APPENDIX E – HYDROGEOLOGY

TABLE OF CONTENTS

List of Figures

TABLE OF CONTENTS (CONTINUED)

1. Summary – Hydrogeology of the Grande Ronde Valley

Low summer flows and increased temperatures in the lower reaches of Catherine Creek may potentially impede spawning in Catherine Creek and contribute to declining populations of salmon and steelhead in the Columbia Basin. Two potential solutions to enhancing flow and temperature issues is to substitute surface water for irrigation with groundwater, and promote cooler groundwater return flows (from natural flows and irrigation returns) to lower the summer streamflow temperature. Ferns et al. (2002) discusses geologic and general hydrogeologic conditions throughout the upper Grande Ronde Valley and much of the following descriptions are garnered from that report.

1.1 Geologic Setting

The Grande Ronde Valley is a broad, flat alluvial plain surrounded by bedrock highlands. The valley is ringed by young faults that have resulted in the valley being lowered relative to the highlands by almost 3,000 feet on the west and 2,400 feet on the east. Downfaulting of the valley has resulted in a structural trap that is being filled by the deposition of alluvial sediments. Large alluvial fan-deltas form gently sloping surfaces where the Grande Ronde River, Catherine Creek, Mill Creek, and Ladd Creek enter the valley. The shape and gradient of these streams change at the fan-delta - alluvial plain interface; shifting from a braided morphology on the fan to a meandering morphology on the plain. As a result, there is a decrease in channel deposit grain size from gravel and sand to clay and silt and a broader distribution of the alluvial channel deposits into the meander zone (Figure 1).

The alluvial deposits vary in gradation, composition, and permeability; depending on their location within the valley and the energy under which they were deposited (e.g., higher energy stream deposit on the fan-delta or lower energy channel deposit on the alluvial plain). Alluvium, composed of moderately to well-sorted gravel, sand, and silt, is found in the active stream channels and on adjoining floodplains of the Grande Ronde River, Mill Creek, Catherine Creek, and Ladd Creek. The alluvial deposits are constantly reworked by the river, and are probably 15 to 30 feet thick (Ferns et al. 2002). They interfinger with fan-delta deposits and are hydraulically connected to older, deeper abandoned channels (Figure 1).

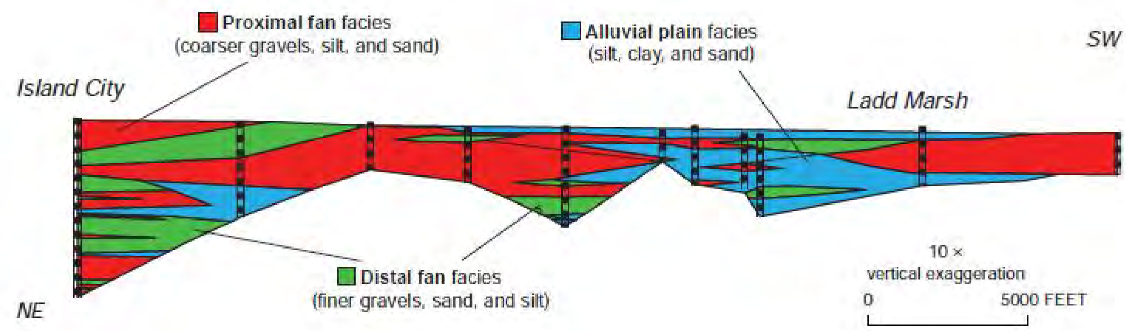

Figure 1. Interpretive cross section in the Grande Ronde Valley (Ferns et al. 2010).

1.2 Groundwater

Groundwater bearing stratum in the Grande Ronde Valley can be separated into three general hydrogeologic zones; the near surface groundwater zone within the current Catherine Creek alluvial plain (+ 50 feet depth); the shallow aquifer within the fan-delta and alluvial plain sediments (+ 700 feet depth); and the deep (volcanic) bedrock aquifer (+ 3,000 feet depth). The geologic units that make the best aquifers in the Grande Ronde Valley occur at two levels, the shallow fan-delta sediments that underlie the Grande Ronde and Catherine Creek fan deltas, and the deep volcanic bedrock (Figure 2). The shallow fan-delta and bedrock aquifers are utilized for water supply wells (irrigation and municipal) in the area; the near-surface groundwater zone is utilized primarily for residential wells.

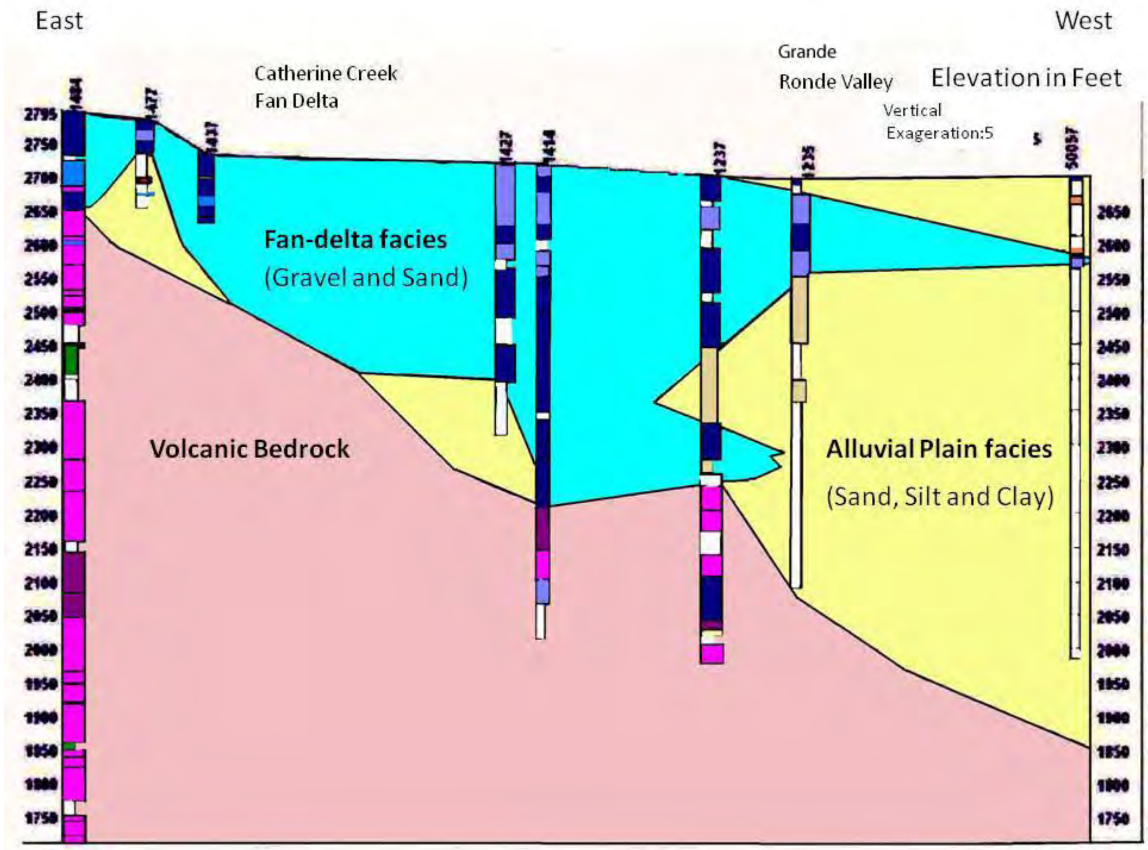

Figure 2. Profile from east to west across the Catherine Creek fan delta (Ferns et al. 2010).

Near-surface Groundwater

The interaction of groundwater with surface water along Catherine Creek, and its tributaries, generally occurs within the upper 50 feet of the ground surface. The fine-grained clay and silt deposits in the alluvial plain have very low permeability and capacity for storing groundwater (Ferns et al. 2002), and are poorly connected to the active river channels. Wells produce moderate amounts of water from gravel and sand lenses at shallow depths within the fine-grained alluvial plain sediments, but the water bearing lenses are generally random and unpredictable making the unit variable as a potential aquifer (Ferns et al. 2002).

For a detailed discussion of the interaction between Catherine Creek streamflows and the near surface groundwater using forward looking infrared data (FLIR) and thermal profile information, refer to the “Groundwater – Surface Water Interaction” and “Thermal Profile of Catherine Creek” sections of this report.

Shallow Aquifer

The depositional history of the Grande Ronde Valley during the Pleistocene and Quaternary that formed the fan delta sediments was dominated by three episodes of alpine glaciation in the adjacent Elkhorn and Wallowa Mountains (Ferns et al. 2002). Both the Grande Ronde River and Catherine Creek carried glacial outwash material into the valley, producing terrace and fan deposits as braided streams flowed across the valley (Ferns et al. 2002). The most productive shallow cold-water wells are those that intersect the well-sorted gravel and sand deposits that extend beneath the Grande Ronde and Catherine Creek fan deltas (Figure 2).

The Grande Ronde River fan-delta enters the valley from the west at La Grande and includes gravel, sand, and silt deposits that grade laterally into silty sand and silt alluvial plain deposits in the basin. Grande Ronde fan-delta gravel deposits are relatively free of clay (Ferns et al. 2002). Fan-delta gravel is as much as 540 feet thick and has been the most important shallow aquifer in the Grande Ronde Valley.

The Catherine Creek/Little Creek fan-delta enters the south end of the valley and merges with the alluvial plain to the north. The fan-delta deposits appear to contain a relatively higher proportion of clay and silt than the Grande Ronde fan-delta, which may have resulted from the introduction of glacial flour during glaciation of the upper drainage basin (Ferns et al. 2002). Catherine Creek fan-delta gravel has a maximum thickness of 500 feet (Ferns et al. 2002). At Union, the unit is at least 290 feet thick and has historically been an important source of groundwater for the city. For much of its extent, the Catherine Creek fan-delta appears to lie directly on bedrock, unlike the Grande Ronde fan-delta, which overlies older alluvial plain deposits.

Mill Creek fan likely has relatively low permeability (Ferns et al. 2002). The proximal end of the fan at Cove appears to contain interbedded clays and poorly sorted clayey gravels with limited permeability. The existence of localized low permeability deposits in the subsurface may influence groundwater flow direction and gradients.

Ferns et al. (2002) describes the location and connectivity of permeable, water-bearing gravel channels within the fan-deltas as random and unpredictable. The abandoned, alluvial filled channels are thought to provide preferential groundwater flow back to the active channels providing groundwater discharge that may influence surface water temperatures. Geologic factors controlling the deposition of alluvial sediments, including rapid lateral and vertical facies changes, influence the distribution of permeable zones in the subsurface.

Deep Bedrock Aquifer

The Grande Ronde Member of the Columbia River Basalt Group is the most extensive aquifer in the valley; wells in the deep aquifer generally produces warmer water, and in places providing artesian flow of more than 2,000 gallons per minute (Ferns et al. 2002). In the southern Grande Ronde Valley and Lower Catherine Creek areas, the aquifer is tapped only by municipal wells at LaGrande and Union, the city of Imbler and about half-dozen irrigation wells produce from the Grande Ronde Basalt in the northern part of the valley (Ferns et al. 2002). Even though the deep volcanic aquifer has potential for high initial production rates, the low vertical permeability could potentially limit recharge (Ferns et al. 2002).

1.3 Historic Conditions

Ladd Marsh is the remnant of an extensive area of marsh and shallow lake deposits that covered more than 52 km^2 of the valley floor prior to construction of the State Ditch (Ferns et al. 2002). Historically, extensive ponding of surface water would have provided more opportunity for infiltration to shallow groundwater aquifers and maintenance of a higher water table that would slowly discharge back to the streams during low flow periods of late summer and fall. There are limited data available that describe annual and long-term water level fluctuations in the Grande Ronde Valley. Figure 3 shows long-term monitoring from 1936 to 1958 of an unconfined aquifer well (well 3/38 – 25B1) located on the La Grande alluvial fan. In addition to seasonal and annual fluctuations, the well also records a water table rise from 1939 into the 1940s, presumably from increased precipitation.

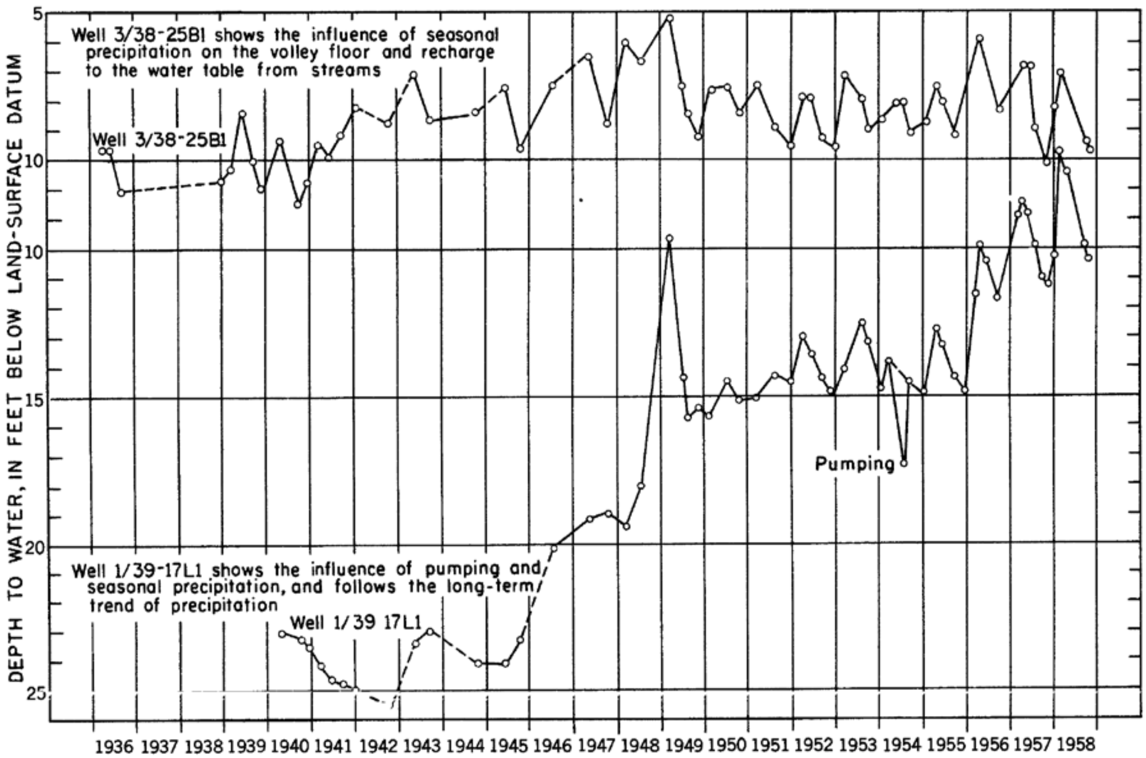

Figure 3. Hydrograph showing water levels in well 3/38-25B1 near the La Grand airport and well 1/39 – 17L1 about 1 mile north of Imbler (Hampton and Brown 1964).

Since the Hampton and Brown study, many groundwater wells have been installed for irrigation supply. Most of the larger producing wells in the valley are completed in the deep, basalt aquifers and their impact on shallow water tables and streamflow is unknown. Figure 4 shows groundwater wells that have water right certificates/permits within close proximity to Catherine Creek; they are mapped by ¼, ¼ section. Total water usage, pumping amounts, and water levels are not known. Most of these wells supply water to fields that are also near Catherine Creek and an unknown quantity of the pumped water probably becomes return flow. Seepage investigations that measure streamflow of designated reaches, along with all known diversions, are necessary to determine losing and gaining reaches of Catherine Creek.

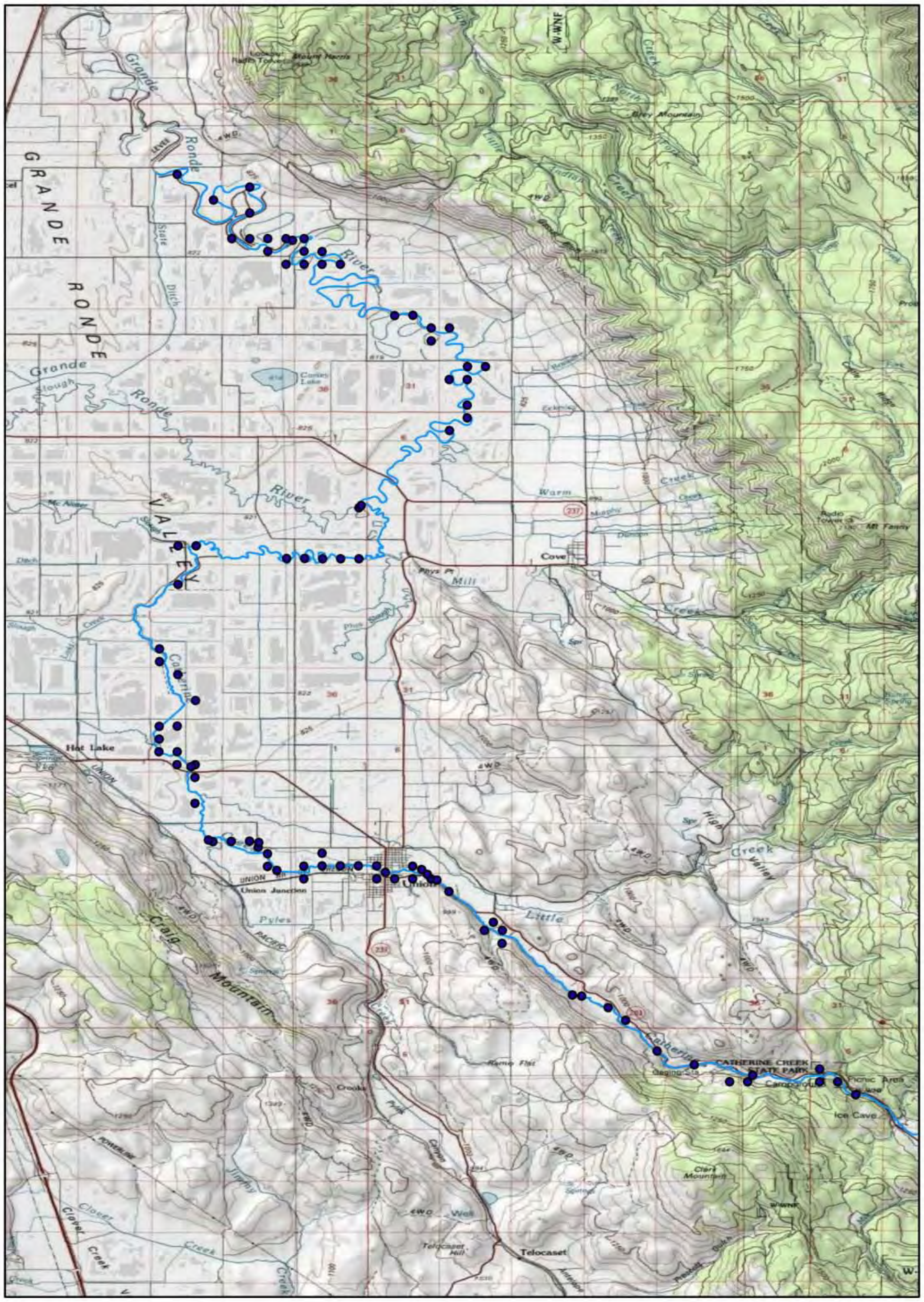

Figure 4. Location of groundwater irrigation wells within ¼ mile of Catherine Creek.

1.3.1 Groundwater – Surface Water Interaction

Various methods are available to measure and quantify the interaction between streamflows and the surrounding aquifer. Measuring the gains and losses of streamflow along stream reaches (called seepage investigations) provides a synoptic view of areas where groundwater is contributing flow or where there are surface water losses to the aquifer. Water chemistry parameters can sometimes be used to indicate the contribution of groundwater to the stream. 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 FLIR (Watershed Sciences 2000), by ground-based infrared thermography (Schuetz and Weiler 2011), and by conducting a thermal profile with a temperature logger (Vaccaro and Maloy 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 FLIR survey was conducted in August 1999, and covered the entire Grande Ronde River basin (Watershed Sciences 2000). A repeat FLIR survey was conducted over portions of the basin during winter 2011. The FLIR survey has the advantage of covering an entire stream basin in a relatively short period. 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.

Watershed Sciences (2000) describes Catherine Creek as thermally stratified from the mouth (at the confluence with the Grande Ronde River at State Ditch) upstream to Davis Dam. This was interpreted by the mixing seen at the stream bends and the magnitude of thermal differences in the surface patterns (Watershed Sciences 2000). Thermal stratification would prevent the FLIR from identifying areas of groundwater discharge that occur near the bottom of the streambed.

1.3.2 Thermal Profile of Catherine Creek

Method

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 Catherine Creek during July 2010 to define the spatial variation of temperature due to groundwater contributions. A reduced area was also profiled during March 2011. A total of 42.1 miles of Catherine Creek were profiled. The U.S. Geological Survey (USGS) developed the method used at Catherine Creek in 2001 in the Yakima River Basin, Washington. The method was shown to document the longitudinal distribution of a river's temperature regime and areas of groundwater discharge (Vaccaro and Maloy 2006).

The thermal profiling method consists of towing a temperature probe from a watercraft (e.g., inflatable kayak or small motorized boat) 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 (Vaccaro 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.

Equipment and Conditions

Onset StowAway® TidbiT™ temperature loggers were deployed at fixed locations along Catherine Creek to record water temperature through time during the thermal profile. The reported accuracy of the Onset StowAway is +/- 0.2ºC (Onset User's Manual). A comparison of air temperature at the Imbler Agrimet station with the Catherine Creek water temperature at Elmer Bridge shows virtually no lag time between the daily high air temperature and the maximum daily water temperature (Figure 5). The daily maximum water temperature generally occurred between noon and 1:00 PM. Although the air temperatures ranged from 90.7ºF to 42.1ºF during the period July 19 to 25, 2010, the water temperatures ranged from 76.9ºF to 69.5ºF, with an average of 72.4ºF.

Streamflows steadily decreased from 86 to 68 cfs during the summer thermal profile (Figure 5) (OWRD 2011).

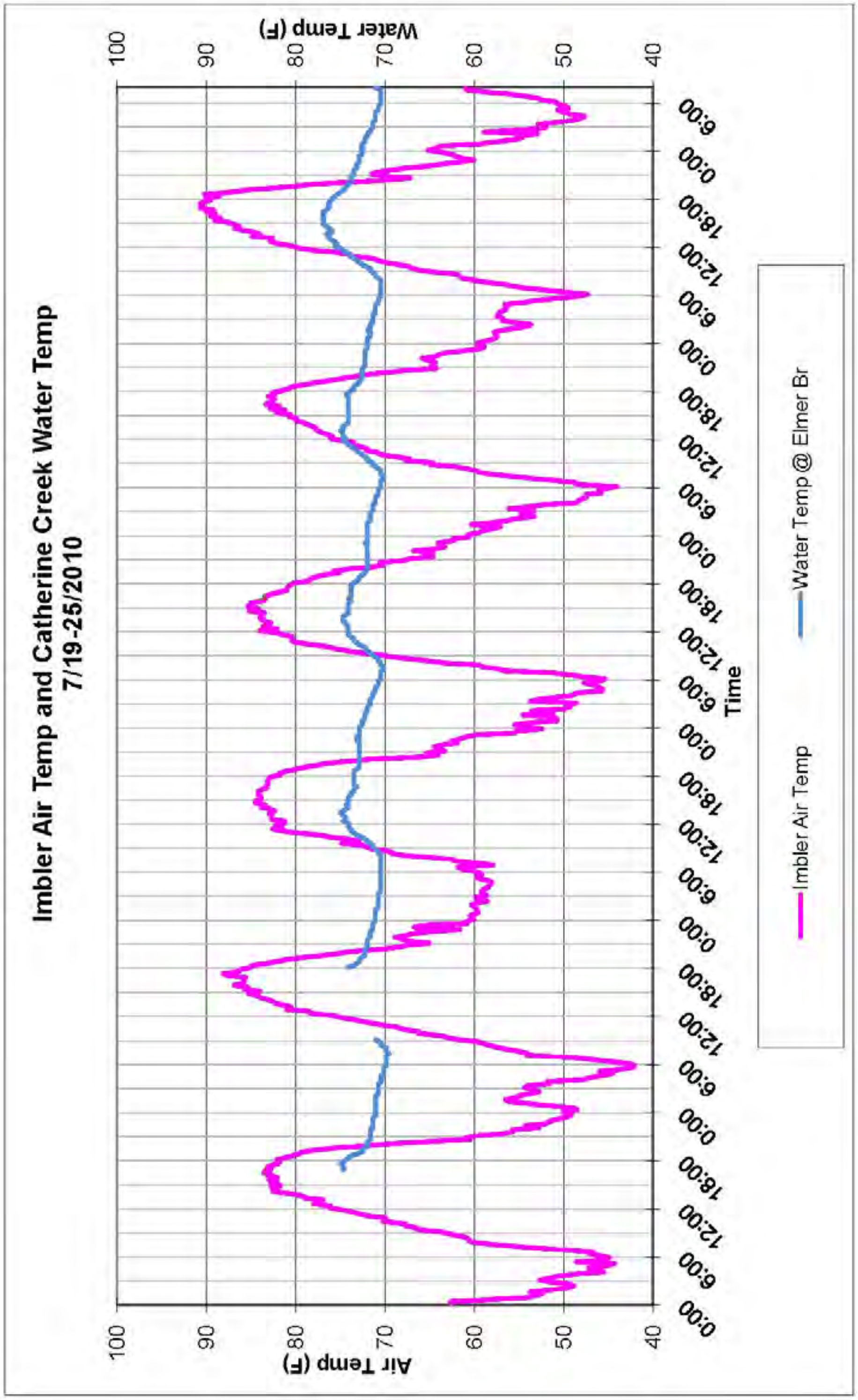

Figure 5. **Air temperature at Imbler; Catherine Creek water temperature at Elmer Bridge, July 19 to 25, 2010.**

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 0.1ºC 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 7). 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 3 seconds. At the end of each day's profile, the data files were processed and combined in an Excel spreadsheet. The data file was then converted to an ArcGIS point coverage.

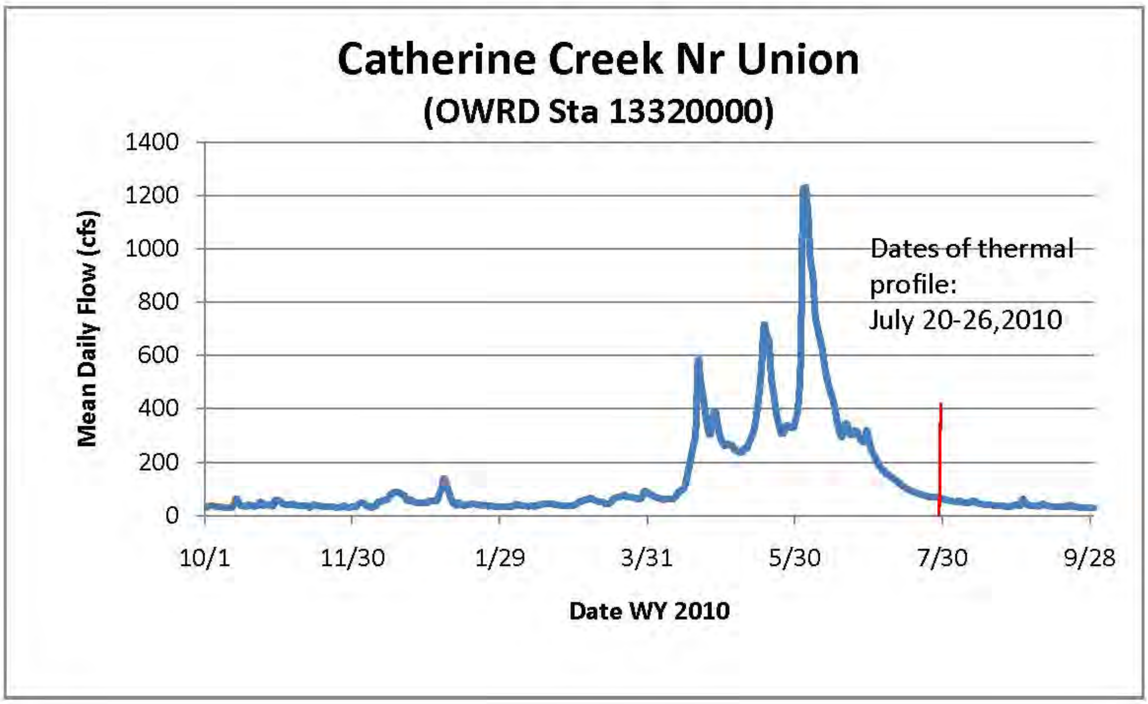

Figure 6. Mean daily flow, Catherine Creek near Union, OWRD Sta. 13320000.

Figure 7. Equipment used during thermal profiling.

The difference in temperature from one measurement point to another was generally very small (less than 0.01ºC) 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 0.002ºC. The temperature differences less than 0.002ºC was not used in order to eliminate “probe noise.”

Most of the profile was conducted from a two-person inflatable kayak. The lowest reach (RM 1.5 to 6.5) and the March 2011 profiles were completed from a motorized john boat. The upper reaches (above the town of Union) were completed by wading, due to obstacles in the river and velocities that jeopardized control of the boat while towing the probe.

1.3.3 Results

Surface-aquifer exchanges vary temporally and by physical setting. Thermal profiling of Catherine Creek shows that water returns from sloughs and old oxbow lakes may provide preferential return flow back to the stream during the summer. These are areas where coarser sediments may be found within the generally finer grained floodplain. Studies in the Yakima Basin, Washington, showed similar results (Vacarro 2011) with the conclusion that wetting-up side channels and sloughs was more important than bank storage in supplying cool water to the shallow groundwater system. Some of the temperature graphs show areas where the temperatures stabilize or deviate from the expected thermal response of streamflow during the diurnal heating period. These are indicative of localized discharge (springs, surface-water inflows, and/or alluvial aquifer discharge from re-connecting channels). They represent "patches" and may be preferred areas of thermal refuge for salmonids.

The geometry of the stream channel and point source water returns may also affect the thermal response recorded during the thermal profiling. The information from the profiles should be considered one source of data and used in conjunction with other information, such as seepage investigations, measured hydraulic gradients and groundwater level information.

Reach 1 – RM 0.0 to 22.5

Reach 1 was profiled over the following days:

River Mile	Date Profiled	Figure # of Temperature vs Time graph
RM 1.5 – 6.5	July 21, 2010	Fig. 7
RM 6.5 - 13.0	July 20, 2010	Fig. 8
RM 13.2 - 20.5	March 10, 2011	Fig. 9
RM 21.4 - 22.5	July 23, 2010	(included in Fig. 12)
RM 18.8 - 21.2 and 22.3 – 22.5	March 11, 2011	Fig. 10

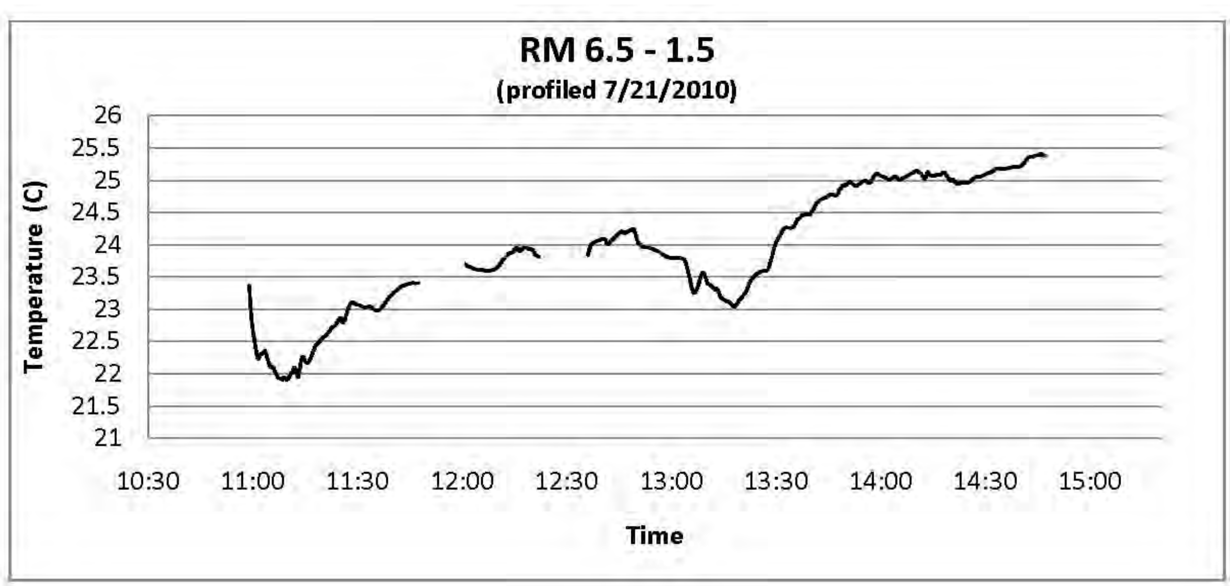

Figure 8. Temperature vs. time. Reach from Market Lane to RM 1.5.

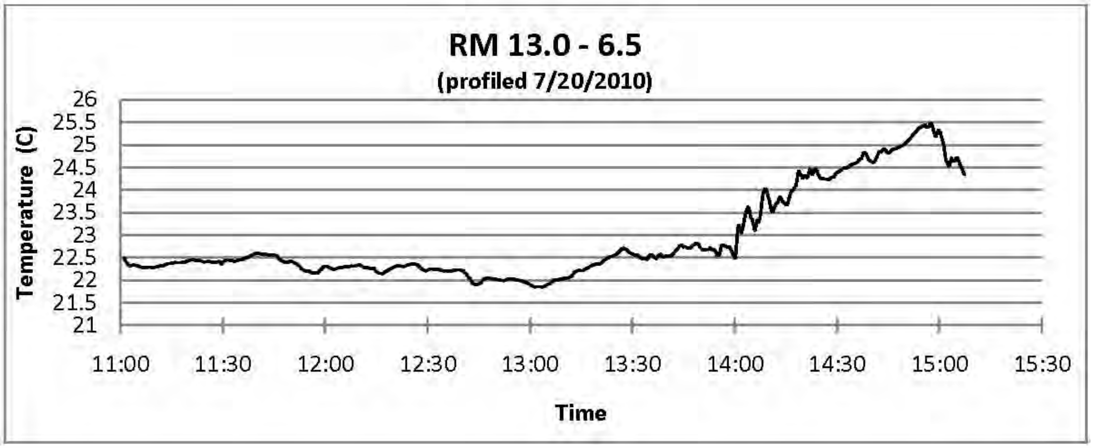

Figure 9. **Temperature vs. time. Reach from Elmer Dam to Market Lane.**

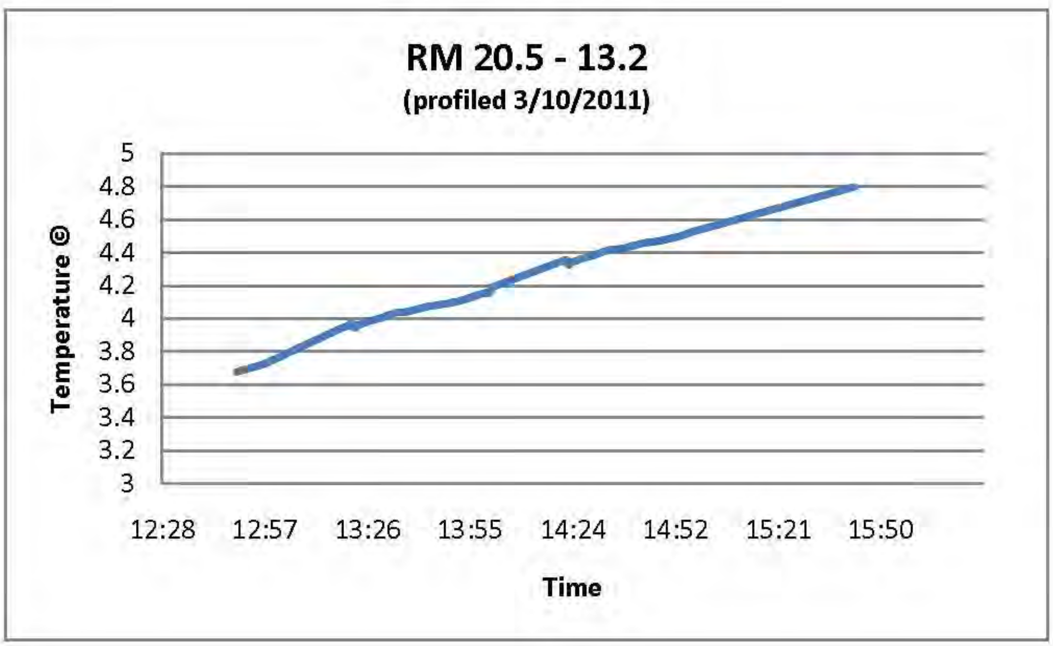

Figure 10. **Temperature vs. time. Reach from RM 20.5 to Elmer Dam.**

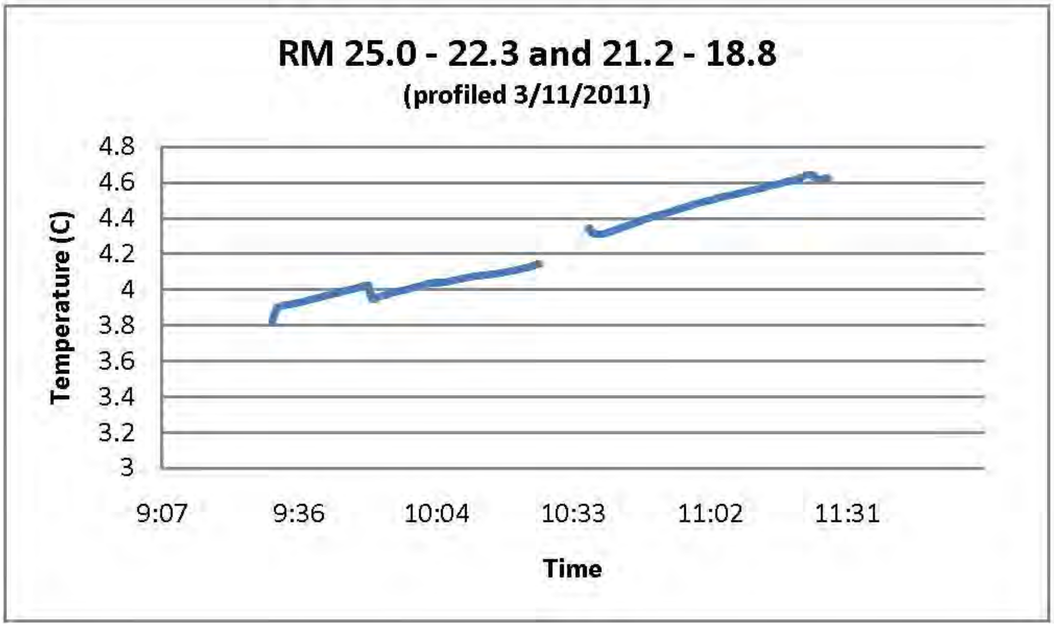

Figure 11. Temperature vs. time. Reach from RM 25.0 to 22.3 and 21.2 to 18.8.

Figure 12 shows locations where patches of cooler temperatures were detected. The areas are generally at the downstream end of bends of the river and at the downstream entrance of old oxbow channels. Although these temperature variations may indicate groundwater discharge, the stream geometry and/or mixing due to the river bend may also influence temperatures. The old oxbow channels are likely coarser grained alluvial materials than the surrounding floodplain sediments and may provide preferential flow to the active channel. A portion of reach 1 that was not profiled during the summer due to the backwater of Elmer Dam was profiled during March 2011. This area includes three large disconnected oxbow lakes adjacent to the stream from RM 13.1 to 14.1 yet no temperature changes were discerned during the March profile. This may indicate a seasonal component to the discharge or may be related to the very cool and decreasing temperature conditions that occurred during the March profile. In addition, no temperature variation was detected at the confluence with Warm Creek (RM 19) during the March 2011 profile.

River Mile	Approximate Temperature Change Detected (^oC)
1.6 – 1.8	0.15
3.3 – 3.5	0.8
6.5 – 6.7	0.8
7.6 – 7.7	0.2
9.0 – 9.1	0.4

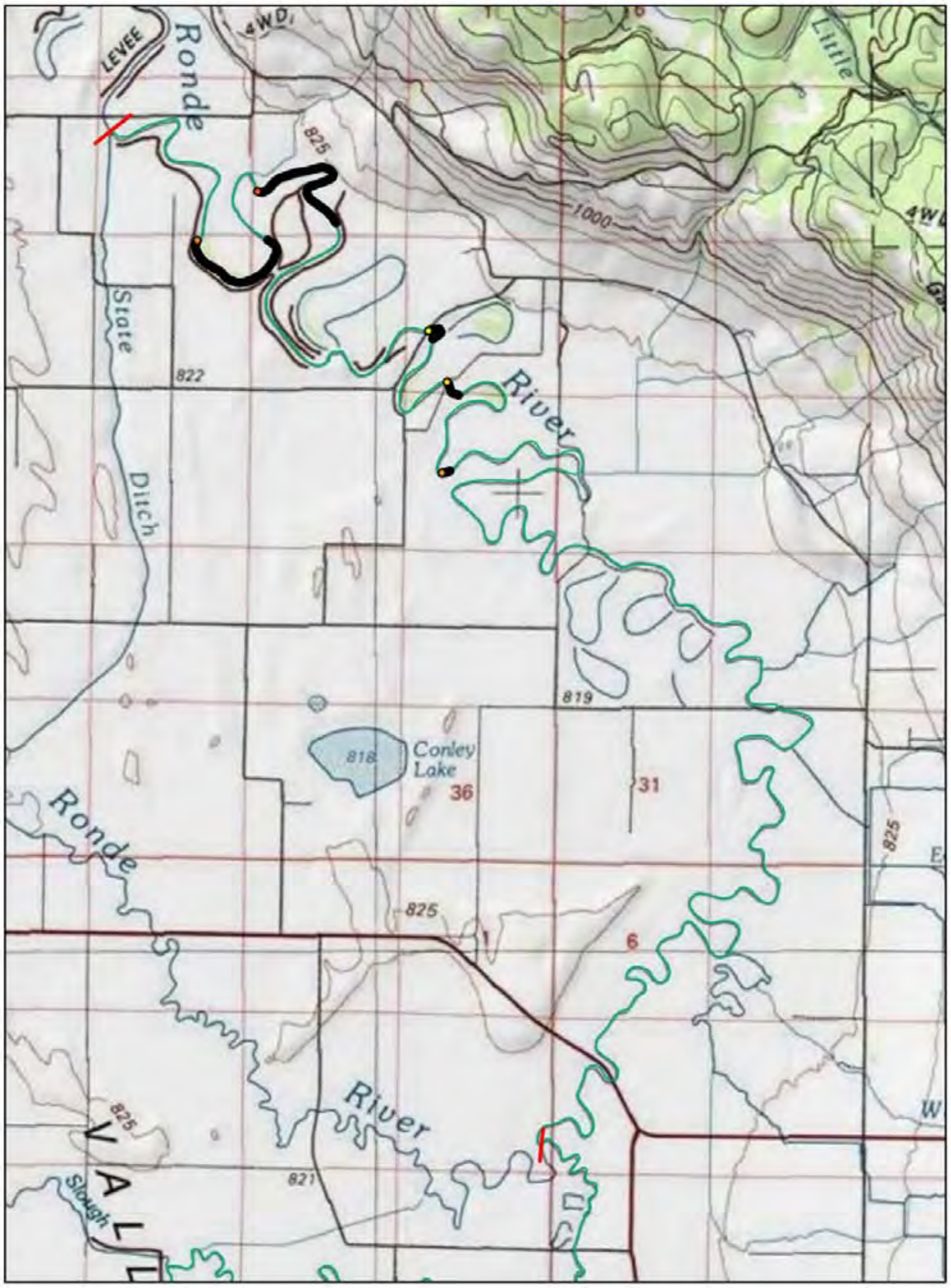

Figure 12. Reach 1 (RM 0.0 to 22.5). Location in reach 1 where cooler temperatures were detected during thermal profile.

Reach 2 – RM 22.5 to 37.2

Reach 2 was profiled over the following days:

River Mile	Date Profiled	Figure # of Temperature vs Time graph
RM 22.5 - 26.9	July 23, 2010	Fig. 12
RM 22.5 – 25.0 re-profiled	March 11, 2011	See Fig. 10
RM 26.9 – 33.9	July 22, 2010	Fig. 13
RM 36.6 – 37.2	July 23, 2010	Fig. 14

RM 33.9 to 36.6 includes the backwater behind the Davis Dams and was not profiled.

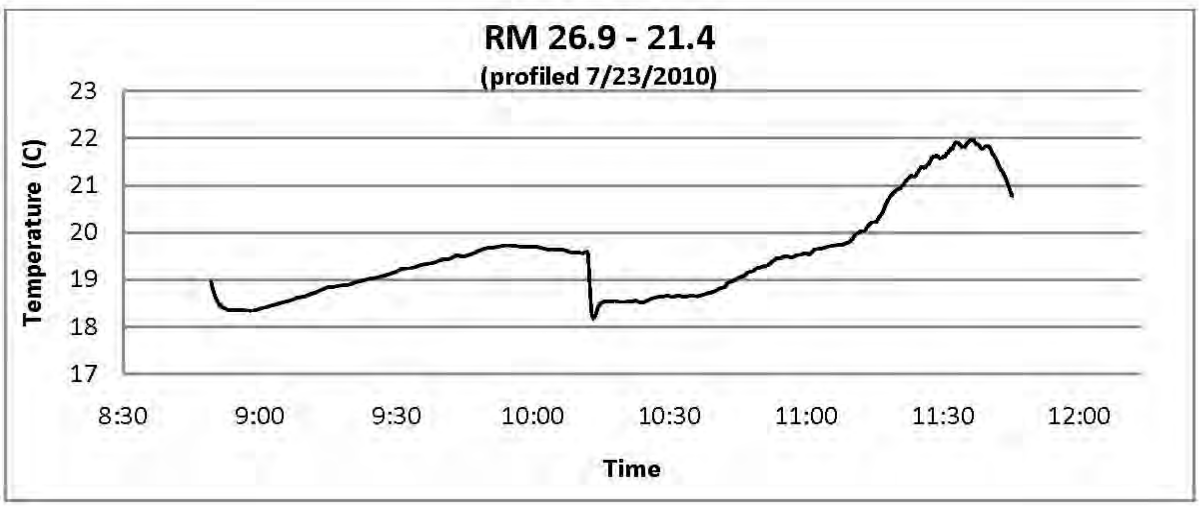

Figure 13. **Temperature vs. time. Reach from Godley Lane to Highway 237 Bridge.**

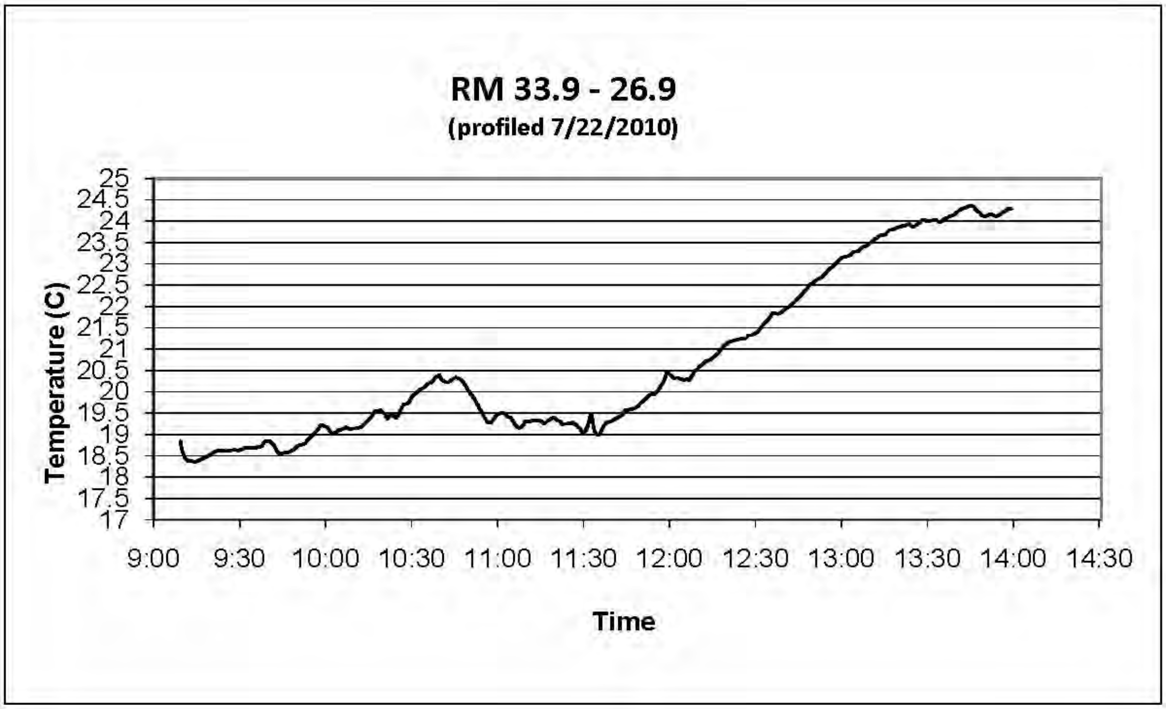

Figure 14. **Temperature vs. time. Reach from Woodruff Road to Godley Lane.**

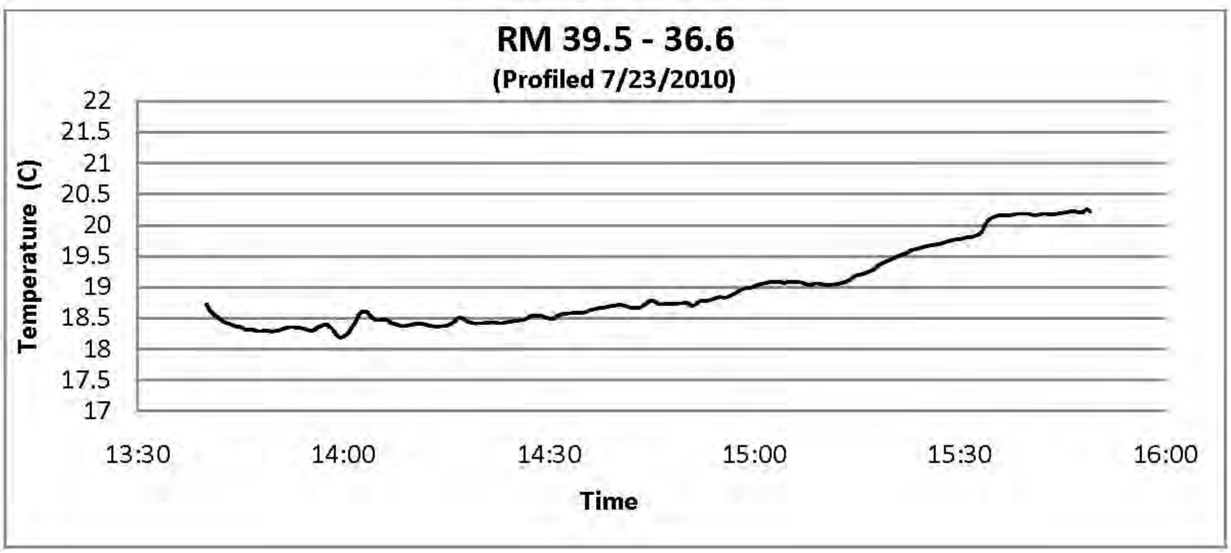

Figure 15. **Temperature vs. time. Reach from Union to Miller Lane.**

Figure 16 shows locations in reach 2 where patches of cooler temperatures were detected. The area at RM 24.1 (near the confluence with Mill Creek) also indicated cooler than ambient temperatures during the re-profile of this reach in March 2011.

River Mile	Approximate Temperature Change Detected (degree C)
24.0 – 24.3	0.35 (confluence w/ Mill Creek)
26.9 – 27.0	0.08
31.3 – 31.4	0.13 (confluence w/ Ladd Creek)

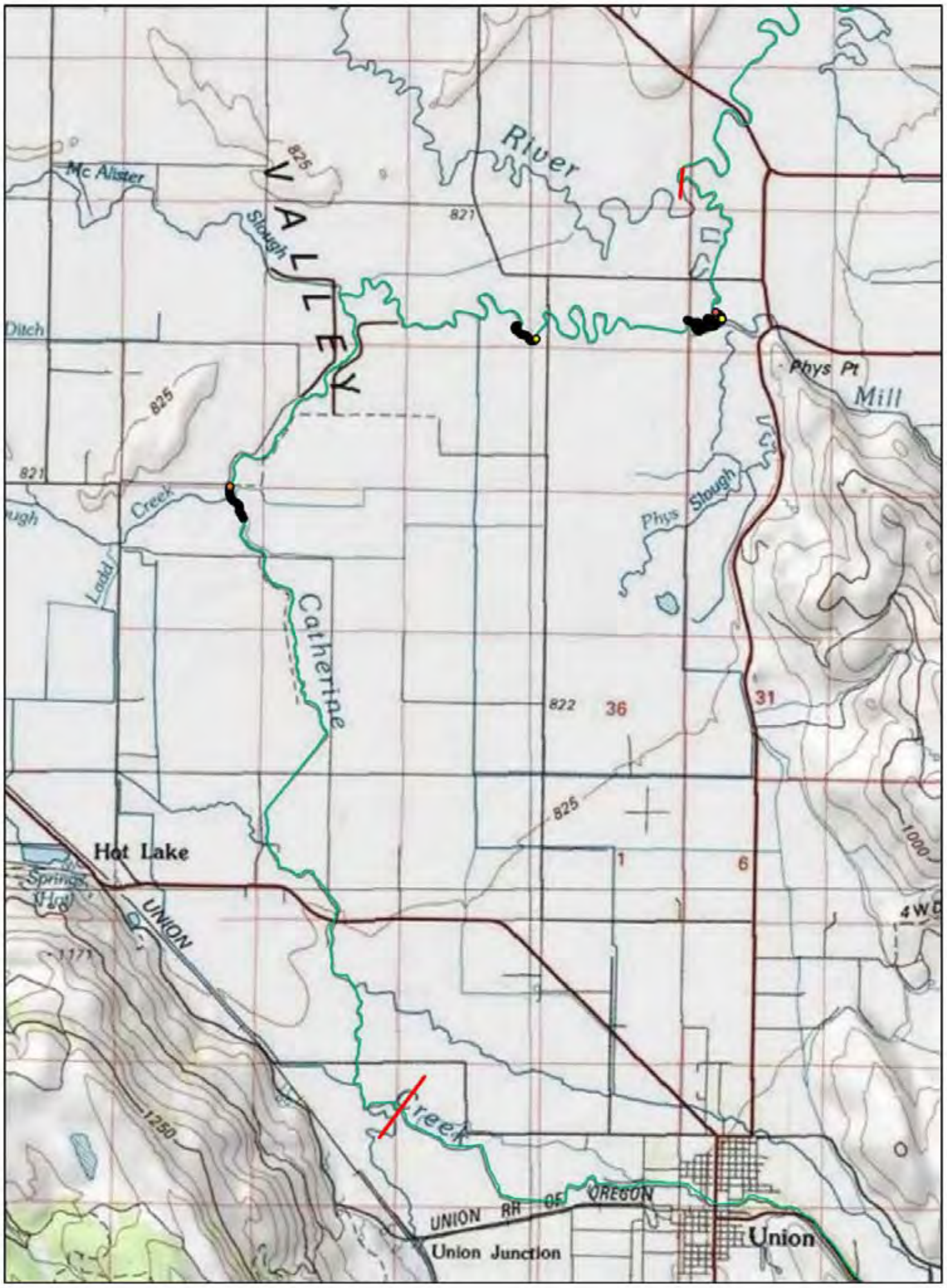

Figure 16. Reach 2 (RM 22.5 to 37.2). Locations in reach 2 where cooler temperatures were detected during thermal profile.

Two of the areas where cooler temperatures were detected are associated with surface water inflows into Catherine Creek. The area at RM 27 appears to be associated with old drainage channels that are shown as surface depressions on the 24:000 scale topographic map near Godley Lane.

Reach 3 – RM 37.2 to 40.8

Reach 3 was profiled over the following days:

River Mile	Date Profiled	Figure # of Temperature vs Time graph
RM 37.2 – 39.5	July 23, 2010	Included in Fig. 14
RM 40.7 – 40.8	July 26, 2010	See Fig. 17

RM 39.5 to 40.7 includes the town of Union and was not profiled.

River Mile	Approximate Temperature Change Detected (degree C)
37.5 – 37.6	0.05
39.2 – 39.3	0.14

Figure 17 shows locations in reach 3 where patches of cooler temperatures were detected.

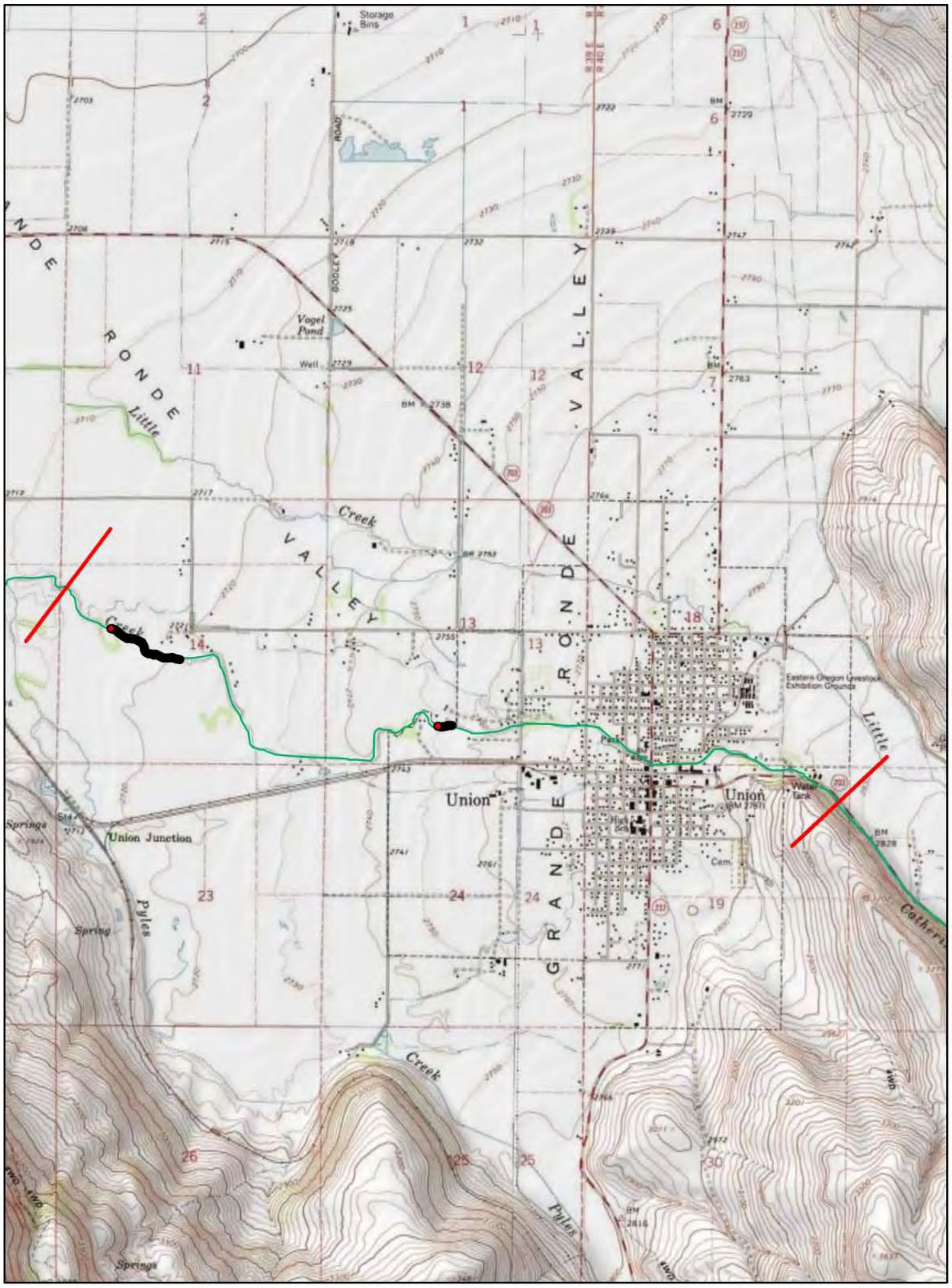

Figure 17. **Reach 3 (RM 37.2 to 40.8). Locations in reach 3 where cooler temperatures were detected during thermal profile.**

Reach 4 – RM 40.8 to 45.8

Reach 4 was profiled over the following days:

River Mile	Date Profiled	Figure # of Temperature vs Time graph
RM 40.8 – 42.4	July 26, 2010	Fig. 17
RM 45.0 - 45.8	July 25, 2010	See Fig. 19

RM 42.4 to 45.0 was not profiled due to accessibility, stream obstacles, and low flow conditions. Reach 4 was profiled by wading the stream and towing the probe. Only one area showed a cooler water trend and was of relatively low resolution. The temperature change may be due to an unknown point source or surface returns at this location.

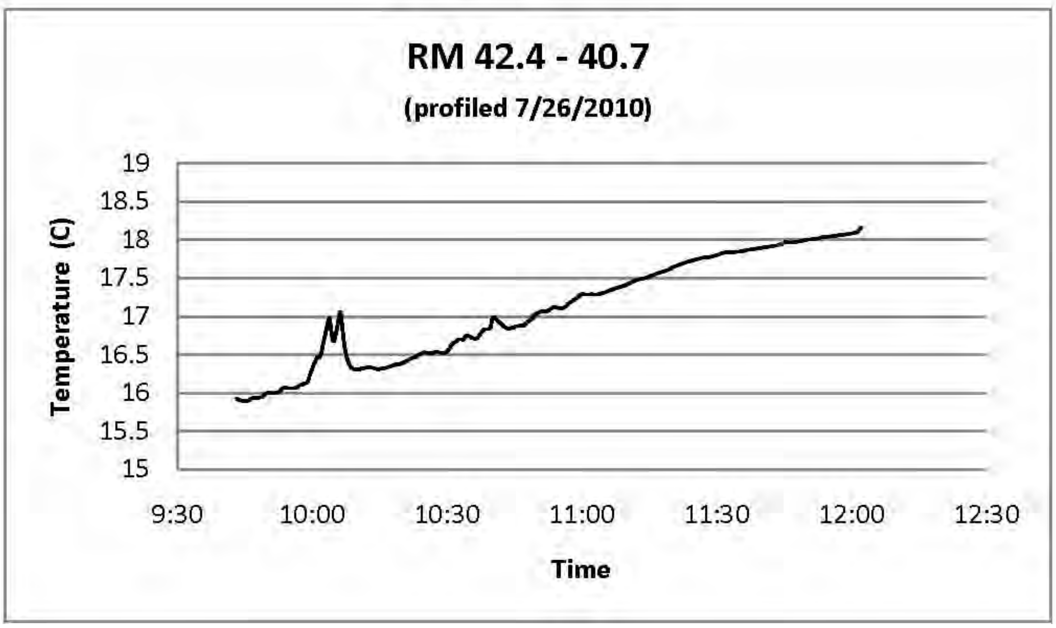

Figure 18. Temperature vs. time. Reach from Fish Trap to Union.

River Mile	Approximate Temperature Change Detected (degree C)
41.7 – 41.8	0.15

Figure 19 shows locations in reach 4 where patches of cooler temperatures were detected.

Figure 19. Reach 4 (RM 40.8 to 45.8). Locations in reach 4 where cooler temperatures were detected during thermal profile.

Reach 5, RM 45.8 to 50.1

RM 45.8 to 48.8 in reach 5 was profiled on July 25, 2010 (Figure 20). No areas were detected with cooler temperature patterns in reach 5.

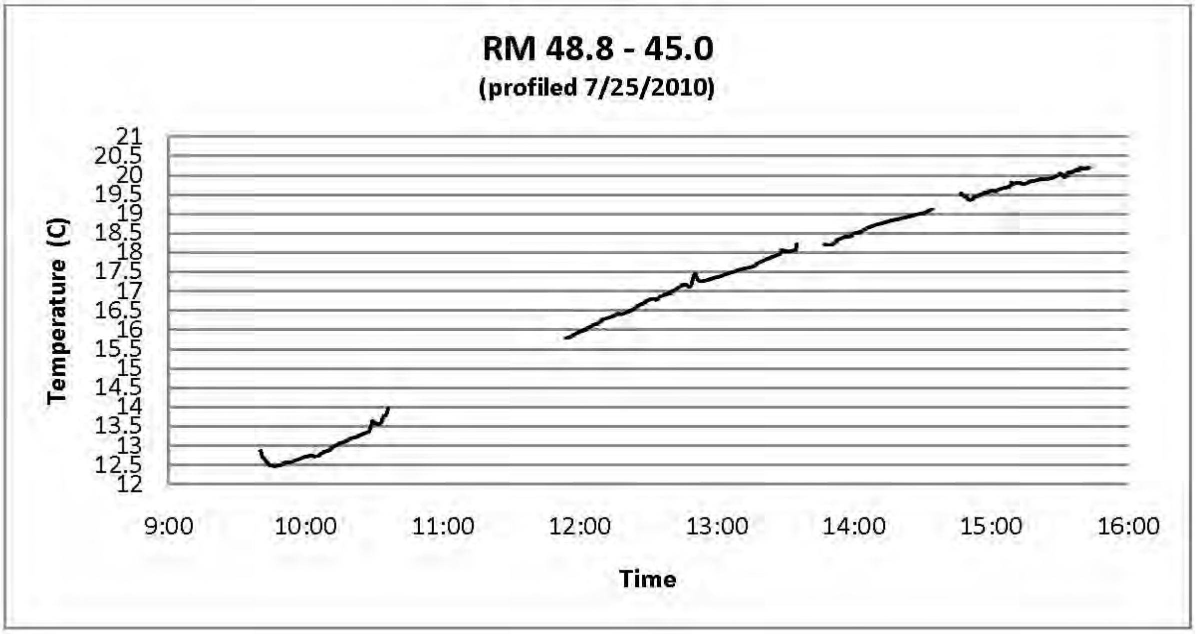

Figure 20. Temperature vs. time. Reach from Catherine Creek State Park to RM 45.0.

This area of the river is underlain by bedrock and landslide debris, the riverbed is composed of cobble, and boulder sized rocks. The boulders and shallow rocks prevented safe operation of the inflatable kayak with the probe in tow so the profile was completed by wading in the stream. The lack of any temperature trends may be due to the mixing of the water and movement of the probe within the stream but also may be the lack of groundwater discharge in this reach due to the shallow bedrock foundation.

Reaches 6 and 7 (RM 50.1 to 54.9) were not profiled.

2. Conclusions

Complex and highly variable characteristics represent the surface water - groundwater relationship; including geology, groundwater levels, temperature, surface water bodies and abandoned channels, alluvial aquifer flow, and irrigation. In a natural system, surface water flows during spring run-off would exceed the riverbanks 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 the Grande Ronde and Catherine Creek, the surface water has been channelized and levied to reduce flooding, ponding, and increase agricultural land and production. In addition, pumping wells have been constructed that lower groundwater levels and intercept water that, under natural conditions, would have discharged to the stream.

Thermal profiling of Catherine Creek shows that water returns from sloughs and old oxbow lakes may provide preferential flow back to the stream during the summer. Some of the temperature graphs show areas where the temperatures stabilize or deviate from the expected thermal response of streamflow during the diurnal heating period. These are indicative of localized discharge (springs, surface-water inflows, and/or alluvial aquifer discharge from reconnecting channels). These represent "patches" and may be preferred areas of thermal refuge for salmonids.

3. References

Parenthetical Reference	Bibliographic Citation
Ferns et al. 2002	Ferns, M.L., I.P. Madin, V.S. McConnell, and J.J. Johnson. 2002. Geology of the Surface and Subsurface of the Southern Grande Ronde Valley and Lower Catherine Creek Drainage. Oregon Department of Geology and Mineral Industries Open File Report O-02-02, 58 p.
Ferns et al. 2010	Ferns, M.L., V.S. McConnell, I.P. Madin, and J.J. Johnson. 2010. Geology of the Upper Grande Ronde River Basin, Union County, Oregon. Oregon Department of Geology and Mineral Industries Bulletin 107, scale 1:100,000, 65 p.
Hampton and Brown 1964	Hampton, E.R., and S.G. Brown. 1964. Geology and Ground-Water Resources of the Upper Grande Ronde River Basin, Union County, Oregon. Geological Survey Water-Supply Paper 1597, 99 p.
OWRD 2011	Oregon Water Resources Department. 2011. http://apps.wrd.state.or.us/apps/sw/hydro_report/default.aspx accessed September 30,2010.
Schuetz and Weiler 2011	Schuetz, T., and M. Weiler. 2011. Quantification of localized groundwater inflow into streams using ground-based infrared thermography. Geophysical Research Letters, Vol. 38, L03401,

Parenthetical Reference	Bibliographic Citation
	doi:10.1029/2010GL046198. 5 p.
Vaccaro and Maloy 2006	Vaccaro, J.J., and K.J. Maloy. 2006. A thermal profile method to identify potential ground-water discharge areas and preferred salmonid habitats for long river reaches. U.S. Geological Survey Scientific Investigations Report 2006-5136. 16 p.
Vaccaro 2011	Vaccaro, J.J., 2011, River-aquifer exchanges in the Yakima River Basin, Washington: U.S. Geological Survey Scientific Investigations Report 2011-5026, 98 p.
Watershed Sciences 2000	Watershed Sciences, LLC. 2000. Remote Sensing Survey of the Grande Ronde River Basin, Thermal Infrared and Color Videography. Prepared for the Oregon Department of Environmental Quality, Portland, Oregon. p. 24.