Surface-water/Groundwater Interactions and Near-stream Groundwater Quality along the Palouse River, South Fork Palouse River, and Paradise Creek

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Most of the field and laboratory data generated during this project are available in digital format from Ecology's Environmental Information Management (EIM) system (www.ecy.wa.gov/eim/index.htm). Data for the South Fork Palouse River and Paradise Creek are archived in EIM under User Study ID: JICA0000. Data for the mainstem Palouse River are archived under User Study ID: JICA0001.

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Cover photo: *South Fork Palouse River, at river mile 3.4, above Colfax, WA (Photo by Kirk Sinclair).*

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By

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Olympia, Washington 98504-7710

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Waterbody Numbers:

WA-34-1010 and WA-34-1030 (Palouse River)
WA-34-1020 (South Fork Palouse River)
WA-34-1025 (Paradise Creek)

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Glossary, Acronyms, Abbreviations, and Data Qualifier Codes

Glossary

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which designated uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Anisotropy: A condition where one or more of the hydraulic properties of an aquifer vary according to the direction of water flow.

Anoxic: Depleted of oxygen.

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

GIS: A computer-based mapping and analysis software system.

Groundwater discharge: The movement of groundwater from the subsurface to the surface by advective flow.

Hydraulic conductivity: A coefficient that describes the rate at which water moves through a permeable medium such as soil or fractured rock.

Hyporheic: The area beneath and adjacent to a stream where surface-water and groundwater intermix.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activity, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Piezometer: A small-diameter, non-pumping well used during this study to (1) measure depth to groundwater, (2) measure streambed water temperatures, and (3) periodically collect groundwater quality samples.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to surface water. Examples of point source discharges include water from municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that encompass more than five acres of cleared land.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Acronyms and Abbreviations

DO	dissolved oxygen
DOC	dissolved organic carbon
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GPM	gallons per minute
MCL	maximum contaminant level
MEL	Manchester Environmental Laboratory
MF	membrane filter
mg/L	milligrams per liter (equivalent to parts per million)
mV	millivolts
RM	river mile
RPD	relative percent difference
SFPR	South Fork Palouse River
TDS	total dissolved solids
TMDL	total maximum daily load
TP	total phosphorus
TPN	total persulfate nitrogen
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant

Data Qualifier Codes

Water Quality Codes

J	The analyte was positively identified; the numeric result is an estimate.
JL	The analyte was positively identified; the true value may be less than the reported estimate.
U	The analyte was not detected at or above the reported value.
UL	The analyte was not detected at or above the reported estimated value.

Water Level Codes

O	Obstruction in well prevented water level measurement.
P	Well pumping, water level not measured.
R	The well water level was recovering from recent pumping or another unidentified stress. The indicated value does not represent a true static condition.

Conversion Factors and Datums

Conversion Factors

Multiply	By	To Obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square ft (ft^2)	0.0929	square meter (m^2)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	28.32	liter (L)
	Flow	
cubic foot per second (ft^3/sec)	0.02832	cubic meter per second (m^3/sec)
gallon per minute (gal/min)	3.785	liter per minute (L/min)
	Hydraulic Conductivity	
foot per day	0.3048	meter per day

Temperature

To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the following equation:
°F= (°C x 1.8) + 32

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation:
°C= (°F-32)/1.8

Datums

The vertical coordinates in this report are referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929). Altitude values represent the distance above or below the datum in feet.

The horizontal coordinates in this report are referenced to the North American Datum of 1983 (NAD83).

Abstract

The Palouse River, the South Fork Palouse River, and Paradise Creek were included on Washington State's 2004 303(d) list of impaired waters for violations of surface-water temperature, pH, dissolved oxygen, or fecal coliform standards.

In summer 2006, the Washington State Department of Ecology initiated several TMDL[1]-based field studies to assess current stream temperatures and water quality conditions along these rivers and streams. This study, which was part of that effort, was undertaken to characterize the thermal and water quality influences that groundwater imparts to these rivers along gaining reaches.

Multiple field techniques were employed to derive both point-based and reach-based estimates of the water volume and nutrient mass load that groundwater contributes to area rivers. These techniques included stream seepage evaluations, installation and monitoring of instream piezometers, collection and evaluation of groundwater quality samples, and monitoring of streambed thermal profiles.

The reach-based gains and losses observed during seepage runs were generally supported by the point-based vertical hydraulic gradients and streambed thermal profiles measured at instream piezometer sites.

Measurable concentrations of dissolved orthophosphate (0.018 to 0.171 mg/L) and dissolved total phosphorus (0.073 to 0.875 mg/L) were found at all sampled piezometer sites. Measurable concentrations of dissolved nitrate+nitrite-N and ammonia were found at roughly half of the sampled piezometers at concentrations ranging from 0.013 to 10.1 mg/L and 0.03 to 0.549 mg/, respectively.

The average estimated unit-area-mass loading to the river from discharging groundwater varied by parameter and location. The loading ranged from 0.03 to 107 mg/d/m^2 of streambed for dissolved total phosphorus, and 0.01 to 3,119 mg/d/m^2 for dissolved nitrate+nitrite-N. These load values are considered upper bound estimates since they do not account for biological or chemical reactions that may potentially reduce nutrient concentrations in discharging groundwater as it passes through the final few feet of the streambed.

Acknowledgements

Many people contributed to this study.

Elaine Snouwaert and Nancy Hoobler provided insights and assistance during pre-project scoping discussions and initial landowner contacts. Brenda Nipp, Scott Tarbutton, Dustin Bilhimer, Bernard Strong, Charles Pitz, and Tighe Stuart helped with sampling and other field activities. Jim Carroll, Martha Maggi, John Covert, Charles Pitz, and Joan LeTourneau provided comments and suggestions for improving the study report.

Michelle Aylward, Daniel Baker, Pam Covey, Kamilee Ginder, Nancy Jensen, Dean Momohara, Aileen Richmond, Sara Sekerak, and Leon Weiks, at Manchester Environmental Laboratory, provided courier and analytical laboratory support.

Lastly, we extend our appreciation to the many landowners who provided us access to their property and wells. This study would not have been possible without their kindness and cooperation.

[1] Total Maximum Daily Load (water cleanup plan)

Introduction

Past monitoring has shown that portions of the Palouse River, the South Fork Palouse River (SFPR), Paradise Creek, and Missouri Flat Creek do not meet state or federal water quality standards for one or more of the following parameters: temperature, dissolved oxygen, pH, and fecal coliform bacteria (Carroll et al., 2006 and 2007; Mathieu et al., 2006 and 2007; Bilhimer., 2006; Kardouni et al., 2007) (Figure 1). Accordingly, these streams were included on the Washington State 2004 303(d) list of impaired waters.

The Washington State Department of Ecology (Ecology) is charged with developing water cleanup plans, or Total Maximum Daily Loads (TMDLs), for waterbodies on the Washington State 303(d) list. During plan development, field studies are conducted to identify and quantify both the point (discrete) and nonpoint (diffuse) sources that contribute pollution to an impaired stream or waterbody. The results from field surveys are then used to develop and calibrate the water quality models Ecology uses to establish target pollutant-load reductions for each of the impaired stream segments.

In summer 2006, Ecology undertook a variety of TMDL-based field studies to assess current stream temperatures, water quality, and other environmental conditions within the Palouse River, SFPR, and Paradise Creek drainages. This study, which was part of that effort, was undertaken to gain a better understanding of groundwater's influence on area stream temperatures and water quality.

Groundwater was specifically targeted for evaluation because discharges of nutrient-rich groundwater to streams can contribute to increased instream aquatic plant growth and biomass production (Angier and McCarty, 2008; Dahm et al., 1998). Left unchecked, such growth can lead to increased biological and chemical oxygen demand within streams and ultimately to a reduction in the amount of oxygen available to support fish and other aquatic organisms.

The primary goals of this investigation were to:

1. Describe the direction, volume, and timing of surface-water and groundwater interactions along the stream reaches of interest during critical summer (baseflow) conditions.

2. Estimate both the concentration and mass loads of phosphorus-based and nitrogen-based nutrients that groundwater contributes to these streams along gaining reaches.

To realize these goals, surface-water discharge balances were prepared for six stream reaches along the SFPR-Paradise Creek stream corridor, between the cities of Moscow, Idaho and Colfax, Washington. Seventeen shallow-instream piezometers were also installed along this reach in late spring 2006. The piezometers were used to monitor streambed thermal profiles and vertical hydraulic gradients between the stream and shallow groundwater at discrete points. The piezometers and a tandem network of nine near-stream domestic wells were also sampled to characterize groundwater quality just prior to its discharge into area streams.

A similar, although much reduced, effort was conducted in summer 2007. This effort included the installation of nine instream piezometers, along the mainstem Palouse River, between the Washington/ Idaho state border and the Palouse River confluence with Willow Creek (Figure 1). Four domestic wells along this reach were also monitored for water level and water quality as were six wells at the town of Colfax wastewater treatment plant.

This report documents the study methods and results of these investigations.

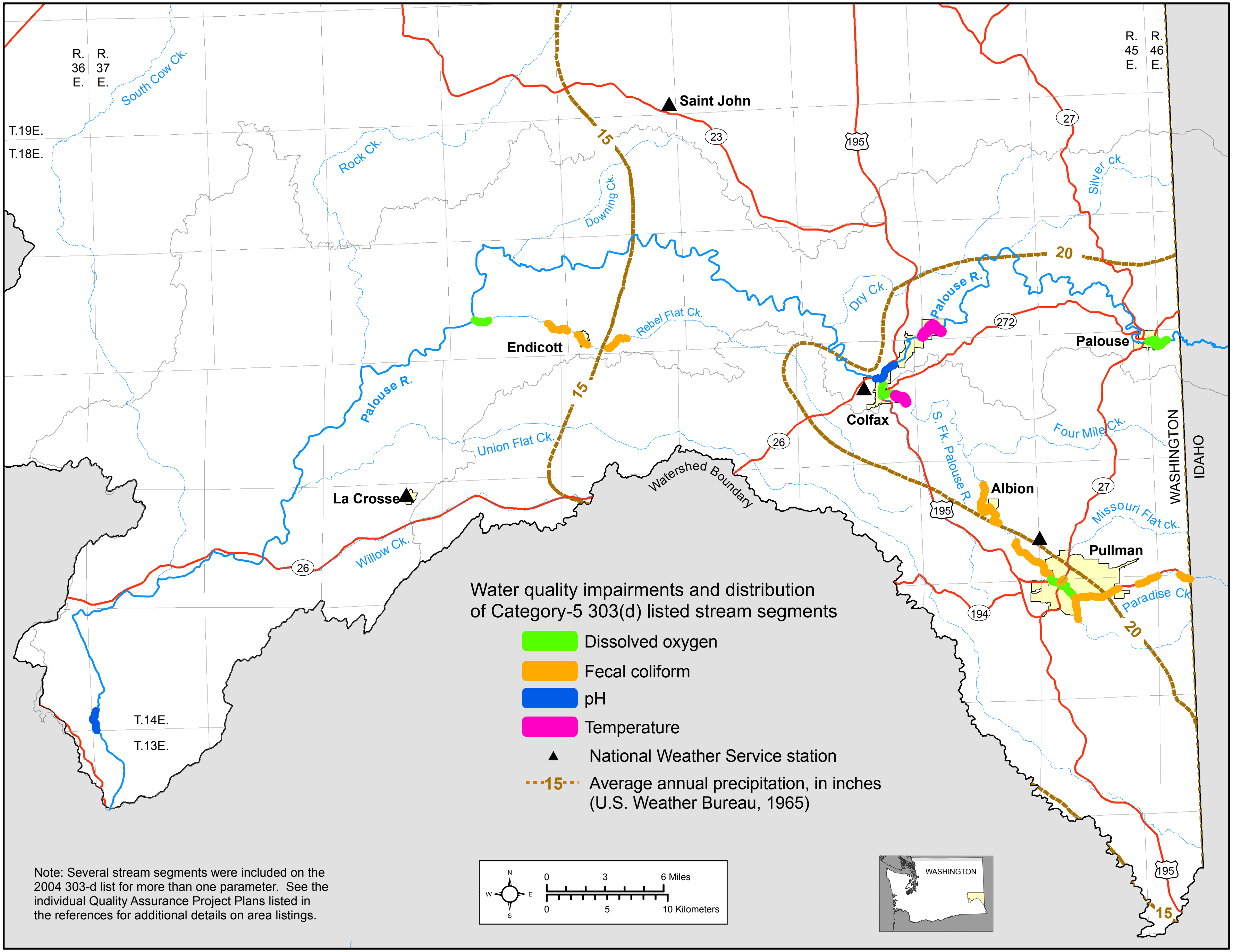

Figure 1 - Study area location and general distribution of Category-5 303(d) listed stream segments

Study Area Description

Physical Setting and Land Use

The Palouse River basin encompasses approximately 3,283 square miles of eastern Washington (2,730 square miles) and western Idaho (553 square miles). The basin includes most of Washington's Whitman County and lesser parts of Spokane, Lincoln, Adams, and Franklin Counties (Nassar and Walters, 1975). Land surface elevations within the watershed range from approximately 541 feet near the Palouse River confluence with the Snake River to approximately 5340 feet near the river's headwaters in the St. Joe National Forest of western Idaho.

The Palouse basin is drained by six primary rivers and streams including the Palouse River, Cow Creek, Rock Creek, Union Flat Creek, Rebel Flat Creek, and the South Fork Palouse River. Roughly half of the total watershed area is contained within the Cow Creek and Rock Creek sub-basins, which drain the channeled scablands of the eastern Palouse basin.

The SFPR basin (the primary study area for this project) encompasses approximately 295 square miles or about 9% of the greater Palouse watershed and includes the cities of Pullman and Moscow. The SFPR drainage is loosely bounded to the south, east, and north by a series of low-lying bedrock hills and mountains. Land surface altitudes range from a maximum of 4983 feet along the eastern watershed perimeter at Moscow Mountain to approximately 1960 feet at the SFPR confluence with the Palouse River at Colfax.

The SFPR basin is drained by five primary rivers and streams including the SFPR, Paradise Creek, Missouri Flat Creek, Four Mile Creek, and Spring Flat Creek. Most of these streams originate along the slopes of the Palouse Range, north and east of Moscow. They flow generally west-southwest into Washington where they merge before joining the mainstem Palouse River near the town of Colfax (Plate 1, Figure 1).

Approximately 82% of the SFPR basin is dry-land farmed, with the principal crops being spring and winter wheat, barley, peas, and lentils. Land use in the remainder of the watershed consists of urban areas, forest lands, rangeland, and riparian or wetland areas (RPU, Inc., 2002).

Most of the watershed population is centered around the Washington State University campus at Pullman (pop. 24,740) and the University of Idaho at Moscow (pop. 21,291) with smaller populations at the towns of Colfax (pop. 2,846) and Albion (pop. 616) (OFM, 2007). Groundwater is the primary source of domestic supply for these communities.

Climate

The climate of the Palouse basin is characterized by hot dry summers and generally cool damp winters. July and August are typically the warmest months with average maximum temperatures in the low-to-mid 80's °F. December and January are generally the coldest months with average minimum temperatures in the low to mid 20's °F (Figure 2).

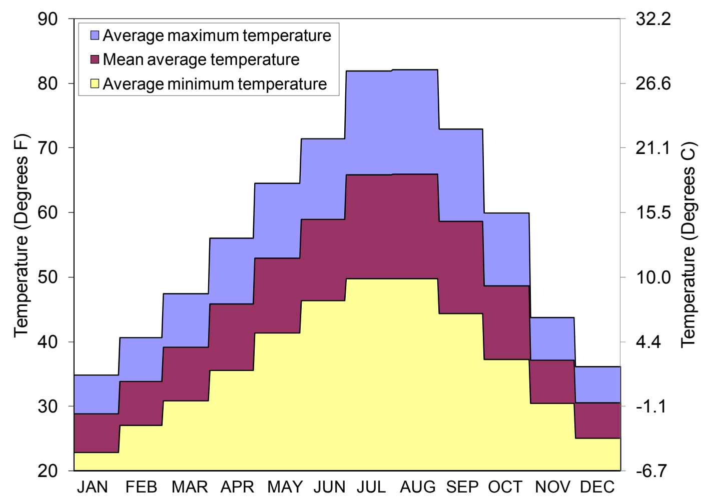

Figure 2 - Monthly-average maximum, minimum, and mean air temperatures at Pullman for 1940 to 2007 (Western Regional Climate Center, 2008).

Average annual precipitation values generally increase from west to east across the study area. These values range from less than 15 inches in the southern and western study area to more than 40 inches along the crest of the Palouse Range north of Moscow (WRCC, 2008).

Roughly two-thirds of the annual precipitation at Pullman falls as rain or snow during the six-month period between November and April, with relatively little precipitation during the summer growing season (Figure 3).

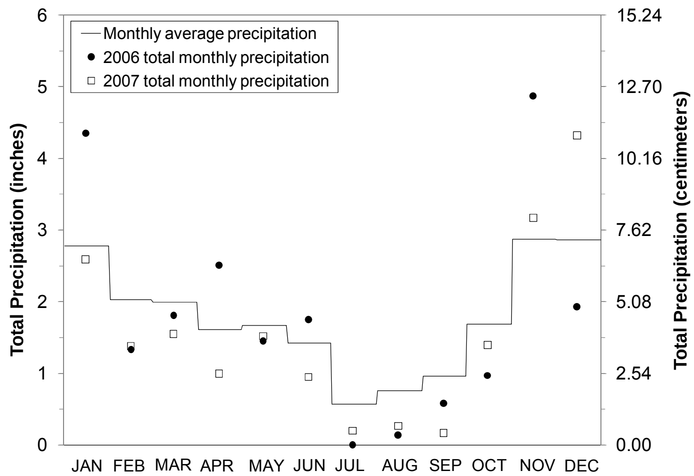

Figure 3 - Monthly average precipitation at Pullman for 1940 to 2007 (Western Regional Climate Center, 2008).

In 2006, the total precipitation at Pullman was 21.75 inches, slightly greater than the station average annual value of 21.32 inches. 2006 was characterized by greater than normal precipitation during January, April, June, and November, while the remaining months were dryer than normal (Figure 3).

In contrast, 2007 had below average precipitation for all months except November and December. The total precipitation at Pullman in 2007 was 18.52 inches or roughly 87% of the station average value.

Streamflow

The U.S. Geological Survey (USGS) currently operates four streamflow gages within the study area: two on the Palouse River (station 13351000 at Hooper and station 13345000 near Potlatch), one on the South Fork Palouse River at Pullman (station 13348000), and one on Paradise Creek at Moscow (station 13346800). To supplement the USGS stations, Ecology installed five short-term gages along the SFPR-Paradise Creek stream corridor in spring 2006, and four additional gages along the Palouse River in spring 2007 (Plates 1 and 2, Figure 1).

The mean annual discharge for the Palouse River at Hooper has averaged approximately 597 ft^3/s (Figure 4) while the discharge near Potlatch averaged approximately 262 ft^3/s. Area streamflows generally follow seasonal precipitation patterns. These streamflows are typically lowest during the summer (July, August, and September) and increase during the winter and spring when precipitation and snowmelt are most abundant.

The flows at both mainstem gages were generally below the station daily average values for most of 2007 with short periods of above average flow during winter storm events in January, February, and March.

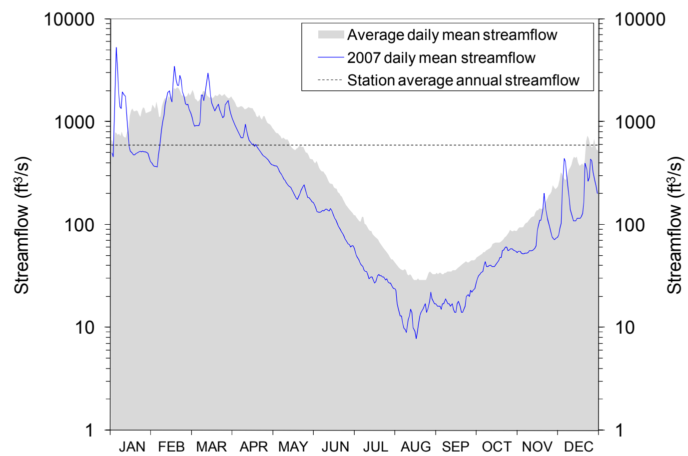

Figure 4 - Streamflow at USGS station 13351000, Palouse River at Hooper for 1897-1916 partial and 1951-2007.

The mean annual discharge for the SFPR at Pullman has averaged approximately 38.1 ft^3/s (Figure 5) while the discharge for Paradise Creek at Moscow averaged approximately 7.22 ft^3/s (Figure 6). Like the mainstem stations, the streamflows at these stations generally follow seasonal precipitation patterns. Flows are typically lowest during the summer (July, August, and September) and increase during the winter and spring when precipitation and snowmelt are most abundant.

During 2006, streamflows at the USGS gaging stations at Pullman and Moscow generally mirrored the seasonal precipitation patterns observed at Pullman. Flows at these stations were generally below station daily average values between mid-June and mid-October and exceeded average values during January, April, and November.

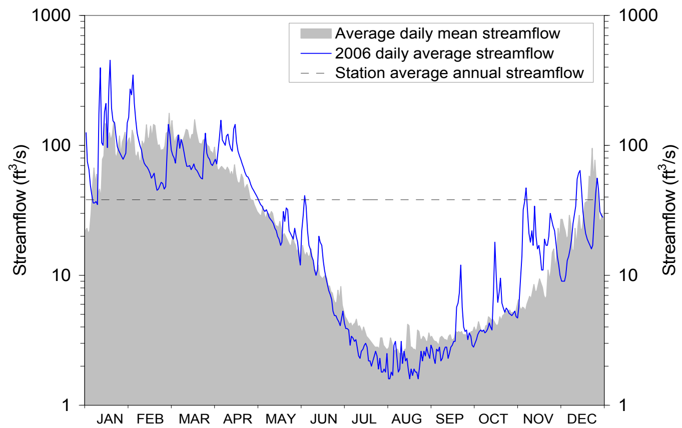

Figure 5 - Streamflow at USGS station 13348000, South Fork Palouse River at Pullman, Washington for 1934-42, 1961-81, and 2002-2006.

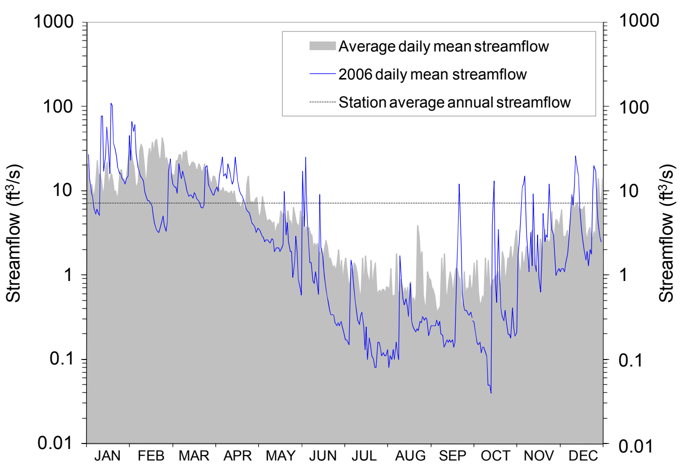

Figure 6 - Streamflow at USGS station 13346800, Paradise Creek at University of Idaho at Moscow, Idaho for 1978-2006.

Hydrogeologic Setting

The primary study area for this project lies within the Palouse sub-province of the Columbia Basin, near the eastern edge of the Columbia Plateau Aquifer System (Drost et al., 1990). The oldest known rocks in the area are quartzites, gneiss, and granites of Cretaceous to pre-Cretaceous age (Table 1). These rocks underlie the Washington portion of the Palouse basin at depth and are exposed locally at land surface, east of the town of Colfax, where they form the cores of several prominent hills and buttes that rise above the surrounding terrain (Figure 7).

Throughout most of the study area, these older rocks are overlain by basalts of the Columbia River Basalt group (Table 1). The Columbia River Basalts were extruded during Miocene time from a series of long linear vents southeast of the study area over a several-million-year period (approximately 17.5 to 6 million years ago).

The Columbia River Basalt Group has been subdivided into numerous sub-groups. Three of these, the Grande Ronde, the Wanapum, and the Saddle Mountains Formations, occur at land surface locally. The Grande Ronde Formation comprises the majority of area basalts by volume and is as much as 2,500 feet thick near Pullman. These basalts occur mostly at depth, however, and outcrop only locally along the Palouse River valley north and west of Colfax and along the lower Palouse valley below the Palouse Falls (Figure 7).

Most of the exposed basalts in the study area belong to the Wanapum Formation. Priest Rapids Basalts (the youngest Wanapum member) directly underlie and border most of the upper Palouse River and SFPR drainages east of the town of Albion. West of Albion, the Priest Rapids Basalts gradually give way to Rosa Basalts: the middle member of the Wanapum Formation.

Both the Wanapum and Grande Ronde formations are composed of numerous discrete flows that range from less than 10 to as much as 150 feet thick. The individual flows are typically characterized by massive flow interiors bounded by fractured (and often permeable) flow tops and bottoms.

Table 1 - Lithologic and hydrologic characteristics of surficial geologic units (Bush and Provant, 1998; Schuster et al., 1997).

Period	Epoch	Geologic Unit / Formation	Unit symbol	Description
Quaternary	Holocene	Alluvium	Qa	Alluvium derived principally from reworked loess and basalt, but locally includes reworked colluvium, alluvial fan, flood, or mass wasting deposits. Generally composed of thin (less than 30 foot thick) deposits of loose-to-compact, poorly-sorted, well-rounded-to-angular basaltic gravel, sand, silt, and granitoid fragments, with local accumulations of basaltic cobbles or boulders. Locally provides small amounts of water to area streams or rivers.
	Pleistocene	Loess	Ql	Up to 300 foot thick deposits of massive, brown-to-tan colored silt, and fine wind-blown sand. May also include discontinuous caliche or ash lenses.
		Outburst flood deposits, undifferentiated	Qf	Mostly catastrophic flood gravels and sands but may include touchet beds, terraced deposits, and lacustrine/fluvial deposits.
Tertiary	Miocene	Saddle Mountains Basalts, undifferentiated	Mvs	Fine-to-medium grained basalt with phenocrysts of plagioclase or olivine. This unit outcrops locally in the western study area and along the upper reaches of Union Flat Creek.
		Wanapum Basalt Formation - Priest Rapids member	Mv(wpr)	Typically medium to coarse grained basalts with microphenocrysts of plagioclase and olivine. Includes basalts and interbedded sediments of the Priest Rapids, Rosa, and Frenchman Springs members. These rocks outcrop within and underlie the Palouse River, the SFPR, and Paradise Creek basins. The Rosa member is widely exposed at land surface in the western and central study area while the Priest Rapids member is most prevalent in the eastern study area between Albion and the WA/ID border. The Frenchman Springs member occurs at land suface in the southwestern scablands portion of the study area. The Wanapum Basalts contain significant regional aquifers and supply water to most of the area's shallower domestic and municipal wells.
		Wanapum Basalt Formation - Rosa member	Mv(wr)	
		Wanapum Basalt Formation - Frenchman Springs member	Mv(wfs)	
		Grande Ronde Basalts	Mv(gN2)	Fine to very-fine-grained basalts that outcrop along the lower South Fork and mainstem Palouse Rivers north and west of the town of Colfax. This unit also underlies the Wanapum Basalts at depth throughout most of the study area. The Grande Ronde basalts contain significant regional aquifers and supply water to many of the areas deeper municipal wells.
Pre-Tertiary Period		Pre-Columbia River Basalt Group Rocks, undifferentiated	KpK	Includes cretaceous intrusive rocks such as granodiorite and tonalite plus precambrian metasedimentary schist and gneiss. This unit is generally not a significant aquifer.

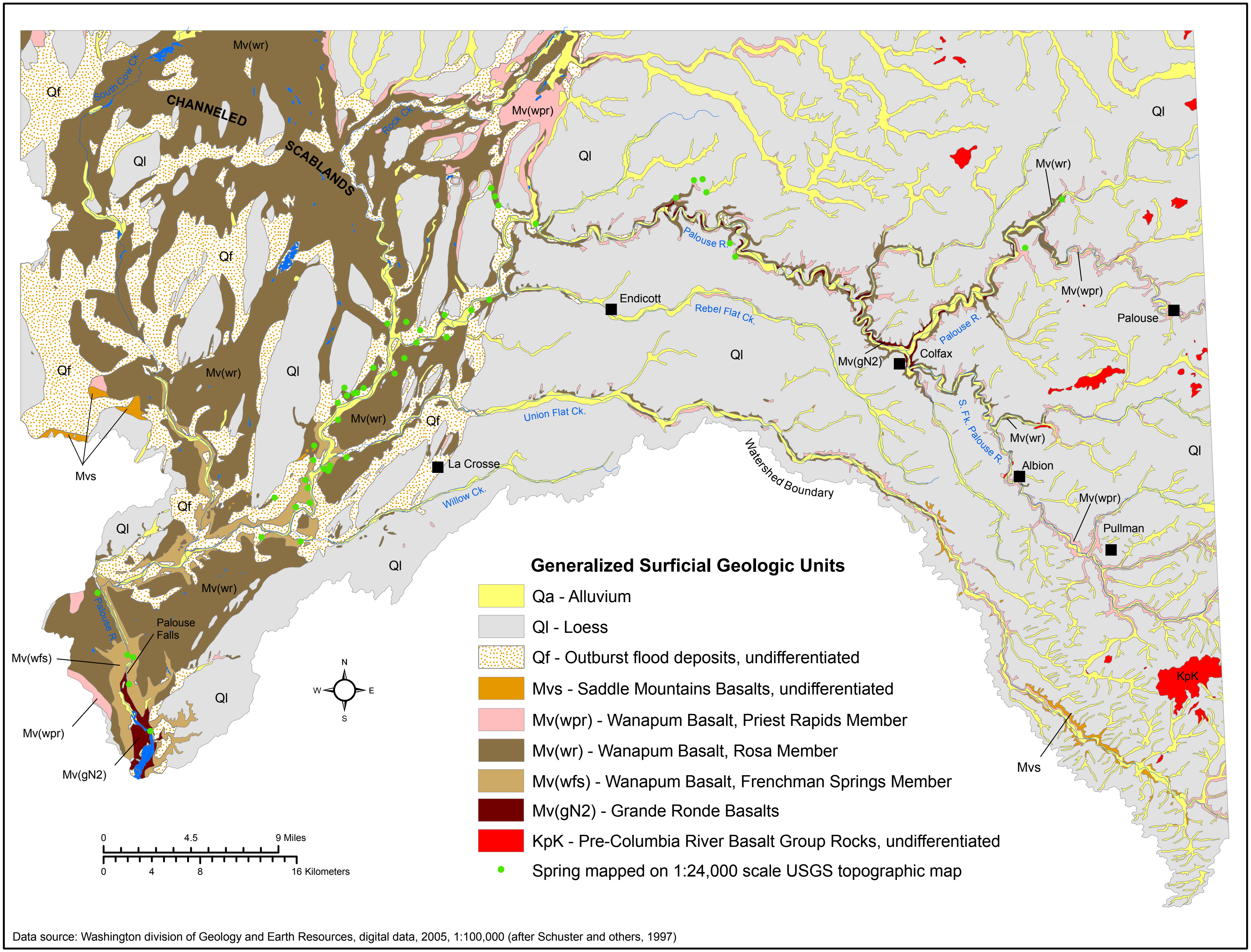

Figure 7 - Generalized surficial geology of the Palouse River basin.

In the western study area, the Columbia River Basalts are several thousand feet thick but progressively thin toward the east where the older crystalline rocks lie nearer land surface. Along the eastern watershed perimeter, the basalt is commonly inter-fingered with thick sedimentary inter-beds composed of fine-grained sand, silt, and clay that were deposited when rocks and sediments eroded from the surrounding hills and mountains between flow events.

During the last continental glaciation, the western third of the study area was scoured by numerous catastrophic glacial floods that traversed eastern and central Washington during periodic breaches of the ice dam that formed glacial Lake Missoula in western Montana (Bretz, 1959). The eastern part of the study area was spared the scouring effects of these floods. The basalts there are overlain by as much as 300 feet of loess (wind-blown sand and silt) which forms the characteristic rolling hills of the Palouse area.

Groundwater Movement and Discharge

The study area's primary aquifers are contained within the Wanapum and Grande Ronde Formation basalts. Most drilled domestic wells obtain water from the shallower Wanapum basalts, while municipal wells often target deeper, more productive aquifers within the Grande Ronde Formation. These formations are both capable of sustained yields of several hundred gallons per minute or more to properly constructed wells. The overlying Palouse Formation and the weathered portions of the older crystalline rocks can also yield small, but usable, amounts of water to larger diameter dug wells, and are an important source of groundwater locally.

Since the 1960s, several studies have been undertaken to better define the geometry and long-term development potential of the area's basalt aquifers (Foxworthy and Washburn, 1963; Walters and Glancy, 1969; Luzier and Burt, 1974; Barker, 1979; Lum et al., 1990). Ambient monitoring of groundwater levels within the Pullman/Moscow area indicates that annual water use typically exceeds the natural recharge from precipitation, seasonal snowmelt, and other sources. This chronic imbalance has resulted in progressive groundwater level declines: 12+ inches per year within the Pullman/Moscow area since at least the mid 1930s (Foxworthy and Washburn, 1963; PBAC, 2009). Concern over the sustainability of groundwater supplies has fostered considerable interest in developing a better understanding of the extent and hydrogeologic characteristics of area aquifers (PBAC, 2009).

While much remains to be learned about the details of area groundwater movement, the studies to date suggest that water within the Palouse Grande Ronde aquifers generally flows from upland recharge zones along the northern and eastern watershed perimeter toward the south-southwest where it naturally discharges as springs and streambed seeps along the Snake and lower Palouse Rivers (Luzier and Burt, 1974; Lum et al., 1990).

Groundwater in the overlying Wanapum aquifers follows a similar west-southwestward flow path but shows more local variability due to its interaction with rivers and streams (Lum et al., 1990). Water within the Palouse Formation loess, which overlies the Wanapum Basalts throughout most of the SFPR basin, likely provides seasonal flow to many of the area's smaller intermittent streams, seeps, and springs (Leek, 2006).

Study Methods and Design

We used several field and analytical techniques during this study to evaluate the timing, magnitude, and spatial distribution of surface-water/groundwater interactions. Streamflow gains and losses were estimated for the reaches between continuous streamflow gages via surface-water seepage evaluations and Darcy flux calculations. These reach scale gain/loss estimates were supplemented with streambed thermal profiles and vertical hydraulic gradient measurements from instream piezometers. This was done to better define the direction and timing of surface-water and groundwater interactions at discrete points.

The locations of monitoring sites were initially determined using a Global Positioning System (GPS) receiver and were refined, where necessary, using geo-rectified digital orthophotos. Land surface altitudes at well and piezometer sites were estimated using a Geographic Information System (GIS)-based pixel matching process and the 10-meter USGS digital elevation model (DEM) for Washington.

Instream Piezometers

Between May and June 2006, we installed 17 instream piezometers along the SFPR and Paradise Creek stream corridors to monitor surface-water/groundwater head relationships, streambed water temperatures, and near-stream groundwater quality (Plate 1, Figure 1). Nine additional piezometers were installed along the mainstem Palouse River in spring 2007.

The piezometers consisted of an upper two-foot removable section and a lower five-foot section of 1.5-inch diameter galvanized pipe (Figure 8 and Table B-4). The piezometers were manually installed into the streambed to a maximum depth of about five feet. Where possible, they were located in quiet water away from riffles, point bars, or other streambed features that might induce local-scale hyporheic exchanges. The piezometers were developed after installation with a manual bladder-type bilge pump using "surge and pump" techniques to ensure a good hydraulic connection between the piezometer and the streambed sediments.

The piezometers were accessed monthly, when flows permitted, to make comparative measurements of stream stage and groundwater level. Stream stage was measured by aligning an engineer's tape parallel to the piezometer pipe and measuring the distance from the stream surface to the top of the piezometer casing. The groundwater level inside the piezometer was measured from the same reference point using a calibrated low-displacement E-tape. For severely angled (off-vertical) piezometers, these "raw" values were corrected using simple trigonometric relationships to obtain true depth-to-water measurements.

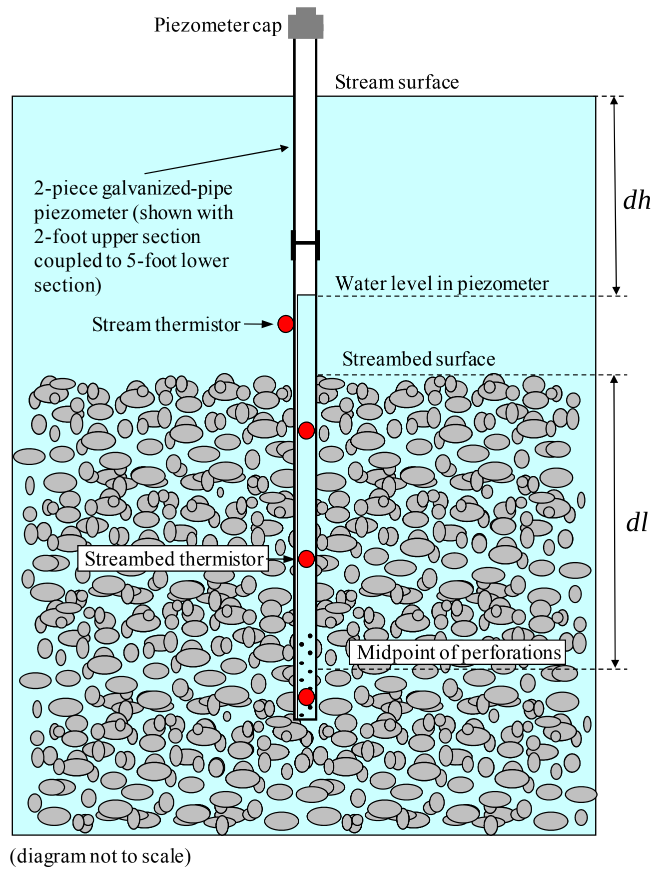

Figure 8 - Schematic of a typical instream piezometer and thermistor array.

The water level difference between the inside and outside of pipe measurements indicates the local direction of water flow between the stream and groundwater. When the piezometer head exceeds (is higher than) the stream stage, groundwater flow into the stream can be inferred. Similarly, when the stream stage is higher than the groundwater level in the piezometer, loss of water from the stream to groundwater can be inferred.

Equation 1 was used to derive vertical hydraulic gradients for each piezometer from paired groundwater level and stream stage measurements. Converting the field-measured water levels to hydraulic gradients normalizes for differences in piezometer depth and screen interval between sites, thereby enabling direct comparisons to be drawn between piezometers.

$$i_v = \frac{dh}{dl} \qquad (1)$$

where:

i_v = vertical hydraulic gradient (dimensionless).

dh = the difference in head between the stream stage and instream piezometer water level (L).

dl = the distance from the streambed surface to the mid-point of the piezometer perforations (L).

where (L) is length.

By convention, negative hydraulic gradient values indicate potential loss of water from the river to groundwater, while positive values indicate potential groundwater discharge into the river.

In addition to measuring water levels, the piezometers were used to conduct constant head injection tests to estimate vertical hydraulic conductivity values for the streambed sediments at each site[2] (Pitz, 2006). The constant head test method assumes that the streambed sediments are hydraulically isotropic[3] at a sub-meter scale.

In most alluvial environments, streambed sediments exhibit some degree of anisotropy owing to the preferential orientation of sediment clasts and clay minerals or the inter-fingering and layering of fine and coarse grained materials (Freeze and Cherry, 1979). To adjust for potential streambed anisotropy effects and well development, we multiplied the hydraulic conductivity values obtained from field tests by 0.1 (based on an assumed 10:1 horizontal to vertical anisotropy ratio; see Freeze and Cherry, 1979) to derive estimated vertical hydraulic conductivity values for the streambed sediments at each piezometer site. The results of this evaluation are summarized in Table B-5.

Thermal Profiling of Streambed Sediments

Streams and other waterbodies that are exposed to atmospheric and solar heating commonly exhibit a several degree diurnal (daily) variation in water temperature. Groundwater, in contrast, is typically insulated from the sun and atmosphere by overlying rocks or sediment and therefore exhibits little if any diurnal thermal variability.

The difference in daily temperature patterns between a stream and groundwater can be monitored to provide a continuous qualitative record of surface-water/ groundwater exchanges while also providing a secondary confirmation of the interactions inferred from periodic hydraulic gradient measurements (Stonestrom and Constantz, 2003).

For this project, we instrumented all but one of the instream piezometers with recording thermistors[4] to monitor groundwater temperatures within the upper four to five feet of the streambed sediments. One thermistor was located near the piezometer bottom within the perforated interval of the pipe, another approximately 0.5 to one foot below the streambed, and one roughly equidistant between the upper and lower thermistors (Figure 8). We also installed single thermistors in seven near-stream domestic wells to define ambient groundwater temperatures (i.e., the groundwater temperature unaffected by nearby streams).

At piezometer sites where streambed water temperatures are highly dampened relative to instream temperatures, one can infer that groundwater is moving upward through the streambed and discharging to the stream (a gaining stream reach) (Figure 9). Conversely, at sites where streambed water temperatures closely mimic those of the stream, one can infer that water is

[2] See Cardenas and Zlotnik (2003) for a detailed discussion of the constant head test method and its limiting assumptions. See Pitz (2006) for details about the individual tests conducted for this study.

[3] Sediments whose hydraulic properties are the same in all directions are said to be isotropic.

[4] For this evaluation we used Hobo pro ™ thermistors manufactured by Onset Corporation. The thermistors have a reported operating range of -20°C to +50°C, a resolution of 0.02°C, and are accurate to about ± 0.2 °C.

leaving the stream and moving down into the streambed at that location (a losing reach) (Stonestrom and Constantz, 2003).

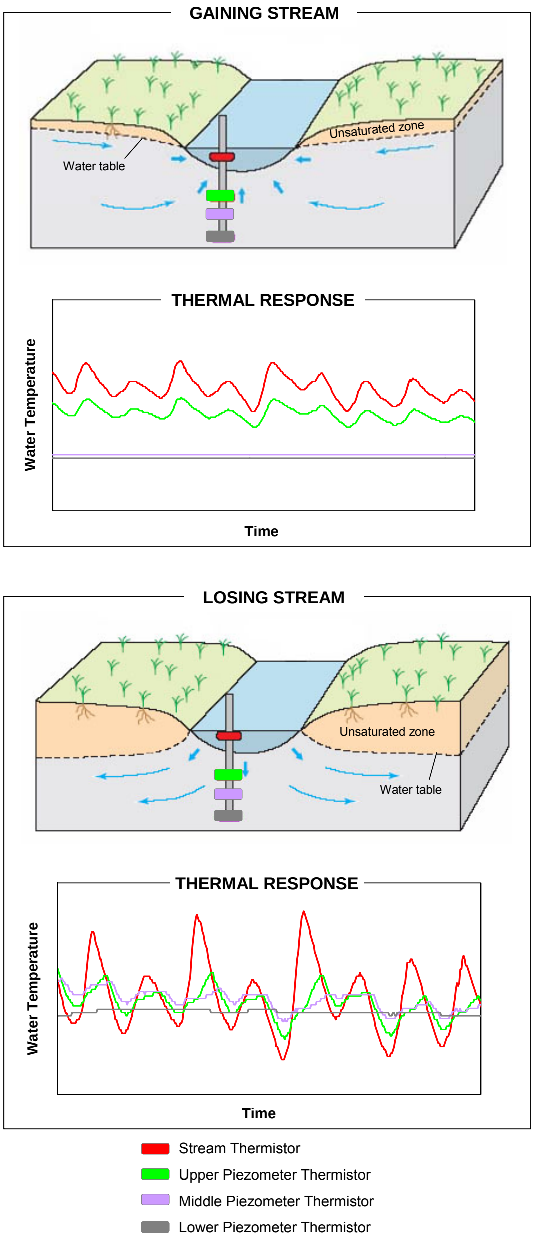

Figure 9 - Idealized streambed thermal responses for a perennial gaining and losing stream reach (adapted from Simonds et al., 2004; and Stonestrom and Constantz, 2003).

Stream Seepage Evaluations

During the summer, discharge from the Moscow Wastewater Treatment Plant (WWTP) comprises as much as 87% of the flow in Paradise Creek at the WA/ID state line. Similarly, the combined WWTP discharges of Moscow and Pullman commonly comprise more than 50% of the flow in the SFPR at Pullman (Carroll and Mathieu, 2006). Since unsteady WWTP discharges dominate the summer flows in these two streams we were not able to use traditional seepage run techniques to define streamflow gains and losses.

Instead, daily average streamflow estimates were derived for selected stream transects along the SFPR and Paradise Creek using a HEC-RAS (USACE, 2008) modeling approach (NHC, 2008; Carroll, 2009). The model was calibrated using streamflows measured at the USGS Pullman (ID 13348000) and Moscow (ID 13346800) gages for the SFPR and Paradise Creek, respectively. Additional model inputs included measured effluent discharges for the Moscow and Pullman WWTPs, estimated quantities for active irrigation withdrawals or other diversions, and inputs to the SFPR and Paradise Creek from tributaries and other point discharges that were measured during Ecology's field surveys.

This modeling and flow averaging approach enabled us to better estimate streamflow gains and losses for six stream reaches along the Paradise Creek/SFPR corridor for three two-day periods (July 25-26, August 29-30, and September 11-12, 2006) (Equation 2 and Table 2).

For the mainstem Palouse River, we used measured streamflows (from Ecology and USGS gages) and a similar flow averaging approach (*but without the HEC-RAS model)* to estimate streamflow gains and losses for two three-day periods during summer 2007 (July 30-Aug 1 and Aug 27-29) (Equation 2 and Table 3).

$$S = Qd - Qu - \Sigma T - \Sigma D + \Sigma W \qquad (2)$$

where:

S is the two (SFPR and Paradise Creek) or three day (mainstem Palouse River) average net streamflow gain or loss along the reach, in ft^3/s. Negative seepage values indicate that the river lost flow as it traversed the reach, while positive values indicate the river gained flow from groundwater discharge to the reach.

Qd is the modeled two-day average (SFPR and Paradise Ck) or measured three-day average (mainstem Palouse River) streamflow at the downstream end of the seepage reach, in ft^3/s.

Qu is the modeled two day average (SFPR and Paradise Ck) or measured three day average (mainstem Palouse River) streamflow at the upstream end of the seepage reach, in ft^3/s.

ΣT is the sum of tributary inputs to the river between the upper and lower boundaries of the seepage reach, in ft^3/s.

ΣD is the sum of known point discharges to the river between the upper and lower boundaries of the seepage reach. Where applicable, this value includes the measured two-day average discharge from area WWTPs, in ft^3/s.

ΣW is the sum of known water withdrawals (diversions) from the river between the upper and lower boundaries of the seepage reach, in ft^3/s.

As a secondary confirmation of the modeled seepage results for the SFPR and Paradise Creek, we conducted a Darcian flux analysis (Darcy, 1856) using the hydraulic gradients and streambed hydraulic conductivity estimates from 14 instream piezometers installed along the SFPR/Paradise Creek corridor (Equation 3).

$$Q = -K_v I_v A \qquad (3)$$

where

Q is the total estimated volume of water gained or lost by the river along the reach (L^3/T).

K_v is the average vertical hydraulic conductivity of the streambed material within the seepage reach (L/T).

I_v is the average vertical hydraulic gradient between the river and groundwater as measured at piezometer sites along the reach (dimensionless).

A is the streambed cross-sectional area across which water exchange occurs (L^2).

where L represents units of length and T units of time.

To perform the analyses (one each for July, August, and September 2006), we used GIS software and geo-referenced digital orthophotos of area streams to subdivide the previously described seepage reaches into 50-meter segments. The wetted width for each segment was then estimated by averaging the orthophotos-derived stream widths for the upper and lower boundaries of the segment.

The streambed area (A) for each 50-meter segment was then estimated by multiplying the segment length by its average estimated width. The vertical hydraulic gradient (I_v) and vertical hydraulic conductivity (K_v) values for each segment and analysis period were derived by interpolating between the values measured at instream piezometer sites. The values for A, I_v, and K_v were then multiplied to define the estimated gain or loss for each segment and analysis period (Equation 3).

Finally, the total estimated gain or loss (Q) for each seepage reach and analysis period was determined by summing the calculated gains and losses for each of the 50-meter segments comprising the reach (Figure 11) [5].

Several simplifying assumptions are implicit in the Darcian flux analysis.

1. The net seepage values (S) estimated from stream seepage evaluations are roughly equivalent to the total (gross) water exchanges estimated from the Darcian flux calculations for each reach.
2. Water exchanges between a river and groundwater occur throughout the wetted area of the streambed and only in a vertical or near-vertical direction.
3. The average vertical hydraulic gradient for a seepage reach is reasonably represented by averaging the vertical hydraulic gradients measured in instream piezometers along the reach.

[5] The data plots for July and September 2006 were intentionally omitted from Figure 11 to maintain graphical clarity. The reach-level results for these months are summarized in the report text by seepage reach.

4. The average vertical hydraulic conductivity of the streambed sediments along a seepage reach can be reasonably approximated by linear interpolation between the values measured at instream piezometer sites.

5. The reach length and average width values estimated from digital orthophotos provide a good approximation of the streambed area across which water exchange occurs.

Well Numbering and Location System

The well locations referenced in this report are described using the township, range, section (TRS), and quarter-quarter section convention. Range designations include an "E," and township designations include an "N," to indicate the well lies east and north of the Willamette meridian and baseline, respectively. Each 40-acre, quarter-quarter section is represented by a single capital letter.

If a quarter-quarter contains more than one inventoried well, a sequence number is added after the letter designation to assure uniqueness. For example, the first inventoried well in the southwest quarter of the southeast quarter of Section 21, Township 15N, Range 38E is represented as 15N/38E-21J01, the second well as 21J02, and so forth (Figure 10).

As an additional aid to future investigators, all wells monitored during this study for water level or water quality were fitted, where possible, with a Department of Ecology well identification tag. Each tag contains a unique six-digit alpha-numeric identifier, consisting of three letters and three numbers (e.g., ALB689). The two-by-three-inch identification tag was secured to the well casing, or another permanent fixture of the water system, with stainless steel banding. This arrangement provides future investigators ready confirmation of well identity and avoids the potential cross-study conflicts inherent in the TRS numbering system.

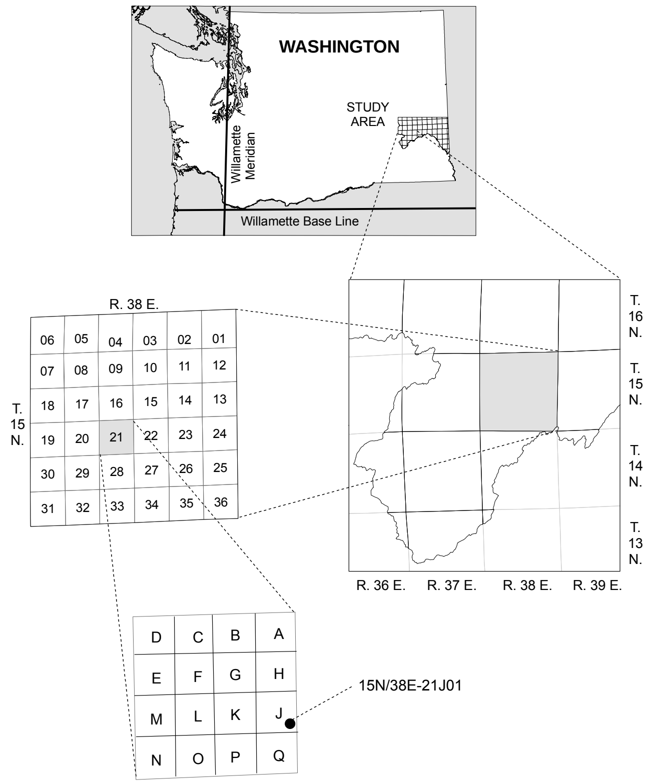

Figure 10 - Well numbering and location system.

Interaction of Groundwater and Surface Water

The idealized depictions of gaining and losing stream reaches shown in Figure 9 present a highly simplified view of the complex physical processes that drive surface-water and groundwater interactions along streams. In reality, these interactions are often highly variable, both spatially and temporally, due to the interplay of local, intermediate, and regional scale exchange processes (Stonestrom and Constantz, 2003).

A stream or stream reach that shows a *net* gain in flow from regional groundwater discharge may, on closer inspection, reveal localized gains or losses due to streambed geomorphic influences. These influences include pool-riffle sequences, channel sinuosity, or variability in the hydraulic properties of the streambed or surrounding aquifer material (Kalbus et al., 2006). Thus, at any given point, the water entering a stream through its bed may originate from local or intermediate scale (hyporheic) exchanges, regional groundwater discharges, or a combination of these sources. There is currently no single field technique or analysis method that adequately characterizes these subtleties.

Accordingly, for this investigation we employed several field and analytical techniques to gain insights into the direction, timing, and spatial distribution of area surface-water/groundwater interactions. Stream seepage runs and Darcy flux evaluations were used to estimate the volume of water gained or lost along the several-mile long reaches that typically separated continuous flow gages. These reach-scale evaluations were supplemented with data from off-stream wells and instream piezometers to better define the timing and direction of water exchanges at discrete points along area streams.

The collective results from these evaluations are depicted graphically in Plate 1 (SFPR and Paradise Creek) and Plate 2 (Mainstem Palouse River) and are discussed below by stream and seepage reach. A summary discussion of the uncertainty surrounding these estimates is provided at the end of this section.

Paradise Creek

Seepage Reach 1

Reach 1 is approximately 1.4 miles long and extends from the USGS gaging station at river mile (RM) 8.1 on Paradise Creek (Map ID G7) to the Ecology gage at RM 6.6 (Map ID G6 on Plate 1, Figure 1). The streambed deposits along reach 1 consist of a thin alluvial veneer of fine-to-coarse sand and silt with local accumulations of fine-to-medium gravel. These deposits grade laterally into loess of the Palouse Formation and overlie Priest Rapids Member basalts of the Wanapum Formation (Figure 7).

The stream seepage balances prepared for reach 1 yielded net water exchanges, between the creek and groundwater, of approximately +0.17 ft^3/s , +0.12 ft^3/s, and +0.18 ft^3/s for the July, August, and September 2006 evaluation periods, respectively (Table 2). This is consistent with the Darcy flux evaluation for reach 1 which yielded an estimated streamflow gain of +0.12 ft^3/s during August 2006 (Figure 11).

These reach-based results are supported by the hydraulic gradients and streambed thermal profiles measured in piezometer P17, located at the lower reach boundary (Plate 1, Figures 1 and 2). The vertical hydraulic gradients measured at piezometer P17 were small (0.003 to 0.07 ft/ft) but consistently positive, which suggests that groundwater potentially discharges to the creek at this location.

The streambed thermal profile at site P17 generally exhibited a 5-10 C° temperature differential between the stream and near-surface groundwater measured at depths of 2.05 and 3.8 feet below the streambed (Plate 1, Figure 2). The groundwater temperatures at both depths were considerably cooler and less variable than the stream during the summer and warmer during the winter.

Viewed together, these results suggest that groundwater likely contributed small but measurable amounts of water to Paradise Creek, along reach 1, during summer 2006.

Seepage Reach 2

Reach 2 is approximately 6.5 miles long and extends from the steam gage at RM 6.6 on Paradise Creek (Map ID G6) to the gage at RM 0.1 (Map ID G5 on Plate 1, Figure 1). The streambed sediments along reach 2 consist of thin alluvial deposits of medium-to-coarse sand and silt with local accumulations of fine to medium gravel and cobble. These deposits overlie basalts of the Priest Rapids Member of the Wanapum Formation, and grade laterally into Palouse Formation loess (Figure 7).

The two piezometers installed along reach 2 exhibited consistently positive hydraulic gradients during the study period:

- Piezometer P16, near the reach center, had gradients ranging from +0.07 to +0.14 ft/ft.
- Piezometer P17, at the upper reach boundary, had generally small but positive gradients ranging from +0.003 to +0.07 ft/ft (Plate 1, Figures 1 and 2).

A pattern of positive hydraulic gradients suggest that groundwater likely discharges to the creek at these locations. This assertion is bolstered by the streambed thermal profiles at these sites, which showed a 7 to 10 C° temperature differential between the creek and near- surface groundwater. The streambed water temperatures at both sites were significantly cooler than the stream during the summer and warmer during the winter, a pattern consistent with groundwater discharge conditions.

These point-based results are consistent with Darcy flux evaluations conducted for July, August, and September 2006. These evaluations yielded estimated streamflow gains of approximately +0.20, +0.19, and +0.22 ft^3/s, respectively, for reach 2 (Figure 11). The corresponding surface-water discharge balances showed no measurable exchange during July and estimated gains of +0.45 ft^3/s and +0.38 ft^3/s during August and September 2006, respectively (Table 2).

Viewed together, the stream seepage balances and Darcy flux estimates for Paradise Creek (reaches 1 and 2) suggest that the creek gained between +0.17 and +0.57 ft^3/s from groundwater discharge during the July-September 2006 evaluation period. These findings are consistent with previous results reported by Heinemann (1994) who concluded, based on stream temperature measurements made in late summer 1993, that groundwater contributed up to 1 ft^3/s to Paradise Creek between Pullman and Moscow. The downstream cooling of Paradise Creek that Heinemann described was also observed during this study, and is further supported by the relatively cool temperatures measured at the mouth of Airport Creek. Airport Creek is a small, partially groundwater-fed stream that discharges into Paradise Creek near the lower end of reach 2 (Plate 1, Figure 3).

Table 2 – Surface-water discharge balances for the South Fork Palouse River and Paradise Creek stream corridor.

River Mile	Measurement transect location	Seepage reach [1]	Reach length (miles)	JUL 25-26, 2006 Flow (ft^3/s)	JUL 25-26, 2006 Estimated Net gain/loss (ft^3/s)	JUL 25-26, 2006 Estimated Net gain/loss ($ft^3/s/mile$)	AUG 29-30, 2006 Flow (ft^3/s)	AUG 29-30, 2006 Estimated Net gain/loss (ft^3/s)	AUG 29-30, 2006 Estimated Net gain/loss ($ft^3/s/mile$)	SEPT 11-12, 2006 Flow (ft^3/s)	SEPT 11-12, 2006 Estimated Net gain/loss (ft^3/s)	SEPT 11-12, 2006 Estimated Net gain/loss ($ft^3/s/mile$)
32.25	USGS PARA8.0			0.16			0.24			0.16		
31.75	34MoscPOTW	1	1.49	1.15	0.17	0.11	1.51	0.12	0.08	1.62	0.18	0.12
31.57	34ParaUnk(07.5)			0.00			0.00			0.00		
30.76	GAGE 34Para06.6			1.48 *			1.87 *			1.96 *		
30.45	34ParaUnk(06.3)			0.00			0.00			0.00		
25.04	34Air00.0	2	6.52	0.01	0.00	0.00	0.00	0.45	0.07	0.00	0.38	0.06
24.42	34ParaWSU3			0.00			0.00			0.00		
24.23	GAGE 34Para00.1			1.49 *			2.32 *			2.34 *		
24.17	34SFPR24.3			0.12			0.04			0.10		
24.11	34SFPR-SD320			0.01			0.00			0.00		
23.98	34SFPR-SD290			0.00			0.00			0.00		
23.80	34SFPR-WSU1			0.77			0.45			0.28		
23.61	34SFPR-SD260			0.00			0.00			0.00		
23.30	34SFPR-WSU2	3	1.43	0.01	**-0.37**	**-0.26**	0.01	-0.05	-0.03	0.00	-0.04	-0.03
23.12	34SFPR-SD180			0.00			0.00			0.00		
23.05	34SFPR-SD170			0.00			0.00			0.00		
22.93	34SFPR-SD140			0.00			0.00			0.00		
22.87	34Dry00.0			0.12			0.09			0.12		
22.80	USGS 34SFPR22.8			2.15			2.86			2.80		
22.68	34Miss00.1			0.14			0.32			0.25		
21.93	34PullPOTW	4	7.02	4.61	**-1.43**	**-0.20**	5.58	-0.98	-0.14	5.62	-0.98	-0.14
21.75	34Hadl00.1			0.00			0.00			0.00		
17.34	34UnkSFPR(17.3)			0.03			0.03			0.03		
15.78	GAGE 34SFPR15.8			5.5 *			7.81 *			7.72 *		
15.22	34AlbPOTW			0.00			0.00			0.00		
10.94	34Four00.3	5	6.59	0.00	0.11	0.02	0.00	0.13	0.02	0.00	-0.08	-0.01
9.32	34Parv00.1			0.00			0.00			0.00		
9.20	GAGE 34SFPR09.2			5.61 *			7.94 *			7.64 *		
	Irrigation withdrawal	6	8.02	-0.30	0.02	0.00	-0.30	0.12	0.01	-0.30	0.04	0.00
1.18	GAGE 34SFPR01.2			5.33 *			7.76 *			7.38 *		
Combined total for seepage reaches 1-6					-1.50			-0.21			-0.50	

1 - The reach numbers shown here correspond to those shown on Plate 1, Figures 1 and 3.

Note: Values in bold font represent estimated gains or losses that exceeded the probable error associated with making the seepage measurements. The error assessment was conducted using the method described by Konrad and others, 2003, and assumed accuracies of +- 7.5% for measured mainstem or triburary flows, and +-20% for flows estimated from HEC RAS modeling. Modeled flows are flagged above with an asterisk (*)

South Fork Palouse River

Seepage Reach 3

Seepage reach 3 is approximately 1.4 miles long and extends from the streamflow gage at RM 0.1 on Paradise Creek (Map ID G5) to the USGS gage at RM 22.8 on the SFPR (Map ID G4 on Plate 1, Figure 1). The streambed sediments along reach 3 consist of a thin veneer of alluvial sand, silt, and fine-to-medium gravel overlying basalts of the Priest Rapids Member of the Wanapum Formation (Figure 7).

The surface-water discharge balances for reach 3 showed small estimated losses of -0.37, -0.05, and -0.04 ft^3/s for July, August, and September 2006 respectively (Table 2). The corresponding Darcy flux evaluations also yielded small but consistent losses of -0.04 ft^3/s for these months (Figure 11).

In contrast, piezometer P13 near the center of reach 3 showed small but consistently positive hydraulic gradients (+0.004 to + 0.075 ft/ft). Piezometer P12, at the mouth of Missouri Flat Creek, showed relatively large and consistently negative vertical hydraulic gradients (-0.125 to -0.88 ft/ft). These results suggest that reach 3 may contain both an upper-gaining segment and a lower-losing segment. However, the reach as a whole may lose small amounts of flow to groundwater. This is supported by a downstream increase in average stream temperature (Plate 1, Figure 3) which would likely not be the case were the river receiving significant inputs of cooler groundwater.

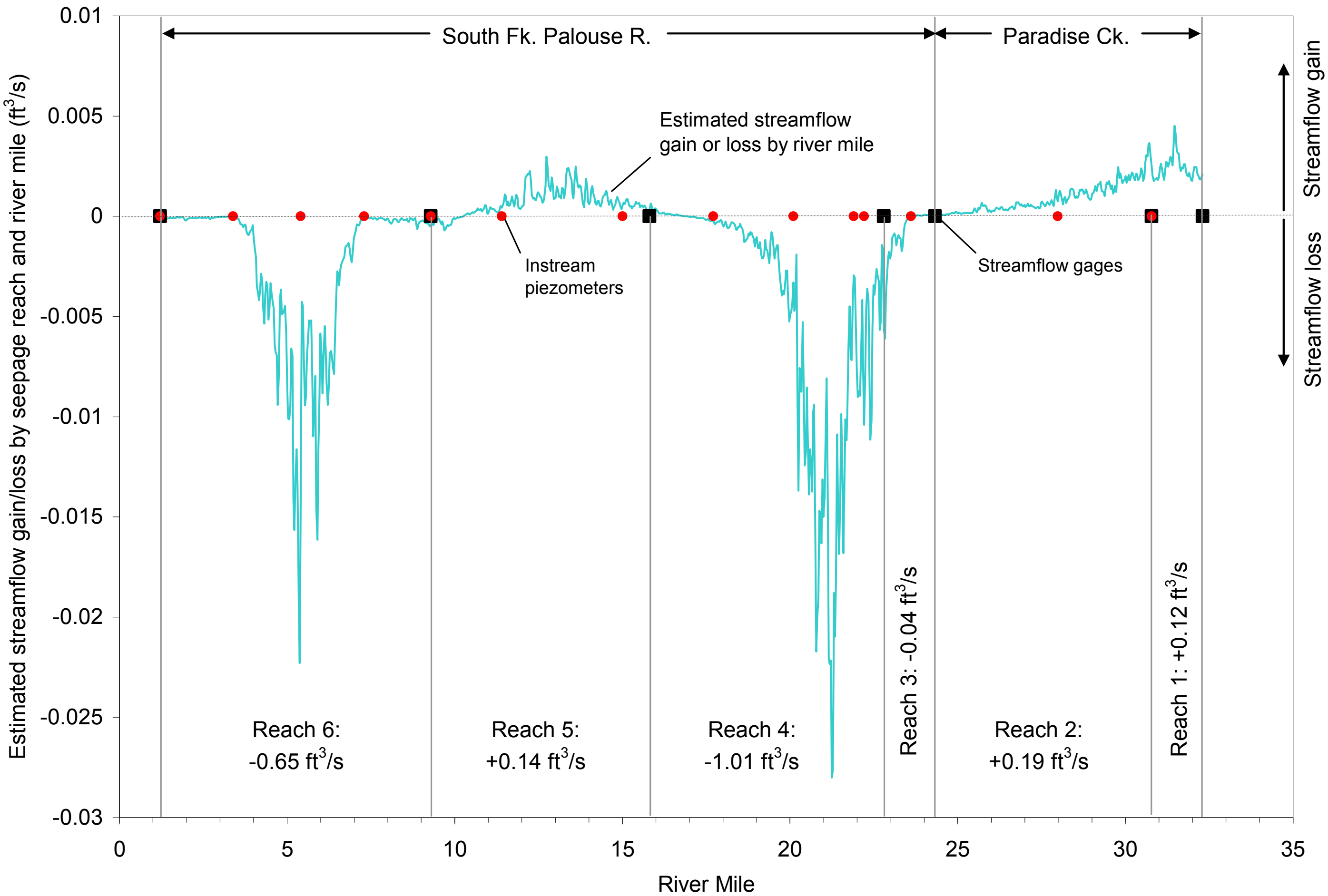

Figure 11 - Darcy flux estimates of potential streamflow gains and losses along Paradise Creek and the South Fork Palouse River, by seepage reach and river mile, for August 14-17, 2006.

Seepage Reach 4

Seepage reach 4 is approximately seven miles long and extends from the USGS gaging station at RM 22.8 on the SFPR at Pullman (Map ID G4) to the Ecology gaging station at RM 15.8 on the SFPR near Albion (MAP ID G3 on Plate 1, Figure 1). The streambed sediments along reach 4 consist of thin alluvial deposits of sand and silt with local accumulations of well-rounded gravel, cobbles, and occasional larger angular to sub-angular bedrock boulders. These sediments overlie basalts of the Priest Rapids Member of the Wanapum Formation (Figure 7).

The surface-water discharge balances for reach 4 yielded values of -1.43, -0.98, and -0.98 ft^3/s for July, August, and September 2006 respectively (Table 2). The corresponding Darcy flux evaluations yielded comparable values of -0.58, -1.01, and -0.38 ft^3/s (Figure 11).

These reach-based losses are generally supported by the streambed hydraulic gradients measured at instream piezometers. Large negative gradients were observed at piezometers P10 (-0.149 to -0.33 ft/ft) , P11 (-0.889 to -1.081 ft/ft), and P12 (-0.125 to -0.88 ft/ft), at the upper end of reach 4, near the confluence of the SFPR and Missouri Flat Creek (Table B-5 and Plate 1, Figures 2 and 3). The City of Pullman and Washington State University both operate well fields in this area. Their water withdrawals offer a possible explanation for the large negative streambed gradients observed at sites P10-P12 and the associated streamflow losses that are inferred to occur along this reach of the river.

The streambed thermal profiles at sites P11 and P12 showed a close correspondence between the river and near-surface groundwater during spring 2006, which supports the assertion of streamflow loss at these locations. By mid-to-late summer, however, the water levels in both piezometers had dropped below their upper and middle thermistors. Consequently, the streambed temperatures measured at these sites become more muted and are less responsive to changes in river temperature during this period.

The two remaining piezometers along reach 4 were located downstream of Pullman. Piezometer P9 near the reach center and P8 near the bottom of reach 4 both exhibited small positive-to-neutral gradients between late-spring and early-summer before transitioning to neutral or slightly negative gradients by mid-summer (Table B-5 and Plate 1, Figure 2).

The streambed thermal profile at site P8 shows a several degree temperature differential between the river and near-surface groundwater between May and July 2006, which suggests the potential for groundwater discharge to the river at this location and period. By August the streambed temperatures begin to converge on and mimic those in the river which suggests that the river likely transitions to losing conditions at site P8 by mid-to-late summer. In contrast, the thermal profile at site P9 generally followed that of the river between May and October, which suggests the river likely lost water at this location during summer 2006.

The groundwater levels for monitored domestic wells drilled adjacent to the creek along reach 4 were all below the average elevation of the streambed in their vicinity (see graphs W5, W6, and W7, on Plate 1, Figure 2). The below streambed water levels in these wells is further support that the creek likely loses water as it traverses this reach.

Collectively these data suggest that the central and lower portion of reach 4 may receive some groundwater inflow during the spring and early summer but that by mid-summer the reach is largely losing.

Seepage Reach 5

Seepage reach 5 extends from the Ecology gaging station at RM 15.8 on the SFPR (Map ID G3) to the gage at RM 9.2 (Map ID G2 on Plate 1, Figure 1). The streambed sediments underlying reach 5 consist of thin alluvial deposits of sand and silt with local accumulations of well-rounded gravel or cobble, and occasional larger angular to sub-angular bedrock boulders.

In the upper reach between Albion and the SFPR confluence with Four Mile Creek, these unconsolidated sediments are underlain mostly by basalts of the Priest Rapids Member of the Wanapum Formation, although localized outcrops of Rosa Member Basalt and older Cretaceous intrusive rocks are also present. Downstream of Four Mile Creek, outcrops of Rosa Member Basalt are more prevalent (Figure 7).

The Darcy flux evaluation for reach 5 yielded estimated values of +0.45 ft^3/s , +0.14 ft^3/s, and +0.23 ft^3/s for July, August, and September 2006 (Figure 11). The corresponding stream seepage balances showed small estimated streamflow gains from groundwater in July (+0.11 ft^3/s) and August (+0.13 ft^3/s) before transitioning to a loss in September (-0.08 ft^3/s) (Table 2).

The vertical hydraulic gradients measured in two instream piezometers near the middle and upper portions of reach 5 (piezometers P6 and P7) were consistently positive and ranged from +0.006 to +0.119 and +0.007 to +0.021 ft/ft, respectively. Gradients in piezometer P5, at the lower reach boundary, were more variable (-0.021 to +0.036 ft/ft) and transitioned from positive to negative values between spring and fall 2006. The thermal profiles at piezometers P6 and P7 show a marked 5-10 C° thermal differential between the river and near-surface groundwater during most periods. In contrast, the thermal profile at piezometer P5 diverged from the river between May and July and then tracked more closely with the river when hydraulic gradients reversed or became neutral after August.

The piezometer hydraulic gradients were supported by the water levels measured in two near-stream domestic wells. Well AHT029 (MAP ID W4 on Plate 1) had groundwater levels above the elevation of the riverbed which is consistent with the groundwater gains inferred from the streambed vertical hydraulic gradients measured in nearby piezometer P7. Well ALB694 (Map ID W3) had water levels lying near to slightly below the elevation of the riverbed which is consistent with the mixed positive and negative hydraulic gradients measured at nearby piezometer P5.

Collectively these data suggests that the SFPR probably gained small amounts of flow from groundwater discharge along reach 5 during spring and early summer 2006. During mid-to-late summer, the river likely transitioned to losing conditions in the vicinity of piezometer P5, at the lower reach boundary.

Seepage Reach 6

Seepage reach 6 is approximately 8.2 miles long and extends from the Ecology gage at RM 9.2 (Map ID G2) to the gage at RM 1.2 at Colfax (Map ID G1 on Plate 1, Figure 1). The streambed sediments along reach 6 consist of thin alluvial deposits of sand and silt with local accumulations of well-rounded gravel and cobble, with occasional larger angular to sub-angular bedrock boulders in some areas. These sediments generally overlie basalts of the Rosa Member of the Wanapum Formation, although Priest Rapids Member basalts are also present locally. At the lower end of the reach, near the town of Colfax, Rosa basalts give way to basalts of the Grande Ronde Formation.

The surface-water discharge balances for reach 6 showed small but consistent streamflow gains of +0.02, +0.12, and +0.04 ft^3/s for July, August, and September 2006, respectively. In contrast, the Darcy flux evaluations yielded consistent losses of approximately -0.66, -0.65, and -0.21 ft^3/s for these months. The cause of this discrepancy is not known, but may be due to streamflow modeling errors, unidentified local exchanges, or a combination of these or other factors.

With the exception of piezometer P3, which exhibited consistently negative hydraulic gradients, the piezometers along reach 6 (P1, P2, and P4) showed a mixture of both positive and negative gradients during summer 2006. This suggests that the river may periodically switch from gaining to losing conditions at these sites.

Viewed together, the data collected along the SFPR for reaches 3-6 suggest that the river likely experienced a net loss in flow of approximately -0.4 to -1.67 ft^3/s between its confluence with Paradise Creek at Pullman and the gage at RM 1.2 at Colfax. These overall losses were tempered somewhat by small inferred streamflow gains from groundwater discharges near the towns of Albion and Parvin.

Palouse River

Seepage Reach 7

Reach 7 is approximately 21 miles long and extends from the Palouse River gage near Potlatch, Idaho (Map ID G13) to the Ecology-installed gage near Elberton (Map ID G12 on Plate 2, Figure 1). The stream seepage balances for reach 7 showed net gains of +1.15 and +0.77 ft^3/s (0.04 to 0.04 $ft^3/s/mi$) for the July 30-August 1, 2007 and August 27-29, 2007 assessment periods (Table 3). If one assumes that all active certificated irrigation withdrawals were in use during these days, then the gains would have been significantly larger at +2.36 and +1.98 ft^3/s, respectively, or about 46 to 52% of the total flow measured at the lower reach transect[6].

Based on six measurements made between June and late October, 2007, the lowermost piezometer along reach 7 (P24) showed small (+0.008 to + 0.018 ft/ft) but consistently positive hydraulic gradients. This suggests the potential for groundwater discharge to the river at this location. Piezometer P25, at the town of Palouse, showed a mixture of slightly gaining to neutral gradients (-0.004 to 0.04 ft/ft). Piezometer P26, near the top of the reach, showed mostly negative gradients (-0.438 to +0.008 ft/ft).

The continuous streambed thermal profiles at these sites tend to support the point hydraulic gradient measurements. The temperatures measured one meter below the streambed at site P24 were as much as 15° C cooler than the river in July 2007 (Plate 2, Figure 2). The temperatures at sites P25 and P26 showed less separation and typically followed the river more closely.

Off-stream well W12, near the reach bottom, had water levels considerably below the elevation of the adjacent riverbed which suggests that the river does not receive baseflow (at least locally) from the basalts this well taps.

Collectively these results indicate that reach 7 probably consists of alternating gaining and losing segments, but that the reach as a whole likely experienced a net streamflow gain from groundwater discharge during summer 2007.

[6] Ecology floated the Palouse River between Colfax and Hooper in late May 2007 to identify and map active irrigation withdrawals. The water -use estimates presented for reaches 9-11 were developed by matching active irrigation diversions with their corresponding water right certificates and permitted withdrawal quantities. The sums of active withdrawals for these reaches are as follows: reach 9 (3.6 ft^3/s); reach 10 (22.2 ft^3/s) and reach 11 (8.2 ft^3/s). The withdrawals for reaches 7 and 8 were not field-confirmed and are based on the sum of permitted withdrawals. The assumed withdrawal values for these reaches were 1.2 ft^3/s and 2.3 ft^3/s, respectively.

Seepage Reach 8

Seepage reach 8 is approximately 12.4 miles long and extends from the Ecology gage at Elberton (Map ID G12) to just above the Palouse R. confluence with the SFPR at Colfax (Map ID G11 on Plate 2, Figure 1). The stream seepage balances for reach 8 yielded a net loss of -1.69 ft^3/s for July 30-Aug 1 and a net gain of +0.54 ft^3/s for Aug 27-29, 2007 (Table 3). If one assumes that all active certificated irrigation withdrawals were in use, the river would have shown net gains of +0.62 and +2.85 ft^3/s for these periods, respectively, or approximately 16 to 59% of the total streamflow measured at the lower reach transect. We had no off-stream wells or piezometers installed along reach 8 to confirm these values.

Seepage Reach 9

Reach 9 is approximately 14.8 miles long and extends from just above the SFPR confluence with the Palouse River (Map ID G11) to the Shields Road bridge (Map ID G10 on Plate 2, Figure 1). The stream seepage balances for reach 9 showed a net loss of -0.90 ft^3/s during July 30-Aug 1 and a net gain of +0.91 ft^3/s during Aug 27-29, 2007 (Table 3). If one accounts for the potential active irrigation withdrawals, these values become +2.71 ft^3/s and +4.52 ft^3/s for the first and second assessment periods, respectively.

These latter values are consistent with the vertical hydraulic gradients and thermal profiles measured at two instream piezometers installed along the reach. Piezometer P22, at the lower end of the reach, showed neutral to small positive gradients (0.0 to +0.015 ft/ft) during June to October 2007. Piezometer P23, near the reach center, showed negative gradients in the spring before transitioning to positive gradients as streamflows dropped in the fall (-0.006 to +0.006 ft/ft) (Plate 2, Figure 2).

The off-stream monitoring wells at the Colfax WWTP also showed above-streambed water levels during summer 2007. This suggests that the river gains flow from groundwater discharge at this location (Plate 2, Figures M1-M6).

Table 3 – Surface-water discharge balances for the Palouse River.

River Mile	Measurement transect location	Seepage reach [1]	Reach length (miles)	Jul 30-Aug 1, 2007 Measured flow (ft^3/s)	Jul 30-Aug 1, 2007 Estimated gain/loss (ft^3/s) [2]	Jul 30-Aug 1, 2007 Estimated gain/loss ($ft^3/s/mile$)	Aug 27-29, 2007 Measured flow (ft^3/s)	Aug 27-29, 2007 Estimated gain/loss (ft^3/s) [2]	Aug 27-29, 2007 Estimated gain/loss ($ft^3/s/mile$)
124.9	G13 (13345000) near Potlatch ID			3.90			2.97		
	34PALWTP (Palouse WWTP)	7	21.0	0.05	**1.15**	0.05	0.06	**0.77**	0.04
103.9	G12 (34A140) Elberton			5.10			3.80		
	34SIL00.0 (Silver Ck)	8	12.4	0.39	**-1.69**	-0.14	0.46	**0.54**	0.043
91.5	G11(34A115) Above SFPR			3.80			4.80		
	34SFPR00.1 (SFPR)	9	13.7	4.75	**-0.90**	-0.07	7.25	0.91	0.067
	Colfax WWTP			0.45			0.44		
	34DRY00.0 (Dry Ck)			0.00			0.00		
77.8	G10 (34A085) Shields Rd			8.10			13.40		
	34LIT00.2 (Little Ck)	10	28.3	0.26	**-3.89**	-0.15	0.20	**-7.62**	-0.269
	34DOW02.5 (Downing Ck)			1.53			1.32		
49.5	G9 (34A080) Above Rebel Flat			6.00			7.30		
	34K050 (Rebel Flat Ck)	11	30.0	1.75	-0.11	0.00	1.28	0.11	0.00
	34ROC00.1 (Rock Ck)			14.25			8.66		
	34UNF00.5			2.41			2.35		
	34WIL00.2 (Willow Ck)			0.00			0.00		
19.5	G8 (13351000) Hooper (34A070)			24.30			19.70		

1 - The reach numbers shown here correspond to those shown on Plate 2, Figures 1 and 3

2 - These values do not account for potential irrigation withdrawals along the reach. See the text discussion for each reach for a summary of the potential effects of irrigation withdrawals on these values.

Note: Values in bold font represent estimated gains or losses that exceeded the probably measurement error associated with making the seepage measurements. The error assessment was conducted using the method described by Konrad and others, 2003, and assumed accuracies of +- 7.5% for the individual measured flows.

Seepage Reach 10

Seepage reach 10 is approximately 28.8 miles long and extends from the Shield Road bridge (Map ID G10) downstream to just above the Palouse River confluence with Rebel Flat Creek (Map ID G9 on Plate 2, Figure 1). The seepage balances prepared for reach 10 showed net losses of -3.89 and -7.62 ft^3/s for the July 30-Aug 1 and Aug 27-29, 2007 periods, respectively (Table 3). If one accounts for the potential active irrigation withdrawals along the reach, the river would potentially have shown net gains of approximately +18.3 and +14.6 ft^3/s, respectively, or about 305 to 200% of the flow measured at the lower reach transect.

The two piezometers installed along reach 10 tend to support these latter values, as does the presence of numerous mapped springs and seeps along the reach (Figure 7). Piezometer P22 at the upper end of the reach showed neutral to small positive gradients (0.0 to +0.015 ft/ft) between June and October 2007. Piezometer P21, near the reach mid-point, also showed neutral to small positive gradients during this period (0.0 to +0.01 ft/ft). The hydraulic gradients are generally supported by the thermal profiles measured at these sites (Plate 2, Figure 2).

The hydraulic gradients from instream piezometers are further supported by the water levels measured at domestic wells (Map IDs W10 and W11) along the reach (Plate 2, Figure 2). Both of these wells had water levels near or above the elevation of the adjacent streambed, which suggest the potential for groundwater discharge to the river at these locations.

Viewed together, these results suggest that the river would likely show a net gain in streamflow along reach 10 were it not for the significant irrigation withdrawals that occur along the reach.

Seepage Reach 11

Reach 11 is approximately 29.5 miles long and extends from the Palouse River confluence with Rebel Flat

Creek (Map ID G9) to the USGS gaging station at Hooper (Map ID G8 on Plate 2, Figure 1). The stream seepage evaluations for reach 11 showed a small net loss of -0.11 ft^3/s during July 30-Aug 1 and a small gain of +0.11 ft^3/s during Aug 27-29, 2007. If one accounts for potentially active irrigation withdrawals along the reach, these values become +8.1 and +8.3 ft^3/s, respectively; or approximately 33 to 42% of the total streamflow measured at the Hooper gage.

The prospect of significant streamflow gains from groundwater along reach 11 is supported by the presence of many mapped springs and seeps that border the river through this reach (Figure 7). In addition, piezometer P18, installed near the mouth of Willow Creek, showed strong positive gradients (+0.031 to +0.326 ft/ft), or groundwater discharge conditions, throughout summer 2007 (Plate 2, Figure 2).

The streambed thermal profile at site P18 is comparable to the values measured in off-stream domestic wells, and was essentially flat for most of the summer. This thermal pattern is consistent with groundwater discharge conditions. The pattern likely results from groundwater that moves down gradient within the Willow Creek alluvium and surrounding outburst flood deposits before discharging into the Palouse River at this location.

The two remaining piezometers along reach 11 (P19 and P20) showed neutral to losing gradients during summer 2007 (0.0 to -0.007 ft/ft and -0.034 to -0.107 ft/ft, respectively) with gradients becoming progressively more negative toward the upper end of the reach (P20) (Plate 2, Figure 2). An off-stream well (Map ID W9, Plate 2, Figure 2) near piezometer P19 had water levels near or slightly below the elevation of the streambed. This tends to support the neutral to slightly negative hydraulic gradients measured in the piezometer.

Viewed together, these results suggest that the Palouse River would likely have shown a net gain in flow along reach 11 were it not for the large volume of irrigation withdrawals that occur there.

Conceptual Model of Surface-water/Groundwater Interactions and Discussion of Uncertainty in Estimated Seepage Values

Each of the field and analytical techniques we used during this study are subject to some degree of inherent error or uncertainty. Uncertainty often arises from:

1. Assumptions that must be made when using a field method or analysis technique.
2. Accuracy limitations of sampling equipment or analysis methods.
3. Measurement variability, or
4. A combination of these or other variables.

To help minimize overall uncertainty in the study conclusions, we used a preponderance-of-evidence approach based on the results from several different field and analytical techniques. This approach both acknowledges and accommodates the natural spatial and temporal complexities of stream-aquifer interactions by providing several data sets and potential lines of evidence from which conclusions can be drawn.

The stream seepage estimates reported in Figure 11 and Tables 2 and 3 were developed using this approach. They represent our best estimates of the likely volume and distribution of surface-water and groundwater exchanges along the reaches we evaluated. Our attempts to further constrain these estimates were hampered by the unsteady nature of area streamflows, which are influenced by municipal wastewater discharges (the SFPR and Paradise Creek) and irrigation withdrawals (the Palouse River).

The results for the SFPR-Paradise Creek stream corridor indicate that the calculated gains and losses for reaches 1, 2, 5, and 6 did not exceed the potential measurement errors associated with the seepage evaluation techniques we employed (Table 2). However, the small inferred exchanges for these reaches were generally supported by the hydraulic gradients and streambed thermal profiles measured at instream piezometers.

It may be that the smaller inferred gains and losses along these reaches represent localized hyporheic exchanges between the streams and the valley fill sediments that underlie them. This interpretation is supported by the relatively small hydraulic gradients and muted streambed thermal profiles we measured at instream piezometers installed along these reaches.

In contrast, reaches 3 and 4 had net exchanges during July 2006 that exceeded the likely measurement error for the seepage evaluation technique. The area of greatest apparent loss along the SFPR (reach 4) coincides with a slight widening and thickening of the valley fill alluvium where the river passes through Pullman proper. This reach also contains significant groundwater withdrawals by the City of Pullman and Washington State University.

The area of greatest apparent gain along the SFPR (reach 5) occurs near the confluence of the SFPR and Four Mile Creek where the river traverses the geologic contact between the Wanapum Priest Rapids and Rosa Member basalts. There is also an apparent gain along Paradise Creek (reaches 1 and 2). This is possibly due to the down-valley flow of groundwater being forced into the creek as the alluvium thins and the creek flows directly over basalts, just above the Paradise Creek/ SFPR confluence near Pullman. This hypothesis is bolstered by the 12°C average temperature recorded at Airport Creek which enters Paradise Creek near this location.

Similarly, the area of greatest gain along the mainstem Palouse River occurs along the spring-rich lower watershed. This gain appears to coincide with the geologic transition from the Wanapum Rosa Member basalts to the Frenchman Springs Member between Union Flat Creek and Willow Creek. There is also an apparent constriction and thinning of the valley-bottom outburst flood deposits in the vicinity of Willow Creek which would tend to force groundwater, flowing down-valley within these deposits, into the river.

Evaluation of Near-stream Groundwater Quality

To assess the potential concentration of phosphorous and nitrogen-based nutrients that groundwater contributes to area streams, we sampled eight domestic wells, eight instream piezometers, and one spring along the SFPR-Paradise Creek stream corridor between June and October 2006. We also sampled eight off-stream wells and three instream piezometers along the Palouse River corridor between July and September 2007. All together, 23 sites were sampled two or three times, and five sites were sampled once for field parameters and a small suite of laboratory analyzed parameters (Table 4**)**.

Sampling Methods

Wells and piezometers were purged prior to sample collection using a commercial closed-atmosphere flow cell. Purging continued until the difference in field-parameter values for two successive 3-minute measurement periods differed by less than 5%.

Samples for dissolved organic carbon (DOC), nitrate+nitrite-N, total persulfate nitrogen (TPN), ammonia, and total phosphorus (TP) were collected in pre-acidified bottles containing sulfuric acid.

DOC samples were field filtered using a Whatman puradisc™ 25PP, 0.45 micron syringe filter. Orthophosphate samples were similarly filtered using a Whatman puradisc™ 25GD/X, 0.45 micron filter. The remaining dissolved parameters were filtered using a new in-line 0.45 micron capsule filter.

Filled sample bottles were tagged and stored on ice pending their arrival at the laboratory.

Groundwater Quality Results

The results of this effort are summarized in Table 5 and are presented graphically in Figures 12 and 13. Tables B-3 and B-6 present the results by site and sample date. The associated data quality assessment is summarized in Appendix A.

Table 4 - Target analytes, test methods, and method reporting limits.

Parameter	Test method	Reporting limit
Field Measurements		
Water level	Calibrated E-tape	0.1 foot
Temperature	Sentix® 41-3 probe[2]	0.1°C
Specific Conductance	Tetracon® 325 probe[2]	1 µS/cm
pH	Sentix® 41-3 probe[2]	0.1 SU
Dissolved Oxygen	Cellox® 325 probe[2]	0.1 mg/L
Laboratory Parameters		
Coliform, fecal (MF)	SM9222D	1 CFU/100mL
Alkalinity	SM2320	10 mg/L
Chloride	EPA300.0	0.1 mg/L
Orthophosphate[1]	SM4500PG	0.003 mg/L
Total phosphorus[1]	EPA200.8M	0.001 mg/L
Nitrate+nitrite-N[1]	SM4500NO3I	0.01 mg/L
Ammonia[1]	SM4500NH3H	0.01 mg/L
Total persulfate nitrogen-N[1]	SM4500NB	0.025 mg/L
Dissolved organic carbon[1]	EPA415.1	1 mg/L
Iron[1]	EPA200.7	0.05 mg/L

[1] Dissolved fraction
[2] Probe used with a WTW multiline P4 meter
MF: Membrane filter method
SU: Standard units

As shown in Figures 12 and 13, the results for most wells and piezometers were relatively consistent across multiple sample events. This suggests that the quality of groundwater that discharges to the river at individual locations varied over a fairly small range during the 2006-07 evaluation period. There were, however, notable differences in water quality between sites.

For example, six piezometers (P1, P6, P7, P14, P21, and P24) had consistently low dissolved oxygen concentrations, with average values less than 0.6 mg/L. These sites had relatively low concentrations of redox-sensitive parameters such as nitrate [7] (average 0.01U - 0.138 mg/L) and measurable concentrations of iron (average 0.25 - 1.53 mg/L).

In contrast, piezometers P5, P13, P16, P17, and P18 had average dissolved oxygen concentrations ranging from 0.76 – 7.34 mg/L and correspondingly higher average nitrate (2.82 - 10.1 mg/L) and TPN-N (3.03 - 9.63 mg/L) concentrations. These sites also had no detectable iron and little to no detectable ammonia.

The water quality results for sampled near-stream wells and springs were generally consistent with those from instream piezometers. However, the temperatures in off-stream wells were typically cooler and more stable than those observed in piezometers, owing to the relative lack of thermal influence from the river (Table 5 and Figures 12 and 13).

Four of the 13 off-stream domestic wells and springs we sampled exceeded the 10 mg/L maximum contaminant level (MCL) standard for nitrate in drinking water, and two additional wells had values between 5 and 10 mg/L (Table B-3 and Figures 12 and 13). This suggests that nitrate contamination may be an emerging problem locally.

Based on the sites sampled, groundwater does not appear to be a significant contributor of fecal coliform bacteria to area streams. Approximately 64% of sampled wells had non-detectable levels of fecal coliform. The remaining wells had average concentrations ranging from 1 to 21.5 CFU/100 ml, considerably lower than the values typically observed in area streams.

Collectively the water quality values encompassed by these data provide a reasonable basis for estimating the potential upper-bound range of nutrient concentrations that have been, or are likely to be, carried into area streams with discharging groundwater.

[7] Nitrite is typically unstable in aerated groundwater. Accordingly, the reported values for nitrate+nitrite-N are considered equivalent to nitrate-N for the purposes of this evaluation (Hem, 1985).

Table 5 - Average analyte concentrations in groundwater from sampled instream piezometers and domestic wells.

				Groundwater Field Parameters				Laboratory Analyses									
Map ID [1]	Well Tag ID Number	Approximate River Mile (miles)	Number of samples used to derive values	Temperature (deg C) [2]	pH (standard units)	Specific Conductance (µS/cm @ 25 deg C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Total Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
South Fork Palouse River																	
P1	AKY496	1.2	1	11.1	7.17	615 J	0.6	1 UJ	288	26.5	0.059	0.875	0.14	0.55	1.12	7 J	-
W1	AHT032	5.4	1	12.8	7.05	414	6.92	1 UJ	138	15.9	0.131	0.132	11.9	0.02 U	12.1	1 U	-
W2	AAW651	7.3	2	12.8	7.46	410	2.86	1 U	163	10.53	0.086	0.084	8.51	0.015 U	8.22	1.65	-
P5	AKY488	9.3	1	18.1	7.08	393	2.83 J	1	132	10.3	0.132	0.139	8.74	0.03	9.37	2.4	-
W3	ALB694	9.8	1	10.8	6.95	548	5.27	1 U	148	32.9	0.105	0.106	15	0.01 U	15.3	1.8 J	-
P6	AKY497	11.4	3	15.13	7.39	369	0.41	2.67	120	3.92	0.019	0.153	0.11	0.10	0.23	1.93	-
P7	AKY498	15	3	15.87	7.26	326.3	0.31	1.00	168	4.78	0.021	0.121	0.014	0.06	0.12	1.23	-
W4	AHT029	15	2	13.25	7.87	299	0.1 U	1 U	162	2.21	0.033	0.025	0.01 U	0.08	0.10	1.85 J	-
W6	AGJ770	17.7	2	12.20	7.08	317.5	1.13	1 U	149	4.47	0.019	0.013 J	0.28	0.015 U	0.33	2.3 J	-
W5	AGJ767	17.8	2	12.60	7.80	307	0.1 U	1 U	165	2.59	0.038	0.030	0.01 U	0.12	0.15	1.85 J	-
S1	AHT033	20.1	2	11.35	7.11	268	7.44	1 U	122	1.25	0.103	0.096	4.87	0.015 U	5.01	1.45 J	-
W7	AGJ768	21.9	2	12.20	6.88	494	3.15	1 U	178	34.5	0.076	0.075	3.88	.015 U	3.30	3.75 J	-
P13	AKY491	23.6	3	14.03	6.87	433	0.76	1	184	18.07	0.081	0.299	3.03	0.01	3.11	1.87	-
P14	ALB689	26.7	2	14.80	6.99	291	0.45	1	145.5	3.00	0.107	0.102	0.01	0.02	0.05	1	-
W8	AHJ874	33.8	2	11.90	7.24	381	7.05	1 U	169.5	3.09	0.123	0.124	9.02	0.01 U	8.37	1.65 J	-
Paradise Creek																	
P16	ALB691	3.8	2	12.10	7.28	456.5	4.46	21.50	157	21.05	0.139	0.139	10.04	0.01	9.63	2.95	-
P17	ALB692	6.6	1	13.4	6.73	572 J	1.1	1 U	211	31.9	0.100	0.105	7.45	0.01 U	6.72	3 J	-
Mainstem Palouse River																	
P18	AHT042	25.7	2	13.35	7.59	598	7.34	1 U	244.5	23.95	0.107	0.111	3.06	0.01 U	3.64	1	0.05 U
W9	AHT040	33.4	2	12.7	7.33	300	7.66	1.5	120.5	8.99	0.148	0.151	1.67	0.01 U	1.71	1.3	0.05 U
W10	AHT098	49.4	2	13.75	7.37	792	8.53	4	274.5	32.75	0.215	0.231	14.7	0.01 U	14.8	3.1	0.05 U
P21	AHT038	66.8	2	17.85	7.29	347.5	0.24	1	167.5	6.7	0.059	0.172	0.01 U	0.09	0.14	1.2	1.53
W11	AHR589	66.8	2	12.75	7.89	300	1.57	1 U	144.5	3.62	0.047	0.038	0.85	0.01 U	0.88	1 U	0.05 U
M1	ACP674	90.9	2	16.2	6.79	763.5	0.53	1 U	274.5	44.85	0.159	0.181	2.76	11.3	12.2	6.5	0.07
M2	ACP673	90.9	2	13.5	6.99	570.5	0.11	1 U	254	14.7	0.096	1.530	0.01 U	0.73	0.89	3.9	25.1
M5	ACP679	91.1	2	15.5	6.84	496.5	0.15	1 U	184.5	17	0.311	0.316	2.01	2.79	5.44	5	3.41
M6	ACP678	91.2	2	13	6.75	725	0.15	1 U	313.5	39.7	0.074	0.781	0.01 U	1.24	1.42	3.25	19.1
W12	AHT044	104	2	10.95	7.26	291	0.39	1 U	117.5	8.53	0.109	0.102	2.73	0.01 U	2.9	1 U	0.05 U
P24	AHT034	112.4	2	17.55	6.88	262.5	0.17	6	133.5	2.12	0.121	0.140	0.01 U	0.01 U	0.025 U	1 U	0.25

[1] - The map IDs listed here correspond with those shown on Plates 1 and 2.

[2] - See Plates 1 and 2 for the continuous temperature records for these sites.

Data qualifier codes: J - the analyte was positively identified, the numeric result is an estimate.
U - analyte was not detected at or above the reported value.
UJ - the analyte was not detected at or above the estimated value.

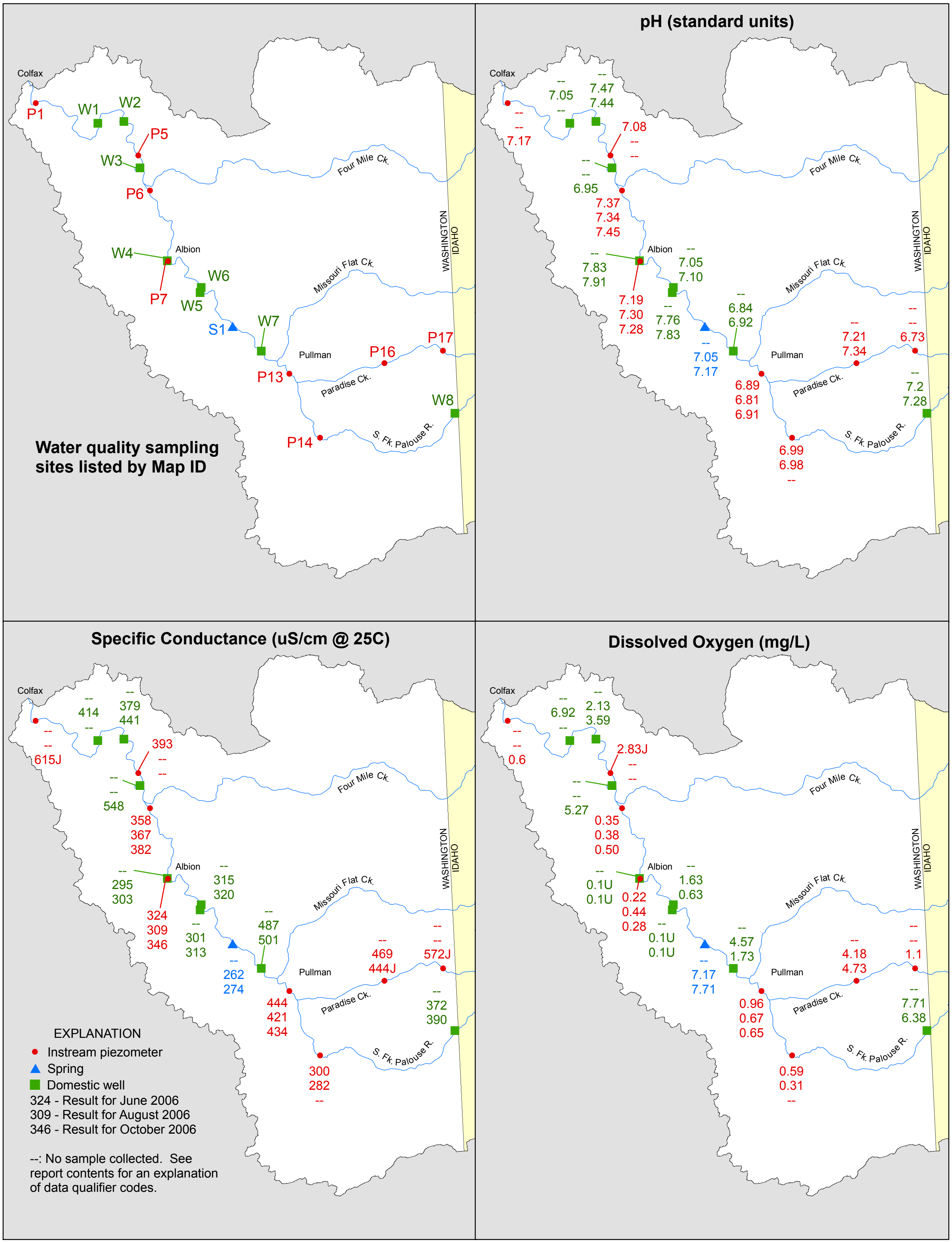

Figure 12 - Groundwater quality at sampled instream piezometers, domestic wells, and springs along the South Fork Palouse River and Paradise Creek

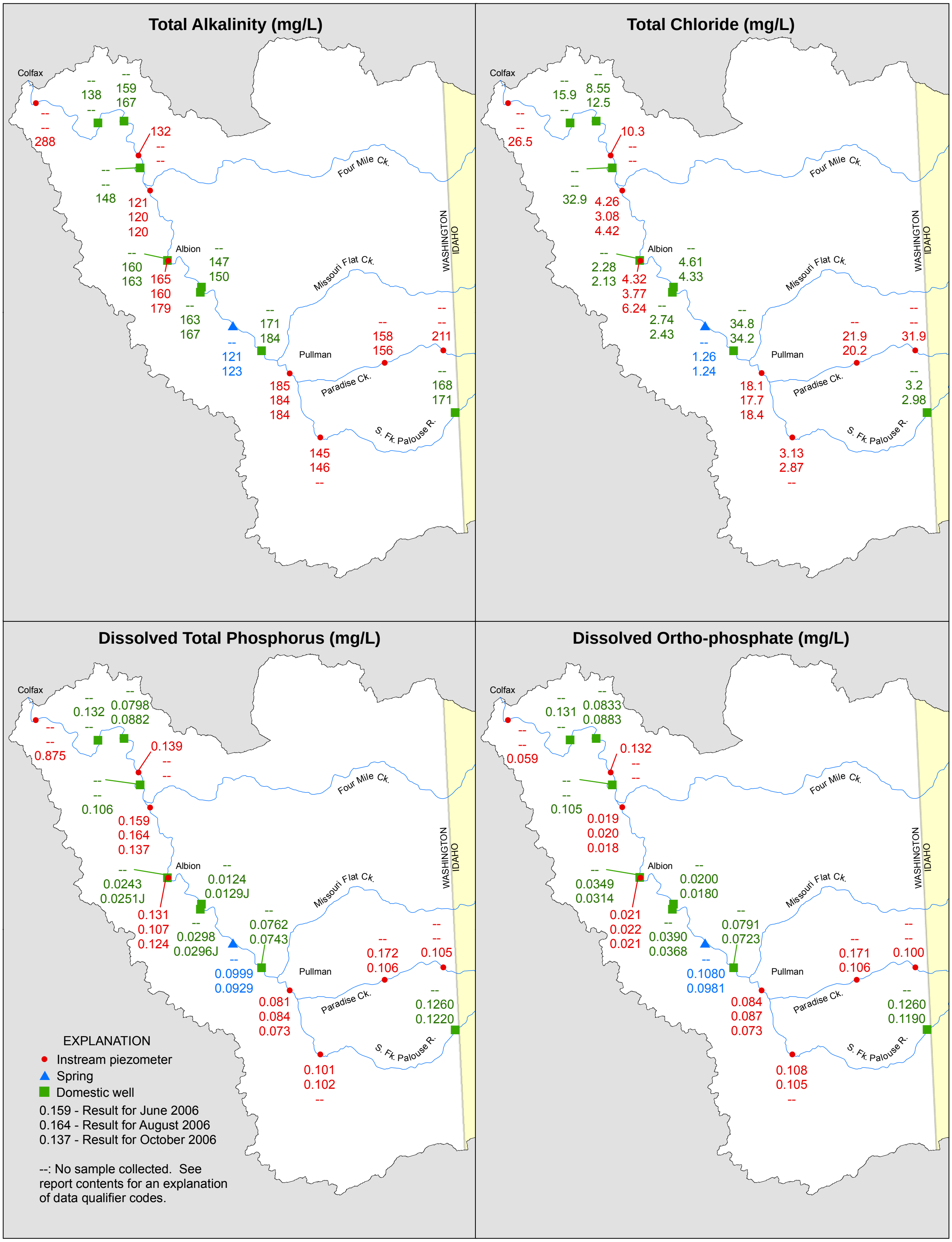

Figure 12 – continued

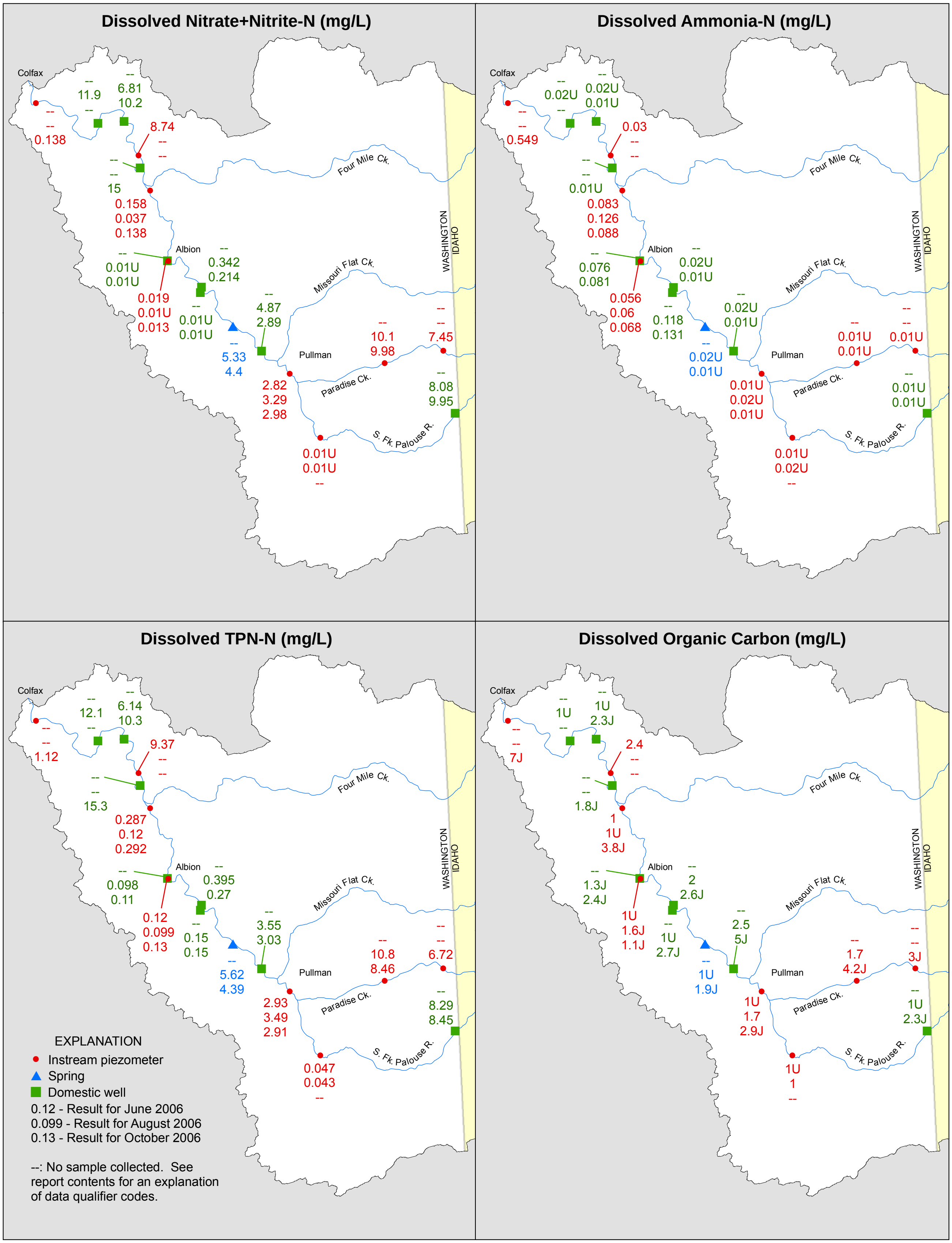

Figure 12 – continued

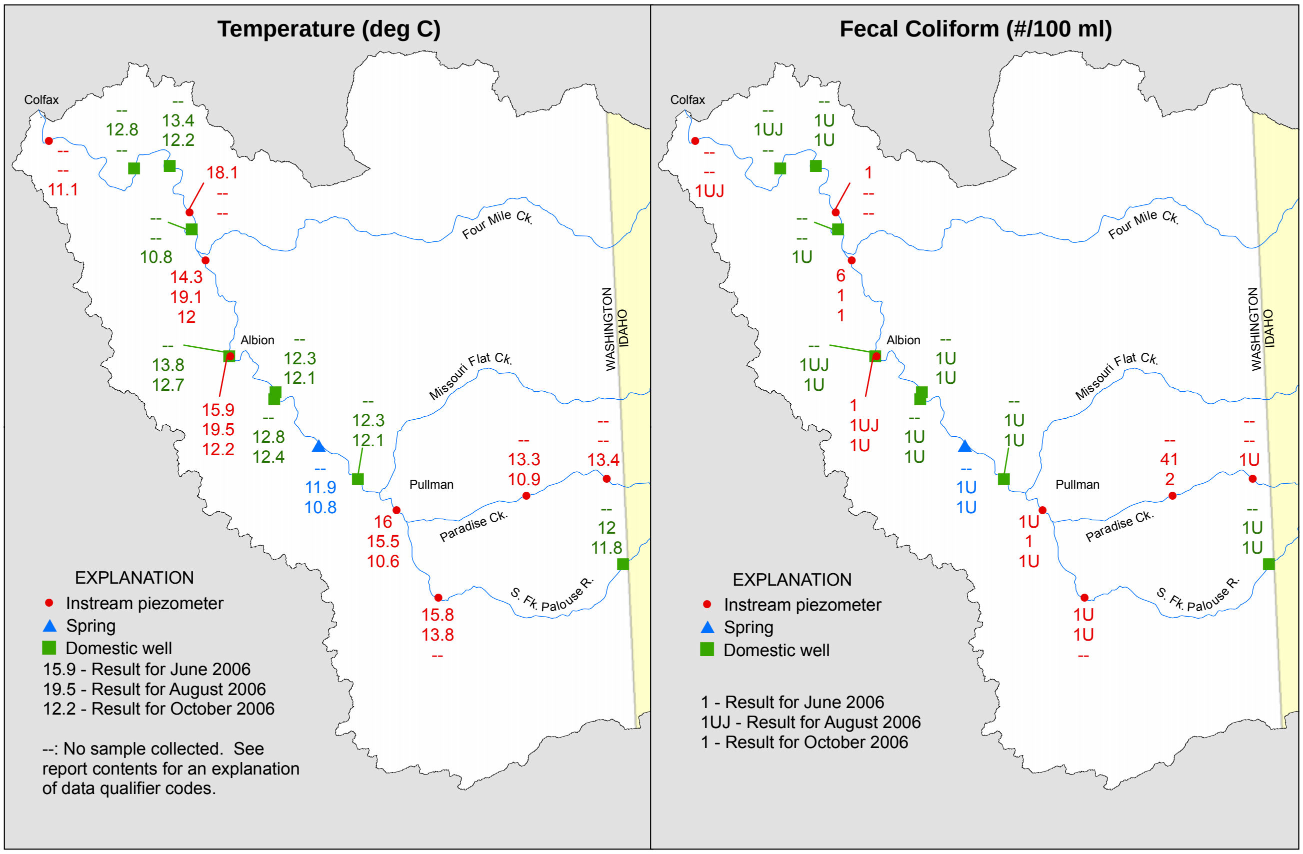

Figure 12 – continued

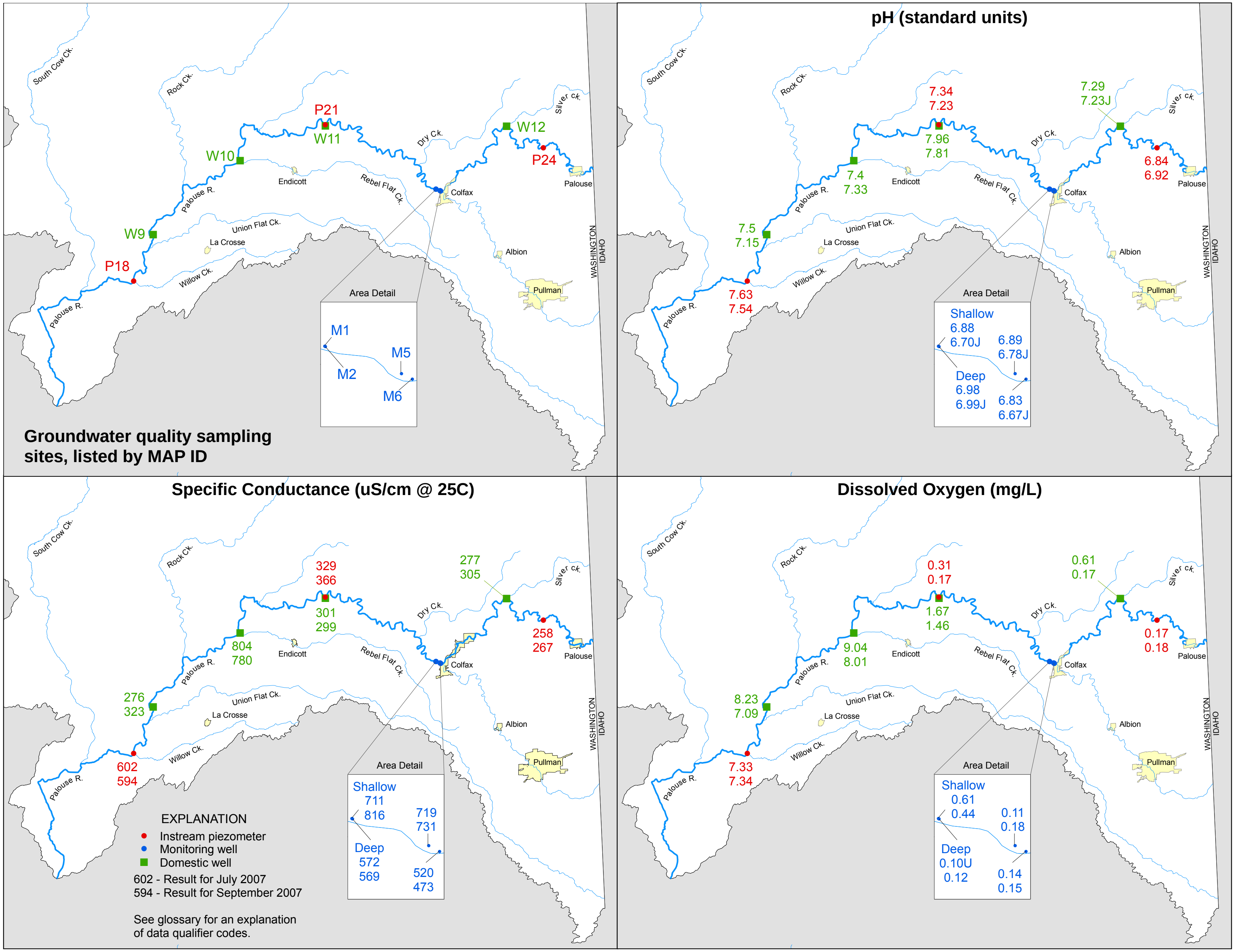

Figure 13 - Groundwater quality at sampled instream piezometers, domestic wells, and springs along the mainstem Palouse River.

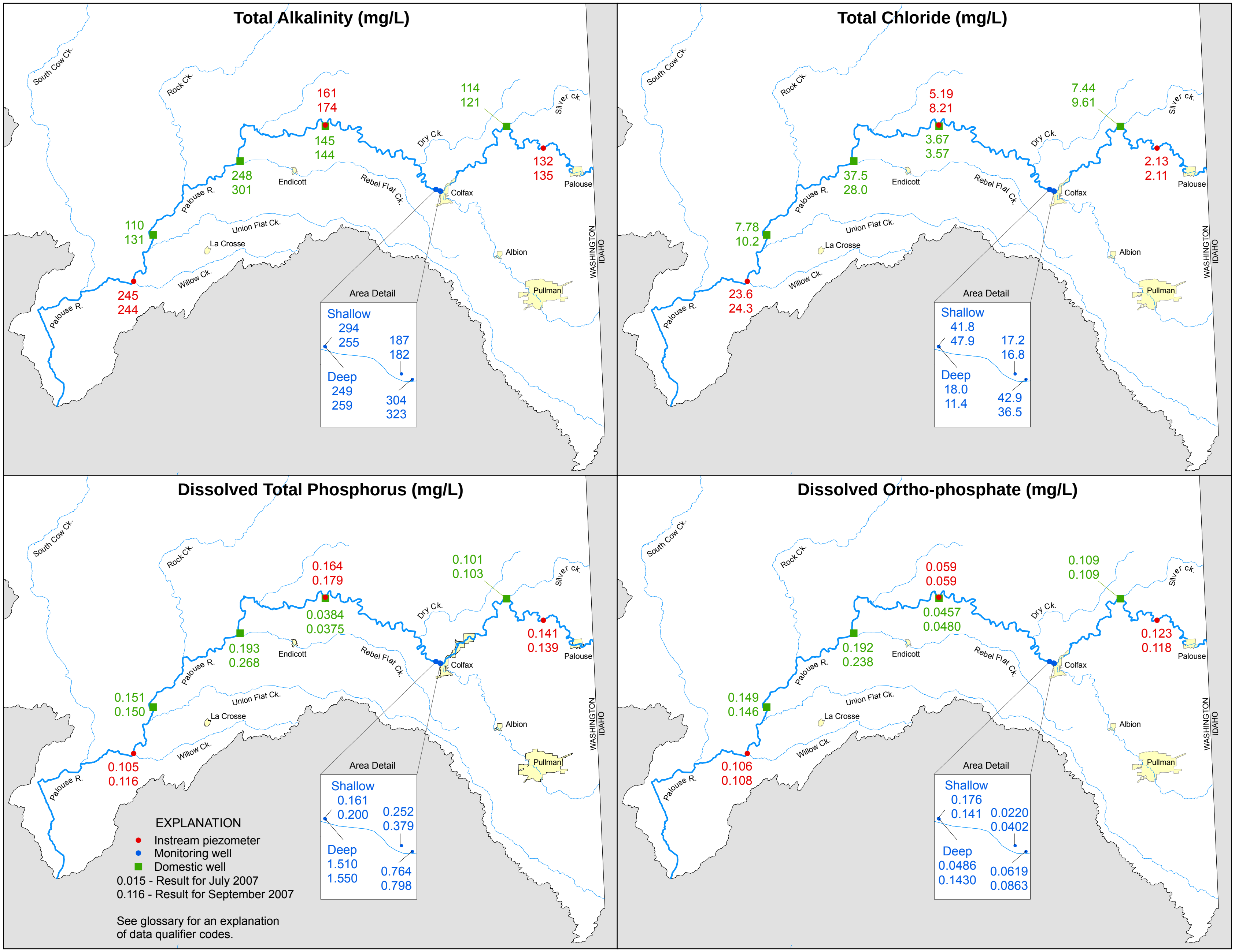

Figure 13 – continued

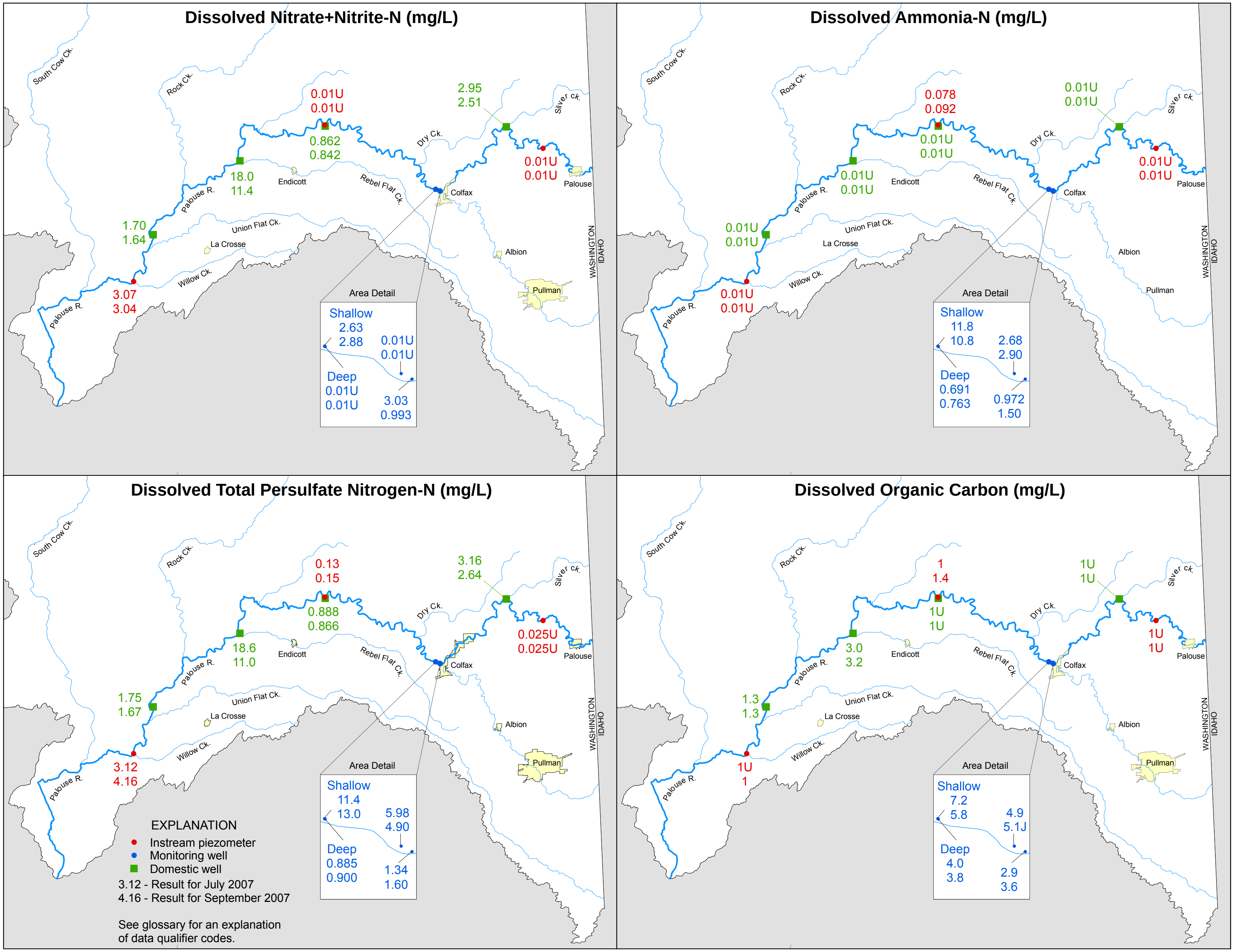

Figure 13 – continued

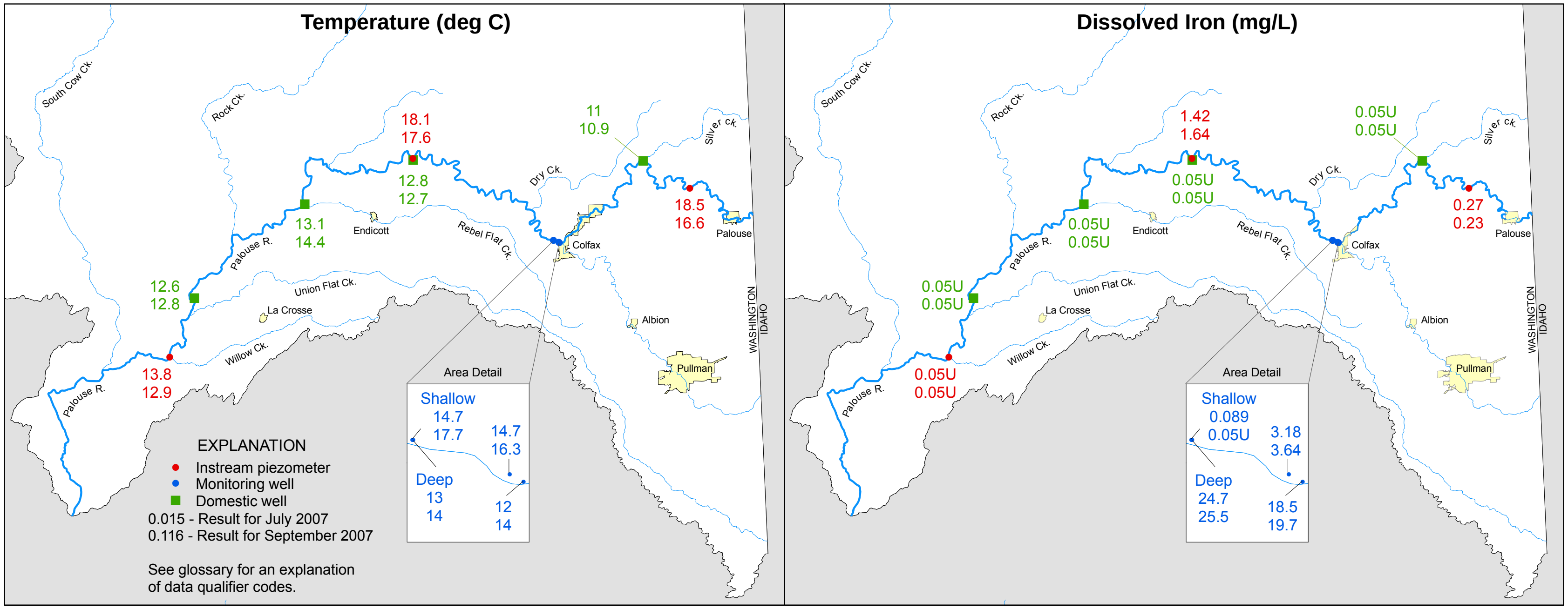

Figure 13 – Continued

Nutrient Loading to Streams from Groundwater

To estimate the potential nutrient mass load that groundwater contributed to area streams along gaining reaches, we combined the nutrient concentrations from each sampled piezometer with the corresponding unit-area groundwater discharge estimates (for that location and sample event) using Equation 4. Load estimates were derived only for those piezometer sites where groundwater discharge was indicated; as evidenced by vertical hydraulic gradient measurements and streambed thermal profiles.

$$M_L = QC \qquad (4)$$

where:

M_L is the mass flux, per unit area, for the analyte of interest (M/T)/A.

Q is the groundwater discharge, per unit area, estimated for the site and sample date using Equation 3 and the inputs from Table B-5 for streambed vertical hydraulic conductivity and hydraulic gradient (V/T)/A.

C is the analyte concentration measured in groundwater (M/V).

where: A is unit area (L^2)
(M/T) is mass per unit of time,
(M/V) is mass per unit of volume, and
(V/T) is the volume per unit of time.

The results of this evaluation are summarized in Table 6 by analyte and sample date. For the five sites evaluated along the SFPR, the calculated load of dissolved orthophosphate to the river from groundwater ranged from 0.03 to 0.94 mg/d/m^2 of streambed. The load of dissolved nitrate at these sites ranged from <0.01 to 62 mg/d/m^2. The two piezometer sites along Paradise Creek (P16 and P17) had larger loads for both dissolved orthophosphate (2.94 to 4.54 mg/d/m^2) and nitrate (174 to 339 mg/d/m^2) (Table 6).

The highest observed loads of orthophosphate (47.7 - 107.7 mg/d/m^2) and nitrate (1341 - 3119 mg/d/m^2) occurred at piezometer P18, along the Palouse River. The unusually high loads at this site are attributed to a combination of large volumetric fluxes and elevated concentrations of both orthophosphate and nitrate in the groundwater at this location.

In undertaking this work, we did not attempt to account for biological or geochemical processes that can potentially attenuate nutrient concentrations in groundwater as it flows through the final few feet of the streambed (Hem, 1985; Jones and Mulholland, 2000). Thus, the results reported in Table 6 should be considered upper-bound estimates of the potential mass load that groundwater contributes to the river at these locations. In addition to providing load estimates for these sites, these data may also be useful in helping to bracket the potential range of nutrient mass loads that occur across larger reaches or at other points along these rivers.

Table 6 - Estimated unit area mass load, by sample date, from groundwater discharging at instream piezometer sites along the South Fork Palouse River, Paradise Creek, and the mainstem Palouse River.

Map ID [1]	Well tag ID number	River Mile (miles)	Sample Date	Total Alkalinity ($mg/d/m^2$)	Total Chloride ($mg/d/m^2$)	Dissolved Ortho-phosphate ($mg/d/m^2$)	Dissolved Total Phosphorus ($mg/d/m^2$)	Dissolved Nitrate+ Nitrite-N ($mg/d/m^2$)	Dissolved Ammonia ($mg/d/m^2$)	Dissolved TPN-N ($mg/d/m^2$)	Dissolved Organic Carbon ($mg/d/m^2$)
Sourth Fork Palouse River											
P1	AKY496	1.2	10/24/2006	342	31.5	0.07	1.04	0.16	0.65	1.3	8.3
P5	AKY488	9.3	06/27/2006	941	73.4	0.94	0.99	62	0.21	67	17.1
P6	AKY497	11.4	06/27/2006	4352	153	0.68	5.7	5.7	3.0	10.3	36
			08/14/2006	1079	27.7	0.18	1.5	0.33	1.1	1.1	9.0 *
			10/24/2006	691	25.4	0.10	0.79	0.79	0.51	1.7	21.9
P7	AKY498	15	06/28/2006	3621	94.8	0.46	2.9	0.42	1.2	2.6	21.9 *
			08/14/2006	1366	32.2	0.19	0.91	0.09 *	0.51	0.84	13.7
			10/23/2006	2401	83.7	0.28	1.7	0.17	0.91	1.7	14.8
P13	AKY491	23.6	06/28/2006	262	25.7	0.12	0.11	4.0	0.014 *	4.2	1.4 *
			08/15/2006	69.5	6.7	0.03	0.03	1.2	0.007 *	1.3	0.6
			10/24/2006	591	59.1	0.23	2.4	9.6	0.03 *	9.3	9.3
P14	ALB689	26.7	06/28/2006	1202	25.9	0.90	0.84	0.08 *	0.08 *	0.39	8.3 *
			08/16/006	157	3.1	0.11	0.11	0.01 *	0.02 *	0.05	1.1
Paradise Creek											
P16	ALB691	3.8	08/16/2006	2718	377	2.94	2.96	174	0.17 *	186	29.2
			10/25/2006	4894	634	3.33	3.33	313	0.31 *	265	132
P17	ALB692	6.6	10/25/2006	9589	1450	4.54	4.77	339	0.45 *	305	136
Mainstem Palouse River											
P18	AHT042	25.7	07/09/2007	248888	23975	107.68	107	3119	10.2 *	3170 *	1016 *
			09/11/2007	107667	10723	47.66	51.2	1341	4.4 *	1836	441
P21	AHT038	66.8	07/11/2007	283	9.1	0.10	0.29	0.02 *	0.14	0.23	1.8
			09/12/2007	623	29.4	0.21	0.64	0.04 *	0.33	0.54	5.0
P24	AHT034	112.4	07/11/2007	1111	17.9	1.04	1.19	0.08 *	0.08 *	0.21 *	8.4 *
			09/12/2007	2653	41.5	2.32	2.73	0.2 *	0.2 *	0.49 *	19.7 *

1 - See Plates 1 and 2 for a map of site locations.

* - Analyte not detected at or above the method reporting limit; the above value is the site maximum potential load assuming a groundwater constituent concentration less than or equal to the reporting limit.

Summary and Conclusions

In spring 2006, the Washington State Department of Ecology initiated TMDL-based field studies to assess surface-water quality and near-stream environmental conditions along the Palouse River, the South Fork Palouse River, and Paradise Creek, in Whitman and Adams County. These waterbodies were included on Washington State's 2004 list of polluted waters for previously documented water quality problems.

This study was part of Ecology's TMDL effort for these rivers and streams and was undertaken to gain a better understanding of groundwater's influence on stream temperatures and water quality. This study was designed around two primary goals:

1. Evaluate and quantify area surface-water and groundwater interactions.
2. Estimate the potential load of phosphorus-based and nitrogen-based nutrients that groundwater contributes to these rivers and creeks along gaining reaches.

Multiple field and analytical techniques were used to achieve these objectives. Baseflow seepage studies and Darcy flux evaluations were conducted to quantify reach-scale gains and losses. These reach-based evaluations were supplemented with information from 26 instream piezometers and 13 near-stream domestic wells and springs. Wells and springs were monitored to define surface-water/groundwater head relationships, streambed thermal profiles, and near-stream groundwater quality conditions at discrete points.

Collectively, these evaluations revealed that net exchanges of surface-water and groundwater along the SFPR/Paradise Creek stream corridor are typically small and often did not exceed the potential measurement error associated with the seepage techniques we used to assess them.

The summer 2006 surface-water-discharge balances prepared for Paradise Creek between Moscow and Pullman yielded estimated overall net streamflow gains of between +0.17 and +0.57 ft^3/s from groundwater discharge (or approximately +0.02 to +0.07 ft^3/s per river mile).

The South Fork Palouse River (SFPR) showed a more complicated gain-loss pattern than Paradise Creek and appears to be composed of alternating gaining and losing reaches. During summer 2006, seepage rates for the four defined reaches between Pullman and Colfax ranged from an estimated net loss of -1.43 to a gain of +0.13 ft^3/s. The combined results for these reaches suggest the river experienced net losses ranging from -0.78 to -1.67 ft^3/s (or -0.03 to -0.07 ft^3/s per river mile) during this period.

A preliminary evaluation of water exchanges along the mainstem Palouse River showed similar gain-loss patterns to those observed along the SFPR. Seepage rates for the five defined reaches along the Palouse River between the WA/ID border and Hooper ranged from an estimated gain of +1.15 to a loss of -7.62 ft^3/s. The combined results for these reaches suggest the river lost between -5.29 and -5.44 ft^3/s (or approximately -0.05 ft^3/s per river mile) during this period. These gain/loss estimates for the Palouse River do not account for the presence of significant irrigation withdrawals which tend to mask apparent streamflow gains from groundwater.

The streamflow gains and losses inferred from surface-water discharge balances were generally supported by the vertical hydraulic gradients and streambed thermal profiles measured in piezometers. These latter measurements provided a more comprehensive record of the water exchanges that occurred at discrete points, and showed that surface-water/groundwater exchanges were more dynamic (with respect to timing, direction, and magnitude) than the discharge balances might suggest.

The groundwater quality results for individual piezometers were generally consistent across sampling events. Measurable concentrations of dissolved orthophosphate and dissolved total phosphorus were found in all piezometer samples at values ranging from 0.018 to 0.171 mg/L and 0.073 to 0.875 mg/L, respectively. Concentrations of dissolved nitrate+nitrite-N and ammonia ranged from < 0.01 to 10.1 mg/L and < 0.01 to 0.549 mg/L, respectively. The highest nitrate+nitrite-N concentrations were observed at sites where the groundwater was well oxygenated. Ammonia concentrations were highest at those sites where anoxic groundwater conditions occurred.

The water quality samples from off-stream wells and springs had concentrations and spatial patterns similar to those observed at instream piezometer sites. However, the nitrate+nitrite concentrations were higher on average in off-stream wells[8] (4.98 mg/L) than at instream piezometer sites (2.48 mg/L). This suggests that nitrate reduction may be occurring locally within the streambed, particularly at those locations where persistent anoxic conditions were encountered.

The potential mass load of phosphorus-based and nitrogen-based nutrients that groundwater contributes to area streams were estimated for six piezometer sites along the SFPR, two sites along Paradise Creek, and three sites along the Palouse River. The average estimated mass loads of dissolved total phosphorus at these sites ranged from 0.03 to 107 $mg/d/m^2$ of streambed. For those sites where measurable concentrations of dissolved nitrate+nitrite-N occurred, estimated mass loads ranged from 0.16 to 3119 $mg/d/m^2$ of streambed.

The mass load estimates presented here do not account for biological or geochemical processes that can potentially attenuate nutrient concentrations in groundwater as it flows through the final few feet of the streambed. Thus, these values should be considered upper-bound estimates.

Many of the field and analytical methods described in this report are subject to simplifying assumptions and limitations which contribute uncertainty to the individual method results. This study used multiple field techniques and a preponderance of evidence approach to help overcome these limitations. The study also sought to define the most probable range of flux volumes and nutrient loads that groundwater likely contributes to area streams and rivers along gaining reaches.

[8] The average nitrate+nitrite value reported for off-stream wells does not include data for the monitoring wells sampled at the City of Colfax Wastewater Treatment Plant.

Recommendations for Additional Study

As a near-term follow-up to this investigation, we recommend that additional groundwater sampling be conducted along the SFPR-Paradise Creek stream corridor to determine both the upland extent and severity of the elevated nitrate problems we observed during our sampling of near-stream domestic wells. Nearly one-third of the domestic wells we sampled exceeded the 10 mg/L MCL criteria for nitrate, and almost 50% had nitrate concentrations over 5 mg/L. These results suggest that nitrate contamination may be a chronic emerging problem within the shallow basalt aquifers and unconsolidated valley-fill deposits that underlie the SFPR-Paradise Creek stream corridor.

Numerous recent studies have documented field techniques for assessing the potential role that streambed biogeochemical processes play in helping to reduce nutrient concentrations (particularly nitrate and phosphorus) in groundwater, prior to its discharge into streams (Duff et al., 1998; Martin et al., 2003; Zimmerman et al., 2005). To further constrain the groundwater load estimates provided to modelers, Ecology should evaluate and where practical employ these techniques during future TMDL investigations.

References

Study Quality Assurance Project Plans

Bilhimer, D., Carroll, J., and Sinclair, K., 2006. Quality Assurance Project Plan, South Fork Palouse River Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Publication No. 06-03-104. www.ecy.wa.gov/biblio/0603104.html. 56 p.

Carroll, J. and Mathieu, N., 2006. Quality Assurance Project Plan, South Fork Palouse River Dissolved Oxygen and pH Total Maximum Daily Load Study. Washington State Department of Ecology, Publication No. 06-03-112. www.ecy.wa.gov/biblio/0603112.html. 63 p.

Carroll, J., 2007. Palouse River Dissolved Oxygen and pH Total Maximum Daily Load study, Water Quality Study Design. Washington State Department of Ecology, Publication No. 07-03-110. www.ecy.wa.gov/biblio/0703110.html. 48 p.

Kardouni, J., Carroll, J., and Sinclair, K., 2007. Quality Assurance Project Plan, Palouse River Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Publication No. 07-03-106. www.ecy.wa.gov/biblio/0703106.html. 45 p.

Mathieu, N. and Carroll, J., 2006. Quality Assurance Project Plan, South Fork Palouse River Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Publication No. 06-03-105. www.ecy.wa.gov/biblio/0603105.html. 53 p.

Mathieu, N., Carroll, J., and Nipp, B., 2007. Palouse River bacteria Total Maximum Daily Load, Water Quality Study Design. Washington State Department of Ecology, Publication No. 07-03-108. www.ecy.wa.gov/biblio/0703108.html. 45 p.

Additional References

Angier, J.T., and McCarty, G.W., 2008. Variations in base-flow nitrate flux in first-order stream and riparian zone. Journal of the American Water Resources Association. Vol. 14, No. 2, pp. 367-380.

Barker, R.A., 1979. Computer Simulation and Geohydrology of a Basalt Aquifer System in the Pullman-Moscow Basin, Washington and Idaho. Washington State Department of Ecology, Water Supply Bulletin 48. 134 p. plus 1 plate.

Bilhimer, D. and Stohr, A., 2008. Standard Operating Procedures for Continuous Temperature Monitoring of Freshwater Rivers and Streams Conducted in a Total Maximum Daily Load (TMDL) Project for Stream Temperature, Version 2.2. Washington State Department of Ecology, SOP Number EAP044. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_044Cont_Temp_Monit_TMDL.pdf

Bradbury, K.R. and Rothschild, E.R., 1985. A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data. Groundwater, Vol. 23, No. 2, pp. 240-246.

Bretz, H.J., 1959. Washington's Channeled Scabland. Washington Division of Mines and Geology, Bulletin No. 45. 57 p.

Bush, J.H. and Provant, A.P., 1998. Geologic map of the Viola Quadrangle, Latah County, Idaho and Whitman County, Washington. Idaho Geological Survey, Geologic Map 25.

Cardenas, M.B. and Zlotnik, V.A., 2003. A simple constant-head injection test for streambed hydraulic conductivity estimation, Groundwater, Vol. 41, No. 6, p. 867-871.

Carroll, J., 2009, Personal communication, Environmental Assessment Program. Washington State Department of Ecology, Olympia, WA.

Dahm, C.N., Grimm, N.B., Marmonier, P., Valett, M.H., and Vervier, P., 1998. Nutrient dynamics at the interface between surface-waters and groundwaters. Freshwater Biology, 40, 427-451.

Darcy, H., 1856. Les fontaines publiques de la ville de Dijon, Paris: Victor Dalmont. 647 p.

Drost, B.W., Whiteman, K.J., and Gonthier, J.B., 1990. Geologic framework of the Columbia plateau aquifer system, Washington, Oregon, and Idaho. U.S. Geological Survey, Water-Resources Investigations Report 87-4238. 10 p. plus 10 plates.

Duff, J. H., Murphy, F., Fuller, C. C., Triska, F. J., Harvey, J. W., and Jackman, A. P., 1998. A mini drivepoint sampler for measuring pore water solute concentrations in the hyporheic zone of sand-bottom streams, Limnology and Oceanography, v. 43(6), p. 1378-1383.

Foxworthy B.L. and Washburn, R.L., 1963. Groundwater in the Pullman Area, Whitman Co. Washington. U.S. Geological Survey, Water-Supply Paper 1655. 71 p.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 604 p.

Heinemann, R., 1994. The relationship between streams and ground water flow system within the Pullman-Moscow area of Washington and Idaho. University of Idaho, M.S. Thesis. 58 p.

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural waters. U.S. Geological Survey, Water-Supply Paper 2254. 263 p.

Jones, J.B. and Mulholland, P.J., (Editors), 2000. Streams and Ground Waters, Academic Press. 425 p.

Kalbus, E., Reinstorf, R., and Schirmer, M., 2006. Measuring methods for groundwater/surface-water interactions: a review. Hydrol. Earth Syst. Sci., 10, pp. 873-887.

Konrad, C.P., Drost, B.W., and Wagner, R.J., 2003. Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington. U.S. Geological Survey, Water-Resources Investigations Report 03-4244. 137 p.

Leek, F., 2006. Hydrogeological characterization of the Palouse basin basalt aquifer system, Washington and Idaho. Washington State University, M.S. Thesis. 39 p. plus plates.

Lum, W.E. II, Smoot, J.L., and Ralston, D.R., 1990. Geohydrology and numerical model analysis of groundwater flow in the Pullman-Moscow area, Washington and Idaho. U.S. Geological Survey, Water-Resources Investigations Report 98-4103. 73 p.

Luzier, J.E. and Burt, R.J., 1974. Hydrology of basalt aquifers and depletion of groundwater in East-Central Washington. Washington State Department of Ecology, Water Supply Bulletin No. 33. 53 p.

Martin, J. B., Hartl, K. M., Corbett, D. R., Swarzenski, P. W., and Cable, J. E., 2003. A Multi-level Pore-water Sampler for Permeable Sediments, Journal of Sedimentary Research, v. 73, no. 1, p. 128-132.

Nassar, E.G. and Walters, K.L., 1975. Water in the Palouse River Basin, WA. Washington State Department of Ecology, Water-Supply Bulletin 39. 246 p.

Northwest Hydrologic Consultants, July 30, 2008. South Fork Palouse River and Paradise Creek low-flow modeling, final report. Memorandum to Jim Carroll from Bob Elliott. 16 p.

Office of Financial Management, State of Washington, 2007. Census 2000 results. www.ofm.wa.gov/census2000/default.asp

Pitz, C.F., 2006. An evaluation of a piezometer-based constant head injection test (CHIT) for use in groundwater/surface-water interaction studies. Washington State Department of Ecology. Publication No. 06-03-042. www.ecy.wa.gov/biblio/0603042.html. 31 p.

Rantz, S.E. and others, 1982. Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge. U.S. Geological Survey, Water-Supply Paper 2175. 284 p.

RPU, Inc., 2002. South Fork Palouse River Watershed Characterization and Implementation Plan. Resource Planning Unlimited, Inc., Moscow, ID.

Schuster, E.J., Gulick, C.W., Reidel, S.P., Fecht, K.R., and Zurenko, S., 1997. Geologic map of Washington - Southeast Quadrant. Washington Division of Geology and Earth Resources, Geologic Map GM-45.

Stonestrom, D.A. and Constantz, J. (Editors), 2003. Heat as a tool for studying the movement of ground water near streams: U.S. Geological Survey, Circular 1260. 96 p.

U.S. Army Corps of Engineers, 2008. River Analysis System, HEC-RAS Version 4.0.0, Users Manual. Publication No. CPD-68. 733 p.

U.S. Weather Bureau, 1965. Mean Annual Precipitation, 1930-57, State of Washington: Portland, Oregon, U.S. Soil Conservation Service, map M-4430.

Walters, K.L. and Glancy, P.A., 1969. Reconnaissance of geology and of ground-water occurrence in Whitman County, Washington. Washington State Department of Ecology, Water Resources Program, Water Supply Bulletin No. 26. 169 p.

Washington State Department of Ecology, 2005. Manchester Environmental Laboratory, Lab Users Manual, 8th Edition.

Zimmerman, M.J., Massey, A.J., and Campo, K.W., 2005. Pushpoint Sampling for Defining Spatial and Temporal Variations in Contaminant Concentrations in Sediment Pore Water near the Ground-Water/Surface-Water Interface, U.S. Geological Survey Scientific Investigations Report 2005-5036. 75 p. http://pubs.usgs.gov/sir/2005/5036/pdf/sir2005_5036.pdf

Appendices

Appendix A. Data Quality Review

The data collected during this 2006-07 study were evaluated to ensure they met the quality objectives specified in the project quality assurance plans (Bilhimer, Carroll, and Sinclair, 2006; Carroll and Mathieu, 2006). The evaluation methods are described below.

Evaluation of Recording Thermistors

The recording thermistors deployed during this study were tested for accuracy prior to initial use and again at the completion of field studies. The tests were conducted to confirm that all thermistors met the manufacturer's accuracy specifications for the range of water temperatures that were likely to be encountered during field deployment (Table A-1).

Table A-1: Thermistor model and manufacturer specifications.

Thermistor model	Temperature range	Manufacturer reported accuracy	Manufacturer reported resolution
Stow-away tidbit	-5°C to +37°C	± 0.2°C at +21°C	0.16°C
Stow-away tidbit	-20°C to +50°C	± 0.4°C at +21°C	0.3°C
Hobo pro (Version 1)	-20°C to +50°C	± 0.2°C at 0 to +50°C	0.02°C

To conduct the tests, a batch of thermistors were pre-programmed to record temperature at one-minute intervals and were set to launch at a common start time. After programming, the thermistors were submerged in a constantly-stirred, room-temperature water bath where they were allowed to equilibrate. A NIST[9] certified reference thermometer was then used to manually measure the water-bath temperature at pre-defined one-minute intervals over a 10-minute period.

When the room temperature reference measurements were complete, the thermistors were transferred to an adjacent stirred-ice bath where they were again allowed to equilibrate before repeating a second set of reference measurements.

Mean temperature values for each thermistor were calculated from the 10 paired-reference temperatures measured for each bath. The mean temperature values for each thermistor (one for the ice bath and one for the room-temperature bath) were then plotted against the mean reference temperature calculated from the corresponding NIST thermometer measurements. Noted temperature differences were then compared to the reported manufacturer specifications, for each thermistor type, to assess thermistor accuracy (Figure A-1).

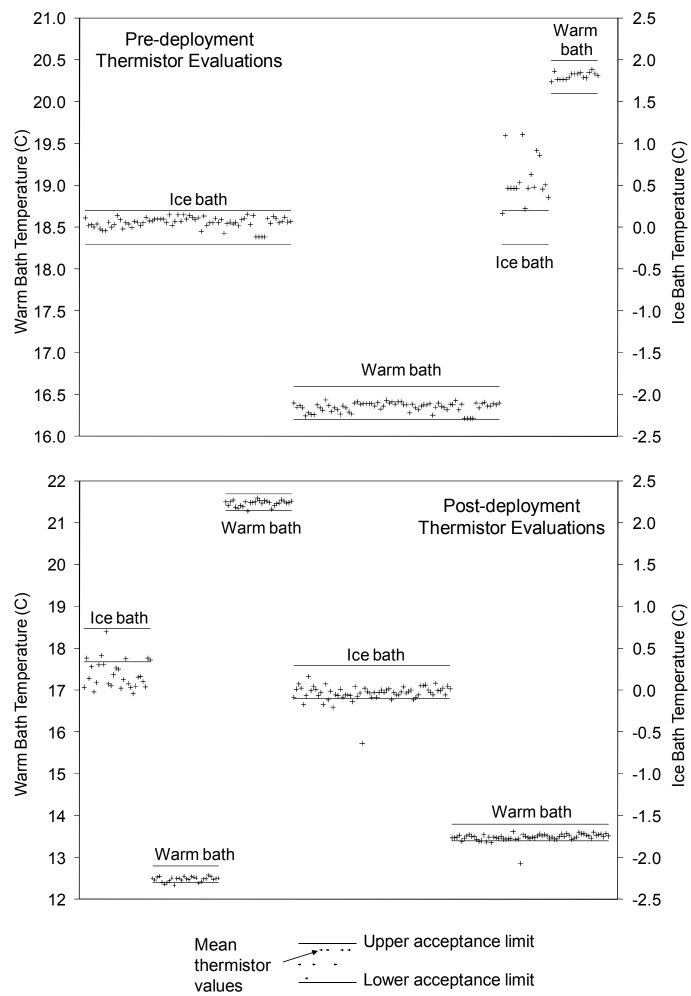

Figure A-1: Results of pre-deployment and post-deployment thermistor calibration checks for room-temperature and ice-water baths

[9] National Institute of Standards and Technology

This evaluation showed that all tested thermistors met the manufacturer's specified accuracy ranges for room-temperature conditions prior to deployment. The ice-bath results were more variable, with many thermistors failing to meet acceptance limits. However, past experience has shown that the ice baths are prone to thermal stratification due to incomplete mixing of the water and ice. Accordingly, thermistors that met room temperature acceptance criteria but failed the ice-bath criteria were still deployed since the primary period of interest for this study was the summer months when stream temperatures are well above freezing.

Two warm-temperature water baths were used during post-deployment calibration checks as a secondary check of thermistor accuracy. Three thermistors slightly exceeded calibration criteria for the 12.6 degree bath but met criteria for the 20.4 degree bath. The slight deviations from acceptance criteria for these thermistors were not considered significant; therefore, the results were used in subsequent data analysis without further qualification.

Field-Meter Calibration

All field meters were calibrated in accordance with the manufacturer's instructions at the start of each sampling day. Fresh commercially prepared buffer solutions and reference standards were used for all pH and specific conductance calibrations, respectively. The dissolved oxygen sensor was calibrated against theoretical water saturated air using the manufacturer-supplied air chamber and instructions.

The initial pH and specific conductance calibrations were checked by placing the probes in pH buffer solutions and reference standards, respectively, and evaluating the difference between the standards and the meter values (Table A-2). The pH calibration was considered acceptable if the resultant pH values differed by less than ± 0.05 pH units from the buffer standards. The specific conductance calibration was accepted if the meter values deviated by no more than ± 5% from the specific conductance check standards.

At the end of each sampling day, field meters were rechecked against the pH and specific conductance reference standards to confirm that they had not drifted unacceptably from the morning calibration. Based on this end-of-day check, the day's results for each parameter were either accepted, qualified as estimates, or rejected as unusable (Table A-2).

Based on this evaluation, the specific conductance results for October 25, 2006 were qualified as estimates due to an exceedance of post-use calibration standards. In addition, the pH values for September 10, 2007 were also qualified as estimates due to unacceptably high errors encountered during the initial and post-calibration tests that day.

Table A-2: Field Meter Calibration Records

Date	Status	pH: Slope (mv/pH)	pH: Asymmetry (mV)	pH: Reference standard (pH)	pH: Meter reading (pH)	pH: Difference from standard (pH units)	pH: Accept or reject calibration/ results [1]	Specific Conductance: Reference standard (µS/cm)	Specific Conductance: Meter reading (µS/cm)	Specific Conductance: Deviation from standard (%)	Specific Conductance: Accept or reject calibration/ results [1]	Dissolved Oxygen: Relative slope	Dissolved Oxygen: Meter reading (mg/L)	Dissolved Oxygen: saturation (percent)	Dissolved Oxygen: Accept or reject calibration/ results [1]
6/27/2006	calibration	-56.4	-5	4.01	3.98	-0.03	Accept	101	104	3.0	Accept	1.05	8.62	-	Accept
6/28/2006	calibration	-56.5	-7	4.01	3.98	-0.03	Accept	101	103	2.0	Accept	1.09	8		Accept
	post-use			4.01	4.04	0.03	Accept	101	103	2.0	Accept	-	6.98	103	Accept
8/14/2006	calibration	-58.4	-1	4.01	3.99	-0.02	Accept	-	-	-	-	-	-	-	-
				7.01	7	-0.01	Accept	-	-	-	-	-	-	-	-
	calibration	-56	-15	4.01	3.98	-0.03	Accept	101	102	1.0	Accept	0.77	7.62		Accept
				7.01	7.03	0.02	Accept								
8/15/2006	calibration	56.6	-10	4.01	3.97	-0.04	Accept	101	104	3.0	Accept	0.87	9.05		Accept
				7.01	7.02	0.01	Accept								
	calibration	-56.8	-15	4.01	4.03	0.02	Accept	101	104	3.0	Accept	0.87	9.18		Accept
				7.01	7.02	0.01	Accept								
8/16/2006	calibration	-56.4	-15	-	-	-	Accept	101	105	4.0	Accept	0.86	8.4		Accept
10/23/2006	calibration	-57.8	0	7.01	7.05	0.04	Accept	101	100	-1.0	Accept	1.05	10.12		Accept
10/24/2006	calibration	-58	0	7.01	7.05	0.04	Accept	101	99	-2.0	Accept	1.03	9.38		Accept
	post-use			7.01	7.05	0.04	Accept	101	103	2.0	Accept	-	8.18		
10/25/2006	calibration	57.9	0	7.01	7.05	0.04	Accept	101	98	-3.0	Accept	0.8	10.27		Accept
	post-use			7.01	7.03	0.02	Accept	101	112	**10.9**	**J qualify**	-	-		

Calibration acceptance criteria by parameter [1]

pH

Slope: Ideal: -58 to -60.5 mV/pH
Acceptable: -50 to -62 mV/pH

Asymmetry: Ideal: < ± 15 mv
Acceptable: < ± 30mV

Deviation from check standards following initial calibration:
- ≤ ± 0.05 deviation from all standards = accept calibration
- > ± 0.05 deviation from any standard = reject calibration

Specific conductance
- ≤ ±5% deviation from all standards = accept calibration
- > ±5% deviation from any standard = reject calibration

Dissolved oxygen

Relative slope
- 0.8 to 1.25 = good calibration
- 0.6 to 1.25 = acceptable calibration
- < 0.6 or > 1.25 = reject calibration

Post-use acceptance criteria - deviations from check standards [1]

pH
- ≤ ±0.15 deviation from all standards = accept results
- > ±0.15 and ≤ ±0.5 deviation from any standard = qualify results as estimates ("J" code)
- > ±0.5 deviation from any standard = reject results

Specific conductance
- ≤ ±5% deviation from all standards = accept results
- > ±5% and ≤ ±10% deviation from any standard = qualify results as estimates ("J" code)
- > ±10% deviation from any standard = reject results

Dissolved oxygen

Relative slope
- 0.6 to 1.25 = accept results
- < 0.6 or > 1.25 = reject results

Table A-2: Continued

		pH						Specific Conductance				Dissolved Oxygen			
Date	Status	Slope (mv/pH)	Asymmetry (mV)	Reference standard (pH)	Meter reading (pH)	Difference from standard (pH units)	Accept or reject calibration/ results [1]	Reference standard (µS/cm)	Meter reading (µS/cm)	Deviation from standard (%)	Accept or reject calibration/ results [1]	Relative slope	Meter reading (mg/L)	saturation (percent)	Accept or reject calibration/ results [1]
7/9/2007	calibration	-56.5	0	7	7.02	0.02	Accept	101	102	1.0	Accept	0.8	8.65	-	Accept
		-	-	10	10.19	0.19	-	-	-	-	-	-	-	-	-
	post-use	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7/10/2007	calibration	-56.4	-2	4.01	4.02	0.01	Accept	101	103	2.0	Accept	0.86	8.62	-	Accept
				7	7.03	0.03	Accept	-	-	-	-	-	-	-	-
	post-use	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7/11/2007	calibration	-56.6	-2	-	-	-	-	101	101	0.0	Accept	0.84	8.46	-	Accept
				7	7.02	0.02	Accept	-	-	-	-	-	-	-	-
9/9/2007	calibration	-	-	-	-	-	-	101	104	3.0	Accept	-	-	-	-
		-	-	-	-	-	-	1413	1412	-0.1	Accept	-	-	-	-
	post-use	-	-	-	-	-	-	101	104	3.0	Accept	-	-	-	-
9/10/2007	calibration	53.9	7	4.01	3.73	-0.28	**Reject**	101	103	2.0	Accept	0.78	8.25	101.9	Accept
				7	7.03	0.03	Accept	1413	1438	1.8	Accept	-	-	-	-
	post-use	-	-	4.01	3.78	-0.23	**J qualify**	101	103	2.0	Accept	0.82	8.35	105.7	Accept
				7	7.04	0.04	Accept	-	-	-	-	-	-	-	-
9/11/2007	calibration	58.6	-4	4.01	4.02	0.01	Accept	101	102	1.0	Accept	0.77	8.73	101.4	Accept
				7	7.04	0.04	Accept	1413	1433	1.4	Accept	-	-	-	-
	post-use	-	-	4.01	3.99	-0.02	Accept	101	101	0.0	Accept		7.78	108.5	Accept
				7	6.97	-0.03	Accept	-	-	-	-	-	-	-	-
9/12/2007	calibration	58.8	-4	4.01	4.03	0.02	Accept	101	102	1.0	Accept	0.76	7.86	101.8	Accept
				7	7.04	0.04	Accept	1413	1421	0.6	Accept	-	-	-	-
	post-use			4.01	3.97	-0.04	Accept	101	102	1.0	Accept	-	7.49	104.4	Accept
				7	6.96	-0.04	Accept	-	-	-	-	-	-	-	-

Calibration acceptance criteria by parameter [1]

pH

Slope: Ideal: -58 to -60.5 mV/pH
Acceptable: -50 to -62 mV/pH

Asymmetry: Ideal: < ± 15 mv
Acceptable: < ± 30mV

Deviation from check standards following initial calibration:
≤ ± 0.05 deviation from all standards = accept calibration
> ± 0.05 deviation from any standard = reject calibration

Specific conductance

≤ ±5% deviation from all standards = accept calibration
> ±5% deviation from any standard = reject calibration

Dissolved oxygen

Relative slope
0.8 to 1.25 = good calibration
0.6 to 1.25 = acceptable calibration
< 0.6 or > 1.25 = reject calibration

Post-use acceptance criteria - deviations from check standards [1]

pH

≤ ±0.15 deviation from all standards = accept results
> ±0.15 and ≤ ±0.5 deviation from any standard = qualify results as estimates ("J" code)
> ±0.5 deviation from any standard = reject results

Specific conductance

≤ ±5% deviation from all standards = accept results
> ±5% and ≤ ±10% deviation from any standard = qualify results as estimates ("J" code)
> ±10% deviation from any standard = reject results

Dissolved oxygen

Relative slope
0.6 to 1.25 = accept results
< 0.6 or > 1.25 = reject results

Review of Water Quality Data

All wells and piezometers were sampled using properly calibrated field meters, dedicated sample tubing, and new in-line-cartridge or syringe filters, where appropriate. Samples were collected in pre-cleaned bottles supplied by Manchester Environmental Laboratory (MEL). Pre-acidified bottles were used for preserved samples. Filled sample bottles were labeled, bagged, and then stored in clean, ice-filled coolers pending their arrival at the laboratory. Sample chain-of-custody procedures were followed throughout the project.

Laboratory Quality Assurance

Manchester Laboratory follows a strict set of quality assurance procedures to both ensure and later evaluate the quality of their analytical results (WA State Department of Ecology, 2005). Where appropriate, instrument calibration was performed before each analytical run and checked against initial verification standards and blanks. Calibration standards and blanks were analyzed at a frequency of approximately 10% during each analytical run and then again at the end of each run. The laboratory also evaluates procedural blanks, spiked samples, and laboratory control samples (LCS) as additional checks of data quality. The results of these analyses were summarized in a case narrative and submitted to the author along with each analytical data package.

The laboratory's quality assurance narratives and supporting data for this project indicate that all samples arrived at the laboratory in good condition and, with the exception of four bacterial samples, were processed and analyzed within accepted EPA holding times. Analyte concentrations for laboratory blank samples consistently fell below the analytical detection limit for target analytes. In addition, matrix spike samples, laboratory replicate samples, and LCS analyses all met applicable acceptance criteria
(Table A-3).

Three fecal coliform samples from the August 2006 sampling event (wells AKY498, AHT029, and AHT032) and one sample for well AKY496 from October 2006 were not processed within the maximum 24-hour holding time recommended by EPA (Ecology, 2005). The results for these wells were "J" coded by the laboratory to indicate they are estimates and are likely less than the true value.

Table A-3: Data quality objectives for water quality parameters.

Parameter	LCS check standards (% recovery limits)	Duplicate sample (RPD)	Matrix spikes (% recovery limits)	Matrix spike duplicates (RPD)
Field Parameters				
pH	± 0.2 pH units	units	NA	NA
Specific Conductance	± 10 µS/cm	± 10 %	NA	NA
Temperature	± 0.1 C	± 5 %	NA	NA
Dissolved Oxygen	± 0.2 mg/L	NA	NA	NA
Laboratory Analyses				
Coliform, fecal (MF)	NA	± 40 %	NA	NA
Total Alkalinity	80-120 %	± 10 %	75-125 %	± 10 %
Chloride	90-110 %	± 5 %	75-125 %	± 5 %
Orthophosphate	80-120 %	± 10 %	75-125 %	± 10 %
Total Phosphorus	85-115 %	± 10 %	75-125 %	± 10 %
Nitrate+Nitrite-N	80-120 %	± 10 %	75-125 %	± 10 %
Ammonia	80-120 %	± 10 %	75-125 %	± 10 %
TPN-N	80-120 %	± 10 %	75-125 %	± 10 %
Dissolved Organic Carbon	80-120 %	± 10 %	75-125 %	± 10 %
Iron	85-115 %	± 10 %	75-125 %	± 10 %

RPD - relative percent difference

Field Quality Assurance

To assess sampling bias and overall analytical precision, field equipment blanks and replicate samples were collected and submitted "blind"[10] to the laboratory during each sample event. Equipment blanks were prepared using laboratory-grade de-ionized water and were handled and filtered in the same manner as actual samples.

Precision for each of the field replicate and laboratory duplicate analyses was quantified by evaluating the relative percent difference [11] (RPD) for each duplicate sample pair. The resulting values (Table A-4) were then tabulated and compared to the project data quality objectives (Table A-3).

[10] The term "blind" refers to "identical" samples that were submitted to the laboratory under different sample numbers.
[11] Calculated for a pair of results, x_1 and x_2, as $100*(x_1-x_2)/average[x_1 \text{ and } x_2]$)

This evaluation revealed that field blank for October 2006 contained small but measurable concentrations of dissolved total phosphorus (0.0043 mg/L) while the laboratory blank contained no detectable phosphorus. The cause of this discrepancy is not known, but was deemed significant enough to warrant qualification of three samples (wells AHT029, AGJ767, and AGJ770) where measured dissolved total phosphorus concentrations were less than or equal to 10 times the field blank concentration (<= 0.043 mg/L). The laboratory results for these wells were "JL" coded by the authors to indicate that they are estimates and may potentially be biased high by field or laboratory contamination.

All dissolved organic carbon values for October 2006 were also "J" coded by the authors due to exceedances of both field and laboratory duplicate precision criteria.

The TPN results for July 9, 2007 for wells AHT098, AHT042, AHT040, and AHR589 were all "J" qualified due to a slight exceedance of the field replicate precision for this date.

Except as noted above, the results from the laboratory and field quality assurance reviews suggest that the water quality data generated during this study are of high quality and can be used, as intended, without further qualification.

Table A-4: Summary of field and laboratory duplicate samples and blanks.

Sample Date		Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Fecal Coliform (#/100mL)	Dissolved Iron (mg/L)
Field Replicates and Equipment Blanks											
8/14/2006	Sample	120	3.08	1 U	0.02	1.64	0.037	0.126	0.12	1	-
# 1	Rep/Duplicate	119	3.06	1 U	0.021	1.64	0.038	0.125	0.13	1	-
	RPD	0.84	0.65	-	4.88	0.00	2.67	0.80	8.00	0.00	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
8/14/2006	Sample	163	2.74	1 U	0.039	0.0298	0.01 U	0.118	0.15	1 U	-
# 2	Rep/Duplicate	164	2.61	1.2 J	0.0398	0.0294	0.01 U	0.119	0.15	1 U	-
	RPD	0.61	4.86	-	2.03	1.35	-	0.84	0.00	-	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
8/16/2006	Sample	-	-	-	-	-	-	-	-	-	-
	Rep/Duplicate	-	-	-	-	-	-	-	-	-	-
	RPD	-	-	-	-	-	-	-	-	-	-
	Sample blank	5.0 U	0.10 U	1 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	1 U	-
10/23/2006	Sample	123	1.24	1.9 J	0.0981	0.0929	4.4	0.010 U	4.39	1 U	-
	Rep/Duplicate	124	1.24	2.7 J	0.0975	0.094	4.42	0.010 U	4.85	1 U	-
	RPD	0.81	0.00	**34.78**	0.61	1.18	0.45	-	9.96	-	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
10/24/2006	Sample	120	4.42	3.8 J	0.018	0.137	0.138	0.088	0.292	1	-
	Rep/Duplicate	120	4.41	2.7 J	0.018	0.139	0.142	0.087	0.313	1 U	-
	RPD	0.00	0.23	**33.85**	0.00	1.45	2.86	1.14	6.94	-	-
	Sample blank	5.0 U	0.10 U	1 U	0.003 U	**0.0043**	0.01 U	0.010 U	0.025 U	1 U	-
7/9/2007	Sample	110	7.78	1.3	0.149	0.151	1.7	0.01 U	1.75 J	2	0.050 U
	Rep/Duplicate	111	7.72	1.3	0.149	0.149	1.88	0.01 U	2.2 J	1	0.050 U
	RPD	0.90	0.77	0.00	0.00	1.33	**10.06**	0.00	**22.78**	**66.67**	0.00
	Sample blank	-	-	-	-	-	-	-	-	-	-
7/11/2007	Sample	161	5.19	1	0.0591	0.164	0.01 U	0.078	0.13	1	1.42
	Rep/Duplicate	160	5.03	1	0.0566	0.166	0.01 U	0.075	0.13	1 U	1.4
	RPD	0.62	3.13	0.00	4.32	1.21	0.00	3.92	0.00	0.00	1.42
	Sample blank	5 U	0.1 U	**1.7**	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	1 U	0.050 U
9/10/2007	Sample	255	47.9	5.8	0.141	0.2	2.88	10.8	13	1 U	0.05 U
	Rep/Duplicate	258	48.6	5.7	0.146	0.2	2.78	10.5	12.7	1 U	0.05 U
	RPD	1.17	1.45	1.74	3.48	0.00	3.53	2.82	2.33	0.00	0.00
	Sample blank	5 U	0.1 U	1 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	1 U	0.050 U
9/11/2007	Sample	244	24.3	1	0.108	0.116	3.04	0.01 U	4.16	1 U	0.05 U
	Rep/Duplicate	244	24.1	1 U	0.109	0.113	3.02	0.01 U	4	1 U	0.05 U
	RPD	0.00	0.83	0.00	0.92	2.62	0.66	0.00	3.92	0.00	0.00
	Sample blank	-	-	-	-	-	-	-	-	-	-
Laboratory Replicates and Blanks											
6/28/2006	Sample	132	-	2.4	0.132	-	-	0.03	0.12	6	-
	Rep/Duplicate	132	-	2.4	0.13	-	-	0.03	0.12	8	-
	RPD	0.00		0.00	1.53			0.00	0.00	28.57	-
	Sample blank	5 U	0.1 U	1 U	0.003 U	0.001 U	0.01 U	0.01U	0.025 U	-	-
8/14/2006	Sample	-	2.28	1.3 J	-	-	-	-	-	1 U	-
	Rep/Duplicate	-	2.28	1.3	-	-	-	-	-	1 U	-
	RPD	-	0.00	-	-	-	-	-	-	NA	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
8/15/2006	Sample	-	-	-	-	-	-	-	-	1	-
	Rep/Duplicate	-	-	-	-	-	-	-	-	2	-
	RPD	-	-	-	-	-	-	-	-	**66.67**	-
	Sample blank	-	-	-	-	-	-	-	-	-	-

Table A-4: Continued

Sample Date		Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Fecal Coliform (#/100mL)	Dissolved Iron (mg/L)
Laboratory Replicates and Blanks (continued)											
8/16/2006	Sample	146	-	-	0.105	-	0.01 U	-	-	1 U	-
	Rep/Duplicate	145	-	-	0.106	-	0.01 U	-	-	1 U	-
	RPD	0.69	-	-	0.95	-	-	-	-	NA	-
	Sample blank	5.0 U	0.10 U	1 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	-	-
10/23/2006	Sample	-	34.2	-	0.0723	-	15	0.01 U	4.39	1 U	-
	Rep/Duplicate	-	34.2	-	0.0722	-	15	0.01 U	4.39	1 U	-
	RPD	-	0.00	-	0.14	-	0.00	-	0.00	-	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
10/24/2006	Sample	-	-	3.8	-	-	-	-	-	1 U	-
	Rep/Duplicate	-	-	1.6	-	-	-	-	-	1 U	-
	RPD	-	-	**81.48**	-	-	-	-	-	-	-
	Sample blank	-	-	-	-	-	-	-	-	-	-
10/25/2006	Sample	156	-	-	-	-	-	-	-	2	-
	Rep/Duplicate	156	-	-	-	-	-	-	-	3	-
	RPD	0.00	-	-	-	-	-	-	-	40.00	-
	Sample blank	5.0 U	0.10 U	1 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	-	-
7/9/2007	Sample	145	-	1 U	-	-	1.7	-	1.75	1 U	-
	Rep/Duplicate	146	-	1 U	-	-	1.7	-	1.77	1 U	-
	RPD	0.69	-	0.00	-	-	0.00	-	1.14	0.00	-
	Sample blank	-	-	-	-	-	0.01 U	-	0.025 U	-	-
7/10/2007	Sample	-	7.44	-	-	-	-	0.972	-	1 U	-
	Rep/Duplicate	-	7.51	-	-	-	-	0.968	-	1 U	-
	RPD	-	0.94	-	-	-	-	0.41	-	0.00	-
	Sample blank	5 U	-	-	0.003 U	-	-	0.01 U	-	-	-
7/11/2007	Sample	5 U	-	-	-	-	-	-	-	1 U	-
	Rep/Duplicate	5 U	-	-	-	-	-	-	-	1 U	-
	RPD	0.00	-	-	-	-	-	-	-	0.00	-
	Sample blank	-	-	-	0.003 U	0.001 U	-	-	-	-	-
7/12/2007	Sample	-	-	-	-	-	-	-	-	-	-
	Rep/Duplicate	-	-	-	-	-	-	-	-	-	-
	RPD	-	-	-	-	-	-	-	-	-	-
	Sample blank	5 U	0.1 U	1 U	0.003 U	-	-	-	-	-	0.050 U
9/10/2007	Sample	-	-	5.1 J	0.146	-	-	-	4.9	1 U	-
	Rep/Duplicate	-	-	3.5 J	0.148	-	-	-	4.8	1 U	-
	RPD	-	-	**37.21**	1.36	-	-	-	2.06	0.00	-
	Sample blank	-	-	-	0.003 U	-	-	-	-	-	-
9/11/2007	Sample	-	3.57	-	-	-	-	-	-	1 U	-
	Rep/Duplicate	-	3.57	-	-	-	-	-	-	1 U	-
	RPD	-	0.00	-	-	-	-	-	-	0.00	-
	Sample blank	-	-	-	0.003 U	-	-	-	-	-	-
9/12/2007	Sample	135	-	-	-	0.179	-	-	-	1 U	-
	Rep/Duplicate	135	-	-	-	0.179	-	-	-	1	-
	RPD	0.00	-	-	-	0.00	-	-	-	0.00	-
	Sample blank	5 U	0.10 U	1 U	0.003 U	0.001 U	0.010 U	0.010 U	0.025 U	-	0.050 U

U -analyte not detected at or above the reported value.
J -analyte positively identified, the numeric result is an estimate.
Values in bold font indicate an exceedence of the project precision criteria.

Appendix B. Tabular Data Summaries

Most of the field and laboratory data presented in this report are available in digital format from Ecology's Environmental Information Management (EIM) database. Readers can access the EIM database from links provided on Ecology's home page at: www.ecy.wa.gov/eim/.

Project data for the South Fork Palouse River and Paradise Creek are archived in EIM under the following study name and user study ID:

EIM study name: S. Fk. Palouse R. TMDL
EIM user study ID: JICA0000

Project data for the mainstem Palouse River are archived under the following study name and user study ID:

EIM study name: Palouse River TMDL
EIM user study ID: JICA0001

To meet EIM data protocols, the continuous temperature records from instream piezometers, wells, and instream thermistors were summarized as daily maximum, minimum, and mean values before uploading to EIM. The continuous (30-minute interval) temperature records depicted graphically on Plates 1 and 2 are available by request.

Table B-1: Physical description and location of monitored domestic wells and springs.

Map ID [1]	Well tag ID number	Well location	Site latitude (decimal degrees)	Site longitude (decimal degrees)	Land surface altitude at well head (feet)	Completed well depth (feet)	Maximum casing diameter (inches)	Well completion type and open interval (feet)	Driller reported groundwater level (feet below land surface)	Water level date	Reported well yield (gpm)	Horizontal hydraulic conductivity [2] (feet/day)
South Fork Palouse Watershed												
W1	AHT032	16N/44E-19G	46.86509	117.31378	2092	458 R	6	unknown	-	-	-	-
W2	AAW651	16N/44E-20G	46.86547	117.29317	2193	103	8	OH (20-103)	-	-	40	-
W3	ALB694	16N/44E-33D	46.83994	117.28203	2176	60 R	8	unknown	11.98	3/30/2006	-	-
W4	AHT029	15N/44E-15E	46.78924	117.26353	2224	103	8	OH (53-103)	-0.3	8/10/1995	25	-
W5	AGJ767	15N/44E-23L	46.77146	117.23875	2271	90	8	unknown	39.58	5/18/2005	-	-
W6	AGJ770	15N/44E-23F	46.77423	117.23769	2276	78	8	OH (67-78)	31.85	12/12/1988	20	-
W7	AGJ768	15N/45E-31P	46.73853	117.19270	2326	90 R	8	unknown	17.5	4/27/1984	-	-
W8	AHJ874	14N/46E-17H	46.70050	117.04289	2528	116	8	OH (50-116)	-	-	14	-
S1	AHT033	15N/44E-25P	46.75261	117.21430	2291	20 S	36	unknown	-	-	-	-
Mainstem Palouse Watershed												
W9	AHT040	16N/38E-26R	46.84035	117.99599	1189	161	10	P(141-160)	27	9/22/1990	30	-
W10	AHT098	17N/40E-20P	46.94546	117.80280	1480	60	8	O	15	9/17/2001	100+	-
W11	AHR589	17N41E-02N	46.99281	117.61542	1603	90 R	8	-	21	6/6/2007	-	-
W12	AHT044	17N/44E-11K	46.98139	117.22311	2188	68	8	OH(17-68)	51	4/3/1976	10	-
M1	ACP674	16N/43E-10K	46.89266	117.38170	1941	19	2	S(14-19)	12	7/24/1997	-	-
M2	ACP673	16N/43E-10K	46.89264	117.38163	1941	32	2	S(27-32)	16.25	7/24/1997	-	110
M3	ACP676	16N/43E-10K	46.89241	117.38005	1939	19	2	S(14-19)	12	7/24/2007	-	-
M4	ACP675	16N/43E-10K	46.89240	117.38002	1939	27	2	S(22-27)	16	7/24/1997	-	-
M5	ACP679	16N/43E-10J	46.89022	117.37281	1933	21	2	S(16-21)	8.6	7/25/1997	-	0.785
M6	ACP678	16N/43E-10R	46.88973	117.37156	1933	20	2	S(15-20)	10	7/25/1997	-	17.6

[1] - The map IDs listed here correspond with those shown on Plates 1 and 2

Completed well depth: R -depth reported by owner, no well report avaulable for well; S -depth sounded, no well report available

Completion type and open interval: OH -uncased open hole; P -perforated well casing; S -commercial well screen

[2] - Horizontal hydraulic conductivity values were estimated from well specific capacity measurements, made during well sampling, via the method detailed in Bradbury and Rothschild (1985).

Table B-2: Drillers lithologic logs for monitored domestic wells.

Map ID [1]	Well tag number	Local number	Year drilled	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)
W2	AAW651	16N/44E-20G	1993	Soil	3	3
				Clay	2	5
				Basalt, gray medium	66	71
				Basalt, gray fractured	1	72
				Basalt, gray medium	10	82
				Basalt, gray fractured	21	103
W4	AHT029	15N/44E-15E	1995	Overburden	38	38
				Basalt, soft	10	48
				Basalt, firm	25	73
				Basalt, soft	11	84
				Basalt, fractured	6	90
				Shale, gray	4	94
				Basalt, soft	3	97
				Basalt, firm	6	103
W6	AGJ770	15N/44E-23F	1988	Soil	1	1
				Clay, brown	17	18
				Basalt, gray medium	29	47
				Clay, white	3	50
				Basalt, gray medium	17	67
				Basalt, gray fractured	8	75
				Basalt, gray medium	3	78
W8	AHJ874	14N/46E-17H	2004	Overburden	16	16
				Basalt, soft	31	47
				Basalt, firm	7	54
				Basalt, broken	4	58
				Basalt, firm	13	71
				Basalt, fractured	4	75
				Basalt, firm	39	114
				Shale, green	2	116
W9	AHT040	16N/38E-26R	1990	Clay, light brown	25	25
				Sand, black, coarse, moist	3	28
				Clay, light brown, with cobbles, moist	4	32
				Bolders, cobbles, and gravel with fine silt	70	102
				Clay, light brown, with basalt chips	2	104
				Basalt, black, medium to soft, with green and brown clay	17	121
				Basalt, black, medium to soft, with quartz inclusions	8	129
				Basalt, black, medium hard	6	135
				Basalt, black, hard	10	145
				Basalt, black, fractured, water bearing	13	158
				Basalt, black hard	3	161

Table B-2: Continued

Map ID [1]	Well tag number	Local number	Year drilled	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)
W10	AHT098	17N/40E-20P	2001	Sand	5	5
				Broken (basalt?)	42	47
				Basalt	3	50
				Broken (basalt?)	10	60
W12	AHT044	17N/44E-11K	1976	Soil	3	3
				Basalt, black, broken	13	16
				Basalt, black, medium	39	55
				Basalt, black, hard	8	63
				Basalt, broken, soft	5	68
M1	ACP674	16N/43E-10K	1997	Fill, gravel	12	12
				Gravel	4	16
				Sand	3	19
M2	ACP673	16N/43E-10K	1997	Fill, gravel	12	12
				Gravel	3	15
				Silt, sandy	1	16
				Silt, brown	9	25
				Gravel	6	31
				Basalt	1	32
M3	ACP676	16N/43E-10K	1997	Gravel	18	18
				Silt, brown	1	19
M4	ACP675	16N/43E-10K	1997	Fill, gravel	18	18
				Silt, some gravel	9	27
				Basalt	-	27
M5	ACP679	16N/43E-10J		Boulders	10	10
				Silt, sandy	5	15
				Gravel	3	18
				Basalt, weathered	3	21
				Basalt, solid	1.5	22.5
M6	ACP678	16N/43E-10R	1997	Cobbles	6	6
				Silt, brown	6	12
				Gravel	6	18
				Basalt	2	20

[1] - The map IDs listed here correspond with those shown on Plates 1 and 2.

Table B-3: Sampling results for monitored domestic wells and springs.

			Groundwater Field Parameters					Laboratory Analyses [4]									
Map ID [1]	Well tag ID number	Sample Date	Depth to groundwater (ft below land surface)[2]	Temperature (deg C)[3]	pH (standard units)	Specific Conductance (µS/cm @ 25 deg C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
W1	AHT032	8/15/2006	**O**	12.8	7.05	414	6.92	1 UJ	138	15.9	0.1310	0.1320	11.9	0.02 U	12.1	1.0 U	-
		9/21/2006	77.81 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2	AAW651	6/29/2006	**P**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/15/2006	**P**	13.4	7.47	379	2.13	1 U	159	8.55	0.0833	0.0798	6.81	0.02 U	6.14	1.0 U	
		9/21/2006	26.28 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/24/2006	**O**	12.2	7.44	441	3.59	1 U	167	12.5	0.0883	0.0882	10.2	0.01 U	10.3	2.3 J	
		11/13/2006	25.59 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	28.03 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	24.57 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	25.03 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	39.03 **P**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	27.85 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	24.58 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W3	ALB694	3/30/2006	11.98	CTR (see Plate 1)		-	-	-	-	-	-	-	-	-	-	-	-
		5/15/2006	11.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/27/2006	12.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/18/2006	13.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/14/2006	13.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/14/2006	14.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	14.87	10.8	6.95	548	5.27	1 U	148	32.9	0.1050	0.1060	15	0.01 U	15.3	1.8 J	
		11/13/2006	14.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	12.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	12.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	12.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	13.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	15.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W4	AHT029	3/30/2006	0.10	CTR (see Plate 1)		-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2006	3.38 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/28/2006	1.59 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/18/2006	1.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/14/2006	2.06	13.8	7.83	295	0.1 U	1 UJ	160	2.28	0.0349	0.0243	0.01 U	0.076	0.098	1.3 J	
		9/21/2006	6.13 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	1.18 **R**	12.7	7.91	303	0.1 U	1 U	163	2.13	0.0314	0.0251 JL	0.01 U	0.081	0.11	2.4 J	
		11/13/2006	1.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	0.98	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	0.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	0.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	11.88 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	0.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	1.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-3: continued

			Groundwater Field Parameters					Laboratory Analyses [4]									
Map ID [1]	Well tag ID number	Sample Date	Depth to groundwater (ft below land surface)[2]	Temperature (deg C)[3]	pH (standard units)	Specific Conductance (µS/cm @ 25 deg C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
W5	AGJ767	5/18/2006	39.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/28/2006	40.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/18/2006	41.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/14/2006	43.66	12.8	7.76	301	0.1 U	1 U	163	2.74	0.0390	0.0298	0.01 U	0.118	0.15	1.0 U	
		9/21/2006	44.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	44.30	12.4	7.83	313	0.1 U	1 U	167	2.43	0.0368	0.0296 JL	0.01 U	0.131	0.15	2.7 J	
		11/13/2006	43.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	41.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	40.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	40.39	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	39.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	39.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	40.71 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	41.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W6	AGJ770	3/29/2006	37.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2006	36.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/28/2006	**P**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/18/2006	40.75 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/14/2006	41.35	12.3	7.05	315	1.63	1 U	147	4.61	0.0200	0.0124	0.342	0.02 U	0.395	2	
		9/21/2006	42.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	41.90	12.1	7.1	320	0.63	1 U	150	4.33	0.0180	0.0129 JL	0.214	0.01 U	0.27	2.6 J	
		11/13/2006	40.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	35.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	37.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	36.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	37.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	38.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	39.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W7	AGJ768	3/29/2006	16.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/15/2006	18.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/28/2006	20.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/19/2006	22.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/14/2006	23.53	12.3	6.84	487	4.57	1 U	171	34.8	0.0791	0.0762	4.87	0.02 U	3.55	2.5	
		9/19/2006	21.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	20.89	12.1	6.92	501	1.73	1 U	184	34.2	0.0723	0.0743	2.89	0.01 U	3.03	5 J	
		11/15/2006	19.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	17.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	16.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	16.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	19.89	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/12/2007	21.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-3: continued

			Groundwater Field Parameters					Laboratory Analyses [4]									
Map ID [1]	Well tag ID number	Sample Date	Depth to groundwater (ft below land surface)[2]	Temperature (deg C)[3]	pH (standard units)	Specific Conductance (µS/cm @ 25 deg C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
W8	AHJ874	6/28/2006	15.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/19/2006	15.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/16/2006	**P**	12	7.2	372	7.71	1 U	168	3.2	0.1260	0.1260	8.08	0.01 U	8.29	1.0 U	
		9/21/2006	16.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/24/2006	16.30	11.8	7.28	390	6.38	1 U	171	2.98	0.1190	0.1220	9.95	0.01 U	8.45	2.3 J	
		11/14/2006	15.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	13.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	12.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	12.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	12.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/17/2007	14.43 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	15.36 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	16.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S1	AHT033	5/16/2006	7.55	CTR (see Plate 1)													
		6/28/2006	6.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/18/2006	8.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		8/15/2006	5.72	11.9	7.05	262	7.17	1 U	121	1.26	0.1080	0.0999	5.33	0.02 U	5.62	1.0 U	
		9/21/2006	4.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/23/2006	4.94	10.8	7.17	274	7.71	1 U	123	1.24	0.0981	0.0929	4.4	0.01 U	4.39	1.9 J	
		11/13/2006	4.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1/17/2007	5.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2/22/2007	4.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3/6/2007	4.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4/19/2007	5.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5/18/2007	8.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/21/2007	7.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/12/2007	7.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W9	AHT040	6/7/2007	12.79	CTR (see Plate 2)		-	-	-	-	-	-	-	-	-	-	-	-
		7/9/2007	14.34	12.6	7.5	276	8.23	**2**	110	7.78	0.1490	0.1510	1.7	0.01 U	1.75 J	1.3	0.05 U
		8/15/2007	18.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/11/2007	21.65 **R**	12.8	7.15	323	7.09	1 U	131	10.2	0.1460	0.1500	1.64	0.01 U	1.67	1.3	0.05 U
		10/10/2007	21.76	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/30/2007	19.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W10	AHT098	6/6/2007	12.54	CTR (see Plate 2)		-	-	-	-	-	-	-	-	-	-	-	-
		7/9/2007	13.68	13.1	7.4	804	9.04	**1**	248	37.5	0.1920	0.1930	18	0.01 U	18.6 J	3	0.05 U
		8/15/2007	13.58 **R**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/11/2007	13.54	14.4	7.33	780	8.01	**7**	301	28	0.2380	0.2680	11.4	0.01 U	11	3.2	0.05 U
		10/10/2007	13.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/29/2007	12.94	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W11	AHR589	6/6/2007	21.04	CTR (see Plate 2)		-	-	-	-	-	-	-	-	-	-	-	-
		7/9/2007	21.51	12.8	7.96	301	1.67	1 U	145	3.67	0.0457	0.0384	0.862	0.01 U	0.888 J	1 U	0.05 U
		8/14/2007	21.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/11/2007	21.87	12.7	7.81	299	1.46	1 U	144	3.57	0.0480	0.0375	0.842	0.01 U	0.866	1 U	0.05 U
		10/10/2007	22.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	21.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-3: continued

			Groundwater Field Parameters					Laboratory Analyses [4]									
Map ID [1]	Well tag ID number	Sample Date	Depth to groundwater (ft below land surface)[2]	Temperature (deg C)[3]	pH (standard units)	Specific Conductance (µS/cm @ 25 deg C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
W12	AHT044	6/4/2007	55.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		7/10/2007	57.04	11	7.29	277	0.61	1 U	114	7.44	0.1090	0.1010	2.95	0.01 U	3.16	1 U	0.05 U
		8/14/2007	**O**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	56.68	10.9	7.23 **EST**	305	0.17	1 U	121	9.61	0.1090	0.1030	2.51	0.01 U	2.64	1 U	0.05 U
		10/9/2007	56.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/31/2007	56.81	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M1	ACP674	7/10/2007	10.91	14.7	6.88	711	0.61	1 U	294	41.8	0.1760	0.1610	2.63	11.8	11.4	7.2	0.089
		8/14/2007	10.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	10.62	17.7	6.7 **EST**	816	0.44	1 U	255	47.9	0.1410	0.2000	2.88	10.8	13	5.8	0.05 U
		10/11/2007	10.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	10.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M2	ACP673	7/10/2007	19.42	13	6.98	572	0.10 U	1 U	249	18	0.0486	1.5100	0.01 U	0.691	0.885	4	24.7
		8/14/2007	19.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	20.85	14	6.99 **EST**	569	0.12	1 U	259	11.4	0.1430	1.5500	0.01 U	0.763	0.9	3.8	25.5
		10/11/2007	21.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	20.02	CTR (see Plate 2)		-	-	-	-	-	-	-	-	-	-	-	-
M3	ACP676	8/14/2007	11.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	11.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/11/2007	11.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	11.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M4	ACP675	8/14/2007	19.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	19.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		10/11/2007	19.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	19.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M5	ACP679	7/10/2007	10.68	14.7	6.89	520	0.11	1 U	187	17.2	0.0220	0.2520	3.03	2.68	5.98	4.9	3.18
		8/14/2007	11.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	11.23	16.3	6.78 **EST**	473	0.18	1 U	182	16.8	0.0402	0.3790	0.993	2.9	4.9	5.1 J	3.64
		10/11/2007	10.82	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	11.48	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M6	ACP678	7/10/2007	12.18	12	6.83	719	0.14	1 U	304	42.9	0.0619	0.7640	0.01 U	0.972	1.34	2.9	18.5
		8/14/2007	12.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		9/10/2007	12.44	14	6.67 **EST**	731	0.15	1 U	323	36.5	0.0863	0.7980	0.01 U	1.5	1.6	3.6	19.7
		10/11/2007	12.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		11/1/2007	12.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] - The map IDs listed here correspond with those shown on Plates 1 and 2.

[2] - Well status codes: **O** - obstruction in well prevented water level measurement. **P** - well pumping, water level not measured. **R** - well recently pumped, water level slowly recovering.

[3] - **CTR**: Site instrumented to record groundwater temperature at 30 minute intervals during the study period. See the indicated plate for data plot.

[4] - Data qualifier codes: **EST** - the reported result is an estimate. **J** - the analyte was positively identified, the numerical result is an estimate.
JL - Analyte positively identified. The true value may be less than the reported estimate. **U** - the analyte was not detected at or above the reported value.
UJ - the analyte was not detected at or above the reported estimated value.

Table B-4: Physical description and location of instream piezometers.

Map ID [1]	Well tag ID number	Approximate river mile (miles)	Well location	Latitude (decimal degrees)	Longitude (decimal degrees)	Site altitude (feet)	Piezometer stickup (feet above streambed)	Piezometer depth (feet below streambed)	Length of perforated interval (feet)	Depth to midpoint of piezometer perforations (feet below streambed)	Estimated horizontal hydraulic conductivity of streambed sediments [2] (feet/day)	Thermistor deployment depths within piezometer (feet below streambed)
South Fork Palouse River												
P1	AKY496	1.2	16N/43E-14L	46.87728	117.36200	1988	2.77	4.34	0.29	4.15	7.8	1.05 2.52 3.82
P2	AKY495	3.4	16N/43E-24H	46.86651	117.33073	2036	3.65	3.57	0.22	3.36	≤ 1	0.62 1.91 3.12
P3	AKY493	5.4	16N/44E-19H	46.86555	117.31282	2082	2.5	4.84	0.28	4.63	59.9	1.76 2.45 4.39
P4	AKY494	7.3	16N/44E-20G	46.86417	117.29404	2118	4.03	2.99	0.49	2.66	2.8	0.85 1.76 2.52
P5	AKY488	9.3	16N/44E-28M	46.84673	117.28290	2152	2.7	2.08	0.52	1.75	6.5	0.68 1.71
P6	AKY497	11.4	16N/44E-33Q	46.82757	117.27486	2179	4.01	3.69	0.3	3.2	11.8	0.87 2.06 3.27
P7	AKY498	15	15N/44E-15E	46.78911	117.26291	2221	4.29	3.04	0.31	2.81	40.0	0.84 1.65 2.51
P8	AKY499	17.7	15N/44E-23F	46.77265	117.23779	2258	3.44	3.89	0.2	3.7	21.7	1.21 2.19 3.39
P9	AKY490	20.1	15N/44E-25P	46.75286	117.21323	2283	3.4	1.82	0.32	1.54	74.0	0.86 1.45
P10	AKY489	21.9	15N/45E-31K	46.73951	117.19099	2320	2.75	2.25	0.49	1.94	4.8	NA
P11	AKY500	22.2	14N/45E-06B	46.73506	117.19051	2320	1.26	3.96	0.23	3.71	3.6	2.58 3.57
P12	AKY492	0	14N/45E-06A	46.73326	117.18180	2338	0.68	4.62	0.31	4.4	21.1	0.61 2.70 4.18
P13	AKY491	23.6	14N/45E-05L	46.72567	117.17134	2343	2.43	2.82	0.28	2.67	3.1	1.68 2.38
P14	ALB689	26.7	14N/45E-16Q	46.69038	117.14949	2399	2.2	3.04	0.24	2.82	3.2	1.14 2.71
P15	ALB688	33.8	14N/46E-17H	46.70054	117.04166	2519	1.04	4.17	0.2	3.86	≤ 1	0.77 2.07 3.73
Paradise Creek												
P16	ALB691	3.8	14N/45E-02H	46.72912	117.09647	2480	2.35	2.85	0.28	2.66	8.3	1.15 2.53
P17	ALB692	6.6	14N/46E-05C	46.73445	117.05012	2518	0.73	4.2	0.52	3.88	21.3	0.75 2.05 3.80

Table B-4: continued

Map ID[1]	Well tag ID number	Approximate river mile (miles)	Well location	Latitude (decimal degrees)	Longitude (decimal degrees)	Site altitude (feet)	Piezometer stickup (feet above streambed)	Piezometer depth (feet below streambed)	Length of perforated interval (feet)	Depth to midpoint of piezometer perforations (feet below streambed)	Estimated horizontal hydraulic conductivity of streambed sediments (feet/day)	Thermistor deployment depths within piezometer (feet below streambed)
Mainstem Palouse River												
P18	AHT042	25.7	15N/38E-21J	46.77205	118.0414	1115	2.7	4.2	0.48	3.83	111.0	1.25 2.5 3.77
P19	AHT041	33.4	16N/38E-35A	46.83802	117.99727	1178	2.7	4.5	0.3	4.27	66.0	1.6 2.73 3.95
P20	AHT039	41.1	16N/39E-05A	46.91156	117.9278	1273	2.7	2.48	0.3	2.34	3.4	0.93 2.02
P21	AHT038	66.8	17N/41E-02M	46.99455	117.61607	1590	2.9	4.16	0.32	3.96	22.9	1.45 2.55 3.79
P22	AHT037	77.8	17N/42E-22L	46.95268	117.50395	1767	2.5	2.78	0.29	2.61	≤ 1	1.15 2.24
P23	AHT036	85.6	17N/43E-32C	46.92902	117.41676	1870	3.5	3.74	0.3	3.58	13.1	0.95 2.25 3.51
P24	AHT034	112.4	17N/45E-21N	46.94723	117.14566	2354	3.3	4.11	0.28	3.93	36.2	0.26 1.94 3.64
P25	AHT043	120.3	16N/45E-01G	46.90824	117.08282	2419	2.6	2.61	0.29	2.47	24.8	0.57 2.12
P26	AHT035	124.3	16N/46E-05A	46.91362	117.04063	2446	3.1	4.06	0.52	3.7	≤ 1	1.13 2.31 3.66

[1] - The map IDs listed here correspond with those shown on Plates 1 and 2.

[2] - Piezometers with reported hydraulic conductivity values of ≤ 1 did not take sufficient water to produce measurable results during the CHIT test. The reported value represents the maximum potential hydraulic conductivity for the site based on an assumed injection rate of 0.034 L/minute.

Table B-5: Summary of water levels, field water quality measurements, streambed hydraulic gradients, and estimated water fluxes at instream piezometer sites along the South Fork Palouse River, Paradise Creek, and the mainstem Palouse River, Whitman and Adams Counties.

Map ID [1]	Well tag ID number	Approximate River Mile (miles)	Depth to midpoint of perforations (dl) (feet below streambed)	Sample Date	Sample Time	Temperature (°C) River water	Temperature (°C) Ground water	Specific Conductance µS/cm@25°C River water	Specific Conductance µS/cm@25°C Ground water	Ground-water level [2] (feet)	Stream stage [3] (feet)	Head Difference (dh) (Stream stage - Groundwater level) (feet)	(Iv) Vertical Hydraulic Gradient (dh/dl) [4] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments [5] (m/s)	Estimated unit area flux [4] (ft3/s/m2)	Estimated unit area flux [4] (L/d/m2)
South Fork Palouse River																
P1	AKY496	1.2	4.15	05/17/2006	16:20	26.0	19.6	402	-	1.20	1.22	0.02	0.005	2.75E-06	4.7E-07	1.1
				06/27/2006	11:10	23.7	15.3	522	-	-	-	-	-		-	-
				06/29/2006	10:50	-	-	-	-	0.39	0.39	0.00	0.000		0.0E+00	0.0
				07/18/2006	11:11	21.1	17.9	565	-	1.40	1.41	0.01	0.002		2.3E-07	0.6
				08/17/2006	15:06	21.5	-	649	-	1.29	1.28	-0.02	-0.004		-3.5E-07	-0.9
				09/15/2006	11:00	11.9	13	667	-	1.23	1.28	0.06	0.014		1.4E-06	3.3
				10/24/2006	13:25	8.0	-	507	-	1.24	1.26	0.02	0.005		4.5E-07	1.1
				10/25/2006	9:45	6.2	11.1	515 J	615 J	-	-	-	-		-	-
				05/17/2007	16:30	-	-	-	-	1.13	1.17	0.04	0.009		9.0E-07	2.2
				06/26/2007	18:00	-	-	-	-	1.27	1.28	0.01	0.004		3.4E-07	0.8
				07/10/2007	17:30	25.9	17	546	-	1.38	1.39	0.01	0.002		2.3E-07	0.6
				09/09/2007	13:00	16.8	16.7	632	-	1.37	1.36	-0.01	-0.002		-2.3E-07	-0.6
P2	AKY495	3.4	3.36	05/17/2006	12:30	22.8	18.8	408	-	7.04R	1.95	-	-	NA	-	-
				06/27/2006	10:20	24.5	14.9	458	-	0.45	0.33	-0.12	-0.036		-	-
				07/18/2006	10:00	20.0	17.4	569	-	0.53	0.54	0.01	0.003		-	-
				08/15/2006	12:00	19.9	17.6	648	-	0.53	0.50	-0.03	-0.009		-	-
				09/14/2006	17:15	14.5	15.6	672	-	0.35	0.37	0.02	0.006		-	-
				10/24/2006	12:00	7.5	10.1	495	-	0.19	0.18	-0.01	-0.003		-	-
P3	AKY493	5.4	4.63	05/17/2006	9:25	19.5	13.5	408	-	0.88	0.71	-0.17	-0.037	2.11E-05	-2.7E-05	-66.9
				06/29/2006	10:00	22.8	18.6	492	-	0.61	0.31	-0.30	-0.065		-4.8E-05	-118.1
				07/18/2006	9:19	20.5	20.2	583	-	0.75	0.42	-0.33	-0.071		-5.3E-05	-129.9
				08/15/2006	9:35	18.5	19.1	658	-	0.69	0.39	-0.30	-0.065		-4.8E-05	-118.1
				10/24/2006	10:45	7.0	9.9	517	-	0.42	0.29	-0.13	-0.028		-2.1E-05	-51.2
				05/18/2007	16:05	-	-	-	-	0.98	0.79	-0.19	-0.041		-3.1E-05	-74.8
				06/26/2007	17:15	-	-	-	-	0.96	0.89	-0.07	-0.015		-1.1E-05	-27.6
				07/12/2007	15:40	-	-	-	-	1.26	1.10	-0.16	-0.035		-2.6E-05	-63.0
				09/09/2007	15:00	17.1	16.8	567	-	1.38	0.97	-0.41	-0.089		-6.6E-05	-161.4
P4	AKY494	7.3	2.66	05/17/2006	11:30	21.0	14.8	410	-	-	-	-	-	9.88E-07	-	-
				06/27/2006	9:15	22.5	17	497	-	-	-	-	-		-	-
				06/29/2006	9:05	-	-	-	-	1.07	1.07	0.00	0.000		0.0E+00	0.0
				07/18/2006	8:28	19.1	19.3	590	-	0.16	0.12	-0.04	-0.015		-5.2E-07	-1.3
				08/15/2006	11:15	18.8	18.5	665	-	0.12	0.09	-0.03	-0.011		-3.9E-07	-1.0
				09/14/2006	15:51	14.8	-	667	-	1.93	1.94	0.01	0.004		1.3E-07	0.3
				10/24/2006	9:00	6.3	9.8	582	-	2.05	2.00	-0.05	-0.019		-6.6E-07	-1.6
P5	AKY488	9.3	1.75	05/17/2006	18:30	23.7	14.2	390	-	0.11	0.16	0.05	0.031	2.29E-06	2.5E-06	6.1
				06/27/2006	13:45	26.0	18.1	479	393	0.44	0.51	0.06	0.036		2.9E-06	7.2
				07/18/2006	13:05	22.4	19.6	580	-	0.54	0.60	0.05	0.031		2.5E-06	6.1
				08/15/2006	16:00	21.0	18.6	671	-	0.65	0.62	-0.04	-0.021		-1.7E-06	-4.1
				09/14/2006	13:45	15.1	15.8	672	-	0.62	0.63	0.01	0.005		4.2E-07	1.0
				10/24/2006	15:00	8.6	9.8	557	-	0.51	0.51	0.00	0.000		0.0E+00	0.0

Table B-5: continued

Map ID [1]	Well tag ID number	Approximate River Mile (miles)	Depth to midpoint of perforations (dl) (feet below streambed)	Sample Date	Sample Time	Temperature (°C) River water	Temperature (°C) Ground water	Specific Conductance µS/cm@25°C River water	Specific Conductance µS/cm@25°C Ground water	Ground-water level [2] (feet)	Stream stage [3] (feet)	Head Difference (dh) (Stream stage - Groundwater level) (feet)	(Iv) Vertical Hydraulic Gradient (dh/dl) [4] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments [5] (m/s)	Estimated unit area flux [4] (ft3/s/m2)	Estimated unit area flux [4] (L/d/m2)
P6	AKY497	11.4	3.2	05/18/2006	10:20	21.0	12.9	419	-	0.63	1.01	0.38	0.119	4.16E-06	1.7E-05	42.7
				06/27/2006	15:52	27.2	14.3	571	358	0.02	0.34	0.32	0.100		1.5E-05	35.9
				07/18/2006	14:25	22.0	17	584	-	1.10	1.30	0.20	0.063		9.2E-06	22.5
				08/14/2006	13:37	20.5	19.1	681	367	1.15	1.23	0.08	0.025		3.7E-06	9.0
				09/14/2006	12:40	15.9	14.8	692	-	1.16	1.26	0.10	0.031		4.6E-06	11.2
				10/24/2006	11:15	7.7	12	551	382	1.06	1.11	0.05	0.016		2.3E-06	5.6
				05/18/2007	13:55	-	-	-	-	0.78	1.09	0.31	0.097		1.4E-05	34.8
				06/26/2007	14:50	-	-	-	-	0.83	1.00	0.17	0.053		7.8E-06	19.1
				07/12/2007	14:30	-	-	-	-	1.03	1.12	0.09	0.028		4.1E-06	10.1
				09/10/2007	17:50	-	-	-	-	1.01	1.03	0.02	0.006		9.2E-07	2.2
P7	AKY498	15	2.81	05/18/2006	13:00	22.1	16.1	437	-	1.76	1.82	0.06	0.021	1.41E-05	1.1E-05	26.0
				06/28/2006	9:32	22.9	15.9	563	324	0.05	0.10	0.05	0.018		8.9E-06	21.7
				07/18/2006	15:19	23.4	18.3	587	-	0.24	0.29	0.05	0.018		8.9E-06	21.7
				08/14/2006	9:45	20.3	19.5	663	309	0.13	0.15	0.02	0.007		3.5E-06	8.7
				09/14/2006	11:20	14.7	15.4	693	-	0.04	0.07	0.03	0.011		5.3E-06	13.0
				10/23/2006	12:50	8.5	10.3	564	-	0.06	0.09	0.03	0.011		5.3E-06	13.0
				10/24/2006	13:00	10.2	12.2	599	346	-	-	-	-		-	-
				05/18/2007	13:15	-	-	-	-	1.92	1.96	0.04	0.014		7.1E-06	17.3
				06/26/2007	15:21	-	-	-	-	1.95	2.03	0.08	0.028		1.4E-05	34.7
				07/12/2007	13:10	-	-	-	-	2.09	2.12	0.03	0.011		5.3E-06	13.0
				09/11/2007	18:10	-	-	-	-	0.12	0.16	0.04	0.014		7.1E-06	17.3
P8	AKY499	17.7	3.7	05/18/2006	17:50	23.9	15.3	415	-	1.68	1.70	0.02	0.005	7.66E-06	1.5E-06	3.6
				06/28/2006	10:35	24.0	15.6	551	-	0.91	0.92	0.01	0.003		7.3E-07	1.8
				07/18/2006	16:20	23.2	17.8	598	-	1.87	1.88	0.01	0.003		7.3E-07	1.8
				08/14/2006	12:00	20.3	18.3	668	-	1.84	1.83	-0.01	-0.003		-7.3E-07	-1.8
				09/15/2006	9:20	11.8	-	687	-	1.84	1.85	0.01	0.003		7.3E-07	1.8
				10/23/2006	13:50	9.9	12	578	-	1.85	1.85	0.00	0.000		0.0E+00	0.0
P9	AKY490	20.1	1.54	05/16/2006	10:20	17.7	16.6	432	-	1.81	1.81	0.00	0.000	2.61E-05	0.0E+00	0.0
				06/28/2006	11:45	22.8	19.6	590	-	1.93	1.92	-0.01	-0.006		-6.0E-06	-14.6
				07/18/2006	16:38	22.8	19.9	614	-	1.81	1.82	0.01	0.006		6.0E-06	14.6
				08/15/2006	14:30	20.3	19.1	608	-	2.00	1.98	-0.02	-0.013		-1.2E-05	-29.3
				09/13/2006	14:30	-	-	-	-	1.94	1.91	-0.03	-0.019		-1.8E-05	-43.9
				10/23/2006	11:32	10.4	11.7	584	-	1.78	1.78	0.00	0.000		0.0E+00	0.0
P10	AKY489	21.9	1.94	05/15/2006	18:34	19.6	16.1	395	-	1.79	1.50	-0.29	-0.149	1.69E-06	-8.9E-06	-21.8
				06/28/2006	12:30	22.6	17.2	578	-	2.28	1.79	-0.49	-0.253		-1.5E-05	-36.9
				07/19/2006	13:25	21.1	18.8	609	-	2.43	1.95	-0.48	-0.247		-1.5E-05	-36.1
				08/14/2006	15:35	21.1	18.6	612	-	2.44	1.84	-0.60	-0.309		-1.8E-05	-45.2
				10/23/2006	9:58	9.8	11.1	614	-	2.24	1.60	-0.64	-0.330		-2.0E-05	-48.2
P11	AKY500	22.2	3.71	06/29/2006	12:15	19.3	15.3	496	-	3.76	0.31	-3.45	-0.930	1.27E-06	-4.2E-05	-102.0
				07/17/2006	16:25	21.0	17.1	558	-	3.70	0.40	-3.30	-0.889		-4.0E-05	-97.6
				08/14/2006	16:10	19.4	17.2	554	-	3.97	0.38	-3.59	-0.968		-4.3E-05	-106.2
				09/13/2006	12:35	14.1	14.7	693	-	3.79	0.49	-3.30	-0.889		-4.0E-05	-97.6
				10/23/2006	15:50	7.9	10.4	602	-	4.25	0.24	-4.01	-1.081		-4.8E-05	-118.6

Table B-5: continued

Map ID [1]	Well tag ID number	Approximate River Mile (miles)	Depth to midpoint of perforations (dl) (feet below streambed)	Sample Date	Sample Time	Temperature (°C) River water	Temperature (°C) Ground water	Specific Conductance µS/cm@25°C River water	Specific Conductance µS/cm@25°C Ground water	Ground-water level [2] (feet)	Stream stage [3] (feet)	Head Difference (dh) (Stream stage - Groundwater level) (feet)	(Iv) Vertical Hydraulic Gradient (dh/dl) [4] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments [5] (m/s)	Estimated unit area flux [4] (ft3/s/m2)	Estimated unit area flux [4] (L/d/m2)
P12	AKY492	0	4.4	05/16/2006	15:20	18.9	14.9	382	-	1.46	0.31	-1.15	-0.261	7.44E-06	-6.9E-05	-168.0
				06/27/2006	18:45	20.1	13.5	447	-	3.39	0.45	-2.94	-0.668		-1.8E-04	-429.5
				07/17/2006	17:34	17.6	13.8	501	-	4.47	0.58	-3.89	-0.884		-2.3E-04	-568.3
				08/14/2006	16:45	15.9	14	511	-	4.11	0.58	-3.53	-0.802		-2.1E-04	-515.7
				09/13/2006	15:30	13.9	13	508	-	3.41	0.57	-2.84	-0.645		-1.7E-04	-414.9
				10/25/2006	16:36	7.9	9.9	-	-	3.05	0.55	-2.50	-0.568		-1.5E-04	-365.2
				04/19/2007	14:35	-	-	-	-	0.74	0.19	-0.55	-0.125		-3.3E-05	-80.4
				05/18/2007	11:30	-	-	-	-	1.24	0.35	-0.89	-0.202		-5.3E-05	-130.0
				06/21/2007	11:45	-	-	-	-	2.98	0.40	-2.58	-0.586		-1.5E-04	-376.9
				07/10/2007	18:32	18.0	13	520	-	3.73	0.40	-3.33	-0.757		-2.0E-04	-486.5
				09/09/2007	17:15	13.0	13.2	530	-	4.01	0.43	-3.58	-0.814		-2.1E-04	-523.0
P13	AKY491	23.6	2.67	05/16/2006	12:58	18.9	13.1	380	-	-	1.08	-	-	1.09E-06	-	-
				06/28/2006	13:50	22.9	16	495	444	1.26	1.30	0.04	0.015		5.8E-07	1.4
				07/17/2006	18:25	19.5	16.2	606	-	1.31	1.33	0.02	0.007		2.9E-07	0.7
				08/15/2006	14:30	16.6	15.5	675	421	1.25	1.26	0.01	0.004		1.4E-07	0.4
				09/13/2006	16:40	-	-	-	-	1.08	1.09	0.01	0.004		1.4E-07	0.4
				10/24/2006	14:06	8.2	10.6	635	434	0.99	1.08	0.09	0.034		1.3E-06	3.2
				03/06/2007	11:20	-	-	-	-	0.57	0.59	0.02	0.007		2.9E-07	0.7
				04/19/2007	14:20	-	-	-	-	0.73	0.93	0.20	0.075		2.9E-06	7.1
				05/18/2007	10:55	-	-	-	-	1.13	1.20	0.07	0.026		1.0E-06	2.5
				06/21/2007	11:15	-	-	-	-	1.25	1.28	0.03	0.011		4.3E-07	1.1
				07/12/2007	11:25	-	-	-	-	1.41	1.42	0.01	0.004		1.4E-07	0.4
				09/09/2007	17:40	13.5	14	754	-	1.33	1.35	0.02	0.007		2.9E-07	0.7
P14	ALB689	26.7	2.82	06/19/2006	15:45	-	-	-	-	0.78	1.05	0.27	0.096	1.13E-06	3.8E-06	9.3
				06/28/2006	15:49	23.4	15.8	282	300	1.16	1.40	0.24	0.085		3.4E-06	8.3
				07/19/2006	8:30	15.4	15	331	-	1.40	1.58	0.18	0.064		2.5E-06	6.2
				08/16/2006	9:10	14.3	13.8	341	282	1.68	1.71	0.03	0.011		4.2E-07	1.0
				09/14/2006	8:52	11.4	11.5	340	-	1.74	1.70	-0.04	-0.014		-5.7E-07	-1.4
				10/25/2006	12:15	4.8	7.6	387 J	-	1.33	1.29	-0.04	-0.014		-5.7E-07	-1.4
P15	ALB688	33.8	3.86	06/28/2006	18:44	21.5	11.5	274	-	-	0.56		-	NA	-	-
				07/19/2006	9:35	14.4	13.3	373	-	0.24	0.69	0.45	0.117		-	-
				08/16/2006	11:00	14.2	13.1	530	227	0.56	0.75	0.19	0.049		-	-
Paradise Creek																
P16	ALB691	3.8	2.66	06/22/2006	12:55	-	-	-	-	1.02	1.20	0.18	0.068	2.93E-06	7.0E-06	17.1
				06/26/2006	18:00	23.2	12.9	678	-	0.84	1.11	0.27	0.102		1.1E-05	25.7
				07/19/2006	11:20	15.8	13.5	689	-	1.02	1.23	0.21	0.079		8.2E-06	20.0
				08/16/2006	13:50	15.4	13.3	686	469	0.96	1.14	0.18	0.068		7.0E-06	17.1
				09/14/2006	10:00	13.2	13.1	735	-	0.47	0.71	0.24	0.090		9.3E-06	22.8
				10/25/2006	13:45	10.4	11	711 J	444 J	0.43	0.76	0.33	0.124		1.3E-05	31.4
				04/19/2007	14:00	-	-	-	-	0.11	0.33	0.22	0.083		8.6E-06	20.9
				05/18/2007	10:35	-	-	-	-	0.69	0.99	0.30	0.113		1.2E-05	28.6
				06/21/2007	10:40	-	-	-	-	0.66	0.91	0.25	0.094		9.7E-06	23.8
				07/12/2007	10:45	-	-	-	-	0.73	1.10	0.37	0.139		1.4E-05	35.2
				09/09/2007	19:30	14.5	13.3	799	-	0.30	0.50	0.20	0.075		7.8E-06	19.0

Table B-5: continued

Map ID [1]	Well tag ID number	Approximate River Mile (miles)	Depth to midpoint of perforations (dl) (feet below streambed)	Sample Date	Sample Time	Temperature (°C) River water	Temperature (°C) Ground water	Specific Conductance µS/cm@25°C River water	Specific Conductance µS/cm@25°C Ground water	Ground-water level [2] (feet)	Stream stage [3] (feet)	Head Difference (dh) (Stream stage - Groundwater level) (feet)	(Iv) Vertical Hydraulic Gradient (dh/dl) [4] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments [5] (m/s)	Estimated unit area flux [4] (ft3/s/m2)	Estimated unit area flux [4] (L/d/m2)
P17	ALB692	6.6	3.88	06/22/2006	14:30	-	-	-	-	-	0.18	-	-	7.51E-06	-	-
				06/26/2006	16:30	23.8	13.2	728	-	-	0.08	-	-		-	-
				07/19/2006	10:49	16.7	14.7	679	-	-	1.17	-	-		-	-
				08/16/2006	12:10	16.9	16.8	687	-	0.83 X	0.85	0.02	0.005 G		-	-
				09/13/2006	9:10	15.3	15	741	-	-	0.91	-	-		-	-
				10/25/2006	16:10	14.1	13.4	740 J	572 J	1.85	2.12	0.27	0.070		1.9E-05	45.4
				04/19/2007	13:20	-	-	-	-	-	0.67	-	-		-	-
				05/18/2007	10:05	-	-	-	-	-	1.15	-	-		-	-
				06/21/2007	10:20	-	-	-	-	-	0.94	-	-		-	-
				07/12/2007	10:00	-	-	-	-	0.5 X	0.51	0.01	0.003 G		-	-
				09/09/2007	18:45	18.7	14.8	793	-	1.6 X	1.62	0.02	0.005 G		-	-
Mainstem Palouse River																
P18	AHT042	25.7	3.83	06/07/2007	16:00	16.2	-	239	-	1.75	3.00	1.25	0.326	3.92E-05	4.5E-04	1105.4
				07/09/2007	10:00	23.2	12.7	350	602	0.33	1.48	1.15	0.300		4.2E-04	1016.9
				08/13/2007	18:10	-	-	-	-	0.90	1.67	0.77	0.201		2.8E-04	680.9
				09/11/2007	9:13	15.9	8.11	361	594	1.21	1.71	0.50	0.131		1.8E-04	442.2
				10/10/2007	9:00	13.8	12.5	294	-	1.21	1.36	0.15	0.039		5.4E-05	132.6
				10/30/2007	9:00	-	-	-	-	1.14	1.26	0.12	0.031		4.3E-05	106.1
P19	AHT041	33.4	4.27	06/07/2007	12:40	14.2	-	223	-	0.11	0.10	-0.01	-0.002	2.33E-05	-1.9E-06	-4.7
				07/09/2007	12:22	23.9	16.8	335	-	0.43	0.41	-0.02	-0.005		-3.9E-06	-9.4
				08/16/2007	17:32	-	-	-	-	0.52	0.49	-0.03	-0.007		-5.8E-06	-14.1
				10/10/2007	12:05	13.8	14.6	313	-	0.40	0.40	0.00	0.000		0.0E+00	0.0
				10/30/2007	14:30	-	-	-	-	1.86	1.86	0.00	0.000		0.0E+00	0.0
P20	AHT039	41.1	2.34	06/06/2007	17:30	15.8	-	204	-	-	0.93	-	-	1.21E-06	-	-
				07/11/2007	9:00	25.0	22.9	322	-	1.56	1.39	-0.17	-0.073		-3.1E-06	-7.6
				08/13/2007	14:25	26.4	-	-	-	1.88	1.63	-0.25	-0.107		-4.6E-06	-11.2
				09/11/2007	13:40	21.0	19	336	-	1.69	1.48	-0.21	-0.090		-3.8E-06	-9.4
				10/10/2007	14:00	14.2	13.9	311	-	1.50	1.25	-0.25	-0.107		-4.6E-06	-11.2
				10/30/2007	16:30	-	-	-	-	1.20	1.12	-0.08	-0.034		-1.5E-06	-3.6
P21	AHT038	66.8	3.96	06/05/2007	17:30	20.1	-	185	-	0.81	0.85	0.04	0.010	8.08E-06	2.9E-06	7.1
				07/11/2007	10:15	26.7	16.9	260	329	1.32	1.33	0.01	0.003		7.2E-07	1.8
				08/14/2007	15:34	-	-	-	-	1.31	1.32	0.01	0.003		7.2E-07	1.8
				09/12/2007	9:05	15.6	17.6	479	366	1.38	1.40	0.02	0.005		1.4E-06	3.5
				10/10/2007	15:30	13.6	14	367	-	0.89	0.91	0.02	0.005		1.4E-06	3.5
				11/01/2007	12:00	-	-	-	-	0.90	0.90	0.00	0.000		0.0E+00	0.0
P22	AHT037	77.8	2.61	06/05/2007	15:00	19.8	-	177	-	-	0.34	-	-	3.41E-07 L	-	-
				07/11/2007	13:00	27.4	19.1	251	-	0.91	0.91	0.00	0.000		0.0E+00	0.0
				08/14/2007	14:30	-	-	-	-	1.12	1.15	0.03	0.011		1.4E-07 L	0.3 L
				09/12/2007	11:15	17.6	18.9	536	-	1.02	1.04	0.02	0.008		9.2E-08 L	0.2 L
				10/10/2007	17:20	13.2	12.8	305	-	0.71	0.75	0.04	0.015		1.8E-07 L	0.5 L
				11/01/2007	10:00	-	-	-	-	0.68	0.70	0.02	0.008		9.2E-08 L	0.2 L

Table B-5: continued

Map ID [1]	Well tag ID number	Approximate River Mile (miles)	Depth to midpoint of perforations (dl) (feet below streambed)	Sample Date	Sample Time	Temperature (°C) River water	Temperature (°C) Ground water	Specific Conductance µS/cm@25°C River water	Specific Conductance µS/cm@25°C Ground water	Ground-water level [2] (feet)	Stream stage [3] (feet)	Head Difference (dh) (Stream stage - Groundwater level) (feet)	(Iv) Vertical Hydraulic Gradient (dh/dl) [4] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments [5] (m/s)	Estimated unit area flux [4] (ft3/s/m2)	Estimated unit area flux [4] (L/d/m2)
P23	AHT036	85.6	3.58	06/05/2007	10:54	20.5	-	168	-	-	1.69	-	-	4.62E-06	-	-
				07/11/2007	13:38	27.6	18.8	261	-	0.16	0.14	-0.02	-0.006		-9.1E-07	-2.2
				08/14/2007	13:45	-	-	-	-	0.33	0.32	-0.01	-0.003		-4.6E-07	-1.1
				09/12/2007	12:30	16.3	17.9	539	-	0.25	0.25	0.00	0.000		0.0E+00	0.0
				10/09/2007	16:22	14.3	13.6	219	-	1.38	1.38	0.00	0.000		0.0E+00	0.0
				11/01/2007	9:00	-	-	-	-	2.01	2.03	0.02	0.006		9.1E-07	2.2
P24	AHT034	112.4	3.93	06/04/2007	15:00	24.2	-	80.9	-	1.13	1.18	0.05	0.013	1.28E-05	5.8E-06	14.1
				07/11/2007	14:40	30.8	16.9	99	258	1.47	1.50	0.03	0.008		3.5E-06	8.4
				08/14/2007	10:30	-	-	-	-	1.64	1.68	0.04	0.010		4.6E-06	11.3
				09/12/2007	13:35	17.3	16.6	168	267	1.61	1.68	0.07	0.018		8.1E-06	19.7
				10/09/2007	12:00	11.8	12.4	81.4	-	0.77	0.81	0.04	0.010		4.6E-06	11.3
				10/31/2007	13:30	-	-	-	-	1.14	1.20	0.06	0.015		6.9E-06	16.9
P25	AHT043	120.3	2.47	06/08/2007	11:00	15.5	-	56.9	-	0.80	0.81	0.01	0.004	8.75E-06	1.3E-06	3.1
				07/11/2007	16:20	29.2	21.2	86	-	1.18	1.18	0.00	0.000		0.0E+00	0.0
				08/15/2007	10:00	19.3	-	-	-	1.32	1.42	0.10	0.040		1.3E-05	30.6
				09/12/2007	15:30	18.6	16.5	113	-	1.49	1.48	-0.01	-0.004		-1.3E-06	-3.1
				10/09/2007	10:15	10.7	11.3	63	-	1.27	1.27	0.00	0.000		0.0E+00	0.0
				10/31/2007	11:30	-	-	-	-	1.01	1.01	0.00	0.000		0.0E+00	0.0
P26	AHT035	124.3	3.7	06/04/2007	18:05	24.0	-	68.5	-	-	0.99	-	-	1.80E-07 L	-	-
				07/11/2007	16:49	29.3	19.9	80	-	2.87	1.25	-1.62	-0.438		-2.8E-06 L	-6.8 L
				08/14/2007	10:00	-	-	-	-	1.40	1.34	-0.06	-0.016		-1E-07 L	-0.3 L
				09/12/2007	16:00	17.9	17.2	101	-	1.25	1.22	-0.03	-0.008		-5.2E-08 L	-0.1 L
				10/09/2007	8:45	9.7	11.8	55.7	-	0.94	0.97	0.03	0.008		5.2E-08 L	0.1 L
				10/31/2007	9:00	-	-	-	-	-	0.95	-	-		-	-

1 The map ID's listed here correspond to those shown on Plates 1 and 2.
2 The listed value represents the distance to groundwater, in feet, below the top of the piezometer casing.
3 The listed value represents the distance to the stream surface, in feet, below the top of the piezometer casing.
4 Negative values indicate loss of stream water to groundwater storage while positive values indicate groundwater discharge into the stream.
5 These values assume a 10:1 horizontal to vertical anisotrophy ratio for the streambed sediments and thus represent only 10 percent of the horizontal hydraulic conductivity previously reported for these wells by Pitz, 2006.

Data qualifier codes:

J The analyte was positively identified, the numeric result is an estimate.
X The measured water level was influenced by water leakage thorugh a vent hole in the piezometer casing and is likely biased low.
G The indicated value is biased low by water leakage from the piezometer through an uncapped vent hole. The hydraulic conductivity and flux estimates presented here represent the sites **minimum** potential value.
L The indicated value represents the sites **maximum** potential value based on an assumed injection rate of 0.034 L/minute during CHIT testing. In reality, the piezometer did not take sufficient water during the CHIT test procedure to produce measurable results.

Table B-6: Summary of water quality results for sampled instream piezometers.

				Groundwater Field Parameters				Laboratory Analyses									
Map ID [1]	Well Tag ID Number	River Mile (miles)	Sample Date	Temperature (deg C)	pH (standard units)	Specific Conductance (µS/cm @ 25 °C)	Dissolved Oxygen (mg/L)	Fecal Coliform (#/100 ml)	Total Alkalinity (mg/L)	Total Chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved Total Phosphorus (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Iron (mg/L)
South Fork Palouse River																	
P1	AKY496	1.2	10/25/2006	11.1	7.17	615 J	0.6	1 UJ	288	26.5	0.059	0.875	0.138	0.549	1.12	7 J	-
P5	AKY488	9.3	06/27/2006	18.1	7.08	393	2.83 J	**1**	132	10.3	0.132	0.139	8.74	0.03	9.37	2.4	-
P6	AKY497	11.4	06/27/2006	14.3	7.37	358	0.35	**6**	121	4.26	0.019	0.159	0.158	0.083	0.287	1	-
			08/14/2006	19.1	7.34	367	0.38	**1**	120	3.08	0.020	0.164	0.037	0.126	0.12	1 U	-
			10/24/2006	12	7.45	382	0.5	**1**	120	4.42	0.018	0.137	0.138	0.088	0.292	3.8 J	-
P7	AKY498	15	06/28/2006	15.9	7.19	324	0.22	**1**	165	4.32	0.021	0.131	0.019	0.056	0.12	1 U	-
			08/14/2006	19.5	7.3	309	0.44	1 UJ	160	3.77	0.022	0.107	0.01 U	0.06	0.099	1.6 J	-
			10/24/2006	12.2	7.28	346	0.28	1 U	179	6.24	0.021	0.124	0.013	0.068	0.13	1.1 J	-
P13	AKY491	23.6	06/28/2006	16	6.89	444	0.96	1 U	185	18.1	0.084	0.081	2.82	0.01 U	2.93	1 U	-
			08/15/2006	15.5	6.81	421	0.67	**1**	184	17.7	0.087	0.084	3.29	0.02 U	3.49	1.7	-
			10/24/2006	10.6	6.91	434	0.65	1 U	184	18.4	0.073	0.073	2.98	0.01 U	2.91	2.9 J	-
P14	ALB689	26.7	06/28/2006	15.8	6.99	300	0.59	1 U	145	3.13	0.108	0.101	0.01 U	0.01 U	0.047	1 U	-
			8/16/2006	13.8	6.98	282	0.31	1 U	146	2.87	0.105	0.102	0.01 U	0.02 U	0.043	1	-
Paradise Creek																	
P16	ALB691	3.8	8/16/2006	13.3	7.21	469	4.18	**41**	158	21.9	0.171	0.172	10.1	0.01 U	10.8	1.7	-
			10/25/2006	10.9	7.34	444 J	4.73	**2**	156	20.2	0.106	0.106	9.98	0.01 U	8.46	4.2 J	-
P17	ALB692	6.6	10/25/2006	13.4	6.73	572 J	1.1	1 U	211	31.9	0.100	0.105	7.45	0.01 U	6.72	3 J	-
Mainstem Palouse River																	
P18	AHT042	25.7	07/09/2007	13.8	7.63	602	7.33	1 U	245	23.6	0.106	0.105	3.07	0.01 U	3.12 J	1 U	0.05 U
			09/11/2007	12.9	7.54	594	7.34	1 U	244	24.3	0.108	0.116	3.04	0.01 U	4.16	1	0.05 U
P21	AHT038	66.8	07/11/2007	18.1	7.34	329	0.31	1	161	5.19	0.059	0.164	0.01 U	0.078	0.13	1	1.42
			09/12/2007	17.6	7.23	366	0.17	1 J	174	8.21	0.059	0.179	0.01 U	0.092	0.15	1.4	1.64
P24	AHT034	112.4	07/11/2007	18.5	6.84	258	0.17	11	132	2.13	0.123	0.141	0.01 U	0.01 U	0.025 U	1 U	0.27
			09/12/2007	16.6	6.92	267	0.16	1 U	135	2.11	0.118	0.139	0.01 U	0.01 U	0.025 U	1 U	0.23

[1] - The map IDs listed here correspond with those shown on Plates 1 or 2

Data qualifier codes:
J - the analyte was positively identified, the numeric result is an estimate.
U - analyte was not detected at or above the reported value.
UJ - the analyte was not detected at or above the estimated value.