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State of Washington

Quality Assurance Project Plan

Sumas-Blaine Surficial Aquifer Long-Term Ambient Groundwater Monitoring

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COVER PHOTO: Department of Ecology staff taking water quality measurements in Whatcom County (photo by Eric Daiber).

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November 2019

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EAP: Environmental Assessment Program

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2.0 Abstract

The Sumas-Blaine aquifer (SBA) is the main source of drinking water for 40,000 to 45,000 rural residents of northern Whatcom County. The aquifer is vulnerable to contamination due to its shallow depth, high winter rainfall, and overlying agricultural and residential land uses. Groundwater nitrate-N in the SBA has been extensively studied since the 1970s, with a focus on characterizing areas that exceed the maximum contaminant limit (MCL) for nitrate+nitrite-N[1,2] of 10 mg/L. The SBA has been identified as a nitrate priority area in Washington State (Erickson, 2000; Morgan, 2016).

In 1997, the Department of Ecology (Ecology) sampled 248 wells across the aquifer for nitrate-N and found that 21% exceeded the nitrate-N MCL (Erickson, 1998). This study evolved into an annual monitoring at a subset of wells. From 2003 to 2016 this monitoring suggested that the average springtime nitrate-N concentrations in 9 of the 25 wells decreased, while 15 wells had no trend and one had an increasing trend (Carey, 2017).

In 2018, Ecology returned to 106 of the 248 wells sampled by Erickson (1998) and 72 new wells for a 21-year retrospective study. The percentage of the 106 common wells (sampled in 1998 by Erickson and again in 2018) exceeding the nitrate-N standard in 2018 decreased from 25% to 21% (Daiber et al., 2019). The decline in the mean nitrate-N concentration potentially suggests improving groundwater quality across the aquifer.

To assess the potentially improving groundwater quality, continued monitoring of the long-term ambient network is needed to confirm the trends observed. Tracking the effectiveness of the best management practices and observing their impacts to groundwater quality is important to understanding the nitrate-N trends across the aquifer. This study is designed to build on the previous monitoring efforts, thus providing continued assessment of the nitrate concentrations.

[1] "Nitrate+nitrite-N" is the sum of the nitrate and nitrite concentration as nitrogen.
[2] "Nitrate+nitrite-N" is referred to as "nitrate-N" in this report because of the negligible contribution of nitrite-N in surface water and groundwater (Sawyer and McCarty, 1978).

3.0 Background

3.1 Introduction and problem statement

The Sumas-Blaine aquifer (SBA) is the U.S. portion of the Abbotsford-Sumas aquifer that spans the United States–Canada border in northern Whatcom County, Washington (Figure 1). The SBA is the main drinking water source for 40,000 to 45,000 people in rural northern Whatcom County. Much of the land overlying the aquifer is intensively cultivated to produce dairy forage crops, berries, and other agricultural products. Residential development over the aquifer is also ongoing, including hobby farms with livestock. The area's shallow depth to water (typically less than 10 feet) and heavy winter precipitation makes the aquifer especially vulnerable to nitrate contamination.

Periodic groundwater monitoring for nitrate-N has been conducted in the SBA since the early 1970s. In 1997, the Washington State Department of Ecology (Ecology) conducted an aquifer-wide survey of nitrate-N in 249 wells across the SBA (Erickson, 1998). Twenty-one percent of wells had nitrate-N concentrations above 10 mg/L. Nitrate-N concentrations appeared to be highest in the central and northeast parts of the SBA. In 2003, a subset of 35 wells in that area were selected for ongoing monitoring (Redding, 2008).

The ongoing monitoring initially consisted of quarterly sampling at 35 mostly private water supply wells for 3 years (2003–2005). Most of the wells sampled during this period were also sampled during the 1997 aquifer-wide sampling (Erickson, 1998). The 2003–2005 study included analysis of nitrate seasonal variations and short-term trends over time. Monitoring continued on an annual basis from this same set of wells (although a few became unavailable) from 2009 to 2016.

This study continues the existing long-term monitoring program to assess trends in nitrate-N concentrations within the SBA aquifer. In addition to nitrate-N, other parameters collected in this study include temperature, pH, conductivity, oxidation-reduction potential, dissolved oxygen, chloride, ammonia-N, and orthophosphate.

3.2 Study area and surroundings

The SBA is located in the Fraser-Whatcom lowland and is bordered by the Cascade Mountain Range to the east and the Salish Sea to the west. Most of the study area is located on the glacial outwash plain that is bisected by the Nooksack River. Hummocky uplands are found in the northeastern and southern parts of the area. The outwash plain consists of sand, silt, and gravel deposited by glaciers advancing and retreating from the area (Cox and Kahle, 1999). The portion of the outwash plain located north of the Nooksack River is 40 to 60 feet higher than the area south of the river and is called the Lynden Terrace.

The original coniferous forests have mostly been logged and the land converted to agricultural production. Dairy-related forage crops cover the most acreage, followed by berry production. Much of the cultivated land in low-lying areas is underlain by tile drains that discharge to larger drains. These in turn flow into to nearby creeks and eventually to the Nooksack River (Figure 1). The Nooksack River is one of the largest tributaries of the Salish Sea. The general groundwater flow direction of the SBA is also toward the Nooksack River (Tooley and Erickson, 1996).

The SBA covers about 150 square miles, with groundwater depths less than 10 feet in much of the area (Tooley and Erickson, 1996). As part of the larger Abbotsford-Sumas aquifer, the SBA north of the Nooksack River is downgradient of groundwater sourced from the Canadian portion (Scibek and Allen, 2005).

The SBA ranges in thickness from less than 25 feet in the west to over 75 feet on the eastern edges, with most aquifer areas less than 50 feet thick. The average reported hydraulic conductivity (rate of water movement through a material at a unit gradient) of the SBA is 270 feet/day with a range of 7 to 7,800 feet/day (Cox and Kahle, 1999).

The local area has a moderate coastal climate influenced by nearby marine water to the west and coastal mountain ranges to the east. These features lead to mostly mild temperatures and an annual precipitation of 35 to 60 inches. Rainfall is concentrated in the months of October to March, with very little rainfall occurring in the summer. Occasional winter storms from the Fraser Valley to the northeast bring colder air and snow.

The combination of shallow depth to groundwater and high winter precipitation make the SBA especially vulnerable to contamination (Carey, 2018).

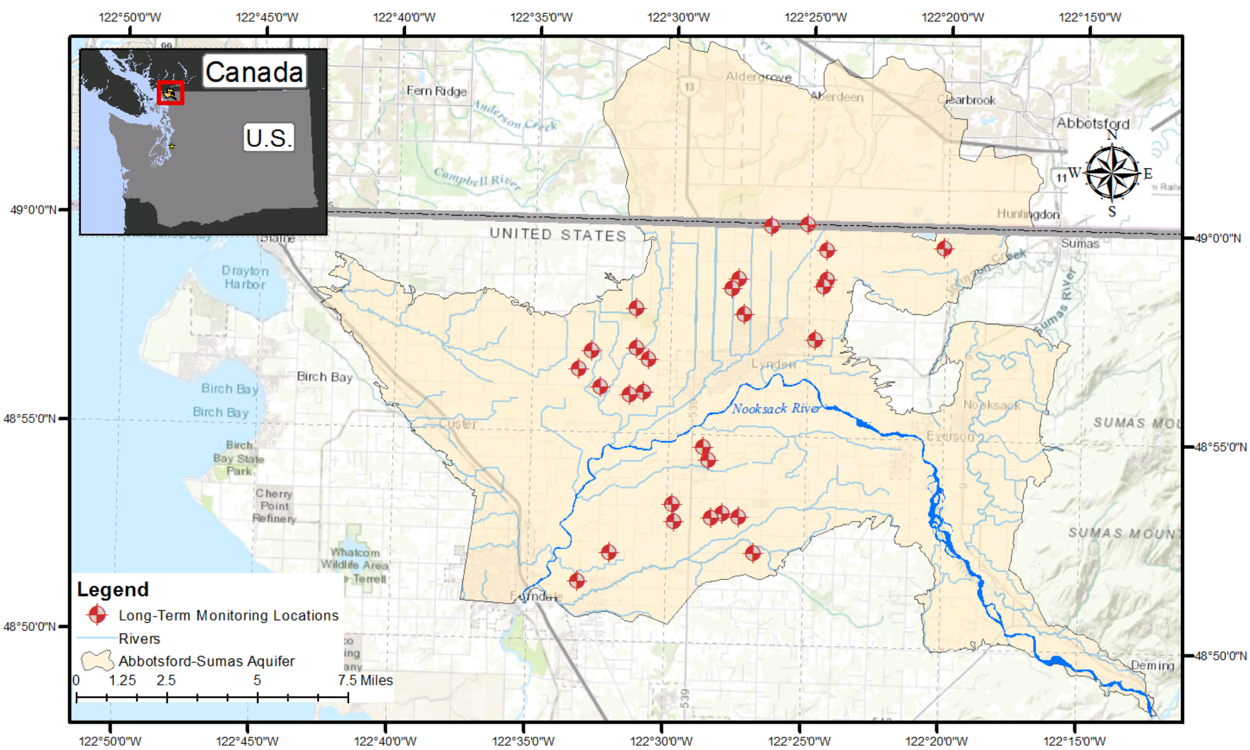

Figure 1. Map of Abbotsford-Sumas aquifer showing the locations participating in long-term monitoring (Carey, 2017; Tooley and Erickson, 1996).

3.2.1 History of study area

Historically, the SBA was covered with dense forest until the beginning of the twentieth century, when the area experienced rapid deforestation. Agriculture developed on the cleared land and became the primary economic source for the population living on the aquifer. The number of people living in the study area has been increasing at a steady rate since the 1950s. Approximately 40,000 to 45,000 people currently live on the aquifer. The majority are concentrated in urban centers such as Lynden, Ferndale, Sumas, Blaine, Everson, and Nooksack.

Approximately 115,000 acres in Whatcom County are used for farmland, with dairy farms occupying the most acreage. The earliest records posted by Whatcom Farm Friends indicate that there were 33,000 cows in Whatcom County in 1950 (Whatcom Farm Friends, 2017). In 2014, the number of dairy cows in the county was down to 44,000 from a peak of over 67,000 in the 1990s. The number of dairies has also declined over time, from approximately 1,000 in 1962 to only 104 in 2014. The average herd size in 2014 was approximately 400 animals (Whatcom Farm Friends, 2017).

Over the past 30 years, raspberries (and more recently blueberries) have been planted in many fields that were formerly used to grow grass and corn to support local dairy operations. In 2015, grass and corn crops encompassed 45,219 acres in the Whatcom County, while berries occupied 15,029 acres (Washington State Department of Agriculture, 2017; Carey, 2018). Land conversion from agricultural and forested areas to residential development, including hobby farms, has also increased in recent years.

3.2.2 Summary of previous studies and existing data

Elevated groundwater nitrate concentrations have been observed in the SBA for over 40 years in many field studies (Table 1). In these studies, the percentage of wells not meeting the nitrate-N drinking water standard of 10 mg/L has ranged from 17% to 64%, depending on the scale of the study.

Table 1. Previous groundwater nitrate studies in the Sumas-Blaine aquifer.

Study dates	Number of wells	Wells exceeding 10 mg/L nitrate-N (%)	Reference
1970–1973	100	19	Obert (1973)
1990	27	26	Erickson and Norton (1990)
Spring 1997	249	21	Erickson (1998)
1990–1991	230	21	Cox and Kahle (1999)
June 1999	53	50	Erickson (2000)
2002–2004	26	64	Mitchell et al. (2005)
2003–2005	35	26	Redding (2008)
2009	27	41	Redding (2011)
2009–016	25	24	Carey (2017)
2018	178	17	Daiber et al. (2019)

3.2.3 Parameters of interest and potential sources

The principal parameters of interest for this study are:

- **Nitrate-N—**sources include animal and human waste, inorganic fertilizer. Nitrate will be analyzed as nitrate-N, because nitrite-N is typically negligible in natural waters (Sawyer and McCarty, 1978).

- **Ammonia-N—**sources include animal and human waste, inorganic fertilizer.
- **Chloride—**can be associated with animal or human waste.
- **Orthophosphate—**a nutrient related to water quality.
- **Specific conductance—**can be associated with many wastes, including animal and human waste.
- **Dissolved oxygen (DO)—**important for interpreting water chemistry.
- **Oxidation-reduction potential (ORP)—**important for interpreting water chemistry.
- **pH—**important for interpreting water chemistry.

3.2.4 Regulatory criteria or standards

The state Ground Water Quality Standards (GWQS) (chapter 173-200 WAC) apply to all groundwaters of the state. The parameter of primary interest for this study is nitrate with an upper limit of 10 mg/L-N. This limit corresponds with the federal maximum contaminant level for nitrate-N in drinking water (40 CFR Part 41).

4.0 Project Description

This study is designed to build on the previous monitoring efforts within the Sumas-Blaine aquifer to provide an annual assessment of nitrate concentrations so that trend evaluation may continue.

4.1 Project goals

The project goal is to continue monitoring the network of domestic water supply wells sampled since at least 2009 to determine trends in the nitrate-N concentrations in the Sumas-Blaine surficial aquifer. Best management practices (BMPs) occurring on the aquifer include the Whatcom County Conservation District's Application Risk Management (ARM) support system. ARM aids farmers with the application of their manure and fertilizers to prevent the unintended migration of nitrogen into the subsurface. A United States Geological Survey (USGS) report recently evaluated the effectiveness of the ARM method using several independent farming plots. The study results comparing plots employing the ARM and conventional application methodologies were inconclusive (Cox et al., 2018). The need to track the effectiveness of these BMPs and observe their impacts to groundwater quality is important to understanding the nitrate-N trends across the aquifer.

The network consists of approximately 25 to 35 domestic wells sampled on an annual basis since 2009 for nitrate-N, chloride, bromide, and field parameters. The purpose of this project is to determine future long-term nitrate-N trends using the same set of wells. In this study, Ecology will sample for nitrate-N, chloride, ammonia-N, and orthophosphate using laboratory analyses and specific conductance, dissolved oxygen, oxidation-reduction potential, temperature, and pH using field probes.

4.2 Project objectives

The project objectives are to:

- Continue to collect annual water quality data in March to limit seasonal variations.
- Compare concentrations to historical data.
- Compare concentrations to the Washington State groundwater quality standards (chapter 173-200 WAC).
- Determine if there are statistically significant trends using the nonparametric Mann-Kendall test for trends (Redding, 2009).

4.3 Information needed and sources

Groundwater quality data are available for the SBA from several studies listed in Section 3.2.2. Existing data include groundwater quality (nitrate-N, ammonia-N, chloride, bromide, and other field parameters), water levels, and aquifer properties.

Data from Ecology studies are available from the Environmental Information Management System (EIM) database[3] (Study IDs: Pilot, SUMAS, DERI001, EDAI0001, and mred0001). Data from the USGS are available from the National Water Information System (NWIS) database.[4]

4.4 Tasks required

The main tasks for this project include:

- Reconfirm annually the permission to sample 25 to 35 wells for water quality across the SBA.
- Schedule well sampling annually during a 2 to 4 week period in March to April.
- Schedule and coordinate sample testing with Ecology and Manchester Environmental Laboratory.
- Measure groundwater levels, where possible.
- Evaluate results for quality assurance (QA) using standard Environmental Assessment Program (EAP) QA procedures.
- Enter results into Ecology's EIM database.
- Evaluate EIM data for QA according to standard EAP procedures.
- Inform property owner of sample results by letter, email, or phone call.
- Plot the nitrate data over time to determine the Mann-Kendall trends.
- Prepare and publish an annual technical report and a 5-year assessment describing the results.

4.5 Systematic planning process

This Quality Assurance Project Plan serves as the planning document for the project.

[3] https://apps.ecology.wa.gov/eim/search/default.aspx
[4] https://waterdata.usgs.gov/nwis

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Jessica Archer Environmental Assessment Program Statewide Coordination Section Phone: 360-407-6698	EAP Client	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP.
Eric Daiber Groundwater, Forest, and Fish Unit Statewide Coordination Section Phone: 360-407-7169	Project Manager Principal Investigator	Writes the QAPP. Oversees field sampling and transportation of samples to the laboratory. Conducts QA review of data, analyzes and interprets data, and enters data into EIM. Writes the draft report and final report.
Pam Marti Groundwater, Forest, and Fish Unit Statewide Coordination Section Phone: 360-407-6768	Unit Supervisor for the Project Manager	Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Jessica Archer Statewide Coordination Section Phone: 360-407-6698	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Dale Norton Western Operations Section Phone: 360-407-6596	Section Manager for the study area	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Alan Rue Manchester Environmental Laboratory Phone: 360-871-8801	Manchester Lab Director	Reviews and approves the final QAPP.
Arati Kaza Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management database
QAPP: Quality Assurance Project Plan

5.2 Special training and certifications

Sampling will include one team of at least two people. One member will be experienced in sampling domestic water supply wells according to Standard Operating Procedure EAP096 (Carey, 2016). Analysis of results will require experience with GIS mapping and statistical software.

A hydrogeologist license is required to oversee hydrogeologic studies (chapter 18.220.020 RCW).

Staff will have completed the 40-hour Hazardous Waste Operations training or be up-to-date with annual refreshers.

5.3 Organization chart

N/A

5.4 Proposed project schedule

According to EAP's Quality Management Plan (Kammin, 2015), a QAPP must be reviewed and recertified every five years if the project exceeds this time frame. Table 3 outlines the proposed schedule of this long-term monitoring project.

Table 3. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Work type	Due date	Lead staff
Field and laboratory work		
Field work completed	March (annually)	Eric Daiber
Laboratory analyses completed	May (annually)	Eric Daiber
Environmental Information System (EIM) database		
EIM data loaded	June (annually)	Eric Daiber
EIM data entry review	July (annually)	Eugene Freeman
EIM complete	August (annually)	Eric Daiber
Final report		
Draft report due to supervisor	October (annually)	Eric Daiber / Pam Marti
Draft report due to client/peer reviewer	December (annually)	Eric Daiber / Pam Marti
Final report (all reviews done) due to publications coordinator	February (annually)	Eric Daiber / Pam Marti
Final report due on web	March (annually)	Eric Daiber / Pam Marti

The Environmental Information System (EIM) Study ID for this project is MRED0001.

5.5 Budget and funding

EAP will provide funding for the project. The itemized costs for the project are listed in Tables 4 and 5. The budget reflects the annual cost of running this project.

Table 4. Annual project budget and funding.

Item	Cost
Equipment and supplies (e.g., tubing, filters, gloves, calibration standards, flow cells, field meter repairs, etc.)	$1,000
Travel (2 staff for 1 week)	$1,200
Laboratory (see Table 5 below)	$1,950
Total Project Cost:	**$4,150**

Table 5. Annual laboratory budget and funding.

Parameter	Number of Samples	Number of QA Samples	Total Number of Samples	Cost Per Sample	Total
Nitrate+nitrite-N	25	5	30	$15	$450
Ammonia-N	25	5	30	$15	$450
Chloride	25	5	30	$15	$450
Orthophosphate	25	5	30	$20	$600
Laboratory Total					**$1,950**

6.0 Quality Objectives

6.1 Data quality objectives[5]

The primary Data Quality Objective (DQO) for this project is to continue the long-term monitoring of domestic water supply wells to develop trends in nitrate-N concentrations in the Sumas-Blaine aquifer. A secondary objective is the measurement of pH, specific conductivity, DO, ORP, temperature, ammonia-N, orthophosphate, and chloride to identify potential relationships between these parameters and nitrate-N. Sampling and analysis will be done using the standard methods described in this QAPP (Sections 8.0 and 9.0).

6.2 Measurement quality objectives

The sampling process should meet the Measurement Quality Objectives (MQOs) described below and are intended to ensure that the results for this study are comparable to previous study results listed in Section 3.2.2. Measurement quality objectives (MQOs) are performance or acceptance criteria for individual data quality indicators, including quantitative factors (precision, bias, sensitivity, and completeness) and qualitative factors (comparability and representativeness).

The measurement quality objectives (MQOs) for this project are presented in Tables 6 and 7. All water quality data collected for this project will be evaluated against the project MQOs. Providing pre-established criteria for data quality in the MQOs allows the determination of potential sources of error when evaluating precision and bias for the analytical method.

6.2.1 Targets for precision, bias, and sensitivity

6.2.1.1 Precision

Precision is a measure of the variability between replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures and climatic factors). Precision for laboratory duplicate samples will be expressed as relative percent difference (RPD) as shown in Table 6. The targets for precision are based on past performance characteristics of measurements performed by Manchester Environmental Laboratory (MEL).

Duplicate field samples will be collected by filling two bottles for each of the planned laboratory analyses. The bottle pairs for each analyte (or group of analytes) will be filled sequentially with minimal time passage between bottles. For example, we will fill one bottle for chloride and then quickly fill a second bottle for chloride. We will repeat this pattern for each constituent/bottle pair until all analytes have been collected.

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[5] DQO can also refer to ***Decision*** Quality Objectives. The need to identify Decision Quality Objectives during the planning phase of a project is less common. For projects that do lead to important decisions, DQOs are often expressed as tolerable limits on the probability or chance (risk) of the collected data leading to an erroneous decision. And for projects that intend to estimate present or future conditions, DQOs are often expressed in terms of acceptable uncertainty (e.g., width of an uncertainty band or interval) associated with a point estimate at a desired level of statistical confidence.

6.2.1.2 Bias

Bias is the difference between the population mean and the true value. Bias will be addressed by calibrating field equipment at the start of the week and checking the calibration each day. If any of the field parameters does not meet the acceptance criterion, then that parameter will be recalibrated (Table 7). Laboratory instruments will be calibrated per standard procedures and by analyzing lab control samples, matrix spikes, and/or standard reference materials. Targets for bias in terms of acceptable percent recovery are listed in Table 6.

Table 6. Measurement quality objectives.

MQO →	Precision		Bias			Sensitivity
Parameter	Duplicate samples (lab samples)	Matrix spike-duplicates	Verification standards (LCS,CRM,CCV)	Matrix spikes	Surrogate standards	MDL or lowest conc. of interest
	Relative percent difference (% RPD)		Recovery limits (%)			Concentration units
Temperature	N/A	N/A	N/A	N/A	N/A	2°C
pH	N/A	N/A	See Table 7	N/A	N/A	N/A
Specific conductivity	N/A	N/A	See Table 7	N/A	N/A	10 µS/cm
Dissolved oxygen (DO)	N/A	N/A	See Table 7	N/A	N/A	0.1 mg/L
Oxidation-reduction potential (ORP)	N/A	N/A	See Table 7	N/A	N/A	N/A
Water level	0.02	N/A	N/A	N/A	N/A	0.01 ft
Ammonia-N	20	N/A	20	+/-25	N/A	0.010 mg/L
Nitrate+nitrite-N	20	N/A	20	+/-25	N/A	0.010 mg/L
Chloride	20	N/A	20	+/-25	N/A	0.1 mg/L
Orthophosphate	20	N/A	20	+/-25	N/A	0.001 mg/L

MDL = method detection limit.

Table 7. Measurement quality objectives for field parameters expressed as acceptance criteria for field instrument pre-calibration and post-calibration.

Pre- and Post-Use Calibration Acceptance Criteria by Parameter		
Parameter	**Pre-calibration**	**Post-calibration**
pH	Less than or equal to ±0.05, Pass	Less than or equal to ±0.15, Pass
	Greater than ±0.05, recalibrate	Greater than ±0.15 and less than or equal to ±0.5, "J" Qualify
		Greater than ±0.5, "Reject" Qualify
Conductivity	Less than or equal to ±2%, Pass	Less than or equal to ±5%, Pass
	Greater than ±2%, recalibrate	Greater than ±5% and less than or equal to ±10%, "J" Qualify
		Greater than ±10%, "Reject" Qualify
DO	N/A	Less than or equal to ±5%, Pass
	N/A	Greater than ±5% and less than or equal to ±10%, "J" Qualify
	N/A	Greater than ±10%, "Reject" Qualify
ORP	Less than or equal to ±2%, Pass	Less than or equal to ±5%, Pass
	Greater than ±2%, recalibrate	Greater than ±5% and less than or equal to ±10%, "J" Qualify
		Greater than ±10%, "Reject" Qualify

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as a *detection limit*. In a regulatory sense, the method detection limit (MDL) is usually used to describe sensitivity. Targets for field and lab measurement sensitivity required for the project are listed in Table 6.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

Comparability expresses the confidence with which one set of data can be compared to another. Comparability will be ensured to the extent possible by implementing standard operating procedures (SOPs) for sampling and analysis. SOPs to be used during the study are listed in Section 8.2. We will compare data collected in this study with data collected in previous studies conducted in this area, especially Erickson (2000, 1998), Redding (2008), Carey (2017), and Daiber et al. (2019).

Overall, laboratory and field methods used in 1997 (Erickson, 1998) are consistent with those used since 2003. The exception is that the samples collected in 1997 were not filtered. Filtering the groundwater does not make a statistical difference in the nitrate-N concentration (Redding, 2011; Daiber et al., 2019). EAP's standard practice for samples collected from 2003 to 2016 has been to filter samples in the field.

6.2.2.2 Representativeness

Representativeness expresses the degree to which data accurately and precisely represent the actual site conditions. In order to obtain samples representative of the aquifer, we will follow SOPs for groundwater sampling as listed in Section 8.2, ensure that field meters are properly calibrated, and ensure consistency in sampling procedures.

Samples will be collected March through April to represent the same season and conditions as those for samples collected in comparable studies (Redding, 2009; Carey, 2018).

6.2.2.3 Completeness

Completeness establishes whether a sufficient amount of valid measurements were obtained to meet project objectives. The number of samples and results expected establishes the comparative basis for completeness. The overall goal for the Sumas-Blaine Aquifer long-term groundwater monitoring project is to correctly collect and analyze 100% of the planned measurements and samples. However, problems occasionally arise during sample collection that cannot be controlled. Therefore, a completeness of 95% is acceptable. Example problems are equipment failure and site access issues.

6.3 Acceptance criteria for quality of existing data

Nitrate-N results collected in this study will be compared with data previously collected by Ecology and the USGS. Existing data for the study area are in the EIM database under the following study IDs: PILOT, BCAR003, SUMAS, DERI001, mkim0001, edai0001, and mred0001. These project data have a high level of quality assurance (Level 4).

Table 8. Quality assurance level descriptions.

QA Level	Description
Level 1	Informal or no QA documentation
Level 2	Generic or incomplete document
Level 3	QAPP, SAP, or equivalent
Level 4	Approved QAPP or SAP

Nitrate data and other parameters collected by the USGS are stored in the National Water Information System (NWIS) database. The data quality are high.

6.4 Model quality objectives

N/A

7.0 Study Design

7.1 Study boundaries

The Sumas-Blaine aquifer study area includes the portion of the Abbotsford-Sumas aquifer that is located in the United States (see Figure 1). Distinct watershed drainages are identified throughout Washington State as Water Resource Inventory Areas (WRIAs). There are a total of 62 WRIAs in Washington State. The Sumas-Blaine aquifer is contained completely within WRIA 1. The aquifer is separated into three hydrologic unit codes (HUC), which are defined by the USGS as the hydrologic units within a river subbasin.[6] The HUC codes for the SBA are 17110001, 17110002, and 17110004.

7.2 Field data collection

The proposed sampling locations are the same as those sampled by Ecology from 2009 to 2016 (Redding, 2009; Carey, 2017).

7.2.1 Sampling locations and frequency

The monitoring locations in this study were selected by Redding (2009) using the following criteria:

- The well must be completed exclusively in the Sumas-Blaine surficial aquifer.
- The property owner must give permission to participate in the study.
- Well construction must meet well construction standards specified in chapter 173-160 WAC.
- The well log should be available and the completed well depth known.
- The well discharges water with elevated nitrate concentrations.
- The well must be accessible to sample using a spigot.
- The water must be untreated prior to discharging from the spigot/sample point.

At least 25 wells meet the above criteria and have been sampled annually for nitrate-N and other parameters since 2009. Locations and well construction details are included in Appendix A.

Wells will continue to be sampled annually in the spring (March/April). Depending on continued availability, wells will be added to the monitoring program to replace lost wells or to fill spatial data gaps in the monitoring program.

7.2.2 Field parameters and laboratory analytes to be measured

The parameters to be measured and sampled include:

- Depth to water (where accessible and owner grants permission) (Field)
- Temperature (Field)
- pH (Field)

[6] https://pubs.usgs.gov/gip/hydrologic_units/pdf/hydrologic_units.pdf

- Specific conductivity (Field)
- Dissolved oxygen (DO) (Field)
- Oxidation-reduction potential (ORP) (Field)
- Nitrate-N (Laboratory)
- Ammonia-N (Laboratory)
- Chloride (Laboratory)
- Orthophosphate (Laboratory)

7.3 Modeling and analysis design

Section 7.3 is relevant only if a numerical or analytical model is being used to describe processes at the site. Since a model is not being used, modeling and analysis will not be addressed.

7.4 Assumptions underlying design

The study design is based on the following assumptions:

- Sampling at the same time of year as previous studies minimizes the influence of seasonal variation when comparing results (Redding, 2009). This assumes that seasonal climate factors that affect sample results are consistent each year (i.e., precipitation, temperature, etc.).
- Distribution of wells sampled will be in three areas of concern: northeast, west, and south of Lynden, Washington.
- Changes in nitrogen loading to groundwater from various land uses (e.g., agriculture and residential) will be reflected in samples from the wells.

7.5 Possible challenges and contingencies

The primary challenge of this study relates to accessing private property to sample domestic water supply wells over the course of this project.

7.5.1 Logistical problems

Miscommunication with property owners is the main potential logistical problem. We will make sure that property owners are given verbal or written permission to sample their wells and that they have agreed to the date and time that we will be there to sample. If our schedule changes during the sampling event, we will notify the affected property owners.

7.5.2 Practical constraints

Sampling between 25and 35 wells within a 1 week period will require efficient logistical planning. We plan to have one team of at least two people working for at most 1 week.

7.5.3 Schedule limitations

Changes in project prioritization and workload for EAP staff could affect the project schedule. Factors that can cause delays to the proposed project schedule include:

- Time required for QAPP review and approval.
- Unforeseen field or laboratory complications (e.g., inability to collect samples from selected wells, problems with laboratory analytical equipment).

8.0 Field Procedures

8.1 Invasive species evaluation

N/A

8.2 Measurement and sampling procedures

Groundwater sampling procedures for the study will follow these Ecology SOPs:

- EAP033 for measurements using a Hydrolab (Anderson, 2016).
- EAP052 for depth-to-water measurements (Marti, 2018).
- EAP096 for sampling water supply wells for general chemistry (Carey, 2016).

Field measurements will be made at all sampling sites and recorded on waterproof field logs. Measurements for temperature, pH, specific conductivity, oxidation-reduction potential, and dissolved oxygen will be collected using a calibrated Hydrolab MiniSonde following Ecology's SOP EAP033 (Anderson, 2016) and manufacturer's recommendations. Field measurement methods are listed in Table 9.

Table 9: Field measurement methods.

Analyte	Sample matrix	Samples (number)	Expected range of results	Detection or reporting limit	Instrumental method
Water level	Water	100	0–20 feet	0.1	Electrical tape
Temperature	Water	200	8–12°C	0.2°C	Hydrolab MS-5
pH	Water	200	4-8 S.U.	N/A	Hydrolab MS-5
Specific conductivity	Water	200	50–1,000 µS/cm	5 µS/cm	Hydrolab MS-5
Dissolved oxygen	Water	200	0.0–10 mg/L	0.1 mg/L	Hydrolab MS-5
Oxidation-reduction potential	Water	200	(-300)–(+350) mv	NA	Hydrolab MS-5

Water supply wells will be purged using a Y-fitting on an outdoor faucet as laterally close to the well head as possible. One discharge from the Y-fitting will be connected to a garden hose and set at a high discharge rate. The other outlet from the Y-fitting will be connected to an airtight flow-through chamber set at a low flow rate (~ 300 mL/minute).

Purging will continue until the volume of water in the well's storage tank has been discharged and field parameters are stable (temperature, pH, specific conductance, dissolved oxygen, and oxidation-reduction potential). This typically requires about 30 minutes. All laboratory-bound samples will be field filtered into the appropriate container (Table 10) using disposable in-line filters (0.45 µm) and then stored on ice. Additional groundwater quality sampling details are specified in SOP EAP096 (Carey, 2016).

8.3 Containers, preservation methods, holding times

Groundwater samples will be analyzed in the laboratory for the parameters shown in Table 10.

Table 10. Sample containers, preservation, and holding times.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
Ammonia-N and Nitrate+nitrite-N	Water	125 mL	poly, clear	H_2SO_4 to pH<2; Cool to 6°C or less	28 days
Orthophosphate	Water	125 mL	poly, amber	Cool to 6°C or less	48 hours
Chloride	Water	500 mL	poly, clear	Cool to 6°C or less	14 days

8.4 Equipment decontamination

Each day a pre-cleaned Y-fitting and sample tube assembly, as shown in Figure 2, will be used. After each location is sampled the Y-fittings and connectors will be cleaned with detergent and rinsed with tap water then deionized water. The cleaned sampling assemblies will be stored in a zip-lock plastic bag between sampling locations. Cleaned sampling assemblies will then be stored in clean zip-lock plastic bags to be used the next sample day.

Sample tubing will be de-contaminated between sites by pre-sample purging of the sample tubing after the well and storage tank have been purged using the Y-fitting shown in Figure 2.

A new pre-packaged in-line filter will be used for each sample. At least 1 liter of water will be rinsed through the sample tubing and filter before a sample is collected.

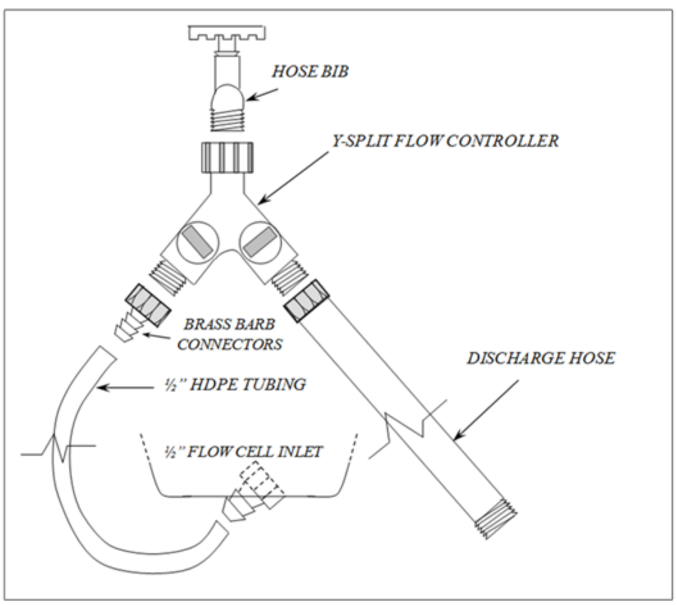

Figure 2. Y-fitting for purging and sampling water supply wells. *Purge water from the well and storage tank discharge from the right side of the Y. The sample tubing is attached to the left side of the Y.*

8.5 Sample ID

Well IDs will use the State of Washington well-numbering system. The State of Washington's well-numbering system uses the public land survey well-numbering system described in Appendix B.

MEL will provide the field lead with work order numbers for all scheduled sampling dates. The work order number will be combined with a field ID number that is given by the field lead. This combination of work order number and field ID number constitute the sample ID. All sample IDs will be recorded in field logs and in an electronic spreadsheet for tracking purposes.

8.6 Chain of custody

Once collected, samples will be properly labeled and stored in ice-filled in coolers inside the sampling vehicle. If the sample vehicle is left unattended, it will be locked to maintain chain of custody. Upon return to Ecology's Operations Center, the chain of custody portion of the "Laboratory Analysis Required" sheet will be filled out and the coolers will be placed in the walk-in cooler.

Sample coolers will be secured with either metal clips or seals. Identification numbers for the metal clips or seals will be recorded on the "Laboratory Analysis Required" form that will be placed in a plastic bag inside one of the coolers.

If the sample team returns to the Operations Center on Friday, samples will be placed in new coolers with blue ice to maintain freezing temperatures in the coolers and stored in the walk-in cooler, for transport to MEL on Monday morning. Samples brought to the Operations Center on Thursday do not require transfer to new coolers and will be transported to MEL on Friday morning (Carey, 2018).

8.7 Field log requirements

A field log will be maintained by the field lead and used during each sampling event. The following information will be recorded:

- Name and location of project
- Field personnel
- Sequence of events
- Any changes or deviations from the project QAPP
- Environmental conditions
- Date, time, location, ID, and description of each sample
- Field instrument calibration procedures
- Field measurement results
- Identity of quality control (QC) samples collected
- Unusual circumstances that might affect interpretation of results

Field logs will consist of waterproof 8.5 × 11-inch field sheets preprinted for ease of recording and kept in an enclosed metal clipboard. Permanent waterproof ink or pencil will be used for all entries.

8.8 Other activities

Additional activities include:

- Any field staff new to the type of sampling conducted for this study will be trained by senior field staff or the project manager following relevant Ecology SOPs.
- The Hydrolab MS5 mini sondes will be calibrated at the beginning of the week and checked at the beginning of each day for issues with calibration. If needed, mini sondes will be re-calibrated to meet MQOs (Table 6).
- The project lead will notify the lab of any changes in scheduling.
- The project lead will work with the laboratory courier to develop a schedule for delivery of sampling containers in order to ensure that the appropriate number and type of required samples containers are available.

9.0 Laboratory Procedures

9.1 Lab procedures table

Analytes for this project along with the expected number of samples and an expected range of results are listed in Table 11.

Table 11. Measurement methods (laboratory).

Analyte	Sample matrix[1]	Samples (number)	Expected range of results (mg/L)	Detection or reporting limit (mg/L)	Sample prep method	Analytical (instrumental) method[2,3]
Ammonia-N	FW	30	0.001 - 2.00	0.010	N/A	SM 4500 NH3 H[2]
Nitrate+nitrite-N	FW	30	0.01 - 60.0	0.010	N/A	SM 4500 NO3 I[2]
Chloride	FW	30	0.1 - 30	0.1	N/A	EPA 300.0[3]
Orthophosphate	FW	30	0.1 – 2	0.1	N/A	SM 4500 PG[2]

[1] Filtered water

[2] *Standard Methods for the Examination of Water and Wastewater, 23rd Edition* (Rice et al., 2017).

[3] EPA/600/R-93/100, *Methods for the Determination of Inorganic Substances in Environmental Samples*, August 1993.

9.2 Sample preparation methods

Well water will be filtered in the field using clean disposable 0.45 µm filters and collected in pre-acidified bottles (nitrogen species) or non-acidified sample bottles (chloride and orthophosphate) supplied by Ecology's Manchester Environmental Laboratory (MEL) as specified in EAP096 (Carey, 2016).

The laboratory will follow standard sample preparation procedures for the measurement methods listed in Table 11.

9.3 Special method requirements

N/A

9.4 Laboratories accredited for methods

All chemical analysis for water samples will be performed at MEL, which is accredited for all methods listed in Table 11.

10.0 Quality Control Procedures

Quality control (QC) procedures provide the information needed to assess the quality of the data that is collected. They can also help identify problems or issues associated with data collection and analysis while the project is underway.

Total precision for field sampling and laboratory analysis will be assessed by collecting replicate samples. MEL routinely duplicates sample analyses in the laboratory to determine laboratory precision. Field blanks, such as an equipment blank, will be used to check for sample contamination.

The primary types of quality control samples used to evaluate and control the accuracy of laboratory analyses are check standards, duplicates, spikes, and blanks (MEL, 2016b). Check standards serve as an independent check on the calibration of the analytical system and can be used to evaluate bias. Duplicates are used to evaluate laboratory precision. Matrix spikes are used to check for matrix interference with detection of the analyte and can be used to evaluate bias as it relates to matrix effects. Blanks are used to check for sample contamination in the laboratory process.

10.1 Table of field and laboratory quality control

Table 12 lists the field and laboratory QC requirements for the project.

Table 12. Quality control samples, types, and frequency.

Parameter	Field		Laboratory			
	Blanks[1]	Replicates[2]	Check standards	Method blanks	Analytical duplicates	Matrix spikes
Ammonia-N	2	15%	1/15 samples	1/15 samples	1/15 samples	1/15 samples
Nitrate+nitrite-N	2	15%	1/15 samples	1/15 samples	1/15 samples	1/15 samples
Chloride	2	15%	1/15 samples	1/15 samples	1/15 samples	1/15 samples
Orthophosphate	2	15%	1/15 samples	1/15 samples	1/15 samples	1/15 samples

[1] Field blanks include: 1 trip blank/week; 1 filter blank/week
[2] All of field replicates samples will be field-filtered

Each type of QC sample listed above has a MQO associated with it (Section 6.2) that will be used to evaluate the quality and usability of the results.

10.2 Corrective action processes

QC results may indicate problems with data during the course of the project. The lab will follow prescribed procedures to resolve the problems. Options for corrective actions might include:

- Recalibrating the measurement equipment.
- Collecting new samples using the method described in the approved QAPP.

- Re-analysis of lab samples that do not meet QC criteria (analytical methods often state what to do when QC criteria are not met).
- Convening project personnel and technical experts to decide on the next steps that need to be taken to improve sampling or laboratory performance.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

All field data will be recorded on field log sheets. Field logs will be checked for missing or improbable measurements before leaving each site. Field-generated data will be entered into Microsoft Excel spreadsheets as soon as practical after returning from the field. Data entry will be checked by the principal investigator against the field log data for errors and omissions. Missing or unusual data will be brought to the attention of the field lead or project manager for consultation. The final reviewed field data will then be entered into EIM.

Lab results will be checked for missing and/or improbable data. Data received from MEL through Ecology's Laboratory Information Management System (LIMS) will be checked for omissions against the Request for Analysis forms by the field lead. Data requiring additional qualifiers due to laboratory or field issues will be reviewed by the project manager.

11.2 Laboratory data package requirements

Laboratory-generated data reduction, review, and reporting will follow the procedures outlined in the MEL *Lab Users Manual* (MEL, 2016a). Variability in lab duplicates will be quantified using the procedures outlined in the MEL *Lab Users Manual*. Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory QA/QC results will be sent to the project manager for each set of samples.

11.3 Electronic transfer requirements

MEL will electronically transfer all laboratory-generated data to the project manager through the LIMS to the EIM data feed. There is already a protocol in place for how and what MEL transfers to EIM through LIMS.

11.4 EIM/STORET data upload procedures

All field and laboratory data will be entered into EIM, following existing Ecology business rules and the EIM User's Manual.

11.5 Model information management

N/A

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

Field audits are always appropriate for a project involving either field measurements or sampling. It is likely that insufficient QA resources are currently available for auditing activities; however, there could be a field consistency review of the project by another experienced EAP hydrogeologist. The aim of such reviews is to improve consistency of fieldwork, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen our data quality assurance program.

12.2 Responsible personnel

See Section 12.1.

12.3 Frequency and distribution of reports

A technical memo or report will be published according to the project schedule shown in Section 5.4.

12.4 Responsibility for reports

The EAP project manager will be the lead on any final technical memo or report. The work will be performed by or under the supervision of a licensed hydrogeologist.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

Initial field data verification will be performed by the team lead (an EAP hydrogeologist) immediately after completing field measurements/sample collection prior to departing the site. This process involves checking the field log sheets for omissions or outliers. If measurement data are missing or a measurement is determined to be an outlier, the measurement will be repeated.

After each sampling day, the project manager will evaluate all field data to determine compliance with MQOs (Table 6). Values that are out of compliance with the MQOs will be noted and, if necessary, wells will be resampled and or equipment recalibrated. At the conclusion of the study, any values that are not in compliance will be compiled and assessed for usability by the project lead.

13.2 Laboratory data verification

MEL staff will perform the laboratory verification following standard laboratory practices. After the laboratory verification, a secondary verification of each data package will be performed by the project manager. This secondary verification will entail a detailed review of all parts of the laboratory data package with special attention being paid to laboratory QC results. If any issues are discovered, they will be resolved by the project manager.

13.3 Validation requirements, if necessary

N/A

13.4 Model quality assessment

N/A

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

After all laboratory and field data are verified, a detailed examination of the data package will be performed. The project manager will examine the entire data package to determine if all the criteria for MQOs, completeness, representativeness, and comparability have been met. If the criteria have not been met, the project manager will decide if affected data should be qualified or rejected, based upon the decision criteria from the QA Project Plan (Tables 6 and 7). The project manager will decide how any qualified data will be used in the technical analysis.

14.2 Treatment of nondetects

Any nondetects will be included in the study analysis. For summary statistics, nondetects will be treated as half the detection limit. Nitrate-N, ammonia-N and orthophosphate results may be nondetects.

14.3 Data analysis and presentation methods

Data will be presented in tabular and graphic form. Groundwater quality results will be presented in tabular, graphic, and geographical form.

Data analysis will include analyzing past and present data by using summary statistics and the nonparametric Mann-Kendall test for trends. This test is a monotonic trend analysis that evaluates trends in data where seasonal variations exist (EPA, 1989; Fisher and Potter, 1989). A monotonic trend is one which is exclusively increasing or decreasing, but not both (EPA, 2000). The null hypothesis (H_O) is that the samples are independent and identically distributed variables that are random with respect to time, and therefore no distinguishable trend is present. The alternate hypothesis (H_A) is that a trend is present, either increasing or decreasing. The type of trend is determined by whether the calculated Mann-Kendall statistic (S) is positive or negative (Aroner, 1994). This nonparametric test can accommodate missing values, values less than the detection limit, and a non-normally distributed data set (Gilbert, 1987; Redding, 2009).

Once the data have been reviewed, verified, and validated, the project manager will determine if the data can be used toward the project goals and objectives. Verified analytical data will be presented in a technical memo or report.

The technical memo or report will be prepared at the completion of the sampling and will include the following:

- Maps of the study area showing sample sites, contaminant concentrations, and distributions.
- Description of field and laboratory methods.
- Discussion of data quality and the significance of any problems encountered.
- Summary tables of field and analytical data.
- Discussion of water quality results and comparison of results to site's historical data if available.

- Conclusions and recommendations.

14.4 Sampling design evaluation

The project manager will decide whether the data package meets the MQOs, criteria for completeness, representativeness, and comparability, and whether meaningful conclusions can be drawn from the data. If so, the sampling design will be considered effective.

14.5 Documentation of assessment

The project manager will include a section in the technical memo/report summarizing the findings of the data quality assessment.

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16.0 Appendices

Appendices:

- Appendix A: Well Construction Information from Drilling Logs
- Appendix B: USGS Well Numbering System
- Appendix C: Glossaries, Acronyms, and Abbreviations

Appendix A. Well Construction Information from Drilling Logs

The wells shown are an adopted list from Carey (2017). Additional details for each well are available in the EIM database: https://apps.ecology.wa.gov/eim/search/default.aspx.

Figure A.1: Well construction information associated with the wells sampled in the historical long-term monitoring projects.

EIM Location ID	Well Tag ID	Calculated Latitude Decimal Degrees NAD83HARN	Calculated Longitude Decimal Degrees NAD83HARN	Land Surface Elevation (ft)[a]	Well Completion Depth (ft)[b]	Well Maximum Casing Diameter (in)
40308P1	BCS965	48.96550568	-122.45574026	117	15 R	36
N39212C1	AGF141	48.88921750	-122.49708341	84	36.5	36
N39212K2	BCS954	48.88235623	-122.49546731	88	20	12
N39215J1	BCS955	48.86901000	-122.53454000	67	22	12
N39221H1	BCS956	48.85739000	-122.55348000	56	25	6
N39307H1	BCS953	48.88593598	-122.46649528	89	29	6
N39317H1	BCS951	48.87019572	-122.44692255	99	118	18
N40211P1	BCS957	48.96709338	-122.52151600	111	31	8
N40214P1	BCS962	48.95121400	-122.52083000	97	42	36
N40221J5	BCS961	48.94233000	-122.55557000	89	17	18
N40222D1	BCS963	48.94972619	-122.54796152	96	Unknown	18
N40223A3	BCS958	48.94672600	-122.51356100	94	23	6
N40226B1	BCS959	48.93368898	-122.51616788	84	38	36
N40226D2	BCS960	48.93241888	-122.52442402	75	15 R	Unknown
N40227C1	BCS969	48.93517030	-122.54201898	78	32 R	18
N40303Q1	AGT433	48.98015933	-122.40625597	138	30	6
N40305N3	BCS964	48.97977161	-122.45937034	130	26	36
N40307H1	No Tag	48.97588306	-122.46361431	123	21	36
N40310F1	BCS968	48.97740000	-122.40799000	136	21	36

EIM Location ID	Well Tag ID	Calculated Latitude Decimal Degrees NAD83HARN	Calculated Longitude Decimal Degrees NAD83HARN	Land Surface Elevation (ft)[a]	Well Completion Depth (ft)[b]	Well Maximum Casing Diameter (in)
N40315L1	BCS973	48.95593000	-122.41259000	109	20 R	6
N41333M1	BCS970	49.00097000	-122.44031000	150	43	6
N41334E1	BCS971	49.00196000	-122.41852000	151	20	36
N41431Q1	ABO112	48.99363178	-122.33551990	171	50	6
N41431Q3	AGO409	48.99387704	-122.33569000	170	49	36
N39307K2	BCS952	48.88399788	-122.47327302	86	24	36
N39308F2	No Tag	48.88459809	-122.45630284	90	20	12
N40331P3	BCS966	48.90698000	-122.47590000	82	36	18
N40331L1	BCS967	48.91228517	-122.47878263	70	30	18
N40303B1	BCS972	48.99206000	-122.40640000	147	29	6

[a] NAVD 88 -Vertical datum

[b] R -Reported well depth, no drillers log available

Appendix B: USGS Well Numbering System

The following excerpt from Jones et al. (2006) explains the USGS well numbering system:

> The USGS assigns numbers to wells and springs in Washington that identify their location in a township, range, and section. Well number 20N/15E-26N01 indicates successively, the township (T. 20 N.) and the range (R. 15 E.) north and east of the Willamette baseline and meridian (Figure B.1). The first number following the hyphen indicates the section (26) within the township, and the letter following the section number (N) gives the 40-acre subdivision of the section, as shown above. The number (01) following the letter is the sequence number of the well within the 40-acre subdivision.

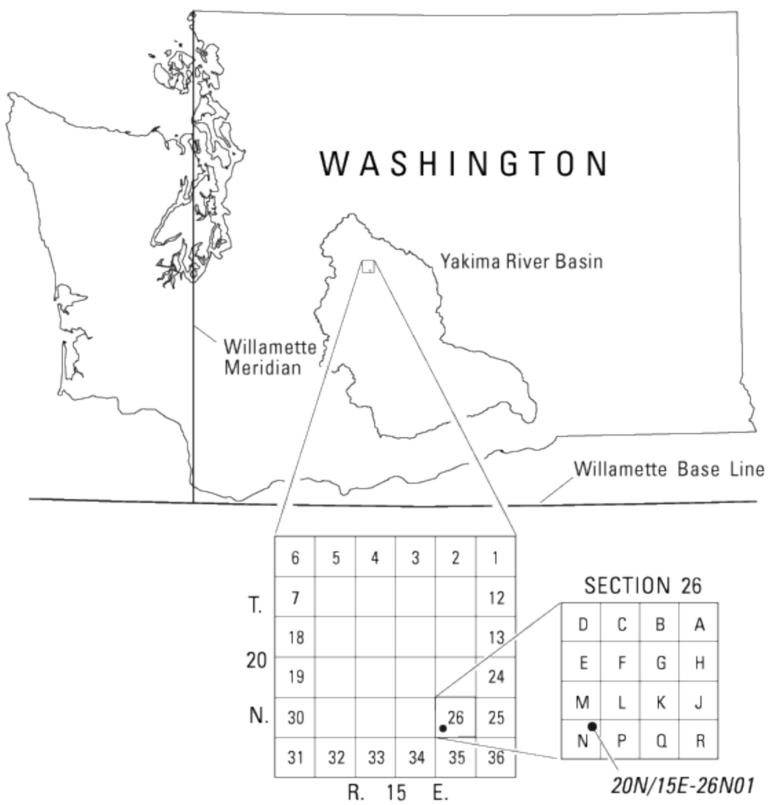

Figure B.1: Example of USGS well numbering system.

Reference for Appendix B:

Jones, M.A., J.J. Vaccaro, and A.M. Watkins. 2006. Hydrogeologic Framework of Sedimentary Deposits in Six Structural Basins, Yakima River Basin, Washington. U.S. Geological Survey Scientific Investigations Report 2006–5116. https://pubs.usgs.gov/sir/2006/5116/.

Appendix C Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Ammonia-N: The ammoniac nitrogen is a measure of the nitrogen ion in the ammonia compound.

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.

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

Nitrate+nitrite-N: The sum concentration of nitrate and nitrite referring to the amount of nitrogen ion present.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Maximum Contaminant Level (MCL): A standard that is set by the U.S. Environmental Protection Agency (EPA) for drinking water quality. An MCL is the legal threshold limit on the amount of a substance that is allowed in public water systems under the Safe Drinking Water Act.

Oxidation-reduction potential (ORP): A measure of the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species affinity for electrons and tendency to be reduced**.**

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.

SAP: Sampling and analysis plan.

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

ARM	Application Risk Management
DO	Dissolved oxygen (see Glossary above)
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
GPS	Global Positioning System
HUC	Hydrologic unit code
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NWIS	National Water Information System
ORP	Oxidation-reduction potential
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
RSD	Relative standard deviation
SAP	Sampling and analysis plan
SBA	Sumas-Blaine aquifer
SOP	Standard operating procedures
SRM	Standard reference materials
USGS	United States Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
ft	feet
mg/L	milligrams per liter (parts per million)
s.u.	standard units
µg/L	micrograms per liter (parts per billion)
µS/cm	microsiemens per centimeter, a unit of conductivity

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy*. (USGS, 1998)

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella. (Kammin, 2010)

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time and is characteristic of both the measurement system and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI). (Kammin, 2010; Ecology, 2004)

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process. (USGS, 1998)

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured. (Ecology, 2004)

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS. (Kammin, 2010; Ecology, 2004)

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator. (USEPA, 1997)

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator. (USEPA, 1997)

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run. (Kammin, 2010)

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system. (Kammin, 2010; Ecology 2004)

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean. (Kammin, 2010)

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading. (Kammin, 2010)

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity. (USEPA, 2006)

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. (USEPA, 2006)

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010)

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability, and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier – data are usable for intended purposes.
- J (or a J variant) – data are estimated, may be usable, may be biased high or low.
- REJ – data are rejected, cannot be used for intended purposes.
  (Kammin, 2010; Ecology, 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set. (Ecology, 2004)

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis. (USEPA, 1997)

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport. (Ecology, 2004)

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples. (Kammin, 2010)

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. (USEPA, 1997)

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects. (Ecology, 2004)

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness. (USEPA, 2006)

Measurement result: A value obtained by performing the procedure described in a method. (Ecology, 2004)

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed. (EPA, 1997)

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples. (Ecology, 2004; Kammin, 2010)

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40 CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples. (Kammin, 2010)

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all "parameters." (Kammin, 2010; Ecology, 2004)

Population: The hypothetical set of all possible observations of the type being investigated. (Ecology, 2004)

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator. (USGS, 1998)

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data. (Kammin, 2010)

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data. (Ecology, 2004)

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled. (USGS, 1998)

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator. (USGS, 1998)

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population. (USGS, 1998)

Sample (statistical): A finite part or subset of a statistical population. (USEPA, 1997)

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit. (Ecology, 2004)

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method. (USEPA, 1997)

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency. (USEPA, 1997)

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin, 2010)

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity. (Kammin, 2010)

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis. (Kammin, 2010)

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning. (USEPA, 2006)

References for QA Glossary

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