.2
No Name (RB)	zz0650	19.5	12.1	3.8	10.6	-6.8
--- Side Channels ---						
Side Channel (LB)	zz0021	0.4	0.2	17.4	16.3	1.1
Side Channel (RB)	zz0075	2.1	1.3	15.4	14.8	0.6

Discussion

TIR remote sensing was used to map stream temperatures for the Sandy River and all major tributaries in the basin, a distance of 152.1 miles. The data were collected on the 8^{th} and 9^{th} of August in order to assess low flow high summer temperatures in support of the ODEQ's TMDL development in the Sandy River basin. Meteorological conditions recorded at the Troutdale Airport afternoon air temperatures exceeded 90^{o}F on both days of the survey. The average difference of ±0.4°C between radiant and in-stream temperatures in this basin was consistent with the average accuracy of ±0.4°C recorded during TIR surveys throughout the Pacific Northwest since 1994 and is well within the specified tolerance of $\pm 0.5^{o}$C.

Assessment of the stream temperature patterns in the Sandy River basin indicated that stream temperatures tended to increase in a downstream direction, but the pattern of this change varied among streams. The Sandy River, along with the major tributaries, has headwaters on the southwest slope of Mt. Hood, OR and, consequently, headwater temperatures were cold ($<8^{o}$C). While temperatures downstream of the headwaters generally increased quickly, downstream temperature patterns and the spatial influence of tributary inputs on stream temperature varied between streams. The Sandy River, for example, had two reaches of lengths greater than 12 miles that showed only small (i.e. $<1^{o}$C) longitudinal variation in stream temperature.

The influence of tributaries on the receiving streams depended on the characteristics of the individual stream. In some reaches, the riparian canopy was a factor in the ability to detect and interpret thermal features within the riparian zone such as small inflows. However, the canopy did not impact the ability to develop a continuous longitudinal temperature profile. Furthermore, several inflows (springs and apparent springs) were detected during the surveys, which were not identified on 7.5' USGS topographic maps. These inflows influenced the spatial thermal variability of the surveyed streams. In addition, our analysis indicated thermal stratification was not an issue on the free flowing sections of the surveyed streams. Thermal stratification was observed behind the impoundment on the Little Sandy River and in the reservoirs on the Bull Run River.

The TIR surveys lay a basic groundwork to integrate the 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 in-stream temperature sensors.

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