Surface Water/Groundwater Interactions and Near-Stream Groundwater Quality along Burnt Bridge Creek, Clark County

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Cover photo: Hemispherical photograph (180 degree "fisheye" view) of the tree canopy at river mile 0.0 on Peterson Channel (by James Kardouni).

Surface Water/Groundwater Interactions and Near-Stream Groundwater Quality along Burnt Bridge Creek, Clark County

by

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Waterbody Number: WA-28-1040

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Glossary, Acronyms, and Abbreviations

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 drinking, recreation, aquatic habitat, and industry – are impaired by pollutants. These are water quality limited-estuaries, lakes, and streams that fall short of Washington 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 measurement.

Anoxic: Depleted of oxygen.

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

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen: A measure of the amount of oxygen dissolved in water.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals. 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 (geographic information system): A computer-based mapping and analysis software system.

Groundwater discharge: Movement of groundwater from the subsurface to the surface by the advective (physical) flow of water.

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

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

Isotropic: A condition where the hydraulic properties of an aquifer are the same regardless of the direction of measurement.

LiDAR (data): LiDAR (Light Detection and Ranging) is an aircraft-based remote sensing system that uses laser pulses to derive high resolution/precision elevation estimates of the land surface or other features.

Nonpoint (pollution) source: Pollution that enters water from a dispersed land-based or water-based activity or source. Nonpoint pollution can originate from atmospheric deposition, surface water runoff from agricultural lands, urban areas, forest lands, subsurface or underground sources, discharges from boats or marine vessels, and other sources.

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 (pollution) 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, and industrial waste treatment facilities.

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
DTP	dissolved total phosphorus
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management (database)
GIS	Geographic Information System (software)
L/min	liters per minute
LiDAR	Light Detection and Ranging (data) (see glossary above)
MEL	Manchester Environmental Laboratory
mg/L	milligrams per liter (equivalent to parts per million)
TPN-N	total persulfate nitrogen (reported as nitrogen)
TMDL	total maximum daily load (see glossary above)

Data Qualifier Codes Used in Data Tables and Figures

Water Quality Codes

B	Analyte detected in sample and field filter blank. The reported value is the sample concentration without blank correction or associated quantitation limit.
J	The analyte was positively identified; the reported numeric result is an 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.

Water Level Codes

G	The piezometer water level was slowly dropping during measurement. The true value is greater than the reported value by an unknown amount.
L	The piezometer water level was slowly recovering (rising) during measurement. The true value is less than the reported value by an unknown amount.

Conversion Factors and Datums

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 reported here are referenced to the National American Vertical Datum of 1988 (NAVD88). Altitude values represent the distance above or below the datum in feet.

The horizontal coordinates reported here are referenced to the North American Datum of 1983 (NAD83 HARN).

# Abstract

Burnt Bridge Creek is a small urban stream that flows through the City of Vancouver, in Clark County, Washington. Portions of the creek were listed on the Washington State 2008 303(d) summary of impaired waters for temperature, dissolved oxygen, and fecal coliform violations of state surface water quality standards.

To support development of a comprehensive water cleanup plan (or Total Maximum Daily Load) for the creek, the Washington State Department of Ecology conducted targeted assessments of the environmental and water-quality issues affecting the creek. This study was part of that effort and was undertaken to evaluate how groundwater influences in-stream temperatures and water quality.

A variety of common field techniques were used for this assessment to derive both point and reach based estimates of the volume and quality of groundwater entering the creek. These included: stream seepage evaluations, installation and monitoring of instream piezometers, collection and evaluation of groundwater quality samples, and monitoring of streambed thermal profiles.

Baseflow seepage evaluations conducted in July and September 2008 showed net overall streamflow gains from groundwater of +2.14 and +3.08 ft^3/s respectively between the creek headwaters at river mile 12.8 and its terminus at Vancouver Lake. The evaluated sub-reaches between these end points showed considerable local variation in both the pattern and volume of streamflow gains from or losses to groundwater.

Groundwater samples collected from 5 instream piezometers and 2 off-stream wells had measurable concentrations of dissolved orthophosphate (range 0.038 to 0.163 mg/L), dissolved total phosphorus (range 0.033 to 0.595 mg/L), and dissolved nitrate+nitrite-N (range 0.011 to 3.52 mg/L). Measurable concentrations of dissolved ammonia were found at roughly half of the sampled sites (range 0.194 to 1.44 mg/L).

Acknowledgements

This study and resulting report would not have been possible were it not for the help we received from others. We are particularly indebted to Skip Haak (PBS environmental), Dorie Sutton (City of Vancouver), and Tonnie Cummings for their insights and guidance during pre-project scoping discussions and site reconnaissance. Marcie Hundis, Mark Von Prouse, George Onwumere, Stephanie Brock, Tonnie Cummings, Martha Maggi, and Margaret Oscilia (PBS) helped at various times with field work. Martha Maggi, Jean Maust, and Charles Pitz provided comments and suggestions for improving the study report. Lastly, we thank staff at the Manchester Environmental Laboratory who provided courier and analytical laboratory support for this project.

Introduction

Washington State is required under Section 303(d) of the federal Clean Water Act to identify and prepare a list of all surface waters in the state whose beneficial use(s)[1] are impaired by pollutants. Portions of Burnt Bridge Creek, a small urban stream in Clark County, were included on the Washington State 2008 303(d) list of impaired waters for temperature, dissolved oxygen, and fecal coliform violations of Washington's surface water quality standards (Kardouni and Brock, 2008) (Figure 1).

The Washington State Department of Ecology (Ecology) is responsible for developing water cleanup plans, or Total Maximum Daily Loads (TMDLs), for Washington's 303(d) listed waters. To develop a cleanup plan, Ecology typically conducts targeted field studies to identify and quantify the point (discrete) and nonpoint (diffuse) sources that are contributing pollution to a stream or water body. The results from these field studies later become inputs to the water-quality models Ecology uses to establish pollutant-load reduction targets for the stream.

In 2008 Ecology began a TMDL study for Burnt Bridge Creek. At that time, field investigations were undertaken to assess environmental conditions along the creek including instream temperatures, water quality, and streamflow. Other factors such as the location of possible pollution sources or the type, height, and distribution of riparian vegetation were also evaluated. This study was part of that larger effort and was undertaken to gain a better understanding of groundwater's influence on area streamflows and surface water quality.

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

[1] Such as water for drinking, recreation, aquatic habitat, or other potential uses

The primary goals of this investigation were to:

1. Evaluate and quantify groundwater discharge volumes to Burnt Bridge Creek during critical summer conditions.
2. Characterize local groundwater quality just before its discharge into the creek.

Numerous field techniques were employed to help realize these goals. In late spring of 2008, thirteen instream piezometers were installed at selected points along the creek to monitor streambed thermal profiles and vertical hydraulic gradients between the stream and near-surface groundwater.

Synoptic streamflow and surface water quality surveys were conducted in July and September, 2008 to develop baseflow seepage balances for the creek between its headwaters near Orchards and its terminus at Vancouver Lake (Figure 1). During these surveys selected piezometers and two adjacent off-stream wells were also sampled to characterize groundwater quality. This report documents the results of these investigations.

Study Area Description

Physical Setting and Land Use

The Burnt Bridge Creek watershed is located a few miles north of the Columbia River in southern Clark County (Figure 1). The drainage area for the creek encompasses approximately 28 square miles of generally low-to-moderate relief terrain within and surrounding the City of Vancouver. Vancouver's estimated population in 2008 was 162,400 people. (WA OFM, 2009). Land surface elevations within the basin range from less than 10 feet near Vancouver Lake to approximately 350 feet in the north-central watershed where a narrow east-west trending ridge separates the Burnt Bridge and Cold Creek drainages.

Before European settlements in the area, most of the watershed was heavily forested. At that time the upper half of Burnt Bridge Creek traversed a series of interconnected wetlands and marshes (Mai and Cummings, 1999). The creek exited the wetlands as a defined channel near present day 18th Avenue and

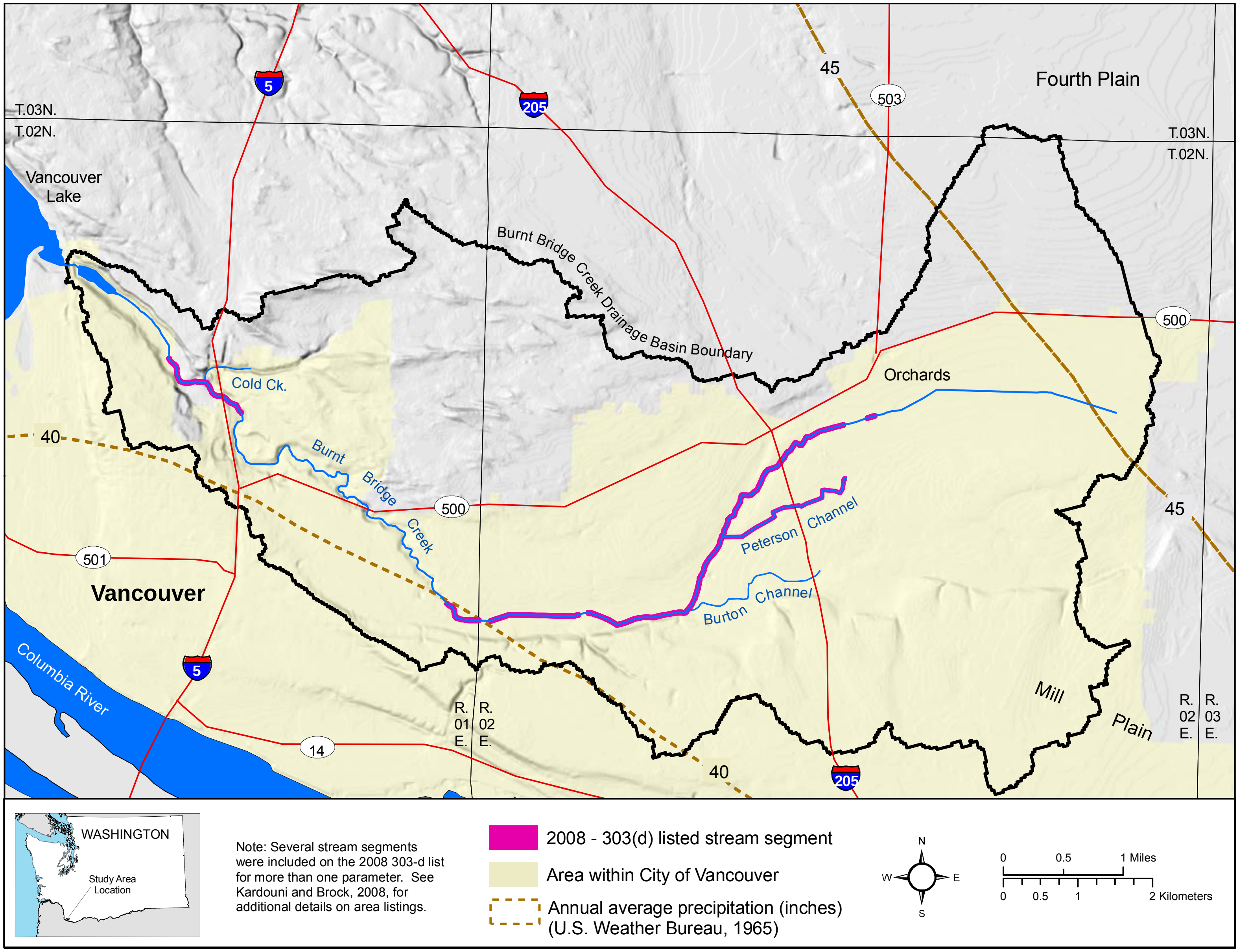


Figure 1. Study area location and distribution of 303(d) listed stream segments.

flowed for approximately 5 miles toward the northwest before entering Vancouver Lake.

In the years following initial settlement much of the watershed was cleared of timber, and the wetlands of the upper basin were progressively ditched and drained to aid local farming (Gaddis, 1994; Wade, 2001). Continued growth within and surrounding the City of Vancouver has since led to urbanization of most of the watershed including the areas historic farmlands.

The current headwater of Burnt Bridge Creek is situated at the far eastern end of the watershed where a deep north-south trending drainage ditch was dug just west of present day 162nd Avenue. Groundwater and seasonal runoff that enters the ditch are subsequently conveyed west in the Burnt Bridge Creek conveyance channel to a point near present day 18th Street where the channel joins the ancestral creek. The Peterson Channel and Burton Channel, two of Burnt Bridge Creek's primary tributaries, enter the creek about a mile west of Interstate-205 (I-205) (Figure 1).

Little is known about the historic distribution of fish species within the basin. Resident and anadromous cutthroat trout and Coho salmon are currently known to inhabit Burnt Bridge Creek below Interstate-5 (I-5) and are presumed to be present above I-5. Similarly, winter steelhead are assumed to be present throughout the basin, but this has not been confirmed. Anecdotal information suggests that chum salmon once spawned in the lower reaches of Burnt Bridge Creek in the past (Wade, 2001).

In recent years the City of Vancouver and Clark County have implemented several land and water management programs for Burnt Bridge Creek to enhance instream habitat and improve surface water quality (City of Vancouver, 2007; Clark County, 2009). The primary objectives of these programs are to:

- Restore and enhance riparian buffers within the Burnt Bridge Creek greenway,
- Fund a sewer construction and incentive program to remove failing or poorly performing septic systems,
- Implement stormwater management and treatment facilities, enhanced erosion control measures, and outfall inspections to minimize stormwater impacts on the creek, and
- Conduct outreach and inspections of waste management and disposal practices at area businesses.

These restoration and enhancement efforts are ongoing.

Climate

The watershed climate is moderated by its proximity to the Pacific Ocean. At Vancouver, the summer maximum temperatures generally occur in July or August and average about 80 °F (Figure 2). The winter minimum temperatures which typically occur in December or January average about 32 °F.

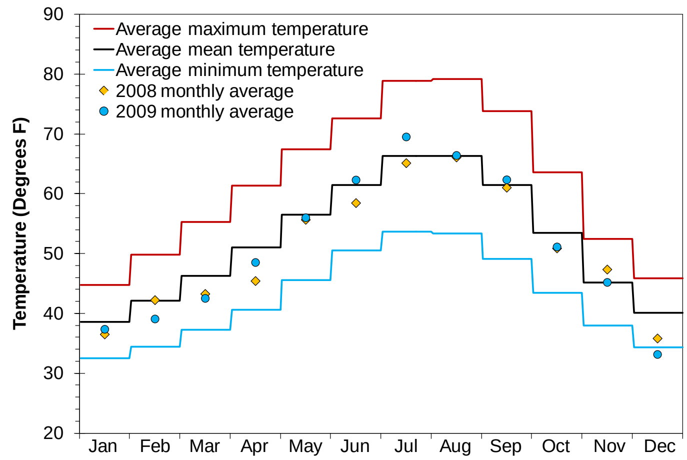


Figure 2. Monthly average maximum, minimum, and mean air temperatures at Vancouver for the period 1891 to 2009 (Western Regional Climate Center, 2010).

Approximately 75 % of the area's annual precipitation falls as rain during the six month period between October and March (Figure 3). The months between November and January are typically the wettest while July and August are typically the driest. The annual average precipitation ranges from slightly less than 40 inches at Vancouver to more than 45 inches in the northeastern watershed (Figure 1).

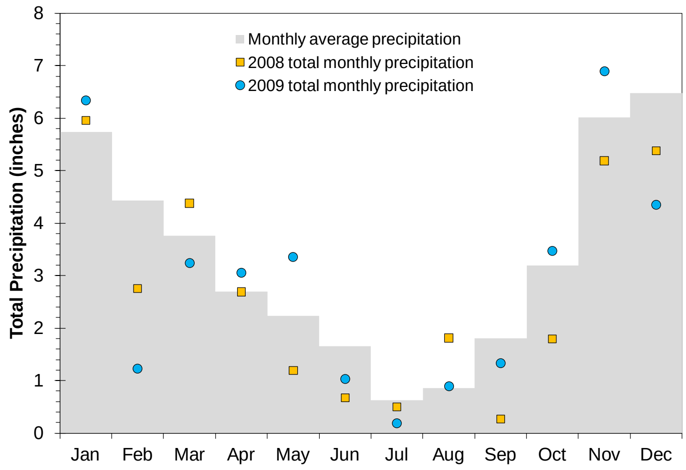


Figure 3. Monthly average precipitation at Vancouver for the period 1891-2009 (Western Regional Climate Center, 2010).

Streamflow

The U.S. Geological Survey (USGS) operated 4 streamflow gages within the Burnt Bridge Creek drainage between October 1998 and September 2000. Three of these gages were installed on Burnt Bridge Creek and one on Cold Creek (Table 1, and Plate 1 Figure 1).

Table 1. Streamflow gage locations and station periods of record

Agency Gage Number	Operating Agency	Location Description[1]	Period of Record
14211902	USGS	BB Ck at 2nd Ave.	Oct 98 - Sept 2000
28C080	Ecology	BB Ck at 2nd Ave.	May 08 - Sept 09
14211898	USGS	BB Ck at 18th Ave.	Oct 98 - Sept 2000
14211895	USGS	BB Ck at 112th Ave.	Oct 98 - Sept 2000
14211901	USGS	Cold Ck near mouth	Oct 98 - Sept 2000
28C110	ECOLOGY	BB Ck at Burton Rd.	May 08 - Nov 09
28C150	ECOLOGY	BB Ck at NE 110th Ave.	May 08 - Nov 09

[1] BB Ck (Burnt Bridge Creek)

To support this project Ecology reestablished a gage at the USGS 2nd Avenue site on Burnt Bridge Creek in May 2008. Additional gages were also established on Burnt Bridge Creek at 110th Avenue and Burton Road (Myers, 2010).

Visual inspection of the streamflow hydrograph for Burnt Bridge Creek at 2nd Avenue indicates that the creek flow tends to mirror annual precipitation patterns (Figure 4). Streamflow is typically highest during the wet winter months (Nov-Mar) and lowest during the summer when precipitation is scarce. Likewise, flows tend to be higher during wet years such as 1999 and lower during dry years such as 2009.

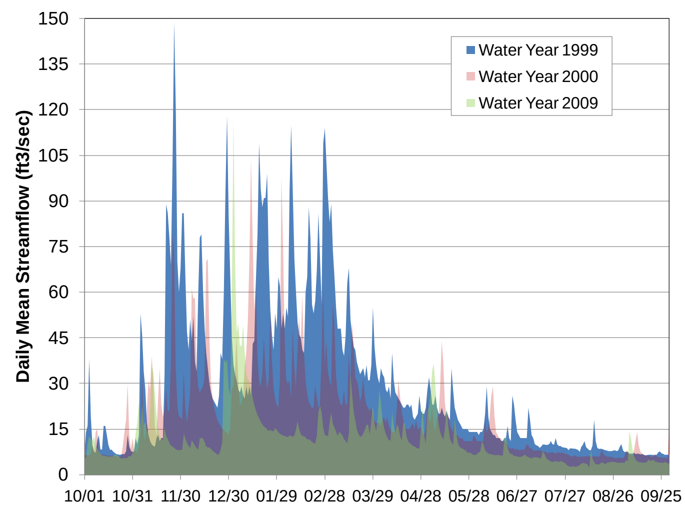


Figure 4. Daily mean streamflow for Burnt Bridge Creek at 2nd Ave for water years 1999, 2000, and 2009.

Since the early 1990s, flows in Burnt Bridge Creek have been artificially enhanced by discharges of industrial cooling water that originates at a computer chip manufacturing facility located near 112th Ave. This water is conveyed to the creek via Peterson Channel and enters Burnt Bridge Creek just south of the Royal Oaks Country Club near 93rd Ave (Figure 1). During the summer months discharged cooling water comprises as much as half (1-3 ft^3/s) of the total flow in Burnt Bridge Creek below its confluence with Peterson Channel (Kardouni and Brock, 2008).

Hydrogeologic Setting

The geology and groundwater resources of the Burnt Bridge Creek area have been topics of active study since at least the 1940s (Trimble, 1963; Mundorff, 1964; Swanson et al., 1993; McFarland and Morgan, 1996). The primary focus for most of these investigations was to describe the character and water development potential of area aquifers. The investigative reports for these studies offer comprehensive descriptions of the local hydrogeology and geologic setting and are a useful complement to the brief summary provided here.

The Burnt Bridge Creek watershed is situated within a shallow-sediment-filled structural trough called the Portland Basin. The Portland Basin is one of several such basins which formed during the early-to-middle Tertiary period, in response to folding and faulting that accompanied crustal movement along the Cascadia Subduction Zone (Evarts, 2006). These local basins are themselves part of the larger Puget-Willamette structural trough that extends from southern British Columbia to northern Oregon and occupies the lowlands between the Cascade Mountains and the coast ranges of Washington and Oregon.

As the Portland Basin subsided it filled with sediments that were carried into the area by the ancestral Columbia River and other local streams. In the vicinity of Burnt Bridge Creek, which lies near the center of the basin, these sediments accumulated to depths of up to 800+ feet and were unconformably deposited upon Eocene to Miocene age bedrock composed of basalts, andesitic-basalts, and other consolidated rock types (Evarts, 2006; Swanson et al., 1993).

Trimble (1963) assigned the name Sandy River Mudstone to the oldest of the locally occurring deposits that accumulated as the Portland Basin subsided during the late Miocene and Pliocene epochs. These deposits which contain important aquifers locally, consists of a thick sequence of generally thin-bedded claystone, siltstone, sandstone and other rocks.

In the vicinity of Burnt Bridge Creek, the Sandy River Mudstone is overlain by a thick sequence of coarser-grained-cemented gravels, conglomerate, and sandstone of the Troutdale Formation (Mundorff, 1964). The Troutdale formation is thought to range in age from late Miocene time to the late Pliocene (or early Pleistocene) time period (Swanson et al., 1993). This unit contains some of the area's most extensive and important water supply aquifers.

In late Pleistocene time (approximately 17,000-12,000 years ago) the Portland Basin was repeatedly inundated by catastrophic glacial floods that originated from periodic failures of an ice dam(s) which impounded huge glacial lakes in northern Idaho and western Montana (Bretz, 1959). With each dam breach massive volumes of water spread laterally and flowed in great torrents across Eastern Washington. The floodwaters eventually coalesced at the eastern end of the Columbia River gorge where they were laterally constrained and directed into the Portland Basin. As the floodwater exited the gorge it scoured and reworked portions of the older previously deposited basin fill sediments and deposited coarse gravel in longitudinal bars downstream of the gorge terminus.

A channel restriction near the northern end of the Portland Basin, at Kalama, caused floodwater to back up and pond to elevations as high as 400 ft (Swanson et al., 1993). As a consequence progressively finer sediments (mostly fine gravel, sand, and silt) were deposited in the central and western portions of the Portland basin where water velocities were lower.

Near Burnt Bridge Creek the flood deposits reach thicknesses of up to 250+ feet and are composed mostly of unconsolidated gravelly sand to the south and silty sand to the north and west (Plate 1, Figure 1). Where they are saturated the coarser flood deposits can contain prolific and locally important aquifers that yield considerable volumes of water to properly constructed wells. It is these flood sediments and other recent deposits of alluvium and peat which are of primary interest to this study since they directly underlie and interact with area streams.

Study Methods and Design

For this study we used several common field methods and analytical techniques to evaluate the timing, magnitude, and spatial distribution of surface water/groundwater interactions. Two synoptic surface water seepage evaluations were conducted to estimate streamflow gains and losses for discrete stream reaches. These reach-scale gain/loss estimates were supplemented with measurements of streambed thermal profiles and vertical hydraulic gradients to better define the direction and timing of surface water and groundwater interactions at specific points.

These field methods and analytical techniques are described in the sections that follow.

Well Numbering and Location System

The well locations referenced in this report are described using latitude/longitude coordinates and more generally 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 northeast quarter of the northeast quarter of Section 15, Township 2N, Range 02E is represented as 02N/02E-15A01, the second well as 15A02, and so forth (Figure 5).

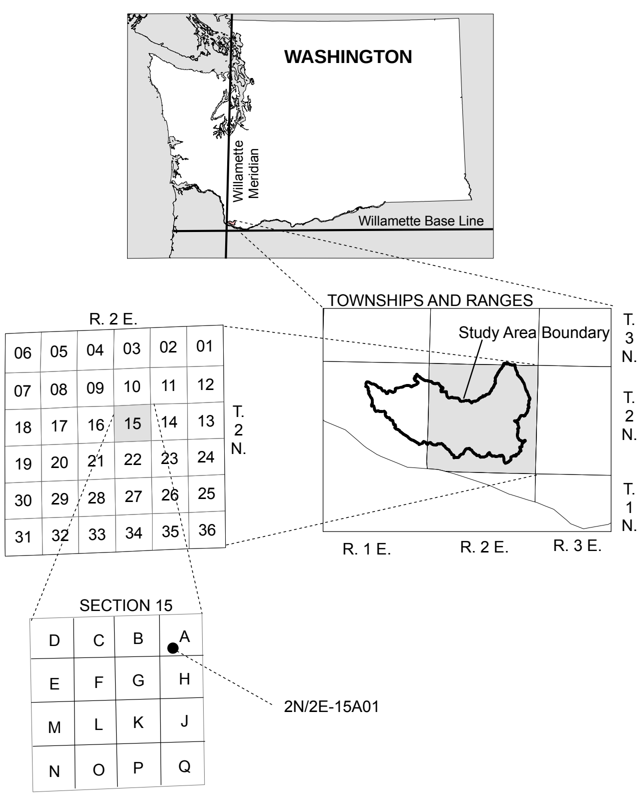


Figure 5. Well numbering and location system

The locations of monitoring sites were initially determined using a Global Positioning System (GPS) receiver and were refined, where necessary, using geo-referenced digital orthophotos.

Land surface altitudes at well and piezometer sites were estimated using a geographic information system (GIS)-based, pixel-matching process and digital LiDAR data for Clark County.

As an additional aid to future investigators, all wells that were monitored for water level or water quality were fitted with a Department of Ecology well identification tag. Each tag contains a unique six-digit alpha-numeric identifier, consisting of three letters followed by three numbers, (e.g., AHT045). 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 investigators ready confirmation of well identity during future site visits and helps avoid the potential cross-study conflicts inherent in the TRS numbering system.

Stream Seepage Evaluations

We conducted two stream seepage evaluations to quantify reach-scale streamflow gains from or losses to groundwater. The evaluations occurred on July 29 and September 23, 2008, following periods of extended dry weather. To perform the evaluations, we subdivided Burnt Bridge Creek into 14 reaches ranging from 0.4 to 1.6 miles in length. The positions of the upper and lower reach boundaries were chosen based on ease of site access and the presence of channel characteristics that tend to favor accurate streamflow measurements.

After selecting and flagging the measurement transects field teams conducted synoptic (same-day) measurements of all 14 reaches to define the individual reach water budget components (Figure 6).

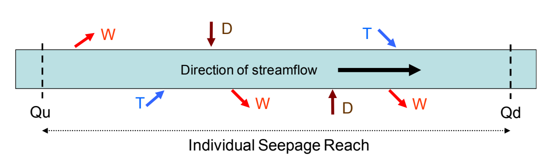


Figure 6. Reach-based water budget components measured during a stream seepage evaluation.
(see symbol explanations below)

Equation 1 was used to estimate the net volume of water exchanged between the creek and groundwater along each reach. An overall water budget for the creek was prepared for each survey, by summing the equation 1 variables for the 14 individual seepage reaches.

$$S = Qd - Qu - \Sigma T - \Sigma D + \Sigma W \qquad (1)$$

Where:

S is the calculated net streamflow gain or loss between the upper and lower reach transects, in ft^3/s. Negative seepage values indicate the creek lost flow to the subsurface as it traversed the reach, while positive values indicate the creek gained flow from groundwater discharge to the reach;

Qd is the streamflow measured at the downstream end of the seepage reach, in ft^3/s;

Qu is the streamflow measured at the upstream end of the seepage reach, in ft^3/s;

ΣT is the sum of tributary inputs (T) to the creek between the upper and lower boundaries of the seepage reach, in ft^3/s;

ΣD is the sum of known point discharges (D) to the creek between the upper and lower boundaries of the seepage reach, in ft^3/s;

ΣW is the sum of known water withdrawals or out-of-stream diversions (W) from the creek between the upper and lower boundaries of the seepage reach, in ft^3/s.

The streamflow measurements for this assessment were made using Marsh McBirney Model 2000 portable current meters and the cross section method described by Rantz, et al. (1982). Since multiple teams and instruments were used to conduct the assessments we made replicate discharge measurements (both within-a-team and between teams) to assess overall measurement quality and reproducibility.

Overall a total of five within-team and four between-team replicate measurements were made during this study. The average relative percent difference (RPD) across all measurements was 5.37% and averaged 2.8% and 8.6% for the within-team and between-team measurements respectively. The results of this evaluation are shown in Table A-1 (Appendix A) and suggest generally good measurement reproducibility and quality.

Instream Piezometers

In June 2008, we installed thirteen shallow instream piezometers along Burnt Bridge Creek using methods described by Sinclair and Pitz, 2009. The piezometers for this project consisted of an upper removable pipe section (or extension) and a lower 5-foot section of 1.5-inch diameter galvanized pipe (Figure 7 and Table B-3).

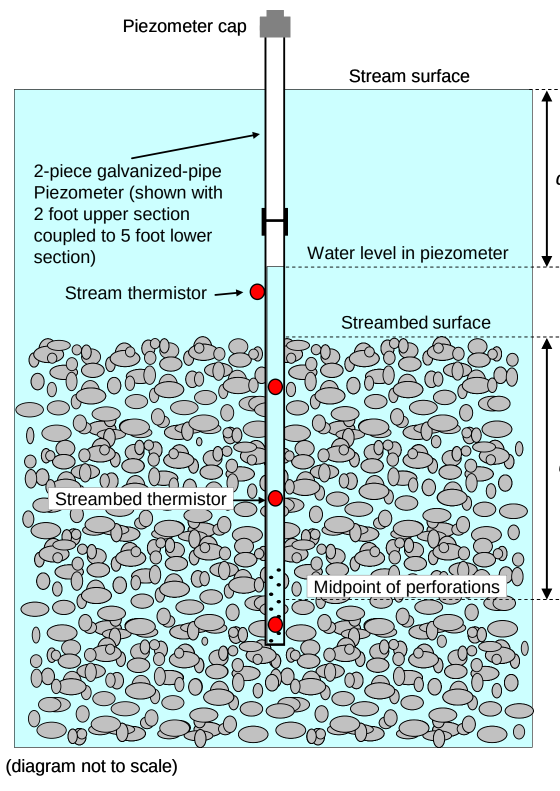


Figure 7. Schematic of a typical instream piezometer installation and thermistor array

The piezometers were used to monitor surface water/groundwater head relationships, streambed water temperatures, and near-stream groundwater quality at discrete points along the creek (see Plate 1, Figure 1 for site locations). Piezometers were manually installed into the streambed to a maximum depth of about 7 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 (Figure 8).

Figure 8. Hydrologists installing an instream piezometer at Site P12, Burnt Bridge Creek at 121st Ave.

The piezometers were developed after installation with a manual bladder-type bilge pump to ensure a good hydraulic connection with the streambed sediments. Piezometers were accessed monthly, when flows permitted, to make comparative stream and groundwater hydraulic head measurements. The stream stage (hydraulic head) was measured by aligning an engineer's tape parallel to the piezometer pipe and measuring the distance from the stream water 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 or steel hand tape (Marti, 2009). For angled (off-vertical) piezometers these "raw" values were corrected using simple trigonometric relationships to obtain true (angle normalized) depth to water measurements.

The water level difference (represented by the inside and outside of pipe measurements) indicates the direction and magnitude of the local hydraulic potential between the stream and underlying 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 2 was used to derive vertical hydraulic gradients for each piezometer, from these 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.

$$i_v = \frac{dh}{dl} \qquad (2)$$

Where:

i_v is vertical hydraulic gradient (dimensionless),

dh is 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),

and (L) is length.

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

Thermal Profiling of Streambed Sediments

Streams and rivers commonly experience pronounced (several degree) daily fluctuations in water temperature due to variations in atmospheric and solar heating over the course of a day. In contrast, groundwater generally shows little if any diurnal temperature variability since it is typically insulated from the sun and atmosphere by overlying rock or sediment. These differences in daily temperature pattern, between a stream and near-surface groundwater, can be monitored to provide secondary confirmation of the surface water/groundwater interactions inferred from periodic hydraulic gradient measurements.

For this project we instrumented each instream piezometer with three recording thermistors to monitor groundwater temperatures within the upper 4 to 7 ft of the streambed sediments. One thermistor was located near the piezometer bottom within the perforated interval of the pipe, one approximately 0.5 to 1 ft below the streambed, and one roughly equidistant between the upper and lower thermistors. A fourth thermistor was mounted to the outside of the piezometer to monitor the stream temperature (Kardouni and Brock, 2008).

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 9A).

Conversely, at sites where streambed water temperatures closely mimic those of the stream, one can infer that water is leaving the stream and moving down into the streambed at that location (a connected losing reach) (Stonestrom and Constantz, 2003) (Figure 9B).

In some geologic settings perennial streams can become separated from the underlying water table (either seasonally or permanently) by an intervening zone of unsaturated sediments (Figure 9C). When this occurs, the streambed thermal profile may show seasonal temperature differences similar to those of a connected losing stream. However, the diurnal variability will likely be muted and significantly subdued relative to that of a connected losing stream.

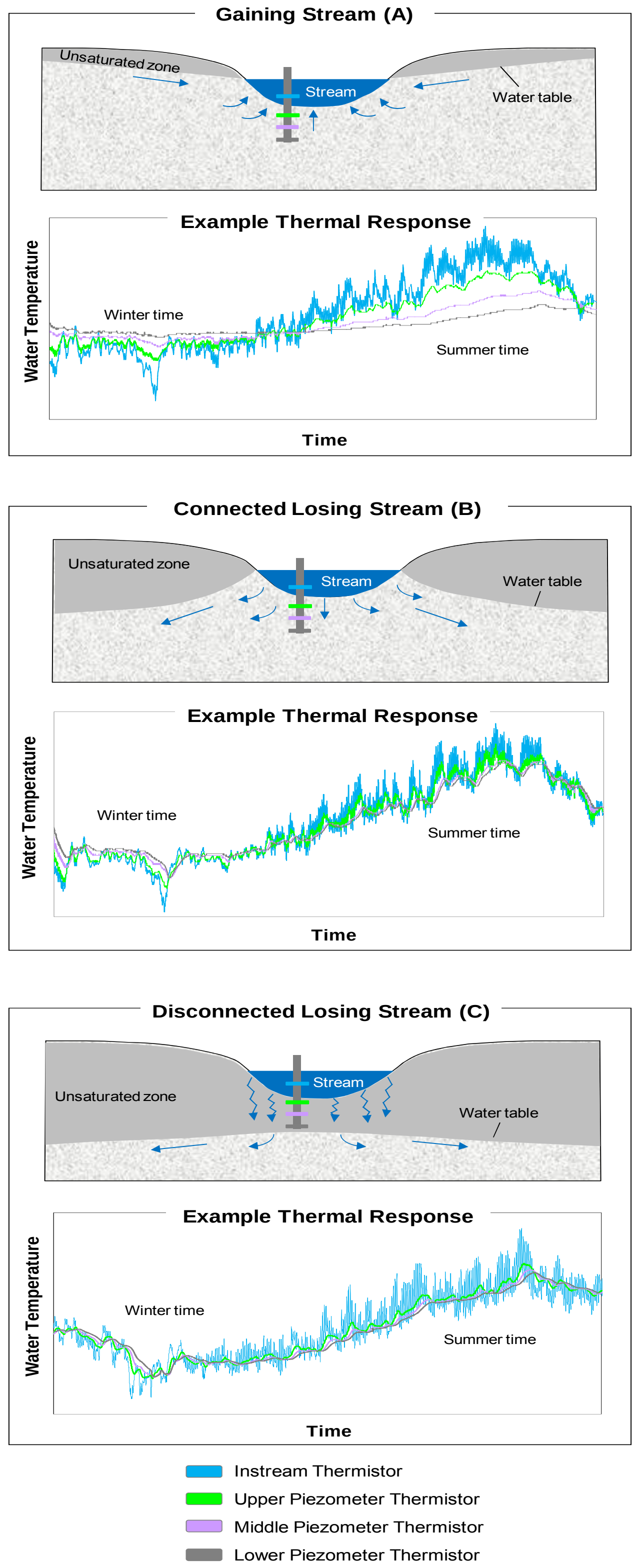


Figure 9. Example streambed thermal responses for a perennial gaining (A), losing (B), or disconnected-losing stream (C).

Estimating Streambed Hydraulic Conductivity Values

Constant head injection tests (CHIT) were used to estimate vertical hydraulic conductivity values for the streambed sediments at each piezometer site. To perform the tests a constant head chamber was attached to the piezometer casing using a standard pipe coupler (Figure 10).

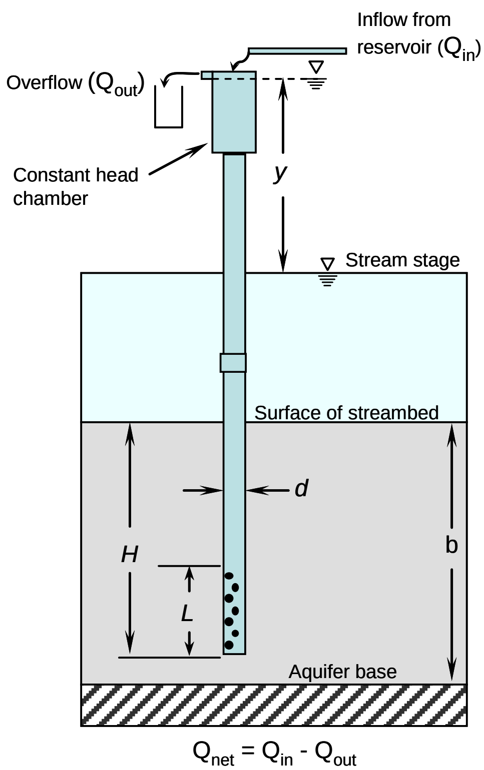


Figure 10. Schematic of the constant head injection test (CHIT) apparatus and field measurements (adapted from Pitz, 2006).

Water was then added to the chamber from an adjacent graduated reservoir at a rate equal to or slightly greater than the piezometers ability to take water. Field measurements of the operating head (y), the net injection rate (Q), and piezometer construction information were used as inputs to a spreadsheet model that solves Equation 3 (Pitz, 2006; Cardenas and Zlotnik, 2003).

$$K = \frac{Q}{2\pi LPy} \qquad (3)$$

where:

K is the isotropic hydraulic conductivity of the streambed sediments adjacent to the piezometer open interval (L/t)

Q is the net injection rate required to maintain a constant head within the piezometer (L3/t)

L is the length of the piezometer open interval (L)

P is the well shape factor (see Cardenas and Zlotnik, 2003 for the derivation of this term)

y is the height of the constant head above the stream surface (L)

The constant head test method assumes the streambed sediments are hydraulically isotropic at a sub-meter scale. In most alluvial environments sediments exhibit some degree of anisotropy; due to the preferential orientation of grains and clay minerals or to local scale inter-fingering or layering of fine- and coarse-grained materials (Freeze and Cherry, 1979).

To adjust for well development (which preferentially removes fine material from the piezometer screen) and potential anisotropy effects, we multiplied the hydraulic conductivity values obtained from the CHIT field tests by 0.1 to obtain estimated vertical hydraulic conductivity values for the streambed sediments at each piezometer site.

The CHIT results are summarized in Table B-4.

Surface Water/Groundwater Interactions

The generalized depictions of gaining and losing stream reaches shown in Figures 9A-C present highly simplified views of the often complex physical processes that drive surface water and groundwater interactions along the length of a stream. 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). There is currently no single field technique or analysis method that adequately characterizes these subtleties.

For this investigation we used three common field and analytical techniques to gain insights into the direction, timing, and spatial distribution of surface water/groundwater interactions affecting Burnt Bridge Creek. Streamflow seepage assessments were conducted on July 28 and September 23, 2008 to quantify reach-based streamflow gains or losses. The seepage assessments were supplemented with periodic point-based measurements of streambed vertical hydraulic gradient and continuous streambed thermal profiles at 13 instream piezometer sites along the creek. The results of these evaluations were combined with findings from previous groundwater studies of the area to develop working conceptual models of surface water/groundwater interactions for the creek.

For the following discussion and presentation of findings we've subdivided Burnt Bridge Creek into two parts (upper and lower watershed) based on our present understanding of surface water/groundwater interactions within each of these areas.

Upper Watershed

As defined here, upper Burnt Bridge Creek extends from the creek headwaters at river mile 12.8 near 162nd Ave NE (site S1) to about river mile 5.9, at 18th Street (site P6) (Plate 1, Figure 1). Throughout most of the upper watershed the creek flows in a deep low gradient drainage ditch[2]. This ditch was initially excavated in the mid-to-late 1800's to drain the wetlands and seasonally-flooded bottomlands that originally occupied this area (Gaddis, 1994).

During the July 28 and September 23, 2008 seepage assessments, upper Burnt Bridge Creek showed net streamflow gains of approximately +1.88 and +2.90 ft^3/s respectively between sites S1 and P6 (Tables B1- B2 and Figures 11-12). The largest gains occurred between sites S1 and P12, and between site P7 and the Burton Channel, where the creek traverses ditched historic wetlands and/or bottomlands. Comparable gains were also observed along the Peterson Channel –a major tributary to Burnt Bridge Creek[3]. Streamflow losses were greatest where the creek directly traverses deposits of coarse-grained alluvium or outwash (i.e., between sites P6-P7, P8-P10, and P11-P12) (Figures 11 and 12).

Most instream piezometers installed along the upper creek exhibited moderate-to-large negative (downward) hydraulic gradients with average values ranging from -0.35 to -1.12 ft/ft (see sites P6, P8, P9, P10, and P12, Figure 2, Plate 1). These piezometers also had streambed thermal profiles that closely followed the creek's seasonal warming trend from spring to summer while exhibiting muted diurnal signals similar to the creek at depths of several feet below the streambed (see graphs P6, P8-P10, and P12, on Figure 2, Plate 1)[4].

[2] The average stream gradient between sites S1 and P6 is approximately 5.3 ft per mile. Across this reach the creek drops from an elevation of approximately 200 feet at Site S1 to about 164 ft at site P6.

[3] Peterson Channel is sustained largely by industrial cooling water discharged by the Shin-Etsu Handotai (SEH) Corporation; a silicon chip manufacturer that operates a facility near the channel headwaters. During this study (2008-2009) an average gain of approximately 1.2 ft^3/s (0.91 ft^3/s per river mile) was noted between the SEH outfall at RM 1.3 on Peterson Channel and its confluence with Burnt Bridge Creek. Upper Peterson Channel also traverses historic wetlands so it too likely receives discharge from adjacent perched aquifers.

[4] The streambed thermistors deployed in piezometers P3, P8-10, and P12 were often above the piezometer water level. Since water is more thermally conductive than air the temperatures measured during these periods are likely muted relative to what they would be had the thermistors been fully submerged.

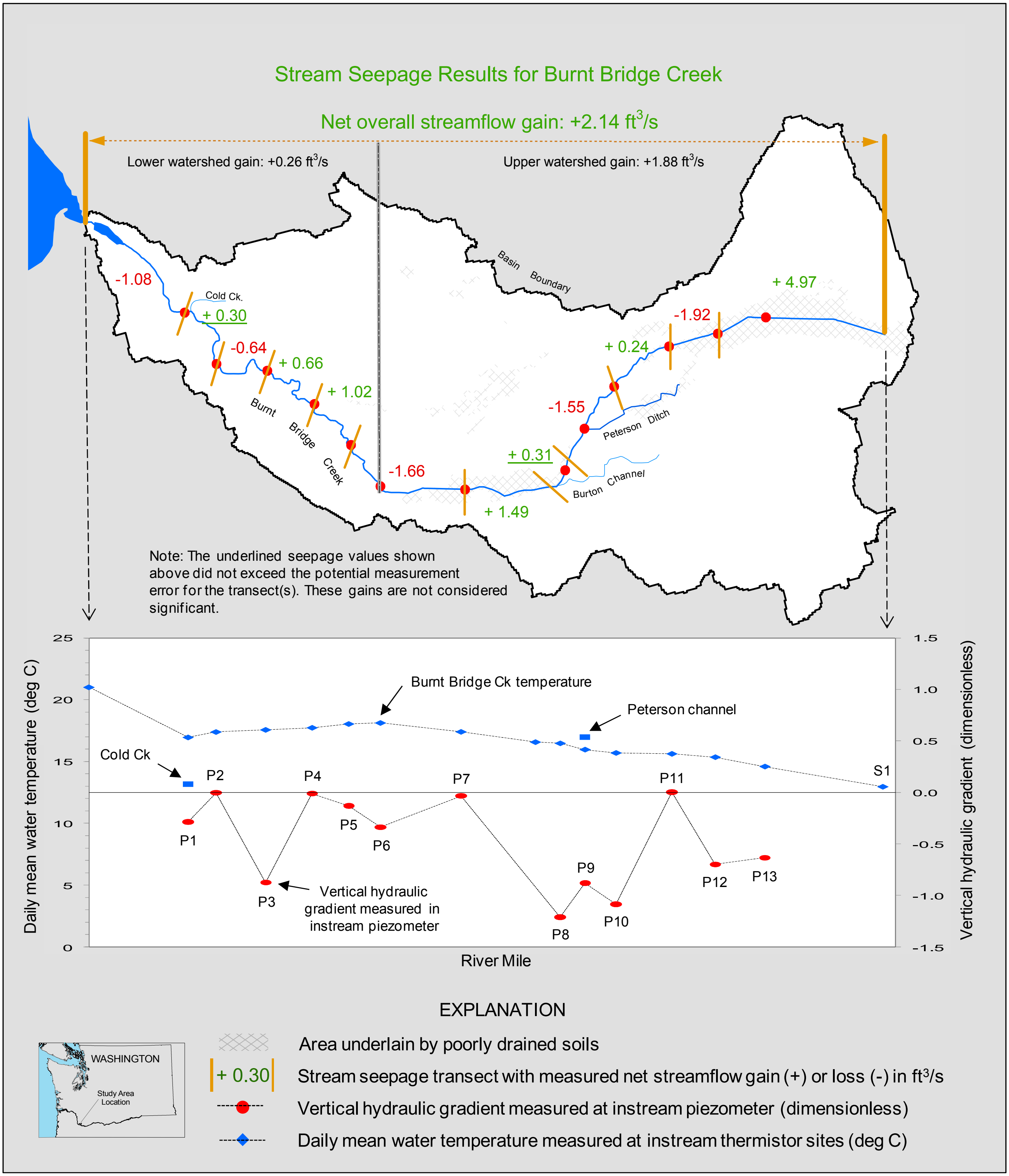


Figure 11. Summary of stream seepage results, daily mean water temperatures, and streambed vertical hydraulic gradients measured during the July 28, 2008 synoptic survey of Burnt Bridge Creek.

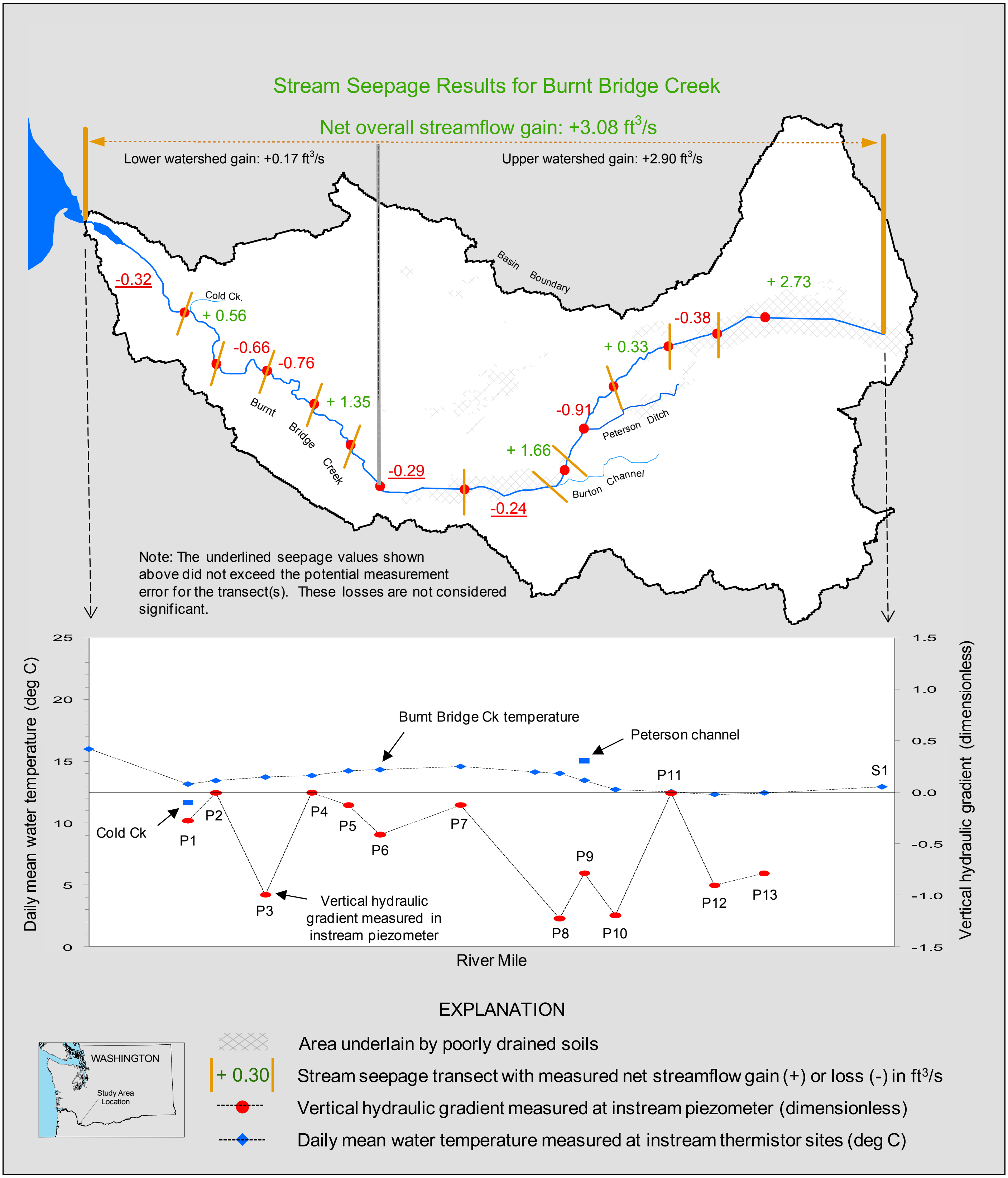


Figure 12. Summary of stream seepage results, daily mean water temperatures, and streambed vertical hydraulic gradients measured during the September 23, 2008 synoptic survey of Burnt Bridge Creek.

Exceptions to this losing pattern were noted at piezometer sites P7, P11, and P13 where small positive to neutral gradients were measured during the winter and early spring. The streambed thermal profiles at these sites were generally stable-to-flat at depths of a few feet or more below the streambed, as is characteristic of groundwater discharge conditions (see graphs P7, P11, and P13 on Figure 2, Plate 1).

Discussion

For a typical stream these point-based instream piezometer techniques and reach-based seepage results are often complimentary, and can be used to subdivide a stream into net-gaining or -losing reaches using a preponderance of evidence approach. In this case, however, the seepage assessments for upper Burnt Bridge Creek showed significant streamflow gains that were not supported by the vertical hydraulic gradients and streambed thermal profiles measured at piezometers installed along the creek. One possible explanation for this discrepancy is that the piezometers were all installed along short losing segments of otherwise gaining reaches. This seems unlikely however, given the shortness of the reaches and the number of piezometers involved.

Mundorff (1964) offers a more likely explanation for the discrepancy. During his study of the geology and groundwater conditions of greater Clark County, Mundorff identified portions of the Burnt Bridge watershed (primarily the upper bottomlands) that are underlain by shallow perched aquifers. Perched aquifers are separated from the underlying regional water table aquifer by an intervening zone of unsaturated sediments. They are thought to form where near-surface silt or clay deposits locally impede the downward movement of recharge through what are otherwise generally coarse-grained sediments (Mundorff, 1964; Swanson and others, 1993). Given their origin, these aquifers are often thin and laterally discontinuous, and may be only seasonally saturated.

At the time of Mundorff's study, perched aquifers were often tapped by shallow dug wells to supply irrigation to area farms. Given the extensive urbanization that has occurred since then, many of the shallow wells initially described by Mundorff probably no longer exist. However, their previous mapped locations closely align with the gaining stream reaches identified during our seepage evaluations. This suggests the shallow-perched aquifers they tapped likely play an important role in helping to sustain the baseflow of upper Burnt Bridge Creek.

Figure 13 shows the dominant mechanisms through which this might occur. Based on this conceptual model net streamflow gains would occur where the lateral groundwater discharge from shallow-perched aquifer(s) outpaces vertical water losses through the streambed itself (due to the large vertical head differences that exist locally between the streambed and underlying regional water-table aquifer) (see Plate 1, cross sections C-C', D-D', and E-E'). Similarly, net streamflow losses would be most apparent along reaches where shallow-perched aquifer(s) are either absent or do not directly intersect the streambed.

This conceptual model aligns well with our current study findings. In the deeply-dredged, wetland-dominated reaches of the upper watershed (where net streamflow gains were coupled with large negative streambed hydraulic gradients) we suggest shallow-perched aquifers provide sufficient lateral discharge to the creek to outstrip vertical streambed losses.

In the central portion of the upper watershed (where the seepage results and instream piezometer measurements both suggested streamflow losses) the shallow-perched aquifer(s) are either absent or are not in direct contact with the streambed. Consequently, the creek experiences net-streamflow losses due to the dominance of vertical streambed leakage.

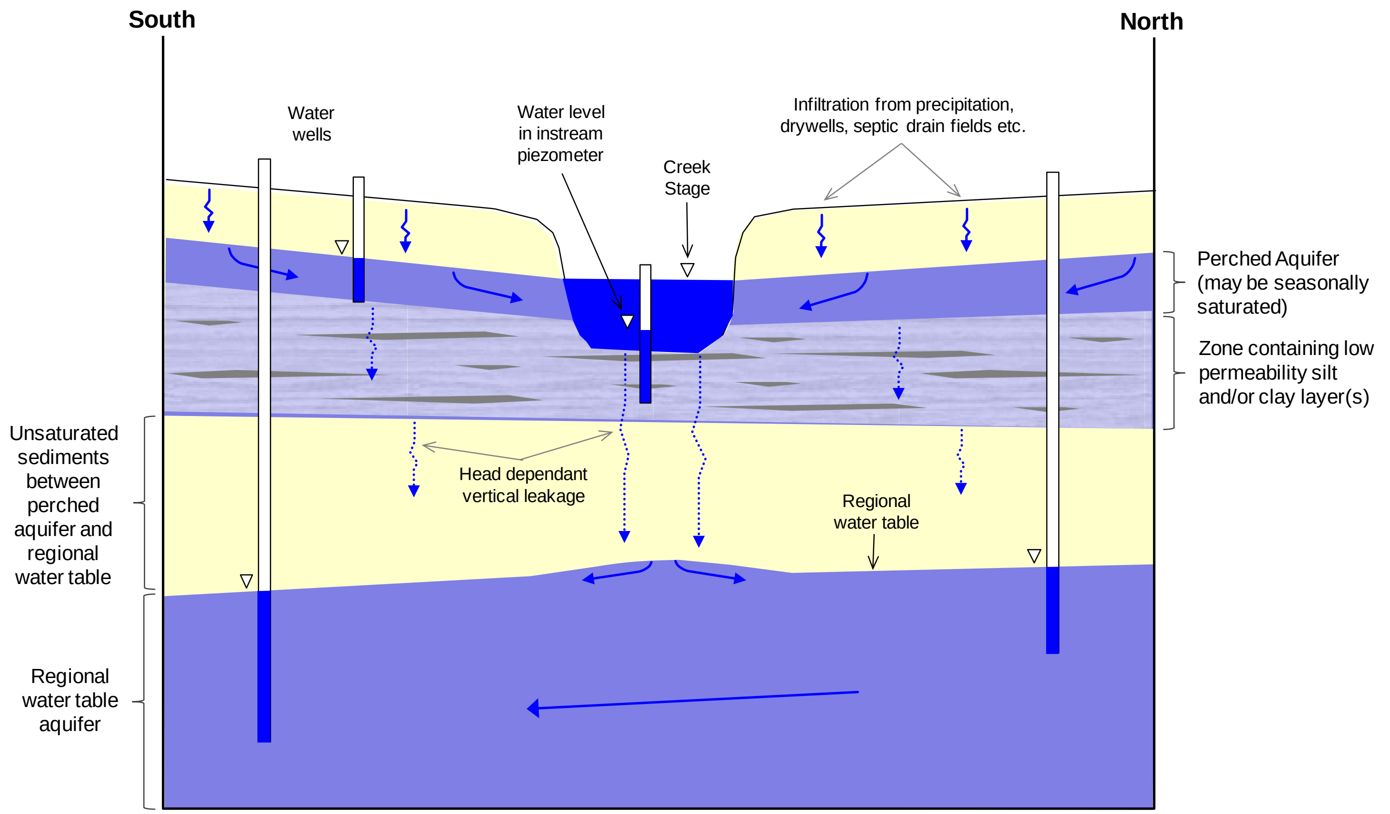


Figure 13. Generalized conceptual model of surface water/groundwater interactions along deeply channelized upper Burnt Bridge Creek.

Lower Watershed

Lower Burnt Bridge Creek extends from river mile 5.9 at 18th Street (Site P6) to the creek terminus at Vancouver Lake. Through most of the lower watershed the creek flows within a broad canyon-like valley that was once occupied by the ancestral Columbia River (Mundorff, 1964). The creek's present, comparatively modest channel follows a mostly natural drainage course along the valley bottom[5].

During the July and September 2008 seepage surveys of Burnt Bridge Creek, the net groundwater discharge to lower creek as a whole was approximately +0.26 and +0.17ft^3/s respectively (Figures 11 and 12).

Considerably larger net gains were observed along the reaches between sites P1-P2 (+0.3 to +0.56 ft^3/s) and sites P4-P5 (+1.02 to +1.35 ft^3/s). These gains were mostly offset by exchanges along the remaining reaches where net streamflow losses ranged from -0.32 to -1.08 ft^3/s (Figures 11 and 12).

Most of the instream piezometers installed along the lower creek showed a consistent pattern of negative hydraulic gradients (see sites P1, P3, P5, and P6). These sites also had streambed thermal profiles that closely followed the creeks seasonal and daily temperature patterns. This suggests the creek is likely losing flow to groundwater at these locations. Two additional piezometers along the lower creek (sites P2 and P4) exhibited little to no measurable gradient which suggests the creek neither gains nor loses much water at these locations.

[5] Unlike the upper watershed, the lower creek has not been significantly altered or channelized except for a few reaches where it passes through heavily urbanized areas.

Discussion

The apparent discrepancy between the seepage findings and instream piezometer results noted along portions of the lower creek can be explained in part by evaluating the groundwater level relationships shown in cross sections A-A' and B-B' (Plate 1, Figures 1 and 2). The thick sequence of unconsolidated flood deposits that form the canyon walls along the lower creek contain small perched aquifers and lenses of saturated sand and gravel. These perched systems are situated above the current streambed and are inferred to discharge water to creek bank seeps and small springs that lie at or above the stream channel. Flow from these features likely enters Burnt Bridge Creek primarily as overland sheet flow (Figures 14 and 15).

The diffuse streamflow gains from these upland sources are apparently large enough along some reaches (for example P1-P2 and P4-P5) to outstrip coincident losses thought to stem from vertical leakage through the streambed itself. The streambed is perched above the regional water table along most of the lower watershed. Where diffuse upland inputs are small or absent, negative (downward) vertical hydraulic potentials within the streambed cause the stream to lose water vertically resulting in net streamflow losses.

Figure 14. Diffuse groundwater discharge to Burnt Bridge Creek just upstream of Site P5[6].

[6] At this location groundwater enters the creek as diffuse sheet flow from a saturated sand lens that overlies lower permeability silt and clay deposits near the stream surface.

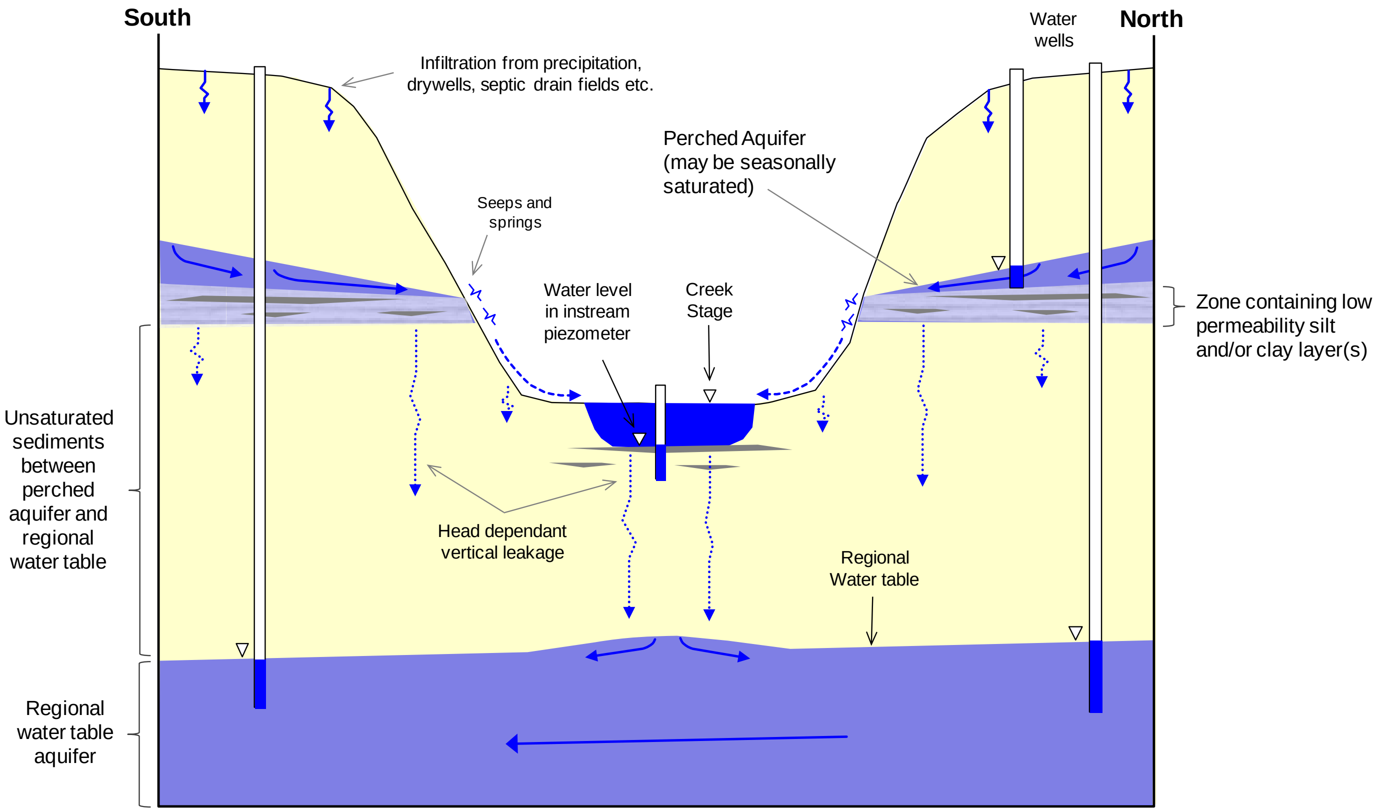


Figure 15. Generalized conceptual model of surface water and groundwater interactions along portions of lower Burnt Bridge Creek.

Evaluation of Near-Stream Groundwater Quality

To assess the concentration of phosphorous- and nitrogen-based nutrients that groundwater potentially contributes to Burnt Bridge Creek we sampled three instream piezometers and two off-stream wells in July and September, 2008. Confirmation samples were collected from two additional piezometers in July 2009. The samples were evaluated for field parameters and a small suite of laboratory analyzed constituents (Table 2) (Kardouni and Brock, 2008).

Table 2. Target analytes, test methods, and method detection 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	5 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

Sampling methods

All wells were purged prior to sampling using either a peristaltic pump or the installed water system pump. The pump discharge was routed through a "Y-splitter" which enabled a portion of the sample stream to be directed through a closed-atmosphere flow cell. This arrangement enabled field parameters to be evaluated prior to the water contacting atmospheric oxygen. Domestic wells were purged at a rate of 3 to 5 gallons per minute and instream piezometers at 0.25 to 0.5 L/min. Purging continued until the difference in measured values for 2 successive 3-minute measurement periods differed by less than 5 % across all field measurements (temperature, specific conductance, pH, and dissolved oxygen).

At the completion of purging, laboratory samples were collected using the second channel of the Y-splitter. Samples for dissolved organic carbon (DOC) analyses were filtered in the field 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 analytes (with the exception of fecal coliform bacteria, chloride, and alkalinity) were filtered using a 0.45 micron in-line-capsule filter.

Samples for DOC, nitrate+nitrite-N, total persulfate nitrogen (TPN), ammonia, and dissolved total phosphorus (DTP) were collected in pre-acidified bottles containing sulfuric acid. Samples for iron analysis were collected in bottles pre-acidified with nitric acid. 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 Figure 16 and presented by well and sample event in Appendix B, Table B-7. The associated data quality assessment is presented in Appendix A. The data are generally of good quality and can be used as reported here without further qualification.

As shown in Table B-7 temporal differences in water quality between the July and September 2008 sampling events were relatively small. This suggests that the groundwater quality at individual wells varied over a fairly small range during summer 2008.

Although the results for individual wells showed little temporal difference between sampling events, there were notable differences in water quality between sites. Four of the five piezometers sampled (P2, P4, P11, and P13) had low concentrations of dissolved oxygen (average 0.31 to 0.61 mg/L). These sites had little measurable nitrate[7] (average 0.014 to 0.025 mg/L) and elevated iron (average 3.24 to 29.2 mg/L), ortho-phosphate (average 0.058 to 0.153 mg/L), and ammonia concentrations (average 0.2 to 1.44 mg/L); this is consistent with suboxic-to-anoxic groundwater conditions (Figure 16).

In contrast, the off-stream wells and headwater drainage ditch (sites W1, A2, and S1) had average dissolved oxygen concentrations ranging from 6.34 to 9.06 mg/L. Consistent with oxygenated conditions, these sites had higher nitrate-N (average 2.09 to 3.51 mg/L) and total persulfate nitrogen-N (TPN-N) concentrations (average 2.32 to 3.36 mg/L) and generally lower concentrations of ortho-phosphate (average 0.0396 to 0.159 mg/L). Samples from these sites had no detectable ammonia or iron.

Piezometer P7 is somewhat unique in having low concentrations of dissolved oxygen (0.3 mg/L), relatively little ortho-phosphate (0.0486 J mg/L), no detectable iron and moderate nitrate concentrations (0.956 mg/L). This piezometer is deeper than the other sampled piezometers and is located at the downstream end of a recently created man-made wetland. It is possible this sample represents a mixture of deeper (regional) and shallower (wetland influenced) water types.

All but two of the sampled wells (P11 and P13) had non-detectable concentrations of fecal coliform bacteria. The range of values found in groundwater (1U to 3UJ /100 ml) were always well below the surface water quality standard of 100 organisms/ 100 ml. This suggests groundwater is not a significant contributor of fecal coliform bacteria to the creek.

Discussion

Our initial intent for this sampling was to evaluate streambed water quality only at piezometer sites where groundwater was actively discharging to the creek during the July and September synoptic streamflow/ surface water quality surveys. The timing of the surveys precluded this possibility however. Candidate piezometers which had previously shown upward hydraulic gradients (GW discharge conditions) during the winter and spring transitioned to downward hydraulic gradients in early summer, prior to the established survey dates.

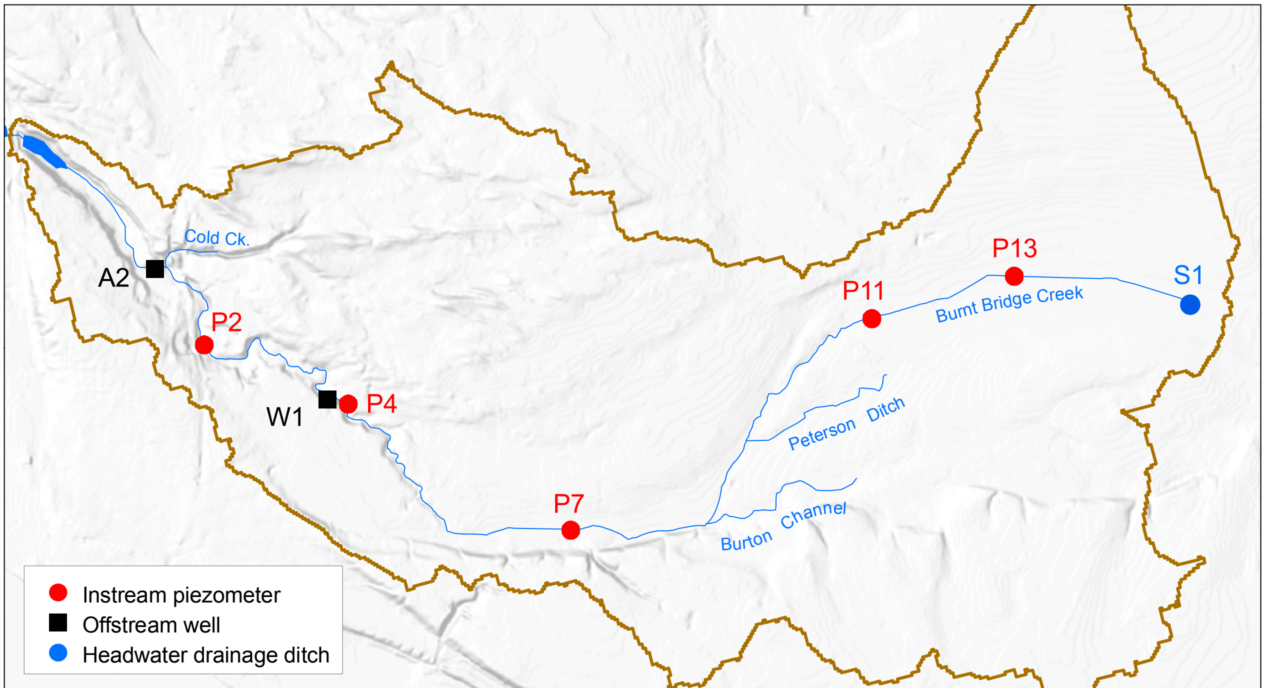
Given this complication we chose to sample piezometers which had previously exhibited groundwater discharge conditions during one or more of the previous field visits. This decision was based on the assumption that water entering the streambed (either from the stream or adjacent aquifers) quickly reaches bio-geo-chemical equilibrium with the surrounding streambed sediments. Since these sites actively transition between gaining and losing conditions seasonally we assume that the water we sampled is representative of groundwater quality at that location and depth within the streambed.

Radar plots such as those shown in Plate 2 provide a convenient visual framework for evaluating similarities or differences in chemical profile between individual samples or sites. For example off-stream wells A2 and W1 have geochemical profiles that closely match the overlying creek. This suggests that the creek is actively recharging groundwater at these locations. This interpretation is bolstered by the large negative head differences between the creek and regional groundwater at these locations (see Plate 1, Graphs W1 and A2).

In contrast most of the instream piezometer sites have lower concentrations of dissolved oxygen and nitrate, and higher concentrations of DOC, ammonia, and DTP than the creek. These differences manifest as geochemical signatures that are noticeably different from those of the creek. This suggests a different (perhaps shallower) origin for the piezometer water and/or the influence of additional geochemical processes such as redox-driven nitrogen and phosphorous-based transformations.

[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).

Since most of the sampled piezometers are completed a few feet below the streambed, the water quality values reported here do not account for biological or geochemical processes that can potentially attenuate nitrate and phosphorous concentrations in groundwater as it flows upward through the final few feet of streambed sediments (Hem, 1985; Jones and Mulholland, 2000). Accordingly, these values should be considered upper-bound estimates. The actual concentration of nitrate-N and phosphorous that enters the creek with discharging groundwater may be lower than reported here.



Sampling Location by map ID

Water Quality Parameter	A2	P2	W1	P4	P7	P11	P13	S1
Water Temperature (deg C)	12.95	15	10.75	15.65	13.6	13.95	15.5	13.15
pH (std units)	6.7	7.16	6.38	6.76	6.41	7.07	6.34	6.5
Specific conductance (us/cm @ 25C)	274	153.5	155.5	179	216	270	320	193
Dissolved Oxygen (mg/L)	6.34	0.615	9.06	0.38	0.3	0.31	0.34	8.95
Fecal coliform (#/100 ml)	1 U	1 U	1 U	1 U	1 U	2 J	2	22
Total Alkalinity (mg/L)	111 J	62.55 J	66.7 J	65.2	85.7	107	161	70.95
Total Chloride (mg/L)	6.64	4.72	3.38	4.78	5.07	5.98	5.95	3.66
Ortho-phosphate (mg/L) *	0.159	0.154	0.040	0.100	0.049	0.064	0.058	0.061
Total phosphorus (mg/L) *	0.1465	0.294	0.0335	0.572	0.027	0.221	0.348	0.053
Nitrate+nitrite-N (mg/L) *	2.75	0.014	2.09	0.0235	0.956	0.0215	0.025	3.51
Ammonia (mg/L) *	0.01 U	0.2	0.01 U	0.88	0.01 U	0.35	1.44	0.01 U
TPN-N (mg/L) *	2.78	0.29	2.325	0.938	0.995	0.4	2.82	3.36
Dissolved organic carbon (mg/L)	1 U	3.25 B	1 U	4.6 B	1.3 B	1.5 B	23.1	1U
Iron (mg/L) *	0.05 U	3.24	0.05 U	14.55	0.05 U	11.15	29.2	0.05 U
Approximate River Mile (RM)	1.6	2.6	4.2	4.3	7	10.4	11.4	12.8

* Dissolved sample fraction

Note: Sites P7 and P13 were sampled once in July 2009. The remaining sites were sampled twice in 2008 (July and September)
See the report glossory for an explanation of result qualifier codes

Figure 16. Average analyte concentrations in groundwater from sampled instream piezometers, domestic wells, and head-water springs

Summary and Conclusions

This study was undertaken to support a TMDL investigation of Burnt Bridge Creek, a small urban stream within the City of Vancouver. The primary study goals were to:

1. Assess the magnitude and direction of surface water/groundwater interactions along the creek, and

2. Characterize groundwater quality along gaining stream reaches.

Multiple field and analytical techniques were used to achieve these objectives. Baseflow seepage studies were conducted in July and September, 2008, to quantify net stream flow gains and losses along selected stream reaches. These reach-based evaluations were supplemented with information from a small network of off-stream wells and instream piezometers that were monitored to evaluate surface water/groundwater head relationships, streambed temperatures, and groundwater quality.

Collectively, these evaluations reveal that Burnt Bridge Creek is comprised of alternating gaining and losing stream reaches. During the July and September seepage evaluations the creek showed net overall gains from groundwater of approximately 2.14 and 3.08 ft^3/s respectively, between its headwaters near Orchards and its terminus at Vancouver Lake. The greatest gains were seen in the upper watershed, where groundwater enters the creek from shallow perched aquifers that were intercepted when the creek was initially dredged and channeled to aid local farming efforts. In the lower watershed streamflow, gains were generally smaller and are thought to originate mostly from seeps and small springs that emanate from the canyon walls that border the creek in this area.

Streamflow losses were concentrated along those reaches that had both a coarse-grained streambed (sand and gravel deposits) and downward (negative) hydraulic gradients between the stream and underlying groundwater.

The groundwater quality results for individual piezometers were generally consistent across multiple sampling events. Measurable concentrations of dissolved orthophosphate and dissolved total phosphorus were found in all piezometer samples at values ranging from 0.038 to 0.163 mg/L and 0.027 to 0.595 mg/L respectively. Concentrations of dissolved nitrate+nitrite-N and ammonia ranged from 0.011 to 3.52 and < 0.01 to 1.44 mg/L respectively. Nitrate+nitrite-N concentrations were highest at sites having oxygenated groundwater while ammonia concentrations were highest at sites where anoxic conditions occurred.

The water quality samples from off-stream wells and springs had concentrations similar to those observed at instream piezometer sites. However, the nitrate+nitrite-N concentrations were higher on average in off-stream wells (2.24 mg/L) than at instream piezometer sites (0.137 mg/L). This suggests that de-nitrification processes may be actively attenuating nitrate as it passes through the streambed sediments.

The water quality values reported here do not account for biological or geochemical transformations that can reduce phosphorous and nitrogen-based nutrient concentrations in groundwater as it passes through the final few feet of the streambed. Accordingly, these values are thought to represent the upper-bound range of nutrient concentrations that groundwater contributes to the creek locally.

Recommendations for Additional Study

As previously noted, the water quality values reported here do not account for biological or geochemical processes that can attenuate nutrient concentrations in discharging groundwater as it passes through the final few feet of streambed sediments. If future TMDL modeling efforts indicate a need to further constrain the nutrient concentrations reported here, it may be beneficial to attempt to quantify the potential influence of these processes where field conditions allow.

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Appendices

Appendix A. Data Quality Review

The data collected during this study were evaluated, prior to use, to ensure they met the project data quality objectives (Kardouni and Brock, 2008). The evaluation methods are described in the following sections.

Seepage Evaluations

To assess the potential measurement variability introduced by using multiple field teams and/or velocity meters, we conducted two types of replicate discharge measurements during the synoptic seepage evaluations of Burnt Bridge Creek. "Within-team" replicate measurements were made at five of 36 transects (14%) and consisted of back-to-back discharge measurements by a single field team. Four "between team" measurements were made at a common transect and consisted of approximate back-to-back measurements by two field teams using different velocity meters.

The results of this evaluation were generally favorable and showed good agreement for both between-team and within-team measurements (Table A-1). The mean RPD across all measurements was 5.37%, and averaged 2.8% and 8.6% for the within-team and between-team measurements respectively. While the mean RPD values met our project acceptance criteria (<10% RPD for paired measurements) two of the between-team paired measurements did not. This discrepancy is attributed to the many cobbles and boulders that blanketed the streambed at this site, which tend to reduce the accuracy and reproducibility of individual discharge measurements.

Table A-1: Field duplicate measurements for the July 29 and September 23, 2008 seepage evaluations for Burnt Bridge Creek

Site ID	Date	Time	Measured discharge (ft^3/sec)	Mean discharge (ft^3/sec)	Relative percent difference between measurements (RPD) [1]
Within-team Replicate Measurements					
PET00.0	7/29/08	15:43	2.57		
PET00.0	7/29/08	16:00	2.45	2.51	4.78
BBC08.4	7/29/08	11:42	4.31		
BBC08.4	7/29/08	12:15	4.13	4.22	4.27
BBC03.4	9/23/08	11:57	5.47		
BBC03.4	9/23/08	12:12	5.64	5.56	3.06
BBC05.2	9/23/08	14:24	4.88		
BBC05.2	9/23/08	14:39	4.83	4.86	1.03
BBC10.4	9/23/08	12:41	2.35		
BBC10.4	9/23/08	12:52	2.37	2.36	0.85
	Mean RPD (within-team measurements) =				2.80
Between-team Replicate Measurements					
BBC02.6	7/29/08	13:10	5.59		
BBC02.6	7/29/08	15:00	4.85	5.22	**14.18**
BBC02.6	7/29/08	15:00	4.85		
BBC02.6	7/29/08	16:50	5.40	5.13	**10.73**
BBC02.6	9/23/08	15:05	4.81		
BBC02.6	9/23/08	15:12	4.92	4.87	2.26
BBC02.6	9/23/08	15:05	4.81		
BBC02.6	9/23/08	15:05	5.17	4.99	7.21
	Mean RPD (between-team measurements) =				8.60

[1] RPD = Absolute value of [(M1-M2)/(M1+M2)/2] x 100, where M1 and M2 are the initial and replicate measurements respectively.
Bolded RPD values represent an exceedence of the project quality assurance target of <10% RPD for replicate measurements.

To aid data interpretation, we used a spreadsheet model to assess the potential effects of measurement error on the calculated reach-based-seepage budgets for Burnt Bridge Creek (Konrad and others, 2003). To perform the evaluation the transects for individual discharge measurements were assigned to one of four quality categories based on how well the local site conditions were thought to approximate those of an ideal transect at the time the measurements were made[8] (Table A2).

Table A-2: Rating categories for streamflow transects

Transect Catagory	Assumed potential measurement error
Excellent	±2% of actual flow
Good	±5% of actual flow
Fair	±7.5% of actual flow
Poor	±10% of actual flow

These transect assignments and associated measurement errors were used in the model to assess the cumulative measurement error and the corresponding confidence (or "uncertainty") interval around the calculated reach-based gain or loss. If the calculated exchange along the reach was greater than the resulting uncertainty interval then the reach likely experienced a "true" gain or loss. Where the calculated exchange was less than the model-predicted uncertainty interval, the exchange was not considered significant since it did not exceed the cumulative potential measurement error for the reach.

Based on this evaluation the exchanges along most reaches were typically greater than the calculated uncertainty interval and thus likely represent actual streamflow gains or losses (Figures 14 and 15 and Tables B1 and B2).

[8] An ideal measurement transect is one that lies on a straight reach where the stream substrate is relatively uniform with few large boulders or cobbles. The flow velocity should be greater than 0.5 ft/s and the minimum water depth greater than 0.5 feet. The flow should be uniform and evenly distributed across the transect with no eddies, slack water, or excessive turbulence (Rantz and others, 1982).

Verification 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 using the methods described by Bilhimer and Stohr, 2008. 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-3).

Table A-3: Thermistor model and manufacturer specifications.

Thermistor model	Temperature range	Accuracy	Resolution
Hobo water temp pro (Version 2)	-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 launch at a common start time and to subsequently measure and record temperature every minute thereafter. The programmed thermistors were then submerged in a constantly-stirred, room-temperature (warm) bath where they were allowed to equilibrate. A NIST[9] certified thermometer was then used to establish an accurate reference temperature for the warm bath against which the thermistor results could be compared. This was done by manually measuring the warm-bath temperature once per minute for a 10-minute period. After completing the warm-bath reference measurements the thermistors were transferred to an adjacent stirred ice bath. There they were again allowed to equilibrate before a second set of 10 manual reference measurements were made for this bath.

Average temperature values were calculated for each thermistor 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 individual thermistor accuracy.

[9] National Institute of Standards and Technology

Thermistors that did not meet our project acceptance criteria during the pre-deployment calibration check were not deployed. The post deployment evaluation showed that all thermistors continued to meet the manufacturers specified accuracy range for both ice-bath and room-temperature water conditions after deployment (Figure A-1). Accordingly, the temperature records they obtained were accepted and used without further qualification.

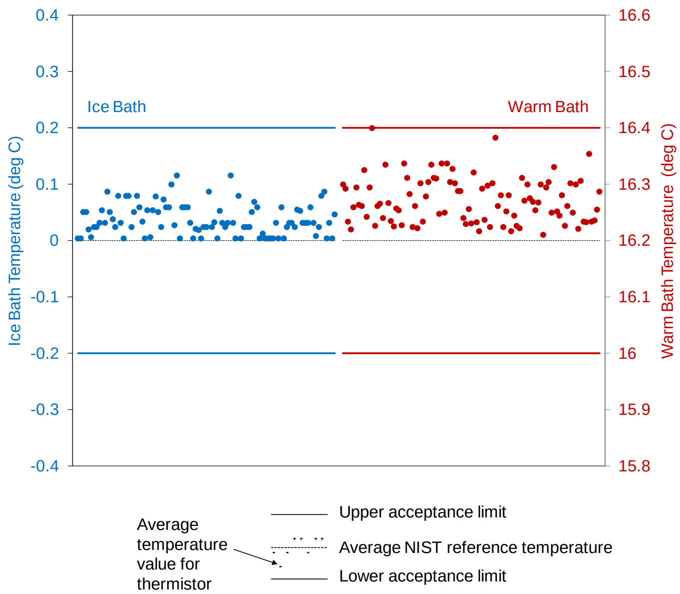

Figure A-1: Post-deployment thermistor calibration check graph.

Field-Meter Calibration and Verification

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.

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-4). 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 the meters were rechecked against reference standards to confirm they had not drifted unacceptably from the morning calibration. Based on this assessment the day's results for each parameter were either accepted, qualified as estimates, or rejected as unusable (Table A-4).

Based on this evaluation the dissolved oxygen results for July 14, 2009 were qualified as estimates due to an exceedance of post use calibration standards. The remaining results were acceptable and are reported here without further qualification.

Table A-4: Field meter calibration records for the 2008 and 2009 synoptic groundwater quality surveys.

		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]
7/29/2008	Pre-use	-58.4	-13	4.01	4	-0.01	Accept	1413	1436	1.6	Accept	1.03	9.62	101.8	Accept
				7	7.02	0.02	Accept	100	102	2.0	Accept				
	Post-use			4.01	4.02	0.01	Accept	1413	-	-	-	-	9.04	102.1	Accept
				7	7.02	0.02	Accept	100	102	2.0	Accept				
9/23/2008	Pre-use	-58.5	-9	4	4	0	Accept	1413	1432	1.3	Accept	0.9	9.61	101.6	Accept
				7	7.05	0.05	Accept	100	99	-1.0	Accept	-	-	-	-
	Post-use			4	3.99	-0.01	Accept	1413	-	-	-	-	8.41	100.9	Accept
				7	7.02	0.02	Accept	100	98	-2.0	Accept	-	-	-	-
7/14/2009	Pre-use	-57.7	-9	4.01	4.02	0.01	Accept	1413	1438	1.8	Accept	0.82	10.06	101.7	Accept
				7	7.04	0.04	Accept	102.5	102	0.1	Accept	-	-	-	-
	Post-use			4.01	4.01	0	Accept	-	-	-	-	-	8.97	106	**J qualify**
				7	6.98	-0.02	Accept	102.5	102	2.5	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 pH deviation from all standards = accept calibration
- > ± 0.05 pH 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 pH deviation from all standards = accept results
- > ±0.15 and ≤ ±0.5 pH deviation from any standard = qualify results as estimates ("J" code)
- > ±0.5 pH 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 clean 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 strict protocols to both ensure and later evaluate the quality of their analytical results (WA State Department of Ecology, 2008). Where appropriate, instrument calibration was performed by laboratory staff 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. Except as discussed below, all samples were processed and analyzed within accepted EPA holding times. Constituent 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-5). Data quality exceptions included:

- Two fecal coliform samples from July 2008 were not processed within the maximum sample holding time. These results for these samples were "J" coded by the laboratory and are reported as estimates.
- The alkalinity samples from September 2008 were also analyzed past accepted holding times and were qualified as estimates by the laboratory.
- The Orthophosphate results for seven samples were greater than the corresponding dissolved total phosphorous values – which was unexpected. Reasons for this discrepancy are not known. The results reported here are "J" qualified as estimates.

Table A-5: Data quality objectives for groundwater samples.

Parameter	Check standards (% recovery limits)	Field duplicate sample (%RSD)	Matrix spikes (% recovery limits)	Matrix spike duplicates (RPD)
Field Parameters				
pH	± 0.2 SU	± 0.1 SU	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	± 30 %	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
%RSD - percent relative standard deviation

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 other samples.

Precision for each of the field replicate and laboratory duplicate analyses was quantified by evaluating the percent relative standard deviation[11] (%RSD) for each duplicate sample pair. The resulting values (Table A-6) were then tabulated and compared to the project data quality objectives (Table A-5).

This evaluation revealed that the field blanks all contained small but measurable concentrations of DOC (1.3-1.6 mg/L) while the laboratory blanks were all less than the reporting limit of 1 mg/L. The cause of this discrepancy is not known, but was deemed significant enough to warrant qualification of all DOC values less than or equal to 5 times the reporting limit. The laboratory results for these wells were “B” coded by the authors to indicate that they are estimates and may potentially be biased high by field or laboratory contamination.

In addition, the July 29, 2008 field replicate samples for nitrate+nitrite-N and total persulfate nitrogen-N (TPN-N) both exceeded our target acceptance criteria of +- 10% RSD. Based on subsequent sampling events this appears to be an isolated incident. The July 29, 2008 results for these analytes were “J” coded by the authors to indicate they are estimates.

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

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[10] The term "blind" refers to "identical" samples that were submitted to the laboratory under different sample numbers, in order to maintain sample anonymity during laboratory analysis.

[11] Calculated for a pair of results, x_1 and x_2, as 100 * (S/Average of x_1 and x_2) where S is the standard deviation of the sample pair.

Table A-6: 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 Duplicate Samples and Equipment Blanks											
7/29/2008	Sample	109	6.87	1 U	0.159	0.147	2.59	0.01 U	2.74	1 U	0.05 U
	Rep/Duplicate	111	6.63	1 U	0.161	0.148	3.04	0.01 U	3.36	1 U	0.05 U
	%RSD	1.29	2.51	0.00	0.88	0.48	**11.30**	0.00	**14.37**	0.00	0.00
	Sample blank	5 U	0.10 U	**1.1**	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	1 U	0.05 U
9/23/2008	Sample	107 J	6.06	1.3	0.0732	0.209	0.021	0.345	0.396	1 U	11.2
	Rep/Duplicate	108 J	6.04	1.4	0.0742	0.206	0.02	0.35	0.379	1 U	11.1
	%RSD	0.66	0.23	5.24	0.96	1.02	3.45	1.02	3.10	0.00	0.63
	Sample blank	5 UJ	0.10 U	**1.3**	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	1 U	0.05 U
7/14/2009	Sample	85.7	5.07	1.3	0.0486	0.0267	0.956	0.01 U	0.995	1 U	0.05 U
	Rep/Duplicate	85.5	5.03	1.3	0.0459	0.0253	0.954	0.01 U	0.998	1 U	0.05 U
	%RSD	0.17	0.56	0.00	4.04	3.81	0.15	0.00	0.21	0.00	0.00
	Sample blank	5.0 U	0.10 U	**1.6**	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	1 U	0.05 U
Mean % RSD by analyte		0.70	1.10	1.75	1.96	1.77	4.97	0.34	5.90	0.00	0.21
Laboratory Replicates and Blanks											
7/29/2008	Sample	-	0.10 U	1.7	-	0.232	3.52	-	3.28	-	-
	Rep/Duplicate	-	0.10 U	1.7	-	0.23	3.46	-	3.36	-	-
	%RSD	-	0.00	0.00	-	0.61	1.22	-	1.70	-	-
	Sample blank	5 U	0.10 U	1 U	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	1 U	0.05 U
9/23/2008	Sample	5 UJ	6.41	3.2	-	-	-	-	0.264	1 U	-
	Rep/Duplicate	5 UJ	6.47	3.2	-	-	-	-	0.273	1 U	-
	%RSD	0.00	0.66	0.00	-	-	-	-	2.37	0.00	-
	Sample blank	5 U	0.10 U	1 U	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	-	0.05 U
7/14/2009	Sample	152	1.86	-	0.014	-	0.01 U	0.01 U	0.047	1 U	-
	Rep/Duplicate	153	1.84	-	0.0137	-	0.01 U	0.01 U	0.054	1 U	-
	%RSD	0.46	0.76	-	1.53	-	0.00	0.00	9.80	0.00	-
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.01 U	0.01 U	0.025 U	1 U	0.05 U

U -analyte not detected at or above the reported value.
J -analyte positively identified, the numeric result is an estimate.
UJ -analyte not detected at or above the reported estimated value.
Shaded values indicate an exceedence of the project quality assurance 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

The data for this study are archived in EIM under the following study name and user study ID:

EIM study name:

Burnt Bridge Creek Fecal Coliform Bacteria, Dissolved Oxygen, and Temperature total Maximum Daily Load Technical Study

EIM user study ID:

STEB0002

To meet EIM protocols, the continuous temperature records for the creek and streambed thermistors were summarized as daily maximum, minimum, and average values before uploading to EIM. The continuous (30-minute interval) temperature records that are depicted graphically on Plate 1 are available by request.

Table B-1: Summary of the July 29, 2008 Seepage Survey of Burnt Bridge Creek.

Map ID [A]	Mainstem Station Description	Site ID	River Mile	Reach Length (miles)	Tributary Name	Measurement Date	Measured Discharge [B] (Ft^3/sec)	Net Seepage Gain or loss for reach [C] (Ft^3/s)	Net Seepage Gain or loss for reach [C] (Ft^3/s/river mile)	Is reach measured gain or loss significant [D]
S1	Burnt Bridge Ck at 162nd Ave.	28BBCK12.7	12.7			07/29/208	0.00			
				1.3				3.25	2.50	Y
P13	Burnt Bridge Ck at 131st Ave.	28BBCK11.4	11.4			7/29/2008	3.25			
				0.6				1.72	2.87	Y
P12	Burnt Bridge Ck at 121st Ave	28BBCK10.8	10.8			7/29/2008	4.97			
				0.4				-1.92	-4.80	Y
P11	Burnt Bridge Ck at 110th Ave	28BBCK10.4	10.4			7/29/2008	3.05			
				0.9				0.24	0.27	Y
P10	Burnt Bridge Ck at 98th Ave	28BBCK09.5	9.5			7/29/2008	3.29			
				0.7				-1.00	-1.43	Y
P9	Burnt Bridge Ck at 93rd Ave	28BBCK08.8	8.8			7/29/2008	2.29			
				0.4	Peterson Channel	7/29/2008	2.57	-0.55	-1.38	Y
P8	Burnt Bridge Ck near Burton Rd	28BBCK08.4	8.4			7/29/2008	4.31			
				0.4	Burton Channel	7/29/2008	0.1 e	0.31	0.78	N
	Burnt Bridge Ck at 87th Ave	28BBCK08.0	8.0			7/29/2008	4.72			
				1.0				1.49	1.49	Y
P7	Burnt Bridge Ck at 65th Ave	28BBCK07.0	7.0			7/29/2008	6.21			
				1.1				-1.53	-1.39	Y
P6	Burnt Bridge Ck at 18th street	28BBCK05.9	5.9			7/29/2008	4.68			
				0.7				-0.13	-0.19	N
P5	Burnt Bridge Ck at Rossiter Lane	28BBCK05.2	5.2			7/29/2008	4.55			
				0.9				1.02	1.13	Y
P4	Burnt Bridge Ck at St. Johns Blvd.	28BBCK04.3	4.3			7/29/2008	5.57			
				0.9				0.66	0.73	Y
P3	Burnt Bridge Ck at 41st Circle	28BBCK03.4	3.4			7/29/2008	6.23			
				0.8				-0.64	-0.80	Y
P2	Burnt Bridge Ck at Leverich Park	28BBCK02.6	2.6			7/29/2008	5.59			
				1.0	Cold Creek	7/29/2008	0.37	**0.30**	0.30	N
P1	Burnt Bridge Ck at 2nd Ave	28BBCK01.6	1.6			7/29/2008	6.26			
				1.6				-1.08	-0.68	Y
	Burnt Bridge Ck at Vancouver Lk.	28BBCK00.0	0.0			7/29/2008	5.18			

[A] The listed map ID corresponds to that shown on Figure 1 of Plate 1

[B] e - flow estimated

[C] See the report study methods section for a description of the seepage calculation

[D] N - The net seepage gain or loss did not exceed the potential cumulative measurement errors associated with making the measurements. The indicated gain or loss is not significant.
Y - The net seepage gain or loss exceeded the potential cumulative measurement errors associated with making the measurements. The gain or loss is considered significant.

Table B-2: Summary of the September 23, 2008 Seepage Survey of Burnt Bridge Creek.

Map ID [A]	Mainstem Station Description	Site ID	River Mile	Reach Length (miles)	Tributary Name	Measurement Date	Measured Discharge [B] (Ft^3/sec)	Net Seepage Gain or loss for reach [C] (Ft^3/s)	Net Seepage Gain or loss for reach [C] (Ft^3/s/river mile)	Is reach measured gain or loss significant [D]
S1	Burnt Bridge Ck at 162nd Ave.	28BBCK12.7	12.7			9/23/2008	0.00			
				1.3				2.33	1.79	Y
P13	Burnt Bridge Ck at 131st Ave.	28BBCK11.4	11.4			9/23/2008	2.33			
				0.6				0.40	0.67	Y
P12	Burnt Bridge Ck at 121st Ave	28BBCK10.8	10.8			9/23/2008	2.73			
				0.4				-0.38	-0.95	Y
P11	Burnt Bridge Ck at 110th Ave	28BBCK10.4	10.4			9/23/2008	2.35			
				0.9				0.33	0.37	Y
P10	Burnt Bridge Ck at 98th Ave	28BBCK09.5	9.5			9/23/2008	2.68			
				0.7				-0.57	-0.81	Y
P9	Burnt Bridge Ck at 93rd Ave	28BBCK08.8	8.8			9/23/2008	2.11			
				0.4	Peterson Channel	9/23/2008	1.88	-0.34	-0.85	Y
P8	Burnt Bridge Ck near Burton Rd	28BBCK08.4	8.4			9/23/2008	3.65			
				0.4	Burton Channel	9/23/2008	0.1 e	1.66	4.15	Y
	Burnt Bridge Ck at 87th Ave	28BBCK08.0	8.0			9/23/2008	5.41			
				1.0				-0.24	-0.24	N
P7	Burnt Bridge Ck at 65th Ave	28BBCK07.0	7.0			9/23/2008	5.17			
				1.1				-0.07	-0.06	N
P6	Burnt Bridge Ck at 18th street	28BBCK05.9	5.9			9/23/2008	5.10			
				0.7				-0.22	-0.31	N
P5	Burnt Bridge Ck at Rossiter Lane	28BBCK05.2	5.2			9/23/2008	4.88			
				0.9				1.35	1.50	Y
P4	Burnt Bridge Ck at St. Johns Blvd.	28BBCK04.3	4.3			9/23/2008	6.23			
				0.9				-0.76	-0.84	Y
P3	Burnt Bridge Ck at 41st Circle	28BBCK03.4	3.4			9/23/2008	5.47			
				0.8				-0.66	-0.83	Y
P2	Burnt Bridge Ck at Leverich Park	28BBCK02.6	2.6			9/23/2008	4.81			
				1.0	Cold Creek	9/23/2008	0.40	0.56	0.56	Y
P1	Burnt Bridge Ck at 2nd Ave	28BBCK01.6	1.6			9/23/2008	5.77			
				1.6				-0.32	-0.20	N
	Burnt Bridge Ck at Vancouver Lk.	28BBCK00.0	0.0			9/23/2008	5.45			

[A] The listed map ID corresponds to that shown on Figure 1 of Plate 1

[B] e - flow estimated

[C] See the report study methods section for a description of the seepage calculation

[D] N - the net seepage gain or loss did not exceed the potential cumulative measurement errors associated with making the measurements. The indicated gain or loss is not significant.
Y - The net seepage gain or loss exceeded the potential cumulative measurement errors associated with making the measurements. The gain or loss is considered significant.

Table B-3: Physical description and location of instream piezometers.

Map ID [1]	Well tag ID number	Approximate river mile location (mile)	Well location	Latitude (decimal degrees)	Longitude (decimal degrees)	Site Elevation (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)	Thermistor deployment depths within piezometer (feet below streambed)
P13	AKY457	11.4	02N/02E-15A	45.66308	-122.53808	200	2.75	4.6	0.28	4.40	1.26 2.46 4.10
P12	AKY458	10.8	02N/02E-15F	45.66031	-122.54881	199	1.91	3.4	0.3	3.16	1.14 1.96 2.98
P11	AKY459	10.4	02N/02E-16H	45.65809	-122.55974	201	2.69	4.5	0.39	4.32	1.00 2.48 3.89
P10	AKY460	9.5	02N/02E-16P	45.65148	-122.57191	190	2.82	4.2	0.44	3.90	1.44 2.49 3.56
P9	AKY461	8.8	02N/02E-21E	45.64468	-122.57837	182	0.92	4.4	0.27	4.19	1.50 2.87 3.95
P8	AKY462	8.4	02N/02E-20R	45.63802	-122.58246	173	1.15	4.1	0.32	3.93	1.44 2.53 3.63
P7	AKY463	7	02N/02E-30A	45.63456	-122.60497	168	3.3	8.1	0.3	7.89	1.92 5.17 7.55
P6	AKY464	5.9	02N/01E-25A	45.63469	-122.62405	164	1.9	4.8	0.31	4.51	1.39 2.71 4.26
P5	AKY468	5.2	02N/01E-24L	45.64112	-122.63094	136	1.84	4.7	0.47	4.44	1.30 2.52 4.13
P4	AKY466	4.3	02N/01E-24D	45.64745	-122.63946	122	1.55	3.7	0.31	3.48	1.04 2.37 3.27
P3	AKY465	3.4	02N/01E-14Q	45.65250	-122.65034	83	2.05	5.1	0.29	4.89	1.35 2.89 4.52
P2	AKY456	2.6	02N/01E-15J	45.65339	-122.66180	64	2.13	4.8	0.51	4.41	0.95 2.60 4.33
P1	AKY455	1.6	02N/01E-15C	45.66137	-122.66934	43	3.96	5.1	0.3	4.82	0.97 2.73 4.53

[1] - The map IDs listed here correspond with those shown on Plate 1

Table B-4: Summary of water levels, field water quality results, and streambed hydraulic gradients measured at instream piezometer sites.

Map ID [1]	Well tag ID number	Site Location	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	(Iv) Vertical Hydraulic Gradient (dh/dl) [2] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments (m/s)
P13	AKY457	131st Ave	06/02/2008	11:50	12.3	14	180	-	-0.433	2.06E-06
			06/16/2008	15:45	16.3	-	187	-	-0.222	
			07/15/2008	9:00	14.0	-	196	-	-0.546	
			07/28/2008	12:13	14.1	-	197	-	-0.632	
			08/12/2008	9:00	-	-	-	-	-0.713	
			08/26/2008	16:03	15.0	15.9	193	-	-0.609	
			09/22/2008	16:00	13.8	15.8	196	-	-0.786	
			10/21/2008	11:50	13.3	14.6	196	-	-0.673	
			11/25/2008	15:40	9.3	-	186	-	0.020	
			01/26/2009	9:15	5.9	11.3	-	-	0.079	
			03/10/2009	9:55	7.7	-	149	-	0.084	
			05/04/2009	11:15	10.7	-	165	-	0.111	
			06/15/2009	11:50	13.6	-	177	-	-0.337	
			07/13/2009	11:00	13.6	15.5	194	320	-0.446	
			08/19/2009	15:35	17.5	16.3	-	-	-0.036	
			09/15/2009	12:02	14.9	16.4	-	-	-0.621	
P12	AKY458	121st Ave	06/02/2008	12:27	12.2	12.4	187	-	-0.791	2.50E-07
			06/16/2008	16:30	15.1	-	187	-	-0.722	
			07/15/2008	10:10	15.6	-	195	-	-0.687	
			07/28/2008	12:38	15.0	-	196	-	-0.699	
			08/12/2008	9:33	-	-	-	-	-0.709	
			08/26/2008	15:40	15.4	14.9	192	-	-0.722	
			09/22/2008	16:25	14.1	14.1	196	-	-0.905 L	
			10/21/2008	11:05	10.7	12.5	191	-	-0.994 L	
			11/25/2008	15:00	8.8	11.4	185	-	-1.073 L	
			01/26/2009	10:00	5.6	8.7	-	-	-1.136 L	
			03/10/2009	10:25	7.4	-	148	-	-1.098 L	
			05/04/2009	12:32	10.9	-	165	-	- 1.076 L	
			06/15/2009	12:55	14.6	-	179	-	-1.18 L	
			07/13/2009	12:50	14.3	-	-	-	- 1.076 L	
P11	AKY459	110th Ave	06/02/2008	16:08	13.1	12.1	183	-	-0.012	2.39E-06
			06/16/2008	17:05	14.1	-	186	-	-0.007	
			07/15/2008	10:55	16.6	-	192	-	-0.014	
			07/28/2008	12:55	15.7	-	193	-	0.002	
			07/29/2008	7:54	15.5	13.8	192	273	-0.007	
			08/12/2008	12:24	-	-	-	-	-0.012	
			08/26/2008	15:09	15.5	13.9	189	-	0.000	
			09/23/2008	14:28	13.3	14.1	192	267	-0.009	
			10/21/2008	10:26	10.6	12.4	191	-	-0.007	
			11/25/2008	14:39	8.8	-	181	-	0.007	
			01/26/2009	10:55	5.6	10.3	-	-	0.012	
			03/10/2009	11:16	7.1	-	147	-	0.009	
			05/04/2009	13:30	11.2	-	163	-	0.000	
			06/15/2009	13:40	15.4	-	177	-	0.002	
			07/13/2009	13:35	-	-	-	-	0.000	
			08/19/2009	14:40	18.2	14.2	-	-	0.000	
			09/15/2009	14:10	16.4	14.6	-	-	0.007	

Table B-4: continued

Map ID [1]	Well tag ID number	Site Location	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	(Iv) Vertical Hydraulic Gradient (dh/dl) [2] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments (m/s)
P10	AKY460	98th Ave	06/02/2008	16:42	13.3	11.9	183	-	-0.946	9.42E-06
			06/16/2008	17:38	14.7	-	185	-	-0.900	
			07/15/2008	12:25	17.6	-	190	-	-1.09 L	
			07/28/2008	13:19	16.8	-	192	-	-1.0 L	
			08/12/2008	13:20	-	-	-	-	-1.105 L	
			08/26/2008	14:34	16.5	15.5	187	-	-0.887	
			09/22/2008	17:05	14.6	14.7	193	-	-1.202 L	
			10/21/2008	9:45	10.5	-	192	-	-1.118 L	
			11/25/2008	14:15	8.5	-	183	-	-0.775	
			01/26/2009	11:50	6.3	8.9	-	-	-0.675 L	
			03/10/2009	12:40	-	-	-	-	-0.824 L	
			05/04/2009	14:50	11.4	-	162	-	-0.522 L	
			06/15/2009	14:49	17.3	-	177	-	-0.944 L	
			07/13/2009	15:07	16.2	-	-	-	-1.23 L	
			08/19/2009	14:15	19.6	16.7	-	-	-0.872 L	
			09/15/2009	14:33	18.0	16.2	-	-	-1.077 L	
P9	AKY461	93rd Ave	06/02/2008	14:38	15.3	14	182	-	-0.788	9.75E-05
			06/16/2008	18:11	17.0	-	184	-	-0.823 L	
			07/15/2008	13:30	20.2	-	188	-	-0.807 L	
			07/28/2008	13:44	19.6	15.7	191	-	-0.881 L	
			08/12/2008	14:00	-	-	-	-	-0.778 L	
			08/26/2008	14:05	18.3	16.1	181	-	-0.785 L	
			09/22/2008	17:36	15.6	15.5	197	-	-0.788 L	
			10/21/2008	9:07	10.1	13.2	190	-	-0.771 L	
			11/25/2008	13:50	8.2	11.5	180	-	-0.905 L	
			01/26/2009	12:35	7.2	9.7	-	-	-0.795 L	
			03/10/2009	13:22	7.3	-	148	-	-0.771 L	
			05/04/2009	15:15	12.0	-	158	-	-0.74 L	
			06/15/2009	15:35	20.5	-	178	-	-0.759 L	
			07/13/2009	15:47	18.0	-	-	-	-0.771 L	
			08/19/2009	13:45	22.9	17.2	-	-	-1.033 L	
			09/15/2009	15:08	20.6	16.4	-	-	-1.029 L	
P8	AKY462	Burton Rd.	06/02/2008	13:47	15.8	14.5	192	-	-1.201	4.77E-05
			06/17/2008	8:53	14.3	-	192	-	-1.262 L	
			07/15/2008	14:20	20.9	-	203	-	-1.209 L	
			07/28/2008	14:21	19.5	17.5	204	-	-1.211 L	
			08/12/2008	15:30	-	-	-	-	-1.221 L	
			08/26/2008	13:27	17.9	18.2	191	-	-1.219 L	
			09/22/2008	14:40	15.8	16.5	198	-	-1.226 L	
			10/21/2008	8:30	10.9	-	201	-	-1.211 L	
			11/25/2008	13:30	9.3	11.2	188	-	-1.204 L	
			01/26/2009	13:48	7.5	8.2	-	-	-1.244 L	
			03/10/2009	14:21	8.8	-	152	-	-1.221 L	
			05/04/2009	16:28	12.7	-	164	-	-1.249 L	
			06/15/2009	16:45	14.5	-	188	-	-1.198 L	
			07/13/2009	16:40	-	-	-	-	-1.193 L	
			08/19/2009	13:02	20.2	18.7	-	-	-1.173 L	
			09/15/2009	15:11	16.8	17.6	-	-	-1.163 L	

Table B-4: continued

Map ID [1]	Well tag ID number	Site Location	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	(Iv) Vertical Hydraulic Gradient (dh/dl) [2] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments (m/s)
P7	AKY463	65th Ave	06/02/2008	17:27	17.4	12.4	194	-	-0.010	7.22E-05
			06/17/2008	9:53	14.8	-	194	-	0.006	
			07/15/2008	15:45	23.5	-	203	-	-0.003	
			07/28/2008	14:47	22.7	-	204	-	-0.034	
			08/13/2008	8:20	-	-	-	-	-0.077	
			08/26/2008	12:50	19.6	13.7	179	-	-0.082	
			09/23/2008	13:45	16.4	13.8	201	-	-0.125	
			10/20/2008	17:00	-	-	-	-	-0.084	
			11/25/2008	13:08	7.4	-	189	-	0.003	
			01/27/2009	8:45	4.2	10.6	-	-	0.056	
			03/10/2009	15:57	8.6	-	151	-	0.022	
			05/05/2009	10:50	12.0	-	79	-	-0.103	
			06/16/2009	9:52	18.1	-	192	-	0.000	
			07/14/2009	9:20	16.8	13.6	194	216	-0.067	
			08/19/2009	12:26	23.6	13.2	-	-	-0.085	
			09/15/2009	14:00	21.9	13.9	-	-	-0.057	
P6	AKY464	18th St	06/02/2008	18:00	16.4	13.8	186	-	-0.313	5.12E-05
			06/17/2008	10:25	15.6	-	195	-	-0.322	
			07/16/2008	8:55	18.3	-	202	-	-0.326	
			07/28/2008	15:11	19.6	-	202	-	-0.337	
			08/13/2008	9:15	-	-	-	-	-0.344	
			08/26/2008	12:23	17.4	18.4	172	-	-0.339	
			09/22/2008	14:03	15.2	17	209	-	-0.412	
			10/20/2008	16:38	-	-	-	-	-0.408	
			11/25/2008	12:44	7.1	-	186	-	-0.361	
			01/26/2008	15:05	5.3	8.3	-	-	-0.224	
			03/10/2009	16:32	7.8	-	150	-	-0.355	
			05/05/2009	11:35	12.3	-	76	-	-0.397	
			06/16/2009	10:40	17.5	-	193	-	-0.335	
			07/14/2009	10:50	16.8	-	173	-	-0.366	
			08/19/2009	12:05	21.1	19.1	-	-	-0.375	
			09/15/2009	11:00	17.6	18.3	-	-	-0.386	
P5	AKY468	Rossiter Ln.	06/02/2008	18:30	15.8	13.7	188	-	-0.120	5.35E-06
			06/17/2008	10:48	15.7	-	196	-	-0.138	
			07/16/2008	9:35	18.2	-	202	-	-0.122	
			07/28/2008	15:33	19.3	-	205	-	-0.129	
			08/13/2008	10:20	-	-	-	-	-0.122	
			08/26/2008	11:44	17.3	17.3	174	-	-0.122	
			09/22/2008	13:32	15.2	16.3	207	-	-0.125	
			10/20/2008	15:58	-	-	-	-	-0.127	
			11/25/2008	12:20	7.3	-	187	-	-0.131	
			01/27/2009	9:40	-	-	-	-	-0.142	
			03/11/2009	15:35	8.1	-	157	-	-0.120	
			05/05/2009	12:28	12.4	-	78	-	-0.154	
			06/16/2009	11:25	17.8	-	194	-	-0.122	
			07/14/2009	11:50	17.0	-	-	-	-0.125	
			08/19/2009	11:40	20.6	17.7	-	-	-0.120	
			09/16/2009	10:32	18.6	17.5	-	-	-0.131	

Table B-4: continued

Map ID [1]	Well tag ID number	Site Location	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	(Iv) Vertical Hydraulic Gradient (dh/dl) [2] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments (m/s)
P4	AKY466	St Johns Blvd.	06/03/2008	18:50	15.3	-	97	-	0.003	7.26E-06
			06/17/2008	11:20	15.7	-	198	-	-0.003	
			07/16/2008	10:15	18.3	-	205	-	-0.003	
			07/29/2008	14:12	17.6	16	212	180	-0.011	
			08/13/2008	10:50	-	-	-	-	-0.011	
			08/26/2008	11:07	17.0	16.1	176	-	0.003	
			09/23/2008	10:45	13.3	15.3	178	181	-0.006	
			10/20/2008	15:16	-	-	-	-	-0.009	
			11/25/2008	11:46	7.0	-	189	-	-0.003	
			01/27/2009	10:20	-	-	-	-	-0.006	
			03/11/2009	14:46	7.9	-	159	-	0.000	
			05/05/2009	13:10	12.9	-	83	-	0.000	
			06/16/2009	12:03	18.1	-	196	-	-0.009	
			07/14/2009	12:30	17.7	-	-	-	-0.006	
			08/19/2009	11:05	20.0	16.3	-	-	-0.009	
			09/16/2009	11:17	18.3	16.3	-	-	-0.011	
P3	AKY465	41st circle	06/03/2008	18:00	15.3	-	102	-	-	2.72E-06
			06/17/2008	12:06	15.9	-	200	-	-0.859 L	
			07/16/2008	11:00	18.9	-	206	-	-0.863 L	
			07/28/2008	16:00	20.5	15.2	212	-	-0.875 L	
			08/13/2008	11:00	-	-	-	-	-0.902 L	
			08/26/2008	10:32	16.7	14.9	172	-	-0.951 L	
			09/22/2008	12:56	15.5	14.6	206	-	-0.998 L	
			10/20/2008	14:20	-	-	-	-	-1.016 L	
			11/25/2008	11:05	6.5	-	190	-	-0.726 G	
			01/27/2009	11:05	-	-	-	-	-0.892	
			03/11/2009	11:38	6.1	-	161	-	-0.806	
			05/05/2009	14:10	13.2	-	82	-	-0.726 G	
			06/16/2009	12:40	-	- -	-	-	-0.593 G	
			07/14/2009	13:15	17.8	-	-	-	-0.865 L	
			08/19/2009	10:37	19.6	15.3	-	-	-0.908 L	
			09/16/2009	13:00	18.8	15.4	-	-	-1.209 L	
P2	AKY456	Leverich Park	06/02/2008	17:40	15.6	12.5	196	-	-0.007	6.98E-07
			06/17/2008	13:03	15.8	-	200	-	-0.009	
			07/16/2008	11:40	18.9	-	205	-	-0.007	
			07/28/2008	16:27	20.0	15.8	-	-	-0.004	
			07/29/2008	12:47	17.4	15.8	212	161	-0.009	
			08/13/2008	12:30	-	-	-	-	-0.011	
			08/26/2008	9:58	16.7	16	169	-	-0.007	
			09/22/2008	12:38	12.3	14.2	200	146	-0.007	
			10/20/2008	13:16	-	-	-	-	-0.009	
			11/25/2008	10:48	6.3	-	189	-	-0.002	
			01/27/2009	11:50	-	-	-	-	-0.007	
			03/11/2009	10:52	5.4	-	159	-	0.000	
			05/05/2009	15:03	13.3	-	82	-	-0.038 L	
			06/16/2009	13:25	18.1	-	198	-	-0.002	
			07/14/2009	14:30	18.0	-	-	-	-0.009	
			08/19/2009	10:10	18.9	16.4	-	-	-0.011	
			09/16/2009	13:48	18.2	16.2	-	-	-0.011	

Table B-4: continued

Map ID [1]	Well tag ID number	Site Location	Sample Date	Sample Time	Temperature (°C) River water	Ground water	Specific Conductance µS/cm@25°C River water	Ground water	(Iv) Vertical Hydraulic Gradient (dh/dl) [2] (L/L)	(Kv) Estimated vertical hydraulic conductivity of streambed sediments (m/s)
P1	AKY455	2nd St	06/02/2008	19:10	15.4	12.2	199	-	-0.281	3.66E-07
			06/17/2008	13:30	15.7	-	202	-	-0.175	
			07/16/2008	12:35	19.2	-	208	-	-0.231	
			07/28/2008	16:50	19.7	-	217	-	-0.288	
			08/13/2008	13:10	-	-	-	-	-0.281	
			08/26/2008	9:18	16.1	15.6	175	-	-0.271	
			09/22/2008	11:50	14.7	15.3	201	-	-0.279	
			10/20/2008	12:01	11.4	14	201	-	-0.267	
			11/25/2008	10:08	6.3	-	192	-	-0.190	
			01/27/2009	12:40	-	-	-	-	-0.154	
			03/11/2009	10:02	5.1	-	161	-	-0.207 G	
			05/05/2009	16:10	13.2	-	84	-	-0.285	
			06/16/2009	14:27	17.2	-	201	-	-0.258	
			07/14/2009	15:12	18.3	-	-	-	-0.296	
			08/19/2009	9:35	18.0	15.9	-	-	-0.283	
			09/16/2009	14:22	17.9	16	-	-	-0.302	

[1] The map IDs listed here correspond with those shown on Plate 1

[2] Negative values indicate potential loss of stream water to groundwater storage. Positive values indicate groundwater discharge to the stream.

L - The piezometer water level was slowly recovering during measurement. The hydraulic gradient reported here is an estimate. The true value is less than the reported value by an unknown amount.

G - The piezometer water level was slowly dropping during measurement. The hydraulic gradient reported here is an estimate. The true value is greater than the reported value by an unknown amount.

Table B-5: Physical description of wells used to construct geologic cross sections

Geologic cross section ID [1]	Well ID number	Well location	Site latitude (decimal degrees)	Site longitude (decimal degrees)	Approximate land surface elevation at well head (feet)	Construction date	Completed well depth (feet)	Maximum casing diameter (inches)	Well completion type and open interval (feet)[2]
A1	900405	02N/01E-15Q01	45.65204	-122.64176	217	1945	278	18	P(232-240, 245-260)
A2	AHT045	02N/01E-15	45.66127	-122.66968	39	1989	78	6	S(73-77)
A4	AAF450 (5134)	02N/01E-15A	45.66173	-122.66197	175	1970	244	16	S(164-180, 185-205)
A5	5118	02N/01E-11P	45.66554	-122.65549	224	1979	46	6	P(31-45)
B1	900409	02N/01E-23Q	45.63693	-122.64702	183	1943	243	18	P(203-238)
B2	APJ508	02N/01E-23H	45.64559	-122.64222	165	2008	26	-	S(16-26)
B3	ALM697	02N/01E-23A	45.64685	-122.64172	145	2007	90	1	S(80-90)
B4	ALM696	02N/01E-24A	45.64759	-122.64074	103.6	2007	40	1	S(30-40)
B5	ABN572 (mw-18)	02N/01E-14R	45.65061	-122.64180	165.6	1994	13.5	4	S(3.5-13.5)
B6	AFT701 (mw-23)	02N/01E-13N	45.65196	-122.63948	237.4	2000	56.5	2	S(36.5-56.5)
B7	Time MW-8	02N/01E-13G	45.65279	-122.63780	241.5	1993	50	2	S(35-50)
B8	Time MW-1	02N/01E-13N	45.65371	-122.63616	236.5	-	35	4	S(20-35)
B9	5127	02N/01E-13L	45.65484	-122.63351	247	1973	404	8	P(365-379,382-390,390-401)
C1	500194 (park hill cem)	02N/02E-30C	45.62766	-122.61003	292	-	284	16	P(239-255, 260-275)
C2	FHA (Ogden meadows)	02N/02E-30C	45.63234	-122.61370	184	-	300	12	P(118-122,124-130,188-194,204-215,240-243,250-255)
C3	AHE556 (pz-1)	02N/02E-30A	45.63419	-122.60940	163	2002	20	2	S(15-20)
C4	APN060	02N/02E-19L	45.63941	-122.61036	187	2006	30	2	S(25-30)
C5	APN058	02N/02E-19L	45.64306	-122.60847	187	2006	29	2	S(24-29)
C6	KDB holding LLC.	02N/02E-19	46.64544	-122.60141	210	1984	117	6	S(107-117)
D1	500192	02N/02E-28L	45.63085	-122.57023	306	1976	272	8	S(262-267, 267-272)
D2	Laws, R.A.	02N/02E-21N	45.6365	-122.57483	194	1955	60	6	O
D3	500182	02N/02E-21M	45.63925	-122.57706	185	1982	90	6	S(85-90)
D4	3555	02N/02E-20M	45.64036	-122.57681	186	1983	53.3	6	O
D5	Vancouver housing	02N/02E-21M	45.64152	-122.57672	182	1985	68	6	O
D6	Hoss	02N/02E-21E	45.6428	-122.57707	181	1983	53.5	6	O
D8	500181	02N/02E-20A	45.64848	-122.58063	212	-	221	12	P(65-96, 170-198, 200-216
E1	074CLR (SEH well 2))	02N/02E-15	45.653446	-122.55482	200	1988	197	12	S(96-101, 117-122, 136-181)
E2	Oak Ck Mobile home	02N/02E-15	45.65979	-122.54912	197	1989	138	6	S (128-138)
E5	Speed	02N/02E-10	45.66696	-122.53850	199	1987	75	6	O
E6	Stevens	02N/02E-10	45.66818	-122.53848	201	1989	113	6	O
E7	500176	02N/02E-11	45.67196	-122.53444	214	1982	20	10	O
E8	500177	02N/02E-11	45.67547	-122.53033	234	1957	155	6	O
W1	APJ519	02N/01E-24D	45.64781	-122.64273	103	2008	30.5	1	S (15.5-30.5)

[1] - The IDs listed here correspond with those shown on Plate 1, cross sections A-A' through E-E'.

[2] - Completion type and open interval: S - screened; O - open bottom casing; P - perforated well casing

Table B-6: Drillers lithologic logs for wells used to construct geologic cross sections.

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
A1	900405	4/3/1989	209.5	Soil	3	3	
				Gravel, pea	59	62	
				Sand, very fine, packed	140	202	
				Gravel, sand, WB	10	212	
				Sand, WB	12	224	
				Sand and coarse gravel, WB	16	240	
				Gravel, fine	27	267	US
				Gravel with fine yellow silt binder	11	278	TG
A2	AHT045	11/1/1989	29.5	Fill sand and gravel	3	3	
				Sand, brown	11	14	
				Silty sand, gray, with some cobbles	4	18	
				Medium Sand, brown	20	38	
				Sand, gravel, and cobbles	20	58	
				Coarse sand and gravel, WB	20	78	US
A3	AKY455	-	-	Sand and silt, compact	5.1	5.1	Qa
A4	AAF450	3/30/1989	158	Soil	10	10	
				Sand and sandy silt	110	120	
				Silt, medium brown	26	146	
				Sand and gravel	12	158	US
				Gravel, cemented	17	175	
				Gravel, WB	6	181	
				Sand and gravel, WB	37	218	
				Gravel, WB	26	244	TG
A5	5118	3/30/1989	29.2	Topsoil	2	2	
				Sand, fine, silty	23	25	
				Sand, fine to medium	5	30	
				Sand, fine to medium, WB	16	46	
				Clay, sandy-fine	5	51	US

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
B1	900409	3/31/1989	189.9	Topsoil	2	2	
				Sand and silt	43	45	
				Sand, coarse and pea gravel	127	172	
				Sand, fine, and some gravel	18	190	
				Sand and gravel, WB	44	234	US
				Gravel with clay binder	9	243	TG
B2	APJ508	6/19/2008	23.7	Silty gravel and sand, dark brown, moist, loose	5	5	
				Silty sand with gravel, dark brown, moist, loose	7	12	
				Sand with some silt, loose dark gray-brown, moist	3	15	
				Sand with some gravel, trace silt, loose, dark gray brown, moist	5	20	
				Sand, dark gray-brown, loose, moist	6	26	US
B3	ALM697	6/19/2008	87.5	Sand, silty and gravel	4	4	
				Gravel, silty and sand, brown, very loose, moist	6	10	
				Sand, brown, medium dense to dense, moist	30	40	
				Sand, brown, with sandy-silt lenses, dense, moist	5	45	
				Sand, brown, very dense, moist	10	55	
				Sand, brown, with sandy-silt lenses, dense, moist	5	60	
				Sand, brown, very dense, moist	20	80	
				Sand, brown, with sandy-silt lenses, dense, moist	10	90	
				Sand and gravel, dark brown, very dense, moist	1	91	US
B4	ALM696	6/19/2008	22.5	Sand, silty, and gravel, green-gray, loose, wet	10	10	
				Sand, silty, dark green-gray, medium dense, wet	5	15	
				Gravel and sand, silty, dark gray to green-gray, very dense, wet	17	32	
				Gravel and sand, silty, gray with brownish-orange staining, very dense, wet	6	38	
				Gravel and sand, silty, brown with yellow-red staining, very dense, wet	4	42	
				Gravel and sand, silty, gray with brownish-orange staining, very dense, wet	5	47	
				Gravel and sand, silty, brownish gray, with cobbles, very dense, moist	5	52	
				Gravel and sand with cobbles, gray, very dense, moist	5	57	
				Gravel and sand, dark gray, very dense, moist	0.5	57.5	US
B5	ABN572	4/11/2006	2.47	Sandy gravel	0.5	0.5	
				Sand, medium to fine, with some silt, brown, moist (WB at 10 feet)	12.5	13	
				Silt, clayey with trace fine sand, orange to gray, stiff, moist	2	15	US
B6	AFT701	4/11/2006	47.91	Sand, silty	25	25	
				Sand, moist to wet	30	55	
				Silt, brown, dense	1.5	56.5	US

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
B7	Time MW-8	4/11/2006	41.75	Sand, fine, silty, light brown	50	50	US
B8	Time MW-1	4/11/2006	13.61	Sand, silty	17	17	
				Silt, sandy	18	35	US
B9	5127	3/31/1989	169.2	Topsoil, clay, brown	9	9	
				Sand and silt, brown	43	52	
				Sand and silt, blue	42	94	
				Sand and silt, brown, cemented	57	151	
				Sand, fine, brown, WB	7	158	
				Sand, fine, gray, cemented	36	194	US
				Sand and gravel, gray, cemented	15	209	
				Sand, fine, gray, with scattered gravel	38	247	
				Gravel and boulders, gray, cemented	62	309	
				Sand, fine, black, WB	19	328	
				Sand, black, with gravel and boulders	34	362	
				Sand, gray, with gravel and small boulders, WB	40	402	
				Gravel and boulders, gray, cemented	14	416	
				Basalt, black, medium-hard	4	420	TG
C1	500194	3/12/1987	185.5	Soil	2	2	
				Gravel with binder	23	25	
				Sand, loose	7	32	
				Sand, dry, packed	68	100	
				Sand, heaving, WB	20	120	
				Sand, dry	25	145	
				Gravel	5	150	
				Sand	12	162	US
				Gravel and boulders, cemented	28	190	
				Gravel, cemented	45	235	
				Gravel and sand, WB	13	248	
				Gravel, with some binder	12	260	
				Gravel, WB	15	275	
				Gravel, cemented	24	299	
				Gravel and boulders, cemented	25	324	
				Gravel with binder	25	349	
				Gravel, cemented, hard	7	356	
				Sand, yellow	8	364	
				Gravel, cemented, hard	32	396	TG

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
C2	FHA	Unknown	71 approx.	Soil	5	5	
				Sand	64	69	US
				Gravel, cemented, WB (in upper 3 feet)	131	200	
				Gravel, cemented, and clay	32	232	
				Gravel, loose, WB	13	245	
				Gravel, loose	13	258	
				Gravel, cemented	42	300	TG
C3	AHE556	10/4/2002	4.2	Silt, very soft, dark, damp, low plasticity		4	
				Organic Peat, very soft, loose, damp		13	
				Silt, very soft, brown-gray, damp, medium plasticity		20	QP
				Sand, medium-fine, gray		21.5	US
C4	APN060	6/1/2006	16.5	Sand, poorly graded, dark brown, trace fines and gravel, moist	15	15	
				Sand, poorly graded, dark brown, trace fines and gravel to 1 inch , WB at 20 ft	10	25	
				Heaving sand	5	30	US
C5	APN058	5/26/2006	13.4	Sand, poorly graded, dark brown, trace fines and gravel, moist	10	10	
				Sand, poorly graded, grayish brown, gravel to 1 inch, WB at 15 ft	10	20	
				Sand, dark brown, heaving	10	30	US
C6	KDB	3/20/1984	57	Topsoil	6	6	
				Sand, coarse	22	28	
				Sandy clay, gray	22	50	
				Sand and gravel, gray, mucky	25	75	
				Sand and gravel, WB	42	117	US
D1	500192	3/29/1988	170.1	Topsoil and gravel	3	3	
				Sand and clay, brown, with gravel	27	30	
				Sand, gray, with gravel	28	58	
				Sand and clay, gray, with gravel	33	91	
				Sand and clay, brown, with gravel	26	117	
				Clay, gray	25	142	
				Clay, brown	50	192	US
				Gravel, gray, cemented, and boulders	48	240	
				Sand gray, and gravel	18	258	
				Sand gray, and gravel, WB	14	272	TG

Table B-6: continued

Cross-section ID[1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
D2	Laws, R.A.	-	-	Topsoil	3	3	
				Gravel, heavy	15	18	
				Gravel, light, WB	5	23	
				Clay, blue	4	27	US
				Gravel, cemented	13	40	
				Gravel, cemented, WB	10	50	
				Gravel, loose, WB, clay at 60 ft.	10	60	TG
D3	500182	3/28/1988	34.4	Topsoil	3	3	
				Gravel and cobbles	27	30	US
				Gravel, cemented	10	40	
				Gravel, cemented, WB-slight	20	60	
				Gravel, coarse, WB (15 gpm)	7	67	
				Gravel, coarse, WB (25 gpm at 85 feet)	18	85	
				Gravel, pea and coarse sand, WB	2	87	
				Sand, finer, WB	3	90	TG
D4	3555	4/11/1989	35.7	Topsoil	1	1	
				Gravel, cemented and cobbles	11	12	
				Gravel, packed, and large cobbles	9	21	US
				Gravel, cemented	10	31	
				Sand, WB	3	34	
				Gravel, packed	13	47	
				Sand and gravel, WB	7	54	TG
D5	Vancouver housing authority	10/11/1985	32	Broken rock with clay, dark brown	8	8	
				Boulders with clay, tan	12	20	US
				Conglomerate	7	27	
				Clay with sand and gravel, tan	13	40	
				Sand and gravel, coarse, WB	29	69	TG
D6	Hoss	11/23/1983	31	Topsoil	2	2	
				Gravel and boulders	14	16	US
				Gravel with some clay	13	29	
				Sand, gravel, and fine black silt, WB	17	46	
				Gravel	8	54	TG
D7	AKY461	-	-	Sand, silt, and fine gravel, semi-compact, with discontinuous boulders	4.4	4.4	US

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
D8	500181			Soil	2	2	
				Gravel	6	8	
				Gravel and sand	12	20	
				Sand	7	27	
				Sand and gravel	16	43	US
				Gravel, cemented	12	55	
				Gravel with clay binder	10	65	
				Gravel and sand, WB	30	95	
				Gravel, cemented	77	172	
				Gravel and sand, WB	26	198	
				Gravel, WB	18	216	
				Gravel with clay binder	5	221	TG
E1	074CLR	2/11/1988	51.1	Topsoil	1	1	
				Brown gravel, sand,clay	4	5	
				Brown gravel, sand, WB	13	18	
				Light brown clay	12	30	
				Brown gravel, clay, sand	24	54	
				Brown gravel, sand, clay	24	78	
				Brown gravel, sand, WB	14	92	US
				Brown gravel, sand, cemented seams, WB	6	98	
				Gray brown gravel, sand, clay	4	102	
				Gray brown gravel, boulders, sand, clay	16	118	
				Gray brown gravel, sand, clay, WB	3	121	
				Gray brown gravel, sand, clay	14	135	
				Gray brown gravel, sand, clay, WB	10	145	
				Gray brown gravel, sand, clay, WB (less)	20	165	
				Gray brown gravel, sand, clay, WB	6	171	
				Gray brown gravel, sand, clay, WB (less)	7	178	
				Gray brown gravel, sand, clay, WB (poor)	7	185	
				Gray brown gravel, sand, clay	12	197	TG
E2	Oak creek	9/22/1989	51	Topsoil, boulders	3	3	
				Gravel boulders, clay	5	8	
				Brown clay	12	20	
				Brown clay and gravel	7	27	
				Silty brown sand	5	32	US
				Sand gravel cobbles	22	54	
				Sand clay and gravel	6	60	
				Sand gravel, WB at 65 ft	20	80	
				Fine sand and gravel, WB (20 gpm)	10	90	
				Brown sand, some gravel, WB	24	114	
				Sand gravel, WB	16	130	
				Sand gravel cobbles, WB	8	138	TG

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
E3	AKY458	-	-	Fine sand and silt with clay binder, compact	3.4	3.4	US
E4	AKY457	-	-	Sand and silt, fine	4.6	4.6	US
E5	Speed	12/28/1987	50	Gravel and boulders	15	15	
				Gravel and sand, medium	20	35	US
				Gravel, cemented	20	55	
				Gravel and sand	5	60	
				Gravel and sand, WB	15	75	TG
E6	Stevens	12/15/1989	55	Topsoil, brown	1	1	
				Gravel, fine to medium	4	5	
				Gravel and cobbles	6	11	
				Sand, gravel, silty brown	39	50	
				Sandy clay, brown	3	53	US
				Gravel and sand	17	70	
				Gravel and sand, WB	12	82	
				Gravel, WB	31	113	TG
E7	500176			Gravel and topsoil	2	2	
				Gravel, sand, and boulders, WB	28	30	US
				Clay and gravel	20	50	
				Cemented gravel, with loose gravel and sand layers, WB	90	140	TG
				Cemented gravel	110	250	Pre-TG sediments
E8	500177			Topsoil	2	2	
				Loose rock	33	35	
				Cemented gravel	10	45	
				Loose rock, WB	7	52	
				Gravel, coarse sand, WB	16	68	
				Sand and clay, WB	12	80	US
				Blue clay	8	88	
				Yellow sand and clay, WB	20	108	
				Brown sand	4	112	
				Blue clay with big rocks	2	114	
				Blue sand, big rock, WB	6	120	
				Cemented gravel, blue clay, WB	28	148	
				Blue-green mud	4	152	TG
				Lava rock	45	197	
				Green sand, rocks, clay	9	206	
				Cemented gravel	14	220	Pre-TG sediments

Table B-6: continued

Cross-section ID [1]	Well ID number	Water level date	Water level (ft below land surface)	Driller's description of materials encountered during well construction	Thickness (feet)	Depth of bottom (feet)	Interpreted hydrogeologic unit
W1	APJ519			Silty sand, some gravel, loose, dark brown,moist, stratified		1	
				Silty sand, with sandy silt strati, loose, olive brown, moist		2	
				Silty sand, with sandy silt strati, trace gravel, medium dense, olive brown, moist		7	
				Silty sand, medium dense, olive brown, moist		9	
				Silty sand, with sandy silt strati, medium dense, olive brown, moist		13	
				Silty sand, with sandy silt strati, medium dense, olive brown, wet		15	
				Silty sand, medium dense, olive brown, wet		20	
				Silty sand, dense, olive brown, wet		25	
				Sand, poorly graded, trace silt, medium dense, olive brown, moist		30.5	US

[1] - The map IDs listed here correspond with those shown on Plate 1

Hydrogeologic unit nomenclature (after Swanson and others, 1993)

US - unconsolidated sediments (may include sediments from the following geologic units: Qa, Qp, Qfs, Qfg, see Plate 1, Figure 1)

TG - Troutdale formation gravels

Table B-7: Summary of water quality results for sampled instream piezometers, off-stream wells, and headwater drainage ditches.

				Groundwater Field Parameters						Laboratory Analyses [2]									
Map ID [1]	River Mile	Well Tag ID Number	Sample Date	Depth to groundwater (ft below land surface)	Vertical Hydraulic Gradient (dimensionless)	Water 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)
S1	12.8	---	7/29/2008	-	-	13.1	6.39	196	8.23	5 J	71.1	3.61	0.061 J	0.056	3.52 J	0.01 U	3.28 J	1 U	0.05 U
			9/23/2008	-	-	13.2	6.61	190	9.67	39	70.8 J	3.71	0.06 J	0.050	3.49	0.01 U	3.44	1 U	0.05 U
P13	11.4	AKY457	7/13/2009	-	-0.446	15.5	6.34	320	0.34	2	161	5.95	0.058	0.348	0.025	1.44	2.82	23.1	29.2
P11	10.4	AKY459	7/29/2008	-	-0.007	13.8	7.09	273	0.32	3 UJ	107	5.9	0.055	0.232	0.022 J	0.355	0.404 J	1.7 B	11.1
			9/23/2008	-	-0.009	14.1	7.06	267	0.3	1 U	107 J	6.06	0.073	0.209	0.021	0.345	0.396	1.3 B	11.2
P7	7	AKY463	7/14/2009	-	-0.067	13.6	6.41	216	0.3 J	1 U	85.7	5.07	0.0486 J	0.027	0.956	0.01 U	0.995	1.3 B	0.05 U
P4	4.3	AKY466	7/29/2008	-	-0.011	16	6.73	180	0.36	1 U	62.7	4.79	0.122	0.595	0.025 J	0.862	0.934 J	4.8 B	14.1
			9/23/2008	-	-0.006	15.3	6.79	178	0.4	1 U	67.7 J	4.77	0.078	0.548	0.022	0.903	0.941	4.4 B	15
W1	4.2	APJ519	7/29/2008	17.91	-	10.9	6.42	134	8.86	1 U	57.4	3.13	0.038 J	0.033	1.59 J	0.01 U	1.61 J	1 U	0.05 U
			9/23/2008	19.83	-	10.6	6.34	177	9.27	1 U	76 J	3.62	0.0412 J	0.034	2.59	0.01 U	3.04	1 U	0.05 U
			11/25/2008	20.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2	2.6	AKY456	7/29/2008	-	-0.009	15.8	7.18	161	0.55	1 U	64.2	4.97	0.163	0.303	0.017 J	0.206	0.317 J	3.3 B	3.18
			9/22/2008	-	-0.007	14.2	7.14	146	0.68	1 U	60.9 J	4.46	0.144	0.285	0.011	0.194	0.264	3.2 B	3.3
A2	1.6	AHT045	6/17/2008	28.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			7/16/2008	28.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			7/29/2008	28.34	-	13.4	6.67	277	6.14	1 U	109	6.87	0.159 J	0.147	2.59 J	0.01 U	2.74 J	1 U	0.05 U
			8/26/2008	29.27	-	-	-	-	-										
			9/23/2008	29.27	-	12.5	6.73	271	6.53	1 U	113 J	6.41	0.159 J	0.146	2.9	0.01 U	2.82	1 U	0.05 U
			10/20/2008	30.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			11/25/2008	31.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			1/27/2009	30.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			3/11/2009	30.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			5/5/2009	29.97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			6/16/2009	29.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			7/14/2009	29.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			8/19/2009	30.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			9/16/2009	31.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] - The map IDs listed here correspond with those shown on Plate 1

[2] - Data qualifier codes:

B - Analyte detected in sample and field filter blank. The reported value is the sample concentration without blank correction or associated quantitation limit

J - the analyte was positively identified. The reported 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 reported estimated value