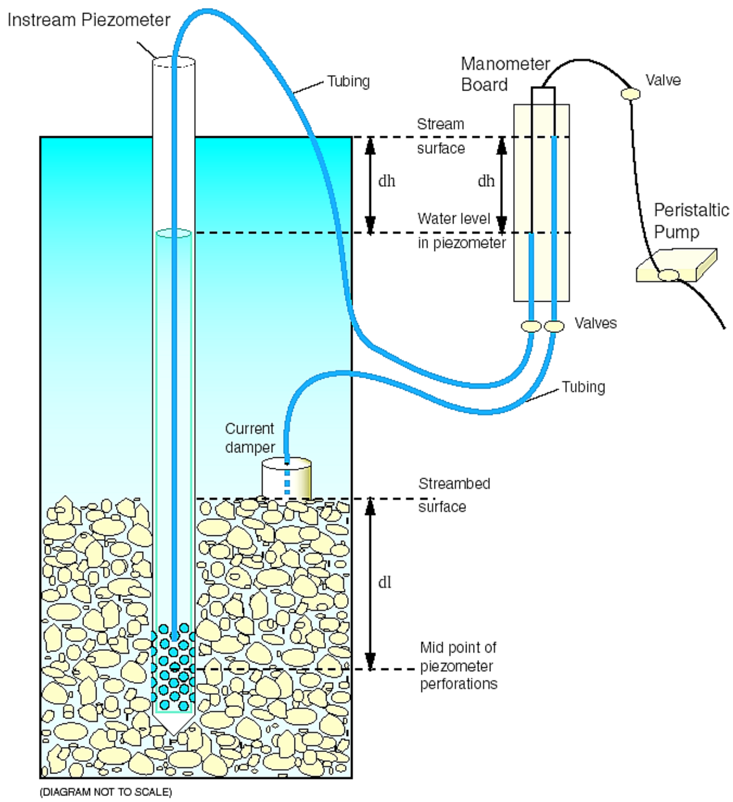


# Surface-Water/Groundwater Interactions and Near-Stream Groundwater Quality, Lacamas Creek, Clark County


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This report was prepared by a licensed hydrogeologist. A signed and stamped copy of the report is available upon request.

Cover image: Cartoon schematic depicting the use of a manometer board to measure hydraulic head differences between a stream and near-surface groundwater (courtesy of F.W. Simonds, USGS)

# Surface-Water/Groundwater Interactions and Near-Stream Groundwater Quality Lacamas Creek, Clark County

by

Kirk Sinclair, Licensed Hydrogeologist

and

Trevor Swanson

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

Waterbody Numbers:

Lacamas Creek, WA-28-2020
Fifth Plain Creek, WA-28-2024
Shanghai Creek, WA-28-2025
Matney Creek, WA-28-2026
China Ditch, WA-28-2023

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# List of Figures and Tables

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## Tables

# 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.

**Anoxic:** Depleted of oxygen.

**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.

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

**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:** Pollution that discharges to surface water at a specific location from pipes, outfalls, and conveyance channels. Examples of point source discharges include water from municipal wastewater treatment plants, municipal storm-water systems, and industrial waste treatment facilities.

**Specific Conductance:** A measure of water's ability to conduct electricity. Specific conductance is related to the concentration and charge of dissolved ions in water.

**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.

**Water Year:** A term used to describe the 12-month period, starting on October 1 and ending on September 30. A water year is designated by the calendar year in which it ends. Thus, the year ending on September 30, 2011 is called the "2011 water year".

# Acronyms and Abbreviations

| | |
|---|---|
| DO | dissolved oxygen (see glossary above) |
| 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) |
| RM | river mile |
| TMDL | total maximum daily load (see glossary above) |
| TPN-N | total persulfate nitrogen (reported as nitrogen) |
| USGS | U.S. Geological Survey |

# Data Qualifier Codes Used in 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. |

# 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) |

## 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).

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# Abstract

Portions of Lacamas Creek and its tributaries were listed on the Washington State 2008 303(d) summary of impaired waters for periodic violations of Washington's surface water quality criteria for temperature, dissolved oxygen, pH, and fecal coliform. Lacamas Creek is located near the City of Camas in Clark County.

To support development of a comprehensive water cleanup plan (i.e. total maximum daily load) for Lacamas Creek, the Washington State Department of Ecology conducted targeted assessments of the environmental and water quality issues affecting the creek between September 2010 and October 2011. This study was part of that assessment effort and was undertaken to evaluate how groundwater influences instream temperatures and water quality.

Several common field techniques were used during this effort 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.

During a seepage evaluation conducted on July 26, 2011, the creek showed a net streamflow gain from groundwater of +1.34 $ft^3/s$ between the uppermost transect at river mile 14.8 and the lowermost transect at river mile 5.6. During a follow-up evaluation on August 30, the creek lost -2.73 $ft^3/s$ across this reach. 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 6 instream piezometers and 1 spring had measurable concentrations of dissolved orthophosphate (range <0.003 to 0.276 mg/L), dissolved total phosphorus (range 0.0221 to 0.602 mg/L), dissolved nitrate+nitrite-N (range <0.01 to 0.292 mg/L), and dissolved ammonia (range 0.014 to 2.83 mg/L).

# Acknowledgements

This study benefited from the efforts of Stephanie Brock, Jenny Hall, James Kardouni, Martha Maggi, Pam Marti, and George Onwumere, who helped complete the field work this report drew upon. In addition to the above, we thank staff at the Manchester Environmental Laboratory who provided courier and analytical laboratory support.

# 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 Lacamas Creek and its major tributaries were included on the Washington State 2008 303(d) list of impaired waters for temperature, dissolved oxygen, pH, or fecal coliform violations of Washington's surface water quality standards (Swanson, 2011) (Figure 1).

In Washington, the Washington State Department of Ecology (Ecology) has primary responsibility for developing water cleanup plans, or total maximum daily loads (TMDLs), for the state'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 become inputs to the water quality models Ecology uses to establish pollutant-load reduction targets for the stream.

In 2010, Ecology began a TMDL study for Lacamas 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 TMDL 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.

The primary goals of this investigation were to:

1. Evaluate and quantify groundwater discharge volumes to Lacamas Creek and selected tributaries during critical summer conditions.
2. Characterize local groundwater quality just prior to its discharge into area streams.

Numerous field techniques were employed to achieve these goals. In early fall of 2010, instream piezometers were installed at selected points along the creek to monitor streambed thermal profiles and vertical hydraulic gradients between the creek and near-surface groundwater. Synoptic streamflow and surface-water quality surveys were conducted in July and August 2011 to develop seepage balances for Lacamas Creek. During these surveys selected piezometers and a tributary spring were also sampled to characterize groundwater quality. This report documents the results of these investigations.

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

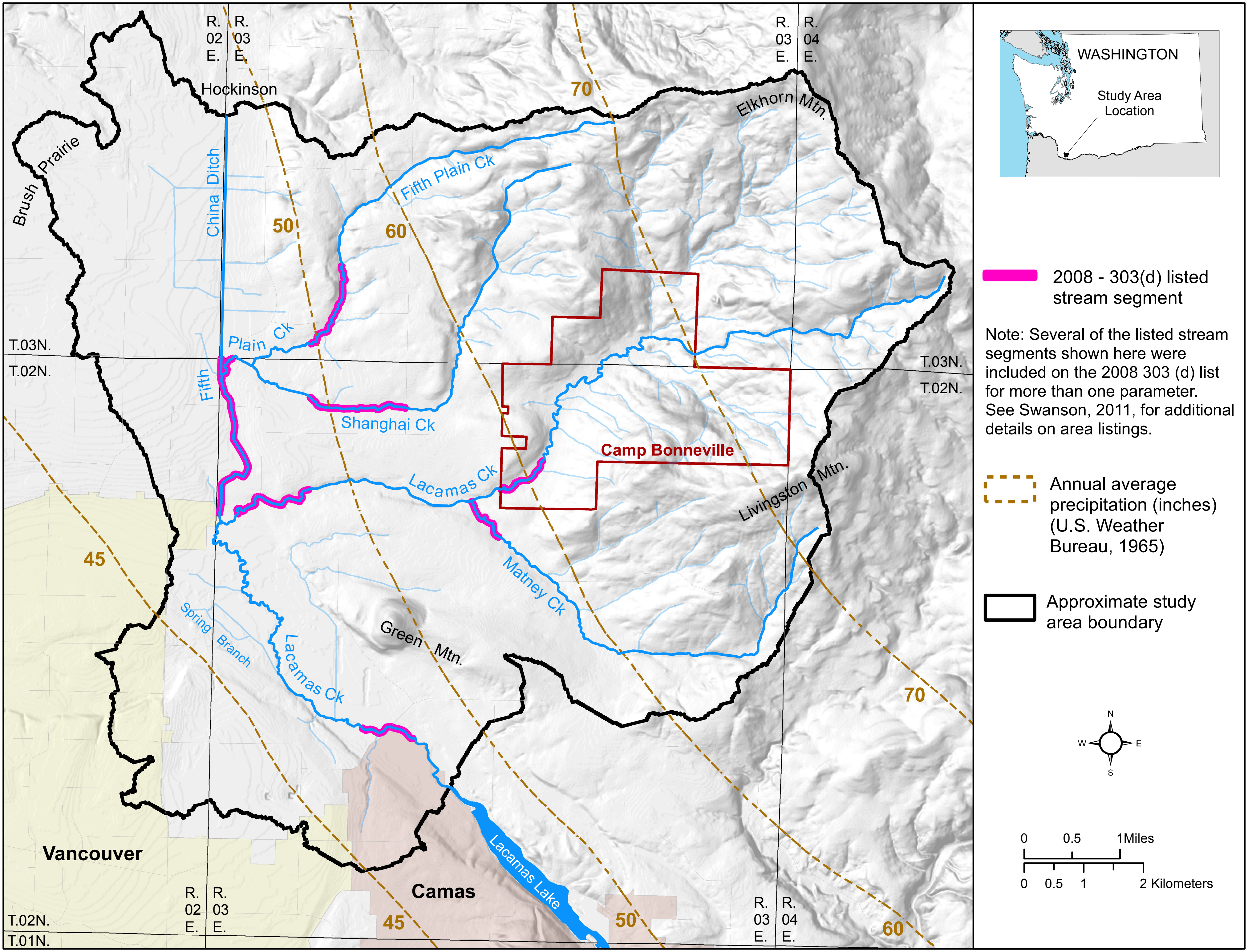



Figure 1: Study area location and distribution of 303(d) listed stream segments

# Study Area Description

## Physical Setting and Land Use

The Lacamas Creek watershed encompasses approximately 67 square miles[2] of variable relief terrain near the City of Camas in southern Clark County (Figure 1). Lacamas Creek originates along the steep western sloping faces of Elkhorn and Livingston mountains at an elevation of approximate 2230 ft and flows west and south for approximately 13.5 miles before it enters Lacamas Lake at an elevation of approximately 182 ft. Along the way it is joined by several tributaries including Matney Creek, Fifth Plain Creek, Spring Branch, and Dwyer Creek. Below Lacamas Lake the creek flows for an additional mile before entering the Washougal River near Camas.

Before European settlement, most of the Lacamas watershed was heavily forested. By the early 1890s the ancestral wetlands of the Brush Prairie area, in the northeastern watershed, were drained, and most of the forested lowlands in the central and western watershed were cleared to prepare the land for farming. In 1883 a dam was built at the southern end of Lacamas Lake to aid local logging efforts. The dam raised the lake level by about 12 feet. Later, a second dam and aqueduct were built at Round Lake to convey water to the paper mill at Camas (Clark Co. Public Works, 2004).

Current land use in the northern and eastern watershed consists mostly of forests, farmland, and rural residential development. Areas of higher-density residential and commercial development are concentrated in the southern and western watershed near the Cities of Camas and Vancouver.

A natural waterfall below Lacamas Lake prevents the upstream passage of anadromous fish beyond river mile 0.9 on Lacamas Creek. Below the waterfall, the creek is known to contain coho salmon and coastal cutthroat trout and is presumed to also support runs of winter steelhead, fall Chinook, and chum salmon. Resident cutthroat trout are present above the waterfall (Wade, 2001).

## Climate

Climate in the study area is generally characterized by mild-wet winters and warm-dry summers. At Vancouver, the summer maximum temperatures normally 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. Approximately 75% of the annual precipitation at Vancouver falls as rain during the period October through March (Figure 3). The period from November through January is typically the wettest, while July and August are typically the driest months.

[2] The study area for this project encompasses the watershed area that lies above Lacamas Lake – or about 52 square miles (78 percent) of the greater Lacamas Creek watershed.

The distribution of annual precipitation within the study area varies by location and ranges from slightly less than 40 inches in the southwestern watershed near Vancouver to more than 70 inches in the Cascade foothills of the northeastern watershed (Figure 1).

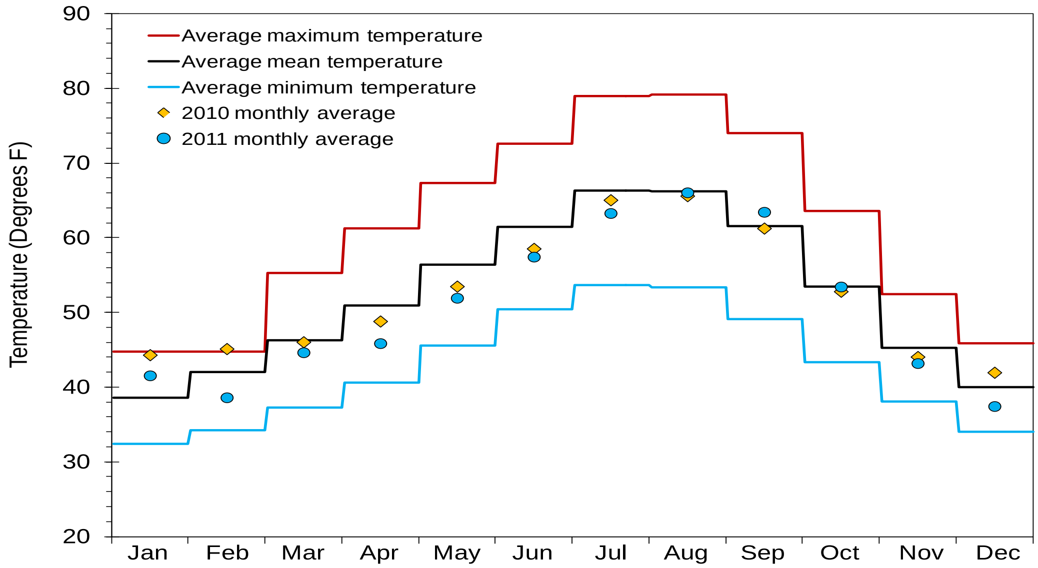



Figure 2: Monthly- average maximum, minimum, and mean air temperatures at Vancouver (458773) for the period 1891-2011 (Western Regional Climate Center, 2012)

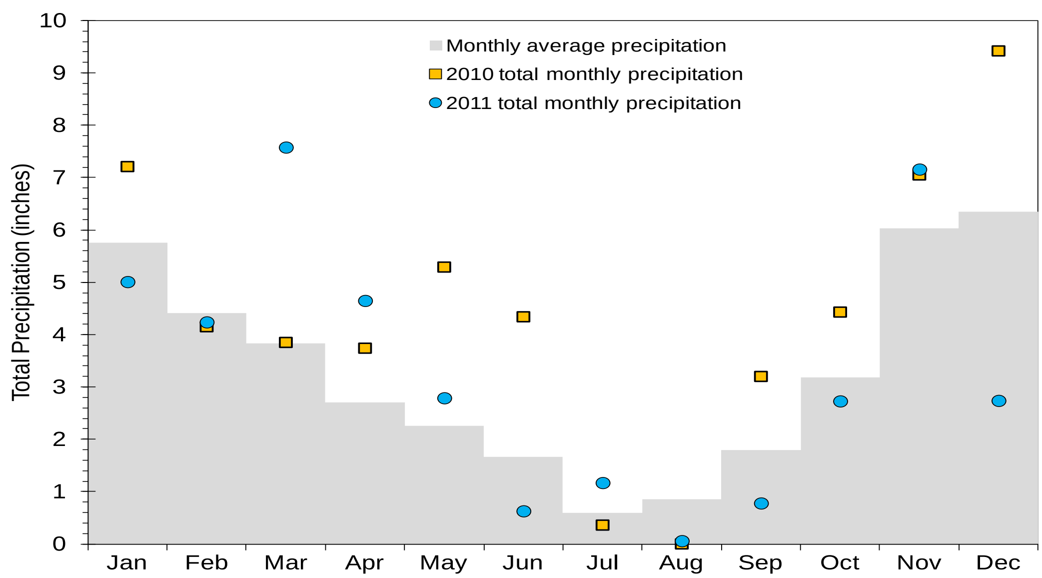



Figure 3: Monthly average precipitation at Vancouver (458773) for the period 1891-2011 (Western Regional Climate Center, 2012)

The annual precipitation totals at Vancouver for 2010 and 2011, the primary study period for this evaluation, were 53.04 and 39.54 inches respectively. Relative to the longer-term station average precipitation of 39.34 inches, 2010 was an abnormally wet year at Vancouver and most months received more than normal rainfall (Figure 3). The total precipitation during 2011 was approximately equal to the station average.

## Streamflow

The Water Resources Branch of Clark County Public Works currently operates two streamflow gages on Lacamas Creek (Table 1). The gages were installed in late September 2002 and have been in continuous operation since that time. Ecology installed three additional short-term gages in October 2010 to support the Lacamas Creek TMDL.

Table 1: Streamflow gage locations and station periods of record.

| Map ID[1] | Agency gage number | Operating agency | Location description | Period of record |
|---|---|---|---|---|
| G1 | LAC050 | Clark County | Lacamas Ck at Goodwin Rd | Oct 2002 - present |
| G2 | 28K060 | Ecology | Fifth Plain Cr at 4th Plain NE (SR-500) | Oct 2010 - Feb 2012 |
| G3 | 28M060 | Ecology | China Ditch at NE Ward Rd near 172nd Ave | Oct 2010 - Feb 2012 |
| G4 | LAC080 | Clark County | Lacamas Ck at NE 217th Ave | Nov 2002 - present |
| G5 | 28L050 | Ecology | Matney Ck at NE 68th St | Oct 2010 - Feb 2012 |

[1] - See Figure 1 on Plate 1 for a map of gage locations

Visual inspection of the streamflow hydrograph for Lacamas Creek at Goodwin Rd (LAC050) indicates that the creek flow generally mirrors annual precipitation patterns. Streamflow is typically highest during the wet winter months of November through March and lowest from July through October when precipitation is generally limited (Figure 4).

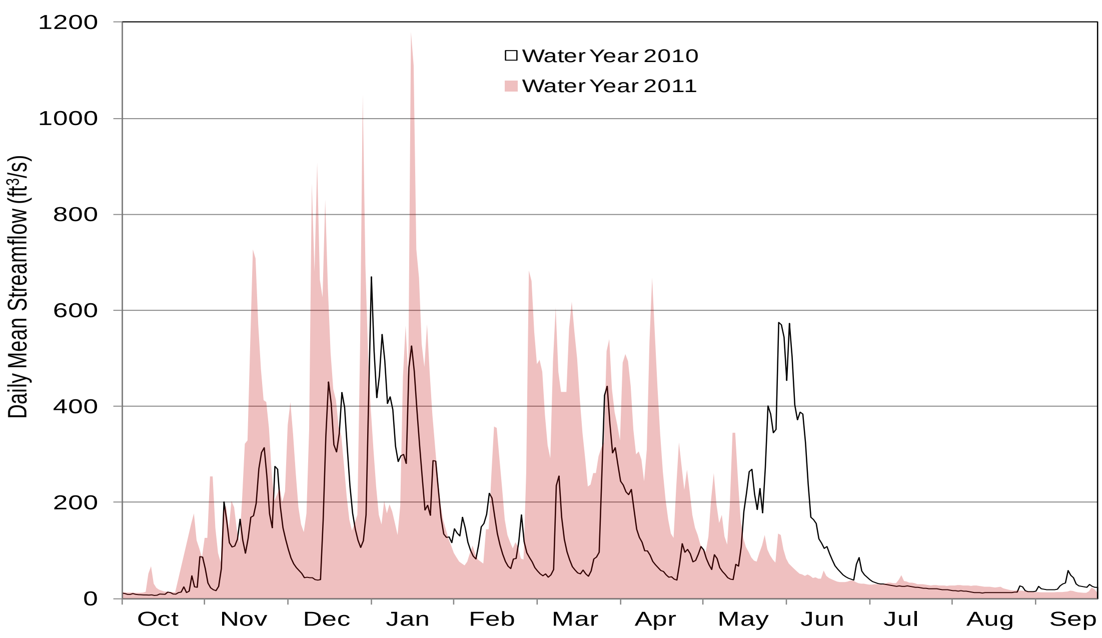



Figure 4: Daily mean streamflow for Lacamas Creek at Goodwin Road (water years 2010-11) (Clark County Public Works).

## Hydrogeologic Setting

The Lacamas Creek drainage is situated at the eastern edge of a sediment-filled structural depression called the Portland Basin. The Portland Basin is part of the larger Puget-Willamette structural trough which extends from southern British Columbia to northern Oregon and occupies the lowlands between the Cascade Mountains and the coast ranges of Washington and Oregon.

The Portland Basin formed upon, and is underlain by, Oligocene-age basalt and basaltic andesite. These rocks constitute area bedrock and occur at ground surface in the eastern half of the Lacamas drainage where they rise to form the Cascade foothills (unit Qva(2), Figure 5). In the lowlands and terraces west of the foothills, these rocks are overlain by a thick sequence of sediments which the ancestral Columbia River carried into the area as the Portland Basin formed (Evarts, 2006; Swanson et al., 1993).

Trimble (1963) assigned the name Sandy River Mudstone to the oldest of these locally occurring sediments. The Sandy River Mudstone is approximately 900 feet thick near Green Mountain and consists of well-bedded, semi-consolidated deposits of Miocene- and Pliocene-age claystone, siltstone, sandstone, and other rocks. Except for localized surficial exposures in the valley bottom west of Camp Bonneville, the Sandy River Mudstone is overlain throughout the study area by 200-400+ feet of semi-consolidated to consolidated deposits of coarse-grained, cemented gravel; conglomerate; and sandstone of the Troutdale Formation (unit PLMc(T), Figure 5) (Mundorff, 1964; PGG, 1998). These deposits contain some of the area's most extensive and important aquifers and are thought to range in age from late Miocene to late Pliocene (or early Pleistocene) time (Swanson et al., 1993). The Troutdale Formation interfingers locally with basalt and basaltic andesite flows that erupted in middle Pleistocene time from small volcanoes and fissures located north and east of Lacamas Lake at present day Green Mountain and Bruner Hill (unit QPLvb(b), Figure 5).

In late Pleistocene time (approximately 17,000-12,000 years ago), the western Lacamas Creek drainage was repeatedly inundated by catastrophic floods that originated from periodic failures of one or more ice dams 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 western Montana, northern Idaho, and eastern Washington. The floodwaters eventually coalesced at the Columbia River gorge where they were laterally constrained and directed into the Portland Basin which abuts the gorge's western terminus. As floodwater entered the Portland Basin it scoured and reworked portions of the older basin fill sediments and deposited coarse gravel in longitudinal bars downstream of the gorge. In the Lacamas Creek drainage, the flood deposits reach thicknesses of 100+ feet west of Lacamas Creek proper and are composed mostly of unconsolidated gravel and sand to the south and silty sand to the north (units Qfs and Qfg, Figure 5). Where they are saturated, the coarser grained flood deposits can contain prolific and locally important aquifers.

Northwest of Lacamas Lake, the flood deposits are capped by a thin layer of Holocene to Pleistocene age lake deposits, peat, and alluvium (units Qp and Qa, Figure 5). These deposits are typically less than 15 feet thick and consist of unconsolidated grey-to-black mud, silt, and organic debris. These sediments immediately underlie most of the low-lying bottomland between Lacamas Lake and the confluence of Lacamas Creek with Fifth Plain Creek (Evarts, 2006). Above this point, the lake deposits transition to mostly coarse grained silty-sand and gravel alluvium.

Swanson et al. (1993) grouped the assemblage of unconsolidated sediments above the Troutdale Formation (units Qa, Qfs, Qfg, Qls, and Qp on Figure 5) into a single hydrogeologic unit which they informally named the unconsolidated sedimentary aquifer. Based on water levels measured in spring 1988, groundwater within the unconsolidated sedimentary aquifer generally flows from recharge areas in the uplands of the northeastern Lacamas watershed toward natural points of discharge in the southwestern watershed (McFarland and Morgan, 1996). Local variations in this general pattern occur where the aquifer intersects and discharges water to area streams (Figure 5).

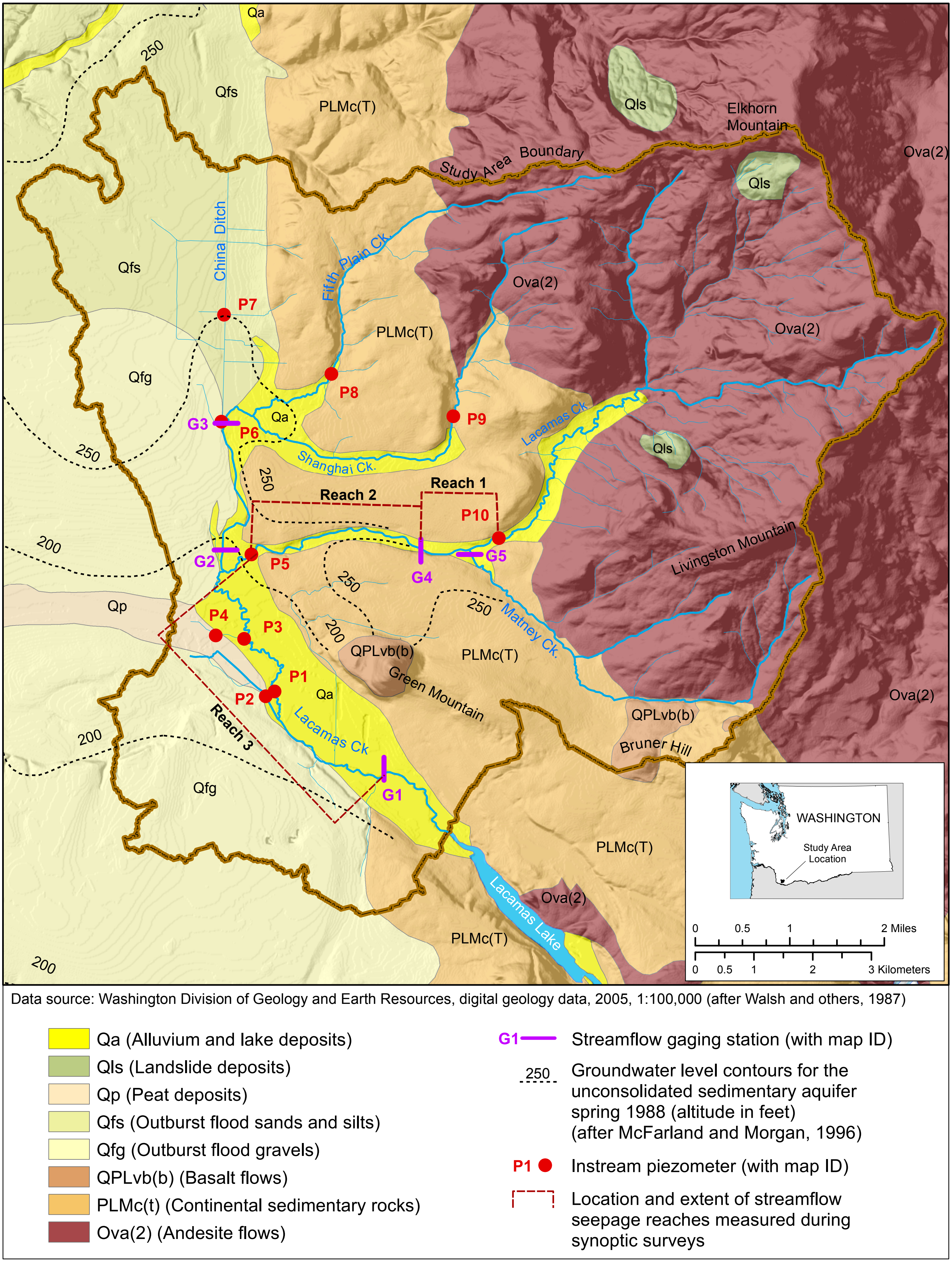



Figure 5: Study area surficial geology, groundwater level contours, and location of streamflow gages and instream piezometers

# Study Methods

For this study we used a variety of common field methods and analytical techniques to evaluate the timing, magnitude, and spatial distribution of surface water/groundwater interactions. Two streamflow seepage evaluations were conducted during summer 2011 to estimate streamflow gains from or losses to groundwater along three reaches of Lacamas Creek proper. These reach scale gain/loss estimates were supplemented with continuous measurements of streambed thermal profiles and periodic measurements of streambed vertical hydraulic gradients at 10 instream piezometer sites. These latter techniques were used to better define the direction and timing of surface water and groundwater interactions at specific points within the study area. Each of these field methods and analytical techniques are described in detail below.

## Stream Seepage Evaluations

We conducted two stream seepage evaluations to quantify reach-scale streamflow gains from or losses to groundwater. 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).

The evaluations occurred on July 26 and August 30, 2011, following periods of extended dry weather. To perform the evaluations we subdivided Lacamas Creek into 3 reaches ranging from 1.3 to 5.5 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 favored accurate streamflow measurements. After selecting and flagging the measurement transects, field teams conducted synoptic (same-day) measurements of all 3 reaches to define the individual reach water budget components (Equation 1).

Equation 1 was later 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 each seepage reach.

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

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

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

In practice, the $\Sigma D$ and $\Sigma W$ terms of Equation 1 are often difficult to estimate or measure accurately. This is due to the dispersed and often intermittent nature of most out-of-stream water withdrawals and smaller point discharges. Thus, the seepage values presented in later sections of this report do not account for these terms. Were we able to accurately account for these influences, the seepage values reported herein would be higher for reaches where active out-of-stream water withdrawals exceeded point discharges to the creek. Similarly, the reported seepage values would be lower for those reaches where point discharges to the creek exceeded water withdrawals.

## Instream Piezometers

In September 2010, we installed ten shallow instream piezometers along Lacamas Creek and selected tributaries using methods described by Sinclair and Pitz (2009). We were able to install piezometers with good success in the western study area, where the creek is underlain by unconsolidated flood deposits and recent alluvium. Our attempts to deploy piezometers in the eastern study area proved less successful, due to surficial exposures of bedrock and consolidated sedimentary rocks in the streambed throughout most of this area.

The piezometers consisted of an upper removable pipe section (or extension) and a lower 5-foot section of 1.5-inch diameter galvanized pipe (Figure 6 and Table B-2). 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 Figure 5 for site locations). Piezometers were manually installed into the streambed to a maximum depth of about 5 feet. Where possible, they were located in quiet water away from riffles, point bars, or other streambed features that might induce local-scale hyporheic exchanges.

The piezometers were developed after installation with a manual bladder-type bilge pump 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.

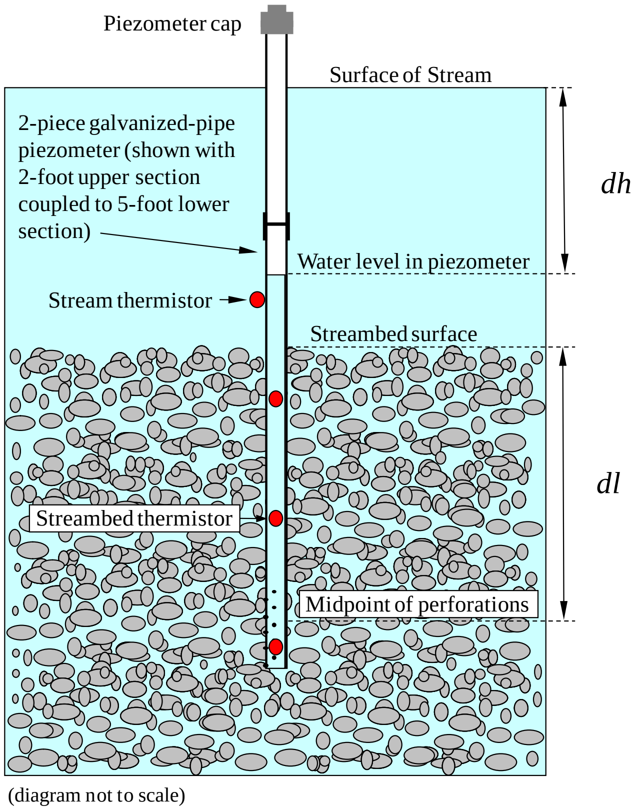



Figure 6: Schematic of a typical instream piezometer and thermistor array.

Equation 2 was used to derive vertical hydraulic gradients for each piezometer, from the 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* is the distance from the streambed surface to the mid-point of the piezometer perforations (L),

where (L) represents units of 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 3 to 6 feet 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 (Figure 6) (Swanson, 2011).

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 7A). 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 7B).

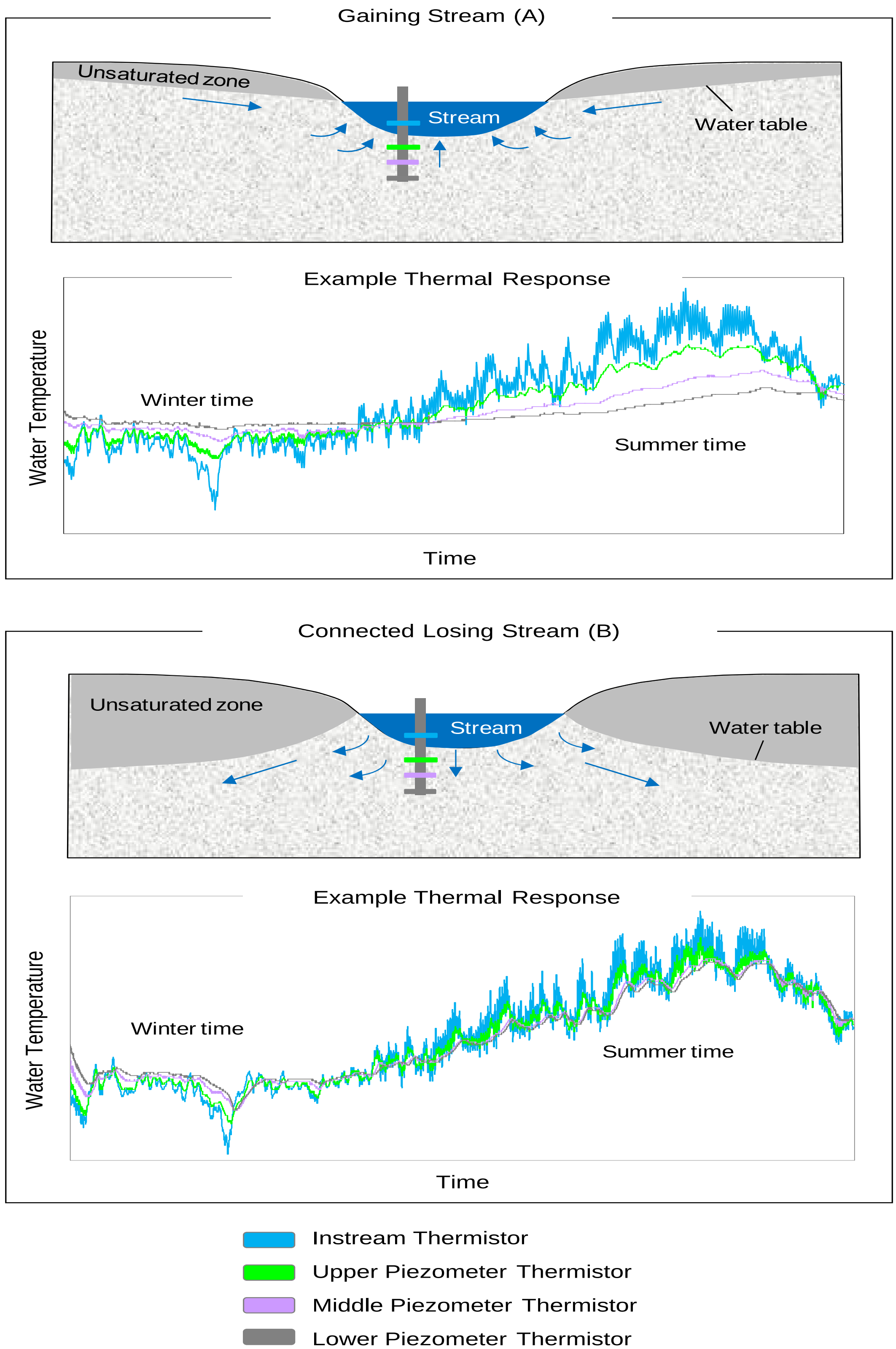



Figure 7: Example streambed thermal response for a perennial gaining (A) and losing (B) stream.

# Surface-Water/Groundwater Interactions

The generalized depictions of gaining and losing stream reaches shown in Figure 7 present highly simplified views of the complex physical processes that control surface-water and groundwater interactions along a stream. These interactions are 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.

Accordingly, for this study we used three common field methods to characterize surface-water/groundwater interactions along Lacamas Creek. Streamflow seepage assessments (synoptic surveys) were conducted on July 26 and August 30, 2011 to quantify net streamflow gains and losses along the creek (Table B1). The seepage surveys were supplemented with periodic measurements of streambed vertical hydraulic gradient and continuous monitoring of streambed thermal profiles at a small network of instream piezometers installed along the creek and select tributaries (Figure B1 sites P1-P10). These latter measurements provide further insights into both the timing and direction of water exchanges at discrete points along a stream.

The collective results of these evaluations are presented below. For the purposes of this discussion we've subdivided Lacamas Creek proper into three reaches based on the locations of continuous streamflow gages.

## Seepage Reach 1

Seepage reach 1 is approximately 1.3 miles long and extends from the western boundary of Camp Bonneville at river mile 14.8 downstream to the Lacamas Creek gage at 217$^{th}$ Ave (river mile 13.3) (Figure 5). During the July 26 synoptic survey Lacamas Creek lost approximately -0.31 ft$^3$/s (or -0.21 ft$^3$/s/river mile) as it traversed reach 1 (Table B-1). The creek showed a net gain of +0.09 ft$^3$/s (or +0.06 ft$^3$/s/river mile) during the August 30 survey.

An instream piezometer installed at the upper end of reach 1, just above the western boundary of Camp Bonneville, exhibited small negative-to-neutral vertical hydraulic gradients during the July and August seepage evaluations respectively (Figure B-1, site P10). The general correspondence between the stream temperature and thermistors within the piezometer suggest that the creek potentially lost water through its bed at this location during both surveys. This inference is supported by the slight downstream warming trend noted in the creek between the upper and lower seepage transects of this reach during both synoptic surveys (Figure 8).

Collectively these results suggest that Lacamas Creek neither gained from nor lost much flow to groundwater as it traversed reach 1. The range of measured streamflow exchange during the surveys (-0.31 to +0.09 ft$^3$/s) represents less than 10 percent of the total measured streamflow at the upper end of the seepage reach. These exchange values likely fall within the potential cumulative error bounds associated with making the streamflow measurements they were derived from. Thus, these exchanges may not represent true streamflow gains or losses.

## Seepage Reach 2

Seepage reach 2 is approximately 2.2 miles long and extends from the Lacamas Ck gage at 217th Ave downstream to the 4th Plain Rd. NE crossing of the creek near river mile 11.1 (Figure 5). During the July 26 survey Lacamas Creek showed an apparent gain of approximately +0.15 $ft^3/s$ (or +0.07 $ft^3/s$/river mile) as it traversed reach 2. During the August 30 survey the creek lost approximately -0.46 $ft^3/s$ (or -0.21 $ft^3/s$/river mile) through reach 2.

There was a single instream piezometer installed along reach 2 just below the SR500 bridge crossing (Figure B-1, site P5). This piezometer exhibited negative vertical hydraulic gradients during the July (-0.04 ft/ft) and August (-0.165 ft/ft) seepage evaluations. In addition, the streambed temperatures at this site closely track those of the stream which suggests the creek potentially lost water through its bed at this location.

As with reach 1, the results for reach 2 suggest that Lacamas Creek neither gained from nor lost much flow to groundwater as it traversed the reach. The small apparent gain in July (+0.15 $ft^3/s$) likely falls within the potential seepage measurement error bounds and is not considered a reliable indicator of actual streamflow gain. The -0.46 $ft^3/s$ loss measured in August does exceed the inferred error bounds for the seepage assessment and likely represents a true streamflow loss.

## Seepage Reach 3

Seepage reach 3 is approximately 5.5 miles long and extends from 4th Plain Rd NE at RM 11.1 to Goodwin Rd at RM 5.6. During the July 26 synoptic survey, Lacamas Creek showed an apparent streamflow gain of approximately +1.5 $ft^3/s$ (or +0.27 $ft^3/s$/river mile) as it traversed reach 3. During the August 30 survey, the creek experienced an apparent streamflow loss of -2.36 $ft^3/s$ (or -0.43 $ft^3/s$/river mile). Both of these values exceeded the probable error bounds for their respective seepage assessments and are inferred to represent actual streamflow gains and losses.

There were two piezometers installed along reach 3: one at RM 9.1 (Site P3) and one at RM 7.5 (site P1) (Figure B-1, sites P3 and P1). During the synoptic survey in July, piezometer P3 exhibited a positive vertical hydraulic gradient (+0.05 ft/ft) while piezometer P1 exhibited a small negative gradient (-0.002 ft/ft). This suggests groundwater was likely discharging to the creek at site P3 during the survey. At site P1 the creek potentially lost a small amount of flow.

During the August survey both piezometers exhibited small positive hydraulic gradients (+0.01 and +0.002 ft/ft at sites P1 and P3 respectively) which suggests the creek potentially gained flow at each of these locations. Both piezometers also exhibited stable streambed thermal profiles which diverged from the stream temperature by several degrees. This offers further support for potential groundwater discharge to the creek at these locations. During the synoptic surveys the two major tributaries to Lacamas Creek along reach 3 were also several degrees cooler than Lacamas Creek proper (Figure 8). This suggests they probably receive relatively large inputs of groundwater prior to entering Lacamas Creek.

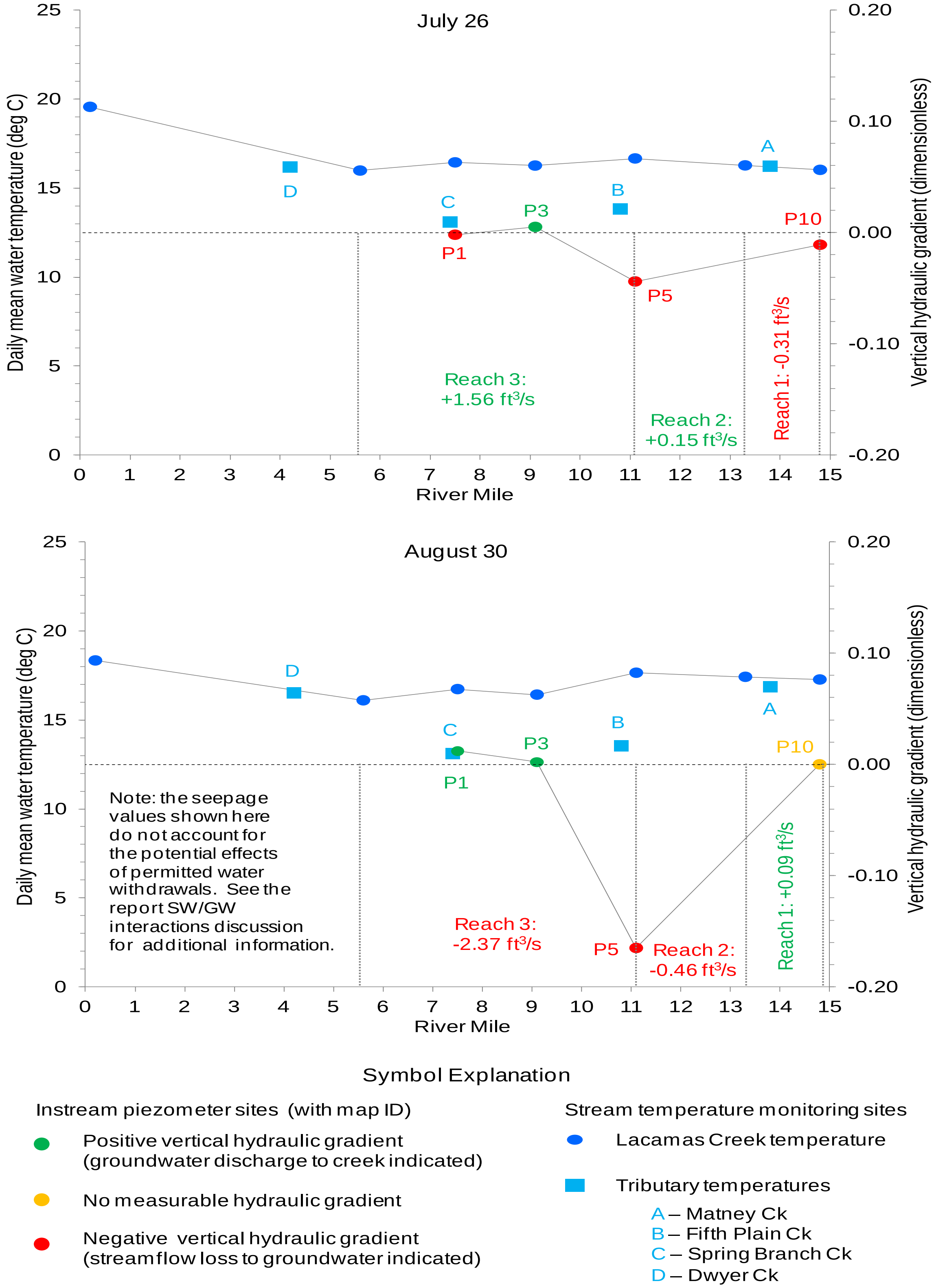



Figure 8: Streamflow seepage values, stream temperatures, and streambed vertical hydraulic gradients measured during the July 26 and August 30, 2011 synoptic surveys of Lacamas Creek.

# Evaluation of Near-Stream Groundwater Quality

To assess the concentration of phosphorous and nitrogen-based nutrients that groundwater potentially contributes to local streams we sampled 6 instream piezometers, where groundwater discharge was indicated, and one spring. Water samples were collected during the July and August, 2011 synoptic surveys and were evaluated for field parameters and a small suite of laboratory-analyzed constituents (Table 2) (Swanson, 2011).

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 | Alcohol Thermometer | 0.1°C |
| Specific Conductance | Hydrolab MS-5 | 1 µS/cm |
| pH | Hydrolab MS-5 | 0.1 SU |
| Dissolved Oxygen | Hydrolab MS-5 | 0.1 mg/L |
| *Laboratory Parameters* | | |
| Coliform, fecal (MF) | SM9222D | 1 CFU/100mL |
| Alkalinity | SM2320B | 5 mg/L |
| Chloride | EPA300.0 | 0.1 mg/L |
| Orthophosphate[1] | SM4500PG | 0.003 mg/L |
| Total phosphorus[1] | SM4500PF | 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] | SM5310B | 1 mg/L |
| Iron[1] | EPA200.7 | 0.05 mg/L |

[1] Dissolved fraction
MF: Membrane filter method
SU: Standard units

All sites were sampled using a peristaltic pump and a length of new ¼ inch HDPE tubing. When sampling a piezometer the installed thermistor string was first removed and set aside. One end of the HDPE tubing was then inserted into the piezometer until it abutted the casing perforations. The other end of the tubing was then connected to a peristaltic pump via a short length of clean silastic tubing. The pump discharge was routed through a closed-atmosphere flow cell connected to a Hydrolab® model MS-5 multimeter to enable field parameters to be evaluated. Piezometers were purged at a maximum rate of 0.25 to 0.5 L/min. Where possible[3], purging continued until

[3] Several of the instream piezometers did not produce sufficient water to enable them to be purged and sampled within the same day. These wells were purged dry the day before sampling and were allowed to recover overnight before sampling. The field parameter values for these wells (temperature, specific conductance, pH, and dissolved oxygen) are flagged as estimates in Table B-4, Appendix B.

the difference in measured field parameter values for 2 successive 3-minute measurement periods differed by less than 5 percent.

At the completion of purging, laboratory bound samples were collected by disconnecting the pump discharge line from the flow cell. Samples for dissolved organic carbon (DOC) analyses were filtered in the field using a Whatman puradisc™ 25 PP, 0.45 micron syringe filter. Orthophosphate samples were similarly filtered using a Whatman puradisc™ 25 GD/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 sampling effort are summarized in Figures 9 and 10 and presented by well and sample date in Appendix B, Table B-3. The associated data quality assessment is presented in Appendix A.

As shown in Table B-3 differences in groundwater quality between the July and August 2011 sampling events were generally small. Nitrate+nitrite-N concentrations were at-or-near analytical detection limits in all sampled piezometers and ranged from 0.01 U to 0.024 mg/L. The concentration at spring site S-1 which discharges to Spring Branch Creek (a tributary to Lacamas Creek) was slightly higher at 0.292 mg/L. Concentrations of TPN-N (range 0.041 to 2.63 mg/L) and ammonia (range 0.023 to 2.83 mg/L) generally exceeded nitrate+nitrite-N concentrations at most piezometer sites.

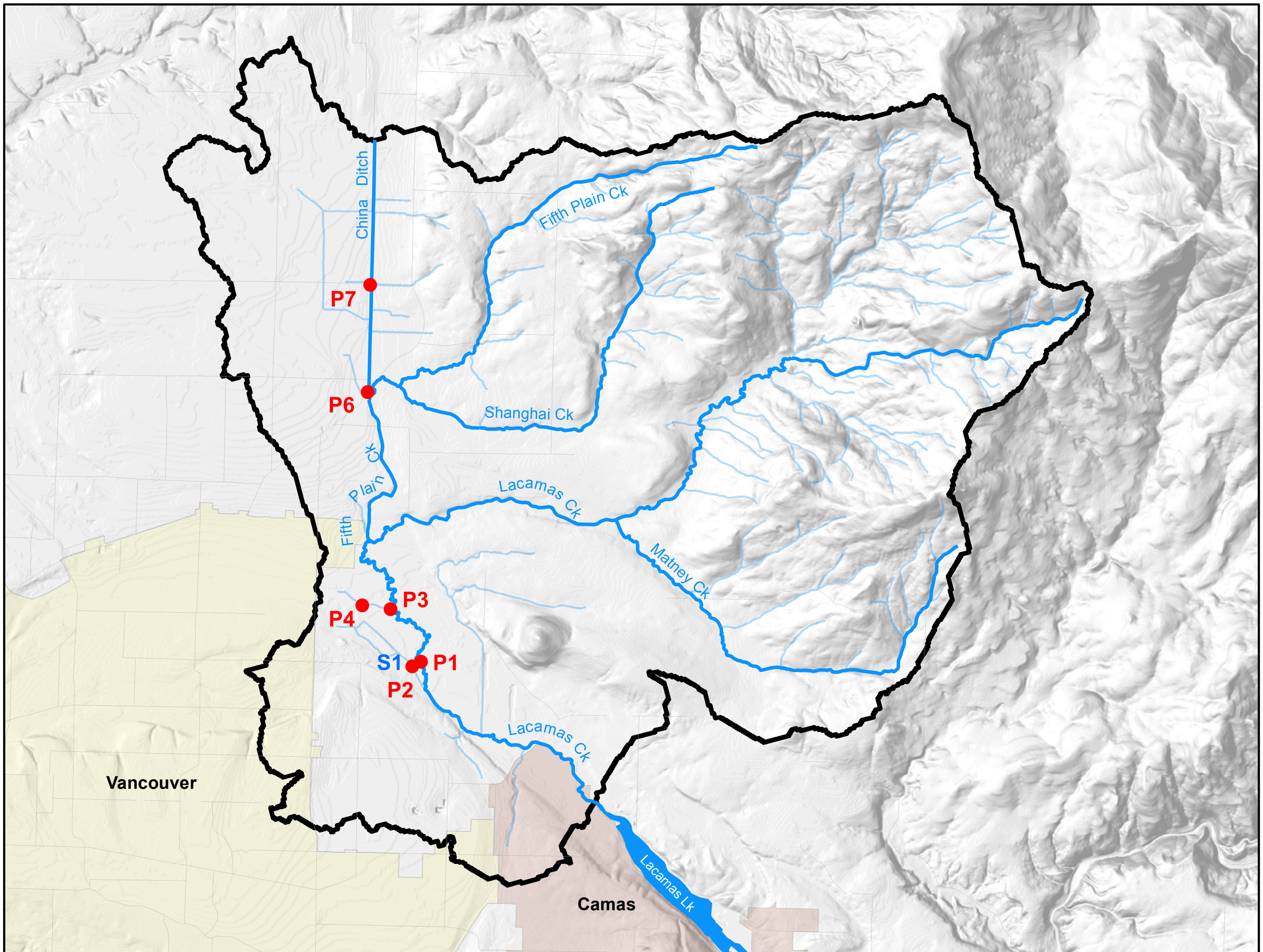
All sampled piezometers had detectible concentrations of total phosphorus (range 0.0221 to 0.602 mg/L) and all but one piezometer had elevated concentrations of iron (range 4.6 to 39.1 mg/L). The absence of nitrate coupled with elevated iron concentrations suggests that the groundwater at most of the sampled piezometer sites likely contains little dissolved oxygen. It was difficult to confirm this assertion by direct DO measurement, however, since most of the piezometers purged dry before field parameters fully stabilized.

The highest groundwater nutrient concentrations were observed at site P3 which is located approximately 700+ feet from a dairy manure lagoon. The groundwater concentrations of ammonia and TPN-N were an order of magnitude higher at this site relative to the values found at other sampled piezometers. This suggests the lagoon complex and/or local manure management practices may be contributing nutrients to groundwater locally.

With the exception of sites P3 and P4, all sampled piezometers had non-detectable concentrations of fecal coliform bacteria. The bacteria samples for sites P3 and P4 were processed a few hours beyond the accepted 24-hour sample holding time. Accordingly, the bacterial results for these wells were qualified by laboratory staff as estimates and were assigned a value of 1 J. The sample for spring site SP-1 was also flagged by the laboratory as an estimate due to interference effects and was assigned a value of 23 J. All of the values reported here were well below the 100 organisms/100 ml surface water quality standard for fecal coliform. This suggests that groundwater is not a significant contributor of fecal coliform bacteria to the creek.

There are four sites (P1, P2, P3, and P6) where both surface water and groundwater samples were collected during the synoptic surveys. Based on this limited sampling, surface water nitrate+nitrite-N concentrations were consistently higher than their corresponding groundwater values while surface water DOC and alkalinity concentrations were typically lower (Figure 10). The remaining analytes did not show a consistent pattern and were sometimes higher or lower in surface water than groundwater.

Since all 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.




| Water Quality Parameter | S1 | P1 | P2 | P3 | P4 | P6 | P7 |
|---|---|---|---|---|---|---|---|
| | Sampling Location by map ID | | | | | | |
| pH (std units) | 6.92 | 7.37 | 7.07 | 6.96 | 6.35 | 7.865 | 7.17 |
| Specific conductance (us/cm @ 25C) | 201.9 | 159.5 | 250.9 | 363.5 | 318.3 | 178.2 | 315.35 |
| Dissolved Oxygen (mg/L) | 3.9 | 2.19 | 0.7 | 2.39 | 0.28 | 3.165 | 0.365 |
| Fecal coliform (#/100 ml) | 23 J | 1 U | 1 U | 1 J | 1 J | 1 U | 1 U |
| Total Alkalinity (mg/L) | 96.5 | 83.6 | 98.7 | 202.5 | 139 | 76.85 | 137 |
| Total Chloride (mg/L) | 3.99 | 4.88 | 5.47 | 2.75 | 4.03 | 11.15 | 8.87 |
| Ortho-phosphate (mg/L) * | 0.0655 | 0.0075 | 0.003 U | 0.0082 | 0.003 U | 0.1813 | 0.0145 |
| Total phosphorus (mg/L) * | 0.0866 | 0.0268 | 0.0899 | 0.0507 | 0.602 | 0.1820 | 0.110 |
| Nitrate+nitrite-N (mg/L) * | 2.920 | 0.015 | 0.0235 | 0.015 | 0.010 U | 0.010 U | 0.0105 |
| Ammonia (mg/L) * | 0.014 | 0.2445 | 0.1085 | 2.815 | 0.049 | 0.0275 | 0.1485 |
| TPN-N (mg/L) * | 0.44 | 0.283 | 0.2795 | 2.605 | 0.284 | 0.056 | 0.171 |
| Dissolved organic carbon (mg/L) * | 3.3 B | 4.4 B | 7.7 | 10.6 | 8.8 | 1.35 B | 1 U |
| Iron (mg/L) * | 0.935 | 7.145 | 24.45 | 19.6 | 39.1 | 0.05 U | 4.67 |

* Dissolved sample fraction

Note: Sites S1 and P4 were sampled once. The remaining sites were sampled twice. See Table B-3 for an explanation of data qualifiers and a listing of individual sample results by well and sample date.

Figure 9: Average analyte concentrations in groundwater from sampled instream piezometers and springs

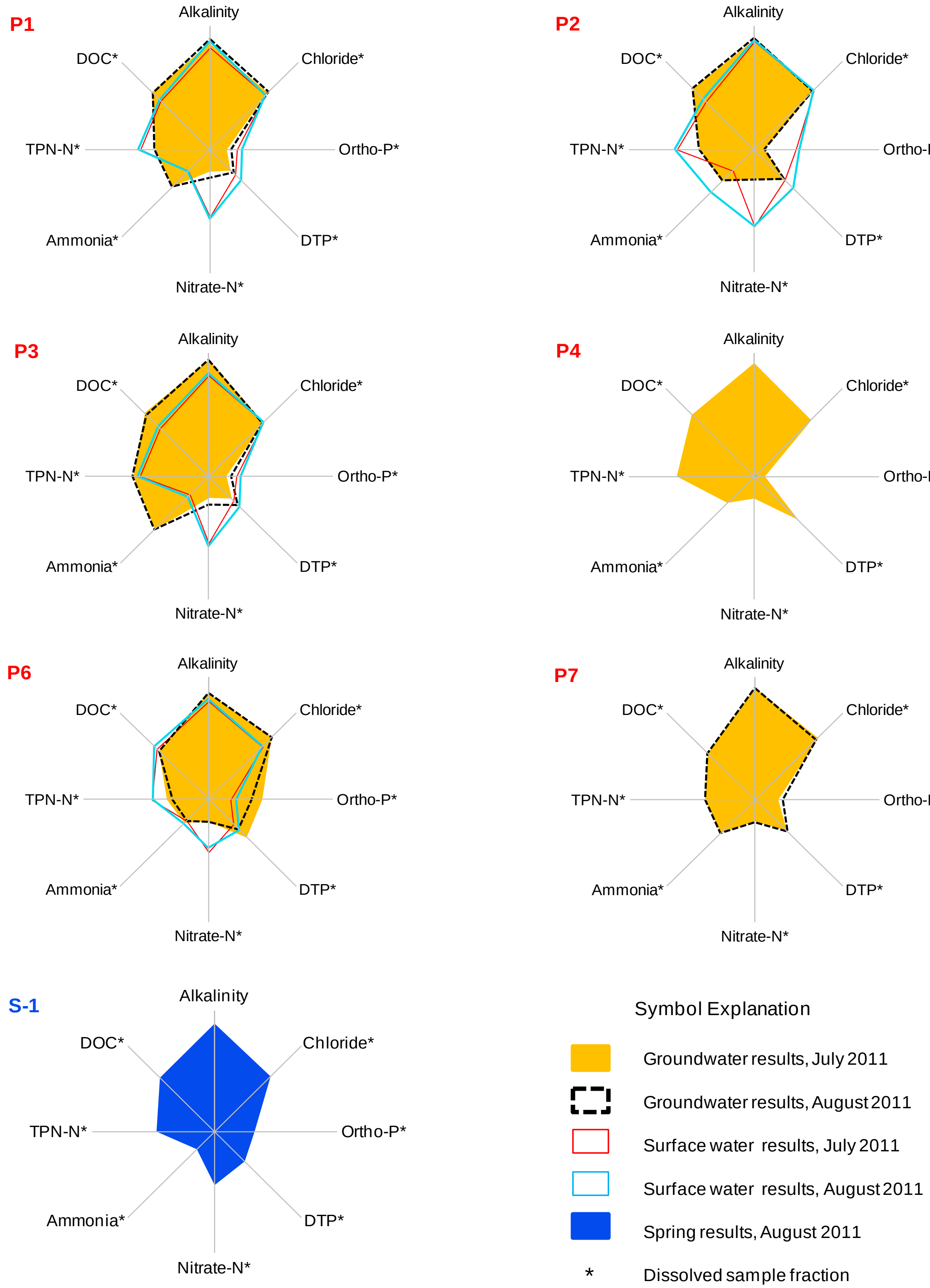



Figure 10: Graphical depiction of the relative analyte concentration in surface water from Lacamas Creek and groundwater from instream piezometers and springs that were sampled during the July 26 and August 30, 2011 synoptic surveys.

# Summary and Conclusions

This study was undertaken to support a TMDL investigation of Lacamas Creek. The primary study goals were to:

1. Assess the magnitude and direction of surface water/groundwater interactions along the creek.
2. Characterize groundwater quality along gaining stream reaches.

Multiple field and analytical techniques were used to achieve these objectives. Stream seepage studies were conducted in July and August, 2011 to quantify net streamflow gains and losses along selected stream reaches. These reach-based evaluations were supplemented with information from a small network of instream piezometers that were monitored to evaluate surface water/groundwater head relationships, streambed temperatures, and near-stream groundwater quality.

Collectively, these evaluations reveal that Lacamas Creek is likely comprised of alternating gaining and losing stream reaches. During the July seepage evaluation the creek showed net overall gains from groundwater of approximately +1.3 $ft^3$/sec between the upper end of reach 1 and the lower end or reach 3. During the August evaluation the creek showed a net loss of approximately -2.7 $ft^3$/s.

During the July and August 2011 synoptic surveys, measurable concentrations of dissolved orthophosphate and dissolved total phosphorus were found in all sampled piezometers at values ranging from 0.003U to 0.276 mg/L and 0.0221 to 0.602 mg/L respectively. Concentrations of dissolved nitrate+nitrite-N and ammonia ranged from 0.01U to 0.024 and 0.023 to 2.83 mg/L respectively.

The water quality values reported here do not account for biological or geochemical transformations that can potentially reduce phosphorous and nitrogen-based nutrient concentrations in groundwater as it passes through the final few feet of the streambed. Accordingly, these values probably represent the upper-bound range of nutrient concentrations that groundwater contributes to the creek locally. If future TMDL modeling efforts indicate a need to further constrain the nutrient concentrations reported here, it may be possible to quantify the potential influence of these processes where field conditions allow.

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# Appendices

# Appendix A.  Data Quality Review

## Stream Seepage Evaluations

To aid data interpretation, we used a spreadsheet model based on the work of Konrad et al. (2003) to assess the potential effects of measurement error on the calculated reach-based-seepage budgets for Lacamas Creek.  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 [4] (Table A-1).

Table A-1: 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 |

Based on a review of project field notes, individual transects were assigned to one of two categories (good or fair).  These transect assignments and associated estimates of measurement error were used in the model to assess the cumulative measurement error and 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, the exchange was not considered significant since it did not exceed the cumulative potential measurement error for the reach.

The results of this evaluation are summarized by seepage reach and measurement date in Figure 8 and Table B-1.

## 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 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-2).

[4] 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 ft.  The flow should be uniform and evenly distributed across the transect with no eddies, slack water, or excessive turbulence (Rantz et al., 1982).

Table A-2: 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. An NIST[5] 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 over 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 temperatures 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.

All tested thermistors met our project acceptance criteria during the pre-deployment calibration checks. The post-deployment evaluation showed that all thermistors continued to meet the manufacturer's specified accuracy range for both ice-bath and room-temperature water conditions (Figure A-1). Accordingly, the thermistor temperature records were accepted and used without further qualification.

[5] National Institute of Standards and Technology

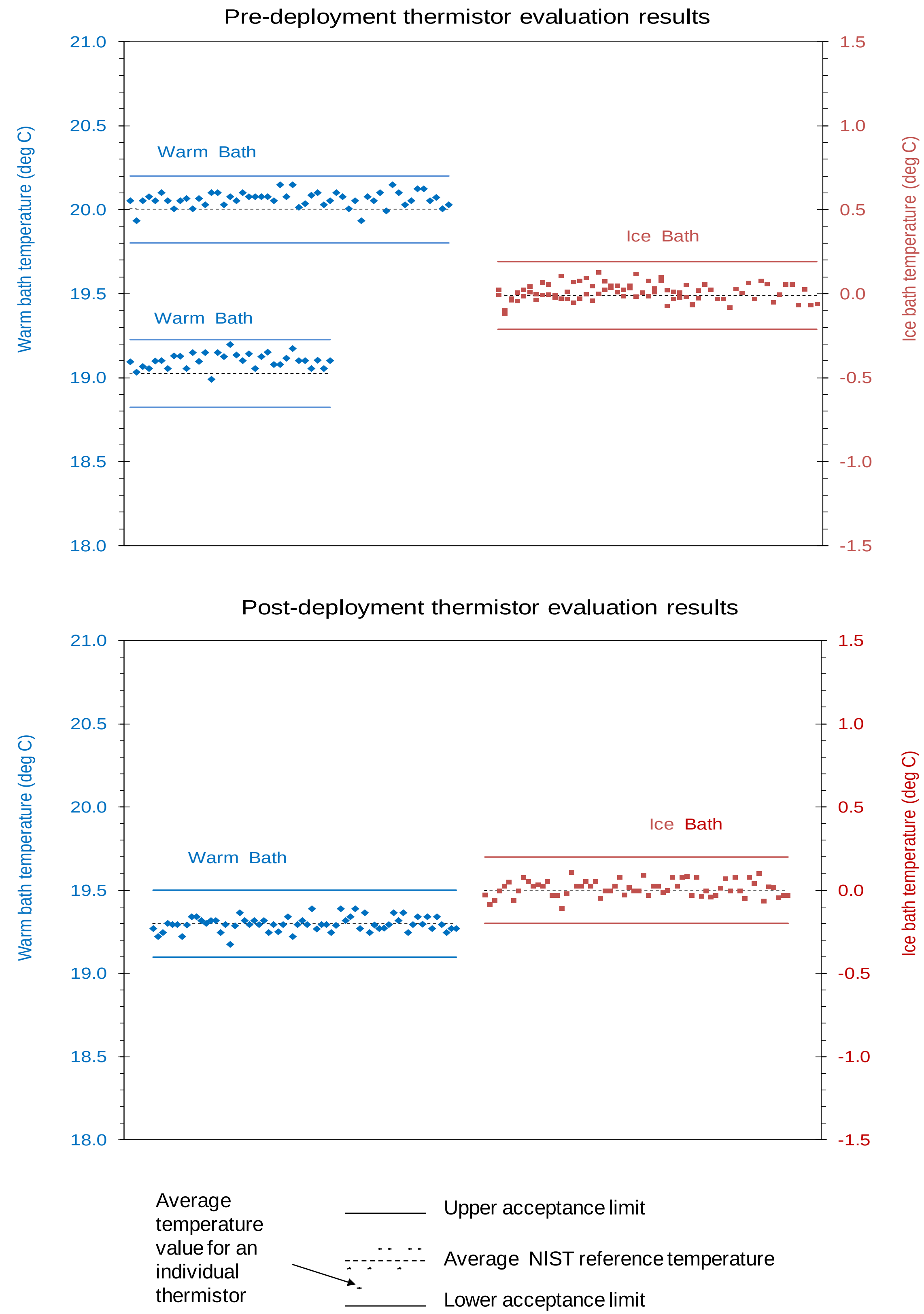



Figure A-1: Results of pre-deployment and post-deployment thermistor calibration checks.

## Field-Meter Calibration and Verification

Water quality field meters were calibrated in accordance with the manufacturer's instructions at the start of each sampling day (Swanson, 2007). 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 calibration 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 standard and the meter values (Table A-3). The pH calibration was accepted if the metered values differed by less than ± 0.05 pH units from the buffer value. The specific conductance calibration was accepted if the meter values deviated by no more than ± 5% from the specific conductance check standards.

Following each sampling event, the meters were rechecked against reference standards to confirm they had not drifted unacceptably since the initial calibration. Using the post-use acceptance criteria listed in Table A-3 the results were either accepted, qualified as estimates, or rejected as unusable. Based on this evaluation, the dissolved oxygen results for the July 2011 sampling event were qualified as estimates due to a small exceedance of our post-use calibration criterion. The remaining field results were acceptable and are reported here without further qualification.

Table A-3: Field meter calibration records for the July and August 2011 synoptic groundwater quality survey.

| | | pH | | | | Specific conductance | | | | Dissolved oxygen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Status | 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] | Meter reading (mg/L | saturation (percent) | Accept or reject calibration/ results [1] |
| 7/22/2011 | Pre-use | 4.01 | 4 | -0.01 | Accept | 100 | 102 | 2.0 | Accept | 8.55 | 100.2 | Accept |
| | | 7 | 7.02 | 0.02 | Accept | | | | | | | |
| 8/3/2011 | Post-use | 4.01 | 4.09 | 0.08 | Accept | 100 | 101.1 | 1.1 | Accept | 8.85 | 101 | J qualify |
| | | 7 | 7.12 | 0.12 | Accept | | | | | | | |
| 8/26/2011 | Pre-use | 4.01 | 4.02 | 0.01 | Accept | 100 | 101.8 | 1.8 | Accept | 8.29 | 100 | Accept |
| | | 7 | 7.01 | 0.01 | Accept | | | | | | | |
| 9/6/2011 | Post-use | 4.01 | 4.03 | 0.02 | Accept | 100 | 101.9 | 1.9 | Accept | 8.33 | 100.4 | Accept |
| | | 7.01 | 7.01 | 0 | Accept | | | | | | | |

Calibration acceptance criteria by parameter [1]

pH

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 (saturation percent)
- ≥ 99.7 and ≤ 100.3 = accept calibration
- < 99.6 or > 100.4 = reject calibration

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

pH

Deviation from check standards following initial calibration:
- ≤ ±0.15 pH deviation from all standards = accept results
- > ±0.15 and ≤ ±0.5 pH deviation from any standard = qualify results as estimat
- > ±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
- > ±10% deviation from any standard = reject results

Dissolved oxygen (saturation percent)
- ≥ 99.5 and ≤ 100.5 = accept calibration
- < 99.4 or > 100.6 = qualify results as estimates ("J" code)

## 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 percent 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-4). Data quality exceptions included:

- Two fecal coliform samples from July (AHT053 and AHT054) and one sample from August, 2011 (AHT053) 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. An additional fecal coliform sample from August (SP-1) was also "J" coded as an estimate due to potential interference issues. The true value for this site may be greater than or equal to the reported value.
- The matrix spike recovery percentage for one sample from July (AHT053) exceeded the acceptance criteria for orthophosphate due to interference issues. The source sample was "J" qualified as an estimate.

Table A-4: Data quality objectives for water quality samples.

| Parameter | Check standards (% recovery limits) | Field duplicate sample (%RSD) | Matrix spikes (% 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 |
| 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"[6] 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[7] (%RSD) for each duplicate sample pair. The resulting values (Table A-5) were then tabulated and compared to the project data quality objectives (Table A-4).

This evaluation revealed that all of the field blanks contained small but measurable concentrations of DOC (1.6 mg/L) while the laboratory blanks were all less than the reporting limit of 1 mg/L. To pinpoint the possible cause for this problem we submitted two blank samples (one field filtered and one unfiltered) to the laboratory during the August 30, 2011 sampling event. The unfiltered sample showed non-detectable concentrations of DOC while the

[6] 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.

[7] 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.

filtered sample had a DOC concentration of 1.6 mg/L. Based on this evaluation, it seems likely that the filtration procedure is imparting a positive bias on our blank (and potentially our sample) results. The contamination is significant enough to warrant qualification of all reported DOC values that were less than or equal to 5 times the method reporting limit of 1 mg/L. Accordingly, the laboratory results for all samples with DOC concentrations less than 5 mg/L were “B” coded by the authors to indicate they are estimates and may potentially be biased high by filter-related contamination.

In addition, the orthophosphate result for one sample collected in August (AHT049) was greater than the corresponding dissolved total phosphorous value. The reason(s) for this discrepancy are not known. The reported value was “J” qualified by the authors to indicate it is an estimate.

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.

Table A-5: Summary of field and laboratory duplicate samples and blanks.

| Sample date | | Total alkalinity (mg/L) | Total 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 Filter Blanks | | | | | | | | | | | |
| 7/26/2011 | Sample | 139 | 4.03 | 8.8 | 0.003 U | 0.602 | 0.01 U | 0.049 | 0.284 | 1 J | 39.1 |
| | Rep/Duplicate | 139 | 4.23 | 9 | 0.003 U | 0.609 | 0.01 U | 0.05 | 0.289 | 1 U | 39.1 |
| | %RSD | 0.00 | 3.42 | 1.59 | 0.00 | 0.82 | 0.00 | 1.43 | 1.23 | 0.00 | 0.00 |
| | Sample blank | 5 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 |
| 8/30/2011 | Sample | 136 | 7.64 | 1.0 U | 0.0184 | 0.119 | 0.011 | 0.15 | 0.167 | 1 U | 4.74 |
| | Rep/Duplicate | 136 | 7.66 | 1.0 U | 0.0178 | 0.119 | 0.012 | 0.15 | 0.167 | 1 U | 4.77 |
| | %RSD | 0.00 | 0.18 | 0.00 | 2.34 | 0.00 | 6.15 | 0.00 | 0.00 | 0.00 | 0.45 |
| | 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 | | 0.00 | 1.80 | 0.79 | 1.17 | 0.41 | 3.07 | 0.71 | 0.62 | 0.00 | 0.22 |
| Laboratory Replicates and Blanks | | | | | | | | | | | |
| 7/26/2011 | Sample | 70.3 | 3.78 | - | 0.003 U | 0.028 | 0.01 U | 0.01 U | 2.57 | 1 U | - |
| | Rep/Duplicate | 67.4 | 3.78 | - | 0.006 J | 0.0281 | 0.01 U | 0.01 U | 2.58 | 1 U | - |
| | %RSD | 2.98 | 0.00 | - | **47.14** | 0.25 | 0.00 | 0.00 | 0.27 | 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 | 1 U | 0.05 U |
| 8/30/2011 | Sample | 96.5 | 3.99 | - | 0.0663 | 0.005 U | 0.081 | 0.102 | 0.465 | 1 U | - |
| | Rep/Duplicate | 96.5 | 4.01 | - | 0.0655 | 0.005 U | 0.082 | 0.1 | 0.44 | 1 U | - |
| | %RSD | 0.00 | 0.35 | - | 0.86 | 0.00 | 0.87 | 1.40 | 3.91 | 0.00 | - |
| | Sample blank | 5.0 U | 0.1 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.
Bold 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: [http://www.ecy.wa.gov/eim/index.htm](http://www.ecy.wa.gov/eim/index.htm)

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

EIM study name:

> Lacamas Creek Fecal Coliform, Temperature, Dissolved Oxygen, and pH total Maximum Daily Load

EIM user study ID:

> TSWA0003

Note: The continuous (30-minute interval) temperature records that are depicted graphically in Figure B-1 are available by request.

## Well Numbering and Location System

The piezometer locations referenced in this report are described using latitude/longitude coordinates (Table B-2).  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 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 of the piezometers 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., AHT046).  The two-by-three-inch aluminum identification tag was secured to the well casing, or another permanent fixture of the water system, with stainless steel banding.  This arrangement provides field personnel ready confirmation of well identity during a site visit.

Table B-1: Summary of the July 26 and August 30, 2011 Seepage Assessments of Lacamas Creek.

| Map ID [A] | Mainstem station description | Site ID | River mile | Seepage reach ID | Seepage reach length (miles) | Sum of certificated water diversons [B] ($ft^3/s$) | Tributary name | Measurement date | Measured discharge [C] ($ft^3/s$) | Net seepage gain or loss for reach [D] ($Ft^3/s$) | Net seepage gain or loss for reach [D] ($ft^3/s$/river mile) | Is reach measured gain or loss significant [E] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | July 26, 2011 Assessment | | | | | | |
| P10 | Lacamas Ck at Camp Bonneville | LAC-14.8 | 14.8 | | | | | 7/26/2011 | 6.34 | | | |
| | | | | Reach 1 | 1.5 | 0.5 | Matney Ck. | 7/26/2011 | 1.53 | -0.31 | -0.21 | N |
| G4 | Lacamas Ck at NE 217th Ave | LAC-13.3 | 13.3 | | | | | 7/26/2011 | 7.56 | | | |
| | | | | Reach 2 | 2.2 | 1.0 | - | - | - | 0.15 | 0.07 | N |
| | Lacamas Ck at 4th Plain NE (SR 500) | LAC-11.1 | 11.1 | | | | | 7/26/2011 | 7.71 | | | |
| | | | | Reach 3 | 5.5 | 3.25 | Fifth Plain Ck. | 7/26/2011 | 7.18 | 1.50 | 0.27 | Y |
| | | | | | | | Big Ditch | 7/26/2011 | 0.00 e | | | |
| | | | | | | | Spring Branch Ck. | 7/26/2011 | 7.48 | | | |
| | | | | | | | Tug Lk. channel | 7/26/2011 | 0.00 e | | | |
| G1 | Lacamas Ck at Goodwin Rd. | LAC-5.6 | 5.6 | | | | | 7/26/2011 | 23.87 | | | |
| | | | | | | | | Combined July 26th total for reaches 1-3 | | 1.34 | 0.15 | Y |
| | | | | | | August 30, 2011 Assessment | | | | | | |
| P10 | Lacamas Ck at Camp Bonneville | LAC-14.8 | 14.8 | | | | | 8/30/2011 | 4.46 | | | |
| | | | | Reach 1 | 1.5 | 0.5 | Matney Ck. | 8/30/2011 | 0.79 | 0.09 | 0.06 | N |
| G4 | Lacamas Ck at NE 217th Ave | LAC-13.3 | 13.3 | | | | | 8/30/2011 | 5.34 | | | |
| | | | | Reach 2 | 2.2 | 1.0 | - | - | - | -0.46 | -0.21 | Y |
| | Lacamas Ck at 4th Plain NE (SR 500) | LAC-11.1 | 11.1 | | | | | 8/30/2011 | 4.88 | | | |
| | | | | Reach 3 | 5.5 | 3.25 | Fifth Plain Ck. | 8/30/2011 | 5.85 | -2.36 | -0.43 | Y |
| | | | | | | | Big Ditch | 8/30/2011 | 0.00 e | | | |
| | | | | | | | Spring Branch Ck. | 8/30/2011 | 5.95 | | | |
| | | | | | | | Tug Lk. channel | 8/30/2011 | 0.00 e | | | |
| G1 | Lacamas Ck at Goodwin Rd. | LAC-5.6 | 5.6 | | | | | 8/30/2011 | 14.32 | | | |
| | | | | | | | | Combined August 30th total for reaches 1-3 | | -2.73 | -0.30 | Y |

[A] See Figure 5 for a map of site locations

[B] The reported value is the sum of certificated water withdrawals from Lacamas Ck. proper along the seepage reach. Which if any of these withdrawals were active during the assessments is not known.

[c] e - Estimated value. The creek was either dry or had standing water but no apparent flow.

[D] These values do not account for the potential influence of out-of-stream water diversions or small point discharges to the creek. Were we able to accurately account for these influences, the seepage values reported here would be higher for those reaches where out-of-stream withdrawals exceeded point discharges to the creek, and lower for those reaches where point discharges exceeded water withdrawals.

[E] N - the net seepage value 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 value exceeded the potential cumulative measurement errors associated with making the measurements. The gaiin or loss is considered significant.

Table B-2: Physical Description and Location of Instream Piezometers.

| Map ID [1] | Well tag ID number | Stream name | Approximate river mile location (mile) | Well location | Latitude (decimal degrees) | Longitude (decimal degrees) | Site elevation (feet) | Piezometer stickup (feet above streambed)[1] | Piezometer depth (feet below streambed)[1] | Length of perforated interval (feet) | Depth to midpoint of piezometer perforations (feet below streambed)[1] | Thermistor deployment depths within piezometer (feet below streambed)[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | AHT047 | Lacamas | 7.5 | 02N/03E-18Q | 45.65076 | -122.4825 | 193 | 2.31 | 4.82 | 0.3 | 4.63 | 1.00<br>2.60<br>4.34 |
| P2 | AHT046 | Spring Branch | 0.3 | 02N/03E-19B | 45.64997 | -122.48440 | 198 | 4.01 | 3.44 | 0.3 | 3.14 | 1.33<br>-<br>2.92 |
| P3 | AHT053 | Lacamas Ck | 9.1 | 02N/03E-18C | 45.65868 | -122.48945 | 197 | 3.6 | 6.6 | 0.49 | 6.21 | 1.35<br>3.11<br>6.01 |
| P4 | AHT054 | Big ditch | 0.2 | 02N/03E-13H | 45.65912 | -122.49564 | 200 | 2.9 | 4.8 | 0.33 | 4.24 | 1.42<br>2.57<br>3.94 |
| P5 | AHT048 | Lacamas | 11.1 | 02N/03E-07L | 45.67165 | -122.48829 | 213 | 1.87 | 3.53 | 0.29 | 3.19 | 1.02<br>1.97<br>2.95 |
| P6 | AHT049 | Fifth Plain Ck | 1.9 | 02N/03E-06D | 45.69187 | -122.49562 | 253 | 0.95 | 4.27 | 0.34 | 3.96 | 1.31<br>2.52<br>3.72 |
| P7 | AHT050 | China ditch | 1.2 | 03N/03E-31D | 45.70826 | -122.49564 | 261 | 2.02 | 4.97 | 0.3 | 4.64 | 1.16<br>2.47<br>4.44 |
| P8 | AHT051 | Fifth Plain Ck | 3.4 | 03N/03E-32K | 45.69960 | -122.47185 | 285 | 1.05 | 4.05 | 0.5 | 3.57 | 1.02<br>2.16<br>3.44 |
| P9 | AHT052 | Shanghai Ck | 2.7 | 02N/03E-04B | 45.69360 | -122.44495 | 346 | 1.41 | 4.94 | 0.31 | 4.64 | 1.22<br>2.99<br>4.37 |
| P10 | AHT055 | Lacamas Ck | 14.8 | 02N/03E-10E | 45.67510 | -122.43436 | 295 | 1.7 | 3.7 | 0.31 | 3.29 | 1.05<br>2.08<br>3.07 |

[1] - These values based on measurements made during piezometer installation.

Table B-3: Summary of Field Measurements and Water Quality Results for Instream Piezometers and Springs.

| | | | Groundwater Field Parameters [3] | | | | | Laboratory Analyses [4] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Map ID [1] | Well tag ID number | Sample date | Vertical hydraulic gradient [2] (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) |
| P1 | AHT047 | 9/14/2010 | -0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | -0.002 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | - | - | - | - | - | - | 67.4 | 4.83 | 0.006 | 0.0221 | 0.010 U | 0.232 | 0.258 | 4.7 B | 6.12 |
| | | 8/29/2011 | 0.012 | 15.97 J | 7.37 J | 159.5 J | 2.19 J | - | - | - | - | - | - | - | - | - | - |
| | | 8/30/2011 | - | - | - | - | - | 1 U | 99.8 | 4.93 | 0.009 | 0.0314 | 0.02 | 0.257 | 0.308 | 4.1 B | 8.17 |
| | | 9/20/2011 | 0.014 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/18/2011 | 0.130 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P2 | AHT046 | 12/6/2010 | 0.000 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 2/1/2011 | 0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/8/2011 | 0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | 0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | - | - | - | - | - | 1 U | 92.4 | 5.74 | 0.003 U | 0.0986 | 0.023 | 0.117 | 0.264 | 7.6 | 24 |
| | | 8/29/2011 | -0.029 | 13.35 J | 7.07 J | 250.9 J | 0.7 J | - | - | - | - | - | - | - | - | - | - |
| | | 8/30/2011 | - | - | - | - | - | 1 U | 105 | 5.2 | 0.003 U | 0.0812 | 0.024 | 0.1 | 0.295 | 7.8 | 24.9 |
| | | 9/20/2011 | -0.029 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/18/2011 | -0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P3 | AHT053 | 9/30/2010 | 0.008 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/8/2011 | -0.086 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | 0.050 | 14.34 J | 6.86 J | 367.3 J | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | - | - | - | - | - | 1 J | 202 | 2.83 | 0.006 J | 0.0281 | 0.010 U | 2.83 | 2.58 | 12.3 | 17.9 |
| | | 8/29/2011 | 0.002 | 15.48 J | 7.06 J | 359.7 J | 2.39 J | - | - | - | - | - | - | - | - | - | - |
| | | 8/30/2011 | - | - | - | - | - | 1 J | 203 | 2.68 | 0.0105 | 0.0733 | 0.02 | 2.8 | 2.63 | 8.9 | 21.3 |
| | | 9/20/2011 | -0.023 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/18/2011 | -0.036 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P4 | AHT054 | 9/30/2010 | 0.009 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 12/6/2010 | 0.231 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 2/1/2011 | 0.173 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/8/2011 | 0.135 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | 0.029 | 13.92 J | 6.35 J | 318.3 J | 0.28 J | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | - | - | - | - | - | 1 J | 139 | 4.03 | 0.003 U | 0.602 | 0.010 U | 0.049 | 0.284 | 8.8 | 39.1 |
| | | 8/29/2011 | -0.130 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 9/20/2011 | -0.207 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/18/2011 | -0.023 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P5 | AHT048 | 2/1/2011 | -0.006 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/8/2011 | -0.061 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | -0.044 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 8/29/2011 | -0.165 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 9/20/2011 | -0.191 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/18/2011 | -0.104 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table B-3: (Continued)

| | | | Groundwater Field Parameters [3] | | | | | Laboratory Analyses [4] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Map ID [1] | Well tag ID number | Sample date | Vertical hydraulic gradient [2] (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) |
| P6 | AHT049 | 12/7/2010 | 0.031 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 1/31/2011 | -0.103 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/7/2011 | 0.062 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | 0.262 | 15.6 J | 7.95 J | 162.6 J | 1.62 J | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | - | - | - | - | - | - | 76.8 | 11.4 | 0.276 | 0.284 | 0.010 U | 0.032 | 0.071 | 1.3 B | 0.05 U |
| | | 8/29/2011 | 0.173 | 16.39 J | 7.78 J | 193.8 J | 4.71 J | - | - | - | - | - | - | - | - | - | - |
| | | 8/30/2011 | - | - | - | - | - | 1 U | 76.9 | 10.9 | 0.0866 J | 0.080 | 0.010 U | 0.023 | 0.041 | 1.4 B | 0.05 U |
| | | 9/20/2011 | 0.113 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/17/2011 | -0.034 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P7 | AHT050 | 9/15/2010 | 0.221 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 12/7/2010 | 0.285 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 1/31/2011 | 0.298 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/7/2011 | 0.322 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | 0.222 | 13.36 | 7.08 | 314.8 | 0.42 | 1 U | 138 | 10.1 | 0.011 | 0.101 | 0.010 U | 0.147 | 0.175 | 1 U | 4.6 |
| | | 8/30/2011 | 0.191 | 12.89 | 7.26 | 315.9 | 0.31 | 1 U | 136 | 7.64 | 0.018 | 0.119 | 0.011 | 0.15 | 0.167 | 1 U | 4.74 |
| | | 9/21/2011 | 0.192 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/17/2011 | 0.194 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P8 | AHT051 | 12/7/2010 | 0.008 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 2/2/2011 | 0.034 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/7/2011 | 0.032 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | 0.089 | 15.96 J | 8.25 J | 152 J | 1.25 J | - | - | - | - | - | - | - | - | - | - |
| | | 8/29/2011 | -0.759 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 9/21/2011 | -1.126 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/17/2011 | 0.035 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P9 | AHT052 | 12/8/2010 | -0.140 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 2/2/2011 | -0.050 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/7/2011 | -0.056 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/25/2011 | -0.042 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 8/29/2011 | -0.036 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 9/20/2011 | -0.036 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/17/2011 | -0.050 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Table B-3: (Continued)

| Map ID [1] | Well tag ID number | Sample date | Groundwater Field Parameters [3]: Vertical hydraulic gradient [2] (dimensionless) | Water temperature (deg C) | pH (standard units) | Specific conductance (µS/cm @ 25 °C) | Dissolved oxygen (mg/L) | Laboratory Analyses [4]: 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P10 | AHT055 | 9/30/2010 | 0.003 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 12/1/2010 | 0.000 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 2/1/2011 | 0.014 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 6/8/2011 | 0.029 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 7/26/2011 | -0.011 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 8/29/2011 | 0.000 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 9/21/2011 | 0.000 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 10/17/2011 | -0.032 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| SP-1 | - | 8/30/2011 | NA | 15.16 | 6.92 | 201.9 | 3.9 | 23 J | 96.5 | 3.99 | 0.0655 | 0.0866 | 0.292 | 0.014 | 0.44 | 3.3 B | 0.935 |

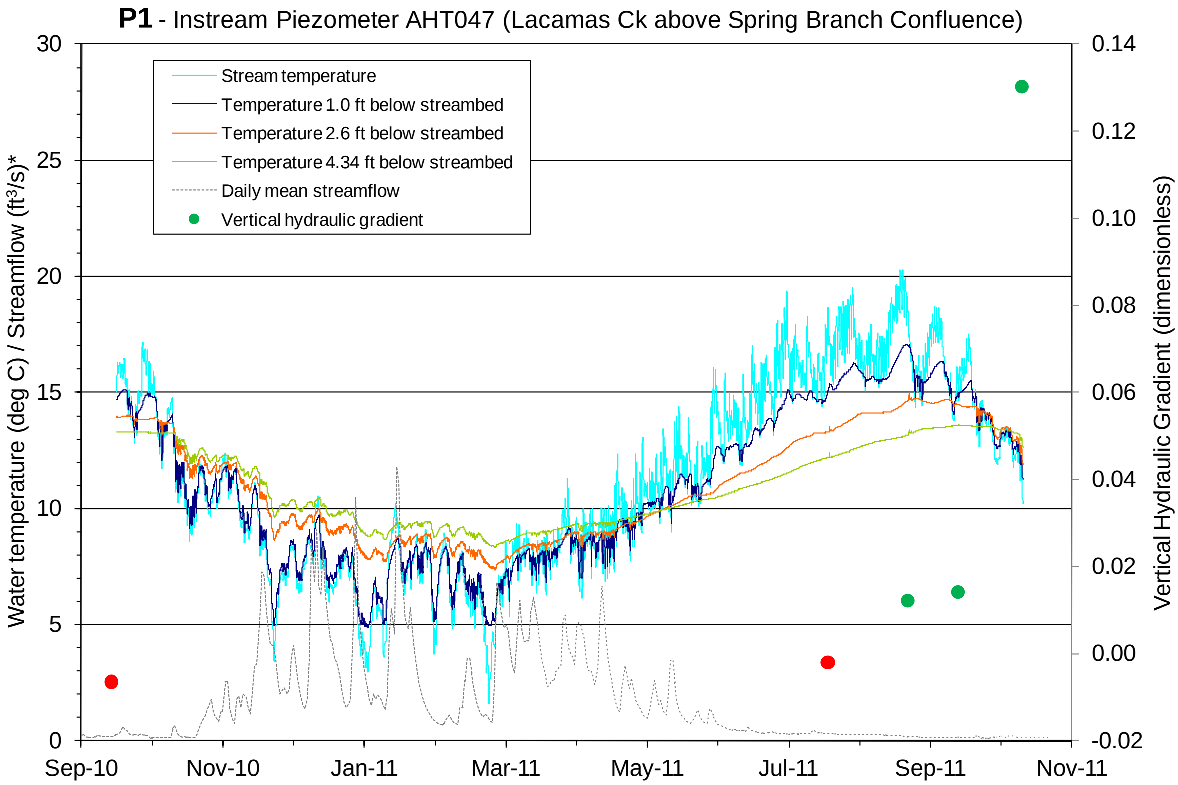
[1] - The map IDs listed here correspond with those shown on Figures 5 and 10

[2] - Negative vertical hydraulic gradient values indicate the potential for loss of stream water to groundwater storage. Positive values indicate the potential for groundwater discharge to the stream.

[3] - Low producing wells were pre-purged dry the day before sampling. The field parameters for these wells are reported as estimates (J-coded) since they may not be indicative of true insitu GW conditions

[4] - 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



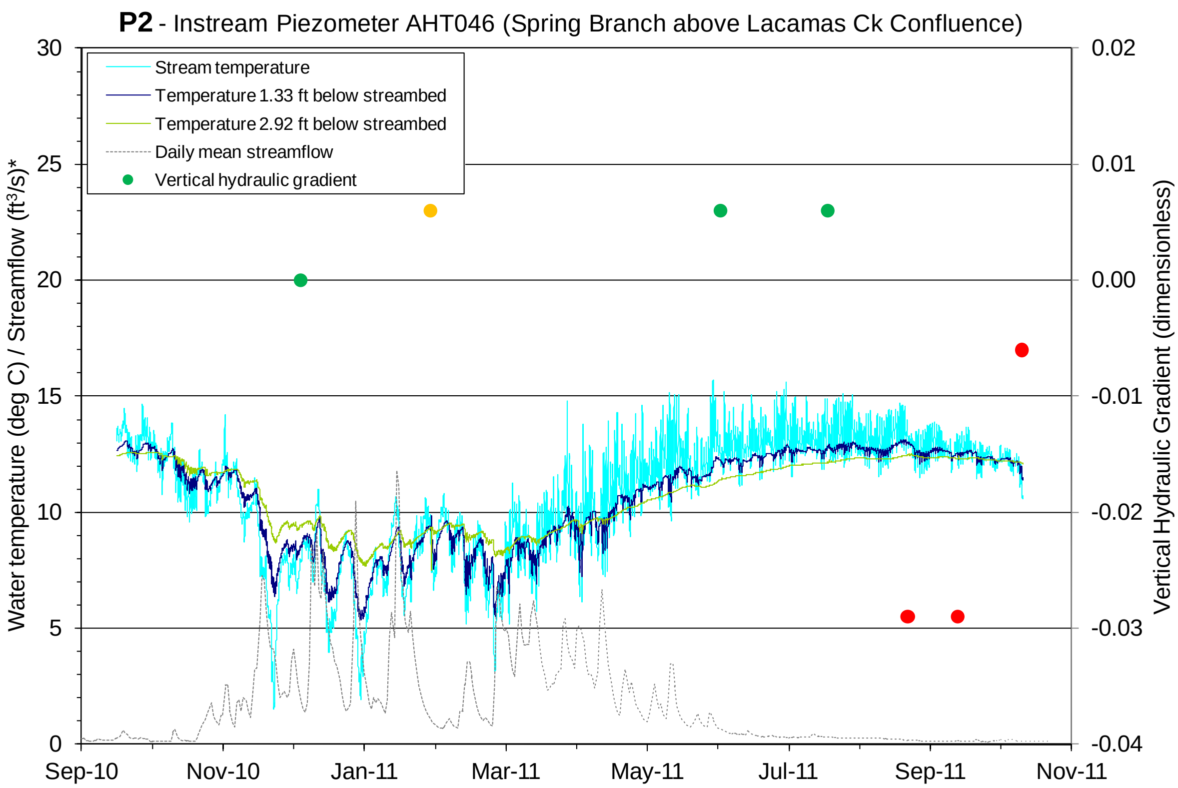
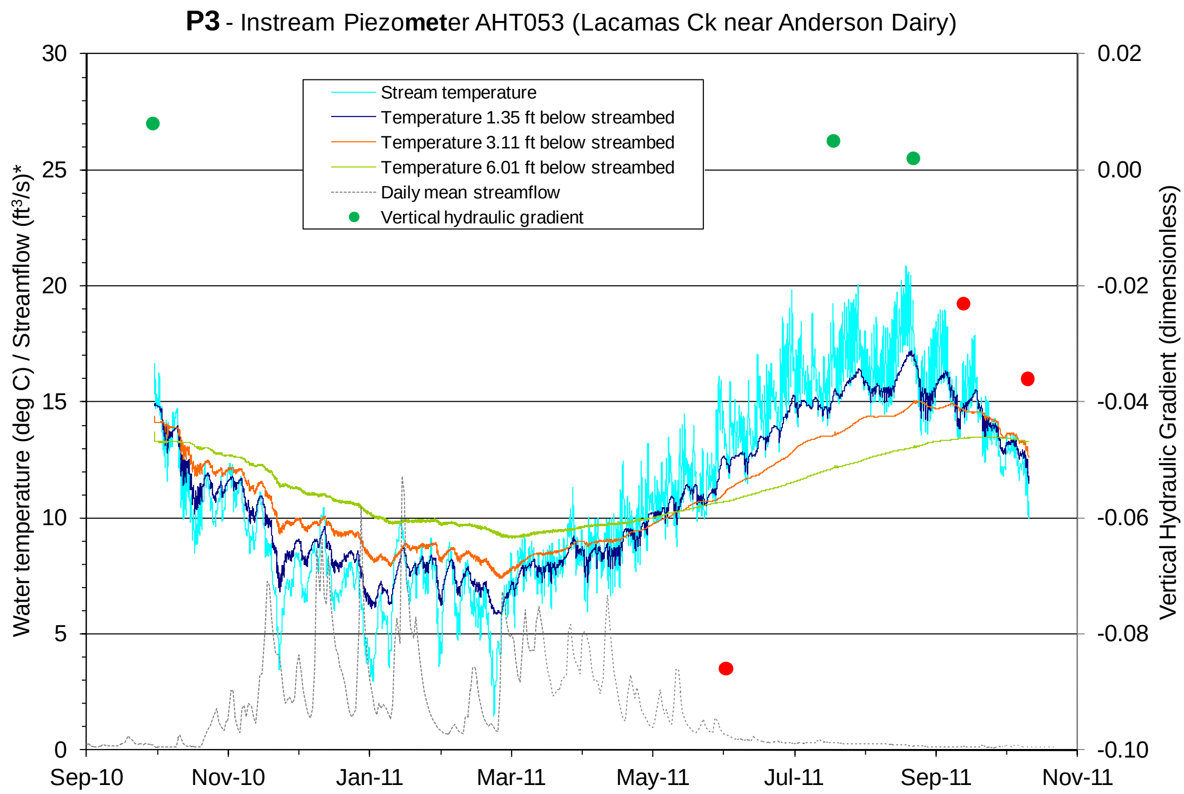




Figure B-1: Instream piezometer thermographs (see Figure 4 for a map of site locations).



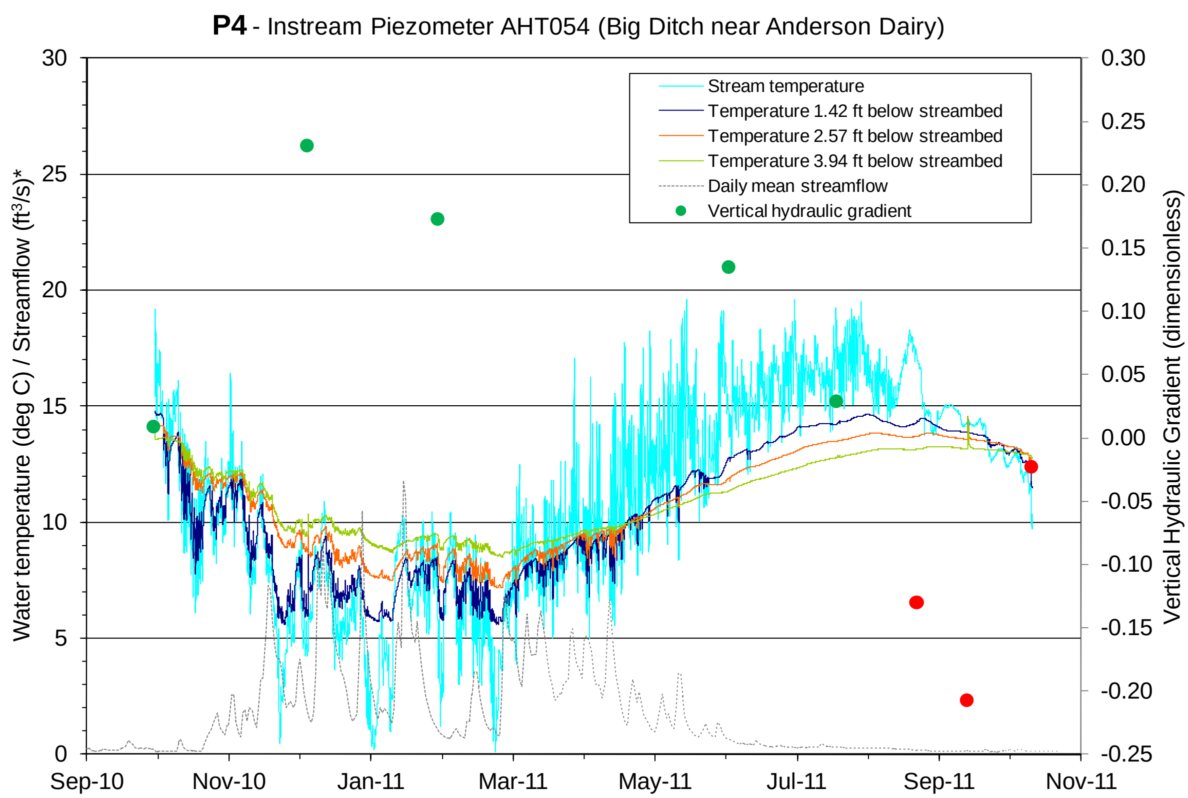
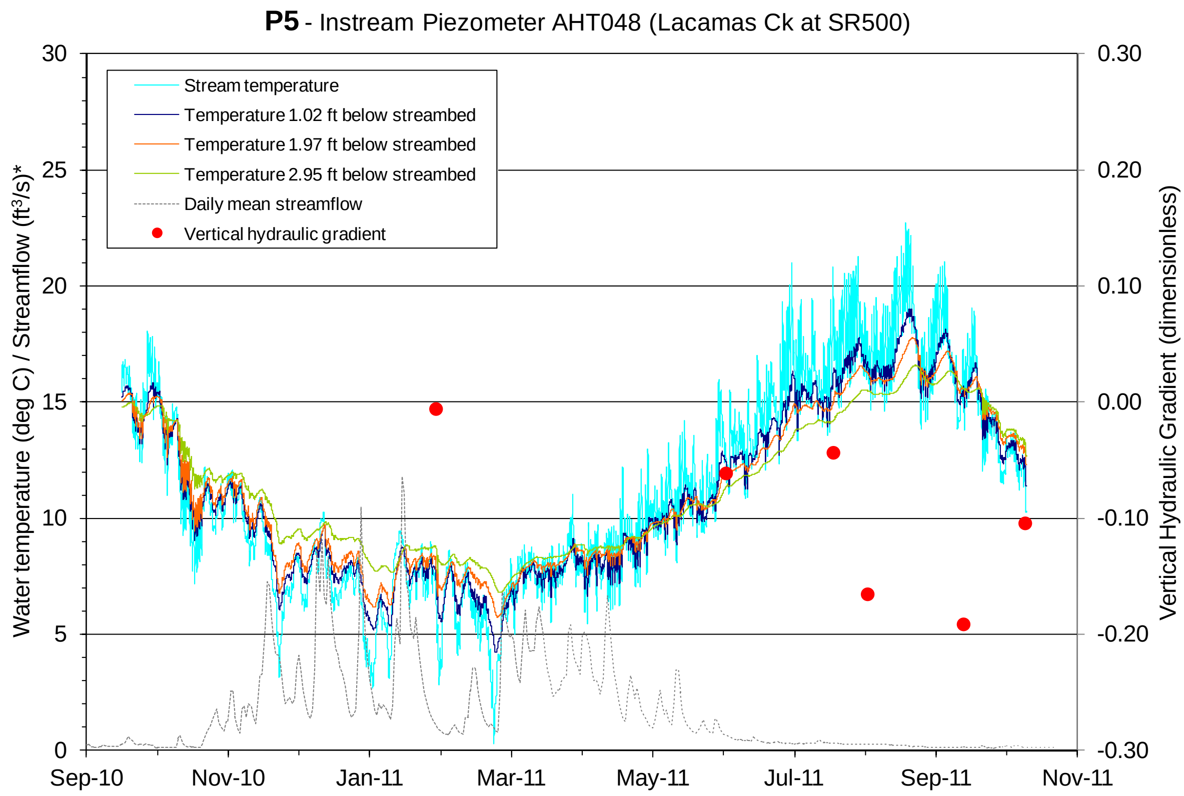




Figure B-1: (continued)



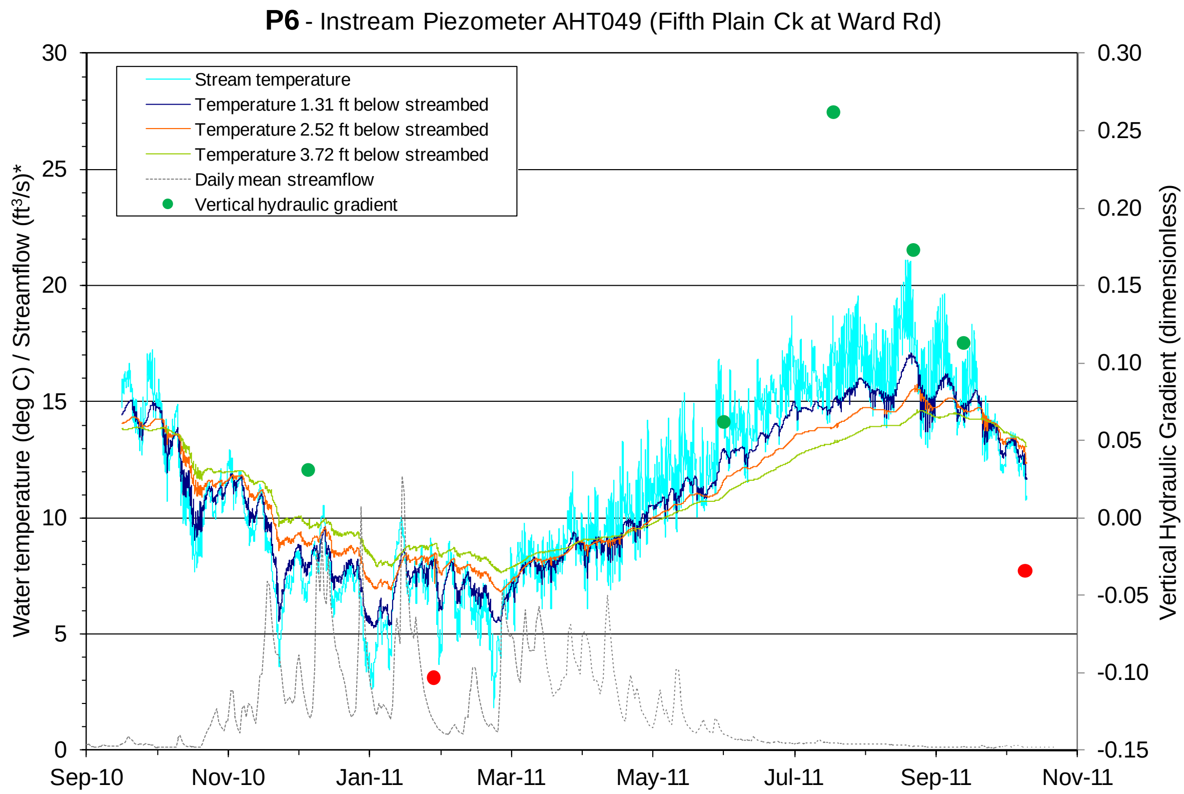
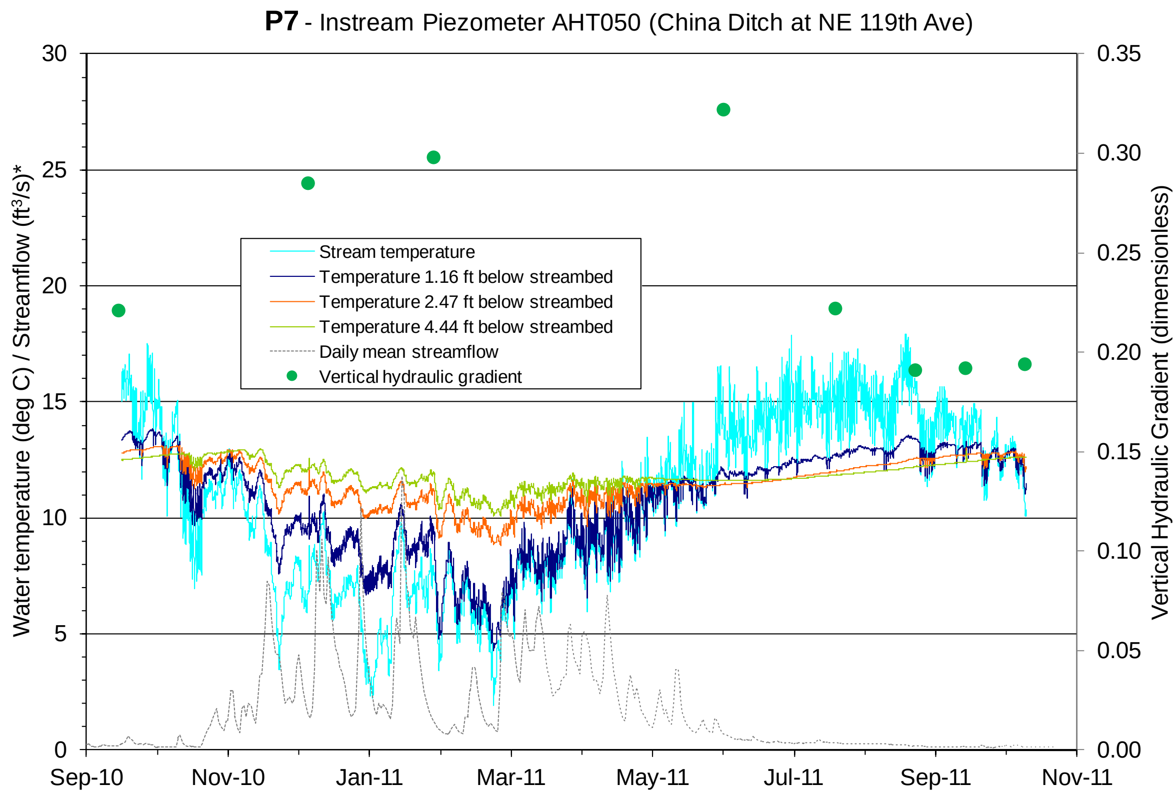




Figure B-1: (continued)



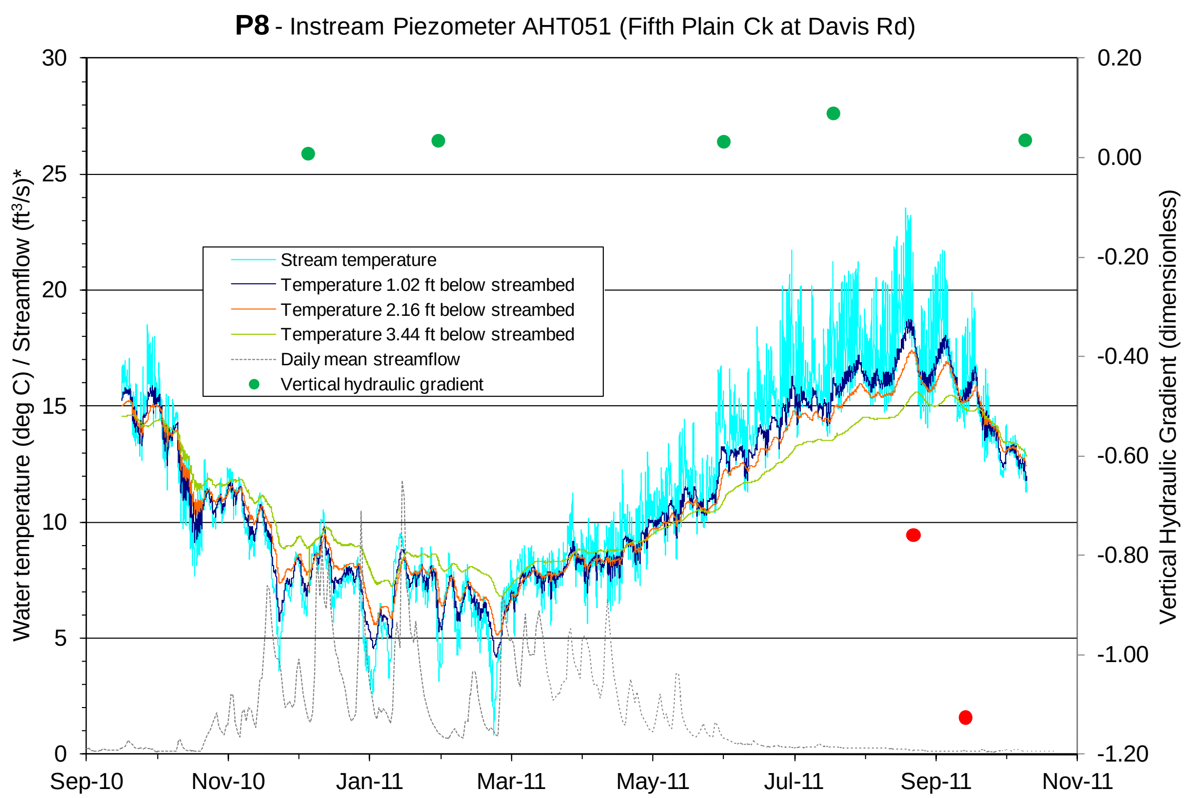
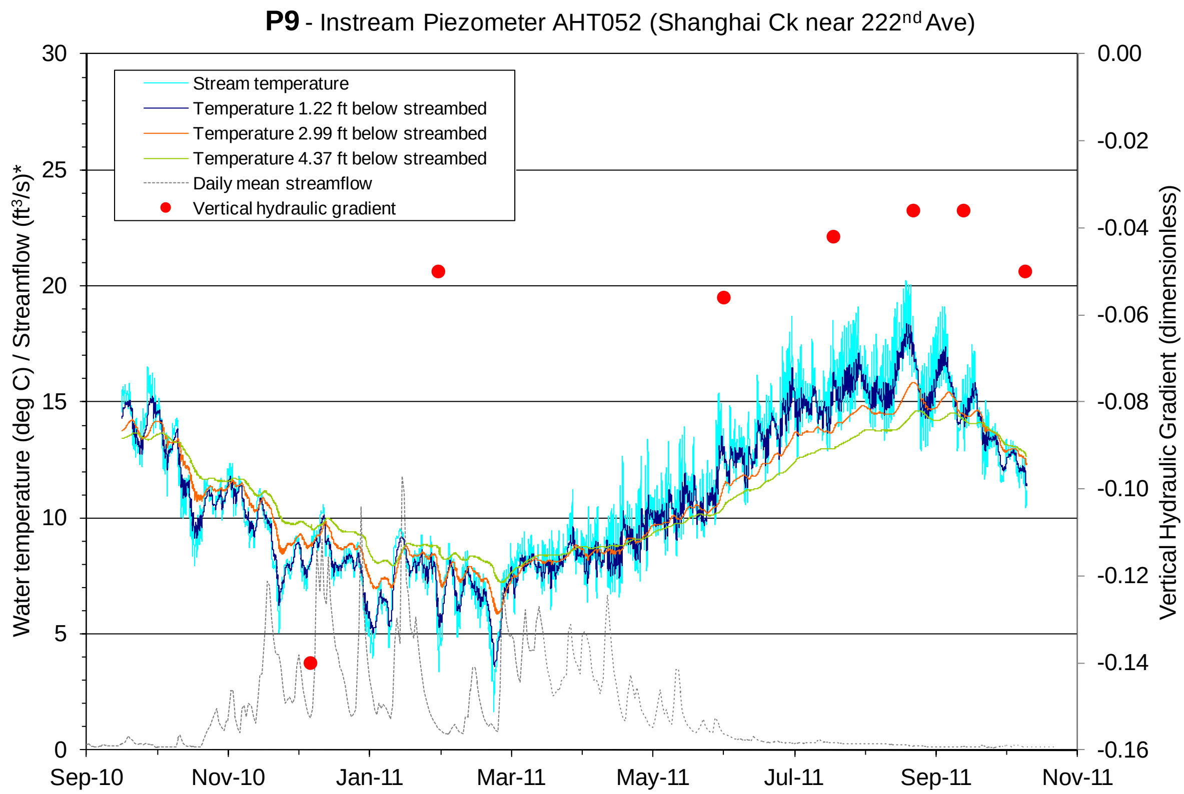




Figure B-1: (continued)



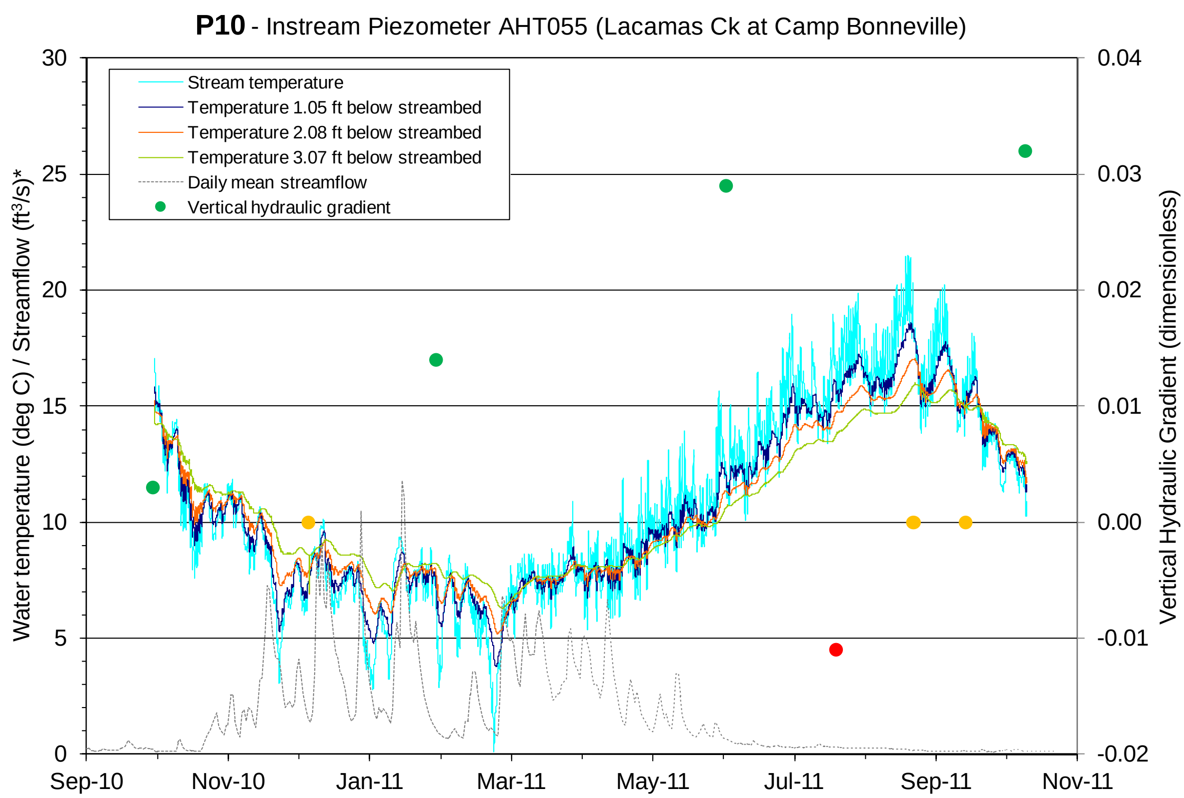




Figure B-1: (continued)

**Figure B-1 Symbol Explanations**

● Positive vertical hydraulic gradient (groundwater discharge to creek indicated)

● No measurable vertical hydraulic gradient

● Negative vertical hydraulic gradient (streamflow loss to groundwater indicated)

* To accommodate graph scale limitations the streamflow values shown in Figure B-1, graphs P1 – P10, represent only 1 percent of the actual daily mean streamflow measured at the Lacamas Creek gaging station at Goodwin Rd. To obtain the actual gaged flow, multiply the graphed values by 100.