Assessment of Surface Water / Groundwater Interactions and Associated Nutrient Fluxes in the Deschutes River and Percival Creek Watersheds, Thurston 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 photo: Vashon drift exposed along the left bank of the Deschutes River, north of Offutt Lake (photo by Dustin Bilhimer)

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by

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January 2007

Waterbody No. WA-13-1010

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Conversion Factors and Datums

Multiply	By	To Obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square ft (ft^2)	0.0929	square meter (m^2)
acre	4,047	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second per mile (ft^3/sec/mi)	0.0176	cubic meter per second per kilometer (m^3/sec/km)
cubic foot (ft^3)	28.32	liter (L)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
gallon (gal/min)	3.785	liter/min (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

Concentration

Concentrations of chemical constituents in water are presented as milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

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

The horizontal coordinates in this report are referenced to the North American Datum of 1927 (NAD27).

Abstract

This report describes the results of a hydrogeologic investigation that was undertaken to support a Total Maximum Daily Load (TMDL) evaluation of the Deschutes River and Percival Creek watersheds in Thurston County, Washington. The Deschutes River was included on Washington State's 1996 and 1998 303(d) lists for temperature, pH, fecal coliform, and fine sediment violations of surface water quality standards. Percival Creek, although not formally listed, was also included in the evaluation due to temperature, fecal coliform, and pH impairments.

Multiple field techniques were employed to (1) evaluate the direction, volume, and timing of surface water and groundwater interactions, and (2) estimate the potential loading of phosphorus and nitrogen-based nutrients that groundwater contributes to gaining reaches of the Deschutes River and Percival Creek. The field techniques included stream seepage runs, installation and monitoring of instream piezometers, analysis of groundwater quality samples, and monitoring of streambed thermal profiles.

During baseflow seepage runs conducted in the summers of 2003 and 2004, the Deschutes River gained 41.4 ft^3/s, between river miles 42.3 and 0.5, while Percival Creek gained 1.7 to 2.6 ft^3/s between river miles 3.3 and 0.1. The reach-based streamflow gains and losses observed during seepage runs were generally supported by point-based vertical hydraulic gradients and streambed thermal profiles measured in instream piezometers.

Measurable concentrations of dissolved orthophosphate (0.008 to 0.086 mg/L) and dissolved total phosphorus (0.046 to 0.152 mg/L) were found at all sampled piezometer sites. Measurable concentrations of dissolved nitrate+nitrite-N and ammonia were found in roughly half of the piezometers sampled at concentrations ranging from 0.011 to 4.76 mg/L and 0.032 to 0.206 mg/L, respectively. The average estimated unit-area-mass loading to the Deschutes River by discharging groundwater varied by location and ranged from 2.8 to 66.4 $mg/d/m^2$ for dissolved total phosphorus to 68.6 to 3913 $mg/d/m^2$ for dissolved nitrate+nitrite-N.

Acknowledgements

Many people contributed time and effort to this study. In particular, we thank Mindy Roberts, Mike LeMoine, and Brian Zalewsky for their insights and assistance during pre-project scoping discussions and the initial deployment of field instrumentation. Darrel Anderson, Joan LeTourneau, Charles Pitz, and Mindy Roberts provided comments and suggestions for improving the study report. Heidi Chuhran, Pam Covey, Kamilee Ginder, Randy Knox, Dean Momohara, Sara Sekerak, and Will White, at the Manchester Environmental Laboratory, provided courier and analytical laboratory support. Lastly, we thank the many landowners who provided access to the Deschutes River and Percival Creek. This study would not have been possible without their cooperation and assistance.

Introduction

Washington State is required under Section 303(d) of the federal Clean Water Act to identify all surface waters in the state where beneficial use(s) are impaired by pollutants. The Deschutes River (Figure 1) was included on the Washington State 1996 and 1998 303(d) lists of impaired waters for temperature, pH, fecal coliform, and fine sediment violations. Waterbodies on the 303(d) list require the preparation of a Total Maximum Daily Load (TMDL) to identify and quantify impairment sources and to recommend strategies for reducing point and nonpoint pollution loads.

In summer 2003, the Washington State Department of Ecology (Ecology) initiated TMDL field studies to assess current stream temperatures, water quality, streamflows, and other environmental conditions within the Deschutes River and Percival Creek drainages. Percival Creek is not currently on the 303(d) list, but was included in this evaluation due to historic violations of temperature, pH, and fecal coliform standards.

This study was undertaken to gain a better understanding of how groundwater affects stream temperatures and water quality conditions along the Deschutes River and Percival Creek.

The study results will serve as input to the broader TMDL effort which seeks to develop one-dimensional water quality models for the Deschutes River and Percival Creek (Roberts et al., 2004).

Study Purpose and Scope

Two goals were formulated for this investigation:

1. Evaluate and describe the direction, volume, and timing of surface water and groundwater interactions as they affect the study reaches of interest.

2. Estimate the potential loading of phosphorus-based and nitrogen-based nutrients that groundwater contributes to gaining reaches of the Deschutes River and Percival Creek.

Multiple field techniques were employed to realize these goals, including stream seepage evaluations, installation and monitoring of shallow instream piezometers, and the collection and analysis of near-stream groundwater quality samples. The water quality sampling was intended to quantify nutrient concentrations within the last few feet of the groundwater flow path, prior to its discharge into surface streams. We made no attempt to assess the biological or chemical reactions that can influence nutrient concentrations within the upper few feet of the streambed sediments or the river itself.

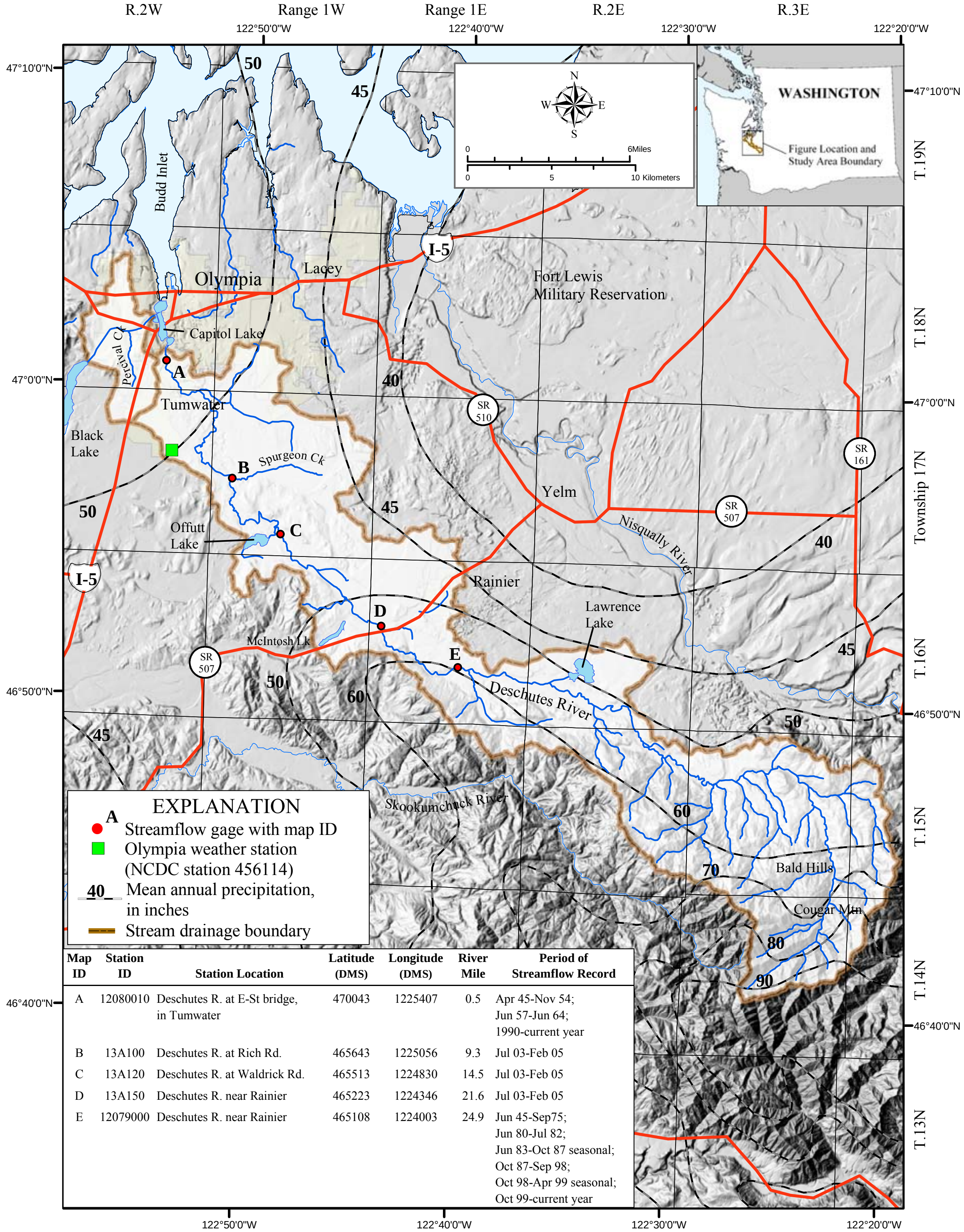
Previous Investigations

Numerous prior investigative reports were consulted during the initial planning phases of this investigation; these reports helped to guide and inform the study design. The geology and groundwater resources of the Deschutes River watershed and surrounding area were previously summarized by Snavely et al. (1951a, 1951b, 1958); Wallace and Molenaar (1961); Noble and Wallace (1966); Pacific Groundwater Group (1995); and Drost et al. (1998, 1999). The glacial drainage history of the area was summarized by Bretz (1913) with recent refinements by Walsh and Logan (2005) and Walsh et al (2003). Thurston County (2002) provided a preliminary evaluation of surface water and groundwater interactions along portions of the mainstem Deschutes River.

Well Numbering and Location System

The well locations referenced in this report are described using the township, range, section (TRS), and quarter-quarter section convention. Range designations include a “W,” and township designations include an “N,” to indicate the well lies west and north of the Willamette meridian and baseline, respectively. Each 40-acre, quarter-quarter section is represented by a single capital letter (Figure 2).

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 northwest quarter of the southwest quarter of Section 28, Township 17N, Range 01W is represented as 17N/01W-28M01, the second well as 28M02, and so forth (Figure 2).



Map ID	Station ID	Station Location	Latitude (DMS)	Longitude (DMS)	River Mile	Period of Streamflow Record
A	12080010	Deschutes R. at E-St bridge, in Tumwater	470043	1225407	0.5	Apr 45-Nov 54; Jun 57-Jun 64; 1990-current year
B	13A100	Deschutes R. at Rich Rd.	465643	1225056	9.3	Jul 03-Feb 05
C	13A120	Deschutes R. at Waldrick Rd.	465513	1224830	14.5	Jul 03-Feb 05
D	13A150	Deschutes R. near Rainier	465223	1224346	21.6	Jul 03-Feb 05
E	12079000	Deschutes R. near Rainier	465108	1224003	24.9	Jun 45-Sep75; Jun 80-Jul 82; Jun 83-Oct 87 seasonal; Oct 87-Sep 98; Oct 98-Apr 99 seasonal; Oct 99-current year

Hillshade modified from 30-meter USGS digital elevation model data, 1:100,000
Precipitation contours from Miller, et al, 1973, Precipitation-frequency atlas of the Western U.S.

Figure 1 - Study area location

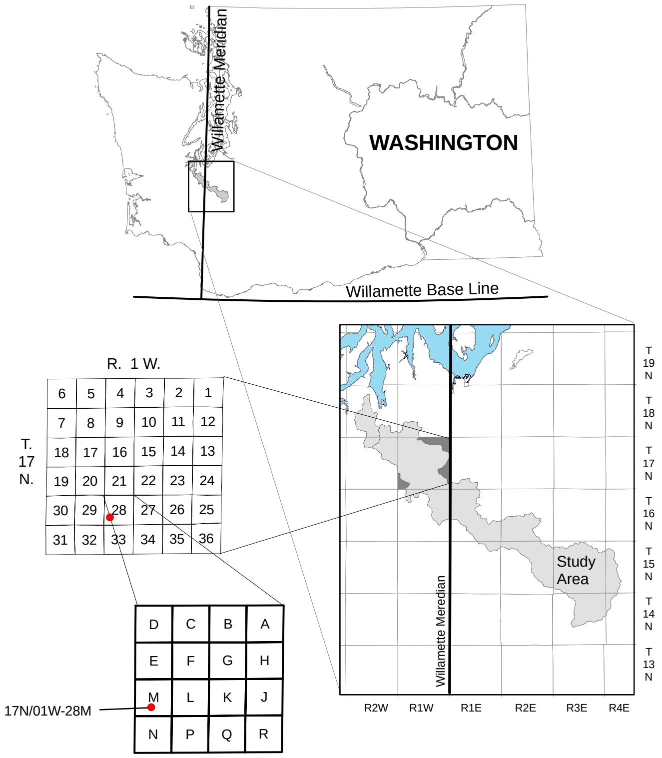


Figure 2 - Well numbering and location system

As an additional aid to future investigators, all wells monitored during this study for water level or water quality were fitted, where possible, with a Department of Ecology well identification tag. The tag contains a six-digit alpha-numeric identifier, consisting of three letters and three numbers, (e.g. AHT016) that uniquely identifies each well, thereby avoiding the potential cross-study conflicts inherent in the TRS numbering system. 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.

Study Area Description

Physical Setting and Land Use

The study area for this project lies near the southern end of the Puget Sound lowland and encompasses approximately 168 square miles (Figure 1). Roughly 94 percent (158 square miles) of the study area is contained within the Deschutes watershed. The remainder lies within the Percival Creek drainage. The Deschutes River originates within the steep, heavily-forested Bald Hills and flows generally northwest for approximately 60 miles, before discharging into Capitol Lake near the city of Tumwater. Numerous named and unnamed tributaries enter the river throughout its length; however, most are concentrated along the steep bedrock-dominated uplands of the southern watershed. The central and northern watershed is dominated by relatively low-relief woodlands and grass-covered prairies that formed upon glacial terraces, outwash plains, and other remnant features of the most recent continental glaciation. Elevations in the watershed range from a few feet above sea level near Capitol Lake to 3,870 feet at Cougar Mountain in the Bald Hills.

Tumwater, the area's first permanent non-native American settlement, was founded in 1845, followed shortly thereafter by Olympia (1846) and Lacey (1848). Olympia was named the Washington State capital in 1889. Olympia, Lacey, and Tumwater have a present combined population of approximately 86,438 residents and collectively form the area's major commercial, industrial, and residential center (2000 U.S. census).

The central Deschutes watershed supports commercial dairies, rangeland, Christmas tree plantations, and other small-scale agricultural uses, while the uplands of the southern watershed are actively managed for commercial timber production.

The Deschutes River has viable populations of resident cutthroat trout, steelhead trout, anadromous (sea-run) cutthroat trout, coho, and chinook salmon (Haring and Konovsky, 1999). Anadromous fish distribution along the Deschutes River proper was historically limited to the reach below the lower falls at Tumwater. However, a fish ladder was installed at the falls in 1954 to provide access to spawning and rearing habitat in the upper watershed.

Percival Creek drains a small urban watershed that includes portions of the cities of Olympia and Tumwater. The creek originates at Trosper Lake near Tumwater, at an elevation of approximately 150 feet, and flows generally north to its confluence with the Black Lake ditch. The ditch was constructed in 1922 to drain water from Black Lake to Budd Inlet. From its confluence with the Black Lake ditch, Percival Creek trends generally east/northeast before emptying into Capitol Lake.

Climate

The study area climate is characterized by generally mild-wet winters and warm-dry summers. Throughout much of the watershed, winter air temperatures rarely drop below freezing due to the moderating effects of the Pacific Ocean and the watershed's relatively low elevation. During most years, summer daily maximum air temperatures are typically in the mid-to-high 70s (21-26ºC) and rarely exceed 80°F (26.7ºC) for more than a few days at a time (Figure 3).

The distribution of annual precipitation varies by location and ranges from an average of less than 45 inches in the northeastern peninsulas of Thurston County to greater than 90 inches in the Bald Hills (Figure 1) (Miller et al., 1973). For the 1948 to 2004 period, the annual precipitation at Olympia averaged approximately 50.44 inches and ranged from 29.92 to 66.71 inches (Figure 4).

Approximately 80 percent of Olympia's annual precipitation falls between October and March (Figure 5). December is typically the wettest month with an average rainfall of 8.23 inches, while July is typically the driest, with an average rainfall of 0.73 inches.

Precipitation totals at Olympia for 2003 and 2004, the primary study period for this project, were 52.56 and 39.42 inches, respectively. 2003 was characterized by above average rainfall in the winter and early spring (January, March, and April) and again in the fall (October and November). Summer 2003 (May-September) was unusually dry. In contrast, 2004 was unusually dry from January to July and unusually wet during August and September (Figure 5).

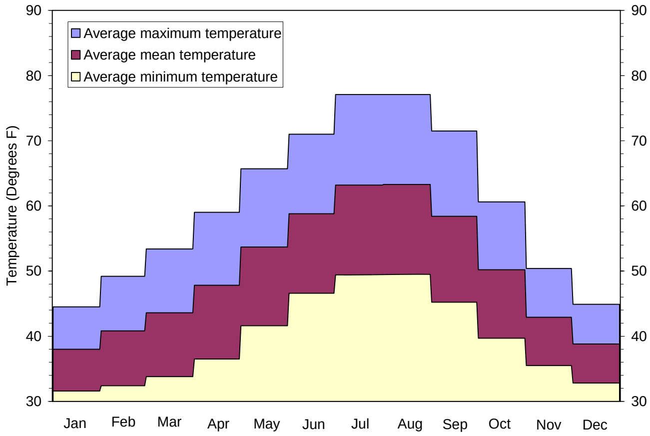


Figure 3 - Average monthly maximum, mean, and minimum air temperatures at Olympia for 1948-2004 (Western Regional Climate Center, 2006).

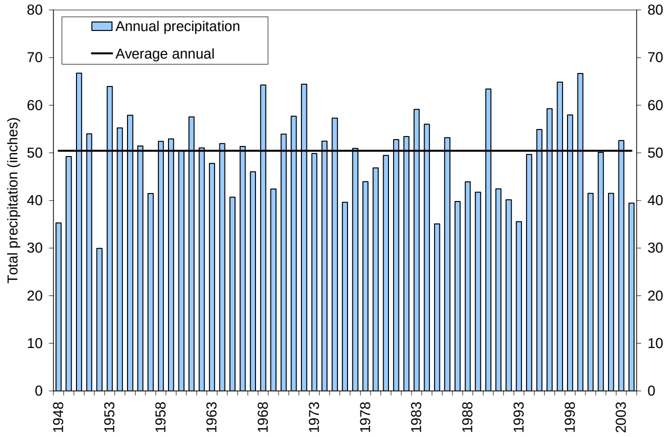


Figure 4 - Annual precipitation at Olympia for 1948-2004 (Western Regional Climate Center, 2006).

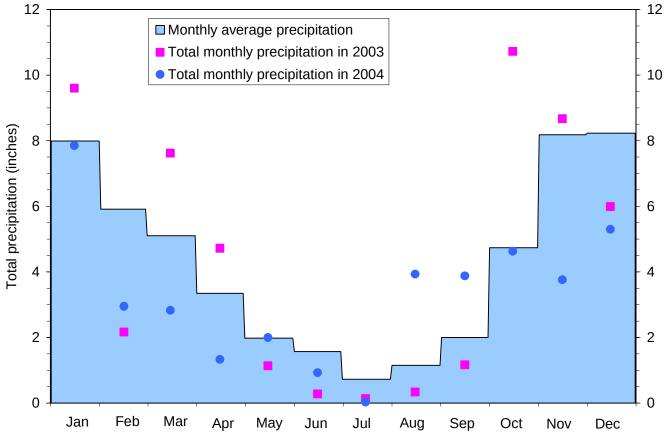


Figure 5 - Average total monthly precipitation at Olympia for 1948-2004 (Western Regional Climate Center, 2006).

Streamflow

The U.S. Geological Survey (USGS) has operated streamflow gaging stations at two locations along the Deschutes River since the mid 1940s: one at river mile (RM) 0.5 (station 12080010, Deschutes River at E Street in Tumwater) and one at RM 24.9 (station 12079000, Deschutes River near Rainier). Three additional short-term gages were installed by Ecology in June 2003 (at river miles 9.3, 14.5, and 20.5) to complement ongoing TMDL investigations (Figure 1).

As of calendar year 2005, the mean annual discharge for the Deschutes River at Rainier has averaged approximately 256 ft^3/s, and ranged from a low of 156 ft^3/s in 1992 to 384 ft^3/s in 1997 (U.S. Geological Survey, 2006a and 2006b). For the USGS gage at E Street, the mean annual discharge averaged 396 ft^3/s, and ranged from a low of

244 ft^3/s in 1993 to 636 ft^3/s in 1999. The discharge rate at both gages closely follows the seasonal and long-term precipitation patterns observed at the Olympia weather station (Figures 6 and 7).

During 2003 the streamflows at both USGS gages (Rainier and E Street) were consistently below station daily average values between May and the beginning of October and periodically exceeded average values during the remainder of the year. Streamflows during 2004 were generally less than station average values between January and mid-August, and generally well above average conditions between mid-August and November.

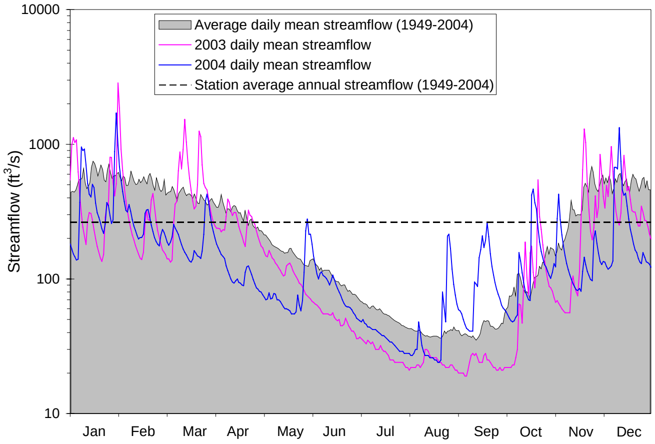


Figure 6 - Streamflow at USGS Station 12079000, Deschutes River near Rainier

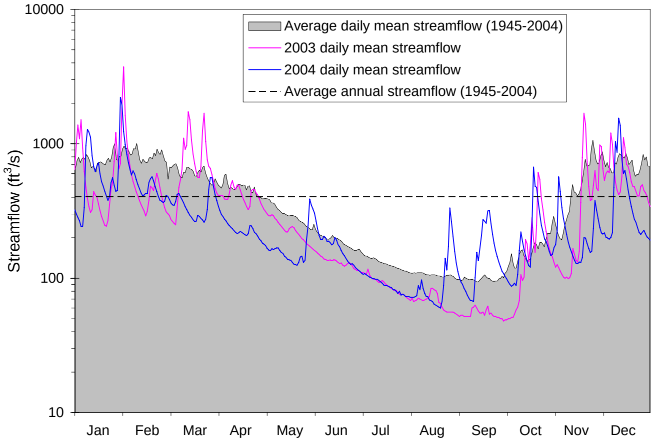


Figure 7 - Streamflow at USGS Station 12080010, Deschutes River at E-Street Bridge in Tumwater

Geologic Setting

The Deschutes watershed lies near the southern end of the Puget Sound lowland, an elongated structural basin that formed during the Tertiary period, when the North American continental plate converged with and partially over-rode denser oceanic rocks of the eastern Pacific Ocean. During the Eocene-to-Miocene Epochs (approximately 45-5 million year ago), subsidence and volcanism associated with these tectonic processes enabled thick deposits of marine, brackish water, and non-marine sediments and volcanic rocks to accumulate within the Puget Sound lowland. These rocks were subsequently modified by compressional folding and faulting in late Miocene and early Pliocene time (approximately 5.3-1.6 million years ago) and comprise the bedrock units that underlie the Deschutes watershed and form the surrounding foothills (Snavely et al., 1958; Noble and Wallace, 1966).

Portions of the present day Deschutes watershed were inundated at least twice during the Pleistocene Epoch, by continental glaciers that advanced south into the Puget Sound lowland from coastal British Columbia (Plate 1). The most recent ice incursion occurred about 15,000 years ago during the Vashon Stade of the Frasier Glaciation. As the Puget (eastern) lobe of the Vashon glacier advanced into the Puget lowland, it blocked previously northward-draining rivers and streams, and diverted them south where they fed large lakes that formed beside and in front of the advancing ice. Sediment-laden melt-water from the glacier and runoff from the surrounding mountains deposited sand, silt, and clay in the progressively deepening lakes. Over time, drainage pathways were opened through topographic lows to the south and west of the ice front, and surface drainage to the Pacific Ocean was reestablished for a short time via the Chehalis River Valley (Brett, 1913).

At its maximum, the Vashon Puget lobe spanned from the Cascade Range to the Olympic Mountains and extended to just beyond Tenino in southern Thurston County. Near its southern terminus, the Vashon Puget lobe is inferred to have formed two sub-lobes. The western ("Olympia") sub-lobe terminated against the southern foothills of the Scatter Creek Valley and was separated from the eastern ("Yelm") sub-lobe by a narrow north-eastward projecting spur of ice-free terrain that extended nearly to Steilacoom (Plate 1) (Bretz, 1913; Noble and Wallace, 1966; Walsh and Logan, 2005).

About 13,500 years ago, the Vashon ice front began a rapid and steady retreat northward. As the ice withdrew, melt water from the glacier deposited vast quantities of recessional gravel and sand throughout the Deschutes lowlands and cut a complex network of melt-water channels and ice-margin terraces that help to define the present topography of the central and northern watershed.

Geologic Units

The Pleistocene glaciations that helped to shape the present morphology of the Deschutes lowlands left behind significant accumulations of glacial drift, glaciolacustrine silt and clay, and other deposits. Collectively, these sediments are more than 600 feet thick along the north-eastern watershed perimeter. They thin toward the south and west, and ultimately give way to bedrock along the northern slopes of the Bald Hills (Plate 1).

The youngest deposits in the area consist of Holocene alluvium and recent landslide deposits. The alluvium (unit Qa on Plate 1) is composed of loose, poorly sorted deposits of sand and well-rounded gravel with variable amounts of interstitial silt. The alluvium of the upper (southeastern) watershed contains local accumulations of cobbles and boulders. These deposits were laid down and/or reworked from older deposits by local streams and are restricted to narrow zones along the valley bottoms and flood plains of the Deschutes River and its major tributaries.

Landslide deposits (unit Qls) are a common feature within the Bald Hills and along the steep-sided outwash channels and terraces of the watershed interior. These deposits consist of un-stratified, generally poorly sorted deposits of clay, silt, sand, gravel, and occasional larger cohesive blocks that slumped or were otherwise disturbed through mass wasting processes.

Late Pleistocene Vashon recessional outwash sand and silt (unit Qgos) is broadly distributed at land surface north of Spurgeon Creek. This unit consists of generally well-sorted deposits of loose, tan-to-brown colored sand and silt, with minor interbeds of gravel. The gravel is moderately-to-well rounded and is typically of non-local plutonic or metamorphic origin.

Much of the land area south and east of Spurgeon Creek is underlain by deposits of Vashon recessional outwash gravel and sand (unit Qgog, Plate 1). This unit consists of gray-to-tan colored deposits of loose sand, gravel, and cobbles that were laid down by melt-water streams as the Vashon glacier retreated. The clasts are moderately-to-well rounded and are mostly of northern source plutonic and metamorphic rock types or cascade origin volcanic rocks. Ice contact deposits are also lumped with this unit in some areas.

Unit Qgd (undifferentiated Vashon drift) is restricted to the Percival Creek and Lower Deschutes watersheds. This unit contains till, recessional or proglacial outwash sand and gravel, and lacustrine or moraine deposits that are too small to be mapped separately.

Vashon till (unit Qgt) is distributed intermittently at land surface throughout much of the study area, particularly in the central Deschutes lowlands. Vashon till is also present in many areas beneath units Qgos, Qgog, and Qa. This unit was deposited directly by Vashon ice and encompasses a broad array of till and till type materials and consists of an unsorted, un-stratified, highly compacted mixture of gray-to-tan colored clay, silt, sand, gravel, and occasional boulders. Locally it contains lenses of outwash sand and or gravel.

Vashon advance outwash (unit Qga) underlies Vashon till in the central and northern watershed and consists of gray-to-light-brown deposits of compact sand and gravel with variable amounts of interstitial clay and silt. The gravel is generally well-rounded and is comprised mostly of metamorphic, plutonic, or poly-crystalline-quartz rock types of non-local origin. This unit outcrops locally along the lower reaches of Percival Creek, along the foothills east and north of Offutt Lake, and along the shoreline of Capitol Lake.

In the northern and central watershed, unit Qga is discontinuously underlain by pre-Vashon continental drift deposits (unit Qgp). These deposits are locally exposed at land surface south of Mcintosh Lake, and at outcrops along the Deschutes River corridor north of Offutt Lake. They include weathered, light-tan-to-gray or yellow-brown till and compact deposits of weathered well-rounded sand and gravel with minor amounts of silt and clay. These sediments were deposited during the penultimate continental glaciation of the Puget lowland and have been tentatively correlated with the Double Bluff drift of northern Puget Sound (Lea, 1984; Walsh and Logan, 2005).

The upper Deschutes watershed contains local accumulations of pre-Frasier alpine deposits of Wingate Hill Drift and the Logan Hill Formation. These localized deposits were grouped into a single unit (Qapu) for this investigation. Wingate Hill Drift is comprised of compact and often oxidized deposits of brown colored till or weathered gravel. The Logan Hill Formation consists of oxidized and often cemented yellow-gray to yellow-brown colored sand and gravel of local origin, with interspersed sand and clay lenses. The upper surface of the Logan Hill Formation sediments is often deeply weathered to a red or red-brown clay soil.

The above units overlie area bedrock (unit Tbu) which consists of Miocene to Eocene age rocks of the Mcintosh, Northcraft, and Crescent Formations, as well as continental sedimentary deposits and rocks of the Puget Group. The Bald Hills and uplands of the south-eastern study area are underlain largely by andesites, basaltic-andesites, and volcaniclastic deposits or rocks of the Northcraft Formation (Schasse, 1987). Bedrock in the central and northern watershed consists of volcanic lithic sandstones, siltstones, and volcanic breccias of the Mcintosh Formation as well as basalt and flow breccia of the Crescent Formation (Walsh and Logan, 2005). Collectively these rocks are typically compact and yield little water to wells except where jointed or deeply weathered. Accordingly, they are of little direct interest to this study. Readers should refer to the works by Noble and Wallace (1966) or Snavely et al. (1958) for a broader discussion of these rocks and their origin.

Groundwater Movement and Discharge

The groundwater flow system of the lower and central Deschutes watershed was characterized by the USGS in 1988-89 during an extensive evaluation of the hydrology and quality of groundwater in Thurston County (Drost et al., 1998). As part of their evaluation, USGS personnel conducted a seepage study of the lower 24.9 miles of the mainstem Deschutes River on August 12, 1988. The study reach spanned from the Deschutes streamflow gage at Rainier (Site F, Figure 1) to the E-street gage near Tumwater (Site A, Figure 1). During the evaluation, the river showed a net gain of 53 ft^3/s across this reach. This equates to an average gain of 2.16 ft^3/s/river mile or approximately 59.5 percent of the total streamflow measured at the lowermost transect (Drost et al., 1999).

The seepage results are supported by groundwater level measurements made during a canvassing of nearly 800 area wells, during summer 1988, as part of the USGS study. Contours developed from these measurements suggest that area groundwater generally moves from upland recharge areas in the interior of Thurston County toward natural points of discharge along the Puget Sound shoreline, the lower Deschutes River, and Percival Creek (Figure 8).

Viewed together, these results suggest that groundwater discharge sustains summer baseflows in the Deschutes River, Percival Creek, and other streams which serve as drains for the local surficial aquifer system.

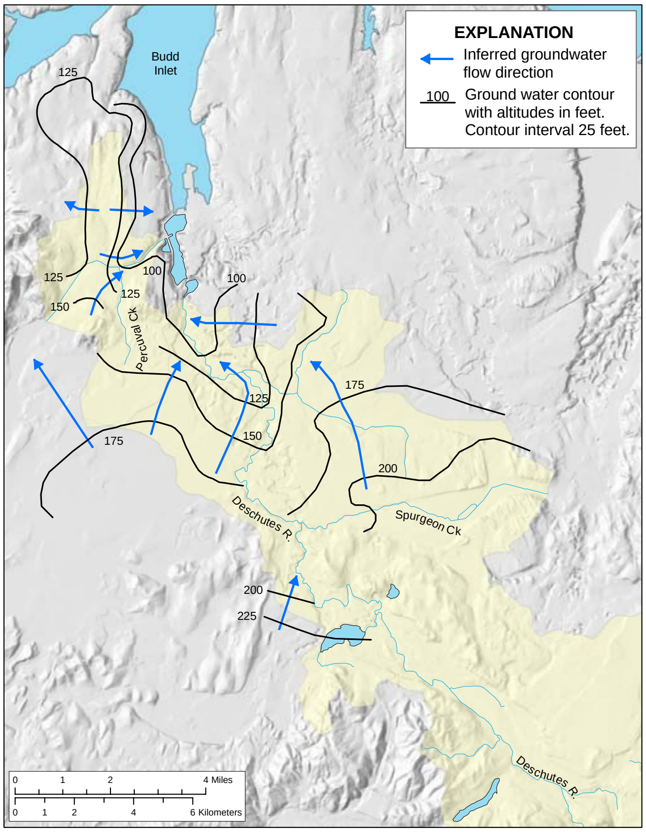


Figure 8 - Approximate groundwater altitudes and flow directions in unit Qga during summer 1988 (modified from Drost et al., 1999).

Study Methods

During this study, we used a combination of field and analytical techniques to help estimate the timing, magnitude, and spatial distribution of surface water and groundwater exchanges affecting Percival Creek and the mainstem Deschutes River. The field-based studies began in late spring 2003 and included stream seepage runs, water level monitoring and sampling of instream piezometers, and thermal profiling of the upper 3-5 feet of the streambed sediments at each piezometer site.

The locations of all seepage transects and instream piezometers were initially determined using a Global Positioning System (GPS) receiver and were later confirmed using geo-rectified digital ortho-photos. Land surface altitudes for each site were estimated using a pixel matching process and digital LIDAR data.

Water level and thermal data from instream piezometers were used to develop and calibrate one-dimensional heat transport models using VS2DHI (Healy and Ronan, 1996;

Hsieh et al., 2000). The model results were combined with groundwater quality data from sampled instream piezometers to estimate the unit area nutrient mass load that groundwater contributes to Percival Creek and the Deschutes River. Each of these field methods and analytical techniques are described in the sections that follow.

Stream Seepage Runs

Four seepage runs were conducted during this study to quantify reach-scale streamflow gains and losses. One seepage run was conducted along the lower 37.4 miles of the Deschutes River in July 2003. Three additional seepage runs were conducted along the lower 3.3 miles of Percival Creek (August 2003, July 2004, and September 2004). The seepage studies were conducted during stable baseflow conditions, following a period of extended dry weather.

During a seepage run, flow measurements are made at numerous points along the river or stream being evaluated, at all tributary inputs and point discharges to the stream, and at all known out-of stream diversions (Figure 9).

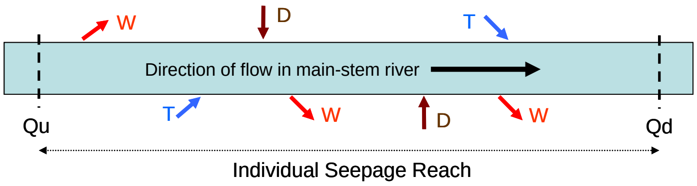


Figure 9 - Schematic depiction of the water budget components typically measured during a seepage run (see symbol explanations below)

Any increase or decrease in streamflow that can not be accounted for through tributary inputs, point discharges, or out-of-stream diversions, represents the net volume of water exchanged between the stream and groundwater along the reach (Equation 1).

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

Where:

S = the net seepage gain or loss along the reach, in ft^3/s;

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

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

ΣT = the sum of tributary inputs to the mainstem river between the upper and lower boundaries of the seepage transect, in ft^3/s;

ΣD = the sum of point discharges to the mainstem river between the upper and lower boundaries of the seepage transect, in ft^3/s;

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

Negative seepage values indicate that the river lost flow as it traversed the reach and contributed water to groundwater recharge. Conversely, positive seepage values indicate that the river gained flow from groundwater discharge as it traversed the reach. An overall water budget for the river is then obtained by summing the results for individual seepage reaches.

The streamflow measurements for this study were made using a Swoffer Model 2100 horizontal axis current meter or a Marsh McBirney Model 2000 portable current meter and the cross section method described by Rantz et al. (1982). Replicate discharge measurements for both within-team and between-team measurements were made to assess measurement quality. The results of this evaluation are shown in Table A-3 (Appendix A) and suggest good measurement reproducibility and overall data quality.

Instream Piezometers

Thirteen instream piezometers were installed along the mainstem Deschutes River in June and July, 2003 to complement the August 2003 seepage run and to enable periodic monitoring of surface water/groundwater head relationships, groundwater temperatures, and specific conductance at discrete points along the river. The piezometers were distributed between river miles 0.5 and 37.4, and where possible their locations corresponded with previously established stream temperature and/or stream-flow monitoring sites (Plate 2, Figure 1). Based on a preliminary evaluation of the 2003 monitoring results, 10 additional piezometers were installed in April 2004. Of these, 5 were installed along the mainstem Deschutes River to fill data gaps. The remaining piezometers were installed along the lower 3.3 miles of Percival Creek to complement the seepage runs planned for summer 2004.

The piezometers for this study were 7 feet long when fully assembled and consisted of an upper 2-foot section and a lower 5-foot section of 1-inch (or 1.5-inch) diameter galvanized pipe. The 2-foot pipe section was threaded at both ends as was one end of the 5-foot pipe, thereby enabling the two pieces to be joined together via a standard pipe coupler. The non-threaded end of the 5-foot pipe was subsequently crimped shut using a hydraulic press to form a drive point. The first few inches of pipe above the drive point was then perforated with 12 - 3/16-inch diameter holes to allow water entry (Table B-1).

The piezometers were manually installed in the streambed to a maximum depth of about 5 feet. Installation was accomplished using a commercially available fence post driver or a custom fabricated 40-pound drop hammer. Where possible the piezometers were installed within a few feet of the streambank, in quiet water away from riffles or point bars, and in areas that could be safely accessed by field staff throughout a wide range of flow conditions.

The piezometers were accessed monthly, when flows permitted, to make comparative measurements of stream stage and groundwater levels, and to measure stream and groundwater temperatures. Groundwater levels and stream stage were measured during each site visit with a calibrated electric well probe (E-tape) or graduated steel hand tape in accordance with standard USGS methodology (Stallman, 1983). Duplicate water-level measurements were made at each site to ensure measurement precision. Individual water-level measurements were made to the nearest 0.01 foot.

The manual temperature measurements were made with a WTW 340i multimeter® and Tetracon® 325 temperature and conductivity probe. All field meters were properly maintained and calibrated in accordance with the project quality assurance plan (Roberts et al., 2004).

The following equation was used to derive vertical hydraulic gradients for each piezometer, from paired groundwater level and stream stage measurements. Converting raw field measurements to hydraulic gradient values normalizes for differences in piezometer depth and screen interval, thereby enabling direct comparisons to be drawn between piezometers.

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

Where:

i_v = vertical hydraulic gradient (dimensionless)

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

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

where (L) is length

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

Thermal Profiling of Streambed Sediments

After installation and development, each piezometer was instrumented with three recording thermistors for twice hourly monitoring of shallow groundwater temperatures at discrete depths up to 5 feet below the streambed. In a typical installation, one thermistor was located near the piezometer bottom within the perforated interval of the pipe, one approximately 0.5-1 foot below the streambed, and one roughly equidistant between the upper and lower thermistors.

The 1-inch diameter piezometers were instrumented with DS 1921-L, i-button® thermistors, manufactured by Dallas Semiconductor. I-button thermistors have a recording range of -20°C to +85°C, a resolution of 0.5°C, and a purported accuracy of 1°C. The 1.5 inch diameter piezometers were instrumented with Stoway® Tidbit® thermistors manufactured by Onset Computer Corporation. The Stoway® thermistors have a recording range of -5°C to +37°C, a resolution of 0.125°C, and are accurate to about 0.2-0.4 °C, depending on the model deployed.

The difference in diurnal (daily) temperature patterns between surface streams and groundwater can be used to track the direction of water movement through streambed sediments. This difference provides a secondary confirmation of the surface water/groundwater interactions inferred from manual hydraulic gradient measurements (Stonestrom and Constantz, 2003).

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

At piezometer sites where streambed water temperatures are highly dampened relative to surface water temperatures, one can infer that groundwater is moving upward through the streambed and discharging into the stream (a gaining stream reach) (Figure 10). Conversely, at sites where streambed water temperatures closely mimic stream temperatures, one can infer that surface water is leaving the stream and moving down into the streambed at that location (a losing stream reach).

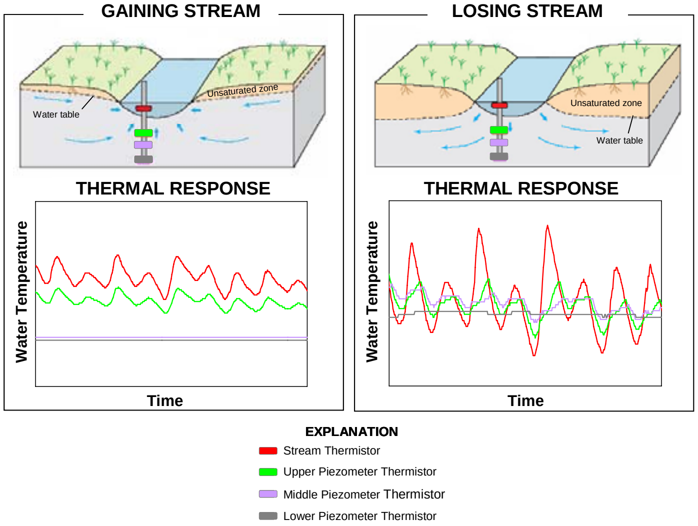


Figure 10 - Typical streambed thermal responses observed beneath a perennial gaining and losing stream reach (adapted from Simonds et al., 2004; and Stonestrom and Constantz, 2003).

Groundwater and Surface Water Interactions

For this study we used three common field techniques to characterize surface water/groundwater interactions. Stream seepage runs were used to develop net daily water balances for the Deschutes River and Percival Creek during summer baseflow conditions. The seepage runs were supplemented by monthly hydraulic gradient measurements in a network of instream piezometers, as well as continuous monitoring of streambed thermal profiles. These two supplemental measurements provide further insights into both the direction and timing of water exchanges at discrete points along each seepage reach. The results of these evaluations are presented below.

Deschutes River

To aid the following discussion, we subdivided the mainstem Deschutes River into 6 primary seepage reaches (3 gaining and 3 losing) based on the distribution of streamflow gains and losses observed during seepage runs and periodic gradient measurements in instream piezometers (Plate 2, Figure 1). These primary seepage reaches range from 1.4 to 13.7 river miles in length. Where data warranted, the primary reaches were further divided into sub-reaches to aid data interpretation.

Seepage Reach 1

Seepage reach 1 is approximately 17.3 miles long and extends from just above the upper Deschutes River falls at river mile (RM) 42.3 downstream to Vail Rd. SE at RM 28.6. Between the upper and lower reach boundaries the river drops in elevation from approximately 778 to approximately 417 feet, at an average gradient of approximately 26.4 ft/mile. Roughly 80 feet of elevation is lost as the river traverses the upper Deschutes Falls, which formed when the river was forced south during the Vashon glaciation and cut its present channel through a narrow bedrock spur that projects northward from the bedrock hills that bound the Deschutes valley through this reach (Bretz, 1913). Below the falls, the river gradient rapidly decreases as the valley widens and the bedrock channel gives way to unconsolidated deposits composed of Vashon till, outwash sand and gravel, and recent alluvium. These unconsolidated deposits thicken toward the north and west from a thin veneer below the falls to more than 300 feet near Lake Lawrence (Plate 1).

During the August 2003 seepage run, the Deschutes River showed a *gross* increase in discharge of 5.5 ft^3/s between the upper and lower transects of reach 1. When tributary inputs were accounted for, the seepage study revealed that the river actually had a *net* loss of 3.8 ft^3/s to groundwater through this reach, or approximately 21.5 percent of its total discharge (Table 1). This apparent contradiction can be explained by the numerous tributary streams that enter the river from the northern flanks of the Bald Hills, and serve to mask the loss of water from the river to groundwater.
The greatest streamflow losses occurred within sub-reaches 1A (RM 42.3 to RM 37.4) and 1B (RM 37.4 to 32.3) where the river lost 1.1ft^3/s and 2.6 ft^3/s to groundwater respectively. The river lost relatively little water (0.1 ft^3/s) through sub-reach 1C (RM 32.3 to RM 28.6) (Table 1).

The vertical hydraulic gradients measured at two instream piezometers during the August 2003 seepage run (Table B-2 and Plate 2, Figures 2A and 2C) support the seepage findings and are further bolstered by subsequent piezometer installations at two additional points along the reach in 2004 (Plate 2, Figures 2B and 2D). A fifth piezometer, AHT006, at the lower boundary of reach 1 (Plate 2, Figure 2E) showed consistently positive hydraulic gradients (groundwater discharge conditions) throughout the study period. The shift to a positive gradient at this location corresponds with the relatively minor seepage loss noted along reach 1C, and to general downstream cooling of the river during the seepage run (Plate 2, Figure 3). Together the data suggest that an overall transition from losing to gaining conditions occurs within sub-reach 1C upstream of piezometer AHT006.

In addition to the gradient patterns described for well AHT006, seasonal and/or short-term gradient reversals from losing to gaining conditions were observed at piezometers AHT016 and AGJ758 (Plate 2, Figures 2A and 2D). These transitory responses may result from rapid stage changes in the river during winter storm events, and/or the lateral migration of the stream/water table interface in response to seasonal groundwater level changes in the underlying aquifer.

The streambed thermal profiles measured at piezometer sites within reach 1 support the water exchanges inferred from hydraulic gradient measurements. Piezometers AGJ753 and AHT005 (Plate 2, Figures 2B and 2C) exhibited consistently negative hydraulic gradients and had streambed thermal profiles that closely followed the river's seasonal warming trend from spring to summer while exhibiting a muted diurnal signal similar to the river at depths up to 4 feet below the streambed.

Those piezometers with consistently positive gradients (AHT006) (Plate 2, Figure 2E) or seasonally positive gradients (AHT016 and AGJ758) (Plate 2, Figures 2A and 2D) exhibited generally stable-to-flat thermal profiles at depths of a foot or more below the streambed, during periods of groundwater discharge. The streambed temperatures at consistently gaining piezometer sites were generally within a few degrees of the off-stream groundwater temperature measured at well AHT017 (Plate 2, Figure 2W).

Viewed together, these data suggest a consistent pattern of streamflow loss to groundwater across most of reach 1 during summer baseflow periods, with some areas transitioning to gaining conditions during the winter months when regional groundwater levels typically lie nearer ground surface.

Seepage Reach 2

Seepage reach 2 encompasses approximately 8.1 river miles and extends from Vail Road SE at RM 28.6 to just below the State Route 507 Bridge crossing of the Deschutes River at RM 20.5. The river maintains an average gradient of approximately 13.1 ft/mile through reach 2, and drops from an elevation of approximately 417 feet at the upper reach boundary to 311 feet at the lower boundary.

The streambed sediments within reach 2 are comprised largely of reworked outwash sand and fine-to-coarse gravel, with local accumulations of cobbles and boulders. These sediments were deposited as the Vashon glacier retreated and are as much as 100+ feet thick beneath the eastern half of the reach. They thin or are absent in the western half of reach 2 where the river channel is more narrowly constrained by, or directly traverses, bedrock (Plate 1).

During the August 2003 seepage assessment, the Deschutes River gained approximately 8.5 ft^3/s, or roughly 27.7 percent of its total flow, from groundwater discharge as it traversed reach 2. Most of this gain, which was accompanied by a general downstream cooling of the river, during the seepage run occurred within sub-reaches 2B and 2C where the river gained 4.1 and 3.6 ft^3/s, respectively (Table 1 and Plate 2, Figure 3).

The seepage findings are supported by the vertical hydraulic gradient measurements made at two piezometers, AHT006 and AHT007, during the seepage assessment (Plate 2, Figure 2E and 2F). A third piezometer, AGJ759, installed in summer 2004 produced comparable results (Plate 2, Figure 2G).

The streambed temperatures at all three piezometers diverged widely from those of the river, and except for the upper thermistors showed little, if any, diurnal variation. Although the monthly hydraulic gradient measurements for these sites were consistently positive, the thermal profiles suggest that the river likely lost water to groundwater (i.e., hydraulic gradients periodically reversed) during major winter storm events. The strong groundwater gains throughout most of reach 2 during the summer months correspond with a general westward thinning of the unconsolidated sediments underlying the stream, coupled with lateral constriction of the river valley by bedrock outcroppings. Both of these factors would tend to force groundwater into the river as it moves down-valley, and offer a possible explanation for the gains observed along reach 2.

A fourth piezometer, AHT008 (Plate 2, Figure 2H), at the downstream boundary of reach 2 showed negative hydraulic gradients during the seepage assessment (streamflow loss to groundwater) but later transitioned to positive gradients (groundwater discharge conditions) with the onset of winter rains. The difference in gradient pattern at this well corresponds with a general thickening of the unconsolidated sediments beneath the stream (Plate 1).

Table 1 - Summary of the August 5, 2003 seepage survey of the mainstem Deschutes River

Map ID[1]	Discharge Measurement Transect Locations	Measured or estimated streamflow[2] (Ft^3/s)	Sum of tributary inflows to reach (Ft^3/s)	Sum of certificated diversions by reach[3] (Ft^3/s)	Seepage reach designation	Net seepage gain or loss for reach[4] (Ft^3/s)	Net seepage gain or loss for reach[4] (Ft^3/s/river mile)	Seepage gain or loss for reach[5] (percent)	Aggregated reach designation	Reach length (miles)	Net seepage gain or loss for reach[3] (Ft^3/s)	Net seepage gain or loss for reach[3] (Ft^3/s/river mile)	Seepage gain or loss for reach[4] (percent)
-	**Deschutes R. above upper falls (RM 42.3)**	**12.20**											
	Thurston Creek, at 3000 Rd.	1.7	**4.9**	**0.79**	**Sub-reach 1A**	**-1.1**	**-0.22**	**-6.9**	**Combined reach 1**	**13.7**	**-3.8**	**-0.28**	**-21.5**
	Johnson Creek, at 3000 Rd.	0.19											
	Huckleberry Creek, at 3000 Rd.	0.46											
	Mitchell Creek, at 3000 Rd.	2.1a											
	Unnamed creek	0.15e											
	Unnamed creek	0.15e											
	Unnamed creek	0.15e											
A	**Deschutes R. at WEYCO 1000 Rd (RM 37.4)**	**16a**											
	Fall Ck., at 1000 Rd.	0.25	**0.70**	**0.68**	**Sub-reach 1B**	**-2.6**	**-0.51**	**-18.4**					
	Unnamed creek	0.32											
	Unnamed creek	0.13e											
C	**Deschutes R. at Old Camp Lane (RM 32.3)**	**14.1**											
	Lake Lawrence outfall	1.7	**3.7**	**1.22**	**Sub-reach 1C**	**-0.1**	**-0.027**	**-5.7**					
	Hull and pipeline creeks	1.6											
	Unnamed creek	0.2e											
	Unnamed creek	0.2e											
E	**Deschutes R. at Vail Rd SE (RM 28.6)**	**17.7a**											
	Unnamed creek	1e	**1**	**1.15**	**Sub-reach 2A**	**0.8**	**0.33**	**4.1**	**Combined reach 2**	**8.1**	**8.49**	**1.05**	**27.7**
-	**Deschutes R. at Woodbrook Lane (RM 26.2)**	**19.5**											
	Reichel Creek, at Vail loop Rd.	0.21	**0.21**	**0.03**	**Sub-reach 2B**	**4.09**	**3.14**	**17.2**					
F	**Deschutes R. Vail Loop Rd (RM 24.9)**	**23.8a**											
	Spring near HWY 507	3.3	**3.3**	**0.13**	**Sub-reach 2C**	**3.6**	**0.82**	**11.7**					
H	**Deschutes R. below SR 507 (RM 20.5)**	**30.7a**											
									Reach 3	**1.4**	**-1.6**	**-1.14**	**-5.5**
I	**Deschutes R. at Military Rd (RM 19.1)**	**29.1a**											
	Unnamed creek	1e	**3**	**2.9**	**Sub-reach 4A**	**9.4**	**2.04**	**22.7**	**Combined reach 4**	**9.9**	**17**	**1.72**	**34.3**
	Silver Spring Creek, near mouth	2.0											
K	**Deschutes R. at Waldrick Rd (RM 14.5)**	**41.5a**											
	Tempo Lake outfall	0.5	**0.5**	**-**	**Sub-reach 4B**	**2.6**	**2.36**	**5.8**					
L	**Deschutes R. off Cowlitz Dr (RM 13.4)**	**44.6a**											
			-	**1.68**	**Sub-reach 4C**	**5**	**1.19**	**10.1**					
N	**Deschutes R. above Spurgeon Ck (RM 9.2)**	**49.6**											
	Spurgeon Creek near mouth	3.5	**3.5**	**1.37**					**Reach 5**	**2.4**	**-1.4**	**-0.58**	**-2.7**
O	**Deschutes R. near 84th Ave SE (RM 6.8)**	**51.7**											
P	**Deschutes R. above Ayer Ck (RM 5.6)**	**53.1**	**-**	**-**	**Sub-reach 6A**	**1.4**	**1.17**	**2.6**	**Combined reach 6**	**6.3**	**22.8**	**3.61**	**28.8**
	Ayer Creek	2	**3.15**	**3.03**	**Sub-reach 6B**	**14.6**	**5.03**	**20.6**					
	Chambers Creek, at 58th Ave	1.15											
Q	**Deschutes R. at Henderson Blvd SE (RM 2.7)**	**70.8**											
	Unnamed creek	1.5e	**1.5**	**0.40**	**Sub-reach 6C**	**6.8**	**3.1**	**8.6**					
R	**Deschutes R. at E-St. in Tumwater (RM 0.5)**	**79.1a**											
									Combined total for reaches 1-6	**41.8**	**41.44**	**0.99**	**52.4**

[1] See Plate 2, Figure 1 for a map of site locations by map ID.

[2] a - The listed flow is the average of replicate discharge measurements for this transect (see Table A-3); e - flow estimated, too little water to measure.

[3] Information about the locations and instantaneous quantities assigned to surface water diversions was derived from Ecology's Water Rights Application Tracking System (WRATS) database.

[4] See Equation 1 for an explanation of the seepage calculation.

[5] Percent gain or loss for reach is relative to the streamflow measured at the downstream end of the seepage reach.

Seepage Reach 3

Seepage reach 3 is approximately 1.4 miles long and extends from State Route 507 at RM 20.5 to the Military Road Bridge at RM 19.1. The river maintains an average gradient of approximately 12.1 ft/mile through reach 3 and drops from an elevation of approximately 311 feet at the upper reach boundary to approximately 294 at the lower boundary.

Reach 3 is underlain largely by loose, poorly-sorted alluvium, derived from reworked Vashon outwash gravel, sand, and clasts of local bedrock. The alluvium and underlying outwash are typically 100+ feet thick beneath the eastern (upper) half of reach 3, but thin and ultimately give way to bedrock at the western end of the reach upstream of Military Road (Plate 1).

Piezometer AHT008 (Plate 2, Figure 2H) at the upper end of reach 3 had a negative hydraulic gradient of -0.009 during the August 2003 seepage survey, while piezometer AHT009 (Plate 2, Figure 2I) at the bottom end of the reach had a positive gradient of 0.003. These results only partially support the 1.6 ft^3/s streamflow loss measured along reach 3 during the seepage run and suggest that the seepage loss probably occurs in the upper portion of the reach in the vicinity of piezometer AHT008 (Plate 1).

The streambed thermal profiles for wells AHT008 and AHT009 exhibit characteristics of both gaining and losing conditions, and support the highly dynamic nature of water exchanges inferred from monthly hydraulic gradient measurements. Well AHT008 had negative gradients during late summer and early fall 2003 before transitioning to neutral or slightly positive gradients during winter 2003 through early summer 2004 (Table B-2, and Plate 2, Figure 2H). By mid summer 2004, gradients once again transitioned to negative values similar to those measured in summer 2003. Well AHT009 had mostly positive gradients during the study period but periodically exhibited neutral or slightly negative gradients during periods of high river discharge.

Seepage Reach 4

Seepage reach 4 extends from the Military Road Bridge at RM 19.1 to just above the Deschutes River/Spurgeon Creek confluence at RM 9.2, and encompasses approximately 8.9 river miles. The river drops in elevations from 294 feet at the upper reach boundary to 182 feet at the lower boundary, at an average gradient of approximately 10.3 ft/mile.

During the August 2003 seepage run, groundwater discharge contributed approximately 17 ft^3/s to the Deschutes River through reach 4. This equates to a net streamflow gain of approximately 34.3 percent and was the largest percentage gain of all the reaches evaluated. Sub-reach 4B showed the greatest gain (2.36 ft^3/s per river mile), followed by 4A (2.04 ft^3/s per river mile), and 4C (1.19 ft^3/s per river mile) (Table 1).

The instream piezometer data for reach 4 reveals a more complicated gain/loss pattern than that suggested by the seepage survey. Piezometer AHT009 (Plate 2 Figure 2I) exhibited a small positive gradient during the seepage run, as did AHT011 (Plate 2, Figure 2L); while two piezometers, AHT010 and AHT012, (Plate 2, Figures 2K and 2N) exhibited small negative hydraulic gradients. Two additional piezometers installed along reach 4 in summer 2004 followed a similar pattern. Piezometer AHT004 (Plate 2, Figure 2J) exhibited neutral to slightly negative hydraulic gradients during summer baseflow conditions, while the second, AGJ760, (Plate 2, Figure 2M) showed positive gradients.

In addition to the lateral variability in hydraulic gradient described above, most of the piezometers along reach 4 showed considerable seasonal variability in hydraulic gradients. Three wells (AHT009, AHT011, and AGJ760) exhibited generally positive gradients during both summer and winter baseflow periods while exhibiting short periods of gradient reversal (losing conditions) during winter storm events. In contrast, wells AHT004, AHT010, and AHT012 exhibited generally negative gradients (losing conditions) during summer baseflow conditions in 2003 and 2004 and transitioned to positive gradients (gaining conditions) during winter 2003 and spring 2004.

The streambed temperature profiles at these sites generally support the seasonal and longitudinal gain/loss patterns inferred from vertical hydraulic gradients. The thermal patterns at sites AHT009, AHT011, and AGJ760 (Plate 2, Figures 2I, 2L, and 2M) show a several degree temperature differential between the instream thermistor and the temperatures measured in the lower-most thermistors. This separation is most pronounced at site AGJ760, suggesting that a greater volume of groundwater discharge occurs at this location (Stonestrom and Constantz, 2003). In contrast, the thermal profiles at sites AHT004, AHT010, and AHT012 (Plate 2, Figures 2J, 2K, and 2N) closely follow the diurnal and seasonal instream temperatures during the summer baseflow period, and then diverge for brief periods during periodic gradient reversals that manifest during major winter storm events.

With the exception of well AGJ760, none of the thermal profile data collected at piezometer sites along reach 4 indicates particularly strong evidence of groundwater discharge through the streambed itself, which stands in stark contrast with the overall gain measured during the August 2003 seepage run. While the cause of this discrepancy is unknown, a possible explanation lies in the numerous named and unnamed springs and seeps that emanate from unit Qgog and/or Qga along the hillside that borders the river to the north along this reach. Water that enters the river directly, via surface seeps or springs, effectively bypasses the streambed and is not accounted for by thermal profiling techniques or vertical hydraulic gradient measurements in instream piezometers.

Seepage Reach 5

Seepage reach 5 marks a transition zone between the generally coarse-grained outwash gravel and sand (unit Qgog) of the southern watershed and the generally finer-grained outwash sand (unit Qgos) that underlies the northern Deschutes watershed. The generally coarse-grained alluvium of the southern watershed gives way in reach 5 to a generally finer-grained assemblage of sand and fine gravel, with relatively few cobbles. Seepage reach 5 is approximately 2.4 miles long and extends from just above the Deschutes River/Spurgeon Creek confluence at RM 9.2 to about 84th Ave SE at RM 6.8. The river maintains an average gradient of approximately 10 ft/mile through reach 5 and drops from an elevation of approximately 182 feet at the upper reach boundary to 158 feet at the lower boundary.

During the August 2003 seepage run, the Deschutes River lost approximately 2.7 percent of its total streamflow as it traversed reach 5; which equates to a net loss of 1.4 ft^3/s or 0.53 ft^3/s per river mile (Table 1). The two piezometers along reach 5 generally support this conclusion. Piezometer AHT012 (Plate 2, Figure 2N), at the upper end of the reach, exhibited generally neutral-to-negative gradients between mid May and November 2003 before transitioning to slightly positive gradients in spring 2004. Piezometer AHT013 (Plate 2, Figure 2O), at the lower end of the reach, exhibited strongly negative gradients throughout the 2003-2004 study period (Table B-2).

These findings are supported by the streambed thermal profiles at these sites, which closely mimic the diurnal patterns observed in the river (Plate 2, Figures 2N and 2O). Together these data suggest that the Deschutes River loses water as it traverses reach 5, particularly during baseflow periods. The river may gain some water from groundwater discharge in the upper portion of reach 5 during the late spring.

Seepage Reach 6

Seepage reach 6 is approximately 6.3 miles long and extends from RM 6.8 near 84th Ave SE, to the E-Street bridge in Tumwater, at RM 0.5. As it traverses reach 6, the river drops in elevation from 158 feet at the upper reach boundary to 94 feet at the lower boundary at an average gradient of approximately 10.2 ft/mile. Reach 6 is underlain throughout most of its length by alluvial sand and fine gravel derived from reworked deposits of unit Qgos and Qgog (Plate 1). Vashon till is absent throughout much of reach 6, which allows direct communication between units Qga and Qgog/Qgos (Drost et al., 1999).

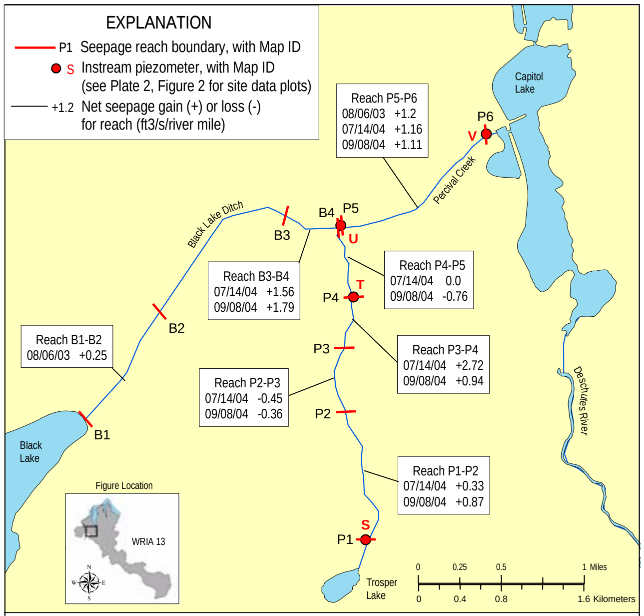
Reach 6 showed a net gain of approximately 22.8 ft^3/s or 3.61 ft^3/s per river mile during the August 2003 seepage run (Table 2). This was the second largest percentage gain of all the reaches evaluated and equates to approximately 28.8 percent of total streamflow. Most of this gain, which was accompanied by a general downstream cooling of the river (Plate 2, Figure 3), occurred within sub-reach 6B (RM 5.6-2.7) where the river gained approximately 14.6 ft^3/s or 5.03 ft^3/s per river mile. Smaller gains were also seen along reach 6C (3.1 ft^3/s per river mile) and 6A (1.17 ft^3/s per river mile).

The instream piezometers along reach 6 support the seepage results for sub-reaches 6B and 6C, but not reach 6A. The hydraulic gradients and streambed thermal profiles for piezometers at the upper and lower ends of reach 6A (AHT013 and AHT018 respectively) (Plate 2, Figures 2O and 2P) suggest that the river loses water through this reach while the seepage run showed a gain of 1.4 ft^3/s or approximately 2.6 percent of total streamflow (Tables 1 and B-2). However, the measured seepage gain is not sufficiently large to exceed potential streamflow measurement error; hence, the inferred gain can not be verified without further study.

The two remaining piezometers along reach 6 (AHT014 and AHT015) (Plate 2, Figures 2Q and 2R) had generally positive hydraulic gradients throughout most of the year. However, well AHT015 at the lower end of the reach showed neutral to slightly negative gradients during the August 2003 seepage run. Based on the streambed thermal profiles for these wells, the area of greatest groundwater discharge appears to lie within reach 6B, in the vicinity of well AHT014 (Plate 2, Figure 2Q). This is consistent with the seepage results.

Percival Creek

Percival Creek drains a small urban catchment that includes portions of Tumwater and Olympia. The creek originates at Trosper Lake in Tumwater, and flows for approximately 3.5 miles before discharging into Capitol Lake (Figure 11). The creek is joined by the Black Lake drainage ditch (its only major tributary) at about RM 1.1. The Black Lake ditch extends about 2 miles upstream to Black Lake and was constructed in 1922 to drain low-lying farmland. Percival Creek maintains an average gradient of approximately 40 feet per mile, and drops from an elevation of approximately 150 feet at Trosper Lake to about 6 feet at Capitol Lake. Most of this elevation loss occurs in the central to lower portions of the creek where it drops from the Tumwater bench down to Capitol Lake.



Map ID	Seepage Transect Location	Stream Segment	Segment length (miles)
B1	Black Lk ditch at Belmont Rd (13BLA02.3)		
B2	Black Lk ditch at Joe's Quarry (13BLA01.5)	B1-B2	0.8
B3	Black Lk ditch at RM 0.34 (13BLA0.34)	B2-B3	1.16
B4	Black Lk ditch at Percival Ck confluence (13BLA00.0)	B3-B4	0.34
P1	Percival Ck at Trosper Rd (13PER03.3)		
P2	Percival Ck at Sapp Rd (13PER02.4)	P1-P2	0.9
P3	Percival Ck at Chaparrelle Rd (13PER01.96)	P2-P3	0.44
P4	Percival Ck at SPSCC (13PER01.6)	P3-P4	0.36
P5	Percival Ck below Black Lk ditch confluence (13PER01.1)	P4-P5	0.5
P6	Percival Ck near mouth (13PER00.1)	P5-P6	1

Figure 11 - Map of seepage results and instream piezometer sites for Percival Creek and the Black Lake ditch.

Percival Creek is underlain throughout most of its length by generally loose deposits of coarse sand and fine gravel that were derived from reworked deposits of Vashon drift. The streambed sediments of the upper watershed are composed largely of sand with progressively greater amounts of fine-to-medium gravel as one nears the creek mouth. Near its confluence with the Black Lake ditch, the creek is underlain by compact deposits of cemented gravel and sand.

Three seepage studies of the Percival Creek drainage were conducted during this investigation. The first evaluation, in August 2003, included Percival Creek and portions of the Black Lake ditch. Two additional studies were conducted in July and September 2004, with primary emphasis on the lower 3.3 miles of Percival Creek (Figure 11 and Table 2).

During the seepage surveys, Percival Creek showed net overall streamflow gains ranging from 1.7 to 2.61 ft^3/s, or approximately 20 to 37 percent of the total streamflow measured at the lower most transect at RM 0.1. Discharge measurements made at intermediate transects during July and September 2004 suggest this larger reach (P1-P6) is actually comprised of alternating gaining and losing reaches (Figure 11 and Table 2). Streamflow losses occurred along reach P2-P3 during both 2004 surveys and along reach P4-P5 during the September 2004 survey. The remaining reaches showed consistent gains during both surveys.

The four instream piezometers installed along Percival Creek in spring 2004 support the seepage observations. The monthly hydraulic gradient measurements at three piezometers (AGJ671, AGJ764, and AGJ754) (Plate 2, Figures 2S, 2T, and 2V) were consistently positive during the April to October period, which suggests the creek gained flow from groundwater discharge at each of these sites throughout summer 2004. This assertion is supported by the streambed thermal profiles for these sites.

The fourth piezometer (AGJ755) was installed at the lower end of reach P4-P5 (a neutral to losing reach) and exhibited neutral to slightly positive hydraulic gradients. The thermal profile at this site showed characteristics of both gaining and losing streamflow conditions (Plate 2, Figure 2U).

Viewed together, the seepage and instream piezometer data for Percival Creek indicate that the creek gains water from groundwater discharge throughout most of its length between late spring and early fall.

Table 2 - Summary of 2003-2004 seepage surveys of Percival Creek and the Black Lake ditch

Map ID [1]	Discharge Measurement Transect Locations	Seepage reach designation	Reach length (miles)	Tributary inputs to reach [2] (Ft^3/s)	Sum of certificated diversions by reach [3] (Ft^3/s)	Non-rounded discharge [B] (Ft^3/sec)	Measured streamflow (Ft^3/s)	Net seepage gain or loss for reach [4] (Ft^3/s)	Net seepage gain or loss for reach (Ft^3/s/river mile)	Seepage gain or loss for reach [5] (percent)
08/06/2003 Seepage Survey										
B1	Black Lk ditch at Belmont Rd (RM 2.3)					2.43	2.4			
B2	Black Lk at Joe's Quarry (RM 1.5)	B1-B2	0.8			2.61	2.6	0.2	0.25	7.7
B4	Black Lk ditch above confluence with Percival Ck (RM 0.0)	B2-B4	1.5			3.48	3.5	0.9	0.6	25.7
	NET SEEPAGE GAIN FOR THE BLACK LAKE DITCH BETWEEN RIVER MILES 2.3 AND 0.0		**2.3**					**1.1**	**0.48**	**31.4**
P1	Percival Ck at Trosper Rd (RM 3.3)					0.99	0.99			
P5	Percival Ck below Black Lk. Ditch Confluence (RM 1.1)	P1-P5	2.2	3.5	0.44	5.94	5.9	1.41	0.64	23.9
P6	Percival Ck near mouth (RM 0.1)	P5-P6	1			7.13	7.1	1.2	1.2	16.9
	NET SEEPAGE GAIN FOR PERCIVAL CREEK BETWEEN RIVER MILES 3.3 AND 0.1		**3.2**					**2.61**	**0.84**	**36.8**
07/14/2004 Seepage Survey										
B3	Black Lk ditch (RM 0.34)					5.25	5.25			
B4	Black Lk ditch above confluence with Percival Ck (RM 0.0)	B3-B4	0.34			5.78	5.78	0.53	1.56	9.2
P1	Percival Ck at Trosper Rd (RM 3.3)					1.52	1.52			
P2	Percival Ck at Sapp Rd (RM 2.4)	P1-P2	0.9		0.06	1.82	1.82	0.3	0.33	16.5
P3	Percival Ck at Chaparrelle Rd (RM 1.96)	P2-P3	0.44		0.38	1.62	1.62	-0.2	-0.45	-12.3
P4	Percival Ck at SPSCC (RM 1.6)	P3-P4	0.36			2.6	2.6	0.98	2.72	37.7
P5	Percival Ck below Black Lk. Ditch Confluence (RM 1.1)	P4-P5	0.5	5.78		8.38	8.38	0	0	0
P6	Percival Ck near mouth (RM 0.1)	P5-P6	1			9.54	9.54	1.16	1.16	12.2
	NET SEEPAGE GAIN FOR PERCIVAL CREEK BETWEEN RIVER MILES 3.3 AND 0.1		**3.2**					**2.24**	**0.7**	**23.5**
09/08/2004 Seepage Survey										
B3	Black Lk ditch (RM 0.34)					5.08	5.08			
B4	Black Lk ditch above confluence with Percival Ck (RM 0.0)	B3-B4	0.34			5.69	5.69	0.61	1.79	10.7
P1	Percival Ck at Trosper Rd (RM 3.3)					1.2	1.2			
P2	Percival Ck at Sapp Rd (RM 2.4)	P1-P2	0.9		0.06	1.99	1.99	0.79	0.87	39.7
P3	Percival Ck at Chaparrelle Rd (RM 1.96)	P2-P3	0.44		0.38	1.83	1.83	-0.16	-0.36	-8.7
P4	Percival Ck at SPSCC (RM 1.6)	P3-P4	0.36			2.17	2.17	0.34	0.94	15.70
P5	Percival Ck below Black Lk. Ditch Confluence (RM 1.1)	P4-P5	0.5	5.69		7.48	7.48	-0.38	-0.76	-5.08
P6	Percival Ck near mouth (RM 0.1)	P5-P6	1			8.59	8.59	1.11	1.11	12.9
	NET SEEPAGE GAIN FOR PERCIVAL CREEK BETWEEN RIVER MILES 3.3 AND 0.1		**3.2**					**1.7**	**0.53**	**19.8**

[1] See Figure 10 for a map of site locations by map ID

[2] Value represents the discharge in Black Lake ditch measured just above its confluence with Percival Creek

[3] Information about the locations and instantaneous quantities assigned to water right diversions was derived from Ecology's WRATS database

[4] See Equation 1 for an explanation of the seepage calculation

[5] The reaches net gain or loss in streamflow relative to the discharge measured at the lower (downstream) transect

Quality of Near-Stream Groundwater

The second major objective of this investigation was to estimate the potential nutrient load that groundwater contributes to gaining reaches of the Deschutes River and Percival Creek. To accomplish this objective, water samples were collected from gaining instream piezometers between June and September 2004 and evaluated for common field parameters and a small suite of laboratory analyzed constituents (Table 3) (Roberts et al., 2004).

Table 3 - Target analytes, test methods, and method detection limits

Parameter	Test Method	Detection Limit
Field Measurements		
Temperature	WTW multiline P4 meter with Sentix 41-3 probe	0.1°C
Specific conductance	WTW multiline P4 meter with Tetracon 325 probe	1 µs/cm
pH	WTW multiline P4 meter with Sentix 41-3 probe	0.1 SU
Dissolved oxygen (DO)	WTW multiline P4 meter with Cellox 325 probe	0.1 mg/L
Laboratory Parameters (dissolved fraction)		
Total persulfate nitrogen (TPN)	SM4500NB	0.10 mg/L
Nitrate + nitrite-N	SM4500NO3I	0.01 mg/l
Dissolved organic carbon (DOC)	EPA 415.1	1.0 mg/L
Orthophosphate (Ortho-P)	SM4500PG	0.003 mg/L
Total phosphorus (TP)	EPA 200.8M	0.001 mg/L
Ammonia	SM4500NH3H	0.01 mg/L

SU: Standard units

The piezometers were purged prior to sampling, using a commercial flow cell and peristaltic pump. Purging continued until the difference in field parameter values for 2 successive 3-minute measurement periods differed by less than 5 percent. At the completion of purging, samples were collected via an inline Y-fitting attached to the pump discharge line ahead of the flow cell. Samples for dissolved organic carbon (DOC) analyses were collected in pre-acidified bottles containing sulfuric acid, and were field filtered using a Whatman puradisc™ 25pp, 0.45 micron (um), polypropylene-membrane-syringe filter.

The remaining analytes were filtered using a 0.45 micron Whatman puradisc™ syringe filter with a cellulose-acetate membrane. Samples for nitrate+nitrite-N, total persulfate nitrogen (TPN), ammonia, and total phosphorus (TP) were collected in pre-acidified bottles containing sulfuric acid. Filled sample bottles were tagged and stored on ice pending their arrival at the laboratory. The sample results and associated data quality assessment are presented in Table 4 and Appendix A, Table A-1, respectively.

As shown in Table 4, the results for individual piezometers were generally consistent across sampling events, suggesting that the quality of groundwater discharging to the river at these locations varied little over the course of summer 2004. Four piezometers (AHT006, AHT009, AHT011, and AHT014) had consistently low dissolved oxygen concentrations (< 0.3 mg/L) and little to no measurable concentrations of redox-sensitive constituents such as nitrate[1]. When compared to other sampled piezometers, these sites had slightly elevated pH, dissolved ammonia, and TPN-N concentrations.

Two piezometers (AHT007 and AGJ759) had median dissolved oxygen concentrations of 4.97 and 5.91 mg/L respectively, and correspondingly higher concentrations of dissolved nitrate+nitrite-N (median values of 1.23 and 4.75 mg/L respectively). These sites had no detectable concentrations of ammonia and slightly lower pH values than those measured at sites where reducing conditions prevailed. Dissolved oxygen concentrations at the final site (AGJ754) averaged approximately 0.42 mg/L. This site had small but measurable concentrations of dissolved nitrate+nitrite-N and TPN-N, no detectable ammonia, and slightly elevated pH values.

Our findings are generally consistent with results obtained during a 1989 synoptic survey of groundwater quality conditions in northern Thurston County (Drost et al., 1998). At that time, water quality samples from 19 broadly distributed wells completed in units Qgog and/or Qgos had median dissolved nitrate concentrations of 1.7 mg/l, dissolved oxygen concentrations of 6.7 mg/L, and dissolved phosphorus concentrations of 0.02 mg/L. These off-stream wells provide a rough, albeit somewhat dated, estimate of ambient groundwater quality conditions in the shallow surficial aquifer that discharges directly to area streams and rivers.

Direct comparisons between the water quality results for instream piezometers and off-stream wells are probably not valid, due to redox-driven water quality changes that can occur within streambed sediments. Nevertheless, the range in values encompassed by the two data sets (off-stream wells and instream piezometers) provides a reasonable basis for estimating the potential range of nutrient concentrations that have, or are likely to be carried into area streambed sediments by discharging groundwater.

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[1] Since nitrite is typically unstable in aerated groundwater, reported concentrations for nitrate+nitrite-N are considered equivalent to nitrate-N for the purposes of this discussion (Hem, 1985).

Table 4 - Groundwater quality results for monitored instream piezometers

			Field Parameters				Laboratory Analyses					
Well Tag Number	Map ID [1]	Sample Date	Temperature [2] (deg C)	pH (standard units)	Conductivity (µS/cm) @ 25C	Dissolved Oxygen [3] (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Ortho-phosphate[4] (mg/L)	Dissolved Total Phosphorous[4] (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)
AHT006	E	6/30/04	10.4	6.78	186	0.27	1.0 U	0.013	0.133	0.011	0.13	0.15
		7/28/04	10.7	6.93	185	0.2	1.0 U	0.008	0.116	0.01 U	0.13	0.14
		8/30/04	11.2 *	6.88	187	0.1 U	1.0 U	0.012	0.135	0.01 U	0.141	0.16
		9/28/04	10.7	-	187	0.1 U	1	0.013 J	0.132 J	0.01 U	0.147	0.16
		Median	**10.7**	**6.88**	**186.5**	**0.13**	**1.0 U**	**0.013**	**0.133**	**0.01 U**	**0.136**	**0.16**
AHT007	F	6/30/04	10.3	6.37	99	5.24	1.0 U	0.051	0.050	1.12	0.01 U	1.11
		7/28/04	11.2	6.37	102	5.55	1.0 U	0.050	0.046	1.21	0.01 U	1.22
		8/30/04	12	6.29	108	0.84	1.0 U	0.055	0.054	1.25	0.01 U	1.25
		9/28/04	10.7	-	107	4.71	1.0 U	0.053 J	0.05 J	1.25	0.01 U	1.21
		Median	**10.95**	**6.37**	**104.5**	**4.98**	**1.0 U**	**0.052**	**0.050**	**1.23**	**0.01 U**	**1.22**
AGJ759	G	8/30/04	10.2	6.36	185	4.07	1.0 U	0.053	0.051	4.76	0.01 U	4.7
		9/29/04	10	-	183	7.75	1.0 U	0.017 J	0.128 J	4.74	0.01 U	4.73
		Median	**10.1**	**-**	**184**	**5.91**	**1.0 U**	**0.035**	**0.089**	**4.75**	**0.01 U**	**4.72**
AHT009	I	9/28/04	13.4	-	133	0.1 U	1.2	0.056 J	0.067 J	0.01 U	0.036	0.064
AHT011	L	8/30/04	14.6	6.71	166	0.1 U	1.0 U	0.029	0.089	0.01 U	0.032	0.051
AHT014	Q	6/30/04	11.2	7.15	179	0.18	1.0 U	0.040	0.136	0.01 U	0.202	0.207
		7/28/04	11.6	7.17	179	0.19	1.0 U	0.086	0.128	0.01 U	0.193	0.22
		8/30/04	12.1	7.13	176	0.1 U	1.0 U	0.081	0.152	0.01 U	0.206	0.22
		9/28/04	12.1	-	174	0.1 U	1.0 U	0.079 J	0.152 J	0.01 U	0.204	0.22
		Median	**11.9**	**7.15**	**177.5**	**0.12**	**1.0 U**	**0.080**	**0.144**	**0.01 U**	**0.203**	**0.22**
AGJ754	V	6/30/04	11.3 *	7.14	149	0.71	1.0 U	0.059	0.060	0.239	0.01 U	0.245
		7/28/04	10.8	7.11	147	0.87	1.0 U	0.055	0.050	0.395	0.01 U	0.403
		8/30/04	11.9 *	7.02	151	0.1 U	1.0 U	0.060	0.058	0.358	0.01 U	0.366
		9/28/04	11.8 *	-	152	0.1 U	1.0 U	0.059 J	0.055 J	0.421	0.01 U	0.428
		Median	**11.6**	**7.11**	**150**	**0.38**	**1.0 U**	**0.059**	**0.056**	**0.377**	**0.01 U**	**0.385**

[1] - See Plate 1, Figure 1, for a map of site locations

[2] - Asterisked temperature values were measured using a sampling flow cell and are likely biased high. All other values were measured in situ.

[3] - When calculating median concentrations for dissolved oxygen, non-detect values were set at one half the method detection limit

[4] - Results for the September 2004 sample event were flagged as estimates by the authors (see Appendix A)

U - Analyte not detected at or above the reported value.

J - Analyte positively identified, the reported result is an estimate

Groundwater Nutrient Loading to Streams

Unit area nutrient loads to the Deschutes River and Percival Creek were estimated for each sampled piezometer site by combining the groundwater nutrient concentrations measured in piezometers with volumetric groundwater fluxes estimated from field-measured hydraulic gradients and streambed hydraulic conductivity values. The following sections describe the thermal modeling conducted to estimate streambed hydraulic conductivity values, and the subsequent use of these values to estimate nutrient loading to the Deschutes River and Percival Creek at sampled piezometer sites.

Thermal Modeling of Streambed Sediments

The continuous temperature and monthly water-level data collected at instream piezometer sites were used to develop one-dimensional, transient simulations of groundwater flow and heat transport within the streambed sediments at each site. The simulations were conducted using VS2DHI (Hsieh et al., 2000), a graphic software package that uses the numerical model VS2DH (Healy and Ronan, 1996) to simulate water movement and energy transport within porous-variably-saturated sediments.

VS2DH solves a form of the advection-dispersion equation (Equation 3) which accounts for changes in stored energy within a volume of porous media, due to advective transport of water, thermal conduction, and energy dispersion into or out of the volume (Healy and Ronan, 1996).

Equation 3:

$$\frac{\partial[\theta C_w + (1-\Phi)C_s]T}{\partial t} = \nabla \times K_t(\theta)\nabla T + \nabla \times \theta C_w D_h \nabla T - \nabla \theta C_w v T + q C_w T^*$$

where t is time; θ is the volumetric water content; v is water velocity; Φ is sediment porosity; T is temperature; K_t is the thermal conductivity of the streambed sediments; D_h is the thermo-mechanical dispersion tensor; q is the water flux; and T^* is the temperature of fluid source. C_s and C_w are the specific heat capacity of the dry sediment and water, respectively.

The left side of Equation 3 is the change in stored energy in a volume of porous media over time. On the right side of the equation, the first term represents energy transport by thermal conduction; the second term accounts for energy transport by thermo-mechanical dispersion; the third term represents advective energy transport; and the final term accounts for heat sinks or sources such as water withdrawn or injected via wells (Healy and Ronan, 1996).

The thermo-mechanical dispersion tensor is defined as

Equation 4:

$$D_h = \alpha_t |v| \delta_{ij} + \frac{(\alpha_l - \alpha_t) v_i v_j}{|v|}$$

where α_l and α_t are the longitudinal and transverse dispersivities of the sediment, respectively; δ_{ij} is the Kronecker delta function; and v_i, v_j are the ith and jth component of the velocity vector, respectively.

A detailed discussion of the theoretical foundation for VS2DH and its use can be found in the works by Lappala et al. (1987), Healy (1990), Healy and Ronan (1996), and Hsieh et al. (2000).

Modeling Approach and Assumptions

The one-dimensional modeling approach adopted for this evaluation is based on several simplifying assumptions including:

1. Water enters and leaves the river or stream only in the vertical direction (i.e., horizontal or oblique flow to or from the river is assumed to be negligible). Although this assumption is probably not valid in all cases, this approach has been used successfully to model river systems elsewhere, and is thought to provide a good first approximation of surface water and groundwater exchanges where one lacks the necessary data to develop 2D or 3D models (Stonestrom and Constantz, 2003; Constantz et al., 2002).

2. The sediments comprising the upper 3-6 feet of the streambed have uniform hydraulic and thermal properties, and can therefore be represented in VS2DH as a single homogeneous layer.

3. It is valid during extended periods of stable streamflow (i.e., baseflow conditions) to estimate hourly vertical hydraulic gradient values by interpolating between two bounding field measurements spaced approximately 20-30 days apart.

4. The water temperature measured at discrete depths inside a piezometer casing accurately represents the streambed water temperatures at that depth (i.e., the water temperatures inside the piezometer are not measurably influenced by heat conduction along – up or down – the pipe or by convective heat flow within the pipe).

Model Domain

Individual model domains were defined for each piezometer site (Figure 12). The domains were 2 meters wide by approximately 1 meter high[2]. A uniform grid was assigned to each domain and consisted of 150 grid elements with dimensions of 2 meters by approximately 0.006 meters. Input temperatures for the upper boundary (which was set at the streambed surface for all simulations) were specified for each recharge period from field measured stream temperatures. Corresponding head values were then estimated for each recharge period by interpolating hourly stage values from the two monthly field measurements bounding the model period.

Model Boundaries, Time Steps, and Initial Conditions

The modeling for this project consisted of 20.8-day simulations composed of 500 one-hour recharge (stress) periods. A 20.8-day simulation period was deemed sufficiently long to remove potential bias in model results from initial starting conditions, while at the same time being short enough to minimize potential error in interpolated hydraulic gradient values. All simulations were defined using data collected during baseflow periods (generally late summer) to minimize the potential error introduced by unaccounted for variations in stream stage or hydraulic gradient.

The lower boundary of the model domain was set at the midpoint of the modeled piezometers screen interval, and had variable head values defined as shown in Figure 12. Temperature records for the lower-most thermistor, which was always located near the midpoint of the screen interval, were used to define groundwater input temperatures for the bottom boundary. The model sides were set as no-flow and no-energy flux boundaries.

Based on surface observations, the streambed sediments at most sites consisted of poorly sorted deposits of well-rounded gravel and fine-to-medium sand, with variable amounts of interstitial silt. Some sites, particularly those in the upper watershed, had local accumulations of cobbles or boulders. Despite observed differences in the streambed sediments between sites, all sites were modeled as a single layer of isotropic medium or fine sand and were assigned soil properties and heat constants based on published literature values (Stonestrom and Constantz, 2003; Healy and Ronan, 1996) (Table 5).

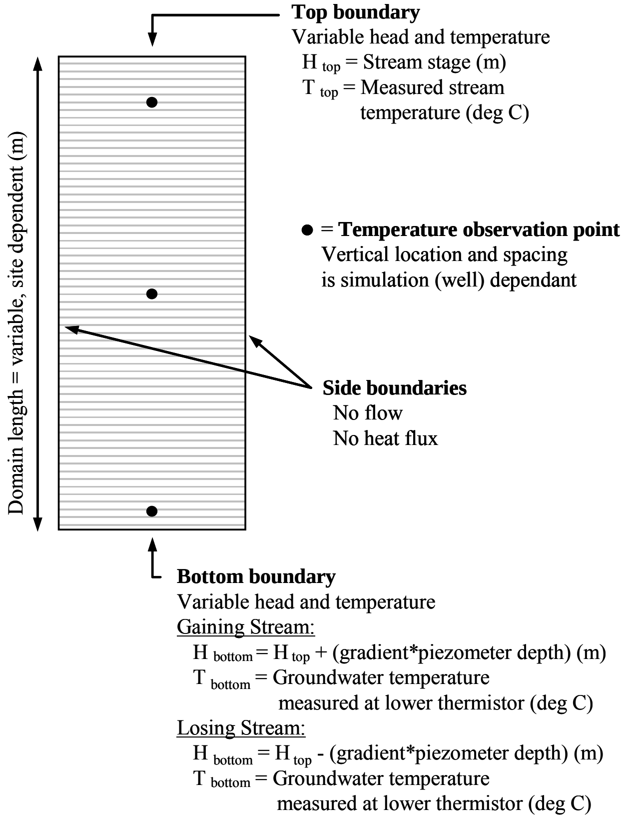

Figure 12 - Schematic of the model domain and boundary array used for VS2DHI thermal simulations

Table 5 - Summary of soil properties and heat constants used in VS2DHI simulations

Property	Range of Values
Porosity (Φ)	0.375 to 0.377 (m^3/m^3)
Heat capacity of water (C_w)	4.18x10^6 (J/m^3 °C)
Heat capacity of dry solids (C_s)	1.2x10^6 to 2.18x10^6 (J/m^3 °C)
Thermal conductivity (K_t)	1.8 (W/m^3 °C)
Longitudinal thermal dispersivity (a_l)	0.01 to 0.1 (m)
Transverse thermal dispersivity (a_t)	0.01 to 0.1 (m)
Anisotropy ratio (K_v/K_h)	1

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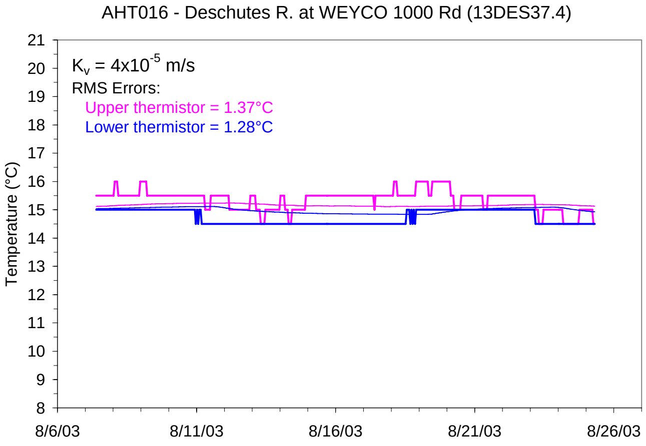
[2] A variable domain height was necessary to accommodate differences in piezometer length and screen intervals/placement between sites.

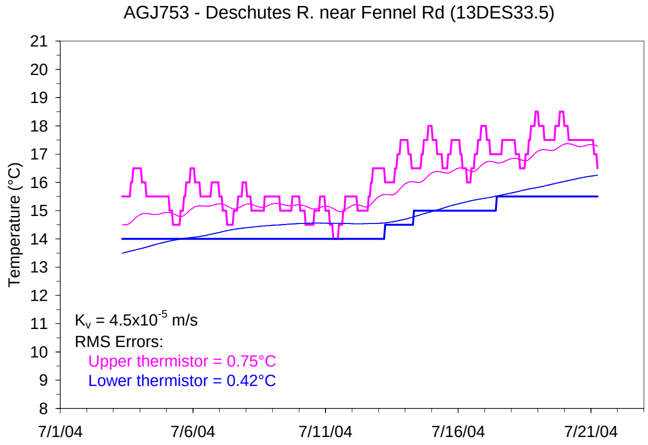
Model Calibration

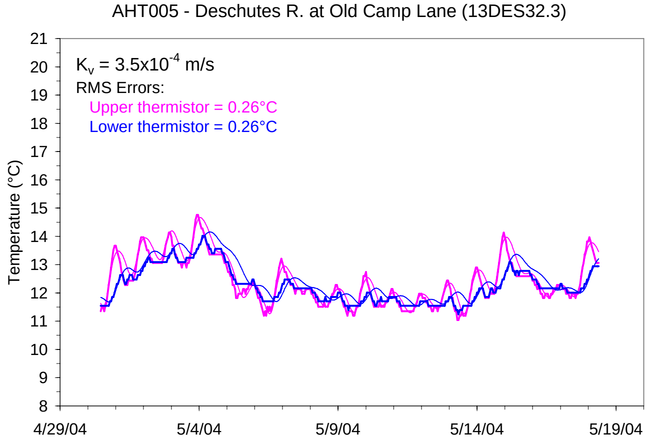
A manual trial-and-error calibration process was used during the simulations and entailed varying the modeled streambed hydraulic conductivity until a "best fit"[3] was obtained between measured and simulated streambed water temperatures (Figure 13).

The best fit calibrations for piezometers instrumented with i-button thermistors (AHT016, AGJ753, AGJ758, AGJ759, AHT004, AHT011, AHT018, AGJ761, AGJ764, AGJ755, and AGJ754) had higher root mean square (RMS) errors (average 0.48 °C) than piezometers instrumented with more sensitive tidbits or hobo thermistors (average 0.2 °C). In most cases, the i-button temperature records exhibited significantly greater diurnal variability than the corresponding temperatures simulated by VS2DH. This disparity is attributed to the 0.5 °C temperature precision registered by i-buttons relative to the higher precision temperatures simulated by VS2DH. Despite this complication, the average RMS error between measured and simulated temperatures at these sites was generally within the thermistor sensitivity range of 0.5 °C.

Deschutes River Watershed


AHT016 - Deschutes R. at WEYCO 1000 Rd (13DES37.4)


AGJ753 - Deschutes R. near Fennel Rd (13DES33.5)


AHT005 - Deschutes R. at Old Camp Lane (13DES32.3)

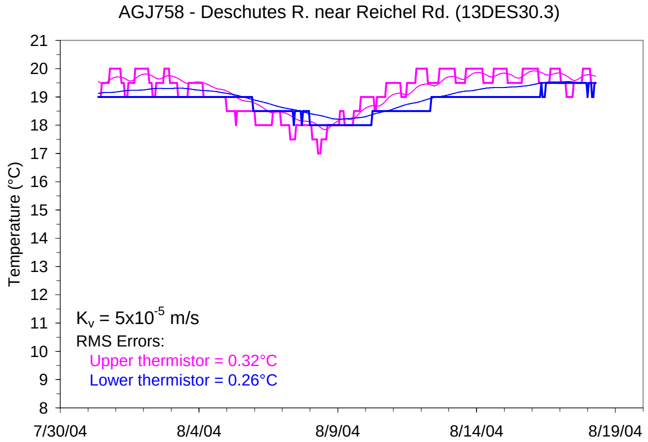

AGJ758 - Deschutes R. near Reichel Rd. (13DES30.3)

Figure 13: Best fit graphs of measured (thick lines) and predicted (thin lines) temperatures with corresponding hydraulic conductivity (K) and RMS errors by piezometer. See Plate 2, Figure 1 for a map of piezometer locations.

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[3] The "best fit" hydraulic conductivity is the value that produced the smallest root mean square (RMS) error between measured and simulated streambed water temperatures. The RMS calculation was based only on the final 10 days of the 20 day simulation period, to minimize any potential bias introduced by the initial starting temperature assigned to the model domain.

Figure 13 (continued): See Plate 2, Figure 1 for a map of piezometer locations.

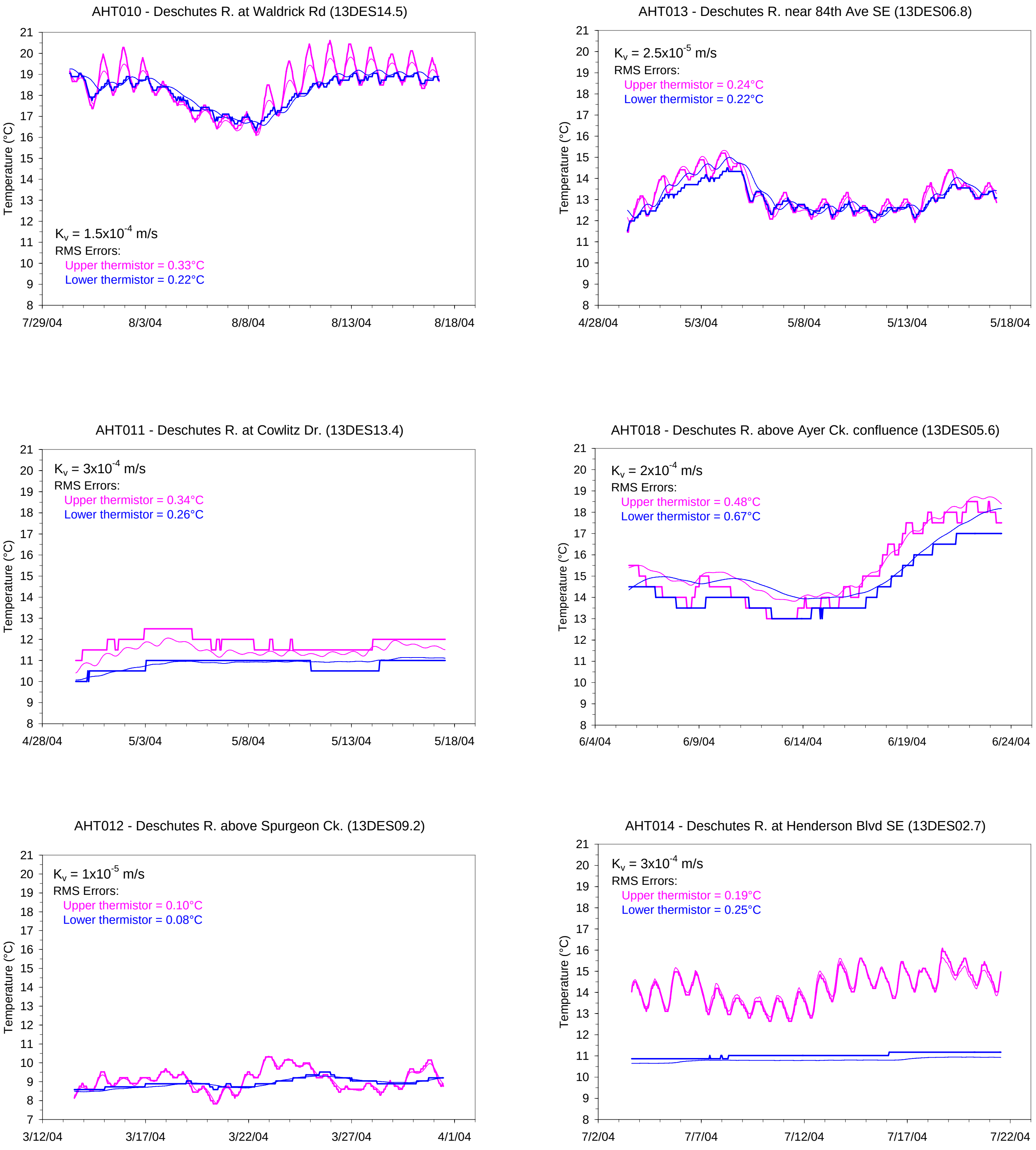
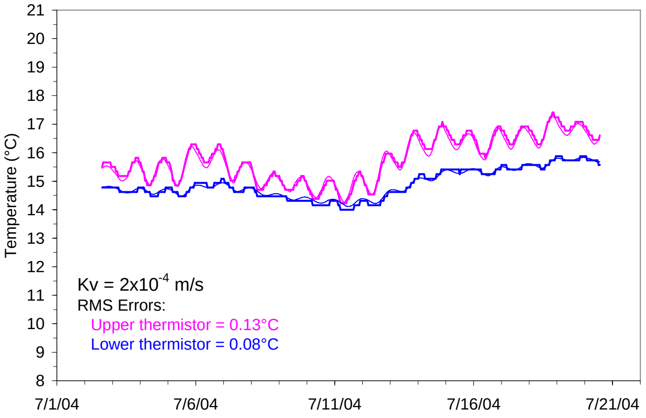
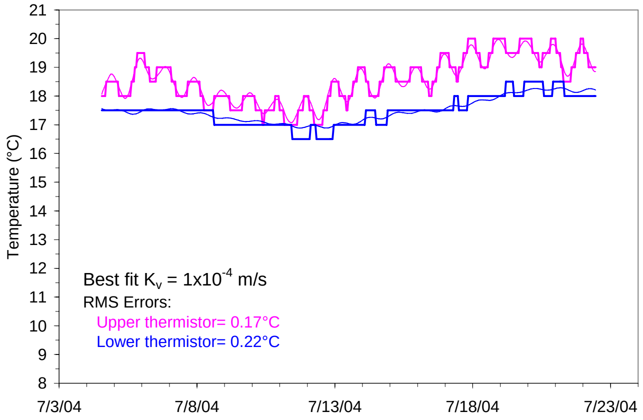
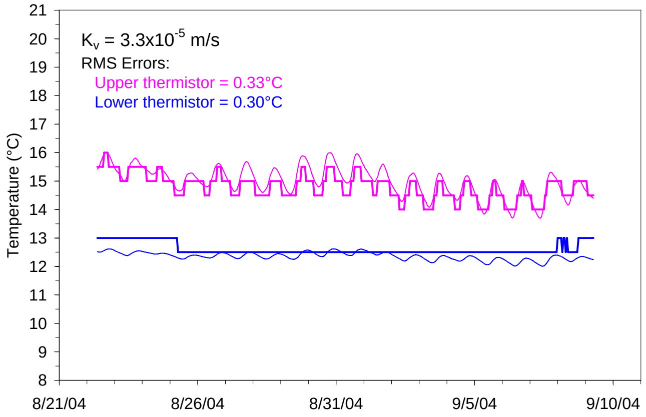


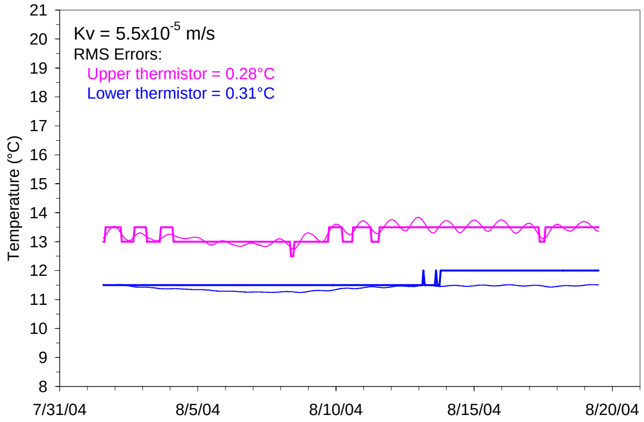
Figure 13 (continued): See Plate 2, Figure 1 for a map of piezometer locations.


AHT015 - Deschutes R. at E-Street Bridge (13DES00.5)


AGJ755 - Black Lk Ditch at Percival Ck Confluence (13BLA00.0)

Percival Creek Watershed


AGJ761 - Percival Ck at Trosper Rd (13PER03.3)


AGJ764 - Percival Ck at SPSCC (13PER01.6)

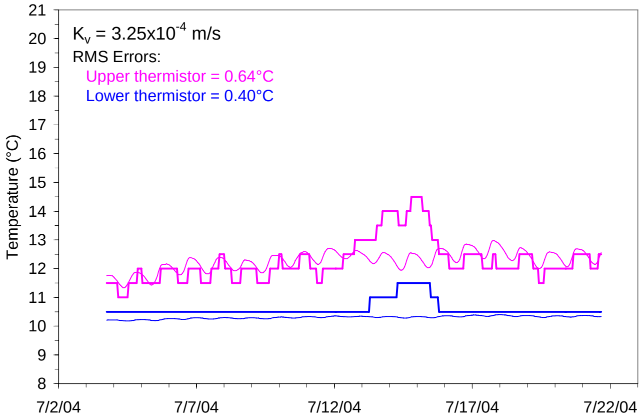

AGJ754 - Percival Ck at Mouth (13PER00.5)

Figure 13 (continued): See Plate 2, Figure 1 for a map of piezometer locations.

Sensitivity Analysis

Sensitivity analyses were conducted for a representative gaining and losing simulation to assess model sensitivity to variations in soil properties, heat constants, and other user-specified variables. The calibrated model for well AHT007 was selected to perform the sensitivity analysis for gaining simulations. The calibrated hydraulic conductivity for well AHT007 was 2.25 x 10^{-5} m/s, near the lower range of values estimated for this project. The model for well AHT018 was chosen to represent losing simulations and had a calibrated hydraulic conductivity of 2.0x10^{-4} m/s, near the upper range of values determined during this study.

To perform the analysis, single input parameters in each of the two representative calibrated models were systematically varied by ± 20% (relative to the final calibrated values) and the models rerun to assess their response to the imposed stresses. Each of the model's relative sensitivity to these imposed stresses was evaluated by summing the RMS temperature deviations that occurred between the simulated thermal profiles from the calibrated model and the profiles generated during the sensitivity runs (Figure 14).

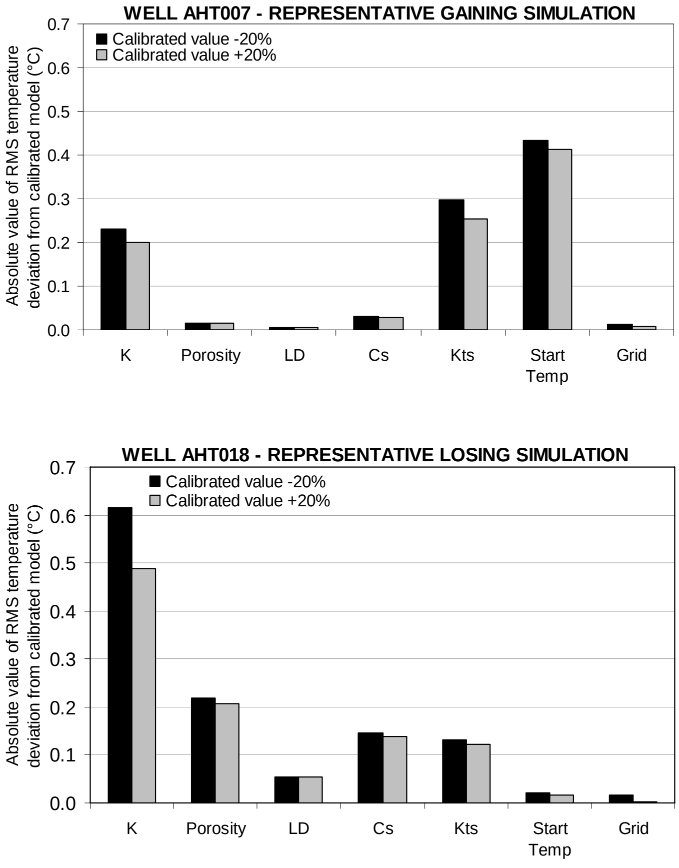


Figure 14: Sensitivity plots for representative gaining and losing model simulations, showing the absolute value of the summed root mean square (RMS) temperature deviation between the calibrated and sensitivity stressed model [4].

This evaluation suggests that the gaining model is relatively insensitive to variations in sediment porosity, longitudinal thermal dispersivity, sediment heat capacity, and model grid spacing. Varying model inputs by ± 20% resulted in less than a 0.1°C RMS temperature difference from the calibrated model. The model is more sensitive to variations in streambed hydraulic conductivity, sediment thermal conductivity, and the initial starting temperature applied to the model domain.

In contrast, the losing model was sensitive to changes in streambed hydraulic conductivity and moderately sensitive to changes in sediment porosity, heat capacity, and thermal conductivity. The model was relatively insensitive to changes in sediment longitudinal thermal dispersivity, initial starting temperature, and model grid spacing.

These results illustrate the importance of obtaining both accurate and precise temperature records for use in setting the initial temperature and model boundary conditions during model simulations. The results also reveal the importance of accurately estimating streambed thermal properties, particularly for sites where streambed seepage velocities are likely to be small. At low velocities, heat conduction rather than advection becomes the dominant heat transport mechanism; hence, simulated temperatures become increasingly sensitive to variations in streambed thermal properties (Stonestrom and Constantz, 2003). In such cases, errors in assigned thermal properties can lead to significant uncertainty in estimated streambed hydraulic conductivity values. At higher seepage velocities, advection is the dominant heat transport mechanism, and uncertainty in streambed thermal properties is less problematic.

Modeling Results

The simulation results for 17 piezometer sites along the Deschutes River yielded streambed hydraulic conductivity values ranging from 1×10^{-5} to 4.2×10^{-4} m/s with a geometric mean of 1.13×10^{-4} m/s (Figure 15). The results at 4 sites along Percival Creek were similar and ranged from 3.3×10^{-5} to 3.25×10^{-4} m/s with a geometric mean of 8.67×10^{-5} m/s.

Table 6 summarizes the range and geometric mean of streambed hydraulic conductivity by underlying surficial geologic unit.

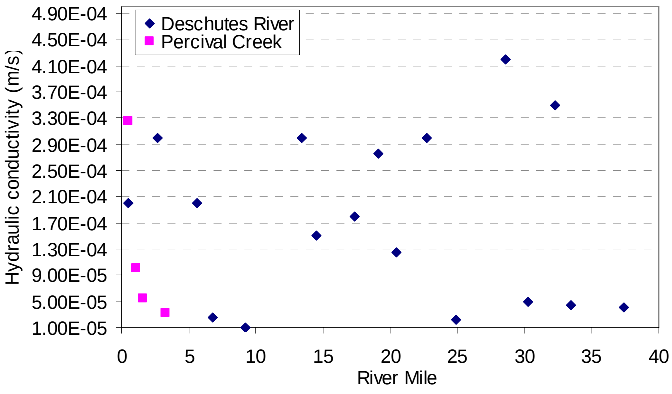


Figure 15 - Distribution of modeled streambed vertical hydraulic conductivity by river mile

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[4] Where K is hydraulic conductivity; LD is longitudinal thermal dispersivity; Cs is heat capacity of dry sediments; Kts is the thermal conductivity of saturated sediments; Start Temp is the initial starting temperature applied to the model domain; and Grid is the vertical grid spacing specified during model development.

Table 6 - Summary of VS2DH estimated streambed hydraulic conductivity values by surficial geologic unit

Surficial Geologic Unit	Number of piezometers evaluated	(Kv) Vertical hydraulic conductivity (m/s)	
		Estimated Range	Geometric Mean
Qa	13	$1x10^{-5}$ to $4.2x10^{-4}$	$1.36x10^{-4}$
Qgos	1	$3.3x10^{-5}$	NA
Qgog	4	$2.25x10^{-5}$ to $3x10^{-4}$	$6.06x10^{-5}$
Qgd	3	$5.5x10^{-5}$ to $3.25x10^{-4}$	$1.21x10^{-4}$

The modeled hydraulic conductivity values for both river systems are comparable to those commonly associated with clean to silty sand and are within the range estimated for mixed alluvial deposits derived from glacial outwash sand and gravel (Freeze and Cherry, 1979; Calver, 2001).

Model Verification

As a secondary confirmation of the streambed hydraulic conductivity values obtained via thermal modeling, a Darcy flux analysis was performed for the Deschutes River using seepage fluxes and vertical hydraulic gradients measured during the August 2003 seepage study. Darcy (1856) demonstrated that the discharge of water (Q) through porous material is equal to the product of the hydraulic gradient (I) and the cross sectional area (A) through which water moves, times the hydraulic conductivity (K) of the material (Equation 5).

$$Q = -KIA \qquad (5)$$

Darcy's equation can be rearranged, and the data from seepage runs and instream piezometers used to solve for streambed vertical hydraulic conductivity (K_v)

$$K_v = -(Q/I_v A) \, , \qquad (6)$$

Where:

K_v	is the average vertical hydraulic conductivity of the streambed material within the seepage reach (feet/sec)
Q	is the total volume of water gained or lost by the river across the seepage reach (ft^3/s)
I_v	is the average vertical hydraulic gradient between the river and groundwater as measured at piezometer sites along the reach (dimensionless)
A	is the streambed cross sectional area across which water exchange occurs (ft^2)

In this case, the streambed area for each seepage reach was estimated by averaging the wetted width measurements determined, at 50 meter intervals, from digital orthophotos and then multiplying this value by the total reach length. The net seepage (Q) for a reach was determined from the August 2003 seepage run (Table 1). The reach-average vertical hydraulic gradient (I_v) was derived by averaging the hydraulic gradients measured in piezometers, along each reach, during the August 2003 seepage study[5] (Table B-2).

Several simplifying assumptions are implicit in this analysis.

1. The net seepage value (Q) estimated from the seepage data for each reach accurately represents the total (gross) water exchange between the river and groundwater.

2. Water exchanges between the river and groundwater occur throughout the wetted area of the streambed and only in a vertical or near vertical direction.

3. The average vertical hydraulic gradient for a seepage reach is accurately represented by averaging the vertical hydraulic gradients measured in instream piezometers along the reach.

4. The estimated reach length and width values derived from orthophotos provide a good approximation of the actual streambed area across which flow occurs.

As shown in Table 7, the reach-average hydraulic conductivity values estimated using Equation 6 support the values derived via thermal modeling. The results for 4 of 6 reaches evaluated (reaches 2, 3, 5, and 6) were within the same order of magnitude as modeled values, while the remaining reaches (1 and 4) were within two orders of magnitude of modeled values. Shorter reaches tended to have better agreement between methods than longer reaches, owing to greater uncertainty in the input parameters for Equation 6 with increasing reach length.

This evaluation suggests that the streambed hydraulic conductivity values derived from thermal modeling of streambed temperatures are within the range of values that might be expected for a glaciated riverine environment and are appropriate for use in this evaluation.

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[5] Vertical hydraulic gradients, from late July 2004, for the five piezometers installed in spring 2004 were included in this calculation.

Table 7 - Comparison of streambed hydraulic conductivity values estimated from stream seepage and instream piezometer surveys of the Deschutes River, and subsequent thermal modeling of streambed temperatures (Seepage results from Table 1; vertical hydraulic gradients from Table B-2)

Primary seepage reach desig- nation	Reach designation (by river miles)	Stream reach length		Average stream width (feet)	Total surface area of reach (A) (ft^2)	Measured seepage gain or loss for reach (Q) (ft^3/s)	Average vertical hydraulic gradient (I_v) (dimension- less)	Average hydraulic conductivity from Darcy analysis (K_v) ft/s	Average hydraulic conductivity from Darcy analysis (K_v) (m/s)	Average hydraulic conductivity from VS2DH modeling (K_v) (m/s)
		(miles)	(feet)							
1	42.3 to 28.6	13.7	72,336	41	2,965,776	-3.8	-0.050	2.56E-05	7.81E-06	2.71E-04
2	28.6 to 20.5	8.1	42,768	40	1,710,720	8.49	0.013	3.82E-04	1.16E-04	2.17E-04
3	20.5 to 19.1	1.4	7,392	42	310,464	-1.6	-0.003	1.72E-03	5.24E-04	2.00E-04
4	19.1 to 9.2	9.9	52,272	44	2,299,968	17	-0.002	3.70E-03	1.13E-03	1.83E-04
5	9.2 to 6.8	2.4	12,672	43	544,896	-1.4	-0.065	3.95E-05	1.20E-05	1.75E-05
6	6.8 to 0.5	6.3	33,264	43	1,430,352	22.8	-0.039	4.09E-04	1.25E-04	1.81E-04

Range of point hydraulic conductivity values estimated via VS2DH modeling by reach

Reach 1: $4.0\text{x}10^{-5}$ to $4.2\text{x}10^{-4}$ m/s

Reach 2: $2.25\text{x}10^{-5}$ to $4.2\text{x}10^{-4}$ m/s

Reach 3: $1.25\text{x}10^{-4}$ to $2.75\text{x}10^{-4}$ m/s

Reach 4: $1\text{x}10^{-5}$ to $3\text{x}10^{-4}$ m/s

Reach 5: $1\text{x}10^{-5}$ to $2.5\text{x}10^{-5}$ m/s

Reach 6: $2.25\text{x}10^{-5}$ to $3\text{x}10^{-4}$ m/s

Groundwater Nutrient Loading to Streams

Unit-area nutrient mass loads to the Deschutes River and Percival Creek were estimated by combining the measured nutrient concentrations in sampled piezometers, with calculated volumetric fluxes estimated from field measured hydraulic gradients and modeled streambed hydraulic conductivity values. Volumetric flux estimates were derived for each modeled piezometer using Equation 5, and the inputs from Table B-3 for hydraulic conductivity and hydraulic gradient. The results of this evaluation are shown in Figure 16 and Table B-3.

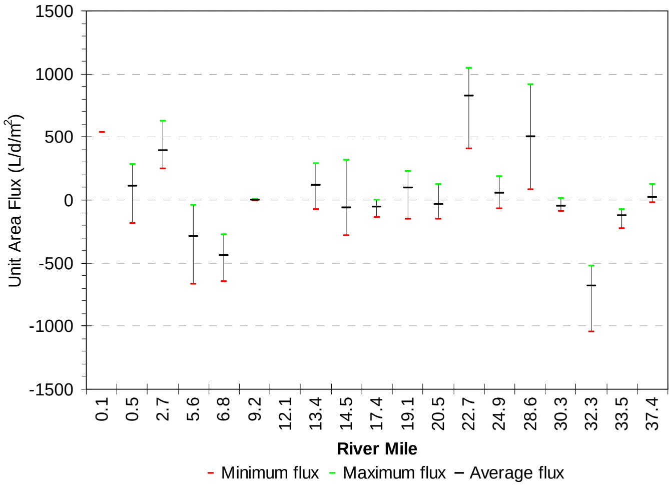


Figure 16 - Calculated maximum, minimum, and average unit area volumetric fluxes by river mile

A range of potential mass flux estimates were then derived for each sampled piezometer and nutrient of interest by combining the volumetric flux estimates from Table B-3 with the median constituent concentrations for sampled piezometers from Table 4 (Equation 7).

$$M_L = QC \qquad (7)$$

Where:

M_L = the unit area mass flux rate for the constituent of interest (M/t)

Q = the unit area groundwater flux rate from Equation 5

C = the mean nutrient concentration, in groundwater (M/V)

The results of this calculation are shown in Figure 17. Table 8 shows the results for individual sample dates. Groundwater loads of dissolved orthophosphate, dissolved total phosphorus, and dissolved total persulfate nitrogen (TPN) were present at all sampled piezometers. For the seven sites evaluated, the average calculated load for dissolved orthophosphate ranged from 2.97 to 45.6 mg/d/m^2 of streambed (Figure 17). The average calculated loads for dissolved total phosphorous were generally larger and ranged from 2.85 to 66.4 mg/d/m^2, while loads for dissolved total persulfate nitrogen ranged from 5.9 to 3,884 mg/d/m^2.

Calculated loads of dissolved ammonia and dissolved nitrate+nitrite-N were present at four of seven sites evaluated. Dissolved ammonia loads from groundwater ranged from 3.35 to 79.3 mg/d/m^2, while loads of dissolved nitrate+nitrite-N ranged from 5.53 to 3,912 mg/d/m^2.

The load estimates presented in Figure 17 and Table 8 are point-based values for specific locations within a complex heterogeneous stream environment. In addition to providing specific loading estimates for these sites, these data may be useful in helping to bracket potential nutrient loads that occur across larger reaches or at other points along the stream.

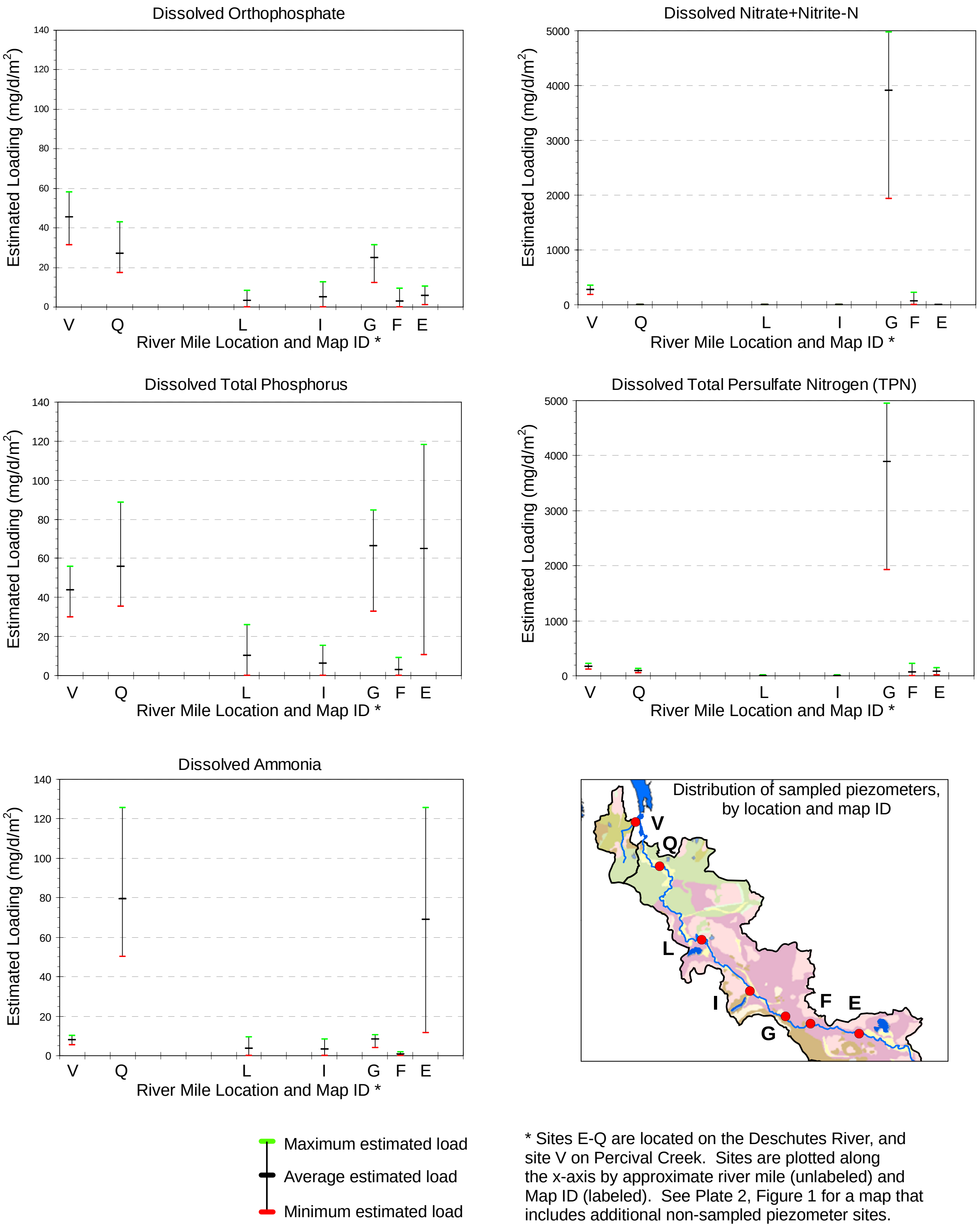
These load estimates do not account for biological or geochemical processes that can attenuate nutrient concentrations (particularly phosphorus) as groundwater flows through the final few feet of the streambed (Hem, 1985). Thus, these values should be considered upper-bound estimates of potential groundwater nutrient mass loading to the river at these locations.

Table 8 - Estimated unit area nutrient mass loading to the Deschutes River and Percival Creek via discharging groundwater, by sample date.

Well Tag Number	Map ID [1]	Sample Date	Dissolved Organic Carbon (mg/d/m^2)	Dissolved Ortho-phosphate (mg/d/m^2)	Dissolved Total Phosphorous (mg/d/m^2)	Dissolved Nitrate + Nitrite-N (mg/d/m^2)	Dissolved Ammonia (mg/d/m^2)	Dissolved TPN-N (mg/d/m^2)
AHT006	E	6/30/2004	584 *	7.59	77.66	6.42	75.91	87.59
		7/28/2004	584 *	4.67	96.93	5.84 *	75.91	81.75
		8/30/2004	584 *	7.01	78.83	5.84 *	82.34	93.43
		9/28/2004	500.52	6.51	66.07	5.01 *	73.58	80.08
AHT007	F	6/30/2004	48 *	2.45	2.40	53.76	0.48 *	53.28
		7/28/2004	28.8 *	1.44	1.32	34.85	0.29 *	35.14
		8/30/2004	33.6 *	1.85	1.81	42.00	0.34 *	42.00
		9/28/2004	28.8 *	1.53	1.44	36.00	0.29 *	34.85
AGJ759	G	8/30/2004	874 *	46.31	44.56	4158.85	8.74 *	4106.43
		9/29/2004	757 *	12.87	96.92	3589.19	7.57 *	3581.62
AHT009	I	9/28/2004	90.51	4.22	5.05	0.75 *	2.72	48.27
AHT011	L	8/30/2004	146 *	4.23	13.00	1.46 *	4.67	7.45
AHT014	Q	6/30/2004	499.7 *	19.99	67.95	5.0 *	100.93	103.43
		7/28/2004	624.6 *	53.71	79.95	6.25 *	120.54	137.41
		8/30/2004	374.8 *	30.35	56.96	3.75 *	77.20	82.44
		9/28/2004	321.3 *	24.98	47.47	3.12 *	63.71	68.70
AGJ754	V	6/30/2004	769.3 *	45.39	46.16	183.87	7.69 *	188.48
		7/28/2004	538.5 *	29.62	26.93	212.72	5.39 *	217.02
		8/30/2004	923.2 *	55.39	53.54	330.50	9.23 *	337.88
		9/28/2004	769.3 *	45.39	42.31	323.88	7.69 *	329.27

[1]- See Plate 1, Figure 1 for a map of site locations

* - Analyte not detected at or above the method reporting limit (see Table 4); the above value is the station maximum potential load assuming a groundwater constituent concentration less than or equal to the reporting limit



* Sites E-Q are located on the Deschutes River, and site V on Percival Creek. Sites are plotted along the x-axis by approximate river mile (unlabeled) and Map ID (labeled). See Plate 2, Figure 1 for a map that includes additional non-sampled piezometer sites.

Figure 17. Estimated maximum, minimum, and average unit area groundwater nutrient mass loading to the Deschutes River and Percival Creek, for the station period of record (see Table B-3).

Summary and Conclusions

In the summer of 2003, the Washington State Department of Ecology initiated TMDL-based field studies to assess current water quality and near-stream environmental conditions within the Deschutes River and Percival Creek watersheds. At that time, both streams had one or more known water quality impairments as described in Roberts et al. (2004).

This study was undertaken to support the Deschutes River TMDL investigation. The study was designed around two primary objectives: (1) to evaluate and describe the distribution, volume, and timing of surface water and groundwater interactions, and (2) to quantify the potential nutrient load that groundwater contributes to the Deschutes River and Percival Creek via gaining stream reaches.

Multiple field techniques were used to achieve these objectives. Four baseflow seepage studies – one along the Deschutes River in 2003 and three along Percival Creek in 2004 – were conducted to quantify reach scale streamflow gains and losses. The seepage runs were supplemented by 22 instream piezometers (18 along the Deschutes River and 4 along Percival Creek) that were installed to monitor surface water/groundwater head relationships, streambed temperatures, and groundwater quality.

The piezometers were instrumented with recording thermistors for half-hourly monitoring of streambed water temperatures. Piezometers were accessed monthly to make comparative measurements of stream stage and groundwater levels, and to measure stream and groundwater temperatures for comparison against, and validation of, the continuous thermistor data. Water quality samples were collected from 7 piezometers located along gaining stream reaches to evaluate near-stream groundwater nutrient concentrations.

The streambed temperature and vertical hydraulic gradient data from piezometers were used to estimate streambed hydraulic conductivity values via one-dimensional fluid flow and energy-transport models (Hsieh et al., 2000). The resultant hydraulic conductivity values were combined with vertical hydraulic gradients and measured nutrient concentrations from sampled piezometers. These data were used to develop unit area estimates of nutrient mass loading to surface water from groundwater at each sampled piezometer.

These evaluations revealed that the mainstem Deschutes River is composed of alternating gaining and losing reaches, with net reach-based seepage rates ranging from a loss of 1.14 to a gain of 3.61 ft^3/s per river mile. Overall, the river showed a net gain from groundwater of 41.4 ft^3/s, or approximately 52 percent of total streamflow, between the upper and lower seepage transects at river miles 42.3 and 0.50, respectively.

Percival Creek showed a similar gain/loss pattern and had net reach-based exchanges ranging from a loss of 0.76 to a gain of 2.72 ft^3/s per river mile. The overall net streamflow gain for the creek ranged from 1.7 to 2.61 ft^3/s or approximately 20 to 37 percent of the total streamflow measured at the lower seepage transect.

The streamflow gains and losses observed during seepage runs were generally supported by point-based vertical hydraulic gradients and streambed thermal profiles measured in piezometers. These latter measurements provided a comprehensive record of water exchanges at discrete points along each reach and show that surface water/groundwater exchanges are more dynamic (with respect to timing, direction, and magnitude) than the seepage runs suggest. Nine of the 22 piezometers installed for this study experienced seasonal (summer to winter) or short-term (storm-based) gradient reversals that were not otherwise apparent.

The groundwater quality results for individual piezometers were generally consistent across four sampling events conducted between June and September 2004. Measurable concentrations of dissolved orthophosphate and dissolved total phosphorus were found in all samples at values ranging from 0.008 to 0.086 mg/L and 0.046 to 0.152 mg/L, respectively. Measurable concentrations of dissolved nitrate+nitrite-N and dissolved ammonia were found in approximately half of the samples at concentrations ranging from 0.011 to 4.76 mg/L and 0.032 to 0.206 mg/L, respectively. Ammonia and nitrate+nitrite-N concentrations in the remaining samples were below the laboratory detection limit of 0.01 mg/L.

Unit-area nutrient mass loads from groundwater discharges to the Deschutes River and Percival Creek were estimated for each sampled piezometer site by combining measured nutrient concentrations with volumetric fluxes estimated from field-measured hydraulic gradients and modeled streambed hydraulic conductivity values. For the seven sites evaluated, average mass loads for dissolved total phosphorus ranged from 2.8 to 66.4 $mg/d/m^2$ of streambed. For the four sties where measurable concentrations of dissolved nitrate+nitrite-N occurred, loads ranged from 5.5 to 3913 $mg/d/m^2$ of streambed.

For the seven sites evaluated, the highest nitrate levels occurred where dissolved oxygen levels in groundwater were highest, whiles sites with low dissolved oxygen concentrations had higher levels of ammonia.

The point loading estimates presented in this study do not account for biological or geochemical processes that can attenuate nutrient concentrations in groundwater as it flows through the final few feet of the streambed; hence, the values presented here should be considered upper-bound estimates of potential unit-area nutrient loads.

Recommendations

This 2003-2004 study used a one-dimensional modeling approach to define streambed hydraulic conductivity values. This approach assumes that all water exchanges between a river and groundwater occur vertically. Future studies would benefit from the installation of well transects at critical points of interest to verify this assumption and to enable two- or three-dimensional modeling to be conducted, if warranted.

Thermal modeling of streambed sediments is both time and labor intensive and is probably not warranted except for those TMDL evaluations where groundwater mass loads to streams or rivers must be estimated. Comparative evaluations of streambed hydraulic conductivity values derived via thermal modeling, and field-based techniques such as constant head injection tests (Pitz, 2006; Cardenas and Zlotnik, 2003), should be conducted to assess the applicability of these latter methods for Ecology's TMDL investigations.

The range of groundwater seepage rates estimated for the streambed sediments underlying the Deschutes River and Percival Creek are sufficiently small that monthly sampling of instream piezometers is not necessary to effectively characterize near-stream groundwater quality. Quarterly or bi-monthly sampling would have sufficed and should be considered during future TMDL evaluations involving streams or rivers in similar hydrogeologic settings.

Both the Deschutes River and Percival Creek are highly dependent on groundwater discharge during the dry summer months. Future TMDL implementation strategies should stress the need to maintain groundwater baseflows in these streams, particularly during the summer when elevated stream temperatures are most detrimental to salmonids and native trout.

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Appendices

Appendix A - Data Quality Assurance

The data quality procedures we followed for this project are described in the study quality assurance plan (Roberts et al., 2004) and summarized below by major task or activity.

Water Quality Sampling and Analysis

Sampling procedures followed those specified in the project quality assurance plan (Roberts et al., 2004). All samples were collected in pre-cleaned bottles supplied by Manchester Environmental Laboratory (MEL). Piezometers were sampled using dedicated tubing and new in-line-cartridge or syringe filters, where appropriate. Pre-acidified bottles were used for samples that required preservation. 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. All samples arrived at the laboratory in good condition and were processed and analyzed within accepted EPA holding times.

Laboratory Quality Control

Manchester Laboratory follows a strict set of quality assurance procedures to both ensure and later evaluate the quality of their analytical results (MEL, 2001). Where appropriate, instrument calibration was performed before each analytical run and checked against initial verification standards and blanks. Calibration standards and blanks were analyzed at a frequency of approximately 10 percent during each analytical run and then again at the end of each run. The laboratory also evaluated 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 project officer as part of the analytical data package prepared by the laboratory.

The laboratory’s quality assurance narratives and supporting data for this project indicated that 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.

Evaluation of Field Duplicate and Filter Blank Samples

In order to assess overall sampling and analytical bias, 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 supplied de-ionized water. Blank samples were handled in the same manner as actual samples and were pumped and filtered, as appropriate, per project protocols.

Precision for each of the field replicate and laboratory duplicate analyses was subsequently quantified by evaluating the relative percent difference[7] (RPD) and percent relative standard deviation[8] (%RSD) for each duplicate sample pair. The resulting values (Table A-1) were then tabulated and compared to the project data quality objectives (Table A-2).

Field replicate analyses were within the project acceptance criteria (5% and 10% for %RSD and RPD respectively) for all but two sample pairs (orthophosphate and total phosphorus) collected in September 2004) (Table A-1). The cause of this discrepancy is not known, but was deemed significant enough to warrant qualification of the data. Accordingly, all orthophosphate and total phosphorus results for the September 2004 sample event were flagged as estimates by the authors.

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

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

Table A-1: Quality assurance review of field and laboratory duplicate samples and laboratory method blanks

		Field Replicate and Filter Blank Results						**Laboratory Duplicate and Blank Results**					
Sample Date		Dissolved Organic Carbon (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorous (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved Total Phosphorous (mg/L)	Dissolved Nitrate+ Nitrite-N (mg/L)	Dissolved Ammonia (mg/L)	Dissolved TPN-N (mg/L)
6/30/2004	Sample	1.0 U	0.0585	0.0601	0.239	0.01U	0.245	1.0 U	0.0512	-	0.011	-	-
	Rep/Duplicate	1.0 U	0.0583	0.06	0.24	0.01 U	0.241	1.0 U	0.0514	-	0.011	-	-
	RPD	NA	0.34	0.17	0.42	NA	1.65	NA	0.39	-	0.00	-	-
	%RSD	NA	0.24	0.12	0.30	NA	1.16	NA	0.28	-	0.00	-	-
	Blank results	-	-	-	-	-	-	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U
7/28/2004	Sample	1.0 U	0.0547	0.0495	0.395	0.01U	0.403	1.0 U	0.05	-	-	0.01 U	1.22
	Rep/Duplicate	1.0 U	0.0554	0.0494	0.393	0.01 U	0.408	1.0 U	0.0506	-	-	0.01 U	1.21
	RPD	NA	1.27	0.20	0.42	NA	1.23	NA	1.19	-	-	NA	0.82
	%RSD	NA	0.90	0.14	0.36	NA	0.87	NA	0.84	-	-	NA	0.58
	Blank results	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U
8/30/2004	Sample	1.0 U	0.0599	0.0576	0.358	0.01U	0.366	-	0.0599	-	0.01 U	0.032	1.25
	Rep/Duplicate	1.0 U	0.0595	0.057	0.358	0.01 U	0.368	-	0.0597	-	0.01 U	0.032	1.23
	RPD	NA	0.67	1.05	0	NA	0.54	-	0.33	-	NA	0	1.61
	%RSD	NA	0.47	0.74	0.00	NA	0.39		0.24		NA	0.00	1.14
	Blank results	-	-	-	-	-	-	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U
9/28-29/2004	Sample	1.0 U	0.017	0.128	4.74	0.01U	4.73	1.2	-	-	1.25	0.010 U	1.21
	Rep/Duplicate	1.0 U	0.0538	0.0475	4.95	0.01 U	4.76	1.2	-	-	1.24	0.010 U	1.23
	RPD	NA	**103.95**	**91.74**	4.33	NA	0.63	0.00	NA	NA	0.80	NA	1.64
	%RSD	NA	**73.51**	**64.87**	3.06	NA	0.45	0.00	NA	NA	0.57	NA	1.16
	Blank results	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U	1.0 U	0.003 U	0.001 U	0.01 U	0.01 U	0.025 U

Relative percent difference (RPD): Calculated for a pair of results, x_1 and x_2, as 100*(x_1-x_2)/(average[x_1 and x_2])

Percent relative standard deviation (%RSD): Calculated for a pair of results, x_1 and x_2, as 100*s/(average [x_1 and x_2]), where s is the standard deviation of the sample pair.

U - analyte not detected at or above the reported value

Bold values indicate a violation of the project precision criteria.

Table A-2: Project data quality objectives

Parameter	Accuracy (% deviation from true value)	Precision (Relative standard deviation, RSD)	Bias (% deviation from true value)	Lowest level of interest
Field Measurements				
pH *	0.2 SU	0.05 SU	NA	1 SU
Specific conductance	25	10	5	1 µs/cm @25°C
Temperature	0.1 °C	0.025 °C	0.05 °C	0 °C
Dissolved oxygen	15	5	5	0.1 mg/L
Laboratory Analyses				
Dissolved total persulfate nitrogen-N	30	10	10	25 µg/L
Dissolved nitrate + nitrite-N	25	10	5	10 µg/L
Dissolved organic carbon	30	10	10	1 mg/L
Dissolved ammonia	25	10	5	10 µg/L
Dissolved orthophosphate	25	10	5	3 µg/L
Dissolved total phosphorus	25	10	5	10 µg/L

*- SU – standard units

Seepage Evaluation

Nine replicate discharge measurements were made during the August 5-6, 2003 seepage evaluation of the Deschutes River to assess the potential variability in measurement results introduced by the use of multiple field teams and/or instrument types. "Within-team" replicate measurements were made at five transects and consisted of back-to-back discharge measurements by a single field team. "Between team" measurements were made at four additional transects and consisted of replicate measurements by two different field teams at the same measurement transect (Table A-3).

Table A-3: Field duplicate measurements for the August 5-6 2003 Deschutes River seepage run

Site ID	Date	Time	Measured Discharge (Ft^3/sec)	Mean Discharge (Ft^3/sec)	Relative Percent Difference (RPD) [1]
Within-team Replicate Measurements					
13-MIT-00.2	08/05/03	13:00	2.20		
	08/05/03	13:30	1.93	2.06	**12.83**
13-DES-24.9	08/05/03	13:00	23.78		
	08/05/03	14:00	23.81	23.79	-0.16
13-DES-19.1	08/05/03	13:12	29.41		
	08/05/03	14:09	28.74	29.08	2.29
13-DES-13.4	08/05/03	11:53	41.59		
	08/05/03	12:27	47.58	44.58	**-13.43**
13-DES-00.5	08/05/03	16:18	79.26		
	08/05/03	16:52	78.97	79.12	0.37
	Mean RPD (within-team measurements) =				5.81
Between-team Replicate Measurements					
13-DES-37.4	08/05/03	13:05	14.82		
	08/05/03	15:00	17.23	16.03	**15.04**
13-DES-28.6	08/05/03	9:23	17.58		
	08/05/03	15:15	17.86	17.72	1.57
13-DES-20.5	08/05/03	11:42	30.96		
	08/05/03	15:06	30.48	30.72	-1.56
13-DES-14.5	08/05/03	10:23	42.22		
	08/05/03	16:51	40.79	41.50	3.44
	Mean RPD (between-team measurements) =				5.40

[1] RPD = [(M1-M2)/(Average of M1 and M2)] x100, where M1 and M2 are the first and second measurement respectively.

Bolded RPD values represent an exceedence of the project quality assurance target of <10% RPD for replicate measurements.

The results of this evaluation were generally favorable and showed good agreement for both the between-team and within-team measurements. The mean RPD across all measurements was 5.81 and 5.4 percent for the within-team and between-team measurements respectively. While mean RPD values were within project acceptance criteria, the duplicate results for three transects did not meet the project data quality objective (<10% RPD) for duplicate discharge measurements. The large difference at these sites is attributed to the array of cobbles and boulders that blanket the streambed at these transects, which tends to reduce the overall accuracy of individual discharge measurements.

The potential effects of measurement error on the calculated seepage budgets was evaluated by assigning an assumed measurement error of ±2.5 percent to each of the field-measured discharge values and then plotting these values against the measured gains and losses by seepage reach (Figure A-1). Seepage gains or losses plotting outside of the resulting uncertainty envelope exceeded the assumed measurement error and were assumed to represent true seepage gains or losses. Seepage values falling within the uncertainty envelope did not exceed the assumed range of potential measurement error and can thus not be confirmed without additional supporting data or measurements.

All but one of the estimated seepage values for Percival Creek plotted outside of the measurement uncertainty envelope and thus are thought to represent real streamflow gains or losses. Three estimated seepage values for the Deschutes River plotted within the uncertainty envelope and thus may not, in and of themselves, be reliable indictors of actual streamflow gains or losses (Figure A-1).

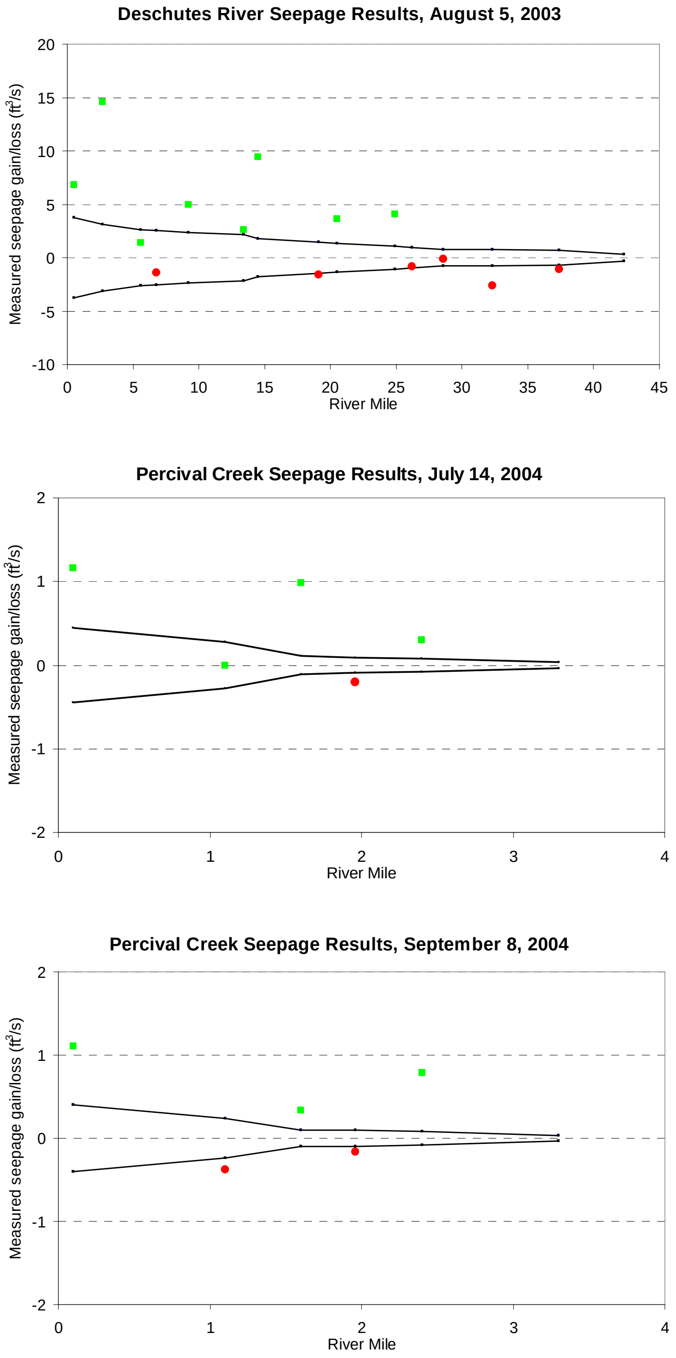

Figure A-1: Evaluation of uncertainty in estimated stream seepage results due to potential streamflow measurement error

Thermistor Calibration

The recording thermistors used during this study were tested for accuracy prior to use and again at the completion of field studies. The tests were conducted to ensure that all deployed thermistors met the manufacturer's design specifications throughout the range of water temperatures that were likely to be encountered during subsequent field deployments (Table A-4).

Table A-4: Thermistor model and manufacturer specifications

Thermistor model	Temperature range	Manufacturer reported accuracy	Manufacturer reported resolution
iButton™ Model DS1921L	-40°C to +85°C	± 1.0°C	0.5°C
Stow-away tidbit	-5°C to +37°C	± 0.2°C at +21°C	0.16°C
Stow-away tidbit	-20°C to +50°C	± 0.4°C at +21°C	0.3°C
Hobo pro	-20°C to +50°C	± 0.2°C at 0 to +50°C	0.02°C

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

Mean temperature values for each thermistor were calculated from the 10 paired-reference temperatures measured for each bath. The mean temperature values for each thermistor (one for the ice bath and one for the room-temperature bath) were then plotted against the mean reference temperature calculated for the NIST thermometer measurements. Noted temperature differences were then compared to the reported manufacturer specifications, for each thermistor type, to assess thermistor accuracy (Figure A-2).

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[9] National Institute of Standards and Technology

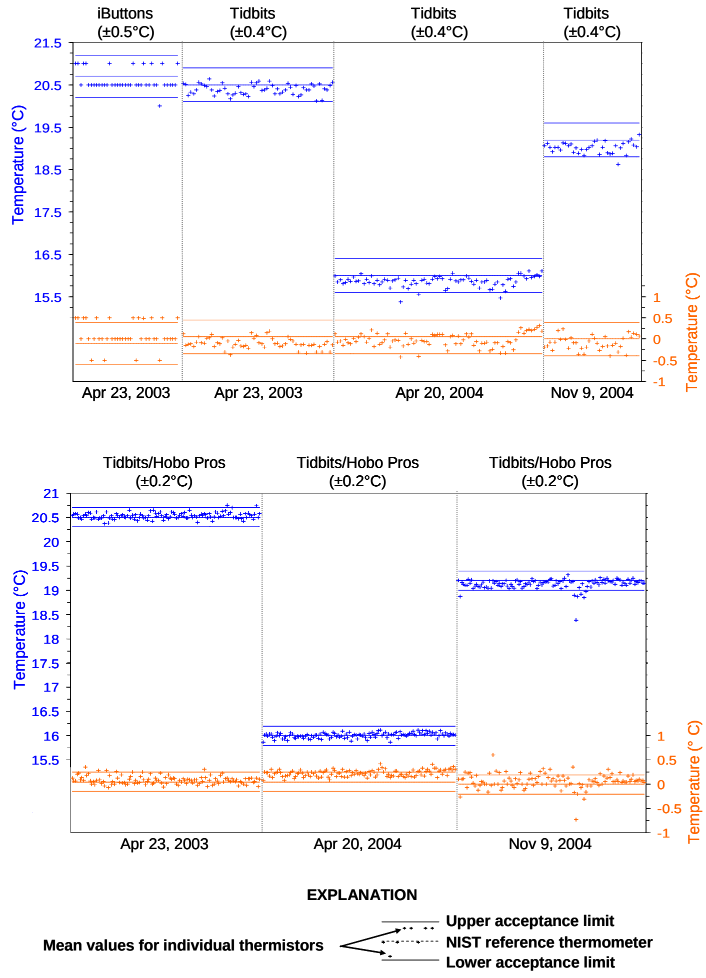

Figure A-2: Results of pre-deployment and post-deployment thermistor calibration checks for room-temperature and iced-water baths

Based on this evaluation, the average room-temperature values for most thermistors fell within the accuracy ranges specified by the manufacturer. The mean ice-bath temperature records were more variable, with roughly 2.4 percent of reported values falling outside of acceptance limits. Those thermistors that failed to meet warm-water acceptance requirements during pre-deployment testing were returned to the manufacturer for exchange. Those thermistors that met room-temperature calibration criteria but failed ice-bath criteria were still deployed since the primary period of interest for this study is the summer months when stream temperatures are well above freezing.

Those thermistors that failed post-deployment calibration tests were set aside and retested. Thermistors that met acceptance criteria during the second calibration test were deemed acceptable, and their temperature records were used without further qualification. The records for three thermistors that failed both the first and second post-deployment calibration tests were “J” coded[10] and used as best guess estimates during subsequent data analysis.

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[10] Temperature records are flagged with a J qualifier (i.e., 10.83J) to indicate the thermistor failed post-season calibration checks and that the reported value is an estimate.

Appendix B - Tabular Data Summaries

Most of the original field measurements and water quality data presented in this report are available in digital format via 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/ecyhome.html. The data for this project are maintained within EIM under the following study name and user study ID:

EIM study name: Deschutes River Watershed (WRIA 13), multi-parameter TMDL

EIM user study ID: MROB0001

To meet EIM data protocols, the continuous temperature records were summarized as daily maximum, minimum, and mean values before uploading to EIM. The continuous (30-minute interval) temperature records are available upon request.

Table B-1: Physical description and location of monitored wells and instream piezometers

Well I.D. Tag No.	Map ID [1]	Site Description	River Mile (miles)	Local Number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Site Altitude (feet)	Piezometer Stickup (feet above streambed)	Piezometer Depth (feet below streambed)	Depth to Midpoint of Piezometer Perforations [2] (dl) * (feet below streambed)	Thermistor Deployment Depths within Piezometer (feet below streambed)
Deschutes River Watershed											
AHT016	A	Deschutes R. at WEYCO 1000 Rd	37.4	15N/02E-12J	464756	1222908	550	3.1	3.9	3.65	1.2 2.4 3.7
AGJ753	B	Deschutes R. near Fennel Rd	33.5	16N/02E-34J	464941	1223151	465	3.1	3.9	3.65	0.6 2.2 3.8
AHT005	C	Deschutes R. at Old Camp Lane	32.3	16N/02E-34E	464952	1223242	453	2.7	4.3	4.05	1.1 2.4 4.1
AGJ758	D	Deschutes R. near Reichel Rd	30.3	16N/02E-29R	465019	1223427	435	3.4	3.6	3.35	0.8 2.1 3.3
AHT006	E	Deschutes R. at Vail Rd SE	28.6	16N/02E-30G	465039	1223603	408	2.4	4.6	4.35	0.7 1.7 4.5
AHT007	F	Deschutes R. at Vail Loop Rd	24.9	16N/01E-22P	465108 (well deepened on 11/3/03)	1224003	362	2.7 2.2	4.3 4.8	4.05 4.55	1.4 2.7 4.5
AGJ759	G	Deschutes R. near WEYCO 860 Rd	22.7	16N/01E-20H	465130	1224207	318	2.3	4.7	4.45	0.3 0.8 2.3 4.5
AHT008	H	Deschutes R. below SR 507	20.5	16N/01E-18F	465224	1224352	301	2.4	4.6	4.35	0.3 2.3 4.4
AHT009	I	Deschutes R. at Military Rd	19.1	16N/01W-40M	465252	1224504	288	1.6	3.4	3.15	0.8 1.8 3.1
AHT004	J	Deschutes R. at Bean Rd	17.4	16N/01W-02P	465352	1224624	274	3.3	3.7	3.45	0.5 1.9 3.5
AHT010	K	Deschutes R. at Waldrick Rd	14.5	17N/01W-33C	465515	1224832	228	1.5	3.5	3.25	0.5 1.8 3.0
AHT011	L	Deschutes R. off Cowlitz Drive	13.4	17N/01W-28M	465540	1224907	215	3.2	3.8	3.55	1.0 1.8 3.4
AGJ760	M	Deschutes R. near Nelson Ranch	12.1	17N/01W-29K	465541	1224952	200	3.5	3.5	3.25	0.4 1.1 2.3 3.3
AHT012	N	Deschutes R. above Spurgeon Ck confluence	9.2	17N/01W-19A	465700	1225052	175	2.8	4.2	3.95	0.6 2.2 3.8
AHT013	O	Deschutes R. near 84th Ave SE	6.8	17N/02E-13C	465759	1225236	158	3.2	3.8	3.55	0.8 1.8 3.5
AHT018	P	Deschutes R. above Ayer Ck confluence	5.6	17N/01W-07M	465830	1225145	138	2.6	4.4	4.15	0.9 2.3 3.9

Table B-1 (cont.)

Well I.D. Tag No.	Map ID[1]	Site Description	River Mile (miles)	Local Number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Site Altitude (feet)	Piezometer Stickup (feet above streambed)	Piezometer Depth (feet below streambed)	Depth to Midpoint of Piezometer Perforations[2] (dl) * (feet below streambed)	Thermistor Deployment Depths within Piezometer (feet below streambed)
Deschutes River Watershed (cont)											
											3.9
AHT014	Q	Deschutes R. at Henderson Boulevard	2.7	17N/02W-01C	465943	1225245	107	2.6	4.4	4.15	0.2 1.6 3.9
AHT015	R	Deschutes R. at E-St Bridge	0.5	18N/02W-60C	470042	1225407	85	2.9	2.1	1.85	0.5 1.1 2.0
AHT017	W	Domestic well off Stedman Rd	NA	17N/01W-33B	465525	1224836	230	3.2	26	unknown	12.4 15.4 18.4 21.4
		Note: This is a 26-foot deep domestic well located approximately 250 feet from the Deschutes River. The well construction information and thermistor depths for this well are referenced to ground surface, rather than the streambed									
Percival Creek Watershed											
AGJ761	S	Percival Ck. at 54th Ave SW	3.3	18N/02W-33R	470000	1225539	150	2.7	4.3	4.05	0.8 2.4 4.1
AGJ764	T	Percival Ck. at SPSCC	1.6	18N/02W-28H	470116	1225548	128	1.3	5.7	5.45	0.5 1.3 3.2 5.5
AGJ756	-	Percival Ck above Black Lk ditch confluence	1.2	18N/02W-21R	470138	1225554	95	2.8	2.2	1.95	NA
AGJ754	V	Percival Ck. near mouth	0.1	18N/02W-55K	470208	1225449	10	3.1	3.9	3.65	0.6 1.6 3.7
AGJ755	U	Black Lk. Ditch above Percival Ck. Confluence	0	18N/02W-21R	470138	1225555	95	2.3	2.7	2.45	0.6 1.5 2.7

* - Value used in Equation 2 to derive vertical hydraulic gradients

1 - See Plate 2, Figure 1 for a map of site locations

2 - All piezometers had a 0.5 foot long perforated interval to allow water entry. The perforations consisted of twelve 0.1875 inch diameter drilled holes.

Table B-2: Summary of monthly water level and water quality measurements made at piezometer sites within the Deschutes River and Percival Creek watersheds

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
AHT016	A	Deschutes R. at	7/9/03 10:55	14.6	-	86	-	1.99	1.99	0	0.000
		WEYCO 1000 Rd	8/4/03 10:35	15.0	15.8	82.3	85.6	2.13	2.11	-0.02	-0.005
			9/5/03 9:50	15.0	15.1	85.3	75.6	2.07	2.06	-0.01	-0.003
			10/9/03 10:20	10.6	12.2	80.7	73	1.53	1.52	-0.01	-0.003
			12/4/03 9:20	5.8	-	43.4	-	-	-	-	-
			2/10/04 10:10	4.3	8.5	58	-	1.13	1.23	0.1	0.027
			3/9/04 9:45	8.0	8.1	60	-	1.24	1.29	0.05	0.014
			4/6/04 11:00	8.0	8.6	-	-	1.49	1.62	0.13	0.036
			4/27/04 10:30	10.4	9.4	70.4	-	1.60	1.61	0.01	0.003
			5/25/04 10:20	11.8	11	80	-	1.88	1.90	0.02	0.005
			6/29/04 10:11	14.1	13.2	79	-	1.94	1.93	-0.01	-0.003
			7/28/04 9:55	16.2	16	88	-	2.05	2.05	0	0.000
			8/24/04 8:55	15.6	16.1	89	-	1.93	1.94	0.01	0.003
			9/29/04 10:10	11.7	12.2	71	-	1.81	1.80	-0.01	-0.003
AGJ753	B	Deschutes R.	4/27/04 15:00	12.2	9.6	81.3	96.8	2.28	2.21	-0.07	-0.019
		near Fennel Rd	5/25/04 11:42	14.1	11.2	96	-	0.23	0.15	-0.08	-0.022
			6/30/04 10:45	15.7	12.9	95	-	0.24	0.15	-0.09	-0.025
			7/27/04 13:00	20.4	15.2	116	-	0.38	0.29	-0.09	-0.025
			8/25/04 9:43	14.5	16.6	79	-	1.26	1.05	-0.21	-0.058
			9/29/04 11:31	12.1	14.5	86	-	2.16	2.00	-0.16	-0.044
			11/8/04 12:05	7.6	10.5	70	-	1.78	1.68	-0.1	-0.027
			12/29/04 10:12	5.0	-	73.3	-	1.80	1.69	-0.11	-0.030
			1/31/05 10:05	7.2	8	74.8	-	1.88	1.82	-0.06	-0.016
			3/14/05 9:55	7.3	7.6	96	-	0.17	0.14	-0.03	-0.008
			4/20/05 10:30	7.6	8	61	-	1.03	1.08	0.05	0.014
			8/18/05 10:55	16.7	15.4	117	-	0.23	0.18	-0.05	-0.014
			9/22/05 12:45	13.3	-	120.3	-	0.14	0.12	-0.015	-0.004
			10/21/05 10:30	11.1	-	102	-	1.97	1.93	-0.04	-0.011
			Extended monitoring data available for this well								
AHT005	C	Deschutes R. at	6/4/03 9:48	13.5	14.1	91	92	1.05	0.97	-0.08	-0.020
		Old Camp Lane	7/8/03 9:30	15.3	-	106	-	1.20	1.12	-0.08	-0.020
			8/4/03 12:20	17.6	18.5	110.6	110.9	1.30	1.22	-0.08	-0.020
			9/5/03 10:45	16.5	17.1	125.1	125.7	1.39	1.27	-0.12	-0.030
			10/9/03 11:55	11.7	13.3	96.8	111.3	0.98	0.84	-0.14	-0.035
			11/3/03 10:30	4.6	7.6	88.4	95.6	-	-	-	-
			12/4/03 9:52	5.8	-	46.9	-	-	-	-	-
			12/30/03 15:30	3.6	-	68	-	-	-	-	-
			2/10/04 10:50	4.6	-	64	-	-	-	-	-
			3/9/04 10:30	8.5	7.3	67	-	0.47	0.39	-0.08	-0.020
			4/6/04 11:30	8.6	8.6	-	-	0.80	0.73	-0.07	-0.017
			4/27/04 12:20	11.1	10.3	81.9	96.8	0.94	0.87	-0.07	-0.017
			5/25/04 12:30	14.8	12.8	96	-	1.11	1.04	-0.07	-0.017
			6/29/04 11:25	16.5	15.2	95	-	1.15	1.06	-0.09	-0.022
			7/28/04 10:40	17.4	18.6	116	-	1.29	1.21	-0.08	-0.020
			8/24/04 9:55	16.5	17.7	110	-	1.18	1.07	-0.11	-0.027
			9/29/04 11:55	12.3	12.9	87	-	1.07	0.95	-0.12	-0.030
AGJ758	D	Deschutes R.	4/29/04 13:00	12.4	11.2	86.7	117.2	1.81	1.82	0.01	0.003
		near Reichel Rd	5/25/04 14:20	15.9	12.3	98	-	2.03	2.03	0	0.000
			6/30/04 11:40	17.7	14.6	98	-	2.10	2.07	-0.03	-0.009
			7/28/04 11:40	19.8	18.5	117	-	0.22	0.15	-0.07	-0.021
			8/24/04 10:40	16.9	19.2	110	-	2.16	2.09	-0.07	-0.021
			9/29/04 13:10	12.7	-	89	-	1.99	1.92	-0.07	-0.021

Table B-2 (cont.)

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
AHT006	E	Deschutes R. at Vail Rd SE	6/3/03 13:22	15.6	10.6	100	180	-	0.90	-	0.013
			7/8/03 10:40	15.7	-	117	-	1.06	1.11	0.05	0.011
			8/4/03 13:15	17.4	10.8	116.6	168.7	1.22	1.27	0.05	0.011
			9/5/03 11:50	16.7	10.5	126.2	166.7	1.32	1.35	0.03	0.007
			10/9/03 13:20	12.1	10.5	102.2	167.2	0.75	0.77	0.02	0.005
			11/3/03 11:15	4.5	8.6	89.5	-	0.80	0.87	0.07	0.016
			12/4/03 10:15	5.6	9.7	50.3	-	1.54	1.60	0.06	0.014
			12/30/03 15:45	3.7	8.9	74	-	0.14	0.21	0.07	0.016
			2/10/04 11:10	4.7	8.7	72	-	2.02	2.10	0.08	0.018
			3/9/04 11:00	9.0	9.7	73		0.10	0.17	0.07	0.016
			4/6/04 12:05	9.2	9.6	-	-	0.45	0.56	0.11	0.025
			4/27/04 16:20	12.7	9.7	90.4	-	0.70	0.77	0.07	0.016
			5/25/04 13:31	15.3	10.2	105	-	0.91	0.98	0.07	0.016
			6/30/04 12:30	17.7	10.4	104	186	0.96	1.03	0.07	0.016
			7/28/04 12:20	19.1	10.7	122	185	1.12	1.19	0.07	0.016
			8/25/04 11:25	15.3	-	86	-	1.97	1.98	0.01	0.002
			8/30/04 10:05	15.5	11.2	93	187	0.75	0.82	0.07	0.016
			9/28/04 10:20	12.0	10.7	92	187	0.79	0.85	0.06	0.014
AHT007	F	Deschutes R. at Vail Loop Rd	6/4/03 11:55	13.9	9.7	106	88	0.71	0.89	0.18	0.044
			7/8/03 11:45	15.3	-	118	-	0.99	1.11	0.12	0.030
			8/4/03 14:30	16.1	11.1	116.6	93.6	1.15	1.22	0.07	0.017
			9/5/03 12:44	15.6	10.8	124	96.6	1.24	1.29	0.05	0.012
			10/9/03 14:30	12.0	10.7	115.1	102.4	0.70	0.71	0.01	0.002
			11/3/03 11:32	4.6	9	91.7	-	0.43	0.50	0.07	0.015
			12/5/03 10:35	7.3	8.4	54.6	-	0.94	1.11	0.17	0.037
			12/30/03 14:45	3.6	8.3	83.6	-	1.63	1.90	0.27	0.059
			2/10/04 11:35	5.0	8.2	79	-	1.32	1.70	0.38	0.084
			3/9/04 11:30	9.1	8.4	80	-	1.65	1.89	0.24	0.053
			4/6/04 12:35	9.1	8.5	-	-	2.05	2.24	0.19	0.042
			4/29/04 10:10	10.2	8.9	98.9	-	0.22	0.38	0.16	0.035
			5/25/04 15:00	14.8	9.6	110	-	0.42	0.54	0.12	0.026
			6/30/04 15:00	17.6	10.3	109	99	0.49	0.59	0.1	0.022
			7/28/04 13:46	18.8	11.2	126	102	0.71	0.77	0.06	0.013
			8/25/04 12:00	15.6	-	94	-	1.83	1.68	-0.15	-0.033
			8/30/04 11:23	15.7	12	99	108	0.33	0.40	0.07	0.015
			9/28/04 11:43	12.3	10.7	96	107	0.38	0.44	0.06	0.013
			11/8/04 13:30	7.6	9	82	-	0.01	0.09	0.08	0.018
			12/29/04 11:15	5.0	-	86.5	-	2.06	2.18	0.12	0.026
			1/13/05 10:50	7.7	8.2	92.4	-	1.90	2.16	0.26	0.057
			3/14/05 10:50	7.5	8.2	112	-	0.37	0.50	0.13	0.029
			4/20/05 11:20	8.1	8.3	74	-	1.22	1.52	0.3	0.066
			6/6/05 10:57	11.8	9.1	103	-	0.07	0.26	0.19	0.042
			8/18/05 11:43	16.1	10.8	130	-	0.59	0.67	0.08	0.018
			9/22/05 14:12	11.2	-	133.5	-	1.00	1.06	0.06	0.013
			10/21/05 12:10	11.4	10.1	118	-	0.79	0.81	0.02	0.004
			Extended monitoring data available for this well								
AGJ759	G	Deschutes R. near WEYCO 860 Rd	4/29/04 16:10	14.0	10.5	102	182.9	0.51	0.69	0.18	0.040
			5/25/04 15:45	15.8	9.9	115	184	0.70	0.85	0.15	0.034
			6/29/04 12:45	18.2	10	114	185	0.74	0.90	0.16	0.036
			7/27/04 14:20	20.3	9.9	152	188	0.93	1.08	0.15	0.034
			8/25/04 12:30	16.0	10	100	186	1.93	2.00	0.07	0.016
			8/30/04 12:48	17.1	10.2	102	185	0.58	0.73	0.15	0.034
			9/29/04 14:30	13.6	10	100	183	0.68	0.81	0.13	0.029

Table B-2 (cont.)

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
AHT008	H	Deschutes R. below SR 507	6/4/03 12:45	14.8	-	125	-	-	0.61	-	-
			7/8/03 12:35	16.0	-	144	-	0.89	0.85	-0.04	-0.009
			8/4/03 15:35	17.8	15.3	143.2	148	1.04	1.00	-0.04	-0.009
			9/5/03 13:40	18.0	14.2	152.4	-	1.01	0.95	-0.06	-0.014
			10/9/03 15:35	11.7	13	147.9	166.3	0.51	0.45	-0.06	-0.014
			11/3/03	4.6	10.5	104.5	174.2	0.62	0.63	0.01	0.002
			12/30/03 14:00	3.4	8.9	86	-	1.56	1.58	0.02	0.005
			2/10/04 12:15	5.9	8.9	79	-	1.29	1.34	0.05	0.011
			3/9/04 12:55	9.9	8.9	88	-	1.73	1.73	0	0.000
			4/6/04 13:05	9.5	9.3	-	-	0.11	0.15	0.04	0.009
			4/29/04 14:35	12.9	10.2	111.3	-	0.33	0.33	0	0.000
			5/26/04 10:00	13.8	11.5	127	-	0.54	0.50	-0.04	-0.009
			6/29/04 14:05	18.0	13.1	127	-	0.61	0.63	0.02	0.005
			7/27/04 15:30	20.2	15	149	-	0.79	0.78	-0.01	-0.002
			8/24/04 11:28	-	-	-	-	0.68	0.65	-0.03	-0.007
			9/27/04 15:27	13.2	13.3	106	-	0.51	0.45	-0.06	-0.014
AHT009	I	Deschutes R. at Military Rd	6/4/03 13:45	16.4	-	124	128	-	0.50	-	-
			7/8/03 13:30	16.7	-	142	-	0.69	0.69	0	0.000
			8/4/03 16:30	19.6	16.3	140.6	185.7	0.78	0.79	0.01	0.003
			9/4/03 9:45	15.9	15.1	167.3	-	0.85	0.86	0.01	0.003
			10/10/03 9:00	10.8	12.4	129.5	184	0.53	0.55	0.02	0.006
			11/3/03 12:40	4.9	9.4	104.2	-	0.52	0.55	0.03	0.010
			12/5/03 11:30	7.5	8.7	58.4	-	0.76	0.77	0.01	0.003
			12/30/03 13:20	3.6	7.7	86	-	1.65	1.65	0	0.000
			2/10/04 12:40	6.0	8.3	84	-	1.39	1.38	-0.01	-0.003
			3/9/04 13:20	10.1	9.5	88	-	1.65	1.67	0.02	0.006
			4/6/04 13:35	10.1	9.6	-	-	0.08	0.11	0.03	0.010
			4/28/04 16:50	13.5	10.3	111.5	-	0.33	0.35	0.02	0.006
			5/26/04 10:40	13.9	11.8	129	-	0.50	0.52	0.02	0.006
			6/29/04 14:40	19.3	13.5	125	-	0.60	0.58	-0.02	-0.006
			7/27/04 16:00	21.2	15.8	147	-	0.71	0.74	0.03	0.010
			8/19/04 15:50	-	-	-	-	0.77	0.78	0.01	0.003
			8/24/04 11:55	-	-	-	-	0.62	0.64	0.02	0.006
			9/28/04 13:45	13.3	13.4	109	133	0.47	0.48	0.01	0.003
AHT004	J	Deschutes R. at Bean Rd	5/27/04 11:00	13.1	12.7	113	210	2.07	2.07	0	0.000
			6/29/04 15:15	19.7	13.7	134	613	0.32	0.31	-0.01	-0.003
			7/29/04 10:25	17.4	15.2	151	-	0.47	0.45	-0.02	-0.006
			8/19/04 15:10	20.4	15.9	169	-	0.49	0.49	0	0.000
			9/27/04 14:45	13.5	13.1	114	-	0.26	0.23	-0.03	-0.009
AHT010	K	Deschutes R. at Waldrick Rd	6/4/03 15:35	17.8	13.4	136	168	0.63	0.63	0	0.000
			7/8/03 14:50	16.9	-	155	-	0.87	0.84	-0.03	-0.009
			8/5/03 9:05	14.7	17.1	153.8	136.8	1.01	0.98	-0.03	-0.009
			9/4/03 10:45	16.2	16.3	184.3	166.7	1.08	1.05	-0.03	-0.009
			10/10/03 9:50	10.8	12.6	150.2	174.6	0.77	0.70	-0.07	-0.022
			11/3/03	5.1	7.7	117.2	-	0.74	0.69	-0.05	-0.015
			12/5/03 12:10	7.6	8.5	65	-	1.28	1.36	0.08	0.025
			12/30/03 12:45	3.8	8.8	95	-	1.95	2.01	0.06	0.018
			2/10/04 13:10	6.4	8.6	92	-	1.77	1.77	0	0.000
			3/9/04 13:50	10.8	8.5	96	-	2.04	2.05	0.01	0.003
			4/6/04 14:00	10.9	9.2	-	-	0.33	0.35	0.02	0.006
			4/28/04 15:40	14.5	10.4	124	-	0.55	0.56	0.01	0.003

Table B-2 (cont.)

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
			5/25/04 16:55	16.3	12.8	139	-	0.74	0.72	-0.02	-0.006
			6/29/04 15:55	20.8	15.8	138	-	0.80	0.77	-0.03	-0.009
			7/27/04 10:17	17.6	18	161	-	0.96	0.90	-0.06	-0.018
			8/19/04 14:30	-	-	-	-	1.00	0.94	-0.06	-0.018
			8/24/04 14:36	17.3	18	136	-	0.83	0.79	-0.04	-0.012
			9/27/04 13:52	13.7	13.3	119	-	0.70	0.65	-0.05	-0.015
AHT011	L	Deschutes R. off Cowlitz Drive	6/5/03 9:48	14.7	12.3	137	147	2.08	2.12	0.04	0.011
			7/8/03 13:40	18.4	-	158	-	2.49	2.49	0	0.000
			7/8/03 15:45	17.3	-	153	-	2.42	2.42	0	0.000
			8/5/03 10:15	15.5	14.1	151.4	133.8	2.60	2.61	0.01	0.003
			9/4/03 11:45	18.0	13.9	170.7	157.3	2.67	2.70	0.03	0.008
			10/10/03 13:30	10.9	12.4	138.5	173	2.23	2.23	0	0.000
			12/30/03 12:00	3.8	8.4	95	-	1.20	1.19	-0.01	-0.003
			2/10/04 13:45	6.8	8.6	92	-	0.94	0.95	0.01	0.003
			3/9/04 14:20	11.0	8.5	96	-	1.27	1.29	0.02	0.006
			4/6/04 14:45	11.2	9.3	-	-	1.77	1.78	0.01	0.003
			4/26/04 15:45	15.7	9.9	118.9	-	2.02	2.04	0.02	0.006
			5/27/04 12:10	13.4	11.2	121	-	1.88	1.90	0.02	0.006
			6/29/04 16:30	21.1	12.7	138	-	0.35	0.37	0.02	0.006
			7/27/04 16:35	21.8	13.9	150	-	0.59	0.62	0.03	0.008
			8/24/04 14:00	17.4	14.6	135	-	0.41	0.44	0.03	0.008
			8/30/04 14:55	18.6	14.6	120	166	0.19	0.21	0.02	0.006
			9/27/04 13:10	12.9	12.8	118	-	0.22	0.24	0.02	0.006
AGJ760	M	Deschutes R. near Nelson Ranch	4/30/04 12:00	14.6	12.3	120.3	106.9	1.66	1.69	0.03	0.009
			6/2/04 12:45	14.6	10.1	93	118	1.42	1.47	0.05	0.015
			7/1/04 10:30	16.1	10.8	139	-	2.10	2.12	0.02	0.006
			7/29/04 11:25	18.3	11.6	160	-	0.15	0.16	0.01	0.003
			8/24/04 12:50	17.0	12.2	135	-	2.07	2.10	0.03	0.009
			9/30/04 13:05	13.7	13.1	123	-	2.00	2.05	0.05	0.015
AHT012	N	Deschutes R. above Spurgeon Ck. confluence	6/5/03 11:38	15.8	14.2	133	123	2.19	2.19	0	0.000
			7/9/03 12:50	16.6	-	148	-	2.58	2.54	-0.04	-0.010
			8/5/03 11:10	16.6	16.9	133.5	125.9	2.81	2.80	-0.01	-0.003
			9/4/03 14:20	18.1	15.8	167.9	160.2	2.93	2.94	0.01	0.003
			10/10/03 12:15	11.2	12.9	151.2	164.4	2.44	2.42	-0.02	-0.005
			11/3/03	5.2	9.2	116	129.1	0.27	0.26	-0.01	-0.003
			3/10/04 15:10	10.1	8.6	99	-	1.27	1.30	0.03	0.008
			4/6/04 15:15	10.9	9.5	-	-	1.78	1.80	0.02	0.005
			4/26/04 14:50	14.3	10.9	118.3	-	2.43	2.44	0.01	0.003
			5/26/04 11:45	14.0	13.1	133	-	0.33	0.34	0.01	0.003
			7/1/04 11:40	16.6	16.1	138	-	0.56	0.55	-0.01	-0.003
			7/29/04 12:14	19.4	18.2	154	-	0.79	-	-	-
			8/24/04 15:00	17.2	17.6	132	-	0.64	0.64	0	0.000
			9/27/04 12:06	12.2	13.1	118	-	0.42	0.42	0	0.000
AHT013	O	Deschutes R. near 84th Ave SE	6/5/03 13:45	17.3	15.7	131	132	-	1.45	-	-
			7/9/03 14:00	18.0	-	145	-	2.14	1.68	-0.46	-0.130
			8/5/03 13:30	17.5	17.7	-	-	2.30	1.85	-0.45	-0.127
			9/4/03 16:10	19.8	17.4	144.7	147.8	4.03	2.97	-1.06	-0.299
			10/10/03 14:45	12.0	12.5	152.9	166	2.19	1.61	-0.58	-0.163
			11/3/03 14:35	5.0	6.5	114.5	-	-	-	-	-
			2/10/04 14:20	6.7	7.3	94	-	1.19	0.40	-0.79	-0.223

Table B-2 (cont.)

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
			3/9/04 15:05	11.3	8.7	98	-	1.52	0.75	-0.77	-0.217
			4/6/04 17:05	11.1	9.6	-	-	1.90	1.18	-0.72	-0.203
			4/26/04 12:00	12.4	11.2	117.3	-	4.41	3.66	-0.75	-0.211
			5/26/04 12:20	14.4	13.6	131	-	2.33	1.62	-0.71	-0.200
			7/1/04 13:50	18.1	16.6	136	-	2.50	1.79	-0.71	-0.200
			7/29/04 13:40	21.2	18.8	149	-	2.69	1.97	-0.72	-0.203
			8/19/04 12:35	19.4	-	154	-	2.75	2.03	-0.72	-0.203
			9/27/04 11:11	12.3	13	117	-	2.58	1.62	-0.96	-0.270
AHT018	P	Deschutes R. above Ayer Ck	7/18/03 12:15	17.4	-	145	-	1.84	1.72	-0.12	-0.029
			8/5/03 12:15	17.4	18.4	131.3	135.1	1.94	1.82	-0.12	-0.029
			9/4/03 15:10	19.5	17.5	159	163.6	2.01	1.85	-0.16	-0.039
			10/10/03 13:35	11.8	13.3	158.4	166.3	1.59	1.54	-0.05	-0.012
			4/6/04 16:30	10.7	9.6	-	-	0.39	0.38	-0.01	-0.002
			4/30/04 15:17	18.2	15.2	113.4	-	1.15	1.14	-0.01	-0.002
			6/2/04 14:25	15.2	12.8	94	-	0.62	0.58	-0.04	-0.010
			7/1/04 12:30	17.9	16.7	135	-	1.64	1.60	-0.04	-0.010
			7/29/04 12:50	-	19.5	-	-	1.82	1.75	-0.07	-0.017
			8/19/04 13:40	-	-	-	-	1.92	1.84	-0.08	-0.019
			9/30/04 11:49	13.6	-	123	-	1.46	1.40	-0.06	-0.014
AHT014	Q	Deschutes R. at Henderson Boulevard	6/5/03 14:45	17.4	-	130	-	1.36	1.41	0.05	0.012
			7/9/03 15:01	17.9	-	139	-	1.69	1.73	0.04	0.010
			8/5/03 14:35	16.3	11.8	-	-	1.86	1.92	0.06	0.014
			9/4/03 16:55	18.3	12.1	135.9	158.3	1.95	2.02	0.07	0.017
			10/10/03 15:45	11.8	12	155.1	179.8	1.53	1.60	0.07	0.017
			11/3/03 15:00	6.2	11.7	116.2	156.4	-	-	-	-
			2/10/04 14:50	7.1	10.5	97	-	0.02	0.10	0.08	0.019
			3/9/04 15:43	11.3	9.9	103	-	0.39	0.46	0.07	0.017
			4/6/04 17:38	11.0	9.9	-	-	0.82	0.88	0.06	0.014
			4/26/04 13:30	13.5	10.1	119.5	-	1.41	1.45	0.04	0.010
			5/26/04 12:50	14.3	10.5	131	-	1.33	1.39	0.06	0.014
			6/30/04 16:30	19.0	11.2	133	179	1.50	1.58	0.08	0.019
			7/28/04 15:52	20.1	11.6	143	179	1.70	1.80	0.1	0.024
			8/30/04 16:10	17.7	12.1	120	175	1.33	1.39	0.06	0.014
			9/28/04 15:23	14.0	12.1	121	174	1.40	1.45	0.05	0.012
			11/10/04 15:10	9.0	11.6	112	170	1.09	1.14	0.05	0.012
			12/29/04 12:22	5.8	-	112.6	-	0.88	0.95	0.07	0.017
			1/31/05 11:41	8.6	-	113.8	-	0.73	0.80	0.07	0.017
			3/14/05 12:15	10.1	10.1	137	-	1.43	1.50	0.07	0.017
			4/20/05 12:40	10.3	10	90	-	1.99	2.08	0.09	0.022
			6/6/05 12:25	12.7	-	127	-	1.15	1.22	0.07	0.017
			8/18/05 13:35	16.7	11.7	152	-	1.69	1.78	0.09	0.022
			Extended monitoring data available for this well								
AHT015	R	Deschutes R. at E-St Bridge	6/5/03 15:50	18.2	14.2	130	189	1.53	1.51	-0.02	-0.011
			7/9/03 16:00	18.3	-	138	-	1.55	1.55	0	0.000
			8/5/03 15:45	16.6	-	-	-	1.80	1.79	-0.01	-0.005
			9/5/03 14:55	17.3	15.1	135.8	169.7	1.86	1.86	0	0.000
			10/10/03 16:30	12.1	12.4	157.9	191	1.42	1.43	0.01	0.005
			11/3/03 15:00	6.3	8.4	135.8	-	1.37	1.38	0.01	0.005
			12/5/03 13:30	7.5	9	73.4	-	0.10	0.11	0.01	0.005
			12/30/03 10:20	4.2	7.2	101	-	0.52	0.52	0	0.000
			2/10/04 15:25	7.2	8.7	98	-	0.35	0.38	0.03	0.016

Table B-2 (cont.)

Well Tag Number	Map ID [1]	Station Description	Sample Date and Time	Temperature (°C)		Specific Conductance µS/cm@25°C		Ground-water Level [2] (feet)	Stream Stage [3] (feet)	Head Difference (Stream stage - Groundwater level) (dh) * (feet)	Vertical Hydraulic Gradient [4] (i_v) (L/L)
				River	Ground water	River	Ground water				
			3/9/04 16:10	11.2	9.5	104	-	0.61	0.64	0.03	0.016
			4/6/04 18:12	11.2	10.1	-	-	0.94	0.95	0.01	0.005
			4/26/04 10:47	12.6	11.1	120.7	-	1.10	1.12	0.02	0.011
			5/26/04 13:23	14.4	12.6	130	-	1.33	1.36	0.03	0.016
			6/29/04 17:55	19.5	14.5	133	-	1.45	1.48	0.03	0.016
			7/27/04 17:40	20.4	15.6	143	-	1.62	1.64	0.02	0.011
			8/19/04 11:40	17.7	15.7	147	-	2.71	2.71	0	0.000
			9/27/04 10:10	12.4	12.9	122	-	1.32	1.35	0.03	0.016
AGJ761	S	Percival Ck. at 54th Ave SW	5/6/04 10:15	14.8	12.1	119	142.8	0.92	1.78	0.86	0.214
			5/26/04 13:48	18.2	11.7	112	-	0.70	1.45	0.75	0.187
			7/1/04 14:35	22.4	11.9	116	-	0.90	1.63	0.73	0.182
			7/29/04 14:30	25.7	12.2	119	-	1.04	1.67	0.63	0.157
			8/19/04 11:05	21.3	12	123	-	0.91	1.62	0.71	0.177
			9/27/04 16:35	15.9	12	127	-	0.57	1.17	0.6	0.150
AGJ764	T	Percival Ck. at SPSCC	5/27/04 14:00	13.8	10.5	116	180	0.08	0.66	0.58	0.106
			7/1/04 16:00	16.1	10.8	125	-	2.31	2.72	0.41	0.075
			7/29/04 16:00	18.7	11	128	-	0.33	0.63	0.3	0.055
			8/19/04 10:33	16.4	11.4	132	-	0.38	0.64	0.26	0.048
			9/30/04 9:11	12	11	128	-	0.24	0.6	0.36	0.066
AGJ756	-	Percival Ck above Black Lk ditch confluence	4/28/04 12:30	10.6	11.2	124.6	160.1	-	2.23	-	-
			5/26/04 14:45	14.1	12.4	123	-	4.27	4.26	-0.01	-0.005
			7/1/04 15:30	15.6	14	127	-	4.38	4.38	0	0.000
			7/29/04 15:25	18.1	15.5	128	-	4.38	4.41	0.03	0.015
			8/19/04 10:05	16.2	15.4	132	-	4.43	4.42	-0.01	-0.005
			9/30/04 9:59	12.1	12.7	130	-	2.42	2.42	0	0.000
AGJ754	V	Percival Ck. near mouth	4/28/04 9:50	11.8	10	100.9	154.8	2.08	2.19	0.11	0.029
			5/26/04 15:28	17.0	10	105	-	0.10	0.19	0.09	0.025
			6/30/04 18:00	20.8	11.6	112	149	0.21	0.31	0.1	0.027
			7/28/04 17:10	20.0	10.8	127	147	0.06	0.13	0.07	0.019
			8/24/04 15:46	16.7	11.5	135	-	2.07	2.17	0.1	0.027
			8/30/04 17:40	18.4	11.9	123	151	0.23	0.35	0.12	0.033
			9/8/04 13:45	15.9	11.6	122	141	0.20	0.33	0.13	0.036
			9/16/04 14:30	-	-	-	-	0.11	0.21	0.1	0.027
			9/28/04 16:55	15.7	11.8	131	152	0.00	0.10	0.1	0.027
AGJ755	U	Black Lk. ditch above Percival Ck confluence	4/28/04 11:40	13.5	12.6	93	262	1.14	1.15	0.01	0.004
			5/26/04 14:27	17.9	14.9	97	-	1.26	1.27	0.01	0.004
			7/1/04 15:15	20.7	17.1	106	-	1.37	1.40	0.03	0.012
			7/29/04 15:33	21.0	17.6	122	-	1.52	1.54	0.02	0.008
			8/19/04 9:45	16.2	15.5	159	-	1.66	1.68	0.02	0.008
			9/30/04 10:30	15.5	15.3	108	-	1.31	1.31	0	0.000

* Value used in Equation 2 to derive vertical hydraulic gradient. See Table B-1 for corresponding values of (dl)

[1] The listed map ID corresponds to the map ID's shown on Plate 1, Figure 1.

[2] The listed value represents the distance to groundwater, in feet, below the top of the piezometer casing.

[3] The listed value represents the distance to the stream surface, in feet, below the top of the piezometer casing.

[4] Negative values indicate potential loss of stream water to groundwater storage while positive values indicate potential groundwater discharge into the stream. See Equation 2 for a discussion of the gradient derivation.

Table B-3: Estimated unit area volumetric fluxes by river mile

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux ($ft^3/s/m^2$)	Unit Area Flux ($L/d/m^2$)
AHT016	A	37.4	7/9/2003	0.000	4.00E-05	0.0E+00	0.0
			8/4/2003	-0.005		-7.7E-06	-18.9
			9/5/2003	-0.003		-3.9E-06	-9.5
			10/9/2003	-0.003		-3.9E-06	-9.5
			2/10/2004	0.027		3.9E-05	94.7
			3/9/2004	0.014		1.9E-05	47.3
			4/6/2004	0.036		5.0E-05	123.1
			4/27/2004	0.003		3.9E-06	9.5
			5/25/2004	0.005		7.7E-06	18.9
			6/29/2004	-0.003		-3.9E-06	-9.5
			7/28/2004	0.000		0.0E+00	0.0
			8/24/2004	0.003		3.9E-06	9.5
			9/29/2004	-0.003		-3.9E-06	-9.5
AGJ753	B	33.5	4/27/2004	-0.019	4.50E-05	-3.0E-05	-74.6
			5/25/2004	-0.022		-3.5E-05	-85.2
			6/30/2004	-0.025		-3.9E-05	-95.9
			7/27/2004	-0.025		-3.9E-05	-95.9
			8/25/2004	-0.058		-9.1E-05	-223.7
			9/29/2004	-0.044		-7.0E-05	-170.4
			11/8/2004	-0.027		-4.4E-05	-106.5
			12/29/2004	-0.030		-4.8E-05	-117.2
AHT005	C	32.3	6/4/2003	-0.020	3.50E-04	-2.4E-04	-597.3
			7/8/2003	-0.020		-2.4E-04	-597.3
			8/4/2003	-0.020		-2.4E-04	-597.3
			9/5/2003	-0.030		-3.7E-04	-896.0
			10/9/2003	-0.035		-4.3E-04	-1045.3
			3/9/2004	-0.020		-2.4E-04	-597.3
			4/6/2004	-0.017		-2.1E-04	-522.7
			4/27/2004	-0.017		-2.1E-04	-522.7
			5/25/2004	-0.017		-2.1E-04	-522.7
			6/29/2004	-0.022		-2.7E-04	-672.0
			7/28/2004	-0.020		-2.4E-04	-597.3
			8/24/2004	-0.027		-3.4E-04	-821.3
			9/29/2004	-0.030		-3.7E-04	-896.0
AGJ758	D	30.3	4/29/2004	0.003	5.00E-05	5.3E-06	12.9
			5/25/2004	0.000		0.0E+00	0.0
			6/30/2004	-0.009		-1.6E-05	-38.7
			7/22/2004	-0.021		-3.7E-05	-90.3
			8/24/2004	-0.021		-3.7E-05	-90.3
			9/29/2004	-0.021		-3.7E-05	-90.3
AHT006	E	28.6	6/3/2003	0.013	4.20E-04	1.9E-04	459.8
			7/8/2003	0.011		1.7E-04	417.1
			8/4/2003	0.011		1.7E-04	417.1
			9/5/2003	0.007		1.0E-04	250.3
			10/9/2003	0.005		6.8E-05	166.8
			11/3/2003	0.016		2.4E-04	583.9
			12/4/2003	0.014		2.0E-04	500.5
			12/30/2003	0.016		2.4E-04	583.9

Table B-3 (cont.)

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux (ft^3/s/m^2)	Unit Area Flux (L/d/m^2)
			2/10/2004	0.018		2.7E-04	667.4
			3/9/2004	0.016		2.4E-04	583.9
			4/6/2004	0.025		3.8E-04	917.6
			4/24/2004	0.016		2.4E-04	583.9
			5/25/2004	0.016		2.4E-04	583.9
			6/30/2004	0.016		2.4E-04	583.9
			7/28/2004	0.016		2.4E-04	583.9
			8/25/2004	0.002		3.4E-05	83.4
			8/30/2004	0.016		2.4E-04	583.9
			9/28/2004	0.014		2.0E-04	500.5
AHT007	F	24.9	6/4/2003	0.044	2.25E-05	3.5E-05	86.4
			7/8/2003	0.030		2.4E-05	57.6
			8/4/2003	0.017		1.4E-05	33.6
			9/5/2003	0.012		9.8E-06	24.0
			10/9/2003	0.002		2.0E-06	4.8
			11/3/2003	0.017		1.4E-05	33.6
			12/5/2003	0.042		3.3E-05	81.6
			12/30/2003	0.067		5.3E-05	129.6
			2/10/2004	0.094		7.5E-05	182.4
			3/9/2004	0.059		4.7E-05	115.2
			4/6/2004	0.047		3.7E-05	91.2
			4/29/2004	0.040		3.1E-05	76.8
			5/25/2004	0.030		2.4E-05	57.6
			6/30/2004	0.025		2.0E-05	48.0
			7/28/2004	0.015		1.2E-05	28.8
			8/25/2004	-0.037		-2.9E-05	-72.0
			8/30/2004	0.017		1.4E-05	33.6
			9/28/2004	0.015		1.2E-05	28.8
			11/8/2004	0.020		1.6E-05	38.4
			12/29/2004	0.030		2.4E-05	57.6
AGJ759	G	22.7	4/29/2004	0.040	3.00E-04	4.3E-04	1048.4
			5/25/2004	0.034		3.6E-04	873.7
			6/29/2004	0.036		3.8E-04	932.0
			7/27/2004	0.034		3.6E-04	873.7
			8/25/2004	0.016		1.7E-04	407.7
			8/30/2004	0.034		3.6E-04	873.7
			9/29/2004	0.029		3.1E-04	757.2
AHT008	H	20.5	7/8/2003	-0.009	1.25E-04	-4.1E-05	-99.3
			8/4/2003	-0.009		-4.1E-05	-99.3
			9/5/2003	-0.014		-6.1E-05	-149.0
			10/9/2003	-0.014		-6.1E-05	-149.0
			11/3/2003	0.002		1.0E-05	24.8
			12/30/2003	0.005		2.0E-05	49.7
			2/10/2004	0.011		5.1E-05	124.1
			3/9/2004	0.000		0.0E+00	0.0
			4/6/2004	0.009		4.1E-05	99.3
			4/29/2004	0.000		0.0E+00	0.0
			5/26/2004	-0.009		-4.1E-05	-99.3
			6/29/2004	0.005		2.0E-05	49.7
			7/27/2004	-0.002		-1.0E-05	-24.8
			8/24/2004	-0.007		-3.0E-05	-74.5
			09/22/204	-0.014		-6.1E-05	-149.0

Table B-3 (cont.)

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux ($ft^3/s/m^2$)	Unit Area Flux ($L/d/m^2$)
AHT009	I	19.1	7/8/2003	0.000	2.75E-04	0.0E+00	0.0
			8/4/2003	0.003		3.1E-05	75.4
			9/4/2003	0.003		3.1E-05	75.4
			10/10/2003	0.006		6.2E-05	150.9
			11/3/2003	0.010		9.2E-05	226.3
			12/5/2003	0.003		3.1E-05	75.4
			12/30/2003	0.000		0.0E+00	0.0
			2/10/2004	-0.003		-3.1E-05	-75.4
			3/9/2004	0.006		6.2E-05	150.9
			4/6/2004	0.010		9.2E-05	226.3
			4/28/2004	0.006		6.2E-05	150.9
			5/26/2004	0.006		6.2E-05	150.9
			6/29/2004	-0.006		-6.2E-05	-150.9
			7/27/2004	0.010		9.2E-05	226.3
			8/19/2004	0.003		3.1E-05	75.4
			8/24/2004	0.006		6.2E-05	150.9
			9/28/2004	0.003		3.1E-05	75.4
AHT004	J	17.4	5/27/2004	0.000	1.80E-04	0.0E+00	0.0
			6/29/2004	-0.003		-1.8E-05	-45.1
			7/29/2004	-0.006		-3.7E-05	-90.2
			8/19/2004	0.000		0.0E+00	0.0
			9/27/2004	-0.009		-5.5E-05	-135.2
AHT010	K	14.5	6/4/2003	0.000	1.50E-04	0.0E+00	0.0
			7/8/2003	-0.009		-4.9E-05	-119.6
			8/5/2003	-0.009		-4.9E-05	-119.6
			9/4/2003	-0.009		-4.9E-05	-119.6
			10/10/2003	-0.022		-1.1E-04	-279.1
			11/3/2003	-0.015		-8.1E-05	-199.4
			12/5/2003	0.025		1.3E-04	319.0
			12/30/2003	0.018		9.8E-05	239.3
			2/10/2004	0.000		0.0E+00	0.0
			3/9/2004	0.003		1.6E-05	39.9
			4/6/2004	0.006		3.3E-05	79.8
			4/28/2004	0.003		1.6E-05	39.9
			5/25/2004	-0.006		-3.3E-05	-79.8
			6/29/2004	-0.009		-4.9E-05	-119.6
			7/27/2004	-0.018		-9.8E-05	-239.3
			8/19/2004	-0.018		-9.8E-05	-239.3
			8/24/2004	-0.012		-6.5E-05	-159.5
			9/27/2004	-0.015		-8.1E-05	-199.4
AHT011	L	13.4	6/5/2003	0.011	3.00E-04	1.2E-04	292.1
			7/8/2003	0.000		0.0E+00	0.0
			7/8/2003	0.000		0.0E+00	0.0
			8/5/2003	0.003		3.0E-05	73.0
			9/4/2003	0.008		9.0E-05	219.0
			10/10/2003	0.000		0.0E+00	0.0
			12/30/2003	-0.003		-3.0E-05	-73.0
			2/10/2004	0.003		3.0E-05	73.0

Table B-3 (cont.)

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux ($ft^3/s/m^2$)	Unit Area Flux ($L/d/m^2$)
			3/9/2004	0.006		6.0E-05	146.0
			4/6/2004	0.003		3.0E-05	73.0
			4/26/2004	0.006		6.0E-05	146.0
			5/27/2004	0.006		6.0E-05	146.0
			6/29/2004	0.006		6.0E-05	146.0
			7/27/2004	0.008		9.0E-05	219.0
			8/24/2004	0.008		9.0E-05	219.0
			8/30/2004	0.006		6.0E-05	146.0
			9/27/2004	0.006		6.0E-05	146.0
AHT012	N	9.2	6/5/2003	0.000	1.00E-05	0.0E+00	0.0
			7/9/2003	-0.010		-3.6E-06	-8.7
			8/5/2003	-0.003		-8.9E-07	-2.2
			9/4/2003	0.003		8.9E-07	2.2
			10/10/2003	-0.005		-1.8E-06	-4.4
			11/3/2003	-0.003		-8.9E-07	-2.2
			3/10/2004	0.008		2.7E-06	6.6
			4/6/2004	0.005		1.8E-06	4.4
			4/26/2004	0.003		8.9E-07	2.2
			5/26/2004	0.003		8.9E-07	2.2
			7/1/2004	-0.003		-8.9E-07	-2.2
			8/24/2004	0.000		0.0E+00	0.0
			9/27/2004	0.000		0.0E+00	0.0
AHT013	O	6.8	7/9/2003	-0.130	2.50E-05	-1.1E-04	-279.9
			8/5/2003	-0.127		-1.1E-04	-273.8
			9/4/2003	-0.299		-2.6E-04	-645.0
			10/10/2003	-0.163		-1.4E-04	-352.9
			2/10/2004	-0.223		-2.0E-04	-480.7
			3/9/2004	-0.217		-1.9E-04	-468.5
			4/6/2004	-0.203		-1.8E-04	-438.1
			4/26/2004	-0.211		-1.9E-04	-456.3
			5/26/2004	-0.200		-1.8E-04	-432.0
			7/1/2004	-0.200		-1.8E-04	-432.0
			7/29/2004	-0.203		-1.8E-04	-438.1
			8/19/2004	-0.203		-1.8E-04	-438.1
			9/27/2004	-0.270		-2.4E-04	-584.1
AHT018	P	5.6	7/18/2003	-0.029	2.00E-04	-2.0E-04	-499.7
			8/5/2003	-0.029		-2.0E-04	-499.7
			9/4/2003	-0.039		-2.7E-04	-666.2
			10/10/2003	-0.012		-8.5E-05	-208.2
			4/6/2004	-0.002		-1.7E-05	-41.6
			4/30/2004	-0.002		-1.7E-05	-41.6
			6/2/2004	-0.010		-6.8E-05	-166.6
			7/1/2004	-0.010		-6.8E-05	-166.6
			7/29/2004	-0.017		-1.2E-04	-291.5
			8/19/2004	-0.019		-1.4E-04	-333.1
			9/30/2004	-0.014		-1.0E-04	-249.8

Table B-3 (cont.)

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux ($ft^3/s/m^2$)	Unit Area Flux ($L/d/m^2$)
AHT014	Q	2.7	6/5/2003	0.012	3.00E-04	1.3E-04	312.3
			7/9/2003	0.010		1.0E-04	249.8
			8/5/2003	0.014		1.5E-04	374.7
			9/4/2003	0.017		1.8E-04	437.2
			10/10/2003	0.017		1.8E-04	437.2
			2/10/2004	0.019		2.0E-04	499.7
			3/9/2004	0.017		1.8E-04	437.2
			4/6/2004	0.014		1.5E-04	374.7
			4/26/2004	0.010		1.0E-04	249.8
			5/26/2004	0.014		1.5E-04	374.7
			6/30/2004	0.019		2.0E-04	499.7
			7/28/2004	0.024		2.6E-04	624.6
			8/30/2004	0.014		1.5E-04	374.7
			9/28/2004	0.012		1.3E-04	312.3
			11/10/2004	0.012		1.3E-04	312.3
			12/29/2004	0.017		1.8E-04	437.2
AHT015	R	0.5	6/5/2003	-0.011	2.00E-04	-7.6E-05	-186.8
			7/9/2003	0.000		0.0E+00	0.0
			8/5/2003	-0.005		-3.8E-05	-93.4
			9/5/2003	0.000		0.0E+00	0.0
			10/10/2003	0.005		3.8E-05	93.4
			11/3/2003	0.005		3.8E-05	93.4
			12/5/2003	0.005		3.8E-05	93.4
			12/30/2003	0.000		0.0E+00	0.0
			2/10/2004	0.016		1.1E-04	280.2
			3/9/2004	0.016		1.1E-04	280.2
			4/6/2004	0.005		3.8E-05	93.4
			4/26/2004	0.011		7.6E-05	186.8
			5/26/2004	0.016		1.1E-04	280.2
			6/29/2004	0.016		1.1E-04	280.2
			7/27/2004	0.011		7.6E-05	186.8
			8/19/2004	0.000		0.0E+00	0.0
			9/27/2004	0.016		1.1E-04	280.2

Table B-3 (cont.)

Well Tag Number	Map ID[1]	River Mile (miles)	Date	(Iv) Vertical Hydraulic Gradient (dimensionless)	(Kv) VS2DH Estimated Vertical Hydraulic Conductivity of Streambed Sediments (m/s)	Unit Area Flux (ft³/s/m²)	Unit Area Flux (L/d/m²)
Percival Ck Watershed							
AGJ761	S	3.3	5/26/2004	0.187	3.30E-05	2.2E-04	533.3
			7/1/2004	0.182		2.1E-04	519.0
			7/29/2004	0.157		1.8E-04	447.9
			8/19/2004	0.177		2.1E-04	504.8
			9/27/2004	0.150		1.7E-04	426.6
AGJ764	T	1.6	5/27/2004	0.106	5.50E-05	2.1E-04	505.7
			7/1/2004	0.075		1.5E-04	357.5
			7/29/2004	0.055		1.1E-04	261.6
			8/19/2004	0.048		9.3E-05	226.7
			9/30/2004	0.066		1.3E-04	313.9
AGJ754	V	0.1	4/28/2004	0.030	3.25E-04	3.5E-04	846.2
			5/26/2004	0.025		2.8E-04	692.4
			6/30/2004	0.027		3.1E-04	769.3
			7/28/2004	0.019		2.2E-04	538.5
			8/24/2004	0.027		3.1E-04	769.3
			8/30/2004	0.033		3.8E-04	923.2
			9/8/2004	0.036		4.1E-04	1000.1
			9/16/2004	0.027		3.1E-04	769.3
			9/28/2004	0.027		3.1E-04	769.3
AGJ755	U	0	4/28/2004	0.004	1.00E-04	1.4E-05	35.3
			5/26/2004	0.004		1.4E-05	35.3
			7/1/2004	0.012		4.3E-05	105.8
			7/29/2004	0.008		2.9E-05	70.5
			8/19/2004	0.008		2.9E-05	70.5
			9/30/2004	0.000		0.0E+00	0.0

[1] - See Plate 1, Figure 1 for a map of station locations

Appendix C - Extended Monitoring and Assessment of Inter-annual Temperature Variability

At the completion of scheduled field studies in fall 2004, three piezometers along the Deschutes River were left in place to assess potential inter-annual variability in stream temperature and streambed vertical hydraulic gradients. A shallow near-stream domestic well (AHT017) was also included to allow continued monitoring of regional groundwater temperatures (Plate 2, Figure 2W, and Plate 3).

The annual summary of the data is consistent with the gaining/losing conditions measured during the 2003-2004 study period. While the annual maximum daily temperature showed a consistent pattern between gaining reaches cooling the stream and a losing reach results in warmer water, the annual average daily stream temperature patterns deviated slightly from that pattern. Both of the two upper-watershed stations followed the same pattern of cooling between 2004 and 2005 while the station near the river mouth showed virtually no change in annual average stream temperature. Station 13DES02.7 is strongly gaining but showed no change in annual average temperature between 2004 and 2005 even though the annual maximum Dmax and annual maximum Dmin showed reductions in temperature. This suggests some other factor is strongly affecting stream temperature other than groundwater discharge alone.

The annual average stream temperatures for AHT007 for the year 2005 was cooler than 2004. A reduction in annual average stream temperature of 0.61ºC at AHT007 nearly matches the change in statewide average air temperature of 0.62ºC (Table C-1) for the same time period as reported by the Office of the Washington State Climatologist (OWSC). The cooler 2005 average stream temperature is opposite the global average temperature increase estimated by NASA as the warmest year for the global average air temperature (http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17166).

The year 2005 was also one of the five driest years on record (1968-2005) according to the OWSC (www.climate.washington.edu/ precip_rankings.html).

Monitoring stations for stream temperature have a naming convention of 13DES (WRIA number and stream abbreviation) with a suffix of the river mile. This naming convention is used to refer to all stream and air temperature stations in Ecology's EIM database and the project database. Instream thermistors were usually attached directly to the piezometers or within a 10-foot radius of the piezometer location.

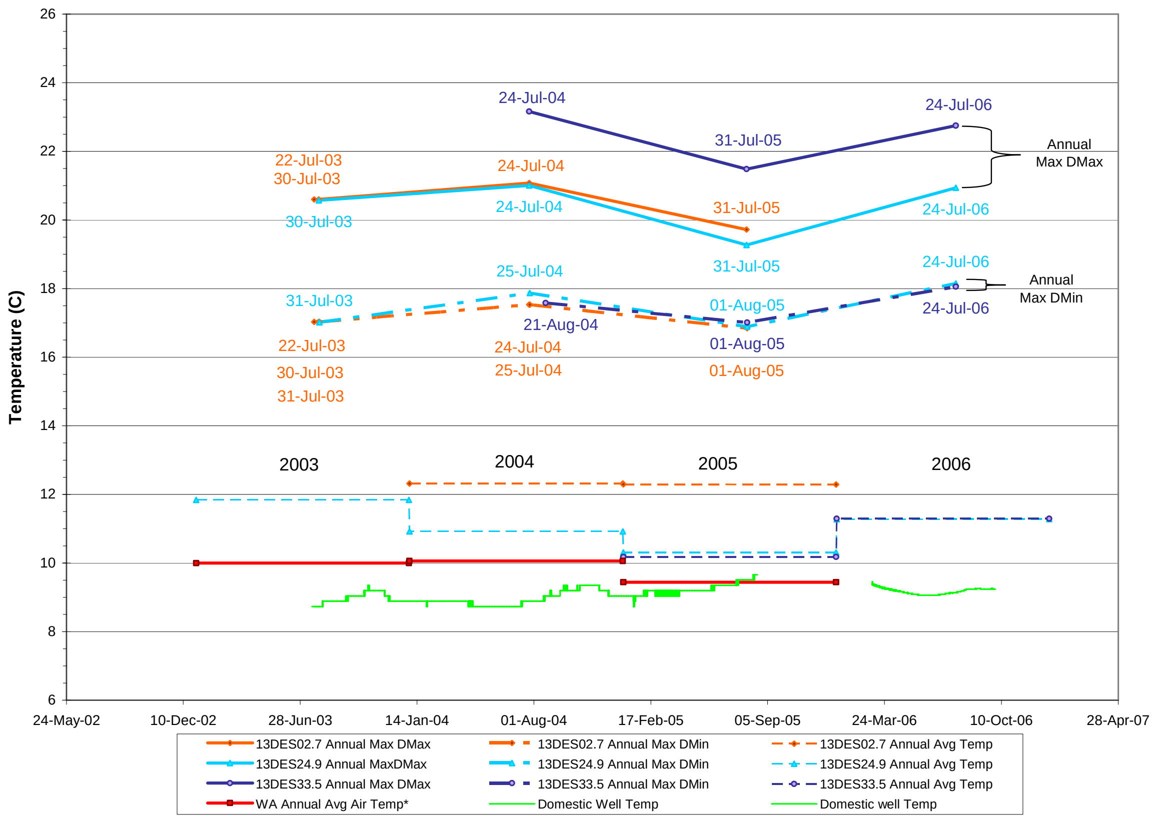
Figure C-1 graphically depicts the summary statistics for these sites. Annual maximum daily maximum temperatures (Max Dmax) and annual maximum daily minimum temperatures (Max Dmin) were derived for the beginning year of the 2003-2004 study period. Even though data collection began in the spring, the Max DMax and Max Dmin temperatures during the initial study year most likely occurred during the summer and therefore are included in this discussion. The average annual stream temperature was only calculated for data sets where the entire year had data measurements. This was to avoid biasing the first monitoring year since data collection typically did not start until the end of spring.

The annual average temperature for 2006 was calculated for the two remaining stations but does not include fall and winter data collected during the writing of this report. Nevertheless, the difference in annual average stream temperature for calendar years 2005 and 2006 between both stations is within the instrument measurement accuracy (0.13º and 0.01ºC).

When comparing the daily temperature range (Dmax minus Dmin), the summer stream temperature ranges are larger for the losing station AGJ753 than the daily temperature range for the other two gaining stations (Figure C-2). Because a gaining reach has an influx of cool groundwater to reduce stream temperatures, it is not surprising that the losing reach has a larger daily stream temperature range and a warmer Dmax. The daily temperature range is very similar for all three stations during the winter months.

Table C-1: Annual statistics for stream temperature. Annual average temperature was not calculated for 2003, the first year of data collection

Location ID	Year	Annual Max Dmax Temperature (ºC)	Date of Max Dmax	Annual Max Dmin Temperature (ºC)	Date of Max Dmin	Annual Average Temperature (ºC)
13DES02.7 (Q)	2003	20.60	7/22/03 7/30/03	17.03	7/22/03 7/30/03 7/31/03	not enough data
	2004	21.08	7/24/04	17.53	7/24/04 7/25/04	12.32
	2005	19.72	7/31/05	16.84	8/1/05	12.29
13DES24.9 (F)	2003	20.57	7/30/03	17.02	7/31/03	not enough data
	2004	21.01	7/24/04	17.87	7/25/04	10.92
	2005	19.27	7/31/05	16.89	8/01/05	10.31
	2006	20.94	7/24/06	18.15	7/24/06	11.28
13DES33.5 (B)	2004	23.16	7/24/04	17.58	8/21/04	10.18
	2005	21.49	7/31/05	17.01	8/01/05	11.29
	2006	22.75	7/24/06	18.06	7/24/06	11.29
WA Air Temp	2003					10.00
	2004					10.06
	2005					9.44



*Data Source for Annual Statewide Average Air Temperature: http://www.ncdc.noaa.gov/oa/climate/research/cag3/wa.html

Figure C-1: Annual Summary for Deschutes River extended stream temperature monitoring stations. Each station is represented by a different color

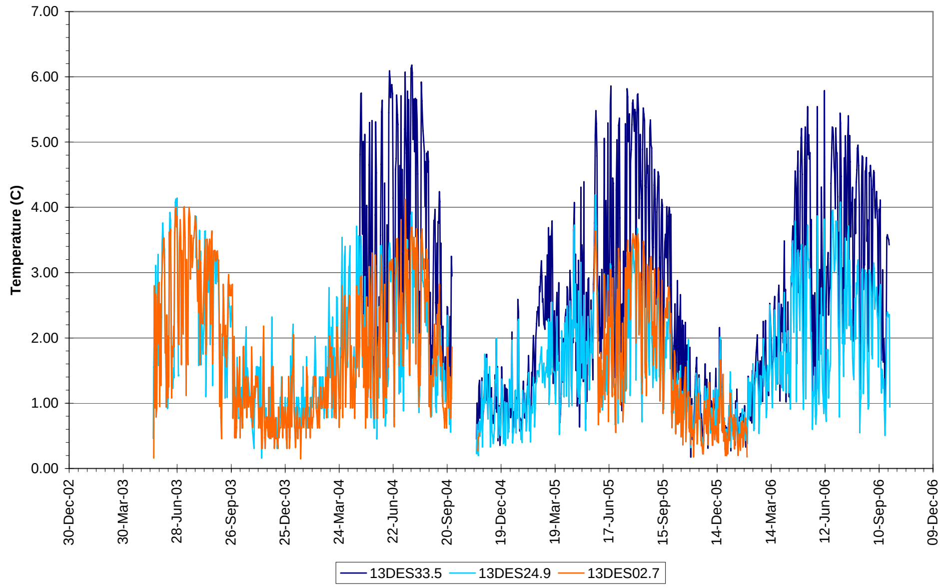


Figure C-2: Daily temperature range for Deschutes River extended stream temperature monitoring stations

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