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Hangman (Latah) Creek Hydrogeologic Assessment

Focusing on the Latah Creek Wastewater Treatment Plant

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Hangman (Latah) Creek Hydrogeologic Assessment

Focusing on the Latah Creek Wastewater Treatment Plant

by

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

- WRIA 56
- HUC number 17010306

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Abstract

Hangman Creek (aka Latah Creek) is a major tributary to the Spokane River. The Spokane River *Dissolved Oxygen Total Maximum Daily Load* (TMDL) study established limits on phosphorus loads coming from Hangman Creek (Moore and Ross, 2010). Phosphorus delivery from Hangman Creek is associated with suspended sediments and turbidity. Hangman Creek is on Washington State's list of impaired water bodies (303(d) list) for fecal coliform bacteria, pH, temperature, dissolved oxygen, and turbidity.

In an effort to address potential sources of these contaminants in groundwater, and which may be discharging to surface water, the Washington State Department of Ecology (Ecology) conducted an investigation to assess the Latah Creek wastewater treatment plant (WWTP) and the surrounding area. Ecology collected samples on three separate occasions. These samples were collected from Hangman Creek, the hyporheic zone next to the creek, and also from four groundwater monitoring wells at the WWTP. While the primary focus was the WWTP, this study also sampled sites upstream to characterize background conditions and inputs from surrounding land use, including a golf course and agriculture.

This study supports the following conclusions about contaminant sources to Hangman Creek:

Wastewater Treatment Plant

- Improvements made with nitrogen treatment to the WWTP in 2011 appear to have reduced nitrogen concentrations in groundwater and surface water. Improvements in water quality were noted by comparing results from the 2010 sampling to the 2012 sampling.
- Groundwater at the WWTP contains nitrate, orthophosphate, chloride, sulfate, and total dissolved solids, but these contaminants do not appear to be increasing in Hangman Creek.
- Boron was detected only in groundwater at the WWTP but was not present in the hyporheic zone or surface water. This indicates that wastewater contaminants are being attenuated in the subsurface before reaching Hangman Creek.

Golf course

- Groundwater adjacent to the golf course contained consistently higher concentrations of nitrate and sulfate than found in surface water.
- There were variable concentrations of total phosphorus, orthophosphate, ammonia, chloride, and total dissolved solids in groundwater and surface water. While groundwater concentrations were consistently higher than surface water concentrations at this site, these contaminants do not appear to be increasing in surface water.

Upstream source

- The highest surface water concentrations of total phosphorus, orthophosphate, and ammonia were detected at the most upgradient site. Concentrations generally decrease as water moves downstream.
- This indicates that a source of phosphorus is likely originating upstream of the study area. The data collected during this study do not clearly identify any total phosphorus or ammonia source.

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Introduction

Hangman Creek is a tributary to the Spokane River, located south of Spokane, Washington in Water Resource Inventory Area (WRIA) 56. This watershed covers about 675 square miles in Spokane and Whitman Counties; with about one third in Idaho. This study is focused on the Lower Hangman Creek, which is closer to the City of Spokane (Figure 1).

Purpose

Excessive nutrient loading from wastewater discharges, on-site sewage systems, agriculture, fertilizer use, golf courses, and animal operations can effect water quality and effect dissolved oxygen (DO) and pH. Understanding the nutrient contribution from groundwater which flows into surface water is important for developing a water quality improvement plan to address the pollution problems in the watershed.

A TMDL on the Spokane river was conducted for DO, which established limits for tributaries, including Hangman Creek (Moore and Ross, 2010). Hangman Creek (aka. Latah Creek) is being evaluated to assess sources that effect pH, DO, and nutrients. (Albrecht et al., 2017).

Goal

The primary goal of this project is to assess the effects of the Latah Creek WWTP on water quality in Hangman Creek, and secondarily to assess nutrient contributions from other potential upgradient sources including a golf course, and agricultural sources.

Ecology collected water quality samples from existing groundwater monitoring wells at the Latah Creek WWTP, as well as from Hangman Creek and in the hyporheic zone next to the creek, on three occasions; August 2010, July 2012 and September 2012, for nitrogen, phosphorus and other inorganic parameters.

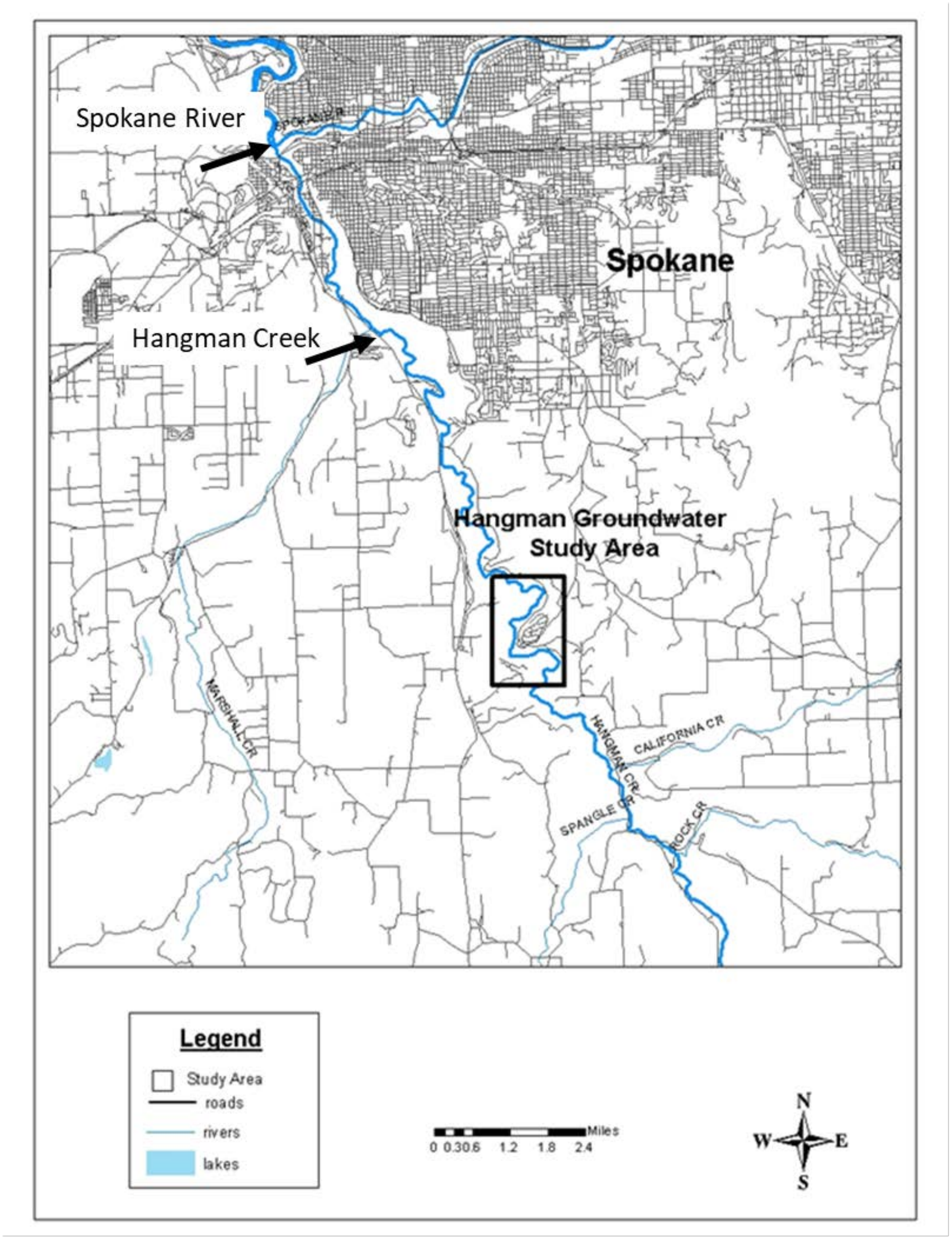


Figure 1. Study location

Background

Hangman Creek originates in the foothills of the Rocky Mountains in Idaho and flows northwest into Washington until it reaches the confluence with the Spokane River. Streamflow peaks during the winter and spring when flows typically range from 100 to 1,000 cubic feet per second (cfs). During the summer months the flow decreases dramatically with average high flows in March at 475 cfs, dropping to an average of 77 cfs in June, then to 23 cfs in July and to an average low flow of 13 cfs in August and September. During the low-flow season, the creek relies on groundwater discharge to the river. (Albrecht et al., 2017)

Issue

Hangman Creek was identified as a significant contributor of phosphorus to the Spokane River. Previous studies identified nutrient loading increases in the lower reaches of Hangman Creek during the low-flow season. This nutrient increase is thought to originate from groundwater discharge to the river. (Joy, 2008). Hangman Creek was identified as the single largest source of nonpoint phosphorus during the March-May season. Additionally it was concluded that efforts to reduce nutrients, especially phosphorus, in the Hangman Creek watershed were critical to address water quality issues in the Spokane River. (Moore and Ross, 2010).

The Clean Water Act (CWA) 303(d) list is a compilation of water bodies that do not meet state water quality standards. The CWA requires that a Total Maximum Daily Load (TMDL) be developed for each of the water bodies on the 303(d) list. The TMDL study is designed to identify pollution problems in the watershed, and then specify the amount of pollution which needs to be reduced or eliminated in order to achieve clean water.

The Latah Creek WWTP is located in the lower reach of Hangman Creek valley. This WWTP collects and treats municipal wastewater and discharges the treated wastewater into lagoons which are located adjacent to Hangman Creek. Groundwater quality near the WWTP was characterized to identify if it is a potential source of nutrients and to determine where groundwater is discharging to surface water (gaining reach).

This study examines the effects of nutrient loading from groundwater sources in the study area adjacent to the Latah Creek WWTP.

Latah Creek WWTP

The Latah Creek WWTP (formerly known as the Hangman Hills Sewage Treatment Plant) is located about five miles south of the City of Spokane and is owned, operated and maintained by Spokane County, to provide wastewater treatment for the Hangman Hills residential development. Other newer developments across the river and further up in the watershed are not connected to this facility.

Ecology re-issued Spokane County a State Waste Discharge Permit (#ST-8045) on June 25, 2007 for discharge of treated wastewater from the WWTP. The facility includes a settling basin, a sludge waste-holding tank, an aerobic digester, one polishing lagoon, and two exfiltration (evaporation) lagoons. The plant has a capacity of 86,000 gallons per day (gpd), and the current average monthly flow is about 50,000 gpd. (Ecology, 2007). The WWTP was constructed in 1972 and upgraded in 1977, 2001 and 2011. (GeoEngineers, 2000; Ecology, 2007; Ecology, 2007a).

Effluent Quality

Latah Creek WWTP plant is required by their permit to sample their effluent for total nitrogen and fixed dissolved solids (FDS). Sampling effluent for total phosphorus is not required.

In the fall of 2011 a nitrification/denitrification treatment system was added, which reduced the effluent concentration from an average total nitrogen concentration of 17 mg N/L, to an average of 5 mg N/L. Figure 2 illustrates the total nitrogen concentration in the effluent. The decrease in concentrations is evident in the fall of 2011, with concentrations primarily less than 10 mg N/L.

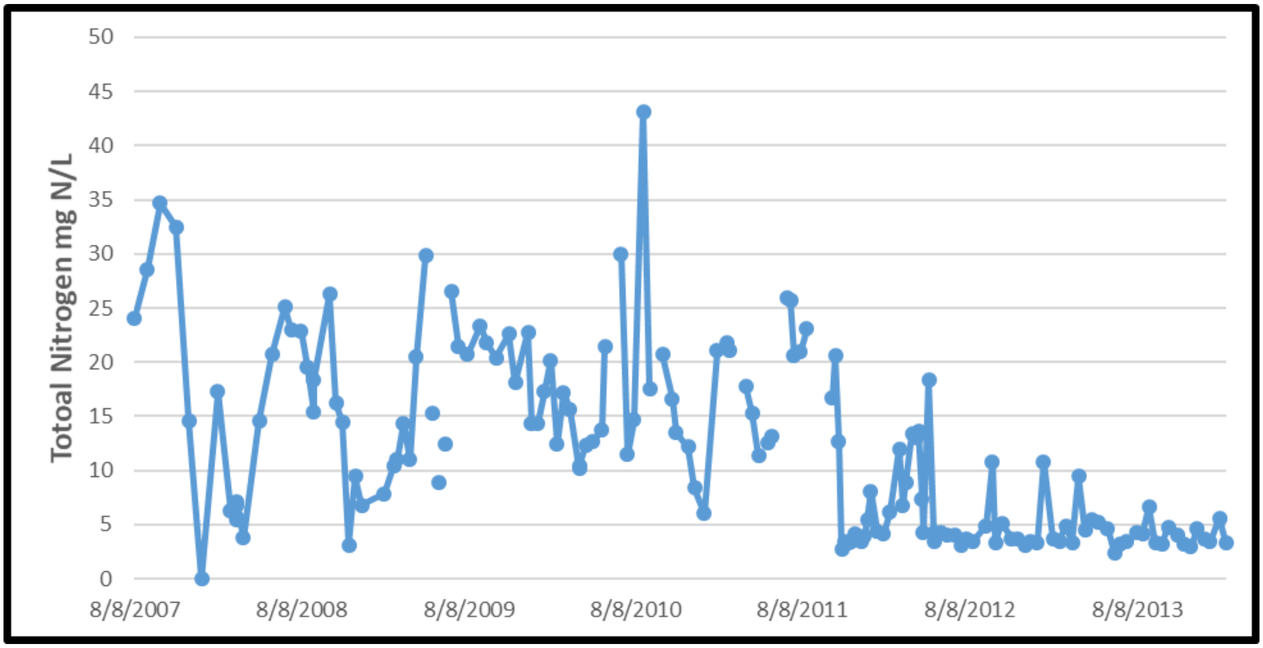


Figure 2. Effluent total nitrogen concentration from Latah Creek WWTP

Total dissolved solids (TDS) are comprised of volatile and fixed solids. The difference between TDS and fixed dissolved solids (FDS) is that the volatile solids portion is removed. The volatile portion is the organic component. The FDS portion is the inorganic component which are comprised primarily of the salt compounds. The average FDS concentration in the WWTP effluent is 467 mg/L with a range between 160 and 600 mg/L. Figure 3 illustrates FDS concentrations in the WWTP effluent.

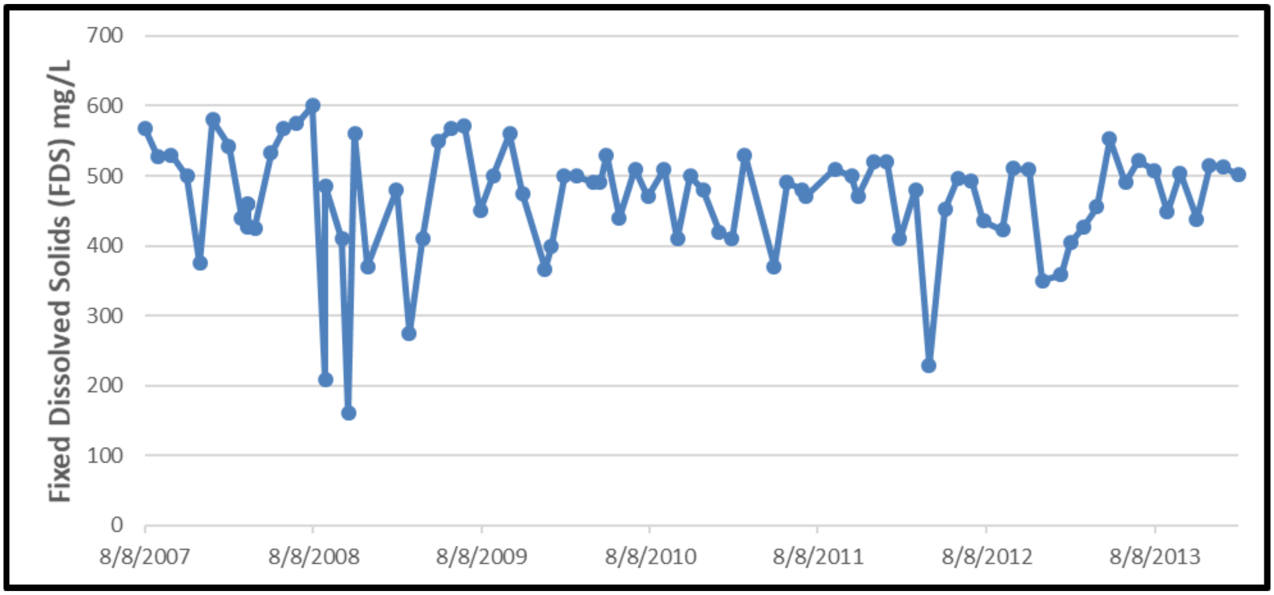


Figure 3. Effluent fixed dissolved solids concentration from Latah Creek WWTP

Geology

Hangman Valley was created through a series of geologic events. (Molenaar, 1988) (Kahle and Bartolino, 2007). Extensive lava flows deposited a series of thick layers of basalt across eastern and central Washington during the Miocene, referred to as the Columbia River Basalt Group (CRBG). Some of these basalt flows blocked stream drainages and created lakes, where fine grain sediments were deposited. Locally these fine grained layers are referred to as the Latah Formation.

The Pleistocene was marked by alternate periods of cooling and warming. During the cooling periods, ice dams were created causing water to back up forming Glacial Lake Missoula. The highest dam was estimated to be 2,150 feet high and created a lake covering about 3,000 square miles. When the ice dam was breached it created what is believed to be one of the largest flood events in history, releasing 500 cubic miles of lake water with flows estimated at 750 million cubic feet per second. (Molenaar, 1988) These flood waters flowed across the Columbia Plateau creating the channeled scablands and massive gravel bars with ripple marks 50 feet high (Bretz, 1930). The Spokane Floods were catastrophic glacial outburst floods, depositing coarse sand, gravel, cobbles and boulders across central and eastern Washington, including the project area.

Locally, remnants of these flood deposits are visible in the surficial unconsolidated sedimentary deposits in the eroded banks along Hangman Creek. This sedimentary unit contains silt and clay interbedded with coarser sand and gravel. These beds are cyclical in nature and theorized to be the result of periodic glacial floods alternating with the lacustrine fine grain deposits from the localized lakes that were formed as the flood waters receded. (Molenaar, 1988)

Hydrogeology

Lower Hangman Creek is situated in a deep V-shaped valley, which is typically formed by a combination of flood deposits, basalt deposition and erosion with flowing water. This valley funnels groundwater and surface water from the uplands into Hangman Creek at the bottom of the valley.

There are two distinct aquifers in the area: the shallow unconfined alluvial aquifer and the lower, confined water-bearing zones in the deeper basalt. Hangman Valley is underlain primarily by glaciofluvial deposits, which are up to 200 feet thick. Depth to water in this uppermost aquifer is about 10 to 20 feet below land surface. The alluvial aquifer is strongly connected to Hangman creek with groundwater predominantly recharging surface water (gaining reach).

The Latah formation is a confining layer comprised of weakly-cemented lacustrine silt and clay mixed with some sand and gravel. The Latah formation separates the upper glaciofluvial deposits from the lower CRBG with a thickness ranging from a few feet to over 100 feet. GeoEngineers (2000) determined that significant hydraulic continuity between the upper and lower aquifers is unlikely.

Locally, the CRBG is comprised of the Wanapum and Grand Ronde members. Depth to basalt varies but is estimated to be about 200 feet below land surface with a formation thickness greater than 400 feet. The basalt group is interspersed with the Latah formation which is interbedded between the basalt flows, containing discontinuous confined water-bearing zones. Groundwater flow direction is estimated to be to the west-southwest. (GeoEngineers, 2000)

Soils which have developed on the alluvial sediments are characterized as sandy silt and silty sand. There are some areas of coarse sand with trace amounts of silt and gravel. (GeoEngineers, 2000)

Groundwater Flow Direction

Recharge to the uppermost alluvial aquifer underlying the WWTP site is from infiltration of precipitation, surface runoff, and discharge of wastewater from the WWTP. The uppermost alluvial aquifer discharges predominantly as recharge to Hangman Creek. Groundwater is hydraulically connected to Hangman Creek and is generally a gaining reach adjacent to the WWTP site (Ecology, 2007; GeoEngineers, 2012).

Groundwater flow in the shallow aquifer was assessed using measurements made during this study, measurements conducted by GeoEngineers during well installation, and measurements taken by Latah Creek WWTP staff as part of permit monitoring requirements. This analysis revealed that groundwater flow is variable seasonally, with flows fluctuating towards the west, southwest, and northwest. The predominant flow direction appears to be to the west/northwest beneath the WWTP flowing towards Hangman Creek (Figure 4).

Figure 4. Groundwater flow direction with seasonal variability (modified from GeoEngineers, 2012)

Methods

This project focuses on quantifying the groundwater contribution of nutrients to Hangman Creek within the study area, with particular emphasis on the Latah Creek Wastewater Treatment Plant (WWTP).

An initial reconnaissance survey was conducted in and adjacent to Hangman Creek along the perimeter of the WWTP site in order to determine appropriate sample sites where groundwater discharges to surface water. This survey relied on field parameters and a thermal comparison of groundwater and surface water.

Samples were collected on three separate occasions from Hangman Creek, the hyporheic zone next to the creek, and groundwater monitoring wells at the WWTP. While the primary focus was the WWTP, this study also monitored sites upstream in an attempt to characterize background conditions and inputs from surrounding land uses, including the county golf course and area agriculture.

Initial samples were collected in the summer of 2010. After this sampling, in the fall of 2011, the Latah Creek WWTP made improvements to their treatment plant reducing the nitrogen concentration in their effluent. Two additional sampling events were added in 2012, in July and September, to evaluate whether improvements in groundwater and surface water quality were evident. (Redding, 2012)

Groundwater monitoring wells (Figure 6) were purged prior to sampling with a peristaltic pump using low-flow sampling procedures until the stability criteria, established in the Quality Assurance Project Plan, were achieved (Redding, 2010). Field parameters (Table 1) were measured prior to being exposed to the atmosphere using a Hydrolab flow-through-cell.

Surface water samples were collected using a peristaltic pump with silastic tubing. Groundwater samples from the hyporheic zone were obtained using a stainless steel drive point and a peristaltic pump with dedicated silastic tubing. The hyporheic zone is the subsurface sediment and porous space adjacent to a stream through which stream water exchanges water, mass, and energy with groundwater. In a gaining stream, sampling the hyporheic zone allows an evaluation of the groundwater quality immediately before entering surface water. Temperature was measured in surface water and groundwater to verify gaining conditions were present, prior to sampling the paired sites. These groundwater samples were collected following similar low-flow sampling procedures described above and in the Quality Assurance Project Plan (Redding, 2010 and 2012).

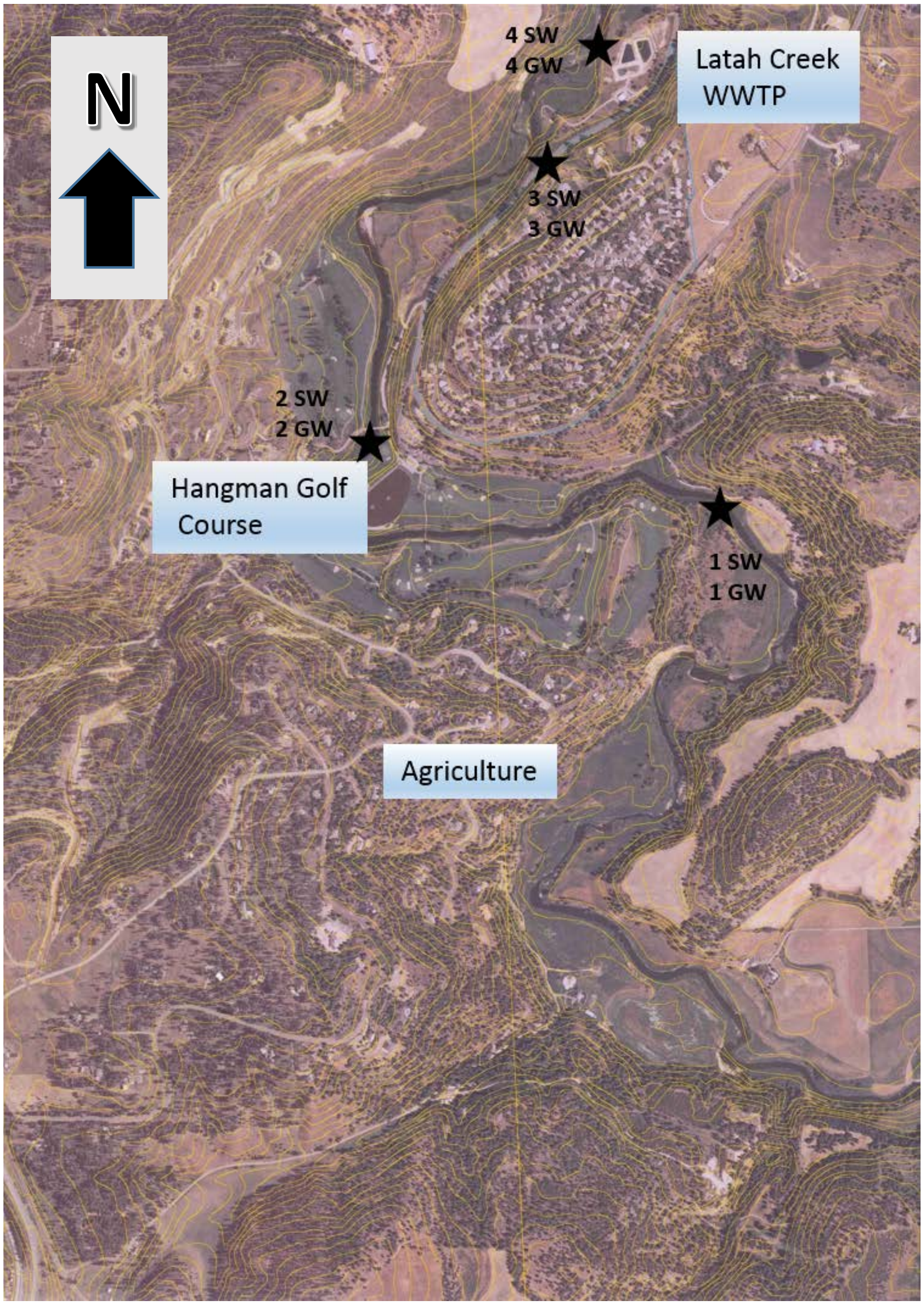


Figure 5. Surface water and groundwater sampling locations.

Thermal Profile

Heat is a natural tracer that can be used to track water that moves between surface water and groundwater (USGS, 2004). Surface water temperatures vary in direct response to air temperatures. However, groundwater maintains a fairly constant temperature year-round. In the summertime surface water temperatures are typically higher than groundwater temperatures. This difference in temperatures can be used to indicate groundwater and surface water interactions. Losing surface water reaches (surface water discharging to groundwater) are marked by groundwater temperatures which are close to surface water temperatures. Gaining surface water reaches are marked by groundwater temperatures which are cooler than surface water temperatures.

A thermal profile comparing surface water temperatures with groundwater temperatures was conducted in two ways: 1) in 2010 an intensive comparison of temperatures were measured at 53 locations along the shoreline adjacent to the WWTP, and 2) a comparison of surface water and groundwater was made at each paired sample location prior to each sampling event.

Water Quality Analysis

Water quality samples were analyzed for the parameters listed in Table 1. Nutrients are the primary focus in this study. Other parameters were also analyzed, including total dissolved solids (TDS), chloride, sulfate, bromide and boron. These inorganic parameters can be useful to help distinguish different sources.

Samples were filtered with 0.45 micron filter, preserved and contained in appropriate laboratory supplied bottles. Samples were transported to the Ecology's Manchester Environmental Lab (MEL) in coolers with ice. The condition of the samples received by MEL was reported to be good and there were no exceedances of lab holding times.

Table 1. Parameters analyzed at all sample sites.

Field Parameters	Laboratory Parameters
pH	Nitrate+Nitrite-N
Conductivity	Ammonia-N
Temperature	Total Dissolved Phosphorus
Dissolved Oxygen	Orthophosphate-P
	Dissolved Organic Carbon
	Total Dissolved Solids
	Chloride
	Bromide
	Boron
	Iron
	Manganese
	Calcium
	Magnesium
	Potassium
	Sodium
	Sulfate
	Bicarbonate
	Alkalinity

Initial water quality samples were collected during August 2010 from the WWTP monitoring wells and the paired groundwater and surface water sample sites. After this sampling, the Latah Creek WWTP made improvements to their treatment plant installing nitrification and denitrification processes in November 2011, which improved the effluent quality. Additional sampling was conducted in July and September 2011 to determine if improvements to the treatment plant resulted in improvements to groundwater and surface water quality. Sample locations remained the same for all sampling events. The Quality Assurance Project Plan was amended to reflect the change in study scope. (Redding, 2012)

Monitoring Wells

There are four monitoring wells at the WWTP which were sampled during this investigation. Three wells (UG-1, DG-1 and DG-2) are located on the lower terrace and one monitoring well (UG-2) is located on the upper terrace directly upgradient of the treatment plant (Figure 6). The lower terrace is about 25 to 30 feet lower in elevation than the upper terrace.

All monitoring wells are completed in the uppermost alluvial aquifer. The three lower terrace wells range in depth from about 20 – 30 feet bgs, while the upper terrace well is 64 feet bgs. Monitoring well construction details are described in Appendix C. The monitoring wells at the WWTP are the only area wells completed in the uppermost aquifer. The majority of area groundwater wells are completed in the lower Columbia River Basalt Group.

Figure 6. Monitoring well locations at the Latah Creek WWTP (GeoEngineers, 2012)

Monitoring well DG-2 could not be sampled in July or August 2012 due to erosion of the creek bank creating unsafe access conditions. Subsequent to our sampling events, monitoring well DG-2 was abandoned and a new monitoring well DG-3 was installed in the vicinity of where monitoring well DG-2 was located. The new monitoring well, DG-3, had not yet been installed at the time of sampling.

Chloride/Bromide Ratios

Chloride/bromide ratios are a source-tracking tool used to distinguish groundwater contamination from domestic sewage, stormwater run-off, agriculture, natural dissolution from aquifer materials, and precipitation (Davis et al., 1998; Vengosh and Pankratov, 1998). Chloride and bromide are negatively charged ions, which are not readily degraded or attenuated in the subsurface by organic material or by sewage treatment processes. These attributes make chloride and bromide mobile ions which move readily with groundwater and make them conservative indicator parameters. Bromide is naturally present in seawater, and it has been used in pesticides, industrial solvents, pharmaceuticals, water purification, and gasoline additives. Chloride is abundant in nature. Chloride is present in seawater and on dining room tables, and it is pervasive in many products (e.g., road de-icers, disinfection products, fertilizers).

Chloride/bromide ratios have been linked to sources in the scientific literature and are summarized in Table 2.

Table 2. Chloride/bromide ratios and the associated sources

Source	Cl/Br Range
Precipitation	50 - 150
Domestic Sewage	300 - 900
Wastewater (high NaCl)	1500
Solid Waste	200 - 1500
Animal Waste	< 300
Stormwater Runoff	10 - 150
Road Salt	> 3,000
Agricultural Return Flows	< 181
Pesticides (bromide based)	300

(Davis et al., 1998; Vengosh and Pankratov, 1998)

Field Quality Assurance

Field duplicate water quality samples were collected for 17% of the sites sampled for each sampling event. They were submitted to the laboratory as blind samples. At least one duplicate sample was collected from groundwater and surface water each sampling event. These results provide an estimate of overall sampling and analytical precision.

One field equipment (filter) blank was collected each sampling event to evaluate bias introduced by the sample collection procedures and from interaction with field equipment.

All field meters were calibrated before and after sampling to determine instrument accuracy. All non-dedicated equipment was decontaminated according to the Quality Assurance Project Plan (Redding, 2010).

Laboratory Quality Assurance

Routine laboratory quality control procedures were determined to be adequate to estimate laboratory precision and accuracy for this project. Laboratory quality control samples consist of blanks, duplicates, matrix spikes, and laboratory control standards (MEL, 2006).

Duplicates were used to assess analytical precision. Matrix spikes were used to indicate bias due to matrix interferences. Check standards were used to estimate bias due to calibration. Laboratory blanks were used to measure the response of the analytical system at a theoretical concentration of zero.

Results

Water quality samples were collected on three dates: August 2010, July 2012 and September 2012. Groundwater and surface water were sampled along the lower Hangman Creek for nutrients, ions, temperature, field parameters and water elevation. A thermal profile of the hyporheic zone and surface water was also conducted in July, 2010 to identify gaining and losing reaches. The data from this study and a map depicting sample sites are in Appendix A.

Quality Assurance

Quality assurance (QA) results for field replicates, duplicate blanks, laboratory method blanks, laboratory control samples, matrix spikes, and matrix spike duplicates are presented in Appendix B. The QA for this project is judged to be acceptable.

Water Quality Data

Water quality sample results are presented in Appendix A, Table A.2. Data are presented for each sampling event. Samples are also categorized by surface and groundwater samples, by parameter, and field data.

Monitoring wells at the WWTP were sampled during each of the sampling events. During the August 2010 sampling monitoring well UG-2 contained insufficient water to collect a sample. In 2012 monitoring well DG-2 could not be sampled due to erosion of the creek bank and hazardous conditions.

Table 3 summarizes the groundwater quality data for nitrate-N, total dissolved solids (TDS), chloride and sulfate. Results are highlighted where there is an exceedance of a groundwater quality standard (WAC 173-200-040).

Nitrate exceeded the groundwater quality standard of 10 mg N/L in the downgradient monitoring well DG-1 in 2010, but did not exceed the standard in 2012. Nitrate was also exceeded in the upgradient monitoring well UG-2 during both sampling events in 2012. In 2010 this well was dry and was not sampled.

The groundwater quality standard for TDS of 500 mg/L was exceeded at monitoring wells UG-1 and DG-1 on all three sampling dates. Well UG-2 also exceeded the standard both times it was sampled in 2012 (no sample was able to be collected in 2010). Groundwater in the hyporheic zone adjacent to the golf course (2-GW) exceeded the groundwater standard for TDS in 2010.

There were no exceedances of the groundwater quality standards for either chloride or sulfate during this study.

Table 3. Groundwater quality data summary for contaminants with Standards.

Groundwater Quality Standard → (WAC 173-200-040)	**10 mg N/L**	**500 mg/L**	**250 mg/L**	**250 mg/L**
Groundwater Sample Location	**Nitrate + Nitrite**	**Total Dissolved Solids**	**Chloride**	**Sulfate**
	mg N/L	**mg/L**	**mg/L**	**mg/L**
August 2010				
1-GW	0.028	184	5.13	7.1
2-GW	0.005	**524**	10.7	4.54
3-GW	1.09	No sample	No sample	No sample
UG-1	3.1	**671**	95.9	37.5
UG-2	No sample			
DG-1	**13.65**	**643.5**	147.5	32.25
DG-2	3.03	407	45.6	14.6
4-GW	0.19	222	10.2	10.9
July 2012				
1-GW	0.70	168	4.59	8.71
2-GW	1.2	390	7.63	46.9
3-GW	0.50	178	5.22	9.61
UG-1	4.09	**557**	62.8	24.3
UG-2	**21.2**	**590**	No sample	23.4
DG-1	5.60	**520.5**	97	17.15
DG-2	No sample			
4-GW	No sample			
September 2012				
1-GW	0.06	198.5	5.58	10.4
2-GW	1.37	354	7.27	38.6
3-GW	2.74	402	21.6	23.1
UG-1	4.41	**599**	78.3	32.9
UG-2	**12.9**	**542**	26.3	25.4
DG-1	5.53	**563.5**	109	17.45
DG-2	No sample			
4-GW	2.77	350	20.9	12.5

Bold = exceeds groundwater quality standard

Table 4 summarizes the nutrient data collected for surface water. These data are arranged based on the flow of surface water from upstream to downstream.

Table 4. Nutrient (nitrogen and phosphorus) data summary for surface water

Sample Site	River Mile	Sample Date	Nitrate + Nitrite	Ammonia	Total N	Total dissolved phosphorus	Orthophos-phate
			mg N/L	mg/L	mg/L	mg/L	mg/L
1-SW	14.7	Aug-10	0.073	0.005	0.078	0.0633	0.0559
		Jul-12	0.8	0.027	0.827	0.0555	0.0478
		Sep-12	0.076	0.013	0.089	0.0482	0.047
2-SW	13.8	Aug-10	0.06	0.005	0.065	0.0524	0.044
		Jul-12	0.843	0.0125	0.8555	0.0464	0.0415
		Sep-12	0.197	0.0225	0.2195	0.04105	0.0402
3-SW	13.1	Aug-10	0.005	0.012	0.017	0.0518	0.0462
		Jul-12	0.503	0.005	0.508	0.0352	0.0298
		Sep-12	0.038	0.005	0.043	0.0292	0.0256
4-SW	12.7	Aug-10	0.1105	0.0115	0.122	0.0588	0.0493
		Jul-12	0.615	0.005	0.62	0.0341	0.0292
		Sep-12	0.04	0.005	0.045	0.0291	0.0252

Thermal Profile

Results of the thermal profile comparing surface and groundwater adjacent to the WWTP was conducted in 2010, and are provided in Table A.1 and Figure A.1 in Appendix A. Groundwater was found to be recharging surface water (gaining reach) at all locations and on all dates sampled.

Discussion

Contaminants in groundwater were evaluated to determine if they were flowing into Hangman Creek and to determine if they were adversely affecting surface water quality.

Gaining Reaches

The thermal profile locations and results conducted in August 2010 are contained in Appendix A and the results are graphed in Figure 7. This figure compares the creek water temperatures adjacent to the WWTP, with the groundwater temperatures in the hyporheic zone. Since groundwater temperatures are lower than surface water temperatures at all measured locations, this indicates that Hangman Creek adjacent to the WWTP is a gaining reach where groundwater is flowing into surface water.

Additionally, the thermal comparison of paired surface water and groundwater sites indicated that at all four locations during each sampling event were also gaining reaches, with groundwater temperatures lower than surface water temperatures. For all areas investigated during this study, Hangman Creek was a gaining water from groundwater.

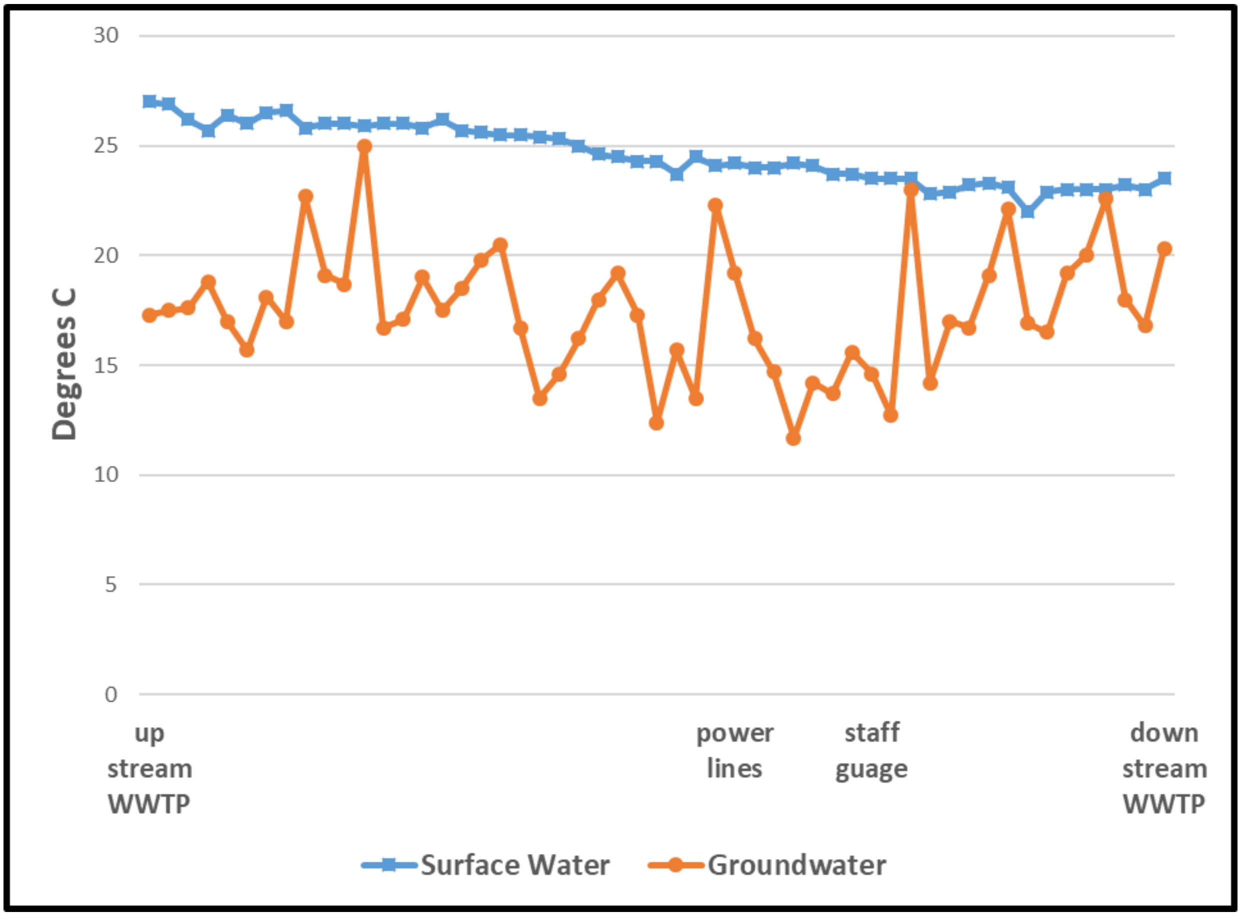


Figure 7. Thermal profile of groundwater and surface water adjacent to the Latah Creek WWTP in August 2010.

Flow data collected as part of synoptic surveys conducted in 2009 and 2018 (Stuart, in preparation) indicate that during the summer low-flow months Hangman Creek near the WWTP is slightly gaining. The degree of groundwater flow into the creek can affect surface water quality.

Table 5. Surface water flows (cfs) (Stuart, in preparation)

Surface Water Site	River Mile	7/29/2009 morning	7/29/2009 afternoon	6/12/2018	7/18/2018	8/15/2018	9/12/2018
3-SW	13.2	9.70	8.03	57	13.1	6.9	9.6
4-SW	12.6	10.7	8.5	56	13.2	7.0	10.5
Difference		*1.0*	*0.47*	*1*	*0.1*	*0.1*	*0.9*

cfs = cubic feet per second

Flow data collected in 2009 and 2018 during the summer months indicate that Hangman Creek (near sample sites 3 and 4) is consistently a gaining reach, but the amount of additional flow entering the creek during this time varies from 1 cfs to 0.1 cfs.

Effects on Hangman Creek - Sampling Events

The three sampling events were evaluated to determine if there were water quality variations based on the sampling date, location to the different potential sources, and variations in contaminant concentrations.

August 2010

Figure 8 illustrates the surface water quality results for August 2010 for total phosphorus, orthophosphate and nitrogen. The WWTP is located between sites 3-SW and 4-SW.

During the August 2010 surface water sampling, total phosphorus and orthophosphate overall had slight decreasing concentrations from upstream (1-SW) to downstream (4-SW), but a slightly increasing concentration in surface water concentrations from upstream of the WWTP (3-SW) to downstream of the WWTP (4-SW). The highest total phosphorus and orthophosphate concentrations were detected at the upgradient site (1-SW). Nitrogen concentrations decreased from the upstream site (1-SW) to 3-SW and then increased adjacent to the WWTP. In 2010 the highest nitrogen concentration is downgradient of the WWTP (4-SW).

All three nutrient parameters show increased concentrations from the surface water site upgradient of the WWTP (3-SW) to downgradient of the WWTP (4-SW) during the August 2010 sampling event, indicating possible increasing nutrient concentrations from the WWTP discharge.

In November 2011, Spokane County installed a nitrogen removal treatment system at the WWTP. The scope of this study was modified to assess the effects of the improvements made at the WWTP in 2011 on Hangman Creek, by adding two additional sampling events in 2012 during low-flow events.

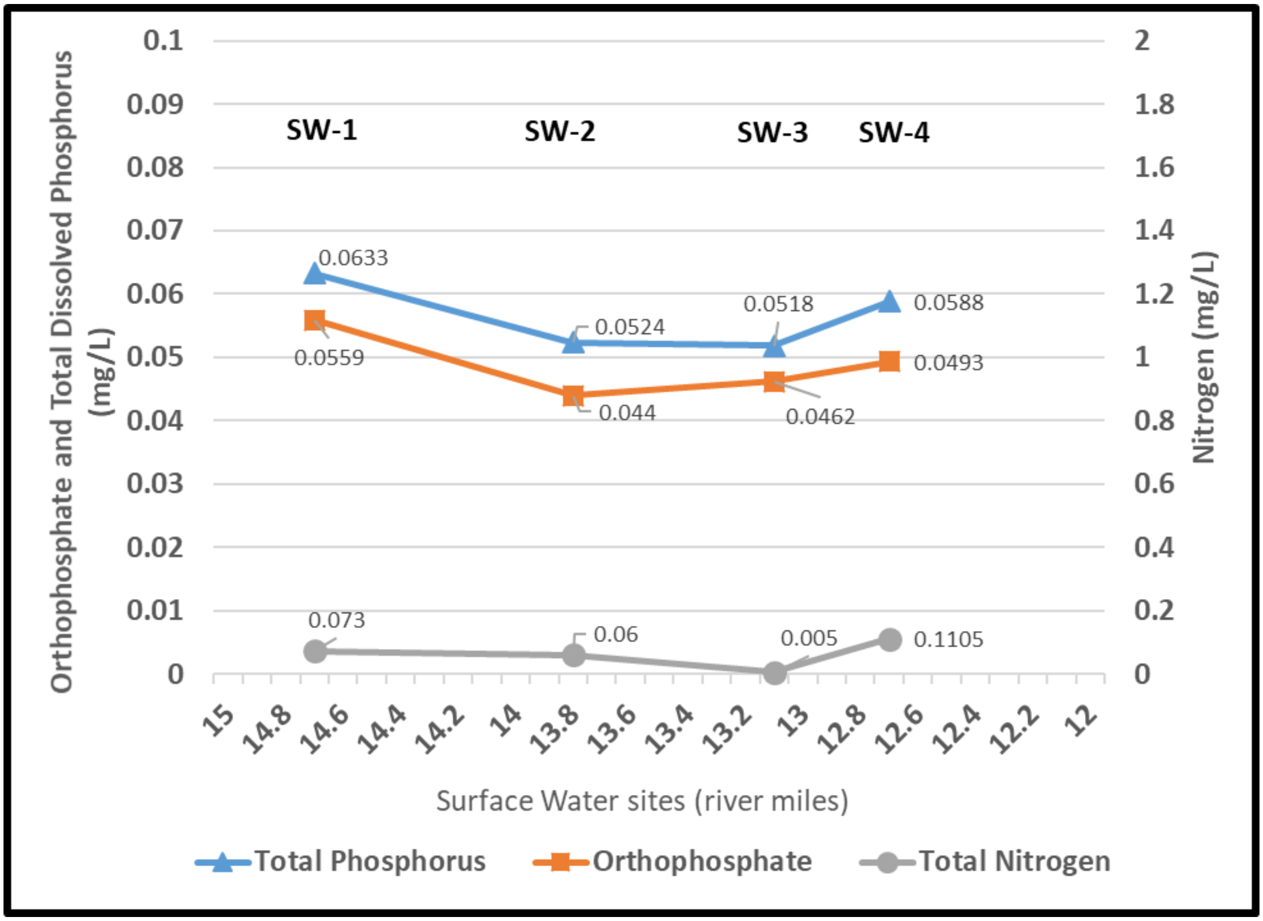


Figure 8. Hangman Creek surface water nutrient results for August 2010

July 2012

Surface water nutrient concentrations for July 2012 are presented in Figure 9.

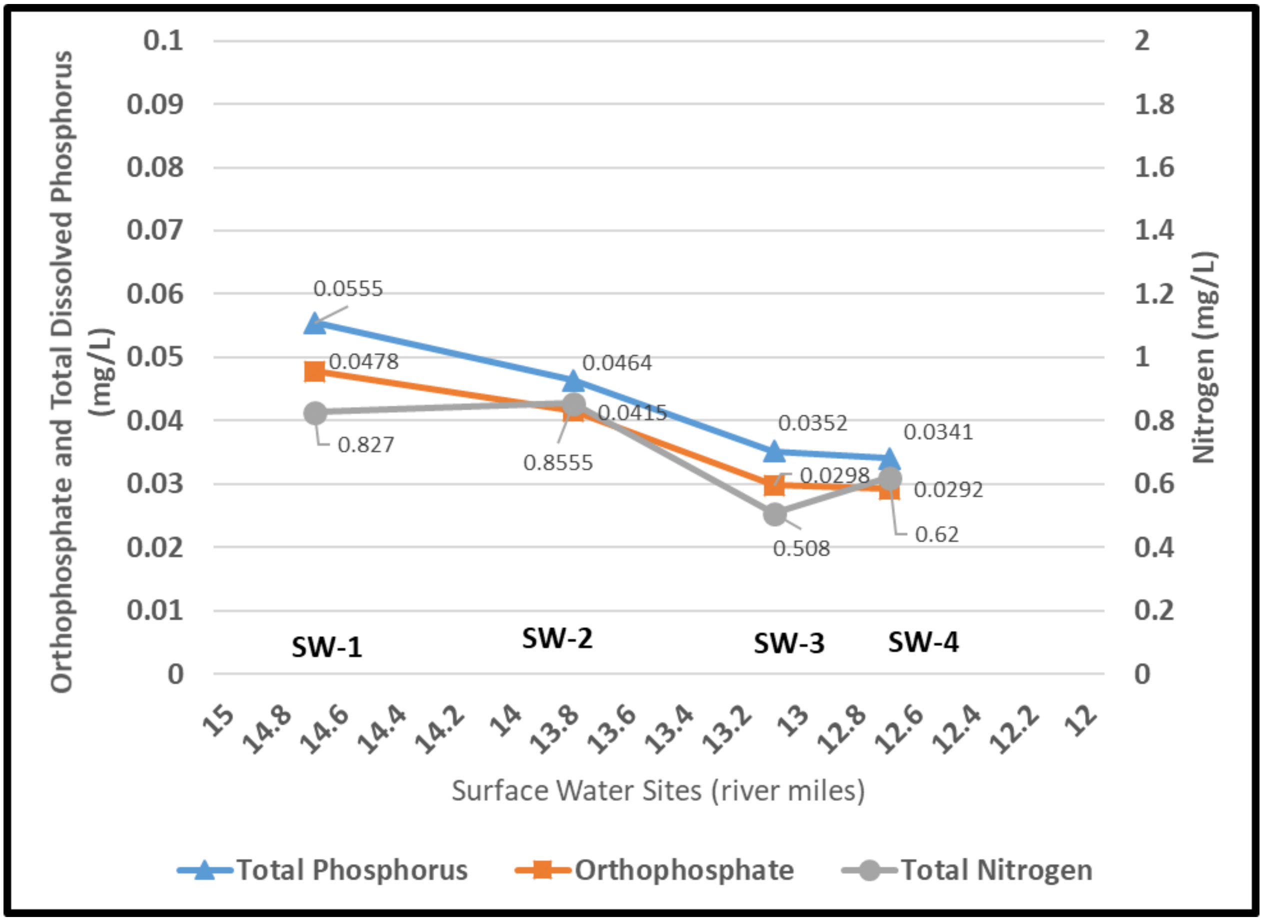


Figure 9. Hangman Creek surface water nutrient results for July 2012.

During July 2012, the highest nitrogen concentration in surface water was at the golf course (2-SW) for this sampling event. Additionally, nitrogen concentrations increased slightly in surface water from 0.508 mg N/L at 3-SW to 0.62 mg N/L downstream of the WWTP at 4-SW.

The highest concentrations for total dissolved phosphorus and orthophosphate occur at 1-SW, the upgradient site, and decrease downstream through the study area. The declining phosphorus concentrations in Hangman Creek are thought to reflect algal uptake in the creek, with the change in slope reflecting a biological equilibrium (Stuart, 2020).

September 2012

Surface water nutrient concentrations for September 2012 are presented in Figure 10.

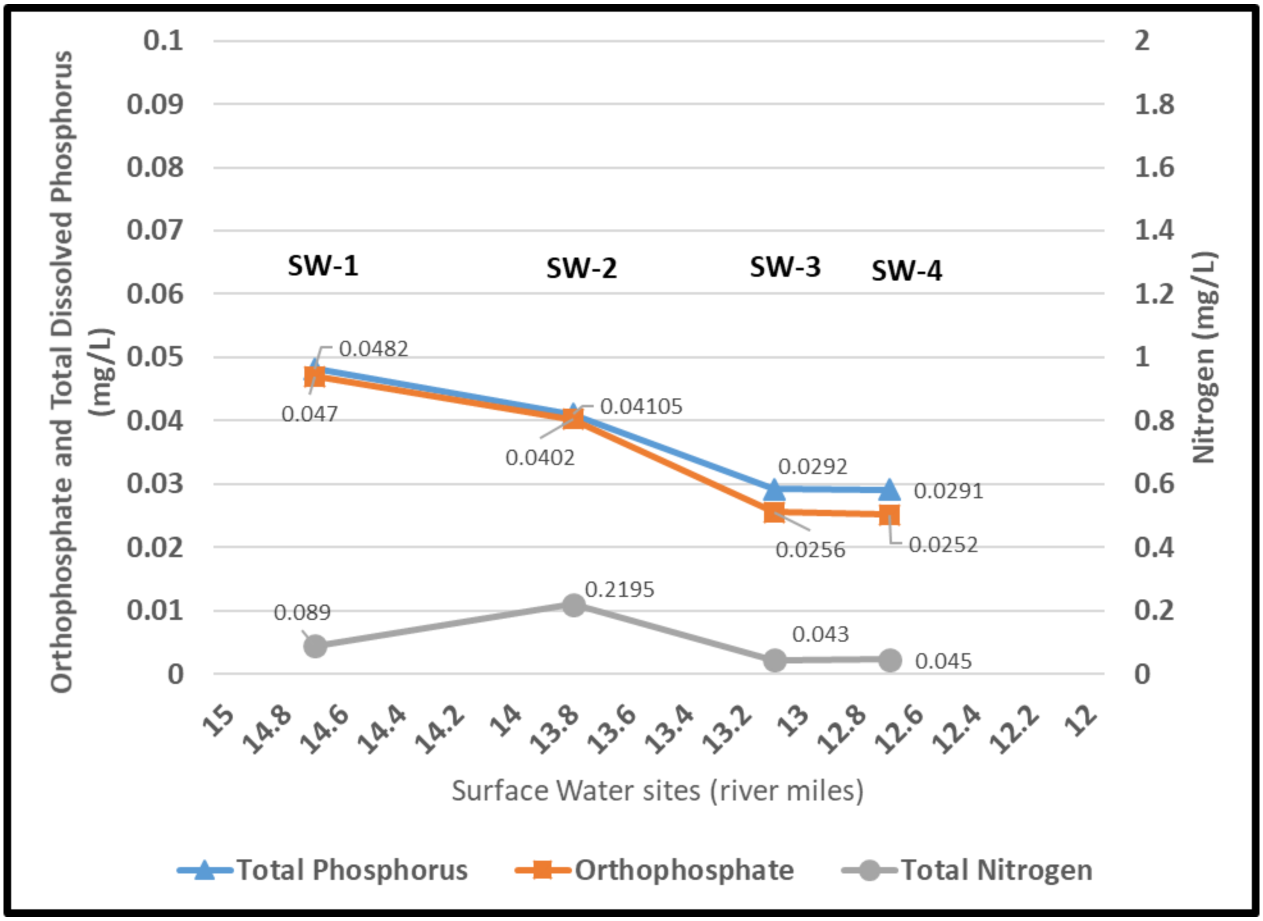


Figure 10. Hangman Creek surface water nutrient results for September 2012.

During September 2012, overall there were decreasing concentrations from the upstream site (1-SW) to the downstream site (4-SW) for all nutrients sampled. The highest concentration of nitrogen occurred at the golf course (2-SW), indicating a potential for groundwater to contribute nitrogen to Hangman Creek.

The highest concentrations for total dissolved phosphorus and orthophosphate occur at 1-SW, the upgradient site, and decrease downstream through the study area. The decrease in nutrient concentration is thought to reflect algal uptake in the creek, with the change in slope reflecting a biological equilibrium (Stuart, 2020).

Effects on Hangman Creek - Parameters

Phosphorus

Nutrients, such as phosphorus and nitrogen, are essential for plants and animals. When there is too much phosphorus in water, it causes eutrophication by spurring excess algae growth which creates large fluctuations in DO. Therefore, a slight increase in phosphorus can result in algae blooms which create low DO conditions and affect fish and other aquatic life. Phosphorus concentrations as low as 0.01 mg/L can cause an imbalance in the stability of the creek. Natural and anthropogenic sources can contribute to water quality issues. These sources include soils, rocks, WWTP effluent, fertilizers, on-site sewage system wastewater, manure and wetlands. Phosphorus adheres to sediments and can enter surface water through run-off, and it can also enter through groundwater in the soluble form of orthophosphate.

Dissolved phosphorus can occur in the organic or inorganic form. Organic forms are associated with carbon such as plant decomposition or animal (and human) waste. Total phosphorus is a measure of both organic and inorganic forms of phosphorus. Orthophosphate is a measure of the soluble inorganic form of phosphorus.

The concentration of total dissolved phosphorus in surface water for each sampling event is illustrated in Figure 11.

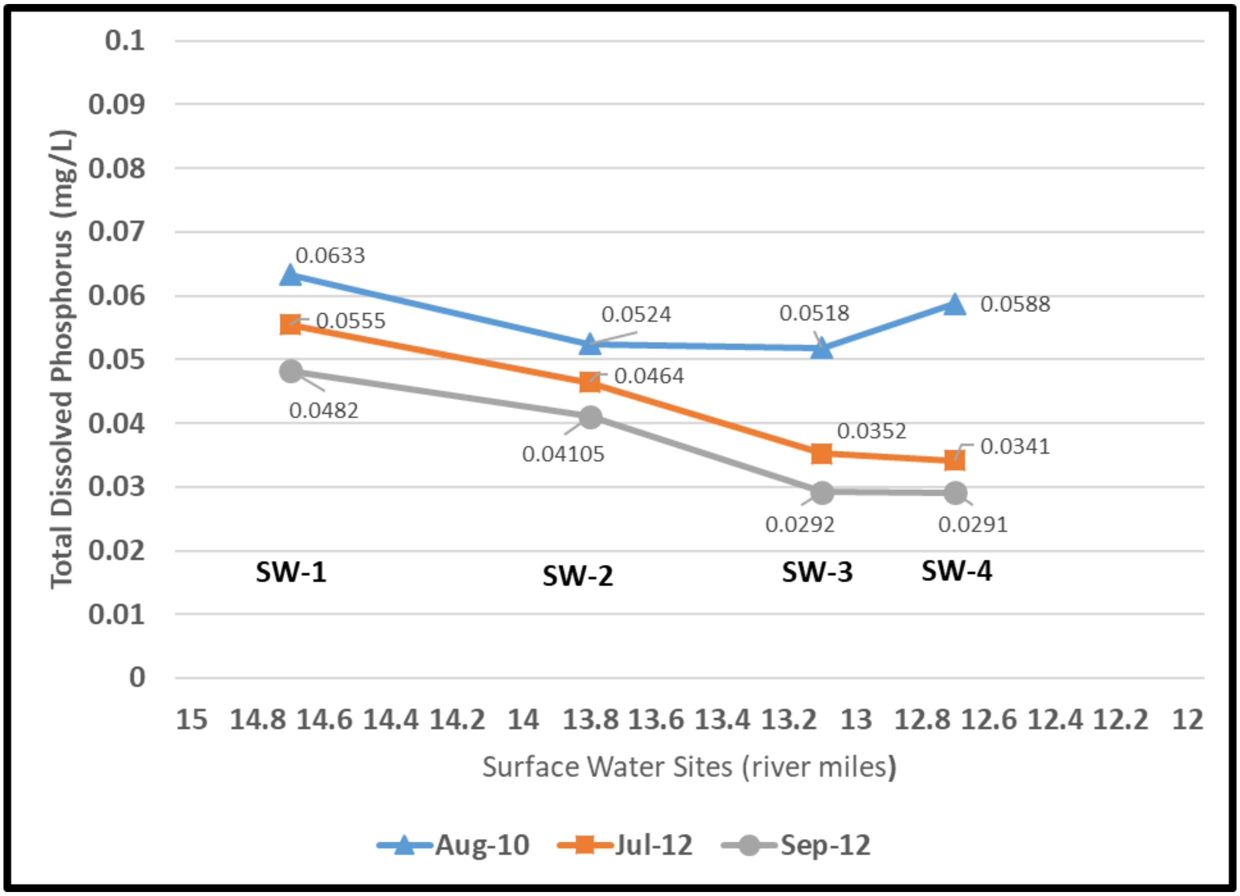


Figure 11. Total dissolved phosphorus concentrations at surface water sites.

Figure 11 shows an increase in total dissolved phosphorus in 2010 downstream of the WWTP at site 4-SW. This increase is not present in either of the sampling events in 2012 after treatment upgrades were added at the WWTP. In 2012 for both sampling events, there are declining concentrations from the upstream site (1-SW) to the downstream site (4-SW).

Each of the total phosphorus concentrations for each sampling event are displayed for all surface water and groundwater paired sites. Figure 12 is color coded by sampling event with surface water results in the darker shade and groundwater results in the lighter shade.

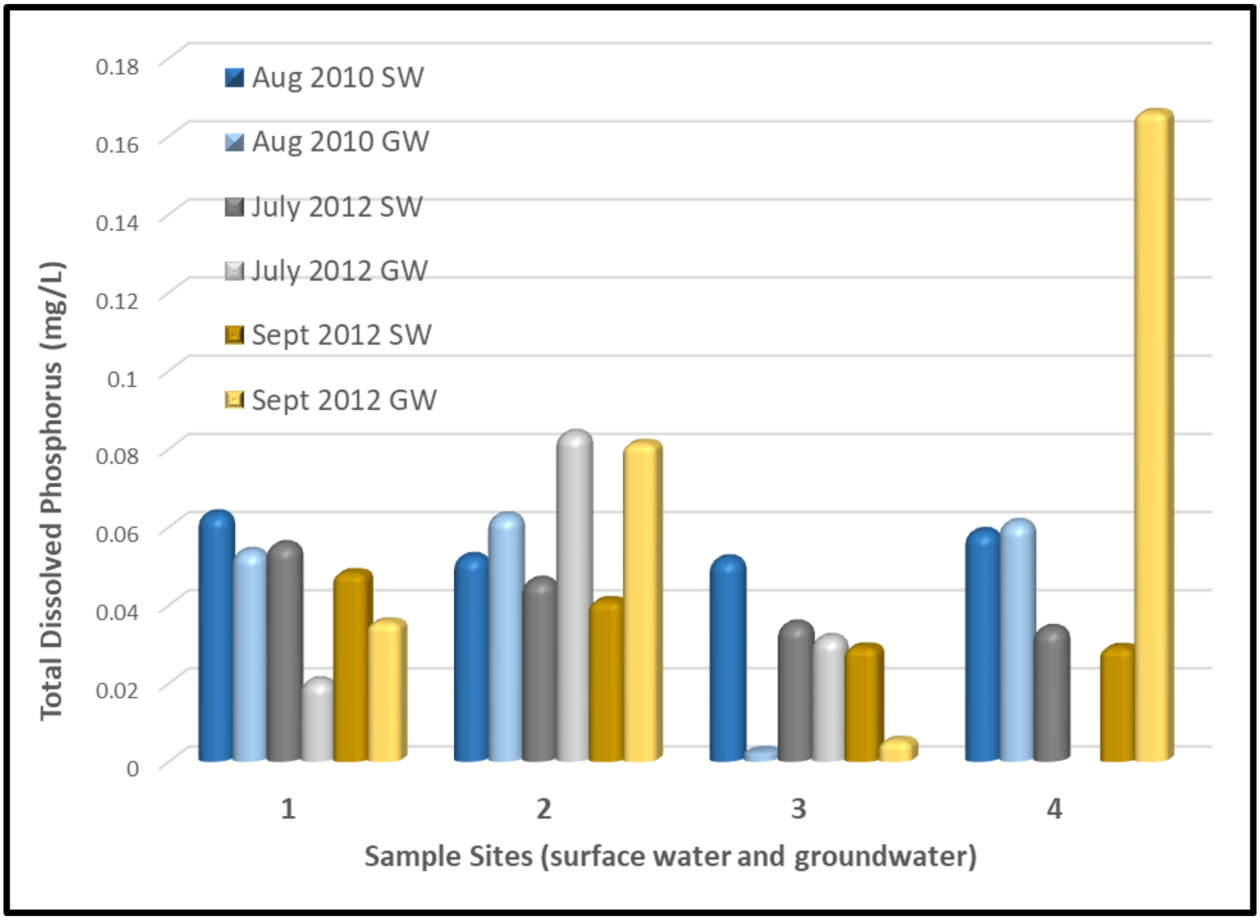


Figure 12. Total dissolved phosphorus concentrations for paired surface and groundwater sites.

Figure 12 indicates where groundwater contributions may be affecting surface water quality. At sample site 1, which is upgradient, groundwater concentrations are less than surface water for each sampling event. At sample site 2, which is located adjacent to the golf course, groundwater concentrations for total dissolved phosphorus were greater than surface water. At sample site 3, which is upgradient of the WWTP, groundwater concentrations are less than surface water for all sampling events. And at sample site 4, which is downgradient of the WWTP, the total phosphorus concentration in groundwater was slightly higher (difference of 0.0023 mg/L) than surface water in 2010, and groundwater was higher than surface water (difference of 0.1369 mg/L) in September 2012 (no groundwater sample was able to be collected in July 2012).

Orthophosphate

Orthophosphate is the soluble inorganic portion of total phosphorus and it is the predominant form found in groundwater.

Orthophosphate concentrations for each sampling event are displayed for all surface water and groundwater paired sites. Figure 13 is color coded by sampling event with surface water results in the darker shade and groundwater results in the lighter shade.

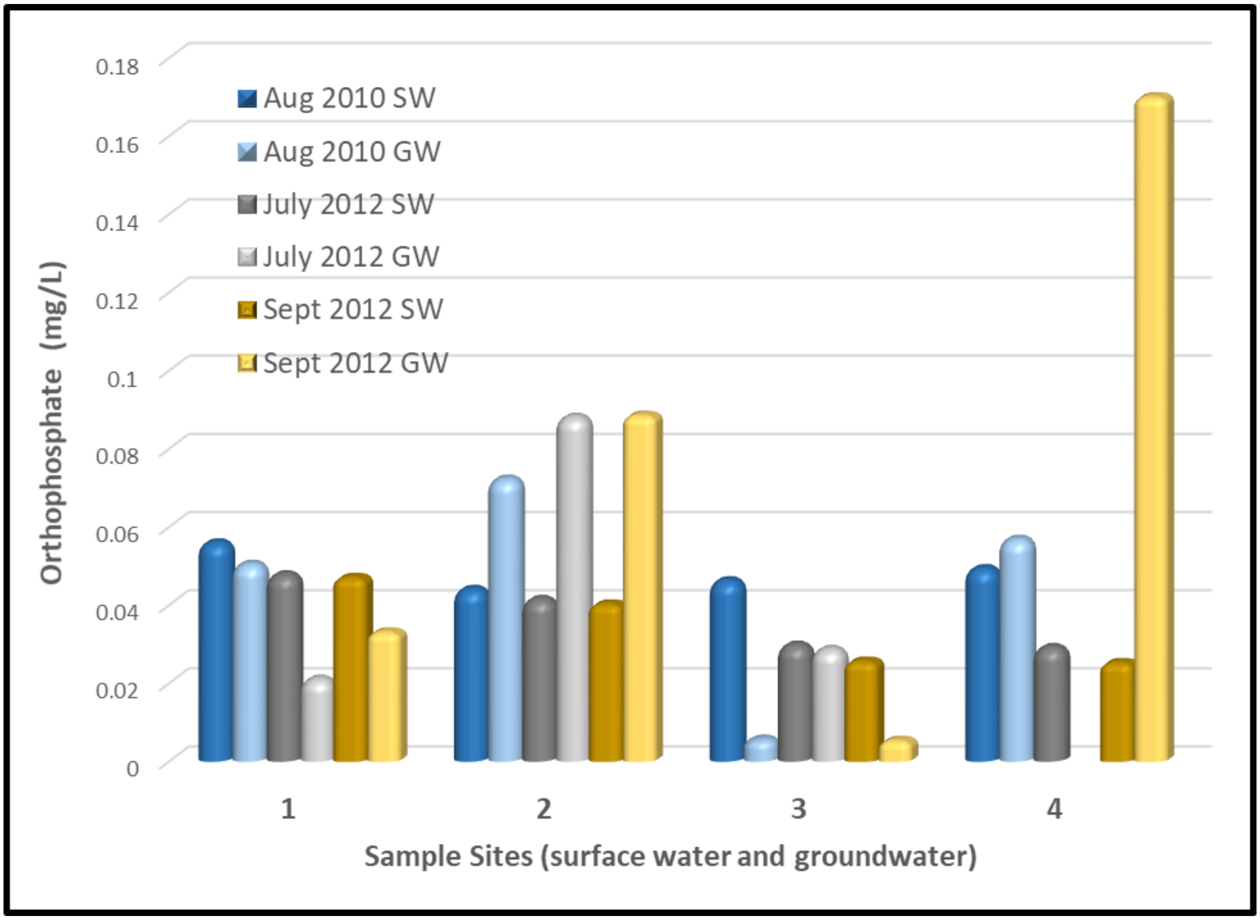


Figure 13. Orthophosphate concentrations for paired surface water and groundwater sites.

Groundwater concentrations of orthophosphate were less than surface water concentrations at sample site 1. At sample site 2, the golf course, groundwater orthophosphate concentrations were greater than surface water concentrations. At sample site 3, which is upgradient of the WWTP, groundwater concentrations were less than surface water concentrations. And at sample site 4, which is downgradient of the WWTP, groundwater orthophosphate concentrations are greater than surface water for August 2010 and September 2012.

Orthophosphate concentrations in surface water decrease from upstream to downstream of the WWTP. This includes September 2012 sampling event when 4-GW had the greatest orthophosphate concentration and the surface water concentration at 4-SW (0.0252 mg/L) was lower than the concentration upgradient at 3-SW (0.0256 mg/L). This indicates that while orthophosphate may be present in groundwater, it does not appear to be increasing in surface water orthophosphate concentrations.

Orthophosphate is the predominant form of phosphorus detected in groundwater and surface water samples during this study. Figure 14 illustrates both total phosphorus and orthophosphate concentrations from all sampling sites. Concentrations are greatest for both parameters in groundwater in the monitoring wells at the WWTP.

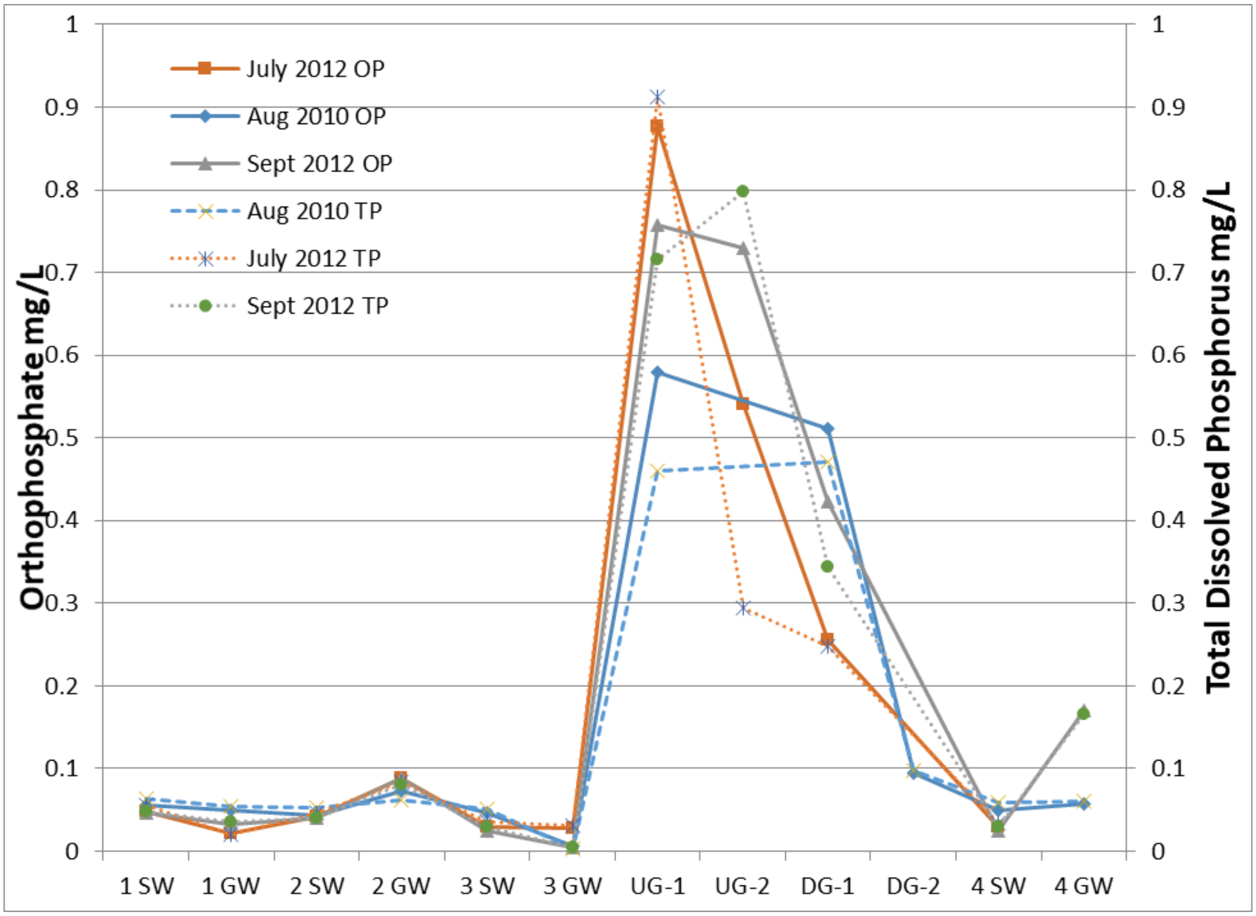


Figure 14. Total dissolved phosphorus and orthophosphate concentrations at surface water and groundwater sites.

Nitrogen

Nitrogen for this study is calculated by adding nitrate + nitrite-N, and ammonia concentrations, which represent the nitrogen species that are actively involved in eutrophication. All nitrate concentrations are reported as nitrogen (nitrate-N).

In Hangman Creek nitrogen is the limiting nutrient which controls the rate at which algae and aquatic plants are produced in fresh water. Stuart (2020) determined that this study area is nitrogen limited during the summer months.

Figure 15 illustrates the nitrogen concentration at Hangman Creek surface water sites for each of the sampling events.

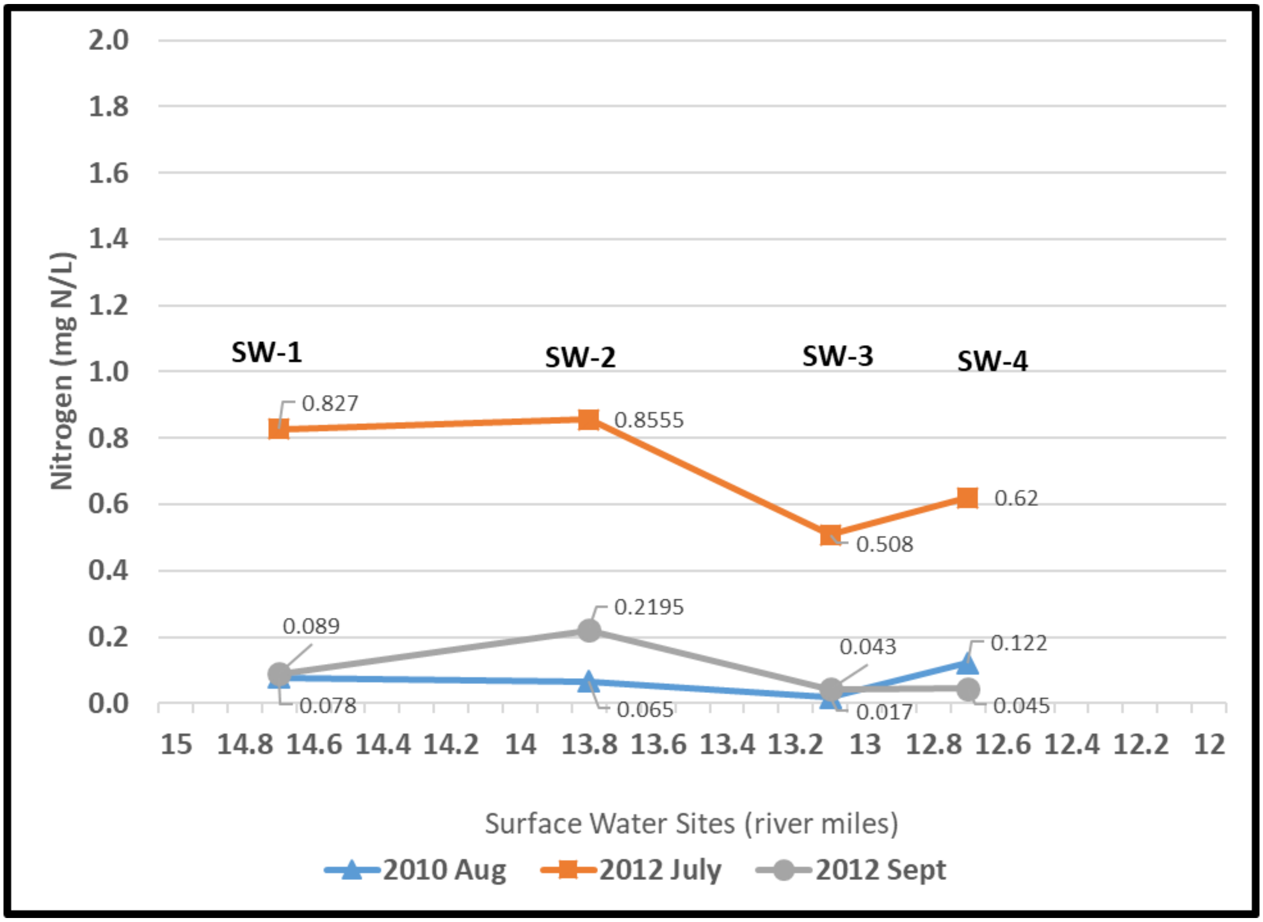


Figure 15. Nitrogen concentrations at surface water sites.

Concentrations are highest for all sample sites in July 2012. The difference between these three events may be based on the flow condition of the creek, considering that flows are higher in July than in August or September.

Figure 16 illustrates nitrogen results for the paired sites and is color coded by sampling event with surface water results in the darker colors and groundwater results in the lighter colors.

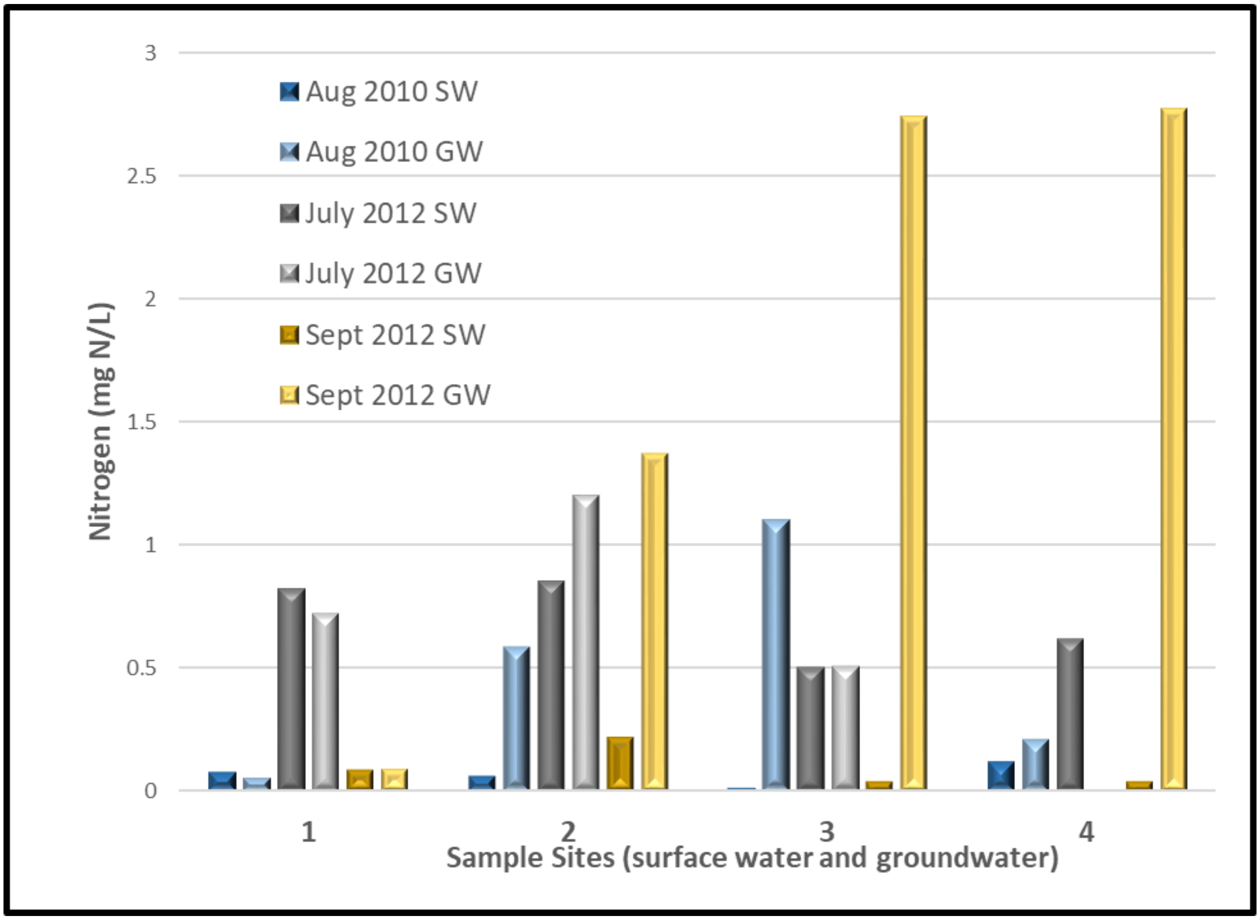


Figure 16. Nitrogen concentrations for paired surface water and groundwater sites.

Figure 16 indicates where groundwater may be contributing nitrogen to surface water. At sample site 1, which is upgradient, groundwater concentrations are less than surface water concentrations for each sampling event, which means that nitrogen in groundwater is likely not increasing in surface water quality at this site. At sample site 2, which is located at the golf course, groundwater concentrations for nitrogen are always greater than surface water, indicating a potential for groundwater to contribute nitrogen to surface water. At sample site 3, which is upgradient of the WWTP, groundwater concentrations are greater than surface water for all sampling events. Additionally, at sample site 4, which is downgradient of the WWTP, groundwater nitrogen concentrations are higher than surface water in August 2010, and in September 2012 (Ecology was not able to collect a groundwater sample in July 2012).

Nitrogen concentrations in the hyporheic zone were essentially the same at 3-GW and 4-GW with respect to 1-GW and 2-GW. This indicates that the addition of nitrogen may be coming from an unidentified background source upgradient of the WWTP. These nitrogen concentrations in the hyporheic zone during the September 2012 sampling at sites 3-GW and 4-GW are elevated (2.7 mg N/L) compared to other locations and sampling events. These higher concentrations do not appear to result in higher surface water concentrations at 3-SW and 4-SW (0.04 mg N/L) and are lower than the upgradient sites 1-SW (0.9 mg N/L) and 2-SW (0.22 mg N/L).

Figure 17 illustrates nitrate and nitrogen concentrations (nitrate, nitrite, and ammonia) at all sample locations for all three sampling events moving from the most upstream sampling site to the most downstream site in the watershed.

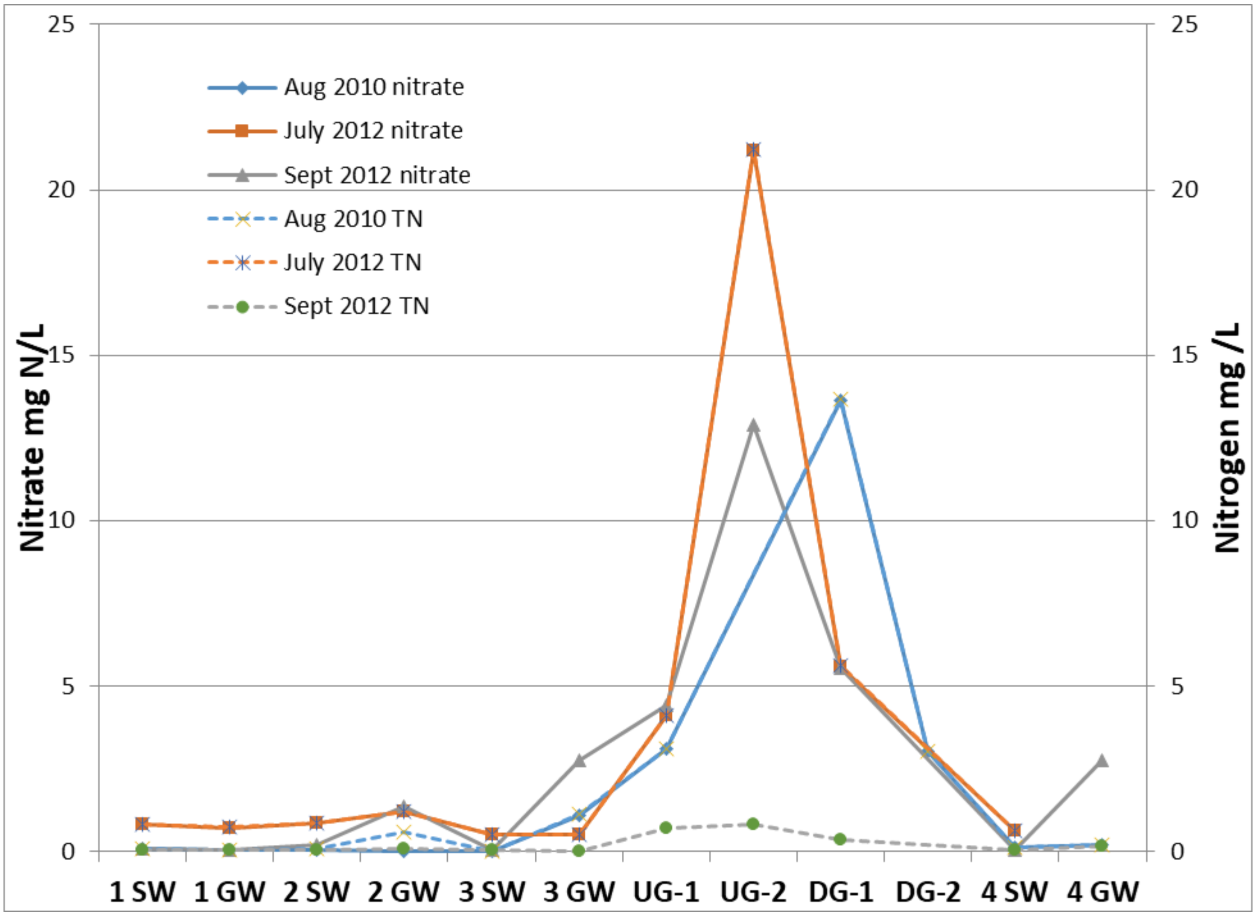


Figure 17. Nitrate and nitrogen concentrations at surface water and groundwater sites.

These results indicate a predominant presence of nitrate in groundwater near the WWTP. The groundwater quality standard of 10 mg N/L was exceeded in the upgradient monitoring well UG-2 (Figure 6) during both July and September 2011 (21 mg N/L and 13 mg N/L respectively). There was insufficient water in UG-2 in August 2010. These elevated concentrations above the drinking water standard in the upgradient well indicate contribution from an unknown background source.

The downgradient monitoring well DG-1 at the WWTP exceeded the nitrate standard in August 2010 with a concentration of 13.6 mg N/L. This concentration dropped during the sampling events in 2012 to 5.5 mg N/L. This dramatic decrease is attributed to the nitrification/ denitrification treatment process installed at the WWTP in November 2011.

Ammonia

Ammonia is one of the nitrogen species and is identified as a parameter of concern for surface water. The mouth of Hangman Creek has an average ammonia load allocation between July and October of 0.009 mg/L. (Moore and Ross, 2010). Figure 18 illustrates the ammonia concentrations for surface water for all sampling events.

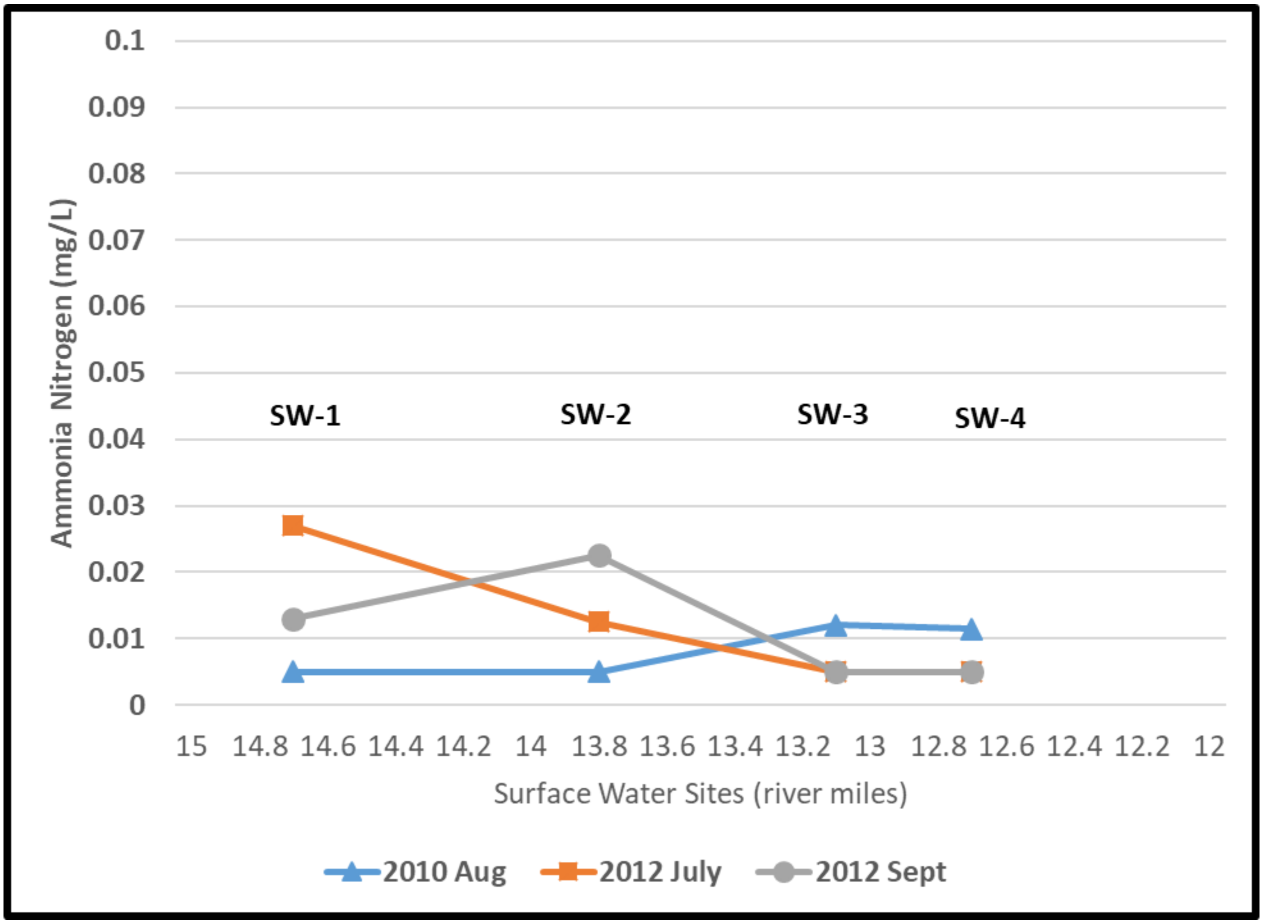


Figure 18. Ammonia nitrogen concentrations at surface water sites.

Figure 18 illustrates an increase in ammonia in surface water samples in the August 2010 sampling downstream of the golf course and upstream of the WWTP. In July 2012, ammonia concentrations decreased downstream, with the highest concentration at the upstream site. In September 2012 there was a slight increase in surface water ammonia concentrations at the golf course.

No clear ammonia source or seasonal period can be identified when ammonia concentrations are an issue (Figure 18). This may be a function of the seasonal application of fertilizers, which are based on climatic conditions and plant needs. It may also be a function of the biology of Hangman Creek caused by low-flow or seasonal conditions.

Ammonia concentrations for each of the sampling events are displayed for all surface water and groundwater paired sites. Figure 19 is color coded by sampling event with surface water results in the darker colors and groundwater results in the lighter colors. This figure indicates where groundwater may be contributing ammonia to surface water.

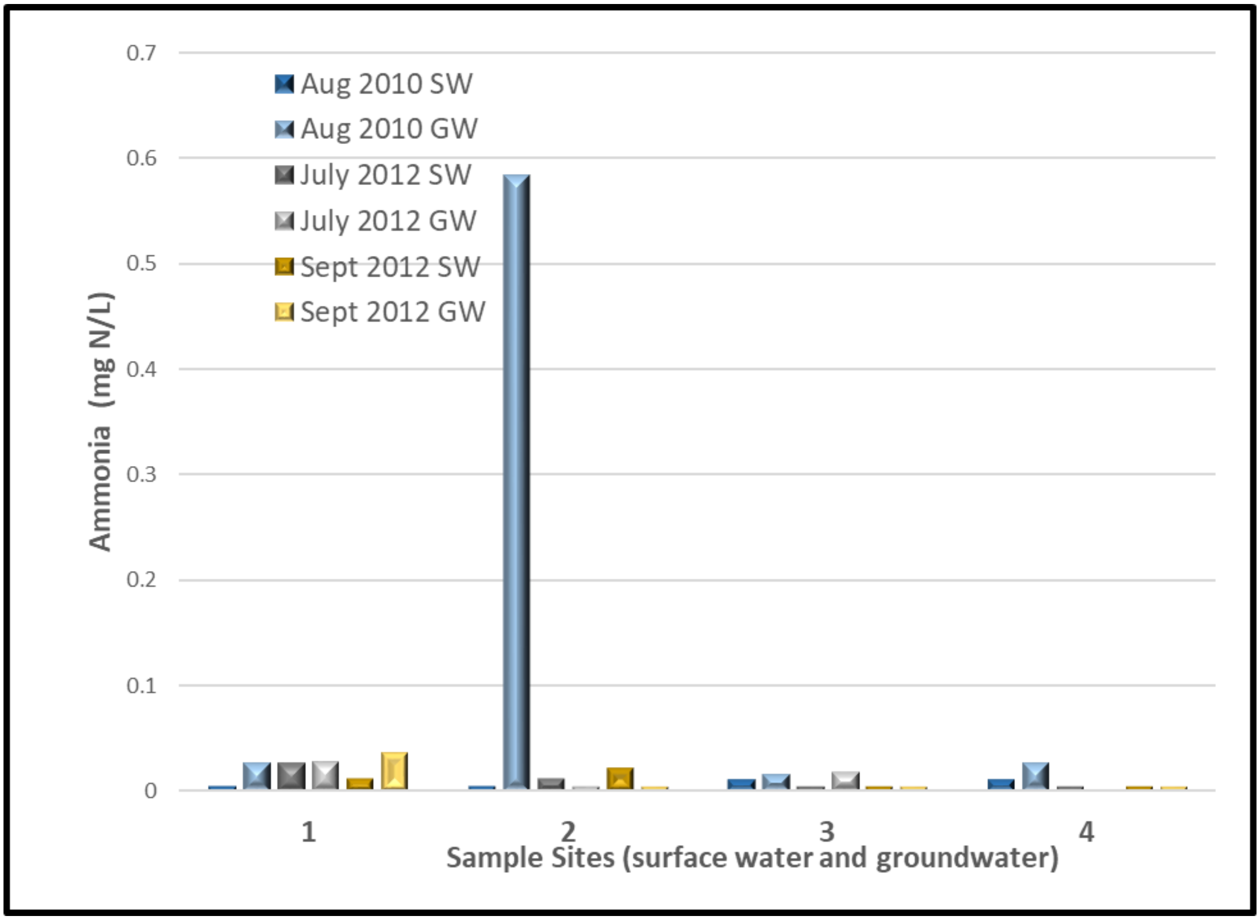


Figure 19. Ammonia concentrations for paired surface water and groundwater sites.

Data from Figure 19 are similarly presented in Figure 20 without the highest value 2-GW collected in August 2010. By removing this value, it highlights the relative concentrations collected from the other sample sites and dates.

Ammonia concentrations were greater in groundwater than in surface water for all sample dates at site 1. At site 2, the golf course, ammonia concentrations were higher in groundwater only during the August 2010 sampling. In 2012, surface water concentrations were greater than groundwater. At site 3, upgradient of the WWTP, ammonia concentrations in groundwater were greater (or equal) for all sampling events, indicating groundwater may be contributing ammonia to Hangman Creek. Downgradient of the WWTP (site 4), the ammonia concentration in groundwater was greater than surface water in August 2010; however, surface water ammonia concentration at 4-SW decreased slightly downstream from the upgradient site (3-SW).

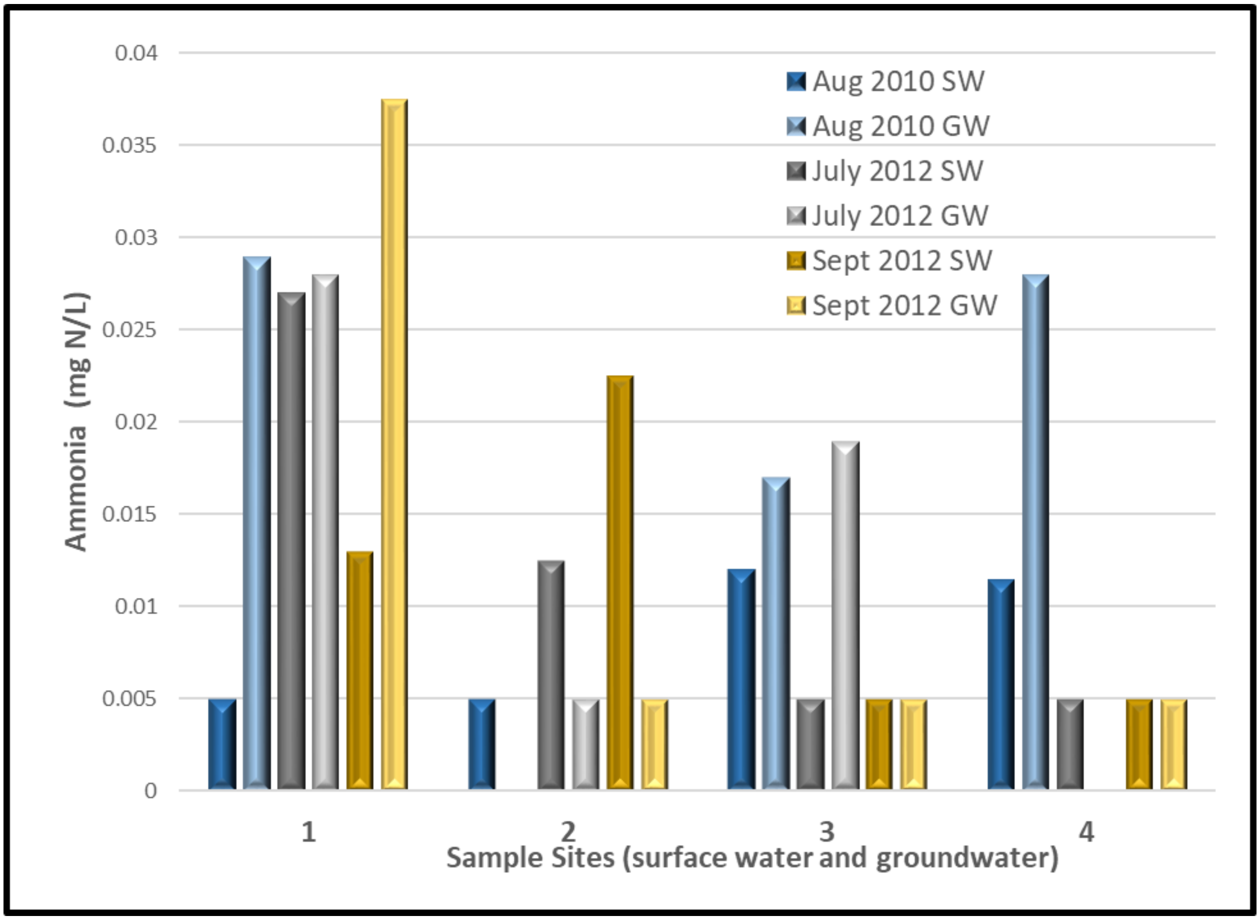


Figure 20. Ammonia concentrations for all paired sampling sites (except for 2-GW August 2010).

Dissolved Oxygen

DO is a concern for the Spokane River and its tributaries. The DO water quality criteria associated with *salmonid spawning, rearing and migration* are applicable to Hangman Creek. This criterion is described as *"dissolved oxygen concentration will not fall below 8.0 mg/L more than once every ten years on average. When a water body's dissolved oxygen is lower than 8.0 mg/L (or within 0.2 mg/L) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the dissolved oxygen of that water body to decrease more than 0.2 mg/L"*. (Moore and Ross, 2010)

DO was measured below 8.0 mg/L twice at sample site 1-SW (July 2011 and Sept 2012) and once at 2-SW (July 2012).

pH

Moore and Ross (2010) identified a concern with pH in the Spokane River and Hangman Creek. The applicable water quality criterion for Hangman Creek for pH is required to be within the range of 6.5 to 8.5 standard units with a human–caused variation with the range of less than 0.5 standard units.

During the study period, surface water pH was measured outside of the acceptable range at two locations during the July 2012 sampling at 3-SW and 4-SW (July 2012). The remaining pH measurements were always within the criteria range specified for surface water of 6.5 to 8.5 standard units.

Other Parameters of Interest

Other parameters were also analyzed, including total dissolved solids (TDS), chloride, sulfate, bromide and boron. These inorganic parameters can be useful to help distinguish different sources.

Total Dissolved Solids

TDS is the sum of the dissolved substances in water. This includes anions (bicarbonate, nitrate, chloride and sulfate) and cations (sodium, calcium, magnesium and potassium). These anions and cations are naturally occurring, but can also be present in fertilizers, municipal wastewater, and other sources. TDS has a drinking water standard and groundwater quality standard of 500 mg/L.

TDS concentrations for both surface and groundwater are presented in Figure 21. This figure illustrates increased TDS concentrations in groundwater at the golf course and the WWTP. Since TDS is comprised of many anions and cations, this increase can be the result of various contaminants that may be present in either fertilizer or municipal wastewater. The elevated concentrations of TDS above the drinking water standard were observed in groundwater only.

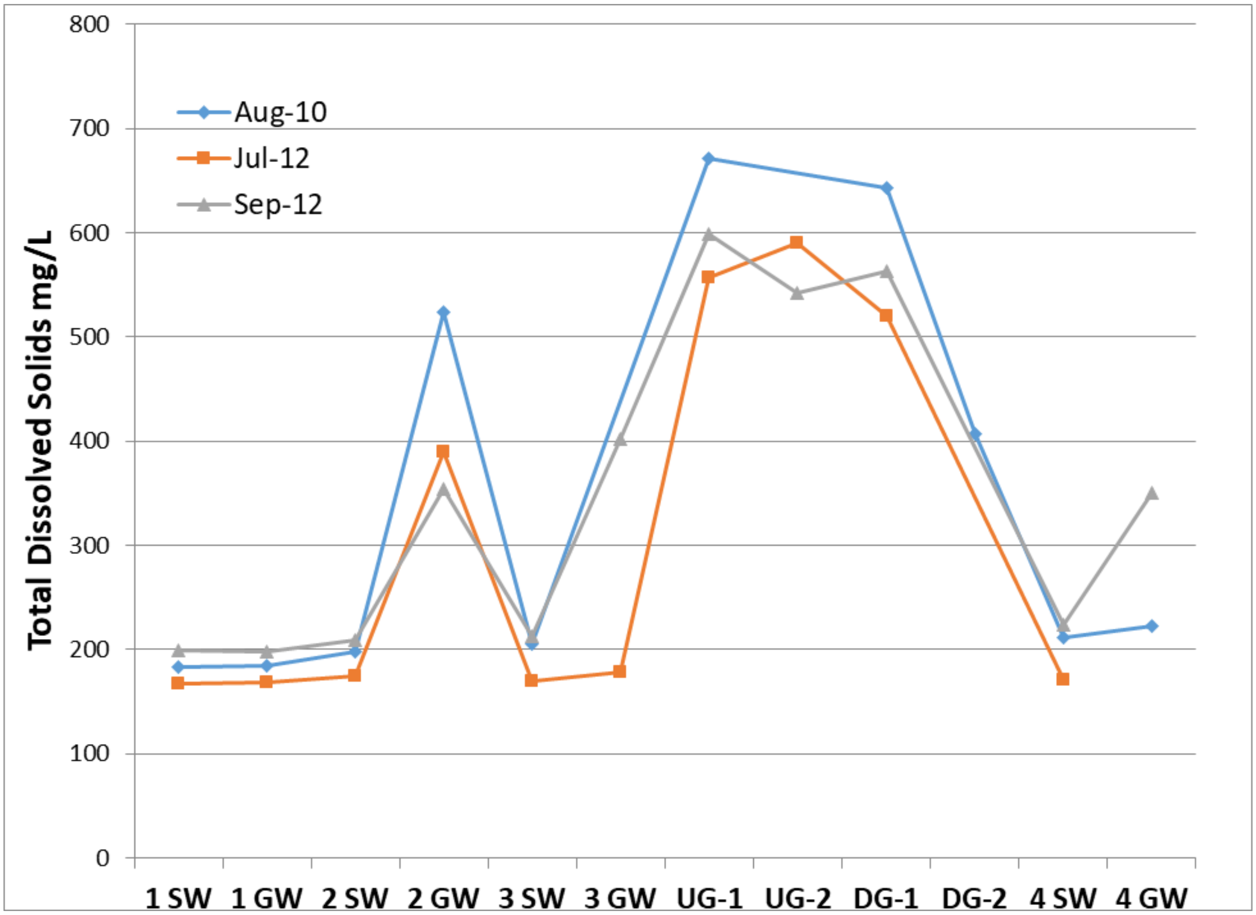


Figure 21. TDS (total dissolved solids) concentrations at surface water and groundwater sites.

TDS concentrations in surface water were relatively stable, ranging from 167 to 224 mg/L. The maximum TDS concentration in groundwater was 671 mg/L. TDS exceeded the 500 mg/L standard in the hyporheic zone at the golf course during the August 2010 sampling. TDS consistently exceeded the standard in monitoring wells UG-1, UG-2, and DG-1 at the WWTP. It does not appear that TDS is increasing in surface water at either the golf course or the WWTP.

Chloride and Sulfate

Chloride concentrations for all samples were less than the groundwater quality standard of 250 mg/L. Concentrations in surface water were consistently less than 10 mg /L. Water quality samples in the hyporheic zone were generally similar to surface water quality samples, but were slightly higher near the WWTP (10 - 20 mg/L). Water quality samples from the monitoring wells were generally higher ranging from 26 – 148 mg/L.

Sulfate concentrations for all samples were less than the groundwater quality standard of 250 mg/L. Sulfate concentrations were similar (less than 40 mg/L) in groundwater and surface water at the upgradient site. Sulfate was higher in groundwater at the golf course for both of the 2012 sampling events. Sulfate was also higher in the groundwater sample upgradient of the WWTP and was higher than surface water concentrations in all of the monitoring wells at the WWTP.

However, downgradient of the WWTP in surface water and groundwater, sulfate concentrations decreased to approximately upgradient concentrations.

Figure 22 illustrates chloride and sulfate concentrations for all sample sites.

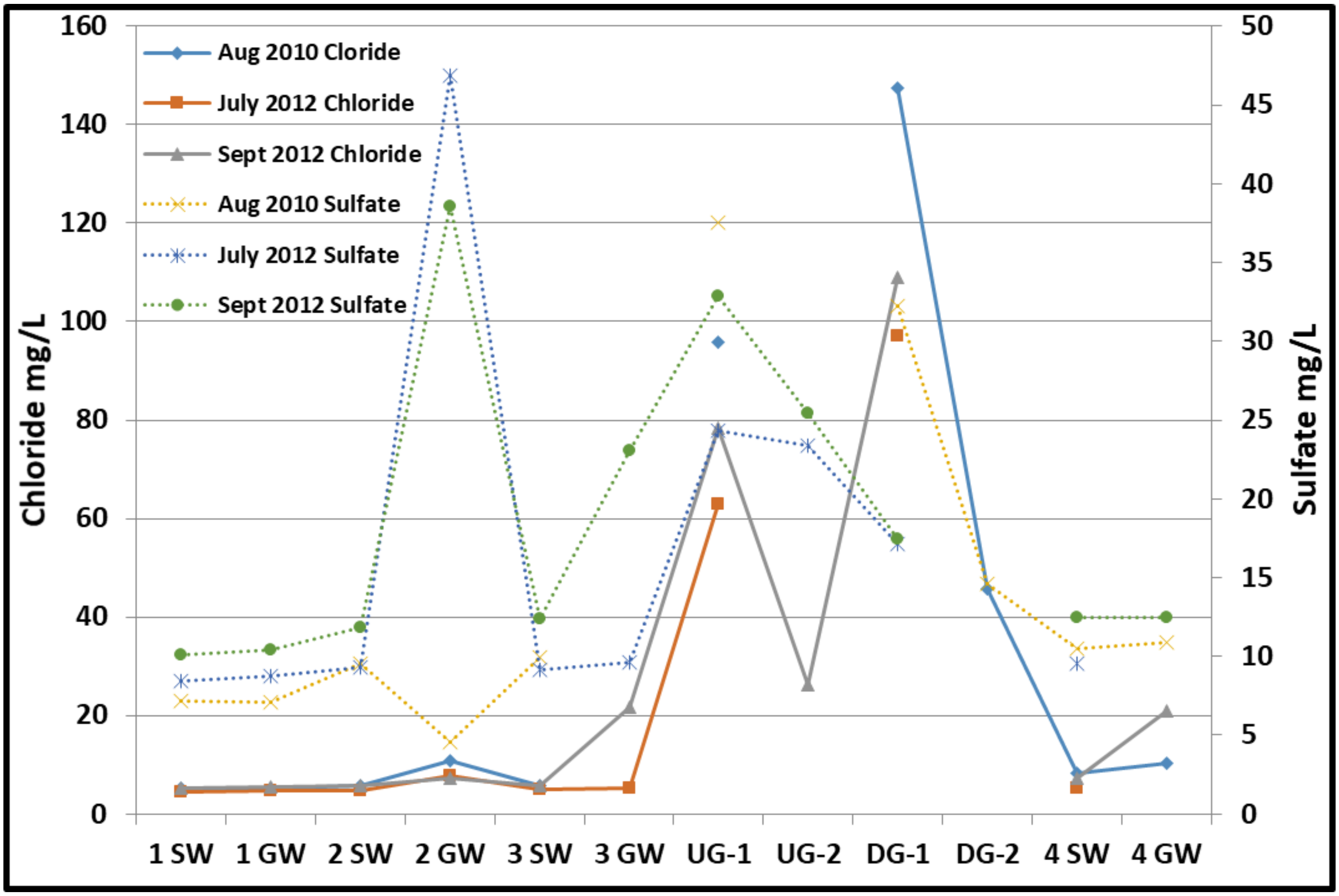


Figure 22. Chloride and sulfate concentrations at surface water and groundwater sites.

It appears that groundwater contains higher concentrations of sulfate adjacent to the golf course at 2-GW (August 2010 and July 2012) with a slight increase in concentration in surface water. The reduction in the groundwater sulfate concentration at the golf course in August 2010 may be the result of turf management practices and the seasonal timing of chemical usage. It also appears that groundwater is affected from the WWTP with higher chloride and sulfate concentrations in monitoring wells UG-1, UG-2 and DG-1. It does not appear that chloride concentrations in surface water are increasing at either the golf course or the WWTP, and sulfate does not appear to be increasing in surface water near the WWTP.

Indicator Parameters

Chloride/bromide ratios were used in conjunction with Boron in an attempt to distinguish possible nutrient sources.

Chloride/Bromide Ratios

The chloride/bromide ratio analyses was inconclusive to determine sources. A discussion of these results and analyses is in Appendix D.

Boron

Boron is a substance that is often added to laundry detergents. The presence of boron can be an indicator that the water originated from a residential wastewater source.

Boron concentrations in groundwater are presented in Figure 23. Boron was only detected at the monitoring wells at the WWTP and was not detected at any other monitored sites in the hyporheic zone or in surface water. The presence of boron in the monitoring wells indicates groundwater at the WWTP site is affected by human wastewater. However it does not distinguish wastewater from an onsite sewage system and a WWTP.

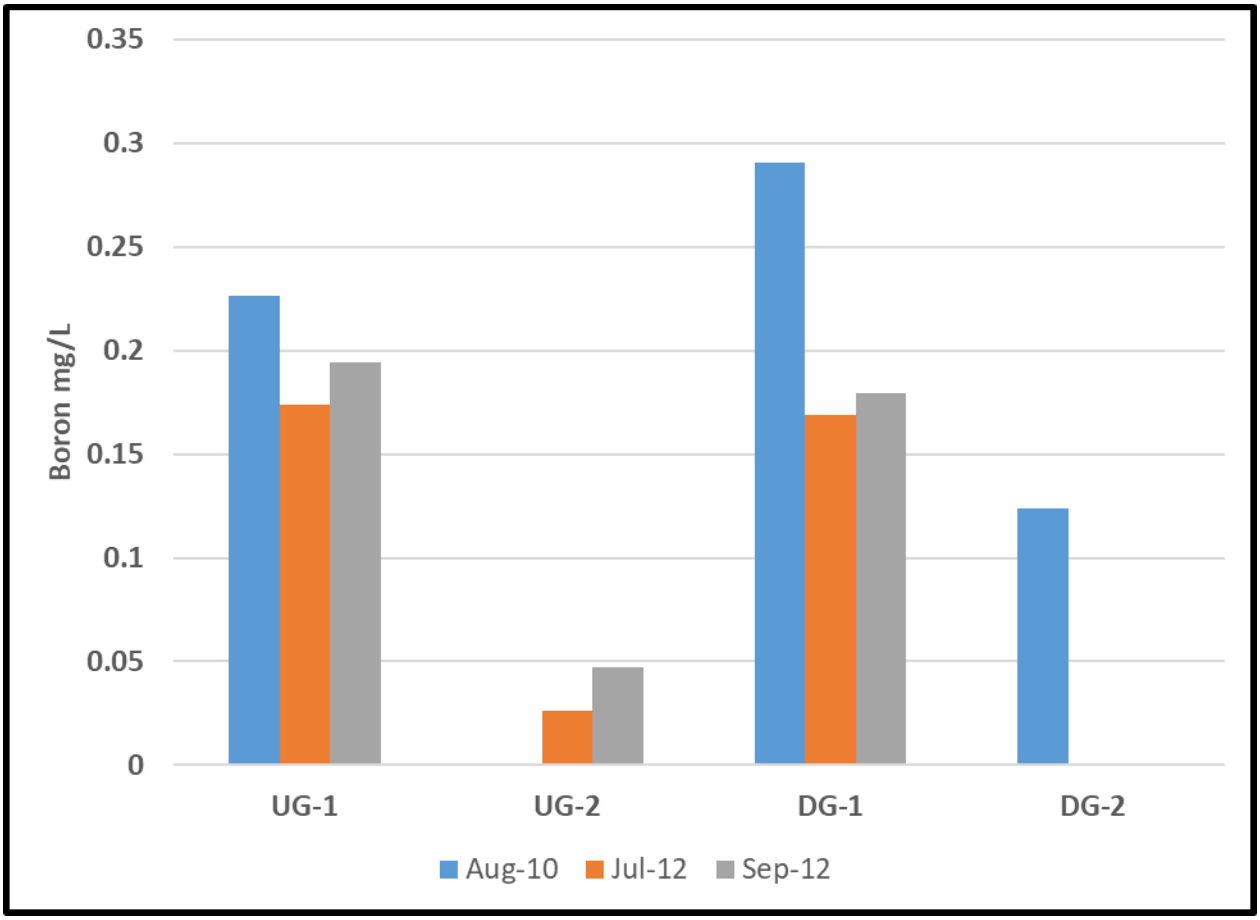


Figure 23. Boron concentrations in WWTP monitoring wells.

The detections of boron in monitoring wells UG-1, DG-1 and DG-2 indicate that the discharge from the WWTP is affecting groundwater quality locally at this site. The detections at UG-2 indicate an upgradient wastewater source, possibly on-site sewage systems.

Ionic Signatures

Ionic concentrations results are displayed in Stiff diagrams to compare water signatures at different sample locations for each sampling event. The shape of the polygon can be compared to other polygons to determine if sample water is similar in composition, but variable in concentration.

Stiff diagrams allow a visualization of general chemistry similarity and differences. Concentrations in milli-equivalents (meq) are plotted with cations on the left side of the diagram and anions on the right side. Each ion is plotted as a point and the points are connected to form a polygon. Since each ion is consistently plotted in the same location, and the scales are the same, the polygon acts as a signature. These polygons represent changing water composition over space and time. This visual display allows a comprehensive look of ions without differences in concentrations obscuring the relationship. For example, orthophosphate effects can occur at concentrations less than 0.01 mg/L, while effects from chloride occur at much greater concentrations.

These polygons illustrate how the ionic composition of water changes along the flow paths over time, considering multiple parameters.

Hangman Creek traverses through primarily rural and agricultural land upstream of the municipal golf course and the WWTP. Samples collected from this area were designed to provide background conditions for this study. Ionic signatures were used to evaluate the relative contribution of different sources to Hangman creek.

Figure 24 highlights an example of how stiff diagrams can be used to determine effects from other sources of water. The diagram on the left represents 3-SW, the one in the middle is 4-SW and the one on the right in the box is 4-GW. All three diagrams have the same scale and were developed from water quality results collected in September 2012. A comparison of these three diagrams show how similar the composition of surface water is at sample sites 3-SW and 4-SW. The ionic composition from groundwater in the hyporheic zone at 4-GW has a different signature with noticeable differences of magnesium, calcium, chloride and bicarbonate. These diagrams can be used to illustrate if groundwater is affecting surface water quality. For example, if groundwater at 4-GW was affecting surface water, the middle Figure (4-SW) would likely resemble 4-GW, rather than its strong resemblance to 3-SW.

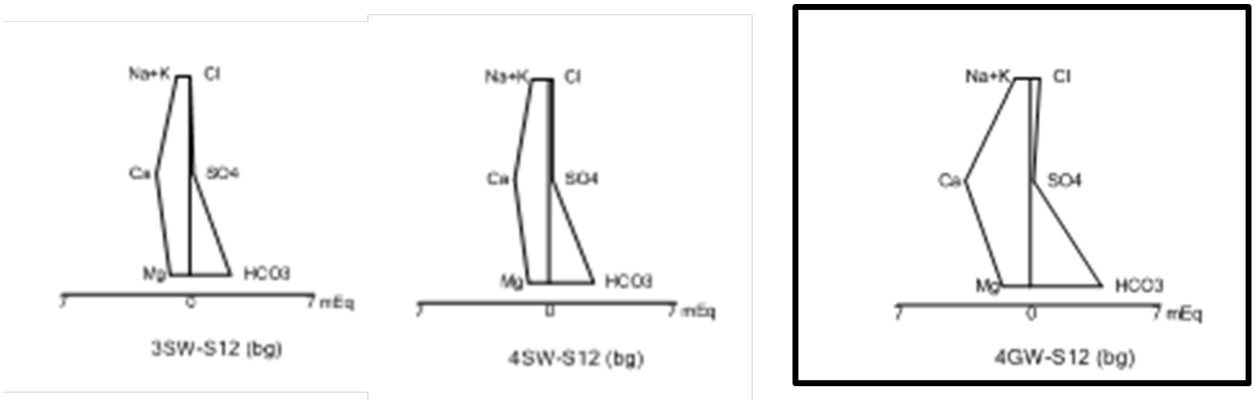


Figure 24. Stiff diagrams comparing the water quality at 4-GW with 3-SW and 4-SW.

Figure 25 compares the ionic composition from 4-GW and monitoring well DG-1. Groundwater in well DG-1 is determined to be affected by discharge from the WWTP. The two Stiff diagrams have different polygon shapes, with noticeable differences from sodium, potassium, and chloride. These differences indicate that the chemical composition of the groundwater is changing before it reaches the hyporheic zone.

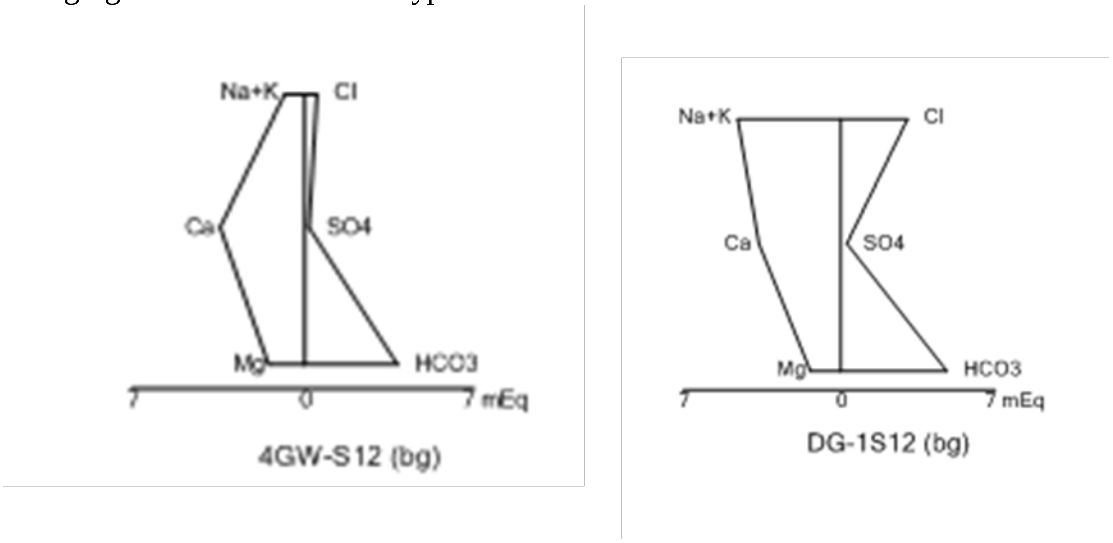


Figure 25. Stiff diagrams from the hyporheic zone 4-GW and monitoring well DG-1.

Figure 26 illustrates the ionic signatures for the surface water sites for each sampling event. The shape of the surface water polygons for all surface water samples for all sampling events is fairly consistent.

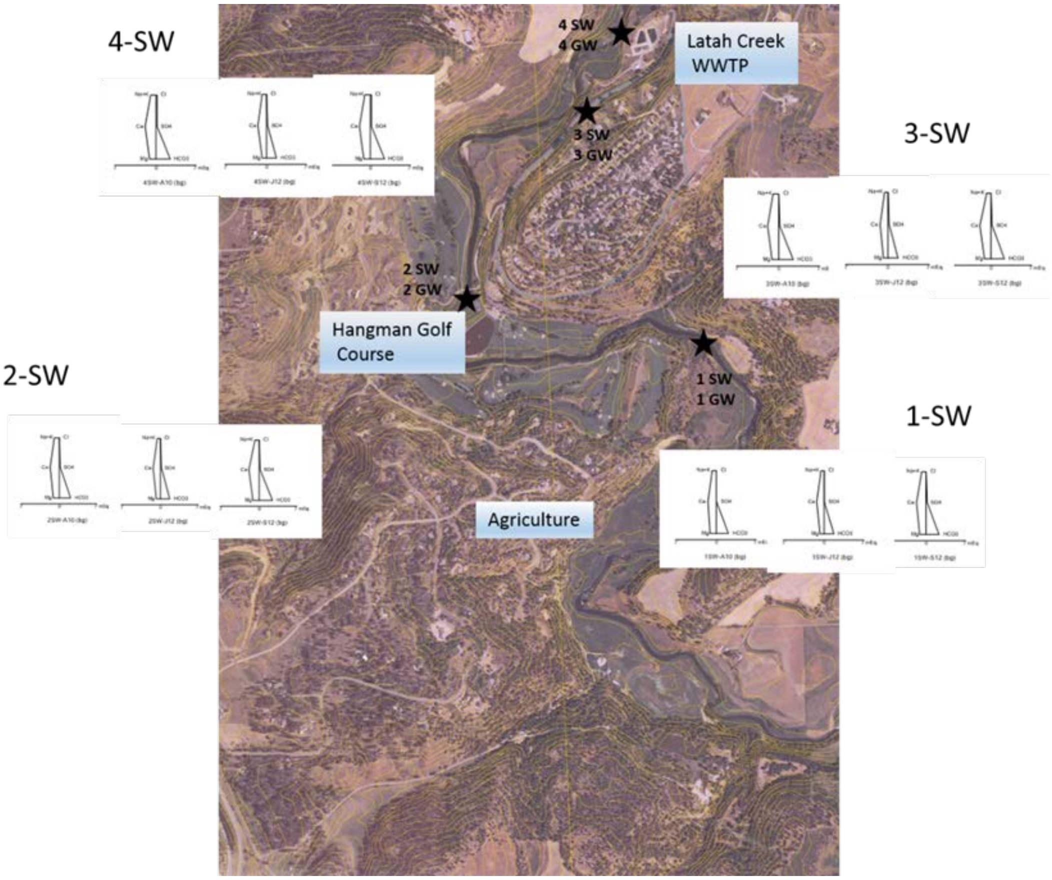


Figure 26. Stiff diagrams for surface water samples.

Figure 27 illustrates Stiff diagrams for the paired groundwater sample sites for each sampling event. For sample site 1-GW all three Stiff diagrams are fairly consistent during each sampling event, and are similar in shape to the surface water diagrams (Figure 26). In contrast, there are distinct differences for each sampling event at each of the other sample sites: 2-GW, 3-GW, and 4-GW. These differences indicate some type of change in the chemical composition to groundwater. Since the surface water diagrams in Figure 26 are similar, it indicates that groundwater does not appear to be significantly affecting surface water quality.

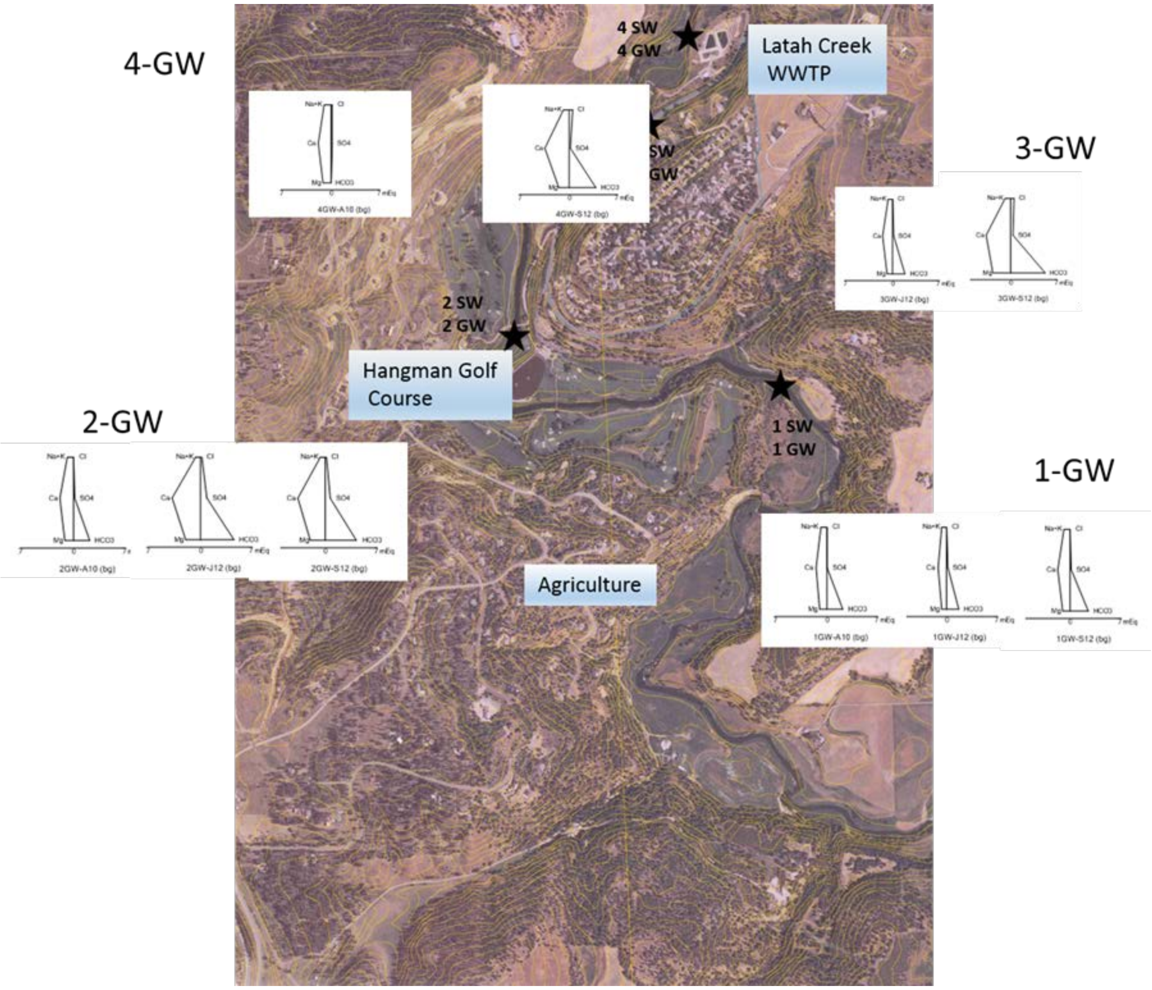


Figure 27. Stiff diagrams for hyporheic sample sites.

Figure 28 illustrates the Stiff diagrams of water quality collected from monitoring wells located at the WWTP. Groundwater samples from these wells have a different ionic signatures than groundwater samples collected from the hyporheic zone (Figure 27) adjacent to surface water sample sites. The ionic signatures for each of the wells are fairly consistent over each sampling event. The ionic signatures of UG-2 are different than the other monitoring wells, with very little chloride.

The chemical composition of the monitoring wells is different than the hyporheic zone at 4-GW (Figure 27), and the wells are also different than the surface water sites (Figure 26). These Stiff diagrams provide supporting information that is useful in assessing the effects of a discharge on water quality.

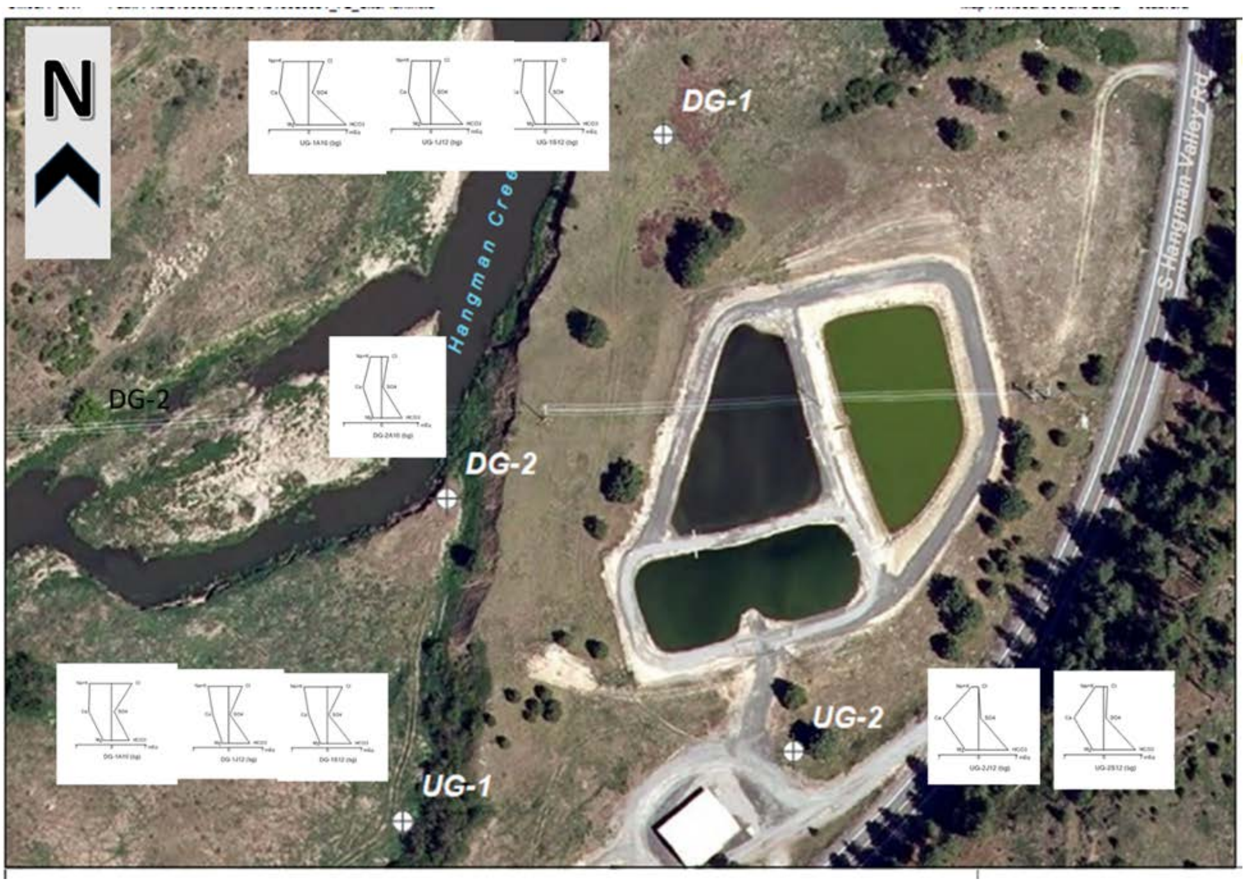


Figure 28. Stiff diagrams for monitoring wells at the WWTP.

Effects on Groundwater Quality

Groundwater quality data, collected from the Latah Creek WWTP as part of their State Waste Discharge Permit requirements, was analyzed to determine if a more extensive data set could determine which wells are affected by the lagoon discharge, and the time of travel for seeing changes based on effluent quality improvements made in the fall of 2011.

In November 2011, a nitrification/denitrification treatment system was added to the WWTP; this system reduced the effluent concentration from an average nitrogen concentration of 17 mg N/L to 5 mg N/L. The WWTP generates about 50,000 gallons per day which are discharged to the lagoons. The monitoring wells at the WWTP are sampled quarterly by the facility to determine effects from this continual discharge.

Figure 29 compares mean nitrate concentrations in each well before the advanced treatment to a running mean nitrate concentration after installation of the advanced treatment. The values to the left of the vertical black line are the mean concentrations before the enhanced treatment. A running mean is a statistical tool that allows a closer examination of a subset of data. The running mean continually changes as more data are collected. In this case the running mean is considering all data collected from the installation date of the enhanced treatment system in November 2011, which provides information on time of travel from the wastewater discharge to the specific monitoring wells. Figure 29 indicates that the time of travel of effluent leaving the lagoon and travelling in groundwater until it reaches the monitoring wells is about one year.

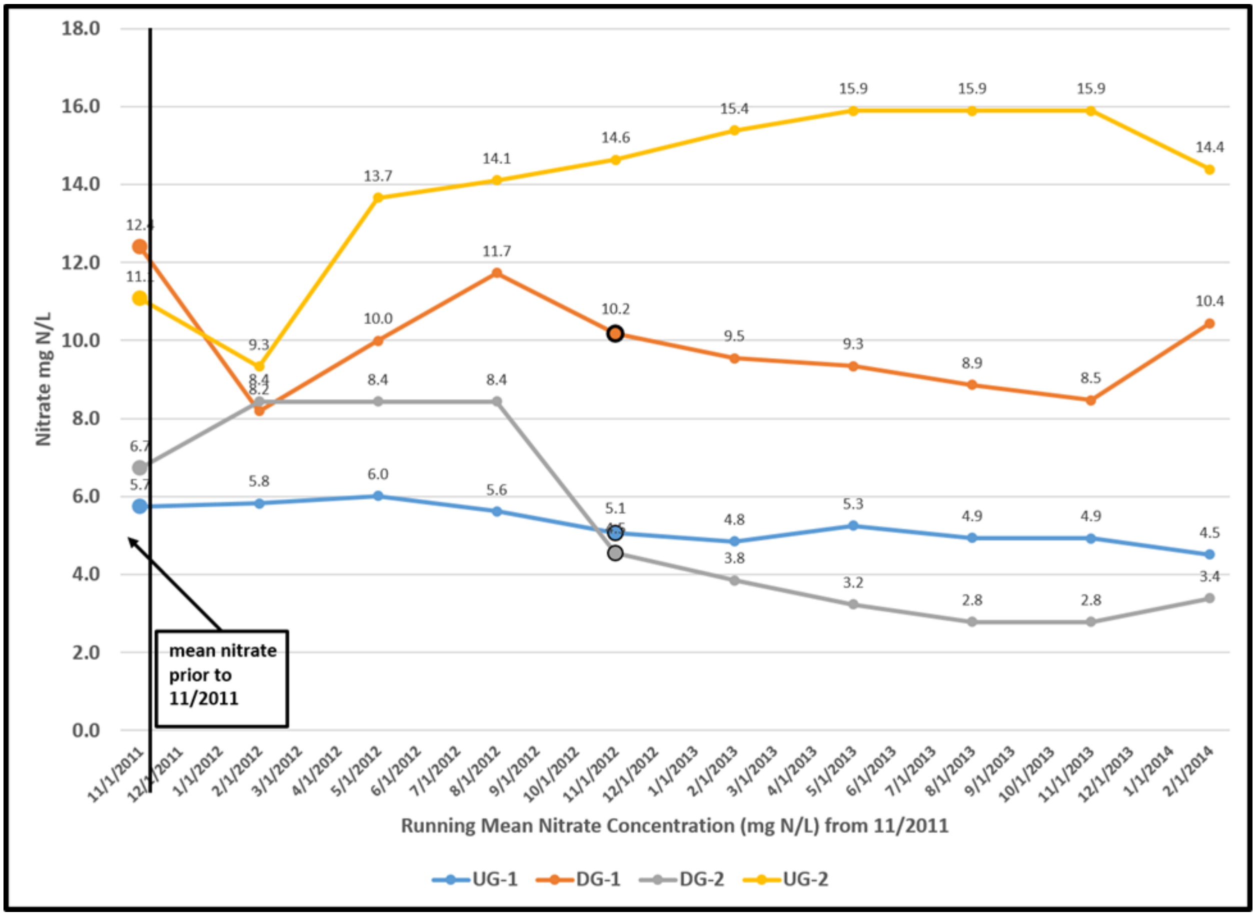


Figure 29. Comparison of mean nitrate concentration in WWTP monitoring wells before and after effluent treatment.

Comparing the running mean concentration to the mean concentration before enhanced treatment (value left of the vertical black line), monitoring wells UG-1, DG-1, and DG-2 appear to have decreased running mean nitrate concentrations which become apparent about one year after installation of advanced treatment (highlighted dots); since the monitoring wells are sampled quarterly, this timeframe is approximate. It is unclear how influenced monitoring well UG-1 is from the lagoon discharge; while mean nitrate concentrations decline in this well, it is less pronounced than monitoring wells DG-1 or DG-2. Based on seasonal groundwater flow, at times monitoring well UG-1 is cross gradient to flow from the discharge, and at times downgradient. This seasonal variation may be the reason the decline in nitrate concentrations is less pronounced in this well.

Monitoring well UG-2 is an upgradient well assessing background conditions from Hangman Valley Road and potential activities from the upgradient area on the bluff. Nitrate concentrations from this well are typically elevated, but it was unclear if the water quality was affected by a possible mounding effect from the effluent discharging from the lagoons. Figure 29 illustrates how concentrations in UG-2 do not respond to the improved treatment from the effluent, with the running mean concentrations generally increasing after the time when advanced treatment at the WWTP was installed.

In Table 6, the mean nitrate concentrations in each monitoring well are compared before and after the effects of the advanced treatment were detected on November 2012.

Table 6. Comparison of mean nitrate concentrations (mg-N/L) before and after advanced WWTP treatment upgrade.

Monitoring Well	Mean Before Treatment (8/2009 to 11/2011)	Mean After Treatment (11/2012 – 2/2014)	Net Change
UG-1	5.75	3.96	-1.79
DG-1	12.41	9.80	-2.61
DG-2	6.73	2.39	-4.35
UG-2	11.07	14.60	3.54

PARIS database - submitted as part of monitoring requirements from SWDP

Monitoring wells UG-1, DG-1, and DG-2 present lower nitrate concentrations after the WWTP reduction in nitrogen. This indicates that these wells are affected by discharge from the WWTP and should be considered downgradient wells.

The nitrate concentration in monitoring well UG-2 does not have a similar nitrate reduction; instead the nitrate concentration illustrates an increasing trend. This indicates that monitoring well UG-2 is not affected by discharge from the lagoons and should be considered an upgradient well.

Conclusions

Results of this study support the following conclusions:

Groundwater Flow

- In August 2010, Hangman Creek was determined to be a gaining reach with groundwater flowing into the creek. This was based on the thermal profile conducted adjacent to the shoreline of the Latah Creek WWTP property.
- All paired groundwater and surface water sample sites adjacent to Hangman Creek were also found to be gaining reaches for all three sampling events. These events occurred during low-flow conditions in the summer: August 2010, July 2012, and September 2012.
- The direction of groundwater flow and the flow gradient beneath Latah Creek WWTP varies seasonally with the predominant flow to the west-northwest towards Hangman Creek.
- Monitoring well UG-2 is determined to be located upgradient of the WWTP and does not appear to be influenced by discharge from the lagoons.
- Monitoring wells UG-1, DG-1, and DG-2 are determined to be located downgradient of the WWTP and appear to be influenced by discharge from the lagoons.

Contaminants Affecting Hangman Creek

- Total phosphorus and orthophosphate concentrations in surface water exhibit a slight decline with each sampling event. It is not clear if this is related to sample collection in different months, algal uptake of phosphorus in the water, flows in Hangman Creek, or if there are source reductions in phosphorus concentrations.
- Total phosphorus and orthophosphate concentrations in Hangman Creek decrease overall from upstream to downstream, which indicates a significant phosphorus source originates upstream of the study area.
- Declining phosphorus concentrations in Hangman Creek are thought to reflect algal uptake in the creek, with the change in slope reflecting a biological equilibrium (Stuart, 2020).
- Ammonia data do not clearly identify any particular source, location, or time when ammonia concentrations are an issue.
- There were no exceedances of the ammonia TMDL threshold in surface water downstream of the WWTP after enhanced treatment was installed.
- Nitrogen concentrations in Hangman Creek were highest at every testing site during the July 2012 event. This may be attributed to higher flows in the creek.

Contaminant Sources

Latah Creek WWTP

- The contribution of nitrogen to Hangman Creek from the Latah Creek WWTP appears to have been reduced from the installation of the nitrification/denitrification treatment process.

  - Enhanced nitrogen treatment was installed in November 2011 at the Latah Creek WWTP. This treatment reduced the average total nitrogen in the effluent from 17.06 mg/L to 5.27 mg/L.
  - The reductions in total nitrogen concentrations in the effluent were detected in groundwater in the monitoring wells about one year later, with reduced groundwater nitrate concentrations in monitoring wells DG-1, DG-2 and UG-1.
  - During this study, the nitrate concentrations in monitoring well DG-1 decreased from 13.6 mg N/L in August 2010 to 5.5 mg N/L in the July and September 2012 samples. This decrease is consistent with the decrease in the WWTP effluent nitrogen reductions from the WWTP modifications.
  - In surface water, nitrogen concentrations increased from upstream (3-SW) to downstream (4-SW) during each sampling event. However, Table 7 illustrates that while nitrogen concentrations increased, the percent increase of nitrogen dropped significantly in 2012. The reduction in the percent increase to surface water is likely attributed to the treatment plant improvements.

Table 7. Nitrogen concentrations in surface water near the WWTP.

Sampling Date	3-SW (mg/L)	4-SW (mg/L)	% Increase
August 2010	0.017	0.122	617.65
July 2012	0.508	0.62	22.05
September 2012	0.043	0.045	4.65

- Groundwater is locally affected by the discharge at the WWTP for nitrate, orthophosphate, chloride, sulfate, and TDS, but these contaminants do not appear to be increasing in Hangman Creek.
- Orthophosphate concentrations in the monitoring wells were higher than at other surface water or groundwater sample locations for all sampling events. Concentrations were higher in the hyporheic zone (4-GW) than in surface water (4-SW) and do not appear to be increasing in surface water.
- Boron was detected only in the monitoring wells at the WWTP, which is indicative of effects from human wastewater.
- Boron in laundry detergents is highly soluble in water. The absence of boron in groundwater in the hyporheic zone and in surface water near the WWTP indicates that wastewater contaminants are being attenuated in the soils before reaching Hangman Creek.

Upgradient Source

- The highest concentrations of total phosphorus, orthophosphate, and ammonia in surface water samples were observed at sampling site 1-SW, the most upgradient site. Overall, concentrations of these contaminants decline downstream.

Golf Course

- Contaminants in groundwater adjacent to the golf course varied during the study. It is not clear if this relates to the timing of turf management practices at the golf course or if there is another reason for these variations.
- Groundwater concentrations of orthophosphate, total phosphorus, and ammonia are slightly higher near the golf course; however, these concentrations do not appear to be increasing in Hangman Creek.
- The highest ammonia concentration detected occurred in the groundwater sample adjacent to the golf course in August 2010.
- Nitrogen concentrations were consistently higher in groundwater than in surface water. There is a slight increase in concentrations in Hangman Creek during the two 2012 sampling events, with nitrate + nitrite being the predominant nitrogen species.
- Total dissolved solids (TDS) and chloride concentrations are consistently higher in groundwater than in surface water, but concentrations in surface water do not appear to be increasing.
- Flow data collected in 2009 and 2018 during the summer months (Stuart, in preparation) indicate that Hangman Creek in this study area is consistently a gaining reach, but the amount of additional streamflow entering the creek during the low-flow summer months is low, varying from 1 to 0.1 cfs.

Contaminant Indicators

- Boron is an effective indicator of contaminants in human wastewater.
- Ionic composition of water and the use of Stiff diagrams is helpful in confirming contaminant effects.
- Chloride/bromide ratios were not effective in distinguishing contaminant sources for this study.

Study Limitations

This study was initiated with a limited scope of work which was expanded to evaluate the potential groundwater and surface water benefits from improvements at the Latah Creek WWTP. The following limitations identify issues that became apparent during interpretation of the study results:

- Samples were collected during three sampling events: August 2010, July 2012, and September 2012. Since samples were not collected during the same month, it is difficult to determine if the differences observed reflect streamflow differences in the creek, climatic conditions, or improvements at the WWTP.
- Sampling further downstream of the WWTP would have helped us understand algal nutrient uptake in Hangman Creek. This may be addressed by continued Ecology study of nutrient contributions in the Hangman Creek watershed and as contaminants entering the Spokane River (Albrecht, Stuart, and Redding; 2017).

References

APHA, 2005. Standard Methods for the Analysis of Water and Wastewater, 21st Edition. Joint publication of the American Public Health Association, American Water Works Association, and Water Environment Federation. www.standardmethods.org/

Albrecht, A., Stuart, T., and Redding, M., 2017. Quality Assurance Project Plan: Hangman Creek Dissolved Oxygen, pH, and Nutrients Pollutant Source Assessment. Washington State Department of Ecology, Publication 17-03-111, 76 pgs. Quality assurance project plan

Bretz, J. H., 1930. Lake Missoula and the Spokane Blood. Geological Society of America Bulletin, V. 41, p. 92-93.7

The Cadmus Group, Inc. & CDM, 2007. Final Model Report for Hangman (Latah) Creek TMDL Model Project. Bellevue, WA, CDM Project No. 48105-3113-003.

CH2MHILL, 2009. Hangman Valley Wastewater Treatment Plant Operations Related to Meeting NPDES Permit Limits, Technical Memorandum from Dave Reynold to Bruce Rawls, Spokane County (April 28, 2009), 12 pgs + figures.

Davis, S. N., Whittemore, D.O., and Fabryka-Martin, J., 1998. “Uses of Chloride/Bromide Ratios in Studies of Potable Water,” Ground Water, Volume 36, Number 2, pp. 338-350.

GeoEngineers, Inc., 2012. Hydrogeologic Review and Replacement Well Siting, Latah Creek Wastewater Treatment Plant, Spokane County, Washington. Spokane, WA., 3 pgs + figures.

GeoEngineers, 2000. Hydrogeologic Study, Hangman Hills Sewage Treatment Plan, Spokane, County, Washington. Spokane, WA. 9 pgs plus tables, figures and appendices.

HDR Engineering, Inc., 2009. Spokane River Non-Point Source Analysis Project Phase 1 Surface Water Total Phosphorus Data Analysis. Spokane, WA, 75 pgs.

Joy, J., 2008. Hangman Creek Watershed Dissolved Oxygen and pH Total Maximum Daily Load, Water Quality Study, Design Quality Assurance Project Plan. Washington State Department of Ecology. 71 pgs. Publication 08-03-117.
https://fortress.wa.gov/ecy/publications/SummaryPages/0803117.html

Joy, J., Noll, R., and Snouwaert, E., 2009. Hangman (Latah) Creek Watershed Fecal Coliform, Temperature and Turbidity Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Publication 09-10-030, 247 pgs.
https://fortress.wa.gov/ecy/publications/SummaryPages/0910030.html

Kahle, S., and Bartolino, J., 2007. Hydrogeologic Framework and Ground-Water Budget of the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho. US Geological Survey, Scientific Investigations Report 2007-5041, 48 pgs.

MEL, 2008. Manchester Environmental Laboratory *Lab Users Manual*, Ninth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

MEL, 2012. Manchester Environmental Laboratory Quality Assurance Manual. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Molenaar, D., 1988. The Spokane Aquifer, Washington: Its Geologic Origin and Water-Bearing and Water-Quality Characteristics. US Geological Survey, Water-Supply Paper 2265, 74 pgs. https://pubs.usgs.gov/wsp/2265/report.pdf

Moore, D., and Ross, J., 2010. Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Publication 07-10-073, 399 pgs. https://fortress.wa.gov/ecy/publications/SummaryPages/0710073.html

Northwest Land & Water, INC., 2011. Hangman Creek Watershed (WRIA 56) Hydrogeologic Characterization & Monitoring Well Drilling, Spokane, WA, 36 pgs.

Redding, M., 2010. Quality Assurance Project Plan: Hangman Hills Sewage Treatment Plant Nutrient Loading and Groundwater Study, Washington State Department of Ecology, Environmental Assessment Program, Publication 10-03-116, 23 pgs. https://fortress.wa.gov/ecy/publications/SummaryPages/1003116.html

Redding, M., 2012. Addendum to Quality Assurance Project Plan: Sumas-Blaine Surficial Aquifer Long-Term Ambient Groundwater Monitoring, Washington State Department of Ecology, Environmental Assessment Program, Publication 09-03-111, 8 pgs. https://fortress.wa.gov/ecy/publications/SummaryPages/0903111.html

Ross, J., 2011. Hangman Creek Watershed Dissolved Oxygen, pH and Nutrients Total Maximum Daily Load Study: Data Summary Report. Washington State Department of Ecology, Publication 11-03-020, 86 pgs. https://fortress.wa.gov/ecy/publications/SummaryPages/1103020.html

Stuart, Tighe; 2020. Personal communication. Eastern Regional Office, Washington State Department of Ecology.

Vengosh, A, and Pankratov, I., 1998. “Chloride/Bromide and Chloride/Fluoride Ratios of Domestic Sewage Effluents and Associated Contaminated Ground Water,” Ground Water, Volume 36, Number 5, pp. 815- 824.

Washington State Department of Ecology, 2007a. Fact Sheet for State Waste Discharge Permit ST-8045 Hangman Valley. Eastern Regional Office, Water Quality Program, 18 pgs + attachments.

Washington State Department of Ecology, 2007b. State Waste Discharge Permit Number ST-8045. Eastern Regional Office, Water Quality Program, 19 pgs.

Appendices

Appendix A. Water Quality Data

Table A.1. Thermal profile data (7/21/2010).

Station (see Figure A.1)	Surface Water Temperature (°C)	Groundwater Temperature (°C)	Δ (°C)
53	27	17.3	9.7
52	26.9	17.5	9.4
51	26.2	17.6	8.6
50	25.7	18.8	6.9
49	26.4	17	9.4
48	26	15.7	10.3
47	26.5	18.1	8.4
46	26.6	17	9.6
45	25.8	22.7	3.1
44	26	19.1	6.9
43	26	18.7	7.3
42	25.9	25	0.9
41	26	16.7	9.3
40	26	17.1	8.9
39	25.8	19	6.8
38	26.2	17.5	8.7
37	25.7	18.5	7.2
36	25.6	19.8	5.8
35	25.5	20.5	5
34	25.5	16.7	8.8
33	25.4	13.5	11.9
32	25.3	14.6	10.7
31	25	16.2	8.8
30	24.6	18	6.6
29	24.5	19.2	5.3
28	24.3	17.3	7
27	24.3	12.4	11.9
26	23.7	15.7	8
25	24.5	13.5	11
24	24.1	22.3	1.8
23	24.2	19.2	5
22	24	16.2	7.8
21	24	14.7	9.3
20	24.2	11.7	12.5
19	24.1	14.2	9.9

Station (see Figure A.1)	**Surface Water Temperature (°C)**	**Groundwater Temperature (°C)**	**Δ (°C)**
18	23.7	13.7	10
17	23.7	15.6	8.1
16	23.5	14.6	8.9
15	23.5	12.7	10.8
14	23.5	23	0.5
13	22.8	14.2	8.6
12	22.9	17	5.9
11	23.2	16.7	6.5
10	23.3	19.1	4.2
9	23.1	22.1	1
1	22	16.9	5.1
2	22.9	16.5	6.4
3	23	19.2	3.8
4	23	20	3
5	23	22.6	0.4
6	23.2	18	5.2
7	23	16.8	6.2
8	23.5	20.3	3.2

Figure A.1. Thermal profile locations.

Water Quality Data

Table A.2 is an Excel file linked to this report online as a Supplemental file:

https://fortress.wa.gov/ecy/publications/SummaryPages/2003013.html

Field Measurements

Table A.3. Field measurements.

Location	Well ID	Date	Depth to Water	Temper-ature	pH	Conduc-tivity	Dissolved Oxygen
			feet	˚ C	standard units	uS/cm	mg/L
August 2010							
1-SW		8/18/2010		20.7	8.17	288.1	9.83
1-GW				no sample			
2-SW		8/18/2010		22.77	8.24	314.2	11.18
2-GW				no sample			
3-SW		8/18/2010		20.93	7.91	321.2	8.23
3-GW				no sample			
UG-1	ABI423	8/17/2010	13.39	11.06	7.12	1105	1
UG-2	BBH655		54.04	no sample			
DG-1	ABI422	8/17/2010	19.18	11.75	7.34	1020	10.1
DG-2	ABI424	8/17/2010	15.59	12.35	7.39	615	11.2
4-SW		8/18/2010		22.98	8.1	338.1	9.04
4-GW				no sample			
July 2012							
1-SW		7/11/2012		23.42	7.9	240.3	6.18
1-GW		7/11/2012		23.92	7.39	236.4	4.53
2-SW		7/11/2012		24.37	7.96	255.2	7.16
2-GW		7/11/2012		11.28	7.49	593.5	1.82
3-SW		7/10/2012		26.75	8.61	251.4	10.75
3-GW		7/10/2012		26.88	8.42	267.7	10.29
UG-1	ABI423	7/10/2012	11.5	10.5	6.96	882	1.54
UG-2	BBH655	7/10/2012	45.54	15.38	7.21	856.4	9.25
DG-1	ABI422	7/10/2012	17.08	9.25	7.46	855.1	8.18
DG-2	ABI424			no sample			
4-SW		7/11/2012		27.37	8.53	260.8	10.45
4-GW		7/11/2012					
September 2012							
1-SW		9/9/2012		17.68	8.03	295.4	7.22
1-GW		9/9/2012		17.98	7.65	297.1	5.74
2-SW		9/9/2012		17.25	8.04	313.7	8.51
2-GW		9/9/2012		11.36	7.17	534.8	2
3-SW		9/9/2012		19.46	8.22	316	11.81
3-GW		9/9/2012		17.1	7.31	661	7.9
UG-1	ABI423	9/10/2012	13.09	10.28	6.77	962	1.3
UG-2	BBH655	9/10/2012	47.34	10.75	7.08	831.3	7.18
DG-1	ABI422	9/10/2012	18.51	10.17	7.11	820	6.31

Location	Well ID	Date	Depth to Water	Temper-ature	pH	Conduc-tivity	Dissolved Oxygen
			feet	˚ C	standard units	uS/cm	mg/L
DG-2	ABI424			no sample			
4-SW		9/10/2012		17.38	8.18	323.2	8.81
4-GW		9/10/2012		11.47	6.79	511.4	3.78

Appendix B. Data Quality Assurance Results

Quality Assurance

The data QA performance requirements are described in Redding (2010). Data that do not meet the specified data quality objectives are highlighted in the data tables below. The quality of the data reported for this project is judged to be acceptable.

Samples were analyzed by Ecology's Manchester Environmental Laboratory (MEL). They reported that all samples were received within the specified temperature range, properly preserved, and in good condition. The lab performed all analyses within the specified holding times. All instrumentation was calibrated and calibration verification checks were within the acceptance limits.

Field Replicates

Field replicates were collected at 17% of the sample sites. Table B.2 summarizes the QA data for the field duplicate results. Ammonia duplicates collected from surface water during the July 2012 sampling and the August 2012 sampling were the only duplicates that fell outside of the data MQOs. The difference in measurements was in the thousandths of mg/L. Using RPD as a statistical tool to measure QA is less precise when the results are so close to the detection limit. On this date all other QA goals were met.

Equipment Blanks

No analytically significant levels of analytes were detected in the equipment blanks. The equipment blank exhibited no indication of cross contamination. Results for all parameters were less than detection limits.

Laboratory Method Blanks

No analytically significant levels of analytes were detected in the laboratory method blanks.

Laboratory Control Samples

All laboratory control sample recoveries were within the acceptance limits.

Matrix Spikes and Matrix Spike Duplicates

The relative percent differences of samples with concentrations greater than 5 times the reporting limit were within the acceptance limits.

All matrix spike recoveries were within the acceptance limits *except* for the following instances:

- August 2010: The matrix spikes for calcium and sodium were outside of the acceptable range. The standard spiking level was insufficient for the elevated concentration in the source sample therefore the recoveries were not evaluated by the laboratory. The MSD for calcium and sodium were outside of acceptable range.
- July 2012: The matrix spike for sodium was outside of the acceptable range. The standard spiking level was insufficient for the elevated concentration in the source sample therefore

the recoveries were not evaluated by the laboratory. The matrix spike duplicate for calcium and sodium were outside the acceptable range.

- September 2012: The matrix spike recoveries were within the acceptance limits except for calcium and sodium. The standard spiking level was insufficient for the elevated concentration in the source sample therefore the recoveries were not evaluated by the laboratory. The matrix spike duplicate for calcium and sodium were outside of the acceptable range.

Other Quality Assurance Issues and Management

Calcium and Sodium

Matrix spike recoveries and matrix spike recovery duplicates exceeded laboratory QA performance standards. Therefore all of the calcium and sodium data were qualified and were not entered into EIM. This data was only used to evaluate ionic signatures of water.

Phosphorus

There were instances during each sampling event where the orthophosphate concentration exceeded the total phosphorus concentration. Since orthophosphate is a measure of the dissolved mobile fraction of phosphorus, only the orthophosphate values will be considered for the following dates and locations.

- August 2010. The orthophosphate concentration in the sample for monitoring well UG-1 was greater than the associated total phosphorus concentration.
- July 2012. The orthophosphate concentration in the sample for monitoring well DG-1 was greater than the total phosphorus concentration.
- September 2012. The orthophosphate concentrations in the samples from monitoring wells UG-1, DG-1, sample sites 2-GW and 4-GW, were greater than the associated total phosphorus concentrations.

In all instances where orthophosphate exceeded the total phosphorus concentration, these samples were collected from groundwater, and do not reflect any surface water conditions. Table B.1 statistically compares the differences measured between orthophosphate and total phosphorus for all groundwater and surface water samples collected.

Table B.1. Difference between Orthophosphate and Total Phosphorus Concentrations (mg/L).

Sample Date	Maximum difference	Minimum difference	Mean difference
August 2010	0.12	0.003	0.01191
July 2012	0.245	0.0004	0.01945
September 2012	0.0795	0.00085	0.00478

Table B.2. Duplicate samples and equipment blanks.

	Downgradient Monitoring Well			Hangman Creek Downgradient of WWTP			Equipment Blank
	DG-1	**DG-1**	**RPD**	**4 SW**	**4 SW**	**RPD**	
Parameter	**mg/L**	**mg/L**	**%**	**mg/L**	**mg/L**	**%**	**mg/L**
August 2010							
Nitrate + Nitrite	13.7	13.6	0.73	0.116	0.105	9.95	< 0.01
Ammonia	< 0.01	< 0.01	NA	< 0.01	0.018	NA	< 0.01
Total dissolved phosphorus	0.469	0.474	1.06	0.0594	0.0582	2.04	< 0.005
Orthophosphate	0.495	0.528	6.45	0.0491	0.0495	0.81	< 0.003
Dissolved Organic Carbon	1.6	1.6	0.00	3.2	3.5	8.96	< 1.0
Total Dissolved Solids	643	644	0.16	212	211	0.47	< 10
Chloride	148	147	0.68	8.37	8.26	1.32	< 0.1
Bromide	< 0.20	< 0.20	NA	< 0.20	< 0.20	NA	< 0.20
Boron	0.292	0.289	1.03	< 0.05	< 0.05	NA	< 0.05
Iron	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Manganese	< 0.01	< 0.01	NA	0.024	0.024	0.00	< 0.01
Calcium	85.8	87	1.39	36.6	35.5	3.05	< 0.05
Magnesium	18.8	19.5	3.66	13.2	13.9	5.17	< 0.05
Potassium	10.2	9.87	3.29	4.35	4.31	0.92	< 0.5
Sodium	92.4	88.5	4.31	18.1	17.8	1.67	< 0.05
Sulfate	32.2	32.3	0.31	10.4	10.6	1.90	< 0.3
Bicarbonate	220	220	0.00	152	153	0.66	< 5
Alkalinity	220	220	0.00	152	153	0.66	< 5
	Downgradient Monitoring Well			**Hangman Creek at Golf Course**			**Equipment Blank**
	DG-1	**DG-1**	**RPD**	**2 SW**	**2 SW**	**RPD**	
Parameter	**mg/L**	**mg/L**	**%**	**mg/L**	**mg/L**	**%**	**mg/L**
July 2012							
Nitrate + Nitrite	5.7	5.49	3.75	0.845	0.841	0.47	< 0.01

Ammonia	0.01	0.01	0.00	0.01	0.015	40.00	< 0.01
Total dissolved phosphorus	0.248	0.249	0.40	0.0459	0.0469	2.16	< 0.005
Orthophosphate	0.263	0.248	5.87	0.0415	0.0415	0.00	< 0.003
Dissolved Organic Carbon	1.9	1.9	0.00	4.5	4.6	2.20	1.4
Total Dissolved Solids	522	519	0.58	174	176	1.14	< 5
Chloride	96.8	97.2	0.41	4.74	4.7	0.85	< 0.1
Bromide	0.036	0.036	0.00	0.025	0.025	0.00	< 0.025
Boron	0.17	0.168	1.18	0.025	0.025	0.00	< 0.025
Iron	0.025	0.025	0.00	0.025	0.025	0.00	< 0.025
Manganese	0.005	0.005	0.00	0.051	0.048	6.06	< 0.005
Calcium	61.3	61	0.49	26.8	25	6.95	0.048
Magnesium	14.7	14.7	0.00	8.85	8.36	5.69	< 0.025
Potassium	5.83	5.84	0.17	2.84	2.63	7.68	< 0.25
Sodium	88.8	87.1	1.93	11.2	10.7	4.57	0.143
Sulfate	17.2	17.1	0.58	9.26	9.3	0.43	< 0.3
Bicarbonate	260	264	1.53	113	114	0.88	< 5
Alkalinity	260	264	1.53	113	114	0.88	< 5
September 2012							
Nitrate + Nitrite	5.43	5.62	3.75	0.198	0.196	1.02	< 0.01
Ammonia	0.01	0.01	0.00	0.02	0.025	22.22	< 0.01
Total dissolved phosphorus	0.343	0.345	0.40	0.041	0.0411	0.24	< 0.005
Orthophosphate	0.422	0.425	5.87	0.0418	0.0386	7.96	< 0.003
Dissolved Organic Carbon	1.9	1.8	0.00	3.1	3.2	3.17	1.2
Total Dissolved Solids	564	563	0.58	209	210	0.48	< 5
Chloride	109	109	0.41	5.77	5.75	0.35	< 0.1
Bromide	0.034	0.031	0.00	0.027	0.025	7.69	< 0.025
Boron	0.178	0.181	1.18	0.025	0.025	0.00	< 0.025
Iron	0.025	0.025	0.00	0.025	0.025	0.00	< 0.025
Manganese	0.005	0.005	0.00	0.025	0.024	4.08	< 0.005
Calcium	70.7	71.8	0.49	35.9	35.5	1.12	0.047

Magnesium	14.8	15.2	0.00	12.6	12.5	0.80	< 0.025
Potassium	7.07	7.34	0.17	3.4	3.38	0.59	< 0.25
Sodium	99.3	98.6	1.93	15	14.8	1.34	0.15
Sulfate	17.4	17.5	0.58	11.8	11.8	0.00	< 0.3
Bicarbonate	295	291	1.53	154	154	0.00	< 5
Alkalinity	295	291	1.53	164	165	0.61	< 5

Shading = duplicate exceeds measurement quality objectives (MQOs)

Table B.3. Laboratory Quality Assurance Data

		Matrix Spike Duplicate		LCS		
Date Collected	Parameter	% Recovery	RPD	Control Samples	Matrix Spikes	Blank
		(+/- 25%)	(+/- 20%)	(+/- 15%)	(+/- 25%)	
Aug-10	Boron	97	0.4	96	97	<
Aug-10	Boron	101	1		102	
Aug-10	Calcium	71	1	104	62	<
Aug-10	Calcium	109	0.2		109	
Aug-10	Calcium	49	1	103	72	<
Aug-10	Iron	103	0.1	104	103	<
Aug-10	Iron	106	0.2		106	
Aug-10	Iron	99	2	100	101	<
Aug-10	Potassium	99	0.8	99	97	<
Aug-10	Potassium	102	0.8		102	
Aug-10	Potassium	102	0.8	101	105	<
Aug-10	Magnesium	96	0.7	99	97	<
Aug-10	Magnesium	98	0.1		99	
Aug-10	Magnesium	99	1	101	102	<
Aug-10	Magnesium	104	0.7		103	
Aug-10	Manganese	98	2	100	99	<
Aug-10	Manganese	101	0.2	103	101	<
Aug-10	Manganese	105	0.05		105	
Aug-10	Sodium	74	0	99	74	<
Aug-10	Sodium	100	0.3		99	
Aug-10	Sodium	56		100	59	<
Aug-10	Alkalinity		0.7	101		<
Aug-10	Alkalinity					
Aug-10	Bicarbonate					<
Aug-10	Chloride		1	102	102	<
Aug-10	Chloride				97	
Aug-10	Chloride		0.5	100	98	<
Aug-10	Chloride				97	
Aug-10	Chloride		8	100		<
Aug-10	Chloride				99	
Aug-10	Chloride				100	
Aug-10	DOC		U	94	91	<
Aug-10	DOC		1	102	101	<
Aug-10	Nitrite/Nitrate		5	102	93	<
Aug-10	Orthophosphate		0.9	94	101	<
Aug-10	Orthophosphate		6	93	91	<

		Matrix Spike Duplicate		LCS		
Date Collected	Parameter	% Recovery	RPD	Control Samples	Matrix Spikes	Blank
		(+/- 25%)	(+/- 20%)	(+/- 15%)	(+/- 25%)	
Aug-10	Sulfate		2	103	105	<
Aug-10	Sulfate				98	
Aug-10	Sulfate		0.9	100	99	<
Aug-10	Sulfate				99	
Aug-10	TDS		0	102		<
Aug-10	TDS		1			
Aug-10	TDS		2			
Aug-10	Total Phosphorus		U	95		<
Aug-10	Bromide		U	102	104	<
Aug-10	Bromide				102	
Aug-10	Bromide		U	99	102	<
Aug-10	Bromide				101	
Aug-10	Ammonia		U	90	104	<
Jul-12	Boron	94	6	101	101	<
Jul-12	Boron	97	2		99	
Jul-12	Calcium	95	3	101	162	<
Jul-12	Calcium	94	3		98	
Jul-12	Iron	91	6	101	97	<
Jul-12	Iron	97	2		99	
Jul-12	Potassium	99	3	103	108	<
Jul-12	Potassium	96	4		102	
Jul-12	Magnesium	92	3	98	111	<
Jul-12	Magnesium	94	2		97	
Jul-12	Manganese	91	5	101	96	<
Jul-12	Manganese	96	3		99	
Jul-12	Sodium	104	3	103	172	<
Jul-12	Sodium	96	4		102	
Jul-12	Nitrite/Nitrate	U		106	92	<
Jul-12	Alkalinity		0.4	85		<
Jul-12	Alkalinity		0.5	104		<
Jul-12	Bicarbonate		0.4	U		<
Jul-12	Bicarbonate		U	U		<
Jul-12	Bromide		4	101	106	<
Jul-12	Bromide				98	
Jul-12	Chloride		1	102	96	<
Jul-12	Chloride				95	
Jul-12	DOC			98		<

		Matrix Spike Duplicate		LCS		
Date Collected	Parameter	% Recovery	RPD	Control Samples	Matrix Spikes	Blank
		(+/- 25%)	(+/- 20%)	(+/- 15%)	(+/- 25%)	
Jul-12	DOC			98		
Jul-12	DOC			98		<
Jul-12	DOC			98		
Jul-12	Ammonia		0.6	99	94	<
Jul-12	Orthophosphate		U	100	96	<
Jul-12	Orthophosphate		2	98	97	<
Jul-12	Sulfate		0.2	98	99	<
Jul-12	Sulfate				101	
Jul-12	TDS		1	104		<
Jul-12	TDS		2			<
Jul-12	Total Phosphorus		2	99	97	<
Sep-12	Boron	99	0.2	98	99	<
Sep-12	Sodium	70	3	102	92	<
Sep-12	Calcium	35	2	101	75	<
Sep-12	Iron	99	0.6	102	100	<
Sep-12	Potassium	91	3	100	99	<
Sep-12	Magnesium	76	2	100	89	<
Sep-12	Manganese	98	0.4	102	98	<
Sep-12	Alkalinity		0.5	91		<
Sep-12	Bicarbonate		0.09	U		<
Sep-12	Bromide		9	97	103	<
Sep-12	Bromide				100	
Sep-12	Chloride		0.03	101	100	<
Sep-12	Chloride				100	
Sep-12	Chloride		3	101	98	<
Sep-12	Chloride				98	
Sep-12	Chloride		0.4	99	97	<
Sep-12	Chloride				96	
Sep-12	DOC			99		<
Sep-12	DOC			99		
Sep-12	DOC			101		<
Sep-12	DOC			101		
Sep-12	Ammonia		0.4	97	94	<
Sep-12	Nitrite/Nitrate		7	108	105	<
Sep-12	Orthophosphate		0.02	106	104	<
Sep-12	Orthophosphate		12	101	101	<
Sep-12	Total Phosphorus		2	97	97	<

		Matrix Spike Duplicate		LCS		
Date Collected	Parameter	% Recovery	RPD	Control Samples	Matrix Spikes	Blank
		(+/- 25%)	(+/- 20%)	(+/- 15%)	(+/- 25%)	
Sep-12	Total Phosphorus		6	98	98	<
Sep-12	Sulfate		0.4	104	101	<
Sep-12	Sulfate				101	
Sep-12	Sulfate		0.2	100	101	<
Sep-12	Sulfate				99	
Sep-12	TDS		0.6	104		<
Sep-12	TDS					<
Sep-12	TDS		0.5	107		<
Sep-12	TDS					<

Highlighted data indicates data quality standards were not met.

Appendix C. Monitoring Well Construction Information and Well Logs

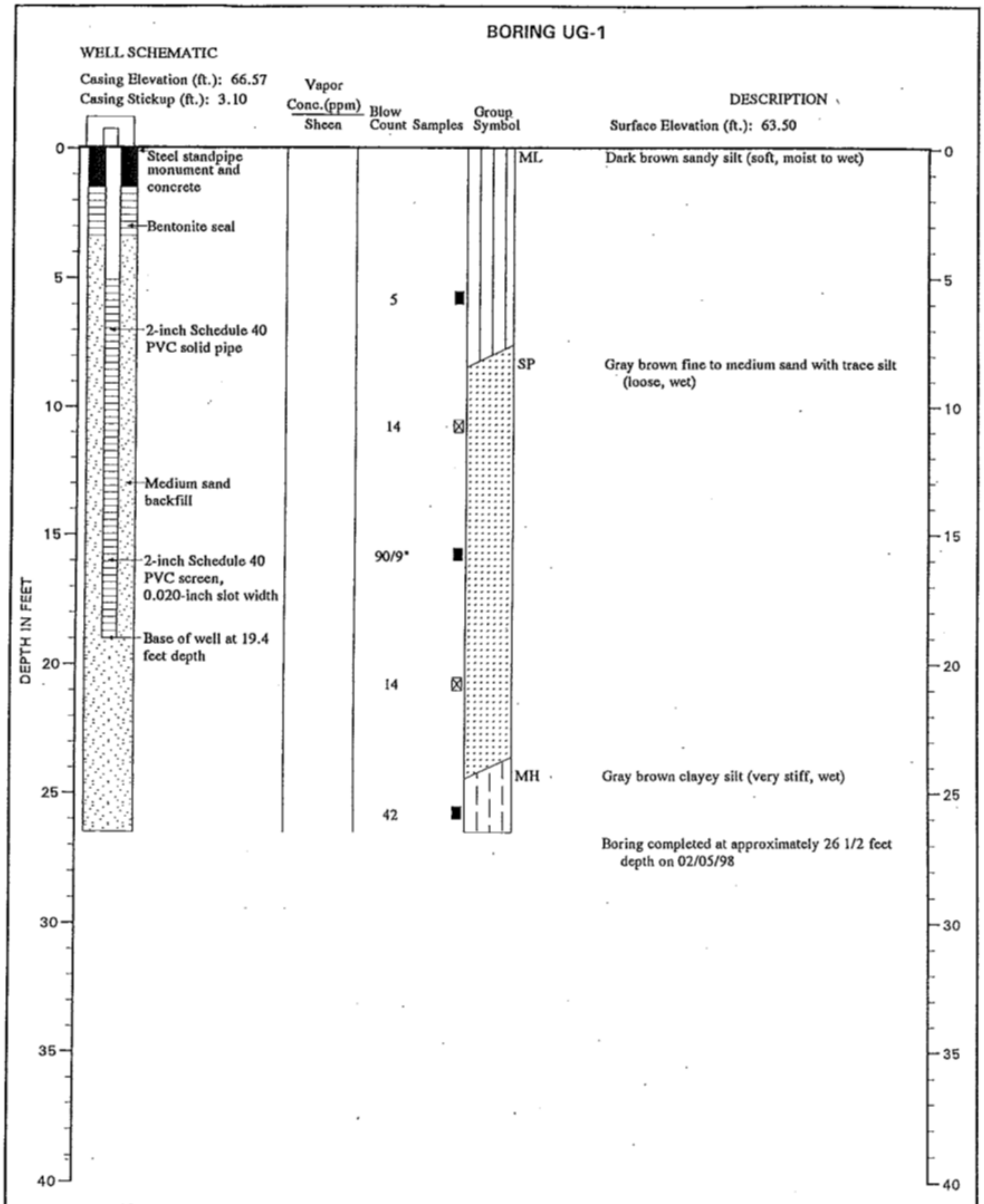
Table C.1. Monitoring well location and construction information

Well ID	Well Tag	Latitude	Longitude	Top of Casing Elevation	Well Depth	Open Interval (feet)	
		decimal degrees	decimal degrees	feet	feet	upper	lower
UG-1	ABI423	47.549829	-117.371716	1876.629	19.4	5	19.4
UG-2	BBH655	47.550096	-117.37014	1913.358	64	33.5	63.5
DG-1	ABI422	47.55139	-117.370643	1883.019	30.5	10	29.5
DG-2	ABI424	47.550596	-117.371625	1876.706	25.2	4.2	25.2

Well Logs

Well logs for monitoring wells UG-1, UG-2, DG-1, and DG-2 are presented below.

BORING UG-1



Note: See Figure A- 2 for explanation of symbols

BWB:GHS:dlw: 2/27/98

0188-033-00

NHMW40

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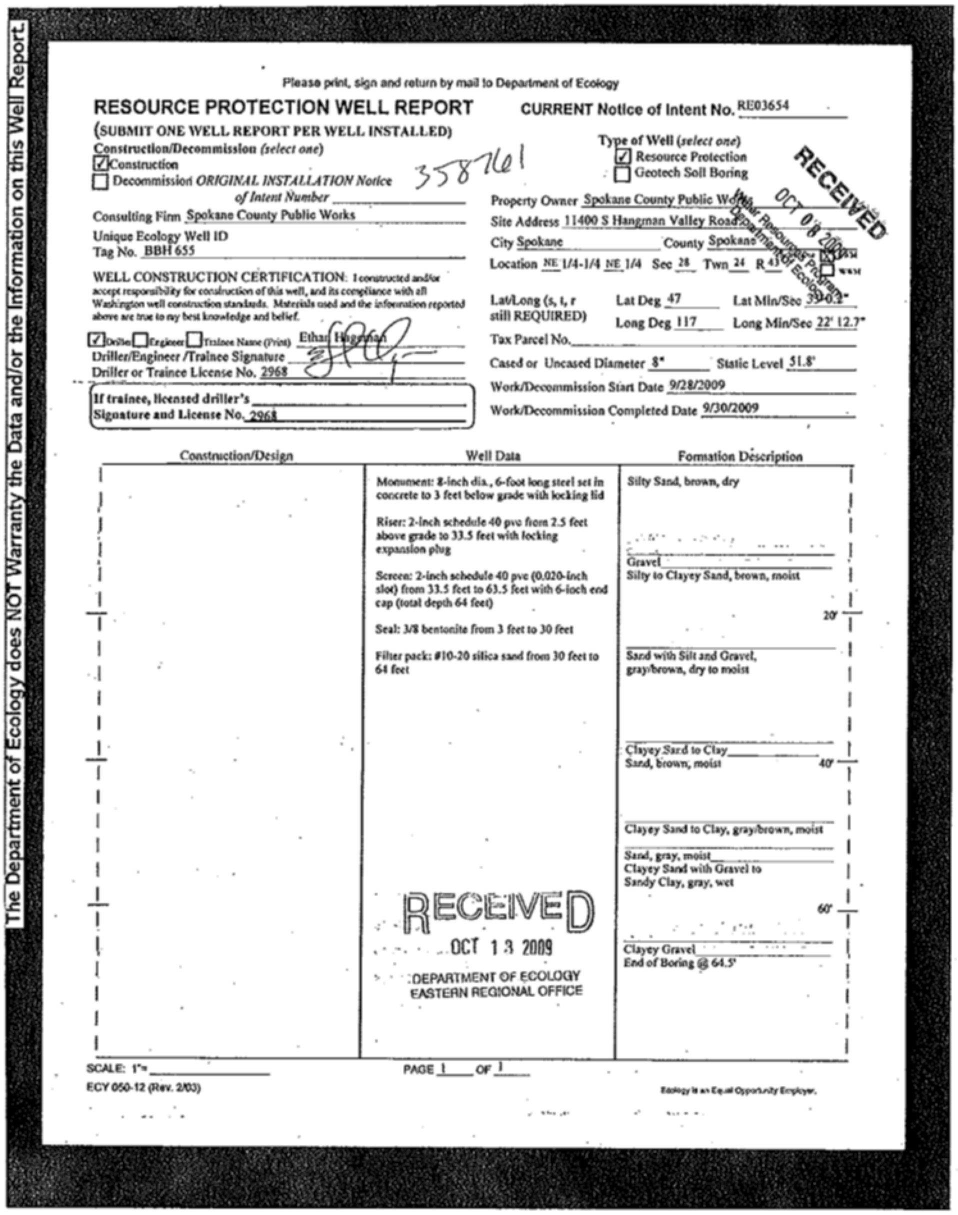
LOG OF BORING

FIGURE A-5



The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

Please print, sign and return by mail to Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. RE03654

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *(select one)*
☑ Construction
☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

358761

Type of Well *(select one)*
☑ Resource Protection
☐ Geotech Soil Boring

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Water Resources Program
Department of Ecology

Consulting Firm Spokane County Public Works
Unique Ecology Well ID Tag No. BBH 655

Property Owner Spokane County Public Works
Site Address 11400 S Hangman Valley Road
City Spokane County Spokane
Location NE 1/4-1/4 NE 1/4 Sec 28 Twn 24 R 43 ☒ EWM ☐ WWM

Lat/Long (s, t, r still REQUIRED) Lat Deg 47 Lat Min/Sec 39'0.2" Long Deg 117 Long Min/Sec 22' 12.7"
Tax Parcel No. ______
Cased or Uncased Diameter 8" Static Level 51.8'
Work/Decommission Start Date 9/28/2009
Work/Decommission Completed Date 9/30/2009

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☑ Driller ☐ Engineer ☐ Trainee Name (Print) Ethan Hagerman
Driller/Engineer /Trainee Signature ______
Driller or Trainee License No. 2968

If trainee, licensed driller's Signature and License No. 2968

Construction/Design	Well Data	Formation Description
	Monument: 8-inch dia., 6-foot long steel set in concrete to 3 feet below grade with locking lid	Silty Sand, brown, dry
	Riser: 2-inch schedule 40 pvc from 2.5 feet above grade to 33.5 feet with locking expansion plug	Gravel
	Screen: 2-inch schedule 40 pvc (0.020-inch slot) from 33.5 feet to 63.5 feet with 6-inch end cap (total depth 64 feet)	Silty to Clayey Sand, brown, moist
	Seal: 3/8 bentonite from 3 feet to 30 feet	20'
	Filter pack: #10-20 silica sand from 30 feet to 64 feet	Sand with Silt and Gravel, gray/brown, dry to moist
		Clayey Sand to Clay
		Sand, brown, moist 40'
		Clayey Sand to Clay, gray/brown, moist
		Sand, gray, moist
		Clayey Sand with Gravel to Sandy Clay, gray, wet
		60'
		Clayey Gravel
		End of Boring @ 64.5'

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EASTERN REGIONAL OFFICE

SCALE: 1"= ______ PAGE 1 OF 1

ECY 050-12 (Rev. 2/03)

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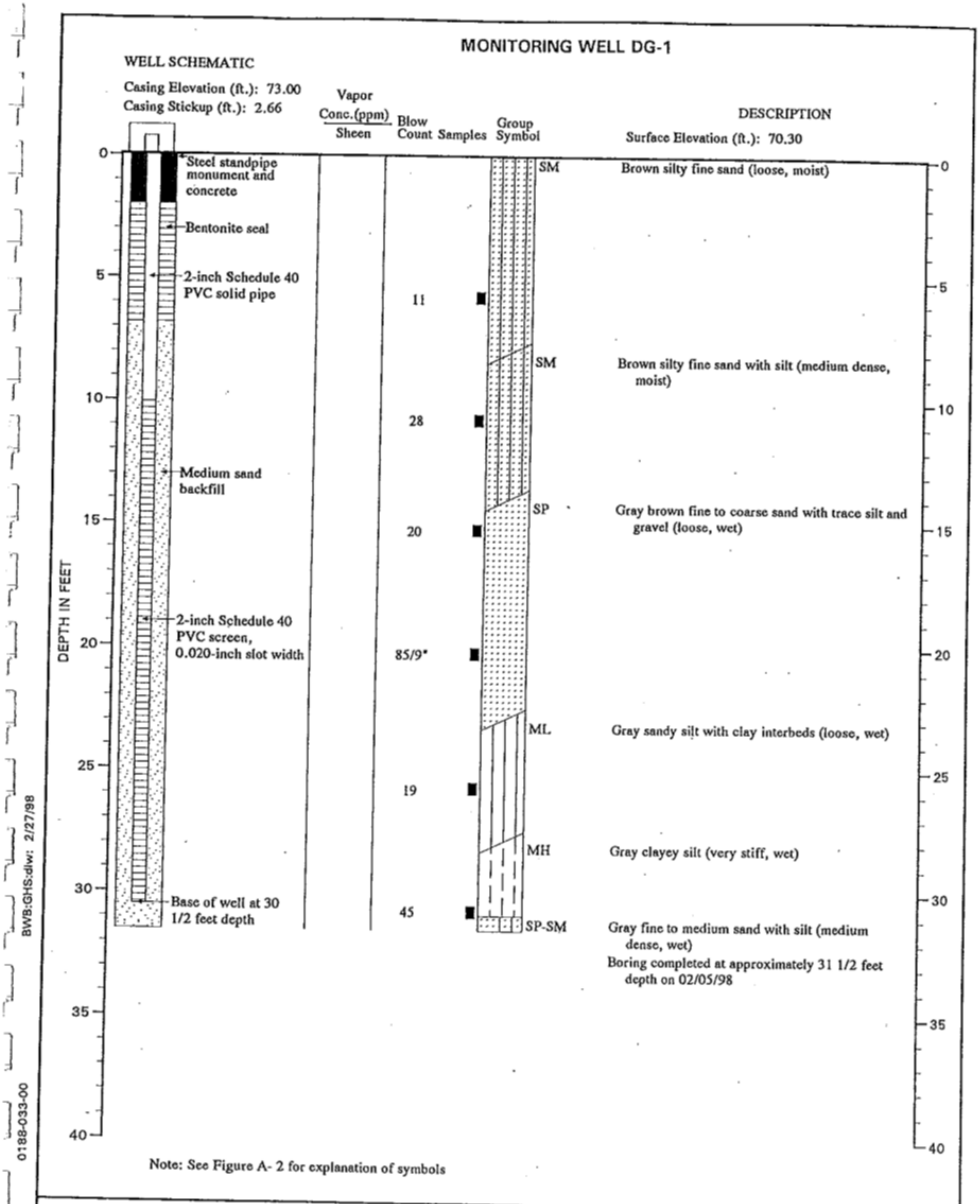

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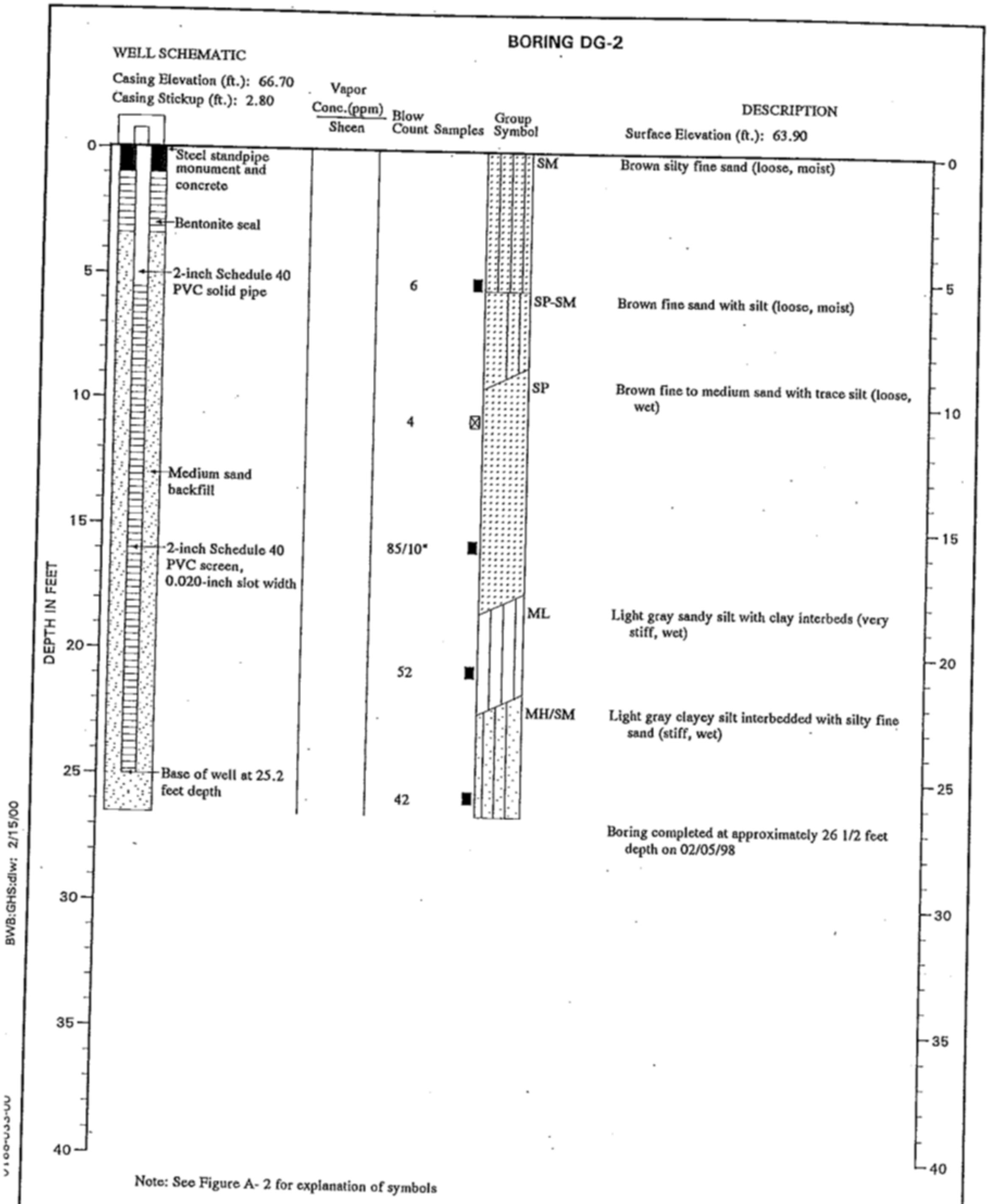
LOG OF MONITORING WELL

FIGURE A-3

BORING DG-2



DESCRIPTION

Surface Elevation (ft.): 63.90

Group Symbol	Description
SM	Brown silty fine sand (loose, moist)
SP-SM	Brown fine sand with silt (loose, moist)
SP	Brown fine to medium sand with trace silt (loose, wet)
ML	Light gray sandy silt with clay interbeds (very stiff, wet)
MH/SM	Light gray clayey silt interbedded with silty fine sand (stiff, wet)

Boring completed at approximately 26 1/2 feet depth on 02/05/98

Note: See Figure A- 2 for explanation of symbols

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LOG OF BORING

FIGURE A-4

Appendix D. Chloride/Bromide Ratios

Calculating the ratio of chloride concentrations to bromide concentrations is an established tool to assist in identifying sources. Figure D.1 was developed by consolidating published research observations. Ranges in chloride concentrations for different products and sources are identified. This tool can be used in conjunction with other information and analyses as an indicator parameter. (Davis et al., 1998; Vengosh and Pankratov, 1998)

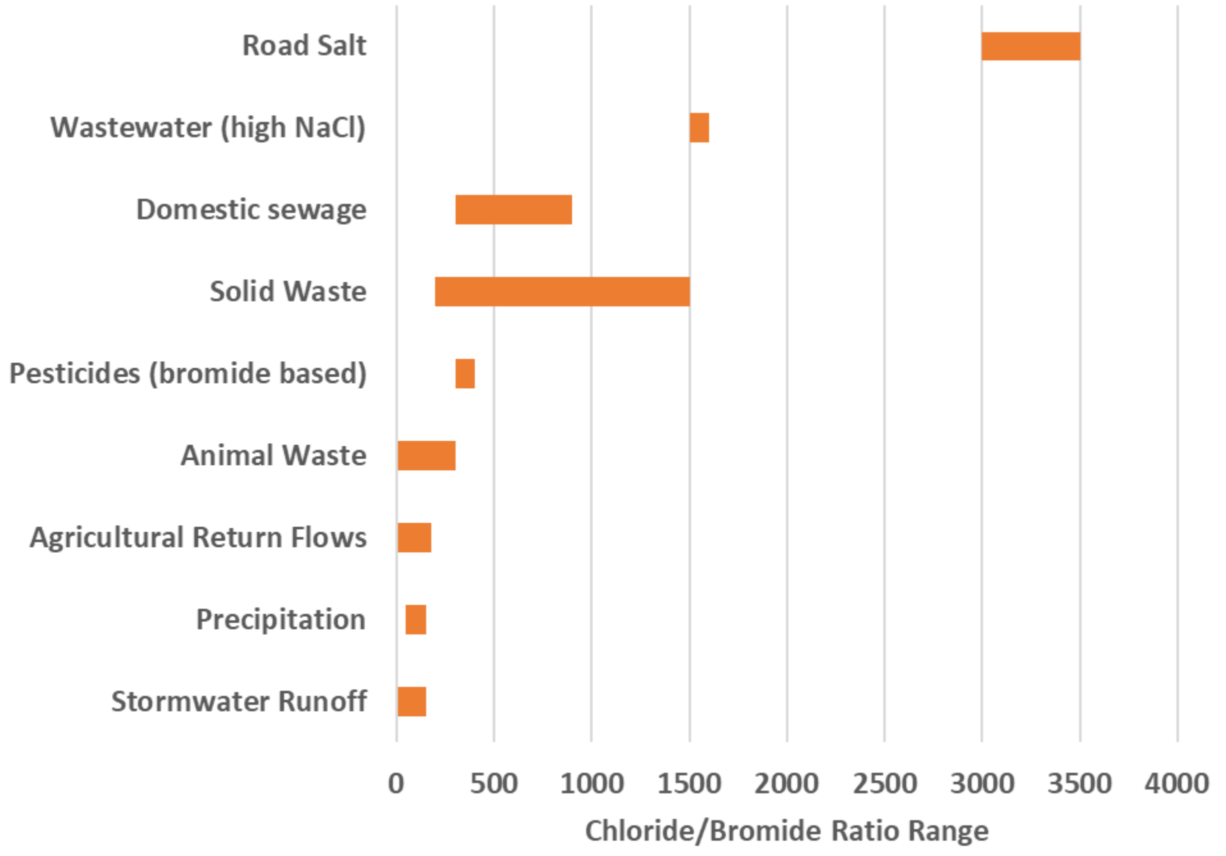

Figure D.1. Chloride/Bromide Ratio Source Ranges

The chloride/bromide ratios measured during this study are plotted in Figures D.2 and D.3. These are a ratio of the concentrations of the ions.

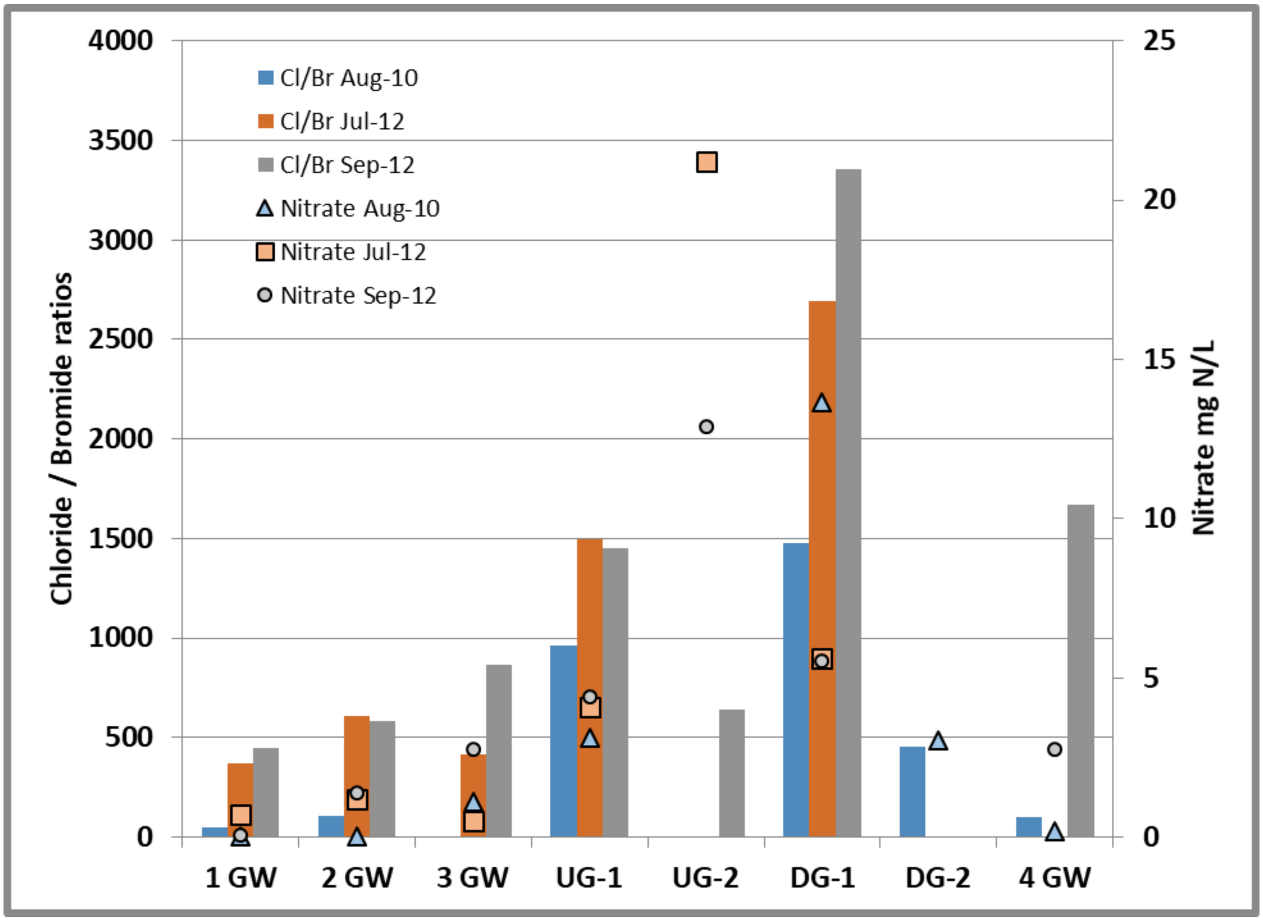

Figure D.2. Chloride/Bromide Ratios with Nitrate Concentrations for Groundwater Sites

Chloride/bromide ratios are indicators of sources based on the range of the ratio. High ratios are not indicative of contamination, they are indicative of a different source in relation to a low ratio. Figure D.2 combines the chloride/bromide ratios along with the nitrate concentration for each sampling event at each groundwater site.

There were no consistent chloride/ bromide ratios for the groundwater sites. Each site has variability between each sampling event.

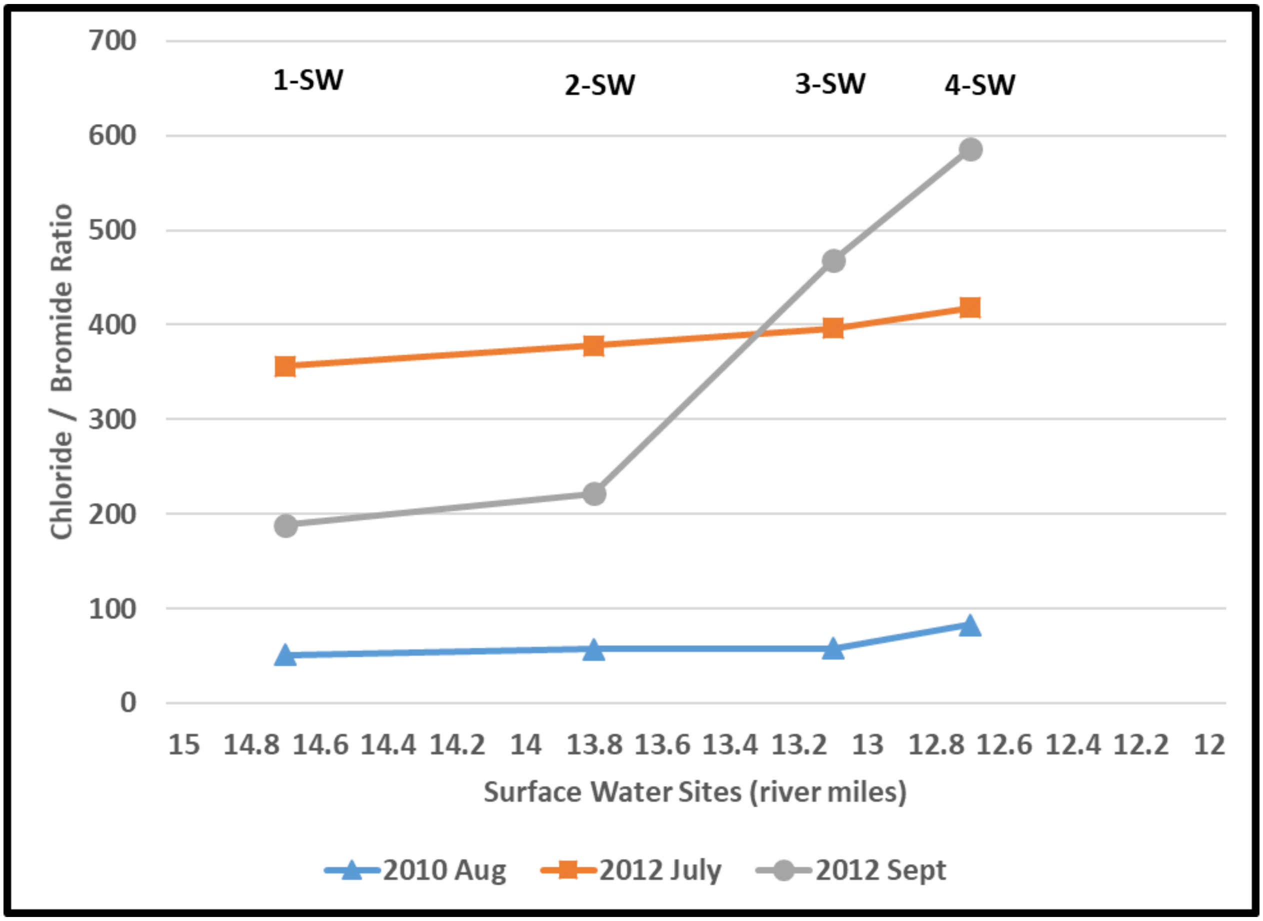

Figure D.3. Chloride/Bromide Ratios for Surface Water

The chloride/bromide ratios in surface water were different during each sampling event (Figure D.3). In August 2010, all surface water sites range from 51 to 83. This is indicative of precipitation or stormwater runoff, with animal waste or agricultural return flows also possible. In July 2012, these same surface water sites had chloride/bromide ratios that ranged from 356 to 418. These ratios are indicative of domestic sewage, or solid waste. In September 2012, the chloride/bromide ratios varied upstream (189) to downstream (586). It appears from this data that surface water is influenced by a different source near the WWTP than upstream locations. The ratios indicate upstream could be influenced by animal waste or agricultural return flows. While near the WWTP surface water could be influenced by domestic sewage, or solid waste.

It is important to note that chloride/bromide ratios are indicators which should be used with other information to determine sources. Since the chloride/bromide ratios were not consistent at any surface water sites during the three sampling events, this tool may be sensitive to streamflows when assessing sources.

Appendix E. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

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.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

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

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.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

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

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

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.

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

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riparian: Relating to the banks along a natural course of water.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

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.

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

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

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

CRBG	Columbia River Basalt Group
DO	Dissolved oxygen
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database

EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
NPDES	(See Glossary above)
QA	Quality assurance
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
STP	Sewage treatment plant
TMDL	(See Glossary above)
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
m	meter
mg	milligram
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
s.u.	standard units
um	micrometer
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity