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Sumas-Blaine Aquifer Long-Term Groundwater Quality Monitoring Network

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Sumas-Blaine Aquifer Long-Term Groundwater Quality Monitoring Network

2009 Annual Report

by
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Table of Contents

Page

List of Figures and Tables....4

Abstract....5

Acknowledgements....6

Introduction....7
  Purpose....7
  Background....8
  Nitrate....10

Geology....13
  Hydrogeology of the Sumas-Blaine Aquifer....13
    Groundwater Flow and Recharge....14

Methods....15
  Sampling and Analysis....15
    Laboratory Methods....17
    Field Methods....17
    Filtered Sample Comparison....18
  Quality Assurance....18

Results....19

Discussion....23
  Nitrate....23
  Chloride and Bromide....23
  Filtered vs. Unfiltered Samples....24

Conclusions....25
  Groundwater Contamination....25
  Filtered Samples....25

Recommendations....26

References....27

Appendices....31
  Appendix A: Quality Assurance Results....33
  Appendix B: Glossary, Acronyms, and Abbreviations....37

List of Figures and Tables

Page

Figures

Figure 1. Map of the Sumas-Blaine Aquifer. 9

Figure 2. Nitrate Concentrations in Wells, 2009. 22

Tables

Table 1. Well Sampling Information. 16

Table 2. Groundwater Quality Results, 2009. 19

Table 3. Statistical Summary of Groundwater Quality Parameters, 2009. 20

Table 4. Results for Field Parameters, 2009. 21

Table 5. Comparison of Filtered Samples with Unfiltered Samples. 24

Abstract

The Sumas-Blaine Aquifer is the primary drinking water source for the majority of residents in northern Whatcom County, and it has been identified as one of the most severely contaminated aquifers in Washington State. The groundwater is contaminated with elevated concentrations of nitrate which exceed (do not meet) the drinking water standard and have been increasing over the last 20 years. Whatcom County is abundant in agricultural activities, including dairy operations, raspberry farms, and other irrigated agriculture.

The Washington State Department of Ecology (Ecology) established a groundwater monitoring network in the Sumas-Blaine Aquifer to study long-term groundwater quality and nitrate concentration trends.

This present 2009 study was designed to build on previous monitoring efforts in order to provide an annual assessment of the status of the groundwater quality. This report is an annual assessment of data quality assurance with the focus on presenting the data. A more detailed data assessment will be reported every three years. This project will continue as long as groundwater remains contaminated and as long as funding is available.

Ecology conducted sampling for this annual study in March 2009. Twenty-seven wells were sampled for nitrate-nitrogen, chloride, and bromide. A total of 41% of the wells sampled contained nitrate concentrations exceeding the drinking water standard of 10 mg N/L. The mean nitrate concentration was 10.12 mg/L, and the maximum nitrate concentration was 28 mg/L.

This annual data summary highlights that the Sumas-Blaine Aquifer remains contaminated with elevated nitrate concentrations. Ecology recommends that annual groundwater monitoring of this network of wells continue.

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Introduction

The Sumas-Blaine Aquifer, located in northern Whatcom County, is the primary drinking water source for residents, and it was identified as one of the most severely contaminated aquifers in Washington State (Erickson, 2000). This aquifer is vulnerable to contamination due to permeable soils, a shallow water table, and high hydraulic conductivity, with historic and continued agricultural land use.

Groundwater contamination has been documented in numerous studies that found elevated nitrate and pesticide concentrations: Obert, 1973; Erickson and Norton, 1990; Garland and Erickson, 1994; Erickson, 1998; Cox and Kahle, 1999; Cox and Liebscher, 1999; Erickson, 2000; Mitchell et al., 2000; Carey, 2002; Mitchell et al., 2005; O'Herron, 1999; and Redding, 2008. These studies indicate that nitrate in the Sumas-Blaine Aquifer has been a persistent problem for more than 40 years, with nitrate concentrations as high as 98 mg/L.

Historically, nitrate concentrations in the Sumas-Blaine Aquifer have been increasing at a rate of approximately 0.5 mg/L per year. In a recent investigation, 71% of the wells sampled had at least one concentration higher than the groundwater quality nitrate standard of 10 mg N/L, and 31% of the wells displayed a statistically increasing nitrate trend over the two-year sampling period, March 2003 to March 2005. Nitrate concentrations ranged from 0.01 to 43 mg/L in the aquifer. (Redding, 2008).

Purpose

The purpose of this project is to implement long-term ambient groundwater monitoring in the Sumas-Blaine Aquifer to monitor water quality trends in the aquifer over time. This report is an annual (2009) assessment of data quality assurance with the focus on presenting the data. A more detailed data assessment will be reported every three years.

An *ambient monitoring program* refers to long-term regional monitoring at fixed stations. An ambient monitoring network can be used to characterize the groundwater quality or quantity, identify new problems, and evaluate the effectiveness of activities over a large area (Carey, 1987). The United States Geological Survey (USGS) uses ambient groundwater monitoring to identify risks to groundwater resources, characterize constituents of concern, and identify trends. The parameters monitored are specific to the area of concern and the activities which have a potential to impact groundwater quality. (Kulongoski and Belitz, 2004)

This localized ambient monitoring project is intended to characterize groundwater nitrate concentration trends. This project continues the nitrate trend assessment in the Sumas-Blaine Aquifer which began in 2003 (Redding, 2008). Groundwater wells will be sampled every year in March beginning in 2009 and continuing as long as groundwater contamination is an issue and as long as funding and interest are available. Data from this long-term monitoring project will provide a basis for judging if current efforts for protecting groundwater are adequate and if additional protection measures are necessary. This information can be used to make informed water resource management decisions and develop pollution prevention strategies.

The primary focus of this project is nitrates; however, the parameters monitored could change as needed in the future. Nitrate is one of the most prevalent groundwater contaminants, and it is also an indicator of general water quality conditions. Agricultural activities are the predominant source of nitrogen loading in the area, including dairy farms, land application of manure, irrigated agriculture, and poultry operations (Almasri and Kaluarachchi, 2003). Other nitrogen sources in the region include on-site sewage systems, residential lawn and garden fertilizer use, and municipal biosolids application. All of these sources have a potential to contaminate groundwater, but the predominance of agricultural activities in the area suggests they may be a primary source of nitrate.

Background

The Sumas-Blaine Aquifer is the principal aquifer in the Nooksack watershed in northwestern Whatcom County. The aquifer extends over 150 square miles and is the primary drinking water source for area residents. Over 100,000 people residing over this aquifer, both within the United States and Canada, rely on groundwater as their drinking water source (Mitchell, 2000).

The study area consists of the central portion of the Sumas-Blaine Aquifer. Chronic groundwater contamination has been documented in this area. The aquifer is located northwest of Bellingham, Washington, and encompasses an area of approximately 80 square miles, with the town of Lynden situated at the center of the study area. The study area is bounded by Tenmile Creek to the south, the Canadian border to the north, Bertrand Creek and South Fork Dakota Creek to the west, and the town of Sumas to the east. Figure 1 illustrates the location of the Sumas-Blaine Aquifer.

The aquifer is comprised mainly of permeable sand and gravel glacial outwash deposits, as well as alluvial deposits from the Nooksack and Sumas Rivers. The aquifer is largely unconfined and shallow, with depths to water commonly less than 10 feet below land surface. These hydrogeologic characteristics create an aquifer which is highly susceptible to contamination from surface activities.

Agriculture is the predominant land use overlying the aquifer, and the density of dairies is among the highest in the state (Erickson, 2000). Whatcom County is also one of the nation’s leading producers of raspberries. Currently the main land uses are agriculture and residential (Cox and Kahle, 1999).

Agriculture is also the predominant land use north of the study area in British Columbia, Canada. British Columbia has a high concentration of poultry farms, raspberry fields, and dairies. All of these activities result in large inputs of nitrogen into the soils. In British Columbia 60% of their poultry industry is near the international border region (Cox and Kahle, 1999). The BC Ministry of Agriculture and Food acknowledge that agricultural activities are a significant contributor to the high nitrate concentrations in the surficial aquifer (Hughes-Games and Zebarth, 1999).

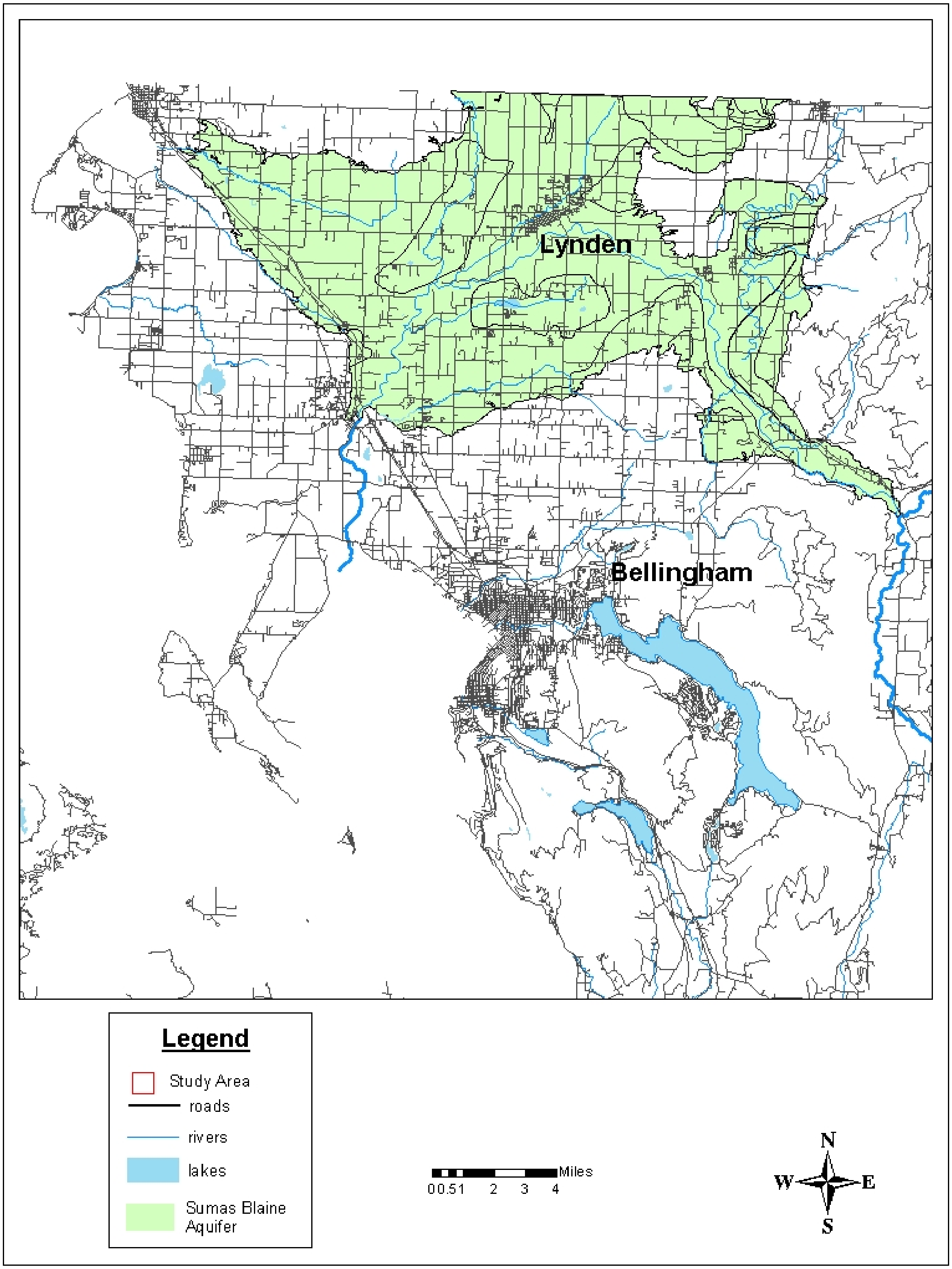

Figure 1. Map of the Sumas-Blaine Aquifer.

The following factors make it difficult to discern where the sources of nitrate originate:

- High nitrogen inputs into the environment in British Columbia and Whatcom County.
- Southern groundwater flow across the international border from British Columbia into Whatcom County.
- Complex geology.
- Nitrogen transformations in the subsurface.
- Lag time between when improvements are made at the land surface and when improvements are observed in groundwater.

These compounding factors make it difficult to observe whether improvements to farming practices translate into improvements in water quality. Mitchell (2005) attempted to correlate land use with nitrate concentrations in groundwater but found that the Canadian contribution confounded the issue and made it difficult to determine a cause-and-effect relationship.

Previous investigations have theorized that the elevated nitrate concentrations in groundwater are the result of agricultural activities, excessive nutrients in the soils, and contributions from British Columbia (Cox and Kahle, 1999; Mitchell et al., 2005; Erickson, 2000; Hughes-Games and Zebarth, 1999). The Nitrate Trends Study determined that nitrate concentrations in groundwater are increasing (Redding, 2008).

Nitrate

Nitrate concentrations above the 10 mg N/L drinking water standard can pose an environmental and public health threat. Elevated nitrate concentrations can cause *methemoglobinemia* in infants. Methemoglobinemia affects infants by converting the nitrate to nitrite in their digestive system. The nitrite reacts with the oxyhemoglobin to bind the available oxygen contained in the blood, depriving the infant of oxygen. Methemoglobinemia is also called *blue baby syndrome* since the child often turns a bluish color from a lack of oxygen. (Washington State Department of Health, 2004).

Consuming water with elevated nitrates can also pose a health risk to pregnant women and people with digestive problems, such as not having enough stomach acid, or the lack of an enzyme which converts red blood cells back to normal (Washington State Department of Health, 2004). There is also a concern that excessive ingestion of nitrate could cause cancer in adults (Plumb and Morrisett, 1988).

The Washington State drinking water standard, the Federal drinking water maximum contaminant level (MCL), the Guidelines for Canadian Drinking Water Quality, and the Washington State Ground Water Quality Standard for nitrate are all 10 mg N/L (Chapter 246-290 WAC; Title 40 CFR Part 141 Subpart B; Health Canada, 1996; Chapter 173-200 WAC).

Nitrogen is a common element in the environment. It is a by-product of animal waste, human waste, plant decomposition, and atmospheric deposition. It is also manufactured as a commercial fertilizer.

Since nitrate is prevalent in the environment and is the most common groundwater contaminant, it is often used as an indicator of general groundwater quality and to indicate anthropogenic impacts on water quality.

Nitrate is an excellent indicator parameter of the vulnerability of groundwater since nitrate is soluble, mobile, and basically non-reactive, and denitrification only occurs in anaerobic zones (Cohen et al., 1984). If elevated nitrate concentrations are present in groundwater, it likely originates from a source which contains other associated contaminants such as metals, pesticides, or other organic chemicals or pathogens (Driscoll, 1986). The relationship between the presence of nitrate and other anthropogenic contaminants is well documented (Burkart and Kolpin, 1993; Baker et al., 1994; Cox and Kahle, 1999).

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Geology

The Sumas-Blaine Aquifer study area lies within the Fraser-Whatcom Lowlands, which were formed within part of the Georgia Basin. The Georgia Basin is a large depression that extends from land and into the marine waters; it was created during the Mesozoic Era by tectonic activity. This tectonic activity also formed the Cascade Mountains and portions of the Pacific coastline (Easterbrook, 1971).

Within the study area, the Fraser Glaciation had several advances and retreats. With each of these movements, another series of glacial sediments were deposited. There were three main stages of glacial advances and retreats; the oldest is the Vashon Stade, then the Everson Interstade, and then the youngest Sumas Stade. The combined glacial deposits range between 0 to 1500 feet thick over the study area. During the Holocene Epoch, the Nooksack River cut through and eroded the Sumas Formation creating the present day alluvial floodplain of the Nooksack River Valley (Easterbrook, 1971).

The Chuckanut Formation is comprised of sandstone, mudstone, and conglomerate with seams of coal interspersed around the area. The Huntingdon Formation is of similar composition but geologically distinct. These two sedimentary units comprise the area bedrock beneath the glacial and alluvial deposits (Easterbrook, 1971).

Peat deposits are present in the area and are typically marked by local depressions, such as Wiser Lake. Some of these deposits are up to 30 feet thick (Easterbrook, 1971). Peat deposits have the potential to be a location where denitrification can occur. The organic carbon levels are high, and typically the saturated-fine-grained soils create a reducing environment which is essential for denitrification to occur (Cox, 2005).

Hydrogeology of the Sumas-Blaine Aquifer

The USGS distinguish four main hydrogeologic units within the project area: the uppermost Sumas aquifer, the Everson-Vashon semiconfining unit, the Vashon semiconfining unit, and the bedrock semiconfining unit (Cox and Kahle, 1999).

The Sumas-Blaine Aquifer is the surficial aquifer and the primary drinking water source for the area. The aquifer extends north into British Columbia, Canada, where the unit is also referred to as the Abbotsford Aquifer. The Abbotsford Aquifer is hydraulically connected across the international border, and the major groundwater flow direction is south from Canada (Cox and Kahle, 1999).

The Sumas-Blaine Aquifer continuously underlies a relatively flat glacial outwash plain between the towns of Sumas, Blaine, and Ferndale and the Nooksack River, comprising an area of approximately 150 square miles. The aquifer is unconfined over the extent of the study area.

The Sumas-Blaine Aquifer is comprised mainly of stratified sand and gravel outwash with minor clay lenses. Fine-grained lenses are more predominant in the Lynden area. This water-bearing unit is a heterogeneous unit which includes glacial outwash sediments and alluvial deposits from the Nooksack and Sumas River systems. There are also isolated lenses of till, fine-grained lacustrine deposits, and peat deposits. This is a highly productive unconfined aquifer and includes the geologic units of the Sumas Outwash, the Sumas fine-grained ice-contact deposits, coarse-grained alluvium, fined-grained alluvium, and peat deposits (Cox and Kahle, 1999).

The glacial outwash plains are comprised of unconsolidated sand, silt, and gravel sediments deposited by glacial streams produced during the advancement and retreat of the glaciers. Overall the topography is fairly flat except for the glacial kettle depressions where lakes, marshes, and peat bogs formed.

The aquifer thickness ranges between 15 feet to 80 feet. Over time the Nooksack River has incised the glacial outwash plain 40 to 60 feet forming the Lynden Terrace near the town of Lynden (Cox and Kahle, 1999). Depth to groundwater is typically less than 10 feet below land surface (Erickson, 2000). The median hydraulic conductivity was calculated to be 270 feet per day, with a range of 7 to 7,800 feet per day (Cox and Kahle, 1999). The extreme variation in hydraulic conductivities indicates substantial heterogeneity within the units, which is typical of a unit from glacial origins. Cox and Kahle (1999) estimate the hydraulic gradient in the Sumas-Blaine Aquifer at about 15 feet per mile or 0.0028 foot per foot. Groundwater flow velocity of two feet per day was determined at a local dairy (Garland and Erickson, 1994).

Groundwater Flow and Recharge

Generally groundwater within the Sumas-Blaine Aquifer flows toward the major river systems and tributaries in the area. Erickson (1998) characterized the groundwater flow based on water level measurements taken from 248 wells across the extent of the aquifer. The aquifer is in hydraulic connection with surface water and provides baseflow during the summer months (Erickson, 2000). The Nooksack River originates in the Cascade Mountain Range and traverses through the lowlands to the marine waters. The main tributaries are Bertrand Creek, Fishtrap Creek, and Tenmile Creek.

The Sumas-Blaine Aquifer is mainly recharged by precipitation and irrigation (Tooley and Erickson, 1996), although wastewater from on-site sewage systems and leachate from manure storage lagoons also contribute to the recharge. Precipitation ranges from 60 inches per year near the international border to 32 inches per year in the southern part of the study area. Recharge rates are affected by precipitation rates, evapotranspiration rates, infiltration rates, and impervious surfaces. Within the study area the recharge rates are estimated to range from 11 to 45 inches per year (Cox and Kahle, 1999).

Methods

Ecology sampled 27 wells during 2009. These wells were primarily the same wells which were sampled in the Nitrate Trends Study (Redding, 2008). These wells have a history of comprehensive sampling where seasonal variations were previously identified. Three new wells were added in 2009 to expand the assessment of groundwater contamination in the aquifer. One upgradient monitor well is part of a dairy manure management study (Carey, 2002), and the other two wells are in the Judson Lake area. Judson Lake is an area of concern which has been studied by Western Washington University and also found to have elevated nitrate concentrations in groundwater (Mitchell et al., 2005).

Well owners were contacted by mail and by phone prior to sampling to inform them of the goals of this study and to gain permission to access their wells.

This ambient monitoring network is comprised predominantly of private domestic wells (Table 1). Groundwater monitoring wells are the ideal type of well for monitoring conditions in the aquifer. Unfortunately, due to limited resources, it was not possible to install a sufficient number of wells to provide adequate areal coverage. Previous studies in the Sumas-Blaine Aquifer have used private domestic wells with much success. The wells in this 2009 study were all shallow wells, completed in the uppermost aquifer, and which met the well construction standards.

Sampling and Analysis

Wells were sampled in March to provide continuity in annual sampling for comparative purposes. Sampling during March was based on the results of previous sampling efforts in the area. These efforts identified March as a critical time when the aquifer is most susceptible to nitrate contamination resulting from excessive nutrient applications from the previous year. Unused nitrogen in the soils is converted to nitrate-nitrogen and migrates downward with precipitation and irrigation water into groundwater.

Groundwater samples for nitrate+nitrite-N, chloride, and bromide were sent to Ecology's Manchester Environmental Laboratory (MEL) for laboratory analysis. Additionally, field staff measured temperature, pH, dissolved oxygen, and conductivity.

Table 1 includes the sampling information for the 27 wells. All wells were checked to verify that a unique Ecology well tag was present.

Table 1. Well Sampling Information.

Well ID	Well Type	Well Depth (feet)	Sampling Point
AGF141	public supply well	32	tap in pump house before storage tank
BCS954	private domestic well	20	tap in front of duplex
BCS955	private domestic well	21	tap near pasture
BCS956	private domestic well	27	tap outside front of garage
BCS953	private domestic well	29	tap outside front of garage
BCS952	private domestic well	24	tap next to well near barn
BCS951	private domestic well	N/A	tap in front of barn
BCS957	private domestic well	31	tap on side of loafing barn
BCS962	private domestic well	43.1	tap in front of shop
BCS961	private domestic well	17	tap in vegetated area next to shop
BCS963	private domestic well	N/A	tap outside of well house between church and residence
BCS958	private domestic well	23	tap next to garage entrance
BCS959	private domestic well	30	tap in yard behind driveway
BCS960	private domestic well	15	tap next to front shop
BCS969	private domestic well	32	hose connection directly from well in front driveway
BCS972	private domestic well	29	tap in front of shop
BCS964	private domestic well	26	tap on side of garage
BCS965	private domestic well	15	tap in back yard
BCS968	private domestic well	21	tap on front of house
BCS973	private domestic well	20	hose connection directly from well in back yard
BCS967	private domestic well	30	tap on side of house next to driveway
BCS966	private domestic well	36	tap on side of shop
BCS970	private domestic well	43	tap behind house next to shop
BCS971	private domestic well	20	tap on well in old barn
LW-5	monitoring well	15	tillage study well
AGO409	irrigation well	N/A	tap on front of house
ABO112	private domestic well	50	tap on well behind house next to garage

N/A = information not available.

To minimize the effects of altering the water chemistry of groundwater during sample collection, Ecology field staff used the following procedures:

- Samples were obtained as close to the wellhead as possible.
- Samples were obtained prior to any water treatment device.
- All wells met the well construction standards specified in Chapter 173-160 WAC.
- Wells were purged until the field parameters stabilized to the criteria established in the Quality Assurance (QA) Project Plan (Redding, 2009).
- Samples were obtained when the pump was running to prevent sampling stagnant water from storage tanks.

Wells were sampled from a faucet with a “Y” fitting. The “Y” adapter allowed the well to be purged while field parameters were constantly measured in a flow cell. The flow cell houses the pH, temperature, conductivity, and dissolved oxygen probes. The flow cell allows field measurements to be made prior to the water being exposed to the atmosphere.

The purging was considered complete and a sample was taken once two consecutive field measurements were made within the stability criteria previously defined in the QAPP (Redding, 2009). Samples were collected from the restricted side of the “Y” adapter after the polyethylene hose was unhooked from the flow cell. This allowed a sampled to be collected from as close to the wellhead as possible while minimizing the contact with field equipment and hoses. This system is also advantageous for residences where a storage tank was in place prior to the closest tap. Variable flow controls allow large volumes of water to be purged from the tank which facilitates the pump cycling on, which then produces water directly from the borehole. One side of the “Y” was connected to a garden hose, which was used to purge the well and discharge the water to a vegetated area. The other side of the “Y” was connected to a flow cell with a polyethylene hose.

All equipment was decontaminated between wells with a mild detergent and then rinsed with deionized water.

All samples were field-filtered using a 0.45 micron filter. Approximately 100 ml of well water was run through the filter before a sample was collected. Samples were placed in a 125 ml clear nalgene bottle preserved with sulfuric acid, obtained from MEL. The sulfuric acid preserves the water sample to pH<2. Samples were placed in coolers with ice while in transit. At the completion of the sampling event, the coolers were transported to the Ecology Operations Center walk-in cooler, where they were picked-up and transported to MEL in Manchester, Washington, via a MEL courier.

Laboratory Methods

Nitrate+nitrite N concentrations were determined using the cadmium reduction flow injection method, standard method 4500 NO3-I. Chloride and bromide concentrations were determined using ion chromatography, U.S. Environmental Protection Agency (EPA) method 300.0 (APHA, 2005; MEL, 2008).

MEL reported receiving the samples in good condition and within the proper temperature range of 0ºC - 6ºC. All analyses were performed within the EPA holding times.

Field Methods

Field parameters are measurements made in the field. They are groundwater quality measurements and also indicators which can also be used to verify when effective well purging has occurred based on when the parameters have stabilized. Groundwater stabilization assures that the groundwater sampled is representative of water in the aquifer formation and not stagnant water which has been residing in the borehole. These measurements can also be used to characterize groundwater conditions and to be indicative of groundwater contamination. Field parameters measured include pH, electrical conductivity, temperature, and dissolved oxygen.

pH, electrical conductivity, and temperature often stabilize within one casing volume while other chemical constituents often take longer to stabilize. Puls and Powell (1992) recommend the use of dissolved oxygen as the best indicator of groundwater stabilization because it typically takes longer to stabilize and it mimics the behavior of other inorganic parameters.

Specific field meters were used to measure field parameters. pH was measured with an Orion meter 4500 H^+, electrical conductivity was measured with a Beckman meter 2510, temperature was measured with the combination pH/temperature Orion meter, and dissolved oxygen was measured with a membrane electrode 4500 O.G. All meters were calibrated twice daily against known standards to assure proper operation.

Filtered Sample Comparison

A total of 20% of the wells in this 2009 study were sampled both with a filter and without a filter. The goal of this comparison was to determine the relative bias present when comparing unfiltered samples from previous studies to the filtered results of this study.

Quality Assurance

Laboratory QA samples for this study include duplicate samples, matrix spikes, control standards, and blanks. The targets for analytical precision are described in the QA Project Plan (Redding, 2009). Appendix A describes the field and laboratory QA results. The quality of the data is judged to be acceptable for this project.

Results

Table 2 lists the results of the groundwater quality sampling for each well. All nitrate concentrations are reported as N (nitrogen).

Table 2. Groundwater Quality Results, 2009.

Well ID	Nitrate (mg N/L)	Chloride (mg/L)	Bromide (mg/L)	
AGF141	9.19	15.9	0.2	U
BCS954	2.07	2.21	0.2	U
BCS955	2.18	3.77	0.2	U
BCS956	3.38	6.98	0.2	U
BCS953	*28.05*	3.83	0.2	U
BCS952	12.9	6.68	0.2	U
BCS951	7.25	10.2	0.2	U
BCS957	0.956	14.2	0.2	U
BCS962	*16.1*	18.1	2.13	
BCS961	4.85	6.04	0.2	U
BCS963	5.52	8.44	0.2	U
BCS958	2.43	2.54	0.2	U
BCS959	5.41	6.93	0.2	U
BCS960	*14.65*	5.08	0.235	UJ
BCS969	5.63	9.96	0.2	U
BCS972	8.82	12.5	0.2	U
BCS964	*23.9*	23.05	0.2	U
BCS965	*14.2*	24.9	0.2	U
BCS968	*13.4*	6.46	0.2	U
BCS973	*11.9*	6.64	0.2	U
BCS967	8.49	7.73	0.2	U
BCS966	5.18	6.98	0.2	U
BCS970	*11.7*	7.16	0.2	U
BCS971	9.41	9.68	0.2	U
LW-5	*19.6*	10.8	0.2	U
AGO409	*12.4*	9.95	0.2	U
ABO112	*13.8*	10.1	0.2	U
Mean	*10.12*	9.51	--	
Drinking Water Standard	10	250	--	

Shaded: Exceeds (does not meet) drinking water standards.
U: less than detection limit. J: approximate value

Table 3 provides a statistical summary of the 2009 groundwater quality sampling.

Table 3. Statistical Summary of Groundwater Quality Parameters, 2009.

	Nitrate (mg N/L)	Chloride (mg/L)	Bromide (mg/L)
Mean	*10.12*	9.5	--
Minimum	0.956	2.21	--
Maximum	*28.05*	24.9	2.13
Median	9.19	7.73	--
Drinking Water Standard	10	250	

Nitrate concentrations in the study area ranged from 0.956 to 28.05 mg/L. The mean nitrate concentration was 10.12 mg/L, and the median nitrate concentration was 9.19 mg/L. Chloride concentrations were all detected well below the drinking water standard of 250 mg/L. The highest concentration detected was 24.9 mg/L. There is no drinking water standard for bromide.

Table 4 lists field measurements for pH, temperature, specific conductance, and dissolved oxygen. On April 1, 2009, the pH and specific conductance probes were malfunctioning. The pH of the aquifer is slightly acidic with a range of 5.73 to 7.04 standard units. The temperature of the groundwater ranged from 7.6 to 13.3 °C. Specific conductance varied from 37 to 441 umhos/cm. Dissolved oxygen concentrations ranged from 0.19 to 11.55 mg/L.

Figure 2 displays the nitrate concentration of each well. Wells with concentrations higher than the drinking water standard are highlighted in red.

Table 4. Results for Field Parameters, 2009.

Well ID	Date	pH (Std Units)	Temperature (°C)	Specific Conductance (umhos/cm)	Dissolved Oxygen (mg/L)
AGF141	3/18/2009	5.81	12.3	59	5.25
BCS954	3/18/2009	6.25	10.4	41	8.66
BCS955	3/18/2009	6.49	10.4	37	5.08
BCS956	3/18/2009	6.42	10.1	141	7.17
BCS953	3/18/2009	6.21	11.4	67	6.67
BCS952	3/18/2009	6.58	12.1	269	5.8
BCS951	3/18/2009	6.08	13.3	167	5.02
BCS957	3/19/2009	6.43	9.1	318	0.38
BCS962	3/19/2009	7.04	9.9	357	9.88
BCS961	3/19/2009	5.91	8	133	6.63
BCS963	3/19/2009	5.9	9.7	216	4.16
BCS958	3/19/2009	5.81	8.7	81	6.56
BCS959	3/19/2009	6.21	11.1	186	3.54
BCS960	3/19/2009	5.94	9.3	243	8.12
BCS969	4/1/2009	--	10	--	8.52
BCS972	4/1/2009	--	9.9	--	10.31
BCS964	3/19/2009	5.82	9	422	6.36
BCS965	3/19/2009	5.88	9.7	441	0.19
BCS968	3/20/2009	6.52	9.6	239	10.32
BCS973	4/1/2009	--	13.2	--	--
BCS967	3/20/2009	6.97	9.6	212	5
BCS966	3/20/2009	6.27	11	249	5.50
BCS970	4/1/2009	--	10.4	--	8.54
BCS971	4/1/2009	--	9.3	--	10.78
LW-5	3/19/2009	5.73	7.6	319	9.04
AGO409	4/1/2009	--	10.2	--	11.83
ABO112	4/1/2009	--	9.7	--	11.55

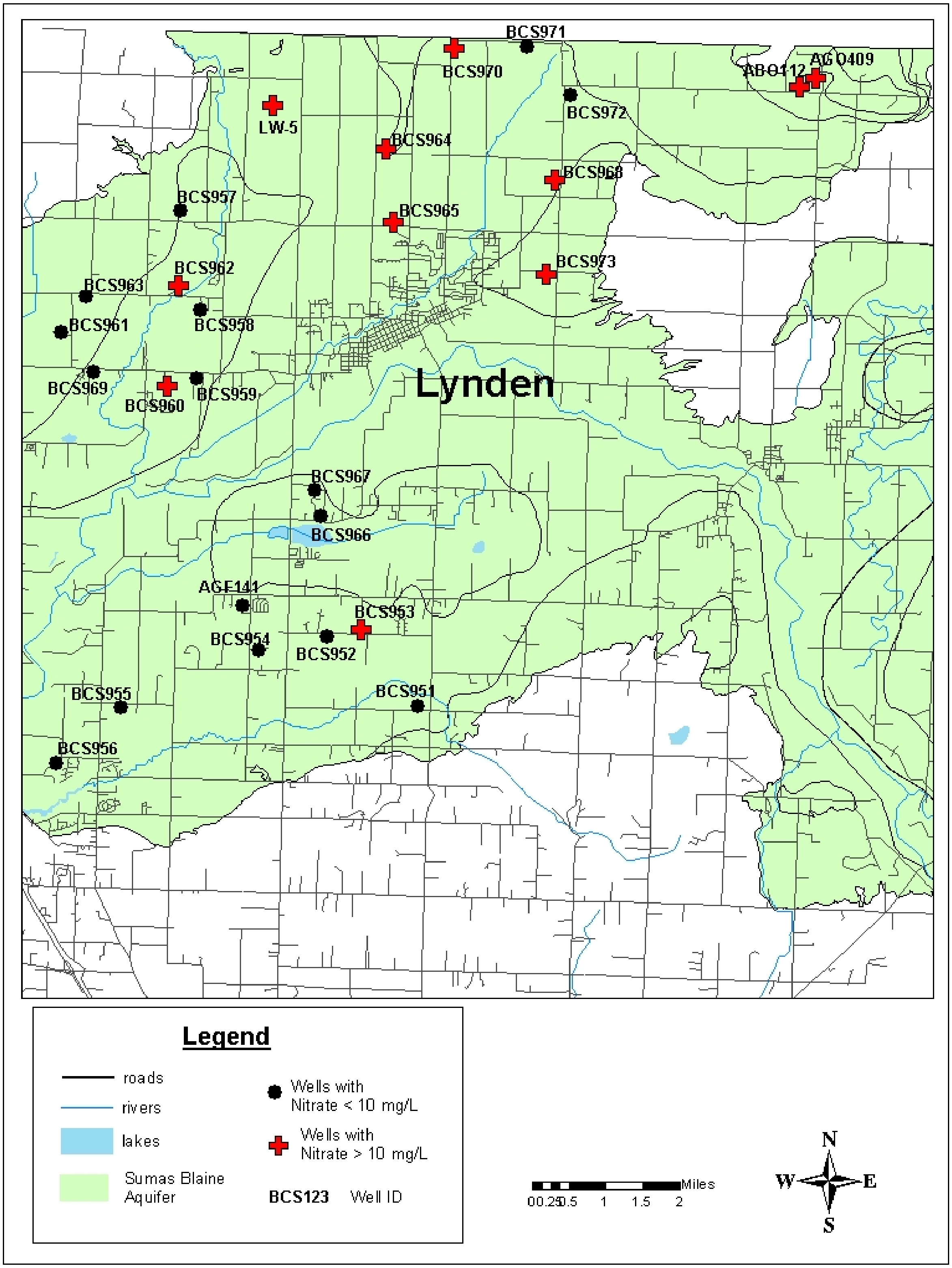

Figure 2. Nitrate Concentrations in Wells, 2009.

Discussion

This report is an annual (2009) assessment of data quality assurance with the focus on presenting the data. A more detailed data assessment will be reported every three years.

Nitrate

Annual sampling within the central Sumas-Blaine Aquifer occurs in March in order to consistently monitor groundwater quality trends. In 2009, twenty-seven groundwater wells were sampled. A total of 41% of the wells sampled in 2009 exceeded (did not meet) the drinking water standard for nitrate of 10 mg N/L.

Chloride and Bromide

Chloride and bromide samples were collected with the intent to use the ion ratio as an indicator of groundwater contamination sources. Chloride/bromide ratios are a source-tracking tool used to distinguish between 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 (Vengosh and Pankratov, 1998). 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).

Vengosh and Pankratov (1998) characterized drinking water bromide concentrations in the range of 1.57 to 0.40 mg/L. Davis et al. (1998) detected bromide concentrations in the range of 0.04 to 0.32 mg/L in groundwater. Information on ambient bromide concentrations in groundwater is scarce since there are no direct health concerns associated with bromide.

The ambient groundwater bromide concentration in the Sumas-Blaine Aquifer was unknown prior to sampling. Due to the proximity to the Pacific Ocean, and the presence of bromide-based pesticides detected in groundwater (Redding, 2007), the assumption was that bromide might occur at concentrations greater than the method detection limit of 0.2 mg/L. Unfortunately, virtually all of the bromide results were reported at concentrations less than detection limit.

Results of this 2009 sampling indicate that bromide concentrations in the Sumas-Blaine Aquifer are predominantly less than 0.2 mg/L (Table 2). While the results from this sampling are not useful as an indicator of contamination sources, it does indicate that future use of chloride/ bromide ratios would require an analytical method with a lower detection limit. Other methods, such as flow injection analysis, are used to achieve concentration results at lower levels and may be a viable option for future use (Davis et al., 1998; Vengosh and Pankratov, 1998).

Filtered vs. Unfiltered Samples

A comparison of filtered samples with paired unfiltered samples is presented in Table 5. While there are some differences in concentrations between the two sets for nitrate and chloride, the relative percent difference (RPD) is within the allowable difference for field duplicate samples without an added variable. In 66% of the paired filtered/unfiltered samples, the unfiltered samples contained slightly higher concentrations than the filtered samples for nitrate. For chloride, 100% of the unfiltered samples contained slightly higher concentrations than the filtered samples. The bromide samples were all less than detection limits in both cases.

Table 5. Comparison of Filtered Samples with Unfiltered Samples.

Well ID	Nitrate			Chloride			Bromide				
	filtered (mg N/L)	unfiltered (mg N/L)	RPD (%)	filtered (mg/L)	unfiltered (mg/L)	RPD (%)	filtered (mg/L)		unfiltered (mg/L)		RPD (%)
BCS952	12.9	13.3	3.05	6.68	6.76	1.19	0.2	U	0.2	U	N/A
BCS959	5.41	5.15	4.92	6.93	7.08	2.14	0.2	U	0.2	U	N/A
BCS960	14.65	14.95	2.03	5.08	5.085	0.10	0.2	U	0.2	U	N/A
BCS967	8.49	8.26	2.75	7.73	7.79	0.77	0.2	U	0.2	U	N/A
BCS970	11.7	12.55	7.01	7.16	7.165	0.07	0.2	U	0.2	U	N/A
AGO409	12.4	13.7	9.96	9.95	10.1	1.50	0.2	U	0.2	U	N/A

RPD: relative percent difference.
N/A: test not applicable.
U: less than detection limit.

Student’s t-test was also used to statistically determine the probability that the two populations of filtered and unfiltered samples are the same. The sample size is relatively small, making it difficult to assess true differences in population means. A comparison of the filtered and unfiltered data using Students t-test validates the null hypothesis that the two populations are the same ($p = 0.86$).

Conclusions

As a result of this 2009 study, the following conclusions are made:

Groundwater Contamination

Nitrate contamination continues to be an issue in the Sumas-Blaine Aquifer, with 41% of the wells sampled exceeding (not meeting) the drinking water standard.

Filtered Samples

Comparison of the paired filtered and unfiltered samples indicates that there is no statistical difference in the water quality results for nitrate and chloride. The protocol of field filtering all samples can continue for future sampling events without introducing bias into the result. Additionally this will allow for a direct comparison to previous investigations that used unfiltered samples.

Recommendations

This 2009 study found that the Sumas-Blaine Aquifer remains contaminated with nitrate concentrations above (not meeting) the drinking water standard. The following recommendations are offered for future groundwater sampling:

- Continue annual monitoring to determine long-term nitrate trends in the central portion of the Sumas-Blaine Aquifer.
- Continue sampling during the month of March to compare historic data and determine trends.
- Add equipment blanks to future sampling.
- Resolve the future use of chloride/bromide ratios as an indicator of groundwater contamination both as a laboratory analytical procedure and as a program policy perspective.
- Correlate land use and nutrient loading with groundwater quality. This information can be used to more definitively determine the source of nitrogen in groundwater and quantify contaminant loading to the aquifer.
- Adopt a long-term view of groundwater remediation and protection. Groundwater moves slowly and documented improvements may take years.
- Work cooperatively with local government agencies and citizen groups to continue monitoring the aquifer and developing a long-term solution to groundwater contamination.
- Work cooperatively with Environment Canada and other research agencies to coordinate data sharing, future groundwater monitoring, and to develop long-term goals.

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Appendices

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Appendix A: Quality Assurance Results

Data QA requirements are described in Redding, 2009. Data that do not meet the specified data quality objectives are highlighted in Tables A-1 and A-3 below. Overall, the quality of the data reported for this project is judged to be acceptable.

Field Duplicates

Field duplicate samples are used to measure the precision of the entire sampling and analytical process. Field duplicates are two samples collected from the same location at the same time. The duplicates are submitted as blind samples to the laboratory (MEL). Differences in the concentrations can be the result of natural heterogeneities in the aquifer, sample collection procedures, variances in the sample containers, preservation methods, or the analytical procedure. Duplicate samples were collected from at least 10% of the wells sampled.

Table A-1 summarizes the QA data for the field duplicate results for nitrate, chloride, and bromide. All field duplicate samples met the pre-specified 15% RPD measurement quality objectives.

Table A-1. Quality Assurance Summary for Field Duplicate Results.

Filtered Samples										
Date	Sample ID	Nitrate+Nitrite as N			Chloride			Bromide		
		mg N/L	mg N/L	RPD	mg/L	mg/L	RPD	mg/L	mg/L	RPD
3/18/2009	BCS953	27.3	28.8	5.35	3.76	3.89	3.40	<0.2	<0.2	N/A
3/19/2009	BCS964	23.7	24.1	1.67	23.1	23	0.43	<0.2	<0.2	N/A
3/19/2009	BCS960	14.6	14.7	0.68	5.07	5.09	0.39	<0.2	0.27	N/A
4/1/2009	BCS970	11.5	11.9	3.42	7.16	7.16	0.00	<0.2	<0.2	N/A
Unfiltered Samples										
Date	Sample ID	Nitrate+Nitrite as N			Chloride			Bromide		
		mg N/L	mg N/L	RPD	mg/L	mg/L	RPD	mg/L	mg/L	RPD
3/19/2009	BCS960	15.5	14.4	7.36	5.04	5.13	1.77	<0.2	<0.2	N/A
4/1/2009	BCS970	12.5	12.6	0.80	7.17	7.16	0.14	<0.2	<0.2	N/A

RPD: relative percent difference.
N/A: test not applicable.

Field duplicate samples were also collected concurrently for two separate studies. Well LW-5 is a monitor well that is part of an ongoing study by Carey (2004), which is being conducted in the Sumas-Blaine Aquifer, www.ecy.wa.gov/biblio/0403112.html. The results are listed below in Table A-2.

Table A-2. Duplicate Results for Monitor Well LW-5.

Date	Site ID	Parameter	Duplicate Results		
			mg/L	mg/L	RPD +/- 20%
3/19/2009	LW-5	Nitrate	19.6	20.1	0.06%
3/19/2009	LW-5	Chloride	10.8	10.5	0.06%

Laboratory Duplicates

Laboratory duplicates are used to estimate analytical precision. This entails analysis of duplicate aliquots from a single sample container. Analytical duplicates run by MEL are typically used with one of the field duplicates to estimate total and analytical variability from the same sample. The RPD is a tool to measure the variability between samples. It is the ratio of the difference of the duplicate results and the mean of the duplicate results expressed as a percentage. The RPD is used to measure analytical precision; the lower the RPD, the more precise the results are (Lombard and Kirchmer, 2004).

Table A-3 summarizes the QA data for the laboratory results for nitrate, chloride, and bromide. All of the laboratory duplicate samples are within the acceptable limits of +/- 20% RPD.

Table A-3. Quality Assurance Summary for Laboratory Results.

Date	Sample ID	Parameter	Duplicate Results			Laboratory Control Samples (LCS)	Matrix Spike	Blank	
			mg/L	mg/L	RPD +/- 20%	90-110%	75-125%	mg/L	
4/9/2009	B09C218	Bromide	0.2	0.2		98%	102%	0.2	U
4/9/2009	B09C218						102%		
4/9/2009	B09C230		0.2	0.27		99%	98%	0.2	U
4/9/2009	B09C230						102%		
4/9/2009	B09D035		0.2	0.2		95%	100%	0.2	U
4/9/2009	B09D035						99%		
4/9/2009	B09D045		0.2	0.2		97%	99%	0.2	U
4/9/2009	B09D045						100%		
4/9/2009	B09C218	Chloride	16.3	14.3	14%	96%	*72%*	0.1	U
4/9/2009	B09C218						77%		
4/9/2009	B09C230		5.1	5.09	0.20%	96%	96%	0.1	U
4/9/2009	B09C230						96%		
4/9/2009	B09D035		9.95	9.96	0.06%	97%	95%	0.1	U
4/9/2009	B09D035						98%		
4/9/2009	B09D045		9.69	9.68	0.10%	97%	96%	0.2	U
4/9/2009	B09D045						93%		
4/9/2009	B09C271	Nitrate	1.74	1.74	0.03%	99%	102%	0.01	U
4/9/2009	B09C272		4.84	4.85	0.20%	99%	91%	0.01	U
4/9/2009	B09D029		0.465	0.464	0.07%	102%	99%	0.01	U
4/9/2009	B09D030		3.5	3.5	0.06%	101%	102%	0.01	U

RPD: relative percent difference.
U: less than detection limits.
Results outside of acceptable limits are shaded.

Blanks

Method blanks determine bias due to laboratory contamination. This is an analytical tool performed by MEL to measure the theoretical concentration of zero. The blanks are prepared and analyzed along with the samples to measure any impacts to the samples from the analytical process.

No analytically significant levels of analytes were detected in the method blanks associated with these samples.

Control Samples

Laboratory control samples, or check samples, are samples prepared with a known concentration of an analyte prepared independently of the calibration standards. This type of quality control is used to verify the analytical precision and determine the level of bias due to calibration (Lombard and Kirchmer, 2004).

All laboratory control samples are within the acceptance limits of 90% to 110%.

Matrix Spikes

Matrix spikes are a process of adding a known amount of an analyte to a portion of one of the submitted samples. Matrix spike recoveries indicate bias due to interference from elements in the sample matrix.

All of the matrix spike recoveries were within the acceptance limits of 75% to 125%, except for one chloride sample, for which MEL qualified the source sample as an estimate.

Appendix B: Glossary, Acronyms, and Abbreviations

Glossary

Ambient: Background (environmental). Away from point sources of contamination.

Anaerobic: Soil conditions where free oxygen is deficient. This occurs in waterlogged or poorly drained soils where water has replaced air in the soil pores.

Anthropogenic: Human-caused.

Areal flow: Surface water discharge per unit of watershed area, in units of length per time (for example, inches per day).

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.

Denitrification: process in which anaerobic bacteria convert nitrate ions into nitrogen gas.

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

Exceeded standard: Did not meet standard.

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

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

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.

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

Acronyms and Abbreviations

CFR	Code of Federal Regulations
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
QA	Quality assurance
RPD	Relative percent difference
USGS	U.S. Geological Survey
WAC	Washington Administrative Code

Units of Measurement

°C	degrees centigrade
ft	feet
mg	milligrams
mg/L	milligrams per liter (parts per million)
N	Nitrate as Nitrogen
umhos/cm	micromhos per centimeter