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TECHNICAL MEMORANDUM

TO:	Mike Kaputa and Mary Jo Sanborn, Chelan County WRIA 45 Planning Unit	**DATE:**	January 6, 2005
FR:	Tim White and Lisa Dally Wilson, Golder Associates Inc.	**OUR REF:**	043-1284.602
RE:	WRIA 45 Summary of Groundwater/Surface Water Interaction and Groundwater Resource References		

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1.0 INTRODUCTION

This Technical Memorandum summarizes the results of Task 602 (Compile Surface Water and Groundwater Interaction Information) and Task 603 (Summarize Information on Groundwater Resources and Availability) of the Scope of Work between Chelan County and Golder Associates (Golder) for watershed planning assistance. The memorandum is presented in two parts. A summary of information addressing the interaction of groundwater and surface water (Task 602) is presented in Section 3.0. Available information characterizing groundwater resources located within WRIA 45 (Task 603) is discussed in Section 4.0. Reference lists for the two tasks have been combined, as many references address both subjects. The reference list is presented in Appendix A, sorted by sub-watershed. The appendix serves as an abbreviated literature review of documents related to groundwater in WRIA 45.

2.0 BACKGROUND

The hydrogeology of WRIA 45 was summarized as a component of the Phase II Watershed Assessment for the Wenatchee River Basin (Montgomery Water Group, Inc. et. al, 2003). The Assessment characterized the nature of groundwater in the WRIA in general terms, including:

- groundwater occurrence in alluvial aquifers vs. bedrock;
- estimated relative hydraulic conductivity (on a WRIA-wide scale) and relative yields of the aquifers;
- common aquifer configurations (on a WRIA-wide scale) that produce recharge and discharge locations; and,
- descriptions of the terms “water present”, “water available” and “water available for further appropriation”, as they relate to watershed planning.

Much of the work included in the Watershed Assessment and other reports (e.g. WRIA 45 Instream Flow Study Final Physical Assessment - Cascadia, 2003; and Department of Ecology Wenatchee River TMDL Quality Assurance Plan - Ecology, 2003) reiterates information originally published in the Initial Watershed Assessment (Montgomery Water Group, Inc. 1995). This information has been useful in characterizing the general hydrogeology of WRIA 45 at a watershed scale; however, it does not represent specific information regarding location and quantity of available groundwater or the nature of groundwater-surface water interaction, in greater detail and at a more localized scale.

This memorandum provides a collection and summary of references pertaining to groundwater-surface water interaction and groundwater resource characterization in WRIA 45. The references contained in this memo were identified from a number of sources including:

- Washington State Department of Ecology Technical Files
- Existing reports related to WRIA 45
- Internet queries
- Unpublished data analyses

3.0 GROUNDWATER-SURFACE WATER INTERACTION

Groundwater-surface water interaction (also referred to as hydraulic continuity) is the degree to which groundwater is connected to a nearby surface water body, such as a river or lake. Surface water bodies may lose water to groundwater, or groundwater may discharge to surface water. Groundwater and surface water may be hydraulically connected in such a manner that no net gain or loss to surface water occurs. The area and length of time over which this "null balance" relationship occurs may vary seasonally and from year to year. Additionally, in some aquifer configurations, there may be very little connection between groundwater and surface water. Where present, the relationship between groundwater and surface water is seldom static. The gaining and losing relationship commonly changes both seasonally and spatially (i.e. along a river's channel) as groundwater and surface water levels fluctuate. Groundwater may also be connected to surface water as a result of irrigation. Irrigation systems may provide a significant portion of recharge to shallow groundwater. The recharge supplied by irrigation may be returned to streams as increased baseflow during the irrigation season.

3.1 Importance in Water Resources Planning

Understanding the interaction between groundwater and surface water is important to water resources planning for a number of reasons, including:

- maintaining instream flow/habitat
- determining impacts on drinking water quality
- providing irrigation supply

Pumping in a well can induce recharge from a surface water body (e.g. river or lake) to groundwater. As a well pumps, a cone of depression in the groundwater around the well extends laterally into the surrounding aquifer. During the early part of the pumping, the water level in the pumping well will drop. However, when the cone of depression intersects a surface water body (e.g. a river channel), a hydraulic gradient develops between the groundwater in the aquifer and the water in the river. If the streambed is hydraulically connected with the aquifer, river water will percolate through the streambed material under the influence of the hydraulic gradient. Therefore, the river recharges the aquifer at an increasing rate, as the cone of depression around the pumping well grows larger. When the rate of recharge to the aquifer equals the rate of discharge from the well, the cone of depression and the water level in the pumping well become stable. This condition is commonly reflected as a horizontal line on a plot of water level drawdown versus time. Groundwater may also be connected to surface water in the absence of pumping. For instance, reaches of streams may go dry seasonally as the result of declining groundwater levels.

3.1.1 Regulatory Issues

Groundwater Under the Influence of Surface Water (GUI)

Public drinking water wells that are in hydraulic connection with surface water bodies in Washington State are increasingly being regulated by the Washington State Department of Health (WDOH). WDOH considers these wells as GUI (groundwater under the direct influence of surface water) and the Federal Surface Water Treatment Rule requires that all Group A public water systems determined to be GUI treat their water source. WDOH's GUI Program focuses specifically on drinking water sources that appear to be at risk of microbiological contamination associated with surface water. The program provides a means for identifying these types of sources (referred to as "potential GUI sources"), characterizing the degree of risk for microbiological contamination (through specific data collection requirements and methodologies), interpreting the results of the characterization, and determining appropriate follow-up contaminant risk mitigation actions.

According to the WDOH database, there are 103 Group A systems in WRIA 45 utilizing groundwater from 150 sources (e.g. wells, springs, infiltration galleries), and 225 Group B systems utilizing groundwater from 238 sources. Some of these systems and sources may be located in sub-watersheds which drain directly to the Columbia River. Because of the configuration of the major hydrogeologic units (i.e. unconsolidated sediments filling river valleys and fractured sedimentary bedrock underlying river valleys), groundwater in many areas WRIA 45 is potentially in hydraulic connection with surface water.

The City of Leavenworth is an example where several methods have been employed to determine if wells are GUI. Statistical analyses of water quality (Golder, 2003 unpublished) (see Appendix C), pumping tests analyses (Golder 1989 [various]), and creation of a groundwater model (Larson, 1991) were all employed to determine if the wells were GUI. As a result of these analyses and others, WDOH has determined that the water pumped from the Leavenworth wells is not subject to the influence from surface water and consequently requires treatment according to requirements for groundwater, not surface water (Riley, 2000).

Instream Flow

Maintaining adequate streamflow in the waterways of WRIA 45 has been identified as a critical need. Streams in the WRIA can face tremendous pressure, both natural (e.g. the flashy spring snowmelt and long, dry summers) and manmade (e.g. water demand for public water and irrigation supply). Instream flow requirements in WRIA 45 were established for the stream management units in WAC 173-545-030 on June 6, 1983. Streams in WRIA 45 currently affected by minimum instream flow requirements include: the Wenatchee River, Icicle and Mission Creeks. These minimum instream flows were codified by rule on June 6, 1983 and are senior to any water rights appropriated after that time. New minimum instream flows are currently being discussed.

Withdrawals in the WRIA that were permitted subsequent to the instream flow rule of 1983 are subject to interruption during periods where the minimum instream flows are not met. An example of this situation is the City of Leavenworth's wells. According to the Report of Examination (ROE) for the City's wells (water right application number G4-29958), the wells are allowed to operate continuously until flows in the Wenatchee River at Peshastin fall below levels specified in the ROE (Ecology, 1993). If/when the streamflow in the Wenatchee River at Peshastin drops below the specified level, no diversions from these wells are allowed to occur.

Stream closures in WRIA 45 were also established in WAC 173-545-040 on June 6, 1983. Currently, only one sub-watershed (Peshastin Creek – closed annually from June 15 to October 15) is affected by a formal closure. Any groundwater withdrawals with priority dates later than this date must not capture surface water from Peshastin Creek for consumptive use.

3.2 Summary of Existing Information Regarding Groundwater-Surface Water Interaction in WRIA 45

The nature of the connection between rivers and shallow sediments in WRIA 45 has been studied by several investigators, including: Washington State Department of Ecology (Ecology), the City of Leavenworth, the City of Cashmere and the U.S. Forest Service. There are few published studies that focus specifically on the relationship between surface water and groundwater in WRIA 45; information on the topic exists in several reports and technical memoranda and much of the data could be further analyzed to provide addition information. A compilation of references that include discussion of groundwater-surface water interaction in WRIA 45 is included in Appendix A. The list has been sorted by geographic area to allow for selection of material for a particular tributary. Hardcopies of most reports are available, but not all reports were obtained for review in this memorandum.

3.2.1 Ecology TMDL Preliminary Assessment of Groundwater-Surface Water Interaction

The groundwater-surface water interaction in WRIA 45 was studied as part of the Preliminary Assessment completed by Ecology in support of the Wenatchee River TMDL (Sinclair et al, 2003). Appendix B contains several graphs from the TMDL Preliminary Assessment that illustrate gaining and losing reaches. The study used two methods (channel hydraulic gradients and hyporheic temperature profiles) to identify gaining and losing reaches of several stream reaches in the WRIA. All data in the study was recorded in 2003, with the exception of the hydraulic gradient data for the (mainstem) Wenatchee River, which was recorded in 2002. Golder has performed some very preliminary assessment of the data presented in the study which is summarized visually in Figure 1. General trends in the data have been identified, and include:

- The (mainstem) Wenatchee River exhibits interspersed gaining and losing stream reaches throughout its length, but is primarily a gaining stream along much of its channel.
- Nason Creek is primarily a gaining stream in its upper one third of channel distance and primarily a losing stream in its lower reaches.
- Mission Creek is a stream with little net groundwater gain or loss, except for the lower two miles of channel, which are strongly losing.
- Some piezometers showed significant seasonal variability in hydraulic gradients, with a few sites transitioning between gaining and losing conditions and vice versa.
- Nason Creek showed considerable seasonal variation, with the overall net gaining/losing point of the stream shifting from river mile (RM) 9.5 in June to approximately RM 19 in September.
- Hyporheic temperature profiles indicate a possible shift from a gaining to losing stream at the end of the irrigation season in some tributaries (e.g. Brender and Mission Creeks).

The overall patterns of gaining reaches in the headwaters of streams and losing reaches in the lower sections of the small streams likely reflects the geology of the WRIA. As the streams flow toward the Wenatchee River, they leave the upland valleys (where bedrock exists beneath a thin cover of sediments) and flow onto thicker sequences of alluvial deposits and fractured bedrock. As the streams make the transition, water in the streams is able to infiltrate downward and be lost from the stream, particularly in the summer when groundwater levels are low. The resultant groundwater lost from tributary streams to the alluvial sediments may rejoin the stream further down-basin or discharge to the Wenatchee River along its channel, with only a small portion remaining as groundwater discharging to the Columbia River.

The TMDL Preliminary Assessment contains a great deal of information and should serve as a model for future investigations in the WRIA. The data from this study have the potential to be analyzed and plotted in a number of ways to provide further insight into the nature of groundwater and surface water interactions in WRIA 45. Figure 1 shows the data plotted on a base map of the WRIA to indicate the location of gaining and losing reaches. This map was created by Golder by “averaging” the data collected between July and September 2003 (Mission and Nason Creeks) as part of the TMDL Preliminary Assessment. Mapping and analysis of data available from studies and individual data collection events is outside of the scope of this work, however, it is strongly recommended that these data be further assessed. Seasonal variation was not considered in the development of Figure 1.

Additional data analysis including measuring and plotting the seasonal movement of the gaining and losing reaches on a geologic map may provide additional insights into the groundwater-surface water interactions in particular streams and the impacts of various land uses. Data collected for this study were graphed by Ecology and are presented in Appendix B.

Figure 1 also shows three locations (on Peshastin at RM 0.3, Brender at Hinman Road, and Mission Creeks at RM 7.6) where temperature profile data were used to estimate whether the river is gaining or losing at that point on the creek. Mission and Brender Creeks have temperature profiles which indicate that they are gaining streams between mid-July and mid to late September. The locations on both creeks show a transition from a gaining configuration to a losing configuration in late summer/early fall. The transition occurred in early-mid September 2003 for Mission Creek and late September 2003 for Brender Creek (see Appendix B). The reason for the change in the temperature profile is unclear. It may coincide with the end of the irrigation season, but the hydraulic gradient data does not change significantly over this time, as might be expected if irrigation return flows ceased to occur. Further analysis is needed to determine the exact cause of the shift, and potentially, to further understand the affects of irrigation on stream recharge.

3.2.2 <u>TIR Study</u>

In 2001, 2002, and 2003, Watershed Sciences LLC conducted an airborne thermal infrared (TIR) remote survey of selected reaches of streams in the Wenatchee Basin. The TIR surveys were conducted to support the ongoing Temperature and Dissolved Oxygen TMDL studies in the Wenatchee Watershed (Watershed Sciences LLC, 2002). TIR remote surveys are sometimes referred to as “FLIR” (forward-looking infrared radar) surveys.

The study consisted of using a helicopter equipped with TIR and visible-band cameras to fly longitudinally along the stream’s channels, collecting data on the radiant temperature of the water. Once analyzed, the TIR data allow subtle (0.5°C) temperature differences to be evident. Since groundwater is often cooler than surface water, stream segments with groundwater contribution will be evident because of their lower temperature. Meteorological data from two Washington State Department of Transportation weather stations were recorded to assist in the correction of the TIR data. Ecology also monitored stream temperatures at several locations in the basin to verify the accuracy of the remotely sensed data.

The Wenatchee River was first flown in August 2001 (Watershed Sciences, LLC., 2002). The 2001 data was on average 2.2°C higher than 2002 (between RM 48 to RM 31), and was over 5°C higher from RM 31 to RM 24 (Watershed Sciences, LLC. 2002). While the cause of this increase is not readily apparent from the TIR study, examination of river flows (particularly downstream from Tumwater Dam – RM 31) will likely assist in the understanding of the difference between the temperature downstream of RM 31. Also, the daily air temperature record for 2001 and 2002 should be examined to determine if 2001 was a warmer year.

The August 2002 data indicate that the temperature of water in the mainstem of the Wenatchee River increases from approximately 18°C in the headwaters (RM 53) to over 20°C near the mouth of the river, at its confluence with the Columbia River. Golder assessed decreases in stream temperature that were not associated with the location of a tributary/spring/side channel in the Wenatchee River. These decreases were evident between: RM 39 and RM 37.5, RM 27 and RM 24.5, RM 10 and RM 8, and RM 6 and RM 4.5 (distances approximate) and indicate that these reaches may be gaining groundwater. The 2002 data also indicate that the temperature of the water in Icicle Creek, increases from approximately 14.5°C in the headwaters (RM 18) to over 17°C near the mouth of the river, at its confluence with the Wenatchee River. Decreases in stream temperature (that were not associated with a tributary/spring/side channel) in Icicle Creek were evident at between: RM 11.3 and RM 10.8, and RM 3.2 and RM 2.7 (distances approximate). The published report contains graphs of stream temperature for the Wenatchee River and Icicle Creek where other decreases were also evident. Additional data analysis and mapping of the information published in this report would be helpful to further understand locations where the Icicle Creek and Wenatchee River are gaining groundwater.

In 2003 Mission, Peshastin, Chumstick, Nason, and Brender Creeks were surveyed with TIR (Watershed Sciences LLC, 2003). Decreasing stream temperature in the absence of tributaries or side channels was assessed by Golder and is summarized below:

- **Mission Creek** – visibility hampered by vegetation from RM 5 to mouth, but water temperature decreases were evident between: RM 8.5 and RM 8, RM 7.7 to RM 7, and various decreases from RM 7 and RM 6.
- **Peshastin Creek** – many of the water temperature decreases were the result of tributaries at RM 13.9, RM 11, and RM 9.1.
- **Chumstick Creek** – visibility hampered by vegetation, but temperature decreases were evident between: RM 8 and RM 5.7, RM 5 and RM 4.3, RM 2.6 and RM 1.6, and RM 1 and RM 0.6.
- **Nason Creek** – the most dramatic temperature decreases not associated with springs or tributaries were between: RM 23.2 and RM 22.7, and RM 3.5 and RM 2.
- **Brender Creek** – insufficient data to produce a longitudinal profile.

In summary, the TIR data provide a good indication of locations where groundwater may be discharging to surface water. Because of its remotely sensed nature, the TIR methodology enables collection of data over a large percentage of the major stream reaches in WRIA 45. The data can and should be used to focus on specific locations where groundwater discharge is indicated by temperature data. When coupled with measurements of river channel hydraulic gradient and verified with in-situ thermistors, the TIR data will likely provide a detailed analysis of groundwater/surface water interaction in the WRIA.

3.2.3 Leavenworth

The City of Leavenworth installed several production wells near the Wenatchee River in the late 1980's and early 1990's. The wells were constructed within approximately 100 feet of the river, so there was regulatory concern about the connection between the river and the wells from both an instream flow and water quality standpoint. The instream flow requirements for the Wenatchee were addressed by Ecology. Golder was contracted by the City to perform pumping tests on the City's wells and determine the impact, if any on the river. A two-day pumping test was conducted, during which the water level did not stabilize (Golder, 1989b, 1989c), indicating that two days of pumping had not induced surface water recharge to groundwater. Stabilization of the water level during the pumping test may have indicated hydraulic connection between the wells and the river as a result of leakage induced during pumping. In order to better understand the system, Ecology created a MODFLOW groundwater model (1991). As a result of the modeling effort and further data review, Ecology concluded that the wells were in hydraulic continuity with the Wenatchee River. As a result, the City's water right associated with the wells was conditioned on instream flow controls, and they were issued an interruptible water right for the wells based upon flows in the Wenatchee River at Peshastin (Ecology, 1993).

Because of the proximity of the wells to the river and their depth (< 200 feet) WDOH was concerned that the water from the wells was GUI. In order to make a determination, the City was required to perform microparticulate analysis (MPA) tests and submit major ion data. As a result of the water quality testing and data analysis, WDOH determined in 2000, that water from the Leavenworth wells was not GUI (Riley, 2000).

In addition, Golder performed a statistical analysis of temperature and conductivity measurements to determine whether the groundwater aquifer where the Leavenworth wells had been installed was potentially in hydraulic communication with surface water (Golder, 2003b - unpublished). The analysis involved assessment of the temperature and conductivity coupling of the well and river water, as well as the variance in groundwater temperature. A statistical analysis of short term temperature and conductivity changes observed in the surface and groundwater was performed to further assess the potential for GUI. This analysis also indicated that two of the Leavenworth wells were not GUI. An overview of this study is presented in Appendix C.

3.2.4 National Wetland Inventory

The presence of wetlands can be indicative of locations where groundwater is discharging to surface water. Examining the hydrogeology of these areas may provide information for identifying groundwater-surface water interactions and guide water resource management decisions. The U.S. Fish and Wildlife Service maintains the National Wetlands Inventory (NWI). NWI manages two websites that allows the general public to create custom maps of wetland areas. The website addresses are:

- National Wetlands Inventory Wetlands Mapper Website. http://wetlandsfws.er.usgs.gov/wtlnds/viewer.htm.

- National Wetlands Inventory, Wetlands Digital Data Download Page. http://wetlands.fws.gov/downloads.htm.

Figure 2 shows the location of wetlands in WRIA 45 according to NWI data. Most wetlands in WRIA 45 are primarily located along the White, Little Wenatchee, and Chiwawa Rivers, as well as Nason, Icicle, and Camas Creeks. Some wetlands are also located near Wenatchee and Fish Lakes. While these areas are important, they may not be as relevant to water resource management because they are located in less populated portions of the watershed.

The NWI data indicates the presence of some wetlands in the vicinity northwest and southeast of Leavenworth (near the confluence of the Wenatchee River and Icicle Creek). Also, some wetlands are indicated near the mainstem of the Wenatchee River east of Cashmere. While wetlands can provide insight into groundwater-surface water interaction, their extent and location should be verified before conducting a hydrogeologic investigation.

3.2.5 Other References

Ecology's Technical Files contain a thorough record of information for very specific areas of WRIA 45, including records of water right decrees, historical water level decline, alleged well interference, and documented water right disputes. While many of these water rights issues are out of the scope of this memorandum, interested parties are directed to examine these Ecology files for specific, historical information that might relate to groundwater-surface water interaction.

4.0 SUMMARY OF EXISTING INFORMATION REGARDING GROUNDWATER AVAILABILITY IN WRIA 45

Few reports focus specifically on the availability of groundwater in WRIA 45. No report currently provides an in-depth estimate or calculation of the amount of groundwater available in the WRIA or a sub-watershed of the WRIA. This is likely a consequence of the detailed aquifer analyses and mass balance calculations required to answer such questions. This memorandum identifies references currently available that may serve as a framework for such a study. Many of the reports are very old (> 20 years) and should serve mainly as a historical reference to document changes in conditions.

As a result of varied geology and geography (e.g. numerous canyons forming separate drainages, faults, and groundwater divides), there is no regional aquifer in WRIA 45 that is continuous over the entire watershed. Consequently, studies to determine the availability of groundwater in the WRIA should focus on specific locations.

4.1 Department of Ecology Mass Balance Calculations

Several cursory water balances were produced by Ecology over 20 years ago and were found in Ecology's technical files for WRIA 45. The results of these water balances are summarized below:

- **Chumstick Creek** (Barwin, 1983) – Precipitation less evapotranspiration is reported to range from 7.2 to 22 inches/year. Using several precipitation ranges, Barwin integrated these values over the sub-watershed (76 square miles) to calculate a total water "crop" (term not defined in memo) for the Chumstick basin equal to 50,080 acre-feet/year. The memo then compares this water to surface water allocation. There is no discussion of the streamflow in the memo.
- **Nahahum Canyon** (Barwin, date unknown) – Precipitation averages for Nahahum Canyon were reported to range from 15 to 17 inches/year. Integrated over the drainage area (12 square miles), the estimated precipitation is equal to between 9,600 and 10,880 acre-feet/year. Average annual yield (term not defined in memo) was calculated to be 960 acre-feet/year, or between 9% and 10% of the precipitation. The memo indicates that appropriation of up to 750 acre-feet should be possible during average precipitation years without seriously depleted aquifer storage. The memo recommends total annual allocations of 397 acre-feet for certificates and 88.5 acre-feet for permits.
- **Brisky and Brender Canyons** (Barwin, 1981) – Annual precipitation totals for Brisky and Brender Canyon were reported to range from 8 to 25 inches/year, with averages for the sub-drainages ranging from 10 to 15 inches/year. Integrated over the three sub-drainages, this is equal to 3,188 acre-feet/year. The available water in the Brender Creek drainage (including Brisky Canyon) is estimated to be 332 acre-feet/year, based on the assumption that 10% of the annual precipitation is available for use.

The memos should serve only as a historical reference and not as official Ecology policy.

4.2 Cashmere

Several reports have focused on the hydrogeology of the Cashmere area. Anderson and Bennett (1964) and Russell (1964) provide historical details about the City's water supply system, including hydrogeologic setting of the wells, estimated well yield and limited water quality information. The reports indicate that at the time (1960's), the main obstacle to water production was well efficiency, not aquifer supply. Water quality from the wells was reported as being good, with one instance of hydrogen sulfide (H_2S) being detected in one of the City's wells.

A report by Shannon and Wilson (1978) provides a hydrogeologic map of the area, limited historical water level data, analysis of pumping tests conducted on the City's wells, and water quality data for the wells. Among the data provided on the hydrogeologic map is depth to water in several wells and estimated elevation to the top of the bedrock. The report suggests that the most productive aquifer zones may be encountered west of Mission Creek, near its confluence with the Wenatchee River. The hydrogeologic map included in the report indicates that this area is likely has some of the thickest alluvial sediments in the Cashmere area.

4.3 Lake Wenatchee

Economic and Engineering Services, Inc. and Golder assessed the groundwater resources in the area of Lake Wenatchee for Chelan PUD (EES and Golder, 1998). A major goal of the study was to evaluate the principal aquifers in the vicinity of Lake Wenatchee and Fish Lake, with respect to occurrence and configuration, as well as vulnerability to contamination and protection needs. The report contains geologic cross-sections of the Lake Wenatchee area.

The investigation indicated that three aquifers were present:

- Sandstone and fractured shale units (bedrock)
  Localized productive zones in the Chumstick Formation and Nahahum Canyon Member. Wells typically have low yields and resulting low specific capacities.
- Localized sand and gravel in vicinity of Kahler Glen Golf Course (alluvial)
  Confined aquifer, located at a depth of approximately 90 feet below ground surface. Aquifer transmissivity is on the order of 1,700 $feet^2$/day. Thickness and extent of the aquifer is unknown, but wells completed in this unit are located approximately one mile south of the eastern end of Lake Wenatchee.
- Sand and gravel underlying the Wenatchee River Valley (alluvial)
  Located at a depth of 90 to 150 feet below ground surface. Estimated yields for wells completed in this unit range from 50 to 500 gpm. Thickness and extent of the aquifer is unknown.

The water quality in these three aquifers was reported to be excellent, with all analyzed constituents meeting the State drinking water standards.

4.4 Wenatchee River Near Leavenworth

City of Leavenworth currently withdraws a portion of their water supply from an aquifer system on the north side of the Wenatchee River (see map in Appendix C). This is another obvious source of groundwater supply in WRIA 45, however, the extent and productivity of the aquifer has not been fully investigated.

4.5 Chumstick Creek

Wildrick (1979) provides a compilation of well log data to develop a generalized hydrogeologic understanding of the Chumstick Creek drainage basin. The report contains well log information, hydrogeologic cross-sections, limited pumping test information, and estimates of hydraulic interference with Chumstick Creek. A supplemental memo (Myers, 1983) provides an estimate of hydraulic conductivity and well yields for the bedrock and alluvial aquifers.

The report indicates that most of the wells are shallow (< 150 feet) and are completed in the alluvial sediments. The hydrogeologic cross-sections indicate that groundwater in the alluvial aquifer likely discharges to Chumstick Creek.

4.6 Icicle Creek

Rieman (1991) examined water levels and allocated water rights in the Icicle Creek sub-watershed in an attempt to estimate the availability of water. The water level analysis indicates that from 1974 to 1991, static groundwater levels in several wells in the Icicle Valley dropped between 10 and 12 feet. No precipitation data were presented in the report to determine climatic effects, if any. Rieman also shows that between 1984 and 1989, the number of wells drilled in the Leavenworth area increased nearly every year. Rieman's report is a cursory investigation to assess whether the Icicle Creek sub-watershed is overallocated with respect to water rights. While the report contains some historical data of potential importance, a more rigorous review of the data contained in this report (as well as current data) is recommended.

4.7 Brisky Creek Water Balance

Wooldridge (1987) uses unpublished data from Mission Creek to construct a water balance in Brisky Creek. The water balance presented in the memo is summarized below:

- Precipitation = 25 to 30 inches in the headwaters of Mission Creek (23 inches at 4,000 feet elevation)
- Runoff = 5 to 15 inches (5 inches at 4,000 feet elevation)
- Actual evapotranspiration = 15 to 18 (18 inches at 4,000 feet elevation)

The mass balance shows that in some years actual evapotranspiration in the Mission Creek basin can equal or exceed the amount precipitation less runoff. This implies that groundwater storage can be reduced by pumping, particularly if several dry years occur sequentially.

The calculations in the Wooldridge memo are hampered by the fact that soil moisture capacity and precipitation are of similar magnitude in the Brisky Creek watershed. Conceptually, most water balances assume that soil moisture is recharged starting in the fall and that precipitation amounts greater than the soil moisture deficit generate runoff. When precipitation and soil moisture capacity are of similar magnitude, this assumption can become inaccurate. The importance of soil moisture in WRIA 45 is likely very important on monthly basis, particularly at the end of the summer when precipitation is diverted to replenish soil moisture instead of generating streamflow. Further analysis of the technique used in this memo is recommended.

4.8 Summary of Groundwater Resources

The areas of WRIA 45 where groundwater is present in significant amounts are the same locations were groundwater rights and many wells have are been located. The sub-watersheds with the highest demand for groundwater production include:

- **Icicle** – City of Leavenworth and USFWS near confluence of Icicle Creek and Wenatchee River, residential and irrigation use
- **Lower Wenatchee** – City of Cashmere, residential and irrigation use (particularly Nahahum and Anderson Canyons)
- **Chumstick** – Residential and irrigation use

- **Mission** – City of Cashmere, residential and irrigation use (particularly Brisky and Brender Canyons)
- **Peshastin** – City of Peshastin area, commercial/industrial, residential and irrigation use
- **Upper Wenatchee** – Town of Plain area, residential and irrigation use

Although the Lake Wenatchee area does not currently have as high a water demand as the areas listed above, it may contain several productive aquifers (Golder, 2003). The quantity of groundwater available in these locations is largely unknown and reliable estimates can only be determined by completing thorough hydrogeologic investigations for the specific locations in each sub-watershed.

5.0 RECOMMENDATIONS FOR FUTURE INVESTIGATION

Sufficient data currently exists for a detailed and comprehensive groundwater-surface water interaction study. Future studies of groundwater-surface water interaction should be properly framed to achieve specific goals (e.g. managing groundwater withdrawals, determining TMDL's). For instance, for studies to determine if water supply from a well is GUI, pumping test and hydrograph analysis may be more appropriate than temperature studies along a channel reach. Likewise, determining gaining/losing reaches of a stream is more effectively accomplished by analyzing TIR data instead of long-term pumping test data. Identifying the objectives of the study will focus the discussion and assist in designing studies to answer specific questions.

Although there are few data currently available for a thorough understanding of groundwater availability in WRIA 45, some data currently exists and should serve as historical reference and a means to prioritize important areas with the WRIA. Future studies on groundwater availability should build upon the hydrogeologic information gained through groundwater-surface water interaction investigations

5.1 Groundwater-Surface Water Interactions

Data currently exists for a fairly rigorous analysis of the groundwater-surface water interaction in WRIA 45. Reports such as Ecology's TMDL Preliminary Assessment contain a great deal of current information on the topic and when coupled with documents from Ecology's Technical Files, could assist in the creation of a WRIA-wide map showing locations of known groundwater-surface water interaction. TIR studies (such as those conducted by Watershed Sciences, LLC in the Wenatchee River Basin) would help create a very good understanding of hydraulic continuity when coupled with investigations such as the TMDL Preliminary Assessment.

While significant data currently exist, there are a number of methods available for future study that would increase the understanding of groundwater-surface water interaction within an aquifer system, including:

- **Stream Seepage Assessments** – Stream gaging to measure flow at several transect locations at regular intervals along the channel reach. Barwin (1983) used this technique for a cursory study of Nahahum Creek. Consider the contribution of tributaries to identify gaining/losing reaches. Seepage studies could also use a combination of instream piezometers and thermistor "nests" to provide a robust and economical method for assessing and quantifying stream aquifer interactions.
- **FLIR/TIR studies** – Airborne temperature studies conducted along-channel to identify areas where cooler groundwater is discharging to warmer surface water.

- **Stream Hydrograph Analysis** – To identify groundwater discharge to streams during low-flow times (e.g. summer baseflow).
- **GUI Investigations** – Use a combination of water quality (e.g. microparticulate analysis [MPA], conductivity, temperature) and pumping test analyses to determine degree of connection between groundwater and surface water.
- **Well Log/Water Level Analysis** – Compare groundwater levels to surface water elevations, identify lithology, collect pumping test information and depth to bedrock
- **Locate Springs/Wetlands** – Use 7.5-minute topographic maps and/or local knowledge to identify groundwater discharge points.
- **Stream Examination** – Identify reaches of streams that go dry seasonally to locate areas where groundwater declines can be significant.

5.2 Groundwater Availability

In order to estimate the groundwater availability in WRIA 45, a rigorous investigation of the aquifers of interest is necessary to understand the nature of the groundwater occurrence at particular locations. In addition, a detailed water balance calculation must be completed to characterize the components of water occurrence in the WRIA. Some data currently exist that support a cursory examination of several sub-watersheds, but much more data are needed to develop a comprehensive understanding of groundwater availability. Some analyses that may be helpful include:

- **Potentiometric Surface (water level) Maps** – Determine groundwater flow directions, recharge/discharge locations, seasonal variability of water levels.
- **Develop Hydrogeologic Cross-Sections** – Understand aquifer configuration, identify confining layers, aquifer boundaries.
- **Groundwater/Surface Water Interactions** – Determine how groundwater withdrawals may impact surface water supply.
- **Pumping Test Analyses** – Long term, constant rate tests with several observation wells will allow for the determination of aquifer parameters, help determine groundwater-surface water interaction and sustainable yield of aquifer zones.
- **Historical Water Level Records** – Determine aquifer response, compare with climate data to observe record during dry/wet periods.
- **Development of Groundwater Flow Models** – Groundwater/surface water interaction, aquifer response to pumping scenarios.
- **Water Usage Estimates –** Determine the amount of groundwater currently produced in particular areas of the WRIA. Aid in the prioritization of areas important to groundwater management.
- **Water Rights Analysis –** Determine the allocation of groundwater resources in a particular area.
- **Streamflow Data –** Determine runoff and identify the components of streamflow (e.g. baseflow and stormwater runoff).
- **Climate Data –** Precipitation and temperature values will allow for calculation of evapotranspiration and aid in the construction of a water balance.

Attachments

Figure 1: Generalized Groundwater-Surface Water Interaction WRIA 45

Figure 2: National Wetlands Inventory – Wetlands Locations in WRIA 45

Appendix A: References Pertaining to Groundwater-Surface Water Interaction and Groundwater Resources in WRIA 45 (Wenatchee) – Sorted by Sub-watershed

Appendix B: Selected Graphs from Ecology's TMDL Preliminary Assessment of Groundwater-Surface Water Interaction WRIA 45 (Wenatchee)

Appendix C: Methodology for Assessing Hydraulic Continuity - City of Leavenworth Wells

APPENDIX A

REFERENCES PERTAINING TO

GROUNDWATER-SURFACE WATER INTERACTION

WRIA 45 (WENATCHEE)

(References Have Been Sorted by Sub-watershed)

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APPENDIX B

SELECTED GRAPHS FROM

ECOLOGY'S TMDL PRELIMINARY ASSESSMENT OF

GROUNDWATER-SURFACE WATER INTERACTION

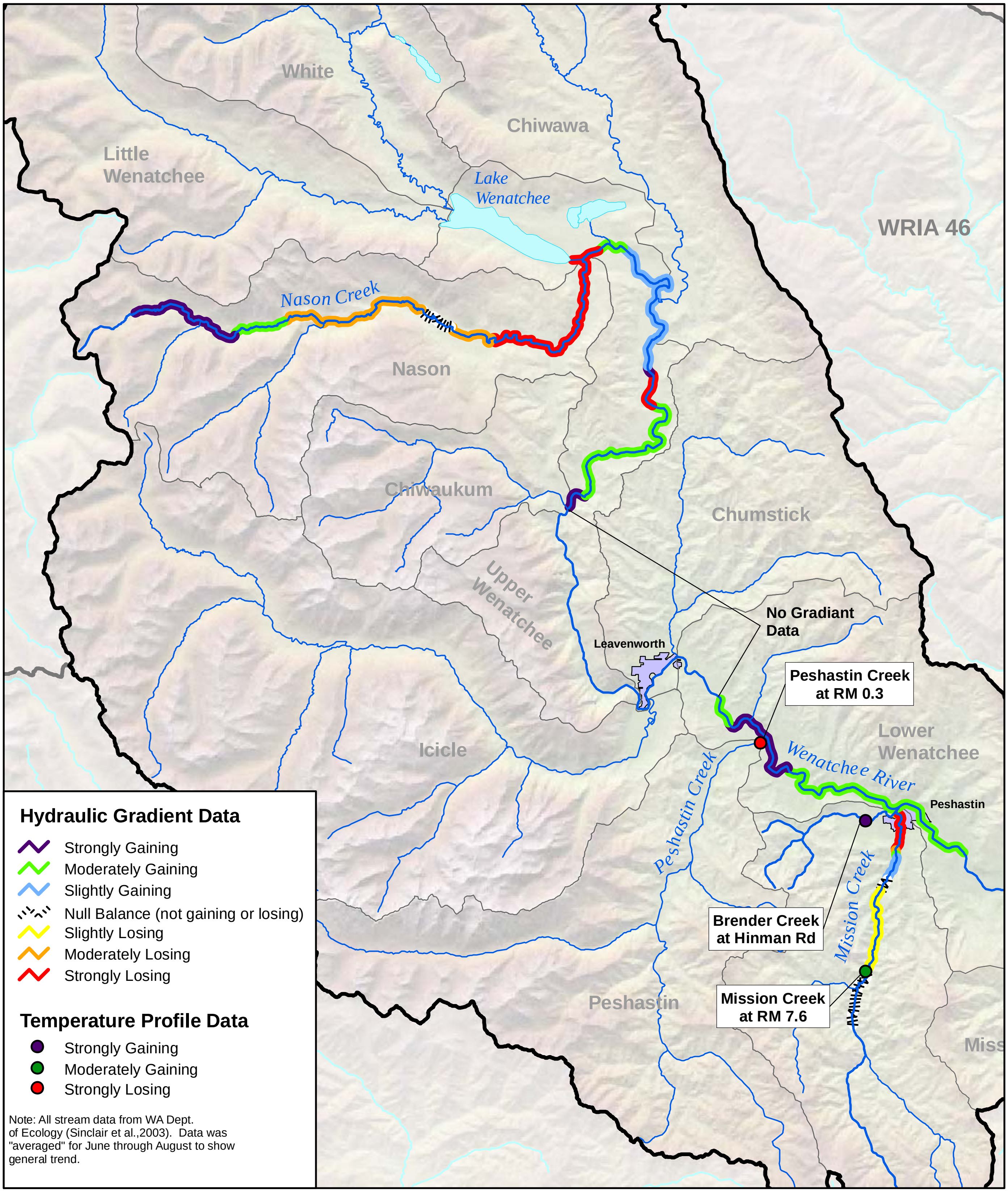
WRIA 45

APPENDIX C

METHODOLOGY FOR ASSESSING HYDRAULIC CONTINUITY

CITY OF LEAVENWORTH WELLS

Golder Associates, Inc.
(2003b, unpublished)



This figure was originally produced in color. Reproduction in black and white may result in loss of information.

LEGEND

- Stream
- Urban Area
- WRIA 45 Boundary

Note: All Stream data from 2003, except mainstem Wenatchee River - 2002.

0 5

Scale in Miles

N

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: USGS, WAGDA, WSDOE, WSDOT

Generalized Groundwater - Surface Water Interaction WRIA 45
Indicated by Hydraulic Gradient and Temperature Profile Data
Chelan/WRIA 45 Watershed Plan/WA

Drawn: ATB	Revision: 0	Date: Dec. 14, 2004	Figure: 1

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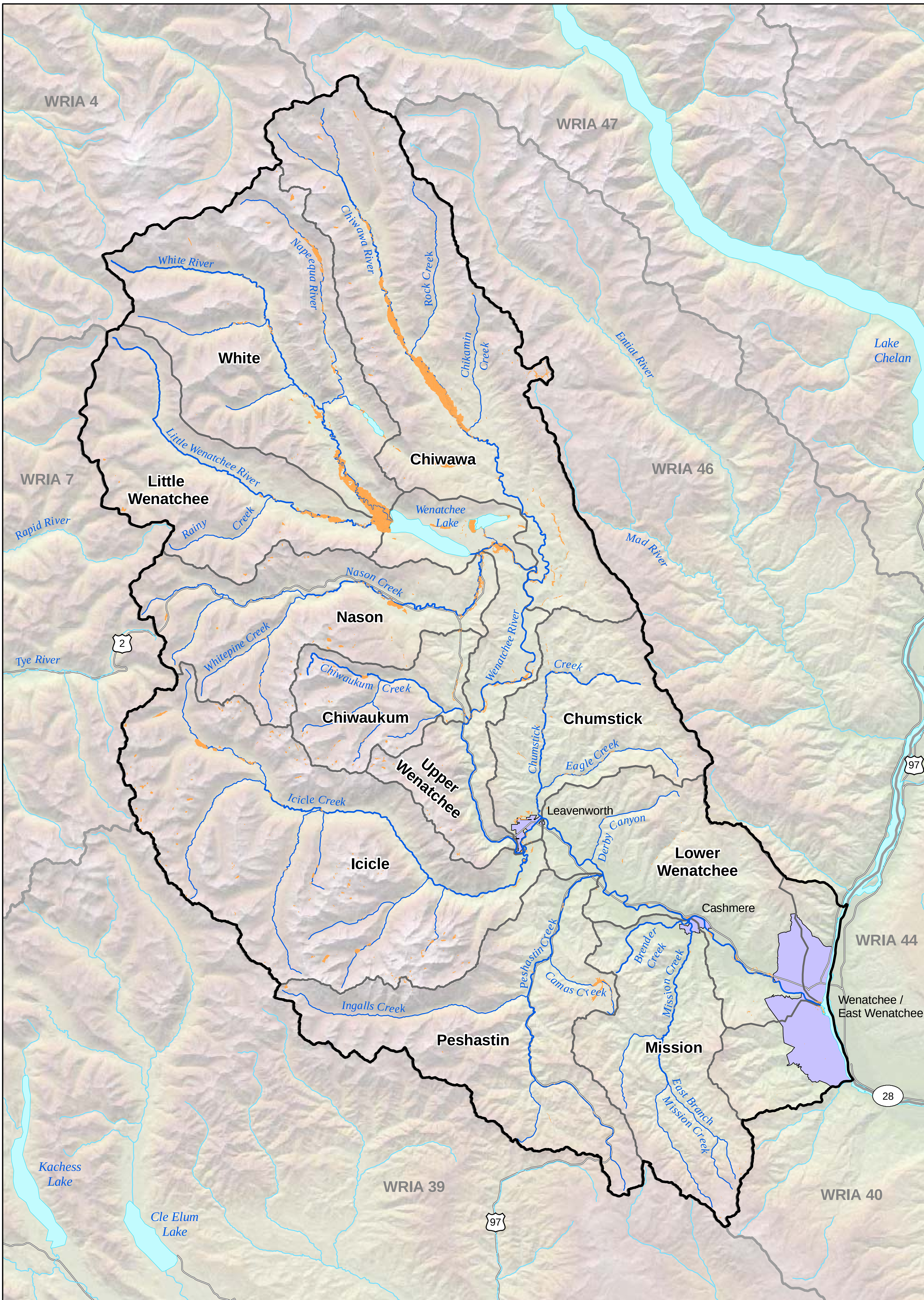
Golder Associates



This figure was originally produced in color. Reproduction in black and white may result in loss of information

LEGEND

	WRIA 45 Boundary		Waterbody
	WRIA Boundary		Urban Area
	Sub-basin Boundary		Watercourse
	Wetlands		Major Road

0 5
Scale in Miles

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: Chelan County, USGS, WAGDA, WSDOE, WSDOT, USFWS NWI

N

DRAFT

National Wetlands Inventory Wetlands Locations in WRIA 45

Chelan/WRIA 45 Watershed Plan/WA

Drawn: BBA	Revison: 1	Date: Dec. 14, 2004	Figure: 2

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Golder Associates

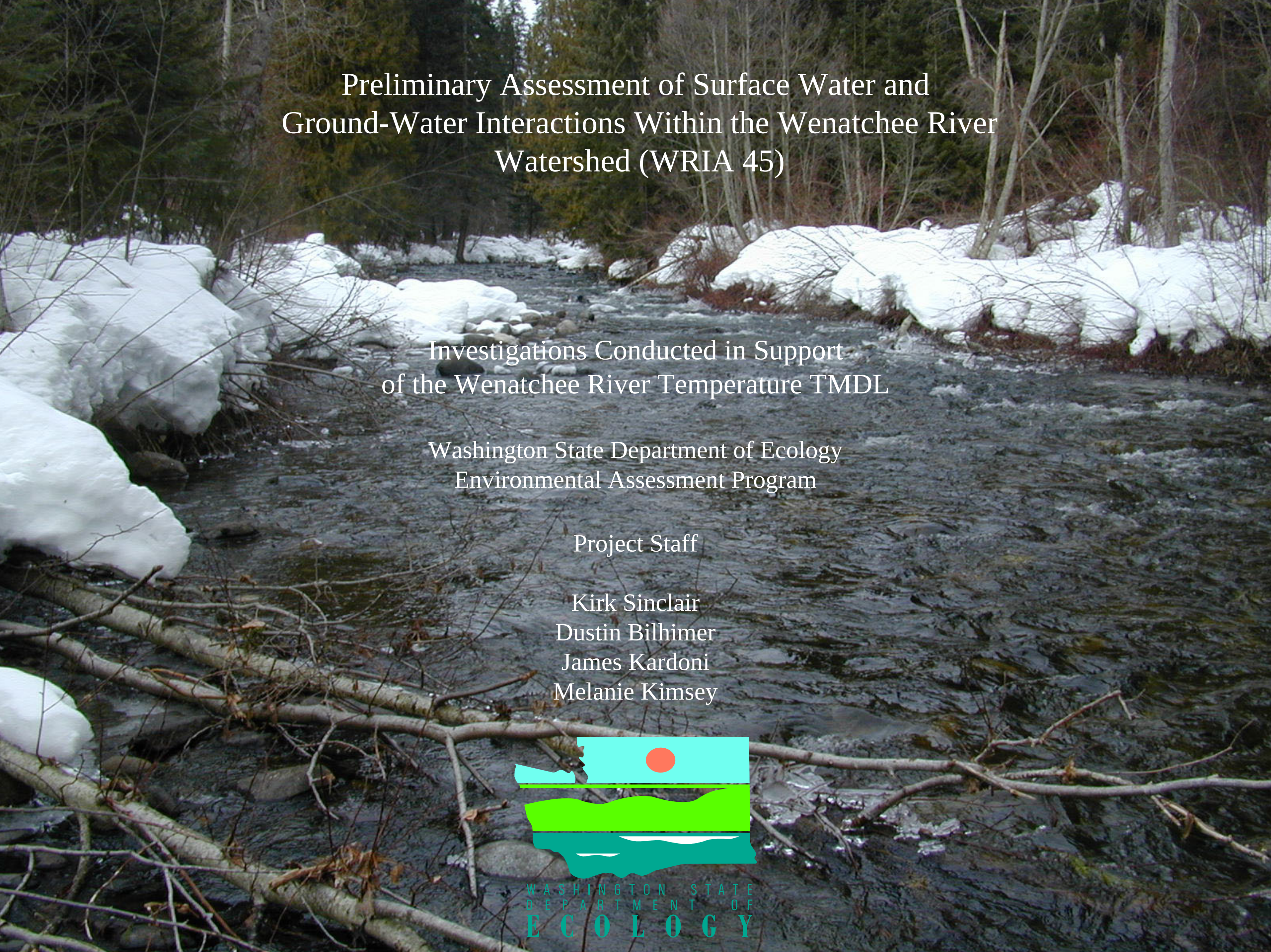
APPENDIX B

SELECTED GRAPHS FROM

ECOLOGY'S TMDL PRELIMINARY ASSESSMENT OF

GROUNDWATER-SURFACE WATER INTERACTION

WRIA 45



Preliminary Assessment of Surface Water and Ground-Water Interactions Within the Wenatchee River Watershed (WRIA 45)

Investigations Conducted in Support of the Wenatchee River Temperature TMDL

Washington State Department of Ecology
Environmental Assessment Program

Project Staff

Kirk Sinclair
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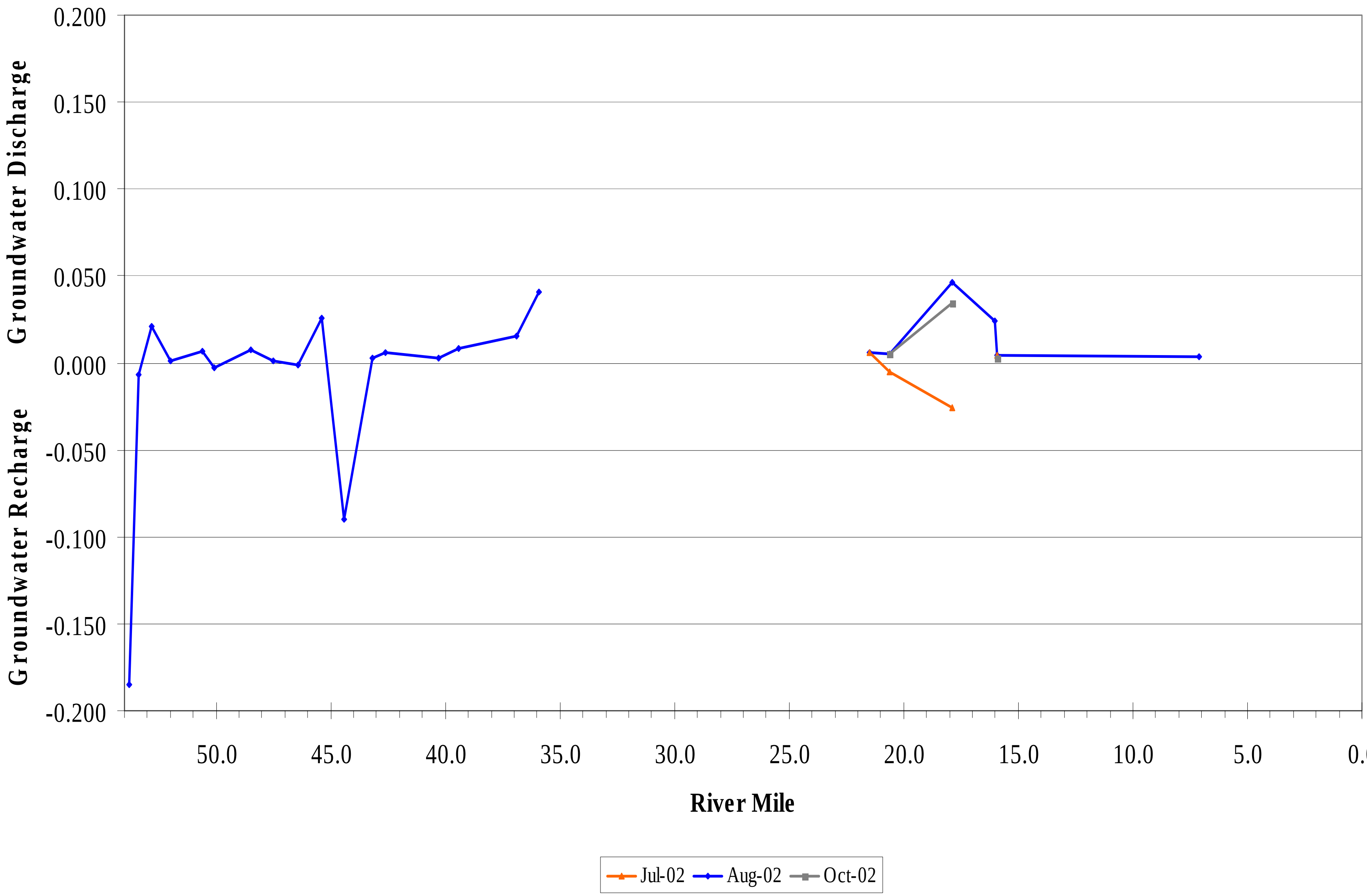
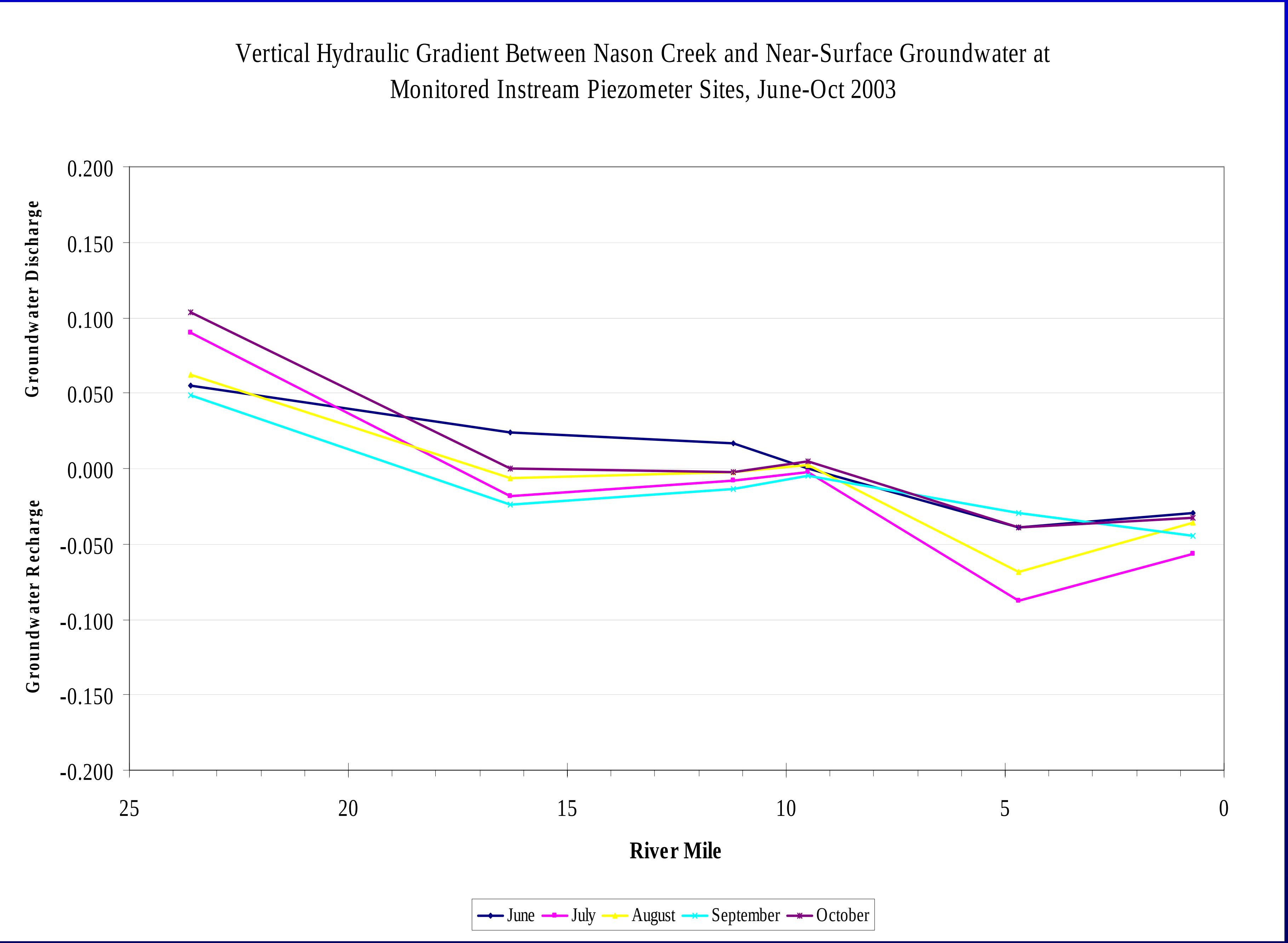
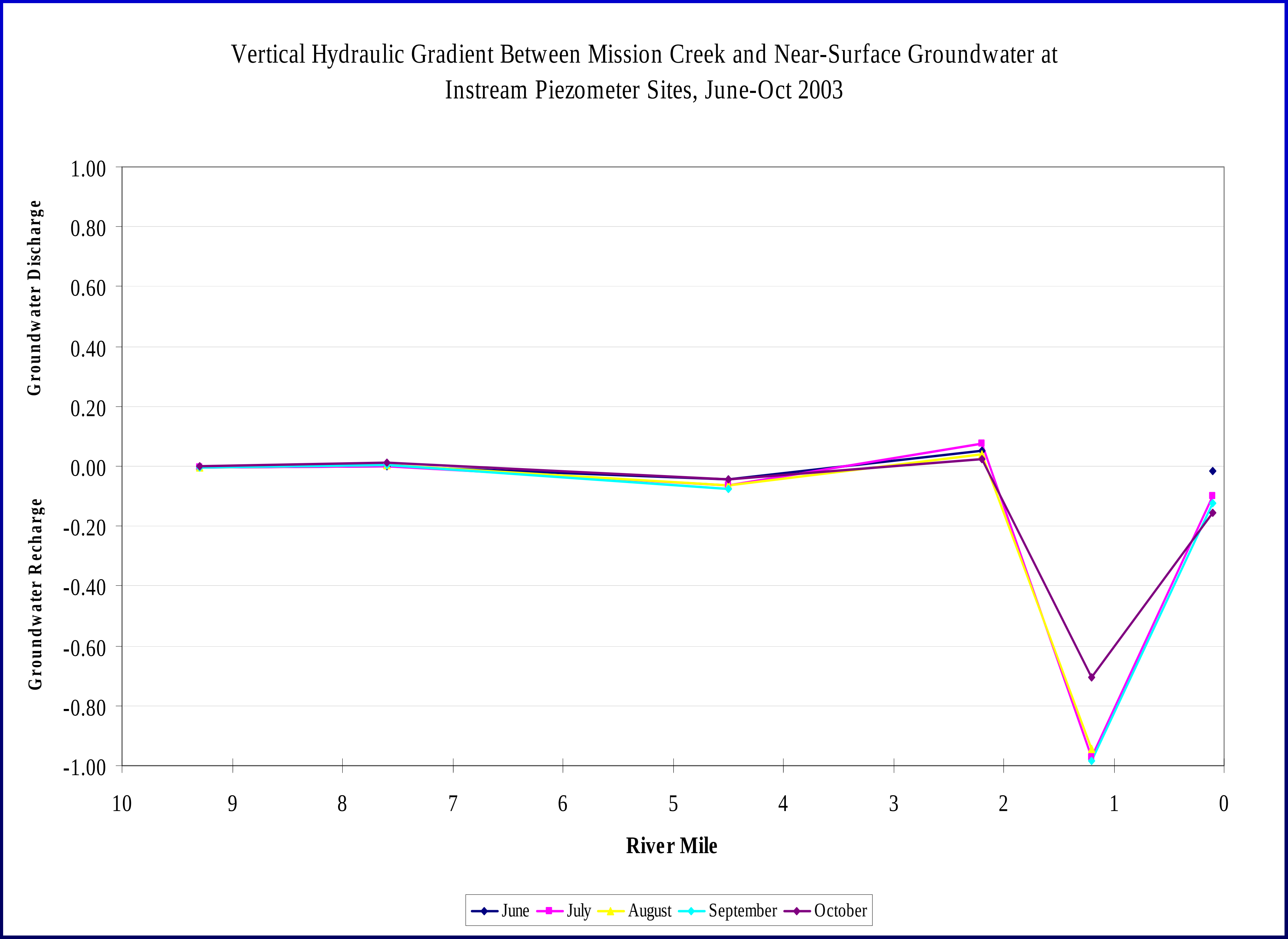
WASHINGTON STATE DEPARTMENT OF ECOLOGY

Vertical Hydraulic Gradient Between the Mainstem Wenatchee River and Near-Surface Groundwater at Monitored Instream Piezometer Sites, Aug-Oct 2002

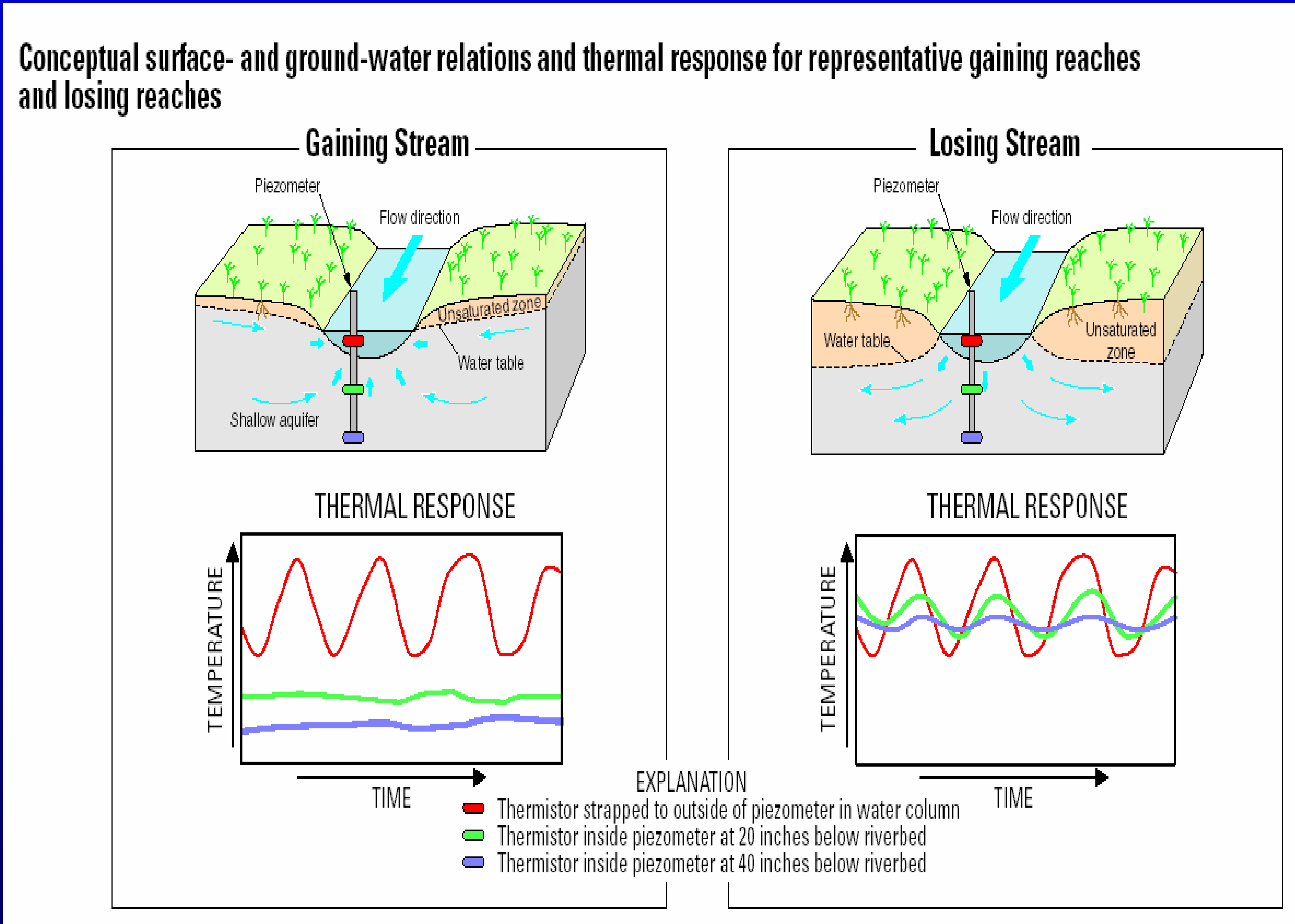




Vertical Hydraulic Gradient Between Nason Creek and Near-Surface Groundwater at
Monitored Instream Piezometer Sites, June-Oct 2003
Groundwater Discharge
Groundwater Recharge
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
25
20
15
10
5
0
River Mile
June
July
August
September
October

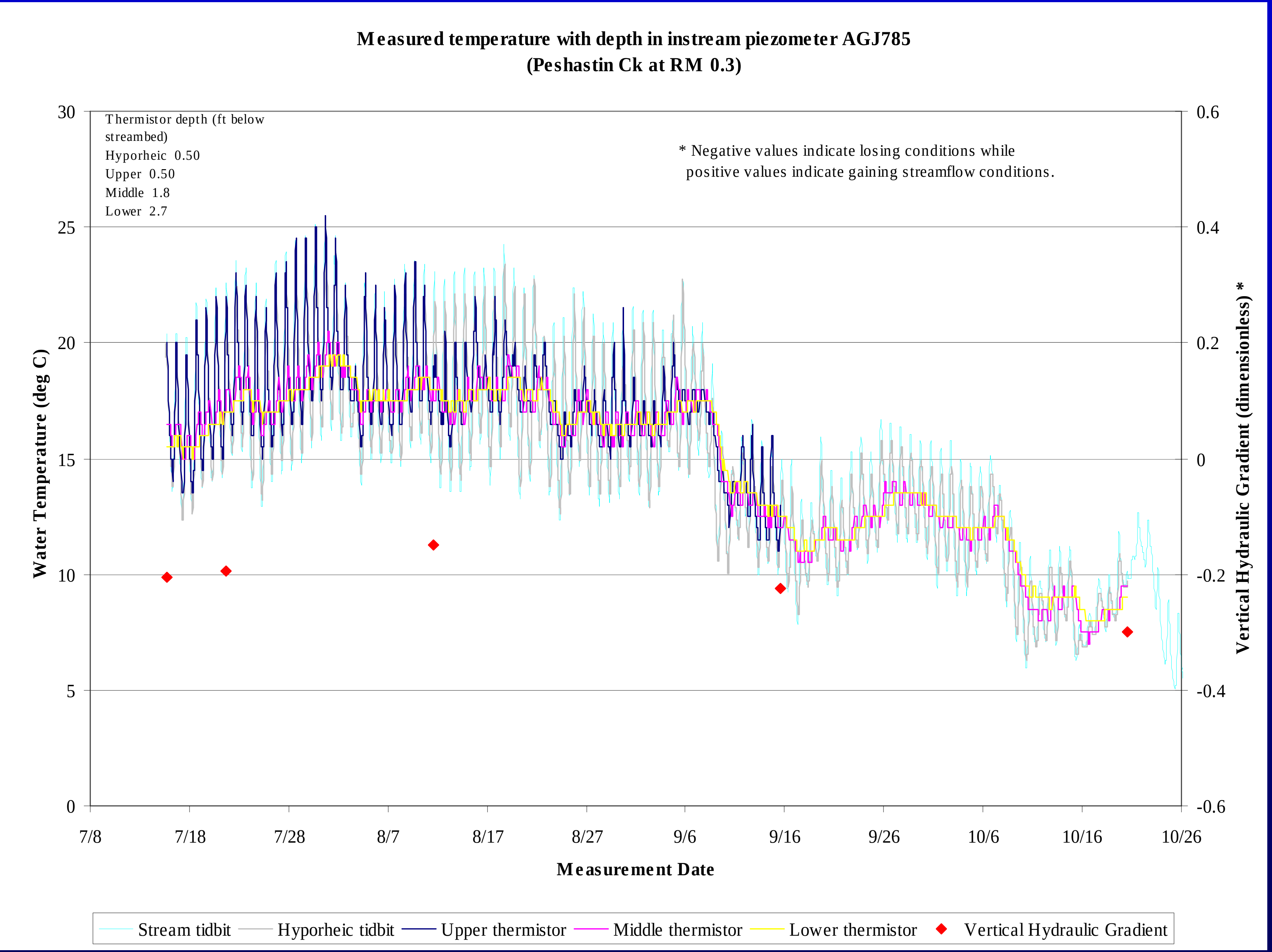


Vertical Hydraulic Gradient Between Mission Creek and Near-Surface Groundwater at Instream Piezometer Sites, June-Oct 2003
Groundwater Discharge
Groundwater Recharge
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
10
9
8
7
6
5
4
3
2
1
0
River Mile
June
July
August
September
October

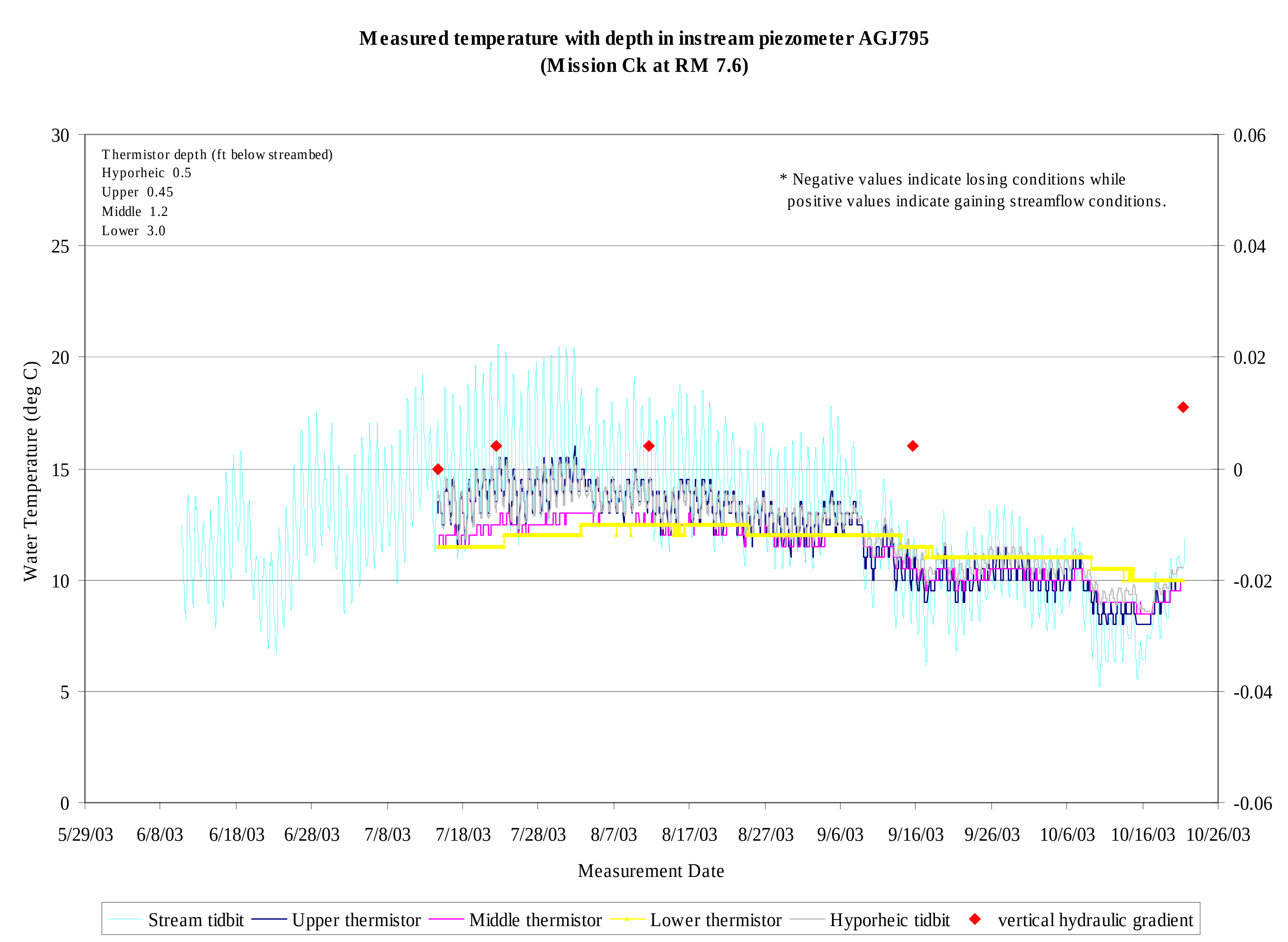


After Simonds, et al 2003

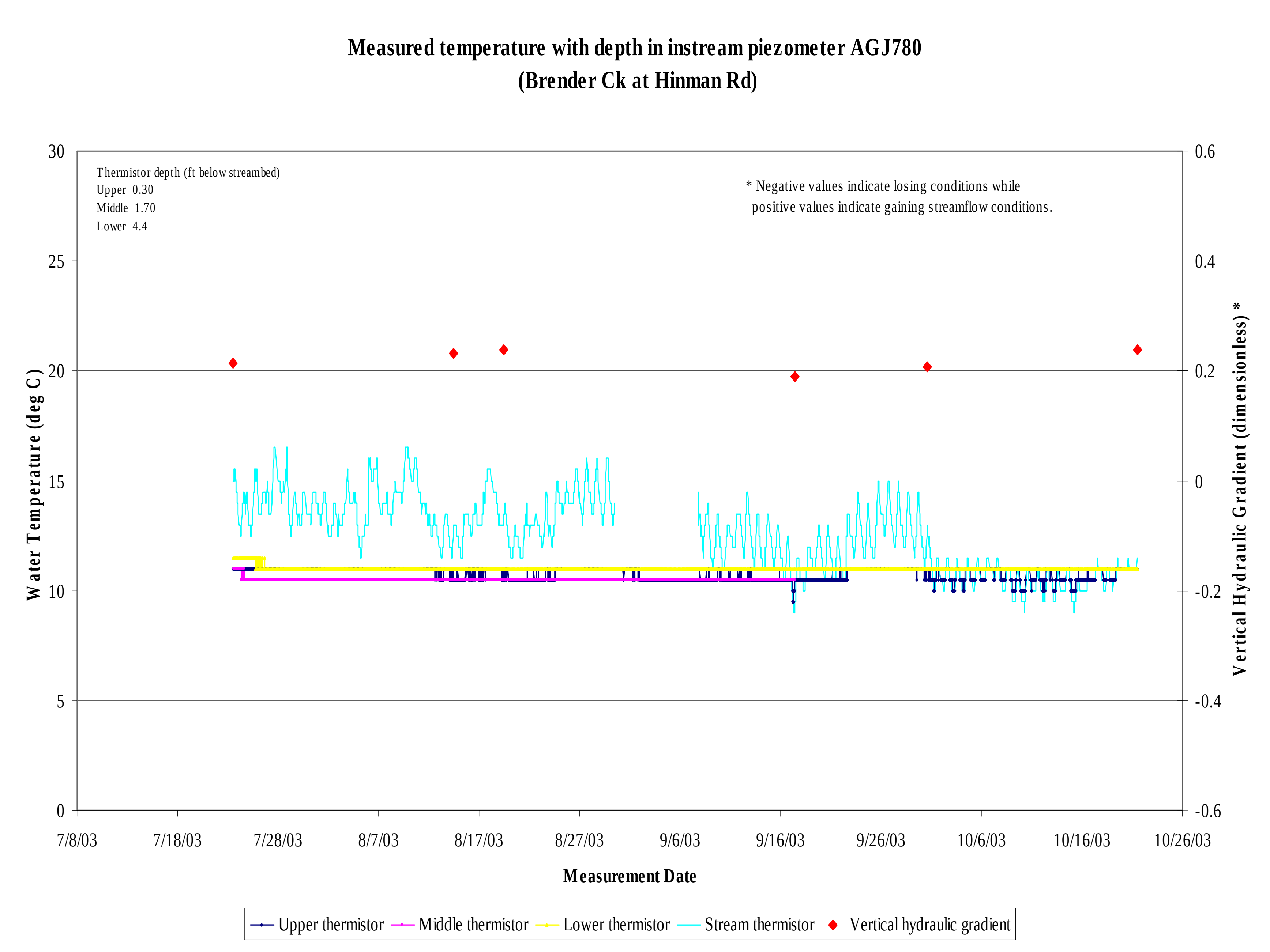
Thermal response for a “strongly losing” stream reach



Thermal response for a "moderately gaining" stream reach



Thermal response for a "strongly gaining" stream reach



APPENDIX C

METHODOLOGY FOR ASSESSING HYDRAULIC CONTINUITY

CITY OF LEAVENWORTH WELLS

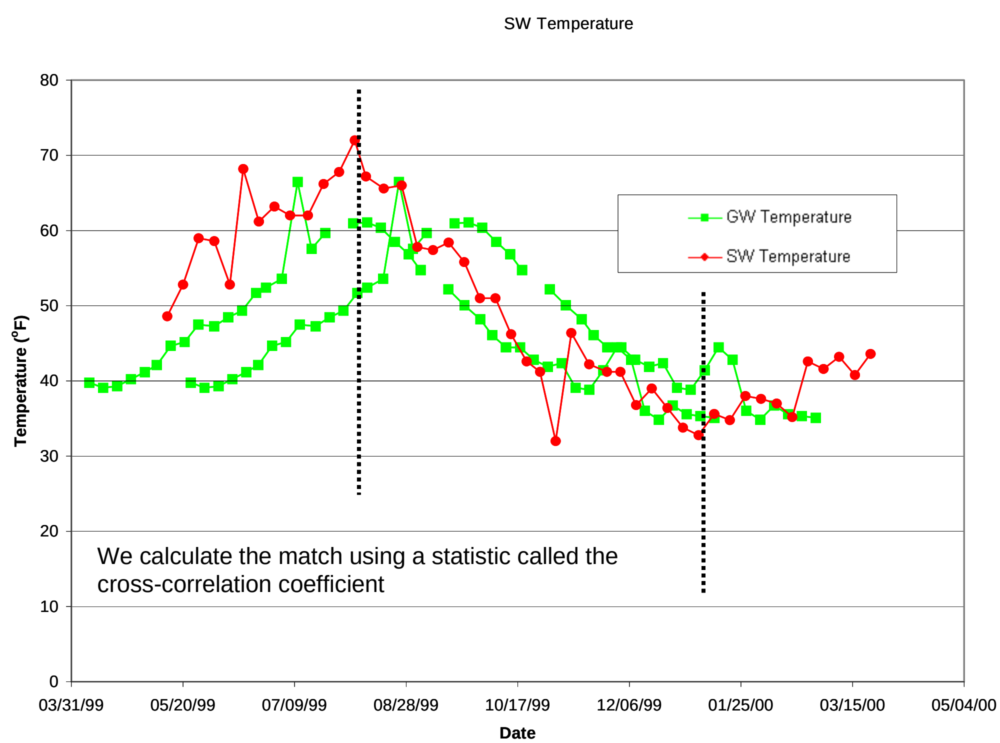
Golder Associates, Inc.
(2003b, unpublished)

Appendix C
Methodology for Assessing Hydraulic Continuity
City of Leavenworth Wells

The goal of this analysis was to determine whether the groundwater aquifers where the City of Leavenworth's wells had been installed were potentially being impacted by surface water from the Wenatchee River. If there is a physical connection between the river and groundwater, then the groundwater resource is at greater risk for various types of contamination than if it has little connection to the surface environment.

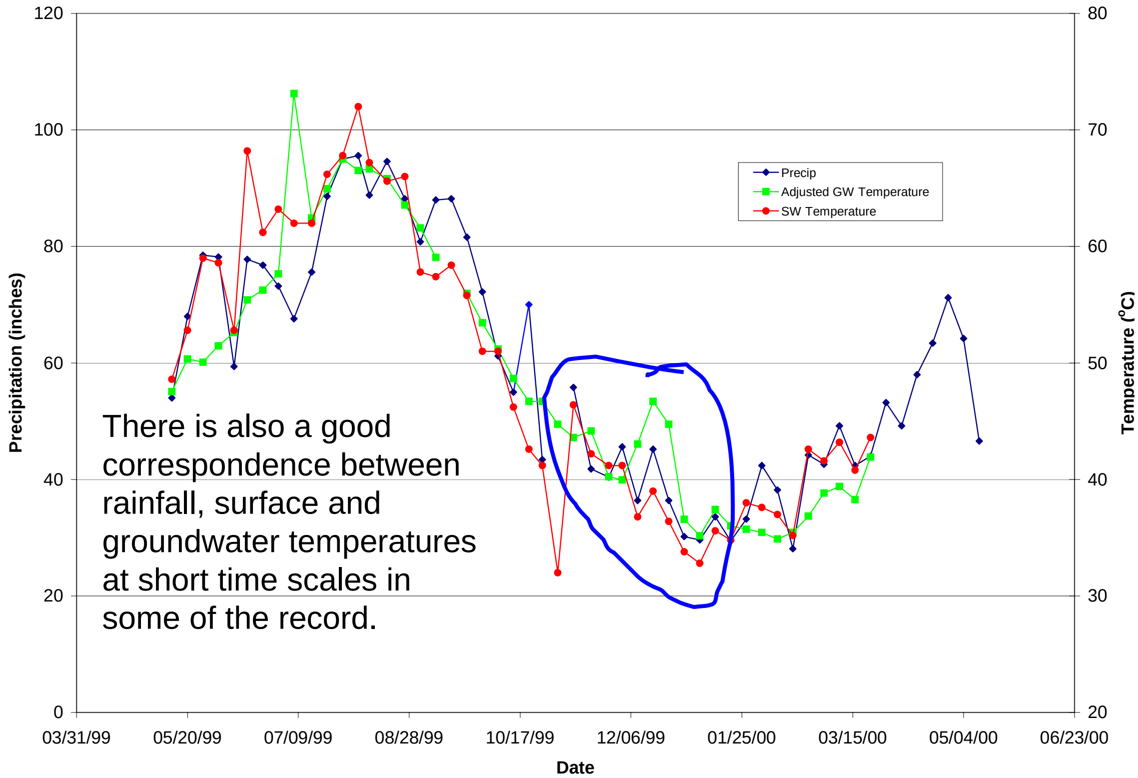
The assessment as to whether the groundwater aquifer is in communication with the surface water is based upon indirect evidence. If the groundwater and the surface water are at different temperatures, as they often are, and have different mineral compositions, which they often do, then temperature or compositional changes in the surface water should produce analogous changes in the groundwater if they are in communication. Of course there are other factors that can lead to changing temperatures and compositions in the groundwater that are not due to surface water infiltration and mixing. To separate the changes that might be due to changes in the surface water composition from those that are not, the temperature and composition of the groundwater are recorded over a long period of time, preferably at least one year, in order to see if the variations in the groundwater track the variations in the surface water over that long period. Since there may be a time delay in the impact of the surface water on the groundwater due to the days or weeks it may take for the surface water to recharge the aquifer, it is necessary to time-shift the groundwater data when looking for a match in temperature or composition profiles over the year. Since the appropriate shift is not known *a priori*, a large range of time shifts are examined to find the one that gives the closest match to the surface water profiles.

The graph below shows an example of the time shifting. In this graph, temperature of the surface water ("SW") is shown in red, while the temperature of the groundwater aquifer



("GW" is shown in green. The two green lines represent the unshifted and optimally shifted groundwater temperature. The unshifted data is the green line with the peak that occurs around 10/17/99, while the optimally shifted data (shifted back in time about 10 weeks) peaks at the same time as the surface water curve. The shifted groundwater temperature is lower in the summer months, but nearly the same in the winter months. The fact that there is a reasonably good match in time when the temperature curves are shifted, and that the relative temperatures behave as they would if they were hydraulically connected (SW warming the GW in the summer, equilibrating with it in the winter), these shifted temperature plots provide evidence that suggests the groundwater could be connected with surface water at this location. However, further analyses of conductance and the correlation of water composition (see below) indicates otherwise.

The graph below shows the GW, SW and precipitation data normalized for the



differences in annual mean temperature and natural variability. The correspondence between all three shows a remarkable match in both long-term and short-term time scales.

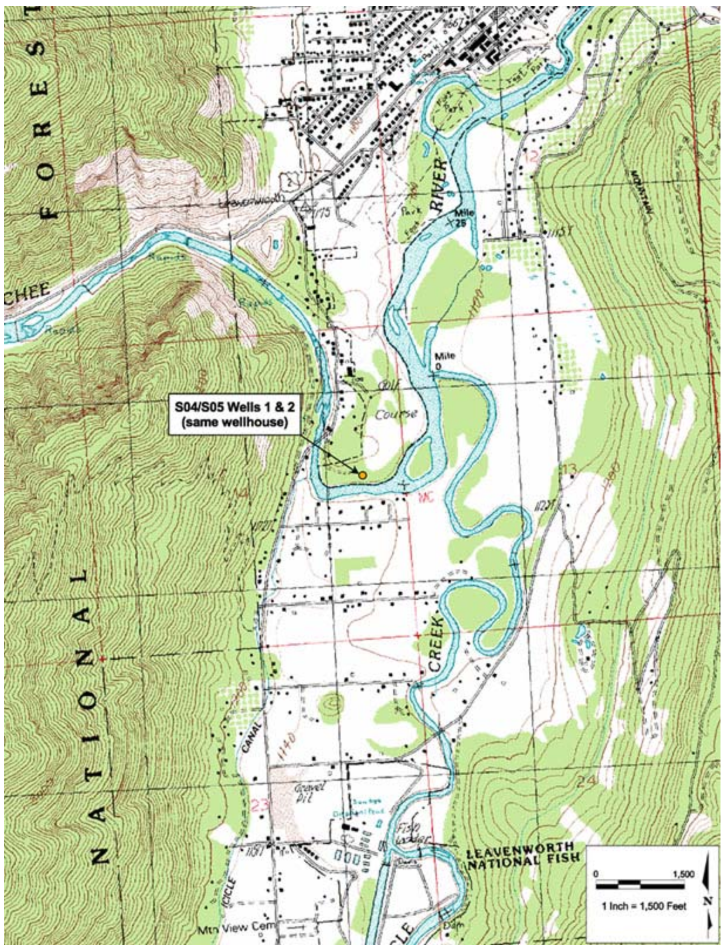
It is possible to mathematically quantify how good the match is by calculating the cross-correlation coefficient (CCC). This coefficient, expressed mathematically as:
(GWi – Mean GW Temperature)*(SWi – Mean SW Temperature)/(std dev GW * std dev SW), which simply looks at the deviation of the GW temperature reading and the SW temperature reading both go up or down more or less in synch, normalized for their different respective annual means and variability. The time shift that produces the highest (closest to 1.0) value of the CCC is the optimal shift.

Correlation between water compositions is assessed through measurements of conductance, which is related to the dissolved mineral content of the water and is easy and inexpensive to measure, as is temperature. The same sort of analysis is applied to this data is applied to the temperature data. If a high CCC is found for approximately the same time shift as for the temperature, then there is strong evidence that the groundwater is under the influence of the surface water.

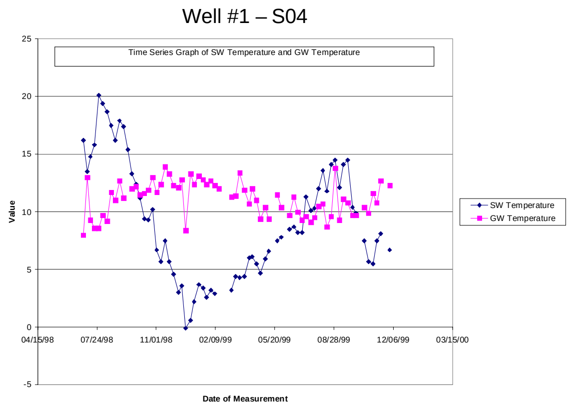
Leavenworth Analyses

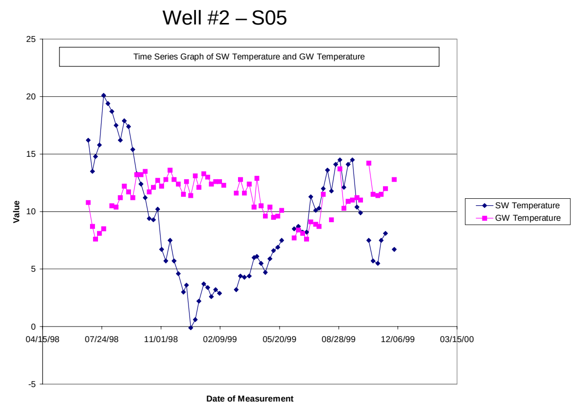
The location of the two wells analyzed are shown in the figure below.

Location of Wells S04 and S05

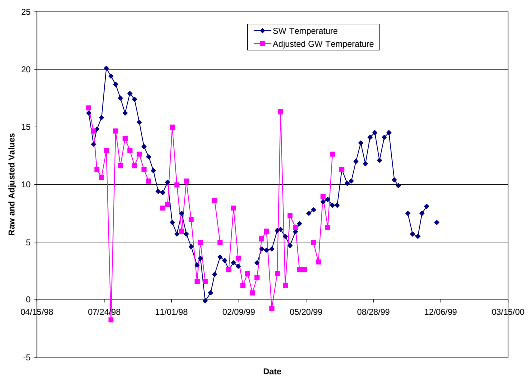


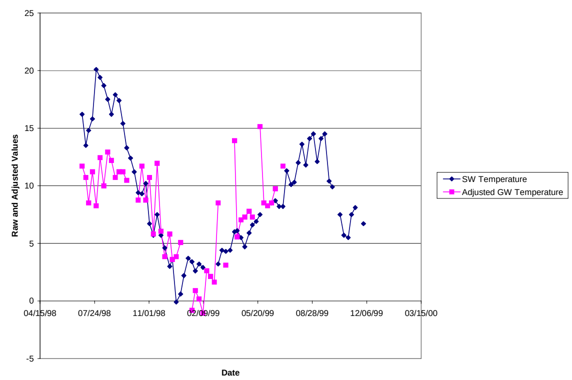
We analyzed the SW and GW temperatures, as well as the conductance of both, determining what time shifts produced the highest CCC's, and then visually assessing whether the time shifted groundwater data appeared to match the surface water data. It did not match very well, as the two graphs shown below indicate.





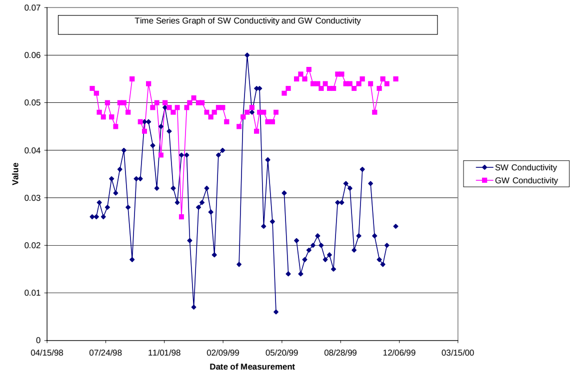
The optimal time shift was 20 weeks for Well #1 and 21 weeks for Well #2. The time-shifted temperature graphs are shown below.

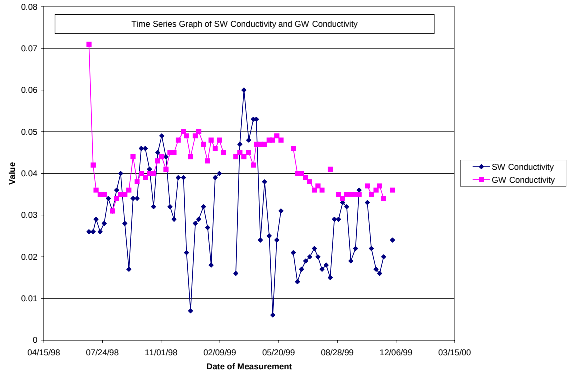


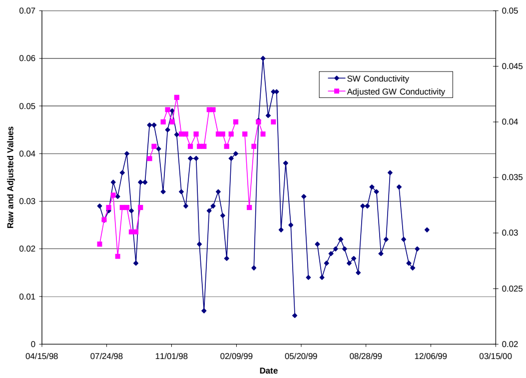


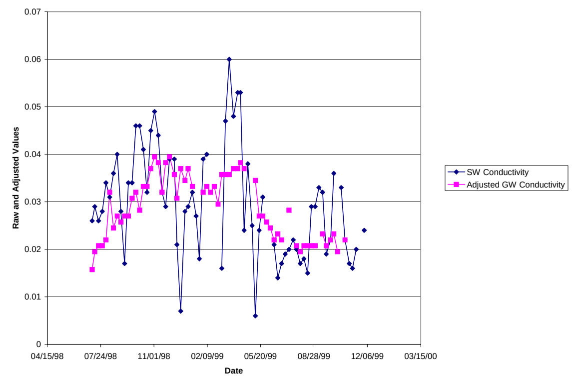
Although the match looks visually reasonable, this may be misleading, as the shift in the data has eliminated five months' worth of GW data, and so the time range over which the two temperature profiles can be compared is shortened.

While the temperature curves shown above could reflect groundwater that is being influenced by surface water, the conductance plots do not show anywhere near as good a match. Well #1 had an optimal time shift of 34 weeks, whereas Well #2 had an optimal shift of 5 weeks. These results are shown in the four graphs below. The lack of correspondence between the time shifts in the temperature data, consistently on the order of 20 weeks for both wells, and the very different optimal shifts for the conductance data, suggest that there is not a strong connection between surface water and groundwater systems, because otherwise, the optimal shifts in the conductance data should be approximately the same as the shifts found for the temperature data.

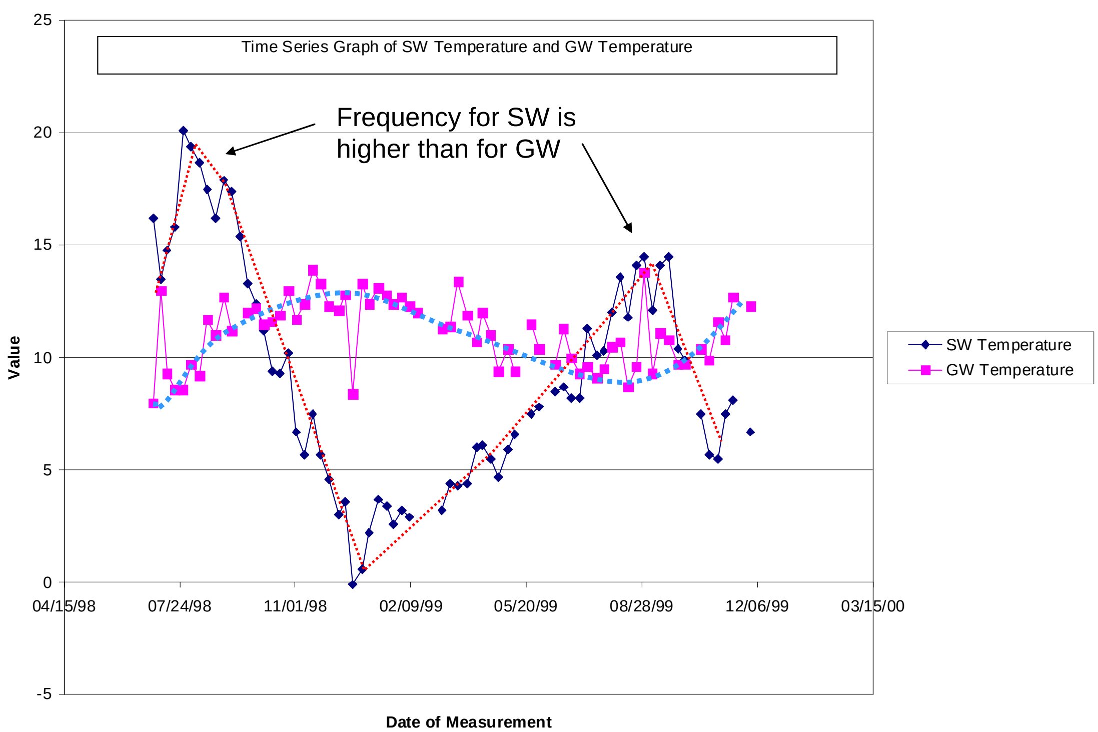








In fact, the explanation for the temperature matches that are around 20 weeks and the conductance matches which are considerably different, is that we are seeing long-term temperature variations in both systems that do not reflect a hydraulic connection, but only a lag time in the conduction of heat from the surface to the subsurface (see figure below).



Further analysis of the GW temperature profile in Well #1 shows a sinusoidal variation in temperature that has an annual cycle, which strongly suggests that most of the temperature variations in the GW is due to the annual changes in ground temperature. The surface water, on the other hand, actually has a shorter period of time between peak temperatures, and is poorly fit by a sine curve. This is because the surface water temperatures are affected by not only the annual temperature variations, but also other factors that occur over different time scales.

Thus, the evidence from these two wells suggests that the groundwater system is not being impacted by the adjacent surface river.