APPENDIX J

Surface Water Temperature Profile

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1. Introduction

River–aquifer exchanges and groundwater discharge are important to the riverine ecosystem because groundwater provides base flow and preferred thermal habitat for fish. Groundwater return flows may be several degrees cooler than the summer streamflow temperature. In the winter, return flows are often warmer than the surface water temperature and provide thermal refugia for salmonids. In intensely modified basins, such as the Yankee Fork, natural river–aquifer exchanges have been modified due to human activities. River segments and floodplains have been significantly altered through dredging and re-channelization. Ponding of water in disconnected channels and tailing ponds can affect the thermal regime. To determine how and where groundwater returns to the river, it is necessary to understand the conditions that control the occurrence and movement of groundwater.

Various methods are available to measure and quantify the interaction between streamflows and the surrounding aquifer. Since groundwater is often a different temperature than surface water in a stream, tracking temperature along a continuous longitudinal profile of the stream indicates specific locations where groundwater enters the stream. Tracking temperature can be accomplished by Thermal Infrared (TIR) Remote Sensing, by air-based infrared thermography (Schuetz and Weiler 2011), and by conducting a thermal profile with a temperature logger (USGS 2006). Each of these methods has advantages and disadvantages for a specific scale of study and provides important information that, when combined with other data, gives insight into the complexity of stream temperature dynamics. A TIR survey was conducted of the Yankee Fork area on August 6, 2010, while a longitudinal profile from the ground was performed from August 11 to 13, 2011.

2. Thermal Infrared Remote Sensing

On August 6, 2010, Trout Unlimited contracted Watershed Sciences, Inc. to perform detailed thermal imaging of major rivers and streams located within the Yankee Fork River basin. The major streams surveyed included the mainstem of the Yankee Fork River, Jordan Creek, West Fork Yankee River, and Rankin Creek. Watershed Sciences utilized airborne TIR remote sensing process, a proven method for developing spatial temperature patterns integrated with surface characteristics of the stream and influential features. The TIR survey has the advantage of covering an entire stream basin in a relatively short period of time. A potential disadvantage, however, is that the method measures surface radiance and cannot precisely locate groundwater discharge until manifested at the water surface. Thermal stratification of the stream or mixing of surface and groundwater can mask the groundwater signature; these conditions are affected by channel morphology, streamflow volume, and velocity. Processed data for this study evaluates temperature variances on both an individual pixel scale and river reach scale (Figure 1). The report submitted by Watershed Sciences, Inc. (Watershed Sciences 2010) details the data collection techniques, instrumentation, weather conditions, ground control, method characteristics, data processing, and accuracy associated with this method and study.

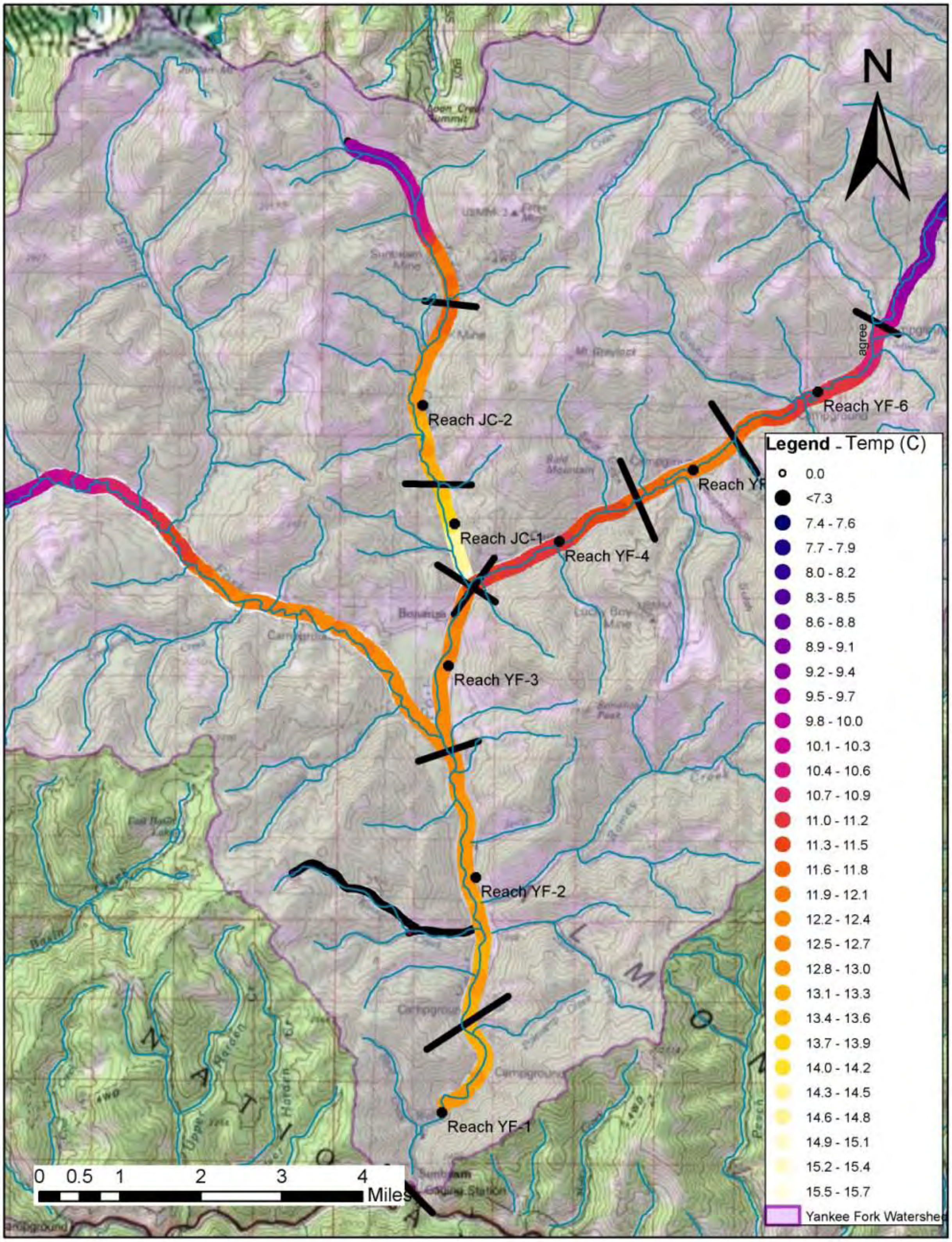

Figure 1. Study area with mean temperatures in degrees Celsius

2.1 Yankee Fork River Mainstem

Watershed Sciences measured TIR data for the mainstem of the Yankee Fork River from Eightmile Creek to the confluence with the Main Salmon River. Prior to and during measurement, flows on the Main Salmon River increased higher than normal due to heavy precipitation prior to the August 6th flight date as seen in Figure 2. No gages currently measure Yankee Fork data; however, values may possibly be affected by the increased amount of water within the watershed related to the precipitation event.

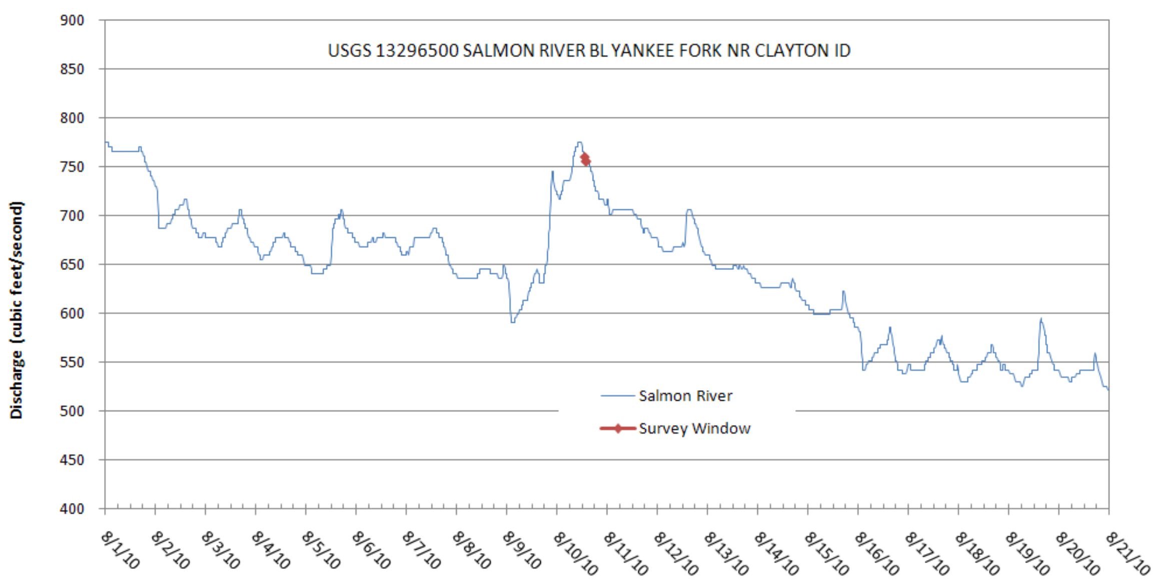

Figure 2. Hydrograph for Main Salmon River during the TIR flight (Watershed Sciences 2010)

2.1.1 Middle Yankee Fork Subwatershed (Eight Mile Creek to Jordan Creek)

Reach YF-6 is located between Eightmile Creek and Fivemile Creek along the mainstem of the Yankee Fork River. Sample temperatures within this subwatershed are listed within Table 1. Eightmile Creek flows into the Yankee Fork River at river mile (RM) 16.38 adding significantly warmer water to the mainstem as seen in Figure 3. The warming trend continues downstream until RM 16.03 and RM 15.72 where two cooler springs enter on the left side. Bedrock outcrops extend down to the river at this location, causing cooler water to come to the surface resulting in a consistent temperature on the mainstem over about a mile. Between RM 13.52 and 13.32, a much cooler spring enters the channel to the right and slightly cooler Fivemile Creek enters to the left. The river channel becomes constricted at this point, entering the bedrock-dominated canyon causing upwelling and a cooling trend.

Table 1. Sample mean temperature mesurements for the lower Yankee Fork subwatershed (Watershed Sciences 2010)

Sub Watershed	Reach	Feature	River Mile	Temp (°C)	Main Temp (°C)	Diff	Remarks/ Source
Middle Yankee Fork	YF-4	seep on side channel (L)	9.52	10.4	11.3	-0.9	End Canyon
		Adair Creek (L)	10.45	10.2	11.1	-0.9	
		Swift Gulch (R)	11.30	10.8	11.3	-0.5	
	YF-5	4th of July/Slaughterhouse	12.16	9.7	11.9	-2.2	
	YF-6	Fivemile Creek (L)	13.32	10.4	12	-1.6	Canyon
		spring (R)	13.52	7.5	11.8	-4.3	Upwelling
		Greylock Creek (R)	14.55	9.9	11.2	-1.3	
		Sixmile Creek (L)	14.70	9.6	11.2	-1.6	
		spring in side channel (L)	15.72	9.8	11.1	-1.3	Bedrock
		seep (L)	16.03	8.7	10.8	-2.1	Bedrock
		Sevenmile Creek (L)	16.09	5.5	8.8	-3.3	
		Unnamed (L)	16.27	8	10.8	-2.8	
		Eightmile Creek (R)	16.38	12.4	10.6	1.8	

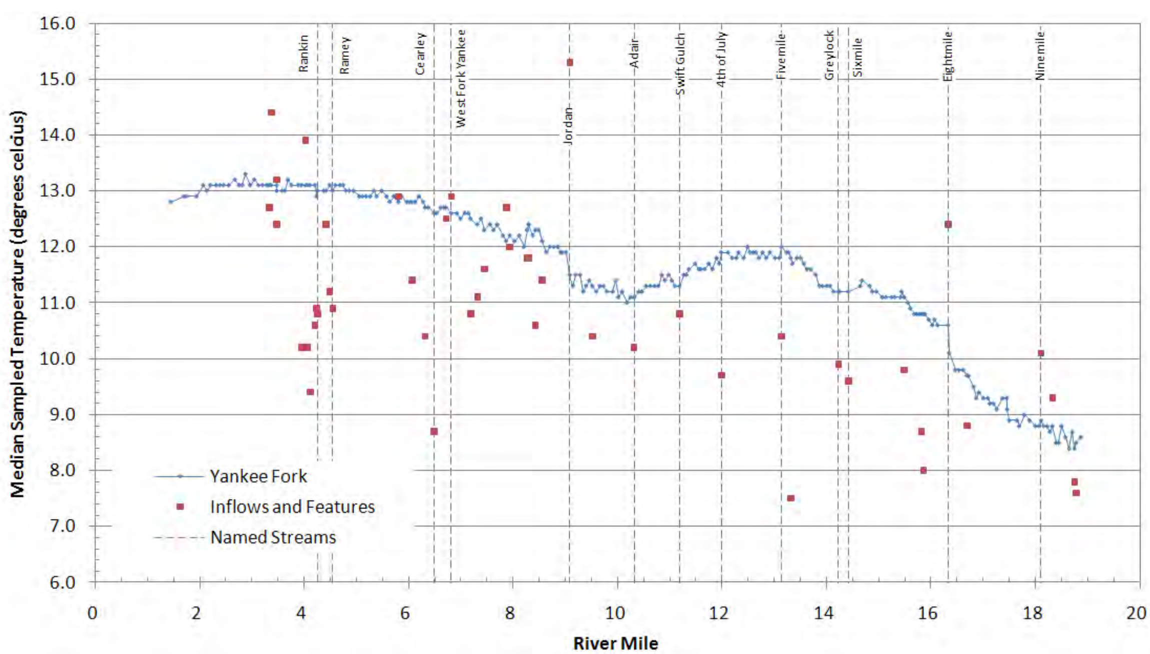

Figure 3. Mean temperature measurements vs. river mile for middle and lower Yankee Fork subwatersheds (Watershed Sciences 2010)

Through Reach YF-5, the mainstem begins a cooling trend as groundwater enters the system prior to the canyon. At RM 12.16, the much cooler Fourth of July/Slaughterhouse Creek enters the system, adding additional cool water to the reach. This is the only major feature observed within this reach.

The mainstem through Reach YF-4 continues the cooling trend with the cooler Swift Creek entering from the left at RM 11.30 and Adair Creek entering at RM 10.45. The canyon ends and the river enters a fluvial valley at RM 9.45, where a cooler seep enters a side channel from the left. At this point, temperatures on the mainstem begin to increase. Table 1 shows detailed features and mean temperature variations throughout the middle Yankee Fork subwatershed as provided by Watershed Sciences and updated to correspond with defined river miles for this report.

2.1.2 Lower Yankee Fork Subwatershed (Jordan Creek to Confluence with Main Salmon River)

Jordan Creek enters the mainstem of the Yankee Fork at RM 9.10, signifying the beginning of the lower Yankee Fork subwatershed and Reach YF-3. Table 2 provides a compilation of mean measured temperatures and features within the lower Yankee Fork subwatershed. The dredged portion of the stream begins at Jordan Creek and throughout Reach YF-3 where water flows through the hyporheic zone between the tailing pools and the mainstem. Mainstem temperatures show an overall increase through this reach, with cooler tailing pools located throughout the reach (Figure 3). At RM 7.19, a cooler stream spring develops west of the mainstem and flows to the West Yankee Fork with tailing pools nearby. TIR observations show no direct link between the tailing pools located throughout this subwatershed and the mainstem; however, cooler temperatures within the pools indicate a connection via hyporheic flows.

Reach YF-2 begins at RM 6.85 where the slightly warmer West Yankee Fork River enters the system. Mainstem temperatures continue to increase through RM 4.85 at a slower rate with the introduction of much cooler branches of Cearley Creek at RM 6.30 and RM 6.50, and a much cooler spring at RM 6.14. Cold water tailing pools also dominate this stretch connected to the mainstem via the hyporheic zone. At RM 4.58, the lower temperature Ramey Creek enters from the left and the temperature of the mainstem begins to plateau (Figure 3). Rankin Creek adds additional cold water at RM 4.30, flowing in from the right after emerging from the sub-surface through a landslide caused by a major fire in 2000. Silver Creek adds additional cool water to the system at RM 4.25. Tailing pools continue through the system until the end of the reach at RM 3.3, where the river once again enters a bedrock-dominated canyon with upwelling water, adding additional water to the system and causing the mainstem to begin a cooling trend.

Table 2. Sample mean temperature measurements for the lower Yankee Fork subwatershed (Watershed Sciences 2010)

Sub Watershed	Reach	Feature	River Mile	Temp (°C)	Main Temp (°C)	Diff	Remarks/ Source
Lower Yankee Fork	YF-2	seep (L)	3.35	12.7	13.1	-0.4	Tailings Pool
		tailings pool (L)	3.40	14.4	13.1	1.3	
		seep (L)	3.50	12.4	13.1	-0.7	Tailings Pool
		tailings pool complex (L)	3.50	13.2	13	0.2	
		tailings pool (L)	3.80	10.2	13.1	-2.9	
		spring complex-small (L)	3.90	13.9	13.1	0.8	Tailings Pool
		tailings pool (L)	3.95	10.2	13.1	-2.9	
		tailings pool (L)	4.08	9.4	13.1	-3.7	
		Silver Ck/pool (L)	4.25	10.6	13.1	-2.5	Tailings Pool
		pool (L)	4.28	10.9	12.9	-2	
		Rankin Creek (R)	4.30	10.8	13	-2.2	
		tailings pool (L)	4.43	12.4	13	-0.6	
		tailings pool (L)	4.54	11.2	13.1	-1.9	
		Ramey Creek (L)	4.58	10.9	13	-2.1	
		pool (R)	5.80	12.9	12.8	0.1	
		spring in dredge pool (L)	6.09	11.4	12.8	-1.4	
		Unnamed Creek/Spring (R)	6.14	8.6	12.8	-4.2	
		cold side ch/Cearley Ck (L)	6.30	10.4	12.7	-2.3	
		spring/Cearley Ck (L)	6.50	8.7	12.6	-3.9	
		seep in off-channel pool (R)	6.70	12.5	12.7	-0.2	Tailings Pool
		West Fork Yankee Fork (R)	6.85	12.9	12.6	0.3	
	YF-3	spring flow to W. Fork (R)	7.19	10.8	12.5	-1.7	Tailings Pool
		tailings pool (R)	7.30	11.1	12.4	-1.3	
		tailings pool (R)	7.50	11.6	12.3	-0.7	
		tailings pool (L)	7.87	12.7	12.1	0.6	
		tailings pool (L)	7.96	12	12.2	-0.2	
		Unnamed (R)	8.28	11.8	12.3	-0.5	Tailings Pile
		seep upstream of bridge (R)	8.32	11.8	12.4	-0.6	Tailings Pool
		tailings pool (R)	8.43	10.6	12.3	-1.7	
		tailings pools (R)	8.56	11.4	12.1	-0.7	
		Jordan Creek (R)	9.10	15.3	11.5	3.8	

2.2 Jordan Creek

On August 6, 2010, Watershed Sciences also measured TIR data for Jordan Creek from about RM 6.7 to the confluence with the Yankee Fork River. Heavy precipitation prior to the August 6 flight date may have caused increased interaction between ground and surface water during this study period as well. No staging gages currently measure Jordan Creek flows to actually quantify increases in volume on this tributary.

2.2.1 Jordan Creek Subwatershed (River Mile 4.03 to Confluence with Yankee Fork)

Jordan Creek Reach JC-2 begins at RM 4.03, approximately the location where dredge pilings and heavy mining activity begins. Mining activity has resulted in a steep, boulder-dominated streambed with high gradient and a straightened channel. At RM 3.6, a slightly cooler spring enters on the left at the bottom of a cooling trend observed on the mainstem (Figure 4) indicating the possibility of groundwater influence. Significantly, warmer mine discharge water enters at RM 3.38, increasing the temperature of the mainstem. With the addition of cooler seeps and springs entering on both sides of the channel, the mainstem temperature remains fairly constant until the end of the reach where the stream enters the rehabilitated area.

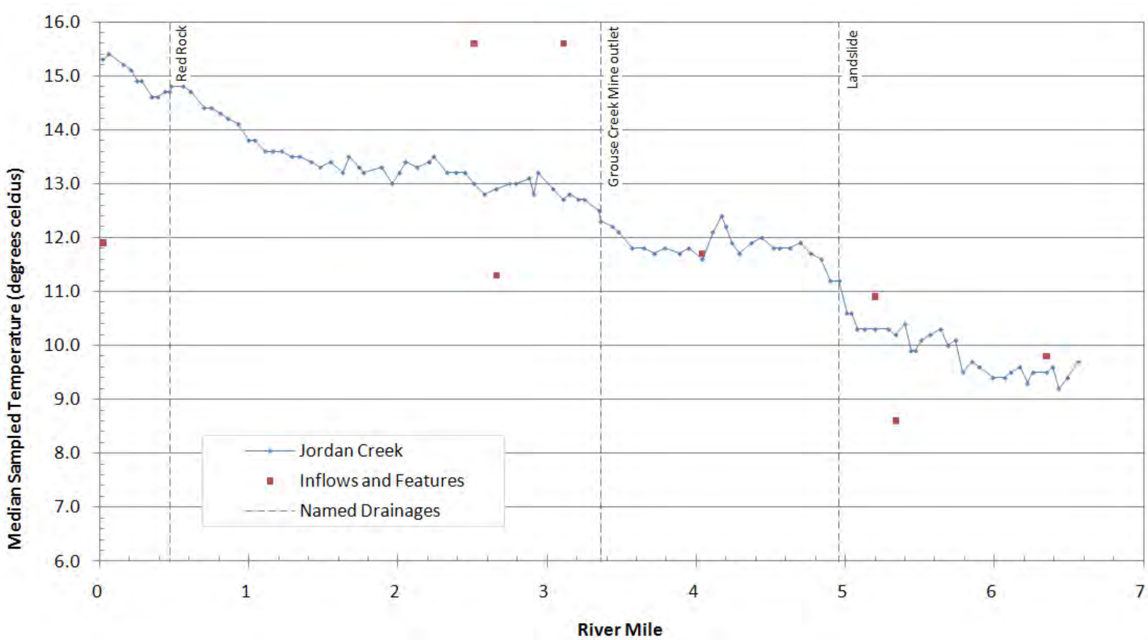

Figure 4. Mean temperature measurements vs. river mile for Jordan Creek subwatershed (Watershed Sciences 2010)

Reach JC-1 consists primarily of the area recently rehabilitated to its original state, including a meandering channel, native substrate and riparian vegetation, and a less steep gradient. This results in a larger temperature increase with slower water and less mixing. A cooler Red Rock Creek enters from the left at RM 0.52 resulting in a slight drop in temperature (Figure 4). Table 3 provides a detailed list of temperature variations with location and possible sources for the variation.

Table 3. Sample mean temperature measurements for the Jordan Creek subwatershed (Watershed Sciences 2010)

Sub Watershed	Reach	Feature	River Mile	Temp (°C)	Main Temp (°C)	Diff (°C)	Remarks/ Source
Jordan Creek	JC-1	Yankee Fork Mainstem	0	11.9	15.3	-3.4	
		Red Rock	0.52	14.1	15.1	-1	Red Rock Creek
	JC-2	pond west of road (R)	2.6	15.6	13	2.6	
		Unnamed (R)	2.75	11.3	12.9	-1.6	
		Unnamed (L)	2.77	11.1	12.9	-1.8	
		Unnamed (L)	2.97	11.5	12.8	-1.3	
		Unnamed (L)	3.06	10.1	12.7	-2.6	
		pool (L)	3.11	15.6	12.7	2.9	
		Unnamed (R)	3.27	11.5	12.7	-1.2	
		Unnamed (L)	3.27	11.5	12.7	-1.2	
		Unnamed (R)	3.38	15.1	12.7	2.4	Mine Discharge
		Unnamed (L)	3.6	11.5	11.8	-0.3	Spring Fed
	N/A	Unnamed (L)	4.1	11.7	11.6	0.1	
		Unnamed (R)	5.25	10.9	10.3	0.6	
		Unnamed (L)	5.4	8.6	10.2	-1.6	
		Unnamed (R)	6.4	9.8	9.5	0.3	

2.3 Results

TIR data shows obvious fluctuation in mainstream surface temperatures and corresponding features possibly attributing to those fluctuations. The TIR method is only able to measure surface temperatures, therefore in turbulent areas, the observe temperatures may be more representative of stream temperatures than less turbulent areas. Groundwater infiltrating through the bottom of the channel will less likely be visible at the point it enters with temperature variances observed further downstream. Results obtained from this method should be used to pinpoint areas of further investigation, rather than the sole method of determining groundwater affects.

3. Water Temperature Profile

Figure 5 shows the location of reaches along the Yankee Fork and lower Jordan Creek that were profiled between August 10 and 13, 2010.

The upper Yankee Fork, above Fivemile Creek, has a relatively broad alluvial channel with low to moderate gradient. Above the historic mining town of Custer, the river becomes more incised and is confined by bedrock and large boulders. Below Custer, the alluvial plain widens again. The Yankee Fork channel below Jordan Creek was dredged in the late 1800s for gold exploration. Unsorted sand to boulder sized rock is piled along the riverbanks and confines the channel within the dredge tailings. Confinement tends to straighten the channel, steepen the gradient, and result in a coarser streambed. In addition, the disconnected tailing ponds are shallow and can affect the thermal regime as the water returns to the river. One of the larger tailing ponds, at about RM 3.9 left bank, was profiled to record depth and water temperature.

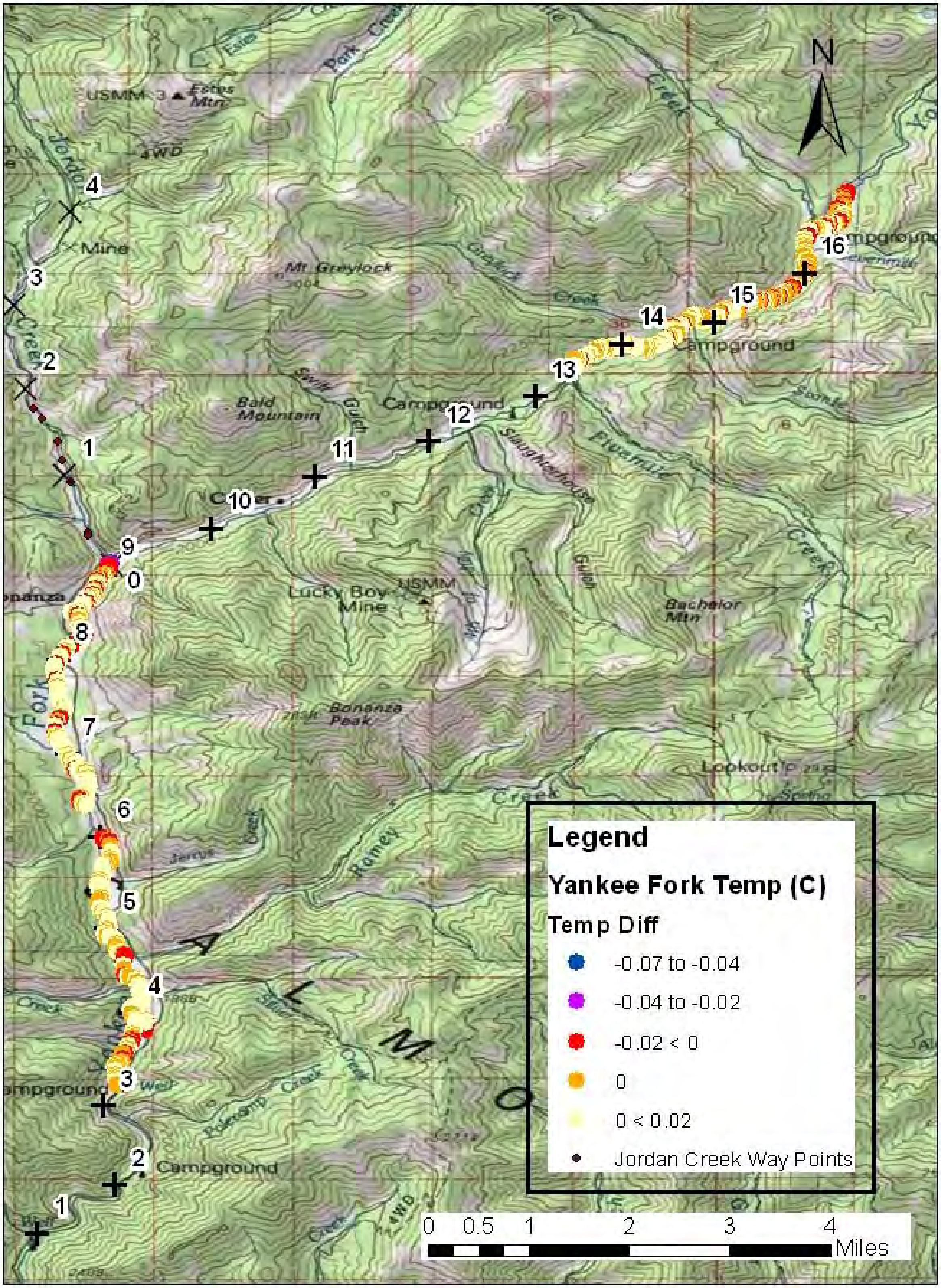

Figure 5. Location of profiled reaches of the Yankee Fork

3.1 Thermal Profile of Yankee Fork

A thermal profile documents the longitudinal temperature gradient of a stream and is a relatively direct method to evaluate river-aquifer exchanges. A thermal profile was conducted on the Yankee Fork August 11 to 13, 2010, to define the spatial variation of temperature due to groundwater contributions. A total of 35 miles of Yankee Fork, and the tributary Jordan Creek, were profiled. The method used was developed by the U.S. Geological Survey (USGS) in 2001 in the Yakima River basin, Washington and is meant for use on stream characteristics of those found in the Yakima River basin. These streams are generally more meandering and have a more subtle gradient than those found in the Yankee Fork River basin. Higher gradients with large boulders may not provide ideal results. The method was shown to document the longitudinal distribution of a river's temperature regime and areas of groundwater discharge (USGS 2006).

The thermal profiling method consists of towing a temperature probe from a watercraft (e.g., inflatable kayak) that measures temperature near the river bottom while concurrently logging spatial coordinates with a Global Positioning System (GPS). Profiling is accomplished during seasonal low flows, when the stream is more confined in the main channel and groundwater discharge is a larger proportion of the total streamflow. Data are collected at a one- to three-second sample rate, depending on flow velocity, reach length and datalogger capacity. The profile is conducted during the diurnal warming part of the daily sinusoidal streamflow-temperature regime. Portable temperature loggers are placed at the upstream and downstream ends of the profiled reach to provide additional information on the diurnal temperature change in water entering and leaving the reach.

Groundwater discharge areas are identified by locating deviations from the diurnal heating pattern. Broad discharge areas are typified by stabilization, cooling, or declining rate of change in temperature increases. Localized discharge (springs, alluvial aquifer discharge, or re-connecting side channels) is exhibited by short temporal variations in the thermal profile. These represent 'patches'; the size and longitudinal distance between patches are important for most life-history stages of salmonids (USGS 2011). After identifying potential groundwater discharge areas by thermal profiling, a more detailed study using other methods could be employed, such as mini-piezometers, to measure vertical gradient between the stream and shallow aquifer.

3.1.1 Equipment and Conditions

Onset StowAway® TidbiT™ temperature loggers were deployed at fixed locations along Yankee Fork to record water temperature through time during the thermal profile. The reported accuracy of the Onset StowAway is +/- 0.2º C (Onset User's Manual). The Tidbits were deployed at the following locations: RM 3.3 (Poleflat), RM 9.2 (Yankee Fork at Jordan Crk), RM 13.3 (Fivemile Crk), Jordan Creek RM 1.5, and lower Jordan Creek Bridge RM 0.1.

An integrated temperature sensor and datalogger, designed for groundwater monitoring (Levelogger Gold Model 3001 manufactured by Solinst®) was used to record water temperatures during the thermal profile. Probe accuracy is rated at 0.1º C for temperature. The probe was housed in a rugged plastic pipe container that provided protection yet allowed the free flow of water around the probe (Figure 6). A handheld Garmin® GPS unit, model Colorado 400T, received and stored location information along the route. Each GPS data point is time stamped and latitude, longitude, length, speed, and course are recorded. At the start of the profile, the internal clock of the temperature probe was closely synchronized to the GPS, and then temperature and location were recorded every three seconds. During data processing, the data files were combined in an Excel spreadsheet. The data file was then converted to an ArcGIS point coverage.

Figure 6. Equipment used during thermal profiling, temperature probe (left), container (middle), and GPS unit (right)

The difference in temperature from one measurement point to another was generally very small (less than 0.01º C) but it is the trend of water temperature changes and their locations, rather than the absolute temperatures that are of interest in determining groundwater discharge locations. A shape file was created of the temperature differences from one reading to the next, highlighting areas where point to point changes exceeded 0.002º C. The temperature differences less than 0.002º C were not used in order to eliminate "probe noise".

A portion of the profile was conducted from a two-person inflatable kayak. Some parts of the river did not have enough water depth to use the kayak and were profiled by towing the probe while walking down the river channel. The reach from Jordan Creek to Fivemile was too difficult to access and had large boulder obstacles that prevented safe passage so that section was not profiled.

3.2 Results

Tidbit Water Temperatures

Tidbit water temperature sensors were placed at five different locations throughout the study area. The daily maximum water temperature generally occurred between 4:00 and 5:30 PM (Figures 7 through 11). The minimum to maximum temperature range warmed downstream during the profile period (August 10 to 13, 2010):

6.5 to 13º C at Fivemile (RM 13.3)

7 to 14º C at Jordan Creek (RM 9.2)

8 to 15º C at Poleflat (RM 3.3)

The temperature range in Jordan Creek was about 8 to 17 º C.

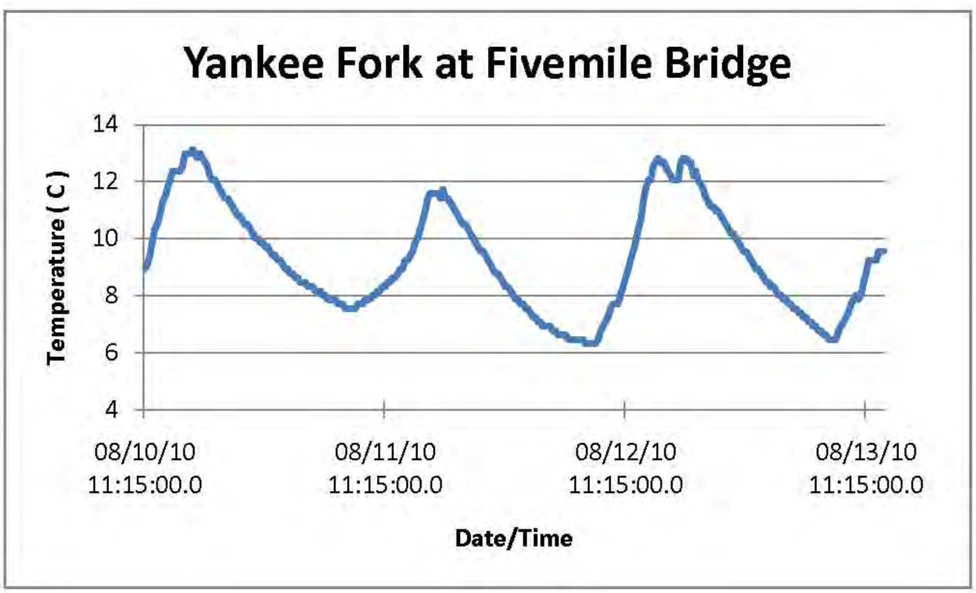

Figure 7. Water temperature at Fivemile Bridge (RM 13.3) from 8/10-13/2010

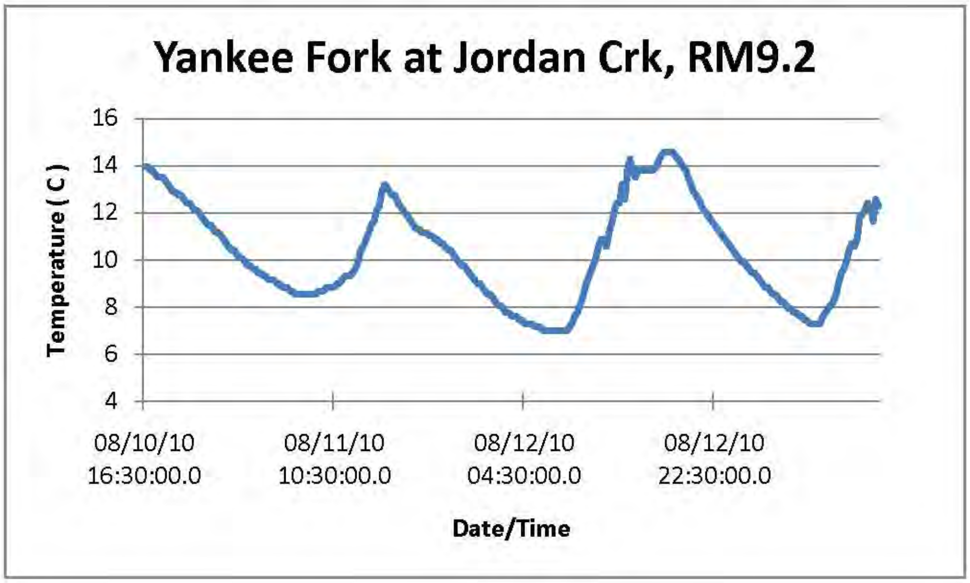

Figure 8. Water temperature at confluence with Jordan Creek (RM 9.2) from 8/10-13/2010

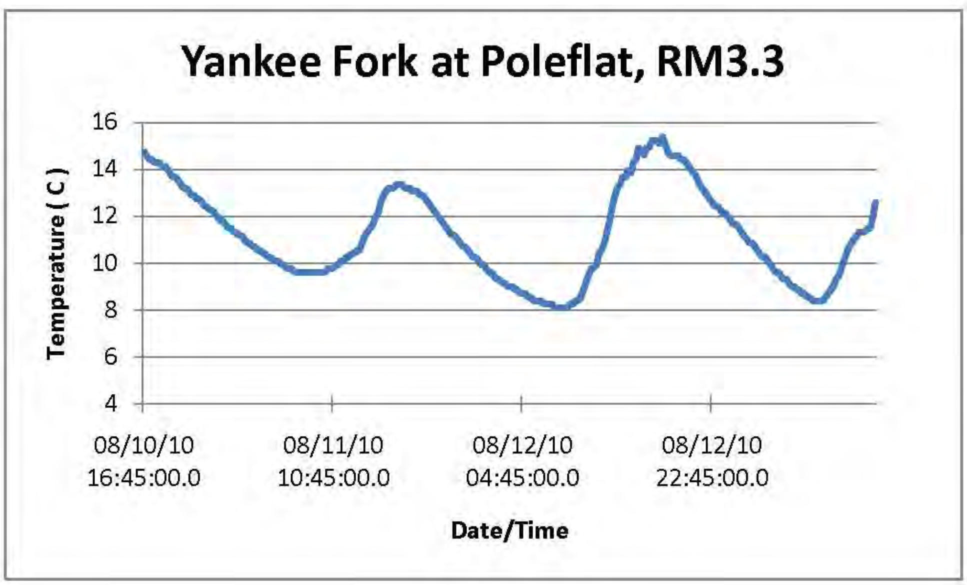

Figure 9. Water temperature at RM 3.3 from 8/10-13/2010

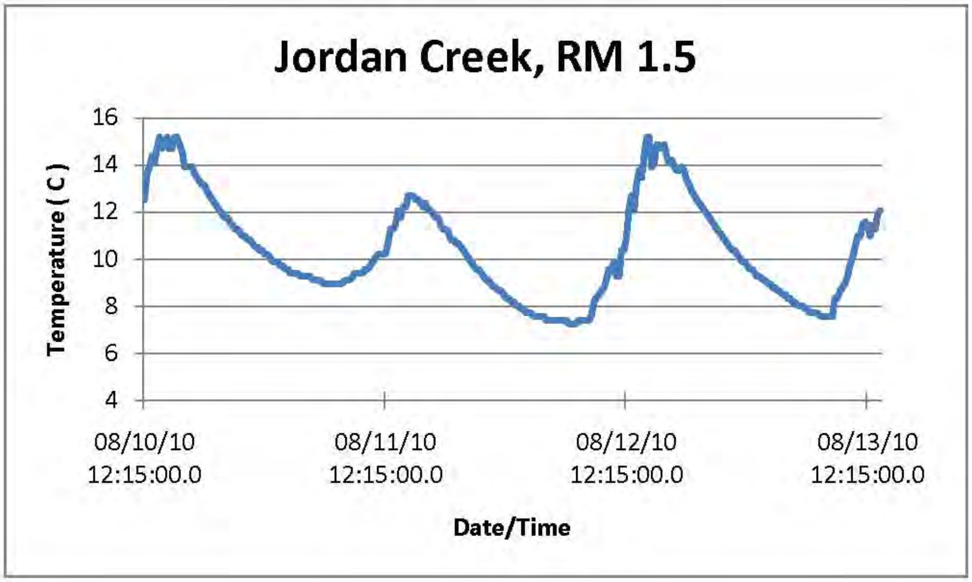

Figure 10. Water temperature of Jordan Creek at RM 1.5 from 8/10-13/2010

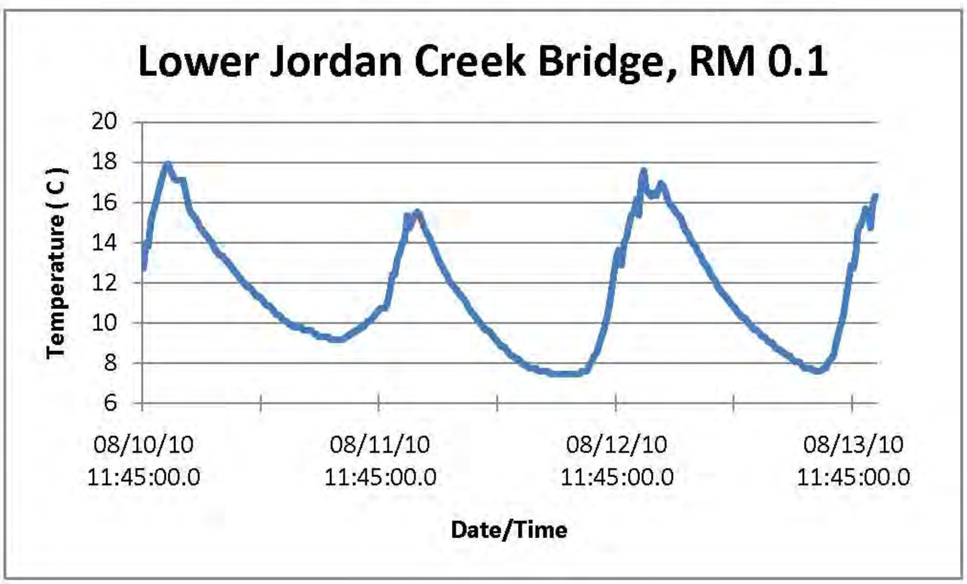

Figure 11. Water temperature of Jordan Creek at RM 0.1 from 8/10-13/2010

Thermal Profiling

Some temperatures deviate from the expected thermal response during the diurnal heating period (Figures 12 through 14). These may indicate localized discharge (springs, surface-water inflows, and/or alluvial aquifer discharge from re-connecting channels) to the stream. On the other hand, the relatively high velocity of the stream during the thermal profile caused the probe to bounce and vary in depth within the water column and prevented it from travelling consistently along the riverbed. Therefore, the recorded temperatures may instead represent the natural variation of temperature within the water column. In some areas the water depth was too low to use the inflatable kayak and the profile was accomplished by towing the probe while walking within the channel. This method does not appear to be as accurate as floating the river since there were some pools that were too deep to walk through and other areas that were difficult to navigate by foot due to boulders and obstacles. When walking the channel the probe did not follow the thalweg as well as it would have by boat.

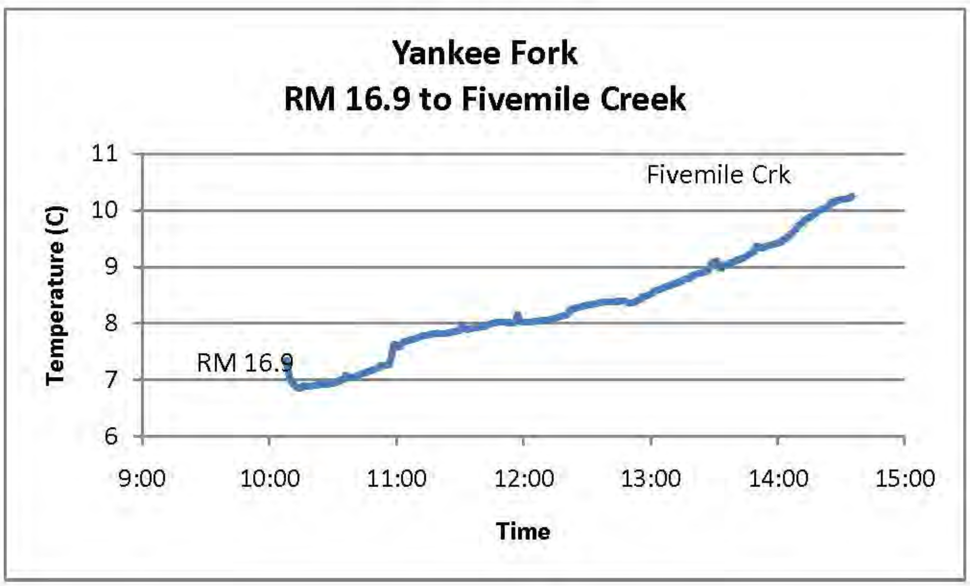

Figure 12. Yankee Fork RM 13.3 - 16.9, Temperature vs Time, Profiled 8/11/2010

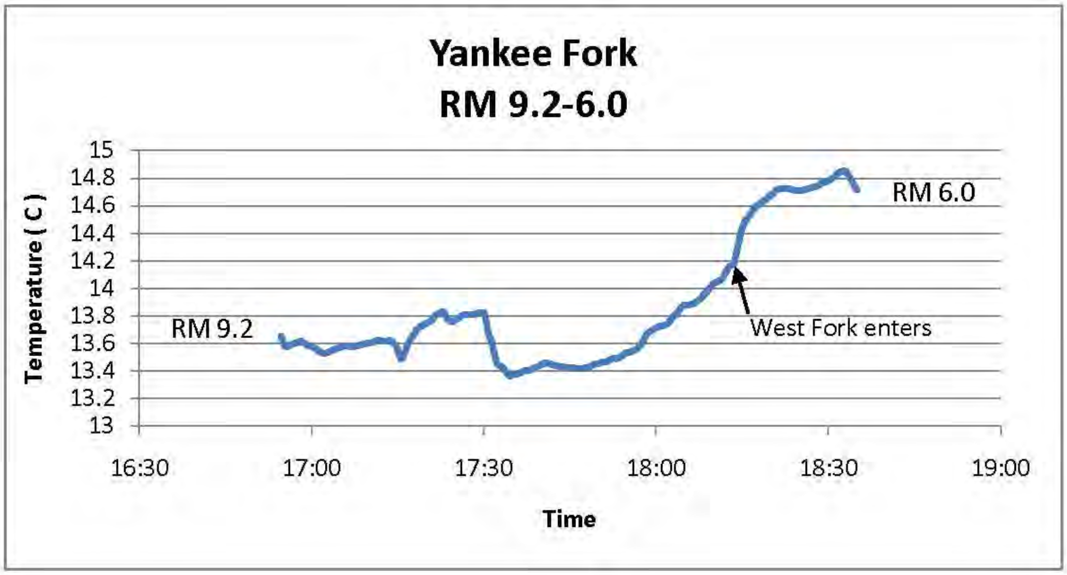

Figure 13. Yankee Fork RM 6.0 - 9.2, Temperatuve vs Time, Profiled 9/12/2010

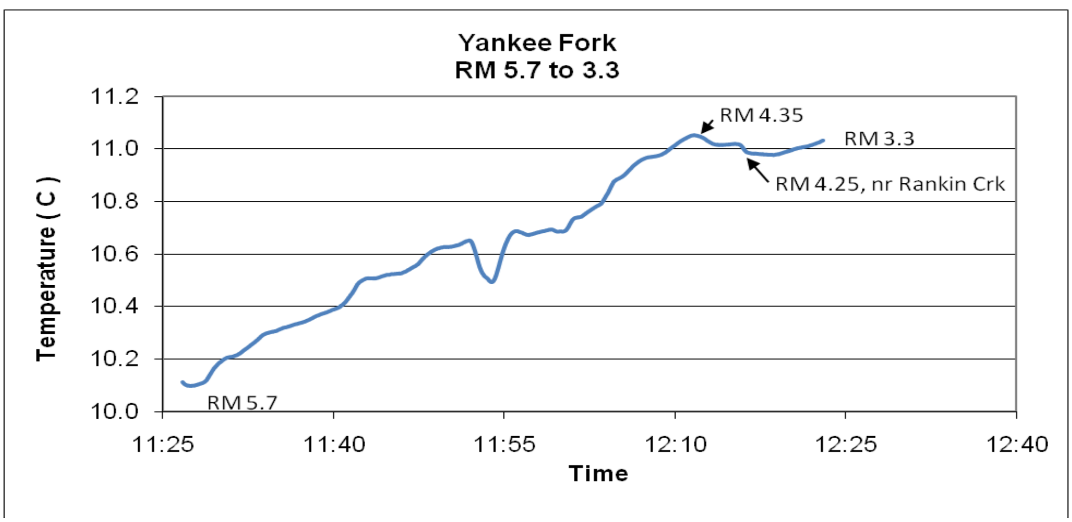

Figure 14. Yankee Fork RM 3.3 - 5.7, Temperature vs Time, Profiled 8/13/2010

Jordan Creek was profiled by walking the small creek but a problem during the setup of the GPS tracking program prevented the GPS unit from recording location data during the profile. Field notes and GPS waypoints indicate location at points along the route but a continuous location profile is not available. Figure 15 shows the temperature profile.

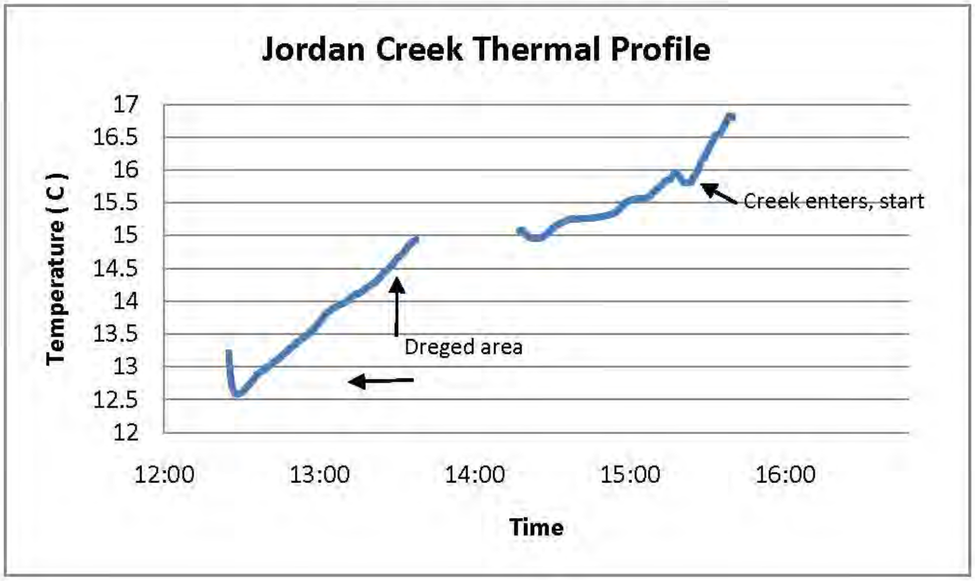

Figure 15. Close-up of RM 8.2 - 8.4 where thermal profile identified temperature deviation

A relatively large tailing pond near RM 3.9 was profiled by boat, from one end to the other and back again (Figure 16).

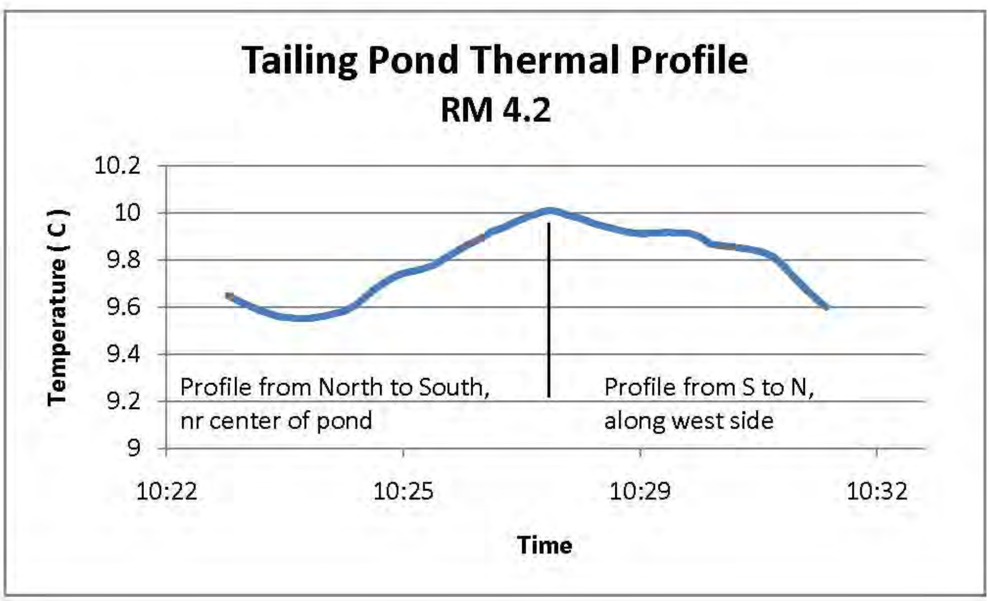

Figure 16. Tailing Pond Temperature vs Time, Profiled 8/13/2010

The information from the profiles should be considered just one source of data and used in conjunction with other information, such as seepage investigations, measured hydraulic gradients, and groundwater level information. Prior to the thermal profile, large precipitation events dominated the area, possibly influencing results, as increased water levels may have altered normal river–aquifer exchanges and groundwater discharge for this area. The thermal profiling has been analyzed at the subwatershed scale; however, future analysis is recommended at the reach scale.

4. Conclusions

Complex and highly variable characteristics represent the surface water - groundwater relationship; including geology, varying quantities of groundwater recharge and discharge, temperature, river channel modifications, surface water bodies and abandoned channels, and alluvial aquifer variability. In a natural system, surface water flows during spring runoff would exceed the river banks and inundate the surrounding floodplain. Groundwater levels would rise to the extent that they may intercept the land surface in depressions and sloughs. As the flows decrease during the summer and fall, groundwater plays an increasingly important role in supplying water (base flow) to streams and tempering the surface water flows with cooler return flows. In a highly modified basin, such as parts of the Yankee Fork, the channel has been dredged and levied, which has created tailing ponds and side channels.

Both the TIR and ground based longitudinal profile data show similar areas where the temperatures stabilize or deviate from the expected thermal response of streamflow during the diurnal heating period. These may be indicative of localized discharge (springs, surface water inflows, and/or alluvial aquifer discharge) and areas of canyon upwelling. High hydraulic conductivities and transmissivities for the unsorted sand to boulder sized rock, located within the dredged areas, allow for hyphoreic flow between the channels and tailings ponds. Warmer mining discharge along Jordan Creek also affects overall stream temperatures causing a steeper increase in temperature at that location. The data from this thermal profile can be used to locate areas where additional study of groundwater and thermal conditions may be warranted.

5. Literature Cited

Parenthetical Reference	Bibliographic Citation
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