Surface Water/Groundwater Exchange Along the East Fork Lewis River (Clark County), 2005

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Cover photo: East Fork Lewis River near La Center (by Dustin Bilhimer).

Surface Water/Groundwater Exchange Along the East Fork Lewis River (Clark County), 2005

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Abstract

The purpose of the study was to provide information on groundwater inflow and outflow along the East Fork Lewis River. This information will be used for a temperature model needed to complete a Total Maximum Daily Load analysis.

Methods used to estimate groundwater inflow and outflow along the river included (1) seepage surveys (surface water discharge balances), (2) vertical hydraulic gradient measurements, and (3) continuous streambed temperature measurements from instream piezometers. The seepage survey was the most comprehensive method used and provided broad-scale measurements. Vertical hydraulic gradients and streambed thermal profiles measured in the lower river provided localized indications of groundwater flow direction. All monitoring activities were conducted in the summer of 2005.

Seepage surveys consisted of two, one-day flow analyses of the lower 32 miles of the East Fork Lewis River. The river was divided into 11 reaches of 0.8-5.6 miles. Streamflow measurements were taken at the upper and lower end of each reach and at the mouth of each major tributary. Because results of the August survey were more representative of baseflow conditions than results from July, analyses are primarily based on August data. Four reaches showed net streamflow gains, and two reaches showed net streamflow losses. No measurable change was seen in five reaches. However, gains and losses below the 7% error in comparative streamflow measurements could not be discerned. The total of streamflow gains was 64 cfs; total of streamflow losses was 18 cfs.

Hyporheic temperature measurements indicated gaining conditions at four downstream sites. Temperature of inflowing groundwater ranged from 10.6º to 12.5°C.

Groundwater temperatures were lower than surface water temperatures except at the most downstream site (river mile 1.8), where warmer, tidally influenced surface water was seeping into groundwater.

Public supply wells withdraw substantial amounts of water from the main aquifer supplying baseflow to the East Fork Lewis River. These withdrawals, which are increasing in some areas, may be changing groundwater flow to the river.

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Introduction

The East Fork Lewis River has been listed as impaired for temperature and fecal coliform bacteria since 1996, based on Section 303(d) provisions of the federal Clean Water Act (Figure 1). Washington State is required to conduct a Total Maximum Daily Load (TMDL) analysis on each 303(d)-listed waterbody. The TMDL is designed to locate and quantify sources of impairment and to develop recommendations for bringing the waterbody into compliance with water quality standards by reducing the loading of pollutants from point and nonpoint sources.

The Washington State Department of Ecology (Ecology) Environmental Assessment Program began TMDL field studies on the East Fork Lewis River and its tributaries in 2005. Surveys conducted from 2005-2006 included evaluations of streamflow, groundwater-surface water interactions, stream temperature, groundwater temperature, fecal coliform bacteria, and environmental conditions.

This report describes the groundwater portion of the TMDL studies. This report also provides input for a one-dimensional, basin-wide predictive model to aid in allocating pollutant loads (Bilhimer et al., 2005).

Purpose

The purposes of the groundwater assessment were to:

- Gather and interpret evidence of groundwater inflow and outflow along the East Fork Lewis River (timing and direction of flow).
- Estimate the temperature of groundwater, where evidence indicates groundwater inflow to the river.

Methods used to identify gaining (groundwater inflow to the river) and losing (streamflow loss to groundwater) reaches of the river include:

- Review of existing geologic and hydrologic information.
- Seepage surveys.
- Vertical hydraulic gradient measurements.
- Hyporheic (below the streambed) temperature measurements.

Previous Investigations

We used several geologic and hydrologic reports related to the East Fork Lewis River watershed and surrounding areas to plan the study and interpret results.

Current interpretations build on the works of Trimble (1963) that focused on the Portland, Oregon area and Mundorff (1964) that focused on Clark County, Washington. Swanson et al. (1993) provided the first basin-wide groundwater study of the Portland-Vancouver area.

McFarland and Morgan (1996) described and quantified groundwater hydrology of the Portland Basin to enable planning for future water resources allocation. Morgan and McFarland (1996) used the flow system description above to develop a conceptual model of the basin for a groundwater flow model.

Howard (2002) and Evarts (2004) updated and refined geologic mapping and interpretations of the Battle Ground and Ridgefield Quadrangles.

Pacific Groundwater Group (PGG) (2003) conducted an assessment of the hydraulic connection between the regional groundwater system and the East Fork Lewis River as well as potential impacts of future local groundwater withdrawals.

Study Area Description

The East Fork Lewis River watershed lies predominantly in northern Clark County, Washington about 20 miles north of Portland, Oregon (Figure 1). The watershed is located in the northern part of the Portland Basin (or Willamette-Puget Trough), a structural depression that includes the Portland area and east to the Cascade Range (Evarts, 2004). The East Fork Lewis River originates in the Cascade Mountains and flows west to its confluence with the North Fork Lewis River west of La Center, Washington. The basin is located in Water Resources Inventory Area (WRIA) 27.

The study area includes the East Fork Lewis River below the boundary of the Gifford Pinchot National Forest and Skamania County from River Mile (RM) 32.3 to RM 1.8 as well as the surrounding area that affects groundwater interactions with the river. The upper, eastern half of the watershed consists of steep, forested foothills. The Cascade Mountains reach elevations of 4,000 feet in this area. The upper river is confined by a steep, bedrock-lined channel with limited unconsolidated streambed material. Yacolt and Rock (South) Creeks are the major tributaries in the upper basin.

The lower river basin forms a south-sloping bench dissected by the East Fork Lewis River and its floodplain. Land use is mainly rural residential, agricultural, and forest. Ponds associated with the Storedahl Gravel Operation are located near RM 8. Several gravel pit ponds in the floodplain of the river have become part of the river as a result of avulsions in 1995-1996 (Norman et al., 1998). A one-mile reach of the river channel has moved southward, slowed, and deepened.

Local climate is temperate with warm, dry summers and cool, wet winters. Annual precipitation ranges from 40 inches/year near the mouth of the river to 120 inches/year at the upper end of the watershed (Figure 1).

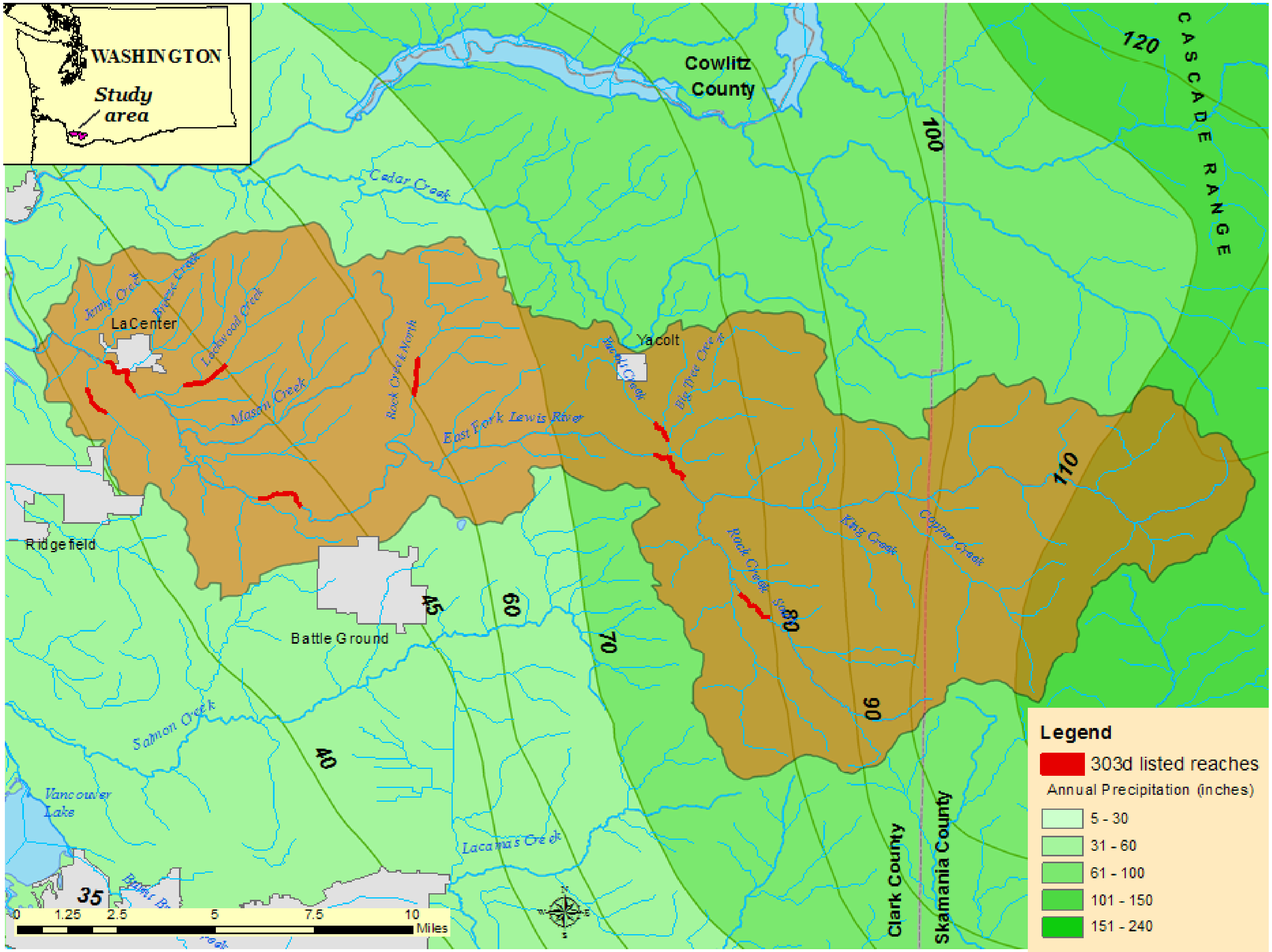

Figure 1. Location and general features of the East Fork Lewis River basin and location of 303(d) listed reaches. Average annual precipitation contours from Miller et al. (1973).

Streamflow

The U.S. Geological Survey (USGS) has operated a stream gaging station at RM 20.4 on the East Fork Lewis River for over 80 years (Station Number 14222500). The mean annual discharge from October 1929 through September 2008 is 734 cfs (USGS, 2009). Mean monthly streamflow was slightly higher than the long-term record in June and July 2005 and lower than the long-term mean in August, September, and October 2005 (Figure 2).

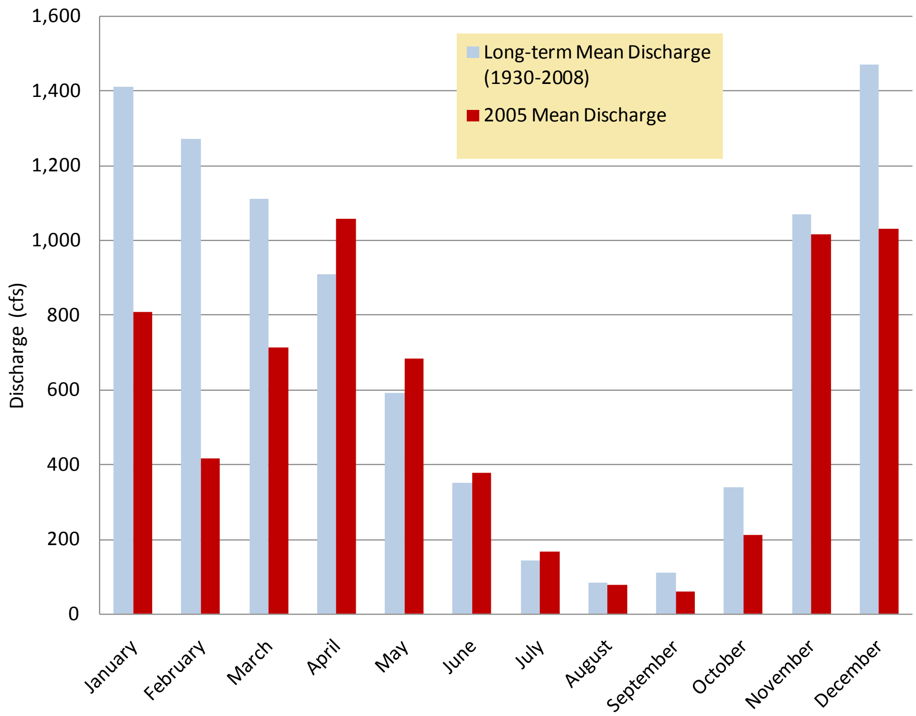

Figure 2. Monthly average streamflow (cfs) at USGS Station No. 14222500 East Fork Lewis River near Heisson Road.

Geologic Setting

The geology of the East Fork Lewis River consists of four main rock types: Paleogene bedrock, Miocene lava flows of the Columbia River Basalt Group, Miocene to Pliocene alluvial sedimentary rocks (Troutdale Formation and Sandy River Mudstone), and Quaternary deposits (Evarts (2004), PGG (2003), Howard (2002), and McFarland and Morgan (1996)).

Bedrock is composed of andesitic lava flows and volcanic rocks which folded, faulted, and eroded to form the Portland Basin. Large flood-basalt flows of the Columbia River Basalt Group later covered the region. Fluvial deposits from the ancestral Columbia River then covered the basalt flows forming the Sandy River Mudstone/ Troutdale Formations (Mundorff, 1964 and Trimble, 1963). In recent times, sea level fluctuations, glaciations, recent basalt eruptions, and cataclysmic Lake Missoula flooding have shaped the East Fork Lewis River basin. Figure 3 shows the local surficial aquifer units.

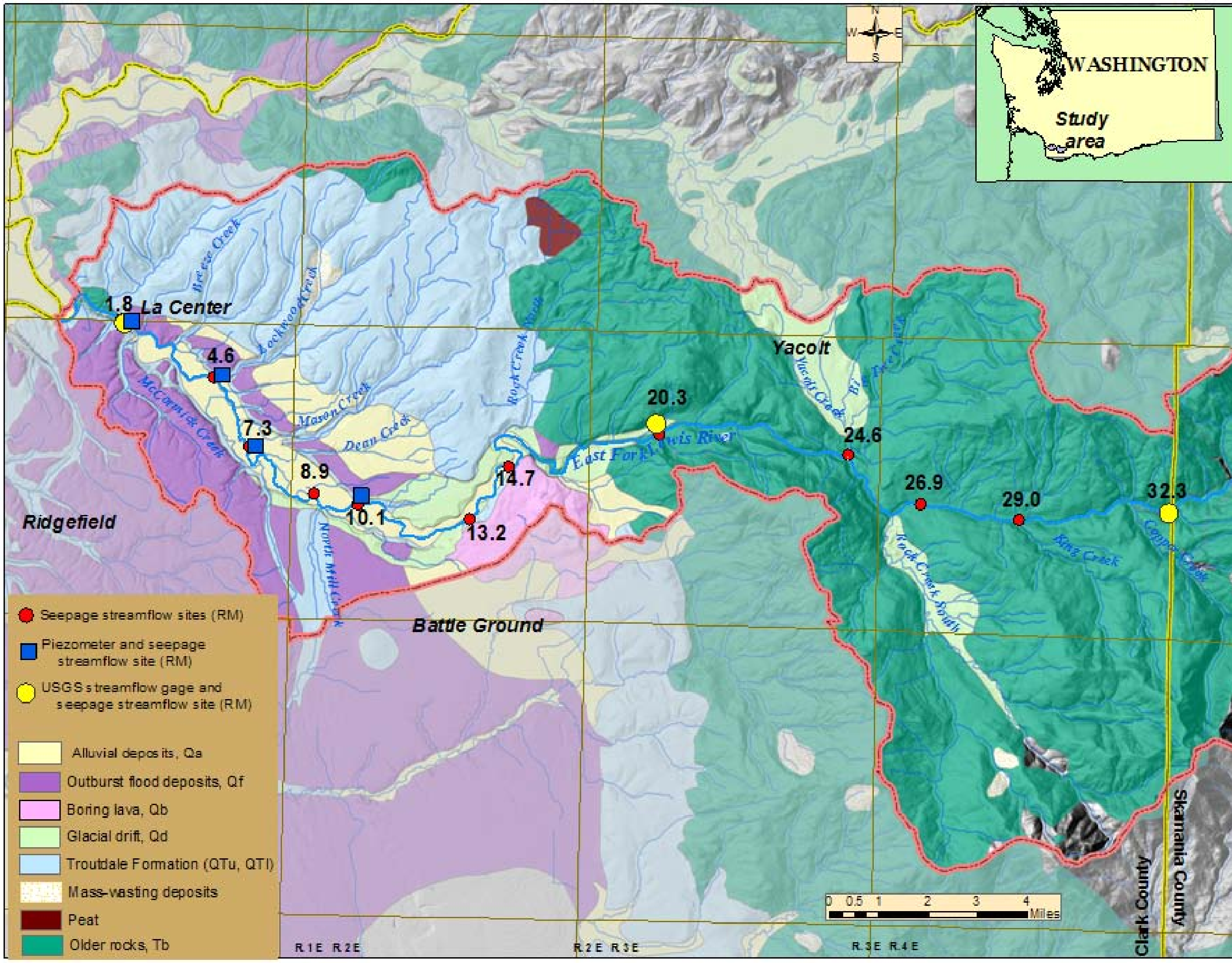

Figure 3. Surficial geology of the East Fork Lewis River study area and locations of USGS streamflow gages, seepage streamflow sites, and piezometers (Washington State Department of Natural Resources, 2005).

The upper part of the East Fork Lewis River basin is mostly consolidated bedrock of volcanic origin (RM 20-32). Groundwater flow in the upper basin is therefore mainly through fractures in the basaltic or andesitic rock. Fracture flow through these formations is usually limited depending on the degree of fracturing. Below RM 20, the East Fork Lewis River cuts through consolidated and unconsolidated units and receives groundwater flow mostly from the deeper Sand and Gravel Aquifer. (This aquifer is also called Sandy River Mudstone or Fine-grained Member of the Troutdale Formation).

Hydrogeologic Units

The study area geologic units have been grouped by previous investigators into hydrogeologic units in the East Fork Lewis basin based on their water development potential (Evarts, 2004; PGG, 2003; Howard, 2002; and McFarland and Morgan, 1996). The units are listed below with details summarized in Table 1.

The surficial unconsolidated units in the area include:

- Alluvial deposits (Qa) along the streams and floodplains of the East Fork Lewis River.
- Fine-grained cataclysmic flood deposits (Qf) south of the lower river, thinning out north of the river.
- Terrace deposits (Qt) on the north side of the river between RM 14 and RM 10.5.
- Glacial drift covering the area from Yacolt to Daybreak Park (RM 10.1).

The consolidated hydrogeologic units include the Basalt of Battle Ground (boring lava) south and east of the East Fork Lewis River near RM 12-17 and the Troutdale Formation. The thick Troutdale Formation has been subdivided into upper and lower members with two confining zones (QTu-Upper Troutdale and QTl-Lower Troutdale). The QTu is a partially cemented gravel unit but is not present in the study area. The intermediate sand and gravel unit (QTl) between the first and second confining layers is also absent in the study area with the exception of the Battle Ground and Pioneer areas south of the East Fork Lewis River (PGG, 2003). Only the second confining unit is found in the study area (PGG, 2003). The river cuts through the second confining layer at RM 12 and 14. The second confining layer is absent at RM 5.

The main groundwater connection to the East Fork Lewis River is the thick Sand and Gravel Aquifer, which lies below the second confining layer of the Lower Troutdale (PGG, 2003). Evarts (2004) refers to this layer as Sandy River Mudstone. PGG (2003) estimated that groundwater discharge from the deeper aquifers to the East Fork Lewis River channel and floodplain is at least four times the discharge from shallower aquifers via tributaries.

The Skamania Volcanics below the Sand and Gravel Aquifer underlie the East Fork Lewis River basin. Typically these rocks yield little water to wells and are not considered a significant aquifer locally.

Table 1. Geologic units underlying the East Fork Lewis River basin and their hydrogeologic characteristics.

Period	Epoch	Geologic Unit[1]	Unit Symbol	Hydro-geologic Unit	Hydrogeologic Unit Characteristics[1]
Quaternary	Holocene	Alluvial deposits	Qa	Unit 1	Loose bouldery cobble gravel of volcanic origin along streams. Underlies terraces up to 18 feet above the East Fork Lewis River. Thickness reported up to 27 feet. Alluvium of smaller streams contains silt, sand, and gravel reworked from older sedimentary units.
	Pleistocene	Cataclysmic flood deposits	Qf	Unit 2	Fine-grained sand to silty fine sand deposited by floodwaters of glacial Lake Missoula about 13,000 years ago. Thickness ranges from 0 to 150 feet and roughly 40 feet near RM 10 (Daybreak Park).
		Unconformity			
		Terrace deposits	Qt	Unit 3	Poorly sorted, unconsolidated boulder-cobble gravel in RM 8-20 portion of study area. Thickness 80-100 feet. Derived from Skamania volcanics (Tb). Shown in Howard (2002). Combined with glacial drift in Figure 3.
		Unconformity			
		Boring lava	Qb	Unit 4	Basalt flows and scoria cinder cones referred to in this area as the Basalt of Battle Ground. Vesicular flows to highly vesicular scoria. This may be a moderately productive aquifer. Basalt flows up to 130 feet thick; scoria cones up to 200 feet. Exposed in bluffs on the south side of the East Fork Lewis River.
		Glacial drift	Qd	Unit 5	Glacial till with boulders exposed at the surface. Pebble gravel in some areas. Thickness at least 100 feet along the East Fork Lewis River near the mouth of Rock Creek (North).
Quaternary and/or Tertiary	Pleistocene and/or Pliocene	Upper Troutdale	QTu	Unit 6	Upper Troutdale (QTu) corresponds to Howard's (2002) Troutdale alluvial fan and volcanic clast members (QTta and QTtv) and Evart's (2004) conglomerate (QTc). Alluvial fan is consolidated, massive, well-sorted sandy cobble and pebble gravel. Volcanic clast consists of moderately consolidated pebble and cobble gravel. Thickness of each unit is 100 feet or more in Battle Ground area. Lower Troutdale corresponds to Howard's (2002) quartzite clast member (QTtq) and Evart's (2004) Troutdale Formation (Ttf). Well-sorted sandy pebble gravel and sand. Thickness up to 150 feet. Both units function as aquifers. Qc1 and Qc2 are confining layers that act as aquitards, but only Qc2 is found in the study area.
		Unconformity	Qc1		
		Lower Troutdale	QTl		
Tertiary	Pliocene and/or Miocene	Unconformity	Qc2		

Period	Epoch	Geologic Unit[1]	Unit Symbol	Hydro-geologic Unit	Hydrogeologic Unit Characteristics[1]
	Miocene	Sandy River Mudstone	Tsr	Unit 7	Fine-grained sandstone, siltstone, claystone, and minor pebble conglomerate (Evarts, 2004). Forms a major aquifer for the East Fork Lewis River. Thickness 200- 400 feet. Referred to as Qsg (Sand and Gravel Aquifer) in PGG (2003). Howard (2002) refers to this as Fine-Grained Member Of Troutdale Formation.
	Paleogene	Older rocks	Tb	Unit 8	Heterogeneous sequence of rocks formed by volcanic lava flows. Referred to as Skamania Volcanics by Howard (2002) and Eocene Rocks by Evarts (2004). Not used as an aquifer in the study area, but produces several hundred gallons/minute in a municipal well south of the study area (PGG, 2003).

[1] Units and characteristics from Evarts (2004), PGG (2003), Howard (2002), Swanson et al. (1993), and Mundorff (1964).

Groundwater Withdrawal Effects

Effects of groundwater withdrawals in the Portland Basin have been documented since 1988, when McFarland and Morgan (1996) found groundwater level declines of 10 feet in the 39-year period between 1949 and 1988. They concluded that recorded water-level declines in a widespread area between the East Fork Lewis River and Salmon Creek (south of the study area) may be due to increased local groundwater use. Because groundwater and surface water are connected, groundwater level declines typically translate into reduced groundwater inflow to rivers. This is especially problematic in the summer, when most of the streamflow in Washington rivers is from groundwater (Pitz and Sinclair, 1999).

A test of the model comparing predevelopment conditions with 1988 water levels indicated a decline of 10-30 feet in the same locations in the aquifer, with the largest declines near the city of Battle Ground. The similarity between the projected water level decline since development began and the measured decline since 1949 indicate that the model results are reasonable.

Morgan and McFarland (1996) projected a further decline in the Sand and Gravel Aquifer of 10 feet in the lower basin of the East Fork Lewis River by 2010. This further decline would tend to reduce summer/fall baseflow and contribute to warming in the river.

Local water use

Municipal well production near the East Fork Lewis River has increased substantially since 1988, especially in the past 13 years. PGG (2003) estimated that public water supply wells capture roughly 3.2 cfs from the East Fork Lewis River, mostly in the City of Battle Ground but also possibly from Clark Public Utility’s Pioneer Well. Three of Battle Ground’s deep wells withdraw from the Sand and Gravel Aquifer and probably capture flow from both the East Fork Lewis River (or groundwater that would have flowed to the river) and Salmon Creek south of the East Fork Lewis River drainage basin.

Water levels in the Sand and Gravel Aquifer near Battle Ground declined 7-8 feet from 1999 to 2003 due to increased withdrawals (PGG, 2003). These withdrawals probably induce capture from the East Fork Lewis River. The time lag between pumping withdrawal and capture is unknown.

The total of certified surface water rights on the East Fork Lewis River is 10 cfs, while certified groundwater rights in the lower part of the basin are 18 cfs. Applications for an additional 16.8 cfs from groundwater have been received by Ecology, mostly from the City of Battle Ground, Clark County PUD, and Clark Public Utilities.

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Methods

Three complementary methods were used to identify the locations and timing of streamflow gains and losses in the East Fork Lewis River. The three methods provided information on surface water gains and losses relative to groundwater at different temporal and spatial scales. Field surveys were conducted from June to October 2005 and included:

- Two seepage surveys, in July and August.
- Installation of instream piezometers for vertical hydraulic gradient, direction of flow and temperature measurements.
- Streambed sediment temperature profiling.

Seepage surveys evaluated the broad-scale gains and losses to the river in mid to late summer in 3-mile to 5-mile reaches along the entire length of the river. In addition, piezometers installed in the lower 10 miles of the river provided localized information about gaining and losing conditions at four locations at 4- to 5-week intervals from June to October. Sediment temperature profiles, like the piezometer data, provided fine-scale information indicating gaining and losing conditions at four locations in the time scale of once every half-hour.

Each of the three methods for measuring surface water-groundwater exchange provided a unique type of evidence, which taken together provide a basis for interpreting the volume and direction of flow.

In addition, the EAP Surface Hydrology Unit conducted a tidal survey at RM 1.8 on August 10, 2005, using an Acoustic Doppler Current Profiler (ADCP). Sixty streamflow measurements were made over 5.5 hours. These streamflow measurements were compared with stream gage data for RM 10.1 to evaluate tidal effects in the lower river (Springer, 2009).

A weather station installed near RM 7.3 provided air temperature and precipitation data for the lower watershed.

Seepage Surveys

Two seepage surveys were conducted to identify gaining and losing reaches along the East Fork Lewis River. One survey was conducted on July 19, and the other on August 9-10. Except for streamflow measurements in Reaches 1 and 2, all other measurements for the second survey were made on August 9. Streamflow measurements were made at 12 sites on the river and at the mouths of tributaries as listed in Appendix B. The difference in discharge between consecutive measurement sites that was not due to surface water inflow or outflow was assumed to be the net water exchange between the river and groundwater.

The 12 discharge measurement sites extended from the Gifford Pinchot National Forest boundary in the upper watershed (RM 32.3) to a location near the river mouth (RM 1.8). The reaches are numbered from lowest to highest beginning at the upper end of the watershed and are shown in Figure 4.

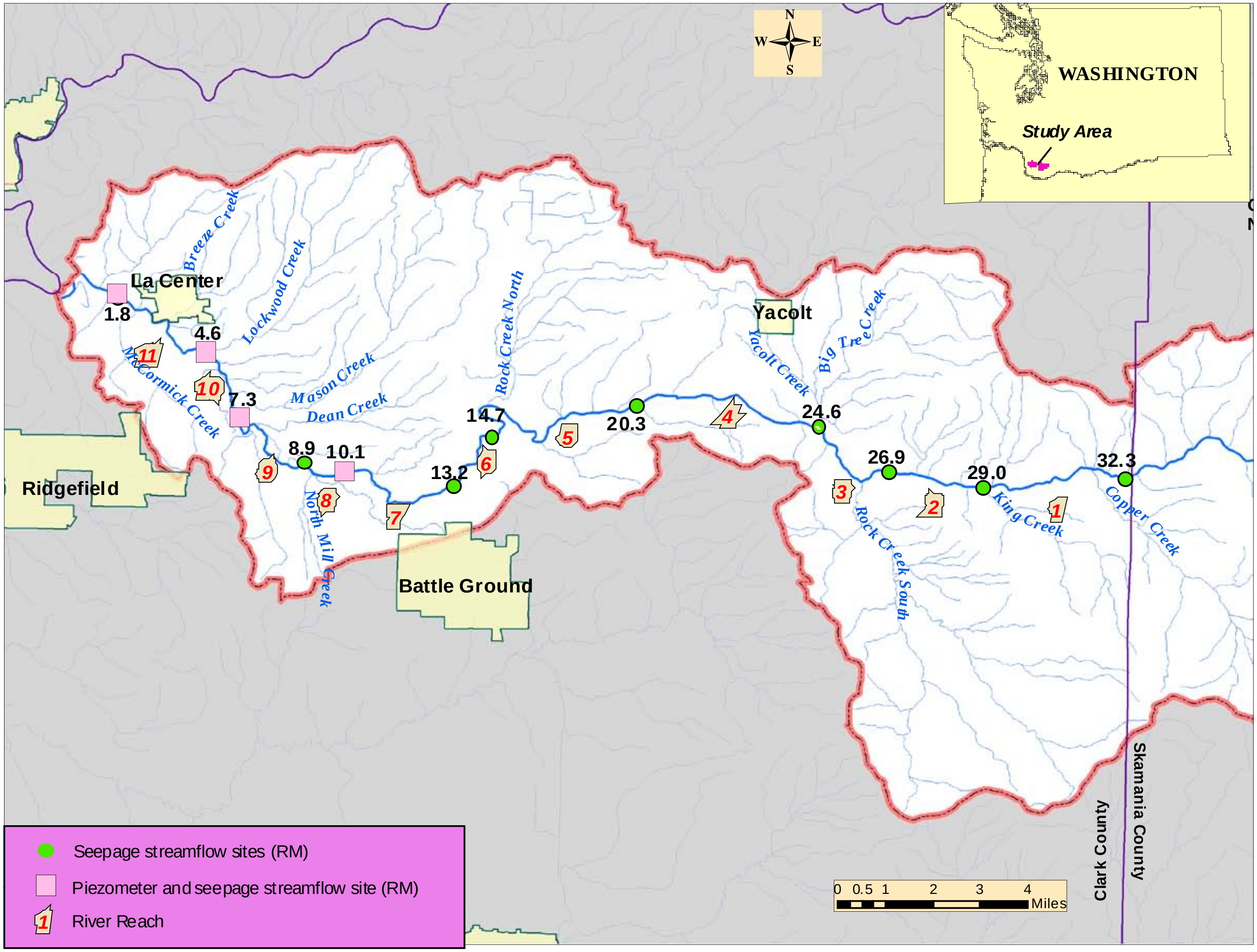
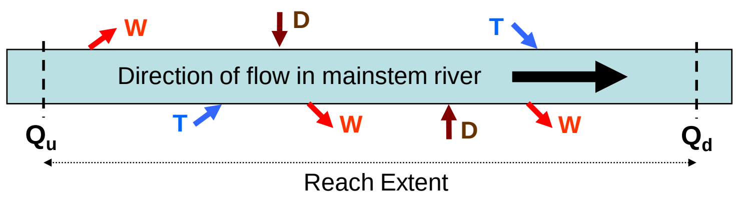


Figure 4. River reach locations for two seepage surveys, July and August 2005.

The purpose of the seepage surveys was to calculate a mass balance for all the measurable inflows and outflows during baseflow conditions (Figure 5). Sites where groundwater inflows or outflows were not related to point discharges or withdrawals were identified and investigated.

Discharge measurements near the mouth of the river are affected by changing tidal cycles. Results of the August 10, 2005, tidal survey indicated that tidal influence was significant at RM 1.8 except for one half-hour per tidal cycle, when the tide was lowest (Springer, 2009). Because of the nearly constant tidal influence, data for RM 1.8 are included but not used in the analysis of groundwater/surface water exchange.



For the seepage reach shown above, the **NET** volume of water exchanged between the river and ground water (Q_n) can be described as:

$$Q_n = Q_d - Q_u - \Sigma T - \Sigma D + \Sigma W \text{ ; Where}$$

Q_d = The discharge measured at the downstream seepage transect (ft^3/s);
Q_u = The discharge measured at the upstream seepage transect (ft^3/s);
ΣT = The sum of tributary inputs to the mainstem river (ft^3/s);
ΣW = The sum of artificial withdrawals from the mainstem river (ft3/s); and
ΣD = The sum of point discharges to the mainstem river (ft^3/s).

Figure 5. Diagram of the water budget elements measured during the two seepage surveys.

Positive values for Q_n suggest that groundwater discharge caused the river flow to increase across the seepage reach. Negative values for Q_n suggest that the river lost water to groundwater across the reach.

Timing of the surveys was designed to minimize fluctuations in flow caused by diurnal snowmelt effects and precipitation. Continuous flow measurements at the following three sites provided information to evaluate baseflow conditions (Bilhimer et al., 2005):

- RM 32.3: U.S. Forest Service boundary, operated by Ecology.
- RM 20.3: Heisson Road, operated by the U.S. Geological Survey.
- RM 10.1: Daybreak Park, operated by Ecology.

A fourth gage was installed by Ecology on the East Fork Lewis River at RM 1.8. However, tidal effects from the lower Columbia River caused the data to be unusable.

Manual streamflow measurements were made using the cross-section method described in Rantz et al. (1982). Two types of current meters were used:

- Swoffer Model 2100 horizontal axis meters.
- Marsh McBirney Model 2000 portable current meters.

Quality Assurance

All but one meter were part of the Ecology Environmental Assessment Program field equipment supply and received annual calibration checks. The remaining meter was supplied by a local volunteer. Duplicate or replicate measurements were made to assess within-team as well as between-team variability. Results of these measurement quality analyses are summarized in Appendix D.

We estimated streamflow for several tributaries using linear regression (Appendix B). Drainage area and measured discharge for similar streams in the same area were used as shown in Figure 6. Despite a high correlation coefficient (r^2=0.94), the range of accuracy for the measured values is 5-80%. Because the drainage areas for the unmeasured tributaries are so small relative to the river flow, and the reaches with estimated flow were clearly gaining or losing, even 100% errors in estimated flows would not have affected gaining or losing status in these reaches.

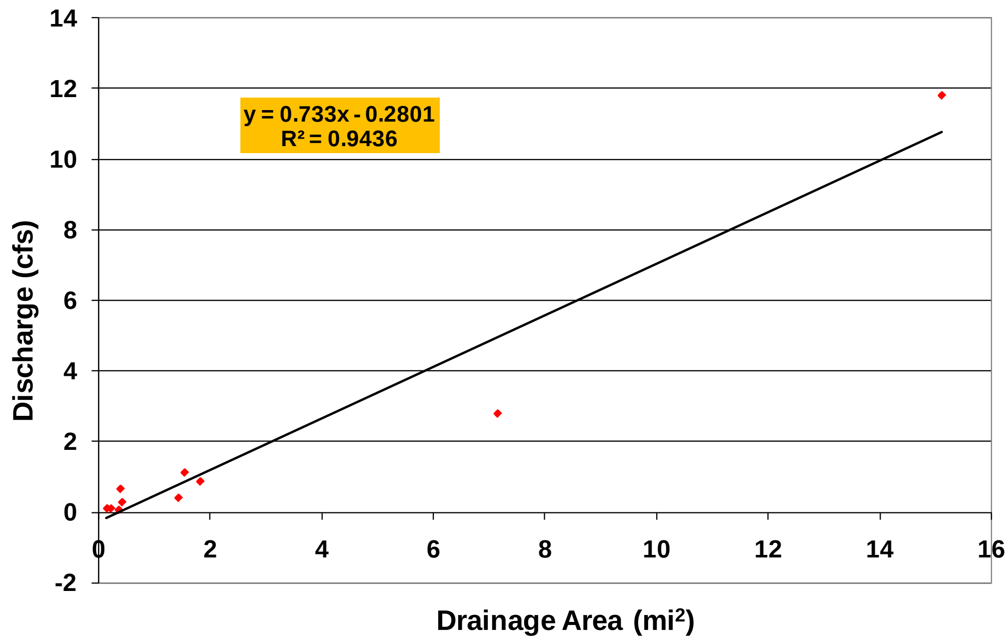


Figure 6. Discharge regression for unmeasured tributaries using streamflow measurements for Anaconda, Copper, Jack Mountain, King, Nichols, Reinhardt, and Rogers Creeks and unnamed tributaries (NNH, NNX, and NNY) on August 9-10, 2005.

Uncertainty of estimated streamflow gains and losses

The accuracy of streamflow measurements affects the reliability of the result and the threshold for determining whether a gain or loss is real or the result of measurement error. We used two methods to evaluate the likelihood that estimated gains and losses were real:

- A 95% confidence interval for the seepage estimate based on two or more measurements (Konrad et al., 2005) incorporating the relative percent difference (RPD) between duplicate streamflow measurements.
- Comparison of instantaneous gains and losses with those calculated using the 3-day average flow at three continuous gages to assess the effect of diurnal variation.

The method used by Konrad et al. (2005) takes into account the accuracy of each flow measurement in a seepage reach to determine a cut-off for significance. For this analysis, the RPD for replicate measurements within measurement teams was used. The RPD for the Rock Creek South measurement was 4.6% on August 9, 2005, when the mean flow was 10.5 cfs. See Appendix D for details of RPD estimates.

The mean flow at the other site where duplicate measurements were taken, Jenny Creek, was only 0.5 cfs. Because the flow was so low at the Jenny Creek site on August 9, 2005, the RPD of 9.9% was not considered a useful measurement for evaluating the significance of flow differences at other sites, where flow was higher.

The 4.6% RPD was therefore considered a reasonable estimate of the accuracy of river flow measurements during the seepage survey. Tributary flows greater than 2 cfs were also included in the calculation of combined uncertainty for reaches where such flows were measured.

The second method for evaluating the reliability of seepage gain/loss estimates was to assess whether the three-day time-of-travel from the headwaters to the mouth of the river was a significant influence. Gains and losses were compared for three-day average flows at the three gaged stations and compared with those estimated using instantaneous flows measured on August 9-10, 2005. Table 2 shows only slight differences between estimates of flow gains and losses in combined reaches based on instantaneous flow measurements and those using the three-day average flow (0.3-1.7%). Therefore it is assumed that diurnal variation did not introduce significant error to gain/loss estimates.

Table 2. Flow gains and losses using instantaneous flows and continuous flows.

Reach (RM)	Gain/Loss Using Instantaneous Flow Aug 9-10, 2005	Gain/Loss Using 3-day Average Flow[1]
32.3-20.3	-0.1 cfs *(-0.2%)*	+1.1 cfs *(1.5%)*
20.3-10.1	+6.1 cfs *(7.4%)*	+5.9 cfs *(7.1%)*

[1] Three-day average is based on stream gage measurements for August 8-10, 2005.

Vertical Hydraulic Gradient

Piezometers were installed in shallow riverbank areas at four sites in the lower East Fork Lewis River to evaluate groundwater flow direction into or out of the river at discrete points (Figure 4). Measurements were made four times between June 7 and October 5, 2005. An attempt was made to locate piezometers in areas where groundwater discharge was suspected, such as wider alluvial areas.

Piezometers consisted of 7-foot long, 1.5-inch diameter galvanized steel pipes crimped closed on the bottom (Figure 7). Small holes (1/8-inch diameter) were drilled into the bottom six inches of the pipe to allow water to enter. Piezometers were hand-driven into the streambed using a fencepost driver until the bottom of the pipe was 4-5 feet below the surface of the streambed and the top was above the water surface. Additional 2-foot long extension pipes were screwed onto the tops of three of the piezometers, allowing the top to remain above the surface water during a variety of water level fluctuations (RM 1.8, 4.6, and 10.1). Extensions were removed when the river level dropped.

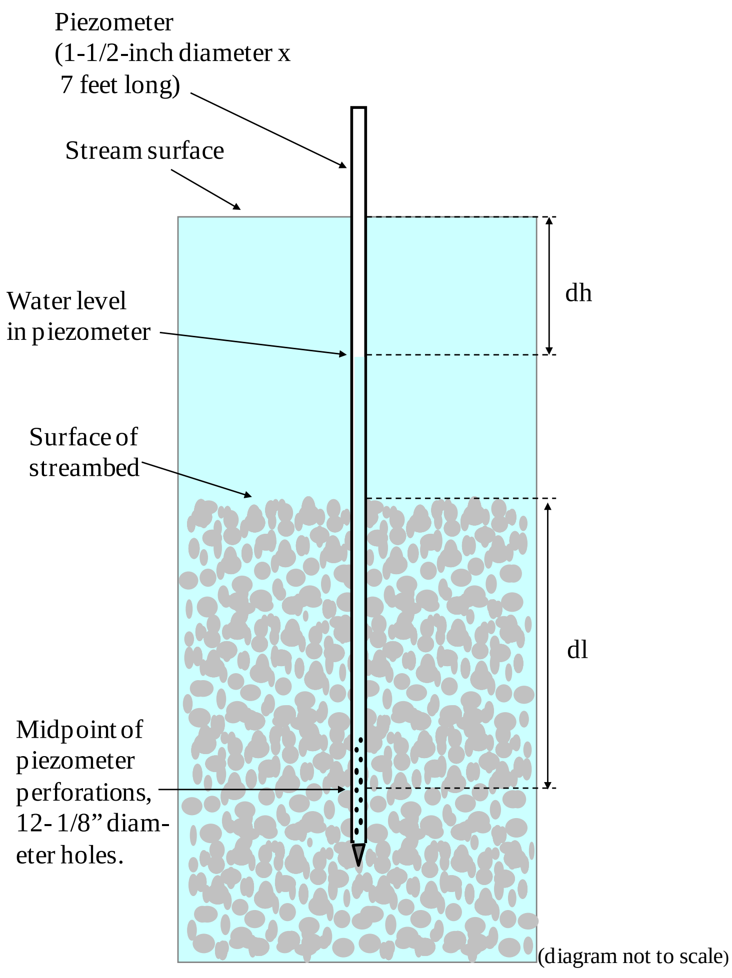


Figure 7. Diagram of instream piezometer installation (from Sinclair, 2001).

Each piezometer was equipped with a screw-on cap to protect the pipe during installation. The piezometer remained capped except when samples were collected. Each piezometer was developed initially using a peristaltic pump to ensure a good hydraulic connection with the streambed sediments.

Piezometer locations were determined using a Global Positioning System (GPS) receiver. See Appendix C for piezometer locations and construction details.

Piezometers were allowed to equilibrate after installation and development. After about 15 minutes, the depth to water inside the piezometer was measured using a calibrated, low-displacement E-tape (electrical water depth sensor). The stream stage was measured by extending an engineer's measuring tape along the outside of the piezometer pipe from the top of the pipe to the river surface. Both measurements were made to the nearest 0.01 foot using the method specified in USGS (1980).

The above procedure was used each time piezometer measurements were taken, excluding the initial pause for equilibration. If the water level inside the piezometer was higher than the outside river stage, then groundwater was assumed to be discharging to the river. If the water level in the river was higher than in the piezometer, then water was assumed to be seeping out of the river and into the streambed.

The vertical hydraulic gradient between the river and the piezometer was calculated as follows:

$$i_v = dh/dl$$

where: i_v = vertical hydraulic gradient (L/L).
dh = difference between the river water level and the piezometer water level (L).
dl = distance from the top of the streambed to the midpoint of the piezometer perforations (L).

Positive values for i_v indicate groundwater discharge to the river, and negative values indicate surface water flow into the streambed.

One piezometer, AKY476 (RM 1.8), was not truly perpendicular to the streambed. The depth to water measurements and installation depth at this site were corrected using trigonometric calculations.

Streambed Sediment Thermal Profiles

Temperature data loggers (thermistors) were installed at three depths inside each piezometer for a total of 12 thermistors. The StowAway Tidbit© thermistors were manufactured by Onset Computer Corporation. The recommended range of operation for Tidbits is -5°C to +37°C; resolution is 0.12°C; accuracy is 0.2°-0.4°C. See Appendix D for thermistor calibration procedures and results.

Thermistors were positioned in each piezometer so that one thermistor was near the top of the streambed, one was in the perforated bottom of the piezometer (3-4 feet below the top of the streambed), and was one mid-way between the top and bottom sensors (2-2.5 feet below the streambed). The thermistors recorded temperatures every half-hour in the piezometers from June through October 2005.

Differences in temperature with increasing depth provide an indication of hyporheic flow direction as shown in Figure 8. In the East Fork Lewis River during the summer, groundwater is cooler than surface water and is relatively constant over the course of a day. Surface water temperatures, on the other hand, typically fluctuate several degrees over the course of a summer day.

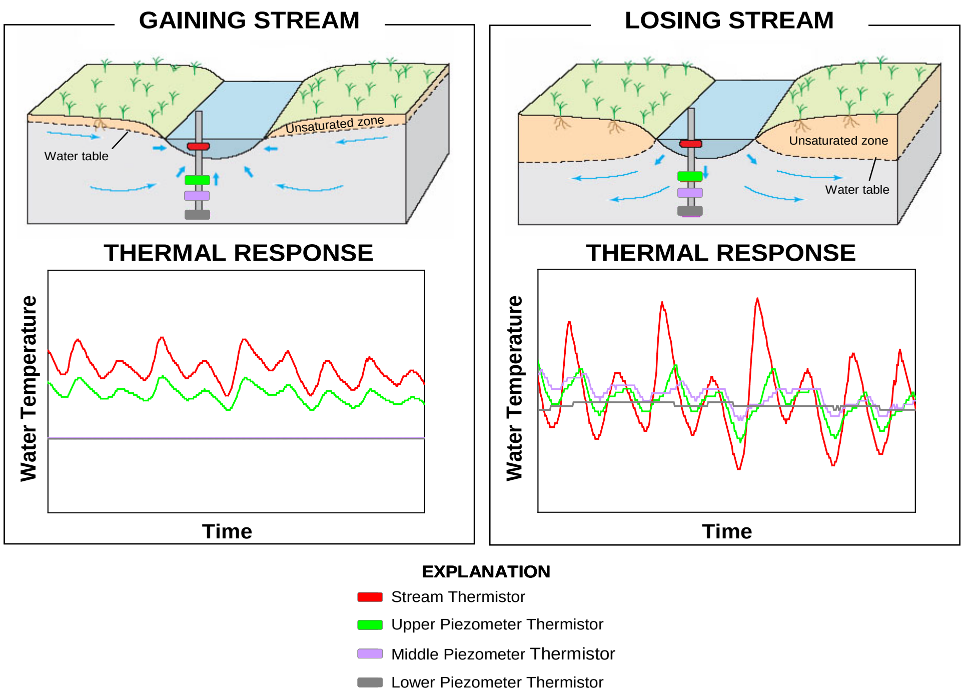


Figure 8. Streambed thermal indicators of gaining and losing conditions in a typical river system (from Sinclair and Bilhimer, 2007; and adapted from Simonds et al., 2004, and Stonestrom and Constanz, 2003).

In the summer, if the temperature in the shallower thermistor(s) is warmer than in the deeper thermistor(s) and fluctuates diurnally similar to the river, then flow is assumed to be away from the river. This is referred to as a losing reach, and groundwater flow would therefore not influence surface water temperature. However, if the temperature in the shallow sediment zone is similar to that in the deeper zone and stable during the day, then flow is assumed to be toward the river. Groundwater flow could, in this case, influence surface water temperature. (The reverse temperature scheme occurs in the winter.)

Streambed water temperatures were also measured using a WTW electronic multi-meter 340i© and Tetracon 325© on four dates.

Results

Seepage Surveys

Streamflow and precipitation conditions were more conducive to analysis of groundwater seepage on August 9-10, than on July 19, 2005. Streamflow at three continuous gages on the East Fork Lewis River and precipitation near RM 7.3 are shown in Figure 9.

Streamflow was dropping at all sites on July 19, as seasonal snowmelt and precipitation tapered off (Figure 9). By August 9-10, streamflow was less variable (Figure 10).

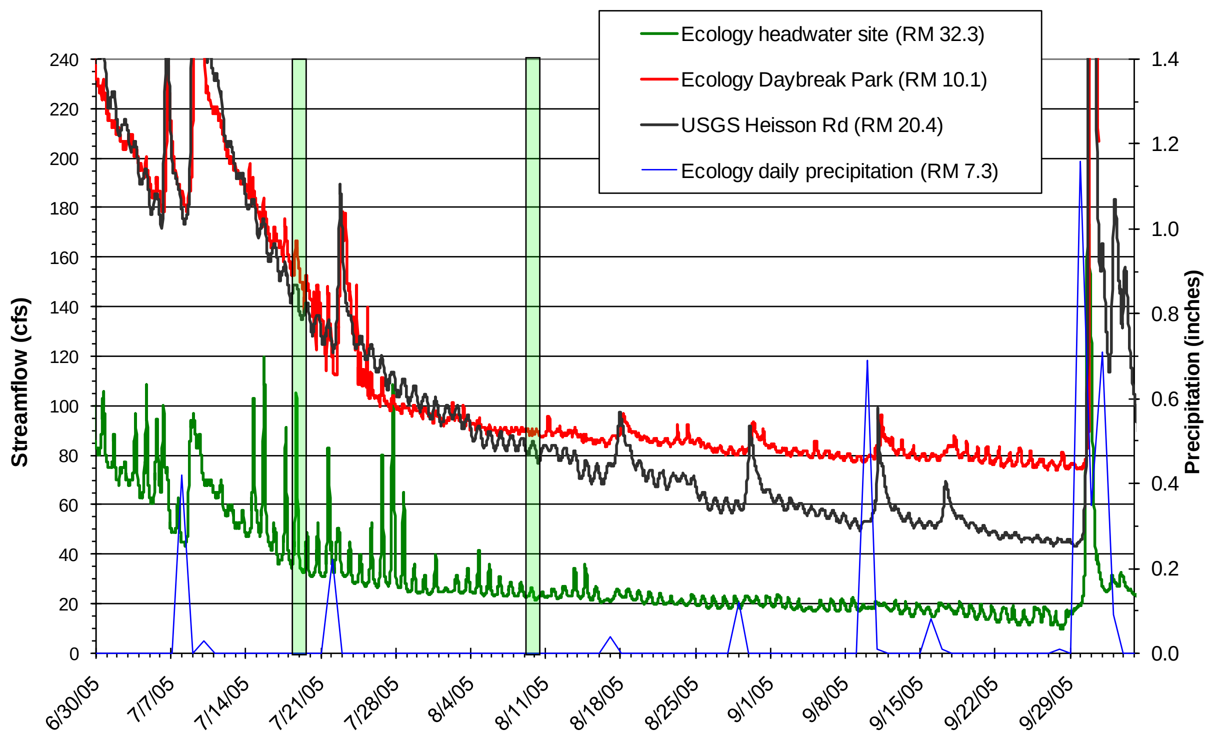
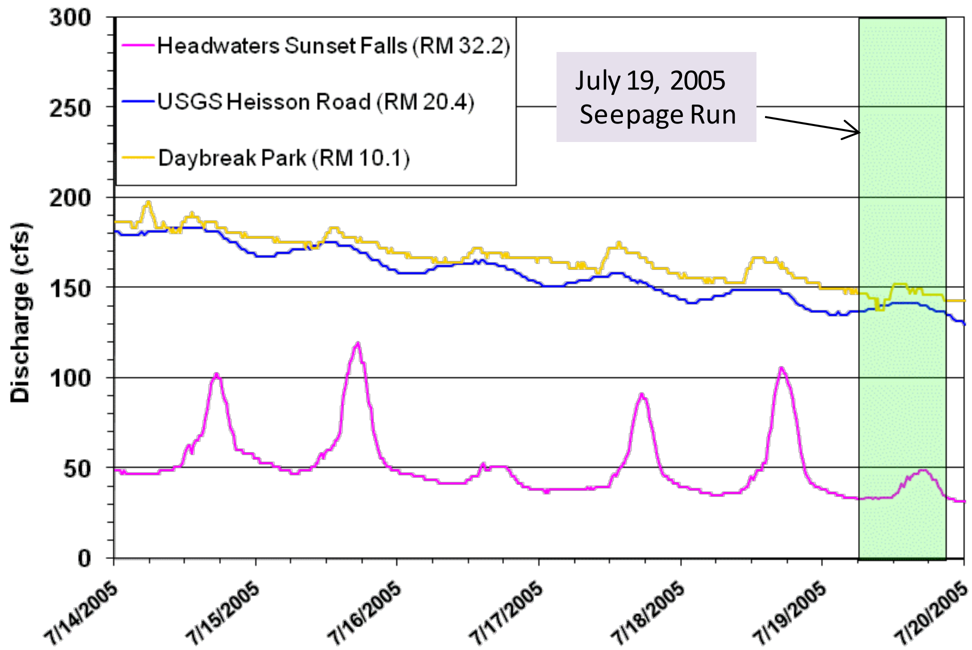


Figure 9. Flow data for three sites on the East Fork Lewis River during the summer of 2005 and precipitation at Ecology's weather station (RM 7.3). The green shaded areas are the seepage survey dates.



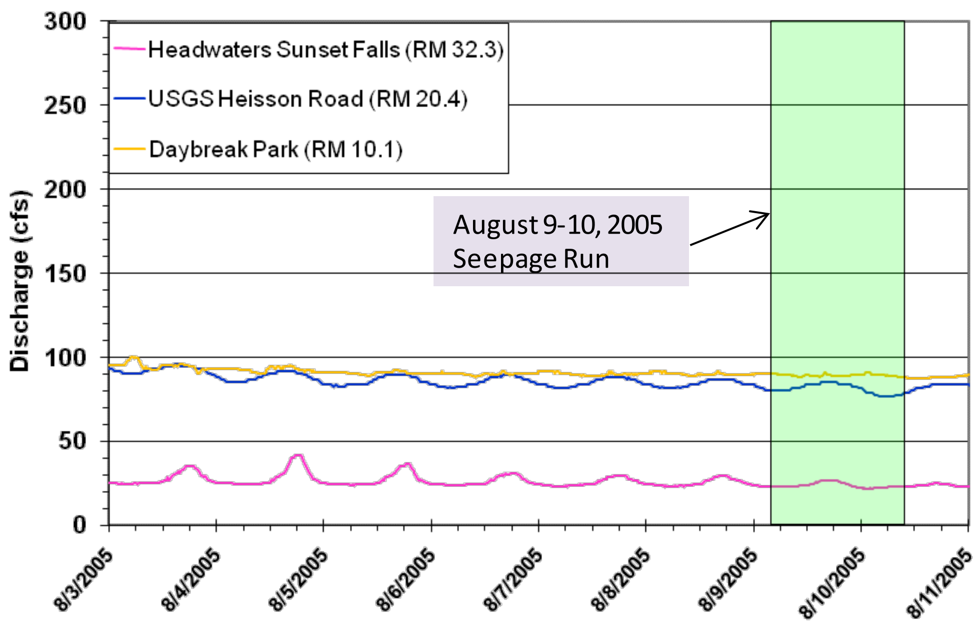


Figure 10. Flow measurements at three gages along the East Fork Lewis River during the July 19 (top) and August 9-10 (bottom), 2005 seepage surveys and one week previous to the surveys.

Diurnal variation as a percentage of flow was similar at the upper two continuous gage sites on July 19 and August 9, as shown in Table 3 (6-21%). However, the furthest downstream site (RM 10.1) had less diurnal variation on August 9 than on July 19 (2.2% compared to 10%).

Table 3. Diurnal variation in streamflow at continuous gaging sites during two seepage surveys on the East Fork Lewis River, July and August 2005.

Site	July 19 cfs *(%)*	August 9 cfs *(%)*
Sunset Campground (RM 32.3)	7 (19)	5 (21)
Heisson Road (RM 20.4)	10 (7.5)	5 (6.0)
Daybreak Park (RM 10.1)	15 (10)	2 (2.2)

Tidal influence was likewise less at the RM 1.8 seepage survey site on August 9 than on July 19. The diurnal stage variation was 3.0 feet on July 19 and 1.9 feet on August 9. Because conditions were more representative of baseflow conditions on August 9, data from that date were used to analyze seepage into and out of the river.

Gains and losses observed during the seepage surveys are shown in Figure 11. Flow gains were observed in four reaches. Flow losses were observed in two reaches. The total of flow gains was 64 cfs. Total flow losses were 18 cfs. Streamflow measurements and gain/loss calculations for both dates are summarized in Appendix B.

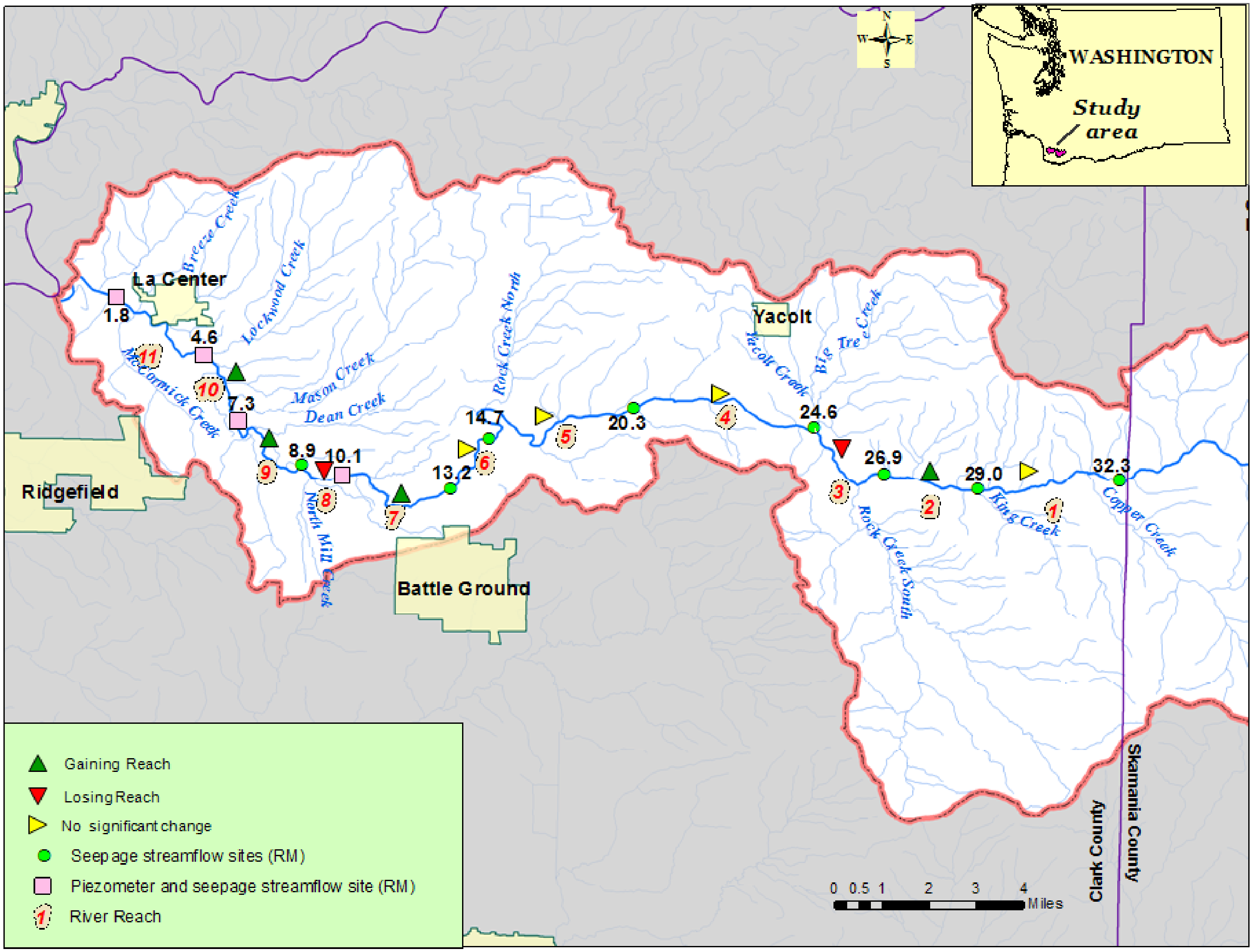


Figure 11. Results of seepage survey discharge gain and loss estimates on the East Fork Lewis River on August 9-10, 2005. Data are listed in Appendix B.

Vertical Hydraulic Gradient

Vertical hydraulic gradient (VHG) results are shown in Figure 12. VHGs were consistently positive (gaining) and highest at RM 7.3 (excluding RM 1.8 which was tidally affected). These results are consistent with the August 2005 seepage survey results, which indicated gaining reaches above and below RM 7.3. VHGs at RM 4.6 and 10.1 were positive except for one date each, when they were negative (June 7 at RM 4.6 and July 11 at RM 10.1). Negative VHGs indicate losing conditions.

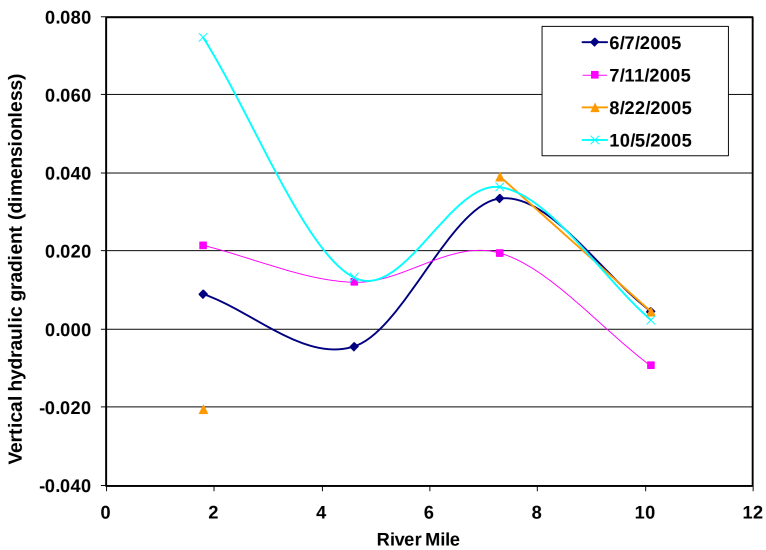


Figure 12. Vertical hydraulic gradient values on the East Fork Lewis River during the 2005 low-flow period. Data are shown in Appendix E.

The greatest seasonal variability in VHG occurred at RM 1.8, the site experiencing the most pronounced tidal effects. The highest value, 0.075, was observed on October 5, and the lowest, -0.020, on August 22.

A 0.42-inch rain event on July 8 probably affected VHG results on July 11. Streamflow at the RM 20.3 and RM 10.1 gages increased from about 190 cfs on July 7 to 350 cfs on July 9. Although the flow was down to 250 cfs by July 10, the elevated river level probably continued to have an effect on groundwater flow direction at RM 1.8 and 4.6. VHG measurements at the upper two piezometer sites on July 18-19 (RM 7.3 and 10.1) were the lowest for the season at these sites and may also have been muted by increased flows earlier in the week.

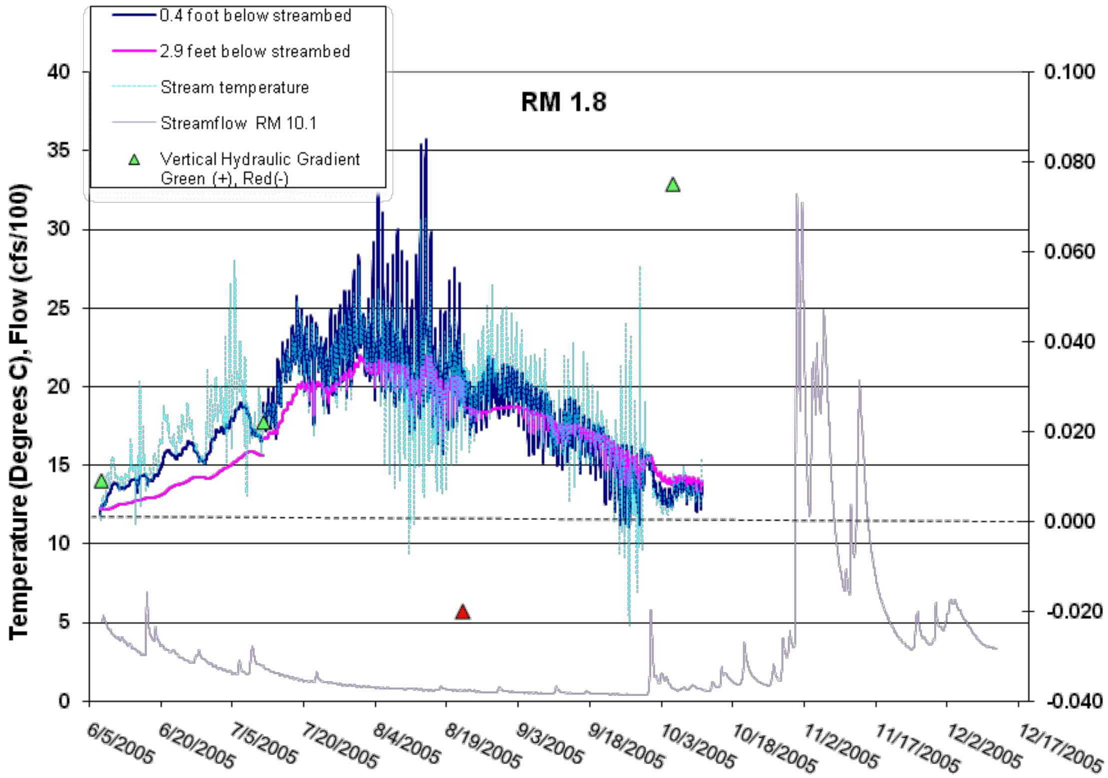
The highest VHG estimates at RM 7.3 and 10.1 (0.039 and 0.005 respectively) occurred on August 22, when streamflow was lowest, 85 cfs at RM 10.1. No measurement was made at RM 4.6 on August 22, because the river was too low to access the piezometer by motorized boat yet too swift to reach by inflatable boat.

A second low-flow rain event occurred on September 30-October 1, 2005. The 2.2-inch rain event caused streamflow to increase from 74 cfs at RM 10.1 and 44 cfs at RM 20.3 to 500 cfs at both sites on September 30. Flow decreased to 90 cfs on October 1. The dramatic change in river stage would likely have dampened the VHGs observed on October 5.

Streambed Sediment Thermal Profiles

Streambed temperature data at all four sites clearly indicate gaining conditions. Deeper temperatures were stable or changed only slightly over the summer and were a few degrees lower than the stream temperature. Temperatures at the shallower depths were closer to and mimicked stream temperature but were still below that of the river (Figures 13 and 14).

Thermistors were properly installed at RM 1.8. But on July 11, they were positioned higher in the piezometer than intended. Therefore data at RM 1.8 collected after July 11 are not representative of target depths. Only data collected from targeted depths were used in analyses.



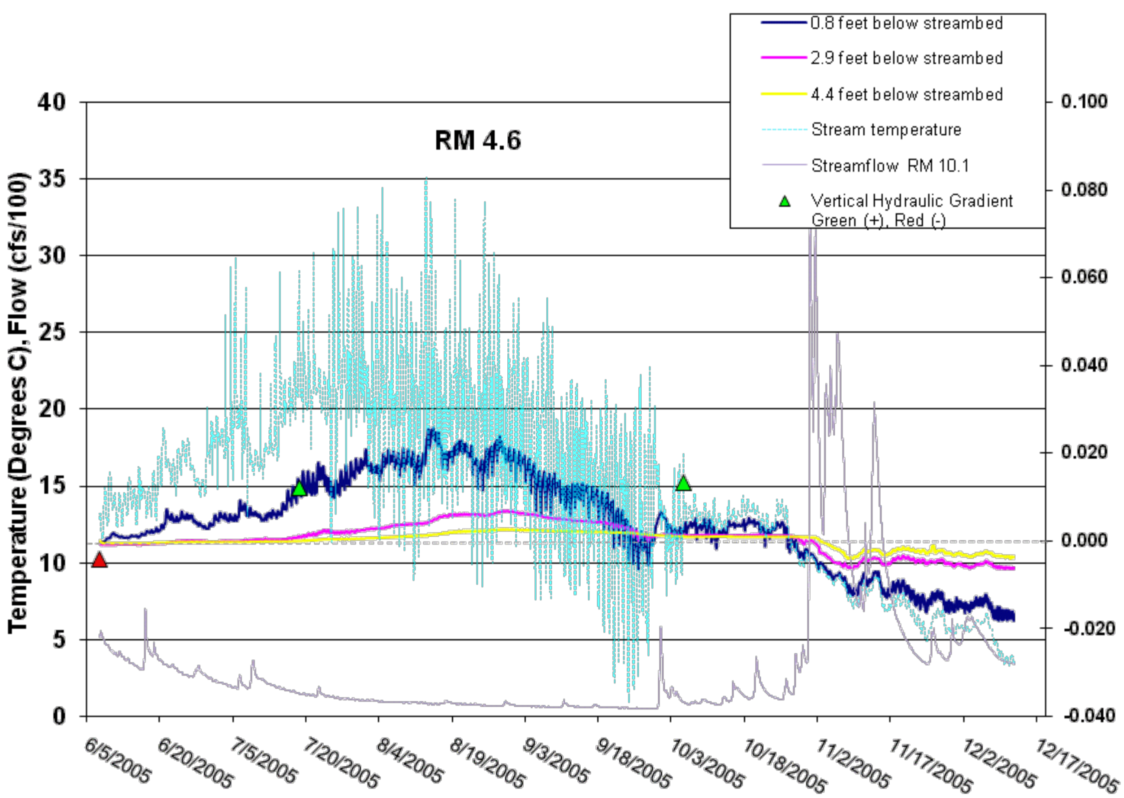
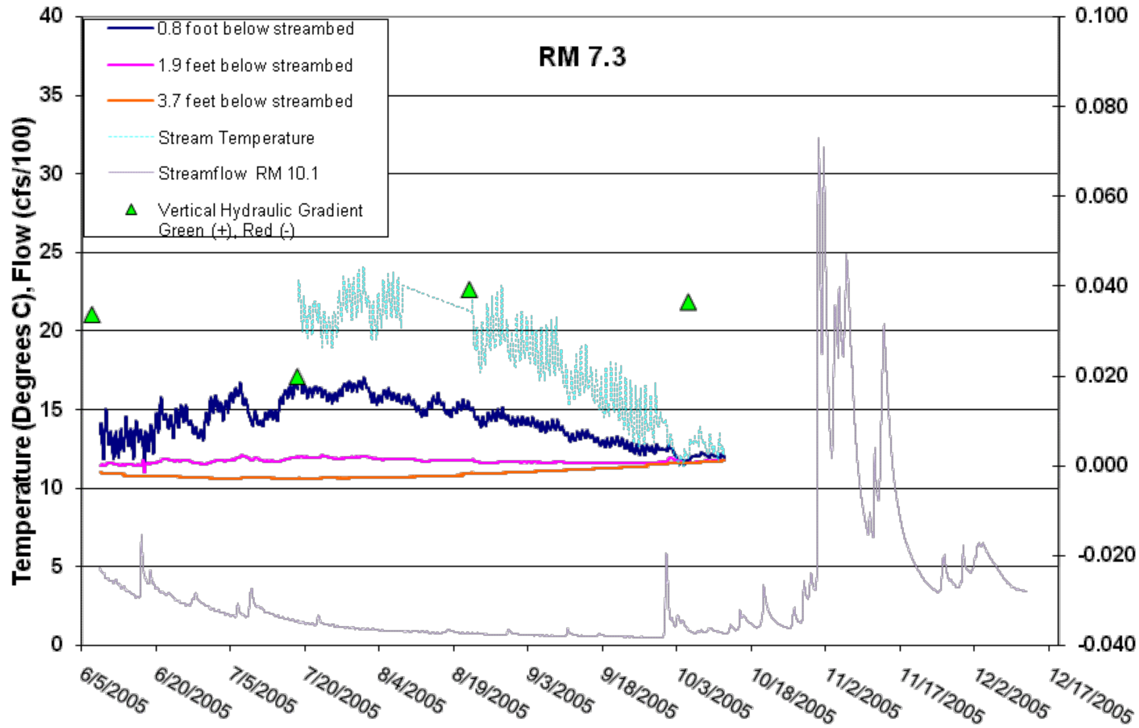


Figure 13. Temperature results for thermistors and vertical hydraulic gradients in the East Fork Lewis River at RM 1.8 (top) and 4.6 (bottom).



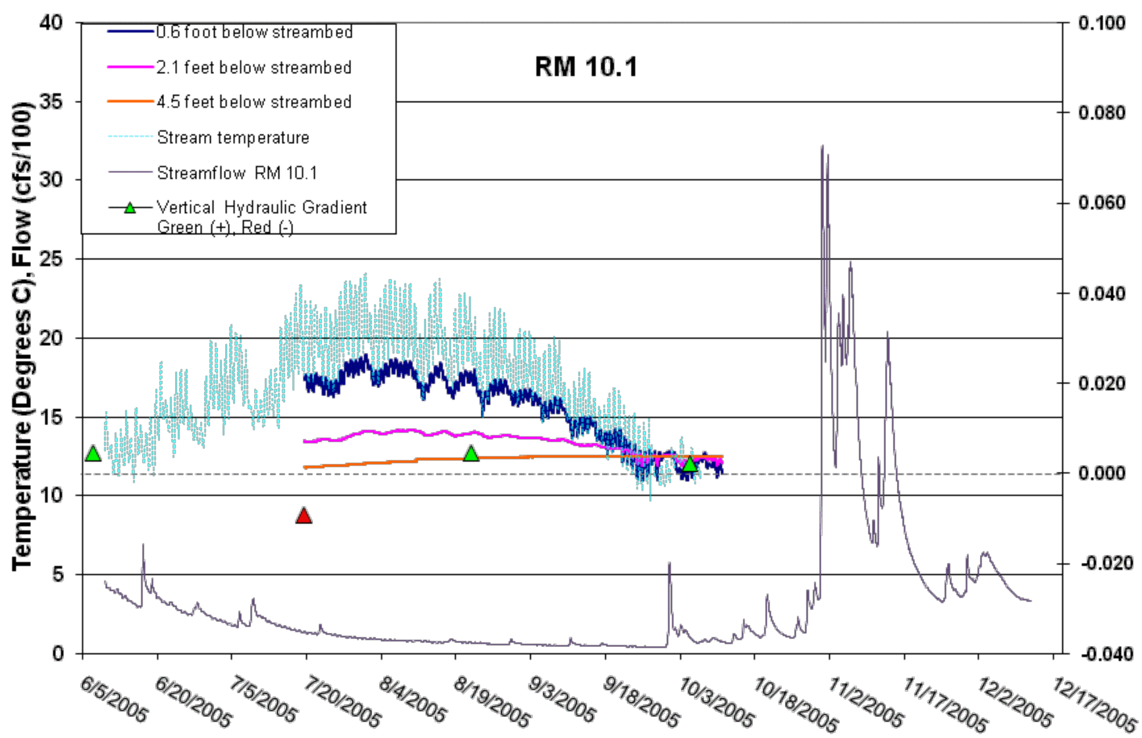


Figure 14. Temperature results for thermistors and vertical hydraulic gradients in the East Fork Lewis River at RM 7.3 (top) and 10.1 (bottom).

Temperature of inflowing groundwater

Temperatures in the deepest hyporheic thermistors were assumed to be most representative of inflowing groundwater as shown in Table 4. Consistently cool temperatures in the three upstream sites indicate gaining conditions. Higher variability and temperatures at RM 1.8 indicate losing conditions possibly due to tidal fluctuations. Maximum temperatures in the three gaining reaches ranged between 10.7° and 12.5°C.

Table 4. Monthly maximum, minimum, mean, and standard deviation of temperatures in the deepest thermistor in each piezometer, June to October 2005.

Month	RM 1.8				RM 4.6				RM 7.3				RM 10.1			
	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
June*	14.3	12.2	13.2	0.7	11.4	11.2	11.3	0.03	10.9	10.6	10.7	0.07	ND	ND	ND	ND
July**	22.0	14.2	18.0	2.3	11.6	11.3	11.4	0.08	10.7	10.6	10.6	0.05	12.1	11.8	11.9	0.08
August	22.0	16.7	20.0	1.2	12.2	11.5	11.9	0.19	10.9	10.7	10.8	0.09	12.5	12.1	12.3	0.10
September	18.7	13.5	16.9	1.3	12.1	11.7	12.0	0.10	11.5	10.9	11.2	0.15	12.5	12.4	12.5	0.01
October***	15.3	13.3	14.1	0.3	11.7	11.6	11.7	0.02	11.7	11.4	11.6	0.06	12.5	12.4	12.5	0.00

SD – standard deviation.

* June 7-30.

** At RM 10.1: July 19-31.

*** At RM 1.8: October 1-11.
RM 4.6: October 1-31.
RM 7.3 and 10.1: October 1-12.

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Discussion

Results from three field techniques for estimating the direction and timing of groundwater/ surface water interactions are analyzed below by reach along the East Fork Lewis River.

Seepage Reach 1 (RM 32.3-29.0)

No significant seepage was measured in the upstream-most reach during the seepage survey as shown in Appendix B. The upper basin of the river is a steep, narrow bedrock canyon underlain by volcanic bedrock with limited water storage capacity and typically little groundwater interaction.

The longitudinal stream temperature profile for the river on July 30, and August 9, 2005 (Figure 15) shows a decrease in the daily maximum temperatures for the larger reach extending from RM 32.3 to RM 26.9. (July 30, 2005 was the date closest to August 9, for which there was a complete data series. Temperature data were not available at RM 29.0.) Although a temperature decrease can be related to groundwater inflow, it is more likely that cooler inflows from Copper Creek at RM 31.8 (11.8 cfs, temperature presumed cooler) and King Creek in Reach 2 at RM 28.9 (2.8 cfs and 5.5°C cooler than the river at RM 32.3) are the causes of the maximum temperature decrease in this reach.

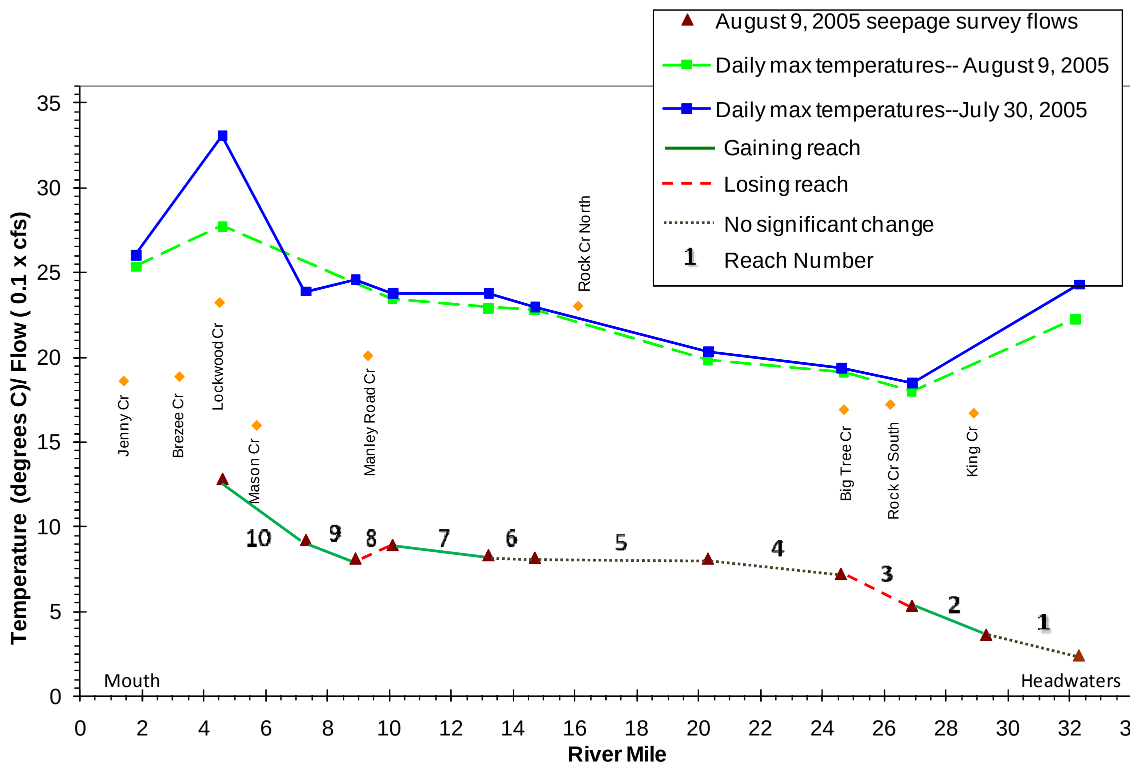

Figure 15. Daily maximum and daily average stream temperature profiles for the East Fork Lewis River on July 30 and August 9, 2005 and streamflow on August 9-10, 2005.

Seepage Reach 2 (RM 29.0-26.9)

The second largest percent streamflow gain in the non-tidally affected river, 34%, occurred in Reach 2 (Figure 15, Appendix B). The river gained 6.1 cfs/river mile.

Cooling in this reach is probably due to both incoming groundwater and 2.8 cfs inflow from King Creek at RM 28.9. The daily maximum temperature of King Creek was 1.3°C cooler than the river at RM 26.9. There is no indication of a geologic change to explain the large increase in streamflow.

Seepage Reach 3 (RM 26.9-24.7)

The river lost 17% of its flow, 3.8 cfs/river mile, between RM 26.9 and 24.7. Like Reaches 1 and 2, the channel is mostly bedrock with Rock Creek South discharging 28 cfs at the lower end of the reach. Water stored in the Rock Creek South glacial drift valley would typically discharge to the creek and the river as well as add to river flow. Losses in other locations along the reach may have overshadowed contributions from the glacial drift.

The daily maximum river temperature increased in this reach despite substantial tributary inputs that typically cool the river. The maximum temperature for Rock Creek South at RM 26.2, which added 28 cfs (52% of the mainstem flow), was about 0.5°C lower than that of the river at RM 26.9. Rising river temperature is consistent with loss of surface water to groundwater.

In contrast to 2005, USGS seepage surveys found substantial gains in this reach in October 1987 and 1988 (Table 5). However, the USGS calculations do not appear to include flow from Rock Creek South, which was 28.1 cfs in August 9, 2005. Omitting Rock Creek South inflow causes an overestimate of the groundwater contribution in this reach.

Table 5. Streamflow during seepage surveys on the East Fork Lewis River measured in October 1987 and 1988 (Morgan and McFarland, 1996) and on August 9-10, 2005.

RM	USGS		Ecology	USGS		Ecology	USGS		Ecology
	flow (cfs)			gain/loss (cfs)			% gain/loss		
	Oct 29, 1987	Oct 11, 1988	Aug 9, 2005	1987	1988	2005	1987	1988	2005
27.0	19.5	27.5	53.2	--	--	--	--	--	--
24.6	34.1	45.4	72.1	4.29	5.38	-9.2	22.0	10.1	-17.2
20.3	32.8	43.8	81.0	-0.32	-0.39	-0.1	-0.9	-0.5	-0.2
14.7	35.0	43.7	81.5	0.31	-0.11	-1.9	0.9	-0.1	-0.3
10.1	35.3	47.8	89.1	0.08	1.08	7.3	0.2	1.3	9.0
7.3-E, 6.5-U	4.18	58.1	92.2	0.98	2.2	2.6	2.8	2.5	2.9

E-Ecology
U-USGS

Seepage Reach 4 (RM 24.7-20.3)

No significant gain or loss was observed in the reach from RM 24.7 to 20.3, where the bedrock substrate is similar to Reaches 1-3. Morgan and McFarland (1996) found small losses in this reach in October 1987 and 1988 (0.9% and 0.1% respectively) as shown in Table 5.

Big Tree Creek (RM 24.5), the major tributary in this reach, drains the Yacolt glacial drift area. McFarland and Morgan (1996) reported glacial outwash deposits underlying the Yacolt area approximately 100 feet thick with well yields up to 600 gal/min. PGG (2003) also suggested that the Yacolt glacial drift may provide groundwater storage capacity and release water as baseflow; however, it was not a significant influence on Reach 4 during this survey.

Further evidence of negligible river and groundwater exchange is the lack of major stream temperature change (Figure 15). The downstream maximum daily temperature was 0.8°C warmer than upstream despite the addition of 8.2 cfs (11% of the mainstream flow) from Big Tree Creek with a maximum daily temperature 2°C cooler than the river.

Seepage Reach 5 (RM 20.3-14.7)

No significant change in flow was measured between RM 20.3 and 14.7 during the August 2005 seepage survey. The river transitions from a constrained bedrock channel to a wider, unconsolidated channel in this reach, cutting through the Lower Troutdale Aquifer. The 1987 and 1988 seepage surveys likewise indicated no gains or losses in this reach (Table 5).

A PGG (2003) cross-section indicates that the river connects with the deeper Sand and Gravel Aquifer (SGA) near RM 14. Because the SGA is considered the major source of flow to the river, and the river and aquifer are in direct contact for at least part of the reach, a gain could have occurred.

The daily maximum stream temperature increased by 2.6 to 3.0°C on July 31 and August 9, 2005 (Figure 15). Warming is expected as the channel widens and is more exposed to solar and air heating. Groundwater inflow, if it occurred in this reach, would tend to counteract warming.

The SGA is used by nearby public water supply wells for the City of Battle Ground and Clark Public Utility. Most of the pumpage from the SGA is from the City of Battle Ground wells which began pumping in 1996 (Figure 16). PGG (2003) estimated that roughly 3.2 cfs was withdrawn from the East Fork Lewis River by municipal wells via the SGA in 2002. The annual withdrawal from the SGA by the City of Battle Ground wells in 2005 and 2006 was 1.5 cfs.

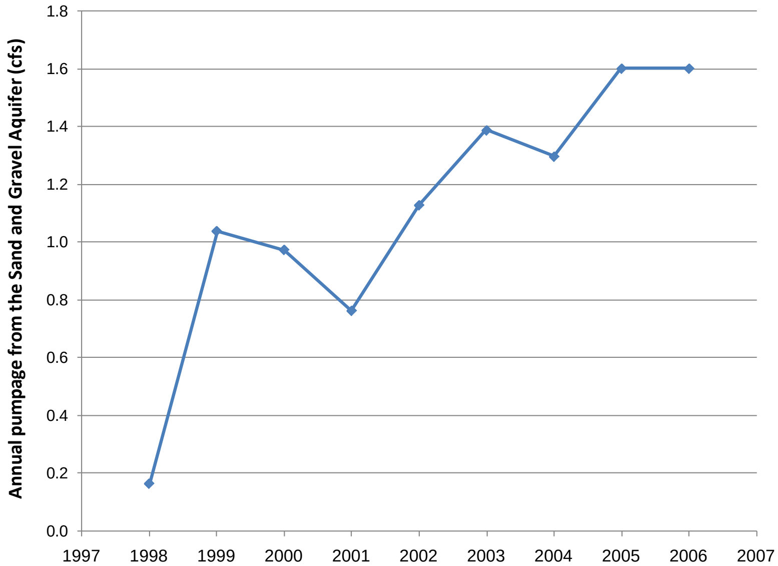

Figure 16. Annual pumpage from the City of Battle Ground wells that withdraw from the Sand and Gravel Aquifer, 1997-2007. (Scott Sawyer, City of Battle Ground, 2007).

Figure 17 shows the rough location of model-based predictions of 10-year time-of-travel for groundwater in wellhead protection zones. These inexact estimates are based on rates of well pumping withdrawal and are included to show the location and relative distance groundwater may travel to public water supply wells near the river. Actual distances for 10-year travel time for groundwater may differ substantially from that shown.

A time lag may occur between the start of pumping and the time that effects on the East Fork Lewis River occur. It is not clear when effects of pumping could be measured in the RM 20.3-14.7 reach.

The slope at the maximum daily stream temperature line is slightly higher in this reach compared to the upstream reach (Figure 15). Tributary inflow was probably not an appreciable influence in Reach 5, because total inflow from tributaries was only 3% of that in the mainstem. Both solar and air heating are greater in this reach than in narrow Reach 4.

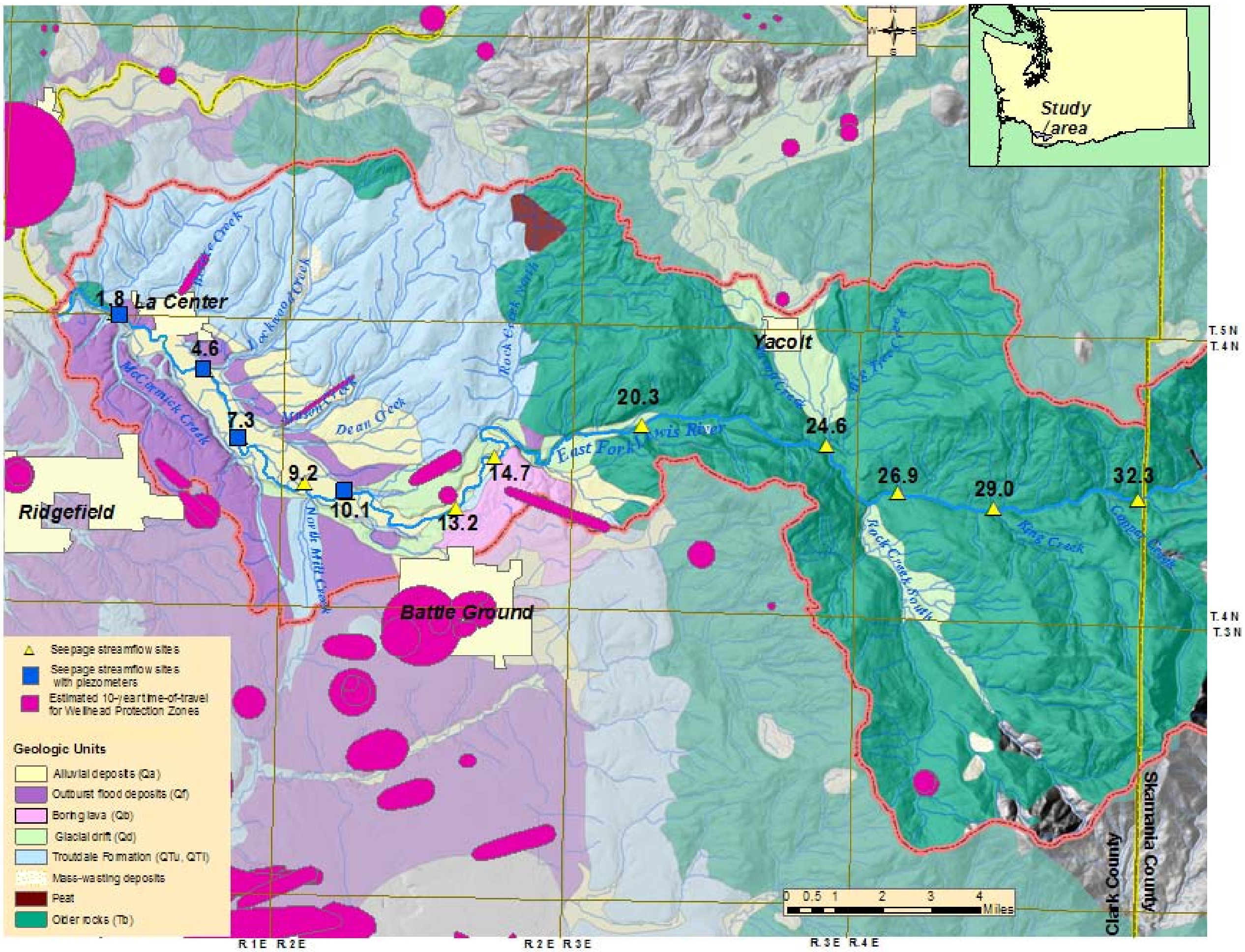

Figure 17. Ten-year time-of-travel estimates for Wellhead Protection Areas in and near the East Fork Lewis River basin. (Washington State Department of Natural Resources, 2005; Washington State Department of Health, 2006.)

Seepage Reach 6 (RM 14.7-13.2)

No significant streamflow gain or loss was observed in the reach between RM 14.7 and 13.2. The river cuts through the SGA at the top of the reach (RM 14.2) as shown in cross-sections by Howard (2002) and PGG (2003).

A cross-section at RM 12 in PGG (2003) shows that the river is underlain by the lower confining layer of the Troutdale Aquifer. Because there are no cross-sections between those at RM 14 and RM 12, it is likely that at least part of Reach 6 is underlain by the SGA, but the confining layer may also be present beneath part(s) of the reach. Groundwater/surface water interaction is possible where the SGA is in contact with the riverbed.

A widening channel and unconsolidated alluvial materials beneath and adjacent to Reach 6 suggest a potential for groundwater storage and summer release from the alluvial aquifer.

Boring lava and glacial drift deposits on the east side of the river and terrace deposits on both sides of the river shown in Howard (2002) and PGG (2003) cross-sections may also serve as aquifer storage and release areas for this reach.

River temperatures are not indicative of major groundwater inflow in Reach 6 (Figure 15). Historical data are not available to evaluate gaining or losing conditions for this reach.

Seepage Reach 7 (RM 13.2-10.1)

A substantial streamflow gain of 7.4%, or 2.0 cfs/river mile, was measured in Reach 7. The VHG at the lower end of the reach, RM 10.1, was likewise positive on three out of four dates (June, August, and September), indicative of groundwater flowing toward the river.

The single negative VHG was measured in July at RM 10.1 following a rain event that may have temporarily reversed the groundwater flow direction (Figure 18). The July measurement likewise corresponded with the maximum temperature in a shallow streambed thermistor, 23.3°C, and is consistent with surface water loss on that date.

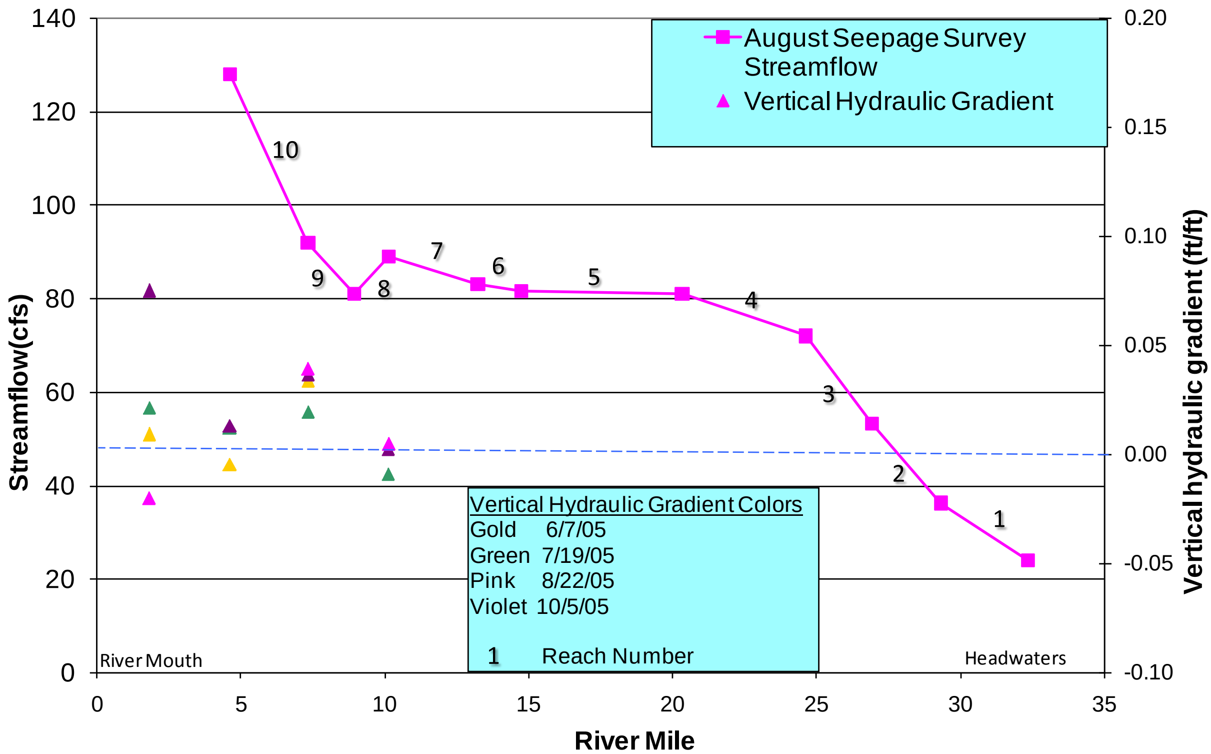

Figure 18. Vertical hydraulic gradients and streamflow measurements at East Fork Lewis River sites used for seepage estimates, June – October 2005.

A comparison of the 1987 and 1988 seepage survey interval, RM 14.4-10.6 (3.8 miles long), with the 2005 combined intervals, RM 14.7-10.1 (4.6 miles long), indicates gaining conditions in all three years (Table 5). The 2005 gain was somewhat higher than gains found in previous years, at least partly due to sampling earlier in the water year.

The daily maximum temperature in the river flattens out somewhat in this reach, indicative of more cooling than the two reaches immediately upstream (Figure 15).

Cross-sections from PGG (2003) and Howard (2002) indicate that the shallow alluvial deposits below the river are underlain by a confining layer at RM 12 and are not in direct connection with the SGA. However, the confining unit ends somewhere between RM 12 and 8, and the river is again in connection with the SGA. Connection with the SGA allows more groundwater exchange with the river. It is also possible that part of the reach above RM 12 is in connection with the SGA, allowing groundwater exchange with the river.

Alluvial deposits in the widening river channel of this reach are another potential area for limited groundwater storage during high flows and later release under baseflow conditions.

Seepage Reach 8 (RM 10.1-8.9)

A substantial seepage loss was observed along Reach 8 during both July and August (8.4 and 6.9 cfs/mile respectfully). The river meanders north from its westerly course at the bottom of this reach causing some flow to continue straight through the gravel bar leaving the riverbed (Figure 19). However, most, if not all, of the lost flow returns to the river as measured downstream at RM 7.3, where a 10.1 cfs gain was measured. Dent et al. (2001) refer to this as inwelling (water moving out of the riverbed at a gravel bar) and outwelling (water moving back into the riverbed).

The cross-section near RM 12 in PGG (2003) shows that the underlying confining layer ends near RM 10.5, allowing a connection with the underlying SGA.

VHGs at RM 10.1, the upper end of the reach, were positive on three out of four dates, including August 22, 2005, the date closest to the seepage survey. Positive gradients indicate groundwater flow toward the river (Figure 18). Hyporheic temperatures at RM 10.1 likewise indicated gaining conditions throughout the summer (Figure 14). Groundwater was probably entering the reach above the large meander and leaving at the bend in the river.

The daily maximum stream temperature increased relatively steeply in this reach (Figure 15). Greater exposure to solar and air heating contributed to increasing temperatures along this reach.

Withdrawals for public water supply in the basin may also be a factor in the flow loss in this reach similar to Reaches 5-7.

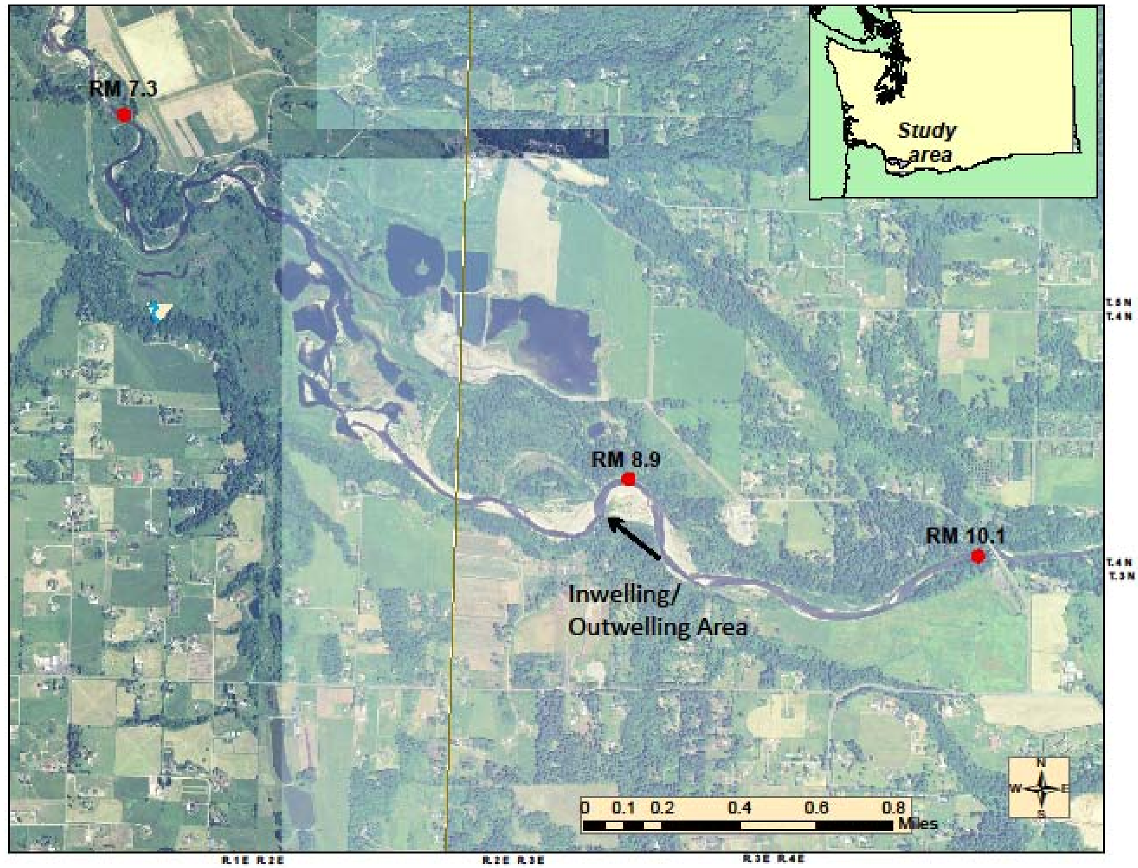

Figure 19. Aerial photo showing inwelling/outwelling area near the lower end of Reach 8.

Seepage Reach 9 (RM 8.9-7.3)

The reach between RM 8.9 and 7.3 was severely impacted by two avulsion events in the winter of 1995-1996 (Norman et al., 1998). During floods that surpassed the 100-year flow, the river avulsed through several large gravel pit ponds, mostly on the south side of the river. As a result, 4,900 feet of river channel was rerouted through a new, shorter path 10 feet deeper than the former channel (Norman et al., 1998).

A major velocity decrease occurs in Reach 9 compared to upstream. The river becomes more lentic (ponded) than lotic (flowing) which may affect temperature characteristics as well as groundwater exchange. The length of the reach may also be less now than shown on current USGS maps.

The river gained 10.1 cfs in the RM 8.9-7.3 reach during the August 2005 seepage survey, an increase of 12.5%. Most of this gain is probably due to water returning to the streambed after flowing out through the gravel bar at the top of the reach (Figure 19).

The maximum temperature profile for the river on July 30, 2005 (Figure 15) indicates a drop in temperature in the reach between RM 8.9 and 7.3. This could be due to both groundwater inflow and the deepened channel.

The channel is composed of the same alluvial materials as the upstream reach with glacial drift and fine-grained outburst flood deposits along the banks. Groundwater inflow is typical in this setting under baseflow conditions.

Vertical hydraulic gradients and hyporheic temperature results at RM 7.3 indicated gaining conditions throughout the summer and fall of 2005 (Figures 12 and 14).

A cross-section at RM 8 in Howard (2002) shows a shallow alluvial layer underlying the wider valley floor, which is in turn underlain by the Sand facies of the Troutdale Aquifer (comparable to the SGA of PGG (2003)). Connection to the deeper aquifer suggests gaining conditions under baseflow conditions.

Seepage Reach 10 (RM 7.3-4.6)

The August seepage survey indicated a 35.8% gain, or 13.3 cfs/RM, in Reach 10. A coinciding tidal survey on August 10, 2005 found a similar 35-40% increase in flow between RM 10.1 and RM 1.8. Springer (2009) found that the tidal bulge was not a significant influence on streamflow in Reach 10.

A cross-section at RM 5 showing a direct connection between the shallow alluvial deposits below the river and the SGA (PGG, 2003), suggests that the river receives groundwater under baseflow conditions along Reach 10.

VHGs and hyporheic temperatures at the upstream and downstream ends of the reach indicate gaining conditions with the exception of June 7, 2005 at RM 4.6 (Figures 12 and 14).

Seepage Reach 11 (RM 4.6-1.8)

Because streamflow at RM 1.8 is tidally affected, we could not estimate seepage. However, Springer (2009) found a 5% streamflow loss in this reach.

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Conclusions and Recommendations

Conclusions

Groundwater inflow and outflow along the East Fork Lewis River were evaluated using three methods: (1) seepage surveys, (2) vertical hydraulic gradient measurements, and (3) continuous streambed temperature measurements from instream piezometers. The seepage survey was the most comprehensive method used and provided broad-scale measurements. Vertical hydraulic gradients and streambed thermal profiles measured in the lower river provided localized indications of groundwater flow direction.

Geologic cross-sections of the river from previous studies indicate that the river is connected with the Sand and Gravel Aquifer in some parts of the lower East Fork Lewis River basin.

The locations and streamflow gains due to groundwater during the August 9-10, 2005 seepage survey are listed below.

- Reach 2: 6.1 cfs/mile
- Reach 7: 2.0 cfs/mile
- Reach 9: 6.3 cfs/mile
- Reach 10: 13.3 cfs/mile

The locations and streamflow losses due to groundwater during the August 9-10, 2005 seepage run are listed below.

- Reach 3: -3.8 cfs/mile
- Reach 8: -6.9 cfs/mile

The total streamflow gain measured on August 9-10, 2005 was 64 cfs, and the total streamflow loss was 18 cfs. Seventy-two percent of the total gains occurred in the lower two reaches. No significant gains or losses were observed in Reaches 1, 4, 5, and 6.

Groundwater seepage gains were larger in August 2005 than in October 1987 and 1988 in the area between RM 14.7 and 10.1 (combined Reach 6-7). Earlier timing in the water year of 2005 could explain the larger gains. Reach 3, which had previously been considered a strongly gaining reach, had no significant gain or loss in 2005. However, the flow from Rock Creek South, a major tributary in the reach, was omitted in the earlier flow balance calculations which could explain the difference.

Loss in streamflow was observed in Reach 8, despite indications that the river is connected with the Sand and Gravel Aquifer, the major source of flow to the river. The location of site RM 8.9 at the bend in the river is the likely cause for this loss, because water flows out of the river at the bend and returns at the bottom of the bend. Large withdrawals from public water supply wells, which are increasing in some areas, probably influence groundwater contributions to the river.

The mean temperature of inflowing groundwater represented by the deepest streambed thermistors located in gaining piezometers (RM 4.6, 7.3, and 10.1) ranged from 10.6° to 12.5°C. The temperature of groundwater seeping into the upper basin may differ from lower basin groundwater; however, measurements were not obtained because piezometers could not be hand-driven into the upper basin basalt. The highest maximum and mean temperatures in the gaining piezometers occurred in September and October 2005.

Recommendations

The following efforts are needed to refine estimates of the groundwater contribution to the East Fork Lewis River during baseflow conditions.

- Track and analyze water levels over time in the Sand and Gravel Aquifer, the main water source for the East Fork Lewis River.
- Determine where the river is directly connected with the Sand and Gravel Aquifer to help clarify where the river is probably gaining groundwater.

We also recommend that decision makers use information about the effects of current and future withdrawals (groundwater and surface water) on the East Fork Lewis River when making water rights decisions in the basin.

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Appendices

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Appendix A. Glossary, acronyms, and abbreviations

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

Advective flow: The transport of a solute by the bulk motion of flowing groundwater.

Alluvium: A general term for all sediment deposits resulting from the operation of modern rivers. The sediments laid down in river beds and flood plains. Often specifically refers to recent stream deposits.

Avulsion: A technical term for sediments moved from one spot to another due to flood.

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

Diurnal: Daytime only, as opposed to nocturnal or crepuscular.

EIM: Washington State Department of Ecology's Environmental Information Management System. The agency's online database for environmental data.

Gaining reach: A defined length of a river or stream that *gains* flow by seepage of water (inflow) *from* the adjacent groundwater system

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

Groundwater: Water in the subsurface that saturates the rocks and sediment in which it occurs. The upper surface of groundwater saturation is commonly termed the water table.

Hydraulic gradient: The difference in hydraulic head between two measuring points, divided by the distance between the two points.

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

Losing reach: A defined length of a river or stream that *loses* flow by seepage of water (outflow) *to* the adjacent groundwater system.

Nonpoint source: Unconfined and diffuse sources of contamination. Pollution that enters water from dispersed land-based or water-based activities. This includes, but is not limited to, atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System program.

Piezometer: A small-diameter, non-pumping well used to collect groundwater quality samples and hydraulic head measurements.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Reach: A specific portion or segment of a stream.

Seepage surveys: Surface water discharge balances.

Thermistor: An electronic device that uses semiconductors to measure temperature.

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

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
PGG	Pacific Groundwater Group
RM	River mile
RPD	Relative percent difference
SGA	Sand and Gravel Aquifer
SOP	Standard operating procedures
TMDL	Total Maximum Daily Load (water cleanup plan)
USGS	U.S. Geological Survey
VHG	Vertical hydraulic gradient
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet

Appendix B. Seepage survey results

Table B-1. Results for July 19, 2005 seepage survey.

Map ID	Mainstem East Fork Lewis River Measurement Station	Site ID	River Mile	Drainage Area** (mi^2)	Measured Date	Measured Discharge (cfs)	Net Seepage Gain or loss for reach (cfs)[1]	Net Seepage Gain or Loss for reach (%)	Net Seepage Gain or loss for reach (cfs/river mile)	Comments
K	EFLR at Sunset CG*	EFL32.3	32.3	30.50		34.20				
		Jack Mtn Cr		0.41	7/19/05	0.34				
		Anaconda Cr		1.42	7/19/05	1.41				
1		NNY		0.35	e	1.01				r^2 is 0.9233
		Copper Cr		15.10	7/19/05	23.20				
		NNX		0.21	e	0.81				r^2 is 0.9233
		Reinhardt Cr		0.14	7/19/05	0.41				Timed estimate of 3 culverts
		Nichols Cr		1.53	7/19/05	1.11				
	EFLR above King Creek	EFL29.0	29.3	51.60	7/19/05	68.64	6.2	18.0	2.1	
		King Cr		7.14	7/19/05	5.26				
		NNH		0.38	e	1.06				r^2 = 0.9233
		NNL		1.13	e	2.14				r^2 = 0.9233
2		Unnamed trib		0.42	e	1.11				r^2 = 0.9233
		Unnamed trib		0.35	e	1.01				r^2 = 0.9233
		Rogers Cr		1.81	7/21/05	4.47				Measured on 7/21
		Total Surface Water Rights				0.01				
	EFLR at Dole Valley Rd	EFL26.9	26.9	64.90	7/19/05	70.88	-12.8	-18.7	-5.3	
3		Rock Creek South RM3.9		12.50	7/19/05	16.08				
		Total Surface Water Rights				0.01				
	EFLR at Moulton Falls Park	EFL24.6	24.6	100.00	7/19/05	110.40	23.4	33.1	10.2	
		Big Tree Creek		18.70	7/19/05	16.38				
		Unnamed trib		0.20	e	0.80				r^2 = 0.9233
4		Unnamed trib		0.37	e	1.04				r^2 = 0.9233
		Unnamed trib		0.86	e	1.75				r^2 = 0.9233
		NNK		1.09		2.08				
	EFLR at USGS gage	EFL20.3	20.3	125.00		135.00	2.6	2.3	0.6	Daily average discharge
		Basket Creek		1.04	e	2.15				r^2 = 0.9233
		NNJ		1.26	e	2.33				r^2 = 0.9233
5		NNI		1.54	e	2.73				r^2 = 0.9233
		Rock Cr N		13.30	7/19/05	2.02				
		Total Surface Water Rights				0.02				
	EFLR at Shultz residence	EFL14.7	14.7	150.00	7/19/05	141.47	-6.8	-5.0	-1.2	
6		Total Surface Water Rights				0.22				
	EFLR at Lewisville Park	EFL13.2	13.2	151.00	7/19/05	141.41	-0.3	-0.2	-0.2	
7		NNG		1.46						
	EFLR at Daybreak*	EFL10.1	10.1	156.00		143.00	1.6	1.1	0.5	
		Mill Creek North		3.54	7/19/05	0.84				
8		Manley Rd Cr			7/19/05	0.55				
		Total Surface Water Rights				2.43				
	EFLR above Ridgefield pits	EFL08.9	8.9	161.00	7/19/05	136.77	-10.0	-7.0	-8.4	Average of two measurements
		NNF		2.83	e	0.60				r^2 = 0.9482
9		Dean Cr		4.91		NM				field notes said no flow
		Total Surface Water Rights				1.36				
	EFLR below Dean Creek	EFL07.3	7.3	166.00	7/19/05	133.95	-4.8	-3.5	-3.0	
		Mason Cr		11.10	7/19/05	0.99				
10		Unnamed trib		1.43	e	0.16				r^2 = 0.9482
		NNB		1.14	e	0.07				r^2 = 0.9482
	EFLR above Lockwood*	EFL04.6	4.6	184.00		180.00	44.8	33.5	16.6	Possible discharge measure-
		Lockwood Cr		10.20	7/19/05	2.93				ment error due to tidal bulge.
11		Brezee Cr		3.44	7/19/05	1.06				
		McCormick Cr		3.99	7/19/05	0.22				
A1	EFLR near mouth	EFL01.8	1.5	206.00		Discharge measurement unreliable due to Columbia River tidal bulge				
		Jenny Cr		4.00	7/19/05	0.65				
		Total Surface Water Rights				5.01				

* Stream Discharge measured by Department of Ecology Stream Hydrology Unit.
** Calculated using the USGS tool StreamStats and based on the upstream area from the point of flow measurement. This software tool can be found in the internet at: http://streamstats.usgs.gov/html/Washington.html.
e = estimated value using a linear regression of drainage areas and measured discharges for similar streams.
NM = Not Measureable. No streamflow or too small to measure. [1] Net Seepage Gain or Loss (%) = (Net gain/loss between upstream and downstream)/ (Upstream flow) X 100.

Table B-2. Results for August 9-11, 2005 seepage run.

Map ID	Mainstem East Fork Lewis River Measurement Station	Site ID	Mainstem River Mile	Drainage Area** (mi^2)	Measured Date	Measured Discharge (cfs)	Net Seepage Gain or loss for reach (cfs)	Net Seepage Gain or Loss for reach (%)[1]	Net Seepage Gain or loss for reach (cfs/river mile)	Is seepage significant? (Konrad et al, 2003)	Comments
	EFLR at Sunset CG*	EFL32.3	32.3	30.50	8/10/05	22.60					
		Jack Mtn Cr		0.41	8/10/05	0.27					
		Anaconda Cr***		1.42	8/10/05	0.39					
		NNY		0.35	8/10/05	0.05					
1		Copper Cr		15.10	8/9/05	11.82					
		NNX		0.21	8/10/05	0.09					
		Reinhardt Cr		0.14	8/10/05	0.09					
		Nichols Cr		1.53	8/11/05	1.11					
	EFLR above King Creek	EFL29.0	29.0	51.60	8/10/05	36.13	-0.3	-1.2	-0.1	No	
		King Cr		7.14	8/10/05	2.78					
		NNH		0.38	8/11/05	0.64					
		NNL		1.13	e	0.55					r^2 = 0.9436
2		Unnamed trib		0.42	e	0.03					r^2 = 0.9436
		Unnamed trib		0.35	e	0.00					r^2 = 0.9436
		Rogers Cr		1.81	8/9/05	0.85					
		Total Surface Water Rights				0.01					
	EFLR at Dole Valley Rd	EFL26.9	27.0	64.90	8/9/05	53.17	12.2	33.7	6.1	Yes	
3		Rock Cr South RM3.9		12.50	8/9/05	28.10					Estimated value
		Total Surface Water Rights				0.01					
	EFLR at Moulton Falls Park	EFL24.7	24.6	100.00	8/9/05	72.08	-9.2	-17.2	-3.8	Yes	
		Big Tree Cr		18.70	8/9/05	8.18					
		Unnamed trib		0.20	e	0.00					r^2 = 0.9436
4		Unnamed trib		0.37	e	0.00					r^2 = 0.9436
		Unnamed trib		0.86	e	0.35					r^2 = 0.9436
		NNK		1.09	e	0.52					r^2 = 0.9436
	EFLR at USGS gage	EFL20.3	20.3	125.00		81.00	-0.1	-0.2	0.0	No	USGS gage data
		Basket Creek		1.04	e	0.56					r^2 = 0.9436
		NNJ		1.26	e	0.64					r^2 = 0.9436
5		NNI		1.54	e	0.85					r^2 = 0.9436
		Rock Cr N		13.30	8/9/05	0.38					
		Total Surface Water Rights				0.02					
	EFLR at Shultz residence	EFL14.7	14.7	150.00	8/9/05	81.53	-1.9	-2.4	-0.3	No	
6		Total Surface Water Rights				0.22					
	EFLR at Lewisville Park	EFL13.0	13.2	151.00	8/9/05	82.96	1.2	1.5	0.8	No	
7		NNG		1.46		NM					
	EFLR at Daybreak*	EFL10.1	10.1	156.00	8/9/05	89.10	6.1	7.4	2.0	Yes	
		Manley Rd Cr				NM					
8		Mill Creek North		3.54		NM					
		Total Surface Water Rights									
	EFLR above Ridgefield pits	EFL08.9	8.9	161.00	8/9/05	80.77	-8.3	-9.4	-6.9	Yes	
		NNF		2.83		NM					
9		Dean Cr		4.91		NM					
		Total Surface Water Rights				1.36					
	EFLR below Dean Creek	EFL07.3	7.3	166.00	8/9/05	92.20	10.1	12.5	6.3	Yes	
		Mason Cr		11.10		NM					r^2 too low for estimation
10		Unnamed trib		1.43							r^2 too low for estimation
		NNB		1.14							r^2 too low for estimation
	EFLR above Lockwood*	EFL04.6	4.6	184.00	8/9/05	128.0	35.8	38.8	13.3	Yes	
		Lockwood Cr		10.20	8/9/05	1.28					Measured by Ecology SHU.
11		Brezee Cr		3.44	8/9/05	0.91					
		McCormick Cr		3.99							r^2 too low for estimation
	EFLR near mouth	EFL01.8	1.8	206.00	8/10/05	120	-10.2	-8.0	-3.6	Yes	Baseflow measured by
		Jenny Cr		4.00	8/9/05	0.50					Ecology EAP SHU.
		Total Surface Water Rights				5.01					

* Stream Discharge measured by Ecology EAP Stream Hydrology Unit.
** Calculated using the USGS tool StreamStats and based on the upstream area from the point of flow measurement. This software tool can be found in the internet at: http://streamstats.usgs.gov/html/Washington.html.
*** Culvert flow calculated using the streamflow calculator a: http://hachflow.com/flow_calc.html
e = estimated value based on linear regression of drainage areas and measured discharges for similar streams.
NM = Not Measureable. No streamflow or too small to measure. [1] Net Seepage Gain or Loss (%)= (Net gain/loss between upstream and downstream)/ (Upstream flow) X 100.

Appendix C. Piezometer information

Table C-1. Locations and construction information recorded during construction on June 6-8, 2005.

ID	Site description	Latitude (DD)	Longitude (DD)	River mile (mile)	Piezometer stick-up above streambed (feet)	Piezometer stick-up below streambed (feet)	Depth to mid-point of piezometer perforations (feet below streambed)[1]	Thermistor depths in piezometer (feet below streambed)
27-EFL-01.8	EF Lewis near mouth	45.86655	-122.69446	1.8	4.81	4.66	4.41	0.41 2.26 4.66
27-EFL-04.6	EF Lewis near Lockwood Creek	45.85060	-122.65628	4.6	4.47	4.79	4.54	0.82 2.91 4.41
27-EFL-07.3	EF Lewis downstream of gravel pits	45.82976	-122.83876	7.3	3.51	3.82	3.57	0.76 1.86 3.72
27-EFL-10.1	EF Lewis at Daybreak Park	45.81422	-122.59273	10.1	4.77	4.60	4.35	0.60 2.18 4.48

[1] Piezometer perforated interval was 0.5 foot long. Perforations consisted of twelve 0.19-inch holes.

Appendix D. Quality assurance

Seepage surveys

Results of within-team and between-team replicate streamflow measurements are shown in Tables D-1 (July 2005) and D-2 (August 2005). Within-team replicates were conducted by the same two people, one measurement immediately following the first. Between-team replicates were conducted by two different teams 1.5-5 hours apart. We did not measure between-team variability during the August seepage survey.

Table D-1. Relative percent differences (RPDs) between replicate streamflow measurements within teams (W) and between teams (B) on July 19, 2005.

Site ID	Time	Measured Discharge (cfs)	Mean Discharge (cfs)	Area (ft^2)	Wetted Width (ft)	Average Velocity (ft/s)	Average Depth (ft)	RPD[1]
27BRZ (W)	13:32 13:15	1.02 1.09	-- 1.06	4.07 4.13	10.70 10.70	0.25 0.26	0.38 0.39	6.7
EFL07.5[2] (B)	10:10 11:28	92.74 133.95	-- 113.35	138.39 128.50	77.60 76.90	0.67 1.04	1.78 1.67	36.4
EFL08.1 (B)	14:40 9:45	132.20 141.35	-- 136.77	88.91 80.01	73.00 70.51	1.49 1.77	1.22 1.13	6.7
27NNE(W)	15:35 16:00	0.84 0.84	-- 0.84	2.26 2.55	12.49 12.49	0.37 0.33	0.18 0.20	0.4
27RKN (B)	13:30 10:00	1.98 2.05	-- 2.02	19.56 19.05	16.60 19.70	0.10 0.11	1.18 0.97	3.6
27ANA (W)	11:39 11:58	1.53 1.28	-- 1.41	4.55 2.78	13.00 13.00	0.34 0.46	0.35 0.21	17.7

[1] Relative percent difference = (Discharge 1- Discharge 2)/(Discharge 1 + Discharge 2) x 200.
[2] Streamflow was measured in slightly different locations.
Bold values exceed the 10% threshold for RPD acceptance.

Table D-2. Relative percent differences (RPDs) between flow measurements within teams on August 9, 2005.

Site ID	Time	Measured Discharge (cfs)	Mean Discharge (cfs)	Area (ft2)	Wetted Width (ft)	Average Velocity (ft/s)	Average Depth (ft)	RPD
27RKS03.9	11:25 11:00	10.77 10.28	-- 10.53	25.64 24.33	28.00 27.80	0.42 0.42	0.93 0.95	4.6
27JEN	11:05 11:19	0.45 0.50	-- 0.48	0.90 0.96	5.60 5.50	0.50 0.52	0.17 0.19	9.9

[1] Relative percent difference = (Discharge 1- Discharge 2)/(Discharge 1 + Discharge 2) x 200.
Bold values exceed the 10% threshold for RPD acceptance.

The relative percent difference (RPD) between replicates was used to evaluate variability. Although the project quality assurance plan did not specify an acceptance threshold for streamflow RPD, we chose 10%. This was the figure used by Sinclair and Bilhimer (2007) for a similar analysis on the Deschutes River. All but two of the eight replicates met the criteria for acceptance. Both replicates that exceeded the accepted RPD were measured on July 19, 2005, one between teams and one within teams. One of the between-team measurements that exceeded the acceptance level was conducted using a flow meter provided by a generous volunteer, but the calibration status was not documented.

Because we focused on the August 9-10, 2005 seepage survey data, we used the RPDs for this date in the analysis. The streamflow at 27RKS03.9 (Rock Creek RM 3.9), 10-11 cfs, was considered most representative of streamflows used in the seepage analysis. The streamflow at the other site where within-team measurements were made, 0.5 cfs at Jenny Creek, was lower than most of the seepage sites. Therefore, we considered the RPD for the Rock Creek site, 4.6%, the most representative measure of variability for seepage estimates. The RPD for the acceptable sites measured in July 2005 were in the same range (0.4-6.7%). The 4.6% RPD was used to evaluate the uncertainty of gains and losses in the Results section of this report.

Streambed sediment thermal profiles—thermistor calibration

Thermistors were tested for accuracy before and after use to ensure that they met accuracy requirements for the study. The manufacturer specifications for the thermistors are shown in Table D-3.

Table D-3. StowAway Tidbit© thermistor manufacturer specifications.

Temperature Range	Reported Accuracy	Reported Resolution
-5°C to +37°C	+/- 0.2^0 C at 21°C	0.16°C
-20°C to +50°C	+/- 0.4^0 C at 21°C	0.3°C

Tests were conducted by placing the thermistors in a room temperature bath that was constantly stirred and allowed to equilibrate. The thermistors were pre-programmed to record measurements every one minute. A National Institute of Standards and Technology (NIST) certified reference thermometer was used to measure the temperature in the water bath manually every one minute for 10 minutes for comparison.

The thermistors were then transferred to a stirred ice bath, where they were again allowed to equilibrate. The NIST thermometer was again used to compare measurements every one minute for 10 minutes.

Mean temperature values were calculated for each thermistor from the 10 paired-reference measurements for each temperature bath. The mean temperature for each thermistor and bath was compared to the corresponding NIST reference temperature. Differences were compared to manufacturer specifications to assess thermistor accuracy as shown in Table D-4.

All of the thermistors with data fell within the manufacturer's acceptable range for both the ice bath and warm water bath before deployment (+/- 0.2°C of the corresponding NIST reference temperature). Pre-calibration data were not available for three thermistors. All thermistors with data available met the post-calibration warm bath standard, but seven did not meet the ice bath standard. Because the thermistor study was conducted during the warm summer months, the data from all the thermistors were considered acceptable. Post-calibration data were not available for seven thermistors.

Kardouni (2009) found that less than 2% of hundreds of StowAway Tidbit© thermistor calibrations did not meet post-calibration accuracy of 0.2°C in warm-water baths. Therefore, data from thermistors lacking calibration data are considered reliable for this study. However, data without calibration information will be qualified as estimates in the Ecology EIM database.

Table D-4. Comparison of water bath calibration results with manufacturer specifications. Pre- and post-calibration values represent the average deviation of 10 thermistor measurements from the NIST thermometer.

RM	Name of site	Depth	Serial number	Pre-calibration		Post-calibration	
1.8	Near Mouth	Top	804105	Ice	0.11	Ice	-0.42
				Warm	0.06	Warm	-0.05
						Warm	0.05
		Middle	804091	Ice	0.07	Ice	-0.51
				Warm	-0.02	Warm	-0.12
						Warm	-0.04
		Bottom	867853	Ice	No data	Ice	No data
				Warm	No data	Warm	No data
		Surface Water	804098	Ice	0.06	Ice	No data
				Warm	-0.01	Warm	No data
4.6	Lockwood Creek	Top	804101	Ice	0.03	Ice	-0.54
				Warm	-0.06	Warm	-0.16
						Warm	-0.09
		Middle	804099	Ice	0.00	Ice	No data
				Warm	-0.09	Warm	No data
		Bottom	804108	Ice	0.10	Ice	No data
				Warm	0.03	Warm	No data
		Surface Water	804097	Ice	0.12	Ice	No data
				Warm	0.07	Warm	No data
7.3	Airfield	Top	767065	Ice	0.10	Ice	0.47
				Warm	-0.04	Warm	-0.03
		Middle	767052	Ice	0.03	Ice	0.69
				Warm	-0.03	Warm	-0.02
		Bottom	867602	Ice	No data	Ice	No data
				Warm	No data	Warm	No data
		Surface Water	598749	Ice	-0.07	Ice	0.08
				Warm	-0.02	Warm	-0.05
10.1	Daybreak Park	Top	767071	Ice	0.11	Ice	0.22
				Warm	0.02	Warm	0.04
		Middle	767049	Ice	-0.01	Ice	0.16
				Warm	-0.06	Warm	-0.06
		Bottom	867602	Ice	No data	Ice	No data
				Warm		Warm	No data
		Surface Water	767054	Ice	0.14	Ice	1.1
				Warm	0.07	Warm	0.07

Appendix E. Piezometer results.

Table E-1. Field data and vertical hydraulic gradients.

Location	River Mile	Well ID	Date	River Temperature (C°)	Groundwater Temperature (C°)	Ground water Depth (ft)[1]	River Level (ft)[1]	dh=difference between groundwater and river levels (ft)	dl=distance from streambed to mid-point of sampler perforations (ft)	Vertical Hydraulic Gradient dh/dl (ft/ft)
Gage near mouth	1.8	AKY 476	6/7/05	11.4	11.5	1.51	1.55	0.04	4.41	0.009
Lockwood Creek	4.6	AKY 477	6/7/05	12.0	11.7	2.17	2.15	-0.02	4.54	-0.004
Airfield	7.3	AKY 478	6/7/05	12.1/12.7	11.3	0.31	0.43	0.12	3.57	0.034
Daybreak Park	10.1	AKY 479	6/7/05	12.1/12.4	11.2	2.31	2.33	0.02	4.35	0.005
Gage near mouth	1.8	AKY 476	7/11/05	18.6	13.3	1.17	1.26	0.10	4.41	0.022
Lockwood Creek	4.6	AKY 477	7/11/05	16.7	11.5	1.25	1.31	0.05	4.54	0.012
Airfield	7.3	AKY 478	7/18/05	21.8	11.1	1.54	1.61	0.07	3.57	0.020
Daybreak Park	10.1	AKY 479	7/19/05	21.8	12.1	3.11	3.07	-0.04	4.35	-0.009
Gage near mouth	1.8	AKY 476	8/22/05	21.0	16.5	1.35	1.26	-0.09	4.41	-0.020
Lockwood Creek	4.6	AKY 477	NA	NA	NA	NA	NA	NA	NA	NA
Airfield	7.3	AKY 478	8/22/05	20.9	11.5	1.96	2.10	0.14	3.57	0.039
Daybreak Park	10.1	AKY 479	8/22/05	20.5	12.8	1.15	1.17	0.02	4.35	0.005
Gage near mouth	1.8	AKY 476	10/5/05	13.6	14.6	1.62	1.95	0.33	4.41	0.075
Lockwood Creek	4.6	AKY 477	10/5/05	12.3	11.6	1.77	1.83	0.06	4.54	0.013
Airfield	7.3	AKY 478	10/5/05	12.7	11.6	1.70	1.83	0.13	3.57	0.036
Daybreak Park	10.1	AKY 479	10/5/05	11.6	12.4	0.99	1.00	0.01	4.35	0.002

[1] Depth to water in feet below the top of piezometer casing.