Water Quality and Invertebrate Analysis of Millstone River in Nanaimo, B.C.

Submitted by:

Mandy Hobkirk, Sarah McKenzie, and Toby Orrick,

Submitted to:

Dr. Eric Demers, Vancouver Island University

Course number: RMOT 306

Date: December 15, 2017

Vancouver Island University, 900 Fifth Street, Nanaimo, BC, V9R 5S5

EXECUTIVE SUMMARY

Vancouver Island University (VIU) students tested the water quality and stream invertebrate health of the Millstone River. This is part of an ongoing project that began in 2008. Five sites were tested along the middle and lower reaches of the river. Samples were collected at two separate events: one during a low river discharge on October 30, 2017, and one during high river discharge on November 20, 2017. Parameters measured during both events include: hydrology, conductivity, pH, total nitrate, hardness, alkalinity, total phosphate, dissolved oxygen, and turbidity. Data was compiled at ALS Laboratories in Burnaby and also in a lab at the VIU campus. Hydrology was only calculated at stations 2 and 4. Stream invertebrates were only sampled on October 30 at sites 1, 2, and 4.

Discharge was higher for the second sampling event, particularly at site 2 which increased from 0.82 m^3/s on October 30, to 34.6 m^3/s on November 20. Turbidity ratings were considerably higher at all sites during the second sampling event. The high turbidity corresponded with the increased rate of discharge. The VIU laboratory phosphorous results indicated that sites 1 and 2 were eutrophic. The ALS results did not correspond to the VIU lab results as it characterized all three sites as oligotrophic. The predominant invertebrate taxa for sites 1, and 2 were aquatic worms (oligochaete), which are categorized as a pollution tolerant species. Alternatively, mayfly nymphs were the predominant taxa at site 4, which are categorized as pollution intolerant species. High stream invertebrate diversity was found at sites 1 and 3, whereas site 2 had moderate diversity. When comparing to previous years, invertebrate stream health is on the decline. Suggested Recommendations: more sampling events throughout the year; collecting samples at more stations; more replicate samples of invertebrates collected at each site; and continuing with long-term analysis.

Table of Contents

1.0 INTRODUCTION AND BACKGROUND

1.1 Project Overview

Since 2008, the Resource Management Program at VIU has monitored the stream health and invertebrate quality of the Millstone River on an annual basis. Fisheries and Oceans Canada (DFO), the BC Conservation Foundation (BCCF), the Regional District of Nanaimo (RDN), and the City of Nanaimo have supported this project since its onset, with funding provided by DFO and RDN. Long-term data analysis is important to observe changes caused by anthropogenic or natural sources that might otherwise go unnoticed through short term or one-off studies (Demers, 2017). For this project, four VIU students, under the supervision of Dr. Eric Demers, propose to continue the project for the 2017 season. During this time, two sampling events will occur between October 30th and November 22nd in an attempt to sample the river during a low-flow and high-flow time of discharge. In addition to analyzing water quality, the results of the study are also intended to monitor any observable effects caused by local human activities.

1.2 Background

The Millstone River watershed is comprised of 16 tributaries and 8 lakes that encompass an area of approximately 93.2 km^2 within the RDN (RDN, 2016). Benson Creek drains Lucid Lake, on the west side of Mount Benson, at an elevation of 617m and flows in a northerly direction into Brannen Lake. The Millstone River drains Brannen Lake and meanders gently in a southeasterly direction eventually emptying into the Straight of Georgia at the Nanaimo Harbour. Divers Lake, Cathers Lake, Long Lake and Westwood

Lake also drain into the Millstone River. The distance from Lucid Lake to the Straight of Georgia is approximately 27 km (RDN, 2016). The river is mostly gently flowing with a gradual declining gradient, except in Bowen Park where the current picks up due to a sharper decline in topography.

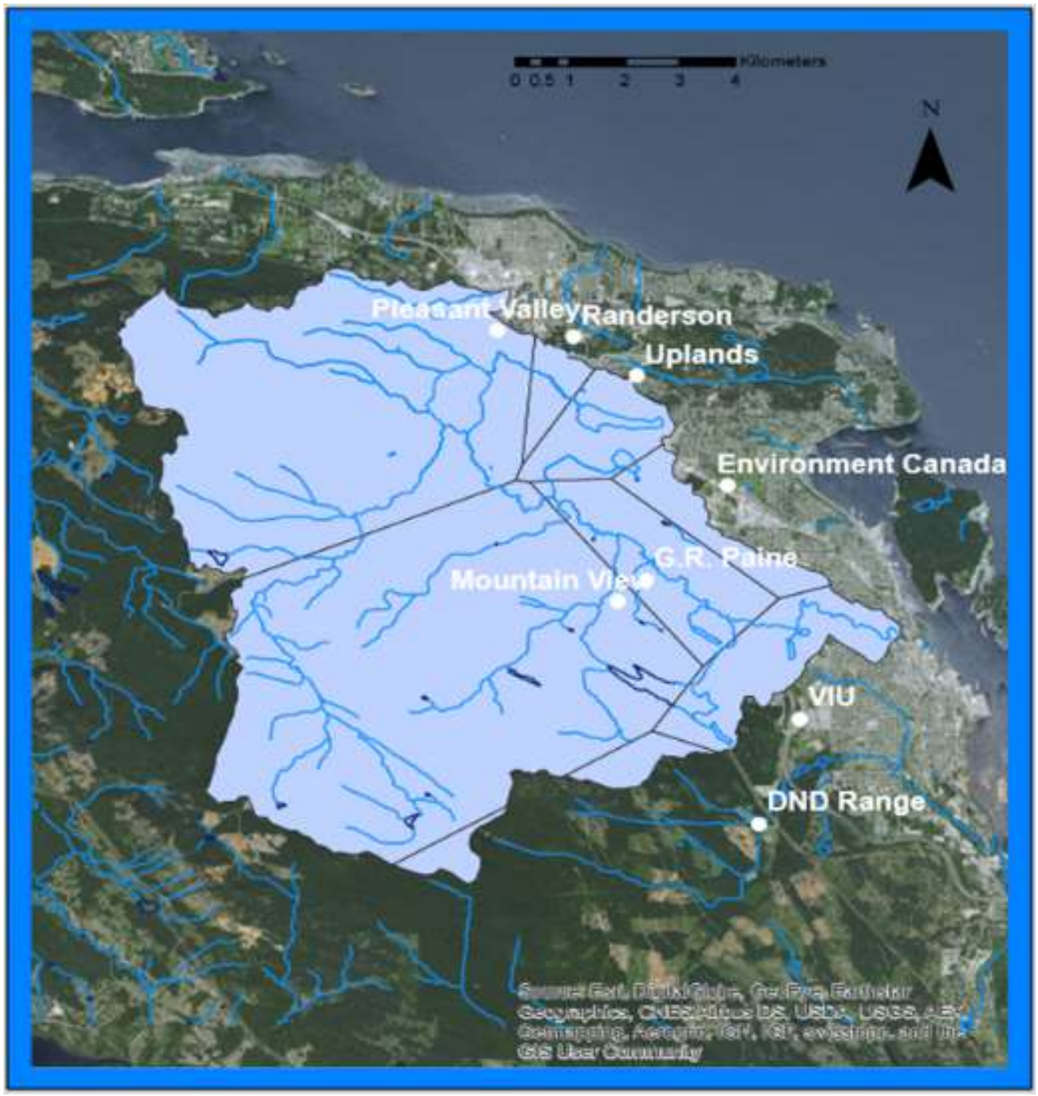


Figure 1. Image of the Millstone River watershed provided by Toby Orrick, 2015. Dismiss the labeled rain gauge stations.

In 1971, a project began to assist salmon in the Millstone River. Studies suggested that female salmon each produced approximately 200 smolts (migrating juvenile salmon)

(City of Nanaimo, 2008). The high production rate indicated that the Millstone had the potential to be a self-sustaining salmon run. However, the coho salmon that were introduced in the early 1980's could not pass the many waterfalls and rock faces as they attempted to migrate. For the adult coho salmon to pass the barriers, they first had to be trapped and then trucked above the falls. In 2007, a side channel was built on the Millstone River in Bowen Park to provide the salmon an easier route to travel up past the falls (City of Nanaimo, 2008). The project was considered a success as 300-500 coho salmon were observed migrating through the channel during the first year.

Figure 2. Side channel outlet to the Millstone River in Bowen Park.

1.3 Historical Review

The Millstone River is located within the Coastal Western Hemlock (CWH) and Coastal Douglas Fir (CDF) Biogeoclimatic zone (Gov. of BC, 2016), and provides a habitat for many indigenous species of flora and fauna (RDN, 2016). With regards to land use, the river is subdivided into 3 areas: the headwaters that run through land that is privately managed by the forestry industry, the mid-section that runs through agricultural areas, and the lower section that runs through urban and residential areas (RDN, 2016).

1.4 Potential Environmental Concerns

Eutrophication threatens the middle reaches of the Millstone River due to agricultural fertilizer and pasture run-off. Slow moving water found frequently throughout the mid-section of the river exacerbates the potential for eutrophication. The lower reaches of the river are at risk of contamination via urban storm water effluents. In addition, natural erosion and sedimentation, as well as the presence of wild and domestic animals, have the potential to impact the water quality throughout the Millstone River.

2.0 PROJECT OBJECTIVES

The main objective for monitoring the Millstone River is to provide data on the present environmental conditions, as well as contributing to the long-term analysis of this river. The same five sample stations that have been analyzed since 2008 will be sampled throughout the project (from Brannen Lake to the Nanaimo Estuary). The sites will be used to observe the hydrology, test the water quality, microbiology, and stream invertebrate quality for the Millstone River. The samples will be analyzed in the VIU lab and some of the water samples will be sent to Australian Laboratory Services in Burnaby. The results of the tests will then be analyzed to determine the present health of the river.

3.0 METHODS

3.1 Proposed Sampling Program

To maintain continuity of consistent environmental monitoring, the study utilized five pre-defined sample locations based on the work of previous water quality and invertebrate studies undertaken by Vancouver Island University (VIU) students from 2008 to 2015 presented in the table below; (Table 1). Each sample location was selected as a best representation of the different stream channel morphologies encountered within the study area to collect data that typified the entire aqueous system. This method considered specific parameters such as design choice (type of equipment required), water flow conditions and substrate, canopy, potential environmental impacts (sources of contamination), ease of access and safety.

Table 1. Sample Locations for water quality and stream invertebrate assessment in the Millstone River, in Nanaimo, BC.

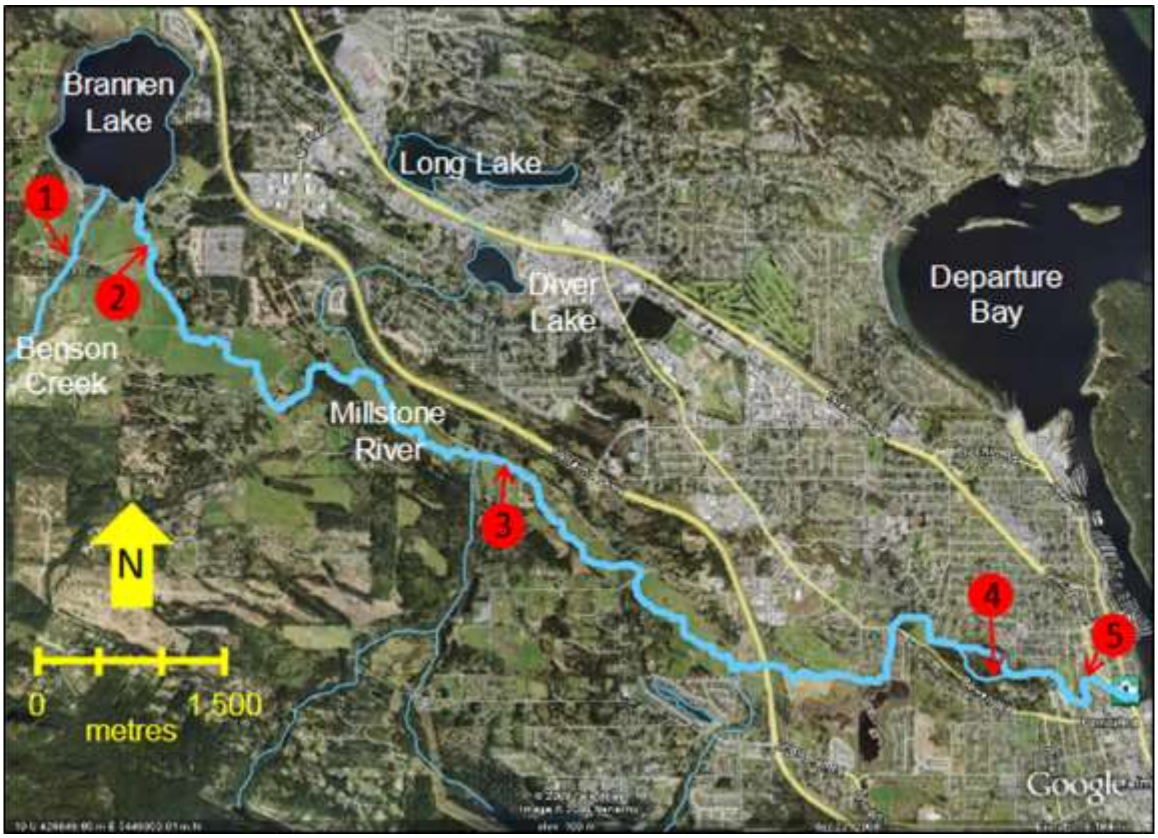
	UTM Co-ordinates		
Sample Station	Easting	Northing	General Location
1	422738	5450707	Benson Creek, Bigs Road Crossing
2	423341	5450828	Millsone River, Biggs Road Crossing
3	426304	5448953	Millstone River, Durnin Road Crossing
4	430233	5447304	Side Channel, Downstream of the Duck Pond
5	430941	5447091	Barsby Park, 170 m Upstream from Estuary

*Note: The co-ordinate data relies upon previous studies using Google Earth and are based on Zone 10U (Demers, 2016). A Garmin eTrex 10 GPS will be used to record the exact locations for the proposed sites and will be submitted as part of the final assessment

3.2 Sample Locations and Frequency

The sampling area was distributed between Benson Creek and the lower section of the Millstone River covering an approximate 14 kilometer stretch of water. The general distribution is as follows: sample sites (1, 2) are located in the upper part of the system, sample site (3) is in the central section, and sites (4, 5) are near the lower reaches of the river where the water discharges into the Georgia Basin at the Nanaimo Harbour (Figure 3). Pictures of each sample location taken during the October 30th site visit on are displayed in the Appendix (A2).

Figure 3. Locations of the water quality stations in the Millstone River, (Demers, 2016).



3.3 Site Descriptions and Habitat Characteristics

Site 1 located on Benson Creek at the Biggs Road Crossing (UTM 10U 422738 mE, 5450707 mN) presented a site access issue due to a fence that obstructed the upper section of the creek above the bridge. The stream channel width ranged from (3 – 5) m and was characterized by shallow riffles and slow moving water on either side of the bridge. The channel substrate was composed of mainly cobble and gravel with well-vegetated stream banks overgrown with Calamagrostis acutiflora (reed grass) and Himalayan blackberry bushes. A mature second growth canopy comprised of Alnus glutinosa (Alder) and Acer macrophyllum (bigleaf maple) form a riparian zone that shelters the stream. The water clarity was clear with a slightly stained tinge. Woody debris and leaf litter was observed in the deeper slow moving water providing good habitat for invertebrates.

Site 2 is located on the Millstone River at the Biggs Road Crossing (UTM: 10U 423341 mE, 5450828 mN) and makes up the outflow of Brannen Lake. The site is located in rural pasture-land with no access issues. The riparian vegetation is mostly comprised of Salix alba (white willows) with Himalayan blackberry bushes. On the downstream side of the bridge the flow conditions were minimal where a 1 – 3 m deep pool located was populated with sparse lily pads. Approximately 30 metres downstream from the bridge, the creek narrowed with ingrown vegetation providing a natural dam to produce a shallow zone. On the south side of the creek a cut bank displaying a thin soil horizon underlain by glacial till and minor clay was observed providing evidence of erosion during high flow conditions; this is a likely source of sediments that contributing to increased turbidity during the rainy season. The stream bottom was composed of fine sediments interspersed with gravel. The water displayed a brown staining and was considered to be an area of risk for contamination of coliform bacteria due to its proximity to pasture-land. It also appeared there may also be an inherent risk for the eutrophication of this section of the river when the water levels in Brannen Lake drop during the summer resulting in the stagnation of pools exposed to high levels of insolation.

Site 3 is located at the Durnin Road – Millstone River crossing (UTM: 10U 426304 mE, 5448953 mN). This part of the study area was comprised of rural properties and pasture-land with no accessibility hazards. The stream bank riparian zone was comprised of immature Alnus glutinosa (Alder) and Acer macrophyllum (bigleaf maple) interspersed with Salix alba (white willows) and a shrub brush understory. The river channel immediately above the bridge displayed a depth of 1 – 2 m transitioning to a shallow zone downstream where a cobble and gravel substrate was visible. The flow conditions were low to moderate with a shallow riffle zone approximately 15 m downstream. There sample site displayed a potential for contamination from coliforms and fertilizers from the nearby pasture-land located immediately to the south and upslope of this location.

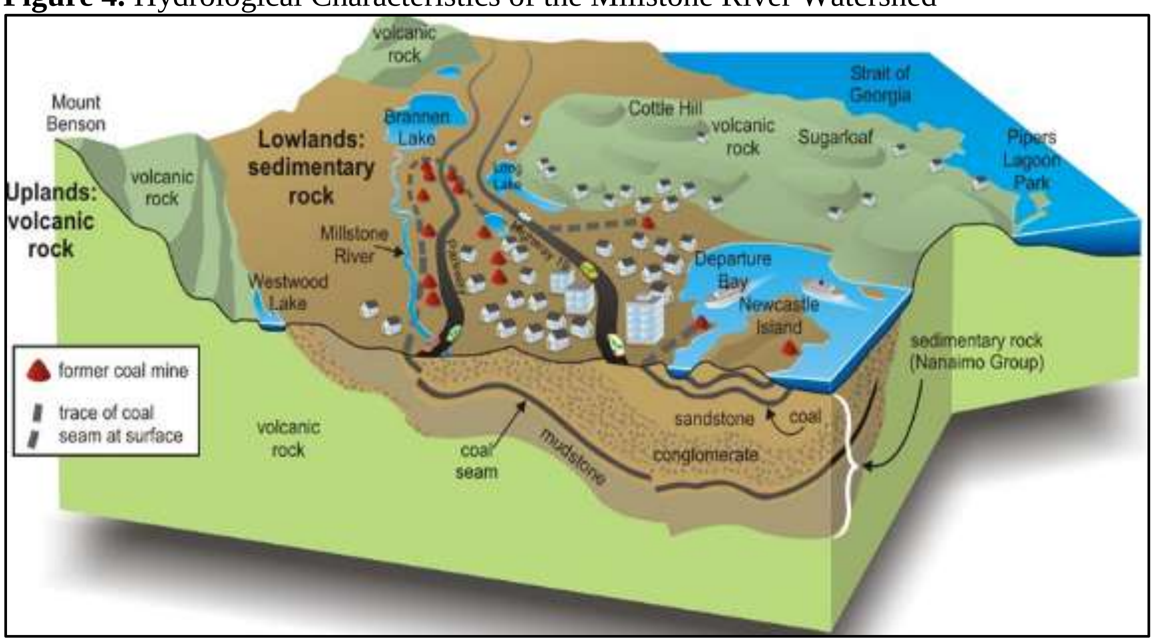
Site 4 located in Bowen Park below the outlet of the duck pond (10 U 430233 mE, 5447304 mN). Site access via the main parking lot leads to a trail that cuts through a wooded area comprised of Pseudotsuga menziesii (Douglas fir) interspersed with Tsuga heterophylla (western hemlock), Thuja plicata (western red cedar) and Acer macrophyllum (bigleaf maple). The sampling area was made up a narrow channel approximately 1 – 2 meters across and less than 30 cm deep. The channel bottom mainly comprises gravel interspersed with boulders to impede high flows during increased rainfall events. The flow velocity was observed to be slightly higher in this location than the previous sites.

The final most downstream site, site 5 was located a few hundred meters west of the Island Highway (10 U 430941 mE, 5447091mN). The channel substrate exhibited a thick package of Nanaimo Group sandstone that has been scoured heavy flowing water over thousands of years and has been emplaced with minor gravel and cobble. The sandstone beds form steps that act as barriers for the formation of deep pools that produce large glides and back eddies. The river was approximately 15 m wide in this location with prominent Alnus glutinosa (Alder), Acer macrophyllum (bigleaf maple) and Salix alba (white willows) displayed along either side of the channel banks. This area exhibits high flow velocities with turbid (brown) water high in sediment. Potential contamination of this site includes urban runoff, animal and pet feces and sediments from nearby upslope eroding banks.

3.4 Hydrology

The hydrological characteristics of a watershed (Figure 4) are dependent on a variety of natural factors such as the subsurface geology, soil composition and topography of the region as well as anthropogenic induced factors from upstream land and water use. Changes in land use, water withdrawals and climate within a watershed can have a dramatic impact on the variability of water resources leading to extreme fluctuations in discharge within a river system. (Interstate Commission on the Potomac River Basin, 2014).

Figure 4. Hydrological Characteristics of the Millstone River Watershed



Source:http://sharkz.ca/links/earthcache/VI-EC-Series/mt-tzuhalem-conglomerate/rocks_home.jpg

Stream discharge, a dynamic combination of temporal and spatial inputs, resulting from surface water runoff and baseflow play a critical role in the results obtained from water quality and biological sampling. The use of hydrological discharge measurements taken in the field as well as discharge data obtained from the Millstone River Hydrological Monitoring Station (08HB032) was used to provide a valuable context to our final results. Basic flow and discharge measurements will be obtained utilizing the float method and measurements for the wetted width, channel depth to calculate discharge. A constant of 0.85 denoted as K will be multiplied to our average timed velocity (m/s) over five trials prior to applying the formula Q = A*V to achieve our results.

3.5 Water Sampling Parameters

Water sampling was carried out on October 30th and November 20th as shown in the proceeding Tables 2 and 3. Hydrological assessments were undertaken at locations 2 and 4, water quality and microbiology sampling at locations 1 through 5, and invertebrate sampling at locations 1, 2 and 4. Note that microbiology and invertebrate sampling will be carried out during the first sampling event (November 1st) only.

Table 2: Water sampling parameters for sample day (1) October 30, 2017

Sample Location	Sample Parameters
1 - 5	Conductivity, pH, Alkalinity, Hardness, Turbidity, Nitrate, Reactive Phosphate, Dissolved Oxygen,
1 - 5	Microbiology
1, 2, 4	ALS Water Analysis (Including Dissolved Metals)
1, 2, 4	Invertebrates Survey
2, 4	Hydrology - Discharge

Table 3: Water sampling parameters for sample day (2) November 20, 2017

Sample Location	Sample Parameters
1 - 5	Conductivity, pH, Alkalinity, Hardness, Turbidity, Nitrate, Reactive Phosphate, Dissolved Oxygen
1,2,4	ALS Water Analysis (Including Dissolved Metals)
2, 4	Hydrology - Discharge

3.6 Quality Assurance / Quality Control

During each sampling event one set of samples was collected for laboratory analysis at Vancouver Island University (VIU), and a second set of samples was collected for analysis at the ALS Laboratory in Vancouver BC. Throughout the sampling process strict procedures were followed in order to maintain integrity in our collection methods and to ensure that quality control guidelines were followed. For the VIU samples (sample locations 1 – 5) pre-labelled 500 ml plastic bottles was rinsed three times before being used for sample collection. The sample collection process involved facing upstream and submerging the bottle below the water surface with gloved hands, taking special care to ensure no sediments were disturbed from the bottom. All water samples were kept in a cooler with ice to maintain an optimum temperature of 4 degrees Celsius until laboratory analysis could be conducted. The ALS sampling (sample locations 1, 2 and 4) utilized the same procedural collection method, however for the analysis of total metals and nutrients preservatives (nitric acid and sulphuric acid) were supplied from the ALS Laboratory to ensure the samples would not degrade prior to analysis. To ensure proper mixing of the preservative, the bottles with the preservatives were inversed 5 times. All samples were kept cool in refrigeration unit prior to being sent to the lab for analysis within the 24 hour allotment period. Trip blanks for sites 2 and 5 as well as replicate samples for sites 1 through 5 were collected to verify the quality assurance and quality control of our samples. A full list of the equipment and lab methods utilized for the VIU water analysis is described in (A3: Table 1).

3.7 Data Analyses, Comparison to Guidelines

The data values from the analyzed samples, from both VIU and ALS, were compared to the Guidelines for Interpreting Water Quality Data (B.C. Ministry of Environment, 1998). By comparing our results to the guidelines, we ascertained whether the water parameters from the Millstone River at the five sites were within the provided maximum guidelines for aquatic life.

4.0 METHODS FOR STREAM INVERTEBRATE COMMUNITIES

4.1 Invertebrate Sample Collection

Benthic invertebrates have limited mobility, and thus they are more affected by pollutants. Due to this and their long life cycle, they make for good indicators of stream and lake health (Demers, 2017). Stream invertebrates were sampled from three of the five sites. Samples were obtained using a Hess sampler at sites 1, 2 and 4 (A5). For each site, we collected three replicate samples in order to provide a representative estimation of the patchy benthic invertebrate communities. All samples were kept in labeled containers and were maintained live until the counts had been completed in the lab. The data we collected will help us assess the health of the stream as well as changes over time and the impacts of pollution (Fisheries & Oceans, 2016).

4.2 VIU Laboratory Analyses

Samples were brought back to the lab at VIU and analyzed. We counted the number of animals as well as the number of taxa, and sorted the invertebrates into their taxonomic groups. Identification of the invertebrates was completed using dissecting microscopes and identification keys. The methods we used in the analysis procedure followed that of the Pacific Streamkeepers. At the end of the laboratory analysis, the data from each site (including replicates) were combined into three data invertebrate survey sheets.

4.3 Quality Assurance/ Quality Control

To obtain sampling accuracy and precision, each of the samples were counted by two group members. This was done to even out the workload between group members in the lab, and because there would be increased variability if we used more counters. As well as this, we used clean and specific containers, sampled from downstream to upstream, and stored samples properly until they were examined in the lab. Using replicates was another measure used to obtain high quality results, and as mentioned previously, we collected a total of three replicate samples per site. This enabled us to establish reproducibility of sampling (Demers, 2017).

4.4 Data Analyses

During data analysis, we calculated species diversity from each site using the Shannon-Weiner Diversity Index. This index has a range from 0 - 1, with 0 indicating low diversity and 1 indicating high diversity. We also calculated abundance and density as well as the predominant taxon. Several water quality assessments were completed as well, an example of this was the pollution tolerance index for which there are three categories. Category 1 includes pollution sensitive species that are found in high quality water, category 2 includes species that tolerate some pollution and are found in high or fair quality water, and category 3 which includes pollution tolerant species that are found in a range of conditions (Fisheries & Oceans, 2016). Other water quality assessments were the EPT (Ephemeroptera, Plecoptera and Trichoptera) index, EPT to total ratio index and the overall site assessment rating for each of the samples.

5.0 RESULTS AND DISCUSSION

5.1 General Field Conditions

The study observed highly variable field conditions between the two sampling days. On October 30th sites 1, 2 and 3 displayed shallow pools ranging from 0.30 - 1.0 meters in depth with minimal flow velocities. The water appeared clear with a slight staining. Further downstream Site 4 and 5 located in Bowen Park and near downtown Nanaimo exhibited pools 1- 4 meters in depth with higher flow velocities. The water clarity at site 5 was noticeably opaque indicating the presence of suspended sediment within the river system. The week prior to the November 20th sampling event the VIU School Based Weather Station recorded 114.5 mm of precipitation had fallen on the Nanaimo campus (A3: Table 3). This sudden increase in rain fall is considered to have caused the significant spike in stream height and discharge observed on the Millstone River during our second sampling day. Site 2 on Biggs Road displayed water levels near the bridge footings, approximately 2 meters higher than previously observed during the October 30th sampling event. The water at all the sites exhibited a muddy brown colour indicating there was a substantial amount of turbidity throughout the entire 14 kilometers stretch of the river.

5.2 Hydrology

By utilizing the equation (Q = A*V) detailed in the Hydrology section of the Methods, a basic discharge calculation was performed for sites 2 and 4 during the two sampling events. Table 20 shows the results, including the discharge data from the Millstone River Hydrological Station (08HB032) in order to compare our results.

Table 4. October 30th and November 20th discharge measurements recorded form sample stations 2, 4 and the Millstone Hydrological Station (08HB032).

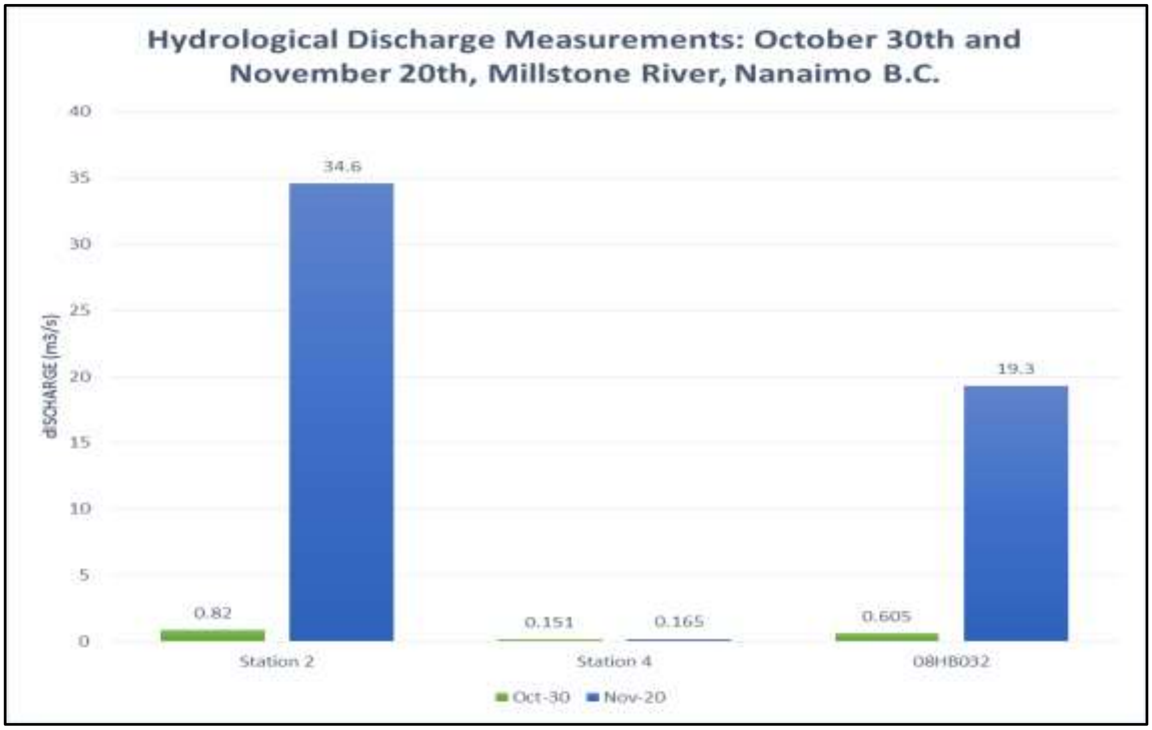
Date	Station	Mean Depth (m)	Wetted Width (m)	Mean Velocity (m/s)	Total Discharge (m3/s)
Oct-30	1st Event Station (2)	0.23	7.2	0.49	0.7
Oct-30	1st Event Station (4)	0.12	1.7	0.77	0.13
Nov-20	2nd Event Station (2)	2.8	16.6	0.74	29.4
Nov-20	2nd Event Station (4)	0.22	1.2	0.63	0.2
Oct-30	1st event (08HB032)	n/a	n/a	n/a	0.605
Nov-20	2nd Event (08HB032)	n/a	n/a	n/a	19.3

Source: Environment Canada, Water Survey for station (https://wateroffice.ec.gc.ca/)

It is important to note that due to the increase in stream height and flow velocities observed at Site 2 on November 20th an improvisation to measure the water depth was attempted by fastening a 10 pound boulder to the end of the measuring tape in order to probe the depth of the river, however it was carried downstream making the effort hopeless. As a safety precaution it was subsequently decided that the water depth across the enlarged channel would to be estimated every 2 meters on a best efforts basis using the height of the water observed at bridge foundation as a guide. Because of this improvisation the accuracy of the calculation cannot be relied upon and should be considered as a rough calculation only. Further to this it should also be noted that station (4) is located within the Millstone River side channel which receives its water from a regulated intake weir several hundreds of meters above. Thus the discharge observed at this location is not a true reflection of the actual discharge in the main channel.

The discharge at station 2 on November 20th was calculated to 29.4 m3/s, albeit imprecise nonetheless it shows the extreme variation between the two sampling days. The Millstone Hydrological station (08HB032) measured a discharge of 19.3 m3/s thus confirming the general trend observed upstream observed in Figure 5. The rate of discharge observed at site 4 between the 2 sampling days shows very little variation.

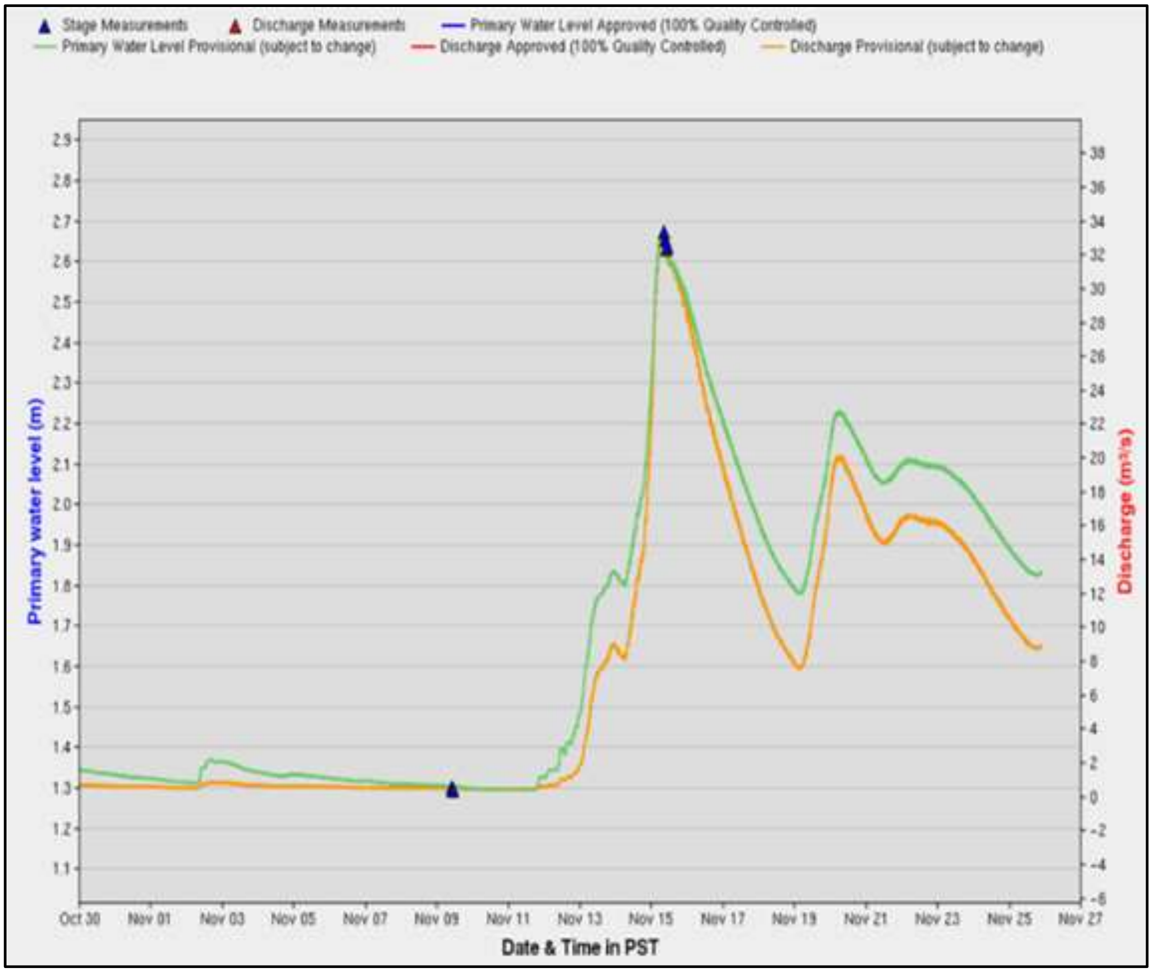
Figure 5. The October 30th and November 20th discharge measurements recorded form sample stations 2, 4 and the Millstone Hydrological Station 08HB032.



Source: Environment Canada, Water Survey for station. https://wateroffice.ec.gc.ca/

The discharge data collected between October 30th and November 27 from the Millstone Hydrological Station (08HB032) is displayed below (Figure 6). Two spikes occur on November 15th and November 20th further validating the results observed in the field. It's interesting to note that the November 15th the discharge exceeded our imprecise measurements taken November 20th.

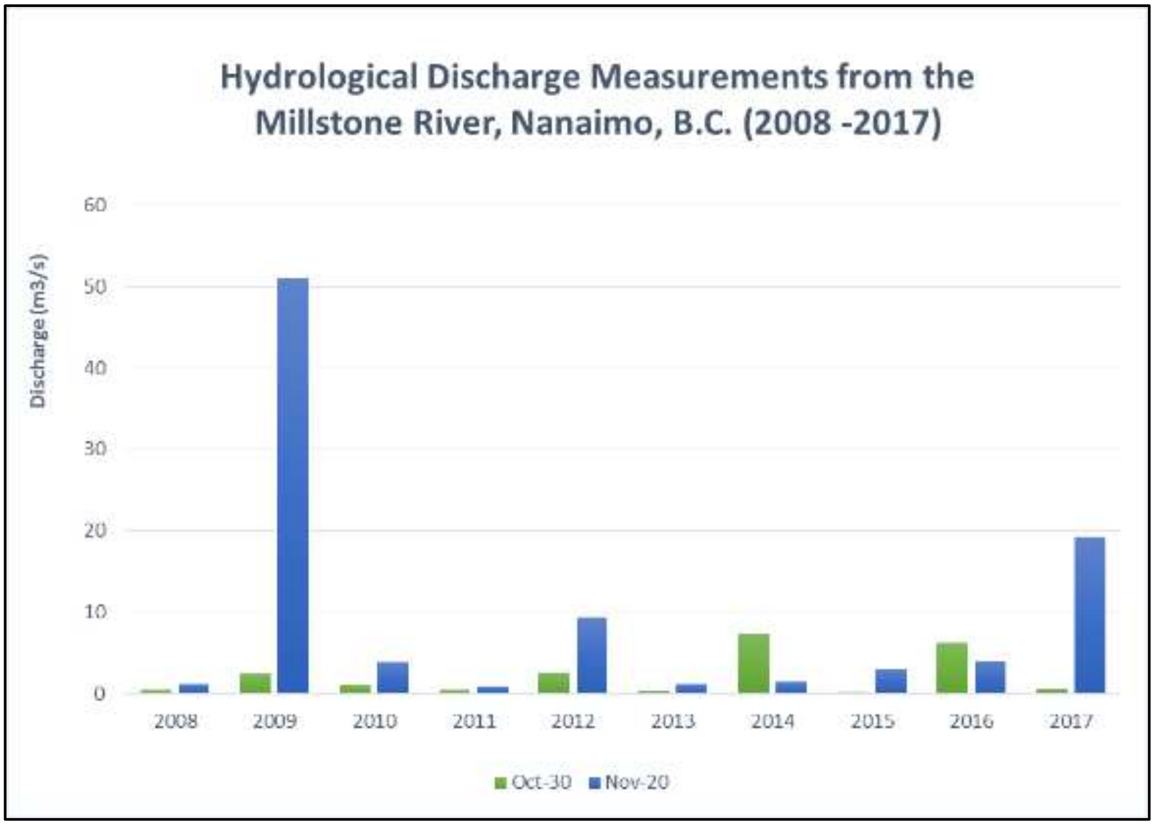
Figure 6. October 30th and November 20th discharge measurements recorded form sample stations 2, 4 and the Millstone Hydrological Station 08HB032.



Source: Environment Canada, Water Survey for station. https://wateroffice.ec.gc.ca/

The preceding graph displays the historical discharge within the Millstone River over the last decade. The discharge observed in November of this year was well above the 10 year average and was the seconds highest in the last decade.

Figure 7. Displays the October 30th and November 20th discharge measurements recorded form sample stations 2, 4 and the Millstone Hydrological Station (08HB032).



Source: Environment Canada, Water Survey for station (https://wateroffice.ec.gc.ca/)

6.0 VIU Water Quality

6.1 Laboratory Analysis

During the two sampling events the VIU water quality analysis tested 9 parameters. The results are presented in the following Tables 5 (a) and 5 (b).

Table 5 (a): The VIU water quality sampling analysis for October 30th, 2017

Date: October 30, 2017									
Sample Station	Alkalinity CaCO3 (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	Hardness (mg/L)	Conductivity (uS/cm)	Turbidity (NTU)	pH	Disolved Oxygen (mg/L)	Water Temp (C*)
1	11.8	0.1	0.11	20	47	0.27	8.1	10.7	9.2
2	32.4	0.04	0.01	27	63	0.78	7.9	9.5	11
3	32.5	0.05	0.03	39	92	0.96	7.7	9.5	11.2
4	35	0.01	0.04	48	116	1.16	7.6	10.9	10.6
5	38.4	0.04	0.04	47	118	1.76	7.8	10.5	10.1
Replicate Site (1)	13.8	0.1	0.16	19	44	0.24	7.8		
Trip Blank	n/a	0.02	0.01			n/a			

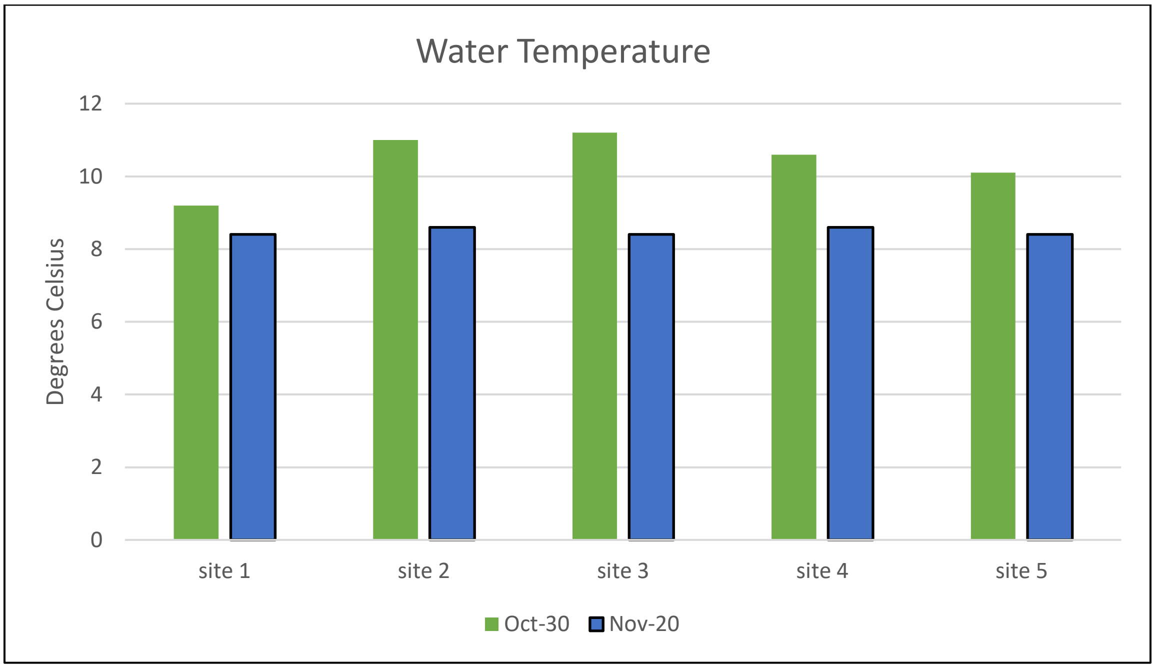
Table 5 (b): The VIU water quality sampling analysis for November 20th, 2017

Date: November 20, 2017									
Sample Station	Alkalinity CaCO3 (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	Hardness (mg/L)	Conductivity (uS/cm)	Turbidity (NTU)	pH	Dissolved Oxygen (mg/L)	Water Temp (C*)
1	9.4	0.38	0.15	26	24	3.25	8.9	10.6	8.4
2	13	0.45	0.06	12	48	10.2	8.2	8.3	8.6
3	15.8	0.11	0.02	21	58	5.43	7.9	9.5	8.4
4	16.7	0.13	0.59	23	70	4.78	7.6	10.4	8.6
5	16.9	0.1	0.76	26	65	5.47	7.7	10.9	8.4
Replicate Site (3)	15.9	0.07	0.62	25	56	4.53	7.6		
Trip Blank	n/a	0.03	0.1			n/a			

Water Temperature

The temperature on October 30th fluctuated from 9.2 to 11.2 degrees Celsius at all five stations. The coldest temperature was recorded at site 1 and the warmest at site 3. The average was 10.4 degrees Celsius. Conversely on November 20th the temperature at all five stations fluctuated between 8.4 and 8.6 degrees Celsius. The average was 8.48 degrees Celsius, almost 2 degrees cooler that the initial sampling event on October 30th. Two trends emerged. First, site (1) displayed the coolest water temperature during both sampling days. This was expected because Benson Creek is positioned near the base of Mount Benson within a thick second growth forest that provides cover from incoming solar radiation. A second trend shows that the water temperature on was almost a 2 degree Celsius cooler on average on the November 20th sampling day. This was attributed as change in ambient air temperature as the season change from fall into winter.

Figure 8. Water temperature measured in degrees Celsius was recorded at each sampling location on October 30th denoted in green and on November 20th denoted in blue.



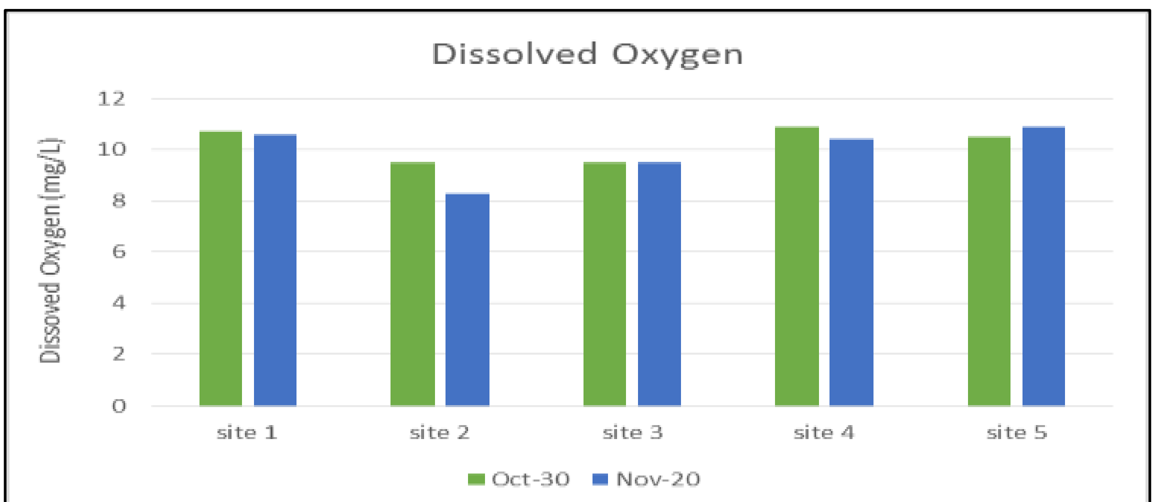
Dissolved Oxygen

The dissolved oxygen (DO) results showed little variation between the two sampling days. The October 30th results displayed a range of 1.4 mg/L; the lowest value (9.5 mg/L) was observed at site 2 whereas the highest value (10.9 mg/L) was observed at site 4. The November 20th results show a slightly larger range of 2.6 mg/L; the lowest value (8.3 mg/L) was observed at site 2 whereas the highest value (10.9 mg/L) was observed at site 5. The percent saturation averaged 90.4% on the October 30th and 86.4% on November 20th respectively. The percent saturation values were consistent with the lowest DO values observed during both sampling events at site 2 and the highest DO values observed at site

4 and 5. The percent oxygen saturation measured at site 2 on November 20th was 72% and appears to correspond with the spike in the turbidity (10.2 NTU) measured on the same day; November 20th. The lower DO and percent saturation values are interpreted to be related to the increase of suspended sediment (silt) eroded from Mount Benson and adjacent pastoral lands. As water increases its suspended sediment load atmospheric oxygen saturation may be inhibited causing the lower values observed.

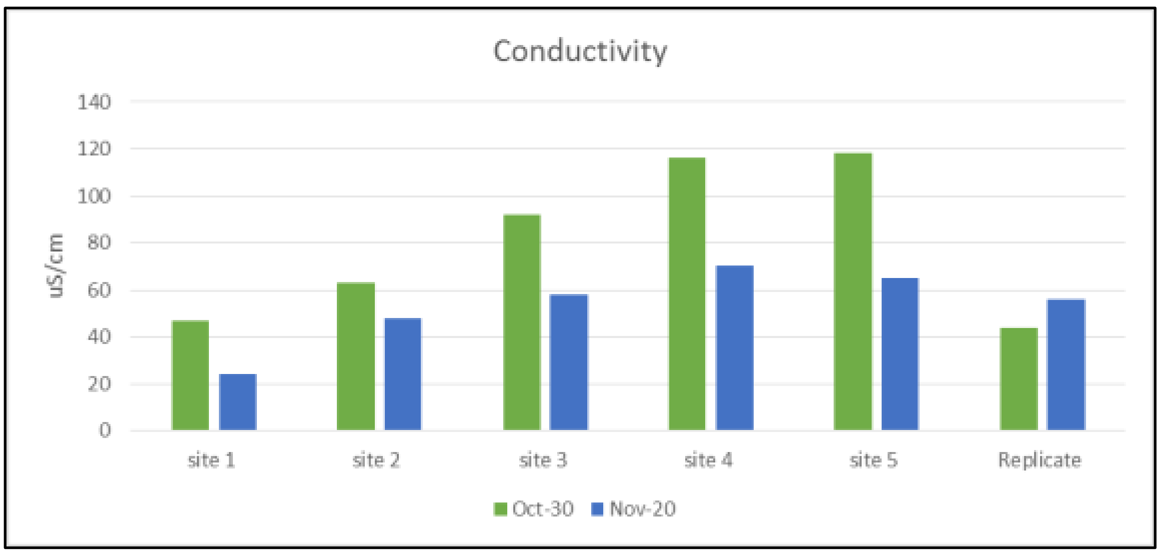
Downstream the dissolved oxygen and saturation levels progressively increase. This is interpreted to be a result of increased aeration caused by more turbulent flows downstream and dropping turbidity as more base-flow and urban runoff carrying less suspended sediment enters the lower section of the river. The turbidity values measured during the analysis showed a strong correlation to turbidity values reported in previous studies between 2008 and 2015 (Demers, 2017). It also should be noted that all the sites sampled for dissolved oxygen concentration exceeded the B.C. Water Quality Guidelines minimum threshold values (9.0 mg/L) for fish – buried embryo / alevin stages, with the exception of site 2 on November 20th (BC Gov., 1998).

Figure 8. Dissolved Oxygen concentrations (mg/L) measured from five sampling locations on October 30th denoted in green and on November 20th denoted in blue.



The conductivity values observed between the two sampling events consistently increased downstream. This trend also correlated well with the ALS results (A4) and the water quality analysis performed by Vancouver Island University between 2008 and 2015 (Demers, 2016). On October 30th the results indicated the conductivity increased by 71 uS/cm whereas on the November 20th the results only increased by 41 uS/cm. The variation observed in the conductivity values between the two sampling events was interpreted to have been caused by the dilution of suspended ions within the water column from the spike in discharge in the latter half of November.

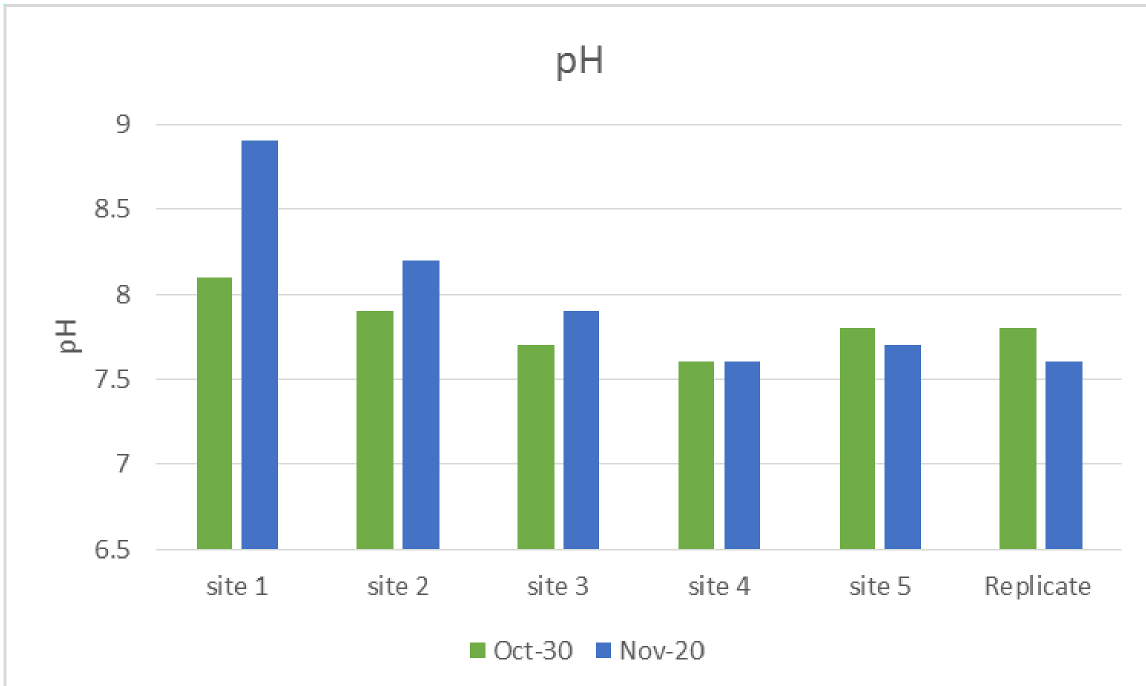
Figure 9. Conductivity (uS/cm) was measured at five locations during two sampling events in the Millstone River. The sampling took place on October 30th denoted in green and November 20th denoted in blue.



pH

The pH values recorded between the two sampling events (October 30th and November 20th) display a similar range (7.6 to 8.2) with the exception of the November 20th site 1 result of a pH of 8.9. This result is anomalously high and is interpreted as a data collection error. All the pH values recorded during the October 30th and November 20th sampling events are within the acceptable guideline thresholds determined in BC Water Quality Guidelines (BC. Gov., 1998).

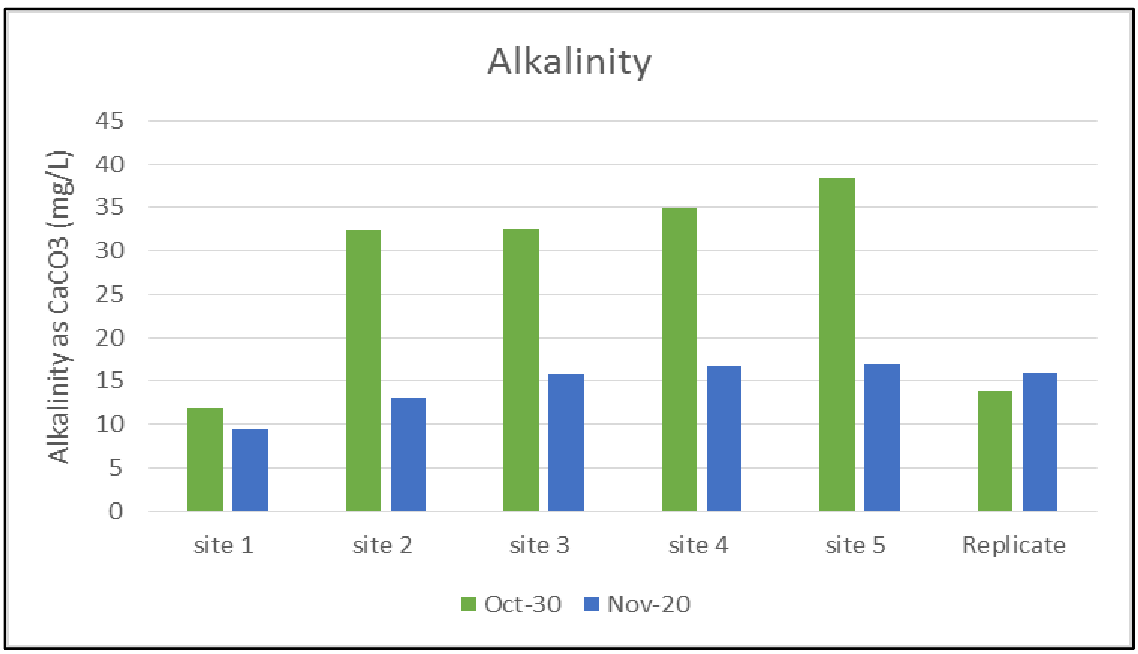
Figure 10. The pH was measured at 5 sampling locations during October 30th denoted in green and on November 20 denoted in blue in the Millstone River.



Total Alkalinity

The Total Alkalinity ranged from 11.8 to 38.4 mg/L as CaCO3 during late October and from 9.4 to 16.9 mg/L CaCO3 during mid-November. A clear trend was observed with significantly lower values (approximately 50%) measured on November 20th. Site 1 measured the lowest alkalinity during both sampling events. This specific trend correlates with previous VIU water quality studies (Demers' 2016), however the overall trend of lower values during the second sampling event does not. The considerable lower alkalinity values observed at sites 2, 3, 4 and 5 on November 20th are interpreted to be a result of dilution from the heavy volume of water discharged through the Millstone River during this week prior to November 20th. The October 30th Alkalinity values averaged 27 mg/L are within the BC Water Quality Guidelines for low acid sensitivity, conversely the November 20th values have an average value of 14.6 mg/L resulting the river displaying moderate acid sensitivity (BC Gov., 1998).

Figure 11. The total alkalinity (mg/L as CaCo3) measured during late October and mid-November. The October 30th sampling event is shown as green and the November 20th sampling event is shown as blue.

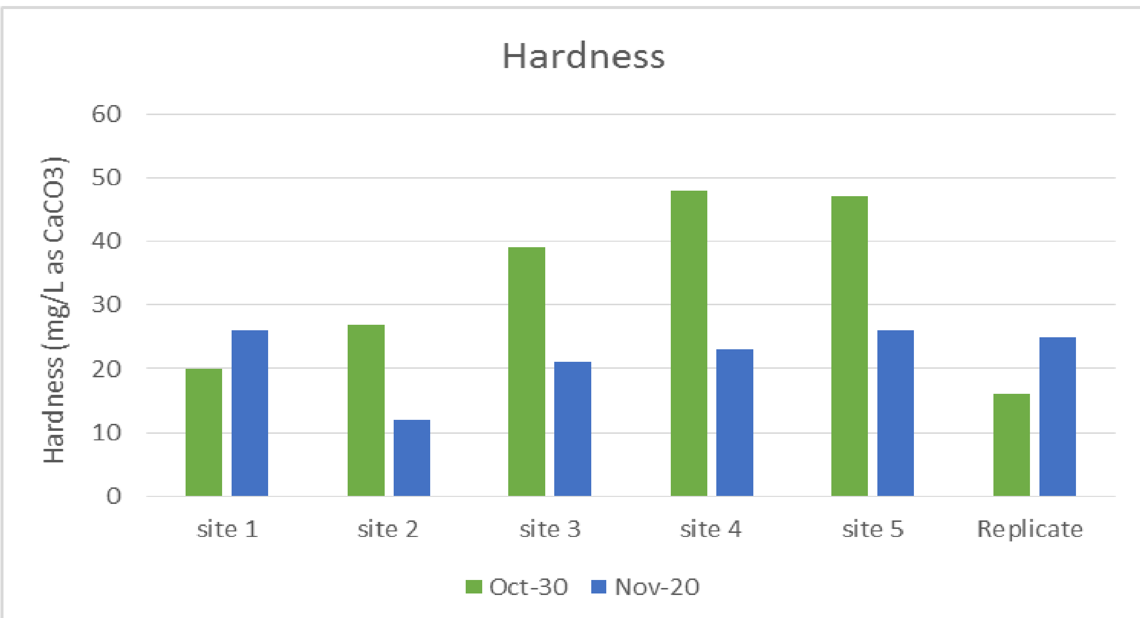


Hardness

The hardness values ranged from 12 to 47 mg/L during both sampling days and exhibited a general increasing downstream trend; excluding the November 20th site 1 result of (26 mg/L) and the October 30th replicate sample. This trend was also observed in the

ALS values and correlates well to the previous water quality studies completed by VIU students from 2008 – 2015 (Demers, 2016). The results of the two sampling events for the most part demonstrate an overall increase in the hardness. These results observed may be a result of surface runoff / urban run-off within the watershed distributing Ca / Mg ions from anthropogenic factors in the Millstone River during the high precipitation between November 15th and November 20th.

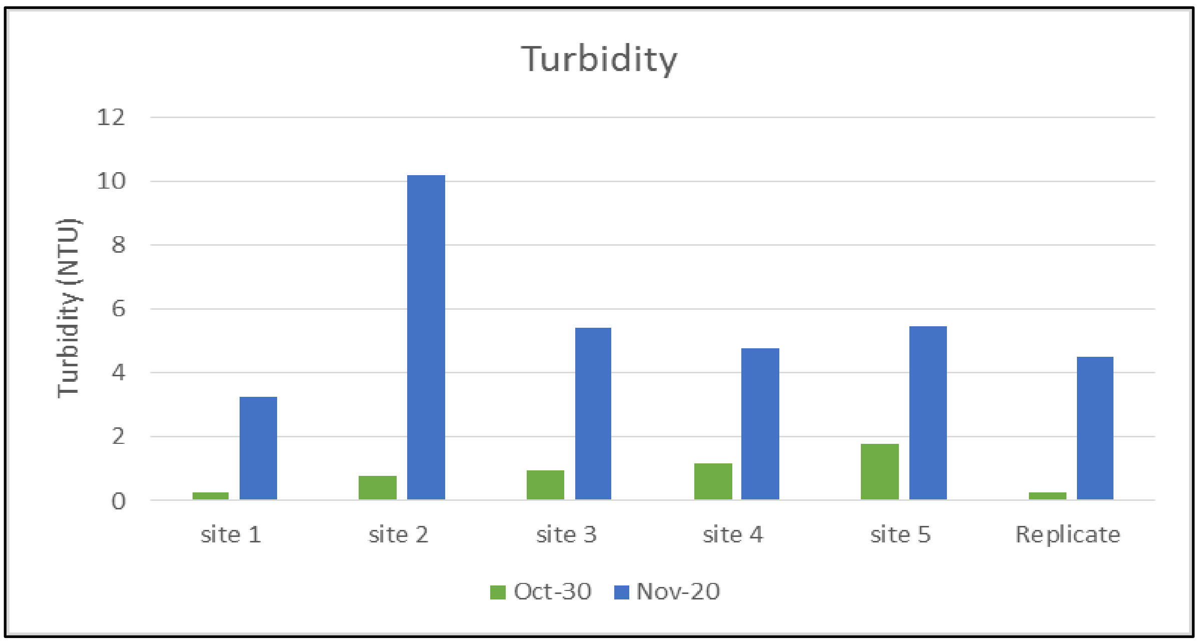
Figure 12. Hardness (mg/L as CaCO3) measures at five stations during the two sampling events in the Millstone River.



Turbidity

The turbidity values observed between the October 30th and November 20th sampling events were highly variable and generally associated with increased precipitation and higher discharge rates. Specifically the turbidity measured on October 30th displayed values ranging from 0.27 to 1.76 NTU, whereas on November 20th the turbidity substantially increased with values ranging from 3.25 to 10.2 NTU. During low precipitation and low to moderate discharge the turbidity within the river channel displayed an increasing trend downstream. However, if high precipitation occurs within the watershed Brannen Lake acts as a collection depot for surface runoff from nearby pastoral lands and creek tributaries emanating from Mount Benson carrying higher loads of suspended sediment. As a result, the water level in the lake rapidly rises further inducing temperature de-stratification within the water column and thus the potential re-mobilization of sediment from the lake bottom further increasing turbidity; analogous to a positive feedback loop. On November 20th site 2 located near the Brannen Lake outflow on Biggs Road recorded a large spike in the turbidity (10.2 NTU) coinciding with such an event.

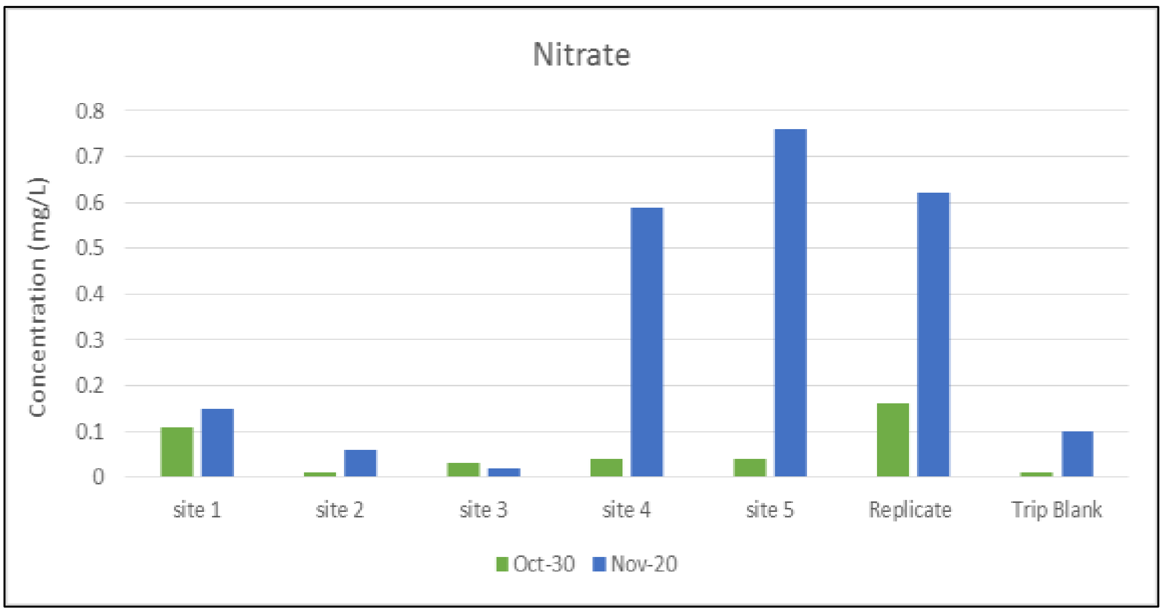
Figure 13. Turbidity levels (NTU) measured during October 30th denoted in Green and November 20th denoted in blue in the Millstone River.



Nitrates

The nitrate values observed on October 30th range from 0.11 to 0.04 mg/L whereas the November 20th values range from 0.15 to 0.76 mg/L. Several trends are apparent. First off the nitrate concentration appear to increase downstream during both sampling days and second, when comparing to the October 30th results, the November 20th sampling event displays a marked increase in nitrate concentrations at all sampling areas with the exception of station 3. These observations suggest that a combination of natural and anthropogenic factors resulting from an increase in precipitation and urban/rural runoff carrying organic compounds (sewage) may be responsible for the results observed. The results observed in lab are correlated to the ALS results and were also found to be consistent with previous water quality studies undertaken on the Millstone River between 2008 and 2016 (Demers, 2016).

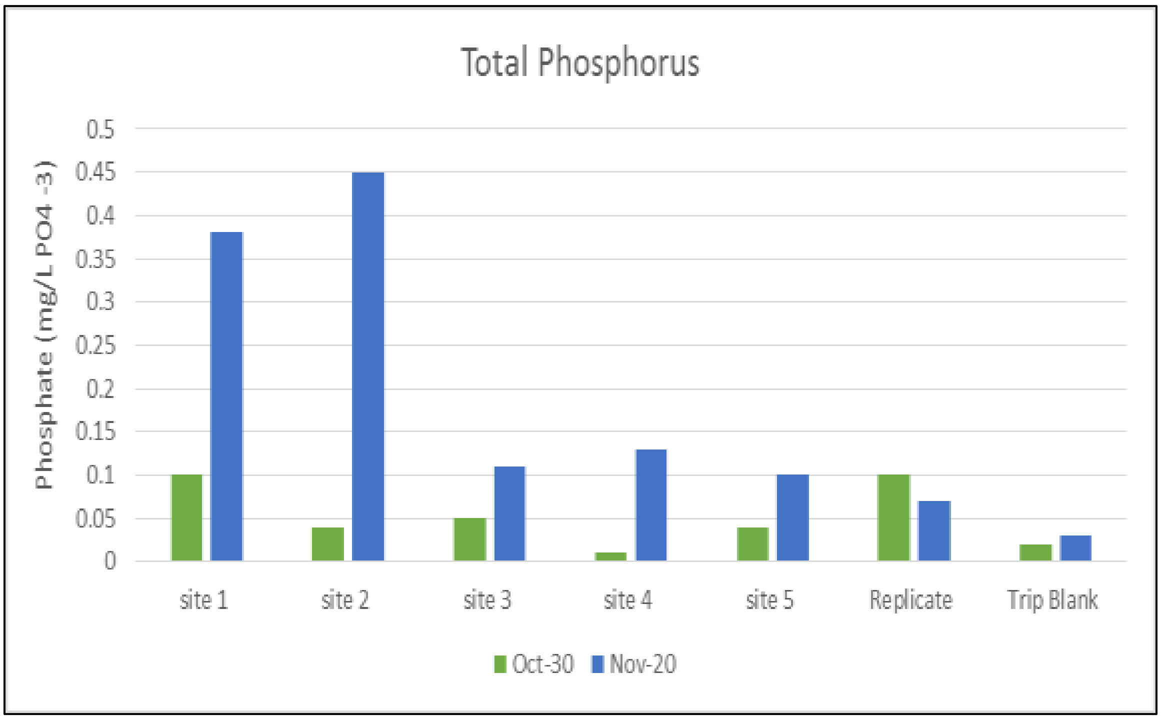
Figure 14. Nitrate concentrations (mg/L) measured during October 30th and November 20th in the Millstone River. The October sampling event is represented in green and the November sampling event is represented in blue**.**



Total Phosphate

Total phosphates sampled on October 30th ranged from <0.01 to 0.10 mg/L whereas on November 20th the values ranged from 0.07 to 0.45 mg/L. It is interpreted that the overall increase in total phosphates observed in the November 20th results may indicate that some decaying organic material within the watershed could have been remobilized via surface runoff and tributaries into the Millstone River during the heavy rain fall event experienced in the Nanaimo region the week prior (VIU Weather Station, 2017). These results show no correlation with past water quality studies undertaken by Vancouver Island University students between 2008 and 2015 (Demers, 2017). Further, no correlation was observed with the ALS results suggesting that are results were unusually high and indicate eutrophic conditions.

Figure 15. Total Phosphorus concentrations (mg/L) measured during October 30th and November 20th in the Millstone River.



7.0. STREAM INVERTEBRATE COMMUNITIES

7.1 Overview

The site assessment rating for both sites 1 and 2 was 1.75, which equates as “poor” to “marginal” invertebrate stream health (Tacogna & Munro, 1995). The low ratings for these two sites coincide with the VIU water quality results that characterized both sites as eutrophic (Figure 15). Yet, when comparing the invertebrate values to the ALS total phosphorous results, the results were undefined. According to the ALS data all of the sites were oligotrophic (A4). On analyzing both the VIU laboratory results (A3) and the ALS results (A4), there were no trends with any other parameters (metals, pH, alkalinity etc.) that might explain the relatively low invertebrate rating of the river. Additionally, studies between 2008-2015 do not indicate trends between the invertebrate health and the parameters tested (Demers, 2016). Analysis between 2008-2015 indicated “marginal” to “acceptable” stream health, suggesting that the overall quality may be declining. This is corroborated with the invertebrate analysis conducted in 2016 at site 4, that had stream health ratings of 1 and 1.75, which is a lower rating than previous years for that site (Lawson et al., 2016)*.

**Note: In 2016, only 2 locations were sampled at site 4 as the river discharge conditions were high making it unsafe to sample at the other sites.*

7.2 Abundance

A total of 377 invertebrates were collected between all three sites on October 30, 2017. Of that, 13 different taxa were identified. The highest abundance of total invertebrates was collected at site 2 with 168. Below that was site 4 with 152, and the lowest was found at site 1 with 57. The predominant taxa for sites 1, and 2 was aquatic worm (oligochaete), and mayfly nymph for site 4 (A5). Aquatic worms are classified as category 3 pollution tolerant as they can adapt to more challenging environmental conditions. The mayfly nymph is classified as category 1 pollution intolerant and their presence generally indicates clean, clear water (Tacogna & Munro, 1995).

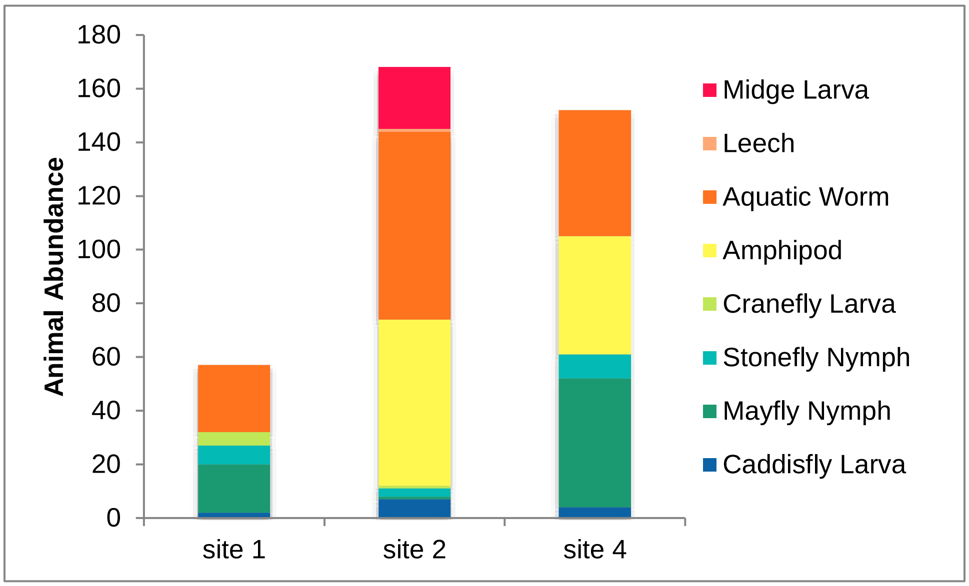


Figure 16. Animal abundance observed at sites 1, 2, and 4. The greatest abundance of invertebrates is observed at site 2. Cooler colours (blue and green) denote pollution intolerant species, whereas warmer colours (yellow, orange and red) represent pollution tolerant species. The greatest amount of pollution-tolerant species were found at site 2. The greatest amount of pollution-intolerant species were found at site 4.

7.3 Density

The greatest overall invertebrate density was collected at site 2 with a total of 622/m^2. A density of 563/m^2 was observed at site 4, and a density of 211/m^2 was found at site 1. The greatest total density was observed at site 2, yet the least amount of pollution intolerant species and the greatest amount of pollution tolerant species were observed at site 2 (Figure 17).

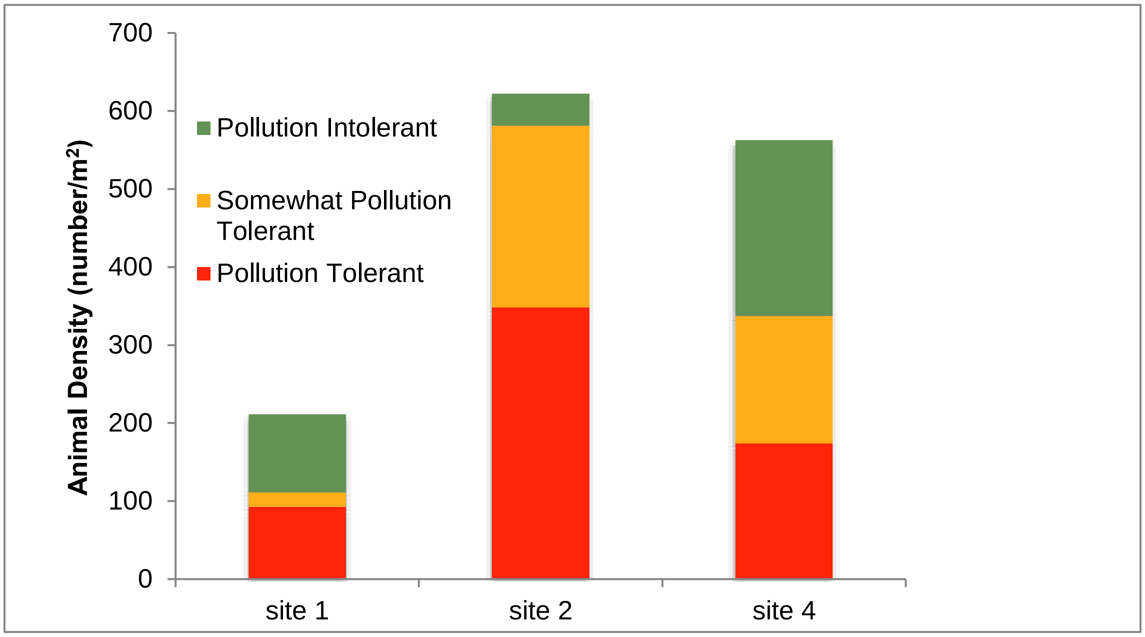


Figure 17. Invertebrate density collected on October 30, 2017, identifying pollution intolerant, somewhat pollution tolerant, and pollution tolerant animals found at sites 1, 2, and 4. The greatest density was found at site 2 with a total of $622/m^2$, yet the greatest pollution tolerant, and the fewest pollution intolerant was also observed at site 2.

7.4 Diversity

The Shannon-Weiner Diversity Index (*H*) was calculated at 0.851 for site 4. Below that was site 1 with an *H* of 0.808. The lowest *H* was calculated at site 2 at 0.673. See A5 for Shannon-Weiner Diversity Index (*H*) calculation (tables 1-3).

7.5 Site Ratings

The highest site assessment was found at site 4 with a rating of 2.75, categorizing the water quality between "marginal and acceptable". The lowest site assessments were observed at sites 1 and 2 with a rating of 1.75, categorizing the water quality between "poor and marginal". The site assessment rating gives a general overall rating of stream health, taking into consideration four factors: the Pollution Tolerance Index, the EPT index (the amount of mayflies, stoneflies, and caddisflies), the EPT to Total Ratio and the Predominant Taxon Ratio. A higher rating indicates better stream health, with 4 being the highest rating (Tacogna & Munro, 1995).

8.0 CONCLUSIONS AND RECOMMENDATIONS

In this study, the authors sampled and tested stream invertebrates, water quality, microbiology and hydrology. The results determined that overall, the environmental quality of the Millstone River ecosystem is poor. Several key results contributed to this determination. Laboratory results from Vancouver Island University indicated that two of the five sample sites were eutrophic based on the phosphorous data collected. In addition to this, overall site assessments were poor to marginal, based on the Streamkeepers Handbook, which were lower than results obtained in previous years.

With this being said, all samples were found to be within the BC water quality guidelines. Many factors may have contributed to these results such as anthropogenic effects, which were noticed as the team travelled downstream. Possible anthropogenic effects that were seen were: agricultural run-off, possible fertilizer addition, animal waste, garbage dumping as well as run-off from the road. Site 5 was the furthest downstream and was found to have the highest number of fecal coliforms present, indicating that animal waste was highly likely (data not shown). In addition to this, the discharge measured in the second sampling event exceeded average discharge rates and was found to be the second highest in the last decade.

Recommendations as to how monitoring could be modified or improved if it were to continue would include long-term studies, as continuing the data collection would be beneficial to determining the causes of changes between the yearly project. More invertebrate samples per site would also be beneficial as there can be variability between samples that are just a few meters apart. We also recommend collecting all sample types at all sites, simply because this would add to the amount of information obtained for each site on the Millstone river. If possible it would be ideal to conduct invertebrate samples earlier in the fall as well as in the second sampling event, this would be weather permitting but would give more valuable information about the sites.

9.0 ACKNOWLEDGEMENTS

We would like to extend a big thank you to the Department of Fisheries and Oceans, the Regional District of Nanaimo, the BC Conservation Foundation and the Nanaimo and Area Land Trust for supporting this project. Additionally, we would like to thank Vancouver Island University for the use of its facilities and equipment to complete lab work and the ALS laboratory for providing us with a significant discount on analytical procedures. Finally, we would like to thank Dr. Eric Demers for providing us with this learning opportunity, as well as his support and guidance throughout the 2017 Millstone River monitoring project.

10.0 REFERENCES

B.C. Government. (2016). Biogeoclimatic Ecosystem Classification Subzone/Variant Map for the South Island Resource District South Coast Region. Retrieved on October 22, 2017, from ftp://ftp.for.gov.bc.ca/HRE/external/!publish/becmaps/PaperMaps/field/DSI_SouthIslandResourceDistrict_SouthCoastRegion__field.pdf

City of Nanaimo. (2008). Millstone River Side-Channel "The Power of Community Partnerships". Nanaimo: 2008 UBCM Community Excellence Awards.

Demers, E. (2016), Water Quality and Stream Invertebrate Assessments for the Millstone River, Nanaimo, BC, 2008-2015. RMOT 306 Environmental Monitoring – Data Reports. https://wordpress.viu.ca/rmot306/author/demerse/

Demers, Eric. (2017). Resource Management Officer Technology: Environmental Monitoring (RMOT 306) lecture notes on D2L from September 5 & 12 "Introduction to the Environmental Sector", slide #17 titled "Why Monitor?".

Demers, Eric. (2017). Resource Management Officer Technology: Environmental Monitoring (RMOT 306). Lecture slides on D2L "Water Quality Monitoring". Retrieved October 20, 2017, from https://d2l.viu.ca/d2l/le/content/105732/view Content/1120677/View

Demers, Eric. (2017). Resource Management Officer Technology: Environmental Monitoring (RMOT 306). Lab 2- Stream Invertebrate Sampling and Analysis. Retrieved October 21, 2017, from https://d2l.viu.ca/d2l/le/content/105732/viewContent/1120689/View

Fisheries and Oceans, 2016. The Streamkeepers Handbook. The Stewardship Series. Retrieved October 20, 2017, from http://www.pskf.ca/publications/Module04.pdf

GEOCACHING. (2000), The Official GPS Cache Site. Vancouver Island Earth-Cache Series: Mount Tzuhalem's Conglomerate Boulders. Retrieved October 29, 2017, from http://kz.ca/links/earthcache/VI-EC-Series/mt-tzuhalem-conglomerate/rocks home.jpg

Interstate Commission on the Potomac River Basin. (1940), Interstate Commission on the Potomac River Basin. Basic Hydrology Part 1. Retrieved October 20, 2017, from https://www.potomacriver.org/wp-content/uploads/2014/12/BasicHydrology Part1.pdf

Lawson, D., Bevans, J., Pancera, N., Sodomsky, S. (2016). Fall 2016 Data Report: Water Quality and Stream Invertebrates Assessment for the Millstone River, Nanaimo, BC. Vancouver Island University. RMOT 306 Environmental Monitoring – Data Reports. http://wordpress.viu.ca/rmot306/files/2017/08/VIU-Millstone-River-WQ-Report-2016.pdf

Ministry of Environment, Lands, and Parks (1998). Guidelines for Interpreting Water Quality Data. Retrieved on December 8, 2017, from https://www.for.gov.bc.ca/hts/risc/ pubs/aquatic/interp/intrptoc.htm

Regional District of Nanaimo. (2016). Millstone River Habitat Survey. Retrieved on October 22, 2017, from http://www.rdn.bc.ca/dms/documents/dwwp-reports/ lantzville-to-south-wellington-water-region/millstone_river_ushp_stream_survey_-_2016.pdf

Tacogna, G., & Munro, K. (1995). The Streamkeepers Handbook: a Practical Guide to. (S.E. Program, Ed.) Vancouver, British Columbia, Canada: Department of Fisheries and Oceans.

11.0 APPENDIX

A1: Health and Safety Plan

While in the field, each group member followed several safety precautions. During our initial site visit, we ensured that each site has cell service, and group members carried their phone with them at all times. When heading out to the sites, we “checked in” with our instructor Eric Demers, and “checked out” upon our return. This way someone always knew where we were. In addition to this, no group members carried out field work on their own, and appropriate equipment and clothing were used at all times. Members did not attempt to wade in fast water or water deeper than knee height. Each member was aware of the various hazards that each site held, and we conducted a briefing upon arrival to each site to go over the information shown in Table 2. Furthermore, our group included two members with CPR training, one with Occupational First Aid level 3 and another with Emergency First Aid for Industry. A first aid kit was on site at all times, and the nearest emergency hospital was the Nanaimo Regional General Hospital.

Table 1: Health and safety considerations gathered from site assessment of the Millstone River on October 18th

Site Location	#1	#2	#3	#4	#5
Site Access	Road (Public)	Road (Public)	Road (Public)	Trail (Public)	50m From Road (Public)

Hazards	Wire fence over river, Slips, trips & falls, Large overhanging trees, High traffic area, Thorn bushes	Possible bank collapse- sediment is exposed, Slips, trips & falls, Cannot see under the water's surface, High traffic area	Large overhanging trees, Less traffic/more remote	Very slippery, waterfall close by, auditory-hard to communicate, drowning	Slippery stairs, slippery rocks, auditory- hard to communicate, fast moving currents, drowning
Embankment	Steep and slippery	Steep and slippery	Steep and slippery	Flat, very slippery	Somewhat flat, Slippery
In-Stream Footing	Large rock- poor footing	Not determined yet- cannot see under the water's surface	Not determined yet- cannot see under the water's surface	Current is too fast for in-stream footing	Current is too fast for in-stream footing
Flow Rate/Depth	Moderate rate, somewhat low	Slow rate, moderate depth	Moderate rate, deep.	Fast flow rate, low	Very fast flow, deep
Evacuation Route	Trail up to road	Trail up to road	Trail up to road	Multiple trails back to the parking lot	Trail back to road

A2: Images from site visits (Figures 1 - 5, Author: T. Orrick)

Figure 1: Sample location (1): Benson Creek, Biggs Road Crossing (Benson Creek)

Figure 2: Location (2) Millstone River, Biggs Road Crossing (Millstone Creek looking downstream from the bridge on Biggs Road)

Figure 3: Location (3) (Millstone River looking downstream from the bridge located at Durnin Road)

Figure 4: Millstone River Diversion Channel viewed from below the Duck pond.

Figure 5: The lower section of the Millstone River looking east towards Nanaimo Harbour.

A3: VIU Water Quality

Table 1. A list if the laboratory parameters measured and the equipment used to complete the VIU water quality analysis.

Parameter Measured	Equipment Used and Calculation Control
Water temperature	YSI 556 MPS electronic probe or Oxyguard Handy Polaris electronic probe (nearest 0.1^{o}C)
Dissolved oxygen	YSI 556 MPS electronic probe or Oxyguard Handy Polaris electronic probe (nearest 0.1 mg/L)
Conductivity	Pinpoint Conductivity Meter (nearest 1 µS/cm)
pH	pHTestr 10 pH (nearest 0.1 pH unit)
Turbidity	HACH 2100 Potable Turbidimeter (nearest 0.01 NTU)
Alkalinity	HACH AL-DT digital titration method (nearest 0.1 mg/L)
Hardness	HACH HA-4P test kit (nearest 1 mg/L
Phosphate	HACH DR2800 Spectrophotometer Method 8048 (nearest 0.1 mg/L)
Nitrate	HACH DR2800 Spectrophotometer Method 8192 (nearest 0.1 mg/L)
Coliform	m-coliBlue24 membrane filtration method (nearest 1 CFU/100 ml)

Table 2. Vancouver Island University: School-Based Weather Station Network
November Summary October Summary

October 2017	Summary at Vancouver Island University										
	Temperature °C			Humidity %			Wind km/hr				Rain (mm)
Day	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Dir	Total
01	10.3	12.8	15.8	51	64	80	0	5	18	WNW	0.0
02	10.2	14.3	18.4	35	50	73	0	6	19	NW	0.0
03	10.3	14.0	17.7	31	46	62	0	2	10	WNW	0.0
04	8.9	13.4	17.4	37	51	63	0	2	9	S	0.0
05	10.4	13.3	17.3	50	60	73	0	1	7	W	0.0
06	9.6	12.0	15.8	58	72	82	0	5	24	SW	1.0
07	8.1	10.5	13.4	62	72	84	0	2	9	WNW	1.0
08	9.6	11.8	15.5	50	67	77	0	4	17	NW	0.0
09	8.4	9.9	12.2	72	80	87	0	2	11	S	0.0
10	6.3	8.9	12.3	60	76	84	0	4	17	WNW	3.6
11	5.7	8.1	11.8	61	76	85	0	2	11	WSW	0.0
12	4.9	7.5	9.6	75	84	89	0	1	12	WSW	5.8
13	5.1	8.6	12.6	49	66	88	0	4	18	W	0.2
14	5.2	7.6	9.4	60	75	85	0	3	12	S	0.0
15	7.6	10.4	14.2	62	76	84	0	5	14	S	0.2
16	9.4	10.9	14.6	69	83	88	0	4	17	SSE	0.5
17	7.3	11.2	13.4	55	74	91	0	6	30	WSW	6.6
18	6.8	8.6	11.1	65	84	92	0	6	22	S	34.5
19	7.9	9.3	12.3	73	86	90	0	5	26	SSW	8.9
20	4.8	8.5	12.3	65	80	88	0	4	20	SW	1.8
21	5.7	7.4	8.9	72	89	92	0	8	23	SSE	34.0
22	8.0	11.2	14.5	56	72	92	0	5	28	SW	2.3
23	8.5	10.4	11.8	64	81	89	0	4	14	S	0.0
24	8.5	12.0	15.9	61	76	87	0	2	11	SSW	0.0
25	8.8	11.3	15.0	57	77	90	0	5	20	NW	0.0
26	7.5	11.1	15.1	60	72	81	0	5	19	WNW	0.0
27	8.6	12.6	16.9	57	69	78	0	1	9	W	0.0
28	10.2	13.3	16.2	59	69	81	0	1	11	W	0.0
29	9.6	13.7	18.0	40	66	81	0	2	12	W	0.0
30	8.8	12.3	15.7	33	47	63	0	2	8	WNW	0.0
31	7.3	9.5	12.0	50	63	74	0	2	8	WSW	0.0
Summary	8.0	10.8	14.1	56	71	82	0	4	16	WSW	100.6

Source: http://www.victoriaweather.ca/mst.php?id=123&year=2017&month=10

Table 3. Vancouver Island University: School-Based Weather Station Network November Summary

November 2017 Summary at Vancouver Island University

	Temperature °C			Humidity %			Wind km/hr				Rain (mm)
Day	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Dir	Total
01	7.2	9.8	13.9	54	70	81	0	5	18	W	0.0
02	1.2	4.0	8.6	65	81	88	0	6	18	W	18.8
03	0.3	1.7	3.7	54	62	83	0	6	17	WNW	0.0
04	-1.2	0.3	1.4	64	81	90	0	3	12	S	0.0
05	-0.7	2.5	5.1	60	71	89	0	5	14	WNW	4.1
06	1.0	2.4	4.8	45	60	67	0	5	18	SSW	0.0
07	2.3	4.4	6.3	55	68	78	0	9	19	SSW	0.0
08	5.2	7.2	8.8	52	62	77	0	10	27	S	0.8
09	6.0	6.9	8.1	70	83	89	0	3	22	SSW	1.0
10	6.1	7.1	8.6	79	87	91	0	2	9	SSW	0.2
11	6.8	7.3	8.2	86	89	92	0	5	19	SSE	7.4
12	7.3	8.0	8.5	91	92	92	0	5	19	SSE	20.1
13	6.1	7.2	8.5	74	88	93	0	10	29	SSE	20.1
14	4.8	6.2	7.0	84	90	91	0	11	27	S	52.1
15	4.3	5.3	7.1	83	88	90	0	8	26	SSW	12.9
16	2.7	4.5	6.7	76	86	90	0	4	19	SW	5.6
17	2.6	5.0	7.2	70	79	86	0	3	15	SW	0.0
18	4.7	7.1	9.7	72	81	88	0	7	28	S	0.0
19	5.8	6.7	7.8	85	91	92	0	6	24	SE	24.4
20	2.3	5.6	8.3	74	89	93	0	3	13	SW	1.5
21	4.2	5.4	8.4	85	90	92	0	9	20	SSW	18.3
22	6.9	12.0	14.7	66	91	93	0	6	27	S	8.1
23	6.8	10.1	14.3	53	75	88	0	7	27	SW	1.3
24	6.4	7.7	9.4	66	82	90	0	5	17	SSE	2.0
25	6.8	7.4	8.4	83	89	92	0	6	22	SSE	15.2
26	4.9	8.3	11.2	54	74	93	0	9	31	SSW	6.9
27	4.2	6.3	8.8	63	74	87	0	4	19	SSW	0.2
28	4.1	5.8	7.2	78	87	90	0	4	20	SW	5.8
29	3.8	5.9	7.8	73	84	91	0	5	21	S	2.0
30	5.2	6.1	7.1	91	92	92	0	5	18	SSE	2.3
Summary	4.3	6.1	8.2	70	81	88	0	6	21	SSW	231.1

Source: http://www.victoriaweather.ca/mst.php?id=123&year=2017&month=10

A4: ALS DATA

Table 1: ALS Data (October 30 2017)

Client Sample ID			MILLSTONE RIVER - STATION 1	MILLSTONE RIVER - STATION 2	MILLSTONE RIVER - STATION 4
Date Sampled			30-Oct-2017	30-Oct-2017	30-Oct-2017
Time Sampled			11:00	11:00	11:00
ALS Sample ID			L2017715-7	L2017715-8	L2017715-9
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Physical Tests (Water)					
Conductivity	2.0	uS/cm	52.1	79.6	132
Hardness (as CaCO3)	0.50	mg/L	19.7	28.7	45.1
pH	0.10	pH	7.37	7.50	7.81
Anions and Nutrients (Water)					
Ammonia, Total (as N)	0.0050	mg/L	<0.0050	<0.0050	0.0117
Nitrate (as N)	0.0050	mg/L	0.486	0.0154	0.182
Nitrite (as N)	0.0010	mg/L	<0.0010	<0.0010	0.0010
Total Nitrogen	0.030	mg/L	0.590	0.213	0.380
Orthophosphate-Dissolved (as P)	0.0010	mg/L	<0.0010	<0.0010	0.0042
Phosphorus (P)-Total	0.0020	mg/L	<0.0020	0.0048	0.0146
N:P	N/A	N/A	295.0	44.4	26.0
Total Metals (Water)					
Aluminum (Al)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Antimony (Sb)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Arsenic (As)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Barium (Ba)-Total	0.010	mg/L	<0.010	<0.010	0.014
Beryllium (Be)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050

Bismuth (Bi)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Boron (B)-Total	0.10	mg/L	<0.10	<0.10	<0.10
Cadmium (Cd)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Calcium (Ca)-Total	0.050	mg/L	5.54	7.70	12.9
Chromium (Cr)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Cobalt (Co)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Copper (Cu)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Iron (Fe)-Total	0.030	mg/L	<0.030	0.098	0.247
Lead (Pb)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Lithium (Li)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Magnesium (Mg)-Total	0.10	mg/L	1.44	2.30	3.16
Manganese (Mn)-Total	0.0050	mg/L	<0.0050	0.0135	0.0208
Molybdenum (Mo)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Nickel (Ni)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Phosphorus (P)-Total	0.30	mg/L	<0.30	<0.30	<0.30
Potassium (K)-Total	2.0	mg/L	<2.0	<2.0	<2.0
Selenium (Se)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Silicon (Si)-Total	0.10	mg/L	4.03	2.77	3.48
Silver (Ag)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Sodium (Na)-Total	2.0	mg/L	2.3	4.0	9.9
Strontium (Sr)-Total	0.0050	mg/L	0.0220	0.0308	0.104
Thallium (Tl)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Tin (Sn)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Titanium (Ti)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Vanadium (V)-Total	0.030	mg/L	<0.030	<0.030	<0.030

Zinc (Zn)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050

Qualifier Legend

HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).

Table 2: ALS data (November 20 2017)

Client Sample ID			MILLSTONE RIVER - STATION 1	MILLSTONE RIVER - STATION 2	MILLSTONE RIVER - STATION 4
Date Sampled			20-Nov-2017	20-Nov-2017	20-Nov-2017
Time Sampled			11:00	11:00	11:00
ALS Sample ID			L2026212-7	L2026212-8	L2026212-9
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Physical Tests (Water)					
Conductivity	2.0	uS/cm	27.0	58.7	79.1
Hardness (as CaCO3)	0.50	mg/L	12	22.6	27.2
pH	0.10	pH	7.07	7.10	7.55
Anions and Nutrients (Water)					
Ammonia, Total (as N)	0.0050	mg/L	<0.0050	0.0072	0.0277
Nitrate (as N)	0.0050	mg/L	0.192	0.109	0.550
Nitrite (as N)	0.0010	mg/L	<0.0010	<0.0010	0.0011
Total Nitrogen	0.030	mg/L	0.318	0.527	0.778
Orthophosphate-Dissolved (as P)	0.0010	mg/L	<0.0010	0.0141	0.0038
Phosphorus (P)-Total	0.0020	mg/L	0.0110	0.0491	0.0178
N:P	N/A	N/A	28.9	10.7	43.7
Total Metals (Water)					
Aluminum (Al)-Total	0.20	mg/L	0.52	0.89	0.39
Antimony (Sb)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Arsenic (As)-Total	0.20	mg/L	<0.20	<0.20	<0.20

Barium (Ba)-Total	0.010	mg/L	<0.010	0.010	0.012
Beryllium (Be)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050
Bismuth (Bi)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Boron (B)-Total	0.10	mg/L	<0.10	<0.10	<0.10
Cadmium (Cd)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Calcium (Ca)-Total	0.050	mg/L	3.25	5.76	7.69
Chromium (Cr)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Cobalt (Co)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Copper (Cu)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Iron (Fe)-Total	0.030	mg/L	0.543	0.963	0.477
Lead (Pb)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Lithium (Li)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Magnesium (Mg)-Total	0.10	mg/L	0.93	2.01	1.94
Manganese (Mn)-Total	0.0050	mg/L	0.0109	0.0226	0.0235
Molybdenum (Mo)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Nickel (Ni)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Phosphorus (P)-Total	0.30	mg/L	<0.30	<0.30	<0.30
Potassium (K)-Total	2.0	mg/L	<2.0	<2.0	<2.0
Selenium (Se)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Silicon (Si)-Total	0.10	mg/L	3.82	5.16	4.12
Silver (Ag)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Sodium (Na)-Total	2.0	mg/L	<2.0	3.8	5.9
Strontium (Sr)-Total	0.0050	mg/L	0.0133	0.0245	0.0445
Thallium (Tl)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Tin (Sn)-Total	0.030	mg/L	<0.030	<0.030	<0.030

Titanium (Ti)-Total	0.010	mg/L	0.026	0.042	0.021
Vanadium (V)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Zinc (Zn)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050

Qualifier Legend

HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).

A5: INVERTEBRATE DATA

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Millstone	Date:	Oct. 30/17
Station Name:	Stn. 1	Flow status:	
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates	0.27 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	2	1
	Mayfly Nymph (EPT)	18	1
	Stonefly Nymph (EPT)	7	1
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		27	3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	5	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)		
	Watersnipe Larva		
Sub-Total		5	1
Category 3	Aquatic Worm (oligochaete)	25	2
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		25	2
TOTAL		57	6

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: **57**

DENSITY: Invertebrate density per total area sampled:

57 / 0.27 m^2 = 211 / m^2 (From page 1)

PREDOMINANT TAXON: Aquatic Worm (oligochaete)

Invertebrate group with the highest number counted (in Col. C)

SECTION 2 - WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: Sub-total number of taxa found in each tolerance category.

Good	Acceptable	Marginal	Poor
>22	22-17	16-11	<11

3 x D1 + 2 x D2 + D3

3 x 3 + 2 x 1 + 2 = 13

EPT INDEX: Total number of EPT taxa.

Good	Acceptable	Marginal	Poor
>8	5-8	2-4	0-1

EPT4 + EPT5 + EPT6

1 + 1 + 1 = 3

EPT TO TOTAL RATIO INDEX: Total number of EPT organisms divided by the total number of organisms.

Good	Acceptable	Marginal	Poor
0.75-1.0	0.50-0.74	0.25-0.49	<0.25

(EPT1 + EPT2 + EPT3) / CT

(2 + 18 + 7) /57= 0.47

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 6

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (S1) divided by CT.

Good	Acceptable	Marginal	Poor
<0.40	0.40-0.59	0.60-0.79	0.80-1.0

Col. C for S1 / CT

18 / 57 = 0.32

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment Rating	
Good	4
Acceptable	3
Marginal	2
Poor	1

Assessment	Rating
Pollution Tolerance Index	2
EPT Index	2
EPT To Total Ratio	2
Predominant Taxon Ratio	1

Average Rating

Average of R1, R2, R3, R4

1.75

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Millstone		Date:	Oct. 30/17
Station Name:	2		Flow status:	
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates		0.27 m²

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	7	1
	Mayfly Nymph (EPT)	1	1
	Stonefly Nymph (EPT)	3	1
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		11	3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	1	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	62	2
	Watersnipe Larva		
Sub-Total		63	3
Category 3	Aquatic Worm (oligochaete)	70	
	Blackfly Larva		
	Leech	1	1
	Midge Larva (chironomid)	23	2
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		94	5
TOTAL		168	11

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 168

DENSITY: Invertebrate density per total area sampled:

168 / 0.27 (From page 1) m^2 = 622 / m^2

PREDOMINANT TAXON: Aquatic Worm (oligochaete)

Invertebrate group with the highest number counted (in Col. C)

SECTION 2 - WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: Sub-total number of taxa found in each tolerance category.

Good	Acceptable	Marginal	Poor
>22	22-17	16-11	<11

3 x D1 + 2 x D2 + D3

3 x 3 + 2 x 3 + 5 = 20

EPT INDEX: Total number of EPT taxa.

Good	Acceptable	Marginal	Poor
>8	5-8	2-4	0-1

EPT4 + EPT5 + EPT6

1 + 1 + 1 = 3

EPT TO TOTAL RATIO INDEX: Total number of EPT organisms divided by the total number of organisms.

Good	Acceptable	Marginal	Poor
0.75-1.0	0.50-0.74	0.25-0.49	<0.25

(EPT1 + EPT2 + EPT3) / CT

(7 + 1 + 3) / 168= 0.07

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 11

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (S1) divided by CT.

Good	Acceptable	Marginal	Poor
<0.40	0.40-0.59	0.60-0.79	0.80-1.0

Col. C for S1 / CT

7 / 168 = 0.04

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment Rating	
Good	4
Acceptable	3
Marginal	2
Poor	1

Assessment	Rating
Pollution Tolerance Index	3
EPT Index	2
EPT To Total Ratio	1
Predominant Taxon Ratio	1

Average Rating
Average of R1, R2, R3, R4
1.75

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Millstone River		Date: 01-Nov-17
Station Name: Station Number 3		Flow status: Low
Sampler Used: Hess Sampler	Number of replicates: 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates: 0.27m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	4	1
	Mayfly Nymph (EPT)	48	3
	Stonefly Nymph (EPT)	9	1
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		61	4
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva		
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	44	1
	Watersnipe Larva		
Sub-Total		44	1
Category 3	Aquatic Worm (oligochaete)	47	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
Pollution Tolerant	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		47	1
TOTAL		152	6

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: **152**

DENSITY: Invertebrate density per total area sampled:

152 ÷ 0.27 m^2 = **563** / m^2 (From page 1)

PREDOMINANT TAXON:
Invertebrate group with the highest number counted (in Col. C): **Mayfly Nymph**

SECTION 2 - WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: Sub-total number of taxa found in each tolerance category.

Good	Acceptable	Marginal	Poor
>22	22-17	16-11	<11

3 x D1 + 2 x D2 + D3

3 x ___4__ + 2 x __1___ + _1____ = **15**

EPT INDEX: Total number of EPT taxa.

Good	Acceptable	Marginal	Poor
>8	5-8	2-4	0-1

EPT4 + EPT5 + EPT6

___1__ + _3____ + ___1__ = **5**

EPT TO TOTAL RATIO INDEX: Total number of EPT organisms divided by the total number of organisms.

Good	Acceptable	Marginal	Poor
0.75-1.0	0.50-0.74	0.25-0.49	<0.25

(EPT1 + EPT2 + EPT3) / CT

_4__ + ___48__ + ___9__) / __152__ **0.4**

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: **6**

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (S1) divided by CT.

Good	Acceptable	Marginal	Poor
<0.40	0.40-0.59	0.60-0.79	0.80-1.0

Col. C for S1 / CT

__48___ / __152___ = **0.32**

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment Rating	
Good	4
Acceptable	3
Marginal	2
Poor	1

Assessment	Rating
Pollution Tolerance Index	2
EPT Index	3
EPT To Total Ratio	2
Predominant Taxon Ratio	4

Average Rating
Average of R1, R2, R3, R4
2.75

Table 1. Calculation table for Shannon-Weiner Diversity Index (*H*) from site 1.

Common Name	Column C	$P_i(C/T)$	$Ln(p_i)$	$p_i*ln(p_i)$
Caddisfly Larva	2	0.03	-3.51	-0.11
Mayfly Nymph	18	0.32	-1.14	-0.36
Stonefly Nymph	7	0.12	-2.12	-0.25
Cranefly Larva	5	0.09	-2.41	-0.22
Aquatic Worm (oligochaete)	25	0.44	-0.82	-0.36
Total	57	1	---	-1.3

$H = -(-1.3)/\ln(5) =$ **0.808**

Table 2. Calculation table for Shannon-Weiner Diversity Index (*H*) from site 2.

Common Name	Column C	$P_i(C/T)$	$Ln(p_i)$	$p_i*ln(p_i)$
Caddisfly Larva	7	0.04	-3.22	-0.13
Mayfly Nymph	1	0.01	-4.61	-0.05
Stonefly Nymph	3	0.02	-3.91	-0.08
Cranefly Larva	1	0.01	-4.61	-0.05
Amphipod (fresh water shrimp)	62	0.37	-0.99	-0.37
Aquatic Worm (oligochaete)	70	0.42	-0.87	-0.37
Leech	1	0.01	-4.61	-0.05

Midge Larva (chironomid)	23	0.13	-2.04	-0.27
Total	168	1	---	-1.4

H = -(-1.4)/ln(8) = **0.673**

Table 3. Calculation table for Shannon-Weiner Diversity Index (H) from site 4.

Common Name	**Column C**	$P_i(C/T)$	**Ln**(p_i)	$p_i * \ln (p_i)$
Caddisfly Larva	4	0.03	-3.51	-0.11
Mayfly Nymph	48	0.32	-1.14	-0.36
Stonefly Nymph	9	0.06	-2.81	-0.17
Amphipod (fresh water shrimp)	44	0.28	-1.27	-0.36
Aquatic Worm (oligochaete)	47	0.31	-1.17	-0.37
Total	152	1	---	-1.37

H = -(-1.37)/ln(5) = **0.851**