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Assessment of Surface Water and Groundwater Interchange in the Walla Walla River Watershed

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Assessment of Surface Water and Groundwater Interchange in the Walla Walla River Watershed

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by

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Abstract

Segments of the Walla Walla River and two of its tributaries, Mill Creek and the Touchet River, are on the 1996 federal Clean Water Act Section 303(d) list as impaired for temperature, fecal coliform bacteria, and pH. To establish load and wasteload allocations for these parameters, Total Maximum Daily Load (TMDL) studies were conducted by the Department of Ecology.

To better understand the interchange between surface water and groundwater within the Walla Walla watershed, data were collected during July through October 2002 using (1) instream mini-piezometers to define the vertical hydraulic gradient and direction of water flow at discrete points, and (2) a seepage run to provide estimates of the net gains or losses across broader river reaches.

Results of this study support previous investigations which determined that the upper areas of the watershed were predominately losing (surface water discharging to groundwater), and the lower reaches were gaining (groundwater discharging to surface water). Even though the study area is divided between two distinct geologic areas, the patterns of gains and losses were consistent during the monitoring period.

The Touchet River flows over loess-covered basalts with a thin layer of alluvium in the valleys. The Walla Walla River and Mill Creek are dominated by a series of coalescent fans. The Touchet River, Walla Walla River, and Mill Creek had negative hydraulic gradients and were losing in their upper reaches. The coalescent fans are composed of coarse gravel in the upper portions of the basin and fine-grained deposits in the lower portions. This distribution of coarse and fine materials influences the movement of groundwater and results in groundwater discharging to surface springs. Discharge to surface water is more significant in the western part of the alluvial fan area, at the confluence of the Touchet and Walla Walla rivers.

Acknowledgements

This report is a synthesis of numerous people's efforts, both physical and intellectual. As such, I wish to thank the following individuals for their contributions to this study:

- Sara Coffler, John Covert, Mike LeMoine, Victoria Leuba, Loren Patton, Tracy Rehwald, Morgan Roose, and Keith Stoffel for field assistance at various points during the project.
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- Randy Coots for assistance with the report maps.
- Joan LeTourneau for final formatting and editing of the report.

Introduction

Segments of the Walla Walla River and two of its tributaries, the Touchet River and Mill Creek, located in southeast Washington (Figure 1), have been listed by Washington State under Section 303(d) of the federal Clean Water Act for non-attainment of state temperature, fecal coliform bacteria, and pH criteria. The U.S. Environmental Protection Agency (EPA) requires states to set priorities for cleaning up 303(d) listed waters and to establish a Total Maximum Daily Load (TMDL) for each parameter that is in noncompliance.

The purpose of the Walla Walla River TMDLs is to characterize temperature, fecal coliform bacteria, and pH in the basin and to establish load and wasteload allocations so that these parameters will meet water quality standards for surface water.

A groundwater study was requested to improve the understanding of the interaction between the water-table aquifer and the watershed's rivers and streams to support the TMDL activities. This report describes the methods used and findings of a study conducted in the summer of 2002 to assess the interchange between rivers and groundwater in the Walla Walla watershed.

Purpose and Scope

The purpose of this study was to evaluate and describe the hydraulic interaction between the major rivers and near surface groundwater within the Walla Walla watershed. Descriptions of the locations and directions of surface water and groundwater interchange during the summer low-flow season (July to October) are provided, along with a general discussion of the hydrogeologic framework within which this interchange occurs.

The approach involved using two data collection and analysis methods to evaluate the distribution of surface water and groundwater exchange. Data were collected between July and October 2002 from 23 instream mini-piezometers and one stream seepage run in which 13 river reaches were evaluated (Figure 2). The mini-piezometers provided information on the vertical hydraulic gradient between the rivers and water-table aquifer at discrete points, while the seepage run provided estimates of the net gains or losses across broader river reaches.

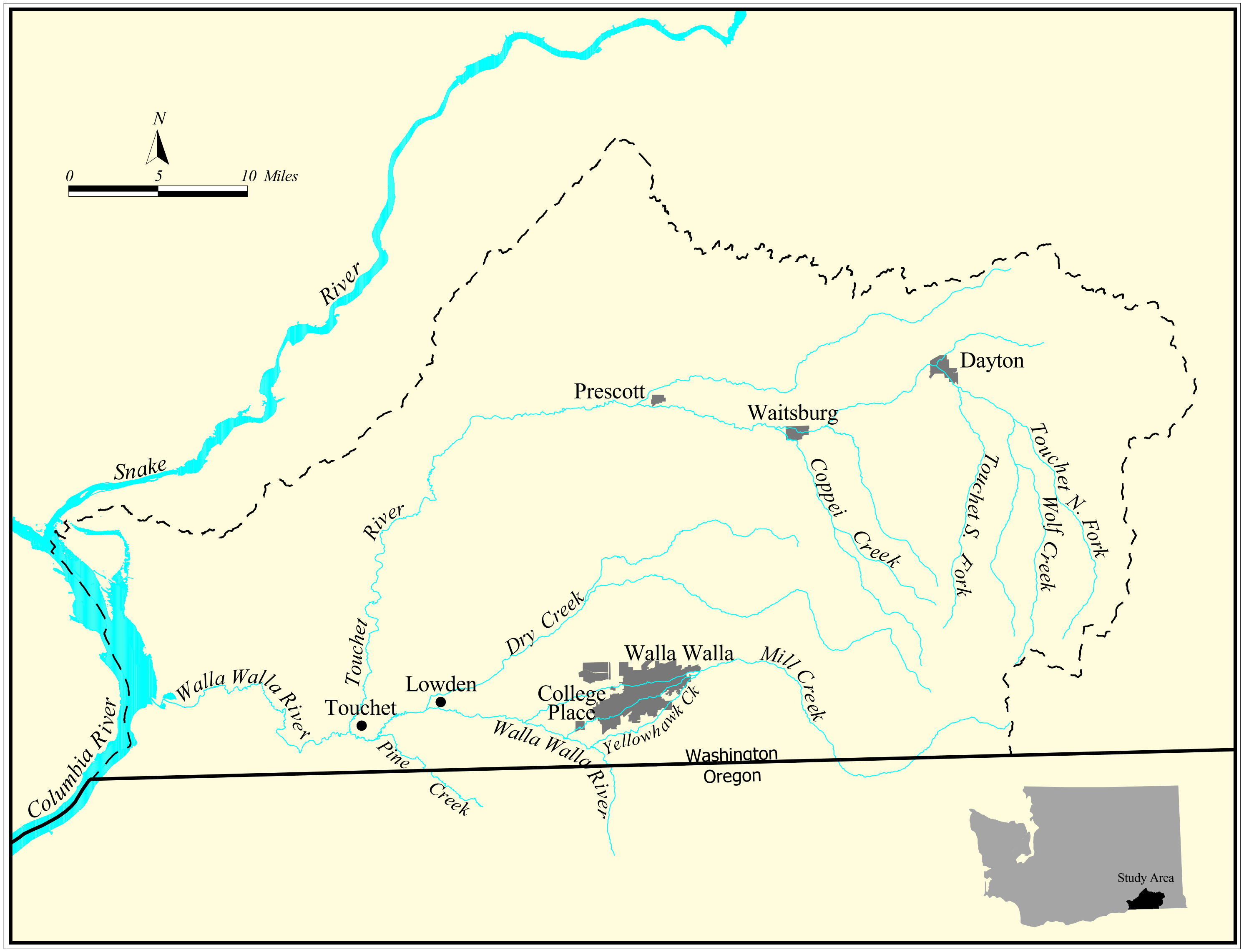

Figure 1. The Walla Walla River Basin

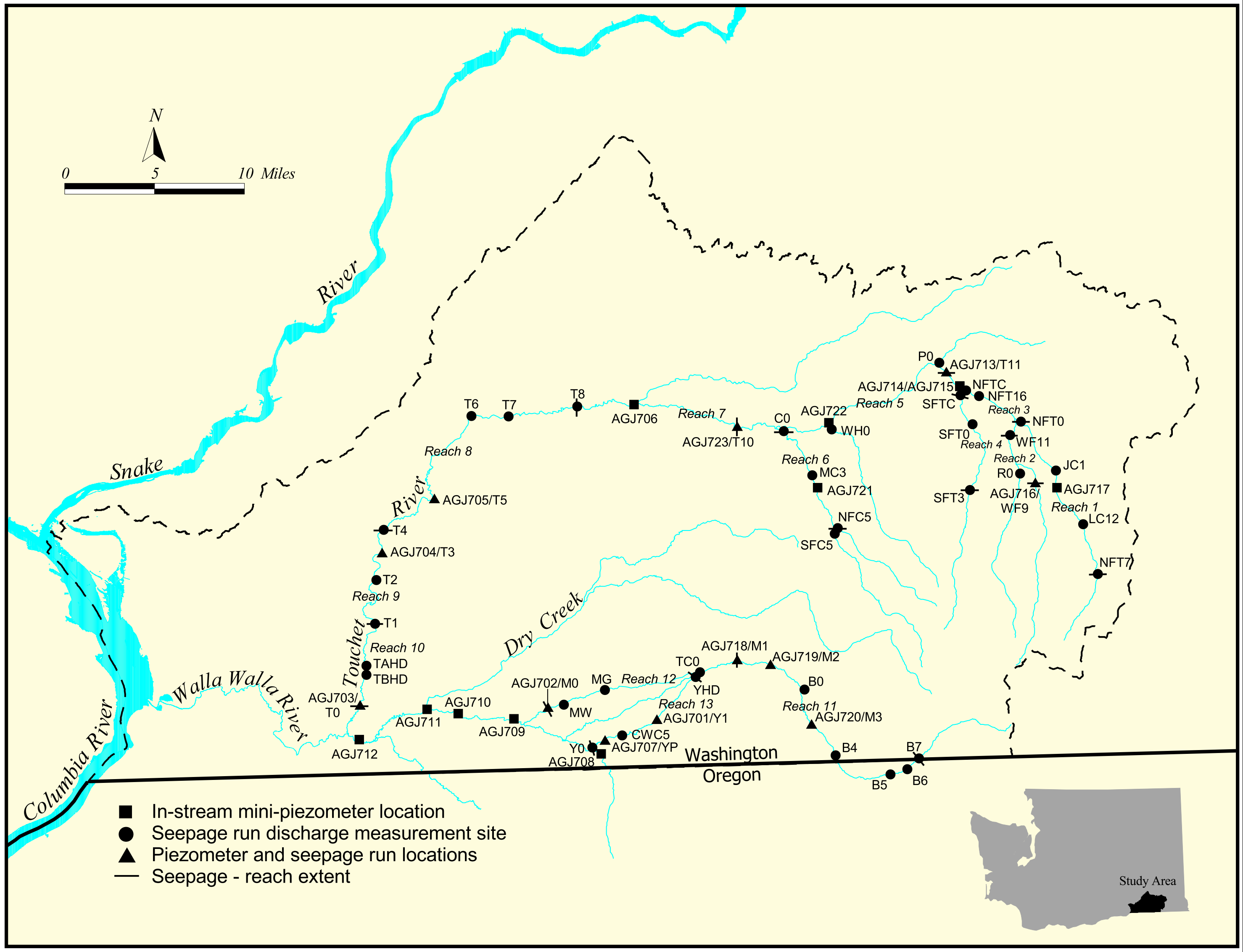

Figure 2. Location of Instream Piezometers, Seepage Run Sites, and Seepage Reaches in the Walla Walla River Basin

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Description of Study Area

The Walla Walla River is located in the southeast corner of Washington State. The river extends approximately 80 miles from its headwaters in northeast Oregon to its confluence with the Columbia River in Washington. The drainage basin covers approximately 1,760 square miles. Three-quarters of the Walla Walla drainage basin and the last 40 miles of the mainstem lie within Washington. In downstream order, the major Washington tributaries are Yellowhawk Creek, Garrison Creek, Mill Creek, Dry Creek, Pine Creek, and the Touchet River.

The Touchet River is the largest Walla Walla River tributary. It originates as four primary forks – South Fork Touchet, North Fork Touchet, Wolf Fork, and Robinson Fork – deep in the Blue Mountains at an elevation of 6,074 feet. The four forks are mainly forested, with only small farms in the valleys. The forks converge just above the city of Dayton to form the mainstem Touchet River. The Touchet River flows through the cities of Dayton, Waitsburg, and Prescott reaching its confluence with the Walla Walla River by the town of Touchet at an elevation of 420 feet. The basin area is 747 square miles. Land use in the Touchet basin from Dayton to the confluence with the Walla Walla River is predominantly agricultural, with both irrigated and non-irrigated crops.

Mill Creek has a basin area of 100 square miles, with 22,000 acres preserved as a drinking water source for the city of Walla Walla. The creek flows from the Blue Mountains in Washington and Oregon and then through the city of Walla Walla. Before entering the city, part of Mill Creek's flow is diverted to Yellowhawk and Garrison creeks from May to October for irrigation purposes. Mill Creek's remaining flow passes through the city of Walla Walla in an engineered concrete channel. Mill Creek enters the Walla Walla River downstream of the city, near the historical Whitman Mission.

Springs supply baseflow to surface waters year-round. Seasonal snowmelt and runoff in the spring increase river discharge volumes. Rivers and streams in the basin experience greatly reduced flows in the summer from a combination of reduced supply and diversion for irrigation. The irrigation season in the Walla Walla basin generally extends from mid-April to mid-October. The Walla Walla River has gone dry at the Oregon-Washington border, and lower Mill Creek usually has little to no flow between points of irrigation withdrawals and returns. Conditions have improved recently in the mainstem Walla Walla River as a result of farmers diverting less water in response to bull trout endangered species listings. Flows near the state line now range from 4-15 cubic feet per second (cfs) in the summer. The typical flow pattern in the Walla Walla River and its tributaries is illustrated in Figure 3.

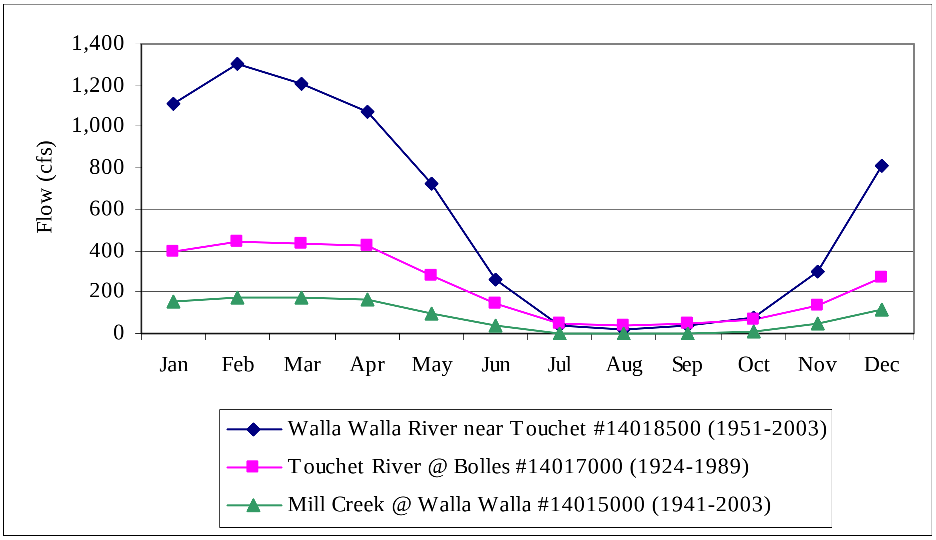

Figure 3. Mean of Monthly Streamflows in the Walla Walla Drainage (USGS data, 1924-2003).

The Walla Walla watershed has a continental type climate with hot, arid summers and cold, wet winters. Temperatures in the basin often reach 37.8°C (100°F) in the summer and drop below freezing in the winter. Precipitation varies dramatically with elevation. Near the mouth of the river, there is less than 10 inches of rainfall annually. Precipitation increases with elevation to a maximum of over 40 inches annually in the headwaters, most falling as snow. Spring thaw, compounded with rain showers, is the source of flooding for the basin.

The Walla Walla basin is predominately rural with few urban areas. The major towns are Walla Walla and College Place, with a combined population of less than 40,000. The wastewater treatment plants (WWTP) for these cities are the two major permitted discharges in the basin. The Walla Walla WWTP discharges to Mill Creek at river mile 5.4, and the College Place WWTP discharges to Garrison Creek at river mile 1.0. The smaller towns of Dayton, Waitsburg, and Milton-Freewater (Oregon) support surrounding agriculture. Currently, spring and summer wheat, alfalfa seed and hay, and peas are the largest percentage of the irrigated crops. Other crops include grapes, apples, asparagus, barley, and onions.

Drinking water for the city of Walla Walla is supplemented by groundwater from a deep basalt aquifer. A relatively dynamic, shallower gravel aquifer is used by residents in the basin as well, mainly for irrigation. Recent studies identified nitrate and coliform bacteria contamination of the gravel aquifer near Walla Walla (Pacific Groundwater Group, 1995).

Previous Investigations

This study drew from a number of previous geologic and hydrologic investigations. The geology of the Walla Walla basin was described by Newcomb (1965). Interpretations of the hydrologic characteristics were provided by Newcomb (1965), Barker and MacNish (1976), and the Pacific Groundwater Group (1995).

Hydrogeologic Setting

The Walla Walla River watershed occupies a broad synclinal trough that is bounded by anticlinal ridges of the Blue Mountains to the east, the Horse Heaven ridge to the south, and the Touchet slope to the north. The Blue Mountains consist of a deeply canyoned upland surface and a ramp-like slope called the Blue Mountain slope. The north side of Horse Heaven ridge rises south of the Walla Walla basin in a series of step-like escarpments. The Touchet slope is a gentle undulating plateau which forms the north side of the Walla Walla basin. The surficial geology of the Washington portion of the watershed is shown in Figure 4.

The youngest geologic deposits in the watershed are comprised of recent alluvial material (Qa) found in and around the river and creek channels throughout the basin. These deposits are made up of a thin layer, usually less than 10 feet, of gravel and some silt. This formation is in connection with surface water in most places.

Most of the northern part of the drainage area is loess-covered terraces with eolian sand dunes (Qd). The sand dunes, which are located in the northwest portion of the watershed near the Columbia River, are composed of medium to fine sand and silt and include both active and stabilized dunes (Schuster, 1997). The loess deposits (Ql) form a thin mantle of unconsolidated material, less than 10 feet thick, in the northwest portion of the watershed, increasing in an easterly direction to a maximum of 100 feet at the base of the Blue Mountains (Newcomb, 1965). The loess is also predominately composed of eolian silt and fine sand derived largely from wind erosion of the Touchet Beds and other older deposits.

Large areas of outburst flood deposits (Qfs/Qfg) from glacial Lake Missoula are widely distributed in the major river courses of the basin. These horizontally bedded deposits are finer than the recent alluvium and consist of silt and sand with some gravel. These deposits, referred to as the Touchet Beds, vary in thickness from 100 feet in Gardena near the town of Touchet to a thin veneer higher in the valleys of the Touchet River and Dry Creek to an elevation of about 900 feet. Silt and fine sand predominate in the uppermost 100 feet, and sand and gravel in the lowest parts. This formation is mostly above the water table.

In the Walla Walla basin, the younger alluvium is underlain by Pleistocene age gravel and clay (Qcg), referred to as the “old gravel and clay” unit, which were deposited into the Walla Walla synclinal trough. This is generally an east-west trending trough-shaped feature which accounts for the basins topography. The gravel zone was deposited as a series of coalescent alluvial fans in the upper valleys of Mill Creek and the Walla Walla River, separating into thin strata which pinch out downvalley into the underlying old clay. The gravel exhibits variable cementation and is often described as “cemented gravel” by local well drillers. The gravel is water-bearing and provides the main “shallow” groundwater in the valley plains. The aquifer is about 200 feet thick near the city of Walla Walla, thinning out to the west (Newcomb, 1965). Below the gravel, the clay deposits fill the lowest part of the synclinal trough, ranging between 200-500-feet thick. The Pleistocene clay serves as a confining layer preventing most upward or downward movement of water.

Miocene Columbia River Basalt (Mv) underlies the entire Walla Walla River basin extending into the Blue Mountains. The Wanapum series is the youngest member which overlies the Grand Rhonde. At higher elevations where unconsolidated material has eroded, the Grand Rhonde unit is exposed at the surface. Newcomb (1965) found that groundwater from the basalt aquifer does not interact significantly with local waterbodies, but instead discharges to the larger Columbia and Snake rivers. However, seeps and springs do flow from the basalts in the ravines and canyon sides and probably contribute flow locally to area surface waterbodies.

Aquifer Characteristics

Groundwater in the recent alluvium occurs in the Walla Walla-Mill Creek area at about the same level as the river or creek (Newcomb, 1965). The rise and fall of the surface water translates to rising and falling depth in the adjacent water table. Newcomb (1965) indicates that the alluvial aquifer serves as a conduit for recharge to the underlying gravel aquifer.

The glacial outburst sediments referred to as the Touchet Beds are mostly above the water table, but in some places such as Gardena and the terrace northeast of Touchet, the lower portions are below the water table. Much of the water percolating into the fine-grained Touchet Beds flows laterally along horizontal laminations, out to the surface of the slope instead of downward as is more typical of the loess formations (Newcomb, 1965). Schuster (1994) places the boundary between glacial outburst sediments and loess arbitrarily at 900 feet elevation. Areas above 900 feet are classified as loess, and those below 900 feet as glacial outburst deposits.

Saturated portions of the Pleistocene gravel unit contain the highly productive “gravel aquifer”. The water table is about 50 feet below ground, with the groundwater movement following the pattern of the surface water drainages. Locally, flow patterns are more complex due to pumping, spring discharge, gaining and losing interactions with streams, and to a lesser degree, variable recharge from (and discharge to) the underlying basalt aquifer system. Over 2,000 wells have been drilled into this aquifer with most of the water being used for irrigation.

Most of the recharge to the gravel aquifer is from precipitation and irrigation. Upward water movement from the basalt aquifer is not significant now, but may have been important before irrigation and well pumpage reversed the former scheme causing groundwater declines in the basalt (PGG, 1995). The gravel aquifer discharges to springs, local streams and rivers, pumping wells, and leakage to the basalt aquifer. Groundwater in the old gravel discharges mainly to two spring zones which arc across the surface of the alluvial fans in the southeastern and western parts of the basin (Newcomb, 1965) as shown in Figure 4. The gravel aquifer is also connected to surface water in the area and provides significant baseflow to rivers and streams in the basin (PGG, 1995). Discharge to surface water is more significant in the western, downgradient part, of the alluvial fan area (Newcomb, 1965). In the Walla Walla River, most of the groundwater discharge appears to occur between the confluence with Mill Creek and the town of Touchet.

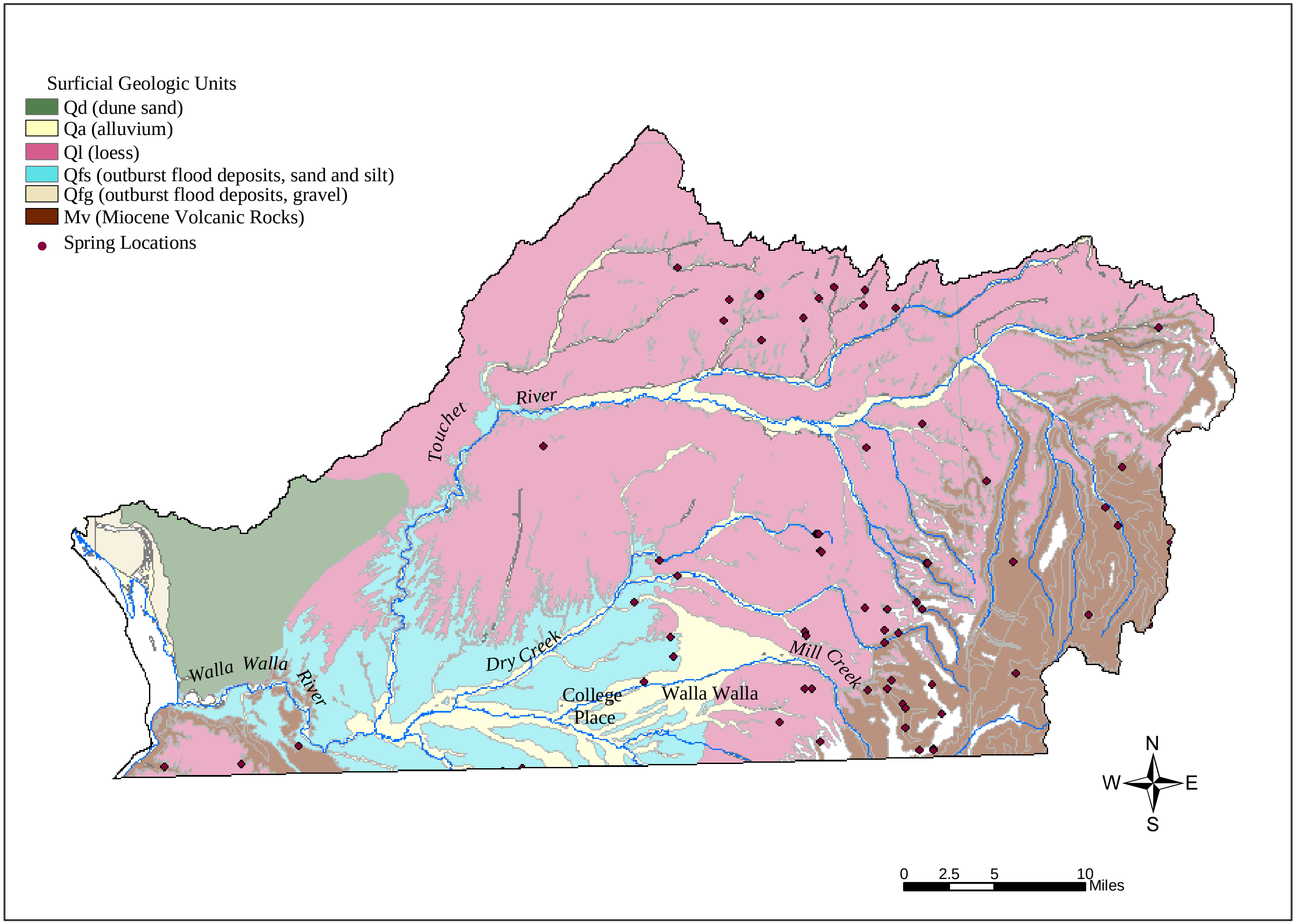

Figure 4. Surficial Geology and Spring Locations of the Walla Walla Watershed.

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Data Collection and Methods of Analysis

The field work for this study spanned a period of approximately four months, July through October 2002. During this time, instream mini-piezometers were installed into the beds of the Walla Walla River, Mill Creek, Yellowhawk Creek, as well as the Touchet River and its tributaries. The seepage run and sample data used in the analysis for this study were collected in August 2002. These activities are discussed in detail below, along with the analysis methods used to evaluate the study results. These are also described in the Quality Assurance Project Plan for this study (LeMoine et al., 2002).

Site locations for the piezometers and seepage runs were determined using a global positioning system (GPS) receiver (Figure 2). The receiver has a reported accuracy of about 50 feet. The latitude and longitude of all data collection sites were entered into a Geographic Information System (GIS) database. River mile designations were determined from 1:24,000 scale topographic quadrangle maps.

Instream Mini-Piezometers

Twenty-three instream mini-piezometers were driven into the streambeds of the rivers and creeks of the Walla Walla watershed to define the vertical hydraulic gradient between the rivers and water-table aquifer (Figure 2). Mini-piezometers were installed along the Walla Walla and Touchet rivers and their tributaries to determine gaining and losing reaches. The 23 mini-piezometers are listed in downstream order in Table 1 for each river basin (Touchet and Walla Walla rivers).

The piezometers for this study were constructed from 7-foot lengths of ½-inch diameter galvanized pipe. One end of the pipe was crimped shut to form a drive point and was then perforated within the bottom 6 inches with several 1/8-inch diameter holes to allow water entry (Figure 5). The upper end of each pipe was threaded and fitted with a standard pipe coupler. The coupler provided a robust “strike” surface and protected the pipe from damage during installation.

The mini-piezometers were hand driven into the streambed, approximately three to five feet from the streambank, using a fence post driver. Each mini-piezometer was driven to a depth of approximately five feet or until downward progress ceased. Installation details are summarized in Table 1. During this study, many of the mini-piezometers could not be installed to a depth of five feet because of the coarse streambed materials. Mini-piezometers could not be installed along the Touchet River south of Prescott up to Luckenbill Bridge because the streambed is primarily composed of bedrock.

A manometer board was used throughout the study to measure differences between water levels in the mini-piezometers and water levels in the river (Figure 5). The manometer has been shown it is capable of reliably detecting water level differences of approximately 0.03 foot or less

Table 1. Physical Descriptions and Locations of Instream Mini-Piezometers in the Walla Walla Watershed, Walla Walla and Columbia Counties, Washington

Well I.D. Tag No.	Stream name	Piezometer Location	Local Number	Site Latitude (dd.mm.ss)	Site Longitude (ddd.mm.ss)	River Mile [1] (miles)	Site Altitude [2] (feet)	Piezometer Stickup Above Streambed (feet)	Piezometer Depth Below Streambed (feet)	Depth to Midpoint of Perforations (feet below streambed)
Touchet River Basin										
AGJ717	N. Fk. Touchet River	near 1628 N. Touchet Rd.	09N/40E-31G	46.13.01	117.50.57	63.7	2400	2.5	4.5	4.25
AGJ716	Wolf Creek	near 521 Wolf Cr. Rd.	09N/39E-36B	46.13.18	117.52.26	4.7	2340	2.3	4.7	4.45
AGJ714	S. Fk. Touchet River	at N. Fork confluence	10N/39E-32K	46.18.04	117.57.30	0.02	1662	4.3	2.7	2.45
AGJ715	Touchet River	50 ft. below NF/SF confluence	10N/39E-32K	46.18.06	117.57.31	54.9	1660	3.5	3.5	3.25
AGJ713	Touchet River	at Dayton City Park	10N/39E-30R	46.18.49	117.58.25	53.8	1615	4.0	3.0	2.75
AGJ722	Touchet River	at Lower Hogeye Rd.	09N/38E-07E	46.16.30	118.06.46	46.2	1310	4.4	2.6	2.35
AGJ721	Coppei Creek	at McCowan Rd. Bridge	09N/37E-25P	46.13.22	118.07.41	5.4	1475	3.5	3.5	3.25
AGJ723	Touchet River	at Hwy 124 Bridge X-ing	09N/37E-07H	46.16.28	118.13.12	40.5	1155	2.2	4.8	4.55
AGJ706	Touchet River	at Hwy 125	09N/36E-05D	46.17.40	118.20.23	34.2	995	4.3	2.7	2.45
AGJ705	Touchet River	at Luckenbill Bridge	09N/34E-32A	46.13.22	118.34.33	17.8	722	2.2	4.8	4.55
AGJ704	Touchet River	at 2nd Bridge	08N/33E-11R	46.10.48	118.38.17	12.8	635	4.7	2.3	2.05
AGJ703	Touchet River	at Cummins Rd.	07N/33E-27L	46.03.26	118.40.04	2.0	442	3.4	3.6	3.35
Walla Walla River Basin										
AGJ720	Mill Creek	at Site M3	06N/37E-02B	46.01.55	118.08.37	19.1	1830	2.4	4.6	4.35
AGJ719	Mill Creek	at 7 Mile Rd. Bridge	07N/37E-16P	46.04.53	118.11.21	14.8	1470	3.6	3.4	3.15
AGJ718	Mill Creek	at 5 Mile Rd. Bridge	07N/37E-37A	46.05.09	118.13.40	12.8	1330	2.4	4.6	4.35
AGJ702	Mill Creek	at Last Chance Rd.	07N/35E-28N	46.03.06	118.26.58	1.7	650	2.4	4.6	4.35
AGJ701	Yellowhawk Creek	at 2505 Cottonwood Rd.	06N/36E-37A	46.02.22	118.19.23	5.0	935	3.9	3.1	2.85
AGJ707	Yellowhawk Creek	at Lower Milton Rd.	06N/35E-01N	46.01.26	118.23.02	1.1	755	3.1	3.9	3.65
AGJ708	Walla Walla River	at Hwy 125	06N/35E-11J	46.00.46	118.23.21	38.6	728	3.4	3.6	3.35
AGJ709	Walla Walla River	at Detour Rd.	07N/35E-31E	46.02.35	118.29.21	32.9	575	2.5	4.5	4.25
AGJ710	Walla Walla River	at McDonald Rd.	07N/34E-33A	46.02.54	118.33.15	29.2	495	4.8	2.2	1.95
AGJ711	Walla Walla River	at Lowden Rd.	07N/34E-29P	46.03.09	118.35.25	27.4	465	4.0	3.0	2.75
AGJ712	Walla Walla River	at Gardenia Farm Rd.	06N/33E-03F	46.01.45	118.40.12	22.7	415	3.0	4.0	3.75

[1] River mile location refers to the site distance, in river miles, from the respective stream mouth as determined from 1:24000 scale USGS topographic maps.

[2] Site altitudes were determined from 1:24000 scale topographic maps and are accurate to +/- 5 to 20 feet, depending on the map contour interval

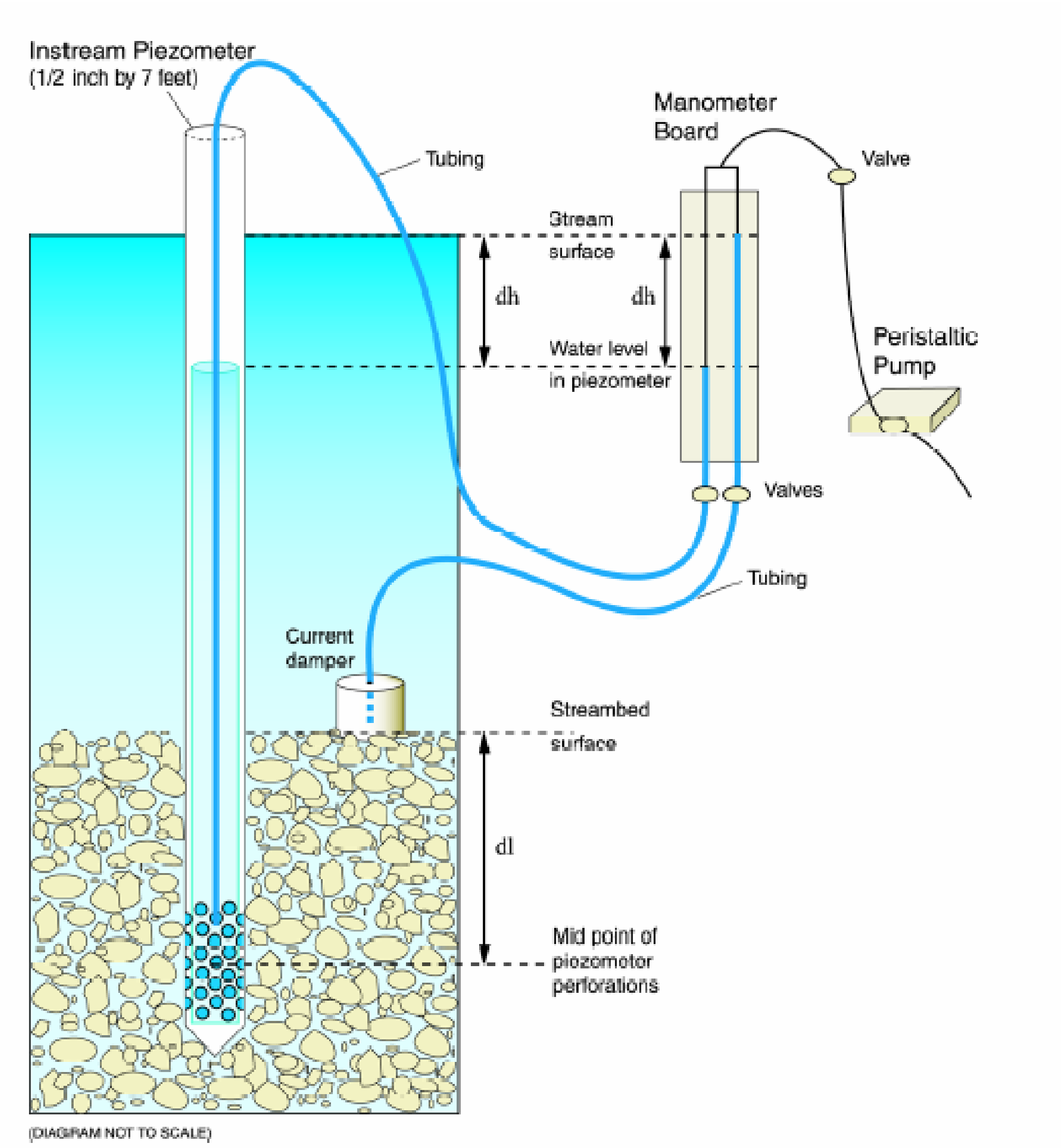

Figure 5. Diagram Showing a Typical Instream Mini-Piezometer Installation and Manometer Board Configuration. From equation 1 in the report, *dh* is the difference between head in the mini-piezometer and river stage, and *dl* is the vertical distance between the streambed and the midpoint of the mini-piezometer perforations. (Figure courtesy of F. William Simonds, U.S. Geologic Survey, Tacoma, WA)

throughout the three-foot working range. Winter et al. (1988) provide a detailed discussion of manometer board construction and use. Comparison measurements were made with an electric tape as shown in Appendix A

The difference in water levels between the mini-piezometer and the river provides an indication of the vertical direction of water flow. When the water level in the mini-piezometer is higher then the river stage, groundwater is discharging to the river in the immediate vicinity of the mini-piezometer. Conversely, when the water level of the mini-piezometer is lower than the river stage, water from the river is seeping into the streambed and recharging groundwater in the immediate vicinity of the mini-piezometer (Figure 5).

Vertical hydraulic gradients between the river and groundwater were calculated from the mini-piezometer and manometer data using the formula

$$iv = dh/dl$$

where

iv is the vertical hydraulic gradient, in units of length per length.

dh is the difference between the mini-piezometer and river stage (mini-piezometer water level – river water level, Figure 5), in units of length.

dl is the vertical distance between the streambed and the midpoint of the mini-piezometer perforations (Figure 5), in units of length.

Negative values of iv indicate loss of water from the river to groundwater (losing reaches), and positive values indicate groundwater discharge into the river (gaining reaches).

During each survey, the mini-piezometers and river were sampled for temperature and specific conductance to provide additional verification of the manometer measurements. In losing reaches, the river temperature and groundwater temperature tend to match closely, and the specific conductance of the two water sources is often very similar. In gaining reaches, groundwater is typically warmer in the winter, or cooler in the summer, than the river, and specific conductance of the river and groundwater may differ significantly (Fryar et al., 2000).

Water temperature and specific conductance were measured at the stream center using a Multiline P4 universal meter and Tetracon 325 conductivity/temperature probe. All field meters were properly maintained and calibrated. The mini-piezometers were purged for approximately five minutes with a peristaltic pump (at a rate of approximately 500 milliliters per minute) prior to sampling. Grab samples were then collected at approximately one-minute intervals as purging progressed, and were evaluated using the above described meters. Water quality values were considered stable when two successive grab samples yielded comparable results (that is, there was less than a 10 percent difference from the mean of the two grab samples for all measurements). Water level and water quality data for the mini-piezometers are summarized in Appendix A.

Seepage Runs

A seepage run was conducted over two days during low-flow conditions in August 2002. During the seepage runs, discharge measurements were made at selected sites along the Touchet River and its tributaries, Mill Creek, Yellowhawk Creek, and other smaller tributary inputs to the Walla Walla River (Figure 2). The increase or decrease in discharge between measurement sites that cannot be accounted for through tributary input or out-of-stream diversions is an estimate of the net volume of water exchanged between the river and groundwater. The seepage measurement sites were arranged in downstream order for each basin and correspond with the piezometer locations (Figure 2). Reaches of the rivers between the measurement sites are termed "seepage reaches" in this report.

To determine the volume of water gained or lost by the river, the seepage data were used in a mass balance calculation as follows.

$$\text{Net seepage gain or loss} = Qd - T - Qu + D$$

where

Qd is the discharge measured at the downstream end of the reach, in ft^3/s.

Qu is the discharge measured at the upstream end of the reach, in ft^3/s.

T is the sum of tributary inflows, in ft^3/s.

D is the sum of irrigation ditch diversions, in ft^3/s.

The result of this equation is the net volume of water entering or leaving the river. The sign of the number indicates if a given seepage reach is gaining water from (positive) or losing water to (negative) groundwater. The data collected during the seepage run is listed in Appendix B

The seepage discharge measurements were made with a Marsh-McBirney Model 201 or a Swoffer Model 2100 current meter using Timber-Fish-Wildlife protocols for bankfull width and depth, and wetted width and depth (Schuett-Hames et al., 1999). Flow measurements were taken in run or glide habitat units or where the streamflow was constant and straight. Site selection for flows were also based on channel morphology, by selecting cross sections uniform in nature to minimize error as much as possible.

Typically during a seepage run, all tributary inflows, as well as irrigation outflows and returns, are measured, so that the discrepancies in the water budget between measuring points reflect only gains or losses through the streambed. Due to the size of the watershed and the complex irrigation network, not all irrigation diversions and returns may have been measured during the August 2002 seepage run.

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Surface Water and Groundwater Interchange

Direct exchanges of water between streams (or rivers) and groundwater occur in three basic ways. Streams can gain water from groundwater inflow through their streambed, they can lose water through their streambed to groundwater, or they may do both, gaining water in some reaches and losing it in others (Winter et al., 1988).

In order for a stream to gain water directly from groundwater, two conditions must exist. First, there must be a saturated connection between the stream and groundwater, and second, the groundwater head adjacent to the stream must be higher than the stream surface (stream stage) (Figure 6A). Water loss from a stream can occur whenever the stream stage exceeds the adjacent groundwater head, regardless of whether the stream and groundwater are connected by saturated materials (Figure 6B) or are separated by a zone of unsaturated material (Figure 6C).

The rate of water exchange between a stream and groundwater depends on several factors, including the vertical hydraulic conductivity of the streambed materials, the vertical hydraulic gradient between the stream and groundwater, and the saturated area of the streambed across which flow occurs. When streams are separated from groundwater by an unsaturated zone, the rate of streamflow loss depends primarily on the stream depth as well as the vertical hydraulic conductivity and geometry of the streambed (Figure 6C).

The simplistic depictions of stream and groundwater interchange shown in Figure 6 are in actuality complicated by the natural heterogeneity of streambed sediments and underlying geologic deposits. Under gaining conditions, lenses or beds of coarse material within finer-grained sediments can preferentially transmit and discharge groundwater to a stream. When lenses or beds of coarse material occur within a losing stream reach, they may coincide with areas of unusually high water loss. In addition, a stream or stream reach may temporarily change from gaining to losing conditions when snowmelt or precipitation runoff temporarily elevates the river stage and causes it to exceed the head in the surrounding groundwater. When the stream stage rises, surface water may be stored in the streambank adjacent to the river, contributing to a local rise in the water table that persists until streamflow returns to a lower level.

In the following discussion, surface water and groundwater exchange processes are evaluated using data provided by the seepage runs and instream mini-piezometers. Seepage runs provide information about the quantity of water being exchanged, and the combination of seepage runs and mini-piezometers provides data to define the spatial distribution of gaining and losing reaches.

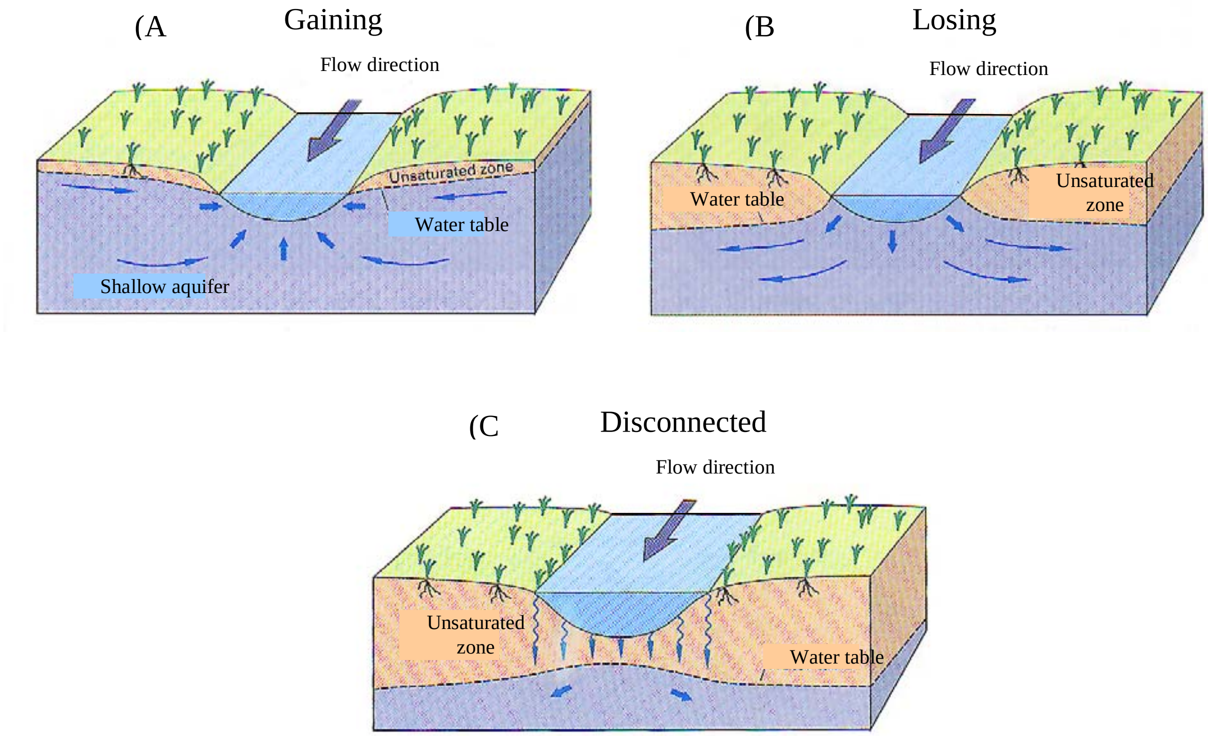


Figure 6. Generalized Depiction of Stream and Groundwater Interchange within Gaining, Losing, and Disconnected Stream Reaches (Winter et al., 1998)

Touchet River

The Touchet River is formed by the confluence of several large creeks draining the northern part of the Walla Walla River basin. The four primary forks, the North Fork Touchet, Wolf Fork, Robinson Fork, and the South Fork Touchet, flow north out of the Blue Mountains and converge southeast of the city of Dayton to form the mainstem Touchet River. At the foot of the mountain slope, the river abruptly changes direction and flows westward to the Eureka Flats passing through the towns of Waitsburg and Prescott, after which it flows southward where it converges with the Walla Walla River at the town of Touchet.

The valleys that dissect the Blue Mountains are mostly narrow, steep gradient canyons with streambeds composed of poorly sorted cobble and gravels. As the North Fork Touchet flows toward Dayton and merges with the South Fork Touchet, the river gradient decreases and the channel becomes broader. The poorly sorted cobble and gravel streambed has increasing amounts of sand. As the Touchet River flows through the valley, the streambed materials grade into poorly sorted coarse gravels and cobbles with sand. West of Prescott, the Touchet River flows over bedrock returning to poorly sorted coarse gravels and cobbles with sand after the river has turned south. The streambed materials alternate between poorly sorted alluvium and bedrock to the mouth of the Touchet River, where it converges with the Walla Walla River.

Seepage run results for the upper reaches of the North Fork Touchet (Reach 1 – R1) indicate the river gains substantial amounts of water as it flows out of the Blue Mountains. The mini-piezometer installed on this fork (AGJ717) consistently had a strong negative vertical gradient ranging from -0.266 to -0.349 ft/ft during the four months it was measured (July – October 2002) as listed in Table 2 and shown in Figure 7. Seepage run results on Wolf Creek (R2) also indicate the creek gains water. The mini-piezometer AGJ716 on Wolf Creek had a negative gradient of -0.048 to -0.065 ft/ft. Although each piezometer indicates the creeks are losing water, there are many small tributaries, seeps, and springs that probably contribute flow to these systems.

As the North Fork converges with the South Fork at the head of the Touchet Valley in reach 3 (R3), seepage run and mini-piezometer data indicate consistent losing conditions as the Touchet River flows across the alluvial deposits at the base of the Blue Mountains. At this point the groundwater probably spreads out as it adjusts to a flatter gradient, lowering the water table in relation to the surface water and creating losing conditions. The two mini-piezometers installed on the Touchet River exhibited increasing negative hydraulic gradients from July through October, ranging from -0.058 to -0.137 ft/ft (AGJ715) and -0.102 to -0.198 ft/ft (AGJ713). Mini-piezometer AGJ714, located at the mouth of the South Fork Touchet (R4), also had a negative vertical gradient for three of the four months it was measured, ranging from -0.012 to -0.037 ft/ft. The vertical gradient reversed to a +0.043 ft/ft, groundwater discharge condition, in September 2002. This piezometer was reported to have very low production.

The Touchet River gains some flow in reach 5 (R5) as it moves west, even though it is bracketed by two piezometers which have negative vertical hydraulic gradients. Mini-piezometer AGJ713 just above the top of the reach had a strong negative gradient, while piezometer AGJ723, at the end of the reach, had a gradient range of -0.037 to -0.046 ft/ft. Mini-piezometer AGJ722,

Table 2. Results of Instream Mini-Piezometer Surveys in the Walla Walla Watershed during 2002

Well I.D.			River	Vertical Hydraulic Gradient [2] (ft/ft)			
Tag No.	Stream name	Piezometer Location	Mile [1]	July 8-12	Aug 6-7	Sept 18-20	Oct 15-17
Touchet River Basin							
AGJ717	N. Fk. Touchet River	near 1628 N. Touchet Rd.	63.7	-0.285	-0.266	-0.346	-0.349
AGJ716	Wolf Creek	near 521 Wolf Cr. Rd.	4.7	-0.058	-0.065	-0.048	-0.058
AGJ714	S. Fk. Touchet River	at N. Fork confluence	0.02	-0.012	-0.014	**0.043**	-0.037
AGJ715	Touchet River	50 ft. below NF/SF confluence	54.9	-0.058	-0.095	-0.125	-0.137
AGJ713	Touchet River	Touchet River @ Dayton City Pk	53.8	-0.102	-0.151	-0.198	-0.185
AGJ722	Touchet River	at Lower Hogeye Rd.	46.2	**0.009**	**0.006**	**0.006**	**0.006**
AGJ721	Coppei Creek	at McCowan Rd. Bridge	5.4	-0.012	-0.025	-0.035	-0.034
AGJ723	Touchet River	at Hwy 124 Bridge X-ing	40.5	-0.037	-0.041	-0.046	-0.046
AGJ706	Touchet River	at Hwy 125	34.2	**0.012**	**0.014**	--	**0.010**
AGJ705	Touchet River	at Luckenbill Bridge	17.8	-0.062	-0.053	-0.054	-0.063
AGJ704	Touchet River	at 2nd Bridge	12.8	-0.005	0.0000	**0.037**	**0.005**
AGJ703	Touchet River	at Cummins Rd.	2.0	**0.039**	**0.030**	**0.021**	**0.033**
Walla Walla River Basin							
AGJ720	Mill Creek	at Site M3	19.1	-0.146	-0.154	-0.180	-0.205
AGJ719	Mill Creek	at 7 Mile Rd. Bridge	14.8	-0.022	-0.022	-0.038	-0.035
AGJ718	Mill Creek	at 5 Mile Rd. Bridge	12.8	-0.090	-0.109	-0.163	-0.090
AGJ702	Mill Creek	at Last Chance Rd.	1.7	**0.016**	-0.005	--	-0.071
AGJ701	Yellowhawk Creek	at 2505 Cottonwood Rd.	5.0	-1.211	-1.105	--	-1.130
AGJ707	Yellowhawk Creek	at Lower Milton Rd.	1.1	-0.014	**0.036**	--	-0.027
AGJ708	Walla Walla River	at Hwy 125	38.6	-0.036	-0.039	--	-0.021
AGJ709	Walla Walla River	at Detour Rd.	32.9	-0.014	-0.009	--	-0.008
AGJ710	Walla Walla River	at McDonald Rd.	29.2	-0.005	**0.008**	**0.008**	-0.005
AGJ711	Walla Walla River	at Lowden Rd.	27.4	-0.004	**0.004**	--	**0.007**
AGJ712	Walla Walla River	at Gardenia Farm Rd.	22.7	**0.471**	**0.440**	--	**0.373**

Bold values indicate groundwater discharge into the stream

[1] River mile location refers to the site distance, in river miles, from the respective stream mouth as determined from 1:24000 scale USGS topographic maps.

[2] Hydraulic gradient = dH/dL where dH is an average of e-tape and manometer board readings for each sampling event and dL is the distance between stream bottom and midpoint of piezometer perforations (all measurements in feet)

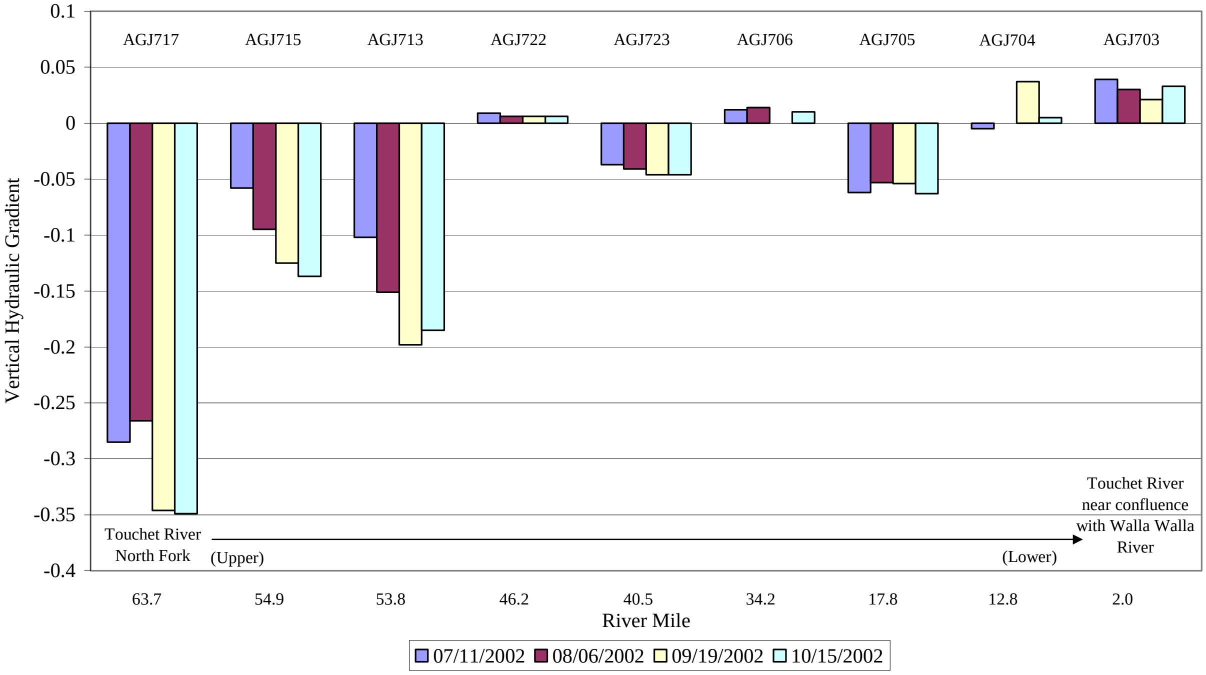


Figure 7. Vertical Hydraulic Gradients for Mini-Piezometers on the Touchet River, July-October 2002

installed near the mouth of Whiskey Creek at the center of the reach, consistently exhibited a small positive hydraulic gradient of +0.006 to +0.009 ft/ft. The positive gradient could be the result of intergravel flow from the tributary. The small increase in flow noted during the seepage run could be attributed to the inflow of Coppei Creek and other small tributaries, as well as the wastewater treatment plant at Dayton.

As the river continues west, downriver of mini-piezometer AGJ723, it losses a considerable amount of flow. Streambed materials in this portion of the river are composed of poorly sorted coarse gravels and cobbles with sand. Mini-piezometer AGJ706, near the center of reach 7 (R7), did exhibit a small positive gradient, ranging from +0.01 to +0.014 ft/ft. As with piezometer AGJ722, AGJ706 was installed near the mouth of a small tributary. Near the end of this reach and the upper portion of reach 8 (R8), the streambed is primarily bedrock. River flows showed little change as it flowed over the bedrock. Flows decreased at mini-piezometer AGJ705 where the streambed materials returned to the coarse gravels and cobbles. Data from this piezometer consistently had a negative gradient, ranging from -0.053 to -0.063 ft/ft.

The vertical hydraulic gradient in the next mini-piezometer (AGJ704) was zero in August, suggesting little or no exchange of water between the surface water and groundwater. This corresponds with the seepage run data which indicates that the river lost a slight amount of water in this reach (R9). Gradient data collected from this piezometer for the other months shifted from a negative -0.005 ft/ft in July to a positive gradient +0.037 ft/ft (September) and +0.005 ft/ft (October).

Seepage run data indicate that the river loses substantial amounts of water in reach 10 (R10)**,** which is presumably accounted for by a number of irrigation diversions that occur in this reach. Mini-piezometer (AGJ703), located at the end of the reach, consistently had a positive vertical hydraulic gradient which ranged from +0.021 to +0.39 ft/ft, indicating that groundwater is discharging to the river. In this area, the water table is at or near river level (Newcomb, 1965) as the old gravel and clays that fill the syncline thins. Recent alluvium also has been deposited as a broad alluvial fan at the mouth of the Touchet River.

Water temperature and specific conductance were also measured at the time that water levels were recorded and vertical hydraulic gradients were determined (see Appendix A). On the Touchet River and its tributaries, surface water temperatures ranged from a high of 15.7 to 28.3ºC in July 2002 to a low of 5 to 11ºC in October 2002. Groundwater temperatures ranged from 13.8 to 19.1ºC in July decreasing to 6.4 to 14.7ºC in October. River and groundwater temperatures are shown in Figure 8 in relation to the vertical hydraulic gradients for each piezometer. Specific conductance measurements were more consistent over the four-month period. Average concentrations in the river ranged from 65 to 129 µS/cm@25ºC and 67 to 187 µS/cm@25ºC in the groundwater. Piezometer AGJ703 is the exception, with an average specific conductance of 561 µS/cm@25ºC. Figure 9 shows specific conductance measurements in relation to the vertical hydraulic gradient for each piezometer.

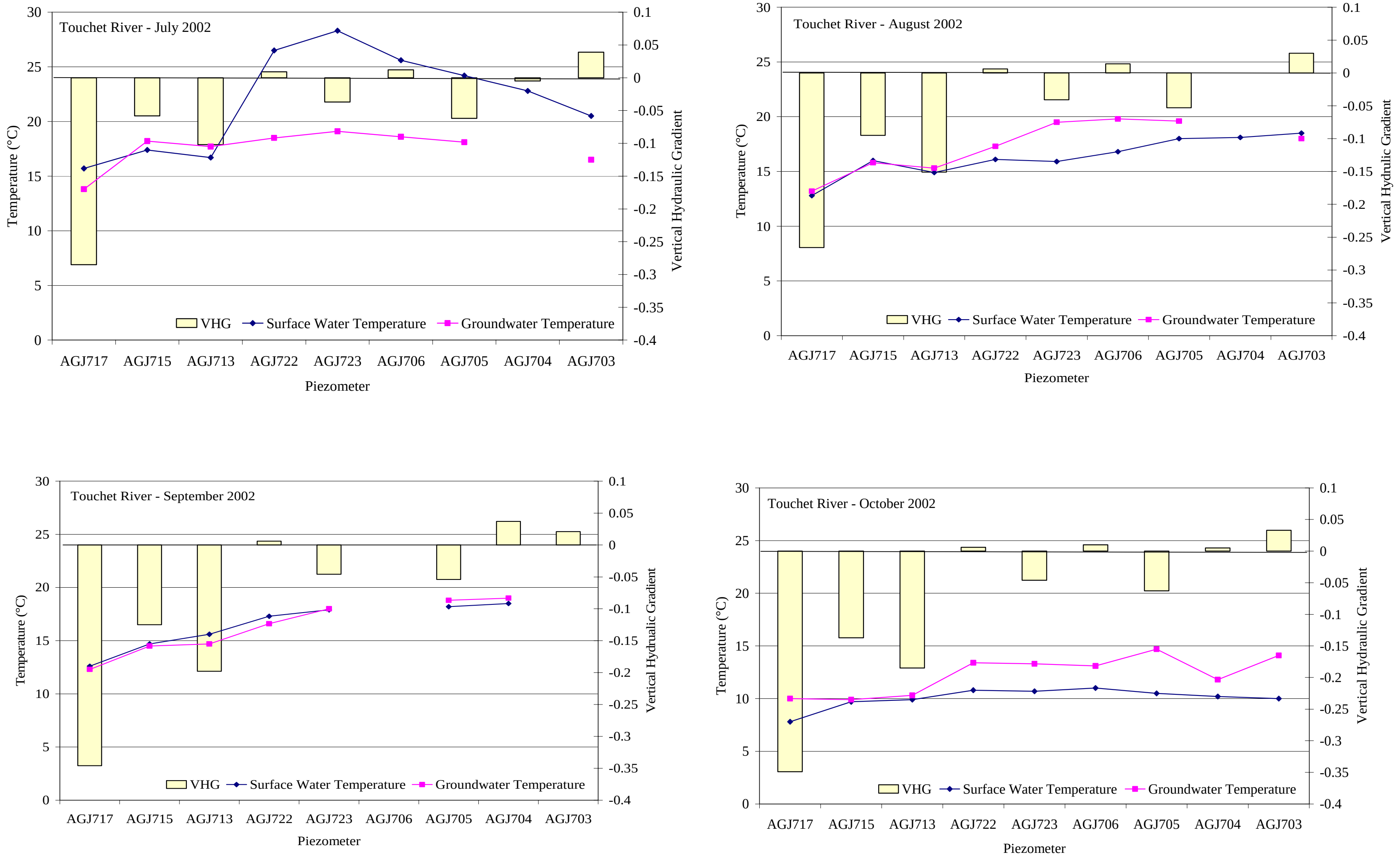


Figure 8. Comparison of Surface Water and Groundwater Temperatures (ºC) to Vertical Hydraulic Gradients on the Touchet River

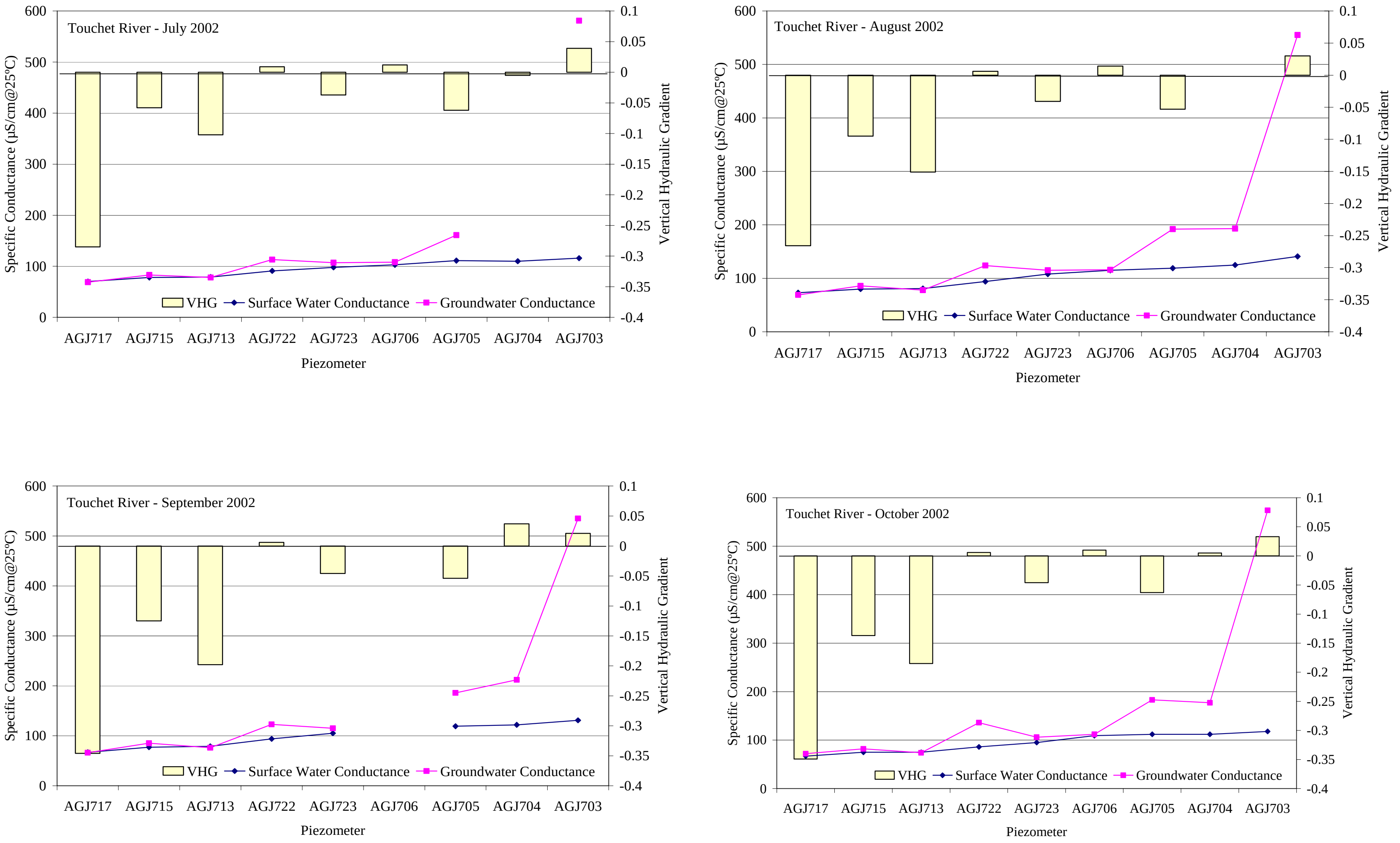


Figure 9. Comparison of Surface Water and Groundwater Specific Conductance (µS/cm@25ºC) to Vertical Hydraulic Gradients on the Touchet River

Mill Creek

Mill Creek originates in the central part of the Blue Mountains and is the largest of the continuously flowing tributaries. Flowing west from its headwaters, it turns southwest passing through northeastern Oregon before turning northwest toward Walla Walla. In the lower part of its mountain canyon, Mill Creek flows across coarse alluvial deposits. Mill Creek gently curves west rounding Prospect Point Ridge.

East of the city of Walla Walla, a flood control structure was built on Mill Creek to divert portions of its flow into Yellowhawk Creek, Garrison Creek, and Bennington Lake from May through October. Mill Creek's remaining flow passes through the city of Walla Walla in an engineered concrete channel. Yellowhawk and Garrison creeks flow southwestward off the south slope of the Mill Creek alluvial fan. The creeks flow is augmented by spring-fed branches (Newcomb, 1965). Yellowhawk Creek converges with the Walla Walla River south of College Place. Garrison Creek enters the Walla Walla River west of Mojonnier. Mill Creek converges with the Walla Walla River downstream of the city, near the historical Whitman Mission. The lower portions of Mill Creek and the Walla Walla River flow across the Walla Walla alluvial fan which is composed of gravel and some silt. The large rivers and small creeks flow through alluvium channels between the outburst flood deposits of the Touchet Beds.

Seepage run results for Mill Creek (R11) indicate that the creek gains water in its mountain headwaters. Many small mountain tributaries and springs probably contribute to Mill Creek's flow. Newcomb (1965) reported that Mill Creek has a baseflow in summer of about 40 to 50 cfs coming from springs where the canyons reach down to the regional water table or to some of the zones of perched groundwater deep in the basalt. Flow decreases near the state line where there is a water intake to provide drinking water for the city of Walla Walla, and the creek passes over the unconsolidated deposits underlying the upper parts of the valley floor. The three instream mini-piezometers installed in the upper part of the Mill Creek valley in reach 11 (R11) had negative vertical hydraulic gradients which ranged from -0.146 to -0.205 ft/ft (AGJ720), -0.022 to -0.038 ft/ft (AGJ719), and -0.090 to -0.163 ft/ft (AGJ718), as shown in Figure 10.

Past the diversion, Mill Creek has very little water as it flows through the city of Walla Walla in a concrete channel. Beyond the city, the creek returns to a natural alluvial channel. Mini-piezometer AGJ702 located in reach 12 (R12) of lower Mill Creek had a small positive vertical hydraulic gradient in July (+0.016 ft/ft) and negative gradients in August (-0.005 ft/ft) and October (-0.071 ft/ft). Cold and Doan creeks enter Mill Creek just before is converges with the Walla Walla River.

On Mill Creek, surface water temperatures ranged from 15.8 to 21.5ºC in July 2002 to 6.2 to 11.7ºC in October 2002. Groundwater temperatures ranged from a high of 13.3 to 18.4ºC in July decreasing to 10.2 to 13.6ºC in October. River and groundwater temperatures are listed in Appendix A and shown in Figure 11 in relation to the vertical hydraulic gradients for each piezometer. Specific conductance measurements were more consistent over the four-month period. Average specific conductance in upper Mill Creek was 77 µS/cm@25ºC in surface water and 82 µS/cm@25ºC in groundwater. Specific conductance increased in lower Mill Creek from an average of 386 µS/cm@25ºC in surface water and 287 µS/cm@25ºC in groundwater. Figure 12 shows specific conductance measurements in relation to the vertical hydraulic gradient for each piezometer.

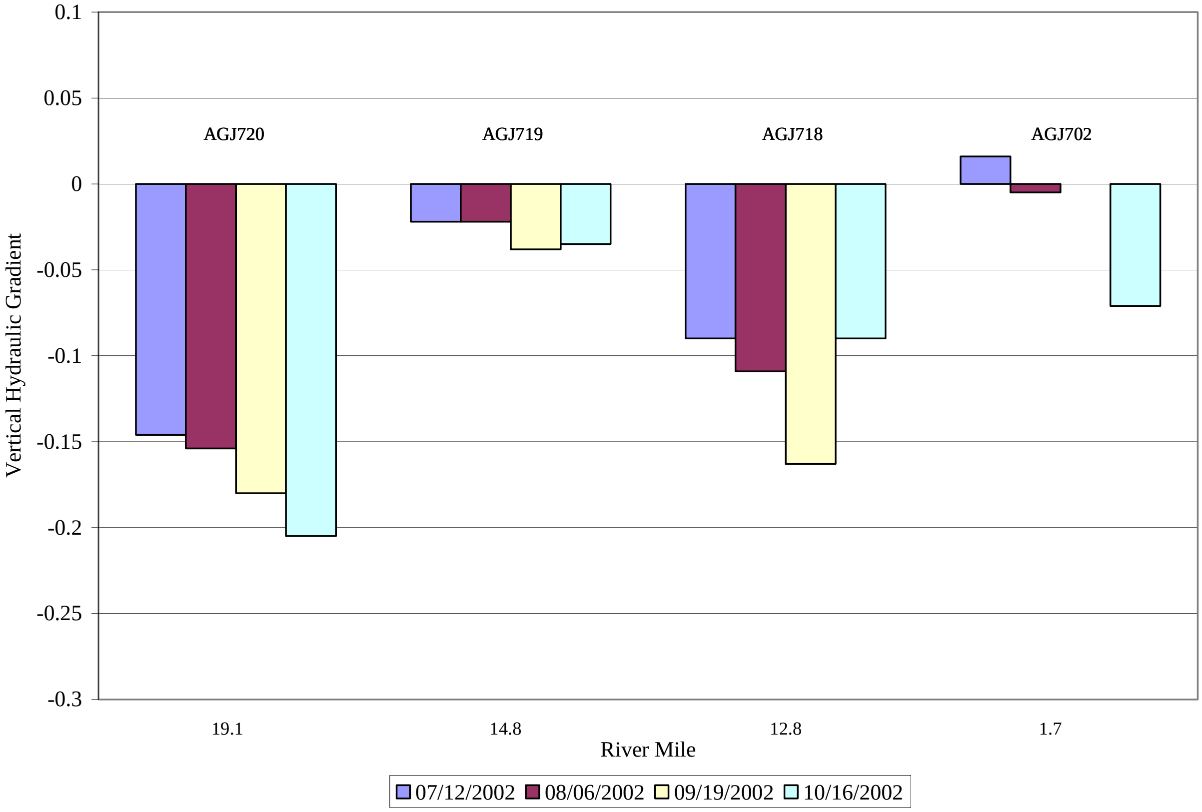


Figure 10. Vertical Hydraulic Gradients for Mini-Piezometers on Mill Creek, July-October 2002

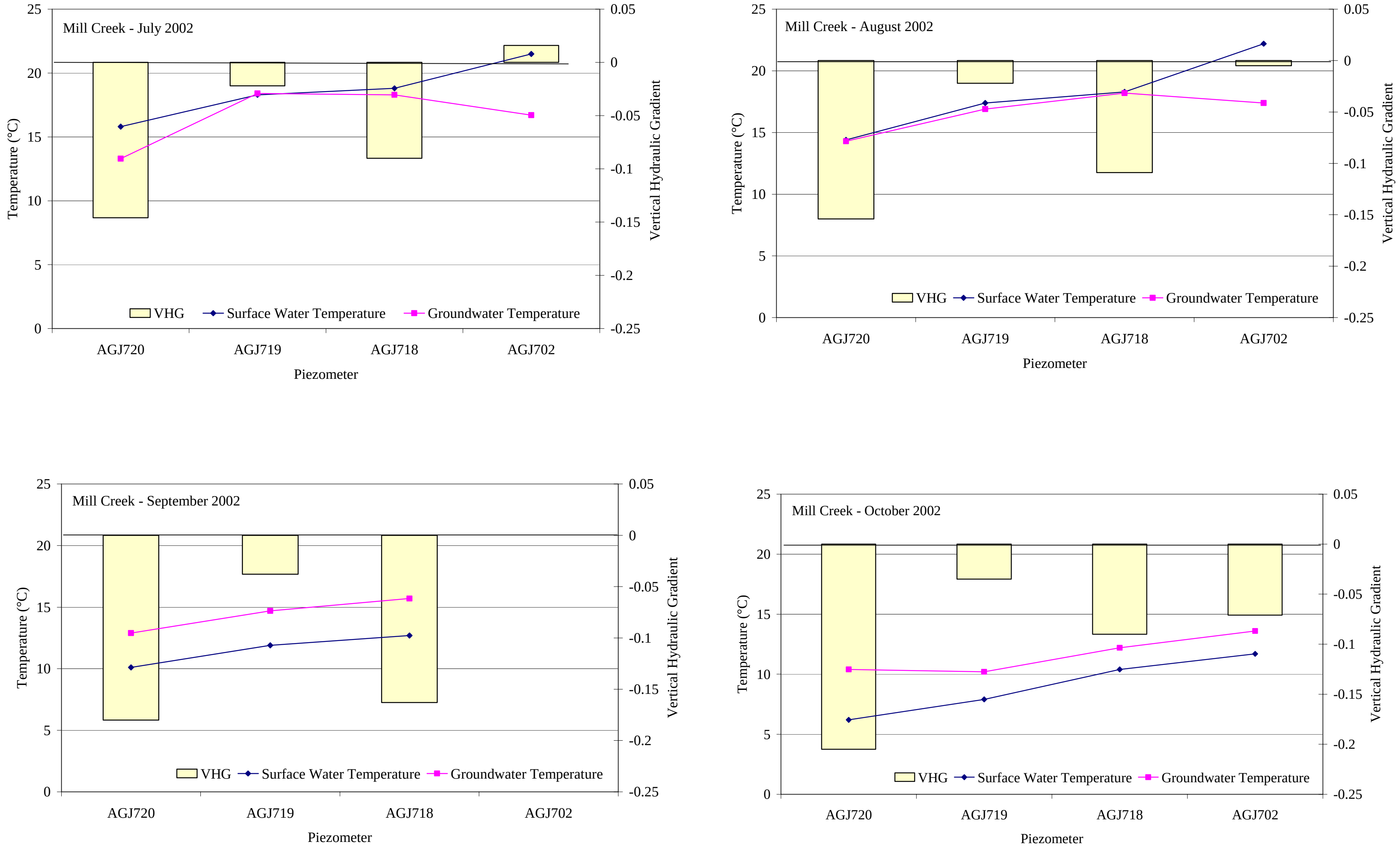


Figure 11. Comparison of Surface Water and Groundwater Temperatures (ºC) to Vertical Hydraulic Gradients on Mill Creek

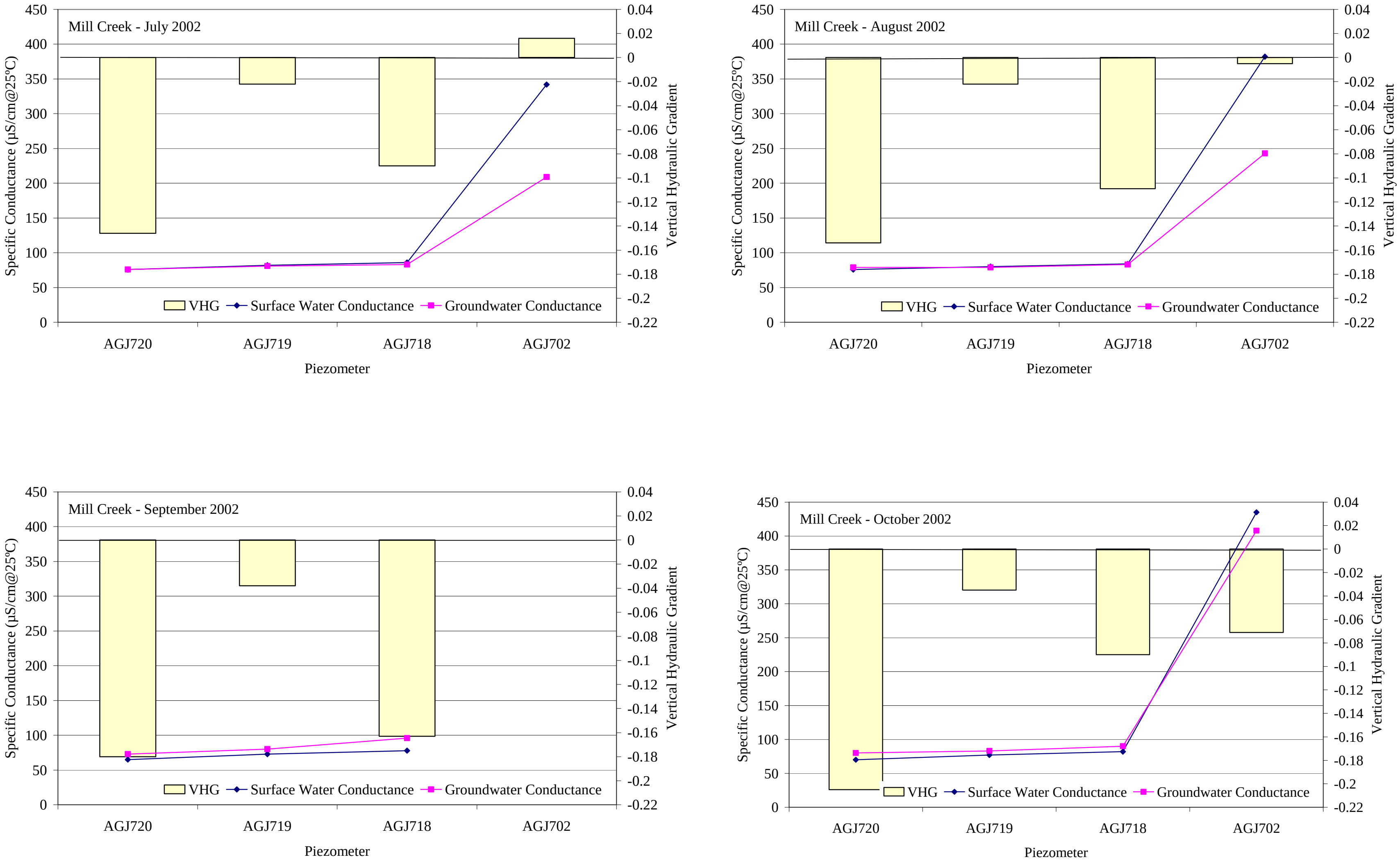


Figure 12. Comparison of Surface Water and Groundwater Specific Conductance (µS/cm@25ºC) to Vertical Hydraulic Gradients on Mill Creek

Yellowhawk Creek

Yellowhawk Creek flows southwestward off the south slope of the Mill Creek alluvial fan. At times the creeks flow is augmented by spring-fed branches (Newcomb, 1965).

Seepage run results in August 2002 for Yellowhawk Creek (R13) indicate that the creek lost a large amount of its flow between the diversion and when it discharges to the Walla Walla River south of College Place. The vertical hydraulic gradient measured in mini-piezometer AGJ701 ranged from -1.105 to -1.211 ft/ft. Newcomb (1965) observed that as the gravel fan widens, the groundwater spreads out and adjusts itself to a flatter gradient, with the water table below the level of adjacent surface water in places. In these areas where the water table is lower, streams were observed to lose substantial amounts of water to the gravel. The infiltrated water moves downslope until it intersects the surface, creating a zone of springs west of Walla Walla and College Place. Mini-piezometer AGJ707, located near the mouth of Yellowhawk Creek, had a much smaller vertical gradient which ranged from -0.014 ft/ft in July, reversing to +0.036 ft/ft in August and back to -0.027 ft/ft in October.

Surface water temperatures measured on Yellowhawk Creek ranged from 18.4ºC in July to 8.7ºC in October 2002. Groundwater temperatures were not measured in the two piezometers during the monitoring period. Average specific conductance measurements at piezometer AGJ701 were 94 µS/cm@25ºC in surface water and 95 µS/cm@25ºC in groundwater. Specific conductance increased in lower Yellowhawk Creek at piezometer AGJ707 to an average of 131 µS/cm@25ºC in surface water and 638 µS/cm@25ºC in groundwater.

Walla Walla River

The Walla Walla River originates in the southern part of the Blue Mountains in Oregon. It is formed by the confluence of the South and North forks, which flow southwest from the mountains and converge just prior to turning north and flowing toward the state line. At Milton-Freewater (Oregon), the river divides into the mainstem and the Little Walla Walla River. Below where the mainstem turns westward in the swale between the alluvial fans of the Walla Walla River and Mill Creek, it is rejoined by the Little Walla Walla River, Mill Creek, and many spring-fed creeks. The Walla Walla follows a normal meandering flow through a valley section that reaches past the mouth of the Touchet River.

As with Mill Creek, the distribution of coarse and fine materials within the coalescent alluvial fans of the Walla Walla basin influences the movement of groundwater. In the upper portions of the basin to the state line area, the shallow aquifer is composed chiefly of coarse gravel which transmits water quite readily. Mini-piezometer AGJ708, which was installed just north of the Washington-Oregon state line, had a negative vertical hydraulic gradient ranging from -0.021 to -0.039 ft/ft as shown in Figure 13.

The lower parts of the valley are flatter and underlain more by silt and fine-grained deposits of the “old clay” which cannot transmit water as readily. This results in a portion of the gravel aquifer flow discharging to surface springs (Newcomb, 1965). Three mini-piezometers installed between Mill Creek and Dry Creek displayed smaller vertical gradients ranging from -0.008 to -0.014 ft/ft in piezometer AGJ709, to reversing directions in piezometers AGJ710 (-0.005 to +0.008 ft/ft) and AGJ711 (-0.004 to +0.007 ft/ft).

The Walla Walla River appears to gain the most groundwater near its confluence with the Touchet River where the permeability and size of the gravel aquifer progressively decreases. Mini-piezometer AGJ712, which was installed in the Walla Walla River between Pine Creek and the Touchet River, had a strong positive vertical gradient which ranged from +0.373 to +0.471 ft/ft. Flow measurements were not collected for the Walla Walla River in August 2002.

Surface water temperatures for the Walla Walla River ranged from a high of 18.8 to 28ºC in July 2002, decreasing to 8.5 to 10.6ºC in October 2002. Groundwater temperatures ranged from 16.5 to 20.3ºC in July decreasing to 13 to 15.2ºC in October. River and groundwater temperatures are listed in Appendix A and shown in Figure 14 in relation to the vertical hydraulic gradients for each piezometer. Specific conductance measurements in the Walla Walla River averaged 119 µS/cm@25ºC at mini-piezometer AGJ708, increasing to an average of 357 µS/cm@25ºC at piezometer AGJ712. Average specific conductance measurements for groundwater from the five mini-piezometers were as follows: 150 µS/cm@25ºC (AGJ708), 950 µS/cm@25ºC (AGJ709), 266 µS/cm@25ºC (AGJ710), 211 µS/cm@25ºC (AGJ711) and increasing to 1296 µS/cm@25ºC (AGJ712). Figure 15 shows specific conductance measurements in relation to the vertical hydraulic gradient for each piezometer.

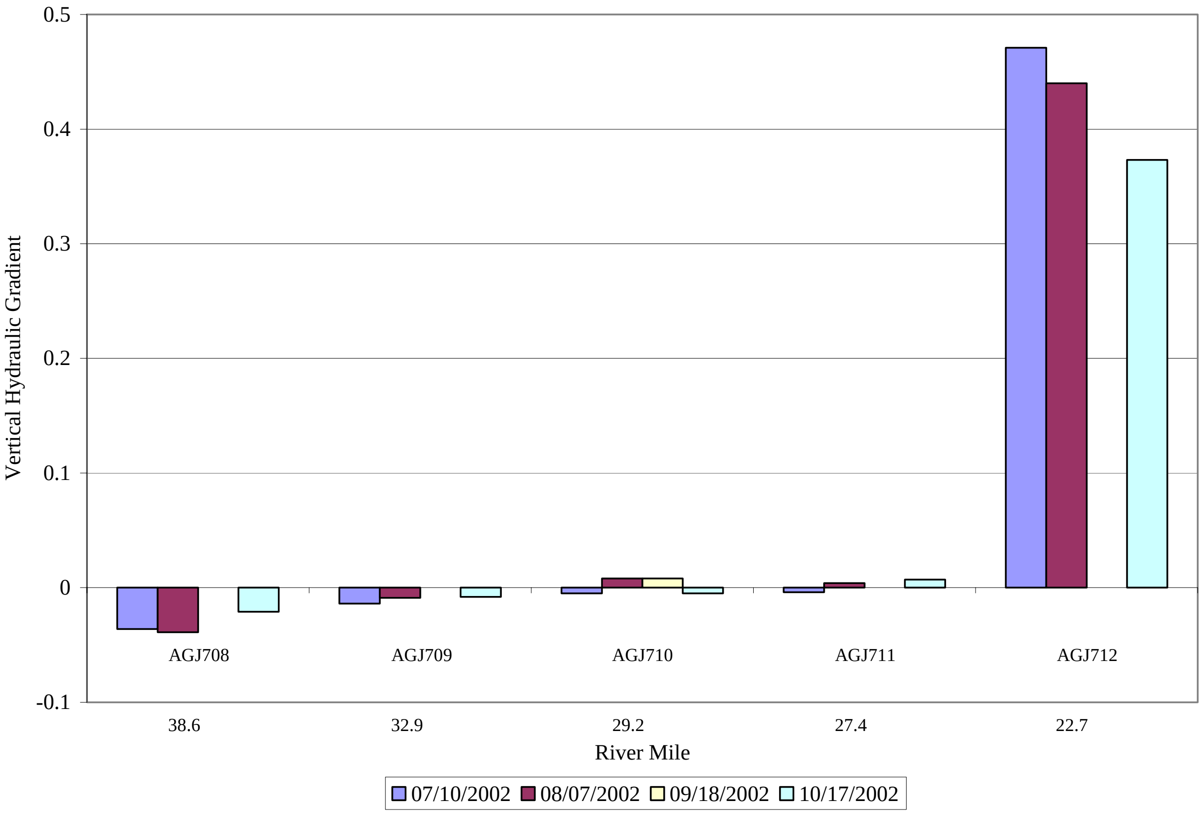
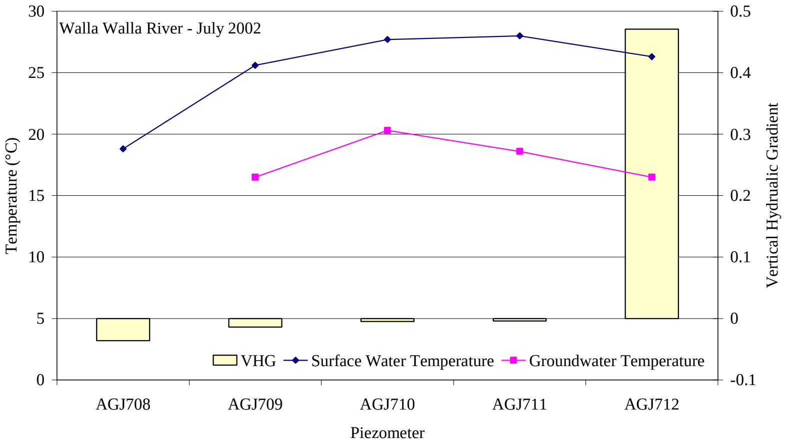
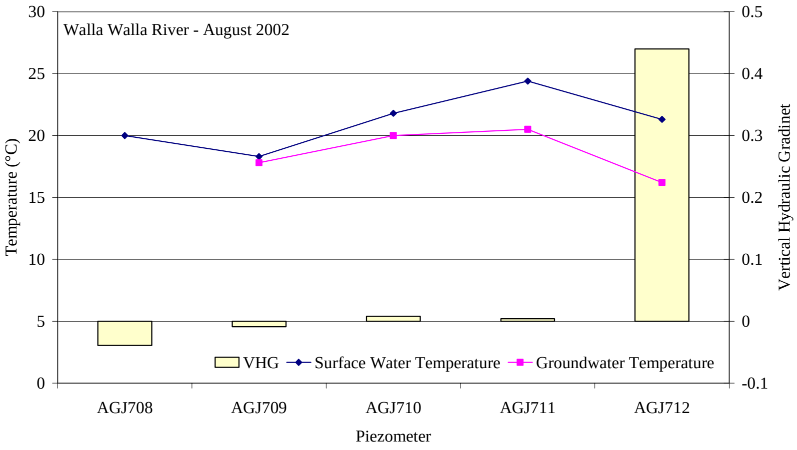


Figure 13. Vertical Hydraulic Gradients for Mini-Piezometers on the Walla Walla River, July-October 2002





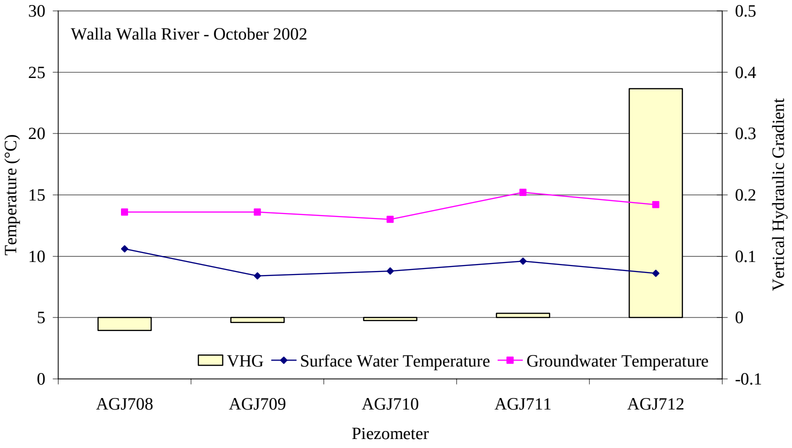


Figure 14. Comparison of Surface Water and Groundwater Temperatures (ºC) to Vertical Hydraulic Gradients on the Walla Walla River

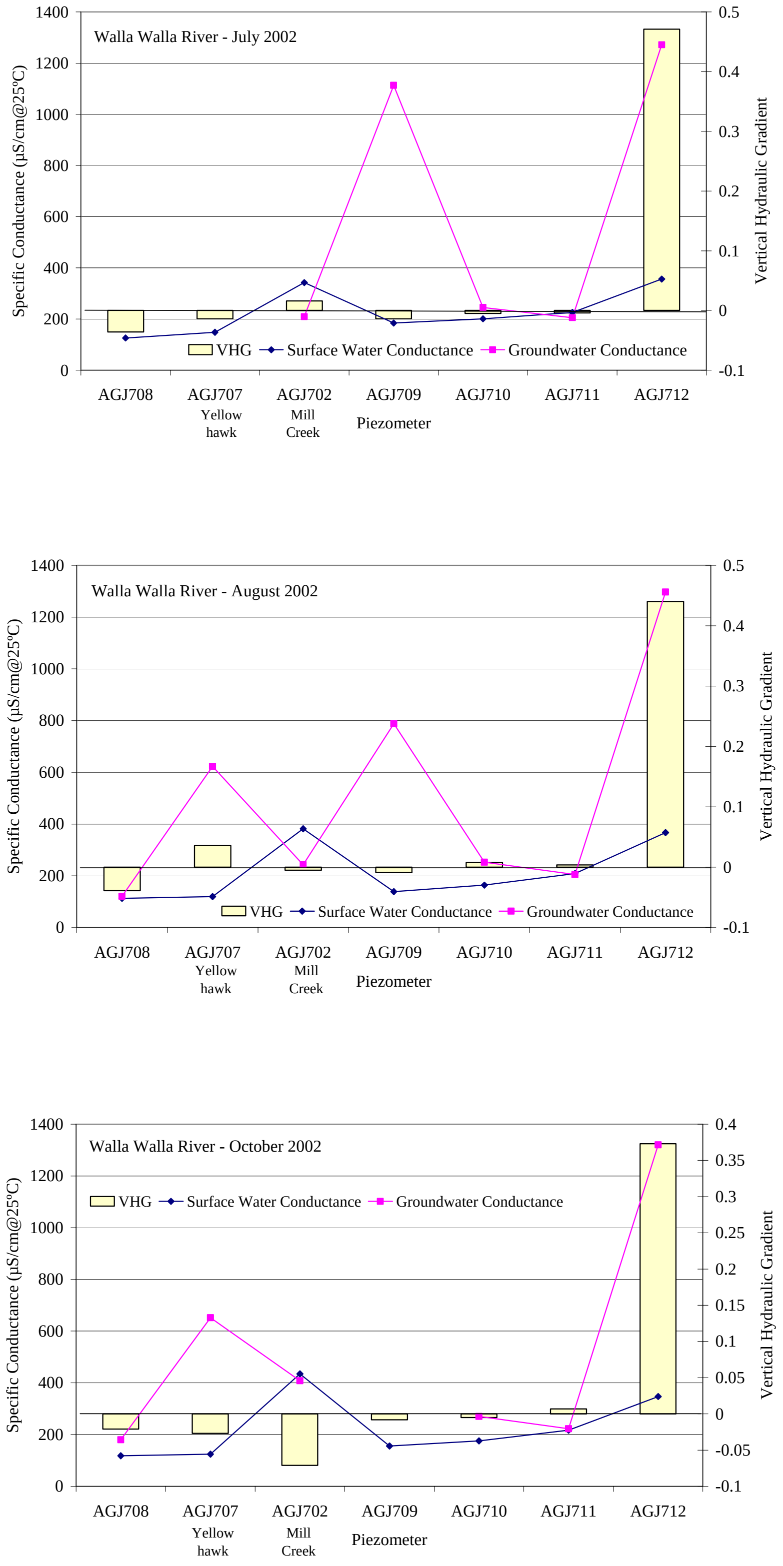


Figure 15. Comparison of Surface Water and Groundwater Specific Conductance (µS/cm@25ºC) to Vertical Hydraulic Gradients on the Walla Walla River

Water quality data were also collected from four mini-piezometers, three on the lower reaches of the Walla Walla River (AGJ710, AGJ711, and AGJ712) and one (AGJ703) near the mouth of the Touchet River. Samples were collected and analyzed for chloride, nutrients (nitrate-nitrite, total persulfate nitrogen, ammonia, phosphorus, and ortho-phosphate), total organic carbon, dissolved organic carbon, and fecal coliform bacteria. Surface water samples were collected multiple times between June and October 2002. Groundwater samples were collected up to two times during the same period. Table 3 shows a comparison of groundwater and surface water quality data.

Chloride concentrations in mini-piezometers AGJ710 and AGJ 711 were 8.10 and 8.15 mg/L, respectively. Surface water concentrations at the time the piezometers were sampled were 3.65 mg/L and 9.01 mg/L, respectively, with a combined range of 3.65 to 9.55 mg/L over the five months that samples were collected. Chloride concentrations increased to 84 mg/L in mini-piezometer AGJ712, with a surface water concentration of 13.7 mg/L and a range of 7.83 to 18.1 mg/L. The chloride concentration in mini-piezometer AGJ703 was 14.8 mg/L, and in surface water was 1.5 mg/L with a range of 1.5 to 3.76 mg/L. Chloride concentrations are shown in Figure 16.

Nitrate+nitrite-N was not detected in groundwater samples collected from mini-piezometer AGJ710, while the average concentration in surface water was 0.107 mg/L. Nitrate-nitrite-N was detected in piezometer AGJ711 in October at a concentration of 0.016 mg/L. The average surface water concentration at this station between June and October was 0.135 mg/L. Nitrate-nitrite-N concentrations increased at station AGJ712 to an average of 1.6 mg/L in groundwater and 0.233 mg/L in surface water. At station AGJ703, on the Touchet River, the average nitrate-nitrite-N concentrations in groundwater was 5.18 mg/L and in surface water was 0.059 mg/L. Nitrate+nitrite-N concentrations are shown in Figure 17.

Total persulfate nitrogen concentrations at mini-piezometers AGJ710 and AGJ711 averaged 0.087 mg/L and 0.179 mg/L, respectively, and in surface water had an average range of 0.216 mg/L to 0.246 mg/L at the two stations. Overall, values of total persulfate nitrogen in mini-piezometers AGJ712 and AGJ703 closely followed those of nitrate+nitrite-N with average concentrations of 1.695 mg/L and 4.99 mg/L, respectively. Total persulfate nitrogen concentrations in the surface water at these two stations had average concentrations of 0.469 mg/L and 0.248 mg/L, respectively. Total persulfate nitrogen concentrations are shown in Figure 18.

Table 3. Summary of Water Quality Data for Instream Piezometers and Streams within the Walla Walla River Watershed

		Chloride (mg/L)		Nitrate-Nitrite (mg/L)		Total Persulfate Nitrogen (mg/L)		Ammonia (mg/L)		Phosphorus (mg/L)		Ortho-Phosphate (mg/L)		Total Organic Carbon (mg/L)		Dissolved Organic Carbon (mg/L)		Fecal Coliform (#/100mL)	
Well I.D. Tag No.	Date	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water	Stream	Ground water
AGJ710	6/26/02	8.75																49	
	7/10/02	9.29																43	
	7/31/02	3.85		0.072		0.216		0.02		0.111		0.0994						84	
	8/7/02				0.01 U		0.073		0.014		0.139		0.0348						1 U
	8/15/02	4.22																5	
	9/5/02	3.83		0.104 J		0.19		0.01 U		0.095		0.0693						47 J	
	9/18/02	3.65	8.02	0.145	0.01 U	0.241	0.102	0.01 U	0.016	0.1	0.157	0.0672	0.02		2.4		1.6	340 J	
	10/17/02	8.2																23	
AGJ711	6/26/02	9.34		0.308		0.504		0.049		0.109		0.08						80	
	7/10/02	9.55		0.118		0.274		0.022		0.1		0.0732						120	
	7/31/02	5.78		0.011		0.154		0.01 U		0.124		0.116		1.9		1.7		20	
	8/7/02				0.01 U		0.206		0.147		0.26		0.027						1 U
	8/15/02	6.72		0.028		0.155		0.016		0.138		0.103						16	
	9/5/02	4.8		0.01 UJ		0.099		0.01 U		0.11		0.0831		1.7		1.6		49	
	9/18/02	3.98		0.059		0.16		0.01 U		0.098		0.0731		1.6		1.6		87	
	10/17/02	9.01	8.15	0.284	0.016	0.376	0.151	0.01 U	0.0987	0.081	0.144	0.0507	0.012	1.7	1.8	1.8	1.6	6	
AGJ712	6/26/02	16		0.361		0.66		0.032		0.166		0.105		2.9		2.7		890 J	
	7/10/02	14		0.246		0.492		0.037		0.156		0.102		2.5		2.3		540	
	7/31/02	18.1		0.312		0.628		0.031		0.214		0.18		3.5		3.5		1300	
	8/7/02				1.6		1.69		0.01 U		0.119		0.0901						1 U
	8/15/02	16.5		0.286		0.551		0.01 U		0.146		0.129		2.9		2.6		120	
	9/5/02	13.2		0.213 J		0.396		0.01 U		0.149		0.113		2.6		2.4		69	
	9/18/02	7.83		0.074		0.244		0.01 U		0.142		0.11		2.6		2.5		160	
	10/17/02	13.7	84	0.141	1.6	0.312	1.7	0.01 U	0.01 U	0.097	0.142	0.0602	0.0815	3.4	3	3.2	3	3 U	
AGJ703	6/25/02	1.17		0.023		0.195		0.021		0.087		0.0607						290 J	
	7/9/02	1.51		0.026		0.199		0.016		0.082		0.0559						230	
	7/29/02	1.93		0.03		0.222		0.011		0.105		0.0881						1800 J	
	8/6/02																		
	8/7/02				5.44		5.44		0.01 U		0.104		0.026						1 U
	8/13/02	1.99		0.127		0.338		0.016		0.082		0.0576						62	
	9/2/02	3.76		0.08 J		0.273		0.011		0.087		0.0559						160	
	9/17/02	1.9		0.067		0.262		0.01 U		0.075		0.0498						72	
	9/19/02																		
	10/15/02	1.5																26	
	10/16/02																		
	10/17/02		14.8		4.99/5.12		4.41/5.12		0.01 U		0.057/0.061		0.022/0.024		2.2/2.1		2.2/2.1		

Surface water data provided by Ecology's Water Quality Studies Unit of the Environmental Assessment Program.

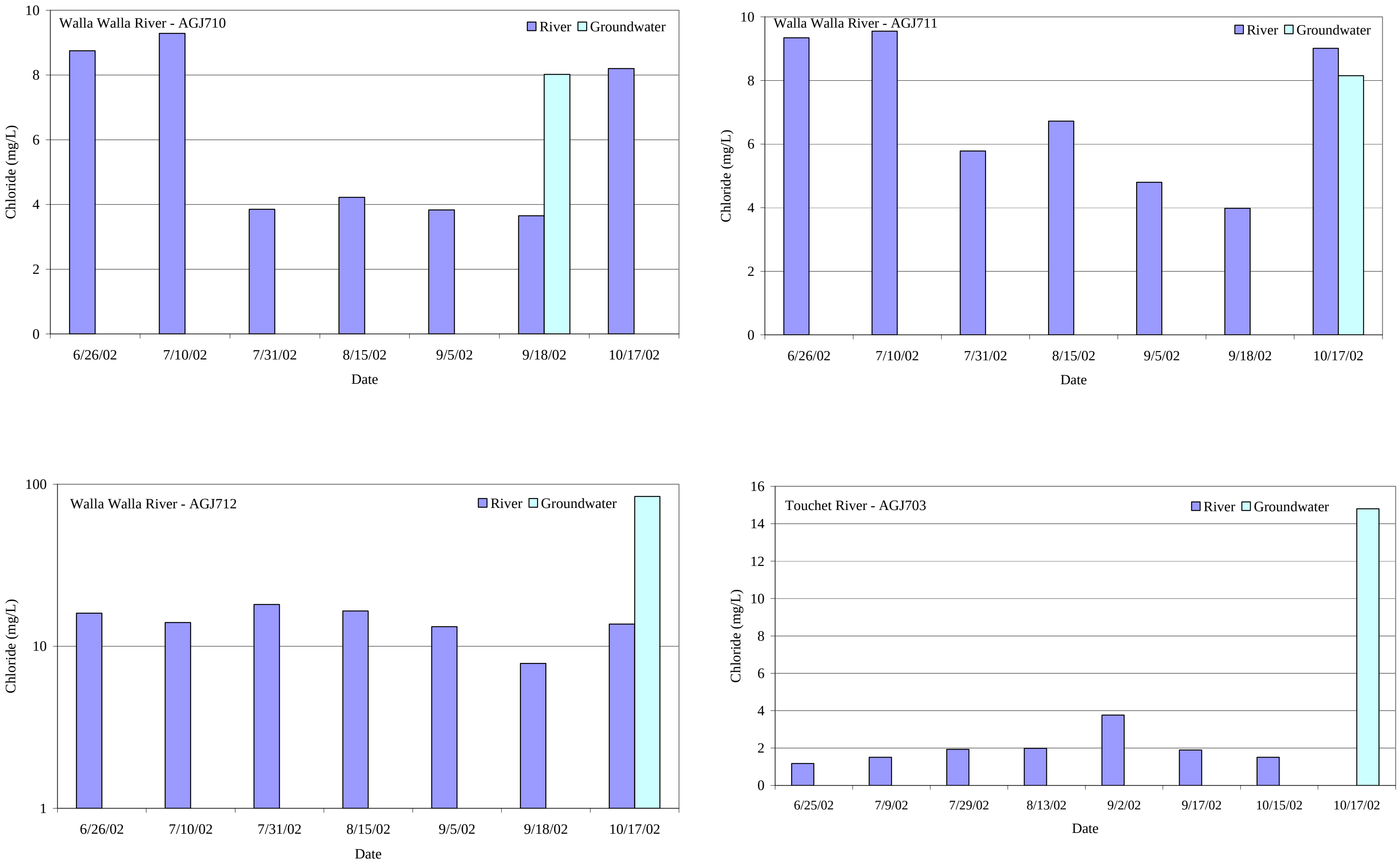
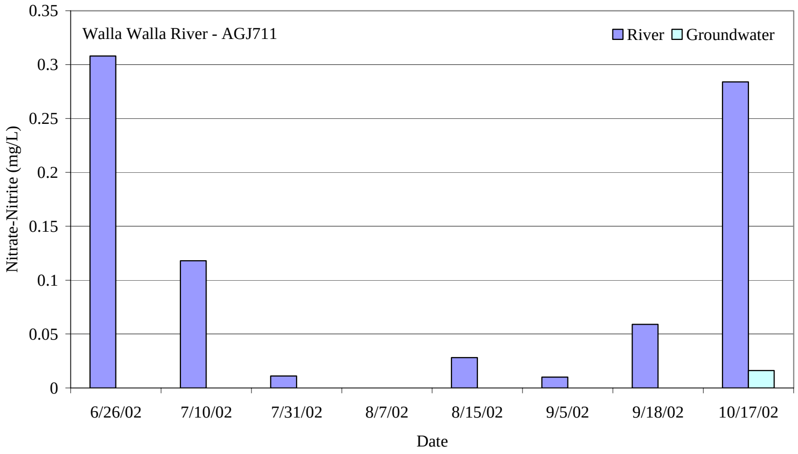
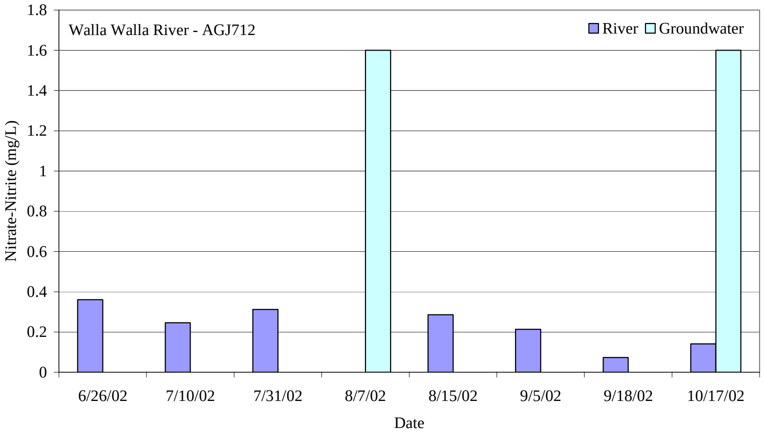


Figure 16. Comparison of Surface Water and Groundwater Chloride Concentrations (mg/L)





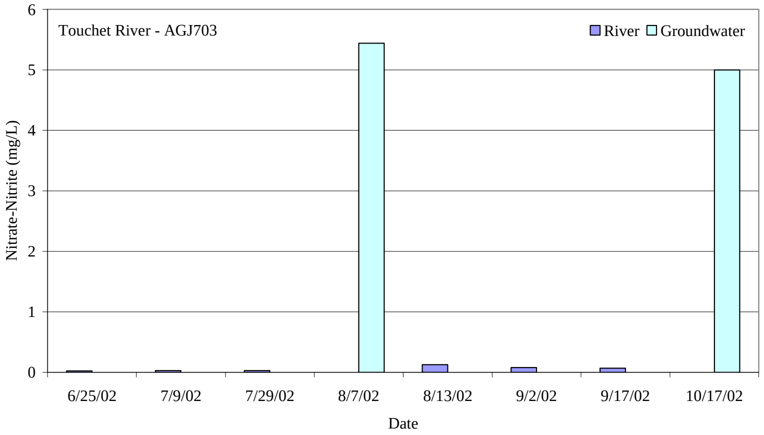


Figure 17. Comparison of surface water and groundwater Nitrate-Nitrite-N Concentrations (mg/L)

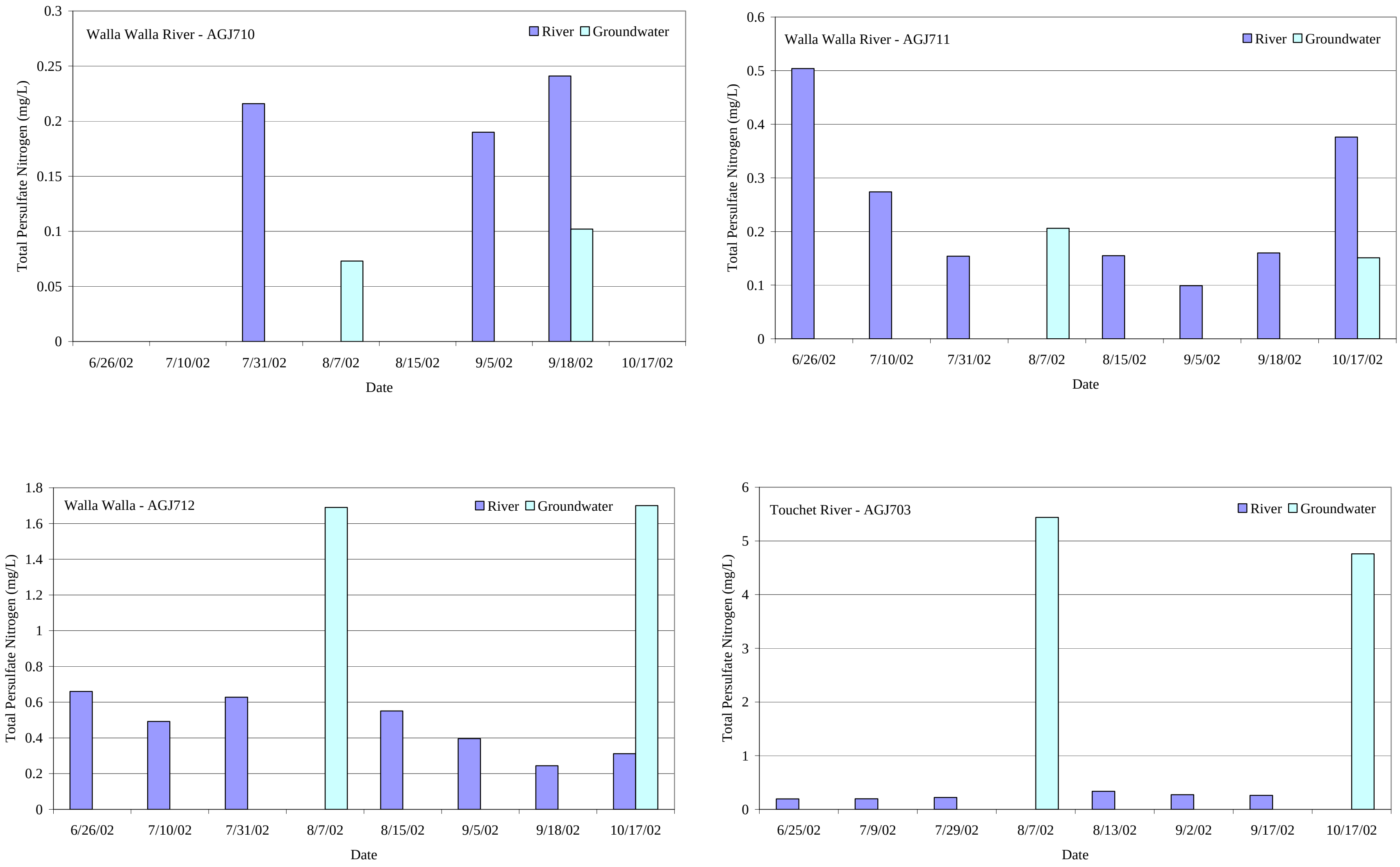
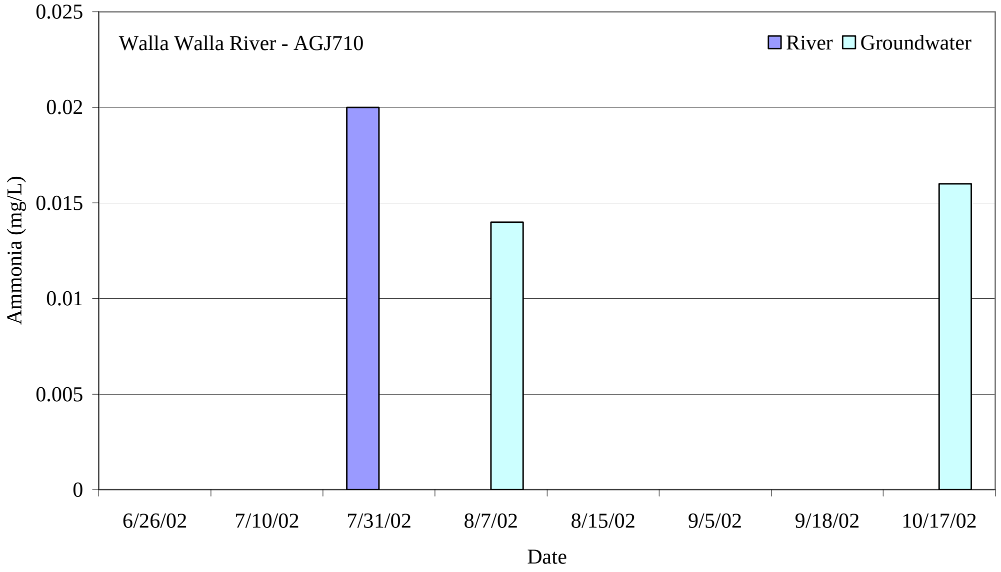


Figure 18. Comparison of Surface Water and Groundwater Total Persulfate Nitrogen Concentrations (mg/L)

Ammonia was detected in piezometers AGJ710 and AGJ711 with average concentrations of 0.015 mg/L and 0.12 mg/L, respectively. The good correspondence between nitrate+nitrite-N and total persulfate nitrogen in mini-piezometers AGJ712 and AGJ703 indicates that concentrations of ammonia are low. Ammonia was not detected in samples collected from either of these piezometers. Average concentrations of ammonia at the four surface water stations ranged from 0.015 to 0.03 mg/L. Ammonia concentrations are shown in Figure 19.



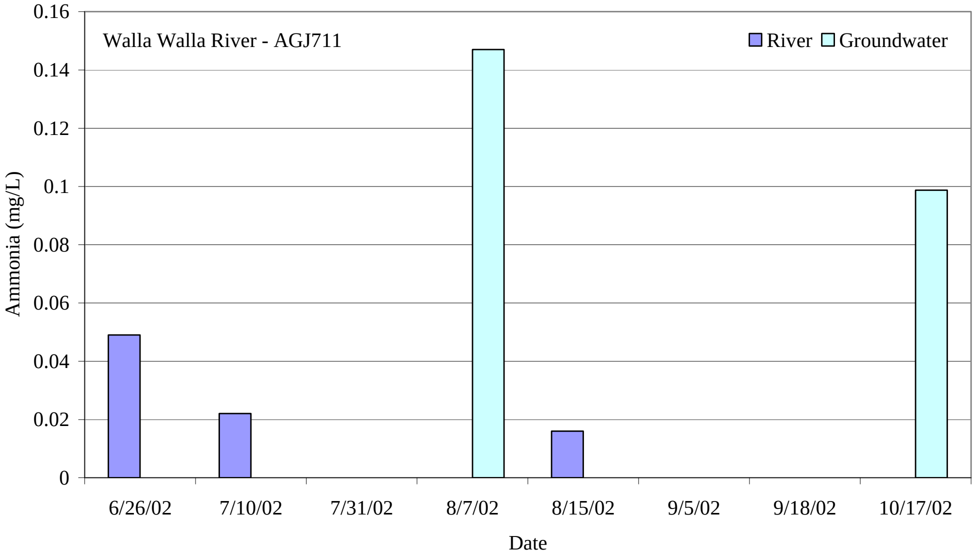


Figure 19. Comparison of Surface Water and Groundwater Ammonia Concentrations (mg/L)

Average concentrations of phosphorus in groundwater and surface water at the three Walla Walla stations were 0.16 mg/L and 0.121 mg/L, respectively. On the lower Touchet River, the average phosphorus concentrations were 0.074 mg/L in groundwater and 0.086 mg/L in surface water. Phosphorus concentrations are shown in Figure 20. Ortho-phosphate concentrations were lower, with average concentrations of 0.04 mg/L in groundwater and 0.09 mg/L in surface water samples collected from the Walla Walla River and 0.024 mg/L and 0.061 mg/L in groundwater and surface water samples from the Touchet River. Ortho-phosphate concentrations are shown in Figure 21.

Total organic carbon (TOC) concentrations were similar, ranging from 1.8 to 3 mg/L in the groundwater and 1.6 to 3.5 mg/L in surface water. Dissolved organic carbon (DOC) concentrations ranged from 1.6 to 3 mg/L in groundwater and 1.6 to 3.5 mg/L in surface water.

Fecal coliform was not detected in groundwater samples collected from the four mini-piezometers. However, fecal coliform concentrations in the surface water ranged from 5 to 1800 CFU/100 ml over the five months that samples were collected.

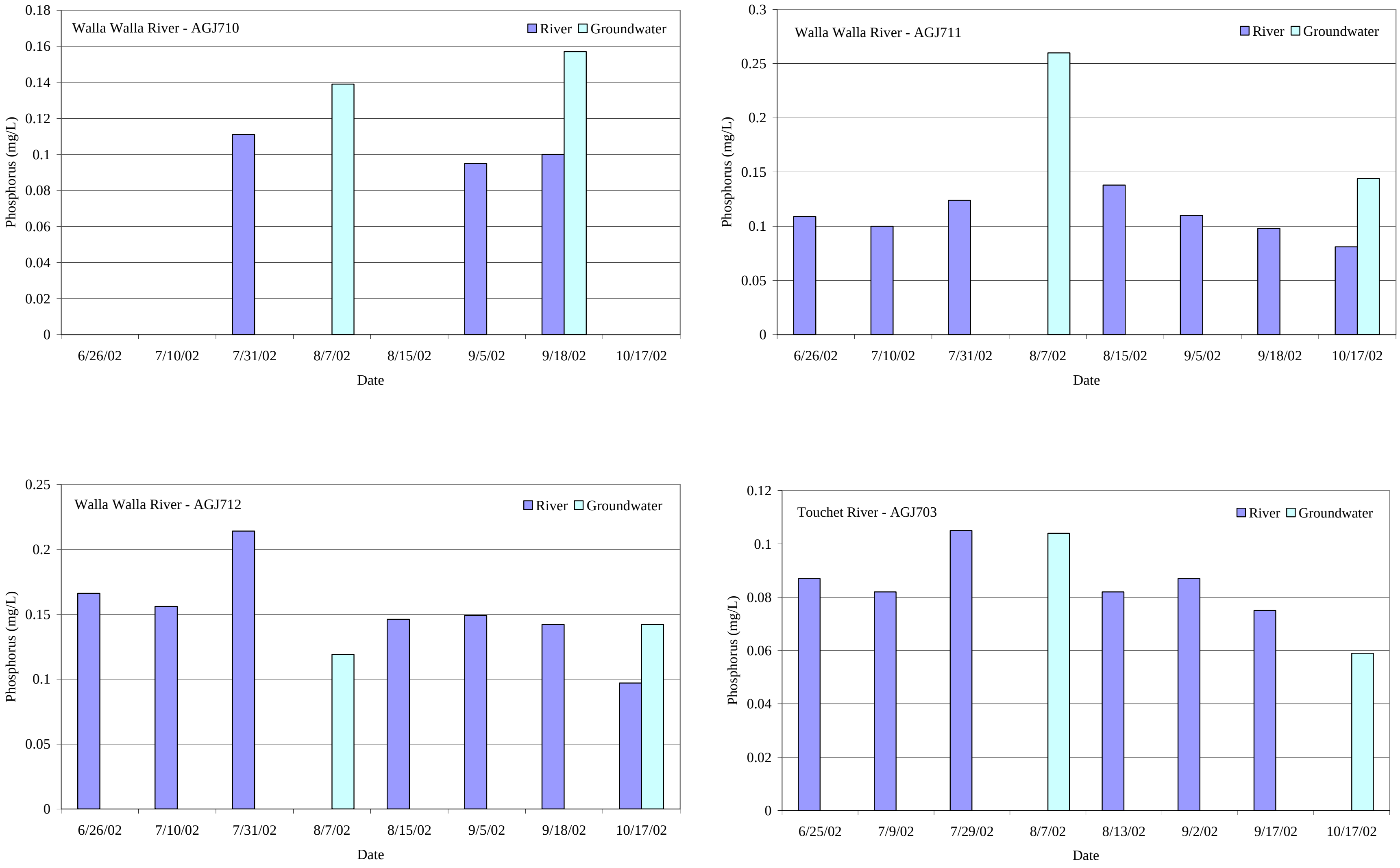


Figure 20. Comparison of Surface Water and Groundwater Phosphorus Concentrations (mg/L)

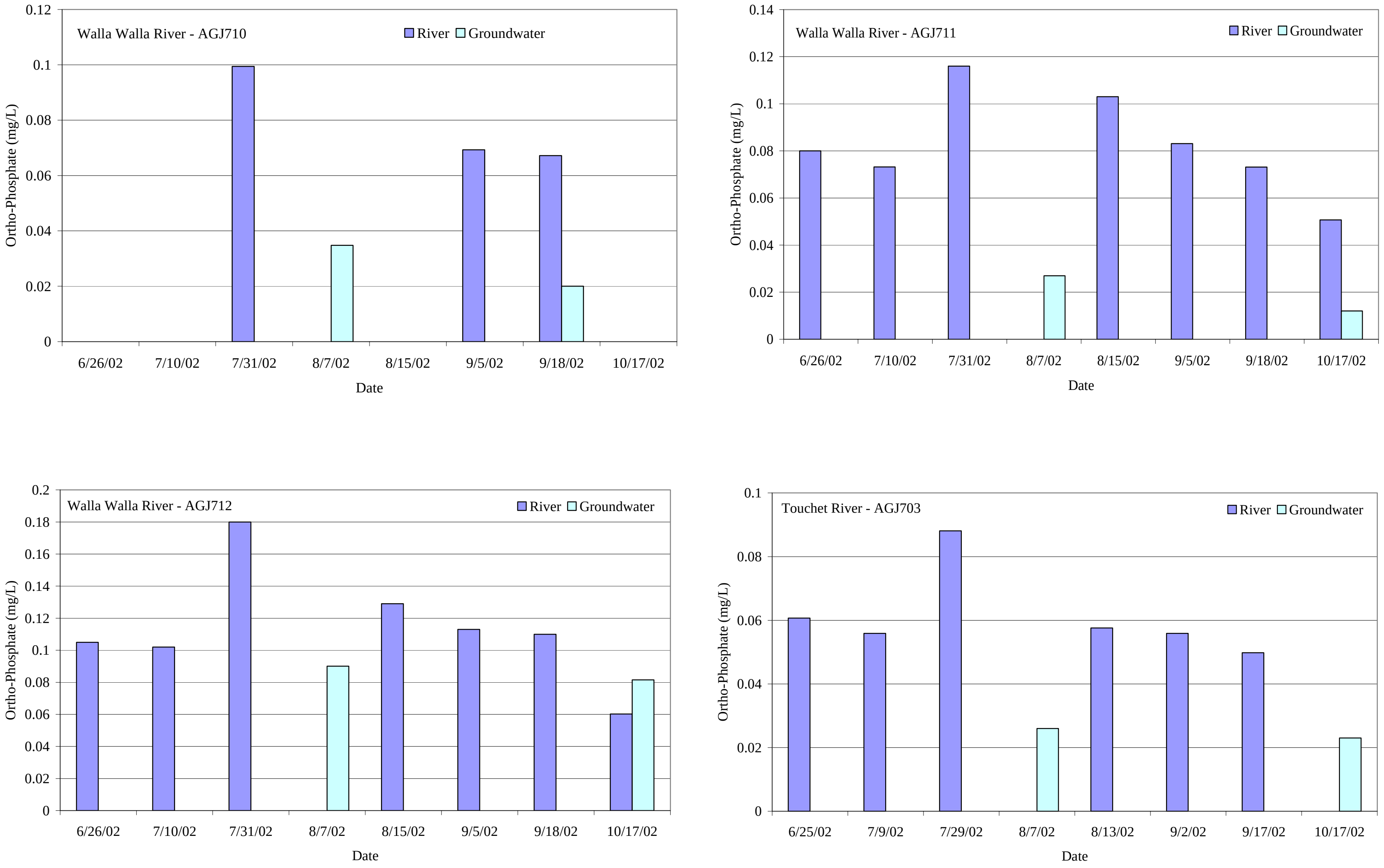


Figure 21. Comparison of Surface Water and Groundwater Ortho-Phosphate Concentrations (mg/L)

Sources of Uncertainty in Data Collection and Methods of Analysis

Each of the field techniques and analysis methods used during this study has respective strengths and weaknesses. No single technique or analysis method can uniquely quantify the distribution, timing, volume, and rate of water exchange between a stream and groundwater.

The use of multiple techniques, as was done here, helps to increase confidence in the collected data. Knowledge of the inherent uncertainty in each of the techniques becomes especially important when assigning confidence to data or combining the data and results from two or more techniques. In the sections that follow, the advantages, disadvantages, and source of uncertainty are discussed for each of the field techniques and analysis methods used during this study.

Instream Mini-Piezometers

In comparison to other field methods, instream mini-piezometers are inexpensive and relatively easy to deploy. They are especially useful for initial reconnaissance, verifying seepage-run results, and optimizing the locations of seepage reach extents. When properly used, a manometer board is capable of accurately measuring the differences in head (in the 0.03- to 3-foot range) that represent the hydraulic gradient at a point location in the streambed. Appendix A provides the collected water level data for the instream mini-piezometers, as wells as the water quality data.

Over the four-month period that the mini-piezometers were measured, the vertical hydraulic gradients were fairly consistent (Table 2). Plots of the calculated hydraulic gradient verses river mile (Figures 7, 10, and 13) illustrate how the magnitude of the gradient varied slightly over time but remained consistent with regard to direction for most of the piezometers. Six piezometers did reverse gradient over the four-month period. In general, these piezometers were characterized by small vertical gradients that typically reversed from negative to positive gradients. Five of the piezometers were located at approximate altitudes of 450 to 750 feet. Piezometer AGJ714 located near the mouth of the South Fork Touchet was the exception, at an altitude of approximately 1660 feet.

Baker and MacNish (1976) generalized for their digital model that water exchange between the gravel aquifer and stream channels could be separated into three categories based on altitude: (1) Perennial stream channels above a land surface altitude of about 850 feet characteristically lost water to the aquifer, (2) Channels with an altitude below 750 feet generally gained water from the aquifer, and (3) Stream channel reaches with altitude between 750 and 850 feet may gain or lose water, depending on the seasonal fluctuation in the gravel aquifer adjacent to the stream channels.

Overall, the mini-piezometer data for July to October 2002 agree with this assumption, with slight variations in the range of altitudes. The mini-piezometers in general had a negative vertical gradient at altitudes above 700 feet, reverse gradients between 750 to 450 feet, and positive gradients below an altitude of 450 feet.

The major disadvantage of mini-piezometers is that, individually, they provide information for only one point within the streambed. Also, in the case of this study, there were portions of the rivers where mini-piezometers could not be installed due to the bedrock or concrete channels. Thus, many mini-piezometers are required to adequately characterize the longitudinal distribution and sign (positive or negative) of streambed hydraulic gradients. The manometer board is not good at measuring small head differences (in the 0 to 0.03-foot range), and care must be taken to ensure a good seal around the mini-piezometer so that a head difference can be measured.

The question of whether the mini-piezometer is measuring flow within the streambed material (hyporheic flow) or groundwater flow can be addressed by comparing temperature and specific conductivity from the mini-piezometer with that of the river (Winter et al., 1998). Groundwater, particularly in gaining reaches, can have temperature and specific conductance values that differ greatly from the river. In losing reaches, the temperature and specific conductance from the mini-piezometer can be similar to the river. Temperature and other water quality data will be discussed in detail in the *Walla Walla River Tributaries Temperature Total Maximum Daily Load Study* and the *Walla Walla River Basin Fecal Coliform Bacteria and pH Total Maximum Daily Load Study*.

Seepage Runs

Seepage runs are labor intensive and expensive to conduct, but provide estimates of the net gain or loss across larger reaches of a river (2 to 17 miles, in this case). Because they provide only net estimates of water exchange, seepage evaluations reveal nothing about the distribution of local gains or losses that may occur within a seepage reach. Care must be taken in defining the reach boundaries. Ideally, the seepage measurement transect should coincide with gaining and losing reach boundaries, and all inflows and outflows within the reach should be accounted for. The seepage measurement transects also should be far enough apart that the measured fluxes exceed the inherent measurement error.

The uncertainty in seepage evaluations can be significant if the stream's discharge is large compared to the loss or gain in seepage along the stream reach. The inherent error in a good discharge measurement in a natural river environment is estimated to be ± 5 percent (Rantz et al., 1982). Thus, the calculated seepage over a reach could range considerably. Figure 22 is a graph depicting the seepage results for the Touchet River. Three of the seven seepage values for the Touchet River do not exceed the potential measurement error bounds for their respective reach and thus may not represent true gains or losses. The four remaining seepage estimates exceed the potential measurement error and thus likely reflect the gains and losses. The range of seepage rates can be narrowed, however, by applying the findings from other techniques. Head relations from mini-piezometers provide additional data that help reduce uncertainty in seepage rates at the time of measurement.

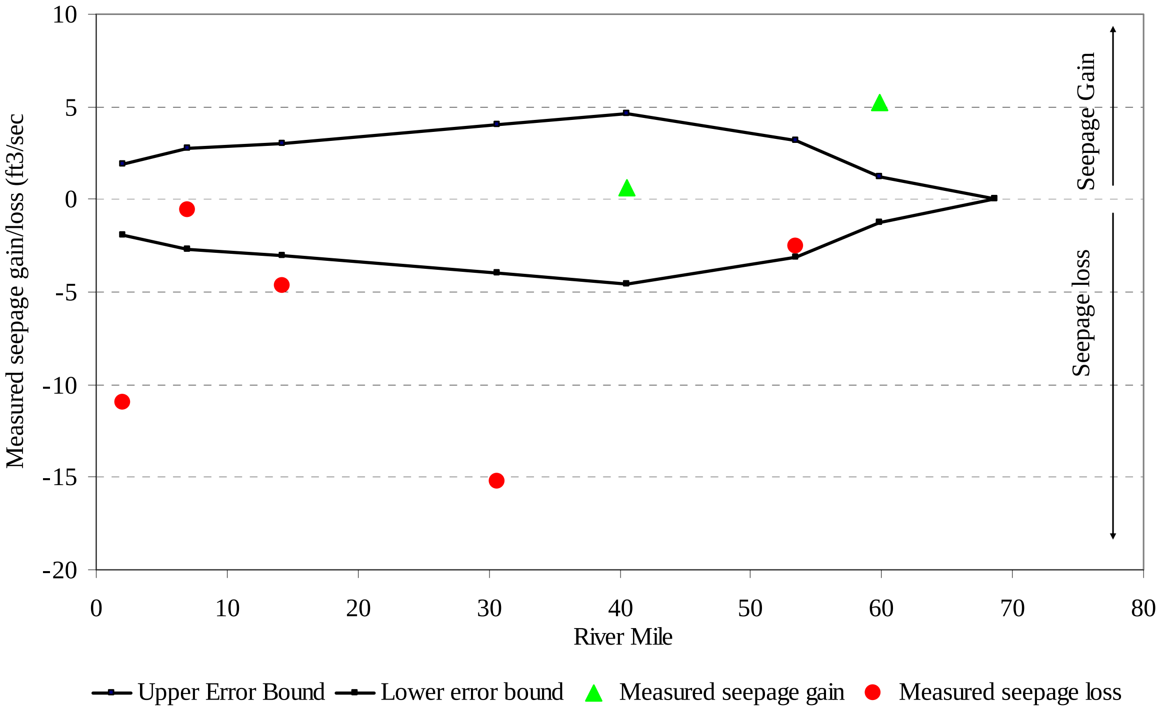


Figure 22. Touchet River Seepage Results and Uncertainty Assessment

The seepage run for the Walla Walla watershed was conducted on August 6-7, 2002. Due to the size of the watershed, discharge measurements were made by several field teams using either the Marsh-McBirney Model 201 or the Swoffer Model 2100 current meters. Typically during a seepage run, all tributary inflows, as well as irrigation outflows and returns, are measured so that discrepancies in the water budget between measuring points reflect only gains or losses through the streambed. Due to the size of the watershed and the complex irrigation network, not all irrigation diversions and returns may have been measured during the August 2002 seepage run.

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Summary and Conclusions

This project was undertaken to provide understanding of the interchange between surface water and groundwater within the Walla Walla watershed during the low-flow season of July through October. This information will be used to support TMDL studies which will (1) characterize temperature, fecal coliform bacteria, and pH in the basin and (2) establish load and wasteload allocations so that these parameters will meet surface water quality standards.

The Walla Walla River extends 80 miles from its headwaters in Oregon to its confluence with the Columbia River in Washington. This study focused on the lower 40 miles of the Walla Walla River and its major Washington tributaries, Yellowhawk Creek, Mill Creek, and the Touchet River. The rivers and creeks originate in the Blue Mountains and flow down to the broad, agricultural valleys below.

The geology of the watershed is characterized by three distinct regions: the Walla Walla basin alluvial fan, loess-covered basalt, and Columbia River basalt. Recent alluvium in the river and creek valleys, and a highly productive gravel aquifer in the Pleistocene gravels, dominate the hydrogeology as related to surface water interaction. Springs from the gravel aquifer supply baseflow to surface water year-round. The springs occur mainly in two zones which arc across the Walla Walla alluvial fan in the southeast and western parts of the basin. Discharge to surface water is more significant in the western, downgradient part of the alluvial fan area.

Surface water and groundwater interactions along the Walla Walla River and its tributaries were evaluated using two field techniques.

1. Mini-piezometers were driven into the active stream channel at 23 locations along the rivers and creeks. These provided point estimates of the vertical hydraulic gradient and the direction of water movement into or out of the rivers.
2. A seepage run was used to quantify net water exchange between the river and groundwater within 13 seepage reaches.

Water quality data were also collected from the mini-piezometers and surface water to provide additional information on the water exchange within gaining (surface water discharging to groundwater) and losing (groundwater discharging to surface water) stream reaches.

Overall, this study supports previous investigations which determined that the upper areas of the watershed were predominately losing and the lower reaches gaining, with a transitional area in between. Even though the study area is divided between two distinct geologic areas, the patterns of gains and losses generally were consistent during the monitoring period.

The Touchet River, Walla Walla River, and Mill Creek originate in the Blue Mountains with coarse streambed material and strong negative hydraulic gradients. At the base of the mountains the Touchet River, in the northern part of the watershed, flows through the loess-covered basalt which is characterized by loess and fine-grained glacial flood deposits overlaying basalt with a thin layer of alluvial material or bedrock in the creek and river valleys. The Walla Walla River and Mill Creek are dominated by a series of coalescent fans. The distribution of coarse and fine materials within the coalescent alluvial fans influences the movement of groundwater. In the upper portions of the basin, the shallow aquifer is composed chiefly of coarse gravel which transmits water quite readily. The lower parts of the valley are flatter and underlain more by silt and fine-grained deposits of the “old clay” which cannot transmit water as readily. This results in a portion of the gravel aquifer flow discharging to surface springs. The Walla Walla River appears to gain the most groundwater near its confluence with the Touchet River where the permeability and size of the gravel aquifer progressively decreases.

Each of the data collection and analysis techniques used during this study is subject to various degrees of uncertainty. Thus, none of the techniques or analysis methods can uniquely quantify surface water and groundwater exchanges. Using multiple techniques, as was done during this study, provides several lines of evidence on which to base findings, and provides greater certainty to those anticipating subsequent data analysis and modeling exercises.

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Appendices

A. Water Level and Water Quality Data

B. Seepage Run Data

Appendix A. Summary of water level and water quality data for instream piezometers and streams within the Walla Walla River Watershed

Well I.D. Tag No.	Stream Name	River Mile (miles)	Date	Time	Temperature (°C)		Temperature Difference (sw-gw) (°C)	Specific conductance µS/cm@25°C		Specific Conductivity difference (sw-gw) µS/cm@25°C	Electric tape readings (feet)			Average head difference measured with manometer (feet))	Vertical Hydraulic Gradient	Flow condition
					Stream	Ground water		Stream	Ground water		Ground water	Stream stage	Head difference			
AGJ717	North Fork Touchet River	8.9	7/11/02	11:20	15.7	13.8	1.9	70	69	1	NA	NA	NA	-1.21	-0.285	Recharge
			8/6/02	12:40	12.8	13.2	-0.4	73	69	4	2.71	1.55	-1.16	-1.11	-0.266	Recharge
			9/19/02	11:45	12.6	12.3	0.3	67	66	1	3.09	1.56	-1.53	-1.41	-0.346	Recharge
			10/15/02	11:17	7.8	10	-2.2	67	72	-5	3.37	1.58	-1.79	-1.18	-0.349	Recharge
AGJ716	Wolf Creek	4.7	7/11/02	12:30	15.8	NA	--	69	77	-8	1.41	1.15	-0.26	NA	-0.058	Recharge
			8/6/02	13:10	11.3	11.2	0.1	70	75	-5	1.42	1.08	-0.34	-0.24	-0.065	Recharge
			9/19/02	11:11	9.7	10.4	-0.7	60	64	-4	1.46	1.26	-0.2	-0.23	-0.048	Recharge
			10/15/02	9:40	5	6.4	-1.4	60	65	-5	1.41	1.14	-0.27	-0.25	-0.058	Recharge
AGJ714	South Fork Touchet River	0.02	7/11/02	-	19	NA	--	74	74	0	3.78	3.75	-0.03	NA	-0.012	Recharge
			8/6/02	13:55	16.5	16.2	0.3	81	78	3	3.9	3.89	-0.01	-0.06	-0.014	Recharge
			9/19/02	12:40	15.7	17	-1.3	83	79	4	3.99	3.88	0.11	0.1	**0.043**	Discharge
			10/15/02	13:24	11	13.8	-2.8	75	77	-2	3.97	3.88	-0.09	NA	-0.037	Recharge
AGJ715	Touchet River	54.9	7/11/02	10:00	17.4	18.2	-0.8	78	83	-5	NA	NA	NA	-0.19	-0.058	Recharge
			8/6/02	14:10	16	15.8	0.2	80	86	-6	2.79	2.43	-0.36	-0.26	-0.095	Recharge
			9/19/02	12:26	14.7	14.5	0.2	77	85	-8	2.88	2.42	-0.46	-0.35	-0.125	Recharge
			10/15/02	13:58	9.7	9.9	-0.2	75	82	-7	2.92	2.46	-0.46	-0.43	-0.137	Recharge
AGJ713	Touchet River	53.8	7/11/02	8:15	16.7	17.7	-1	79	78	1	3.78	3.45	-0.33	-0.23	-0.102	Recharge
			8/6/02	11:55	14.9	15.3	-0.4	81	78	3	3.96	3.54	-0.42	-0.41	-0.151	Recharge
			9/19/02	13:06	15.6	14.7	0.9	79	76	3	4.18	3.57	-0.61	-0.48	-0.198	Recharge
			10/15/02	-	9.9	10.3	-0.4	75	74	1	4.1	3.59	-0.51	NA	-0.185	Recharge
AGJ722	Touchet River	46.2	7/12/02	15:00	26.5	18.5	8	91	113	-22	3.96	3.98	0.02	0.02	**0.009**	Discharge
			8/6/02	11:20	16.1	17.3	-1.2	94	124	-30	3.96	3.97	0.01	0.02	**0.006**	Discharge
			9/19/02	13:38	17.3	16.6	0.7	94	123	-29	3.98	4	0.02	0.01	**0.006**	Discharge
			10/15/02	16:06	10.8	13.4	-2.6	86	136	-50	3.92	3.94	0.02	0.01	**0.006**	Discharge
AGJ721	Coppei Creek	5.4	7/12/02	12:30	23.9	16.3	7.6	124	127	-3	2.48	2.44	-0.04	-0.04	-0.012	Recharge
			8/6/02	15:35	17.7	16.8	0.9	114	135	-21	2.53	2.44	-0.09	-0.07	-0.025	Recharge
			9/19/02	10:09	13	15.7	-2.7	107	123	-16	2.55	2.41	-0.14	-0.09	-0.035	Recharge
			10/15/02	17:18	10.4	11	-0.6	107	113	-6	2.42	2.31	-0.11	-0.11	-0.034	Recharge
AGJ723	Touchet River	40.5	7/12/02	15:45	28.3	19.1	9.2	98	107	-9	0.92	0.75	-0.17	-0.17	-0.037	Recharge
			8/6/02	10:47	15.9	19.5	-3.6	108	115	-7	1.1	0.92	-0.18	-0.19	-0.041	Recharge
			9/19/02	14:26	17.9	18	-0.1	105	115	-10	1.1	0.89	-0.21	-0.21	-0.046	Recharge
			10/15/02	-	10.7	13.3	-2.6	95	106	-11	1.1	0.91	-0.19	-0.23	-0.046	Recharge

Appendix A. Summary of water level and water quality data for instream piezometers and streams within the Walla Walla River Watershed

Well I.D. Tag No.	Stream Name	River Mile (miles)	Date	Time	Temperature (°C)		Temperature Difference (sw-gw) (°C)	Specific conductance µS/cm@25°C		Specific Conductivity difference (sw-gw) µS/cm@25°C	Electric tape readings (feet)			Average head difference measured with manometer (feet))	Vertical Hydraulic Gradient	Flow condition
					Stream	Ground water		Stream	Ground water		Ground water	Stream stage	Head difference			
AGJ706	Touchet River	34.2	7/9/02	17:40	25.6	18.6	7	103	108	-5	3.51	3.51	0	0.03	**0.012**	Discharge
			8/6/02	10:25	16.8	19.8	-3	115	116	-1	3.76	3.78	0.02	0.05	**0.014**	Discharge
			10/16/02	18:20	11	13.1	-2.1	109	112	-3	3.68	3.69	0.01	0.04	**0.01**	Discharge
AGJ705	Touchet River	17.8	7/9/02	14:10	24.2	18.1	6.1	111	161	-50	NA	NA	NA	-0.28	-0.062	Recharge
			8/6/02	9:25	18	19.6	-1.6	119	192	-73	1.36	1.12	-0.24	-0.24	-0.053	Recharge
			9/19/02	15:10	18.2	18.8	-0.6	119	186	-67	1.4	1.18	-0.22	-0.27	-0.054	Recharge
			10/16/02	17:20	10.5	14.7	-4.2	112	183	-71	1.37	1.08	-0.29	-0.28	-0.063	Recharge
AGJ704	Touchet River	12.8	7/9/02	12:00	22.8	NA	--	110	NA	--	3.81	3.8	-0.01	NA	-0.005	Recharge
			8/6/02	8:48	18.1	NA	--	125	193	-68	3.96	3.96	0	NA	0	No Gradient
			9/19/02	15:44	18.5	19	-0.5	122	212	-90	4	4.1	0.1	0.05	**0.037**	Discharge
			10/16/02	16:10	10.2	11.8	-1.6	112	177	-65	3.95	3.96	0.01	NA	**0.005**	Discharge
AGJ703	Touchet River	2.0	7/9/02	8:20	20.5	16.5	4	116	581	-465	NA	NA	NA	0.13	**0.039**	Discharge
			8/6/02	8:05	18.5	18	0.5	141	555	-414	2.07	2.18	0.11	0.1	**0.03**	Discharge
			8/7/02	14:15	20.6	18	2.6	137	547	-410	NA	NA	NA	NA	NA	NA
			9/19/02	16:20	-	-	--	131	535	-404	2.1	2.14	0.04	0.1	**0.021**	Discharge
			10/16/02	15:05	10	14.1	-4.1	118	574	-456	1.98	2.1	0.12	0.1	**0.033**	Discharge
			10/17/02	12:40	8.5	14	-5.5	103	512	-409	NA	NA	NA	NA	NA	NA
AGJ720	Mill Creek	19.1	7/12/02	9:50	15.8	13.3	2.5	76	76	0	2.17	1.51	-0.66	-0.61	-0.146	Recharge
			8/6/02	18:45	14.4	14.3	0.1	76	79	-3	2.16	1.47	-0.69	-0.65	-0.154	Recharge
			9/19/02	9:35	10.1	12.9	-2.8	65	73	-8	2.24	1.43	-0.81	-0.76	-0.18	Recharge
			10/16/02	8:30	6.2	10.4	-4.2	70	80	-10	2.38	1.49	-0.89	-0.89	-0.205	Recharge
AGJ719	Mill Creek	14.8	7/12/02	-	18.3	18.4	-0.1	82	81	1	NA	2.25	NA	-0.07	-0.022	Recharge
			8/6/02	18:20	17.4	16.9	0.5	80	79	1	2.37	2.28	-0.09	-0.05	-0.022	Recharge
			9/19/02	8:55	11.9	14.7	-2.8	73	80	-7	2.34	2.19	-0.15	-0.09	-0.038	Recharge
			10/16/02	9:35	7.9	10.2	-2.3	77	83	-6	2.32	2.21	-0.11	-0.11	-0.035	Recharge
AGJ718	Mill Creek	12.8	7/12/02	8:00	18.8	18.3	0.5	86	83	3	NA	NA	NA	-0.39	-0.09	Recharge
			8/6/02	17:50	18.3	18.2	0.1	84	83	1	2.02	1.53	-0.49	-0.46	-0.109	Recharge
			9/20/02	8:10	12.7	15.7	-3	78	96	-18	2.08	1.37	-0.71	NA	-0.163	Recharge
			10/15/02	18:10	10.4	12.2	-1.8	82	90	-8	1.88	1.5	-0.38	-0.4	-0.09	Recharge
AGJ702	Mill Creek	1.7	7/8/02	19:45	21.5	16.7	4.8	342	209	133	NA	0.8	NA	0.07	**0.016**	Discharge
			8/7/02	11:05	22.2	17.4	4.8	382	243	139	1.43	1.42	-0.01	-0.02	-0.005	Recharge
			10/16/02	13:55	11.7	13.6	-1.9	435	408	27	0.39	0.08	-0.31	-0.31	-0.071	Recharge

Appendix A. Summary of water level and water quality data for instream piezometers and streams within the Walla Walla River Watershed

Well I.D. Tag No.	Stream Name	River Mile (miles)	Date	Time	Temperature (°C)		Temperature Difference (sw-gw) (°C)	Specific conductance µS/cm@25°C		Specific Conductivity difference (sw-gw) µS/cm@25°C	Electric tape readings (feet)			Average head difference measured with manometer (feet))	Vertical Hydraulic Gradient	Flow condition
					Stream	Ground water		Stream	Ground water		Ground water	Stream stage	Head difference			
AGJ701	Yellowhawk Creek	5.0	7/10/02	7:40	18.4	NA	--	99	NA	--	6.31	2.86	-3.45	NA	-1.211	Recharge
			8/6/02	16:20	17.9	NA	--	94	95	-1	6.03	2.88	-3.15	NA	-1.105	Recharge
			10/16/02	10:40	8.5	NA	--	89	NA	--	6.03	2.81	-3.22	NA	-1.13	Recharge
AGJ707	Yellowhawk Creek	1.1	7/10/02	9:15	18.3	NA	--	148	NA	--	2.12	2.07	-0.05	NA	-0.014	Recharge
			8/6/02	16:45	17.5	NA	--	120	623	-503	2.01	2.14	0.13	NA	**0.036**	Discharge
			10/16/02	12:17	8.8	NA	--	124	652	-528	2.2	2.1	-0.1	NA	-0.027	Recharge
AGJ708	Walla Walla River	38.6	7/10/02	10:30	18.8	NA	--	126	NA	--	3.02	2.9	-0.12	NA	-0.036	Recharge
			8/6/02	17:05	20	NA	--	113	121	-8	3.02	2.89	-0.13	NA	-0.039	Recharge
			10/15/02	12:48	10.6	13.6	-3	118	180	-62	2.9	2.83	-0.07	NA	-0.021	Recharge
AGJ709	Walla Walla River	32.9	7/10/02	16:50	25.6	16.5	9.1	184	1113	-929	1.44	1.38	-0.06	NA	-0.014	Recharge
			8/7/02	11:45	18.3	17.8	0.5	139	788	-649	1.39	1.36	-0.03	-0.05	-0.009	Recharge
			10/17/02	9:05	8.4	13.6	-5.2	156	NA	--	1.5	1.47	-0.03	-0.04	-0.008	Recharge
AGJ710	Walla Walla River	29.2	7/10/02	17:00	27.7	20.3	7.4	201	245	-44	3.87	3.86	-0.01	NA	-0.005	Recharge
			8/7/02	12:45	21.8	20	1.8	164	253	-89	2.98	2.99	0.01	0.02	**0.008**	Discharge
			9/18/02	17:45	18.2	17.7	0.5	138	295	-157	3.43	3.45	0.02	0.01	**0.008**	Discharge
			10/17/02	9:52	8.8	13	-4.2	176	270	-94	2.68	2.65	-0.03	-0.01	-0.005	Recharge
AGJ711	Walla Walla River	27.4	7/10/02	16:25	28	18.6	9.4	226	205	21	3.04	3.03	-0.01	NA	-0.004	Recharge
			8/7/02	15:00	24.4	20.5	3.9	209	205	4	3.12	3.13	0.01	0.01	**0.004**	Discharge
			10/17/02	10:15	9.6	15.2	-5.6	217	223	-6	2.95	2.97	0.02	0.02	**0.007**	Discharge
AGJ712	Walla Walla River	22.7	7/10/02	15:20	26.3	16.5	9.8	356	1272	-916	0.14	1.9	1.76	1.77	**0.471**	Discharge
			8/7/02	13:35	21.3	16.2	5.1	367	1297	-930	0.45	2.1	1.65	NA	**0.44**	Discharge
			10/17/02	11:08	8.6	14.2	-5.6	347	1320	-973	0.45	1.85	1.4	NA	**0.373**	Discharge

Appendix B. Seepage run data for the Walla Walla River Watershed, August 6-7 2002

River Mile	Station Name (EIM)	Map Symbol	Date	Time	Measured Discharge (ft3/s)	Tributary/ Irrigation Return	Diversion	Vertical Hydraulic Gradient	Computed Gain (+) Loss (-)
Reach 1 (R1) *- RM 13.7 just below Spangler Creek to RM 4.9 @ Wolf For*					--	--	--	--	--
13.7	NF Touchet	NFT-7	8/6/02	12:20	6.73	--	--	--	--
0.1	Lewis Creek	LC-12	8/6/02	12:55	--	4.79	--	--	--
63.7	AGJ717	AGJ717	8/6/02	12:40	--	--	--	-0.266	--
0.1	Jim Creek	JC-1	8/6/02	13:15	--	1.32	--	--	--
4.9	NF Touchet	NFT0	8/6/02	10:10	18.04	--	--	--	+5.2
Reach 2 (R2) *- RM 4 @ Wolf Fork Rd to RM 1.7 @ Wolf Fork Rd at Homberg Bridge*						--	--	--	--
4	Wolf Fork	WF-9	8/6/02	15:45	24.92	--	--	--	--
4.7	AGJ716	AGJ716	8/6/02	13:10	--	--	--	-0.065	--
0.7	Robinson Fork	R0	8/6/02	11:25	--	0.79	--	--	--
1.7	Wolf Fork	WF-11	8/6/02	16:10	25.75	--	--	--	--
Reach 3 (R3) *- RM 4.9 on North Fork Touchet @ Wolf Fork Rd to RM 53.9 of Touchet Mainstem at Dayton City Park*									
4.9	NF Touchet	NFT0	8/6/02	10:10	18.04	--	--	--	--
1.7	Wolf Fork	WF-11	8/6/02	16:10	--	25.75	--	--	--
1.6	NF Touchet	NFT_16	8/6/02	16:30	43.70	--	--	--	--
0	NF Touchet	NFT-C	8/6/02	12:20	46.09	--	--	--	--
54.9	AGJ715	AGJ715	8/6/02	14:10	--	--	--	-0.095	
0	SF Touchet	SFT-C	8/6/02	12:45	--	3.53	--	--	--
53.9	Touchet	T11	8/6/02	1:45	44.78	--	--	--	--
53.8	AGJ713	AGJ713	8/6/02	11:55	--	--	--	-0.151	--
53.5	Touchet	TR-4	8/6/02	17:30	44.78	--	--	--	-2.5
Reach 4 (R4) *- RM 9 on South Fork Touchet to Confluence with North Fork Touchet*									
9.2	SF Touchet	SFT-3	8/6/02	16:58	5.94	--	--	--	--
2.5	SF Touchet	SFT0	8/6/02	13:30	5.03	--	--	--	--
0	SF Touchet	SFT-C	8/6/02	12:45	3.53	--	--	--	--
0.02	AGJ714	AGJ714	--	--	--	--	--	-0.014	-2.41
Reach 5 (R5) *- RM 53.9 Touchet River at Dayton City Park to RM 40.5 @ Hwy 124 near Bolles Rd*									
53.5	Touchet	TR-4	8/6/02	17:30	44.78	--	--	--	--
0.1	32PAT-00.1	P0	8/6/02	15:30	--	0.79	--	--	--
--	Dayton WWTP	--	8/6/02	--	--	0.48	--	--	--
46.2	AGJ722	AGJ722	8/6/02	11:20	--			+0.006	
0.1	Whiskey Creek	WH0	8/6/02	10:20	--	0.07	--	--	--
0.5	Coppei Creek	C0	8/6/02	12:00	--	0.76	--	--	--
40.5	32TOU-40.5	T10	8/6/02	11:15	47.54	--	--	--	--
40.5	AGJ723	AGJ723	8/6/02	10:47	--	--	--	-0.041	+0.66
Reach 6 (R6) *- RM 0.1 on North Fork Coppei Creek to RM 0.5 near mouth of Coppei Creek*									
0.1	NF Coppei Creek	NFC-5	8/6/02	9:05	1.51	--	--	--	--
0.8	SF Coppei Creek	SFC-5	8/6/02	9:30	--	0.98	--	--	--
5.4	AGJ721	AGJ721	8/6/02	15:35	--	--	--	-0.025	--
4.6	Coppei Creek	MC-3	8/6/02	9:50	1.02	--	--	--	--
0.5	Coppei Creek	C0	8/6/02	12:00	0.76	--	--	--	-1.73
Reach 7 (R7) *- RM 40.5 @ Hwy 124 near Bolles Rd to RM 30.6 @ Pettyjohn Rd*									
40.5	32TOU-40.5	T10	8/6/02	11:15	47.54	--	--	--	--
40.5	AGJ723	AGJ723	8/6/02	10:47	--	--	--	-0.041	--
34.2	AGJ706	AGJ706	8/6/02	10:25	--	--	--	+0.014	--
30.6	32TOU-30.6	T8	8/6/02	10:00	32.3	--	--	--	-15.24
Reach 8 (R8) *- RM 30.6 @ Pettyjohn Rd to RM 14.2 @ Touchet N Rd south of Luckenbell Rd*									
30.6	32TOU-30.6	T8	8/6/02	10:00	32.3	--	--	--	--
26.1	32TOU-26.1	T7	8/6/02	8:30	35.13	--	--	--	--
25	32TOU-25.0	T6	8/6/02	17:00	34.64	--	--	--	--
17.8	32TOU-17.8	T5	8/6/02	16:00	28.24	--	--	--	--
17.8	AGJ705	AGJ705	8/6/02	9:25	--	--	--	-0.053	--
14.2	32TOU-14.2	T4	8/6/02	15:06	27.66	--	--	--	-4.64

Appendix B. Seepage run data for the Walla Walla River Watershed, August 6-7 2002

River Mile	Station Name (EIM)	Map Symbol	Date	Time	Measured Discharge (ft3/s)	Tributary/ Irrigation Return	Diversion	Vertical Hydraulic Gradient	Computed Gain (+) Loss (-)
Reach 9 (R9) *- RM 14.2 @ Touchet N Rd south of Luckenbell Rd to RM 7 @Touchet N Rd above Hoffer Diversion*									
14.2	32TOU-14.2	T4	8/6/02	15:06	27.66	--	--	--	--
12.8	32TOU-12.8	T3	8/6/02	14:07	34.1	--	--	--	--
12.8	AGJ704	AGJ704	8/6/02	8:48	--	--	--	0	--
10.8	32TOU-10.8	T2	8/6/02	14:10	21.64	--	--	--	--
7	32TOU-7.0	T1	8/6/02	11:48	27.08	--	--	--	-0.58
Reach 10 (R10) *- RM 7 @ Touchet N Rd above Hoffer Diversion to RM 2 @ Cummins Rd*									
7	32TOU-7.0	T1	8/6/02	11:48	27.08	--	--	--	--
3.9	32TOU-03.9	TAHD	8/9/02	9:30	15.26	--	--	--	--
--	Irrigation Diversion	ID	--	--	--	--	4.95	--	--
3.8	32TOU-03.8	TBHD	8/6/02	10:48	10.31	--	--	--	--
2	32TOU-02.0	T0	8/6/02	8:20	11.5	--	--	--	--
2	AGJ703	AGJ703	8/6/02	8:05	--	--	--	+0.03	-10.98
Reach 11 (R11) *- RM 28.4 @ WA/OR border to RM 12.8 @ Five Mile Rd*									
28.4	32MIL-28.4	M7	8/7/02	10:05	30.61	--	--	--	--
27.5	32MIL-27.5	M6	8/7/02	11:03	39.93	--	--	--	--
26.5	32MIL-26.5	M5	8/7/02	12:35	38.23	--	--	--	--
--	Walla Walla Water Intake	--	--	--	--	--	10.7	--	--
21.3	32MIL-21.3	M4	8/7/02	13:44	27.53	--	--	--	--
19.1	32MIL-19.1	M3	8/7/02	8:52	28.8	--	--	--	--
19.1	AGJ720	AGJ720	8/6/02	18:45	--	--	--	-0.154	--
0.2	32BLU-00.2	B0	8/7/02	9:38	--	0.68	--	--	--
14.8	32MIL-14.8	M2	8/7/02	8:05	27.04	--	--	--	--
14.8	AGJ719	AGJ719	8/6/02	18:20	--	--	--	-0.022	--
12.8	32MIL-12.8	M1	8/7/02	12:45	25.86	--	--	--	--
12.8	AGJ718	AGJ718	8/6/02	17:50	--	--	--	-0.109	5.27
Reach 12 (R12) *- RM 12.8 @ Five Mile Rd to RM 1.7 @ Last Chance Rd*									
12.8	32MIL-12.8	M1	8/7/02	12:45	25.86	--	--	--	--
12.8	AGJ718	AGJ718	8/6/02	17:50	--	--	--	-0.109	--
0.3	Titus Creek	TC0	8/7/02	9:30	--	1.89	--	--	--
8.5	Yellowhawk Creek	YHD	8/7/02	14:30	--	--	14.37	--	--
--	Mill Creek Gage @ WW	--	8/7/02	--	4.4	--	--	--	--
--	Walla Walla WWTP	--	--	--	--	~6	--	--	--
4.8	32MIL-04.8	MG	8/7/02	13:30	0.37	--	--	--	--
2.8	32MIL-02.8	MW	8/7/02	9:55	2.96	--	--	--	--
1.7	32MIL-01.7	M0	8/7/02	14:09	0.04	--	--	--	--
1.7	AGJ702	AGJ702	8/7/02	11:05	--	--	--	-0.005	-19.34
Reach 13 (R13) *- RM 8.5 @ Yellowhawk Creek Diversion to RM 0.2*									
8.5	Yellowhawk Creek	YHD	8/7/02	14:30	14.37	--	--	--	--
5	32YEL-05.0	Y1	8/7/02	11:55	16.30	--	--	--	--
5	AGJ701	AGJ701	8/6/02	--	--	--	--	-1.105	--
0.9	Cottonwood Creek	CWC-5	8/7/02	13:15	--	0.23	--	--	--
1.1	32YEL-01.1	YP	8/7/02	16:15	14.39	--	--	--	--
1.1	AGJ707	AGJ707	--	--	--	--	--	+0.036	--
0.2	32YEL-00.2	Y0	8/7/02	17:00	10.12	--	--	--	-4.48

Negative gradients indicate loss of water from the stream to groundwater, and positive gradients indicate groundwater discharge into the stream