Water Quality and Stream Freshwater Macroinvertebrate for the Millstone River, Nanaimo, BC

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Executive Summary (Kevin)

As part of Vancouver Island University's environmental monitoring class, the Millstone River was used for a stream monitoring project. Utilizing the resources available at the school, water quality and invertebrate sampling was conducted over two sampling periods. Water quality was collected on October 24th and November 20th, and invertebrate sampling was collected on October 31st and November 21st. Additional water quality samples from site 3 and site 5 was also collected and sent to ALS in Vancouver for more detailed water quality analysis. Water quality tests conducted at Vancouver Island University were focused on parameters such as temperature (°C), pH, conductivity (µS/cm), turbidity (NTU), dissolved oxygen (mg/L), hardness (mg/L), nitrate (mg/L), total alkalinity (mg/L) and phosphorus (mg/L). The Vancouver Island University water quality measurements were compared to the ALS sample results, which indicated an error in the campus tested phosphate being the only outlier. This is most likely an error in the field test conducted on campus and the ALS sample will be utilized. All water samples fell within the healthy range outlined by the British Columbia Approved Water Quality Guidelines. Invertebrate sampling was conducted by utilizing a Hess sampler three times per sample period on sites 2, 3 and 5. These samples were analyzed on campus at Vancouver Island University and the Shannon-Weiner Species Diversity Index was calculated. Overall assessment of the invertebrate communities classified the stream health as marginal, and the Shannon-Weiner Diversity Index scored the river at 1.55 which may indicate mild pollution present. With no immediate indicators of stream pollution, the Millstone River should be considered as a healthy functioning stream system. Further monitoring should be considered to maintain consistent data and to further monitor the effects of urban expansion in the surrounding area.

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1.0 Introduction (Erik)

1.1 Project Overview & Objectives

The students who carried out this study respectfully acknowledge and thank the Coast Salish peoples of the Snuneymuxw, Quw'utsun and Tla'Amin First Nations on whose traditional lands it was completed.

The Millstone River is a significant salmonid-bearing watershed located in the Nanaimo, BC area. The watershed contains significant amounts of coho salmon *(Oncorhyncus kisutch)*, pink salmon *(Oncorhynchus gorbuscha)*, chum salmon *(Oncorhyncus keta)*, cutthroat trout *(Oncorhyncus clarkii)*, and rainbow trout *(Oncorhyncus mykiss)* habitat in addition to other groups including various birds, amphibians, bats and other mammals (Bonar and Zamora 2018). The 98.6-square-kilometre system is comprised of 8 lakes and 26 kilometres of streams made up of 16 tributaries. Most notably Benson Creek, Brannen Lake and the Millstone River itself. The main drainage system begins in Lucid Lake, adjacent to Mount Benson, BC then moves into Benson Creek which flows into Brannen Lake. This is where the Millstone River originates and continues to flow for 14 kilometres through agricultural land, high-traffic flow areas, privately owned properties, and parkland until it reaches Nanaimo Harbour and the greater Georgia Strait (Demers 2016; Gaboury and Kehler 2012; City of Nanaimo 2008). Other significant watershed tributaries include Beaver Creek, Darough Creek, McClure Creek, McGarrigle Creek, Morgan Creek, and Sabiston Creek which flow directly into the Millstone River. Heikkila Creek, Metral Creek, and an unmarked creek flow into Benson Creek in the upper watershed (Thirkill 1998).

Between October 24th, 2023, and December 2nd, 2023, students Erik Dunn, Aaron Jordens, Kevin Petersen, and Paul Veit with Vancouver Island University’s Bachelor of Natural Resource Protection conducted an environmental monitoring project on the Millstone River as part of an environmental monitoring course. The purpose of the project was to build on the dataset of an annual study that monitors the system's water quality and assesses the quality of fish habitat. The study has been run on an annual basis since 2008 and utilizes the same water quality metrics to maintain dataset continuity. Additionally, samples were taken at low and high-water levels to gain a better understanding of changes to water quality and invertebrate communities at different flow levels.

The project was broken down into three primary goals that sit under the project's overarching objective of ascertaining data that will be available to the public, the City of Nanaimo, and Fisheries and Oceans Canada to aid in watershed management decisions to the benefit of salmonids, wildlife, water licensees, and human health. Subsequently, if poor watershed health is found researchers will attempt to determine the cause and recommend management decisions. The three primary objectives are as follows:

Objective 1 – Water Quality: Attaining accurate water quality metrics is critical in the assessment of a stream's health. Various metrics play crucial roles at every life cycle stage in salmonids. Directly affecting, spawning success, juvenile survival rates, and subsequently the overall population recruitment (Fellman et al. 2015). All sites will be tested for dissolved oxygen, pH, salinity, turbidity, alkalinity, hardness, temperature, and nutrients. Additional samples will also be sent to Australian Laboratory Services (ALS) to test for nutrients and heavy metals.

Objective 2 – Hydrological Analysis: Hydrology plays a crucial role in the regulation of stream health and watershed processes. Water quality parameters such as temperature, dissolved oxygen, and turbidity are heavily influenced by the hydrological conditions of the watershed (Fellman et al. 2015). Researchers will assess various parameters to determine the hydrological health of the Millstone including stream flow and discharge, and discharge, bank full width and depth, wetted width will be measured at all sites. Additionally, each sites riparian characteristics and conditions will be assessed at allowing for greater insight to potential water quality impacts that may be occurring. Comparing depth and discharge to previous years result will be of particular interest given current drought conditions and the ongoing salmon migration.

Objective 3 – Macroinvertebrate Analysis: The presence and composition of macroinvertebrates are essential in the rearing and subsequent recruitment of juvenile salmonids (Winder et al. 2005). Sampling and analysis of sites will provide a species composition and thus a watershed health metric based on the ratio of pollution-tolerant to intolerant species. Juvenile salmonids tend to favour EPT taxa i.e., Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly). Therefore, attaining a species composition is crucial in determining overall watershed health.

1.2 Watershed Historical Review

The Millstone watershed resides on the territory of the Coast Salish peoples, specifically the Snuneymuxw, Quw'utsun and Tla'Amin. The Millstone, like other watersheds in the area, was of great significance culturally and as a means of subsistence and trade for its salmon. Salmon are seen as gift-bearing relatives in Coast Salish culture and are regarded with the highest respect. Salmon were preserved for year-round consumption and trade by means of smoking, curing, and drying. (UBC First Nations and Indigenous Studies 2009).

Colonial nations initially discovered the Nanaimo and Millstone River area in 1592 when the Spanish sailed up the East Side of Vancouver Island. In 1778 Commodore Alejandro Malaspina arrived in the area and renamed several bays inlets that were later renamed again by the British. Centuries later Malaspina would have Malaspina College named after him before it was later changed to Vancouver Island University (Leduc and Hoffman 2022). In 1794 the British took over the entirety of Vancouver Island from the Spanish after the negotiation of the Nootka Convention. However, exploitation of the Nanaimo area didn't begin until around 1852 when the Hudson's Bay Company began to mine vast seams of coal discovered in the area. The town of Colviletown (named after Andrew Colvile, the Governor of the Hudson's Bay Company) was subsequently founded and a sawmill was built along the Millstone River to provide timber for the mine, and for housing its employees (Leduc and Hoffman 2022). Many Snuneymuxw were employed by the sawmill after they were displaced from their traditional village near Cameron Island and relocated to a southern village site known as Reserve No. 1. In 1860 the town was renamed Nanaimo, which was derived from the name Snuneymuxw (snuh – nay – mow) (Leduc and Hoffman 2022).

1.3 Land Use & Environmental Concerns

The Millstone River runs through an extensively developed landscape with about two-thirds running through agricultural land and the other third through the City of Nanaimo. Subsequently, the Millstone River is subject to a large influx of pollutants and excess nutrients from these sources. The possibility of excess phosphorus and nitrogen inputs from artificial fertilizers as well as heavy metals and inorganic compounds from urban runoff pose a risk of increased water toxicity. Of significant concern is the low water levels that the Millstone River faces during the summer months from July to September (Figure 1). This can result in an increase in nutrient and toxin concentration and a reduction in dissolved oxygen levels (Gaboury and Kehler 2012).

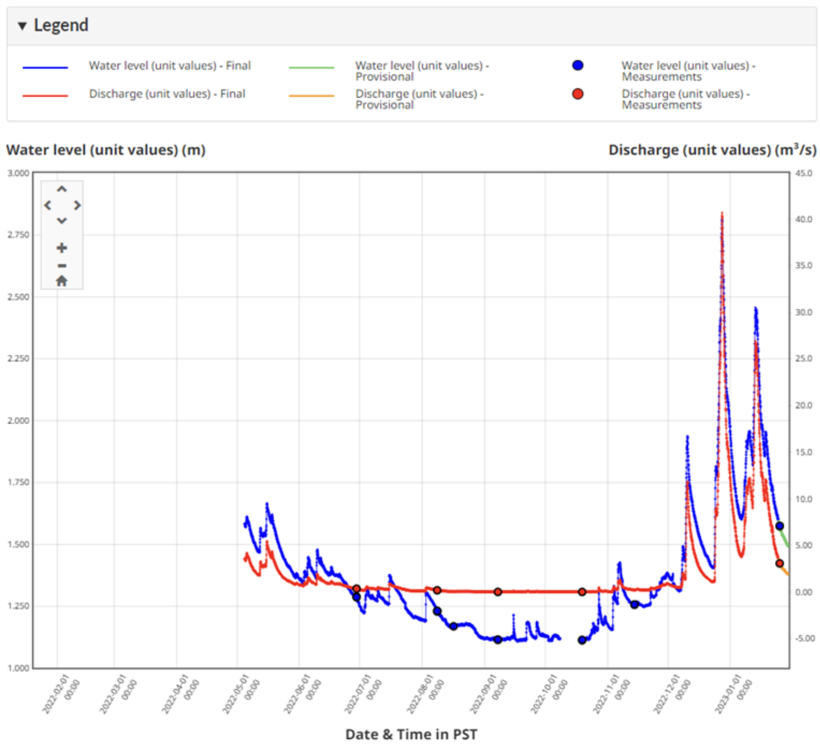

Figure 1. Hydrometric data of the Millstone River between May 2022, and January 2023 (Natural Resources Canada 2023).

The Millstone River has been utilized for its water extensively for the past 70 years. To date the systems water licenses, amount to 229427 cubic meters of water per year. The vast majority of these licences are utilized for agricultural irrigation purposes however the Ministry of Forests utilizes 185022 cubic meters for “conservation/storage” purposes (Table 1) (Ministry of Forests 2023). This volume of water likely has significant impacts on the

Millstone Rivers water levels, particularly in the early summer months when alfalfa water consumption peaks and precipitation is minimal (Sloan 2009).

Table 1. Current water license authorizations on the Millstone River (Ministry of Forests 2023).

Priority Date	Client Name	Purpose Use	Quantity M3/Year
1948	City of Nanaimo	Land Improve: General	0
1954	Phyllis Maria Brooks	Irrigation: Private	1110.132
1954	Peter Reynold Nesselbeck and Cindy Marie Nesselbeck	Irrigation: Private	2096.916
1954	Gayle Jackson	Irrigation: Private	2466.96
1952	James M Lighthart and Kather Lighthart	Irrigation: Private	5550.66
1976	Fish and Wildlife Nanaimo, Ministry of Forests, Lands and Natural Resource Operations	Conservation: Storage	185022
1952	Millstone River Farm Ltd.	Irrigation: Private	7400.88
1952	Millstone River Farm Ltd.	Lwn, Fairway & Grdn: Watering	1850.22
1985	Fisheries & Oceans Canada	Conservation: Construct Works	0
1951	Catherine Elizabeth Bibbs	Irrigation: Private	7400.88
1951	Stephen W Ellis and Audrey L Ellis	Irrigation: Private	863.436
1982	Fish and Wildlife Nanaimo, Ministry of Forests, Lands and Natural Resource Operations	Conservation: Construct Works	0.19822
1952	Michael J Charlton and Diane E Harris	Irrigation: Private	5180
1954	Regional District of Nanaimo	Irrigation: Private	2466.96
1954	Morgan David Carey	Irrigation: Private	2466.96
1954	Norman E Mitton	Irrigation: Private	1480.176
1954	Douglas John McCallum	Irrigation: Private	986.784
1954	Russell A Mccallum	Irrigation: Private	1850.22
1954	0812159 B.C. Ltd.	Irrigation: Private	1233.48

Riparian areas are essential for productive fish habitat. They provide shade, filtration, bank stability and erosion control, substrate control, organic matter and instream cover (LWD & SWD), and habitat which contribute to improved water quality, invertebrate community diversity, and overall fish habitat (Hyatt 2023; Winder et al. 2005). The Millstone Rivers riparian area is comprised of a coniferous and deciduous canopy containing a dense shrubby understory (Chatwin Engineering 2011). However, this is mostly present in the lower fifth of the system below Bowen Park with the vast majority of the watershed comprised of a narrow strip of deciduous vegetation surrounded by urban or agricultural land (Figure 2). A GIS analysis was conducted to survey the past twenty years of the Millstone Rivers riparian area. The analysis comprised of satellite imagery from 2003 – 2023 and showed little to no change in the volume of riparian vegetation. This means that the Millstone Rivers riparian area has remained in a degraded state for more than twenty years leaving little room from agricultural and urban expansion around the system (Google Earth 2023). Nearly all of the agricultural irrigation licensees for the Millstone River were created in the 1950s. This suggests that most of the agricultural development and subsequent degradation of the systems riparian area occurred during this time (Ministry of Forests 2023).

Figure 2. Snapshot of riparian area GIS analysis of the Millstone Rivers Agricultural and Urban Areas (Google Earth 2023).

A field riparian and substrate analysis was conducted at all five sites. Sites three, four, and five contained adequate amounts of instream and canopy cover to provide necessary shade and bank stability. Contrarily sites one and two contained minimal instream and canopy cover and are unlikely sufficient enough to support productive salmonid habitat in the upper reaches of the stream. Substrate remained consistent throughout the system and primarily consisted of cobble in all sites with the exception of site 5 which had a large quantity of gravel present.

A number of restoration efforts have been undertaken on the Millstone River system by various organizations. Most notably, in 2007 Fisheries and Oceans Canada commissioned the construction of an 800-meter bypass channel around the falls in Bowen Park to allow salmonids (primarily coho) to access habitat in the upper watershed (Vancouver Island

University 2023). The project followed several previously failed initiatives to construct fish ways and stepping pools in the 1980s that had resulted in the need for seasonal intervention to allow the structures to function (City of Nanaimo 2008). The channel has been met with moderate success and in 2009 camera technology was installed to monitor the quantity of fish entering the system by Vancouver Island University Resource Management Officer Technology Students (Vancouver Island University 2023).

Other notable restoration projects include work by the Pacific Salmon Foundation to restore riparian and spawning habitat. This included the planting of 217 native flora in the habitat adjacent to the Pryde Vista Golf Course in 2011. During this time 244 metric tonnes of spawning gravel were used to create a 197 m^2 spawning pad in the same area (Pacific Salmon Foundation 2012).

The Regional District of Nanaimo has also undertaken its own Ecological Accounting Process to preserve and restore the system through land acquisitions and donations of surrounding land to be converted to parkland for conservation. To date this City of Nanaimo has acquired 40 hectares of land for the project worth approximately $2,220,000 at the time of purchase. An additional $2,725,000 has been spent on research, restoration, enhancement, and maintenance of the system (Regional District of Nanaimo 2021).

2.0 Methods (Paul)

The following section describes the methods used for achieving a meaningful and comparable monitoring result. This includes the choice of location, the parameters measured, and how the samples were analyzed.

2.1 Sampling Programme

To ensure that the long-term monitoring project of the Millstone River is adequately presented, the 5 sites chosen from the previous years were monitored. However, Site 1 and Site 5 were changed from the downstream to the upstream side of the bridge, moving the sampling station a few meters upstream compared to previous years. Monitoring the same sites enables good comparability. In addition, trends in changes to the stream system can be identified more reliably based on this data. Using existing sites is according to the Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (Cavanagh et al., n.d.).

Each of the 5 selected sites was carefully chosen to accurately reflect the characteristics of the stream system, avoiding any uncharacteristic representations. The selection criteria considered the stream type, flow patterns, widths, depths, and canopy cover to ensure that these locations served as representative stream samples. The evaluation of these sites focused on water quality, habitat conditions, and biodiversity abundance. It is crucial to acknowledge that access to these sites significantly influenced the bias in site selection, and these locations were chosen based on data from previous years (Figure 3) (Table 2).

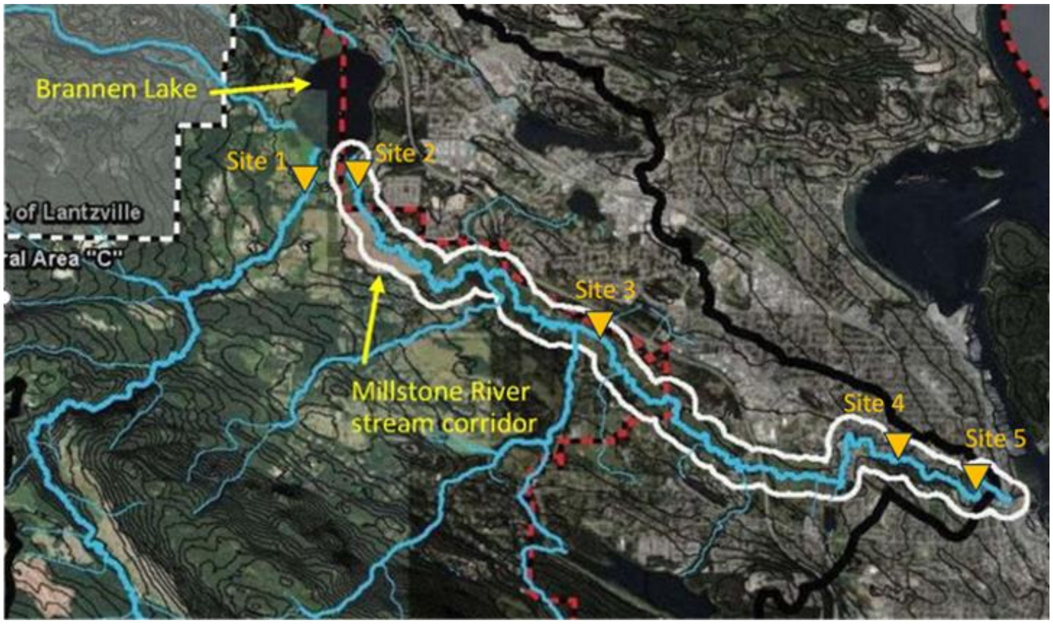

Figure 3. Selected sampling sites (Water Bucket 2021).

Table 2. Sample site UTM coordinates (Google Earth 2023).

Site Number	UTM
1	10 U 422740 E 5450751 N
2	10 U 423343 E 5450840 N
3	10 U 426310 E 5448965 N
4	10 U 430329 E 5447276 N
5	10 U 431008 E 5447205 N

Site 1 was located on Benson Creek, a tributary of the Millstone River, which flows into Brannen Lake. Access to this site was available upstream of the Biggs Rd bridge. This tributary served as a water quality control site that discharges to the overall system and the adjacent lake. The stream was lined with dense vegetation on both sides, but this did not provide any significant protection above the water. The tree canopy above the stream also offered only minimal protection. Extensive rural properties were nearby, including the local scout camp "Camp Caillet". The creek bed was mainly cobblestone with some gravel substrate, and plenty of leaf litter was in the creek bed (Figure 4).

Figure 4. Photograph of Millstone River Site 1.

Site 2 was also situated on Biggs Rd, positioned downstream of Brannen Lake, adjacent to the bridge crossing. It was the first monitoring site on the Millstone River. When considered alongside Site 1, it provided data on the lake's potential impacts on the Millstone stream system. Access to this location was close to the river crossing bridge and bordered an agricultural property. The site was characterized by a dense streambank cover, posing challenges to access. Moreover, a moderate tree canopy was overhead, offering cover and shade to this section of the stream. The streambed predominantly consisted of cobblestone, with abundant leaf litter covering the bottom (Figure 5).

Figure 5. Photograph of Millstone River Site 2.

Site 3 was located at the junction of Maxey Rd and Durnin Rd at the bridge beside a residential property. This site is downstream of another small tributary and allowed data to reflect on any changes this flow may have caused to the stream. Stream banks at this site were lined with shrubs and a few tall trees. This left a very open canopy, and tall grasses were present leading up to the site. The streambed was mostly cobblestone and had no minimal leaf litter present, unlike other sites (Figure 6).

Figure 6. Photograph of Millstone River Site 3.

Site 4 was in Bowen Park, just downstream of a small duck pond that waterfowl frequently utilize. This site allowed data to reflect any impacts these pools in the park may have on the stream system. This area was well kept; very few shrubs were on the stream banks, and large fir trees provided little canopy coverage. The streambed was mostly cobblestone, and a few larger rocks were in some areas, with little to no leaf litter present in this section of the stream (Figure 7).

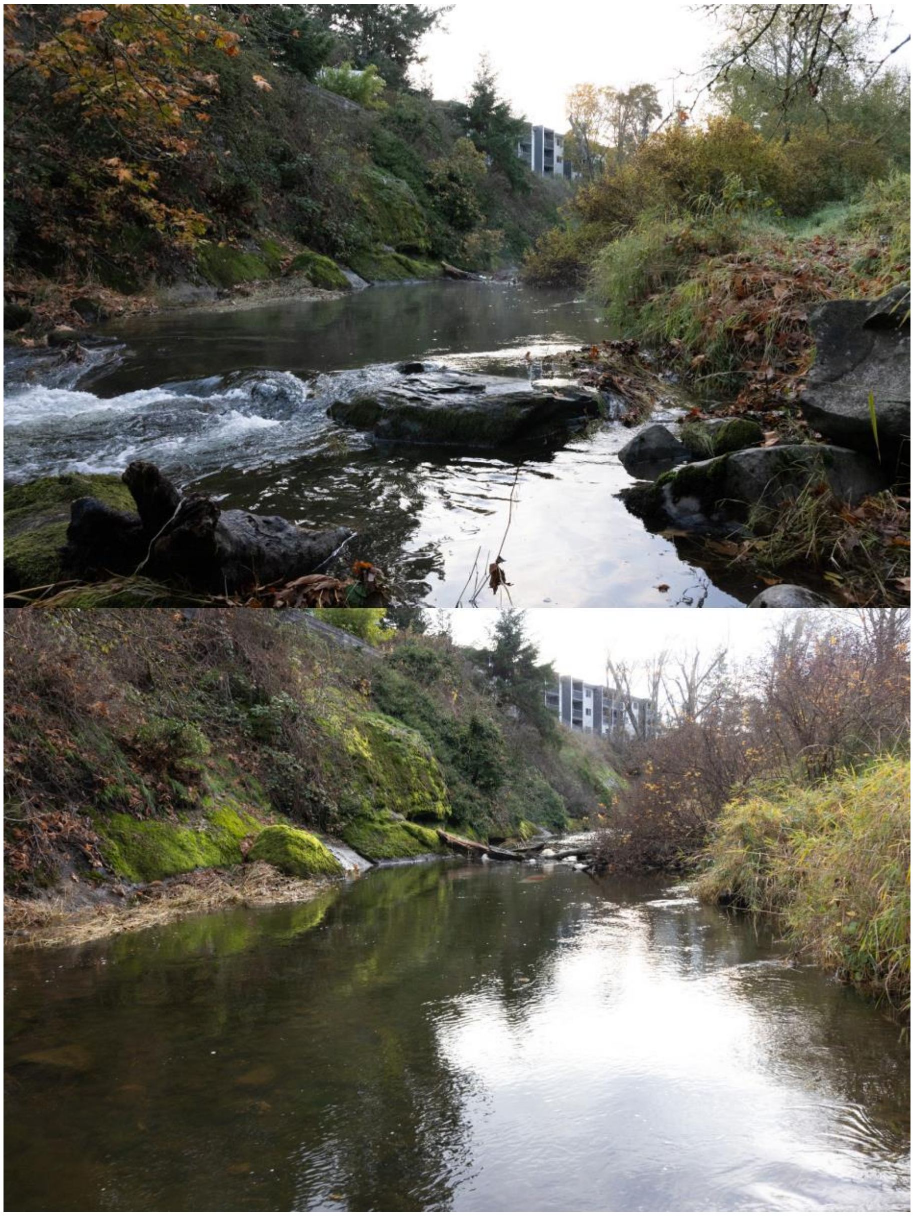

Figure 7. Photograph of Millstone River Site 4.

Site 5 was further downstream of the park, near some residential buildings, before flowing into the ocean. This site was far enough away from the sea not to be affected by tidal impacts and allowed data to show the last of any impacts to the river system. This site was just upstream of a walkway bridge by the German Culture Center. Streambanks were moderately covered with shrubs and a few big fir trees above, leaving most of the canopy cover open. The streambed mainly consisted of larger rocks and bedrock, with little to no leaf litter in the stream itself (Figure 8).

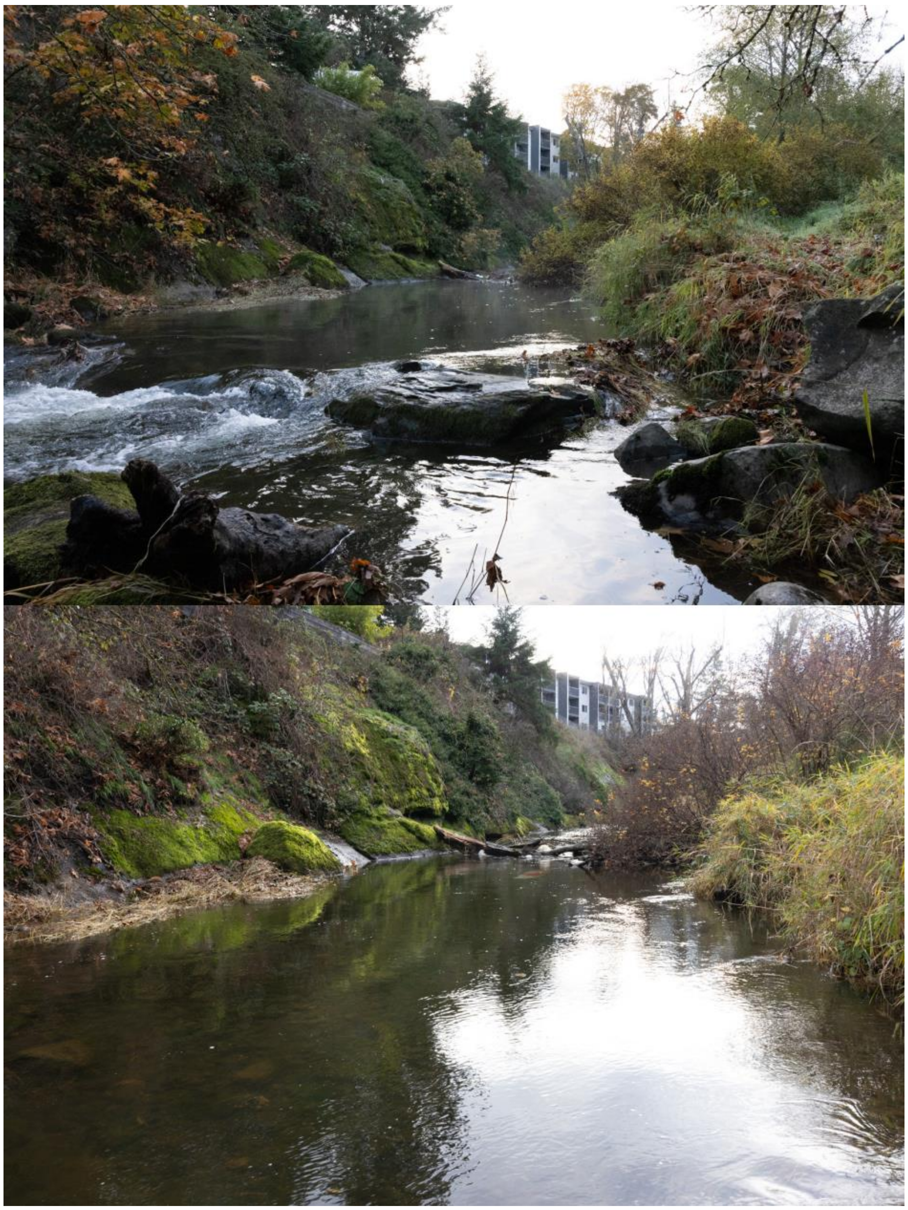

Figure 8. Photograph of Millstone River Site 5.

2.2. Sampling Procedures

Samples were taken twice to obtain a more representative result. Table 3 provides an overview of which samples and measurements were taken at which site. Sampling periods took place around October 20th and November 21st. The VIU Water quality samples and the hydrology assessment were done at each site in October and November. The macroinvertebrate samples were taken at sites two, three, and five in October and November. The invertebrate sampling sites were changed from previous years to better represent the condition of the Millstone River. Site 2 represents the first site of the river and provides data on the influences of Brannen Lake. Site 3 serves as a data source in the middle of the river system and site five serves as the final site reflecting all the influences of Bowen Park. Samples for the ALS water quality analysis was taken in October and November at sites three and five. Sampling in October and November allowed data to be collected during low and high-water levels. The sites for macroinvertebrate sampling were selected based on the respective water levels. The sites for the ALS analysis were chosen because of their proximity to agricultural land and Highway 19 (Site 3), and the urban centre, and the possibility of nitrogen influences from Bowen Park (Site 5).

Table 3. Study sampling and analysis schedule.

Environmental Sampling Schedule				
Site	Hydrology	Macroinvertebrate	VIU Water Quality Analysis	ALS Water Quality Analysis
1	A, B	--	A, B	--
2	A, B	A, B	A, B	--
3	A, B	A, B	A, B	A, B
4	A, B	--	A, B	--
5	A, B	A, B	A, B	A, B

Symbols "A" or "B" represent sampling days in October (A) and November (B)

2.2.1 Hydrology

Basic water hydrology was observed at each of the sites. Depending on the time available, observations occurred either during the sampling days or on another date during the same sampling period. The measured parameters were bankfull width and depth, wetted width and depth, and water flow rate. The riparian area along the stream at each site was also assessed. This method made it possible to see all changes in the current in relation to the data of the samples.

2.2.2 Water Quality

The water quality analysis was split into the ALS analysis and the analysis at VIU. Both sampling procedures followed the Ambient Freshwater and Effluent Sampling Manual of the Government BC (2013). Each sampling period contained one trip blank, which was analyzed as well. The ALS sampling took place in an external laboratory. The parameters measured were conductivity, hardness, pH level, different anions and nutrients such as nitrate and phosphorus, and total metals.

The internal water quality analysis occurred in the field and the laboratory at VIU. Temperature and dissolved oxygen were measured in the field using an electric probe. Due to the limited availability of the measuring device, both parameters could only be measured in the second collection round in November. Water samples were tested at VIU for total hardness, alkalinity, suspended solids (turbidity), phosphorus, and nitrates. Sampling and analysis were conducted following guidelines laid out in RMOT 306 Water Quality Lab as well as the British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (British Columbia Ministry of Environment and Climate Change Strategy, 2023) and the Guidelines for Interpreting Water Quality Data (Cavanagh et al., 1998).

2.2.3 Macroinvertebrates

The macroinvertebrate sampling was done with a Hess sampler. In accordance with the sampling guidelines provided in the Stream Invertebrate Lab, three samples were collected at each site to represent the macroinvertebrates living in the stream accurately. In October, the three samples were each collected by different people. In November, each site was sampled by another person. There was some sampling bias as the sampler selected the most "representative" part of the streambed during sampling.

The macroinvertebrates sampled were recorded on the RMOT 306 Stream Invertebrate Survey Data Sheets, and the Shannon-Weiner index was used in this sampling method. Samples were separated from coarse substrate in the field and then returned to VIU. Final identification and counting then took place in the laboratory.

3.0 Results & Discussion

3.1 Water Quality (Aaron)

The water quality measurements taken over the course of this survey produced acceptable results that fell within the healthy range outlined by the British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (BCMOE 2023) and the Guidelines for Interpreting Water Quality Data (Cavanagh et al. 1998). Each measurement was compared against this guideline to ensure that the current health of the stream was within the parameters required to sustain aquatic life. Comparisons were also made to the results of previous surveys conducted by past RMOT 306 students on the Millstone River. These comparisons allow the data to be displayed in a manner that can reveal any positive or negative trends that have occurred over time. This type of analysis is important when considering the health of the ecosystem on a large scale, it also helps us to understand what activities over time have had positive or negative impacts on the ecosystem as well as what future actions can be taken to improve ecosystem health and function.

3.1.1 Field Measurements of Stream Temperature and Dissolved Oxygen

Both temperature and dissolved oxygen were measured in the field using a portable YSI meter that could be submerged directly in the stream. Unfortunately, this meter was only acquired for the November 20th sampling date and, therefore, only one set of measurements were collected. This data set is organized in Table 4 which shows the relatively steady temperature and dissolved oxygen levels. The measurements of site 2 are slightly different than those of the other four sites and this is likely due to the influence of Brannen Lake. We can see that the lake contributes to a slight rise in temperature as well as a drop in dissolved oxygen; however, these changes are reversed as the water returns to a faster velocity and continues downstream. Overall, there is very little change in temperature throughout the 14 km of the Millstone River with only a 0.9º C drop between the start of the river at site 2 and the end at site 5. The change in dissolved oxygen is slightly more significant throughout the Millstone River with a range of 8.3 mg/L to 12.4 mg/L. This range difference is not alarming when considering the influence of Brannen Lake, the lakes proximity to site 2, and the slow-moving water at site 2 (0.807 m/s).

When considering the needs of salmonids during embryo and alevin development, the Millstone River meets the required levels of dissolved oxygen and temperature in most locations (BCMOE 2023). This is important data to consider when surveying the Millstone River because of the large amount of effort that has been exerted to establish a sustainable population of coho salmon in the stream (City of Nanaimo 2008). Optimal temperature ranges for incubating salmon fall between 4º C and 13º C, with dissolved oxygen levels meeting an 11 mg/L level in the water column and an 8 mg/L level within the substrate (BCMOE 2023). This means that sites 1, 4, and 5 are currently at optimal levels for developing salmon embryos while sites 2 and 3 meet the temperature requirements but fall short of the required levels of dissolved oxygen (Table 4).

Table 4. Temperature and dissolved oxygen measurements of the Millstone River on November 20th, 2023.

	Site 1	Site 2	Site 3	Site 4	Site 5
Temperature (ºC)	6.8	7.3	7.3	6.5	6.4
Dissolved Oxygen (mg/L)	11.3	8.3	10.8	12.0	12.4

Several factors may be affecting the temperature and dissolved oxygen levels of the Millstone River resulting in the different measurements at each site surveyed. These factors include the influence of Brannen Lake, the amount of canopy and instream cover, and the velocity of the stream in different locations. Site 2 was observed to have the largest variation in both temperature and dissolved oxygen levels. This variation is likely a result of the sites close proximity to Brannen Lake, narrow riparian area, and low flow velocity. A large canopy cover was observed directly over the stream at site 2; however, because of the agricultural land use in the area, the depth of the riparian area was observed to be very narrow. It is possible that the temperature at site 2 is heavily dependent on the temperature of Brannen Lake and there may be little that can be done to change that. If a lower temperature is desired throughout the Millstone River or more specifically, between sites 2 and 3, then developing a wider and more dense riparian area may be a good strategy towards achieving that goal.

3.1.2 Field Measurements of Turbidity

The turbidity of the Millstone River was measured from samples taken from each of the five surveyed sites on November 20th, 2023. These samples were taken back to Vancouver Island University to be tested in a campus laboratory. Unfortunately, only the November 20th sample set was tested for turbidity and there is no data from the October 24th sample date to compare it to. However, there is turbidity data from past surveys completed on the Millstone River. Comparing the 2023 turbidity data to previous years will help to determine if there has been any significant change over time that needs to be addressed.

Figure 9 illustrates the turbidity trend that has occurred from 2015 to 2023 at site 3. There was no survey conducted on the Millstone River in 2022 and, as a result, there is no data to include from that year. Site 3 was chosen for this graph because it was deemed to be the best representation of the whole stream at a single site and because there was insufficient data from previous surveys to show turbidity levels at all five sites. All data in Figure 9 are from samples collected in the month of November and were collected at period of high-water flow.

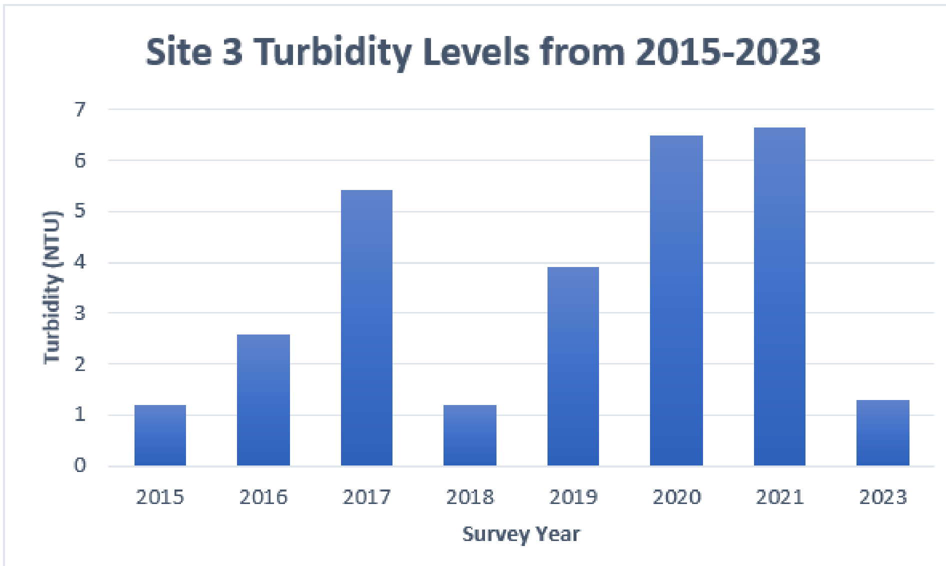

Figure 9. Turbidity levels measured at Site 3 of the Millstone River between 2018 and 2023 (Kollman et al. 2021; Arsenault et al. 2020; Ng Cornish et al. 2019; Boldt et al. 2018; Hobkirk et al. 2017; Lawson et al. 2016; Sunduk et al. 2015).

The drastic differences illustrated in Figure 9 are likely the result of the differences in rainfall and weather activity between each year. Environment and Climate Change Canada shows that 2021 had very high levels of fall precipitation, and 2020 had lower levels similar to 2023 in the fall but had more precipitation throughout the summer (Gov of Canada 2023). Using the same government data, high precipitation levels are seen in the fall of 2016 and 2017 while 2015 and 2018 had far lower levels of fall precipitation. This data correlates with the turbidity levels observed over the 9-year period. It is also possible that previous construction and development projects near the Millstone River contributed to the amount of sediment entering the stream (Arsenault et al. 2020 and Ng-Cornish et al. 2019). Since acceptable turbidity levels vary from stream to stream, it is hard to gauge whether the turbidity levels observed in the Millstone River can be considered normal (Taccogna and Munro 1995). If the previous high turbidity levels observed in 2020 and 2021 have not had significant impacts on the ecosystem, then it is likely that the low turbidity levels observed in 2023 are not alarming. With previous construction projects ending, the lower levels observed in 2023 may actually be an indicator of the stream turbidity returning to normal levels. Further monitoring of turbidity in the future and possibly more frequent surveys throughout the year may be necessary to better determine a normal level of turbidity within the Millstone River.

3.1.3 VIU Water Quality Laboratory Results

500 ml water samples were collected at each of the five sites surveyed along the Millstone River on two separate occasions. These samples were then brought to a laboratory at the Vancouver Island University campus to be tested for several water quality parameters. Testing was done to measure the conductivity, pH, nitrate, phosphate, hardness, and alkalinity of the water collected at each site. The test results from the five sites were compared to each other as well as to the findings of other survey years in order to see if any significant changes had occurred from site to site or over time. The first sampling date was conducted on October 24th, 2023, with the results being described in Table 5. The second sample date was conducted on November 20th, 2023, with the results being described in Table 6. The samples collected on October 24th were intended to provide water quality measurements at a state of low flow in the Millstone River and the samples collected on November 20th were intended to provide water quality measurements at a state of high flow. Some differences were observed between the two dates, and almost all of the measurements observed fell within provincial guidelines (BCMOE 2023).

Phosphate levels were the only parameter tested that was observed to be at levels beyond what is considered healthy by the Guidelines for Interpreting Water Quality Data (Cavanagh et al. 1998). However, it is likely that the observed levels of phosphate resulting from the test are not an accurate representation of the levels within the Millstone River and there may have been an error in the test.

Table 5. VIU water quality measurements collected on October 24th, 2023.

Site	**Conductivity (µS/cm)**	**pH**	**Nitrate (mg/L)**	**Phosphate (mg/L)**	**Hardness (mg/L)**	**Alkalinity (mg/L)**
1	031	7.5	0.12	0.08	18	13
2	077	7.2	0.08	0.11	34	23
3	104	7.3	0.13	0.06	52	26
4	122	7.2	0.11	0.08	60	16
5	124	7.2	0.14	0.04	44	32
Field Blank	000	7.7	0.12	0.04	0	12*

**Due to a limited amount of sample water, this test was done with a 25 ml sample instead of a 100 ml sample.*

Table 6. VIU water quality measurements collected on November 20th, 2023.

Site	Conductivity (µS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)	Hardness (mg/L)	Alkalinity(mg/L)
1	031	7.6	0.14	0.21	15	13
2	064	7.4	0.15	0.10	21	19
3	097	7.2	0.30	0.09	20	26
4	106	7.2	0.48	0.03	28	28
5	110	7.3	0.50	0.04	24	28
Field Blank	010	7.3	0.01	0.00	1	1.8

Conductivity: The level of conductivity found between the five sites was observed to have a steady increase from the site 1 to site 5 (Table 5 and Table 6). This may be result of sediment and suspended solid levels increasing as the water travels downstream eroding more of the stream bank (Genereux et al. 2008). Another factor that may contribute to this increase in conductivity further downstream may be the amount of urban activity and infrastructure that the Millstone River travels through. The Millstone River starts in an agricultural area, passes through a municipal park, and travels through the City of Nanaimo before it reaches the Nanaimo Harbour. Morgan et al. (2012) describes the influence that roads and urban land use can have on the conductivity of a stream. This influence can be from road salts as well as run-off from urban and agricultural areas. Because of the land use around the Millstone River, it is very possible that the stream conductivity is influenced by such activity.

When looking at the change in conductivity of the Millstone River between October 24th and November 20th, it is interesting to see that there was an overall decrease in conductivity. With an increase in water velocity, it would be expected that there would also be an increase in erosion and sediment introduction into the Millstone River. However, the influence of ground water also needs to be considered. Woelfle-Erskine et al. (2017) describe how ground water can contain higher concentrations of dissolved salts which can lead to higher water conductivity during periods of low precipitation. Therefore, it is possible that the increase in rainwater after the October 24th sampling date may have been a factor in the observed decrease in conductivity in the November 20th water samples (Gov of Canada 2023).

pH: The pH readings that resulted from both sample dates show that the Millstone River seems to have a fairly stable pH level. Figure 10 illustrates the minimal changes in pH over the five sites during each sampling date. Higher pH levels were observed at site 1 in Benson Creek from both sample dates. However, the levels observed in the Millstone River itself do not diverge very far from each other. The highest degree of change within the river was observed in the November 20th samples where there was a 0.2 reading drop between sites 2 and 3. It is possible that the initial water coming from Brannen lake may have a slightly higher pH and that the alkalinity within the stream may help to reduce that level. When compared to the British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (BCMOE 2023), the pH levels are at a suitable level for a freshwater habitat and the fluctuations of <0.3 are acceptable.

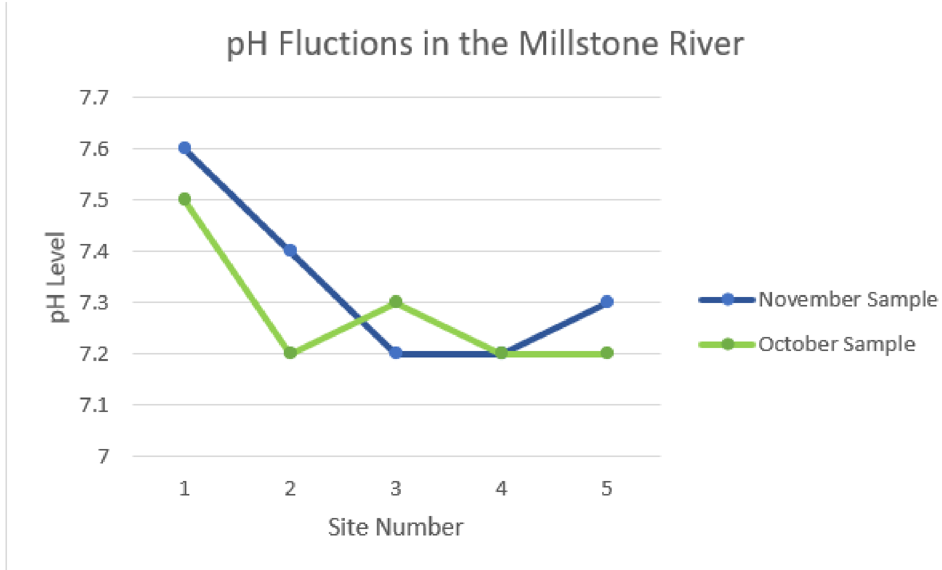

Figure 10. Changes in pH over all 5 sites sampled on October 20th and November 20th, 2023.

Nitrate: Levels of nitrogen, in the form of nitrate (mg/L), were measured using the samples collected on October 24th and November 20th. A significant change was observed between the two sampling dates at every site location. The samples from October 24th show levels of nitrate ranging from 0.08 mg/L to 0.14 mg/L (Table 4). Measurements from the November 20th samples show readings of double and triple those of the October readings, with ranges between 0.14 mg/L and 0.50 mg/L (Table 5). However, the nitrate levels found in both samples are considered to be low when compared to the 3.0 mg/L safe maximum outlined in the nitrogen guideline for long-term exposure in freshwater aquatic ecosystems (BCMOE 2023).

When looking at the nitrate level increases from site 1 up to site 5 there are gradual increases in the October 24th samples with the largest being 0.05 mg/L, but in the November 20th samples the highest increase is 0.18 mg/L. This indicates that an environmental change occurred during the time between samples. Environmental changes that can influence nitrate levels in a stream can be linked to excess nutrient input from environmental leeching, the decomposition of organic matter, and the input of sewage or manure (Taccogna and Munro 1995). Since the larger increases of nitrate levels begins to occur at site 3 in the November 24th samples, it may be possible that the surrounding agricultural land is one of the sources of influence. Another source of nitrate increase may be the congregation of ducks that are seen near site 4 in Bowen Park. The waterfowl tend to gather in a pond area that is part of the fish bypass channel within the park. Site 4 is just downstream of where the bypass channel reconnects with the Millstone River and it possible that the refuse from the waterfowl is impacting the river.

Phosphate: Phosphate levels measured in the Vancouver Island University campus laboratory from the samples gathered on October 24th and November 20th were uncharacteristically high. Acceptable levels of total phosphorus in a freshwater environment are between 0.005 and 0.015 mg/L (5-15 μg/L) according to the Guidelines for Interpreting Water Quality Data (Cavanagh et al. 1998). This guideline describes that levels of phosphate beyond 0.025 mg/L would indicate that the stream is eutrophic. There was no other data or observations that would indicate that the Millstone River was experiencing eutrophication. Increases in phosphate are generally a result of agricultural leeching, runoff from urban areas, the introduction of industrial effluent, or the introduction of sewage treatment plant effluent (Cavanagh et al. 1998). While there is a possibility that the areas surrounding the Millstone River currently influence the phosphate levels within the stream, it is unlikely that the level is as high as what was measured in the Vancouver Island University laboratory. A more likely reason for the high phosphate results is an error in the testing at Vancouver Island University. There are several possible errors that could have occurred during the test including equipment contamination, misuse of equipment, and misinterpretation of test results.

Hardness: Hardness levels of the Millstone River were tested from samples taken at each site on both sample days. There is no specific guideline for what is an optimal versus what is an unacceptable hardness level for a stream, rather it is important to understand the level of hardness because it directly effects the toxicity that certain minerals may have within that stream (BCMOE 2023). Hardness is determined by the amount of available calcium and magnesium, expressed together as $CaCO_3$, that is present in the stream (Cavanagh et al. 1998). The levels measured in the samples were as low as 15 mg/L and as high as 60 mg/L, with levels being lower overall on the November 20th sample day (Table 4 and Table 5). Typically, water hardness is classified as soft ($CaCO_3$ <50 mg/L), moderately hard ($CaCO_3$ 50-150 mg/L), hard ($CaCO_3$ 150-300 mg/L), or very hard ($CaCO_3$ >300 mg/L) (Boyd 2015). Therefore, based on the measurements resulting from the hardness analysis, the Millstone River can be considered to have soft to moderately hard water.

Alkalinity: Alkalinity is similar to hardness in that they are both measured as $CaCO_3$ in mg/L; however, hardness helps to understand the level of toxicity of metals in a stream whereas alkalinity helps to understand the stream's ability to buffer and neutralize acids (Cavanagh et al. 1998). Again, alkalinity is not necessarily rated in a scale that has acceptable, optimal, and unacceptable ranges. Instead, alkalinity is gauged according to how sensitive the stream will be to the effects of an increase in acidity. A highly sensitive stream will have an alkalinity range of 0-10 mg/L, a moderately sensitive stream will measure between 10-20 mg/L, and a low sensitivity stream will have an alkalinity greater than 20 mg/L (Cavanagh et al. 1998). Based on this guideline, the Millstone River has a fairly high level of alkalinity and a good buffer against fluctuations in acidity.

Over the past nine surveys that have been conducted on the Millstone River there has been a fairly stable trend in alkalinity levels. When using measurements from site 3 as an example, alkalinity levels have typically remained between 20-28 mg/L (Figure 11). Levels closer to 15 mg/L were observed in 2017 but returned to levels over 20 mg/L the following year. Very low alkalinity levels were observed in 2021 and this may have been influenced by a heavy rainfall and flood event that preceded the November water sampling day (Kollman et al. 2021).

This high level of alkalinity is likely acting as an excellent buffer against acidity in the Millstone River. This may be why pH levels observed in the river between sites 2 and 5 remain between 7.2 and 7.4 regardless of weather influences (Figure 10). This healthy buffer will likely persist in the future as there is a significant amount of exposed bedrock in the Millstone River and there is likely a fair amount of $CaCO_3$ introduced from several tributaries that empty into the river. However, the alkaline buffer against acid influence in the ecosystem does not mean that the stream is impervious to damage from foreign effluents. Clean water inputs are required in order to maintain a healthy stream ecosystem and to prevent the natural buffer system from being stressed beyond its limits.

Figure 11. November alkalinity readings at site 3 between 2015 and 2023 (Kollman et al. 2021; Arsenault et al. 2020; Ng Cornish et al. 2019; Boldt et al. 2018; Hobkirk et al. 2017; Lawson et al. 2016; Sunduk et al. 2015).

3.1.4 ALS Water Quality Laboratory Results

Along with the water quality tests that were completed at the Vancouver Island University campus there were also water samples sent into ALS Labs for additional analysis. These samples were collected on the same dates as the VIU samples in October and November; however, ALS samples were only taken at sites 3 and 5. The results of the October 24th samples are displayed in Table 7, and the results from the November 20th samples are displayed in Table 8. These ALS samples were taken to measure the same water quality parameters as the VIU samples as well as a number of additional parameters that are beyond the capabilities of the students conducting the survey. The results of the ALS analysis support some of the findings from the VIU analysis; however, there is some variation that is worth exploring.

Table 7. ALS water quality results from the samples collected on October 24th, 2023.

Site	Conductivity (μS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)	Hardness (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Copper(mg/L)
3	110	7.33	0.106	<0.0010*	38	10.4	2.92	0.00104
5	130	7.53	0.164	<0.0010*	42.6	11.8	3,19	0.00183

** The water sample did not contain a level of substance above the Lowest Detection Limit.*

Table 8. ALS water quality results from the samples collected on November 20th, 2023.

Site	Conductivity (μS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)	Hardness (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Copper(mg/L)
3	097	7.26	0.272	<0.0010*	32.6	9.24	2.32	0.00114
5	117	7.63	0.311	0.0011	36.5	10.5	2.49	0.00113

Similar readings between the ALS results and the VIU results occur for most of the shared parameters. Conductivity, pH levels, nitrate levels, and water hardness were all observed to have similar results between the two analyses. There is only slight difference in conductivity between the two analyses. The ALS results were 6 μS/cm higher at each site for the October 24th sample and 7 μS/cm lower at site 5 in the November 20th sample when compared to the VIU results (Table 4 and Table 5). There was similar variation in the pH readings where the ALS pH levels read 0.03-0.33 higher than what was determined in the VIU analysis. Nitrate levels did not exceed 0.50 mg/L in both analyses, and the highest difference between the two analyses was 0.024 mg/L for the October 24th sample and 0.189 mg/L for the November 20th sample. Small variation was also observed between the hardness levels determined by the two analyses. The differences between the results ranges from 1.4-12.6 mg/L with the ALS results supporting the classification of the Millstone River as having soft water (<50 mg/L of $CaCO_3$).

Where the two analyses differ is in the results for the phosphate levels; however, a different result for the levels of phosphate was expected. The phosphate results from the VIU analysis seemed abnormal when compared to the rest of the stream observations conducted and it is likely that an error has occurred somewhere in the VIU analysis (Table 4 and Table 5). The ALS analysis was only able to detect levels of phosphate in one of the four water samples that were submitted. The November 20th site 5 sample was determined to have 0.0011 mg/L of phosphate while the other 3 samples contained no detectable amount of phosphate (< 0.0010 mg/L) (Table 7 and Table 8). The nutrient ratio of nitrogen (N) to phosphorus (P) from the ALS results of November sample at site 5 is 0.311:0.0011 or 282.73:1. This ratio does not align with the optimal balance of the Redfield ratio (16:1) which indicates that phosphorus is the limiting nutrient in the Millstone River (Redfield 1958).

3.1.5 Quality Control and Quality Assurance

Industry standard procedures around quality control and quality assurance were practiced throughout the collection, transportation, and testing of the water quality samples. The procedures followed were taken from the Streamkeepers Handbook: A Practical Guide to Stream and Wetland Care (Taccogna and Munro 1995) and the Guidelines for Interpreting Water Quality Data (Cavanagh et al. 1998). A key component of the surveys that are completed by the RMOT 306 students each year is in the design of the surveys so that they can be duplicated each year. This allows for a large range of monitoring data to be complied over time. During the completion of this year’s survey, it was important to uphold this standard and to continue to design the survey with the same repeatability as before. Some site location changes were made for the purposes of safety and practicality, but these changes were well documented, and it should be easy for future surveyors to duplicate the work completed in 2023.

When collecting samples for water quality analysis a field blank was brought along for the duration of all transport. These field blanks consisted of distilled water and were tested alongside the site samples at the Vancouver Island University campus laboratory. It should be noted that the field blank from the October 24th collection date was provided by the university and the field blank from the November 20th collection date was acquired by the surveyors. This is worth noting because there were significant differences in the water quality measurements results of the field blanks. The October 24th field blank contained levels of nitrate and phosphate and also showed levels of alkalinity (Table 4). The November 20th field blank showed some levels of conductivity, nitrate, hardness, and alkalinity (Table 5). These levels observed are very low, but they do suggest that there was some level of contamination throughout the process. Once in the field, the field blanks were not opened so it is unlikely that any influence came from transport. Adequate rinsing of all testing equipment between samples was also practiced; however, the testing of field blanks was always completed after the testing of the rest of the samples. It is possible that contamination occurred during collection, transportation, or testing but it is likely that it occurred as either a result of contaminated collection bottles or insufficiently rinsed testing equipment. It may be wise for future RMOT 306 surveyors to use increased attention when testing phosphate levels in order to acquire more accurate determinations.

The possibility of error in the water quality testing portion of the survey is one of the reasons why samples were taken on multiple days and why samples were also sent to a commercial laboratory for professional testing. Because of the comparable levels observed between the VIU analysis and the ALS analysis it is unlikely that any significant errors occurred, aside from those associated with the phosphate testing. The results obtained by both analyses should be considered when determining the health of the Millstone River. The equipment used by the ALS laboratory is more sophisticated than what is available for the VIU analysis, but the ALS results are limited to sites 3 and 5 of the Millstone River. By comparing the results of the two analyses and finding them to have little variation, we can consider the results of the VIU analysis with confidence and use them to gain a better understanding of the health of the Millstone River over its entire length.

3.2 Hydrology (Kevin)

Basic hydrology was looked at and recorded on site visits. This included wetted width, mean wetted depth, bankfull width, and mean bankfull depth. Slope and velocity were also recorded at each visit as well as velocity so that discharge could be calculated (Table 9). October had a high rainfall amount when compared to the last 5 years with a total of 185.8mm of rainfall. This is especially high when compared to 2022 where they had a total of 42.2mm. As for November there was 121.6mm for the month, this is comparable to previous years exempting 2022 and a low rainfall in 2019. With this data we can conclude that October was a higher flow month and November is relatively average.

Table 9. Chart of Millstone Creek Site numbers with associated Gradient (% Slope), Velocity m^3/s and the difference in Velocity.

Site #	Gradient (slope)	Velocity (m/s)		Difference in Velocity	Average site Discharge (m^3/s)
		October Sample	November Sample		
1	2%	1.267	1.334	0.067	1.931535
2	1%	1.063	0.807	(-)0.256	3.620203
3	3%	1.689	1.712	0.023	3.217771
4	1%	0.831	1.289	0.458	3.616853
5	2%	0.444	0.769	0.325	3.104522

When measuring the site for the October 31, 2023 visit, the last rainfall was observed on the 24th with 60mm recorded. On the flow chart (Figure 12), it is observed that the two site measurements were both recorded just after rain events with measurements being on the tail end of high flows. Though the water level was slightly higher on the second visit, it was also recorded that velocity was slightly higher except for site 2 which is the first site off Brannen Lake (Figure 13). Table 10 lays out the recorded measurements of the stream during this "low" site visit, while Table 11 Shows the "high". Site 1 is a shallow stream site as demonstrated by the wider wetted width but losing some of the mean depth. Site 3 also tapered off with water level rising but did not affect mean depth as much as site 1. The rest of the sites are relatively similar in width with an increase in mean depth. It is also important to note that site 2 is the first site after Brannen Lake with no other tributaries affecting its flow, so after rain events it is expected to be more consistent to the lake level and outflow.

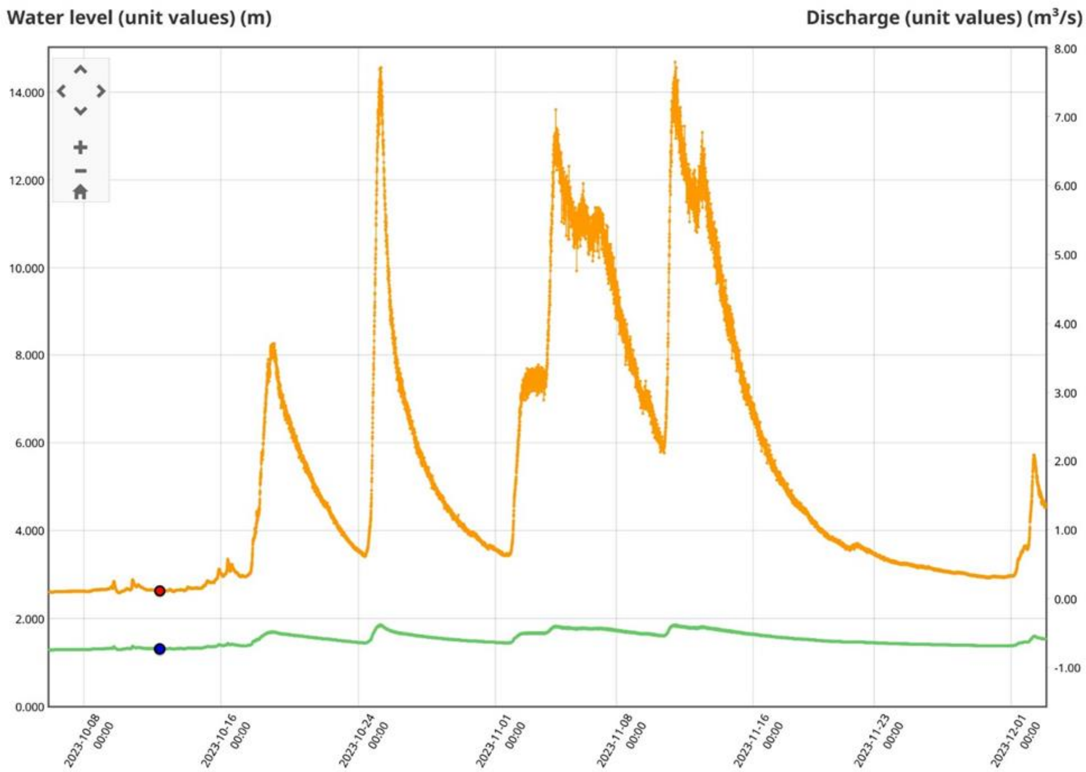

Figure 12. Millstone River Water level in meters and Flow Discharge in m³/s between October 10, 2023, and December 1, 2023.

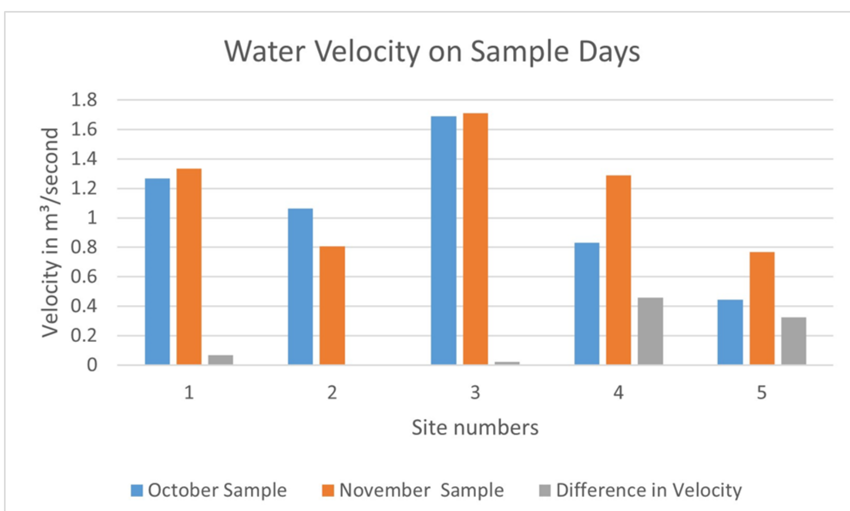

Figure 13. Millstone River Water Velocity (m³/2) site comparison between sites and sample periods of October 31, 2023 and November 21, 2023.

Table 10. Stream measurements of the Millstone River for October 31, 2023 “Low” flow with associated measurements of Wetted Width, Mean Wetted Depth, Bankfull Width and Mean Bankfull depth in meters.

Site #	**Wetted Width (m)**	**Mean Wetted Depth (m)**	**Bankfull Width (m)**	**Mean Bankfull Depth (m)**
1	6.90	0.287	12.12	0.827
2	8.75	0.590	15.60	0.847
3	8.70	0.290	15.00	0.567
4	13.5	0.337	14.00	0.570
5	10.5	0.650	10.85	0.800

Table 11. Stream measurements of the Millstone River for November 21, 2023 “High” flow with associated measurements of Wetted Width, Mean Wetted Depth, Bankfull Width and Mean Bankfull depth in meters.

Site #	**Wetted Width (m)**	**Mean Wetted Depth (m)**	**Bankfull Width (m)**	**Mean Bankfull Depth (m)**
1	8.15	0.183	12.12	0.827
2	8.80	0.600	15.60	0.847
3	10.6	0.377	15.00	0.567
4	13.7	0.417	14.00	0.570
5	10.8	0.75	10.85	0.800

3.3 Aquatic Macroinvertebrates (Kevin)

Previous years had sampled sites 1, 2 and 4 with the lowest number of invertebrates being seen at site 1. Since site 1 is a stream flowing into Brannen Lake and had the lowest counts, this site was omitted from this year's testing sites. Site 2 was chosen to be the first site to sample as it would show the stream health before any inputs from the other tributaries flowed into the river. Site 3 was chosen as the next site as it had the largest amount of agriculture influence nearby. Lastly, site 5 was chosen to be able to take the full impact of Bowen Park and was the last site before it flowed into the ocean. With these sites, we believe that we were able to get a strong representation of the stream and its health.

Using the Hess sampler, invertebrates were collected at site 2, site 3 and site 5. They were collected a total of three times per site on both sampling days. With this method we were able to compare the streams to each other on different sampling days and flow events. Though the flows were similar on both sampling days, October 31st, and November 21st, it is important to note that the fist sampling method had very little EPT taxa (caddisfly, mayfly and stonefly) when compared to the second sites. With no other data indicating any significant change, it is assumed that the second sampling time had a better hatch period that was collected. These samples yielded a total of 572 individuals, and 50 taxa with amphipods and aquatic worms making up over 60% of the invertebrates (Figure 14). Overall, the Millstone River scored a “Marginal” site assessment rating and had an overall Shannon-Weiner score of 1.55 which scores poorly.

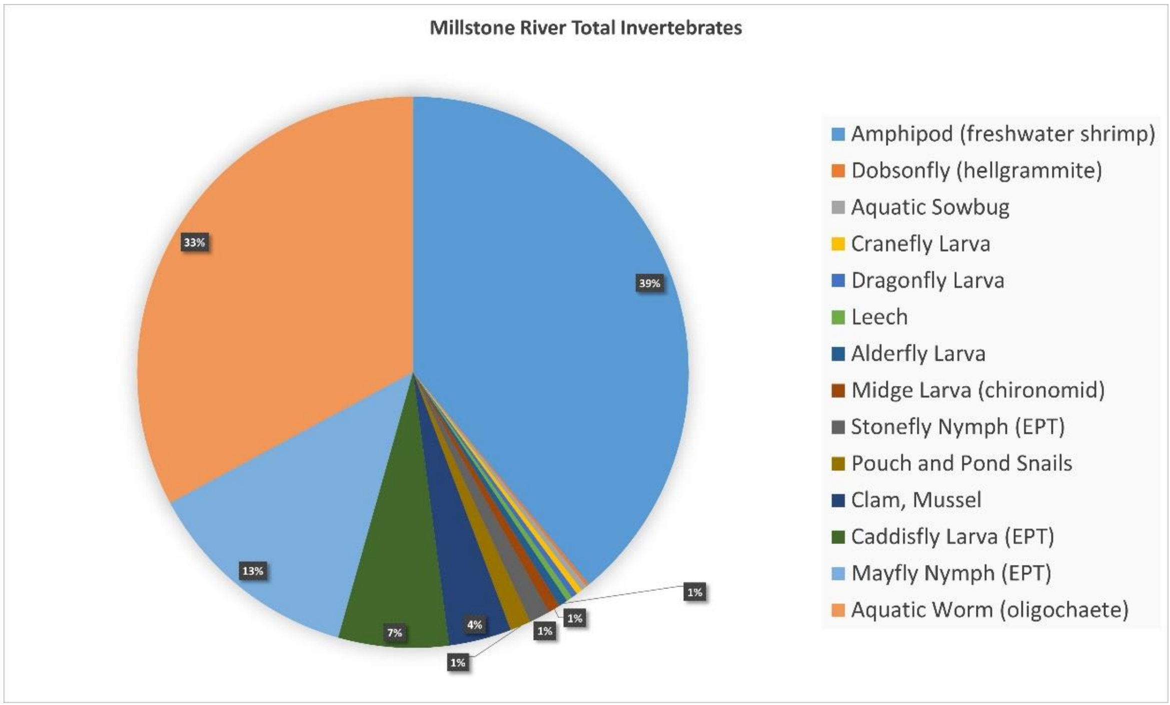

Figure 14. Millstone River Total Invertebrates of the collected 572 individuals.

Site 2's sampling period resulted in a total of 167 invertebrates collected with 16 taxa which gave us a density of 618/m². The "low" flow sampling period had an abundance of aquatic worms and amphipods, making up 89% of the total invertebrate population (Figure 15). The first sample also yielded no pollution intolerant species while it was divided almost evenly between the tolerant and somewhat tolerant species. While the "high" sampling period yielded a higher amphipod population, though there were more of the pollution intolerant species present, such as caddisfly and mayfly. A comparison of the two samples can be seen on Figure 3 with the relative species and the percentage they make up. The Shannon-Weiner index for this site was scored at a 1.22 which is relatively low. (Table 12).

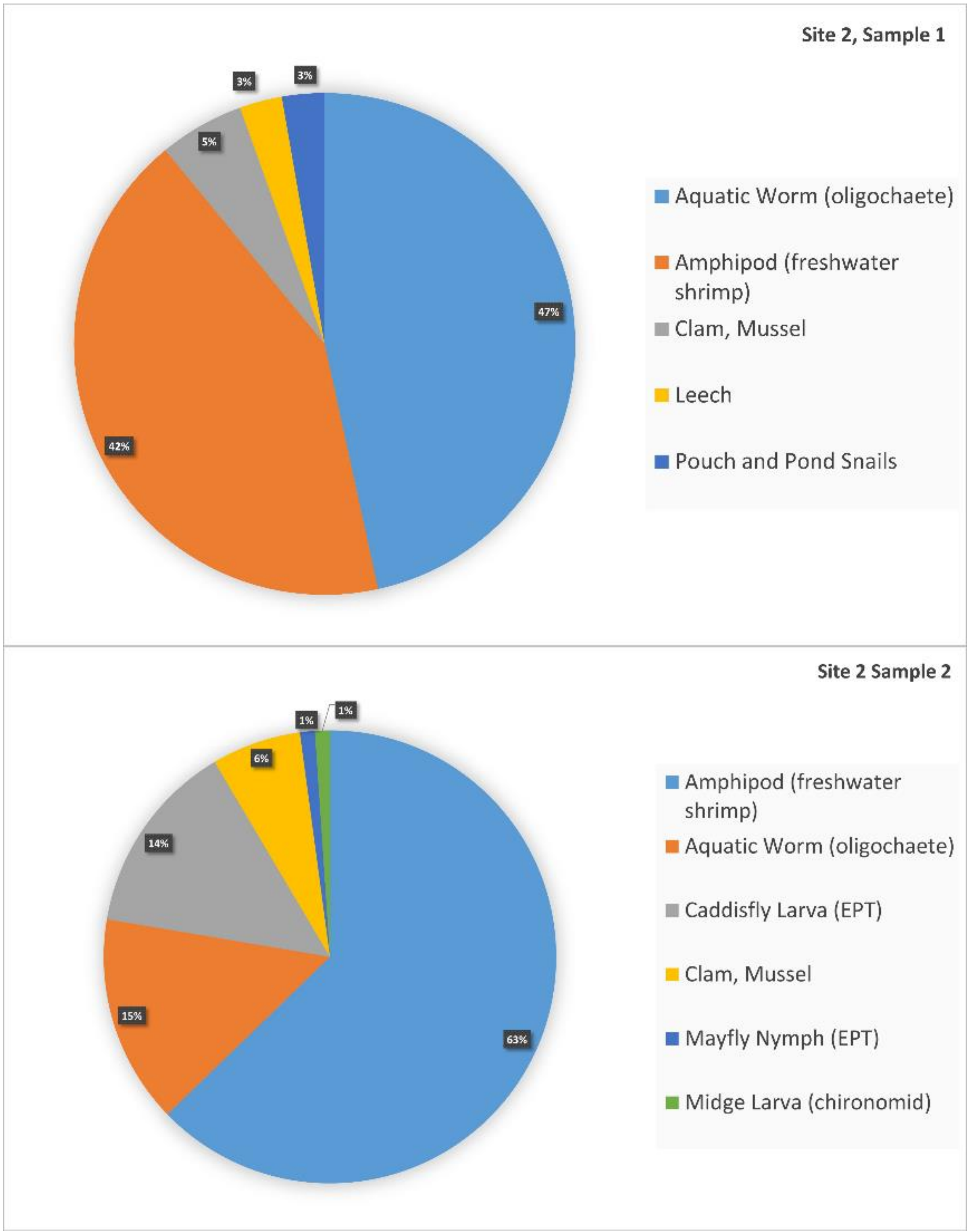

Figure 15. Millstone River Site 2 invertebrate population charts with sample 1 (low) and sample 2 (high).

Table 12. Millstone River Site 2 total invertebrate count and Shannon-Weiner index calculations.

Species Common Name	Site 2				Shannon-Weiner Index		
	Sample 1		Sample 2				
	Counted	Taxa	Counted	Taxa	pi	ln*Pi	Pi(ln*Pi)
Caddisfly Larva (EPT)	0	0	13	2	0.077844311	-2.553044455	-0.198739988
Mayfly Nymph (EPT)	0	0	1	1	0.005988024	-5.117993812	-0.03064667
Sum Category 1	0	0	14	3			
Clam, Mussel	4	1	6	2	0.05988024	-2.815408719	-0.168587348
Amphipod (freshwater shrimp)	31	1	59	4	0.538922156	-0.618184142	-0.33315313
Sum Category 2	35	2	65	6			
Aquatic Worm (oligochaete)	34	1	14	1	0.28742515	-1.246792802	-0.358359608
Leech	2	1	0	0	0.011976048	-4.424846632	-0.052992175
Midge Larva (chironomid)	0	0	1	1	0.005988024	-5.117993812	-0.03064667
Pouch and Pond Snails	2	1	0	0	0.011976048	-4.424846632	-0.052992175
Sum Category 3	38	3	15	2			
Total	73	5	94	11		Total	1.226117764

Site 3 resulted in a total of 238 invertebrates collected and 17 taxa total with a density of 881/m². It also replicated the same results as site 2 with the "low" sample period resulting in 51% amphipods and 36% aquatic worms (Figure 16). Although this sample period also yielded some pollution intolerant species, it was still very low. The "high" flow rating was mostly dominated by aquatic worms at 53% but it also had a strong percentage of mayflies at 36% shown in Figure 15. The overall Shannon-Weiner index score for this site was 1.32 totaled, which is only slightly better than site 2 but still poor (Table 13).

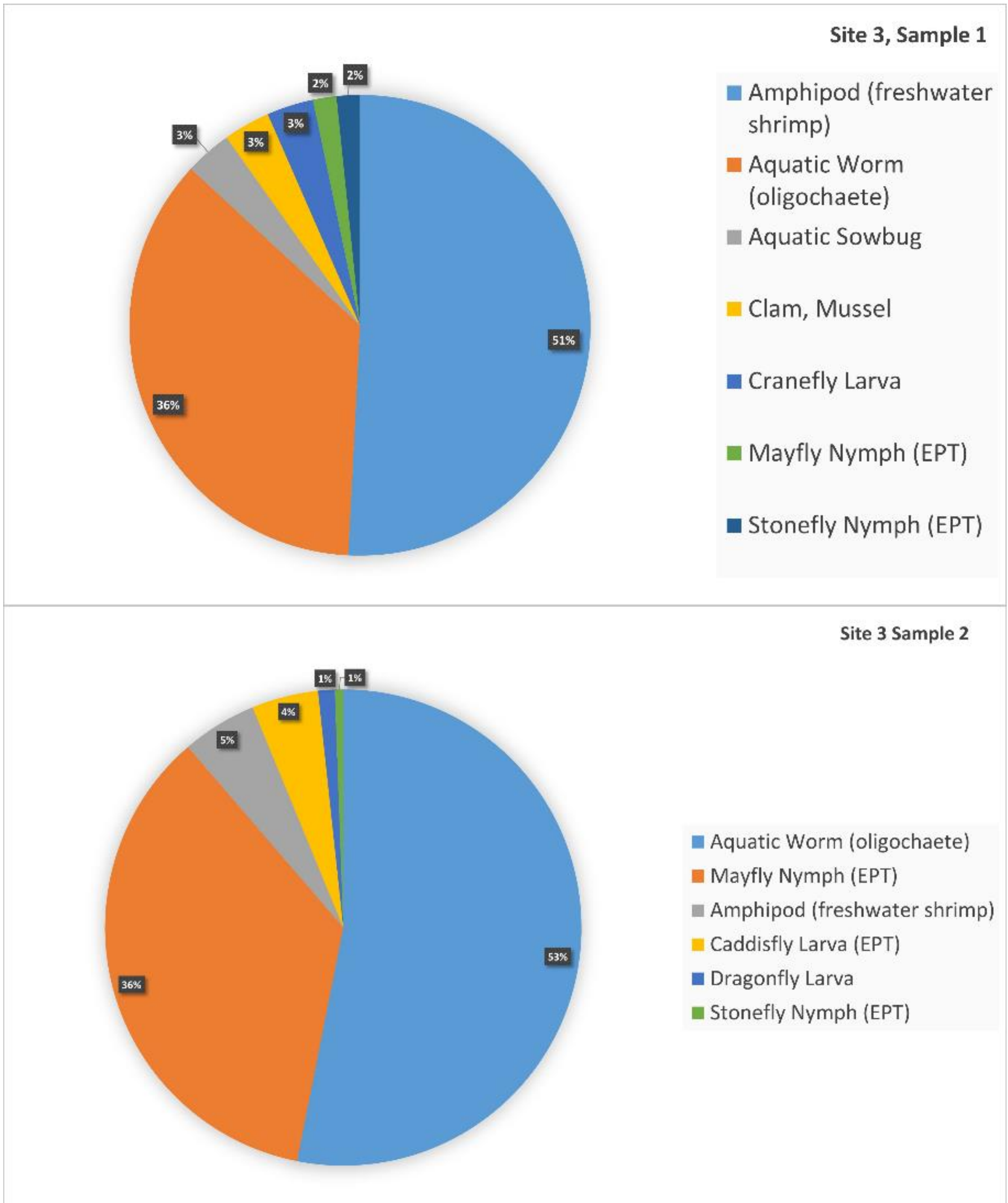

Figure 16. Millstone River Site 3 invertebrate population charts with sample 1 (low) and sample 2 (high)

Table 13. Millstone River Site 3 total invertebrate count and Shannon-Weiner index calculations.

Species Common Name	Site 3				Shannon-Weiner Index		
	Sample 1		Sample 2				
	Counted	Taxa	Counted	Taxa	pi	ln*Pi	Pi(ln*Pi)
Caddisfly Larva (EPT)	0	0	8	1	0.033613445	-3.392829132	-0.114044677
Mayfly Nymph (EPT)	1	1	63	2	0.268907563	-1.31338759	-0.353179856
Stonefly Nymph (EPT)	1	1	1	0	0.008403361	-4.779123493	-0.040160702
Sum Category 1	2	2	72	3			
Aquatic Sowbug	2	1	0	0	0.008403361	-4.779123493	-0.040160702
Clam, Mussel	2	1	0	0	0.008403361	-4.779123493	-0.040160702
Cranefly Larva	2	2	0	0	0.008403361	-4.779123493	-0.040160702
Dragonfly Larva	0	0	2	1	0.008403361	-4.779123493	-0.040160702
Amphipod (freshwater shrimp)	31	1	9	1	0.168067227	-1.78339122	-0.299729617
Sum Category 2	37	5	11	2			
Aquatic Worm (oligochaete)	22	3	94	2	0.487394958	-0.718680483	-0.350281244
Sum Category 3	22	3	94	2			
Total	61	10	177	7		Total	1.318038901

Site 5 yielded 167 invertebrates with 17 taxa present and a density of 618/m². The "low" sampling period duplicated the same result as the other sites with high amphipods and aquatic worms, although it did produce some clams. The "high" sampling period was largely dominated by amphipods at 60% with only 14% caddisfly and 12% aquatic worms (Figure 17). Total Shannon-Weiner index score for this site was 1.52 which was the highest of all the sites, however still rated poor (Table 14).

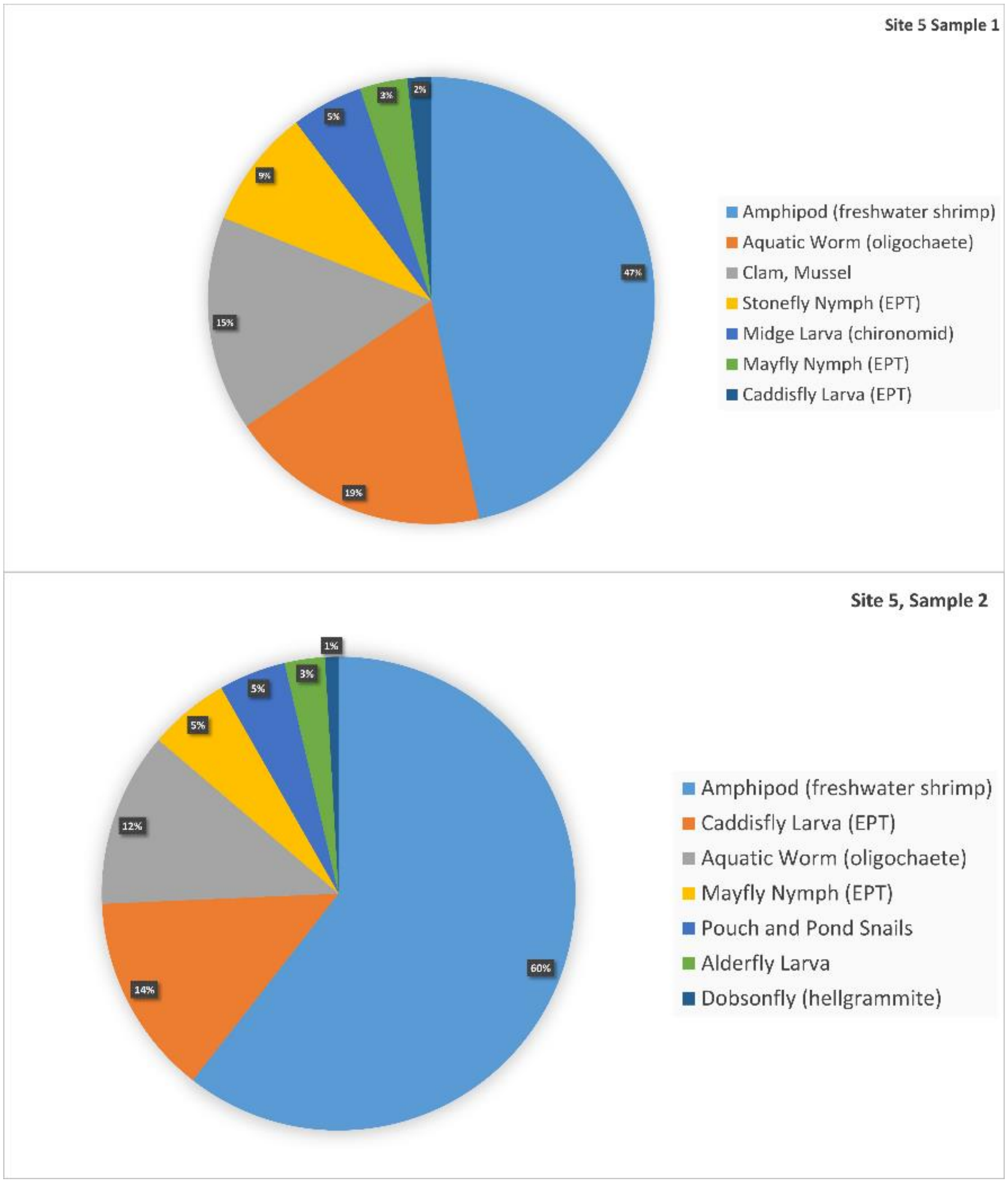

Figure 17. Millstone River Site 5 invertebrate population charts with sample 1 (low) and sample 2 (high).

Table 13. Millstone River Site 3 total invertebrate count and Shannon-Weiner index calculations.

Species Common Name	Site 5				Shannon-Weiner Index		
	Sample 1		Sample 2				
	Counted	Taxa	Counted	Taxa	pi	ln*Pi	Pi(ln*Pi)
Caddisfly Larva (EPT)	1	1	15	1	0.095808383	-2.34540509	-0.22470947
Mayfly Nymph (EPT)	2	1	6	1	0.047904192	-3.038552271	-0.14555939
Stonefly Nymph (EPT)	5	2	0	0	0.02994012	-3.5085559	-0.105046584
Dobsonfly (hellgrammite)	0	0	1	1	0.005988024	-5.117993812	-0.03064667
Sum Category 1	8	4	22	3			
Alderfly Larva	0	0	3	1	0.017964072	-4.019381524	-0.072204459
Clam, Mussel	9	1	0	0	0.053892216	-2.920769235	-0.157406725
Amphipod (freshwater shrimp)	27	2	66	1	0.556886228	-0.585394319	-0.325998034
Sum Category 2	36	3	69	2			
Aquatic Worm (oligochaete)	11	1	13	1	0.143712575	-1.939939982	-0.27879377
Midge Larva (chironomid)	3	2	0	0	0.017964072	-4.019381524	-0.072204459
Pouch and Pond Snails	0	0	5	1	0.02994012	-3.5085559	-0.105046584
Sum Category 3	14	3	18	2			
Total	58	10	109	7		Total	1.517616143

4.0 Conclusion & Recommendations (Erik)

As a result of this study the Millstone River was found to be in fair condition. Water quality and hydrological aspects were found to be within acceptable condition with the exception of a few parameters. The most significant concern was from the invertebrate analysis which was found to be poor to marginal at best when scored on the Shannon-Weir Index. Dissolved oxygen in sites 2 and 3 was also deemed to be slightly below acceptable levels and may pose some concern if sustained.

Several recommendations are proposed to improve the quality of the Millstone Rivers habitat. The most significant concern regards the Millstone Rivers riparian areas. Restoration to improve these areas in urban and agricultural zones would help to provide the necessary shade, stability and organic matter to aid the invertebrate population. Other initiatives that could be undertaken include further land acquisitions within the watershed and surrounding areas as well as the monitoring of Benson Creek which is the Millstones largest tributary and exhibits significant influence on the watershed.

We recommend the continuation of the annual study on the Millstone River by Vancouver Island University Bachelor of Natural Resource Protection students as we believe that it will continue to provide valuable management data in the coming years as the City of Nanaimo, Regional District of Nanaimo, and the surrounding areas continues to grow.

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5.0 Appendix Index (Erik)

5.1 Photos

Site Number 1, Low Flow

Site Number 2, Low Flow

Site Number 3, Low Flow

Site Number 4, Low Flow

Site Number 5, Low Flow

Site Number 1, High Flow

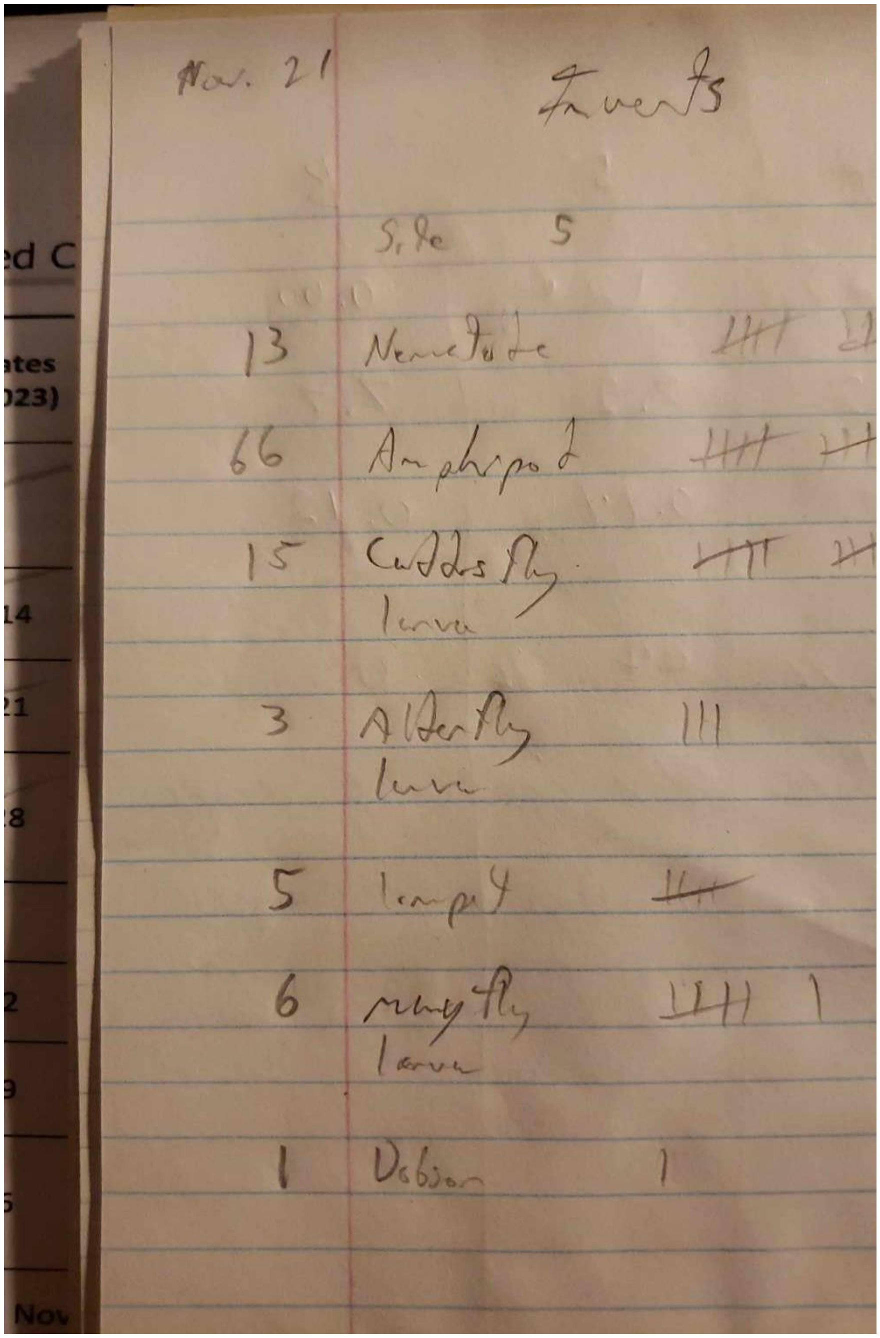
Site Number 2, High Flow

Site Number 3, High Flow

Site Number 4, High Flow

Site Number 5, High Flow

5.2 Field Notes & Lab Data



Nov. 21

Inverts

Site 5

13	Nematode
66	Amphipod
15	Caddis fly larva
3	Alderfly larva
5	limpet
6	mayfly larva
1	Dobson

Oct , 2023
Site 5 9:10
Aaron (Emile, Kevin)

Site 5 access beside bridge. 2 access points, one on each side of bridge.
A: Long grass, black berry, steep slope, & dead overhead branches off off maple tree.

B: Signs of unhoused people presence, garbage, broken glass. Steep slope.

Stream safety: algae, slow water

Wildlife: GB Heron

Site 4 9:48

Site 4 access beside large alder tree near the sandbars & duck pond. Steady moving, shallow water

Site 3 10:25

Site 3 access directly beside bridge pool on one side of bridge, riffle on

48

Rite in the Rain

the other. Close proximity to the road, traffic is largest hazard. Site is next to private property.

Site 2 1105

Access along bridge, must climb down along corner of bridge. Downed barb wire fence, slippery rocks, low overhead branches, steel rods in ground near stream bank.

Site 1 11:14

Access beside bridge. Driveway with gate, follow fence down through black berries to ripple in stream. Some overhead trees, mostly healthy. Lots of black berries to move through.

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Oct 28, 2023
Millstone River
Team: AG, BD, KP, PV
Weather: Rain, 6°C

9:45: Arrive at Site 5
High flow
Took water quality samples
at mid stream, up stream
of cascade failure

10:10 Depart
10:20 Add Nitric Acid to sample from
Site 5 (ALS)

10:35 Arrive at Site 4 to collect
VIU water sample

10:50 Depart Site 4

11:00 Arrived at site 3
11:05 Samples taken for VIU &
ALS
11:10 Depart Site

Rite in the Rain

11:20	Arrived at site 2
	NO sample taken
11:30	Depart site
11:35	Arrive at site 1
11:40	Sample taken
11:50	Depart site 1

Oct 26, 2023
Millstone River
Team: AJ, KP, ED
Weather: Sun, 8°C,

10:30	Arrive at site 1			
	RB			LB
WW	6.90 m			
WD	40 cm		23cm	23 cm
BFW	12.12 m			
BFD	91 cm		89 cm	68 cm
Flow	7.81 s	over	10 m	
	7.47			
	8.38			~ 7.84
Gradient:	-2%	-4		
	L	R		
11.10	Depart			
11:15	Arrive at		site 2	
WW	8.75 m			
WD	66 cm		79 cm	32 cm
BFW	15.6m			
BFD	80 cm		116 cm	72

Flow		9.49 s	over	10 m	
		8.42 s	over	10 m	
		9.83	over	10 m	~9.41
Gradient		1.0		1.5	
		L		R	

Oct 31st, 2023
Millstone River
Team: ED, PV, KP, AJ
Time: 08:30
Weather: Clear, 1°C
Arrive at ~~state~~ site 5 to take measurements and collect ~~a~~ mussel sample.

	RB			LB
WW	10.5m			
WD	70cm	63cm		62cm
BFW	10.85m			
BFD	105cm	90cm		105cm
	70cm	63cm		62cm
Flow	23.83	over	10m	
	23.29			
	20.50			
				~22.54

		R		L	
Gradient		-3		-1.8	
GBH	seen	at	site 5	at	09:15
Departed	site	at	09:30		
09.45	Arrive	at	site 4	to	
	take	stream	measurements		
	RB				LB
WW	13.5 m				
WD	47		39		15 cm
BFW	14				
BFD	54		67		50
Flow	11.83				
	13.39				
	10.87			~	12.03
		R		L	
Gradient		1		0.5	
Departed	site	at	10:15		

10:30 Arrive at Site 3 to take
measurements and take invert samples.

	RB		LB
WW	8.7 m		
WD	2 cm	35	50
BFW	15		
BFD	33 cm	42	95 cm

Flow 5.78 over 10 m
5.47
6.02 ~ 5.92

	R	L
Gradient	-2	-4

11:05 Depart Site 3
11:20 Arrive at site 2 to take
three invert samples

Dead frog observed under the
bridge at site 2

Nov 20th, 2023
Millstone River
Team : AJ ED
Weather : Sun / cloud, 8°C

14:05 : Arrive at site 5 to take VIU & ALS water samples
14:20 : Depart site 5
14:25 Arrive at site 4 to take samples
14:30 Depart site 4
14:35 Arrive at site 3 to take samples
14:50 Depart site 3
15:00 Arrive at site 2 to take samples
15:05 Depart site 2
15:10 Arrive at site 1 to take samples
15:15 Depart site 1
15:25 Arrive at VIU to drop of ALS samples to Phillip Morrison.
16:00 Depart VIU.

40

Nov 21, 2023
Aaron, Emily, Kevin
Weather: overcast, calm

09:45 : Arrive at site 5 to conduct Hess sampling

10:15 : Depart site 5

10:30 : Arrive at site 3 to conduct Hess sampling. Sampling done under the bridge due to fast current & stream depth.

Site 3 bank comp:
Alder, Maple, H. Black Berry, Daphne, english holly, grasses & other shrubs.

10:45 : Depart site 3

10:55 : Arrive at site 2 to conduct Hess sampling.

Site 2 bank comp.
Alder, Snow Berry, Rose, H. BB, grasses, shrubs

38

11:30 Depart site 2

Nov 28, 2023
Weather: Cloudy, 3°C, calm

10:43 Arrive at site 1 to take DO measurements and habitat observations

DO	11.3 mg/L		6.8°C
Substrate	70%	cobble	
	20%	gravel	
	10%	fines	
Canopy	80%		
In stream	10%		

Himalayan BB, Red alder, salmon berry, snow berry, maple, red cedar

10:55 Depart
11:00 Arrive at site 2

DO	8.3 mg/L		7.3°C

11:05 Depart

11:20 Arrive at site 3

DO 10.8 mg/L 7.3 °C

11:25 Depart

11:35 Arrive at Site 4

Substrate

Fines 5
Gravel 15
Cobble 60
Boulder 20%

Canopy 70%
In stream 20%

Salmon B., Cedar, maple, sword fern,
snow berry, English ivy, Salal

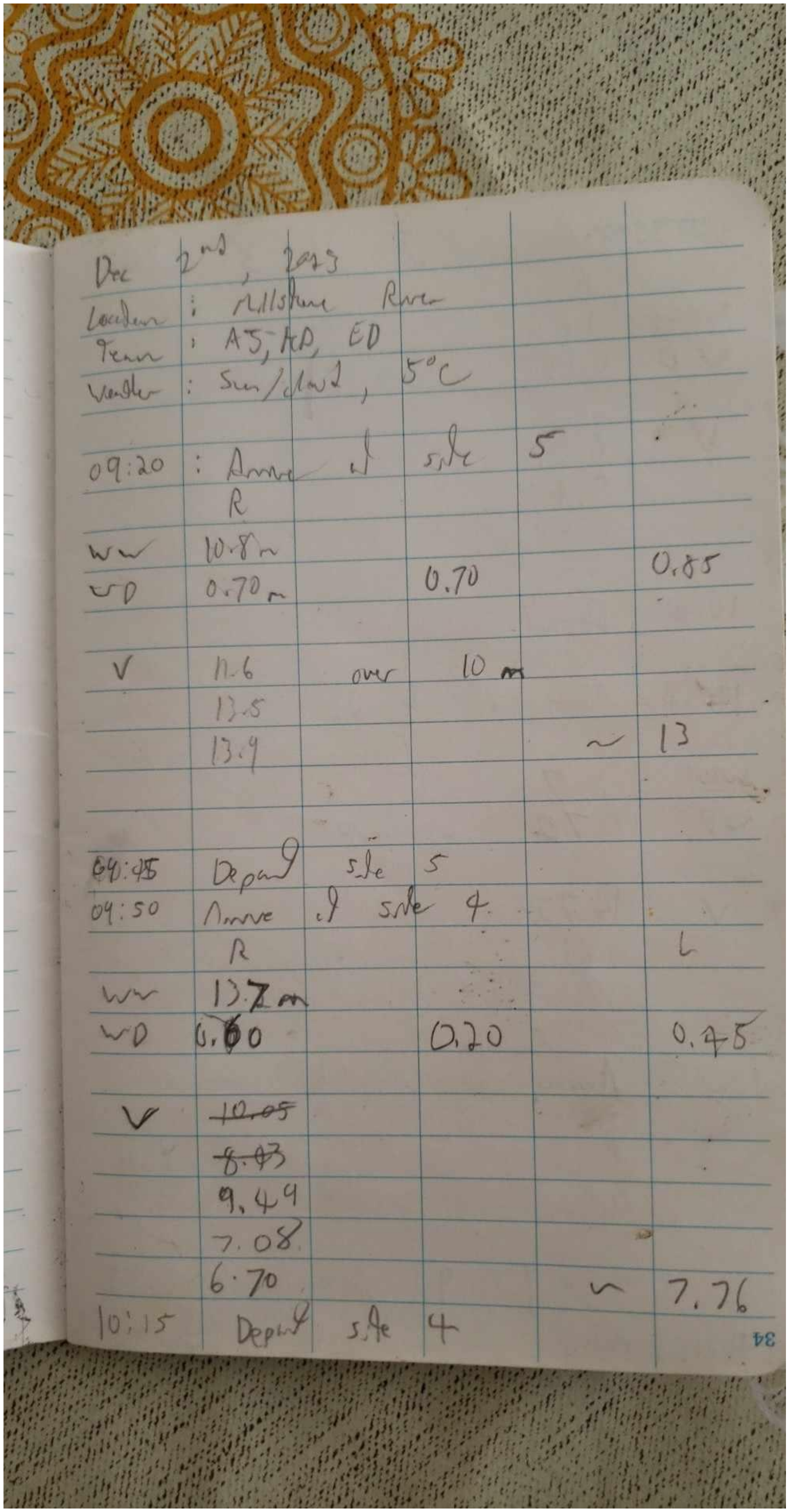
DO 12.0 mg/L 6.5 °C

11:45 Depart

11:50 Arrive at Site 5

Rite in the Rain

DO		12.4 mg/L		6.4°C	
12:00	Depart				



Dec	2nd, 2023				
Location	: Millstone River				
Team	: AJ, AD, ED				
Weather	: Sun/cloud,	5°C			
09:20	: Arrive at	site	5		
	R				
WW	10.8 m				
WD	0.70 m		0.70		0.85
V	11.6	over	10 m		
	13.5				
	13.9			~	13
09:45	Depart	site	5		
09:50	Arrive at	site	4		
	R				L
WW	13.7 m				
WD	0.60		0.20		0.45
V	~~10.05~~				
	~~8.03~~				
	9.49				
	7.08				
	6.70			~	7.76
10:15	Depart	site	4		

10:30	Arrive	at	site	3	
	R				L
WW	10.6				
WD	0.13		0.50		0.50
V	6.71				
	5.47				
	5.35			~	5.84
10:40	Depart				
10:50	Arrive	at	site 2		
	R				L
WW	8.8				
WD	0.70		0.80		0.30
V	14.72				
	8.78				
	13.86			~	12.39
10:55	Arrive	at	site 1		
	R				L
WW	8.15				
WD	0.02		0.10		0.43
V	7.29	7.59	7.61		~7.497
33 11:10	Depart	site 1			

Site 5	
Habitat Unit Type	Glide
Canopy Cover (%)	30
Instream Cover (%)	
Large Woody Debris	10
Small Woody Debris	0
Boulders	0
Instream Vegetation	30
Over stream Vegetation	20
Deep Pools	0
Undercut Banks	0
Substrate Composition (%)	
Fines	20
Gravel	30
Cobble	40
Boulders	0
Bedrock	10

Site 4	
Habitat Unit Type	Riffle
Canopy Cover (%)	70
Instream Cover (%)	
Large Woody Debris	5
Small Woody Debris	0
Boulders	0
Instream Vegetation	5
Over stream Vegetation	5
Deep Pools	0
Undercut Banks	5
Substrate Composition (%)	
Fines	5
Gravel	15
Cobble	60
Boulders	20
Bedrock	0

Site 3	
Habitat Unit Type	Riffle
Canopy Cover (%)	40
Instream Cover (%)	
Large Woody Debris	5
Small Woody Debris	0
Boulders	0
Instream Vegetation	40
Over stream Vegetation	5
Deep Pools	0
Undercut Banks	0
Substrate Composition (%)	
Fines	10
Gravel	10
Cobble	70
Boulders	10
Bedrock	0

Site 2	
Habitat Unit Type	Glide
Canopy Cover (%)	10
Instream Cover (%)	
Large Woody Debris	0
Small Woody Debris	0
Boulders	0
Instream Vegetation	5
Over stream Vegetation	0
Deep Pools	0
Undercut Banks	5
Substrate Composition (%)	
Fines	10
Gravel	20
Cobble	70
Boulders	0
Bedrock	0

Site 1	
Habitat Unit Type	Glide
Canopy Cover (%)	2.5
Instream Cover (%)	
Large Woody Debris	0
Small Woody Debris	0
Boulders	0
Instream Vegetation	0
Over stream Vegetation	2.5
Deep Pools	0
Undercut Banks	7.5
Substrate Composition (%)	
Fines	20
Gravel	0
Cobble	70
Boulders	10
Bedrock	0

Results Summary VA23C5578

Project	
Report To	Phillip Morrison, Vancouver Island University
Date Received	25-Oct-2023 08:30
Issue Date	06-Nov-2023 08:10
Amendment	0

Client Sample ID			Millstone River Site 3	Millstone River Site 5
Date Sampled			24-Oct-2023	24-Oct-2023
Time Sampled			11:05	10:10
ALS Sample ID			VA23C5578-001	VA23C5578-002
Analyte	Lowest Detection Limit	Units	Sub-Matrix: Water	Sub-Matrix: Water
Physical Tests (Matrix: Water)				
Conductivity	2.0	µS/cm	110	130
Hardness (as CaCO3), from total Ca/Mg	0.50	mg/L	38.0	42.6
pH	0.10	pH units	7.33	7.53
Anions and Nutrients (Matrix: Water)				
Ammonia, total (as N)	0.0050	mg/L	0.0064	0.0229
Nitrate (as N)	0.0050	mg/L	0.106	0.164
Nitrite (as N)	0.0010	mg/L	0.0012	0.0030
Nitrogen, total	0.030	mg/L	0.298	0.423
Phosphate, ortho-, dissolved (as P)	0.0010	mg/L	<0.0010	<0.0010
Phosphorus, total	0.0020	mg/L	0.0124	0.0209
Total Metals (Matrix: Water)				
Aluminum, total	0.0030	mg/L	0.0541	0.207
Antimony, total	0.00010	mg/L	<0.00010	<0.00010
Arsenic, total	0.00010	mg/L	0.00056	0.00037
Barium, total	0.00010	mg/L	0.00773	0.0127
Beryllium, total	0.000020	mg/L	<0.000020	<0.000020
Bismuth, total	0.000050	mg/L	<0.000050	<0.000050
Boron, total	0.010	mg/L	0.028	0.039
Cadmium, total	0.0000050	mg/L	<0.0000050	<0.0000050

Calcium, total	0.050	mg/L	10.4	11.8
Cesium, total	0.000010	mg/L	<0.000010	0.000012
Chromium, total	0.00050	mg/L	<0.00050	0.00052
Cobalt, total	0.00010	mg/L	<0.00010	0.00016
Copper, total	0.00050	mg/L	0.00104	0.00183
Iron, total	0.010	mg/L	0.150	0.409
Lead, total	0.000050	mg/L	<0.000050	0.000389
Lithium, total	0.0010	mg/L	<0.0010	<0.0010
Magnesium, total	0.0050	mg/L	2.92	3.19
Manganese, total	0.00010	mg/L	0.0152	0.0300
Molybdenum, total	0.000050	mg/L	<0.000050	0.000127
Nickel, total	0.00050	mg/L	<0.00050	0.00056
Phosphorus, total	0.050	mg/L	<0.050	<0.050
Potassium, total	0.050	mg/L	0.357	0.468
Rubidium, total	0.00020	mg/L	0.00041	0.00056
Selenium, total	0.000050	mg/L	<0.000050	0.000067
Silicon, total	0.10	mg/L	3.20	3.51
Silver, total	0.000010	mg/L	<0.000010	<0.000010
Sodium, total	0.050	mg/L	6.50	9.04
Strontium, total	0.00020	mg/L	0.0868	0.0898
Sulfur, total	0.50	mg/L	2.30	2.51
Tellurium, total	0.00020	mg/L	<0.00020	<0.00020
Thallium, total	0.000010	mg/L	<0.000010	<0.000010
Thorium, total	0.00010	mg/L	<0.00010	<0.00010
Tin, total	0.00010	mg/L	<0.00010	<0.00010
Titanium, total	0.00030	mg/L	0.00256	0.0108
Tungsten, total	0.00010	mg/L	<0.00010	<0.00010
Uranium, total	0.000010	mg/L	<0.000010	<0.000010
Vanadium, total	0.00050	mg/L	0.00051	0.00117
Zinc, total	0.0030	mg/L	<0.0030	0.0034
Zirconium, total	0.00020	mg/L	<0.00020	<0.00020

Results Summary VA23C8156

Project

Report To Phillip Morrison, Vancouver Island University

Date Received 22-Nov-2023 08:30

Issue Date 29-Nov-2023 14:16

Amendment 0

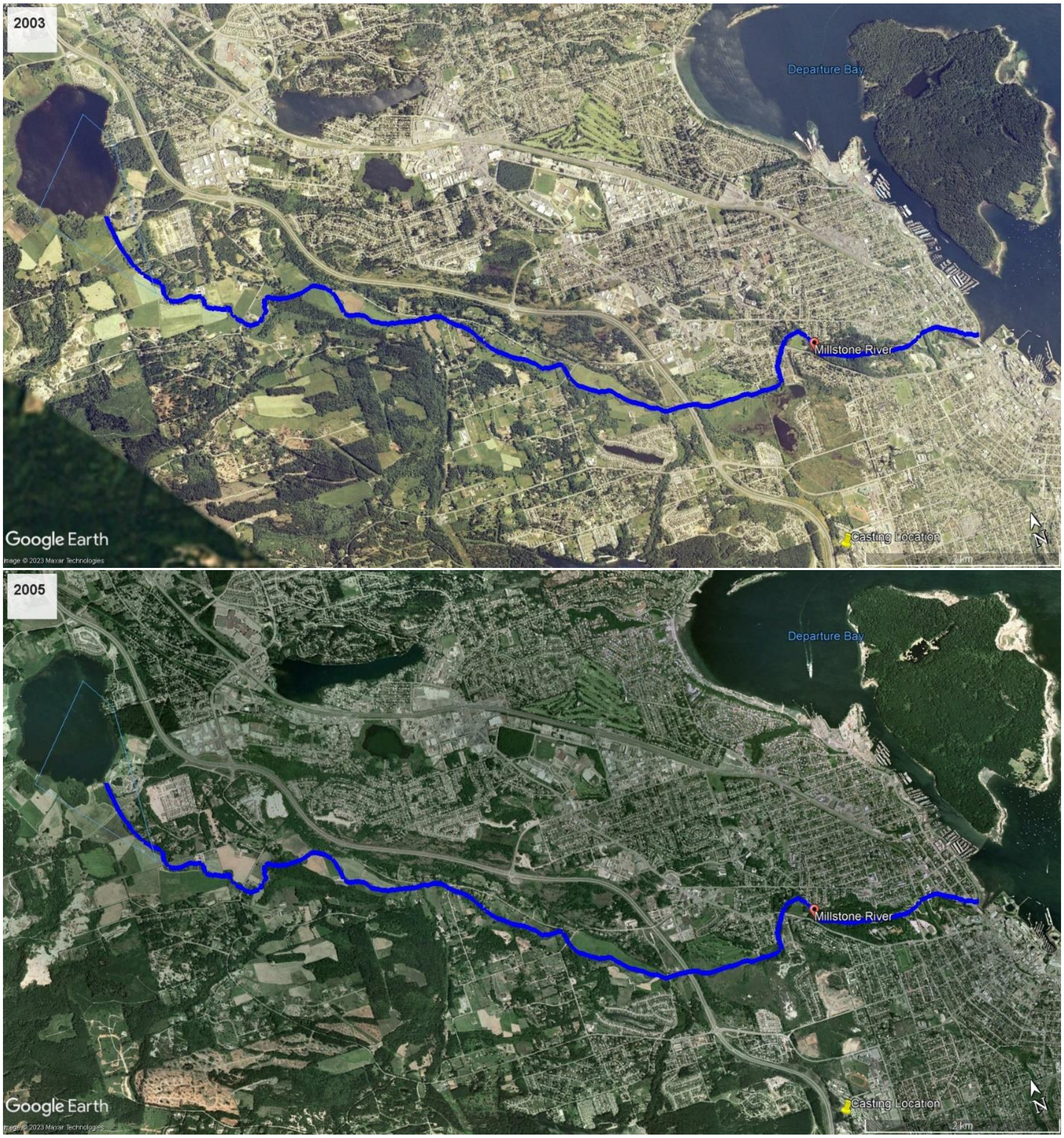
Client Sample ID			Millstone Site 3	Millstone Site 5
Date Sampled			20-Nov-2023	20-Nov-2023
Time Sampled			14:40	14:15
ALS Sample ID			VA23C8156-003	VA23C8156-004
Analyte	Lowest Detection Limit	Units	Sub-Matrix: Water	Sub-Matrix: Water
Physical Tests (Matrix: Water)				
Conductivity	2.0	µS/cm	97.4	117
Hardness (as CaCO3), from total Ca/Mg	0.50	mg/L	32.6	36.5
pH	0.10	pH units	7.26	7.63
Anions and Nutrients (Matrix: Water)				
Ammonia, total (as N)	0.0050	mg/L	0.0099	0.0071
Nitrate (as N)	0.0050	mg/L	0.272	0.311
Nitrite (as N)	0.0010	mg/L	0.0015	0.0010
Nitrogen, total	0.030	mg/L	0.428	0.476
Phosphate, ortho-, dissolved (as P)	0.0010	mg/L	<0.0010	0.0011
Phosphorus, total	0.0020	mg/L	0.0100	0.0108
Total Metals (Matrix: Water)				
Aluminum, total	0.0030	mg/L	0.0587	0.102
Antimony, total	0.00010	mg/L	<0.00010	<0.00010
Arsenic, total	0.00010	mg/L	0.00021	0.00025
Barium, total	0.00010	mg/L	0.00721	0.00884
Beryllium, total	0.000020	mg/L	<0.000020	<0.000020
Bismuth, total	0.000050	mg/L	<0.000050	<0.000050
Boron, total	0.010	mg/L	0.030	0.033
Cadmium, total	0.0000050	mg/L	<0.0000050	<0.0000050
Calcium, total	0.050	mg/L	9.24	10.5

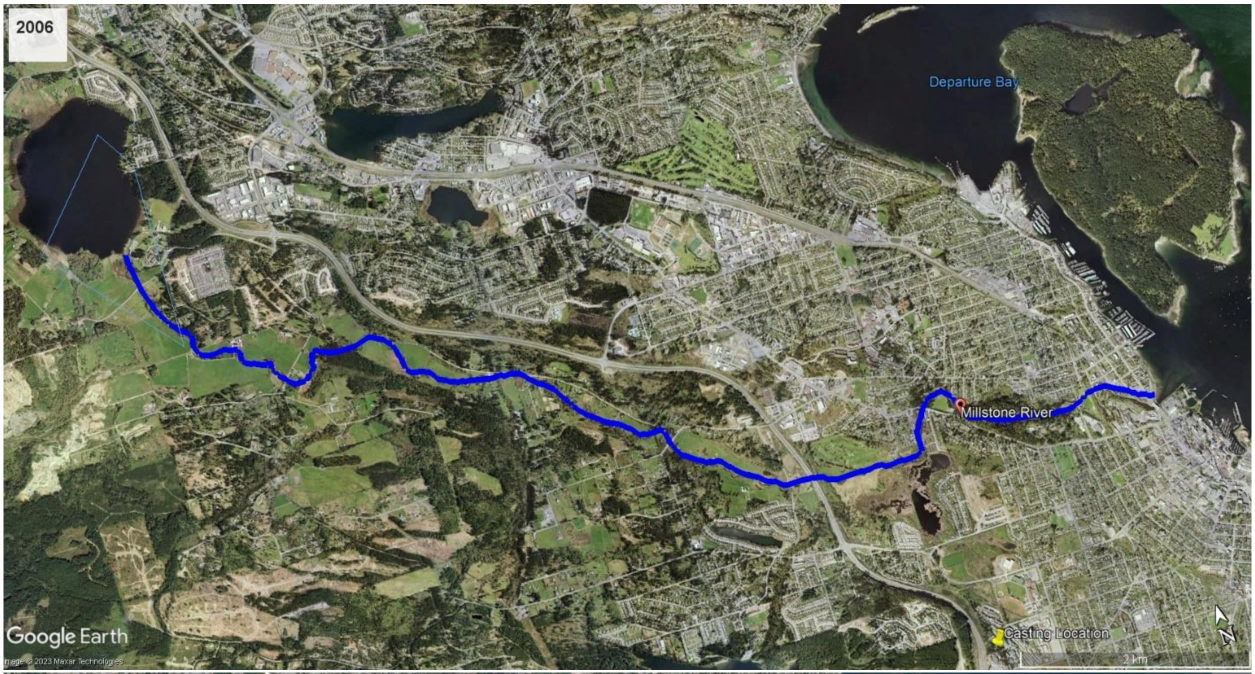
Cesium, total	0.000010	mg/L	<0.000010	<0.000010
Chromium, total	0.00050	mg/L	<0.00050	<0.00050
Cobalt, total	0.00010	mg/L	<0.00010	0.00011
Copper, total	0.00050	mg/L	0.00114	0.00113
Iron, total	0.010	mg/L	0.171	0.260
Lead, total	0.000050	mg/L	<0.000050	0.000053
Lithium, total	0.0010	mg/L	<0.0010	0.0010
Magnesium, total	0.0050	mg/L	2.32	2.49
Manganese, total	0.00010	mg/L	0.0180	0.0186
Molybdenum, total	0.000050	mg/L	<0.000050	<0.000050
Nickel, total	0.00050	mg/L	<0.00050	<0.00050
Phosphorus, total	0.050	mg/L	<0.050	<0.050
Potassium, total	0.050	mg/L	0.365	0.406
Rubidium, total	0.00020	mg/L	0.00038	0.00042
Selenium, total	0.000050	mg/L	<0.000050	0.000060
Silicon, total	0.10	mg/L	3.66	3.78
Silver, total	0.000010	mg/L	<0.000010	<0.000010
Sodium, total	0.050	mg/L	5.92	8.02
Strontium, total	0.00020	mg/L	0.0786	0.0805
Sulfur, total	0.50	mg/L	1.82	2.02
Tellurium, total	0.00020	mg/L	<0.00020	<0.00020
Thallium, total	0.000010	mg/L	<0.000010	<0.000010
Thorium, total	0.00010	mg/L	<0.00010	<0.00010
Tin, total	0.00010	mg/L	<0.00010	<0.00010
Titanium, total	0.00030	mg/L	<0.00240	0.00511
Tungsten, total	0.00010	mg/L	<0.00010	<0.00010
Uranium, total	0.000010	mg/L	<0.000010	<0.000010
Vanadium, total	0.00050	mg/L	<0.00050	0.00072
Zinc, total	0.0030	mg/L	<0.0030	<0.0030
Zirconium, total	0.00020	mg/L	<0.00020	<0.00020

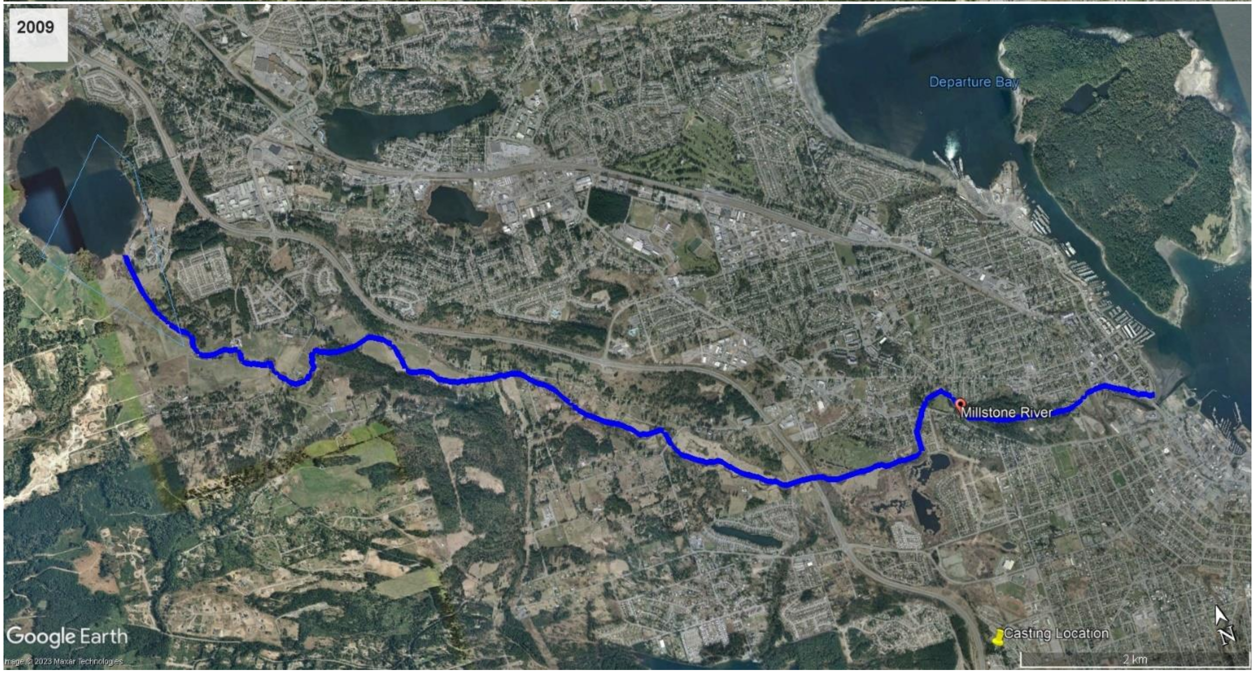
Qualifier Legend

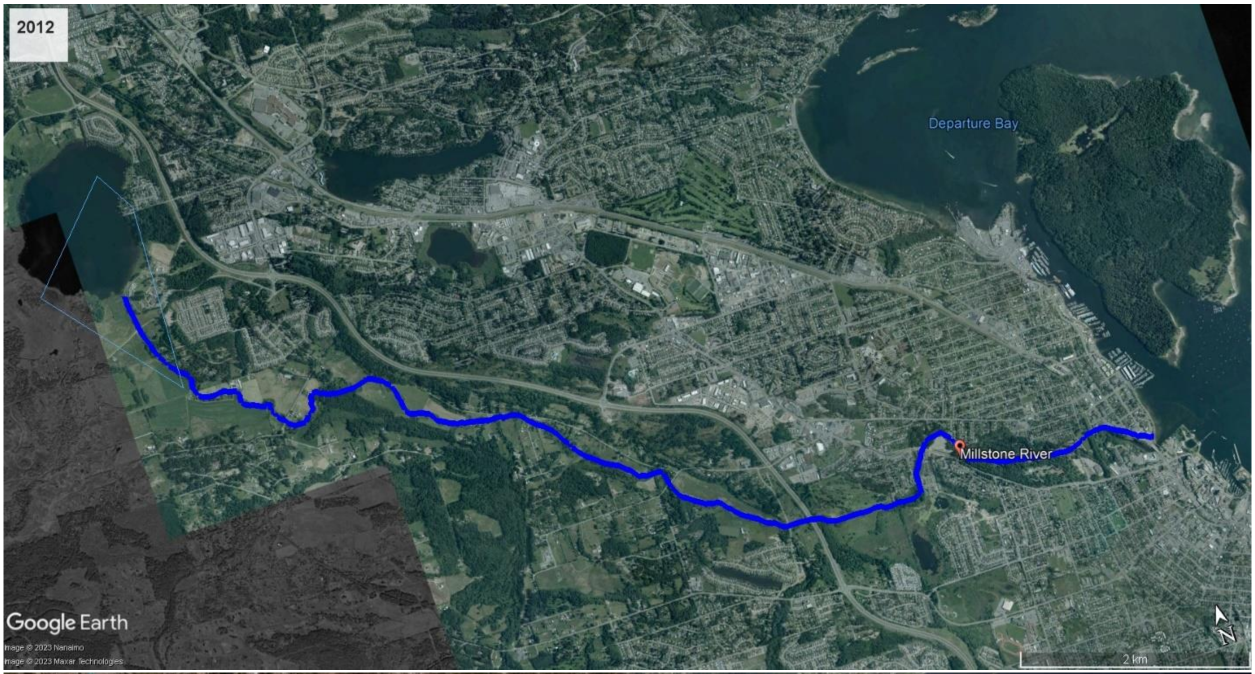
DLM Detection Limit Adjusted due to sample matrix effects (e.g. chemical interference, colour, turbidity).

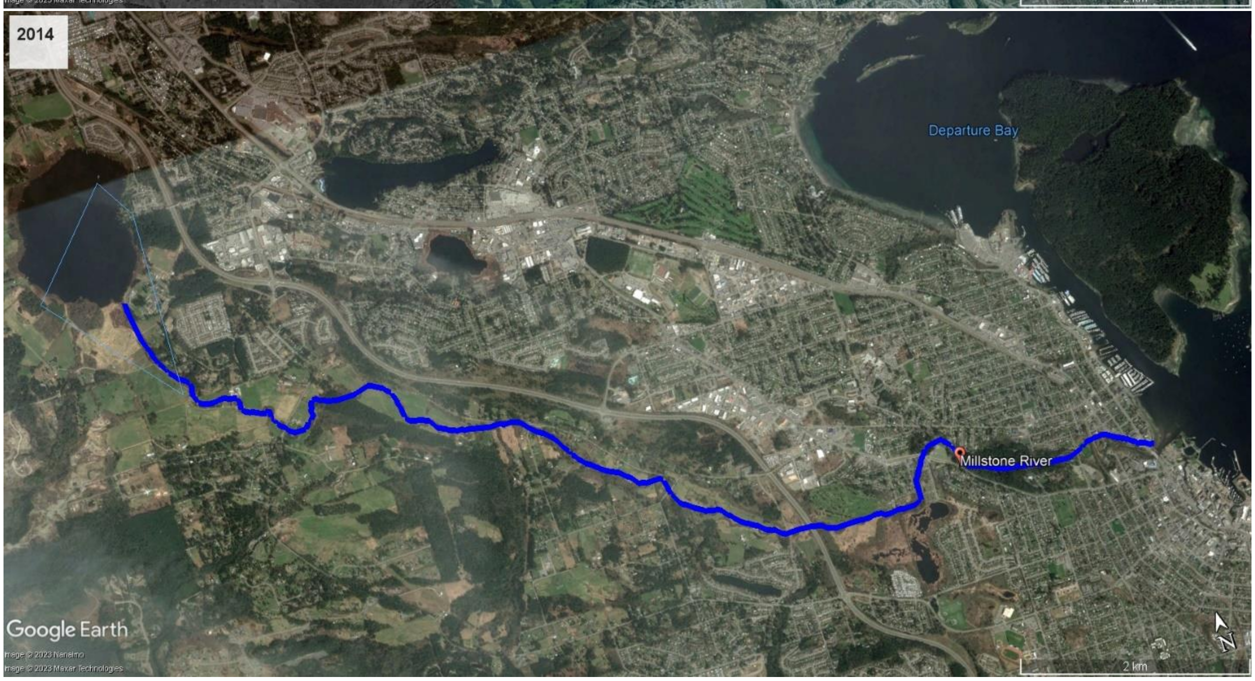
5.3 GIS Analysis

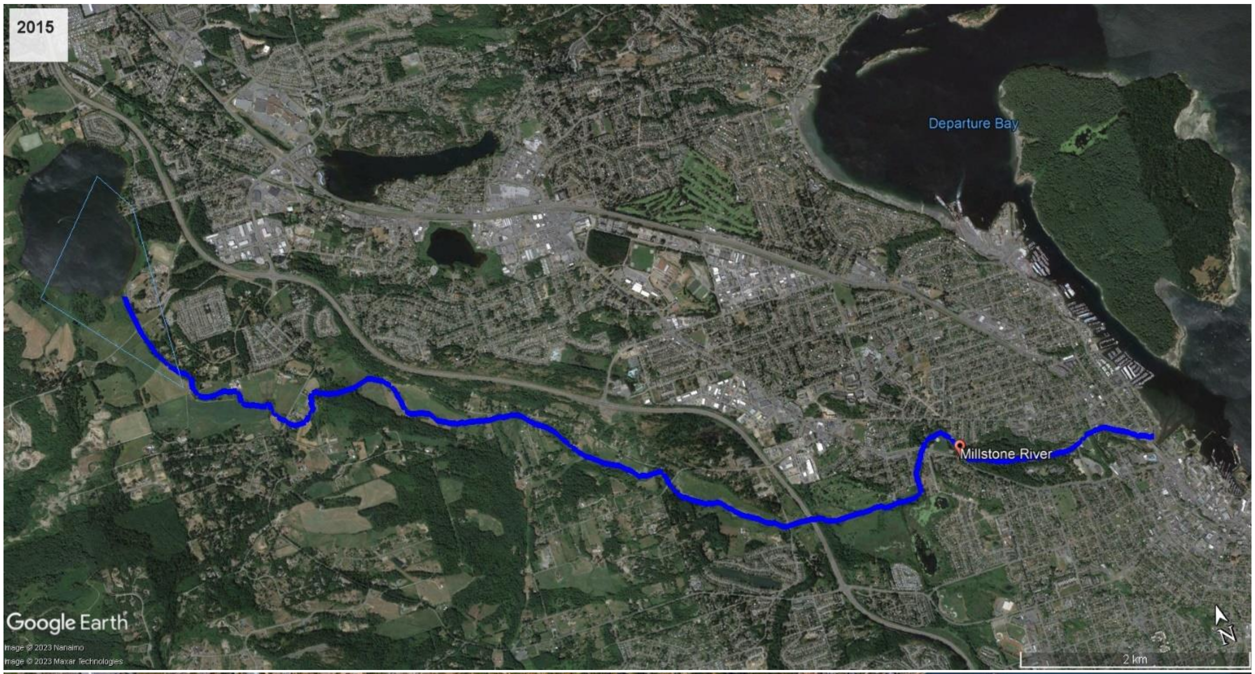


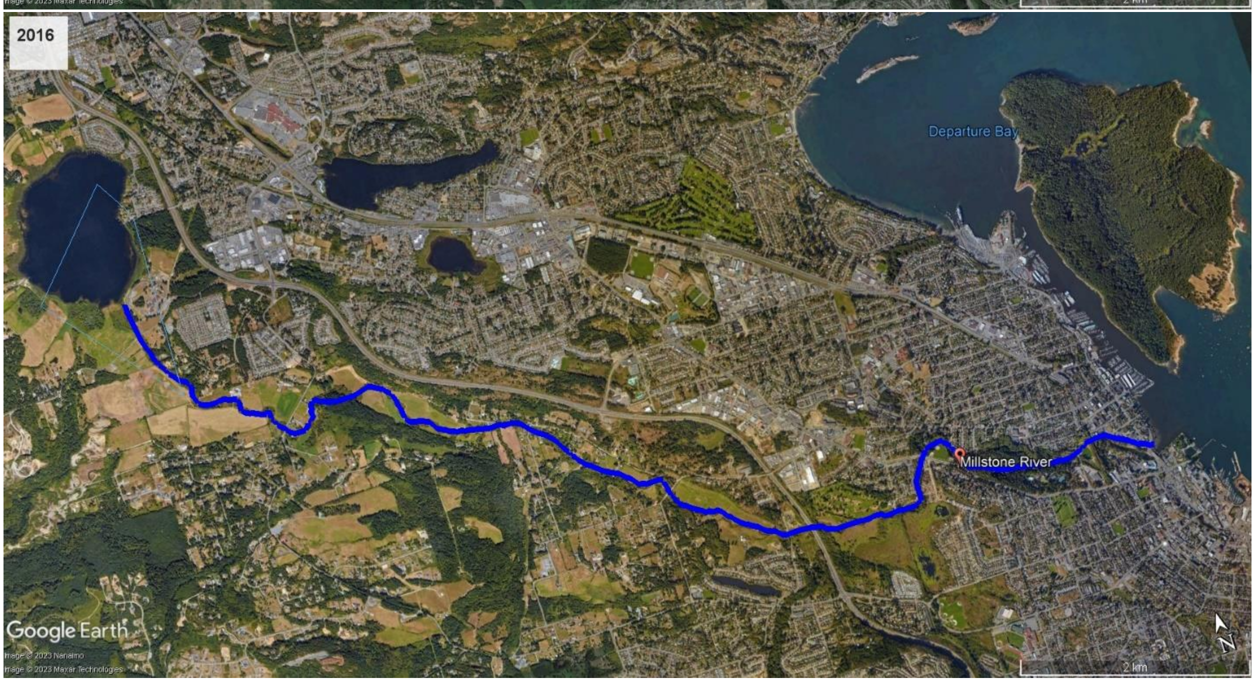

2006
Departure Bay
Millstone River
Casting Location
2 km
Google Earth

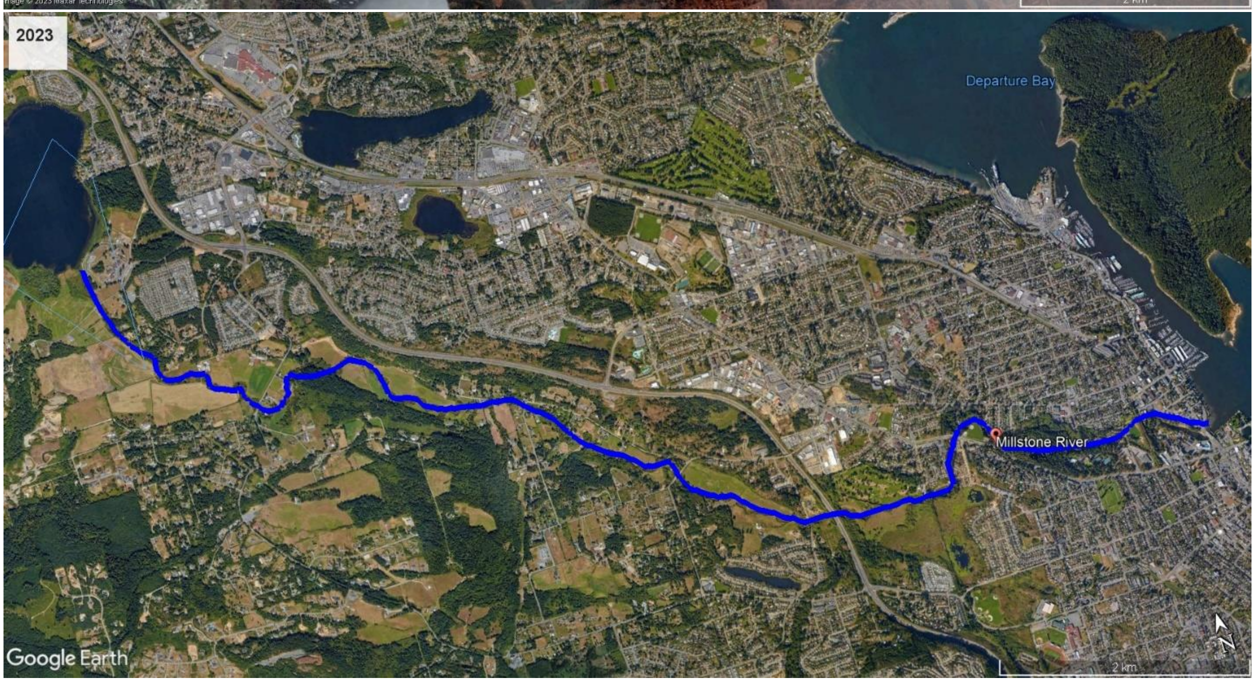

2009
Departure Bay
Millstone River
Casting Location
2 km
Google Earth


2012
Departure Bay
Millstone River
Google Earth
2 km


2014
Departure Bay
Millstone River
Google Earth
2 km


2015
Departure Bay
Millstone River
Google Earth
2 km


2016
Departure Bay
Millstone River
Google Earth
2 km


2017
Departure Bay
Millstone River
Google Earth
2 km

2023
Departure Bay
Millstone River
Google Earth
2 km

5.4 Additional Figures and Tables

Millstone River Site 5 invertebrate population charts with sample 1 (low) and sample 2 (high).

Species Common Name	Site 5				Shannon-Weiner Index		
	Sample 1		Sample 2				
	Counted	Taxa	Counted	Taxa	pi	ln*Pi	Pi(ln*Pi)
Caddisfly Larva (EPT)	1	1	15	1	0.095808383	-2.34540509	-0.22470947
Mayfly Nymph (EPT)	2	1	6	1	0.047904192	-3.038552271	-0.14555939
Stonefly Nymph (EPT)	5	2	0	0	0.02994012	-3.5085559	-0.105046584
Dobsonfly (hellgrammite)	0	0	1	1	0.005988024	-5.117993812	-0.03064667
Sum Category 1	8	4	22	3			
Alderfly Larva	0	0	3	1	0.017964072	-4.019381524	-0.072204459
Clam, Mussel	9	1	0	0	0.053892216	-2.920769235	-0.157406725
Amphipod (freshwater shrimp)	27	2	66	1	0.556886228	-0.585394319	-0.325998034
Sum Category 2	36	3	69	2			
Aquatic Worm (oligochaete)	11	1	13	1	0.143712575	-1.939939982	-0.27879377
Midge Larva (chironomid)	3	2	0	0	0.017964072	-4.019381524	-0.072204459
Pouch and Pond Snails	0	0	5	1	0.02994012	-3.5085559	-0.105046584
Sum Category 3	14	3	18	2			
Total	58	10	109	7		Total	1.517616143

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Mill Stone Creek	Date:	31. October 2023
Station Name:	Site 2	Flow status:	low

Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates
Hess	3	0.09 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	0	0
	Mayfly Nymph (EPT)	0	0
	Stonefly Nymph (EPT)	0	0
Pollution Intolerant	Dobsonfly (hellgrammite)	0	0
	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		0	0
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	0	0
	Aquatic Sowbug	0	0
	Clam, Mussel	4	1
	Cranefly Larva	0	0
	Crayfish	0	0
Somewhat Pollution Tolerant	Damselfly Larva	0	0
	Dragonfly Larva	0	0
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	31	1
	Watersnipe Larva	0	0
Sub-Total		35	2
Category 3	Aquatic Worm (oligochaete)	34	1
	Blackfly Larva	0	0
	Leech	2	1
	Midge Larva (chironomid)	0	0
	Planarian (flatworm)	0	0
Pollution Tolerant	Pouch and Pond Snails	2	1
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		38	3
TOTAL		73	5

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: **61**

DENSITY: Invertebrate density per total area sampled:

61 ÷ 0.27 m^2 = 225.926 / m^2 (From page 1)

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

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 = **7**

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6 = **0**

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 = **0**

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: **10**

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 = **0.465753425**

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	4

Average Rating
Average of R1, R2, R3, R4
2.5

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 2 Sample 1.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Mill Stone Creek		Date: 21-Nov-23	
Station Name: Site 2		Flow status: High	
Sampler Used: Hess	Number of replicates 1	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.09 m^2	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	13	2
	Mayfly Nymph (EPT)	1	1
	Stonefly Nymph (EPT)	0	0
	Dobsonfly (hellgrammite)	0	0
Pollution Intolerant	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		14	3
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	0	0
	Aquatic Sowbug	0	0
	Clam, Mussel	6	2
	Cranefly Larva	0	0
	Crayfish	0	0
Somewhat Pollution Tolerant	Damselfly Larva	0	0
	Dragonfly Larva	0	0
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	59	4
	Watersnipe Larva	0	0
Sub-Total		65	6
Category 3	Aquatic Worm (oligochaete)	14	1
	Blackfly Larva	0	0
	Leech	0	0
	Midge Larva (chironomid)	1	1
Pollution Tolerant	Planarian (flatworm)	0	0
	Pouch and Pond Snails	0	0
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		15	2
TOTAL		94	11

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 94

DENSITY: Invertebrate density per total area sampled:

94 ÷ 0.27 m^2 = 348.148 / m^2 (From page 1)

PREDOMINANT TAXON: Invertebrate group with the highest number counted (in Col. C): Amphipod (freshwater shrimp)

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 0 + 2 x 1 + 3 = 23

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

0 + 0 + 0 = 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

(0 + 0 +0) / 0= 0.14893617

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

_59 / 101 = 0.627659574

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	4
EPT Index	2
EPT To Total Ratio	1
Predominant Taxon Ratio	2

Average Rating
Average of R1, R2, R3, R4
2.25

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 2 Sample 2.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Mill Stone Creek	Date:	31. October 2023
Station Name:	Site 3	Flow status:	low
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.09 m²	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	0	0
	Mayfly Nymph (EPT)	1	1
	Stonefly Nymph (EPT)	1	1
	Dobsonfly (hellgrammite)	0	0
Pollution Intolerant	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		2	2
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	0	0
	Aquatic Sowbug	2	1
	Clam, Mussel	2	1
	Cranefly Larva	2	2
	Crayfish	0	0
Somewhat Pollution Tolerant	Damselfly Larva	0	0
	Dragonfly Larva	0	0
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	31	1
	Watersnipe Larva	0	0
Sub-Total		37	5
Category 3	Aquatic Worm (oligochaete)	22	3
	Blackfly Larva	0	0
	Leech	0	0
	Midge Larva (chironomid)	0	0
	Planarian (flatworm)	0	0
Pollution Tolerant	Pouch and Pond Snails	0	0
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		22	3
TOTAL		61	10

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 61

DENSITY: Invertebrate density per total area sampled: 61 ÷ From page 1 0.27 m² = 225.926 / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: Sub-total number of taxa found in each tolerance category. 3 x D1 + 2 x D2 + D3: 19

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

EPT INDEX: Total number of EPT taxa. EPT4 + EPT5 + EPT6: 2

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

EPT TO TOTAL RATIO INDEX: Total number of EPT organisms divided by the total number of organisms. (EPT1 + EPT2 + EPT3) / CT: 0.032786885

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

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 10

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (S1) divided by CT. Col. C for S1 / CT: 0.360655738

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

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	4

Average Rating
Average of R1, R2, R3, R4
2.5

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 3 Sample 1.

Stream Name: Mill Stone Creek		Date: 21-Nov-23
Station Name: Site 3		Flow status: High
Sampler Used: Hess	Number of replicates 1	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.09 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	8	1
	Mayfly Nymph (EPT)	63	2
	Stonefly Nymph (EPT)	1	0
Pollution Intolerant	Dobsonfly (hellgrammite)	0	0
	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		72	3
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	0	0
	Aquatic Sowbug	0	0
Somewhat Pollution Tolerant	Clam, Mussel	0	0
	Cranefly Larva	0	0
	Crayfish	0	0
	Damselfly Larva	0	0
	Dragonfly Larva	2	1
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	9	1
	Watersnipe Larva	0	0
Sub-Total		11	2
Category 3	Aquatic Worm (oligochaete)	94	2
	Blackfly Larva	0	0
	Leech	0	0
Pollution Tolerant	Midge Larva (chironomid)	0	0
	Planarian (flatworm)	0	0
	Pouch and Pond Snails	0	0
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		94	2
TOTAL		177	7

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 177

DENSITY: Invertebrate density per total area sampled:
25 ÷ From page 1 0.27 m^2 = 92.5926 / m^2

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

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 0 + 2 x 1 + 3 = 15

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6
0 + 0 + 0 = 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
(0 + 0 +0) / 0= 0.406779661

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 7

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
0.531073446

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	3

Average Rating
Average of R1, R2, R3, R4
2.25

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 3 Sample 2.

Stream Name:	Mill Stone Creek	Date:	31. October 2023
Station Name:	Site 5	Flow status:	low
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates	0.09 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	1	1
	Mayfly Nymph (EPT)	2	1
	Stonefly Nymph (EPT)	5	2
Pollution Intolerant	Dobsonfly (hellgrammite)	0	0
	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		8	4
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	0	0
	Aquatic Sowbug	0	0
	Clam, Mussel	9	1
	Cranefly Larva	0	0
	Crayfish	0	0
Somewhat Pollution Tolerant	Damselfly Larva	0	0
	Dragonfly Larva	0	0
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	27	2
	Watersnipe Larva	0	0
Sub-Total		36	3
Category 3	Aquatic Worm (oligochaete)	11	1
	Blackfly Larva	0	0
	Leech	0	0
	Midge Larva (chironomid)	3	2
Pollution Tolerant	Planarian (flatworm)	0	0
	Pouch and Pond Snails	0	0
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		14	3
TOTAL		58	10

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 58

DENSITY: Invertebrate density per total area sampled:

58 ÷ 0.27 m^2 = 214.815 / m^2 (From page 1)

PREDOMINANT TAXON: Invertebrate group with the highest number counted (in Col. C): Amphipod (freshwater shrimp)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

3 x D1 + 2 x D2 + D3 = 21

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

EPT INDEX: Total number of EPT taxa.

EPT4 + EPT5 + EPT6 = 4

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

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

(EPT1 + EPT2 + EPT3) / CT = 0.137931034

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

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 10

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

Col. C for S1 / CT = 0.465517241

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

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	3

Average Rating
Average of R1, R2, R3, R4
2.25

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 5 Sample 1.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Mill Stone Creek	Date:	November 21 2023
Station Name:	Site 5	Flow status:	High
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates	0.09 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	15	1
	Mayfly Nymph (EPT)	6	1
	Stonefly Nymph (EPT)	0	0
Pollution Intolerant	Dobsonfly (hellgrammite)	1	1
	Gilled Snail	0	0
	Riffle Beetle	0	0
	Water Penny	0	0
Sub-Total		22	3
Category 2	Alderfly Larva	0	0
	Aquatic Beetle	3	1
	Aquatic Sowbug	0	0
	Clam, Mussel	0	0
Somewhat Pollution Tolerant	Cranefly Larva	0	0
	Crayfish	0	0
	Damselfly Larva	0	0
	Dragonfly Larva	0	0
	Fishfly Larva	0	0
	Amphipod (freshwater shrimp)	66	1
	Watersnipe Larva	0	0
Sub-Total		69	2
Category 3	Aquatic Worm (oligochaete)	13	1
	Blackfly Larva	0	0
	Leech	0	0
	Midge Larva (chironomid)	0	0
Pollution Tolerant	Planarian (flatworm)	0	0
	Pouch and Pond Snails	5	1
	True Bug Adult	0	0
	Water Mite	0	0
Sub-Total		18	2
TOTAL		109	7

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 109

DENSITY: Invertebrate density per total area sampled: 109 ÷ 0.27 (From page 1) m^2 = 403.704 / m^2

PREDOMINANT TAXON: Invertebrate group with the highest number counted (in Col. C): Amphipod (freshwater shrimp)

SECTION 2 - WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: Sub-total number of taxa found in each tolerance category. 3 x D1 + 2 x D2 + D3 = 15

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

EPT INDEX: Total number of EPT taxa. EPT4 + EPT5 + EPT6 = 2

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

EPT TO TOTAL RATIO INDEX: Total number of EPT organisms divided by the total number of organisms. (EPT1 + EPT2 + EPT3) / CT = 0.19266055

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

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 10

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (S1) divided by CT. Col. C for S1 / CT = 0.605504587

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

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	1
Predominant Taxon Ratio	2

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

Millstone River Invertebrate Collection Form and Stream Assessment Form for Site 5 Sample 2.