Streaming Nooksack Report
Whatcom County, Washington

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Prepared by:
U.S. Environmental Protection Agency, Region 10
Lummi Natural Resources
Whatcom Conservation District

Streaming Nooksack Final Report

Contents

Overview

This report summarizes the findings of the Streaming Nooksack pilot project. The Streaming Nooksack pilot project involved the installation of five real-time water quality monitors known as ZAPS LiquID™ Monitor (monitor) (LID), in the Nooksack River watershed and evaluation of monitor accuracy. Section 1 provides background information about the watershed in which the pilot project was conducted. It provides the context of the water quality challenges and existing monitoring efforts in the Nooksack River watershed. Section 2 provides further details on the Streaming Nooksack pilot project including: monitor information, installation, and maintenance procedures; installation locations; data quality objectives; lab sampling strategy and monitor data use; data management; and dataset limitations. Section 3 summarizes the results of the pilot project including several statistical approaches for evaluating monitor accuracy, with additional details on these analyses presented in Appendices A-E. Section 4 provides a discussion of the data quality objectives. Section 5 presents the conclusions of the Streaming Nooksack pilot project.

Contributors and authors include Nichole Embertson and Scarlett Graham of the Whatcom Conservation District, Hanna Winter of the Lummi Natural Resources, Steven Potokar and Fran Kremer of the U.S. Environmental Protection Agency, and Nicholas Tallant of the Virtual Student Federal Service (VSFS) program.

1. Background

Water quality in the Nooksack River watershed has been challenged with high fecal bacteria densities for decades. The sources of fecal coliform bacteria pollution are varied, widespread, and dependent upon surrounding land use. Progress has been made in reducing fecal numbers in many Nooksack River sub-watersheds as a result of inter-agency coordination (particularly the Whatcom Clean Water Program's Pollution Identification and Control Program), water quality monitoring, compliance enforcement inspections, and technical assistance (WCWP 2018, 2019). However, persistent seasonal and storm event water quality issues still arise within the Nooksack drainage, threatening the safety and sustainability of shellfish production at its mouth in Portage Bay.

The Nooksack River watershed comprises the majority of the Water Resources Inventory Area 1 (WRIA 1) located primarily in Whatcom County in Washington State and includes a portion of its watershed in Skagit County and British Columbia, Canada (Figure 1). From its headwaters in the northwestern Cascade Mountains, the Nooksack River drains approximately 786 square miles, comprising most of western Whatcom County, including agricultural areas and the developed lowlands surrounding the towns of Deming, Everson, Lynden, and Ferndale. The Nooksack River enters the Lummi Indian Reservation at its eastern extent, which contains a large portion of the river delta before it discharges into the marine waters of Bellingham Bay. The Nooksack River is also the primary source of freshwater into Portage Bay, which is located approximately 5 miles southwest of the Nooksack River delta (DOH 1997).

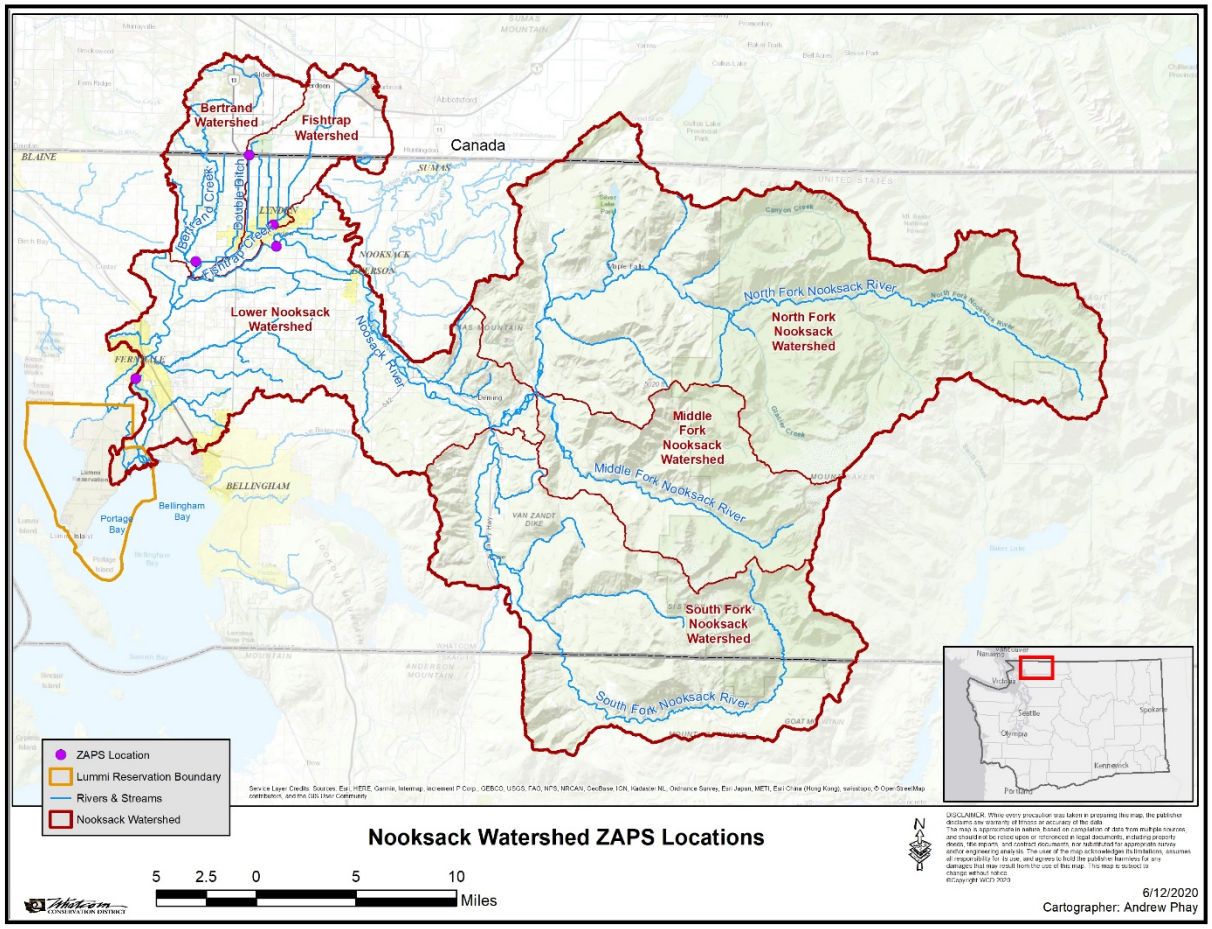

Figure 1. Regional Location of the Nooksack River Watershed, the Lummi Reservation, and Portage Bay.

Portage Bay is located within the Lummi Indian Reservation boundaries and contains important shellfish beds harvested for commercial, ceremonial, and subsistence purposes by members of the Lummi Nation. Fecal coliform contamination from the Nooksack River presently and historically has threatened Portage Bay shellfish growing areas and resulted in shellfish harvest closures. Runoff from the Nooksack River watershed also includes nutrients and sediment.

In order to protect public health and safety, the Lummi Nation, in consultation with the Washington State Department of Health (DOH; *United States v. Washington [Shellfish]* 1994), restricted shellfish harvesting year-round in a portion of Portage Bay from 1996 to 2006. The cause of the downgrades was attributed to polluted Nooksack River water entering Portage Bay (DOH 1997; Ecology 2000); a Total Maximum Daily Load (TMDL) for the Nooksack River was developed (Ecology 2000) and a TMDL implementation plan was executed (Ecology 2002). Water quality in the Nooksack River watershed and the Portage Bay shellfish growing area improved and shellfish harvest was fully reopened in 2006.

Beginning in 2010, water quality began to decline in the Nooksack River watershed and Portage Bay shellfish growing area. In September 2014, in order to protect public health and safety, the

Lummi Nation voluntarily closed 335 acres of shellfish growing area in Portage Bay when the National Shellfish Sanitation Program (NSSP) standards were not achieved at two water quality monitoring stations. After poor water quality affected additional stations in November 2014, the Lummi Nation and DOH reclassified a total of nearly 500 acres from "approved" to "conditionally approved" beginning in 2015 (DOH 2015). Continued poor water quality resulted in the expansion of the conditional closure to over 300 additional acres in 2016, resulting in a total closure area of 820 acres (DOH 2016). The conditional closure classification prohibited shellfish harvest from affected areas from April 1 through June 30 and from October 1 through December 31. Following water quality improvements during the spring season, all of Portage Bay was reopened to shellfish harvest from April 1 through June 30 beginning in 2019. Poor water quality persists during the fall season and the affected 820-acre area of Portage Bay remains closed to commercial, ceremonial, and subsistence shellfish harvest from October 1 through December 31 annually (DOH 2018).

The Whatcom Clean Water Program (WCWP) has provided collaboration and coordination of the response to fecal coliform pollution in Portage Bay and the Nooksack River watershed by local, state, tribal, and federal entities and agencies since 2012. [1] WCWP functions include implementation of the Pollution Identification and Correction (PIC) program in the Nooksack watershed by local and state agencies, as well as coordination of local, state, and tribal partners in water quality monitoring efforts throughout the watershed.

While improvements in water quality have been made over time, the sources and trends of water quality pollutants are not fully understood and threaten the current and long-term safety and viability of shellfish harvest. More information is needed on the contributions and timing of pollutants into the Nooksack River from tributaries throughout the watershed.

1.1 Current Nooksack Water Quality Monitoring

There is a long-term record of water quality sampling in the Nooksack Watershed and Portage Bay. This section summarizes those past and on-going activities.

Portage Bay. Fecal coliform concentrations and *in situ* water quality (temperature and salinity) have been monitored in Portage Bay by the Lummi Natural Resources (LNR) in partnership with the DOH since 1989. A total of 12 sample sites in the Portage Bay shellfish growing area are currently monitored monthly. In addition, fecal indicator bacteria such as fecal coliform, *Escherichia Coli (E. coli)*, and enterococci, and *in situ* water quality parameters (temperature, pH, dissolved oxygen, specific conductivity, and salinity) are monitored at 12 sites on the Lummi Reservation, including the Nooksack River, that flow to Portage Bay as part of the Lummi Nation's Water Quality Monitoring Program. These sites are sampled 6-12 times per year with the exception of the Nooksack River at Marine Drive, which is sampled 3-5 times per month.

[1] The WCWP includes the following federal, tribal, state, and local partners: EPA, Natural Resources Conservation Service, Lummi Nation, Nooksack Indian Tribe, WA Department of Agriculture, WA Department of Ecology, WA Department of Health, WA Conservation Commission, the Puget Sound Partnership, Whatcom County Public Works, Whatcom County Health Department, Whatcom County Planning and Development Department, and the Whatcom Conservation District.

Nooksack River Watershed. The Whatcom County Public Works Department Natural Resources Division has been monitoring 17 freshwater sites in the Nooksack River watershed since 1998. Sites are currently sampled twice per month for water temperature, turbidity, and fecal coliform bacteria. Several WCWP partner agencies sample sites throughout the Nooksack watershed on the day prior to marine monitoring in Portage Bay in order to provide a snapshot of fecal densities and identify hotspots in the watershed. Coordinated sampling is conducted by Whatcom County Public Works Department Natural Resources Division, Lummi Natural Resources, Nooksack Indian Tribe, Whatcom Conservation District, Washington State Department of Agriculture, and the Washington State Department of Ecology.

The current water quality monitoring conducted in the Nooksack River watershed by multiple agencies, as described above, includes fecal indicator bacteria (fecal coliform) sample collection as discrete grab samples from the water body that are taken to an accredited laboratory for enumeration. Grab sampling is a practical and cost-effective method for monitoring water quality along a water body at a given time. However, grab sampling has some downsides including the long turnaround time (1-3 days between sample collection and receiving results) and the fact that it provides only a snapshot of the water conditions at single point in time.

1.2 Real-time Bacterial Water Quality Monitoring

Despite the long-term and on-going grab sample water quality monitoring programs in the Nooksack River and Portage Bay, there are still a number of questions about pollution sources and water quality trends in the watershed. As part of the response, EPA identified ZAPS LiquID™ Monitor as an advanced monitoring technology that could be piloted in the Nooksack watershed as a way to better characterize water quality trends and overcome the limitations of bacterial grab sampling. The ZAPS LiquID™ Monitors were selected due to their ability to measure real-time continuous bacteria concentrations (*E. coli*), in addition to other important water quality parameters (total suspended solids [TSS], biochemical oxygen demand [BOD], nitrate+nitrite, and hydrocarbons).

Development of a pilot project, "Streaming Nooksack", began in 2016 to test the ZAPS LiquID™ Monitor in remote locations within the Nooksack watershed. The project began in the spring of 2016, when the Lummi Nation worked with EPA to deploy the ZAPS LiquID™ Monitor in May of that year. The Lummi Nation, Washington State Department of Ecology, Washington State Department of Agriculture, and EPA collaborated and now defunct ZAPS Technologies, Inc(ZTf) in a Cooperative Research and Development Agreement CRADA (CRADA 913-16)to expand the pilot project from a single monitor to a real-time network of monitors in the Nooksack Watershed. In September of 2016, the CRADA was finalized and signed, and installation of five remote ZAPS LiquID™ Monitors was initiated. A subsequent CRADA was signed with a new cooperator, G6Nine LLC, and interested party ZAPS Technologies, LLC under CRADA Amendment 913-A-18 in August 2018. In August of 2018, all five monitoring stations were deployed and reporting data to the real-time ZAPS' Web User Interface (WUI) for review and analysis. This report documents the pilot project results and fulfills the EPA reporting deliverable for the CRADA.

2. Streaming Nooksack Pilot Project

The goal of the Streaming Nooksack pilot project was to demonstrate the use and effectiveness of the ZAPS LiquID™ Monitor to better characterize ambient water quality in freshwater tributaries and the mainstem of the Nooksack River.

ZAPS LiquID™ Monitors were deployed in a network design within the Nooksack watershed to identify trends in water quality parameters with nearly continuous sampling and reporting. In addition to *E. coli*, other parameters (total suspended solids [TSS], biochemical oxygen demand [BOD], nitrate+nitrite, and hydrocarbons) were selected for measurement to address other concerns and interests in the watershed and/or for site characterization.[2] The data were reported to the WUI and stored online to allow stakeholders to assess water quality impacts in near real-time measures and over several seasons. Lab samples were collected from each monitor station to test the accuracy of the ZAPS LiquID™ Monitor compared to standard laboratory methods that are used for traditional grab sampling in the Nooksack watershed.

2.1 ZAPS LiquID™ Monitors

The ZAPS LiquID™ Monitor is a "Spectrometer" instrument, a proprietary hybridization of spectrophotometric techniques, further described as "Hybrid Multispectral Analysis" and/or ''HMA". HMA is the hybridization of spectrophotometric techniques applied at multiple wavelengths, from the deep UV through the visual portions of the light spectrum. HMA is unique to ZAPS' spectrometer which is a real-time optical instrument (called the "ZAPS LiquID™ Monitor" or "LID") for online water quality monitoring, and is a powerful analytical tool for continuous characterization of chemical bonding and molecular structure in a wide range of sample water matrices. The LID continually analyzes a flowthrough stream (24/7) from a pressurized water sample using multispectral light and proprietary software algorithms to help mitigate risks and lower operational costs in municipal drinking water and wastewater treatment plants, including environmental monitoring for rivers, lakes, bays, estuaries, and sea water (Figure 2). ZAPS Technologies, Inc now defunct, thereafter referred to as "ZTI" to distinguish the company from the ZAPS LiquIDTM Monitor and a new company ZAPS Technologies, LLC.

[2] TSS was of interest for site characterization due to seasonal patterns in sediment load in the Nooksack River, nitrate+nitrite was of interest due to presence of agricultural land uses in the watershed, hydrocarbons were of interest due to urban areas located within the watershed, and BOD was selected for site characterization due to the varied land uses that may contribute organic matter to the watershed.

Figure 2. ZAPS LiquID Monitor

The ZAPS LiquID™ Monitor technology includes a flash lamp that shines light into a water sample flowing through a flow cell. The light is then collected/reflected by a submerged optical lens and returned back to a fiber optic bundle assembly. Upon return to the fiber optic bundle, the LiquID uses proprietary photon-counting technology to make HMA measurements including UV/vis absorption, fluorescence, and reflectance. The HMA measurements are then run through an internal algorithm (proprietary) to produce concentration data of multiple water quality parameters at once (i.e. *E. coli*, TSS, temperature, etc.).

2.2 Install Locations

The Whatcom Conservation District (WCD) staff worked with EPA, Whatcom County Department of Health (DOH), local WCWP partners, and ZTI and G6Nine LLC to install four stationary ZAPS LiquID™ Monitors. The EPA and LNR also previously partnered in the installation of one EPA-owned stationary ZAPS LiquID™ Monitor .The five stationary monitors for this project were located in the lower Nooksack Watershed in Whatcom County, WA (Figure 1) and installed incrementally between May 2016 and May 2018 as shown in Figure 3.

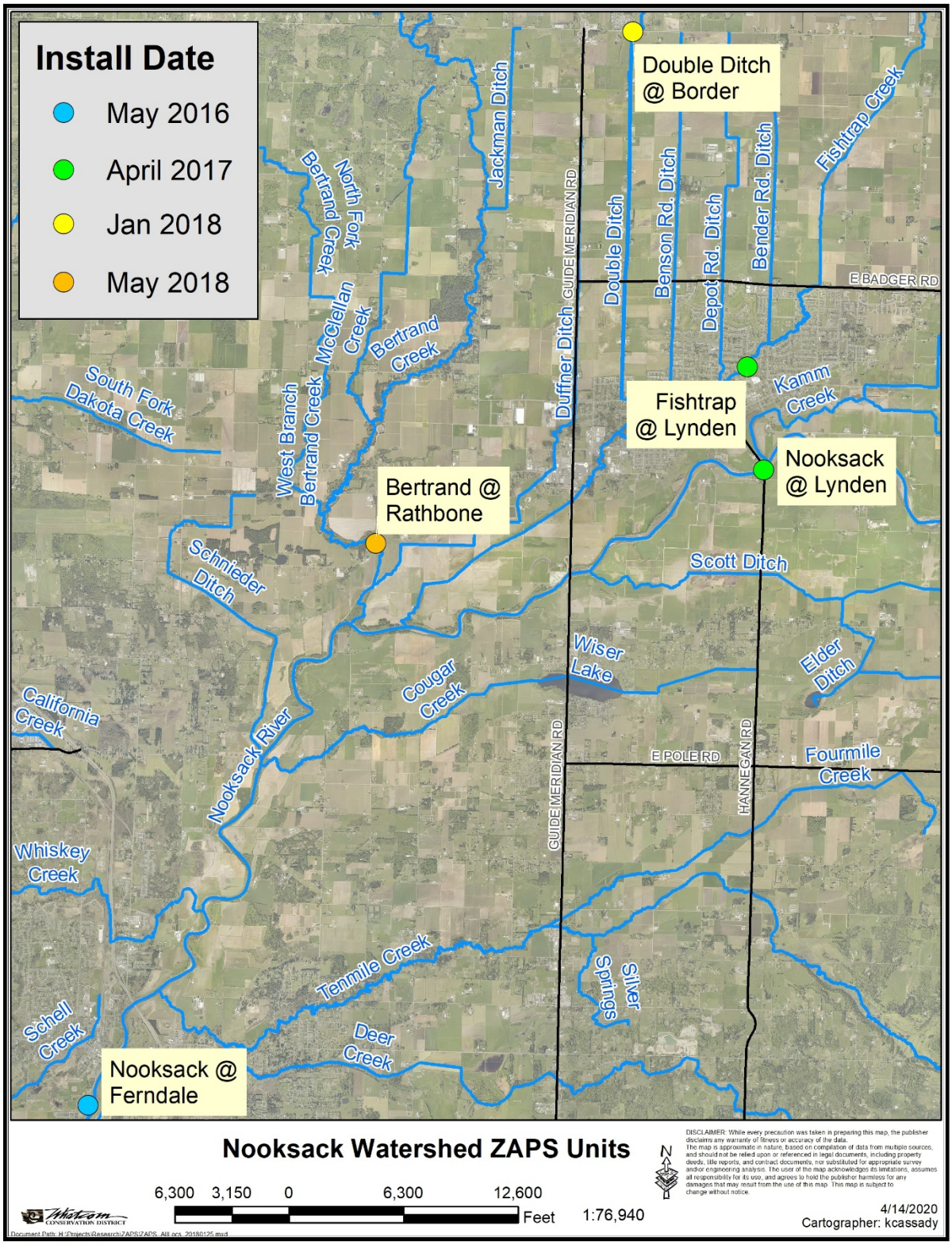

Figure 3. Location and installation dates of the five semi-permanent ZAPS LiquID™ Monitor in the lower

Nooksack watershed.

The locations of the monitors were determined based on multiple factors including selection of perennial waterways of interest and finding locations along those waterways that met the physical site requirements for installation (see more onsite requirements in Section 2.3). Details of the site and waterway characteristics are provided in Table 1.

As shown in Figure 3, two ZAPS LiquID™ Monitors bracketed the length of the mainstem Nooksack river between the cities of Lynden and Ferndale. The Nooksack at Lynden site was located upstream of major lowland tributaries, while the Nooksack at Ferndale site was located downstream of the major tributaries of Fishtrap and Bertrand creeks and near the mouth of the river where it discharges to Portage/Bellingham Bay, but above tidal influence (Table 1). Three of the monitors were placed on major tributaries to the mainstem Nooksack River including Double Ditch, Fishtrap Creek, and Bertrand Creek. Sites were selected based on project partner input and at sites where tracking and detecting changes in water quality would be helpful for tracking the timing, proportion, and location of potential sources. Table 1 provides more description of each waterway. All ZAPS LiquID™ Monitors were located, installed and made functional in compliance with physical site requirements and local permitting needs.

Table 1. Site descriptions for ZAPS LiquID™ Monitors installed for the Streaming Nooksack Project.

Station Name	Nooksack at Ferndale	Nooksack at Lynden	Fishtrap at Lynden	Double Ditch at Border	Bertrand Creek
Ambient Water Quality Characteristics	The mainstem Nooksack River is a large, glacially fed river with headwaters in Mount Baker National Forest. The river waters vary from glacial green-blue tinted to "chocolate milk" colored during high flows/precipitation events. Monitor was installed downstream of Ferndale, near river mouth, but above tidal influence from Portage/Bellingham Bay.	The mainstem Nooksack River is a large, glacially fed river with headwaters in Mount Baker National Forest. The river waters vary from glacial green-blue tinted to "chocolate milk" colored during high flows/precipitation events. Monitor was installed just upstream of the city of Lynden, and above most lowland inputs.	Fishtrap Creek flows into Whatcom County from Canada, passing through northern agricultural lands and into the city of Lynden where the monitor was installed. A large number of field drainage pipes and ditches flow into the creek. Fishtrap Creek has high iron levels and orange-brown colored water from peat soils in north Whatcom County.	Double Ditch/Pepin Creek flows into Whatcom County from Canada. The monitor was installed in the eastern fork of Double Ditch at the Canadian border. Double Ditch is a tributary to Fishtrap Creek. Water in Double Ditch is clearer compared to Fishtrap and does not have elevated iron levels.	Bertrand Creek flows into Whatcom county from Canada, passing through agricultural lands and into the Nooksack River between the cities of Lynden and Ferndale. The monitor was installed near the mouth of Bertrand Creek. The Bertrand stream channel is less modified than Fishtrap or Double Ditch.
Install Date	May 2016	April 2017	April 2017	January 2018	May 2018
Property ownership	Whatcom County	City of Lynden	Private - LYNCS School	Private - Berry Farm	Private -Berry Farm
Latitude	48.879027	48.9365	48.951954	49.0021	48.9242
Longitude	-122.563542	-122.4417	-122.44592	-122.4738	-122.5301
Potable Rinse Water	Yes, City of Ferndale drinking water	No	Yes, City of Lynden drinking water	No	No

2.3 Data Quality Objectives (DQOs)

The overall objective of this project was to demonstrate the use and effectiveness of ZAPS LiquID™ Monitors to better characterize ambient water quality in the Nooksack watershed. Three Data Quality Objectives (DQOs) were identified in the Streaming Nooksack Umbrella QAPP (EPA Region 10 2017) to guide the evaluation of ZAPS LiquID™ Monitor data:

1. Compare performance of ZAPS LiquID™ Monitor data to grab samples taken from the sampling port and analyzed via standard approved EPA Clean Water Act laboratory methodology.
2. Determine the ability to identify and interpret artificial spikes and natural spikes in measured parameters and the relationships between parameters3.
3. Once multiple monitors were online, determine the ability of a real-time network to help identify potential water pollution sources and conditions in the watershed upstream of the monitors.

2.3.1 Performance Criteria

The real-time data from the ZAPS LiquID™ Monitors were expected to perform within the following manufacturer-reported accuracies as presented in Appendix A of the Streaming Nooksack Umbrella Quality Assurance Project Plan (QAPP) (EPA Region 10, 2017):

- *E. coli* +/-10%
- TSS +/-13%
- BOD +/-8%
- Nitrate+nitrite +/-9%

For the purposes of this project, the laboratory data that was analyzed via EPA Clean Water Act lab methodology was used as the accurate standard for comparison of the monitor data. Lab samples were collected from a spigot on the ZAPS LiquID™ Monitor that was connected to the sample water supply line just before the water entered the flow cell. Per the Streaming Nooksack Umbrella QAPP (EPA Region 10, 2017), the laboratory performed internal instrumentation accuracy checks against known standards, and accuracy performance criteria was set at 70-130% recovery. Duplicate grab samples were also collected for 10% of the lab samples and precision criteria were set at +/- 25% Relative Percent Difference (RPD).

[3] Sometimes ZAPS LiquID™ Monitor data exhibits artificial spikes that are unwanted and need to be removed in the post-processing of the finished data. Thus, one of the DQOs was to methodically identify and remove these artificial spikes.

2.4 ZAPS LiquID™ Monitor Installation Procedures

The monitors were installed at locations that met site requirements listed in the Operation and Maintenance manual (ZAPS Technologies, Inc ZTI. [ZAPS] 2015) which included:

- Continuous sample water supply from waterbody (2-60 psi; ½ inch supply line and 0.5 gallon/minute (GPM) minimum flow rate; no rapid fluctuations);
- Electrical power;
- Operating air temperature of 32 to 104°F;
- Not subject to flooding;
- Mounting surface that supports 300 lb vertical load;
- Intermittent clean rinse-water such as tap water if available (40-75 psi; 2.5 GPM);
- Open drain for outflow sample water and clean water;
- Connectivity to cellular network.

Additional site specifications were provided in the Operation and Maintenance Manual (ZAPS 2015).

For each installation, ZAPS Technologies technicians were on-site to help with setup and calibration of each monitor as well as to advise on plumbing for the continuous sample water supply. Finding sites along waterways with access to clean rinse-water was particularly challenging, and ultimately potable water was only available at the Nooksack at Ferndale and Fishtrap at Lynden sites from existing City of Ferndale and City of Lynden treated municipal drinking water lines (Table 1). The primary use of the rinse-water was to flush debris and film from the internal optics surface; as such the rinse-water needed to be supplied at a higher pressure than the sample water. After consultation and testing, ZAPS Technologies technicians decided to eliminate the rinse cycle from sites without potable water.

The continuous sample water was conveyed from the waterbody to the ZAPS LiquID™ Monitors via one of two methods: 1) direct connect to existing pressurized water line or 2) pumped from a submersible pump (flow rate ranged between 5-40 GPM depending on head height) placed in the stream.

At the two mainstem Nooksack River sites (Nooksack at Lynden and Nooksack at Ferndale), the first method was used, and sample water was able to be teed from existing pressurized lines installed at local public utility facilities (City of Lynden and Whatcom County Public Utility District #1). These ZAPS LiquID™ Monitors were installed inside of the facility buildings and non-treated river water from pressurized water intake lines was continuously supplied to the ZAPS mointors. The water intake point at the Nooksack at Lynden site was located 3.3 feet from the bottom of the river channel, and the intake at the Nooksack at Ferndale site was located at 1 foot above the channel bottom.

At all other sites, the second method was used, and submersible pumps were placed directly in the stream to supply sample water. The pumps were installed inside of stainless-steel fish

screened (3/32-inch perforated plate) boxes to comply with Washington Department of Fish and Wildlife requirements that all water diversion devices have compliant fish screens (77.57 RCW). The screened boxes were anchored to the stream channel bottom on top of gravel or other hard substrate and water was pumped via black polyethylene or polyvinyl chloride (PVC) tubing to the ZAPS LiquID™ Monitor. Water from the drain was returned to the stream downstream of the intake. The water intakes for the submersible pumps were located at approximately two inches from the channel bottom.

2.5 ZAPS LiquID™ Monitors Maintenance Procedures

Throughout the duration of the project, WCD and LNR staff conducted regular maintenance on the ZAPS LiquID™ Monitors in accordance with Section 4 of the Operation and Maintenance Manual (ZAPS 2015). Regular maintenance tasks included manual cleaning of the internal optics, checking the pressure and flow of sample water, and checking the rinse-water filter metal mesh (if applicable). In addition, as-needed maintenance was performed on the ZAPS LiquID™ Monitors if an error in the computer system or sample supply system occurred, as well as all site housekeeping like lawn mowing, pump maintenance, and cleaning.

The ZAPS LiquID™ Monitors continuously reported a "Clean" parameter data point that ranged from to 0 (dirty) to 1 (clean). Per ZAPS Technologies, LLC recommendations, the optics were cleaned whenever the Clean parameter fell to 0.6, or at least monthly. The cleaning procedure included using the WUI to set the ZAPS LiquID™ Monitor to Manual Optics Clean mode, removing the optics lens from the flow cell, and cleaning the optic surfaces with a special cleaning tool and optical wipes. After the cleaning procedure was completed, the monitor was switched back to normal operation using the web interface. The monitor would then automatically perform internal checks on the effectiveness of the cleaning and warn the user if the cleaning was not adequate. The Operation and Maintenance Manual (ZAPS, 2015) provides a detailed step-by-step procedure.

The ZAPS LiquID^{TM} Monitors that were installed on tributary streams (Double Ditch, Bertrand, and Fishtrap) required more cleanings than the mainstem Nooksack sites. The tributary sites required optics cleanings approximately one time per week, whereas the mainstem Nooksack sites required cleaning only one time per month. The difference was likely due to differences in ambient water quality as the tributaries tended to have higher nutrient content and therefore potential for greater biologic growth that could foul the optics surfaces. Table 1 provides a general description of the ambient water quality at each site.

During each manual optics cleaning, the rinse-water filters were also checked for debris or clogging, and the pressure was checked on the sample supply lines. In addition, the fish screen surface on the submersible pumps was scrubbed with a brush to remove any sediment or debris build-up. The sample lines were also backflushed on a quarterly basis or as needed to remove any sediment buildup.

The ZAPS LiquID™ Monitor sent error code alerts to the WCD and LNR whenever errors occurred (e.g. insufficient sample supply, modem offline) or maintenance was required (e.g. clean optics warning). Field staff worked closely with ZAPS Technologies, LLC technicians to

understand and resolve these errors in a timely manner. Many issues were resolved within hours by partner staff re-setting the ZAPS LiquID™ Monitors or within 24 hours through remote technical support; but others required a company technician to make a site visit. Early in the project, the 2G cellular network had connectivity issues and the modems would regularly go offline, making data unavailable. To resolve this, field staff manually reset the modems. Eventually, all modems were replaced with 4G technology and the connectivity problems were resolved.

2.6 Lab Sample and ZAPS LiquID™ Monitor Data Collection

Two types of data were collected: laboratory sample data and monitor data. Grab samples were collected from a spigot on the ZAPS LiquID™ Monitor and delivered to a laboratory for comparison to real-time data from the monitors, and real-time monitor data was continuously reported to a WUI website for viewing and download for analysis.

2.6.1 Lab Sampling Strategy

Grab samples were collected at least once monthly from all monitors, as well as during rain and high stream flow events. Samples were collected from the sample spigot located on the ZAPS LiquID™ Monitors, chain of custody was maintained, and samples were delivered to the laboratory within specified hold times in accordance with Streaming Nooksack Umbrella QAPP (EPA Region 10 2017) and subsequent QAPP Addenda (#1 and #2; EPA Region 10 2018). Samples were targeted to represent a range of bacteria and water quality conditions for comparison to the ZAPS LiquID™ Monitors real-time data. Concentration bins were created for each parameter (Table 2).

Table 2. Concentration bins for each parameter. Concentration bins range from [inclusive minimum value, exclusive maximum value).

***E. coli* (MPN/100ml)**	**Total Suspended Solids (mg/L)**	**Nitrate+nitrite (mg/L)**	**Biological Oxygen Demand (mg/L)**
[0, 50)	[0, 5)	[0, 1)	[0, 2)
[50, 100)	[5, 10)	[1, 2)	[2, 6)
[100, 500)	[10, 50)	[2, 3)	[>6)
[500, 1000)	[50, 100)	[>3)	-
[>1000)	[>100)	-	-

The *E. coli* parameter was of greatest interest in this study because of the impact of fecal indicator bacteria on the consumption safety and classification of shellfish from the Portage Bay shellfish growing area, and was used as a guide to decide when to collect lab samples. Five to ten samples were targeted for each *E. coli* bin per site.

Rain events greater than 0.5 inches in a 48-hour period were chosen for grab sampling to capture high *E. coli* densities, and dry period sampling was chosen for lower *E. coli* densities. In

addition, when the ZAPS LiquID™ Monitor data indicated elevated *E. coli* events during dry weather periods, grab samples were also taken.

2.6.1.1 Description of Lab Sample Analysis

Lab samples were analyzed at Exact Scientific Services, Inc. in Ferndale, WA per EPA approved methods outlined the Streaming Nooksack Umbrella QAPP (EPA Region 10 2017). Regular analysis included:

- *E. coli* (IDEXX Colilert® Quanti-Tray Standard Methods (SM) 9223B)
- Total suspended solids (TSS) (SM 2540D-1997)
- Nitrate+nitrite as nitrogen (NO_3, NO_2) (EPA 300.0)
- Biological oxygen demand (BOD) (SM 5210B-2001)

Analysis of BOD was done on a smaller subset of samples than other parameters (57 samples). After initial BOD lab data were frequently below the detection limit (<4 mg/L), collection of BOD samples was discontinued for the remainder of the project period. The lab analyzed *E. coli* by the membrane filtration method (SM 9222 D+G) for one sample due to it arriving late to the lab. Given that SM 9222D+G is also an EPA approved lab method, the membrane filtration result was carried through to the analyses below.

Refined hydrocarbons (NWTPH-Dx + motor oil range and NWTPH-Gx) analysis was conducted by EPA Region 10 Manchester Environmental Laboratory on a small subset of samples (17), but ultimately dropped from regular analysis because results were frequently below the detection limits (250-500 µg/L). All hydrocarbon sampling was conducted prior to the useable ZAPS LiquID™ Monitor dataset.

2.6.1.2 Quality Control of Lab Samples

All lab samples were collected in accordance with the Streaming Nooksack Umbrella QAPP (EPA Region 10 2017). Quality control procedures included collecting samples with aseptic field techniques and collecting periodic field blanks and field duplicates. Field duplicates were collected once a month for a total of 10 duplicate analysis for all lab sample parameters. Two field/transfer blanks were collected during the project.

The ZAPS LiquID™ Monitor uses a proprietary algorithm to analyze and interpret optical HMA measurements into concentration data. The concentration data can then be graphically represented on the WUI (Figure 4).

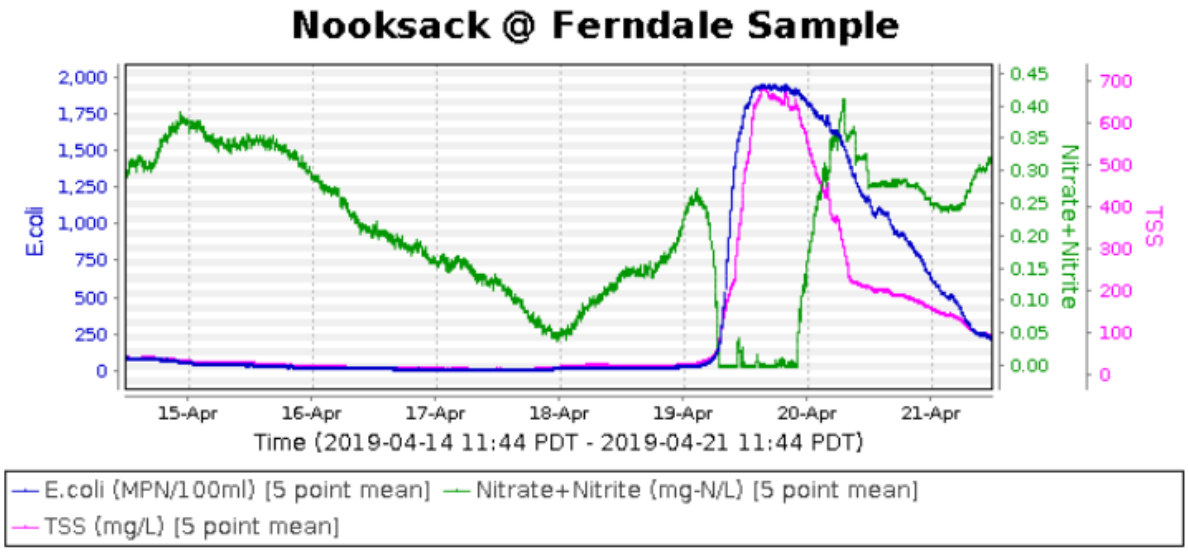

Figure 4. Example of web user interface (WUI) showing continuous data and 5 point mean statistic for several parameters at the Nooksack at Ferndale site.

The ZAPS LiquID™ Monitor reported measurements every 2-3 minutes under normal conditions. The ZAPS LiquID™ Monitor data was made available to the user in finished format, as well as in automatically calculated statistics including 5-point mean (data point is the average of the five data points ending at the indicated time) and daily averages. The 5-point mean dataset was primarily used for comparison of the ZAPS LiquID™ Monitor data to lab data.

2.6.1.3 Identification and Interpretation of Parameter Artificial and Natural Spikes

Artificial spikes were defined as a 5-point mean data point with an increase of 10% or more from the previous 5-point mean data point. Artificial spikes comprised less than 1.5% of all continuous data.

Appendix A provides counts of artificial spikes by location and parameter. A total of thirteen artificial spikes were present at the time of lab sample collection. When lab data was obtained during an artificial spike in the ZAPS LiquID™ Monitor, the next previous reading that was not considered an artificial spike was paired with the lab data.

2.7 Data Management

EPA's 2015 Continuous Monitoring Data Sharing Strategy outlined basic data storage and elements. Because Streaming Nooksack was a pilot project, the data are maintained and stored on EPA cloud-based servers. and are not stored in the Water Quality Exchange. (The Water Quality Exchange stores data that is obtained through regulatory requirements under the Clean Water Act rather than this pilot project). Data from Streaming Nooksack was managed as follows: 1) Site and deployment metadata was stored in the EPA Cloud; 2) Data were available through the WUI while the ZAPS LiquID™ Monitors were active. Since the project is now

decommissioned, the data are stored on EPA Cloud based servers and archived for backup and redundancy.

2.8 ZAPS LiquID™ Monitor Data

ZAPS LiquID™ Monitors data were stored on the WUI, which was maintained by ZAPS Technologies, LLC. The WUI was password protected and project partners were given two sets of login credentials; one for viewing data only, and one for uploading grab sample data and controlling the ZAPS LiquID™ Monitor (i.e. for setting the monitor to Clean mode). At the end of the project, all monitor data (both in finished format and in the 5-point mean statistic format) were downloaded from the WUI and stored according to EPA data management policies.

The monitor data were checked by WCD for quality control and data "flags" were used to indicate data quality issues. Issues that were flagged included: 1) pump issues – sample supply not pushing fresh sample through the monitor; and 2) ZAPS LiquID™ Monitor issues – monitor not functioning properly. Flags were used to indicate problematic data but preserve the original measurements in the dataset. Notes were recorded for each monitor that describe time periods when issues occurred (e.g. pump issues).

2.8.1 Laboratory Grab Samples

Laboratory grab sample results were sent to the WCD, LNR, and EPA via email in PDF format. Electronic copies of the results were stored in a joint project folder accessed by both the WCD and EPA, and the WCD maintained a spreadsheet of lab sample results with paired ZAPS Technologies, LLC data. In addition, the WCD and LNR uploaded lab sample results to the WUI as soon as the data were available. All project partners had access to view the uploaded lab data as well as the monitor data. Field notes were kept on chain-of-custody (COC) forms and scanned copies were stored to the project folder.

2.9 Algorithm Adjustments and Dataset Limitations

The dataset used for the analyses presented in Section 3 were ZAPS LiquID™ Monitor data and lab data collected between October 22, 2018 and September 17, 2019. Although monitor and lab data were available from as early as May 2016, all data prior to October 22, 2018 were determined to be unusable due to issues identified by ZAPS Technologies, LLC in October 2018. Issues included calibration of the zero values for each parameter and algorithm adjustments. Technicians also made upgrades to the units during this time including new optics filters that blocked secondary light scattering. ZAPS Technologies, LLC was unable to provide corrected monitor data for the project period prior to October 22, 2018.

For the time period of October 2018 through December 2018, ZAPS Technologies, LLC adjusted the internal algorithm of all monitors for the following parameters: *E. coli*, nitrate+nitrite, TSS, TOC, and BOD. These adjustments were made remotely by ZAPS Technologies, LLC and involved changing the overlying data model of how the monitor produces concentration values based on monitor data. The adjustments were based in part on laboratory grab sample results collected between October and December 2018 that were uploaded to the WUI. Once these algorithm adjustments were complete, ZAPS Technologies, LLC provided a corrected monitor dataset for

the period of October 22, 2018 through December 2018 which adjusted the original dataset to the new algorithm. The corrected data was incorporated into the final monitor dataset used for the analyses included in this report.

3. Results

Results from the ZAPS LiquID™ Monitor(hereafter "monitor data") and paired laboratory grab samples (hereafter "lab data") are presented below for the five semi-permanent sites where ZAPS LiquID™ Monitors were deployed. The analyses include a summary of the paired data collected, accuracy analysis of the monitor data compared to performance criteria, and a significance test for the differences between the monitor and lab methods.

Results were analyzed by site and parameter during the data collection period of October 22, 2018 to September 17, 2019. In general, the ZAPS LiquID™ Monitor did not meet performance criteria when compared to lab data.

3.1 Comparison of ZAPS LiquID™ Monitor Data with Laboratory Grab Samples

Each lab sample result was paired with a corresponding monitor 5-pt mean data point based on the sample collection date and time. If lab data were not collected at the same time as a monitor data point, then it was paired with the nearest previous monitor data point. 40% of the ZAPS LiquID™ Monitor data points were less than one minute apart from the lab sample collection, 97% of data points were less than 5 minutes apart, and all lab sample and monitor data pairs were less than 10 minutes apart. Pairing the lab data to a previous 5 point mean monitor reading was considered acceptable because the lag 1 autocorrelations for the monitor data were above 0.99 for all parameters and sites. Lag 1 autocorrelations refers to the correlation of a given data point and the data point preceding it by one-time interval.

Table 3 provides a summary of the number of pairwise observations of monitor and lab data used in the analyses by location.

Table 3. Counts of pairwise lab data and ZAPS LiquID™ Monitors data observations by parameter and site.

Site	Biological Oxygen Demand (BOD)	E. Coli	Nitrate+nitrite	Total Suspended Solids (TSS)	Total Count by Parameter
Bertrand Creek	10	27	26	27	90
Double Ditch at Border	14	40	39	39	132
Fishtrap at Lynden	13	44	40	40	137
Nooksack at Ferndale	8	48	44	44	144
Nooksack at Lynden	12	40	35	35	122
Total by Site	**57**	**199**	**184**	**185**	**625**

3.1.1 Descriptive Statistics

Water quality data from both the lab and monitor data varied across the five sites as shown in Figure 5. The two mainstem Nooksack stations (Nooksack at Ferndale and Nooksack at Lynden) tended to have lower *E. coli* and nitrate+nitrite, and higher TSS than the three tributary stations (Double Ditch at Border, Fishtrap at Lynden, and Bertrand Creek). This overall pattern was evident in both the monitor and the lab sample data.

When looking at a single parameter, there were differences in the monitor bias across sites. For example, the ZAPS LiquID™ Monitor tended to read higher than the lab result for the nitrate+nitrite parameter at Bertrand Creek, whereas the monitor tended to read lower than the lab result for nitrate+nitrite at Double Ditch. Because of these site-to-site differences, statistical analyses in the proceeding sections were performed with the data separated by site. Appendix B provides additional visualizations of the lab and monitor data over time.

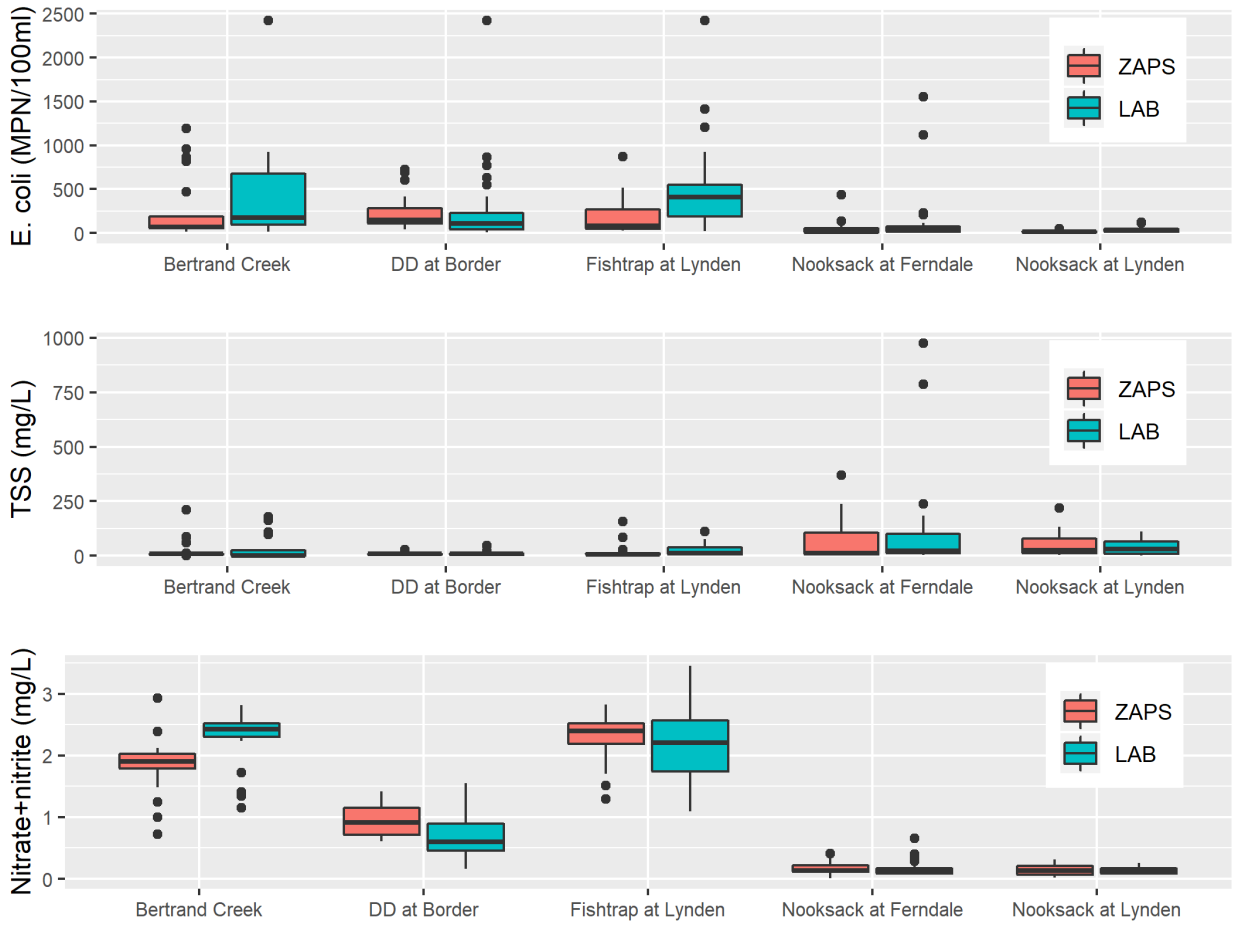

Figure 5. Summary of ZAPS LiquID™ Monitors data (LID) versus lab data (LAB) by site and parameter. TSS = Total suspended solids; DD = Double Ditch. Boxes represent second (bottom) and third (top) quartiles; whiskers represent first (bottom) and fourth (top) quartiles; points represent statistical outliers (1.5 times the interquartile range).

3.1.1.1 Laboratory Field Duplicate Results

In total, ten field duplicates were collected during the sampling period from November 2018 through September 2019. Relative percent difference (RPD) was calculated for each duplicate pair as a measure of lab precision and field variability. Some of the duplicate results (two samples for TSS, one for nitrate+nitrite, and two for BOD) were non-detect for both the duplicate and parent sample, and these results were excluded from the RPD calculations. Per the Streaming Nooksack Umbrella QAPP (EPA Region 10 2017), duplicate water samples will have RPDs less than 25%. As shown in Table 4, the RPD for *E. coli*, TSS, BOD and nitrate+nitrite were within 25%.

Table 4. Laboratory duplicate analysis summary.

Lab Parameter	Average and (Range) of Relative Percent Difference (RPD)	Number of duplicate pairs
E. coli	25% (4-54%)	10
Total suspended solids (TSS)	13% (4-35%)	10
Nitrate+nitrite	1% (0-4.6%)	10
Biological Oxygen Demand (BOD)	3% (0-3%)	3

3.2 ZAPS LiquID™ Monitor Accuracy Analysis

For the purposes of this project, the laboratory sample results using standard methods were assumed to be accurate measurements of parameter concentration. The performance criteria accuracies, which were based on the Streaming Nooksack Umbrella QAPP (EPA Region 10 2017), as well as the average observed accuracy per site, are provided in Table 5. The average observed accuracy value in Table 5 was calculated as the average percent difference between the lab and monitor data (lab – monitor)/lab. Positive percent differences indicate that the lab data were higher than the monitor data, and negative differences indicate that the monitor data were higher. The average observed percent difference statistic obscures the variability in the accuracy on a point by point basis but is valuable for observing the broad trends in the monitor accuracy.

Table 5. ZAPS LiquID™ Monitor average observed accuracy and range reported as percent difference (lab - monitor)/lab between the monitor data and the lab data.

Parameter	*E. coli* (±10%)[†]	Total Suspended Solids (TSS) (±13%)	Nitrate+nitrite (±9%)	Biological Oxygen Demand (BOD) (±8%)
Bertrand Creek	33%	-264%	17%	-27%

Double Ditch at Border	-148%	-50%	-62%	-81%
Fishtrap at Lynden	19%	-7%	-29%	-24%
Nooksack at Ferndale	-82%	24%	-18%	-19%
Nooksack at Lynden	***-6%****	-34%	-15%	-12%

†Number in parenthesis is the expected accuracy as reported by ZAPS Technologies, LLC.
**Indicates that the average observed percent difference was within the expected accuracy range.*

The ZAPS LiquID™ Monitor data observed accuracy only met the expected accuracies for the *E. coli* parameter at the Nooksack at Lynden site, (Table 5). The ZAPS LiquID™ Monitor data did not meet expected accuracies for nitrate+nitrite, TSS, or BOD parameters at any site.

For the *E. coli* parameter, the ZAPS LiquID™ Monitor data were biased higher than the lab data (negative percent difference) for all sites except Bertrand Creek and Fishtrap Creek (Table 5). For the TSS parameter, the monitor data were higher on average than the lab data (negative percent difference) for all sites except Nooksack at Lynden. For nitrate+nitrite, the monitor data were higher than the lab data for all sites except Bertrand Creek. The monitor data were higher than the lab data for BOD at all sites. Additional analysis presented in the next section breaks the data apart by concentration bins.

3.2.1 Accuracy by Concentration Bins

A more in-depth analysis of the accuracy of the ZAPS LiquID™ Monitor data was conducted by dividing the parameters into concentration and accuracy bins or ranges. The purpose of this analysis was to understand if the monitor accuracy was different at low versus high concentration ranges.

Concentration bins were selected for each parameter based on values of interest (e.g. regulatory values) as described in Section 2.5.1. Accuracy bins were set to within 10%, 20%, 30%, 40%, and 50% of the lab sample value to account for a range of accuracies.

The accuracies of monitor data were calculated for discrete groups of their associated concentration bins. *E. coli* results are presented in Table 6 and TSS, BOD, and nitrate+nitrite accuracy by bin are presented in Appendix C. For example, when 45% of *E. coli* monitor data between 0 and 50 MPN/100ml were within 20% of the lab data, the “Within 20%” accuracy will designate 0.45 for that range [0, 50 MPN / 100 ml). Two sets of accuracies were calculated to account for the uncertainty in the lab results. The accuracies presented in Table 6 are the point estimates for *E. coli* data which do not consider the uncertainty in the lab measurement. Appendix D contains accuracies regarding lab estimates at a standard error closer to the monitor data.

For the results provided in Table 6, “bin” refers to the concentration range of the monitor data and “n” refers to the number of data points in that bin. The bin “All Data” uses the same method to compute accuracy but using all available monitor data for the parameter and location.

There were no clear patterns for which *E. coli* concentration bin had the greatest accuracy

across all sites. For example, at Nooksack at Ferndale, the bin with the greatest accuracy appears to be [0,50) where 0.308 fraction of the monitor data was within 30% of the lab data. However, at the Double Ditch at Border site for the same [0,50) bin, none of the monitor data is even within 50% of the lab data. Appendix C provides similar accuracy comparison tables for the nitrate+nitrite, TSS, and BOD parameters.

Using a comparison between the lab result and monitor data does not take into account the associated laboratory measurement precision error. To account for this, an additional accuracy analysis was conducted to determine a precision error rate around each lab result (Appendix D). Even with this additional error added around each lab sample point, the percentage of data points that met the expected accuracy was rarely over 50%. Appendix C provides summary tables of this additional accuracy analysis.

Table 6. Accuracies of the E. coli ZAPS LiquID™ Monitor data compared to the lab data for multiple concentration bins and accuracy ranges. Concentration bins range from [inclusive minimum value, exclusive maximum value).

Site	Bin (concentration and accuracy)	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0,50)	0.04	0.12	0.31	0.31	0.35	26
	[50,100)	0.18	0.27	0.27	0.27	0.27	11
	[100,500)	0	0	0.11	0.22	0.22	9
	[1000,10,000)	0	0	0	0	0	2
	All Data	0.06	0.13	0.25	0.27	0.29	48
Nooksack at Lynden	[0,50)	0.04	0.04	0.18	0.25	0.43	28
	[50,100)	0	0	0	0	0.25	4
	[100,500)	0.17	0.17	0.17	0.17	0.17	6
	[500,1000)	0	0	0	0	0	2
	All Data	0.05	0.05	0.15	0.2	0.35	40
Double Ditch at Border	[0,50)	0	0	0	0	0.09	11
	[50,100)	0.17	0.17	0.17	0.17	0.17	6
	[100,500)	0.08	0.25	0.25	0.25	0.42	12
	[500,1000)	0	0.13	0.13	0.13	0.38	8
	[1000,10,000)	0	0	0.67	0.67	0.67	3
	All Data	0.05	0.13	0.18	0.18	0.3	40
Bertrand Creek	[0,50)	0	0	0	0	0	3
	[50,100)	0	0	0.17	0.67	0.67	6
	[100,500)	0.07	0.07	0.14	0.21	0.29	14
	[500,1000)	0.25	0.5	0.5	0.75	0.75	4
	All Data	0.07	0.11	0.19	0.37	0.41	27

Fishtrap at Lynden	[0,50)	0	0	0	0	0	3
	[50,100)	0	0	0	0	0	1
	[100,500)	0.04	0.08	0.12	0.16	0.16	25
	[500,1000)	0	0.13	0.25	0.25	0.25	8
	[1000,10000)	0	0	0.14	0.14	0.14	7
	All Data	0.02	0.07	0.14	0.16	0.16	44

3.2.2 Accuracy Compared to Clean Parameter

Accuracy of the monitor data and its relationship to the cleanliness (clean parameter) of the monitor was also assessed. The clean parameter is based on internal measurements of the cleanliness of the optical surface and ranges from 0.0 to 1.0. Manual optics cleanings were performed by WCD and LNR on a regular basis to ensure the clean parameter stayed above the 0.6 level per ZAPS Technologies, LLC recommendations.

There was no meaningful relationship – practically or statistically – observed between a monitor's percent difference from the lab result and its associated clean parameter. The Pearson correlation coefficient for the clean parameter and the percent difference was -0.016, indicating no relationship between the two variables.

3.3 Testing the Equivalence of Lab and ZAPS LiquID™ Monitor Data

An analysis was conducted to test if, on average, lab and monitor data are equivalent using a hypothesis test and permutation methods. This method was used, rather than a parametric test, to avoid making false assumptions about the distribution of water quality data. Additionally, the statistical power of more tradition methods is limited with the limited sample of lab data. Given that the sample water measured for paired lab and monitor data was in fact the same, we constructed the *null hypothesis* that**:** "there is no difference between pairwise lab and monitor data." If this null hypothesis is rejected, then we could assume with confidence that the lab and monitor data were not the same.

The test statistic is the average difference (lab – monitor) between pairwise lab and monitor data for each site and parameter (Table 7). A positive test statistic indicates that, on average, lab results are higher than their corresponding monitor data points. If the null hypothesis is completely true and all pairwise data are the same, then the test statistic is zero. The test was conducted by comparing the real observed difference in pairwise data to a distribution of 9,999 test statistics (the reference distribution), where each test statistic's underlying data has half of its lab and monitor observations randomly swapped.

The p-value for a test is the fraction of times the reference distribution is more extreme than the real observed difference. If the p-value is very small and the null hypothesis is rejected, there is a low probability that the differences are due to random chance and we cannot assume that the ZAPS LiquID™ Monitor had no effect on the data.

For most sites and parameters, the null hypothesis was rejected, and we may assume with confidence that the lab and monitor data are not the same. Notable exceptions where the test

failed to reject the null hypothesis are shown in Table 8 in italics, and include *E. coli* at Nooksack at Ferndale, TSS and BOD at Bertrand Creek, and nitrate+nitrite at Fishtrap at Lynden. For these instances, the average difference test statistic is relatively low, and the monitor data and the lab data appear to be, on average, the same.

Table 7. Average observed difference between the lab and monitor data and hypothesis test result of the equivalence test between the two measurement methods.

Parameter	Site	Observed Difference, Average (Lab – Monitor)	p-value
***E. Coli* (MPN/100 ml)**	Nooksack at Lynden	-48.6	0.044
	Fishtrap at Lynden	407.5	<0.001
	DD at Border	216.4	<0.001
	Bertrand Creek	113.6	<0.001
	Nooksack at Ferndale	*-6.0*	*0.432* [†]
Total Suspended Solids (mg/L)	Nooksack at Lynden	48.9	<0.001
	Fishtrap at Lynden	10.4	0.007
	DD at Border	-11.5	0.002
	Bertrand Creek	*2.4*	*0.325* [†]
	Nooksack at Ferndale	98.9	<0.001
Nitrate+nitrite (mg/L)	Nooksack at Lynden	-1.9	<0.001
	Fishtrap at Lynden	*-0.1*	*0.255* [†]
	DD at Border	-1.2	<0.001
	Bertrand Creek	0.4	<0.001
	Nooksack at Ferndale	-1.9	<0.001
Biological Oxygen Demand (mg/L)	Nooksack at Lynden	-1.2	0.004
	Fishtrap at Lynden	1.1	0.026
	DD at Border	-0.8	0.086
	Bertrand Creek	*-0.8*	*0.231* [†]
	Nooksack at Ferndale	-0.9	0.008

[†] *Notable exceptions where the test failed to reject the null hypothesis that on average there is no difference between the lab and monitor data.*

4. Discussion

Three Data Quality Objectives (DQOs) were identified in the Streaming Nooksack Umbrella QAPP (EPA Region 10, 2017) to guide the evaluation of the ZAPS LiquID™ Monitor data. Each of

the DQOs are discussed herein assessing how the ZAPS LiquID™ Monitor performed relative to each DQO.

4.1 DQO#1: Compare performance of ZAPS LiquID™ Monitor data to grab samples taken from the sampling port and analyzed via standard approved EPA Clean Water Act laboratory methodology.

ZAPS LiquID™ Monitor data did not meet the expected accuracy performance criteria when compared to the grab samples analyzed with laboratory methodology. The ZAPS LiquID™ Monitor data only met the expected accuracy, on average, for the BOD and TSS parameters at two sites. Further analysis was conducted on the accuracy by expanding the accuracy criteria up to ±50% and evaluating the accuracy by concentration bins at each site. The number of data points that met the expanded ±50% was still less than half of the samples for most bins and sites.

4.2 DQO#2: Determine the ability to identify and interpret artificial spikes and natural spikes in measured parameters and the relationships between parameters

Artificial spikes were defined as a 5-point mean monitor data point that increased by 10% or more from the previous 5-point mean monitor data point. As discussed in Section 2.5.2.1, very few were found, and none were found to be present during paired lab and monitor data points. This project was not able to test the causes of artificial spikes. The relationship between parameters was also not addressed further due to the low accuracy of monitor data compared to laboratory methods (DQO #1).

4.3 DQO#3: Once multiple monitors were online, determine the ability of a real-time network to help identify potential water pollution sources and conditions in the watershed upstream of the monitor.

In total, five stationary ZAPS LiquID™ Monitors were successfully deployed in a network at remote settings in the Nooksack watershed. The real-time data were helpful to local water quality professionals in detecting real-time changes in water quality. Although the monitor data was not accurate, the trend of the continuous data (i.e. increasing or decreasing) appeared to be more accurate and useful for alerting project partners that a visual site visit may be needed to investigate potential pollution sources. To facilitate notifications to project partners, the WUI was programmed to send email or text alerts when water quality conditions were surpassing set thresholds (e.g. *E. coli* > 500 MPN/100ml) allowing project partners to take action or collect confirmatory lab samples if necessary. An example of this process in practice occurred at the Double Ditch at Border site in summer of 2019 when the monitor indicated pulses of water with elevated *E. coli* and TSS concentration, paired with dips in the nitrate+nitrite concentration, alerted project partners that there may be a discharge to the creek occurring upstream. This was an exceptional case; it was not a typical use of the monitor data provided by the small network installed. To provide more useful data for water pollution action, a more concentrated network installed with multiple units per stream reach would be necessary.

The monitors required a higher frequency (up to once per week) of cleaning and maintenance than initially anticipated for this project. Monitors that were installed in smaller tributaries (Bertrand Creek, Double Ditch at Border, Fishtrap at Lynden) with higher turbidity and organic loading needed frequent cleaning, which made the network labor-intensive and time-consuming to maintain. Additional challenges to consider and address in remote settings included internet and modem connectivity, electrical source, access to high pressure rinse-water, climate control (protecting monitors from temperature extremes), vandalism protection, travel time for frequent maintenance, and private property access.

5. Conclusion

While the ZAPS LiquID™ Monitor and associated network held much promise, the water quality data provided by the monitors was not within the stated accuracy overall when compared to standard laboratory methodology. Given the lack of accuracy of the monitor data, tracking and determining the sources for water quality impairment in the watershed was not feasible during this project. However, if the monitor, and specifically the *E. coli* data were accurate, the real-time data would greatly assist in knowing when to deploy water quality agency staff and local professionals to track and remediate pollution sources to the Nooksack watershed and ultimately Portage Bay shellfish beds.

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Appendix A. Artificial Spikes

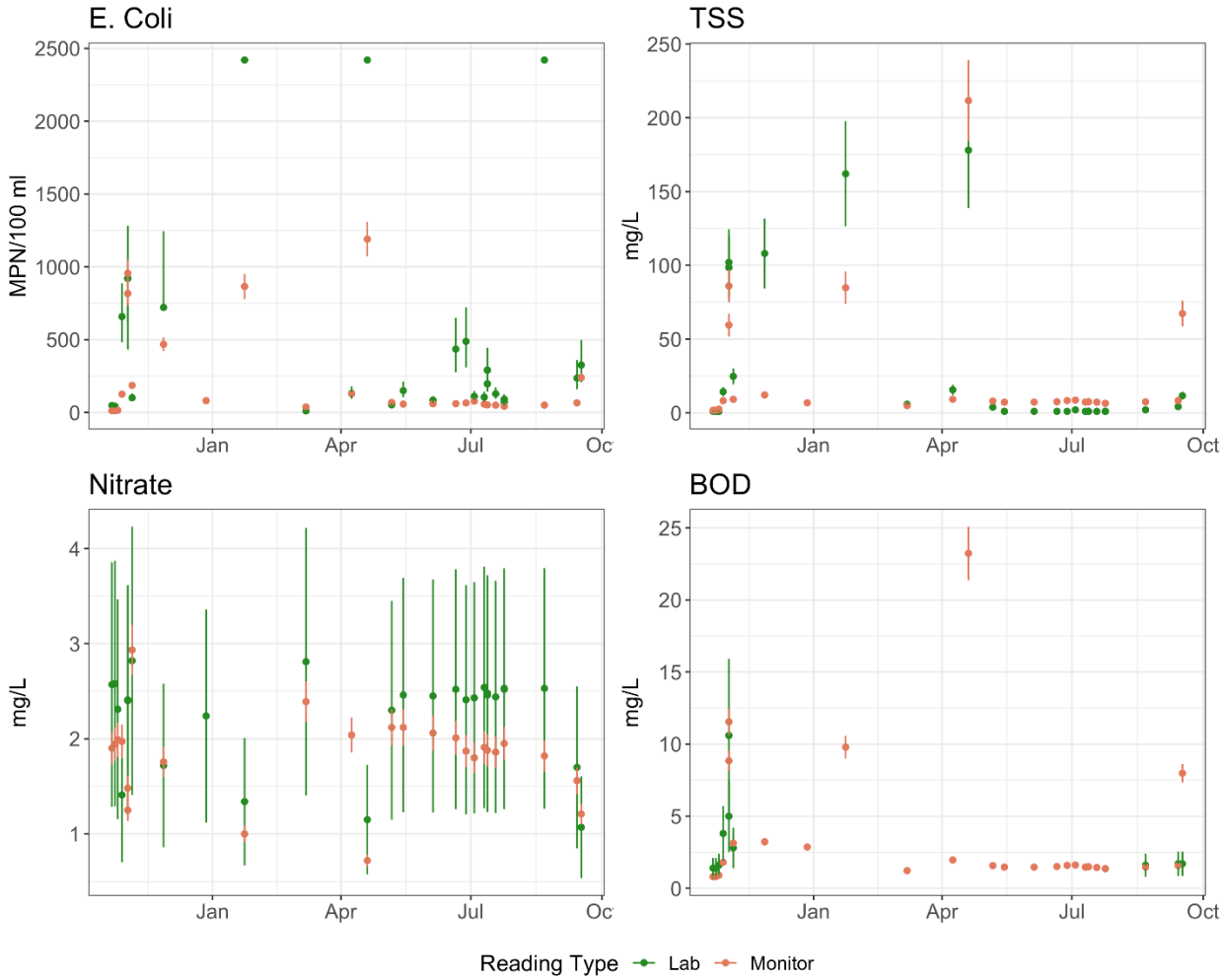
The following tables show the total amount of paired data used at a location and the number of artificial spikes found within that data before imputation. As described in section3.6.2.1, an artificial spike was defined as a lab data point that experienced a 10% change from its predecessor.

Summary of Artificial Spikes		***E. Coli*. (MPN/100 ml)**	**Total Suspended Solids (mg/L)**	**Nitrate+nitrite (mg/L)**	**Biological Oxygen Demand (mg/L)**
Bertrand Creek	Number of Artificial Spikes	0	0	0	0
	Number of Total Observations	26	26	26	26
Double Ditch at Border	Number of Artificial Spikes	1	1	0	2
	Number of Total Observations	39	39	39	39
Nooksack at Ferndale	Number of Artificial Spikes	0	0	0	0
	Number of Total Observations	45	45	45	45
Fishtrap at Lynden	Number of Artificial Spikes	2	1	0	3
	Number of Total Observations	39	39	39	39
Nooksack at Lynden	Number of Artificial Spikes	0	2	1	0
	Number of Total Observations	32	32	32	32

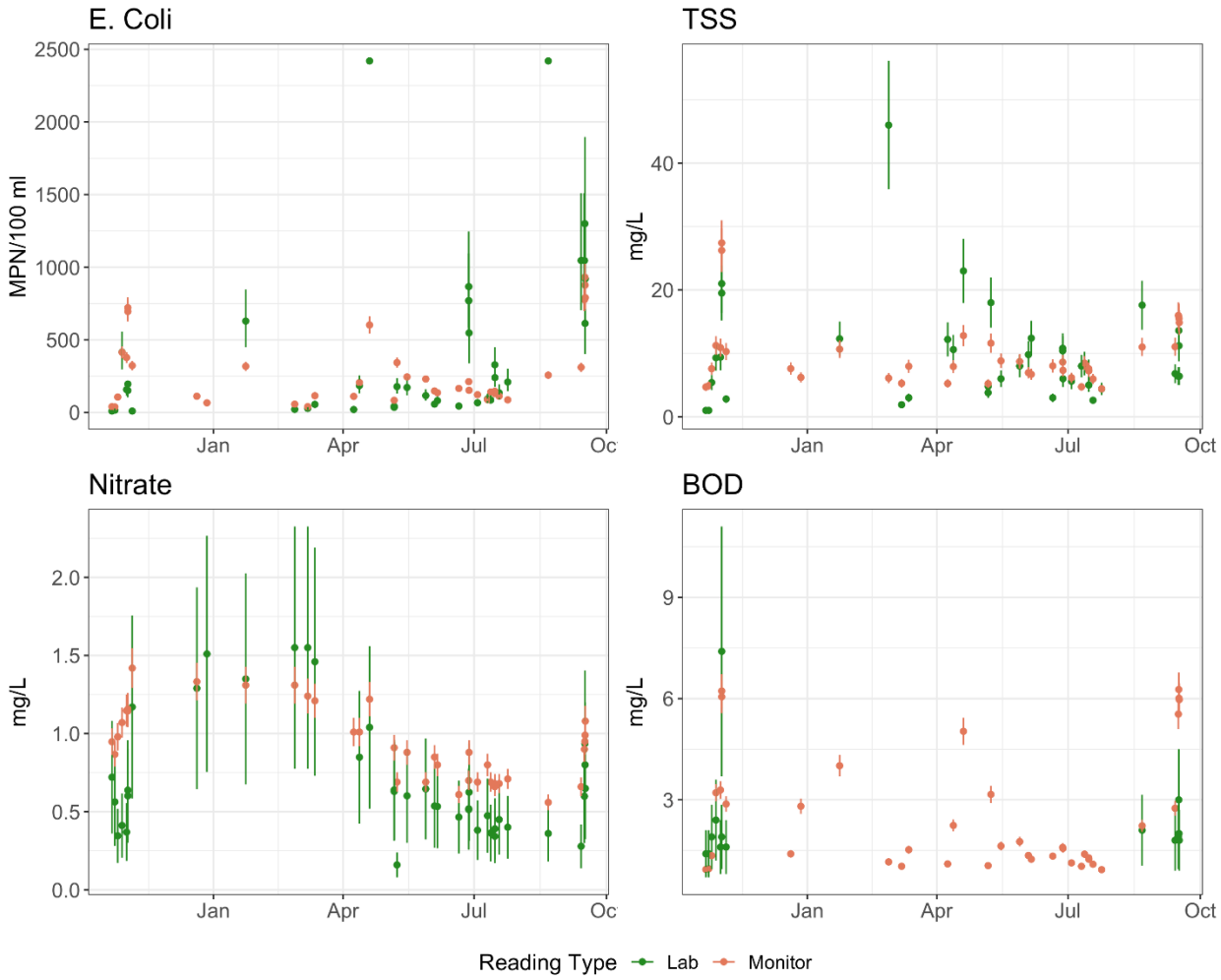
Appendix B. Paired Monitor and Lab Data Over Time

The following figures show the individual lab and Monitor data with error by parameter and location over time. The points are the monitor and lab measurements and the bars surrounding the points are the expected error for the measurements. The expected error for the ZAPS LiquID™ Monitor data is the percent expected accuracy as presented in Section 3.3.1. The expected error for the lab data is the relative percent difference (RPD) from the duplicate analysis of quality control samples for this project summarized in Table 4.

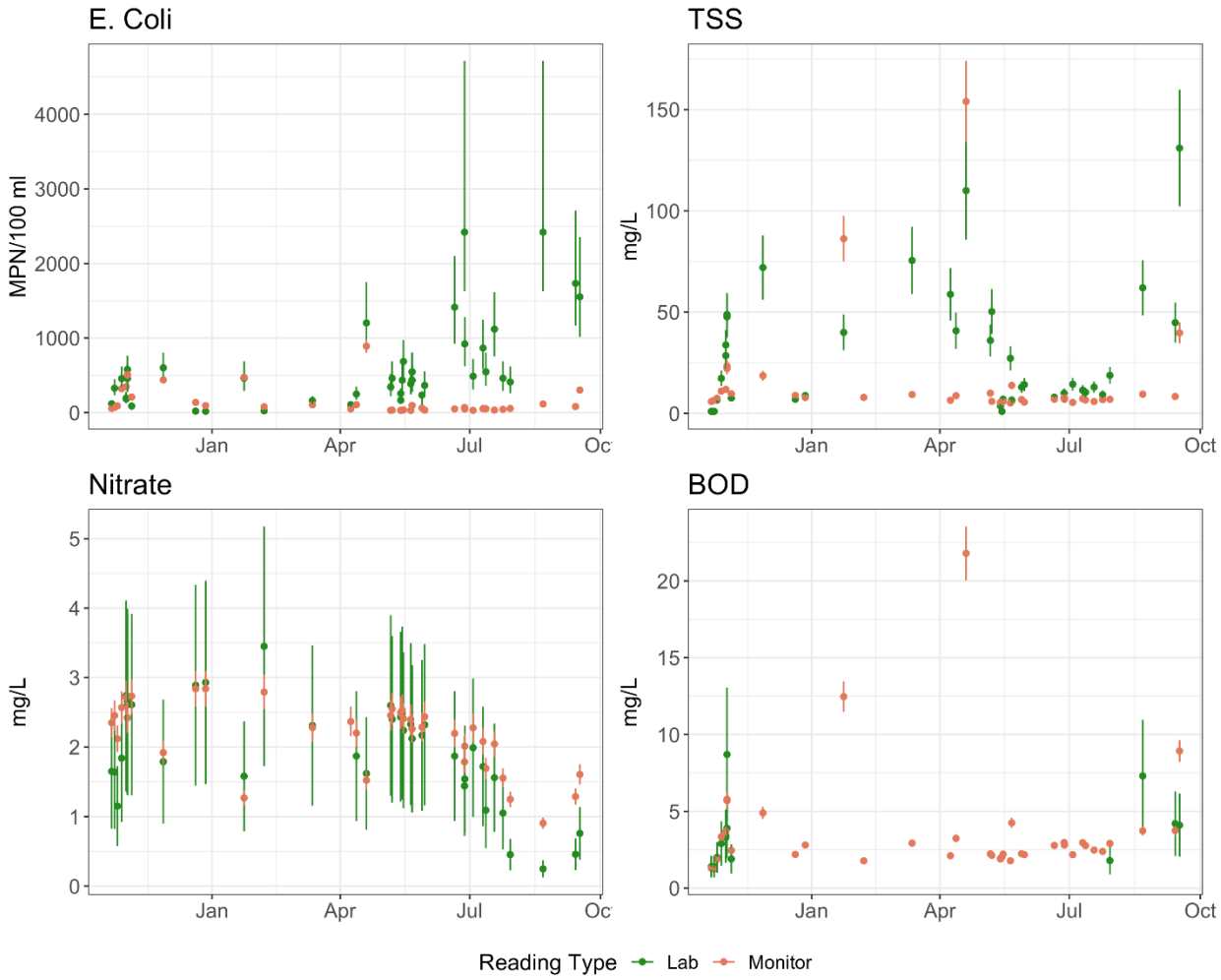
Bertrand Creek



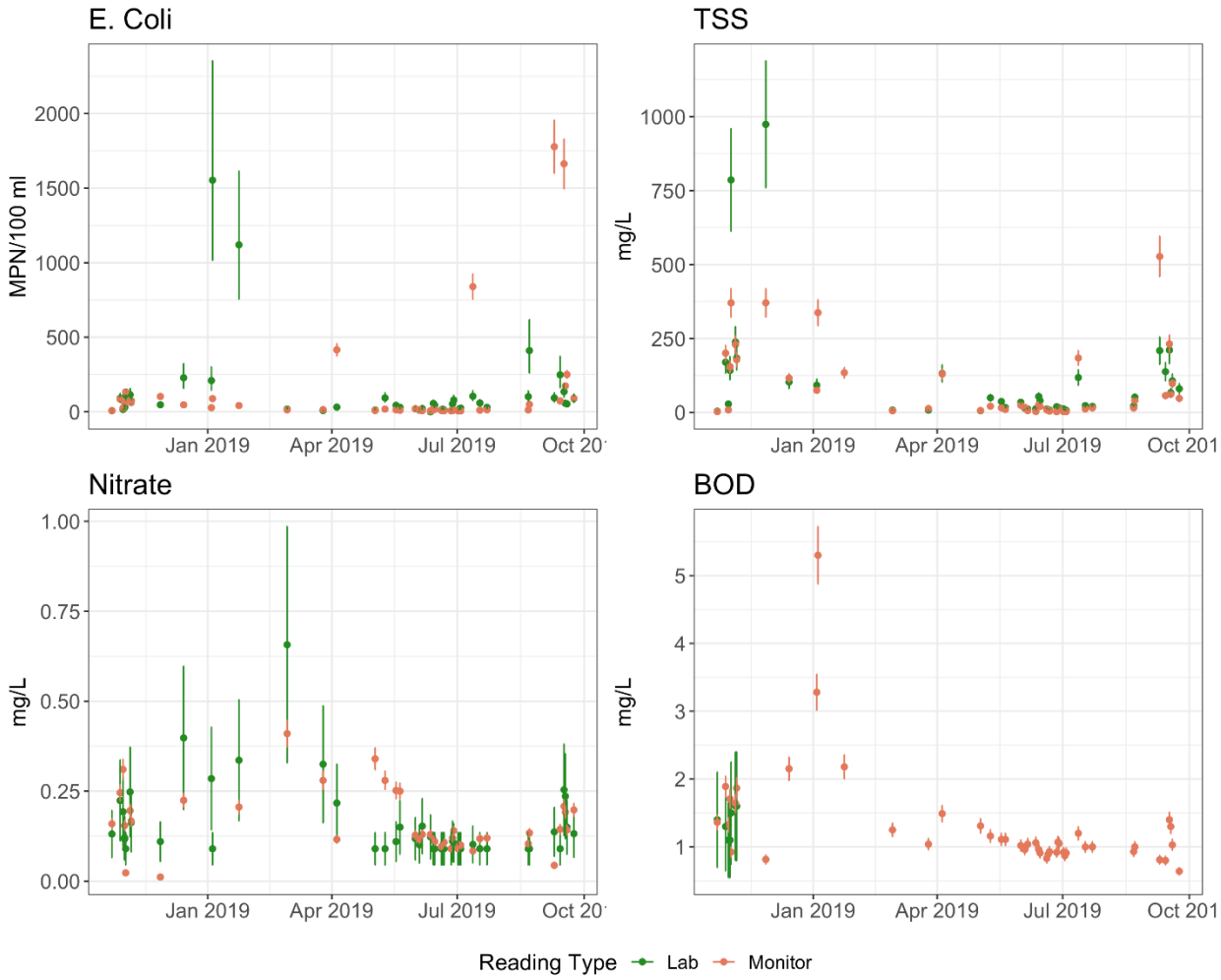
Double Ditch at Border



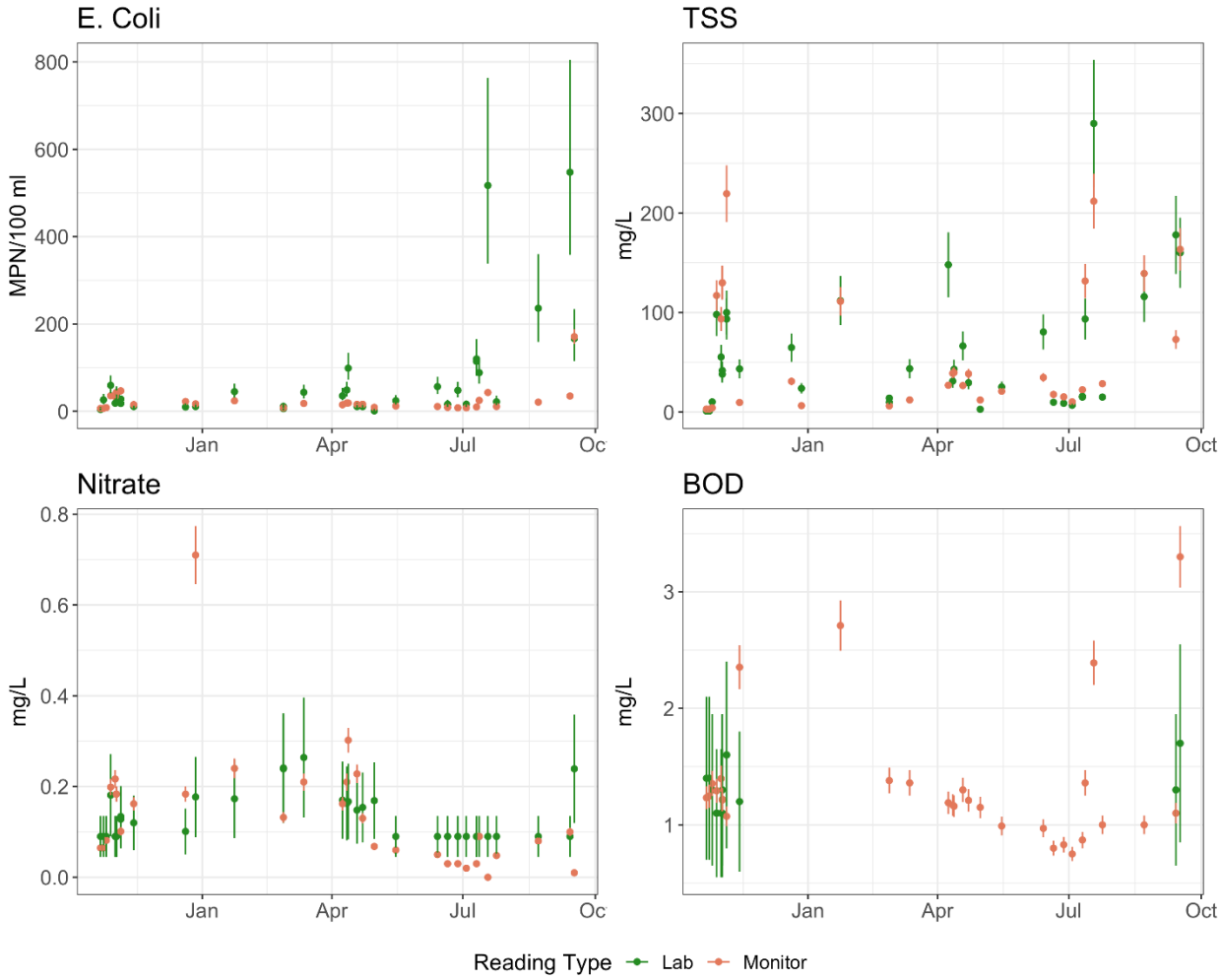
Fishtrap at Lynden



Nooksack at Ferndale



Nooksack at Lynden



Appendix C. Accuracy by Concentration Bin

Concentration bins were selected for each parameter based on values of interest (e.g., regulatory values) as described in Section 3.6.1. Accuracy bins were set to within 10%, 20%, 30%, 40%, and 50% of the lab sample value to account for a range of accuracies. A full description of the accuracy by concentration bin analysis is provided in Section 4.2.1.

The accuracies of monitor data were calculated for discrete groups of their associated concentration bins. For example, when 45% of *E. coli* monitor data between 0 and 50 MPN/100ml were within 20% of the lab data, the "Within 20%" accuracy will designate 0.45 for that range [0, 50 MPN / 100 ml). Two sets of accuracies were calculated to account for the uncertainty in the lab results. The accuracies presented in this appendix (Appendix C) are the point estimates for *E. coli* data which do not consider the uncertainty in the lab measurement. Appendix D contains accuracies regarding lab estimates at a standard error closer to the monitor data.

For the results provided in the tables below, "bin" refers to the concentration range of the monitor data and "n" refers to the number of data points in that range. The bin "All Data" uses the same method to compute accuracy but using all available monitor data for the parameter and location.

E. Coli

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0,50)	0.04	0.12	0.31	0.31	0.35	26
	[50,100)	0.18	0.27	0.27	0.27	0.27	11
	[100,500)	0	0	0.11	0.22	0.22	9
	[1000,10000)	0	0	0	0	0	2
	All Data	0.06	0.13	0.25	0.27	0.29	48
Nooksack at Lynden	[0,50)	0.04	0.04	0.18	0.25	0.43	28
	[50,100)	0	0	0	0	0.25	4
	[100,500)	0.17	0.17	0.17	0.17	0.17	6
	[500,1000)	0	0	0	0	0	2
	All Data	0.05	0.05	0.15	0.2	0.35	40
Double Ditch at Border	[0,50)	0	0	0	0	0.09	11
	[50,100)	0.17	0.17	0.17	0.17	0.17	6
	[100,500)	0.08	0.25	0.25	0.25	0.42	12
	[500,1000)	0	0.13	0.13	0.13	0.38	8
	[1000,10000)	0	0	0.67	0.67	0.67	3
	All Data	0.05	0.13	0.18	0.18	0.3	40
Bertrand Creek	[0,50)	0	0	0	0	0	3
	[50,100)	0	0	0.17	0.67	0.67	6
	[100,500)	0.07	0.07	0.14	0.21	0.29	14
	[500,1000)	0.25	0.5	0.5	0.75	0.75	4
	All Data	0.07	0.11	0.19	0.37	0.41	27
Fishtrap at Lynden	[0,50)	0	0	0	0	0	3
	[50,100)	0	0	0	0	0	1
	[100,500)	0.04	0.08	0.12	0.16	0.16	25
	[500,1000)	0	0.13	0.25	0.25	0.25	8
	[1000,10000)	0	0	0.14	0.14	0.14	7
	All Data	0.02	0.07	0.14	0.16	0.16	44

TSS

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0,5)	0	0	0	1	1	1
	[5,10)	0.14	0.29	0.43	0.43	0.57	7
	[10,50)	0	0	0.29	0.47	0.65	17
	[50,100)	0.2	0.4	0.6	0.6	0.8	5
	[100,1000)	0.5	0.64	0.64	0.64	0.64	14
	All Data	0.21	0.30	0.46	0.55	0.66	44
Nooksack at Lynden	[0,5)	0	0	0	0	0	3
	[5,10)	0	0	0	0.25	0.25	4
	[10,50)	0.07	0.14	0.21	0.29	0.43	14
	[50,100)	0	0.14	0.14	0.14	0.29	7
	[100,10000)	0.29	0.29	0.57	0.57	0.57	7
	All Data	0.09	0.14	0.23	0.29	0.37	35
Double Ditch at Border	[0,5)	0.2	0.2	0.2	0.3	0.3	10
	[5,10)	0.2	0.33	0.53	0.53	0.8	15
	[10,50)	0	0.21	0.43	0.64	0.86	14
	All Data	0.13	0.26	0.41	0.51	0.69	39
Bertrand Creek	[0,5)	0	0	0	0	0	17
	[5,10)	0	1	1	1	1	1
	[10,50)	0	0	0	0	0.5	4
	[50,100)	0	0	0	1	1	1
	[100,10000)	0	0.5	0.5	0.5	0.75	4
	All Data	0	0.11	0.11	0.15	0.26	27
Fishtrap at Lynden	[0,5)	0	0	0	0	0.25	4
	[5,10)	0.18	0.55	0.82	0.82	0.82	11
	[10,50)	0	0.06	0.06	0.22	0.28	18
	[50,100)	0	0	0	0	0	5
	[100,10000)	0	0	0	0.5	0.5	2
	All Data	0.05	0.18	0.25	0.35	0.4	40

BOD

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[1,2)	0.25	0.38	0.5	0.63	0.75	8
	All Data	0.25	0.38	0.5	0.63	0.75	8
Nooksack at Lynden	[1,2)	0.17	0.58	0.67	0.83	0.83	12
	All Data	0.17	0.58	0.67	0.83	0.83	12
Double Ditch at Border	[1,2)	0	0	0.11	0.33	0.33	9
	[2,6)	0.25	0.25	0.25	0.5	0.5	4
	[6,10000)	0	1	1	1	1	1
	All Data	0.07	0.14	0.21	0.43	0.43	14
Bertrand Creek	[1,2)	0.33	0.33	0.33	0.33	0.83	6
	[2,6)	0	0.33	0.33	0.33	0.33	3
	[6,10000)	1	1	1	1	1	1
	All Data	0.3	0.4	0.4	0.4	0.7	10
Fishtrap at Lynden	[1,2)	0.25	0.5	0.75	0.75	0.75	4
	[2,6)	0.29	0.71	0.71	0.71	0.86	7
	[6,6+)	0	0	0	0.5	1	2
	All Data	0.23	0.54	0.62	0.69	0.85	13

Nitrate+Nitrite

	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0.03,1)	0.21	0.43	0.57	0.71	0.80	44
	All Data	0.21	0.43	0.57	0.71	0.80	44
Nooksack at Lynden	[0.03,1)	0.11	0.2	0.37	0.46	0.57	35
	All Data	0.11	0.2	0.37	0.46	0.57	35
Double Ditch at Border	[0.03,1)	0.06	0.09	0.13	0.25	0.41	32
	[1,2)	0.29	0.71	1	1	1	7
	All Data	0.10	0.21	0.28	0.39	0.51	39
Bertrand Creek	[1,2)	0.33	0.5	0.67	1	1	6
	[2,3)	0.1	0.3	0.9	0.95	1	20
	All Data	0.15	0.35	0.85	0.96	1	26
Fishtrap at Lynden	[0.03,1)	0	0	0	0	0	4
	[1,2)	0.13	0.38	0.5	0.69	0.88	16
	[2,3)	1	1	1	1	1	19
	[3,10000)	0	1	1	1	1	1
	All Data	0.53	0.65	0.7	0.78	0.85	40

Appendix D. Accuracy by Concentration Bins (-Lab Error)

The following accuracies were computed as described in Section 3.2.1 and Appendix C using lab data that included estimated lab error to account for the uncertainty in the lab measurement. For the *E. coli* parameter, IDEXX Quanti-tray 95% upper and lower confidence intervals were used to estimate error. For all other parameters, lab error was estimated as 2 times the average standard deviation between field duplicates. Note that "bin" refers to the concentration range of the parameter and "n" refers to the number of data points in that range.

E. Coli

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0,50)	0.12	0.35	0.58	0.62	0.81	26
	[50,100)	0.18	0.27	0.27	0.27	0.36	11
	[100,500)	0.11	0.22	0.22	0.22	0.22	9
	[1000,10000)	0.00	0.00	0.00	0.00	0.00	2
	All Data	0.13	0.29	0.42	0.44	0.56	48
Nooksack at Lynden	[0,50)	0.11	0.29	0.64	0.75	0.82	28
	[50,100)	0.00	0.25	0.25	0.25	0.25	4
	[100,500)	0.17	0.17	0.17	0.17	0.17	6
	[500,1000)	0.00	0.00	0.00	0.00	0.00	2
	All Data	0.10	0.25	0.50	0.58	0.63	40
Double Ditch at Border	[0,50)	0.09	0.09	0.09	0.09	0.36	11
	[50,100)	0.17	0.17	0.50	0.67	0.83	6
	[100,500)	0.17	0.33	0.42	0.50	0.75	12
	[500,1000)	0.13	0.25	0.38	0.38	0.38	8
	[1000,10000)	0.33	0.67	0.67	0.67	0.67	3
	All Data	0.15	0.25	0.35	0.40	0.58	40
Bertrand Creek	[0,50)	0.00	0.00	0.00	0.00	0.00	3
	[50,100)	0.33	0.67	0.67	1.00	1.00	6
	[100,500)	0.14	0.21	0.29	0.29	0.50	14
	[500,1000)	0.50	0.50	0.50	0.75	0.75	4
	All Data	0.22	0.33	0.37	0.48	0.59	27
Fishtrap at Lynden	[0,50)	0.00	0.00	0.00	0.00	0.00	3
	[50,100)	0.00	0.00	0.00	0.00	0.00	1
	[100,500)	0.12	0.16	0.24	0.44	0.48	25
	[500,1000)	0.13	0.25	0.25	0.25	0.25	8
	[1000,10000)	0.14	0.14	0.14	0.14	0.14	7
	All Data	0.11	0.16	0.20	0.32	0.34	44

TSS

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[0,5)	0.00	1.00	1.00	1.00	1.00	1
	[5,10)	0.29	0.43	0.57	0.71	0.71	7
	[10,50)	0.29	0.47	0.53	0.65	0.76	17
	[50,100)	0.60	0.60	0.80	1.00	1.00	5
	[100,10000)	0.64	0.64	0.71	0.79	0.86	14
	All Data	0.43	0.55	0.64	0.75	0.82	44
Nooksack at Lynden	[0,5)	0.00	0.00	0.00	0.00	0.00	3
	[5,10)	0.00	0.25	0.50	0.50	1.00	4
	[10,50)	0.29	0.36	0.43	0.43	0.57	14
	[50,100)	0.14	0.29	0.29	0.57	0.86	7
	[100,10000)	0.57	0.57	0.57	0.57	0.71	7
	All Data	0.26	0.34	0.40	0.46	0.66	35
Bertrand Creek	[0,5)	0.00	0.00	0.00	0.00	0.12	17
	[5,10)	1.00	1.00	1.00	1.00	1.00	1
	[10,50)	0.00	0.00	0.50	0.50	0.50	4
	[50,100)	0.00	0.00	1.00	1.00	1.00	1
	[100,10000)	0.50	0.50	0.50	0.75	0.75	4
	All Data	0.11	0.11	0.22	0.26	0.33	27
Double Ditch at Border	[0,5)	0.20	0.30	0.30	0.30	0.30	10
	[5,10)	0.53	0.67	0.80	0.87	0.87	15
	[10,50)	0.36	0.71	0.79	0.86	0.93	14
	All Data	0.38	0.59	0.67	0.72	0.74	39
Fishtrap at Lynden	[0,5)	0.00	0.00	0.25	0.25	0.25	4
	[5,10)	0.64	0.82	0.82	0.82	0.82	11
	[10,50)	0.06	0.22	0.22	0.33	0.56	18
	[50,100)	0.00	0.00	0.00	0.00	0.00	5
	[100,10000)	0.00	0.50	0.50	0.50	0.50	2
	All Data	0.20	0.35	0.38	0.43	0.53	40

BOD

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Nooksack at Ferndale	[1,2)	0.25	0.38	0.5	0.63	0.75	8
	All Data	0.25	0.38	0.5	0.63	0.75	8
Nooksack at Lynden	[1,2)	0.17	0.58	0.67	0.83	0.83	12
	All Data	0.17	0.58	0.67	0.83	0.83	12
Double Ditch at Border	[1,2)	0	0	0.11	0.33	0.33	9
	[2,6)	0.25	0.25	0.25	0.5	0.5	4
	[6,10000)	0	1	1	1	1	1
	All Data	0.07	0.14	0.21	0.43	0.43	14
Bertrand Creek	[1,2)	0.33	0.33	0.33	0.33	0.83	6
	[2,6)	0	0.33	0.33	0.33	0.33	3
	[6,10000)	1	1	1	1	1	1
	All Data	0.3	0.4	0.4	0.4	0.7	10
Fishtrap at Lynden	[1,2)	0.25	0.5	0.75	0.75	0.75	4
	[2,6)	0.29	0.71	0.71	0.71	0.86	7
	[6,6+)	0	0	0	0.5	1	2
	All Data	0.23	0.54	0.62	0.69	0.85	13

Nitrate+Nitrite

Location	Bin	Within 10 %	Within 20 %	Within 30 %	Within 40 %	Within 50 %	n
Bertrand Creek	[1,2)	0.50	0.67	1.00	1.00	1.00	6
	[2,3)	0.15	0.35	1.00	1.00	1.00	20
	All Data	0.23	0.42	1.00	1.00	1.00	26
Double Ditch at Border	[0.03,1)	0.41	0.72	0.84	0.84	0.84	32
	[1,2)	0.29	0.86	1.00	1.00	1.00	7
	All Data	0.38	0.74	0.87	0.87	0.87	39
Nooksack at Ferndale	[0.03,1)	0.32	0.77	0.86	0.89	0.91	44
	All Data	0.32	0.77	0.86	0.89	0.91	44
Fishtrap at Lynden	[0.03,1)	0.00	0.00	0.00	0.00	0.25	4
	[1,2)	0.44	0.94	1.00	1.00	1.00	16
	[2,3)	1.00	1.00	1.00	1.00	1.00	19
	[3,10000)	0.00	1.00	1.00	1.00	1.00	1
	All Data	0.65	0.88	0.90	0.90	0.93	40
Nooksack at Lynden	[0.03,1)	0.23	0.46	0.66	0.86	0.86	35
	All Data	0.23	0.46	0.66	0.86	0.86	35

Appendix E. ZAPS LiquID™ Monitor (LID) Compared to the ZAPS LiquID™ XR+ Station

A next generation ZAPS LiquID™ XR+ model was also tested side-by-side with the ZAPS LiquID™ Monitor (LID) model at four of the five sites starting in January 2019 (excluded Bertrand due to accessibility issues). The ZAPS LiquID™ XR+ Station was deployed inside a 10-foot trailer, which was custom outfitted as a self-contained monitoring station complete with off-the-grid power. The main upgrade for the XR+ model was the addition of a motor which allows for variable path length HMA measurements. It was expected that the XR+ model would have improved accuracy for some water quality parameters.

The ZAPS LiquID™ XR+ Station was deployed side-by-side and measured the same sample water as the ZAPS LiquID™ Monitor (LID). The site with the largest side-by-side dataset was the Nooksack at Ferndale, and a comparison of the two monitors is provided below. The ZAPS LiquID™ XR+ Station and ZAPS LiquID™ Monitor (LID)were at the Nooksack at Ferndale site during June 2019; these data are plotted on the same scale in Figure E1. The visual comparison clearly shows that the two monitors had different continuous data readings for the given parameters. In particular, the ZAPS LiquID™ XR+ Station appeared to have more variability in *E. coli* and nitrate+nitrite concentrations in the sample water than the ZAPS LiquID™ Monitor (LID), whose data remained relatively flat-lined over the comparison time period. On the contrary, the ZAPS LiquID™ XR+ Station TSS data remained relatively flat-lined over the time period and the ZAPS LiquID™ Monitor (LID) detected more variability in water quality.

Figure E1. Comparison of the ZAPS LiquID™ (LID)and ZAPS LiquID™ XR+ Station for June 2019 at the Nooksack at

Ferndale site. NO_3NO_2 = nitrate+nitrite. TSS = Total suspended solids.

Figure E2 compares the hourly average of the two models during the Nooksack at Ferndale side-by-side comparison deployment. The Pearson correlation coefficient is relatively better for nitrate+nitrite (0.67), and weak for E coli (0.39) and TSS (0.46). While the hourly monitor data is significantly correlated, it is clear that the two monitors provide different readings of the same sample source when comparing the correlation to the 1:1 line shown on each graph.

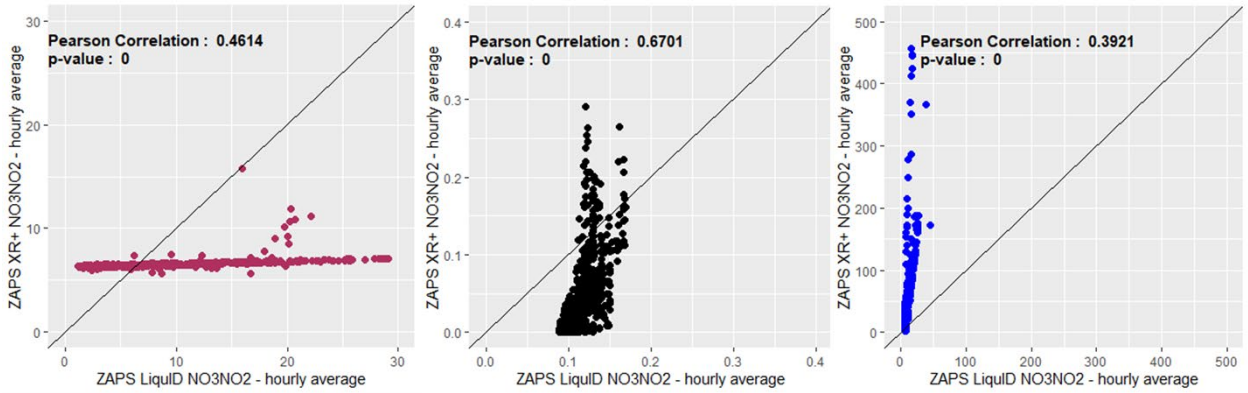


Figure E2. Comparison of the ZAPS LiquID™ and ZAPS LiquID™ XR+ Station hourly average data for June 2019 at the Nooksack at Ferndale site. NO_3NO_2 = nitrate+nitrite. TSS = Total suspended solids.

Accuracy of the ZAPS LiquID™ XR+ Station

In general, the XR+ model was less accurate than the ZAPS LiquID™ stationary monitors when comparing the lab to monitor data (Table E1). It should be noted there were a relatively smaller number of lab samples (6-16) collected from the XR+ at each site compared to the ZAPS LiquID™ comparison

The only parameter that met expected accuracy for the XR+ station was the TSS parameter at the Double Ditch at Border site as shown in Table E1 below. Similar to the ZAPS LiquID™ data, the XR+ data percent differences between the lab and monitor were highly variable between sites. For example, for the *E. coli* parameter, the average percent difference ranged from -109% at the Double Ditch at Border site (monitor data higher than lab data) up to 154% (lab data higher than monitor data) at the Fishtrap at Lynden site.

Table E1. Average percent difference (lab-monitor) for the next generation ZAPS LiquID™ XR+ Station at each site

where it was deployed.

Parameter and Expected Accuracy (±%)	E. coli (±10%)†	Total Suspended Solids (TSS) (±13%)	Nitrate+nitrite (±9%)	Number of lab samples
XR+ Double Ditch at Border	-109%	-8%*	75%	6
XR+ Fishtrap at Lynden	154%	115%	236%	10
XR+ Nooksack at Ferndale	-69%	-38%	10%	16
XR+ Nooksack at Lynden	74%	43%	16%	6

†Number in parenthesis is the expected accuracy as reported by the ZAPS Technologies, Inc.
**Indicates that the average observed accuracy met the expected accuracy.*