Water Quality and Stream Invertebrate Assessment for the Millstone River, Nanaimo, BC (Fall 2019)

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Prepared for:

RMOT 306 - Environmental Monitoring

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December 13, 2019

EXECUTIVE SUMMARY

Water quality and stream invertebrate monitoring was conducted on the Millstone River as part of an on-going long term study on the health of the river and surrounding tributaries. Sampling occurred at five stations within the Millstone watershed, over two separate sampling events on October 29 and November 19, 2019. *In situ* measurements of hydrologic parameters such as wetted width and flow velocity were taken along with temperature and dissolved oxygen. Stream discharge was determined to be a major controlling factor on the results of all other water quality parameters. Samples of water from the Millstone River were also collected at each of the five sites for further analysis in VIU and ALS Laboratories for measurements of pH, alkalinity, hardness, tubidity, nitrate, phosphate, and microbiology. Overall, the results of these water quality parameters yielded levels that are in agreement with BC Water Quality Guidelines for freshwater aquatic life. However, some observations indicate that there may be areas that are at risk to potentially unacceptable levels of contamination in the future. In particular, turbidity, nitrate, phosphate, and coliform levels are currently below the BC guidelines, but with increasing urban and agricultural land development, these levels may rise above the BC guidelines. Additional samples were collected to conduct stream invertebrate assessments to further understand the environmental conditions of the Millstone River.

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1.0 INTRODUCTION

1.1 Project Overview

Since 2008, water quality and stream invertebrate assessments have been conducted annually on the Millstone River in Nanaimo, BC. Students of VIU's Environmental Monitoring course (RMOT 306) have conducted field sampling and laboratory analysis to provide an overview of the environmental conditions of the Millstone River. Fisheries and Oceans Canada (DFO), the BC Conservation Foundation (BCCF), the Regional District of Nanaimo (RDN), and the City of Nanaimo have been ongoing supporters of this project, with funding provided by DFO and RDN. The continuation of data collection for this project is important for observing any changes to the environment, through both anthropogenic and natural impacts. To contribute to this long-term data, three VIU students monitored the Millstone River over two events on October 29 and November 19, 2019, and samples that were collected were then analyzed in VIU and ALS laboratories for water quality parameters are stream invertebrate assessments. Measured water quality parameters include temperature, dissolved oxygen, conductivity, pH, alkalinity, hardness, turbidity, nitrate, and reactive phosphate. Samples were also collected to perform microbiology counts to further assess the quality of the stream.

The location of Millstone River in central Nanaimo exposes the watershed to impacts of human activities such as agriculture, forestry, and urban and residential development. These activities contribute to both point and nonpoint source pollution of the Millstone River watershed, with a variety of implications such as decreased biodiversity, temperature changes, and chemical changes. The importance of conducting environmental monitoring in this area is to provide both short- and long-term assessments of current and future environmental concerns.

1.2 Historical Overview

The Millstone River watershed occupies an area of approximately 93 km^2 which includes 26 streams, 16 tributaries, and 8 lakes (City of Nanaimo, 2008). The primary drainage network flows southeasterly from Lucid

Lake on the side of Mount Benson to the Strait of Georgia in Nanaimo Harbour (RDN, 2016). The area of interest for this project is along the Millstone River, which drains from Brannen Lake southeasterly into the Strait of Georgia (Figure 1). Most of the river is gently flowing, except in Bowen Park, where the topographic gradient increases and causes conditions of high flow. For nearly 45 years, local organizations have been working to make the Millstone River accessible to salmon, and in 1971, the Millstone River Enhancement Project was initiated to assist salmon in navigating the fast-flowing river and a series of waterfalls (City of Nanaimo, 2008). Beginning in 2007, the construction of a side-channel in the Bowen Park region of the Millstone River created an 800 m low-flowing habitat for salmon, cutthroat trout, steelhead trout, and aquatic insects (City of Nanaimo, 2008).

1.3 Potential Environmental Concerns

The Millstone River watershed is located in a region where land use changes throughout the course of the river's length. The headwaters run through land that is privately owned by the forestry industry, the middle reaches are agricultural areas, and the lower reaches are urban and residential areas (RDN, 2016). Environmental concerns for the Millstone River exist as a combination of point and non-point sources. Forestry activity is a potential cause of erosion and sedimentation in the Millstone River, while agricultural run-off poses risks of eutrophication. The urban and residential development areas can contribute to contamination through storm water effluents and various commercial and residential chemical pollutants, as well as erosion and sedimentation from construction and recreational use. These potential concerns can alter the entire aquatic and riparian ecosystems within the watershed, posing threats to the health of plant and animal populations, as well as water quality for human use.

1.4 Project Objectives

The primary objective for this assessment of the Millstone River is to examine its environmental condition, which will provide an understanding of the health of the river ecosystem and it's ability to support aquatic life. Analysis of water quality, stream invertebrate populations, and microbiology data collected are used to deliver results that can be compared to data collected from 2008-2018, and used to further strengthen the viability of the long-term study. There are five sample site locations - four along the Millstone River and one on Benson Creek, a tributary into Brannen Lake (Figure 1). These locations will be used to collect samples and conduct some *in situ* measurements of water quality and hydrology, as well as to collect samples for further analysis on additional water quality parameters, stream macroinvertebrates, and microbiology. Water samples were analyzed at laboratory facilities located at Vancouver Island University as well as Australian Laboratory Services (ALS) in Burnaby, B.C.. The combination of laboratory and *in situ* data was then analyzed to determine overall water quality and environmental health of the Millstone River. Conducting sampling over two events, one during low-moderate flow conditions on October 29, 2019, and one during moderate-high flow conditions on November, 19, 2019, allowed for the comparison of water quality parameters between changing climatic conditions.

3.0 METHODS

3.1 Sampling Stations

3.1.1 Locations and Habitat Characteristics

The Millstone River and its tributaries has been a continuous study from 2008 to 2019. Each sampling station is incorporated into the project on the basis that the five monitoring sites proposed have been monitored in previous years, and therefore present site sampling was evaluated without deviation from the protocols already established in order to properly compare results.

Sampling at these particular sites was favoured partly due to ease of access, as most sampling locations were located directly or nearby roadways or parking lots. Additionally, potential pollution and contamination of sampling stations from nearby roadways and agricultural areas was considered and referenced to when analyzing potential impacts on ecosystem health. Present riparian and substrate composition of each site was assessed in order to assist in determining the potential diversity and sensitivity of site macro-invertebrate populations. Due to all sampling stations being in developed non-remote areas, there is not a high degree of hazard associated with travel and access to each site; however, heavy rainfall may elevate hazards such as loose footing and trail entry (Refer to Site Safety and Hazard Assessment p. 15).

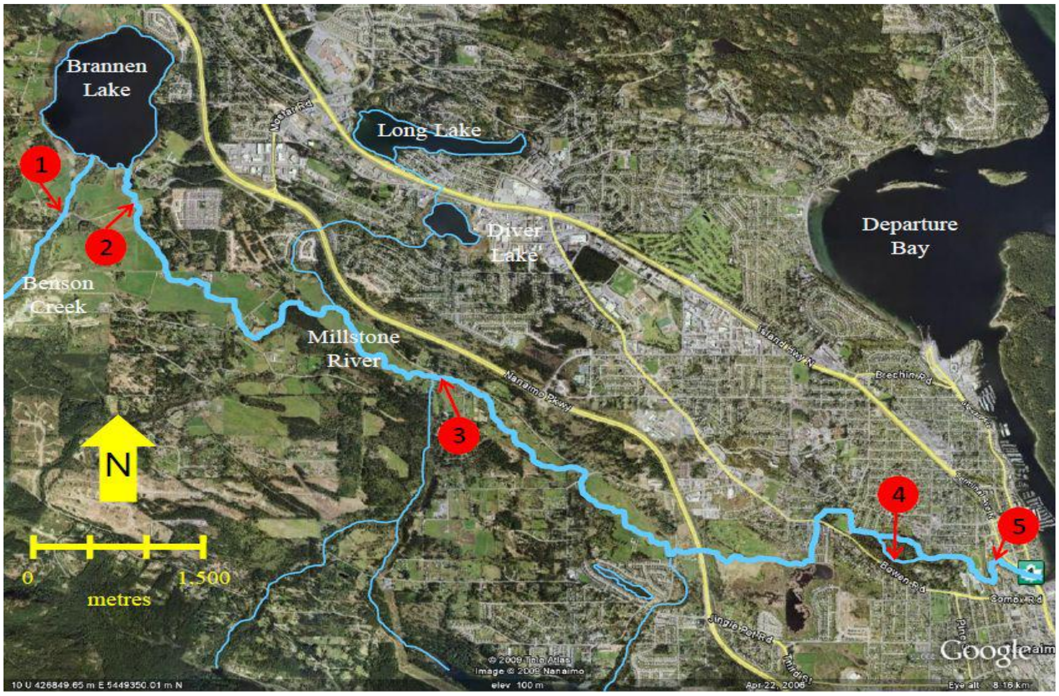

Figure 1. Sampling site locations on the Millstone River

Site #1 (Figure 2) is located on the Benson Creek, which flows into Brannen Lake from the southwest. Access to the sampling site is from the bridge where Biggs road crosses the creek, and the safest route of access is to hike down southwest from the bridge to the rocky embankment running along the creek. Due to Benson creek passing through agricultural lands, it is possible that nutrient levels, such as phosphorus and nitrogen, may be higher than normal due to runoff from fertilizer and manure. There is little riparian vegetation along the bank within the low-lying floodplain where the sampling site is located due to frequent flooding. The substrate mainly consists of bare sands (~10%), gravel (50%), and cobbles (~40%) at the sampling site; however there are also large amounts of organic material (leaves and plant matter) providing potential habitat and food sources for invertebrates. The canopy is composed dominantly of alder and big leaf maple, which provides patches of cover for the creek. This is important as trees help maintain the integrity of the river bank, preventing erosion during high flows observed in the second sampling event (Nov. 19 2019).

Figure 2. Sampling site 1 - Benson Creek at Biggs Road.

Site #2 (Figure 3) is located at the initial stage at which the Millstone River exits Brannen Lake and crosses below Biggs Road. The safest point of access at this sampling location is off of the Northeast corner of the bridge crossing and down a grassy embankment. Potential hazards correspond to prolonged exposure of the site to rainfall, causing the bank to potentially become loose or eroded. The sited is heavily vegetated, with heavy shrub and tree cover approximately 5 metres upstream, and the site itself is resided mainly by grasses and shrubs. Due to the slow/moderate flow of the river at this site, the substrate was mainly composed of sediment with a sparse covering of gravel (~30%), course rock (~20%) and organic material (~50%).

Figure 3. Sampling site 2 - Millstone River at Biggs Road

Site #3 (Figure 4) is located at the junction of Maxey Road and Durnin Road. Access to the sampling site was gained by traversing down a gravel path off of the Southwest side of the bridge. Similar to Site #2, the river bank is heavily vegetated with shrub and tree cover along the river bank. The substrate is mainly composed of fines/silt (~40%) and organic material (~40%) with a small portion of gavel/rock present (~20%). Potential concern associated with this site is in the case of water levels rising due to increased rainfall, which would cause erosion and flooding of the small gravel bar where sampling would occur from.

Figure 4. Sampling site 3 - Millstone River at the corner of Maxey and Durnin Road.

Site #4 (Figure 5) is located in Bowen Park, at the downstream outlet of the duck pond in the side channel. Due to the heavy presence of water fowl directly upstream from the sampling station, it would be assumed that the water sampled may contain significant microbial activity due to feces and organic material produced and disturbed flowing into the outlet. There is little to no hazard associated with accessing this site, where the only potential for concern is loose footing on the surrounding bank and rock when entering the stream. The substrate is mainly composed of large rock (~60%), leaf litter (~20%) and fine sand/silt (~20%).

Figure 5. Site 4 - Millstone River side channel at Bowen Park

Site #5 is located at the end of Barsby Avenue and is accessed via a 50 metre foot trail located directly to the right of the southeast bridge entrance. Due to the steep elevation change from the bridge to sample site, access may be hazardous in wet conditions and caution should be exercised. During sampling events, heavy construction and development was occurring less than 100 metres from the sampling site. However, this was not believed to be a significant source of sediment and effluent run-off into the Millstone. Present Riparian habitat consists of big leaf maples and heavy shrub/herb cover along the embankment, the substrate consists mainly of rock/gravel (~50%) and sand/silt (~40%) as well as dead/decaying organic material (~10%).

3.1.2 Sampling Frequency

Over the course of the monitoring project, two sets of field samples were collected. In order to ensure availability of sampling equipment and laboratory, sampling was conducted within the prescribed date ranges and coordination with fellow groups was established. An important aspect of this project is ensuring that it is possible to collect invertebrate and microbiology samples at each chosen sampling station, therefore the 3 invertebrate samples and 5 microbiology samples were collected in late October, where the flow of the river was safe to wade in to. Hydrology was measured at sites 2 and 4 in both October and November in order to measure a difference between low flow in October with high flow in November; however, hydrological data was unable to be collected at site 2 in the second sampling event as river flow was too high to allow for safe river entry.

🟧 - Event 1: Oct. 29
🟦 - Event 2: Nov. 19

Station	Water Quality*	Hydrology	Invertebrates	Microbiology
1	🟧 🟦 VIU & ALS	--	🟧	🟧
2	🟧 🟦 VIU & ALS	🟧 🟦	--	🟧
3	🟧 🟦 VIU	--	🟧	🟧
4	🟧 🟦 VIU & ALS	🟧 🟦	🟧	🟧
5	🟧 🟦 VIU	--	--	🟧
5 (replicate)	🟧 🟦 VIU	--	--	🟧

*Water quality includes temperature, DO, & sample collection for lab analysis

Figure 6. Sampling schedule for lab analysis

3.2 Basic Hydrology

Hydrologic parameters including water depth, wetted width, velocity, and stream discharge were measured at sites 2 and 4 during both sampling events. A cross-sectional area was measured by stretching a measuring tape across the total width of the stream and dividing the transect into 9 increments at site 2 and 8 increments at site 4, depending on the stream width. The water depth was then measured at each increment with a meter stick, and the cross-sectional area was calculated from the width and average water depth. Flow velocity was measured along a length of 5 m at site 2 and 3 m at site 2, using an empty aluminum can as a float. Starting at the transect laid out for the cross section, the aluminum can was dropped into the stream and the time it took to reach the end of the measured length was timed with a stopwatch. Five runs were recorded and the average of them was taken as an average time in seconds.

The *in situ* average velocity and field measurements were used to calculate total stream discharge. During the second sampling event in November, the water level at site two was too high to safely measure wetted width and average depth, but velocity was measured using the same procedure as outlined above. For accuracy, the average velocity for the November site 2 event was then compared to data from Environment Canada's Water Office, which has a hydrometric station slightly further downstream from site 2 on the Millstone River.

3.3 Water Quality

3.3.1 Field Measurements

In addition to hydrologic parameters, *in situ* measurements collected included water temperature and dissolved oxygen using electronic probes. Both measurements were conducted in October and November, at each of the 5 sampling sites.

3.3.2 Water Sample Collection

Sample collection for water quality occurred over two separate field visits – one during low-flow conditions (October 29) and one during high-flow conditions (November 19). At sites 1, 2, and 4, two sets of samples were taken for measurement of each parameter, as one was sent to ALS Labs and one was tested in VIU lab facilities. A trip blank was also used to assess potential contamination from transport and storage, and a field blank was used to assess potential contamination from the field environment.

3.3.3 VIU Laboratory Results

The Biology department at VIU Nanaimo provides laboratory equipment for analysis of the water quality parameters required for this environmental monitoring project. Following water sample collection, all samples were immediately placed in a cooler with ice packs and stored at approximately 4°C before undergoing laboratory analysis. Tests conducted in the VIU lab included pH, conductivity, hardness, alkalinity, turbidity, reactive phosphorus, total nitrate, and coliform infiltration and incubation.

3.3.4 ALS Laboratory Results

ALS is a private analytical environmental laboratory located in Burnaby, BC. Samples from sites 1, 2, and 4 were sent to ALS Lab for analyses of approximately 30 different metals, nutrient analysis, and general water quality parameters such as conductivity, hardness, pH, and alkalinity. Water samples were shipped to ALS in Styrofoam coolers on October 30 and November 20. The results of these samples were then sent back to VIU, and comparison was made to results from VIU lab analysis.

3.3.5 Quality Assurance/Quality Control

For quality assurance, containers used to collect samples were cleaned prior to going out into the field as well as rinsed with the sample water three times prior to filling the container with the sample. All students ensured that their hands have been cleaned prior to taking each sample to ensure there is no contamination between sites or from outside sources. Samples were also appropriately stored under cool conditions in a cooler until lab tests were performed at VIU or until the samples were shipped to ALS.

For quality control, as mentioned, a trip blank and a field blank was used for the VIU lab samples to assess potential contamination from equipment and containers or from the field environment. One replicate sample was also taken during each sampling event at site 5, from which the precision of test results could then be calculated. Additionally, during the first sampling event on October 29th 2019. For consistency in long-term data collection, the sample sites were collected as close as possible to those from which samples were taken in previous years.

3.3.6 Data Analyses and Comparison to Guidelines

Following VIU and ALS lab analysis, all water quality results were compared not only to each other, but also to the applicable BC water quality guidelines for the protection of freshwater life. These guidelines were obtained from the BC Ministry of Environment *Approved Water Quality Guidelines.* (Ministry of Environment and Climate Change Strategy, 2019). The results of this comparison demonstrate whether water quality parameters are met in order to support aquatic life.

3.4 Microbiology

3.4.1 Water Sample Collection

Microbiology testing occurred at all five sites during the first sampling event in October, and samples were collected in sterile 100 ml Whirl-Pak plastic bags, with one replicate sample taken at site 5. Collection and assessment of microbiology at each station is an important factor and cornerstone of water quality, as it proves helpful in identifying potential contamination of the river system at sampling locations located near different potential pollution sources such as agricultural and urban runoff.

3.4.2 VIU Laboratory Analysis

Water samples collected for microbiology were stored along with the water quality samples in the cooler until lab analysis was conducted in the VIU lab. The procedure for coliform analysis includes vacuum pumping the samples through a filter and placed on a petri dish. The samples were then covered in m-ColiBlue24 Broth and incubated for 24 hours at a temperature of 35°C before being analyzed. Following the 24-hour incubation period, the number of coliforms present was determined through manual counting. Blue dots indicated the presence of fecal coliform (E. Coli) and red dots represented non-fecal coliforms.

3.4.3 Quality Assurance/Quality Control

For quality assurance, the Whirl-Paks used for collecting sample water remained sealed sterile until in the field and ready for use. Once filled with sample water, the Whirl-Paks were stored in the cooler and kept at a lower temperature until lab analysis was conducted. For quality control, a replicate sample was taken at site 5 to avoid inaccuracies when analyzing the results.

3.5 Stream Invertebrate Communities

3.5.1 Invertebrate Sample Collection

Invertebrate samples were collected by using a Hess sampler, and only during the first sampling event in October under low-flow conditions at sites 1, 2, and 4. The invertebrate samples collected were kept alive and transported back to the VIU lab for counting and analysis. The species identified from these samples provides an assessment of organisms' pollution tolerance and a representation of the overall health of the aquatic ecosystem in Millstone River. If point-source pollution is suspected in the proximity of sampling sites 1, 2, and 4, benthic communities will also help to determine the effects of such pollution (Demers, 2019).

3.5.2 VIU Laboratory Analyses

Analysis of invertebrate samples involved sorting the animals among different taxonomic groups, firstly by grouping animals into apparently similar taxa, and then by using a dissecting microscope for more accurate identification. Triplicate samples that were collected in the field were combined so that only one laboratory analysis was completed for each site. Data sheets provided by Pacific Streamkeepers were used to record the count of each taxonomic group by number of individuals that belong to a group, and by the different number of taxa observed that belong to a group (Demers, 2019).

3.5.3 Quality Assurance/Quality Control

For quality assurance, sample containers and all components of the Hess sampler were appropriately cleaned prior to going into the field. Once in the field, sample containers were rinsed three times using water from the Millstone River, at each site where samples were collected. Sample containers were all pre-labeled and filled with the appropriate preservative. In the field, samples were all taken from downstream to upstream to avoid environmental contamination. While performing taxonomic identification in the lab, proper identification keys provided by VIU were used to eliminate incorrect taxonomic identification.

3.5.4 Data Analyses

Upon completion of laboratory analysis and taxonomic identification, the Pacific Streamkeepers data sheets were used for calculations to determine abundance and density of organisms, predominant taxon, water quality assessments (from pollution tolerance index, EPT index, and EPT to total ratio index), diversity, and an overall site assessment rating. The Shannon-Weiner Diversity Index was then used to calculate species diversity, in which the index is defined as a measure of uncertainty in predicting to what taxon a randomly chosen individual will belong (Demers, 2019).

4.0 RESULTS AND DISCUSSION

4.1.1 Hydrology

Hydrometric data demonstrated 56.5 mm of rainfall between Oct 29th 2019 and Nov 19th 2019 (Water Office, GC, 2019). Approximately 18.4 mm of rainfall occurred on November 18 before our second sampling event (Water Office, GC, 2019), which contributed to an increase in discharge to $3.75m^3/s$ on November 19, up from $1.2m^3/s$ on October 29 (Figure 7).

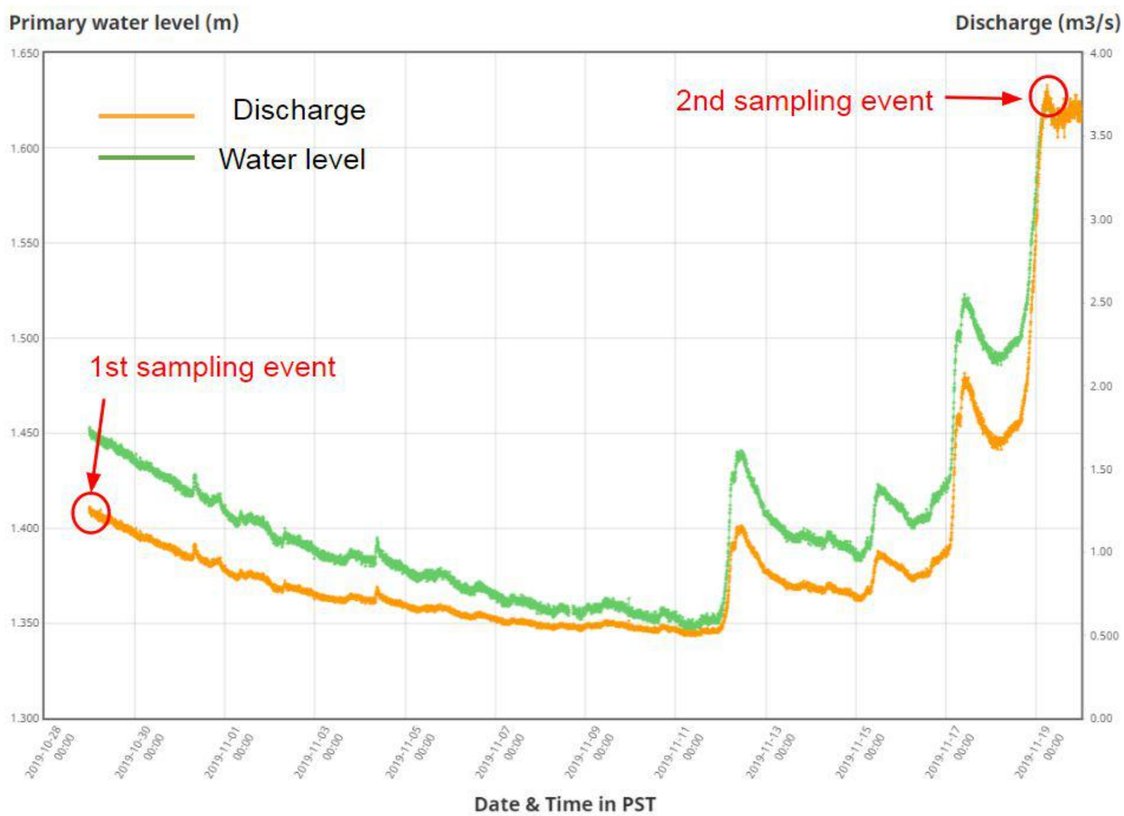

Figure 7. Hydrometric data on Oct 29th 2019 and Nov 19th 2019. (Water Office, GC, 2019).

Data collected from site 4 shows that flow velocity decreased from 0.72-0.49 m/s between the first and second sampling events. As previously mentioned, stream data is not available for site 2 on November 19 due to high water levels. Our calculated total discharge from site 4 demonstrates a decrease from 0.49-0.35 m/s^3 between the two sampling events, which correlates with a decrease in average velocity. However, this trend does not reflect data from Environment Canada's hydrometric station and the heavy rainfall on November 18. This is likely due to the fact that site 4 is located on the Millstone River side channel, which has controlled flow. Mean depth at site 4 remained fairly consistent over both sampling events at 0.17-0.18 m, along with wetted width at 4.1-4.0 m (Table 1). Given that hydrologic measurements were only conducted at site 4 during both low flow and high flow conditions, additional field data would need to be collected in order to produce a more in depth hydrological report.

Table 1. Mean water velocity and discharge recorded on Oct 29th and Nov 19th, 2019.

Date	Station	Mean depth (m)	Wetted width (m)	Mean Velocity (m/s)	Total Discharge (m3/s)
Oct. 29	2	0.23	9.5	0.55	1.2
Oct. 29	4	0.17	4.1	0.72	0.49
Nov. 19	2	n/a	n/a	n/a	n/a
Nov. 19	4	0.18	4	0.49	0.35

4.2 Water Quality

4.2.1 *Field Measurements*

Measures of both dissolved oxygen and temperature were taken in the field during both sampling events, with varying results. Station 1 is situated on Benson creek, a small tributary flowing into Brannen Lake. Water sampled at this site is faster flowing and therefore potentially better aerated than sites located along the Millstone River. Water samples (in both sampling events) collected at station 1 contain some of the highest levels of dissolved oxygen (avg. 11.6mg/L DO) of all sites. Station 2 shows a significant decrease in dissolved oxygen (~9.8mg/L DO) as it is receiving epilimnetic water from mesotrophic Brannen Lake which may not have high levels of dissolved oxygen in its surface waters due to noticable levels of primary production. Water flowing through station 3 shows an increase in dissolved oxygen levels (~10.8mg/L) as the water would have more time to mix throughout its course from station 2 to station 3, becoming more saturated with oxygen through diffusion.

Dissolved oxygen levels measured at stations 3 to 5 continue to increase as water travels further down the Millstone river.

Temperature levels measured throughout all sampling stations exhibits less of a linear pattern than measures of dissolved oxygen. The lower temperature (in the first event) of water sampled at station 1 may have been attributed to the higher elevation which Benson creek flows from (Lucid Lake), the lower temperature measured (7.8 degrees celsius) at station 1 is correlated with the high levels of dissolved oxygen observed. As expected, temperature measurements at station 4 are among the highest of all stations as it is located directly at the outlet of the duck pond in Bowen Park. However, the temperature measured at station 4 does not correlate with a decrease in dissolved oxygen levels. Unexpectedly, water temperatures taken during the second event are not consistently lower than temperatures observed in the first sampling event, potentially due to low levels of precipitation over the period of time separating the two sampling events as well as mild temperatures for most of the month of November.

According to BC water quality guidelines, dissolved oxygen levels at all sampling stations (apart from stations 2 and 3) are above the minimum guideline of 11.0 mg/L DO needed to support all fish life stages, including the Buried Embryo/Alevin stage (Ministry of Environment and Climate Change Strategy 2019). Temperature levels at all sites are within all optimal ranges (4.0-16.0 degrees celsius) needed to support the migration, spawning, incubation and rearing of Coho salmon, which were present over the course of late fall when sampling was occuring in the lower reaches of the millstone river (Ministry of Environment and Climate Change Strategy 2019).

Table 2: Millstone River in situ measurements taken over low flow (October) and high flow (november)

Date	Station	Dissolved Oxygen (mg/L)	Temperature (°C)	Discharge (m3/s)
Oct. 29	1	11.8	7.8	--
	2	9.7	9.7	1.2
	3	10.8	9.1	--
	4	11.6	11.6	0.49
	5	11.8	8.9	--
Nov. 19	1	11.4	9.6	--
	2	10	9.4	3.57
	3	10.7	8.9	--
	4	11.3	9.5	0.42
	5	11.6	9.4	--

events.

4.2.2 VIU Laboratory Analyses

As discussed in the *Methods* section, all water samples collected during both sampling events were analysed in the VIU Laboratory. The parameters measured in the lab include pH, conductivity, alkalinity, hardness, turbidity, nitrate, and phosphate.

pH The pH values measured for sampling events 1 and 2 displayed similar values, ranging between 6.5 - 7.5. These values are within the range of normal freshwater pH values of 6.0 - 9.0 (MOE, 2019). In both October and November, sites 1 and 2 were slightly more alkaline, with values of 7.0 - 7.5 than sites 3 and 4, with values of 6.5 - 6.8 (Figure 7). However, a change in pH value was seen at site 5 between the first and second sampling events, with a decreased from 7.3 in October to 6.7 in November. The replicate samples taken for site 5 supported these results. These observed trends in pH, decreasing from upstream to downstream are reflective of the values measured for temperature (Figure 7). In general, as water temperature increases, the pH value can be expected to decrease. For example, between the five sampling sites in October, temperature increased as moving further downstream, and pH followed this trend by decreasing further downstream. As mentioned, an exception to this trend was at site 5 during the first sampling event, where pH had decreased from 7.5 to 6.6 between sites 1 and 4, but then increased to 7.3 at site 5. The temperature results also reflect this slight disruption to the trend, as the temperature increased from 7.8°C to 11.6°C between sites 1 and 4, and then decreased to 8.9°C at site 5.

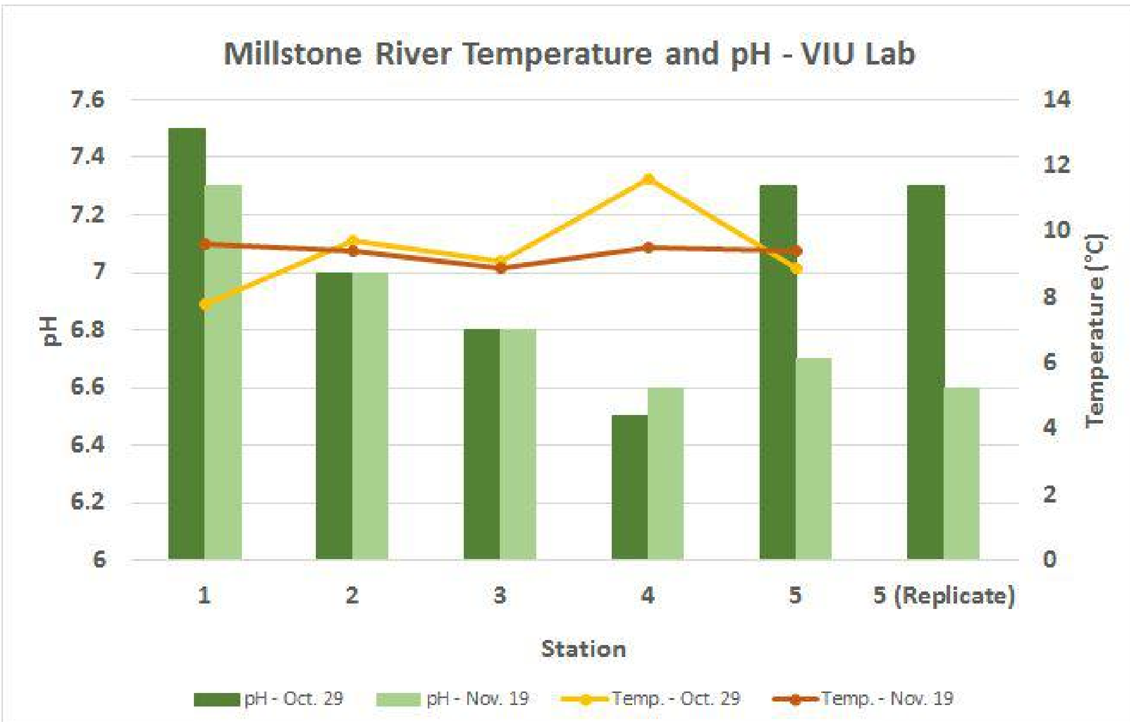

Figure 7. Temperature and pH values of the Millstone River analyzed at the VIU lab.

Conductivity Across both sampling events, conductivity significantly increased downstream from site 1 to 5. In October, the conductivity at site 1 was 43 µS/cm and consistently increased to 116 µS/cm at site 5. Between sites 1 and 2 was the most significant increase from 43 µS/cm at site 1 to 80 µS/cm at site 2. Similar results were seen in November, with an increase from 26 µS/cm at site 1 to 117 µS/cm at site 5, and an increase from 26 to 74 µS/cm between sites 1 and 2. These results are trends that are to be expected as moving further downstream, as with increasing distance from the headwaters, the more sediment and suspended solids will be picked up. Increase in sediment and suspended solids can be indicated by conductivity as sediment and suspended solids increase the concentration of ions, which defines conductivity. The significant increases in conductivity between sites 1 and 2 likely reflects conditions present in Brannen Lake. Site 1, on Benson Creek, flows into Brannen Lake and Site 2, on the Millstone River flows out of Brannen Lake (Figure __). Therefore, water coming out of Brannen Lake is more conductive than water that flows into the lake.

Turbidity Turbidity results measured at VIU increased downstream along the Millstone River, supporting the trend of conductivity and increased sediment and suspended solids further downstream (Figure 8). Nephelometric turbidity units (NTU) increased from site 1 to 5 during both sampling events in October and November. However, a minor anomaly during sampling event 2 shows that turbidity decreased slightly from 1.28 NTU at site 1 to 1.09 NTU at site 2. Other than this, turbidity increased from 1.01 to 3.49 NTU in October and 1.28 to 5.44 NTU in November. The overall higher values in November are reflective of the increased volume of water and stream discharge (Figure 1).

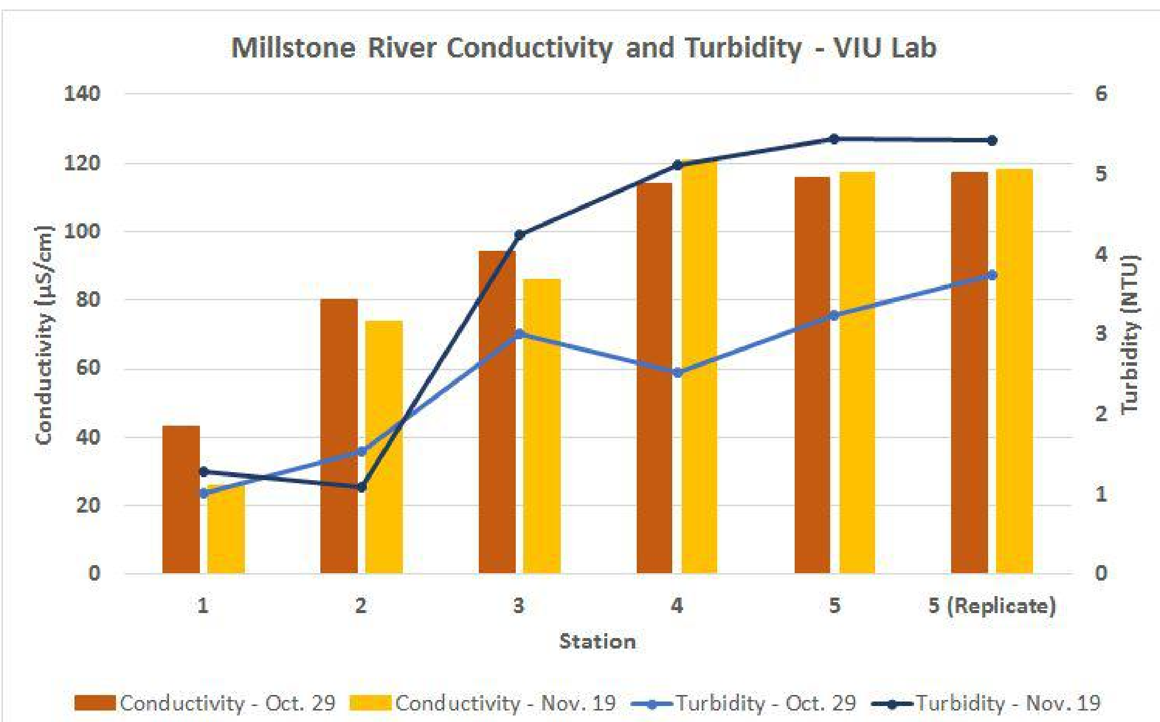

Figure 8. Conductivity and Temperature values of the Millstone River analyzed at the VIU lab.

Alkalinity Results from the first sampling event show that alkalinity ranged from 10.3 to 38 mg/L as $CaCO_3$ between sites 1, 2, 3, and 5, with a significantly higher value of 76.4 mg/L as $CaCO_3$ at site 4. Similarly, results from samping event 2 showed alkalinity ranging from 9.6 to 33.2 mg/L as $CaCO_3$ between sites 1, 2, 3, and 5, and 43 mg/L as $CaCO_3$ at site 4. As mentioned, site 4 is located at the downstream outlet of the Bowen Park duck pond, and is part of a constructed side channel of the Millstone River, in which discharged is controlled (Northwest Hydraulic Consultants. 2008). The presence of water fowl in close proximity to the sampling site along with the control of water flow has greater control on water quality parameters than the actual environmental conditions of the Millstone.

The general trend of increasing alkalinity further downstream is another expected result, as higher alkalinity represents higher levels of calcium carbonate ($CaCO_3$). An increase in $CaCO_3$ levels downstream demonstrates that water travelling a greater distance picks up sediment and other particles containing minerals composed of calcium carbonate. These higher levels of calcium carbonate near towards the downstream portion of the Millstone indicate that these regions have a greater ability to neutralize acid that is added to the water, in other words, it has a greater buffering capacity. According to BC water quality guidelines, site 1 had moderate acid (10-20 mg/L as $CaCO_3$)sensitivity on October 29 and high acid sensitivity on November 29 (0-10 mg/L as $CaCO_3$). Sites 2, 3, 4, and 5 all had low acid sensitivity (>20 mg/L as $CaCO_3$) in both October and November.

In comparison to previously collected data, similar trends in alkalinity were observed in 2016, 2017, and 2018. Most similar is data from 2018, which shows an increase from7.5 - 14.6 mg/L at site 1 to a peak, to a peak of 32.8 - 36 mg/L at site 4 and then a slight decrease to 30 - 35.2 mg/L at site 5 (Boldt et al., 2018). Data from 2008 also shows a similar trend of increasing alkalinity downstream, but the values show a more gradual increase between the first and late sites, rather than a significant increase near the duck pond followed by a decrease downstream (Brooks et al., 2008).

Hardness Also correlating with conductivity and alkalinity trends, hardness of Millstone River water increased with increasing distance from the headwaters. The first sampling event yielded an increase from 14 to 44 mg/L as $CaCO_3$ from site 1 to 5 and an increase from 14 to 42 mg/L as $CaCO_3$ for the second sampling event. Hardness is a measure of the amount of dissolved divalent cations present in water, where soft water is typically less than 60 mg/L and hard water is typically greater than 120 mg/L (BC Ministry of Environment, Lands and Parks, 1998). Therefore, all sampling sites indicate that the Millstone River has soft water. These results are similar to values obtained from previous monitoring projects, where hardness ranged from 12 to 47 mg/L in 2017 (Hobkirk et al., 2017) and 18 to 48 mg/L (Boldt et al., 2018). Looking back at data from the beginning of this project in 2008, hardness results are similar to current results in that they show increasing hardness between the first and last sampling sites. However, hardness values in 2008 were in a smaller range, from 20 to 35 mg/L in October and 25 to 30 mg/L in November (Brooks et al., 2008). It's possible that an increased variation in range of hardness between sites 1 and 5 in more recent years is reflective of increasing urban development and land use change within the Millstone watershed. Increasing urban development often results in greater volumes of runoff, therefore increasing the volume of water that passes through geologic material and picks up divalent cations.

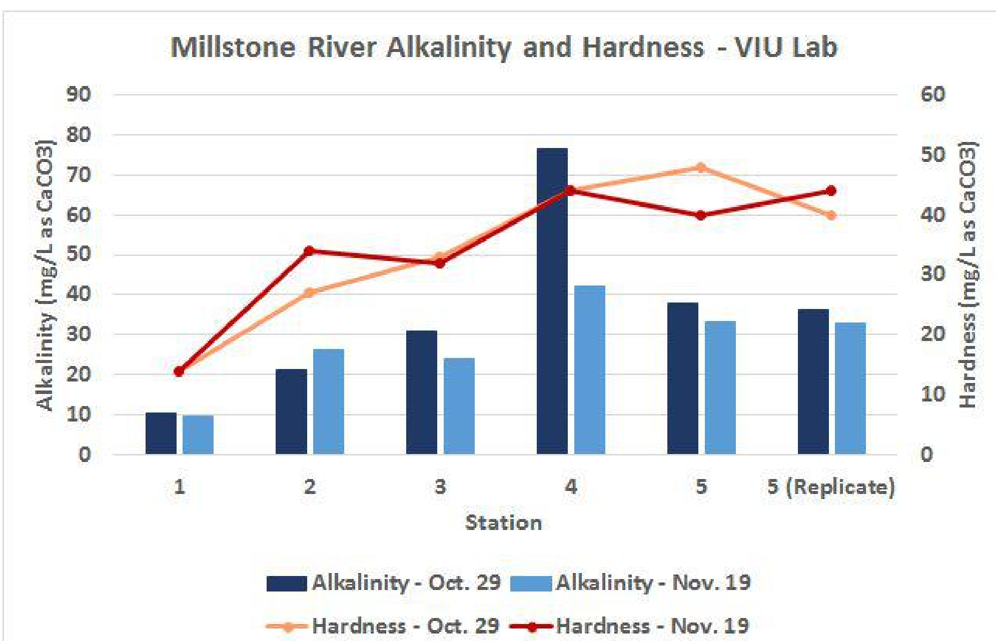

Figure 9. Alkalinity and Hardness levels of the Millstone River analyzed at the VIU lab.

Nitrate Water samples analyzed in the VIU laboratory for nitrate show variable results (Figure 10). From sampling event 1, nitrate ranged from 0.04 to 0.5 mg/L as NO_3^- and was highest at sites 2, 3, and 4. Site 2 showed a value of 0.5 mg/L as NO_3^- and is located adjacent to agricultural land and is directly downstream from Nanaimo Correctional Centre, which may influence the increased level of nitrate from fertilizer runoff into the Millstone River. However, it is also possible that the significantly higher value at site 2 is a result of error in performing laboratory techniques, as both 2017 and 2018 data indicates that site 2 had the lowest value of nitrate in comparison to all other sites (Hobkirk et al., 2017; Bolt et al., 2018). Results from the second sampling event in November yielded results ranging from 0.03 mg/L as NO_3^- at site 1 to 0.1 mg/L as NO_3^- at site 5. An overall decrease from an average of 0.2 to 0.07 mg/L from October to November is an expected trend as a large precipitation event between the two sampling events and increase in stream discharge resulted in dilution of initial nitrate levels. However, a trend that was expected but not observed was that nitrate would be highest at site 4, near the Bowen Park duck pond and at sites 1 and 2, which are in close proximity to agricultural lands. Either way, the BC Water Quality Guideline for aquatic life is 32.8 mg/L NO_3^- (MOE, 2019), and all sites, during both sampling events, have nitrate levels well below the guidelines.

Phosphate In October, phosphate levels remained relatively stable throughout the course of the 5 sampling locations, with an average of 0.09 mg/L as PO_4^{3-}, the highest value observed at site 5 (.13 mg/L) and the lowest value at site 3 (0.06 mg/L). In November, phosphate levels at all sampling sites were lower than those observed from the first sampling event (Figure 10), within a range of 0.02 to 0.07 mg/L. The decrease between sampling events was an expected trend as with increasing stream discharge and greater precipitation in November, dilution lowered the phosphate levels throughout the Millstone River. These observed trends do not correlate to data from previous years, however, when compared to early data from 2008, overall phosphate levels have not increased (Brooks et al., 2008).

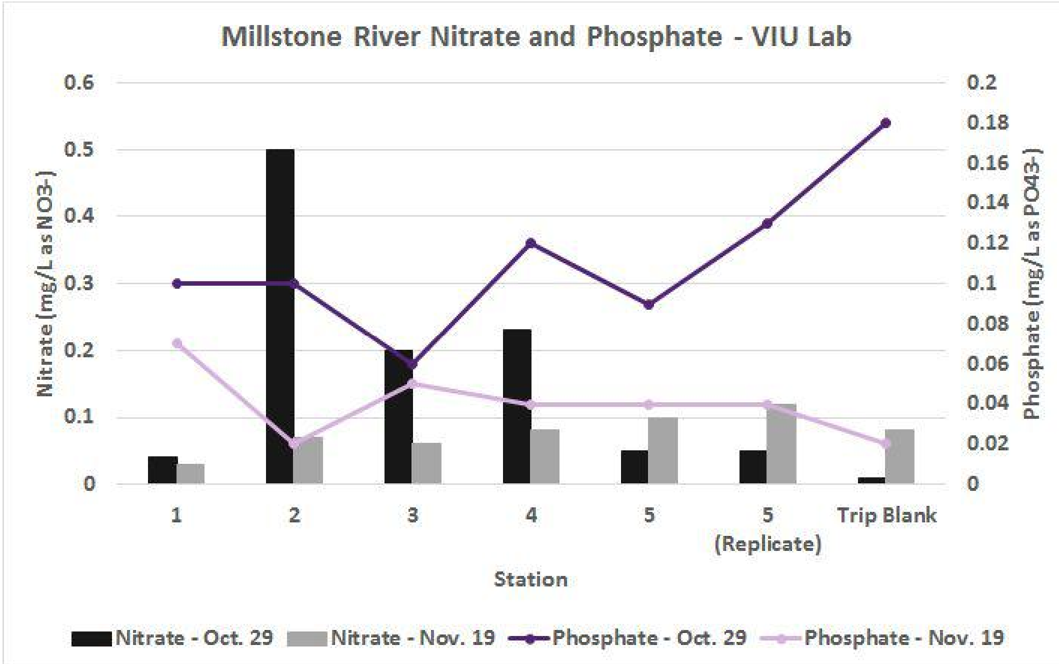

Figure 10. Nitrate and Phosphate levels of the Millstone River analyzed in the VIU lab.

4.2.3 ALS Laboratory Analyses

Physical tests Analytical results from the ALS Environmental lab from station 1, 2 and 4 from both sampling events were compiled and compared to the applicable BC water quality guideline. The results we found for ALS are summarized in tables 3 and 4 respectively. Results from the physical parameters demonstrated increases in conductivity, hardness and pH in both sampling events. Conductivity increased from 32.1 to 134 µs/cm from station 1 to station 4 as we went downstream. This makes sense as more nutrient run-off would occur and gather the further downstream we sampled. Hardness also increased from 13.2-42.3 $CaCO_3$ mg/L from station 1 to 4. Similar results were observed from the second sampling date with rises in both hardness and conductivity the further downstream. Hardness still fell below the BC water quality guideline of 60 mg/L $CaCO_3$ for both sampling events.

Table 3. ALS Water quality results for the first sampling event on the Millstone RIver (Oct 29th, 2019). Results were compared to the appropriate BC water quality guidelines.

			Station			
Physical tests (Water)	**Unit**	**1**	**2**	**4**	**Guidelines**	**Observation**
Conductivity	µs/cm	32.1	84.5	134	-	
Hardness ($CaCO_3$)	mg/L	13.2	30.7	42.3	<60 mg/L	Soft Water
pH	pH	7.14	7.48	7.66	6.5-9.0	
Anions/Nutrients (Water)						
Ammonia, Total (as N)	mg/L	<0.0050	0.0083	0.0233	19.7-23.2	
Nitrate (as N)	mg/L	0.182	0.0541	0.337	200	
Nitrite (as N)	mg/L	<0.0010	<0.0010	0.0028	0.06	
Total Nitrogen	mg/L	0.386	0.325	0.662	-	
Orthophosphate-Dissolved (P)	mg/L	<0.0010	<0.0010	0.0039	-	
Phosphorous (P)- Total	mg/L	0.0068	0.0082	0.0379	<0.10	Oligotrophic
N:P	N/A	56.8	39.6	17.5	16	
Total Metals						
Calcium (Ca) -Total	mg/L	3.68	8.32	12.1	4-8	Above guideline

Aluminum (AI)- Total	mg/L	<0.20	<0.20	0.41	0.1	
Iron (Fe)- Total	mg/L	0.172	0.144	0.683	1	
Magnesium (Mg)-Total	mg/L	0.97	2.41	2.97	-	
Silicon (Si)-Total	mg/L	3.76	3.09	4.41	-	

Nutrients Total ammonia results were found to be below the detection limit for station 1 during both sampling events. Station 2 showed an increase in ammonia at 0.0083 mg/L -NH_3 on Nov 19th, 2019 which still lies below the BC water quality guidelines. Station 4 demonstrated the highest total ammonia concentration during both sampling events with values at 0.0233 mg/L -NH_3 (Oct 29th) and 0.0117 mg/L -NH_3 (Nov 19th). Total nitrogen results were higher during our first sampling event. This could be due to lower water levels during this time, which allows the run-off from agricultural land to become more concentrated when in the river. Total nitrogen from the first sampling event increased from 0.386 mg/L to 0.662 mg/L whereas the total nitrogen from the second sample date was 0.220 -0.352 mg/L which is nearly half of what it was on Oct 29th. N:P ratios in the millstone river showed the system becoming overall more eutrophic the further we samples downstream with the closest N:P ratio of 17.5:1 on Oct 29th found in sample site 4. This makes sense as this is near the duck pond which has high amount of organic waste material flowing from it. The other sample sites suggest that the millstone river is oligotrophic with ratios of 39.6:1 or higher for total phosphorus and total nitrogen. Total phosphorus concentrations were found well below the BC water quality guidelines as well which suggests that the system is not eutrophic.

Table 4. - ALS water quality results for the second sampling event on the Millstone River (Nov 19th 2019). Results were compared to the appropriate BC Water quality guidelines.

Physical tests (Water)	Unit	Station 1	Station 2	Station 4	Guidelines	Observation
Conductivity	µs/cm	42.8	86	118	-	
Hardness (CaCO3)	mg/L	17	31.2	40	<60 mg/L	Soft Water
pH	pH	4.2	7.47	7.64	6.5-9.0	
Anions/Nutrients (Water)						
Ammonia, Total (as N)	mg/L	<0.0050	<0.0050	0.0117	19.7-23.2	
Nitrate (as N)	mg/L	0.0785	0.0402	0.071	200	
Nitrite (as N)	mg/L	<0.0010	<0.0010	0.0014	0.06	
Total Nitrogen	mg/L	0.22	0.244	0.352	-	
Orthophosphate-Dissolved (P)	mg/L	<0.0010	<0.0010	0.0021	-	
Phosphorous (P)- Total	mg/L	0.0026	0.006	0.0192	<0.10	Oligotrophic
N:P	N/A	84.6	40.6	18.3	16	
Total Metals						
Calcium (Ca) -Total	mg/L	4.78	8.41	11.2	4-8	Above Guideline
Aluminum (AI)- Total	mg/L	<0.20	<0.20	0.2	0.1	
Iron (Fe)- Total	mg/L	<0.030	0.1	0.373	1	

Magnesium (Mg)-Total	mg/L	1.22	2.47	2.92	-	
Silicon (Si)-Total	mg/L	3.92	3.04	3.71	-	

Total Metals Calcium and Aluminum appeared to be the only metal above its water quality guideline. All other metals were found to be below their detection limit or below the maximum allowable water quality guideline. For both sampling events station 4 exhibited calcium and aluminum levels that were well above the water quality guideline at concentrations of 11.2 mg/L and 12.1 mg/L- Ca. This contamination makes sense as there is likely a lot of organic waste effluent that flows from the nearby duck pond. In the millstone river we found the calcium concentrations to increase gradually downstream which suggests that station 1 would be the most sensitive to acidification while station 4 would be the least sensitive out of all of our sites sampled.

4.2.4 Quality Assurance/Quality Control

The replicate sample obtained from station 5 and the trip blank obtained prior to sampling were used in analysis at the VIU laboratory to help ensure the quality of results obtained. General parameters of the replicate sample were recorded and found to only deviated slightly from the original samples taken, exhibiting high precision between results. As expected Phosphate and Nitrate concentrations in the trip blank showed minimal flucu from the range of concentrations observed in other samples collected, proving little to no contamination from sampling equipment used.

Samples being sent to the ALS Laboratory for evaluation were collected in sterile containers to ensure no contamination of the sample and prepared with the correct preservatives to ensure that analysis results were accurate and comparable to those obtained from VIU laboratory analysis. Furthermore, the dates at which samples were collected was documented to ensure that sample analysis occurred before preservation expiration and within the recommended period of holding.

4.3 Microbiology

After VIU laboratory analysis, counts of total coliform and fecal coliform were tabulated and are shown below.

Table 5. Coliform analysis results from sampling on October 29, 2019

Site	Fecal (CFU/100ml)	Non-Fecal (CFU/100ml)	Total Coliform (CFU/100ml)	Percent Fecal (%)
1	4	180	184	2.17%
2	4	100	104	3.85%
3	16	444	460	3.48%
4	96	420	516	18.6%
5	24	324	348	6.90%
Replicate	28	480	508	5.51%

***Counts multiplied by 4**

All water samples taken at each sampling location exhibited the presence of coliforms, potentially due to agricultural activity and urban development surrounding a significant portion of the Millstone River and Brannon Lake. Among all sampling stations tested, site 4 showed the highest total coliform count (516 CFU/100ml) and percentage of fecal coliform (18.6%). This proportion of fecal matter was expected as the sampling site is located at the outlet of the duck pond situated along the side channel of the millstone river in Bowen Park. This section of the millstone river is subject to dense populations of water fowl and therefore significant organic and fecal matter is present in the water. Coliform levels are highest at station 3 and 4, suggesting the highest levels of anthropogenic input from human activity.

(Insert coliform comparison bar plot when document is converted to word doc)

According to the guidelines for interpreting water quality data, water in the Millstone River is not suitable for raw drinking water or crop processing/disinfection (0, ≤10). However, it is sufficient for general livestock use and irrigation as well as recreation (200, ≤1000).

4.4 Stream Invertebrate Communities

4.4.1 Abundance/Density

A total of 418 organisms and 13 different taxa were counted between sites 1, 2, and 4, collected on October 29. The highest abundance of total organisms (219) was observed at site 4 and included taxa of Caddisfly Larva, Mayfly Nymph, Damselfly Larva, Amphipod, Aquatic Worm, and Leech. The lowest abundance was found at site 1 with a total of 62 organisms. The greatest overall invertebrate density was collected at site with a calculated total of 811.1/m^2 and the lowest density was at site 1 with a calculated total of 237/m^2. Aquatic worms (oligochaetes) were the most common taxonomic group overall, found at each site, however, the dominant taxon at each site varied. At site 1, Stonefly Nymph were the most dominant, Caddisfly Larva the most dominant at site 2, and Aquatic worms dominated site 4 (Figure __). The dominant taxa at sites 1 and 2 are pollution intolerant organisms, whereas the dominant taxon at site 4 is a pollution tolerant organism. These results correlate to water quality results, which indicated that pollution is likely greater further downstream. Additionally, since site 4 is located at the downstream outlet of the Bowen Park duck pond, where the highest levels of fecal coliform, conductivity, alkalinity, hardness, and turbidity were observed, it is expected that a greater number of pollution tolerant organisms than pollution intolerant organisms be present.

Table 6. Total invertebrate counts for sites 1, 2, and 4 on the Millstone River

Pollution Tolerance	Invertebrate Taxa	Station 1	Station 2	Station 4
Category 1 Pollution Intolerant	Caddisfly Larva	1	68	11
	Mayfly Nymph	25	0	52
	Stonefly Nymph	26	0	0
Total		50	68	64
Category 2 Somewhat Pollution Intolerant	Damselfly Larva	0	0	4
	Amphipod	0	10	58
Total			10	62
Category 3 Pollution Tolerant	Aquatic Worm	12	54	92
	Leech	0	0	2
	Midge Larva	0	1	0
	Water Mite	0	2	0
Total		12	57	94

4.4.2 Diversity and Site Ratings

The highest Shannon-Weiner Diversity Index of value of 0.82 was calculated for site 1, followed by 0.75 at site 4, and the lowest at site 2 of 0.55. The Shannon-Weiner Diversity Index accounts for the proportions of each taxon in the sample, and the higher the calculated value, the higher the diversity. A higher diversity of invertebrates at site 1 is likely correlated to the location of the site further upstream, and closer to the headwaters where the effects of anthropogenic activities have had a lower impact on the river ecosystem than further downstream.

On a rating scale from 1 to 4, where 1 represents poor site conditions and 4 represents good site conditions, the highest rating of assessed sites was 2.75 at site 1 (Table 9). This indicates marginal to acceptable conditions, and sites 2 and 4 both received ratings of 2.5, also indication marinal to acceptable conditions. The site assessment rating gives an overall rating of stream health, with consideration of four factors: the pollution tolerance index, EPT index, the EPT to total ratio, and the predominant taxon ratio (Table 9). There is a correlation between highest site assessment rating at site 1 and highest invertebrate density at site 1, indicating that pollution levels are lowest in the region of the downstream outlet of Brannen Lake. This is also reflected in the water quality parameters previously discussed. Overall, this assessment of stream health indicates that the condition of the Millstone River is acceptable, and supports aquatic life of pollution intolerant species, however, these conditions are not ideal as there is significant room for improvement in the site assessment ratings.

Table 7. Shannon-Weiner Diversity calculates for invertebrate density at site 1.

Organism	Total count	P_i (C/T)	Ln (p_i)	p_i*ln (p_i)
Caddisfly Larva	1	0.02	-3.91	-0.08
Mayfly Nymph	25	0.39	-0.94	-0.37
Stonefly Nymph	26	0.41	-0.89	-0.36
Aquatic Worm	12	0.19	-1.66	-0.32
Total	**64**	**1.01**	**-7.4**	**-1.13**
H = - (-1.13)/ln(4) = **0.82**				

Table 8. Shannon-Weiner Diversity calculates for invertebrate density at site 2.

Organism	Total count	P_i (C/T)	Ln (p_i)	p_i*ln (p_i)
Caddisfly Larva	68	1.03030303	0.03	0.030909
Amphipod	10	0.151515152	-1.9	-0.28788
Aquatic Worm	54	0.818181818	-0.2	-0.16364
Midge Larva	1	0.015151515	-4.2	-0.06364
Water Mite	2	0.03030303	-3.51	-0.10636
Total	**66**	**1.01**	**-9.78**	**-0.59061**
H = - (-0.59)/ln(5) = **0.55**				

Table 9. Shannon-Weiner Diversity calculates for invertebrate density at site 4.

Organism	Total count	P_i (C/T)	Ln (p_i)	p_i*ln (p_i)
Caddisfly Larva	11	0.05	-2.9	-0.15
Mayfly Larva	52	0.24	-1.43	-0.34
Damselfly Larva	4	0.02	-3.91	-0.08
Amphipod	58	0.26	-1.35	-0.35
Aquatic Worm	92	0.42	-0.87	-0.37
Leech	2	0.01	-4.61	-0.05
Total	**219**	**1**	**-15.07**	**-1.34**
H = - (-1.34)/ln(6) = **0.75**				

Table 10. Site assessment rating of the Millstone River based on invertebrate assessment.

Date	Station	Predominant Taxon	Pollution Tolerance Index (Rating)	EPT Index (Rating)	Predominant Taxon Ratio Index (Rating)	Overall Site Assessment Rating
Oct. 29	1	13 (2)	4 (2)	0.81 (4)	0.41 (3)	2.75
Oct. 29	2	11 (2)	2 (2)	0.5 (3)	0.5 (3)	2.5
Oct. 29	4	21 (3)	4 (2)	0.29 (2)	0.42 (3)	2.5

4.4.3 Quality Assurance/Quality Control

For quality assurance, sample containers and all components of the Hess sampler were appropriately cleaned prior to going into the field, as well as rinsed in the field using the sample water at each site were samples were collected. Sample containers were all pre-labeled prior to collecting the sample to ensure accurate identification. In the field, samples were taken from downstream to upstream to avoid environmental contamination from disturbed streambed materials. While performing taxonomic identification in the lab, identification keys provided by VIU were used to eliminate incorrect taxonomic identification. For quality control, triplicate samples were collected at site 1, 2, and 4 to account for variation between samples. When conducting lab analysis, samples were double-counted to eliminate variability in results due to the counter.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on water quality parameters and stream invertebrate assessments, the overall environmental condition of the Millstone River was deemed “acceptable” according to BC Water Quality Guidelines for Aquatic Life (BC Ministry of Environment, Lands and Parks, 1998). 2019 to support this conclusion identified trends similar to those identified in previous years of environmental monitoring projects on the Millstone River. Water quality parameters indicated that although water is not potable, it is sufficient for the support of aquatic life, since no significant deficiencies or extremes were observed. The stream invertebrate assessment also indicates that the overall condition of the Millstone River is "acceptable" as pollution intolerant species were identified. However, the rating derived from the invertebrate communities does indicate that there is room for improvement in the water quality of the Millstone River, as the species diversity was calculated to be relatively low. However, it is important to note that there is a potential for changes in water quality parameters in the future and the possibility for an increase in contamination and pollution to the Millstone Watershed, as urban and agricultural development continues to rise.

The data collected during this project provides a continuous assessment of the Millstone River, and it is recommended that environmental monitoring projects continue each year. For future projects, collecting invertebrate samples and conducting hydrologic measurements at each of the five sites may help to provide a more complete representation of the ecosystem's health. Additionally, since site 4 at the outlet of the Bowen Park duck pond was were most anomalies occurred in the results, it may be beneficial to include a sampling site at the upstream inlet of the duck pond to evaluate how the reservoir impacts the water quality of the area that is downstream.

6.0 ACKNOWLEDGEMENTS

The authors of this report would like to acknowledge and thank Dr. Eric Demers for his support and guidance over the course of this project conducted on the Millstone River. We would also like to thank Vancouver Island University for providing the necessary facilities and materials needed for proper analysis of the water samples collected, as well as the Regional District of Nanaimo and Department of Fisheries and Oceans Canada for contributing funding towards laboratory analysis expenses, and the ALS Laboratory for providing secondary analysis of our water samples and administering a significant discount for the use of their services. Lastly, we would like to acknowledge the Snuneymuxw first nation for allowing us to conduct our research on their traditional land.

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8.0 APPENDICES

A1 - Comparison of VIU and ALS Lab Results

October 29, 2019							
Station	**1**	**2**	**3**	**4**	**5**	**5 (Replicate)**	**Trip Blank**
Temperature (°C)	7.8	9.7	9.1	11.6	8.9	--	--
Dissolved Oxygen (mg/L)	11.8	9.7	10.8	11.6	11.8	--	--
Discharge (m3/s)	--	1.2	--	0.49	--	--	--
pH (ALS)	7.5 (7.24)	7 (7.47)	6.8	6.5 (7.64)	7.3	7.3	--
Conductivity (µS/cm) (ALS)	43 (42.8)	80 (86.0)	94	114 (118)	116	117	--
Alkalinity (mg/L as CaCO3)	10.3	21.3	30.9	76.4	38	36.4	--
Hardness (mg/L as $CaCO_3$) (ALS)	14 (17)	27 (31.2)	33	44 (40)	48	40	--
Turbidity (NTU)	1.01	1.53	3	2.53	3.23	3.75	--
Nitrate (mg/L as NO_3^-) (ALS)	0.04 (0.0785)	0.5 (0.0402)	0.2	0.23 (0.0710)	0.05	0.05	0.01
Phosphate (mg/L as PO_4^{3-}) (ALS)	0.1	0.1	0.06	0.12	0.09	0.13	0.18
Total Phosphorus (P) (ALS)	(0.0026)	(0.006)	--	(0.0192)	--	--	--
N:P (ALS)	84:6	40:7	--	18:3	--	--	--

November 19, 2019							
Station	**1**	**2**	**3**	**4**	**5**	**5 (Replicate)**	**Trip Blank**
Temperature (°C)	9.6	9.4	8.9	9.5	9.4	--	--
Dissolved Oxygen (mg/L)	11.4	10	10.7	11.3	11.6	--	--
Discharge (m3/s)	--	3.67	--	0.42	--	--	--
pH (ALS)	7.3 (7.14)	7 (7.48)	6.8	6.6 (7.66)	6.7	6.6	--
Conductivity (µS/cm) (ALS)	26 (32.1)	74 (84.5)	86	121 (134)	117	118	--
Alkalinity (mg/L as CaCO3)	9.6	26.2	24	42	33.2	32.8	--
Hardness (mg/L as $CaCO_3$) (ALS)	14 (13.2)	34 (30.7)	32	44 (42.3)	40	44	--
Turbidity (NTU)	1.28	1.09	4.25	5.12	5.44	5.43	--
Nitrate (mg/L as NO_3^-) (ALS)	0.03 (0.182)	0.07 (0.0541)	0.06	0.08 (0.337)	0.1	0.12	0.08
Phosphate (mg/L as PO_4^{3-})	0.07	0.02	0.05	0.04	0.04	0.04	0.02
Total Phosphorus (P) (ALS)	0.0068	0.0082	--	0.0379	--	--	--
N:P (ALS)	56:8	39:6	--	17:5	--	--	--

A2 - Site summary and safety concerns

Site Location	#1	#2	#3	#4	#5
Access	Road	Road/bridge	Road/bridge	200m trail from parking lot	100m hike from end of road
Hazards	Loose footing on river rock	Heavy shrub cover, loose soil on	Slippery grasses on bank, access	Slippery rock lining stream	Sudden change in elevation,

		access trail	path slippery		steep loose access trail
Conditions at time of visit	Heavy rainfall	Heavy Rainfall	Moderate rainfall	Light Rainfall	Light Rainfall
Flow rate/depth	Slow/Moderate	Moderate/Deep	Slow/Moderate	Moderate/Shallow	Moderate/ Moderate
Slope	River rock	Gradual	Gradual	None	Steep