Inland Empire Paper Company Nutrients and Common Ions

Source Water Study

June 2016

Publication No. 16-03-023

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and contact information

This report is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1603023.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search Study ID JROS0022.

The Activity Tracker Code for this study is 13-008.

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Cover photo: Bing aerial photograph of the Inland Empire Paper Company, Millwood, WA.

Inland Empire Paper Company
Nutrients and Common Ions

Source Water Study

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

- WRIA: 57 – Middle Spokane
- HUC number: 17010305

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Abstract

In May 2010, the U.S. Environmental Protection Agency approved a dissolved oxygen total maximum dissolved load (TMDL) assessment for Lake Spokane and the Spokane River (Moore and Ross, 2010). As a consequence of the TMDL, wasteload allocations for point source discharges, which include the phosphorus discharge limits for Inland Empire Paper Company (IEP), were significantly reduced.

During the comment period for their most recent permit revision in 2011, IEP requested that their non-contact cooling water (NCCW) be exempted from their phosphorus discharge limits. The NCCW is pumped from wells located within a few hundred feet of the Spokane River. Therefore the Spokane River likely contributes a natural phosphorus load to the groundwater that IEP uses for its NCCW. The Washington State Department of Ecology (Ecology) agreed to work with IEP to formally evaluate the relationship between the river and underlying aquifer at the IEP facility.

Ecology collected surface water and groundwater data from 10 sites along and within the IEP facility during 2012-2013. These data were analyzed to (1) determine whether an allowance for phosphorus in the NCCW is appropriate and (2) provide recommendations for future revisions to IEP's National Pollutant Discharge Elimination System (NPDES) permit.

A mixing model was employed to calculate the volume fraction of river water pumped by IEP's NCCW production well. It appears that an allowance addressing this fraction of river water phosphorus load is appropriate.

Acknowledgements

We thank the following people for their contributions to this study:

- Doug Krapas, Chris Averyt, Travis Hall, and Ryan Ekre – Inland Empire Paper Company
- Cleve McCoul and Tom Richardson – City of Millwood
- Jacob McCann – Washington State Department of Fish and Wildlife
- Washington State Department of Ecology staff:
    - Jim Ross, Andy Albrecht, Brian Gallagher, Martha Maggi, Bill Kammin, Joan LeTourneau, and Cindy Cook – Environmental Assessment Program
    - Pat Hallinan and Dave Knight – Water Quality Program
    - Nancy Rosenbower, Dean Momohara, Meredith Jones, and Leon Weiks – Manchester Environmental Laboratory

Introduction

In May 2010, the U.S. Environmental Protection Agency (EPA) approved a dissolved oxygen (DO) total maximum dissolved load (TMDL) assessment for Lake Spokane and the Spokane River (Moore and Ross, 2010). Both the lake and river have a history of DO problems, particularly during April through October when streamflow is typically lowest. These problems originate from nutrient inputs, especially phosphorus, which causes excessive aquatic plant growth that contributes to depressed DO concentrations in the lake (Cusimano, 2004).

To support implementation of the Spokane River TMDL, the Washington State Department of Ecology (Ecology) has begun the process of modifying the discharge permits and wasteload allocations for five facilities that discharge to the Spokane River between Lake Spokane and the Washington-Idaho border. One of these is the Inland Empire Paper Company (IEP) industrial wastewater treatment plant (IWTP) at Millwood, Washington (Figure 1).

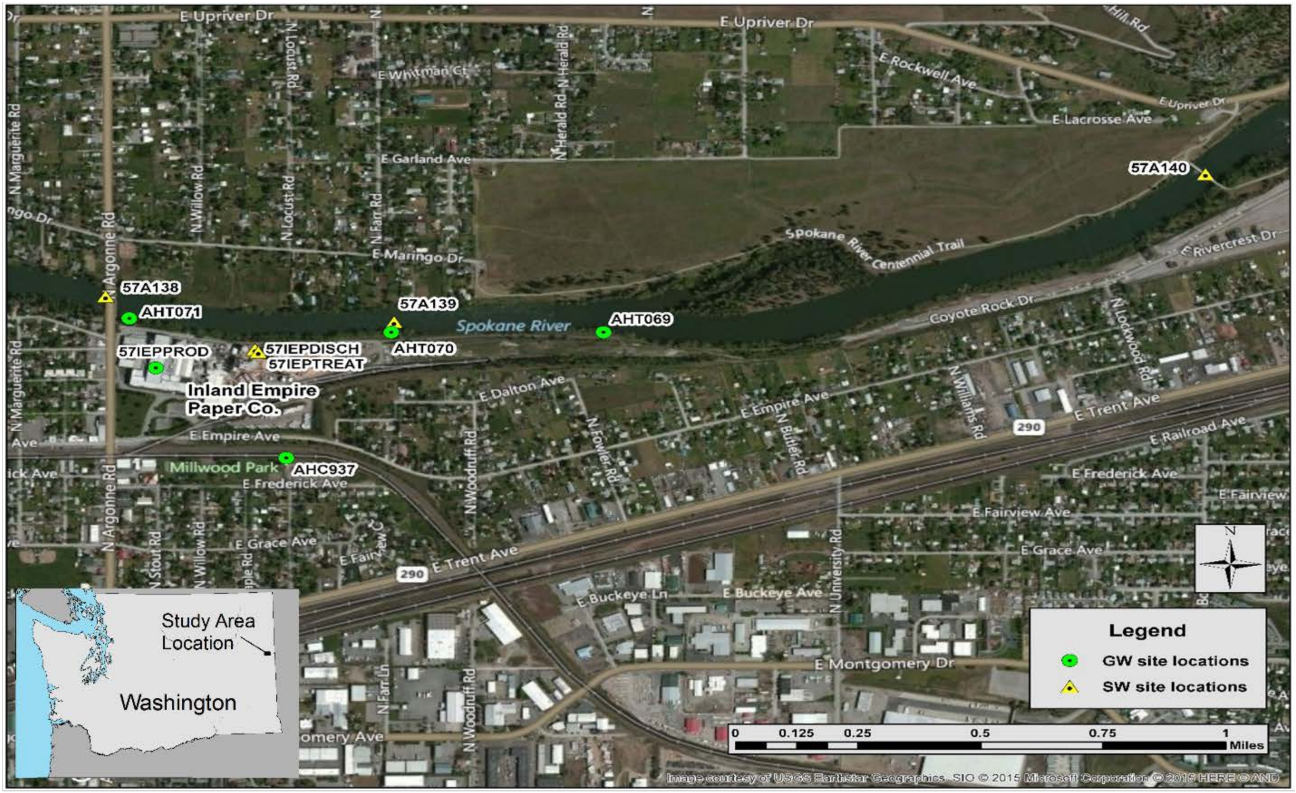

Figure 1. General location of project study area and sampling sites.

During the comment period for their most recent permit revision in 2011, IEP requested that their non-contact cooling water (NCCW) be exempted from (not count against) their phosphorus discharge limit. IEP based its request on the following factors:

- A significant portion of IEP's total discharge volume is NCCW comprised of groundwater pumped from well(s) located within a few hundred feet of the Spokane River.
- Past studies of the Spokane River suggest that IEP's Millwood facility is likely located along a losing reach where the river naturally recharges the underlying aquifer (Kahle and Bartolino, 2007; Kahle et al., 2005).
- The Spokane River likely contributes phosphorus to the groundwater IEP uses for its NCCW.
- Since the river and aquifer are thought to be hydraulically connected, IEP asserts it should not be responsible for mitigating the phosphorus contained in its NCCW.

In response to the above request, Ecology agreed to work with IEP to formally evaluate the relationship between the Spokane River and underlying aquifer at the IEP facility during at least one critical season (February through October). Depending on the study outcome, Ecology also agreed to consider an allowance for nutrient concentrations in the facility's NCCW, to the extent nutrient concentrations in groundwater at the IEP site are equivalent to those in the river upstream of the site. Full details of the final permit for IEP and responses to comments can be found at the following Ecology web page: Facility Summary: Inland Empire Paper Company

This report documents the field investigations and data evaluation that were undertaken by Ecology and IEP to support the above agreement.

Study Goal and Objectives

The primary goal of this study was to determine whether the cooling water extracted by the IEP supply well(s) is chemically similar to Spokane River water in the vicinity of the plant.

During this study, a variety of field techniques were employed to meet three technical objectives:

- Characterize the direction and magnitude of the hydraulic connection between the Spokane River and the underlying aquifer at the IEP facility.
- Collect monthly water quality samples from the IEP supply well(s) and the Spokane River for one year.
- Perform an evaluation of the study water quality results based on the river/aquifer interactions determined in the first objective above.

The results of this study will be used by Ecology's Water Quality Program to calculate potential nutrient allowance(s) during future revisions to IEP's NPDES permit.

Study Methods

Ecology used a combination of field measurements and water quality evaluations to determine whether the cooling water extracted by the IEP supply well is chemically similar to, and hydraulically connected with, the Spokane River in the vicinity of the IEP Millwood facility. The study methods are summarized below by principal activity and are described in detail in the *Quality Assurance Project Plan: Inland Empire Paper Company Nutrients and Common Ions Source Water Study* (Ross, 2012).

Ten sites were sampled for this evaluation: three surface water sites on the Spokane River, two sites for effluent within the IEP facility, and five groundwater wells which included three instream piezometers (Table 1, Figures 1-2).

Table 1. List of sampling sites.

Location ID	Sample Type	Sample Frequency	Location Description	Longitude (NAD83)	Latitude (NAD83)
57A138	surface water	monthly	Spokane R. downstream of IEP facility at Argonne Rd bridge	-117.2829	47.6899
57A139	surface water	monthly	Spokane R. at IEP facility (upstream of IEP discharge)	-117.2737	47.6893
57A140	surface water	monthly	Spokane R. at Centennial Trail bridge crossing off Upriver Dr.	-117.2504	47.6929
57IEPDISCH	IEP effluent	monthly	IEP combined discharge to Spokane R.	-117.2785	47.6885
57IEPTREAT	IEP effluent	monthly	IEP treated effluent just prior to mixing with NCCW	-117.2784	47.6885
57IEPPROD	groundwater	monthly	IEP NCCW well located inside the facility	-117.2820	47.6886
AHC937	groundwater	periodic	City of Millwood well at the NE corner of the park	-117.2775	47.6858
AHT069	groundwater	periodic	Instream piezometer upstream of IEP well at RM 83.3	-117.2682	47.6890
AHT070	groundwater	periodic	Instream piezometer upstream of IEP well at RM 83.0	-117.2744	47.6890
AHT071	groundwater	periodic	Instream piezometer downstream of IEP well at RM 82.6	-117.2822	47.6893

RM: river mile

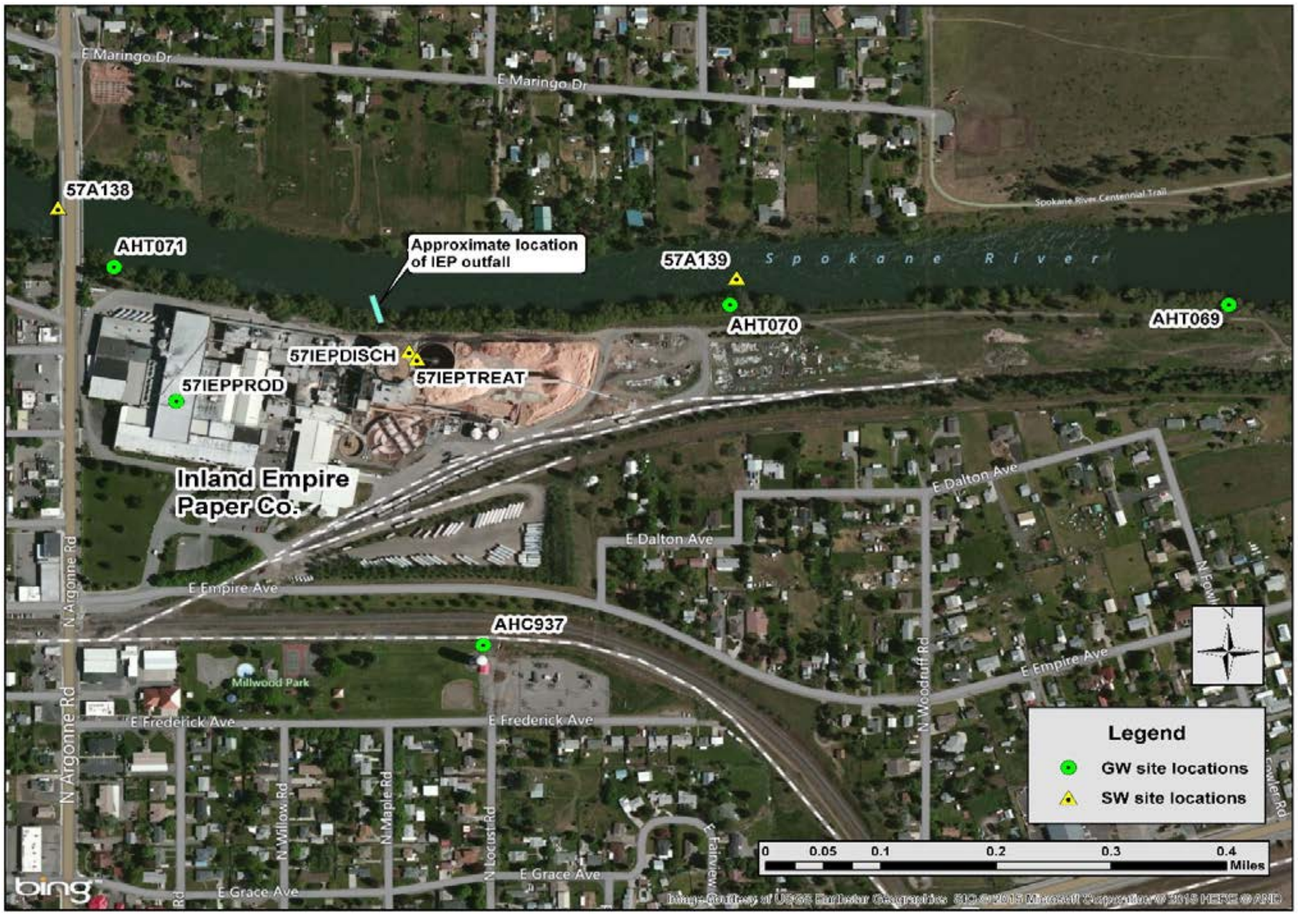

Figure 2. Detail of IEP facility and sampling site.

Instream Piezometer Installation and Measurement

In early August 2012, Ecology installed three shallow instream piezometers within the active channel of the Spokane River, near the IEP facility. The piezometers were manually driven into the streambed to a maximum depth of about 5 feet, using methods described by Sinclair and Pitz (2013). The piezometers consisted of an upper removable pipe section (or extension) and a lower 5-foot section of 1.5-inch diameter galvanized pipe (Figure 3). Each piezometer was constructed with a short, perforated open-interval at the base of the pipe. The piezometers were used to monitor surface-water/groundwater head relationships, streambed water temperatures, and near-stream groundwater quality at discrete points along the river (Figure 2). The piezometer locations were recorded on field maps at the time of construction. These positions and coordinates were later refined using geo-rectified digital orthophotography.

The piezometers were developed after installation with a manual bladder-type bilge pump to ensure a good hydraulic connection with the streambed sediments. The piezometers were accessed monthly to make comparative stream and groundwater hydraulic head measurements. The stream stage (hydraulic head) was measured by aligning an engineer's tape parallel to the piezometer pipe and measuring the distance from the stream water surface to the top of the piezometer casing. The groundwater level inside the piezometer was measured from the same reference point, using a calibrated low-displacement E-tape or steel hand tape (Marti, 2009). A manometer board was used for measurements during high streamflow when the piezometers were not accessible. For angled (off-vertical) piezometers, these "raw" values were corrected using simple trigonometric relationships to obtain true (angle normalized) depth-to-water measurements.

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

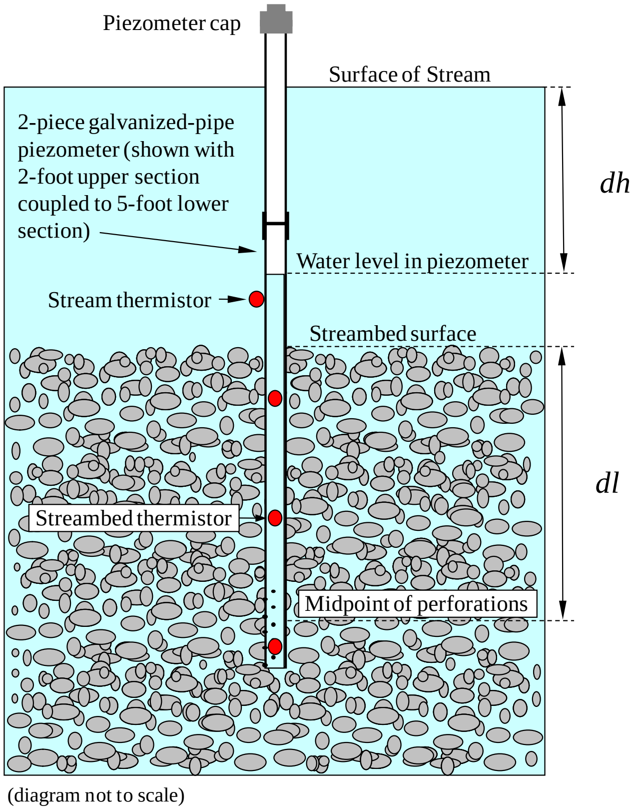

Figure 3. Schematic of a typical instream piezometer and thermistor array.

Equation 2 was used to derive vertical hydraulic gradients for each piezometer, from the paired groundwater level and stream stage measurements. Converting the field-measured water levels to hydraulic gradients normalizes for differences in piezometer depth and screen interval between sites, thereby enabling direct comparisons to be drawn between piezometers.

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

where:

i_v is vertical hydraulic gradient (dimensionless),

dh is the difference in head between the river stage and instream piezometer water level (L),

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

where (L) represents units of length.

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

Thermal Monitoring

Streams and rivers commonly experience pronounced (several degree) daily fluctuations in water temperature due to variations in atmospheric and solar heating over the course of a day. In contrast, groundwater generally shows little if any diurnal temperature variability since it is typically insulated from the sun and atmosphere by overlying rock or sediment. These differences in daily temperature patterns, between a stream and near-surface groundwater, can be monitored to provide secondary confirmation of the surface-water/groundwater interactions inferred from periodic hydraulic gradient measurements (Stonestrom and Constantz, 2003).

For this project, we instrumented each instream piezometer with three recording thermistors (Onset Computer Corp. HOBO Pro^{TM} v.1) to monitor groundwater temperatures within the upper 5 feet of the streambed sediments[1]. One thermistor was located near the piezometer bottom within the perforated interval of the pipe, one approximately 1.5 feet below the streambed, and one roughly equidistant between the upper and lower thermistors. A fourth thermistor was mounted to the outside of the piezometer to monitor the river temperature (Figure 3).

At piezometer sites where streambed water temperatures are highly dampened, relative to instream temperatures, one can infer that groundwater is moving upward through the streambed and discharging to the stream (a gaining stream reach) (Figure 4A). Conversely, at sites where streambed water temperatures closely mimic those of the stream, one can infer that water is leaving the stream and moving down into the streambed at that location (a connected losing reach) (Stonestrom and Constantz, 2003) (Figure 4B).

In some situations, perennial rivers and streams can become separated from the underlying water table (either seasonally or permanently) by an intervening zone of unsaturated sediments (Figure 4C). When this occurs, the streambed thermal profile may show seasonal temperature differences similar to those of a connected losing stream. However, the diurnal variability may be muted and significantly subdued relative to that of a connected losing stream or river.

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[1] The thermistors were programmed to monitor water temperatures on a synchronized 30-minute cycle and were deployed during piezometer installation in early August 2012. All thermistors were calibrated pre- and post-deployment against a certified NIST reference thermometer to confirm accuracy and quantify potential drift. HOBO Pro^{TM} thermistors are typically accurate to approximately ± 0.2 °C.

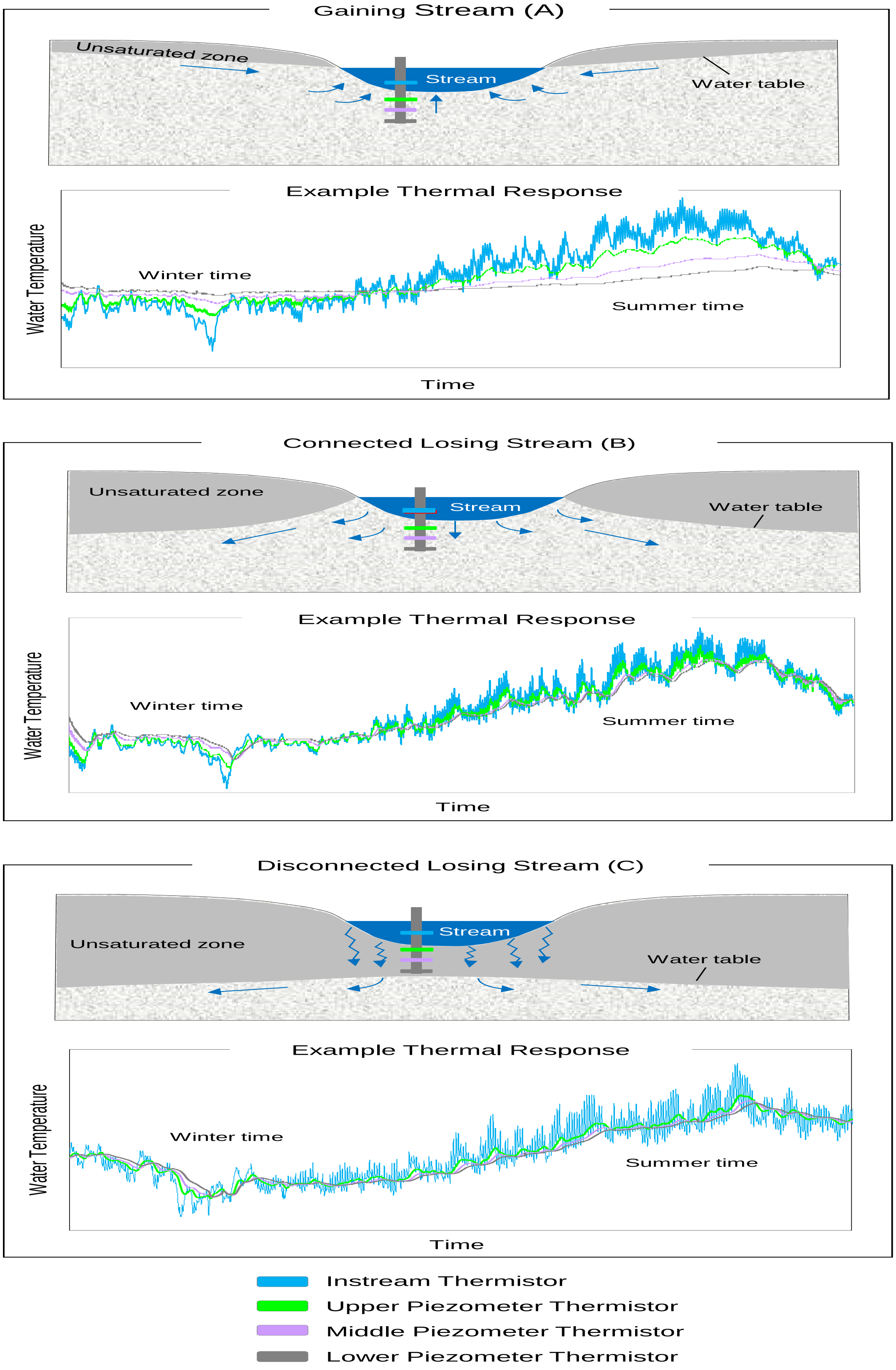

Figure 4. Example streambed thermal response for a perennial gaining (A) and losing (B and C) stream.

Water Quality Sampling

From April 2012 through September 2013, Ecology collected monthly surface water samples at three sites along the Spokane River. Samples of IEP's treated effluent and combined discharge were also collected during these visits, as were groundwater samples from IEP's production well. In addition, groundwater samples were periodically collected, when conditions allowed, from an off-site well and three instream piezometers (Table 1, Figures 1 and 2). All sites were sampled for a common set of field parameters and laboratory analyzed constituents (Table 2). Field measurement methods followed Ecology's Environmental Assessment Program (EAP) standard operating procedures (Swanson, 2007).

Table 2. Target analytes, test methods, and reporting limits.

Parameter	Method	Reporting Limit
Field Measurements		
pH	Hydrolab®	1 - 14 s.u.*
Temperature	Hydrolab®	1 - 40 °C
Dissolved Oxygen	Hydrolab®	0.1 - 15 mg/L
Specific Conductance	Hydrolab®	1 µS/cm
Laboratory Analyses		
Total Reactive Phosphorus	SM 4500-P G	0.003 mg/L
Orthophosphate-P[1]	SM 4500-P G	0.003 mg/L
Total Phosphorus	SM 4500-P F	0.005 mg/L
Total Dissolved Phosphorus[1]	SM 4500-P F	0.005 mg/L
Alkalinity[1]	SM 2320B	1 mg/L
Chloride[1]	EPA 300	0.1 mg/L
Sulfate[1]	EPA 300	0.1 mg/L
Nitrate[1]	EPA 300	0.1 mg/L
Calcium[1]	EPA 200.7	0.05 mg/L
Magnesium[1]	EPA 200.7	0.05 mg/L
Sodium[1]	EPA 200.7	0.05 mg/L
Potassium[1]	EPA 200.7	0.5 mg/L
Iron[1]	EPA 200.7	0.05 mg/L
Silicon[1]	EPA 200.7	0.05 mg/L

* Standard units
[1] Dissolved sample fraction

Surface Water Quality

Water samples from the Spokane River at the Centennial Trail bridge (site 57A140) and Argonne Road bridge (site 57A138) were initially collected in clean laboratory-supplied poly bottles and were subsequently transferred or filtered into analyte-specific sample containers. Samples at the third Spokane River site (57A139) and at the IEP treated effluent (57IEPTREAT) and combined discharge (57IEPDISCH) sites were collected using a peristaltic pump and laboratory-grade polyethylene tubing. To facilitate deployment, the polyethylene tubing was either temporarily inserted into a piece of rigid PVC pipe (sites 57A139 and 57IEPTREAT) or deployed with stainless-steel weights (site 57IEPDISCH) to enable the tubing intake to be safely placed at the desired sampling location.

A Hydrolab DataSonde® was used to measure water temperature, specific conductivity, pH, and DO concentrations at each site, prior to commencing sample collection. A peristaltic pump and flow cell were used to facilitate these measurements at site 57IEPDISCH, since the Hydrolab could not be safely lowered into the water column at this location.

All surface water samples, with the exception of total phosphorus and total reactive phosphorus, were filtered during collection using a new QED™ 0.45 micron inline capsule filter. A minimum of 200 mL of water was purged through the filter and discarded before filling the first sample bottle. Filled sample bottles were tagged and placed in iced coolers immediately after collection and were transported to Ecology's Manchester Environmental Laboratory (MEL) via overnight shipment at the end of each sampling event.

Groundwater Quality

Three of the five wells sampled for this study (AHT069, AHT070, and AHT071) were instream piezometers Ecology installed near IEP, along the southern bank of the Spokane River in August 2012. The remaining wells were water supply wells operated by IEP (57IEPPROD) or the City of Millwood (well AHC937) (Table 1 and Figure 2). Table 3 depicts the frequency of groundwater sample collection at each of these wells. The Millwood well supplies water to a city park south of IEP; this well was sampled opportunistically when it was in operation during the late spring and early summer months.

Groundwater samples for the IEP NCCW well and the Millwood well were collected by connecting a clean Y-splitter and sample line to a hose bib located ahead of any water treatment or filtration. During pre-sample purging, water temperature, specific conductance, pH, and DO concentrations were measured using a Hydrolab DataSonde® and flow cell. Equilibrium with subsurface conditions was assumed when all field parameters had stabilized[2], particularly DO, which was often the last parameter to stabilize.

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[2] Purging continued until the difference in field–parameter values for two successive 3-minute measurement periods differed by less than 5% across all parameters.

Table 3. Groundwater sample frequency by site.

Date	57IEPPROD	AHC937	AHT069	AHT070	AHT071
4/3/2012	X				
5/1/2012	X				
6/12/2012	X				
7/17/2012	X				
8/14/2012	X				
9/18/2012	X		X	X	X
10/10/2012	X				
11/6/2012	X				
12/18/2012	X				
1/8/2013	X				
2/5/2013	X				
3/5/2013	X		X	X	X
4/10/2013	X		X	X	X
5/14/2013	X	X	X	X	X
6/18/2013	X	X	X	X	X
7/9/2013	X	X	X	X	X
8/20/2013	X		X	X	X
9/24/2013	X		X	X	X

Our sampling methods for the instream piezometers followed the procedures described by Sinclair and Pitz (2013) which require pre-sample determination of surface water quality conditions (temperature, specific conductance, pH, and DO) at each piezometer. These measurements provide a convenient benchmark for judging the potential influence of casing annular leakage during subsequent piezometer purging and sample collection.

Sampling of the actual piezometers began by suspending a clean polyethylene tube down the interior of the casing so that the tubing intake was positioned adjacent to the mid-point of the casing open-interval. A peristaltic pump was then used to purge the piezometer, at a flow rate ≤ 0.5 L/min, while groundwater field parameters were monitored with a Hydrolab DataSonde® and flow cell. Purging continued until all field parameters stabilized.

After completing the purging activities at a well, groundwater samples were collected for the laboratory parameters shown in Table 2. All samples, except those for total phosphorus and total reactive phosphorus, were field filtered using a new, clean, QED^{TM} 0.45 micron inline capsule filter. A minimum of 200 mL of the well water was purged through the filter and discarded before filling the first sample bottle. Samples were collected in clean, laboratory-supplied containers (pre-preserved as necessary), then placed in ice filled coolers immediately after collection. The sample coolers were transported to MEL via overnight shipment at the end of each sampling survey.

Water Quality Mixing Model

A spreadsheet-based mixing model was used to estimate the relative proportions of ambient groundwater and Spokane River water that make up the non-contact cooling water (NCCW) IEP pumps to meet its facility needs. The model is based on dilution mixing/attenuation models proposed by Walecka-Hutchison and Walworth, 2005, and Schmidt et al., 2007.

The spreadsheet simplifies the process of using a conservative tracer (e.g. chloride) to calculate the proportion of one water type (e.g. surface water) in a mixture of two distinct water types (e.g. surface water and ambient groundwater). This information can be used to determine what proportion of the observed concentration reduction for a non-conservative parameter (e.g. phosphorus) is attributable simply to dilution by mixing. Concentration reductions that are not attributable to dilution may indicate the presence of other attenuation reactions (e.g. decay, sorption). This model is useful for determining if attenuation processes are active in the vicinity of the groundwater/surface-water interface.

The spreadsheet solves the following mixing equation for a conservative tracer:

$$C_c = C_a X + C_b(1 - X)$$

where:

C_a = the initial or undiluted tracer concentration of end point water type A (the “diluting” water: defined as Spokane River water at site 57A139 in this case)

C_b = the initial or undiluted tracer concentration of end point water type B (the “contaminated or diluted” water: defined as ambient groundwater at the City of Millwood well in this case)

C_c = the tracer concentration of mixed water type C (the “mixed” water: defined as the groundwater pumped by the IEP NCCW well in this case)

X = the volume fraction of diluting water (V_a / V_a + V_b) where V_a is the volume of water type A, and V_b is the volume of water type B

Solving for X, the equation rearranges as:

$$\frac{C_c - C_b}{C_a - C_b} = X$$

Simple Loading Analysis

A simple load analysis was performed using a spreadsheet to evaluate the mass balance of phosphorus within the IEP facility. Loads were not used to determine the amount of phosphorus that is contributed by the river. A simple mass-balance was performed to show the general pattern of loading and sources of phosphorus within the IEP facility. The patterns will help in directing phosphorus-reduction implementation to the highest loading sources first.

Loads were calculated by multiplying the phosphorus concentration by the flow at each site. Total phosphorus, total dissolved phosphorus, total reactive phosphorus, and orthophosphate are measured in mg/L. Flow is measured in cubic feet per second. The resulting product was converted to lbs/day.

Loads were averaged from months within the critical season, and then compared to other loads within the facility to develop an overall loading pattern. Averaging the loads lessened the impact of any one individual survey load, which helped smooth out the inherent variability of the loads.

Again, the goal of the simple mass-balance was to show the general pattern of loading within the IEP facility during the critical season to help in directing phosphorus-reduction implementation efforts.

Data Quality Assurance/Quality Control

A variety of steps were taken to both ensure and verify the integrity of the water quality data and field measurements presented in this report. All samples were collected using applicable EAP standard operating procedures and the methods detailed in the Quality Assurance (QA) Project Plan (Ross, 2012). Table 4 summarizes the target data quality objectives for field blank and replicate sample frequency, reporting limits, and holding times by parameter. The data quality objectives for field measurements are summarized in Table 5.

Additional details on the overall data quality review are provided in Appendix A.
After completing applicable QA checks, field and laboratory data were entered into Ecology's Environmental Information Management (EIM) database and are available on Ecology's website at: www.ecy.wa.gov/eim/index.htm. Search Study ID, JROS0022.

Table 4. Target data quality objectives.

Parameter	Field Blanks	Field Replicates	Precision (RSD)	Holding Time
Field Measurements				
pH	N/A	N/A	0.05	N/A
Temperature	N/A	N/A	0.025	N/A
Dissolved Oxygen	N/A	N/A	< 15%	N/A
Specific Conductance	N/A	N/A	< 15%	N/A
Laboratory Analyses				
Total Reactive Phosphorus	1/survey	1/10 samples	< 20%	48 hours
Orthophosphate-P[1]	1/survey	1/10 samples	< 20%	48 hours
Total Phosphorus	1/survey	1/10 samples	< 20%	28 days
Total Dissolved Phosphorus[1]	1/survey	1/10 samples	< 20%	28 days
Alkalinity[1]	1/survey	1/10 samples	< 20%	14 days
Chloride[1]	1/survey	1/10 samples	< 20%	28 days
Sulfate[1]	1/survey	1/10 samples	< 20%	28 days
Nitrate[1]	1/survey	1/10 samples	< 20%	28 days
Calcium[1]	1/survey	1/10 samples	< 20%	6 months
Magnesium[1]	1/survey	1/10 samples	< 20%	6 months
Sodium[1]	1/survey	1/10 samples	< 20%	6 months
Potassium[1]	1/survey	1/10 samples	< 20%	6 months
Iron[1]	1/survey	1/10 samples	< 20%	6 months
Silicon[1]	1/survey	1/10 samples	< 20%	6 months

* Standard units

[1] Dissolved sample fraction

Table 5. Hydrolab measurement quality objectives.

Parameter	Units	Accept	Qualify	Reject
pH	standard units	≤ ± 0.2	± 0.2 to ± 0.5	> ± 0.5
Temperature	°C	≤ ± 0.2	± 0.2 to ± 0.5	> ± 0.5
Dissolved Oxygen*	% saturation	≤ ± 5	± 5 to ± 10	> ± 10
Specific Conductivity*	µS/cm	≤ ± 5	± 5 to ± 15	> ± 15

* Criteria expressed as a percentage

Results and Discussion

Quality Assurance

The data collected during this study generally met our target data quality objectives. For some water quality parameters, particularly sodium, calcium, and silicon, there were occasional instances of positive bias being introduced during sampling (as evidenced by measurable concentrations of these and other parameters in field blanks) (see Appendix A, Table A-3). However, field sample concentrations were typically greater than 10X the blank concentration in most of these cases, so the reported laboratory value is considered acceptable for use without further qualification. In the few cases where sample concentrations were less than 10X the blank concentration, sample results were qualified as estimates with a potentially high bias ("JL" qualified). On balance, the data reported here are of good quality, have been properly qualified where necessary, and are acceptable for use as reported. See Appendix A for a full discussion of the project data quality assessment.

Streamflow and IEP Discharge

Spokane River Streamflow

For this evaluation, discharge estimates for the Spokane River were obtained from two streamflow gages operated by the U.S. Geological Survey (USGS). The gage of principal interest for this study is located approximately 2 river miles upstream of the IEP facility, near the Trent Rd Bridge (USGS 12421500). In 2012 and 2013, this gage was only in operation from June through September of each year. The second gage (Spokane R. at Spokane, USGS 12422500) is located approximately 10 river miles downstream of IEP and was operated year-round during the 2012-2013 study period.

We used measured streamflows at the Trent Bridge gage for the June–Sept period, and estimated discharges for the Oct–May period, based on a linear regression relationship between the Trent Bridge gage and the Spokane R at Spokane (Figure 5). Historically, the monthly average discharge at the Trent Bridge gage appears to be lowest from July through November and is highest from April through June (Figure 6). The streamflows observed during 2012–2013 generally followed this pattern.

Measured streamflows at the Trent Rd. gage (USGS 12421500) are generally lower than the corresponding flows measured at the downstream gage near the city of Spokane (USGS 12422500). For the 2012-2013 monitoring period, differences in daily mean discharge between the gages averaged approximately 252 cfs and ranged from a net downstream gain of 700 cfs in mid-June 2012 to a net loss of 310 cfs in late June 2013 (Figure 7).

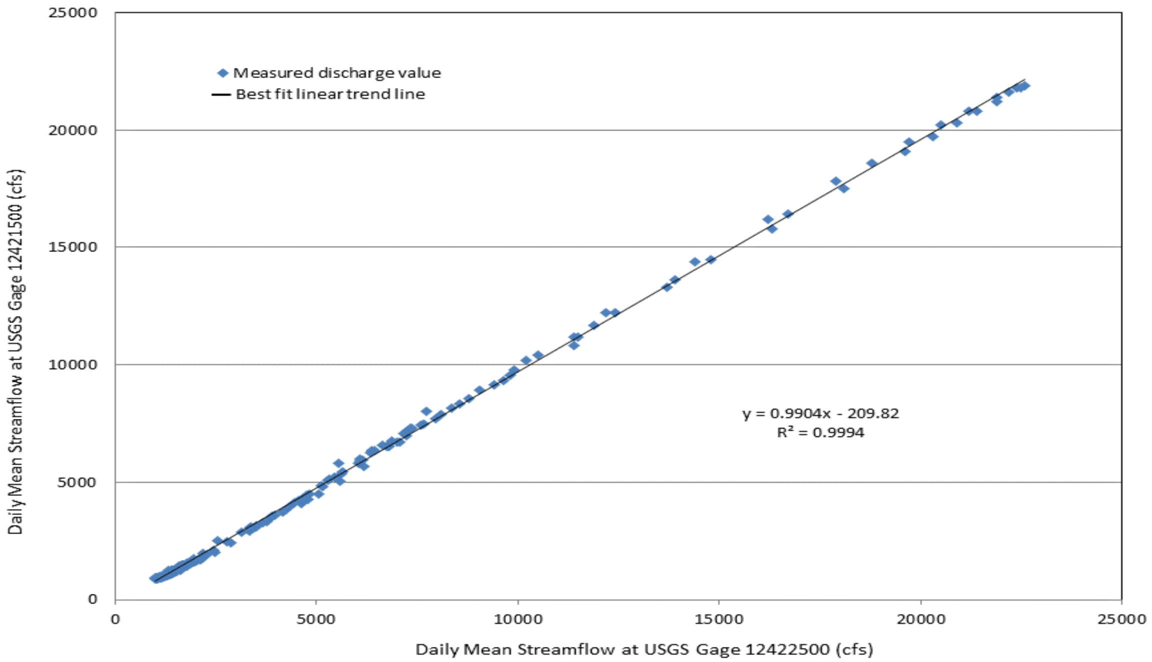

Figure 5. Relationship between daily mean streamflow at USGS Gages 12421500 and 12422500.

The data for this evaluation included measured streamflows at these gages for the periods June 1 - Oct 10, 2012 and May 17 - Sept 30, 2013.

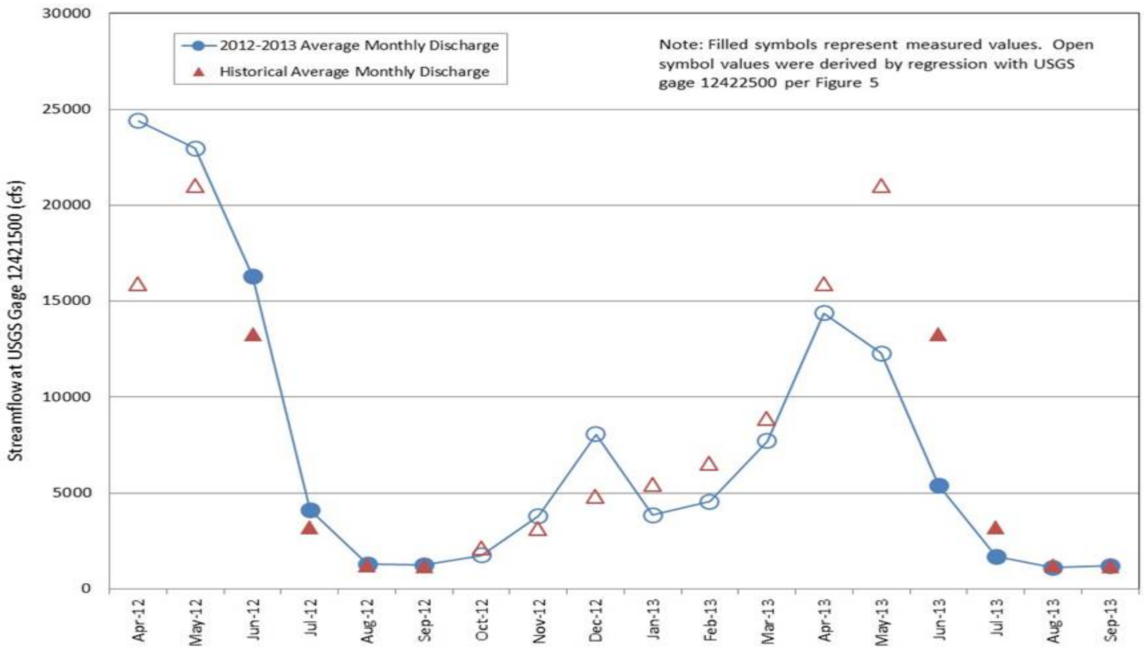

Figure 6. Measured and estimated monthly average streamflow at USGS gage 12421500 for the 2012-2013 period.

The historic monthly average streamflow values were derived using measured stream values at gage 12421500 for the period 1948-54 and estimated values for 2010-2014.

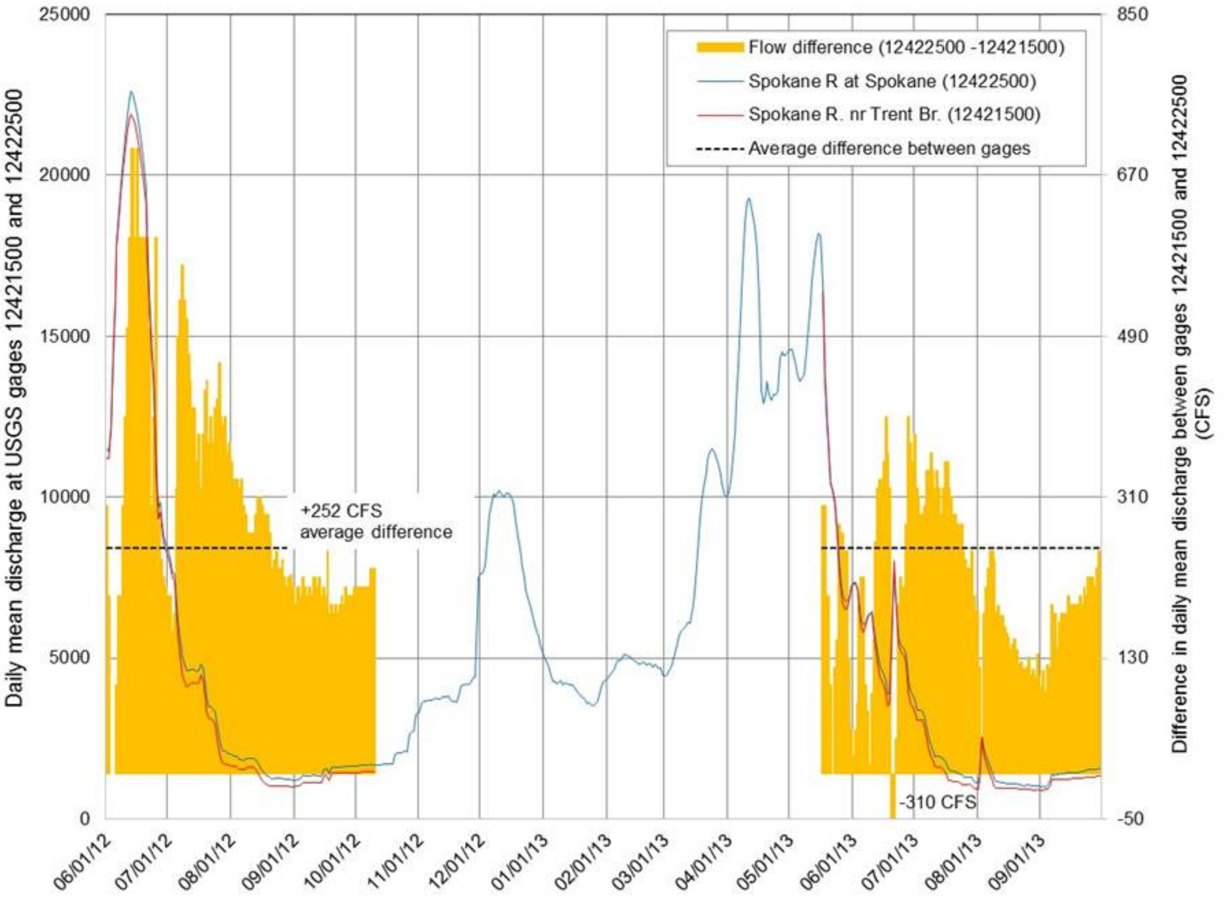

Figure 7. Comparison of measured daily mean discharge at the Spokane River gage near Spokane (12422500) and Trent Bridge (12421500) and net streamflow differences between the gages for the June 2012 to October 2013 period.

IEP

Water flows within the IEP facility were measured and recorded by facility personnel during the course of this study (Table 6). Discharge measurements were collected for the raw water production well (57IEPPROD), the non-contact cooling water (NCCW), and the final facility effluent (57IEPDISCH) which was measured just before water is discharged to the Spokane River. The treated effluent volume (57IEPTREAT) was determined by subtracting the NCCW volume from the final discharge volume.

Based on these measurements, IEP's final effluent consisted of approximately 49-59% NCCW, depending on the date evaluated (Table 6). On average, IEP's discharge consists of approximately 54% NCCW and 46% treated effluent by volume.

Table 6. Summary of volumetric water fluxes within the IEP facility.

Date	Spokane River at USGS gage 12421500 (cfs)	57IEPPROD (cfs)	NCCW (cfs)	57IEPTREAT (cfs)	57IEPDISCH (cfs)	NCCW percentage of 57IEPDISCH (%)
4/3/2012	27000 e	9.81	5.26	4.55	9.82	53.6
5/1/2012	34500 e	10.23	5.37	5.17	10.53	51.0
6/12/2012	21800	10.29	5.46	4.41	9.88	55.3
7/17/2012	4490	10.29	5.78	4.11	9.89	58.4
8/14/2012	1440	11.04	6.20	4.32	10.52	59.0
9/18/2012	1210	10.59	5.82	5.06	10.88	53.5
10/10/2012	1460 e	10.79	5.84	4.39	10.23	57.1
11/6/2012	3440 e	10.41	5.79	5.11	10.90	53.1
12/18/2012	8970 e	10.21	5.80	4.63	10.43	55.6
1/8/2013	3970 e	10.86	5.66	5.21	10.87	52.0
2/5/2013	4510 e	9.61	4.90	5.09	9.99	49.0
3/5/2013	4740 e	9.79	5.01	4.97	9.98	50.2
4/10/2013	18800 e	9.73	4.69	4.70	9.39	50.0
5/14/2013	17500 e	9.92	5.03	4.84	9.87	51.0
6/18/2013	3530	9.47	4.95	4.46	9.41	52.6
7/9/2013	1910	9.66	5.18	3.69	8.87	58.4
8/20/2013	941	10.50	5.87	4.66	10.52	55.8
9/24/2013	1300	10.17	5.18	5.02	10.20	50.7

e: value estimated based on regression with gage 12422500 (see Figure 6)

Streambed Vertical Hydraulic Gradients and Thermal Monitoring

Figures 8-10 are graphic depictions of the streambed thermal profiles and vertical hydraulic gradients that were measured at each of the three instream piezometers installed for this investigation. These data are plotted in tandem with the daily mean streamflows recorded at the Spokane River gage at Spokane[3] (USGS 12425000). Tabular summaries of the piezometer vertical hydraulic gradient information are provided in Table A-3 (Appendix A).

The vertical hydraulic gradients measured at each of the piezometers were consistently negative, indicating a pattern of streamflow loss to groundwater at each site. The piezometer nearest the IEP production well (AHT071) consistently exhibited the largest downward gradients. At times, the groundwater level at this piezometer periodically fell below the piezometer perforations, rendering the well unmeasurable. The anomalously large negative gradients at this location are likely related to nearby pumping at IEP's production well.

The piezometer gradients at all three sites exhibit an inverse relationship to streamflows in the Spokane River. During extended periods of high streamflow (i.e. winter and late spring), the piezometer gradients generally become smaller (less negative) and then progressively increase (become more negative) over the summer months as streamflows decline (Figures 8-10). This may be related to management of the Upriver Dam which is located approximately 2.5 river miles downstream of IEP. The dam maintains an artificially high river stage through the low-flow season to benefit recreational uses of the river. Therefore when streamflow is low, the groundwater table is low, but the river stage is kept high. This results in large negative hydraulic gradients between the river and underlying groundwater during the summer low-flow season.

The streamflow losses inferred from the hydraulic gradient measurements are supported by the corresponding streambed thermographs at each site, which exhibit vertical temperature profiles consistent with those expected for a losing stream (i.e. temperatures for the piezometer thermistors closely track those in the overlying surface water, per Figures 4 B and C). Collectively, the piezometer gradients and thermal data suggest the Spokane River likely lost water to the underlying sediments during the study period, within the stream reach encompassed by the piezometers.

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[3] To accommodate graph scale limitations, the streamflow values depicted in Figures 8-10 represent only 1/1000th of the actual daily mean discharge measured at the Spokane River gage at Spokane (USGS gage 12422500).

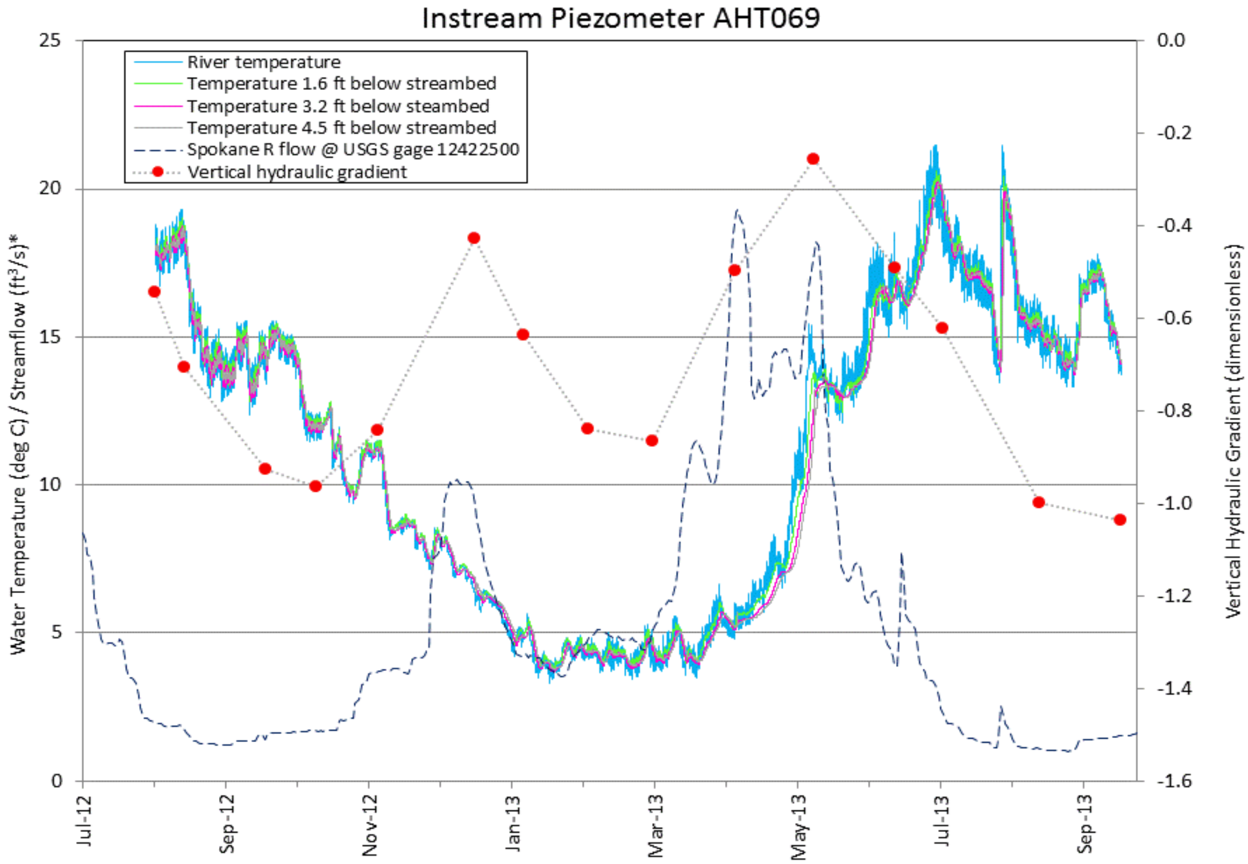

Figure 8. Streambed thermograph for piezometer AHT069.

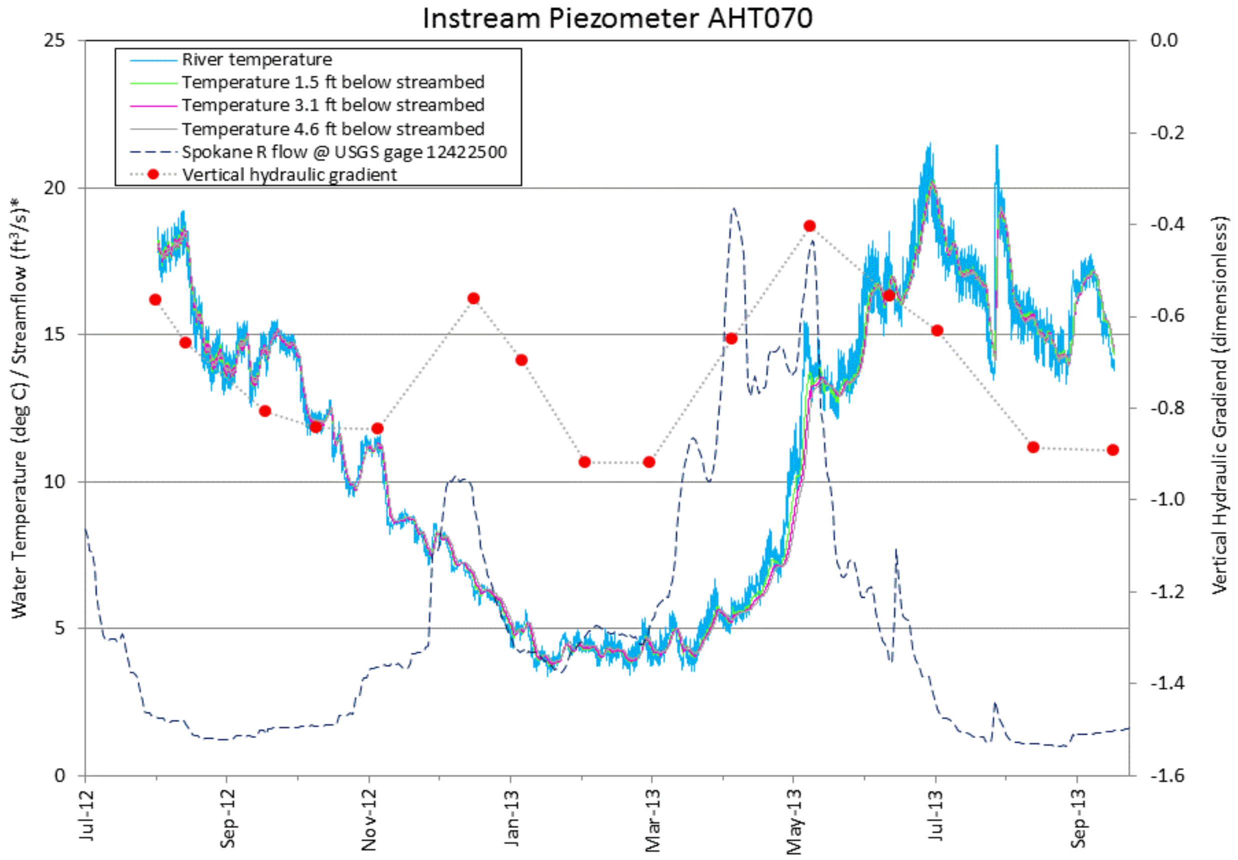

Figure 9. Streambed thermograph for piezometer AHT070.

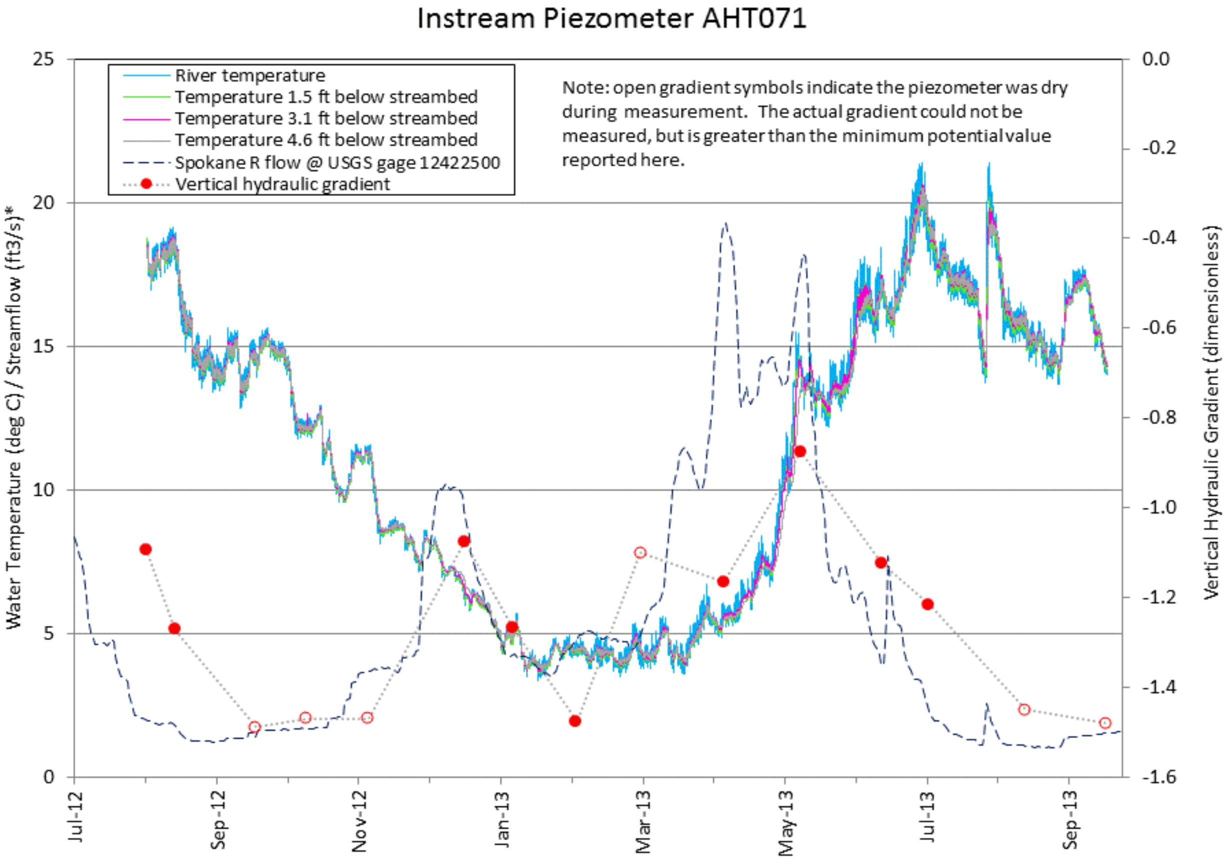

Figure 10. Streambed thermograph for piezometer AHT071.

Water Quality

The field and laboratory results for water quality samples collected during this evaluation are presented in Tables B-2 and B-3 (Appendix B). We prepared individual Stiff diagrams for each of the sites sampled during the May, June, and July 2013 surveys and aggregated them by sample date (Figures 11-13)[4]. These dates were chosen for evaluation since they were the only times when all of the study sites, including the City of Millwood well (AHC937), were available for sampling.

Stiff diagrams offer a convenient graphical means for visually depicting similarities or differences in the ionic composition of water samples. To prepare the diagrams, concentrations for each of the sample analytes are first converted from laboratory-reported mass/volume units (e.g. mg/L) to an equivalent concentration expressed as milli-equivalents per liter (meq/L). The resultant equivalent concentrations for the analytes in each sample are then arranged into cation/anion pairs[5], ordered in like fashion, and plotted (with cations to the left and anions to the right) along parallel horizontal axes that extend outward from a zero point center line. The plot values are then connected with a line to form a polygonal shape that represents the overall sample composition (see site A57140, Figure 11 as an example). The size of the shape is approximately equal to the total sample ionic content.

Visual inspection of the assembled Stiff diagrams for the May 2013 sampling (Figure 11) suggests a high degree of similarity in the shape (i.e. ionic content) of the river sample polygons (57A140, 57A139, and 57A138) and instream piezometer samples (AHT069, AHT070, and AHT071). The piezometer polygons are somewhat larger than the river polygons however, indicating their overall greater ionic content. The sample polygons for the IEP production well (57IEPPROD) and City of Millwood well (AHC937) are also very similar in shape to those of the river and piezometer sites. However, both are noticeably larger, indicating higher ionic content (particularly Ca and HCO3+Co3) than the adjacent river samples. The sample polygons for IEP's treated effluent (57IEPTREAT) and final discharge (57IEPDISC) are markedly larger still, indicating their significantly greater ionic content relative to other sampled sites.

Viewed in aggregate, the assembled Stiff diagrams for the May, June, and July 2013 sample events suggest a high degree of similarity in the ionic makeup of the river and piezometer samples. The slight differences in overall ionic content that were apparent in May are less so in June and July, as the sample shapes and sizes become nearly uniform except for two IEP sites (57IEPTREAT and 57IEPDSCH) and the City of Millwood well. The timing of these shifts coincide with observed increases in negative streambed vertical hydraulic gradients at the study instream piezometer sites from May through July 2013 and offer further support that the river is recharging groundwater locally.

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[4] In Figures 11-13, the individual Stiff diagrams are arranged in downstream order, with the uppermost sample station at the top of the page. Surface water samples are depicted in yellow and groundwater samples in red.

[5] The five cation–anion pairings used for this evaluation are: Na+K–Cl; Ca–HCO3+CO3; Mg–SO4; Fe–PO4; Si–NO3.

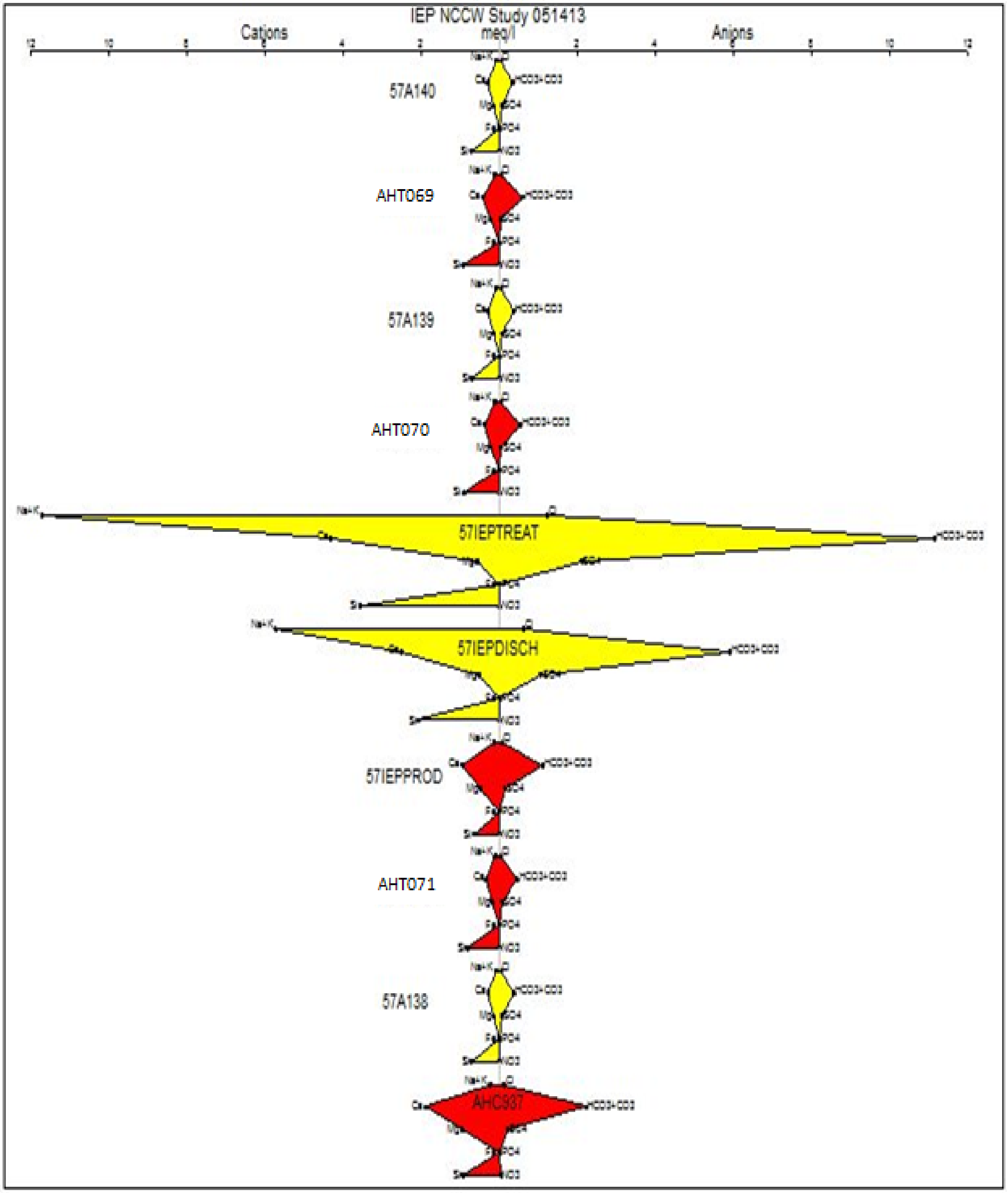

Figure 11. Stiff diagrams for data collected during the May 2013 sampling survey.

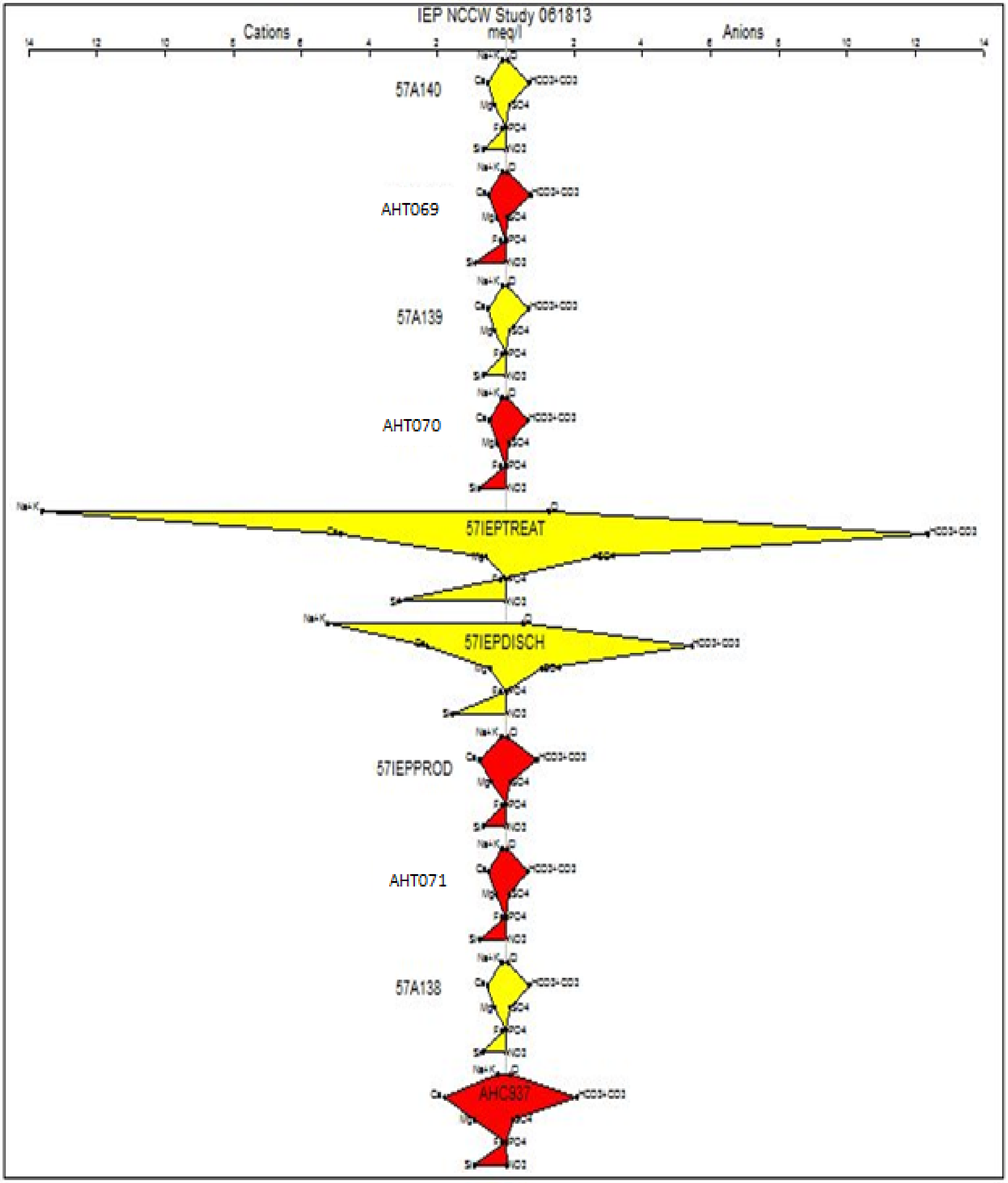

Figure 12. Stiff diagrams for data collected during the June 2013 sampling survey.

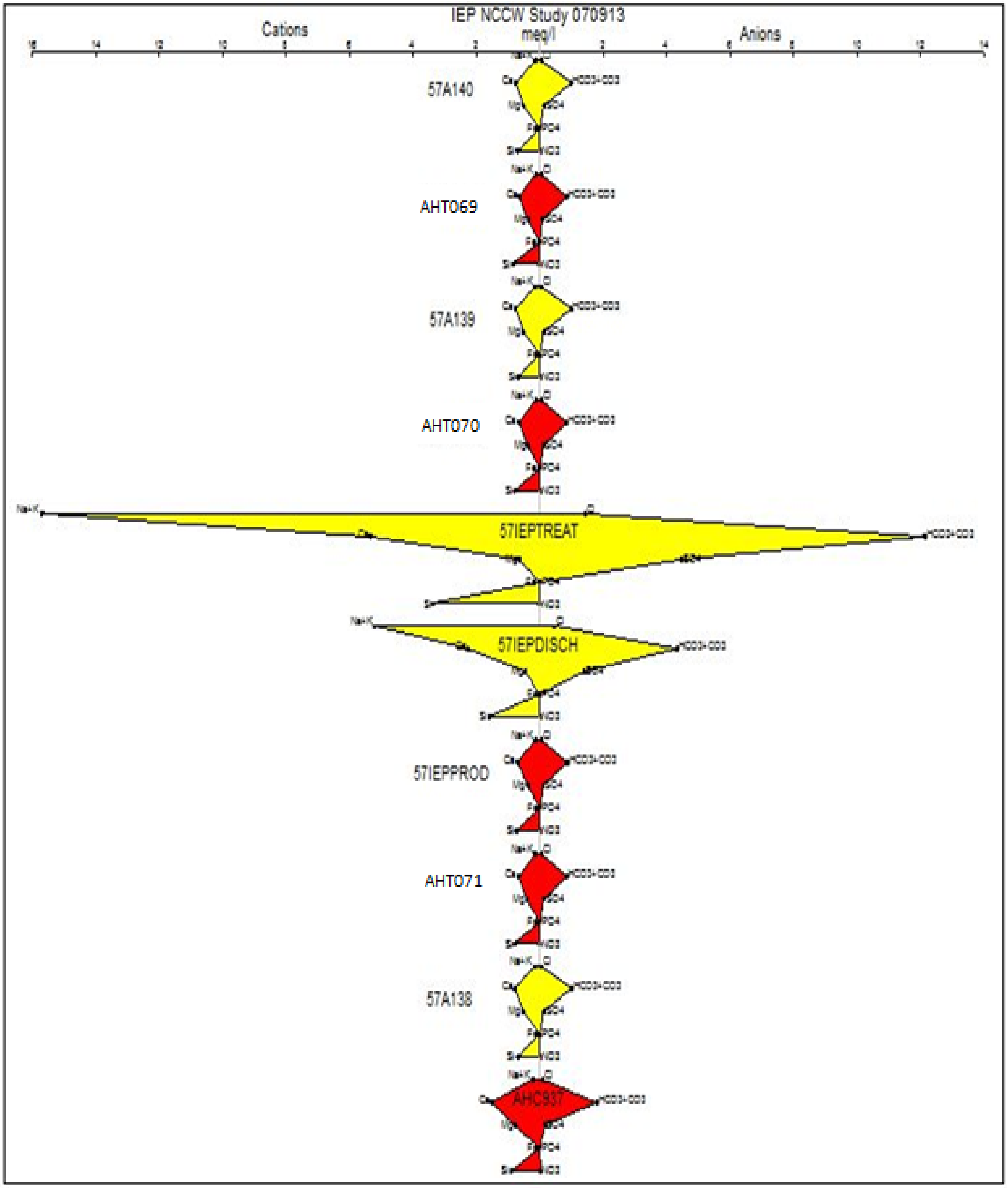

Figure 13. Stiff diagrams for data collected during the July 2013 sampling survey.

Mixing Model

We used the previously discussed spreadsheet mixing model to estimate the relative proportions of ambient groundwater and Spokane River water that make up the non-contact cooling water (NCCW) IEP pumps to meet its facility needs. We used chloride concentrations for the Spokane River upstream of the IEP discharge (site 57A139) and the City of Millwood supply well (site AHC937) to represent the initial endpoint water types within the model (e.g. ambient river and groundwater conditions, respectively). Chloride concentrations for the IEP production well (57IEPPROD) were used to represent the "mixed water" that results when the river and ambient groundwater end members combine[6]. The production well is the source of IEP's NCCW.

The model was run for three dates (May, June, and July 2013) which coincide with sampling of well AHC937, which could only be sampled opportunistically. The mixing model results for these surveys suggest that the fraction percentage of river water pumped by the IEP production well increased from 59.1% to 100% from May through July 2013 (Table 7)[7]. This is consistent with the Stiff diagrams discussed previously (Figures 11-13) and the observed increases in streambed vertical hydraulic gradient over this period (Figures 8-10).

Table 7. Mixing model results for field sampling conducted in May, June, and July 2013.

Date	57IEPPROD Chloride (mg/L)	57A139 Chloride (mg/L)	AHC937 Chloride (mg/L)	Volume Fraction of River Water (%)
5/14/2013	2.43	1.06	4.41	59.1
6/18/2013	1.79	1.35	4.32	85.2
7/9/2013	1.43	1.62	3.74	100.0

The three surveys used for the mixing model covered a majority of the observed streamflow range for the Spokane River during the 2012–2013 study period. The model results were used to develop a correlation between streamflow and the volume fraction of river water pumped by IEP's production well (Figure 14). This correlation was used to extrapolate the mixing model results throughout the remainder of the study period (Table 10). Based on this relationship, the volume fractions of river water in IEP's production water (i.e. NCCW) appears to be greatest during periods of lower streamflow.

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[6] For the purposes of this evaluation we assumed that the travel time required for water to exit the river and make its way to the IEP NCCW well was insignificant (i.e. that the two end-point water types, river and ambient groundwater, mixed instantaneously).

[7] The fraction can range from 0% - 100% of river water, with the remainder being the volume fraction of ambient groundwater.

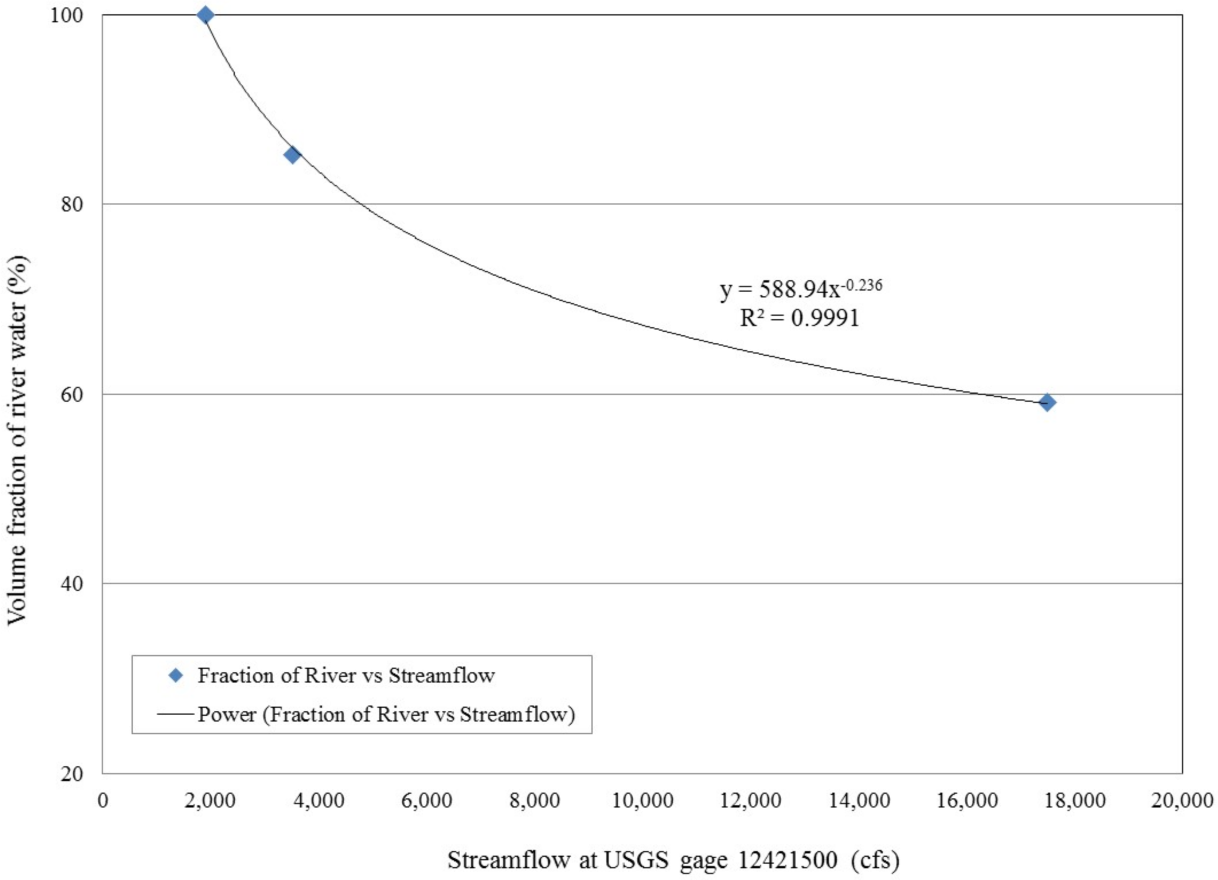

Figure 14. Relationship between mixing model results and streamflow in the Spokane River.

To derive monthly estimates of the phosphorus concentration contributed to IEP's production well/NCCW by the river, we multiplied the observed river concentrations at site 57A139 for each of the monthly sample events by the corresponding percentage values listed in Table 8. Table 9 is a summary of the observed phosphorus concentrations in IEP's NCCW and the estimated concentrations contributed by the river[8].

Table 8. Estimated volume fraction of river water in IEP's NCCW by sample date.

Date	Volume Fraction of River Water (%)
4/3/2012	53
5/1/2012	50
6/12/2012	55.7
7/17/2012	80.9
8/14/2012	100
9/18/2012	100
10/10/2012	100
11/6/2012	86.2
12/18/2012	68.7
1/8/2013	83.3
2/5/2013	80.9
3/5/2013	79.9
4/10/2013	57.7
5/14/2013	59.1
6/18/2013	85.2
7/9/2013	100
8/20/2013	100
9/24/2013	100

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[8] To perform this evaluation, sample concentrations reported by the laboratory as "non-detects" were set to one-half the reported detection limit.

Table 9. Monthly concentrations for the observed NCCW and the estimated river fraction.

Date	Observed Concentration in NCCW (mg/L)				Estimated Concentration from Fraction of River (mg/L)			
	TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)	TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)
4/3/2012	0.0055 a	0.0025 a	0.0053 a	0.0054 a	0.0059	0.0013	0.0020	0.0018
5/1/2012	0.0056	0.0058	0.0063	0.0068	0.0099	0.0032	0.0037	0.0031
6/12/2012	0.0057	0.0065	0.0042	0.0043	0.0052	0.0014	0.0008	0.0008
7/17/2012	0.0052 a	0.0053 a	0.0053 a	0.0050 a	0.0062	0.0020	0.0035	0.0033
8/14/2012	0.0025	0.0050	0.0015	0.0039	0.0064 a	0.0066 a	0.0015 a	0.0039 a
9/18/2012	0.0025	0.0050	0.0039	0.0038	0.0051 a	0.0025 a	0.0015 a	0.0032 a
10/10/2012	0.0025 a	0.0052 a	0.0044 a	0.0046 a	0.0062	0.0025	0.0015	0.0015
11/6/2012	0.0025	0.0053	0.0046	0.0044	0.0058 a	0.0056 a	0.0031 a	0.0028 a
12/18/2012	0.0025	0.0076	0.0067	0.0058	0.0056	0.0017	0.0038	0.0032
1/8/2013	0.0063	0.0068	0.0048	0.0049	0.0069 a	0.0052 a	0.0032 a	0.0032 a
2/5/2013	0.0056	0.0061	0.0048	0.0050	0.0050	0.0020	0.0024	0.0027
3/5/2013	0.0063 a	0.0061 a	0.0051 a	0.0047 a	0.0072	0.0045	0.0029	0.0029
4/10/2013	0.0025	0.0062	0.0055	0.0057	0.0051	0.0014	0.0023	0.0018
5/14/2013	0.0057	0.0025	0.0050	0.0051	0.0050	0.0030	0.0021	0.0018
6/18/2013	0.0059	0.0069	0.0049	0.0045	0.0057	0.0073	0.0013	0.0013
7/9/2013	0.0025	0.0025	0.0061	0.0059	0.0057	0.0025	0.0042	0.0043
8/20/2013	0.0080 a	0.0074 a	0.0056 a	0.0056 a	0.0086	0.0056	0.0015	0.0015
9/24/2013	0.0065 a	0.0057 a	0.0051 a	0.0048 a	0.0066	0.0052	0.0015	0.0015

a: This value derived using the average of two sample concentrations reported for field replicate samples.
TP: total phosphorus
TDP: total dissolved phosphorus
TRP: total reactive phosphorus
OP: orthophosphate

The estimated river fraction phosphorus concentrations in the non-contact cooling water (NCCW) (Table 9) were multiplied by the reported flow values for the NCCW (Table 6) and converted to lbs/day. The resulting estimated loads from the river fraction were then compared to the observed NCCW loads that were calculated using the observed concentrations from the IEP production well (Table 10).

Table 10. Calculated monthly loads for the observed NCCW concentrations and estimated river fraction concentrations.

Date	Observed Load from NCCW (lbs/day)				Estimated Load from Fraction of River (lbs/day)			
	TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)	TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)
4/3/2012	0.156	0.071	0.150	0.153	0.167	0.038	0.056	0.051
5/1/2012	0.162	0.168	0.182	0.195	0.287	0.091	0.107	0.088
6/12/2012	0.168	0.192	0.124	0.127	0.153	0.041	0.025	0.025
7/17/2012	0.160	0.165	0.165	0.154	0.192	0.063	0.108	0.103
8/14/2012	0.084	0.167	0.050	0.130	0.212	0.219	0.050	0.129
9/18/2012	0.078	0.157	0.122	0.119	0.160	0.078	0.047	0.099
10/10/2012	0.079	0.162	0.137	0.143	0.195	0.079	0.047	0.047
11/6/2012	0.078	0.166	0.144	0.137	0.182	0.176	0.096	0.087
12/18/2012	0.078	0.238	0.210	0.181	0.174	0.054	0.120	0.101
1/8/2013	0.192	0.207	0.146	0.149	0.211	0.159	0.098	0.099
2/5/2013	0.148	0.161	0.127	0.132	0.132	0.053	0.064	0.073
3/5/2013	0.169	0.163	0.136	0.126	0.194	0.121	0.078	0.078
4/10/2013	0.063	0.157	0.139	0.144	0.130	0.037	0.058	0.047
5/14/2013	0.155	0.068	0.136	0.138	0.137	0.081	0.056	0.049
6/18/2013	0.158	0.184	0.131	0.120	0.153	0.194	0.034	0.034
7/9/2013	0.070	0.070	0.170	0.165	0.161	0.069	0.116	0.119
8/20/2013	0.253	0.233	0.177	0.176	0.272	0.177	0.047	0.047
9/24/2013	0.181	0.158	0.141	0.133	0.184	0.145	0.042	0.042

Critical and Non-Critical Season

IEP has a National Pollutant Discharge Elimination System (NPDES) permit that determined final water quality based effluent limitations (WQBELs) during the critical and non-critical season for total phosphorus (Ecology, 2011). These seasons were based on wasteload allocations from the Spokane River DO TMDL (Moore and Ross, 2010). The permit critical season for total phosphorus is from February through October. Table 11 shows the seasonal average total phosphorus NPDES permit limits for IEP during the critical and non-critical season.

Table 11. Seasonal average NPDES permit limits for total phosphorus (lbs/day) at the IEP facility.

Critical Season (Feb - Oct)	Non-Critical Season (Nov - Jan)
2.39	NA

Average critical and non-critical season concentrations and loads were calculated using the values from Tables 9 and 10 discussed previously. Tables 12 and 13 show the average seasonal concentrations and loads for the 2012-2013 study, respectively.

Table 12. Average seasonal phosphorus concentrations for the NCCW and river fraction.

Critical Season Average Observed NCCW Concentration				Critical Season Average Estimated Fraction of River Concentration			
TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)	TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)
0.0048	0.0052	0.0049	0.0050	0.0063	0.0034	0.0022	0.0024
Non-Critical Season Average Observed NCCW Concentration				**Non-Critical Season Average Estimated Fraction of River Concentration**			
TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)	TP (mg/L)	TDP (mg/L)	TRP (mg/L)	OP (mg/L)
0.0038	0.0066	0.0054	0.0050	0.0061	0.0042	0.0034	0.0031

Table 13. Average seasonal phosphorus loads for the NCCW and river fraction.

Critical Season Average Observed NCCW Load				Critical Season Average Estimated Fraction of River Load			
TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)	TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)
0.139	0.152	0.139	0.144	0.182	0.099	0.062	0.069
Non-Critical Season Average Observed NCCW Load				**Non-critical Season Average Estimated Fraction of River Load**			
TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)	TP (lbs/day)	TDP (lbs/day)	TRP (lbs/day)	OP (lbs/day)
0.116	0.204	0.167	0.156	0.189	0.130	0.105	0.096

The estimated seasonal average total dissolved phosphorus, total reactive phosphorus, and orthophosphate concentrations for the fraction of the river are less than the observed concentrations in the NCCW. In contrast, the estimated seasonal average total phosphorus concentrations for the fraction of the river are greater than the observed concentrations in the NCCW. Possible explanations for this difference are that total phosphorus is being sorbed or otherwise attenuated as the river water is transported underground to the production well. In addition, the TP samples were not filtered during collection, so it’s possible that particulate phosphorus that potentially occurs in the river samples is not present in the corresponding groundwater samples.

Simple Loading Analysis

A simple loading analysis within the IEP facility was conducted using data from monthly surveys during the critical season. Since IEP’s treated effluent (57IEPTREAT) and final combined discharge (57IEPDISCH) were sampled from May 2013 to September 2013, these were the months used for the analysis. Figure 15 shows the phosphorus loading within the IEP facility. Table 14 summarizes the average phosphorus loads as their percentage of the total load for the IEP discharge to the Spokane River. Nearly all of the May 2013 through September 2013 phosphorus loads were from the treated effluent just prior to mixing with the NCCW. All of the phosphorus loads that contribute to the IEP final discharge appear to be accounted for with the sampling locations.

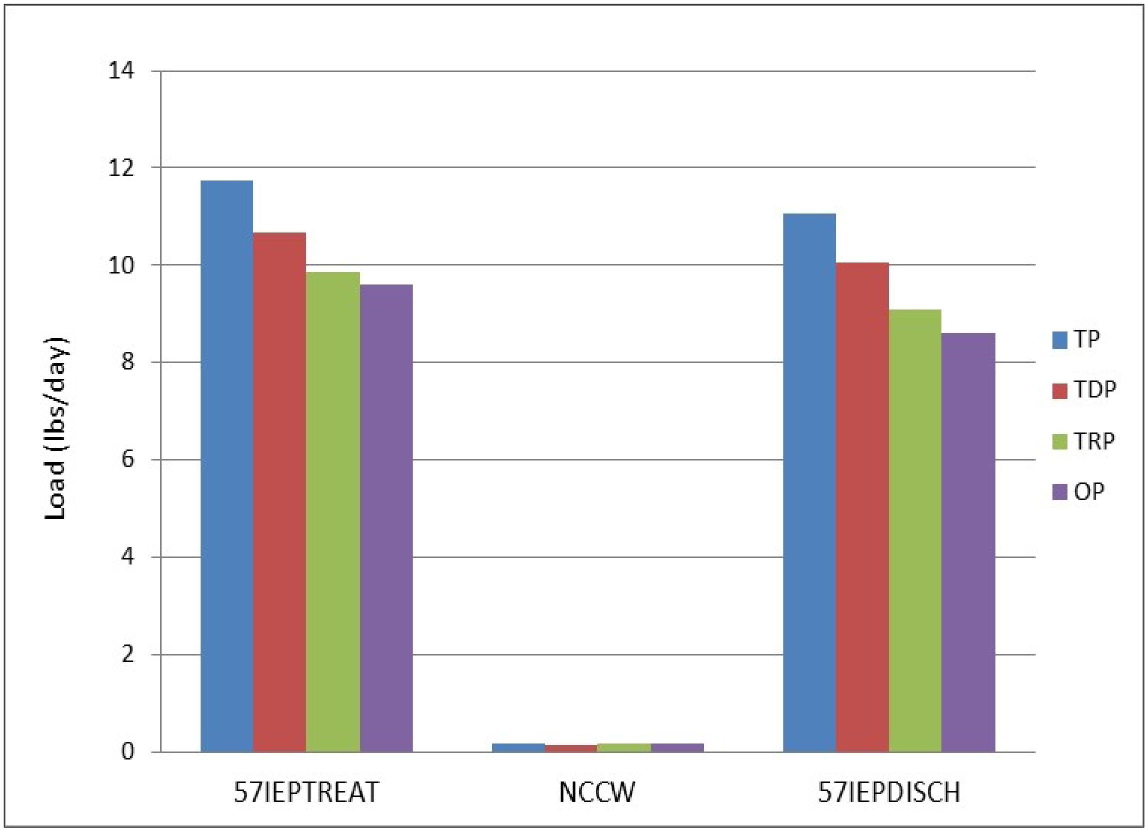

Figure 15. Average phosphorus loading within the IEP facility for May-September 2013.

Table 14. Phosphorus loading percentages within the IEP facility for May-September 2013.

Reach (IEP)	Location (End of Reach)	TP	TDP	TRP	OP
After Effluent Treatment	57IEPTREAT	98.6%	98.7%	98.5%	98.5%
Non-Contact Cooling Water	57IEPPROD*	1.4%	1.3%	1.5%	1.5%

* NCCW flows and 57IEPPROD concentrations were used in loading calculations for this reach.

Conclusions

Results of this 2012-2013 study support the following conclusions.

Vertical hydraulic gradient and thermal monitoring indicate a losing condition for this reach of the Spokane River. Vertical hydraulic gradients appear to become more negative during periods of low streamflow in the Spokane River.

Water quality in the production well (57IEPPROD) appears to be more similar to the river during periods of low streamflow. This is consistent with the vertical hydraulic gradient measurements.

A mixing model was employed using chloride concentration data from the Spokane River upstream of the Inland Empire Paper Company (IEP) discharge (57A139), ambient groundwater (AHC937), and the IEP production well (57IEPPROD). The model results suggest that the volume fraction of the river being pumped by the IEP production well appears to be greater during periods of low streamflow. Model results suggest the fraction percentage of river water in the IEP production well water increased from 59.1% to 100% from May 2013 to July 2013. The model results are consistent with the streambed vertical hydraulic gradients and water quality observed during the study.

Average seasonal phosphorus concentrations and loads for the non-contact cooling water (NCCW) and the fraction of river were compared. During the critical season, the total phosphorus load from the fraction of the river (0.182 lbs/day) was greater than the observed total phosphorus load from the NCCW (0.139 lbs/day). Therefore it appears that a portion (24%) of the total phosphorus from the river is attenuated as it flows underground to the production well. Total dissolved phosphorus, total reactive phosphorus, and orthophosphate loads from the fraction of the river were less than the observed loads from the NCCW.

The simple loading analysis determined that nearly all of the phosphorus loading within the IEP facility is from the treated effluent. The NCCW phosphorus loading percentages were small, between 1.3% and 1.5%.

Recommendations

Results of this 2012-2013 study support the following recommendations.

Phosphorus loading from the IEP discharge to the Spokane River must be reduced to comply with the NPDES permit limits. The phosphorus loading from the treated effluent prior to mixing with NCCW needs to be reduced significantly and should be the priority for implementation actions.

A nutrient allowance should be considered by Ecology's Water Quality Program for the fraction of river phosphorus loads in the NCCW. This allowance should be the lesser of the two loads: observed NCCW loads and estimated fraction of river loads.

If more precise estimates of the volume fraction of water the river contributes to the production well are required to calculate nutrient allowances for IEP, the following additional field investigations could help to narrow uncertainty:

- Install dedicated monitoring wells to determine ambient groundwater concentrations for target analytes in the aquifer that supplies IEP's production well.
- Consider an alternative field method, such as the use and comparison of isotope data, to further determine chemical similarity between the Spokane River and the IEP production well.
- Consider collecting additional information to help define water travel times between the river and IEP production well. This information could be used to help further refine the mixing model results reported here.

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Appendices

Appendix A. Data Quality Review

The field and laboratory data from this study were evaluated to ensure they met the data quality objectives specified in the project study plan (Ross, 2012). The evaluation methods are described below by principal data type.

Evaluation of Recording Thermistors and Data

A total of 13 recording thermistors were deployed during this study to monitor streambed thermal profiles at the three instream piezometers Ecology installed for this investigation. The thermistors were checked both before and after deployment against a National Institute of Standards and Technology (NIST) reference thermometer to confirm proper operation. We used a two point (warm water bath and ice bath) verification procedure for the evaluation per Bilhimer et al. (2013). The calibration tests are conducted to confirm that all thermistors were operating within the advertised vendor accuracy (± 0.2°C). The pre- and post-deployment calibration approach also allows assessment of instrument drift over time.

All thermistors, except one, met the stated instrument accuracy criteria both before and after deployment. Thermistor 1000396 calibrated slightly above the criteria for the ice bath (both before and after deployment) but was within acceptable values for the warm bath. The slight deviation for this single thermistor is not considered problematic since the period of greatest interest for this project is the summer low-flow season when water temperatures are at or near seasonal high values.

Field-Meter Calibration

Field meters were calibrated prior to each sampling event in accordance with the instrument manufacturer instructions and applicable Ecology standard operating procedures (SOPs) (Swanson, 2007). Fresh commercially prepared buffer solutions and reference standards were used for all pH and specific conductivity calibrations, respectively. The dissolved oxygen (DO) sensor was calibrated against theoretical air saturated water using the manufacturer-supplied calibration chamber.

The initial (pre-deployment) pH and conductivity calibrations were checked by placing the probes in pH buffer solutions and reference standards, respectively, and evaluating the difference between the standards and the meter values (Table A-1). The initial pH calibration was considered acceptable if the meter values differed by less than ± 0.2 pH units from the buffer standards. The conductivity calibration was accepted if the meter values deviated by no more than ± 5% from the conductivity check standards.

At the end of each sampling event, the meters were rechecked using these same procedures to confirm they had not drifted unacceptably from the initial calibration during use. Based on the post-deployment check, the results for a sample event were either accepted, qualified as estimates before acceptance, or rejected as unusable (Table 5 and Table A-1).

Based on this evaluation, the conductivity results for April and June 2012 were qualified as estimates, as were the pH results for April 2013 and the conductivity results for June, July, and August, 2013. The remaining results are acceptable for use as reported.

Table A-1. Hydrolab pre- and post-use calibration results.

Calibration Date	Sonde Number	Pre-deployment calibration	Post-deployment calibration	Conductivity 0 or 100 µS Standard				Conductivity 1000 µS Standard				pH 7 Standard					pH 10 Standard					Dissolved Oxygen % Saturation			
				Reference standard value	Hydrolab value	Difference	Conclusion[1]	Reference standard value	Hydrolab value	Difference	Conclusion[1]	Temperature	Temperature corrected standard value	Hydrolab value	Difference	Conclusion[1]	Temperature	Temperature corrected standard value	Hydrolab value	Difference	Conclusion[1]	Reference saturation value	Hydrolab value	Difference	Conclusion[1]
4/3/12	34	X		0	6			1001	993	-0.8%		14.00	7.04	6.99	-0.05		0.00	10.13	10.04	-0.09		100%	100.9%	0.9%	
4/3/12	34		X	100.8	94	-7.0%	Q	1001	1003	0.2%	A	16.08	7.03	7.12	0.09	A	16.23	10.11	10.21	0.1	A	100%	95.3%	-4.7%	A
5/1/12	34	X		0	0			1001	1007	0.6%		15.04	7.04	7.06	0.02		15.11	10.12	10.1	-0.02		100%	96.7%	-3.3%	
5/1/12	34		X	99.3	96.5	-2.9%	A	1001	987.2	-1.4%	A	15.52	7.04	7.18	0.14	A	15.36	10.12	10.21	0.09	A	100%	102.4%	2.4%	A
6/12/12	24	X		0	0			998	1001	0.3%		17.00	7.03	7.02	-0.01		17.26	10.08	10.09	0.01		100%	106.4%	6.4%	
6/12/12	24		X	99.5	94.2	-5.5%	Q	998	997.4	-0.1%	A	17.42	7.03	7.12	0.09	A	17.38	10.08	10.11	0.03	A	100%	97.1%	-2.9%	A
7/17/12	35	X		0	0			998	991	-0.7%		24.30	7.01	7.05	0.04		24.32	10.01	10	-0.01		100%	97.6%	-2.4%	
7/17/12	35		X	99.5	97.5	-2.0%	A	998	994	-0.4%	A	24.46	7.01	7.05	0.04	A	24.55	10	10.03	0.03	A	100%	100.5%	0.5%	A
8/14/12	35	X		0	0			999	999.8	0.1%		24.19	7.01	7	-0.01		24.48	10	10.04	0.04		100%	97.4%	-2.6%	
8/14/12	35		X	99	98	-1.0%	A	999	999.5	0.1%	A	25.46	7	7.04	0.04	A	25.34	10	10.01	0.01	A	100%	99.5%	-0.5%	A
9/18/12	35	X		0	0			999	998.6	0.0%		21.01	7.02	7.09	0.07		20.82	10.04	10.03	-0.01		100%	98.6%	-1.4%	
9/18/12	35		X	99.5	97.8	-1.7%	A	999	999.7	0.1%	A	21.87	7.02	7.05	0.03	A	22.33	10.03	10.03	0	A	100%	98.6%	-1.4%	A
10/10/12	35	X		0	0			999	1001	0.2%		16.55	7.03	7.06	0.03		16.87	10.08	10.07	-0.01		100%	98.5%	-1.5%	
10/10/12	35		X	99	98.5	-0.5%	A	999	997.6	-0.1%	A	18.08	7.03	7.08	0.05	A	19.16	10.06	10.04	-0.02	A	100%	101.4%	1.4%	A
11/6/12	35	X		0	0			999	997.2	-0.2%		15.29	7.04	7.08	0.04		15.27	10.11	10.1	-0.01		100%	99.6%	-0.4%	
11/6/12	35		X	99	98.1	-0.9%	A	999	999.9	0.1%	A	15.18	7.04	7.08	0.04	A	15.14	10.11	10.13	0.02	A	100%	99.4%	-0.6%	A
12/17/12	35	X		0	0			999	1001	0.2%		16.26	7.03	7.1	0.07		16.67	10.09	10.07	-0.02		100%	96.4%	-3.6%	
12/18/12	35		X	99	97.5	-1.5%	A	999	1001	0.2%	A	15.55	7.04	7.08	0.04	A	15.39	10.11	10.13	0.02	A	100%	99.8%	-0.2%	A
1/7/13	35	X		0	0			999	994.1	-0.5%		15.13	7.04	7.11	0.07		14.93	10.11	10.11	0		100%	99.8%	-0.2%	
1/8/13	35		X	99	97.9	-1.1%	A	999	999	0.0%	A	14.28	7.04	7.07	0.03	A	13.72	10.12	10.13	0.01	A	100%	100.8%	0.8%	A

Calibration Date	Sonde Number	Pre-deployment calibration	Post-deployment calibration	Conductivity 0 or 100 µS Standard				Conductivity 1000 µS Standard				pH 7 Standard					pH 10 Standard					Dissolved Oxygen % Saturation			
				Reference standard value	Hydrolab value	Difference	Conclusion [1]	Reference standard value	Hydrolab value	Difference	Conclusion [1]	Temperature	Temperature corrected standard value	Hydrolab value	Difference	Conclusion [1]	Temperature	Temperature corrected standard value	Hydrolab value	Difference	Conclusion [1]	Reference saturation value	Hydrolab value	Difference	Conclusion [1]
2/4/13	34	X		0	0			999	1007	0.8%		15.52	7.04	7.2	0.16		15.67	10.1	10.09	-0.01		100%	99.1%	-0.9%	
2/5/13	34		X	99	101.6	2.6%	A	999	1007	0.8%	A	15.27	7.04	7.13	0.09	A	14.43	10.12	10.19	0.07	A	100%	101.8%	1.8%	A
3/4/13	35	X		0	0			999	1002	0.3%		14.47	7.04	7.11	0.07		14.35	10.12	10.11	-0.01		100%	97.7%	-2.3%	
3/5/13	35		X	99	97.6	-1.4%	A	999	996	-0.3%	A	14.80	7.04	6.93	-0.11	A	13.80	10.12	10.13	0.01	A	100%	99.9%	-0.1%	A
4/9/13	34	X		0	0.1			999	1008	0.9%		15.05	7.04	7.66	0.62		15.08	10.11	9.8	-0.31		100%	96.8%	-3.2%	
4/11/13	34		X	99	97	-2.0%	A	999	992	-0.7%	A	15.44	7.04	7.44	0.4	Q	15.31	10.11	10.48	0.37	Q	100%	99.5%	-0.5%	A
5/13/13	39	X		0	0			1000	1010	1.0%		19.90	7.02	7.04	0.02		19.86	10.05	10	-0.05		100%	97.6%	-2.4%	
5/15/13	39		X	100	97.6	-2.4%	A	1000	995.4	-0.5%	A	17.41	7.03	7.06	0.03	A	15.99	10.08	10.15	0.07	A	100%	100.9%	0.9%	A
6/17/13	38	X		0	0			1000	989	-1.1%		21.63	7.02	7.02	0		20.38	10.05	10.1	0.05		100%	101.0%	1.0%	
6/19/13	38		X	100	91.4	-9.0%	Q	1000	990.4	-1.0%	A	18.13	7.03	7.1	0.07	A	18.64	10.07	10.11	0.04	A	100%	96.1%	-3.9%	A
7/8/13	38	X		0	0			1000	1005	0.5%		23.50	7.02	7.05	0.03		23.50	10.03	10.03	0		100%	99.7%	-0.3%	
7/10/13	38		X	100	90.7	-9.8%	Q	1000	993.3	-0.7%	A	24.62	7.01	7.1	0.09	A	24.10	10.01	10.06	0.05	A	100%	100.4%	0.4%	A
8/19/13	38	X		0	0			1000	998.3	-0.2%		26.30	7	7.1	0.1		25.91	9.99	9.97	-0.02		100%	100.0%	0.0%	
8/20/13	38		X	100	90.8	-9.6%	Q	1000	998.3	-0.2%	A	25.11	7	7.07	0.07	A	25.18	10	10.03	0.03	A	100%	100.2%	0.2%	A
9/23/13	35	X		0	0			1000	988.8	-1.1%		18.63	7.03	7.01	-0.02		18.81	10.06	10.09	0.03		100%	98.0%	-2.0%	
9/25/13	35		X	100	98.6	-1.4%	A	1000	1001	0.1%	A	17.45	7.03	7.07	0.04	A	17.55	10.08	10.09	0.01	A	100%	98.6%	-1.4%	A

[1] A: accept result.
Q: qualify result prior to acceptance.

Review of Water Quality Data

All of the project field sites were sampled using properly calibrated field meters, dedicated sample tubing, and new in-line cartridge filters where appropriate. Samples were collected in pre-cleaned bottles supplied by Ecology's Manchester Environmental Laboratory (MEL). Pre-acidified bottles were used for preserved samples. Filled sample bottles were labeled, bagged, and then stored in clean, ice-filled coolers pending their arrival at the laboratory. All samples for laboratory analysis were delivered to MEL within 48 hours of collection via Horizon Air and MEL courier. Sample chain-of-custody procedures were followed throughout the project.

Laboratory Quality Assurance

MEL follows a strict set of QA procedures to both ensure and later evaluate the quality of their analytical results (MEL, 2014). The results of these evaluations are summarized in a case narrative that is submitted to the study project manager along with each analytical data package. The case narratives describe quality control procedures and results for sample transport and storage, sample holding times, and instrument calibration. They also include a QA summary of check standards, matrix spikes, method blanks (used to check analytical bias), and laboratory splits (used to check for analytical precision).

The case narratives and supporting data for this project indicate that all samples, except one, were received in good condition and were properly preserved, where necessary. Total phosphorus sample 1304001-03 arrived at the laboratory frozen. The result for this sample was qualified as an estimate. The temperatures of shipping coolers were otherwise within the proper range.

All samples were analyzed within the maximum holding time, except for one. Dissolved total phosphorus sample 1309001-05 was analyzed past the digestion hold time. The result for this sample was qualified as an estimate.

The laboratory data for this project generally met MEL's quality assurance/quality control (QA/QC) criteria. The lab qualified ("J" coded) rare individual results as estimates in the summary data tables and case narratives. On occasion, the orthophosphate concentrations for a sample event were greater than the total phosphorus concentrations. This is acceptable as long as the orthophosphate concentrations don not exceed the total phosphorus concentrations by more than 20%. This condition indicates that all of the phosphorus present is orthophosphate.

Overall analytical precision for the project laboratory samples was determined by calculating an average relative standard deviation (%RSD) of laboratory split results. A laboratory split was analyzed for each sampling event. The laboratory analytical precision was within QA targets for all parameters. Laboratory blank results were consistently below the analytical detection limit for all target analytes (Table A-2).

Table A-2. Laboratory precision and blank results.

Parameter	Target Precision %RSD	Average Precision %RSD	Lab Blank
Total Reactive Phosphorus	20	1.93	< 0.003
Orthophosphate-P	20	3.08	< 0.003
Total Phosphorus	20	3.92	< 0.005
Total Dissolved Phosphorus	20	7.09	< 0.005
Total Alkalinity	20	0.94	< 5
Chloride	20	0.46	< 0.1
Sulfate	20	0.97	< 0.3
Nitrate and Nitrite Nitrogen	20	1.36	< 0.01
Calcium	20	1.00	< 0.05
Magnesium	20	1.35	< 0.05
Sodium	20	1.18	< 0.05
Potassium	20	1.44	< 0.5
Iron	20	1.33	< 0.05
Silicon	20	0.78	< 0.05

Field Quality Assurance

To assess sampling bias and overall analytical precision, field equipment blanks and replicate samples were collected and submitted "blind"[9] to the laboratory during each sample event. Field replicates were collected at a rate of approximately 10% of total samples (1 replicate per 10 samples). One field equipment/filter blank was submitted per sample event. Field blanks were prepared using laboratory-supplied de-ionized water and were handled and filtered in the same manner as actual field samples.

The field blank results indicate the sample collection/filtration procedure may have introduced bias into the study results for a few parameters of interest. Sample results were appropriately qualified by the project manager in the relatively few cases where the sample concentration was ≤ 10 times the field blank concentration for a parameter. Table A-3 summarizes the sample dates and parameters that had field blank detections and also any resultant data qualifiers that were applied.

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[9] The term "blind" refers to "identical" samples that were submitted to the laboratory under different sample numbers.

Table A-3. Summary of field blank detections by parameter and sample date.

Date	Parameter	Blank concentration (mg/L)	Qualifier
4/3/2012	Calcium	0.326	None - all sample concentrations > 10x field blank concentration
4/3/2012	Sodium	1.08	JL (Estimate with high bias) applied to all samples
4/3/2012	Silicon	0.731	JL (Estimate with high bias) applied to all samples
5/1/2012	Sodium	0.1	None - all sample concentrations > 10x field blank concentration
7/17/2012	Calcium	0.088	None - all sample concentrations > 10x field blank concentration
7/17/2012	Sodium	0.164	None - all sample concentrations > 10x field blank concentration
8/14/2012	Silicon	0.074	None - all sample concentrations > 10x field blank concentration
8/14/2012	Sodium	0.213	None - all sample concentrations > 10x field blank concentration
8/14/2012	Calcium	0.066	None - all sample concentrations > 10x field blank concentration
9/18/2012	Calcium	0.13	None - all sample concentrations > 10x field blank concentration
9/18/2012	Sodium	0.151	None - all sample concentrations > 10x field blank concentration
10/10/2012	Sodium	0.141	None - all sample concentrations > 10x field blank concentration
11/6/2012	Calcium	0.071	None - all sample concentrations > 10x field blank concentration
11/6/2012	Silicon	0.05	None - all sample concentrations > 10x field blank concentration
11/6/2012	Sodium	0.226	JL (Estimate with high bias) applied to all samples except IEPProd (concentration > 10x blank concentration)
12/18/2012	Calcium	0.078	None - all sample concentrations > 10x field blank concentration
12/18/2012	Sodium	0.26	JL (Estimate with high bias) applied to all samples
12/18/2012	Chlorides	0.43	JL (Estimate with high bias) applied to all samples
1/8/2012	Sodium	0.128	None - all sample concentrations > 10x field blank concentration
3/5/2013	Sodium	0.086	None - all sample concentrations > 10x field blank concentration
3/5/2013	Silicon	0.054	None - all sample concentrations > 10x field blank concentration
5/15/2013	Sodium	0.074	None - all sample concentrations > 10x field blank concentration
5/15/2013	Silicon	0.09	None - all sample concentrations > 10x field blank concentration
5/15/2013	Nitrite/ Nitrate	0.09	JL (Estimate with high bias) applied to all samples except AIEPP1/QA1 (concentration was non-detect) and AHC937 (concentration > 10x blank concentration)
6/19/2013	Sodium	0.098	None - all sample concentrations > 10x field blank concentration
7/10/2013	Sodium	0.114	None - all sample concentrations > 10x field blank concentration
8/20/2013	Total Phosphorus	0.0065	JL (Estimate with high bias) applied to all samples except IEPTreat and IEPDisch (concentrations > 10x blank concentration)
8/20/2013	Calcium	0.102	None - all sample concentrations > 10x field blank concentration
8/20/2013	Sodium	0.117	None - all sample concentrations > 10x field blank concentration
9/25/2013	Calcium	0.066	None - all sample concentrations > 10x field blank concentration
9/25/2013	Nitrite/ Nitrate	0.034	JL (Estimate with high bias) applied to only IEPDisch (all other sample concentrations were non-detect or > 10x blank concentration)

Precision for each of the field replicate analyses was quantified by evaluating the percent relative standard deviation[10] (%RSD) for each duplicate sample pair (Table A-5). The resulting values for each parameter were then averaged to define the total precision by parameter (Table A-4). The average %RSD for field replicates was higher than reported for laboratory splits since average %RSD is a measure of the total "sampling" variability, which includes both field and analytical components.

Although the total average precision results were within project QA targets for all parameters (Table A-4), one sample pair for orthophosphate and two sample pairs for total phosphorus exceeded the target precision criteria (Table A-5). In each of these cases, the reported sample concentrations were only slightly above the method reporting limit, and the results were deemed acceptable for use as reported.

Table A-4. Summary of total precision by parameter.

Parameter	Target Precision %RSD	Average %RSD
Total Reactive Phosphorus	20	4.21
Orthophosphate-P	20	6.60
Total Phosphorus	20	8.95
Total Dissolved Phosphorus	20	10.55
Total Alkalinity	20	0.44
Chloride	20	1.25
Sulfate	20	1.04
Nitrate and Nitrite Nitrogen	20	0.89
Calcium	20	0.50
Magnesium	20	0.71
Sodium	20	0.67
Potassium	20	3.33
Iron	20	1.30
Silicon	20	0.26

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[10] Calculated for a pair of results, x_1 and x_2, where: %RSD = [Standard deviation ($x_{1:}x_2$)/(average $x_{1:}x_2$)]*100

Table A-5. Field replicate concentrations and %RSD values by sample pair.

Parameter	Site	Date	Sample (mg/L)	Duplicate sample (mg/L)	%RSD for sample pair
Nitrate and Nitrite Nitrogen	57IEPPROD	5/1/12	0.729	0.719	0.98
	57IEPPROD	7/17/12	0.918	0.887	2.43
	57A139	8/14/12	0.626	0.628	0.23
	57A139	9/18/12	0.698	0.698	0.00
	57IEPPROD	10/10/12	0.633	0.633	0.00
	57A139	11/6/12	0.239	0.240	0.30
	57A140	12/18/12	0.109	0.108	0.65
	57A139	1/8/13	0.275	0.277	0.51
	57A140	2/5/13	0.198	0.193	1.81
	57IEPPROD	3/5/13	0.353	0.344	1.83
	AHT070	4/10/13	0.054	0.053	1.32
	AHT069	5/14/13	0.010 U	0.010 U	NA
	57A138	6/18/13	0.269	0.273	1.04
	AHT069	7/9/13	0.010 U	0.011	NA
	57IEPPROD	8/20/13	0.680	0.677	0.31
	57IEPPROD	9/24/13	0.694	0.705	1.11
Total Reactive Phosphorus	57IEPPROD	5/1/12	0.0064	0.0062	2.24
	57IEPPROD	7/17/12	0.0058	0.0048	13.34
	57A139	8/14/12	0.0030 U	0.0030 U	NA
	57A139	9/18/12	0.0030 U	0.0030 U	NA
	57IEPPROD	10/10/12	0.0044	0.0043	1.63
	57A139	11/6/12	0.0041	0.0030 U	NA
	57A140	12/18/12	0.0055	0.0059	4.96
	57A139	1/8/13	0.0036	0.0041	9.18
	57A140	2/5/13	0.0034	0.0033	2.11
	57IEPPROD	3/5/13	0.0051	0.0050	1.40
	AHT070	4/10/13	0.0058	0.0056	2.48
	AHT069	5/14/13	0.0049	0.0051	2.83
	57A138	6/18/13	0.0032	0.0030	4.56
	AHT069	7/9/13	0.0061	0.0057	4.79
	57IEPPROD	8/20/13	0.0058	0.0055	3.75
	57IEPPROD	9/24/13	0.0050	0.0051	1.40
Orthophosphate	57IEPPROD	5/1/12	0.0065	0.0070	5.24
	57IEPPROD	7/17/12	0.0050	0.0049	1.43
	57A139	8/14/12	0.0047	0.0030	31.22
	57A139	9/18/12	0.0030 U	0.0033	NA
	57IEPPROD	10/10/12	0.0045	0.0046	1.55
	57A139	11/6/12	0.0030	0.0035	10.88
	57A140	12/18/12	0.0046	0.0043	4.77
	57A139	1/8/13	0.0036	0.0042	10.88
	57A140	2/5/13	0.0038	0.0035	5.81
	57IEPPROD	3/5/13	0.0045	0.0048	4.56
	AHT070	4/10/13	0.0058	0.0058	0.00
	AHT069	5/14/13	0.0044	0.0051	10.42
	57A138	6/18/13	0.0041	0.0039	3.54

Parameter	Site	Date	Sample (mg/L)	Duplicate sample (mg/L)	%RSD for sample pair
	AHT069	7/9/13	0.0055	0.0055	0.00
	57IEPPROD	8/20/13	0.0055	0.0056	1.27
	57IEPPROD	9/24/13	0.0050	0.0045	7.44
Total Phosphorus	57IEPPROD	5/1/12	0.0054	0.0058	5.05
	57IEPPROD	7/17/12	0.0053	0.0050 U	NA
	57A139	8/14/12	0.0061	0.0066	5.57
	57A139	9/18/12	0.0050 U	0.0052	NA
	57IEPPROD	10/10/12	0.0050 U	0.0050 U	NA
	57A139	11/6/12	0.0080	0.0055	26.19
	57A140	12/18/12	0.0090	0.0084	4.88
	57A139	1/8/13	0.0089	0.0077	10.22
	57A140	2/5/13	0.0088	0.0065	21.26
	57IEPPROD	3/5/13	0.0060	0.0065	5.66
	AHT070	4/10/13	0.0054 J	0.0050 U	NA
	AHT069	5/14/13	0.0102	0.0108	4.04
	57A138	6/18/13	0.0076	0.0084	7.07
	AHT069	7/9/13	0.0132	0.0128	2.18
	57IEPPROD	8/20/13	0.0080	0.0080	0.00
	57IEPPROD	9/24/13	0.0058	0.0072	15.23
Total Dissolved Phosphorus	57IEPPROD	5/1/12	0.0051	0.0065	17.07
	57IEPPROD	7/17/12	0.0050 U	0.0056	NA
	57A139	8/14/12	0.0071	0.0060	11.88
	57A139	9/18/12	0.0050 U	0.0050 U	NA
	57IEPPROD	10/10/12	0.0050 U	0.0053	NA
	57A139	11/6/12	0.0059	0.0072	14.03
	57A140	12/18/12	0.0069	0.0050 U	NA
	57A139	1/8/13	0.0060	0.0065	5.66
	57A140	2/5/13	0.0050 U	0.0054	NA
	57IEPPROD	3/5/13	0.0064	0.0057	8.18
	AHT070	4/10/13	0.0050 U	0.0059	NA
	AHT069	5/14/13	0.0099	0.0084	11.59
	57A138	6/18/13	0.0083	0.0067	15.08
	AHT069	7/9/13	0.0130	0.0125	2.77
	57IEPPROD	8/20/13	0.0069	0.0078	8.66
	57IEPPROD	9/24/13	0.0063	0.0050 U	NA
Alkalinity	57IEPPROD	5/1/12	67.5	67.4	0.10
	57IEPPROD	7/17/12	79.1	79.6	0.45
	57A139	8/14/12	71.9	71.5	0.39
	57A139	9/18/12	78.4	78.5	0.09
	57IEPPROD	10/10/12	77.7	78.5	0.72
	57A139	11/6/12	38.5	38.8	0.55
	57A140	12/18/12	24.6	24.7	0.29
	57A139	1/8/13	40.2	40.5	0.53
	57A140	2/5/13	33.5	33.4	0.21
	57IEPPROD	3/5/13	55.1	55.5	0.51
	AHT070	4/10/13	28.6	29.2	1.47
	AHT069	5/14/13	37.2	36.9	0.57

Parameter	Site	Date	Sample (mg/L)	Duplicate sample (mg/L)	%RSD for sample pair
	57A138	6/18/13	42.0	41.6	0.68
	AHT069	7/9/13	52.1	52.2	0.14
	57IEPPROD	8/20/13	79.5	79.5	0.00
	57IEPPROD	9/24/13	84.6	85.1	0.42
Chloride	57IEPPROD	5/1/12	5.61	5.29	4.15
	57IEPPROD	7/17/12	2.61	2.61	0.00
	57A139	8/14/12	1.83	1.84	0.39
	57A139	9/18/12	1.86	1.80	2.32
	57IEPPROD	10/10/12	1.70	1.69	0.42
	57A139	11/6/12	1.19	1.17	1.20
	57A140	12/18/12	1.14	1.16	1.23
	57A139	1/8/13	1.40	1.39	0.51
	57A140	2/5/13	1.48	1.42	2.93
	57IEPPROD	3/5/13	1.70	1.69	0.42
	AHT070	4/10/13	1.40	1.40	0.00
	AHT069	5/14/13	1.29	1.25	2.23
	57A138	6/18/13	1.42	1.39	1.51
	AHT069	7/9/13	1.52	1.55	1.38
	57IEPPROD	8/20/13	1.93	1.93	0.00
	57IEPPROD	9/24/13	2.04	2.00	1.40
Sulfate	57IEPPROD	5/1/12	8.37	8.16	1.80
	57IEPPROD	7/17/12	7.20	7.20	0.00
	57A139	8/14/12	8.14	8.16	0.17
	57A139	9/18/12	9.14	9.01	1.01
	57IEPPROD	10/10/12	8.61	8.67	0.49
	57A139	11/6/12	5.08	4.98	1.41
	57A140	12/18/12	4.18	4.08	1.71
	57A139	1/8/13	5.45	5.37	1.05
	57A140	2/5/13	5.00	5.04	0.56
	57IEPPROD	3/5/13	6.25	6.31	0.68
	AHT070	4/10/13	4.69	4.68	0.15
	AHT069	5/14/13	0.99	1.05	4.16
	57A138	6/18/13	5.09	5.18	1.24
	AHT069	7/9/13	4.46	4.51	0.79
	57IEPPROD	8/20/13	8.97	9.11	1.10
	57IEPPROD	9/24/13	9.43	9.39	0.30
Calcium	57IEPPROD	5/1/12	20.20	20.10	0.35
	57IEPPROD	7/17/12	20.20	20.30	0.35
	57A139	8/14/12	18.40	18.60	0.76
	57A139	9/18/12	19.70	19.80	0.36
	57IEPPROD	10/10/12	22.00	22.10	0.32
	57A139	11/6/12	9.97	10.00	0.21
	57A140	12/18/12	7.07	7.21	1.39
	57A139	1/8/13	10.40	10.40	0.00
	57A140	2/5/13	9.35	9.33	0.15
	57IEPPROD	3/5/13	16.00	16.10	0.44
	AHT070	4/10/13	7.36	7.54	1.71

Parameter	Site	Date	Sample (mg/L)	Duplicate sample (mg/L)	%RSD for sample pair
	AHT069	5/14/13	8.29	8.44	1.27
	57A138	6/18/13	10.90	10.80	0.65
	AHT069	7/9/13	13.00	13.00	0.00
	57IEPPROD	8/20/13	22.10	22.10	0.00
	57IEPPROD	9/24/13	24.50	24.50	0.00
Iron	57IEPPROD	5/1/12	0.05 U	0.05 U	NA
	57IEPPROD	7/17/12	0.05 U	0.05 U	NA
	57A139	8/14/12	0.05 U	0.05 U	NA
	57A139	9/18/12	0.05 U	0.05 U	NA
	57IEPPROD	10/10/12	0.05 U	0.05 U	NA
	57A139	11/6/12	0.05 U	0.05 U	NA
	57A140	12/18/12	0.05 U	0.05 U	NA
	57A139	1/8/13	0.05 U	0.05 U	NA
	57A140	2/5/13	0.05 U	0.05 U	NA
	57IEPPROD	3/5/13	0.05 U	0.05 U	NA
	AHT070	4/10/13	0.05 U	0.05 U	NA
	AHT069	5/14/13	0.213	0.208	1.68
	57A138	6/18/13	0.05 U	0.05 U	NA
	AHT069	7/9/13	0.463	0.457	0.92
	57IEPPROD	8/20/13	0.05 U	0.05 U	NA
	57IEPPROD	9/24/13	0.05 U	0.05 U	NA
Magnesium	57IEPPROD	5/1/12	6.40	6.37	0.33
	57IEPPROD	7/17/12	6.44	6.45	0.11
	57A139	8/14/12	7.77	7.86	0.81
	57A139	9/18/12	8.34	8.34	0.00
	57IEPPROD	10/10/12	7.13	7.22	0.89
	57A139	11/6/12	3.80	3.79	0.19
	57A140	12/18/12	2.38	2.44	1.76
	57A139	1/8/13	3.99	4.07	1.40
	57A140	2/5/13	3.43	3.42	0.21
	57IEPPROD	3/5/13	5.10	5.15	0.69
	AHT070	4/10/13	2.63	2.70	1.86
	AHT069	5/14/13	2.89	2.96	1.69
	57A138	6/18/13	4.24	4.17	1.18
	AHT069	7/9/13	4.32	4.32	0.00
	57IEPPROD	8/20/13	7.15	7.15	0.00
	57IEPPROD	9/24/13	7.86	7.88	0.18
Potassium	57IEPPROD	5/1/12	1.10	1.15	3.14
	57IEPPROD	7/17/12	1.10	1.09	0.65
	57A139	8/14/12	1.23	1.23	0.00
	57A139	9/18/12	1.30	1.33	1.61
	57IEPPROD	10/10/12	1.32	1.36	2.11
	57A139	11/6/12	0.82	0.86	3.37
	57A140	12/18/12	0.69	0.78	8.66
	57A139	1/8/13	0.90	0.84	4.88
	57A140	2/5/13	0.80	0.88	6.73
	57IEPPROD	3/5/13	1.02	0.91	8.06

Parameter	Site	Date	Sample (mg/L)	Duplicate sample (mg/L)	%RSD for sample pair
	AHT070	4/10/13	0.74	0.81	6.39
	AHT069	5/14/13	0.97	0.98	0.73
	57A138	6/18/13	0.89	0.87	1.61
	AHT069	7/9/13	1.10	1.13	1.90
	57IEPPROD	8/20/13	1.38	1.44	3.01
	57IEPPROD	9/24/13	1.47	1.46	0.48
Sodium	57IEPPROD	5/1/12	3.68	3.57	2.15
	57IEPPROD	7/17/12	2.98	2.97	0.24
	57A139	8/14/12	2.59	2.59	0.00
	57A139	9/18/12	2.64	2.63	0.27
	57IEPPROD	10/10/12	2.87	2.89	0.49
	57A139	11/6/12	1.86	1.86	0.00
	57A140	12/18/12	1.76	1.80	1.59
	57A139	1/8/13	2.04	2.08	1.37
	57A140	2/5/13	2.06	2.03	1.04
	57IEPPROD	3/5/13	2.19	2.18	0.32
	AHT070	4/10/13	1.86	1.91	1.88
	AHT069	5/14/13	2.13	2.15	0.66
	57A138	6/18/13	2.27	2.27	0.00
	AHT069	7/9/13	2.23	2.22	0.32
	57IEPPROD	8/20/13	3.05	3.06	0.23
	57IEPPROD	9/24/13	3.08	3.09	0.23
Silicon	57IEPPROD	5/1/12	4.88	4.87	0.15
	57IEPPROD	7/17/12	4.89	4.86	0.44
	57A139	8/14/12	5.20	5.19	0.14
	57A139	9/18/12	5.00	4.99	0.14
	57IEPPROD	10/10/12	5.74	5.75	0.12
	57A139	11/6/12	4.83	4.81	0.29
	57A140	12/18/12	5.12	5.03	1.25
	57A139	1/8/13	5.11	5.11	0.00
	57A140	2/5/13	4.87	4.86	0.15
	57IEPPROD	3/5/13	4.76	4.78	0.30
	AHT070	4/10/13	5.25	5.26	0.13
	AHT069	5/14/13	6.55	6.53	0.22
	57A138	6/18/13	4.75	4.73	0.30
	AHT069	7/9/13	5.95	5.95	0.00
	57IEPPROD	8/20/13	5.99	6.03	0.47
	57IEPPROD	9/24/13	6.09	6.09	0.00

U: The analyte was not detected at or above the reported result.
J: The analyte was positively identified. The associated numerical result is an estimate.
NA: %RSD values were only calculated for sample pairs that exceeded the laboratory detection limit
Shaded %RSD values indicate an exceedance of the project QA precision target of +-20% RSD

Appendix B. Tabular Data Summaries

Table B-1. Piezometer vertical hydraulic gradient measurements.

Location ID	Date	Head Difference between SW stage and GW level, dh (ft)	Depth to Midpoint of Piezometer Perforations, dl (ft)	Vertical Hydraulic Gradient, dh/dl
AHT069	8/1/12	-2.56	4.72	-0.54
	8/14/12	-3.34	4.73	-0.71
	9/18/12	-4.39	4.73	-0.93
	10/10/12	-4.57	4.74	-0.96
	11/6/12	-4.00	4.75	-0.84
	12/18/12	-2.03	4.75	-0.43
	1/8/13	-3.02	4.75	-0.64
	2/5/13	-3.99	4.75	-0.84
	3/5/13	-4.11	4.74	-0.87
	4/10/13	-2.36	4.75	-0.50
	5/14/13	-1.22	4.74	-0.26
	6/18/13	-2.34	4.75	-0.49
	7/9/13	-2.96	4.76	-0.62
	8/20/13	-4.77	4.77	-1.00
	9/24/13	-4.93	4.75	-1.04
AHT070	8/1/12	-2.72	4.83	-0.56
	8/14/12	-3.19	4.85	-0.66
	9/18/12	-3.94	4.88	-0.81
	10/10/12	-4.07	4.83	-0.84
	11/6/12	-4.08	4.83	-0.84
	12/18/12	-2.74	4.90	-0.56
	1/8/13	-3.40	4.88	-0.70
	2/5/13	-4.49	4.89	-0.92
	3/5/13	-4.54	4.94	-0.92
	4/10/13	-3.20	4.92	-0.65
	5/14/13	-1.99	4.92	-0.40
	6/18/13	-2.72	4.91	-0.56
	7/9/13	-3.07	4.87	-0.63
	8/20/13	-4.46	5.03	-0.89
	9/24/13	-4.57	5.13	-0.89
AHT071	8/1/12	-5.29	4.83	-1.09
	8/14/12	-6.17	4.85	-1.27
	9/18/12	*	4.83	-1.48 *
	10/10/12	*	4.88	-1.44 *

Location ID	Date	Head Difference between SW stage and GW level, dh (ft)	Depth to Midpoint of Piezometer Perforations, dl (ft)	Vertical Hydraulic Gradient, dh/dl
AHT071	11/6/12	*	4.83	-1.46 *
	12/18/12	-5.28	4.91	-1.07
	1/8/13	-6.22	4.91	-1.27
	2/5/13	-7.13	4.82	-1.48
	3/5/13	*	4.81	-1.09 *
	4/10/13	-5.74	4.92	-1.17
	5/14/13	-4.28	4.88	-0.88
	6/18/13	-5.42	4.82	-1.12
	7/9/13	-5.90	4.84	-1.22
	8/20/13	*	4.94	-1.41 *
	9/24/13	*	4.90	-1.44 *

* The groundwater level was not measurable because it was below the piezometer perforations (piezometer was dry). The reported vertical hydraulic gradient represents the *minimum potential gradient* for this date. The actual gradient is likely larger (more negative) that the value reported here.

SW: surface water

GW: groundwater

dh/dl: The change in hydraulic head (dh) divided by the distance between the stream bed surface and the piezometer screen midpoint (dl)

Table B-2. Field water quality results.

Location ID	Date	pH (standard units)	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/L)	Temperature (°C)
57A138	3/5/13	7.19	75.1	12.42	4.42
	4/10/13	7.73 J	55.1	12.94	5.85
	5/15/13	7.52	50.9	10.71	12.87
	6/18/13	7.67	90.0 J	8.69	17.06
	7/9/13	7.87	132.0 J	8.84	18.73
	8/20/13	7.82	222.4 J	8.07	14.99
	9/24/13	7.88	165.8	8.81	14.09
57A139	4/3/12	8.00	46.9 J	13.59	3.95
	5/1/12	7.41	46.4	12.70	8.52
	6/12/12	7.56	44.1 J	10.99	11.87
	7/17/12	7.36	86.5	7.83	20.69
	8/14/12	7.60	163.6	8.03	17.33
	9/18/12	7.50	177.4	8.43	13.60
	10/10/12	7.57	152.0	9.60	11.98
	11/6/12	7.23	88.9	10.02	10.92
	12/18/12	7.02	63.5	11.60	6.13
	1/8/13	7.25	92.9	11.49	4.90
	2/5/13	7.87	78.1	12.23	4.43
	3/5/13	7.17	78.5	12.32	4.15
	4/10/13	7.57 J	55.0	12.96	5.60
	5/14/13	7.65	51.0	10.58	13.47
	6/18/13	7.59	86.3 J	8.37	16.58
	7/9/13	7.81	129.3 J	8.41	17.75
	8/20/13	7.76	209.0 J	7.80	14.35
	9/24/13	7.75	160.2	8.34	13.77
57A140	4/3/12	8.25	47.1 J	13.63	3.83
	5/1/12	7.84	46.2	12.72	8.42
	6/12/12	7.57	44.6 J	11.50	11.76
	7/17/12	7.36	86.6	7.93	20.67
	8/14/12	7.62	162.5	8.25	17.26
	9/18/12	7.51	176.7	8.70	13.47
	10/10/12	7.58	151.6	9.74	12.11
	11/6/12	7.31	89.8	9.86	10.89
	12/18/12	7.17	63.0	11.48	6.09
	1/8/13	7.14	93.0	11.37	4.93
	2/5/13	7.91	78.1	12.08	4.37
	3/5/13	7.17	78.1	12.15	4.05

Location ID	Date	pH (standard units)	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/L)	Temperature (°C)
57A140	4/10/13	7.63 J	55.1	12.94	5.54
	5/14/13	7.67	50.7	10.44	13.37
	6/18/13	7.56	86.5 J	8.40	16.45
	7/9/13	7.72	128.4 J	8.10	17.27
	8/20/13	7.79	207.4 J	8.04	14.06
	9/24/13	7.80	160.8	8.39	13.81
57IEPDISCH	5/14/13	8.06	804.0	7.66	23.95
	6/18/13	8.06	829.0 J	7.20	23.83
	7/9/13	8.09	752.0 J	7.77	23.56
	8/20/13	8.05	847.7 J	6.86	27.73
	9/24/13	7.99	1081.0	6.54	26.47
57IEPPROD	4/3/12	8.06	137.8 J	8.10	8.70
	5/1/12	7.90	161.8	8.76	8.45
	6/12/12	7.88	192.4 J	7.85	8.13
	7/17/12	7.70	165.0	6.25	8.54
	8/14/12	7.40	155.5	4.44	12.23
	9/18/12	7.23	190.8	5.26	13.86
	10/10/12	7.25	177.2	5.37	14.09
	11/6/12	7.33	164.0	5.97	13.66
	12/18/12	7.43	143.4	6.58	12.39
	1/8/13	7.54	134.5	7.08	11.81
	2/5/13	8.20	126.6	8.22	10.41
	3/5/13	7.51	125.4	8.22	9.52
	4/10/13	7.98 J	130.7	8.35	9.05
	5/14/13	7.85	150.5	7.93	8.91
	6/18/13	7.86	116.3 J	5.73	8.42
	7/9/13	7.75	109.7 J	4.70	10.19
	8/20/13	7.40	166.2 J	4.47	14.25
	9/24/13	7.49	189.3	4.65	14.85
57IEPTREAT	5/14/13	7.84	1557.0	3.09	30.66
	6/18/13	7.86	1720.0 J	2.95	31.84
	7/9/13	7.89	1882.0 J	3.41	33.84
	8/20/13	7.96	1741.0 J	3.81	32.09
	9/24/13	7.85	1844.0	3.35	31.64
AHC937	5/15/13	7.77	293.3	9.12	10.23
	6/19/13	7.76	268.6 J	8.94	10.07
	7/10/13	7.82	233.4 J	8.18	9.97
AHT069	9/18/12	6.88	172.9	0.88	14.50
	3/5/13	6.51	83.2	5.42	4.58

Location ID	Date	pH (standard units)	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/L)	Temperature (°C)
AHT069	4/10/13	6.71 J	67.5	1.92	5.98
	5/14/13	6.75	75.4	0.31	12.72
	6/18/13	6.61	83.5 J	0.44	16.45
	7/9/13	6.68	106.2 J	0.35	19.24
	8/20/13	6.96	199.8 J	0.44	15.32
	9/24/13	7.01	161.6	0.00	13.82
AHT070	9/18/12	6.95	173.0	2.50	14.64
	3/5/13	6.40	84.7	5.35	4.61
	4/10/13	6.86 J	68.0	3.44	5.89
	5/14/13	6.78	71.0	0.00	13.16
	6/18/13	6.64	80.3 J	0.66	16.61
	7/9/13	6.72	109.4 J	1.01	19.31
	8/20/13	7.06	201.2 J	2.12	15.60
	9/24/13	7.12	162.4	2.31	14.13
AHT071	4/10/13	6.76 J	64.6	4.41	5.81
	5/14/13	6.73	61.6	0.81	13.71
	6/18/13	6.64	80.9 J	0.68	16.85
	7/9/13	6.68	111.0 J	0.50	18.95

J: Analyte was positively identified. The reported result is an estimate.

Table B-3. Laboratory water quality results.

Location ID	Date	Total Phosphorus (mg/L)	Total Dissolved Phosphorus* (mg/L)	Total Reactive Phosphorus (mg/L)	Ortho-Phosphate (mg/L)	Nitrate-Nitrite* (mg/L)	Chloride* (mg/L)	Sulfate* (mg/L)	Alkalinity* (mg/L)	Calcium* (mg/L)	Iron* (mg/L)	Magnesium* (mg/L)	Potassium* (mg/L)	Silicon* (mg/L)	Sodium* (mg/L)
57A138	3/5/13	0.0095	0.0075	0.0036	0.0040	0.152	1.57	5.20	32.0	8.73	0.050 U	3.05	0.94	5.12	2.63
	4/10/13	0.0081	0.0050 U	0.0039	0.0031	0.040	1.46	4.35	22.2	6.16	0.050 U	1.96	0.76	5.19	2.00
	5/15/13	0.0107	0.0052	0.0042	0.0036	0.034 JL	1.05	3.13	22.2	5.75	0.050 U	1.79	0.57	5.03	1.77
	6/18/13	0.0076	0.0083	0.0032	0.0041	0.269	1.42	5.09	42.0	10.90	0.050 U	4.24	0.89	4.75	2.27
	6/18/13 Dup	0.0084	0.0067	0.0030	0.0039	0.273	1.39	5.18	41.6	10.80	0.050 U	4.17	0.87	4.73	2.27
	7/9/13	0.0067	0.0050 U	0.0050	0.0053	0.481	1.76	6.99	61.9	15.50	0.050 U	6.38	1.14	4.90	2.72
	8/20/13	0.0146 JL	0.0103	0.0066	0.0071	0.856	2.56	12.60	104.0	25.70	0.050 U	10.90	1.65	5.47	5.64
	9/24/13	0.0082	0.0058	0.0030 U	0.0030	0.600	2.11	9.32	74.4	19.30	0.050 U	7.93	1.43	5.15	4.50
57A139	4/3/12	0.0111	0.0050 U	0.0037	0.0034	0.021	1.37	4.42	19.0	6.06	0.050 U	1.85	0.72	5.13 JL	1.91 JL
	5/1/12	0.0198	0.0063	0.0074	0.0061	0.039	1.22	3.15	15.3	5.17	0.050 U	1.64	0.71	6.02	1.81
	6/12/12	0.0093	0.0050 U	0.0030 U	0.0030 U	0.035	0.95	2.73	15.8	5.26	0.050 U	1.65	0.72	5.02	1.57
	7/17/12	0.0076	0.0050 U	0.0043	0.0041	0.269	1.26	4.53	42.4	9.13	0.050 U	3.55	0.84	4.93	1.92
	8/14/12	0.0061	0.0071	0.0030 U	0.0047	0.626	1.83	8.14	71.9	18.40	0.050 U	7.77	1.23	5.20	2.59
	8/14/12 Dup	0.0066	0.0060	0.0030 U	0.0030	0.628	1.84	8.16	71.5	18.60	0.050 U	7.86	1.23	5.19	2.59
	9/18/12	0.0050 U	0.0050 U	0.0030 U	0.0030 U	0.698	1.86	9.14	78.4	19.70	0.050 U	8.34	1.30	5.00	2.64
	9/18/12 Dup	0.0052	0.0050 U	0.0030 U	0.0033	0.698	1.80	9.01	78.5	19.80	0.050 U	8.34	1.33	4.99	2.63
	10/10/12	0.0062	0.0050 U	0.0030 U	0.0030 U	0.573	1.58	7.82	66.4	17.20	0.050 U	7.21	1.23	5.06	2.47
	11/6/12	0.0080	0.0059	0.0041	0.0030	0.239	1.19	5.08	38.5	9.97	0.050 U	3.80	0.82	4.83	1.86 JL
	11/6/12 Dup	0.0055	0.0072	0.0030 U	0.0035	0.010	1.17	4.98	38.8	10.00	0.050 U	3.79	0.86	4.81	1.86 JL
	12/18/12	0.0081	0.0050 U	0.0056	0.0047	0.114	1.17 JL	4.25	24.7	7.24	0.050 U	2.46	0.79	5.03	1.78 JL
	1/8/13	0.0089	0.0060	0.0036	0.0036	0.275	1.40	5.45	40.2	10.40	0.050 U	3.99	0.90	5.11	2.04
	1/8/13 Dup	0.0077	0.0065	0.0041	0.0042	0.277	1.39	5.37	40.5	10.40	0.050 U	4.07	0.84	5.11	2.08
	2/5/13	0.0062	0.0050 U	0.0030	0.0034	0.197	1.46	4.98	33.4	9.38	0.050 U	3.41	0.79	4.87	2.03
	3/5/13	0.0090	0.0056	0.0036	0.0036	0.172	1.52	5.25	33.3	8.94	0.050 U	3.28	0.94	5.09	2.14
	4/10/13	0.0089	0.0050 U	0.0040	0.0032	0.036	1.49	4.28	21.3	6.06	0.050 U	1.94	0.73	5.09	1.96
	5/14/13	0.0086	0.0051	0.0035	0.0031	0.034 JL	1.06	3.21	22.5	5.81	0.050 U	1.83	0.58	5.02	1.70
	6/18/13	0.0067	0.0085	0.0030 U	0.0030 U	0.268	1.35	4.91	40.3	10.70	0.050 U	4.14	0.85	4.67	2.02
	7/9/13	0.0058	0.0050 U	0.0042	0.0043	0.489	1.62	6.76	61.0	15.30	0.050 U	6.39	1.19	4.86	2.32

Location ID	Date	Total Phosphorus (mg/L)	Total Dissolved Phosphorus* (mg/L)	Total Reactive Phosphorus (mg/L)	Ortho-Phosphate (mg/L)	Nitrate-Nitrite* (mg/L)	Chloride* (mg/L)	Sulfate* (mg/L)	Alkalinity* (mg/L)	Calcium* (mg/L)	Iron* (mg/L)	Magnesium* (mg/L)	Potassium* (mg/L)	Silicon* (mg/L)	Sodium* (mg/L)
	8/20/13	0.0086 JL	0.0056	0.0030 U	0.0030 U	0.868	2.16	10.80	100.0	25.10	0.050 U	10.90	1.54	5.32	2.96
	9/24/13	0.0066	0.0052	0.0030 U	0.0030 U	0.604	1.93	8.31	71.1	18.50	0.050 U	7.77	1.26	4.95	2.53
57A140	4/3/12	0.0089	0.0050 U	0.0035	0.0032	0.023	1.38	4.36	22.6	6.06	0.050 U	1.85	0.75	5.17 JL	1.93 JL
	5/1/12	0.0200	0.0057	0.0076	0.0056	0.037	1.19	3.25	14.3	5.16	0.059	1.64	0.75	5.98	1.81
	6/12/12	0.0097	0.0065	0.0030 U	0.0030 U	0.034	0.97	2.96	15.8	5.26	0.050 U	1.67	0.67	4.98	1.61
	7/17/12	0.0084	0.0072	0.0041	0.0045	0.263	1.35	4.51	42.1	9.17	0.050 U	3.51	0.82	5.01	1.98
	8/14/12	0.0058	0.0063	0.0030 U	0.0049	0.622	1.92	8.16	71.6	18.50	0.050 U	7.83	1.28	5.35	2.65
	9/18/12	0.0054	0.0052	0.0030 U	0.0030 U	0.710	1.89	9.07	78.3	19.80	0.050 U	8.37	1.29	5.01	2.66
	10/10/12	0.0059	0.0050 U	0.0030 U	0.0030 U	0.573	1.59	7.72	66.0	17.10	0.050 U	7.13	1.18	5.08	2.47
	11/6/12	0.0079	0.0058	0.0043	0.0036	0.244	1.19	4.94	38.7	9.93	0.050 U	3.81	0.90	4.90	1.94 JL
	12/18/12	0.0090	0.0069	0.0055	0.0046	0.109	1.14 JL	4.18	24.6	7.07	0.050 U	2.38	0.69	5.12	1.76 JL
	12/18/12 Dup	0.0084	0.0050 U	0.0059	0.0043	0.108	1.16 JL	4.08	24.7	7.21	0.050 U	2.44	0.78	5.03	1.80 JL
	1/8/13	0.0110	0.0050 U	0.0038	0.0037	0.278	1.43	5.44	39.6	10.50	0.050 U	4.06	0.96	5.16	2.07
	2/5/13	0.0088	0.0050 U	0.0034	0.0038	0.198	1.48	5.00	33.5	9.35	0.050 U	3.43	0.80	4.87	2.06
	2/5/13 Dup	0.0065	0.0054	0.0033	0.0035	0.193	1.42	5.04	33.4	9.33	0.050 U	3.42	0.88	4.86	2.03
	3/5/13	0.0074	0.0050 U	0.0034	0.0032	0.176	1.52	5.16	33.3	9.05	0.050 U	3.45	0.93	5.07	2.27
	4/10/13	0.0087	0.0050 U	0.0037	0.0036	0.040	1.45	4.33	22.1	6.08	0.050 U	1.94	0.61	5.12	1.98
	5/14/13	0.0101	0.0050 U	0.0033	0.0030	0.036 JL	1.04	3.14	21.5	5.81	0.050 U	1.82	0.58	5.04	1.69
	6/18/13	0.0098	0.0061	0.0033	0.0032	0.281	1.40	4.95	41.5	10.80	0.050 U	4.12	0.92	4.69	2.02
	7/9/13	0.0072	0.0050 U	0.0050	0.0052	0.505	1.61	6.62	60.6	15.20	0.050 U	6.30	1.13	4.92	2.34
	8/20/13	0.0088 JL	0.0087	0.0030 U	0.0034	0.896	2.20	10.80	99.7	24.80	0.050 U	10.70	1.57	5.38	2.95
	9/24/13	0.0074	0.0064	0.0031	0.0031	0.625	2.38	8.25	72.5	18.70	0.050 U	7.82	1.25	4.97	2.60
57IEPDISCH	5/14/13	0.2860	0.3030	0.2430	0.2470	0.312 JL	21.70	50.90	359.0	50.30	0.088	6.28	9.59	14.50	126.00
	6/18/13	0.2280	0.1830	0.1910	0.1690	0.245	17.70	50.00	332.0	46.40	0.121	5.79	8.91	11.10	115.00
	7/9/13	0.1650	0.1500	0.1480	0.1350	0.230	16.20	67.30	264.0	45.20	0.153	5.55	9.05	11.20	114.00
	8/20/13	0.2740	0.2560	0.2350	0.2280	0.381	18.00	96.90	325.0	47.80	0.141	7.28	7.28	12.40	138.00
	9/24/13	0.0903	0.0583	0.0434	0.0345	0.326 JL	25.80	127.00	418.0	54.90	0.216	8.16	11.40	16.00	191.00
57IEPPROD	4/3/12	0.0055	0.0050 U	0.0053	0.0054	0.485	3.10	6.97	65.9	18.10	0.050 U	5.79	1.07	4.74 JL	2.84 JL
	5/1/12	0.0054	0.0051	0.0064	0.0065	0.729	5.61	8.37	67.5	20.20	0.050 U	6.40	1.10	4.88	3.68
	5/1/12 Dup	0.0058	0.0065	0.0062	0.0070	0.719	5.29	8.16	67.4	20.10	0.050 U	6.37	1.15	4.87	3.57

Location ID	Date	Total Phosphorus (mg/L)	Total Dissolved Phosphorus* (mg/L)	Total Reactive Phosphorus (mg/L)	Ortho-Phosphate (mg/L)	Nitrate-Nitrite* (mg/L)	Chloride* (mg/L)	Sulfate* (mg/L)	Alkalinity* (mg/L)	Calcium* (mg/L)	Iron* (mg/L)	Magnesium* (mg/L)	Potassium* (mg/L)	Silicon* (mg/L)	Sodium* (mg/L)
57IEPPROD	6/12/12	0.0057	0.0065	0.0042	0.0043	1.250	3.67	8.82	83.8	24.30	0.050 U	7.69	1.20	4.81	3.43
	7/17/12	0.0053	0.0050 U	0.0058	0.0050	0.918	2.61	7.20	79.1	20.20	0.050 U	6.44	1.10	4.89	2.98
	7/17/12 Dup	0.0050 U	0.0056	0.0048	0.0049	0.887	2.61	7.20	79.6	20.30	0.050 U	6.45	1.09	4.86	2.97
	8/14/12	0.0050 U	0.0050	0.0030 U	0.0039	0.620	1.90	7.57	69.0	19.40	0.050 U	6.23	1.15	5.80	3.10
	9/18/12	0.0050 U	0.0050	0.0039	0.0038	0.750	1.98	9.56	84.7	23.50	0.050 U	7.56	1.39	5.65	3.11
	10/10/12	0.0050 U	0.0050 U	0.0044	0.0045	0.633	1.70	8.61	77.7	22.00	0.050 U	7.13	1.32	5.74	2.87
	10/10/12 Dup	0.0050 U	0.0053	0.0043	0.0046	0.633	1.69	8.67	78.5	22.10	0.050 U	7.22	1.36	5.75	2.89
	11/6/12	0.0050 U	0.0053	0.0046	0.0044	0.539	1.69	7.75	74.0	20.60	0.050 U	6.62	1.28	5.47	2.65
	12/18/12	0.0050 U	0.0076	0.0067	0.0058	0.387	1.57 JL	6.47	63.0	18.10	0.050 U	5.71	1.14	5.20	2.42 JL
	1/8/13	0.0063	0.0068	0.0048	0.0049	0.360	1.45	5.96	61.8	16.50	0.050 U	5.29	1.14	5.14	2.29
	2/5/13	0.0056	0.0061	0.0048	0.0050	0.388	1.60	6.02	56.7	16.40	0.050 U	5.19	1.01	4.77	2.15
	3/5/13	0.0060	0.0064	0.0051	0.0045	0.353	1.70	6.25	55.1	16.00	0.050 U	5.10	1.02	4.76	2.19
	3/5/13 Dup	0.0065	0.0057	0.0050	0.0048	0.344	1.69	6.31	55.5	16.10	0.050 U	5.15	0.91	4.78	2.18
	4/10/13	0.0050 U	0.0062	0.0055	0.0057	0.440	2.03	6.37	58.6	17.00	0.050 U	5.41	1.01	4.71	2.23
	5/14/13	0.0057	0.0050 U	0.0050	0.0051	0.687 JL	2.43	6.99	67.2	19.00	0.050 U	5.94	0.97	4.61	2.48
	6/18/13	0.0059	0.0069	0.0049	0.0045	0.418	1.79	5.45	55.4	15.80	0.050 U	5.07	0.95	4.70	2.50
	7/9/13	0.0050 U	0.0050 U	0.0061	0.0059	0.357	1.43	5.26	53.5	14.10	0.050 U	4.58	0.97	5.13	2.38
	8/20/13	0.0080 JL	0.0069	0.0058	0.0055	0.680	1.93	8.97	79.5	22.10	0.050 U	7.15	1.38	5.99	3.05
	8/20/13 Dup	0.0080 JL	0.0078	0.0054	0.0056	0.677	1.93	9.11	79.5	22.10	0.050 U	7.15	1.44	6.03	3.06
	9/24/13	0.0058	0.0063	0.0050	0.0050	0.694	2.04	9.43	84.6	24.50	0.050 U	7.86	1.47	6.09	3.08
	9/24/13 Dup	0.0072	0.0050 U	0.0051	0.0045	0.705	2.00	9.39	85.1	24.50	0.050 U	7.88	1.46	6.09	3.09
57IEPTREAT	5/14/13	0.6100	0.5720	0.5230	0.5110	0.011 JL	43.40	101.00	679.0	86.50	0.187	7.06	18.60	25.00	258.00
	6/18/13	0.5270	0.4870	0.4540	0.4490	0.010 U	44.30	126.00	754.0	97.30	0.347	7.12	21.90	22.00	300.00
	7/9/13	0.5260	0.4860	0.4540	0.4390	0.010 U	51.10	215.00	741.0	107.00	0.457	7.88	25.30	23.60	346.00
	8/20/13	0.6150	0.5690	0.5380	0.5340	0.010 U	34.60	188.00	667.0	84.10	0.337	7.95	15.70	21.40	328.00
	9/24/13	0.1560	0.0994 J	0.0803	0.0668	0.010 U	46.80	230.00	693.0	83.10	0.409	8.77	20.30	24.30	354.00
AHC937	5/15/13	0.0068	0.0076	0.0086	0.0083	2.030	4.41	9.95	135.0	38.10	0.050 U	11.60	2.28	6.61	4.23
	6/19/13	0.0087	0.0087	0.0066	0.0066	1.840	4.32	9.44	126.0	36.30	0.050 U	11.30	2.41	6.52	4.26
	7/10/13	0.0064	0.0068	0.0090	0.0089	1.410	3.74	8.43	110.0	30.50	0.050 U	9.50	2.18	6.31	3.91

Location ID	Date	Total Phosphorus (mg/L)	Total Dissolved Phosphorus* (mg/L)	Total Reactive Phosphorus (mg/L)	Ortho-Phosphate (mg/L)	Nitrate-Nitrite* (mg/L)	Chloride* (mg/L)	Sulfate* (mg/L)	Alkalinity* (mg/L)	Calcium* (mg/L)	Iron* (mg/L)	Magnesium* (mg/L)	Potassium* (mg/L)	Silicon* (mg/L)	Sodium* (mg/L)
AHT069	9/18/12	0.0057	0.0059	0.0048	0.0043	0.602	1.84	9.06	76.7	19.10	0.050 U	7.89	1.25	5.14	2.59
	3/5/13	NA	0.0061	0.0037	0.0034	0.174	1.59	5.31	35.4	9.44	0.050 U	3.57	0.94	5.02	2.18
	4/10/13	0.0050 U	0.0050 U	0.0046	0.0041	0.049	1.43	4.31	29.4	7.44	0.050 U	2.73	0.75	5.24	1.95
	5/14/13	0.0102	0.0099	0.0049	0.0044	0.010 U	1.29	0.99	37.2	8.29	0.213	2.89	0.97	6.55	2.13
	5/14/13 Dup	0.0108	0.0084	0.0051	0.0051	0.010 U	1.25	1.05	36.9	8.44	0.208	2.96	0.98	6.53	2.15
	6/18/13	0.0132	0.0104	0.0053	0.0052	0.010 U	1.34	1.72	44.0	10.20	0.381	3.43	1.07	6.31	1.95
	7/9/13	0.0132	0.0130	0.0061	0.0055	0.010 U	1.52	4.46	52.1	13.00	0.463	4.32	1.10	5.95	2.23
	7/9/13 Dup	0.0128	0.0125	0.0057	0.0055	0.011	1.55	4.51	52.2	13.00	0.457	4.32	1.13	5.95	2.22
	8/20/13	0.0089 JL	0.0073	0.0034	0.0046	0.338	2.17	11.70	95.6	24.90	0.050 U	10.10	1.22	5.14	2.92
	9/24/13	0.0060	0.0066	0.0044	0.0045	0.355	1.87	8.68	72.7	18.50	0.050 U	7.91	1.04	4.99	2.52
AHT070	9/18/12	0.0079	0.0082	0.0063	0.0070	0.566	1.81	9.05	76.1	19.40	0.050 U	7.86	1.32	5.07	2.61
	3/5/13	0.0060	0.0065	0.0048	0.0044	0.178	1.58	5.58	35.7	9.53	0.050 U	3.55	0.90	5.03	2.17
	4/10/13	0.0054 J	0.0050 U	0.0058	0.0058	0.054	1.40	4.69	28.6	7.36	0.050 U	2.63	0.74	5.25	1.86
	4/10/13 Dup	0.0050 U	0.0059	0.0056	0.0058	0.053	1.40	4.68	29.2	7.54	0.050 U	2.70	0.81	5.26	1.91
	5/14/13	0.0117	0.0114	0.0054	0.0050	0.024 JL	1.18	2.49	32.7	7.72	0.221	2.61	1.01	6.40	2.05
	6/18/13	0.0104	0.0089	0.0039	0.0039	0.190	1.34	4.08	38.2	9.87	0.177	3.35	1.04	5.60	2.04
	7/9/13	0.0083	0.0074	0.0052	0.0045	0.323	1.54	5.74	51.7	13.20	0.173	4.47	1.04	5.49	2.26
	8/20/13	0.0110 JL	0.0100 J	0.0061	0.0058	0.680	2.17	11.00	96.3	25.10	0.050 U	10.10	1.43	5.31	2.90
	9/24/13	0.0065	0.0070	0.0059	0.0059	0.494	1.91	8.30	71.8	19.00	0.050 U	7.78	1.22	5.05	2.53
AHT071	4/10/13	0.0051	0.0050 U	0.0062	0.0060	0.113	1.42	4.75	26.5	7.10	0.050 U	2.58	0.71	5.38	1.95
	5/14/13	0.0083	0.0077	0.0064	0.0064	0.080 JL	1.10	3.41	27.5	6.62	0.050 U	2.28	0.77	5.74	1.88
	6/18/13	0.0079	0.0109	0.0055	0.0055	0.174	1.32	4.69	38.5	10.20	0.076	3.56	1.08	5.46	2.04
	7/9/13	0.0083	0.0077	0.0076	0.0076	0.292	1.60	6.46	52.3	13.30	0.053	4.84	1.14	5.44	2.35

J: Analyte was positively identified. The reported result is an estimate.

JL: Analyte was positively identified. Value may be less than the reported estimate.

U: Analyte was not detected at or above the reported result.

NA: Analyte not measured.

* Dissolved sample fraction.

Dup: Field duplicate sample.

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

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

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

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Acronyms and Abbreviations

DO	Dissolved oxygen
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
IEP	Inland Empire Paper Company
IWTP	Industrial wastewater treatment plant
MEL	Manchester Environmental Laboratory
NCCW	Non-contact cooling water
NIST	National Institute of Standards and Technology

NPDES	(See Glossary above)
OP	Orthophosphate
RM	River mile
%RSD	Percent relative standard deviation
SOP	Standard operating procedures
TDP	Total dissolved phosphorus
TMDL	(See Glossary above)
TP	Total phosphorus
TRP	Total reactive phosphorus
USGS	U.S. Geological Survey
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
lbs/day	pounds per day
meq/L	milliequivalents per liter
mg	milligram
mg/L	milligrams per liter (parts per million)
s.u.	standard units
uS/cm	microsiemens per centimeter, a unit of conductivity