Data Report

# Water Quality and Stream Invertebrate Assessment for the Millstone River, Nanaimo, BC

# (Fall 2014)

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Submitted to:
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## 1.0 Executive Summary

Students attending Vancouver Island University taking the (RMOT 306) Environmental-monitoring course performed a water quality and stream invertebrate assessment on the Millstone River located in Nanaimo, British Columbia. A total of six sampling stations along the river were analyzed. These sampling locations were determined in previous years and were revisited to gather new results to compare to the previous years findings. These sampling stations ranged from upstream at Benson Creek to downstream 170 m upstream from the estuary in Barsby Park.

Two sampling events occurred at each station on October 26, 2014 during a high flow period and Nov 16, 2014 during a low flow period. The parameters analyzed and tested at each site were stream invertebrates, microbiology, basic hydrology, pH, hardness (mg/L as $CaCO_3$), phosphate (mg/L $PO_4^{3-}$), nitrate (mg/L $NO_3^-$), temperature ($^oC$), conductivity (µs/cm), dissolved oxygen (DO% and $DO^{mg}{}_L$), total suspended solids (TSS), alkalinity (mg/L as $CaCO_3$), stream nutrients and metals present. Most samples were analyzed in the lab at Vancouver Island University, and some samples were sent to ALS Environmental Laboratories in Burnaby, BC for further analysis. Results were attained and compared to the data collected from the previous years. The analysis revealed that the water quality parameters tested, except coliform values at all stations, met the BC water quality guidelines. The coliform data from each station revealed a large number of fecal coliforms at all stations, which was also seen in the previous years data. The samples sent to ALS revealed that all stations met water quality guidelines for metals except for aluminum and iron, which were present in excess during the first sampling event.

Dissolved oxygen levels were revealed to be above base limits at all stations showing healthy conditions for aquatic life. Stream invertebrates sampled revealed the stream to be moderately healthy with an average stream rating of marginal. The Regional District of Nanaimo and Fisheries and Oceans Canada provided Funding and support for this project. Additionally Dr. Eric Demers undertook project assistance, assessment and supervision.

## 2.0 Table of Contents

# 3.0 Introduction and Background Information

## 3.1 Project Overview

An environmental monitoring project was conducted on the Millstone River in Nanaimo, British Columbia by our team of Vancouver Island University students. The team was made up of four students in the RMOT306: Environmental Monitoring course – three who are part of the Bachelor of Natural Resources Protection program and one who is completing a Bachelor Degree in Biology. Environmental monitoring took place at six sites along the Millstone River and Benson Creek during the months of October and November, 2014. Combined with data that has been collected by students since 2006, our results provide an up-to-date perspective on the health of the Millstone River based on parameters such as water quality and benthic macroinvertebrates. The data that has been collected identifies where contamination exists within the six sites and allows for our team to propose potential reasons for this contamination.

The Millstone River originates from a point just west of Mount Benson around Lucid Lake, at an elevation of 619 metres. Benson Creek (where Site #1 is located) flows north from Lucid Lake into Brannen Lake. The Millstone River flows in a southeasterly direction from Brannen Lake to its mouth at the Strait of Georgia (Cook and Baldwin, 1994). The length of the river from Brannen Lake to the Strait of Georgia measures over 14 kilometres. The Millstone River is part of a greater watershed which covers approximately 100 square kilometres (Regional District of Nanaimo, 2013). Some of the other water bodies that drain into the Millstone River along its length include Diver Lake, Cathers Lake, Long Lake and Westwood Lake (see figure 6 in the appendix). The total drainage area of the Millstone is 93.2km$^2$, 46km$^2$ of which is located upstream of Brannen Lake (Cook and Baldwin, 1994).

### 3.2 Historical Overview

Much of Vancouver Island north of Victoria was not inhabited until the discovery of coal which drew the British to the northern part of Vancouver Island. In 1849, the Hudson's Bay Company began mining on the northern tip of the island and in 1852 it was confirmed that there were coal seams in, what is today, downtown Nanaimo. In order to support all the miners, a saw mill was built on the Millstone River to provide finished wood for the mine and for the building of homes (Leduc, 2014).

In 2007, the Nanaimo Fish and Game Protective Association, in partnership with Fisheries and Oceans Canada and the City of Nanaimo, constructed a side channel in Bowen Park that is 800 metres long. The channel was built in order to provide Coho salmon, steelhead and sea-run cutthroat trout new spawning and juvenile rearing habitat. The channel also allowed the fish to access the river above Deadman Falls in Bowen Park. As a result of this bypass channel, the fish have been able to migrate and spawn in the upper watershed and tributaries in the Brannen Lake area (City of Nanaimo Parks, Recreation and Culture, 2007).

### 3.3 Potential Environmental Concerns

The Millstone River belongs to a watershed that has a relatively high population density because it flows through the City of Nanaimo; this plays a large part in the condition of the river due to the urban nature of its course. The Millstone River is directly impacted by urban development because when rain falls it flows over pavement and into storm drains, picking up potentially harmful chemicals and litter on its way. There is also agricultural land use along the Millstone River which means that rainfall is flowing directly from farmland into the river as surface or groundwater flow, bring more potentially harmful substances such as fertilizers (Regional District of Nanaimo, 2013).

### 3.4 Project Objectives

The objective of this project was to acquire accurate data from numerous sampling techniques which, when added to the previous year's data, provided a clear representation of the health of the Millstone River. The three areas of monitoring that were carried out included 1) water quality, 2) microbiology and 3) stream invertebrates. The Department of Fisheries and Oceans, British Columbia Conservation Foundation, Regional District of Nanaimo and the City of Nanaimo are all interested in long-term sampling. This monitoring project also allows the city and the province to plan in a more informed and sustainable way by using the current data as a building block. Building upon previous year's data and using the same site locations means that the data can be used to look at annual trends within the watershed. The results of the data collected will be used to help improve the living conditions of local fish populations that live in the Millstone River such as three-spine stickleback (*Gasterosteus aculeatus),* coho salmon (*Oncorhynchus kisutch),* cutthroat trout (*Oncorhynchus clarkii*) and pumpkinseed (*Lepomis gibbosus).* Other animals also use the Millstone River as a source of drinking water and as a natural corridor. Our team assessed the condition of the riparian areas at each site which also plays a key role in the health of the overall ecosystem by providing shelter, a source of food, regulating water temperature and much more.

# 4.0 Methods

## 4.1 Site Descriptions

We took samples from six locations consistent with previous environmental monitoring projects on the Millstone River. They were at the same general locations to show results from consecutive years. All the sites had good access points and were located next to bridges aside from site #4 and #5. We chose to sample upstream of the bridges to be consistent and also because we felt that any contamination from the road would be more evident on the downstream side of the bridge and that it was important to monitor the creek at a location that gave a general representation of the site. These sites demonstrated a suitable overall depiction of the river and were distributed along the length of the system starting at site #1 on Benson Creek, which is part of the Millstone River watershed and ending at site #6 near the estuary in Barsby Park (see figure 6 in the appendix).

**Site #1** is located on Benson Creek close to where it enters Brannen Lake (10U 422738mE, 5450707mN (Google Earth, 2014)). The sample site is located where Biggs Road crosses Benson Creek. The best way to access the site is to cross the bridge and to hike down at the SW corner. We noticed an oily film on the bridge possibly from vehicles passing by and saw this as a potential site contamination. This portion of the stream had a slope of 2° and steep embankments housing a riparian collection of Himalayan blackberry, grass and willow (see figure 8 in the appendix). The substrate consisted of approximately 60% cobble, 30% gravel, 5% boulder and 5% sand. Canopy cover was estimated at 50% (see figure 7 in the appendix).

**Site #2** is located where the Millstone exits Brannen Lake and then crosses Biggs road (10U 423341mE, 5450828mN (Google Earth, 2014)). Access was available through tall grass on the NW side of the bridge. This section of the river is directly next to agricultural fields which we believe could possibly affect water quality due to the spreading of manure and or pesticides/herbicides. We also noticed that a Terasen Gas pipe runs directly through the sample site underneath the streambed. This site had a slope of 1°and a shallow embankment home to a riparian collection of grass, red alder and willow (see figure 10 in the appendix). The substrate was estimated at 50% cobble, 30% gravel, 15% silt and 5% boulder. Canopy cover was approximately 80% (see figure 9 in the appendix).

**Site #3** is located at the junction of Maxey Road and Durnin Road (10U 426304mE, 5448953mN (Google Earth, 2014)). Access was gained at the NW corner of the bridge. This site had a slope of 1° and a generally shallow embankment, but was fairly steep at the access point. It is home to a riparian compilation of grass and shrubs (see figure 12 in the appendix). The substrate consisted of leaf litter, approximately 80% cobble, 15% gravel, 4% sand and 1% boulder. Canopy cover was approximately 60% (see figure 11 in the appendix).

**Site #4** is accessed by the Pryde Vista Golf Club at the south side of the parking lot (10U 429076mE, 5447227mN (Google Earth, 2014)). We traveled down the overgrown path to the North side of the river. This site had a slope of 1° and a shallow embankment with slight undercutting in various locations. It is home to a riparian collection of salmonberry, horsetail, Himalayan blackberry and English oak (see figure 14 in the appendix). The substrate consisted of leaf litter, approximately 80% cobble, 15% gravel, 4% sand and 1% boulder. This site showed a significant presence of large woody debris

(LWD) and the canopy cover was approximately 80%, made up of English Oak (see figure 13 in the appendix). Garbage was also observed around the site.

**Site #5** is located further from vehicle access than the other sites, which required carrying equipment a little further (10U 430233mE, 5447304mN (Google Earth, 2014)).This site is on the west side of the duck pond in Bowen Park just downstream from a small footbridge, therefore it had the most human traffic of all the stations. The river is altered from its natural state in the park and the sample site is located in a human made bypass around a waterfall. This site was also the steepest of the sites with a measured 5° slope. The bypass had lower water flow than the other sites and was well structured with LWD and in-stream cover. This site had little to no embankment as it was mostly lined with rocks. It is home to a riparian area consisting of salmonberry, red alder, Western red cedar and big leaf maple. The substrate consisted of leaf litter and approximately 70% gravel, 20% boulder, and 10% cobble (see figure 16 in the appendix).

**Site #6** is the closest to the estuary and is located just upstream of the footbridge that connects Prideaux Street and Caledonia Avenue in Barsby Park (10U 430941mE, 5447091mN (Google Earth, 2014)). Access was gained by taking the footpath from Prideaux Street on the north side of the bridge and crossing under it. This site showed the highest water flow as well as significant turbidity. Remnants of the foundation of an old bridge are still present next to the existing bridge. We observed this site to have the most garbage present of any site. It had a slope of 1° and a fairly steep embankment near the bridge, but was shallower upstream. It is lined with big boulders and is home to a riparian assemblage of grass, salmonberry and big leaf maple. The substrate was hard to gauge due to the high turbidity but boulders were visible (see figure 18 in the appendix).

**Table 1**: Millstone River sample station locations

| Station | UTM Coordinates | | General Location |
|---|---|---|---|
| | Easting | Northing | |
| 1 | 422738 | 5450707 | Benson Creek, Biggs crossing |
| 2 | 423341 | 5450828 | Millstone River, Biggs crossing |
| 3 | 426304 | 5448953 | Durnin Road crossing |
| 4 | 429076 | 5447227 | Near Pryde Vista Golf Course parking area |
| 5 | 430233 | 5447304 | Bypass channel, downstream of duck pond |
| 6 | 430941 | 5447091 | Barsby park, 170 m upstream from estuary |

(Table by authors)

**Table 2**: Slope and riparian vegetation of six sites on the Millstone River

| Station | Slope | Riparian Vegetation |
|---|---|---|
| **1** | 2° | HB, G, W |
| **2** | 1° | G, RA, W |
| **3** | 1° | G, S |
| **4** | 1° | SB, HT, HB, EO |
| **5** | 5° | SB, RA, WRC, BLM |
| **6** | 1° | G, SB, BLM |

Riparian Codes:

| | | |
|---|---|---|
| | HB – Himalayan blackberry | HT – Horsetail |
| | G – Grasses | EO – English oak |
| | W – Willow | SB – Salmonberry |
| | RA – Red alder | WRC – Western red cedar |
| | S – Shrubs | BLM – Big leaf maple |

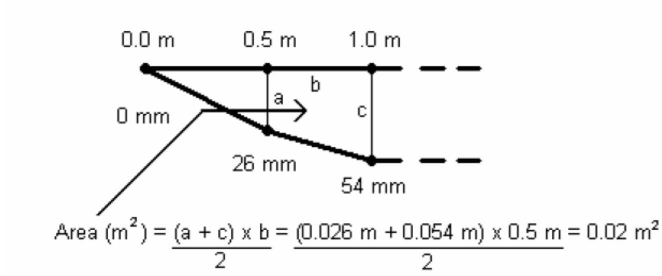
(Table by authors)

## 4.2 Water Quality

Water quality testing was performed twice at all six stations of the project. The first sampling event occurred during the high flow period on Oct. 26$^{th}$, 2014. The second sampling event occurred during a low flow period on Nov. 16$^{th}$, 2014. Given the testing occurred with two different flow rates and water levels, the differences in both flow conditions were compared. During each sampling event, one field sample was collected from each site, in addition to one replicate sample collected from site #1. These samples were analyzed in a lab at the Nanaimo campus of Vancouver Island University. Further, an additional three separate samples were collected at stations 1, 2 and 5 (bypass channel) during the first sampling event only and were sent to the ALS Environmental Laboratory in Burnaby, BC where the samples were analyzed for general water quality parameters, nutrients and total metal content. All samples collected were refrigerated and analyzed in no longer than 4 days after collection. When examining our results we used the Guidelines for Interpreting Water Quality Data (BCMELP, 1998) to evaluate the conditions at each of our six stations.

The water quality at each station was determined by examining a variety of parameters. These parameters included conductivity (μS/cm), pH, turbidity (NTU), alkalinity (mg/L as $CaCO_3$), hardness (mg/L as $CaCO_3$), nitrate (mg/L), phosphate (mg/L), temperature (°C) and dissolved oxygen (mg/L). Dissolved oxygen and water temperature was determined on site at each station using an electronic probe while the other parameters were analyzed in the laboratory. Discharge was also measured at sites 2 and 5 on both sampling dates. A measurement of the wetted width of the stream was taken, then approximately ten depth measurements equal distances apart were taken across the width of the stream. With these numbers we were able to calculate the total cross sectional area of the stream using the formula below.

**Figure 1.** Calculation of cross-sectional area from stream transect data.




(Demers, 2014a)

Once the area measurements were taken, a length of five metres was measured down the middle of the stream. A foam fishing bobber was floated down the five metre length and timed on a stopwatch. This was repeated three times at both sites 2 and 5 to gain an average time in seconds. This gave us the surface velocity once we calculated it using the formula $V_s = L/t$ where $L$ is the five metre length and $t$ is the average time it took the bobber to float the five metres. A correction factor of $k$ = 0.85 was then applied to account for the roughness of the streambed when determining the mean water column velocity using the formula $V = k \cdot V_s$. At site #5, due to restricted available measuring space, we had to time the bobber as it floated down a one metre section of the stream and then multiply the time it took by 5 to get an average time over a 5 metre length to remain consistent in the way we did our calculations. Once the area (A) and velocity (V) were determined, discharge (Q) was calculated using the formula $Q = A \cdot V$ (Demers, 2014a).

## 4.3 Microbiology

The water sampling for microbiology occurred at all six stations on the first sampling event only. The samples were acquired using sterile 100 mL Whirl-Pak plastic bags. Each sample was analyzed using the Total Coliforms and *E. coli* Membrane Filtration Method, provided by the U.S Environmental Protection Agency (USEPA, 2003). Using this method, the total coliform and *E. coli* coliform present was determined via suction filtration through a specific membrane. After filtration, the filter and contents were transferred to a membrane pad covered with m-ColiBlue24 broth which, after 24 hours of incubation at 37°C, revealed either the presence or absence of both coliform types. For quality assurance when doing the filtration, we wore gloves when touching any samples or equipment, the filter flask was rinsed thoroughly with sterile water before our sample water was added, and the tweezers used to transfer the filter paper were dipped in ethanol and flamed to remove all contamination before the filter membrane was moved. For quality control, the m-ColiBlue24 Broth was tested for quality during production so it was predetermined to be pure when it arrived in the lab and was certified for use in the filtration procedure. Further, replicates and a filtration blank were taken to allow for any contamination to be assessed and thus improve the quality of our results.

## 4.4 Stream Invertebrates

Macroinvertebrate sampling was conducted at stations 1, 2 and 5 only during the first sampling event. Three samples were taken at each site to determine the presence and taxonomic composition of macroinvertebrates in the stream. The samples were taken using the Hess sampler which covered an area of the streambed of 0.09m$^2$ and allowed for a calculation of the number of individuals per square metre to be made. Indicator species were noted and used to help determine the level of pollution in the water. Mayflies (Order *Ephemeroptera*), stoneflies (Order *Plecoptera*), and caddisflies (Order *Trichoptera*) are pollution intolerant species. Presence of these taxa, known as EPT taxa, indicates good water quality. Conversely, where there are only pollution-tolerant invertebrates present such as midges or worms, poor water quality is suggested (Demers, 2014b).

Samples were taken back to the lab at VIU to be analyzed. The invertebrates were kept alive for analysis. Calculations were made using the Shannon-Weiner diversity index to determine species diversity, along with other calculations to determine species abundance and density, predominant taxon, pollution-tolerance index, EPT index, EPT to total ratio index, and an overall site assessment rating.

Measures were taken to ensure that the quality of the assessment was not compromised. Only clean containers were used, along with all other equipment that touched the samples. All containers were labeled accurately before sampling to prevent any errors in analysis. All members of the assessment team had clean hands when handling samples. Any preservatives used were fresh and valid. All samples were stored in a clear, understandable way that all team members recognize so that samples were not mixed up or lost. Any calculations and counts made were recalculated and recounted by two other team members to ensure precision.

Furthermore, measures were taken to control the quality of all tests and experiments. Replicate samples were taken simultaneously to ensure correct sampling techniques and to establish reproducibility of sampling. The precision of the replicate samples was then calculated which is further discussed in the results section of this report.

# 5.0 Results and Discussion

## 5.1 General Field Conditions

Water velocity measurements were similar between the sampling events with an average velocity of 0.65 m/s on the first event and 0.565 m/s on the second event. Discharge was observed to be significantly higher at 2.27 $m^3/s$ at station 2 on the first sampling event than the 1.17 $m^3/s$ calculated on the second event. This was as a result of a high rainfall event that occurred during the week prior. This however was not observed at station 5 in the bypass channel where the water flow is regulated.

115 mm rainfall levels were recorded in the 7 days prior to the first event and 0mm of rain in the 7 days prior to the second sampling event. Mean air temperature measured at the Nanaimo airport during the first and second sampling event were 10.62° C and 1.24° C respectively (Government of Canada, 2014).

## 5.2 Water Quality

### 5.2.1 Field Measurements

Temperature compared between both sampling events showed a consistent trend even with an average reading of 11.5° C on the first event and 6° C on the second event (see tables 6 and 7 in the appendix). This 5.5° C difference was a result of significantly lower air temperatures on the second event. The temperature monitored in Benson Creek was the coldest measured with an increase measured at station 2 coming out of Brannen Lake and decreasing as we sampled down stream.

This temperature increase is believed to be a result of the sun warming the water in Brannen Lake.

Dissolved Oxygen (DO) showed a trend that followed the temperature recorded. This was expected, as DO increases when temperature decreases. The levels measured on both events exceeded the >9 mg/L required for fish embryo growth indicating healthy levels (BCMELP, 1998), (see tables 6 and 7 in the appendix).

### 5.2.2 VIU Laboratory Analyses

Conductivity measured between 38-101 μS/cm on the first event and between 35-90 μS/cm on the second event. The levels increased heading downstream, aside from station 5 on the first event which was higher than station 6, but only by 2 μS/cm (see tables 6 and 7 in the appendix). The increase heading downstream is expected as ion inputs from mineral weathering increase conductivity. Both events 1 and 2 had similar results and were generally consistent with levels recorded in previous years.

The pH results ranged between 7.55-7.85 on the first event to average 7.70, and between 7.19-7.46 on the second event to average 7.31, which is 0.39 lower pH than the first event average (see tables 6 and 7 in the appendix). This change could be due to factors such as seasonal variation and longer daylight hours on the first event causing the higher pH, or the increased discharge observed during the first event. Previous results typically show an increase in levels during the second event in correlation with increased discharge.

All but two of the values for alkalinity are above 20mg/L which, according to the guideline, indicates low acid sensitivity demonstrating that the water chemistry is not easily affected by introduction of acid to the watershed and there are more bicarbonate and carbonate ions to neutralize any added acid. As with hardness, an increase should be observed moving downstream, which is observed when examining data moving from station 1 to 6 (see tables 6 and 7 in the appendix).

Turbidity was high at the lower stations on the first sampling event ranging between 2.12 and 14.7 NTU. This is most likely due to the high rainfall event. Levels were lower on the second event ranging between 1.09 and 2.92 NTU (see tables 6 and 7 in the appendix). Increased turbidity is an issue for fish as it can influence the respiratory tissues in fish gills. This could potentially be an issue as the time of the high rainfall event was during typical salmon migration as the water levels rise high enough for them to travel through the waterfall bypass to the spawning grounds.

Hardness levels measured were from 17-39, all below 60mg/L, which indicates as outlined by the guideline that the Millstone River has soft water (BCMELP, 1998). The data indicates a hardness increase moving downstream which is consistent with previous data and is indicative of increased ions and nutrient deposits as water flows over a longer distance (see tables 6 and 7 in the appendix). Given the soft rating of this watershed metals dissolved in the water will have a more toxic affect.

Nitrate levels averaged 0.353 mg/L on the first event. These levels are consistent with the ALS results with a 0.0416 mg/L variance. An average of 0.1 mg/L was detected on the second event, which had a larger variance of 0.1 mg/L than the results from the first event. Orthophosphate levels averaged 0.085 mg/L on the first event and 0.0983 on the second event (see tables 6 and 7 in the appendix). A large variance was observed when comparing the ALS laboratory orthophosphate results to the VIU Laboratory results. This is most likely due to the quality of equipment and technology used. Although the result differed to 10x disparity a trend was observable when sites where compared between the results (see tables 6, 7 and 9 in the appendix).

### 5.2.3 ALS Laboratory Analyses

Conductivity results from the first sampling event ranged from 33-119 µS/cm averaging 77.76 µS/cm with an 11.76 µS/cm variance from VIU results. The second event ranged from 44.3-106 µS/cm averaging 74.23 µS/cm with a variance of 14.9 74.23 µS/cm (see table 9 in the appendix). The results from both analyses showed consistent trends, but had a noteworthy differential from VIU laboratory and ALS laboratory results. The levels increased from upstream to downstream during both events and results were relatively consistent between events.

Hardness (as $CaCO_3$) ranged from 13.7- 40.5 mg/L on the first event and 18.3-39.5 mg/L on the second event, which is consistent with previous data. Levels increased heading downstream similar to the trend seen in conductivity (see table 9 in the appendix).

The pH was measured from 7.16-7.66 on the first event with an average of 7.473 and 7.42-7.73 on the second event with an average of 7.557 which is the opposite trend observed in the VIU laboratory results where the second event displayed lower pH than the first (see table 9 in the appendix). However, this discrepancy is not significant as the results from both VIU and ALS all fall within the recommended range of 6.5-9.0 for aquatic health (BCMELP, 1998).

Anion and nutrient levels measured generally met the guideline. Ammonia levels were generally below detectable limit, and always met the guideline with the highest level detected at 0.0168 mg/L at station 5 on the first event (see table 9 in the appendix). Nitrite levels were always below the detectable limit except for station 5 with 0.0031 mg/L, but were always below the guideline (see table 9 in the appendix). Nitrate levels were measured well below the guideline with station 5 exhibiting the highest levels of the 3 stations monitored on both events (see table 9 in the appendix). Results varied from 0.01180-0.726 mg/L. Total phosphorus levels were below the oligotrophic level except station 5 on the first sampling event. It measured 0.0353 mg/L, higher than the ≥0.025 lower limit for eutrophication and 0.0113 mg/L on the second event falling into the mesotrophic range (BCMELP, 1998), (see table 9 in the appendix). Orthophosphate levels were very low in comparison with the levels measured at the VIU Laboratory. They were always below the detectable limit aside from station 5 with 0.0073 mg/L on the first event and 0.0029 mg/L on the second event (see table 9 in the appendix).

Total metal concentrations were all below detection limit or below the BC Water Quality Guideline except aluminum and iron, which were detected above the guideline at station 5 on the first event, but were below the guideline on the second event. Aluminum was detected at 0.72 mg/L and Iron was detected at 1.16 mg/L. The only rational explanation identified for this is that as it is a site further downstream than the others tested there is the possibility of mineral accumulation. The levels of calcium were higher than 8 mg/L, which is the guideline for low sensitivity to acid, but station 1 on the first event had levels of calcium indicating high sensitivity and station 1 and 2 on the second event were below 8 indicating moderate sensitivity (see table 9 in the appendix).

### 5.2.4 Microbiology

A high number of fecal coliform was observed at all the stations sampled. Therefore none of the stations contain water that is safe to drink untreated according to the maximum value of 0 CFU/100mL set by the BC Water Quality Guideline. In addition all stations but 1 and 2 exceed guidelines for use in raw drinking water, livestock use, recreation and industry. The only use for this water that adheres within guidelines is for general irrigation where the maximum fecal coliform guideline is 1000CFU/100mL. At station 1 and 2 the water is safe for livestock use (General use max 200CFU/100mL), irrigation (Crops eaten raw max

200CFU/100mL) and recreation (primary contact max 200CFU/100mL). The results did not show a consistent pattern as seen in data from previous years. Station 2 showed the highest percentage of fecal coliform at 56%, but had the lowest total coliform count of all the stations (see table 8 in the appendix).

#### 5.2.5 Quality Assurance / Quality Control

Replicate samples were taken at station 1 for quality assurance and quality control. Nutrient level results showed a variance of 0.055 mg/L for nitrate and 0.09 mg/L for orthophosphate, which are significant variances, but as discussed earlier the equipment used to measure levels is unreliable and often inaccurate. Turbidity had an average 0.645 NTU variance, which is not significant. Hardness also only showed a 2.5 mg/L variance from the replicate to station 1 which is also a small variance. An average variance of 0.16 was calculated for pH, which also is not a significant difference. Conductivity had a 6 μS/cm variance which isn't significant compared to the 63 μS/cm range observed between stations. The 6 mg/L variance for alkalinity is a significant difference as it is 20% of the range observed from station to station. This error could have been due to error during acid titration during lab analyses.

## 5.3 Stream Invertebrates

Invertebrate sampling was conducted on October 28$^{th}$, 2014 at site 1, site 2 and site 5 along Benson Creek and the Millstone River. Invertebrate sampling is conducted in order to gain insight into the communities that a certain habitat can support. Unlike fish, benthos cannot move around easily and therefore cannot escape the effects of sediment and other pollutants that affect water quality (Demers, 2014b). Due to this lifestyle and the fact that they have long lifecycles, reliable information can be gathered to determine declines in environmental quality (Demers, 2014b). There are three main categories of invertebrates: pollution intolerant, somewhat pollution tolerant and pollution tolerant. The first category is made up of species which are sensitive to pollution because they have external gills. Because of this morphology, water is absorbed into their body from their surroundings and if the water they are living in is not healthy then their gills may become clogged or damaged. As the species become more pollution tolerant they show different body plans and types. For example, a true bag is a pollution tolerant invertebrate and can resist pollutants due to their hard external shell and lack of external gills.

At each site there were three replicates collected from similar habitat types within the site. Site 1, which is located in Benson Creek, was experiencing very fast flow on the day of sampling due to a week of heavy rainfall. The banks were submerged and the fast flow impacted the use of the Hess sampler but the collection was successful. Table 3 shows which invertebrates were collected from site 1 and figure 2 gives a visual of what proportion these invertebrates were found in. Invertebrate Survey Field Data Sheets were completed for each of the three sites (see tables 10, 11 and 12 in the appendix).

**Table 3:** Invertebrates collected from Site 1 on October 28, 2014

| **Column A**: Pollution Tolerance | **Column B:** Common Name | **Column C:** Number Counted | **Column D:** Number of Taxa |
|---|---|---|---|
| *Pollution Intolerant* | Caddisfly Larva (EPT) | 1 | 1 |
| | Stonefly Nymph (EPT) | 6 | 1 |
| *Somewhat Pollution Tolerant* | Aquatic Sowbug | 1 | 1 |
| | Cranefly Larva | 5 | 2 |
| *Pollution Tolerant* | Aquatic Worm | 170 | 2 |
| | Midge Larva | 2 | 1 |
| | Water Mite | 1 | 1 |
| **Total** | | **186** | **9** |

(Table by authors)

Table 3 above shows that a total of 186 invertebrates were collected at Site 1 from a total of three replicates. Two pollution intolerant groups were identified: one caddisfly larva and six stonefly nymphs. Both of these groups are considered to be a part of the EPT index which includes *Ephemeroptera (*mayflies)*, Plecoptera (*stoneflies) and *Trichoptera (*caddisflies). All members of the EPT group have external gills and are the best indicators of healthy water due to their high sensitivity to pollutants. Two groups within the somewhat pollution tolerant category were found: one aquatic sowbug and five cranefly larvae. The largest concentration of invertebrates from Site 1 was in the last category: pollution tolerant. A total of 170 aquatic worms were identified, as well as two midge larvae and one water mite.

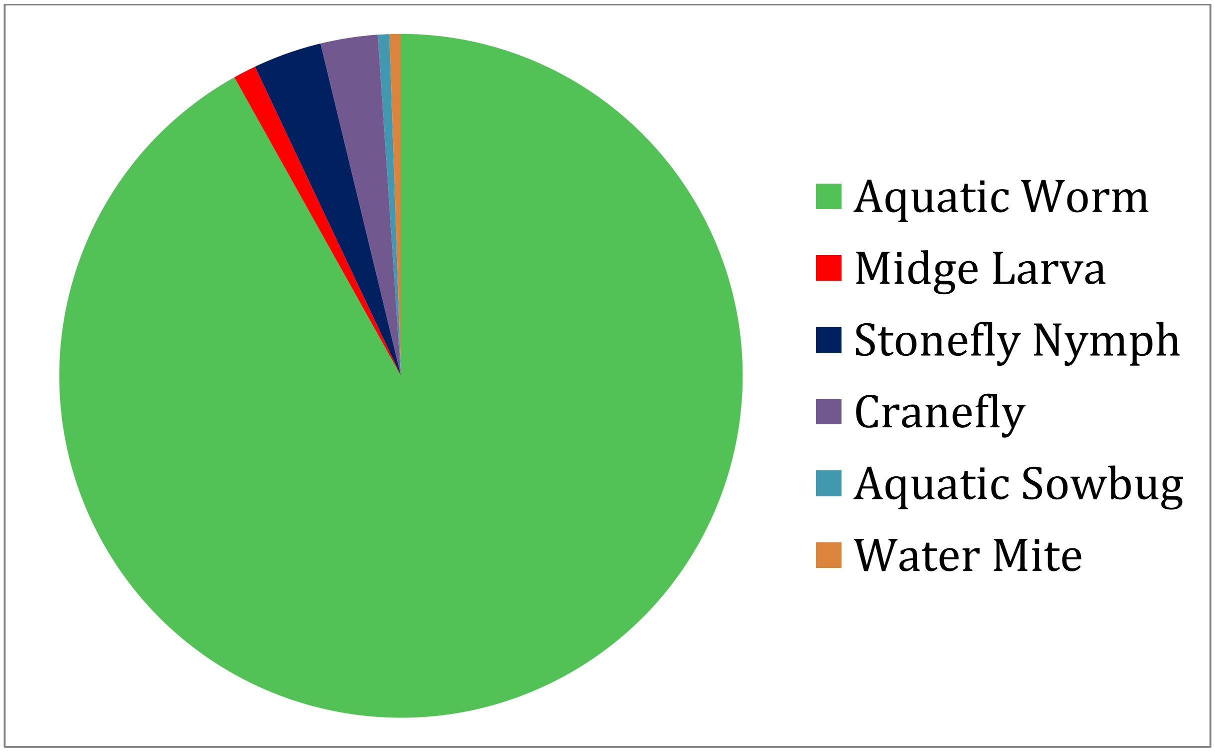



**Figure 2:** Distribution of invertebrates collected from Site 1 on October 28, 2014 (chart by authors).

The figure above shows the proportion of aquatic worms that were found compared to the other groups. This is a strong indication that the water quality at Site 1 was not healthy enough to support a higher diversity of species and more pollution intolerant groups. Site 1 has an overall average rating of 1.5 based on an average from four indices: pollution tolerance index (marginal, 2), EPT index (marginal, 2), EPT to total ratio (poor, 1) and predominant taxon ratio (poor, 1). The average of 1.5 falls between poor and marginal for this site. The calculations for these indices can be found in the invertebrate survey field data sheets in the Appendix. However, it is known that Site 1 was dry for most of the summer months and had only begun flowing again in September. Therefore, there was not enough time for an invertebrate community to re-establish itself before the sampling took place. It is also likely that some invertebrates that may have been living in Site 1 were swept away by the high flow occurrence around the sampling date.

**Table 4:** Invertebrates collected from Site 2 on October 28, 2014

| **Column A**: Pollution Tolerance | **Column B:** Common Name | **Column C:** Number Counted | **Column D:** Number of Taxa |
|---|---|---|---|
| *Pollution Intolerant* | Caddisfly Larva (EPT) | 13 | 2 |
| *Somewhat Pollution Tolerant* | Alderfly Larva | 1 | 1 |
| | Amphipod | 170 | 1 |
| *Pollution Tolerant* | Aquatic Worm | 83 | 2 |
| **Total** | | **267** | **6** |

(Table by authors)

The above table shows which invertebrates were collected at Site 2 on the Millstone River. The only EPT index group that was found was caddisfly larva, of which there were 13 found, and within those 13 there were two taxa found. In the somewhat pollution tolerant category, one alderfly larva was identified and 170 amphipods were identified. Lastly, 83 aquatic worms were present in the pollution tolerant category. Overall, the total number of organisms collected was larger at Site 2 with a total of 267. However, the taxa diversity was lower at Site 2 with only six. Site 2 flows directly out of Brannen Lake and on the day of the sampling it also had very high flow.

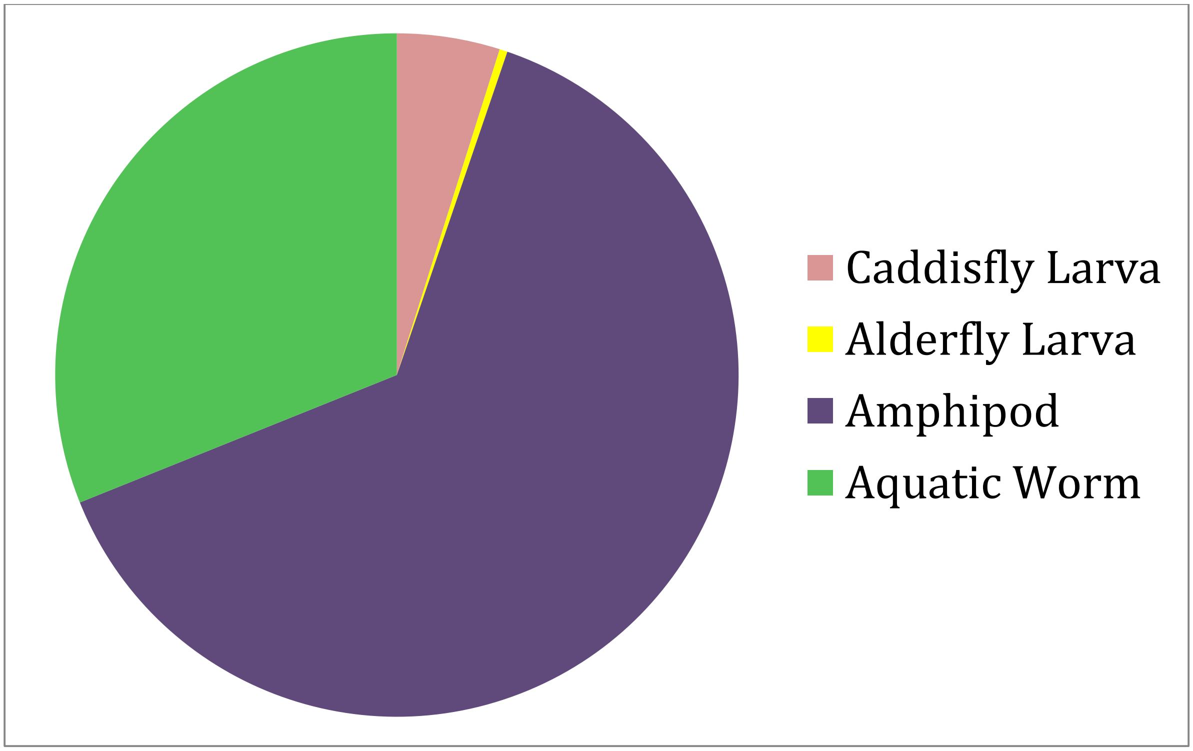



**Figure 3:** Distribution of invertebrates collected from Site 2 on October 28, 2014 (chart by authors).

The figure above shows the proportion of invertebrates that were found at Site 2. The largest group is amphipods which make up over 60% of the total sample. Aquatic worms make up approximately 30% of the total sample. Site 2 has an overall average rating of 1.75 based on an average from four indices: pollution tolerance index (marginal, 2), EPT index (marginal, 2), EPT to total ratio (poor, 1) and predominant taxon ratio (marginal, 2). The average of 1.75 falls between poor and marginal for this site. This site had flow during the summer and so this distribution is one that is likely consistent year round. Even though this site has a poor-marginal rating, it will be shown in the next section that this site has the highest species diversity according to the Shannon-Weiner Diversity Index.

**Table 5:** Invertebrates collected from Site 5 on October 28, 2014

| **Column A**: Pollution Tolerance | **Column B:** Common Name | **Column C:** Number Counted | **Column D:** Number of Taxa |
|---|---|---|---|
| *Pollution Intolerant* | Caddisfly Larva (EPT) | 22 | 2 |
| | Stonefly Nymph (EPT) | 370 | 2 |
| *Somewhat Pollution Tolerant* | Alderfly Larva | 1 | 1 |
| | Aquatic Sowbug | 3 | 1 |
| | Amphipod | 413 | 1 |
| *Pollution Tolerant* | Aquatic Worm | 70 | 2 |
| | Leech | 2 | 2 |
| | Midge Larva | 11 | 1 |
| **Total** | | **892** | **11** |

(Table by authors)

The table above shows the invertebrates that were collected at Site 5 on October 28, 2014. Site 5 is unique because it is part of the manmade bypass channel in Bowen Park. As a result of this different habitat setting, the site experiences relatively steady water levels all year round. The site is also narrower and has many more habitat types occurring in a shorter distance (including deep pools, riffles and glides) whereas the other sites tend to be a steady glide habitat. In comparison to Site 1 and Site 2, Site 5 has a very high total number of organisms collected: 892. It also shows the highest number of taxa: 11. However, the total is made up predominantly by two groups, stonefly nymphs (370 organisms) and amphipods (413 organisms). The fact that more species from all three categories of pollution tolerance are present is a positive sign and indicates good water quality.

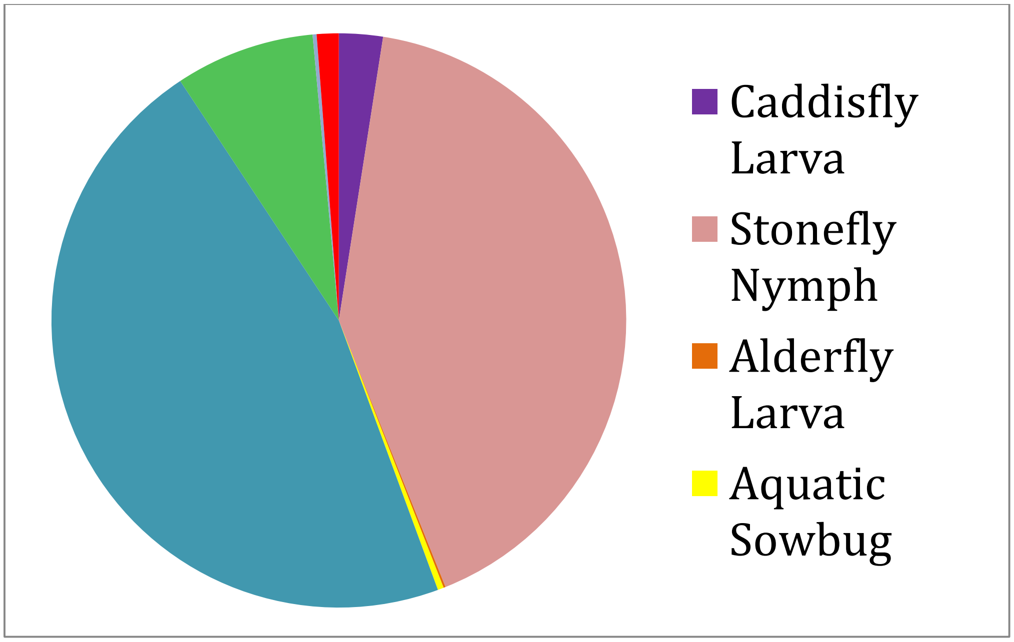



**Figure 4:** Distribution of invertebrates collected from Site 5 on October 28, 2014 (chart by authors).

The figure above shows that the majority of the sample was comprised of amphipods and stonefly nymphs. Although more species are present, they occur in relatively small amounts compared to the total. However, it is encouraging that the sample is almost 50% stonefly nymphs which are an EPT index species. Site 5 has an overall average rating of 2.5 based on an average from four indices: pollution tolerance index (acceptable, 3), EPT index (marginal, 2), EPT to total ratio (marginal, 2) and predominant taxon ratio (acceptable, 3). The average of 2.5 falls between marginal and acceptable for this site. The calculations that were done to achieve this overall rating can be seen on the invertebrate survey field data sheet in the Appendix. Based on this average rating, Site 5 has the best overall site assessment rating, but in terms of species diversity, the Shannon-Weiner diversity index shows a different perspective.

### 5.3.1 Shannon-Weiner Diversity Index Rating

The Shannon-Weiner Diversity Index is the most common way to calculate species diversity. The index is a measure of uncertainty in predicting to which taxon an individual chosen at random from a collection of taxa and individuals will belong. The larger the value that is reached after calculating the numbers using the formula, the greater the species diversity (Demers, 2014b). Figure 5 shows the Shannon-Weiner Diversity Index values for the three sites where invertebrates were collected. Site 2 shows the highest value (0.590), Site 5 shows the second highest value (0.528) and Site 1 shows the lowest species diversity (0.208). As mentioned briefly already, the index takes into account the proportion of the total that each group makes up. Therefore, even if there is a high number of different species present, the diversity may still be low if the total is dominated by only a select few. The calculations that were done to reach the values in the figure below can be seen in tables 13, 14 and 15 in the appendix.

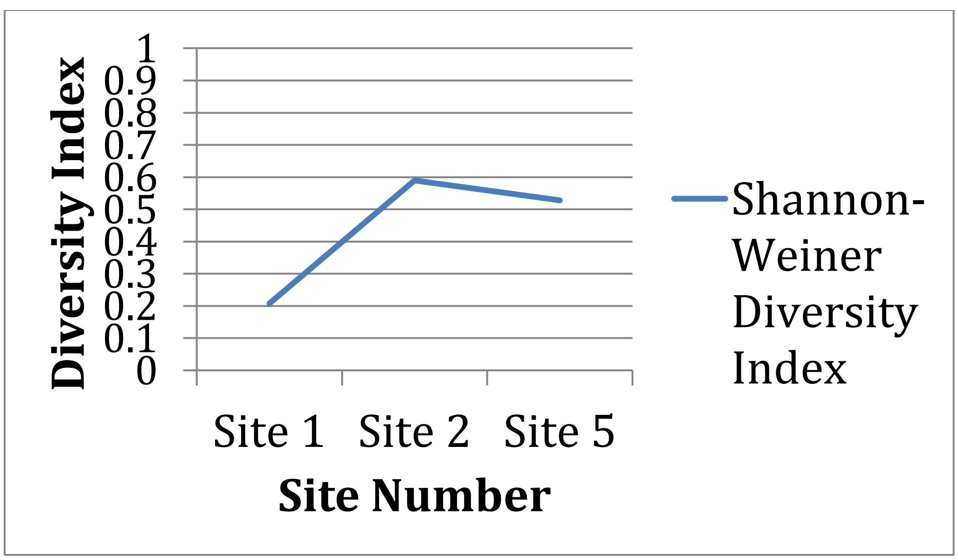



**Figure 5:** Shannon-Weiner diversity index of invertebrates collected from sites 1, 2 and 5 from the Millstone River on October 28, 2014 (graph by authors).

## 6.0 Conclusion and Recommendations

After conducting sampling of water quality, hydrology, microbiology, and stream invertebrates in the Millstone River, it can be concluded that the stream is in overall good health. The Millstone is an important river for salmon spawning. The bypass channel in Bowen Park provides members of the public with a great experience during spawning season since the trails run alongside the stream and salmon can be seen spawning right there in front of them. The riparian areas full of trees and overhanging brush provide fish with suitable cover needed for survival. There is lots of food available for fish in the form of invertebrates which occur in diverse populations throughout the various sites studied, the most abundant being at station 5.

Though the stream is in good health overall, there are a couple of issues we noticed. Since the stream runs through agricultural and residential areas for approximately 12 kilometres, pollution is a problem in more ways than one. Pesticides/herbicides, fertilizers, and other runoff from farms is a potential source of pollution leeching into the stream. In the residential areas, pollution in the form of garbage, plastic, and waste metal is evident. To help reclaim the ecosystem to its natural and unpolluted state, we recommend clean-up programs be introduced to high schools and elementary schools within the watershed. These programs would not need anything in the way of funding, only transport for the students to and from the sites to be cleaned up.

Other recommendations we have as far as sampling goes is to change the location of site 5 at the bypass channel. When measuring velocity, a glide is the ideal habitat type to measure it in. Where the site was located, there were a lot of different habitat types such as riffles and short glides, but they were all too short in length to be able to measure velocity accurately without the foam fishing bobber hitting rocks or back eddies which affected the time it took to travel the distance we needed to accurately calculate the velocity. Aside from that, the sampling efforts were very efficient.

## 7.0 Acknowledgements

The authors would like to acknowledge The Department of Fisheries and Oceans, British Columbia Conservation Foundation, Regional District of Nanaimo and the City of Nanaimo for providing continuous support and funding to continue this monitoring project year after year. Thus giving us the ability to provide quality long-term data and to assess changes and trends within the watershed. Special thanks to the Vancouver Island University Biology and Natural Resource Protection departments for providing us with the various pieces of sampling and laboratory equipment vital to our monitoring procedures. In addition a thank you to ALS laboratory's for providing a significant discount for analyzing our samples. Lastly a thank you to Eric Demers and Sarah Greenway for their help and guidance throughout the monitoring project.

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# 9.0 Appendix

## 9.1 Figures

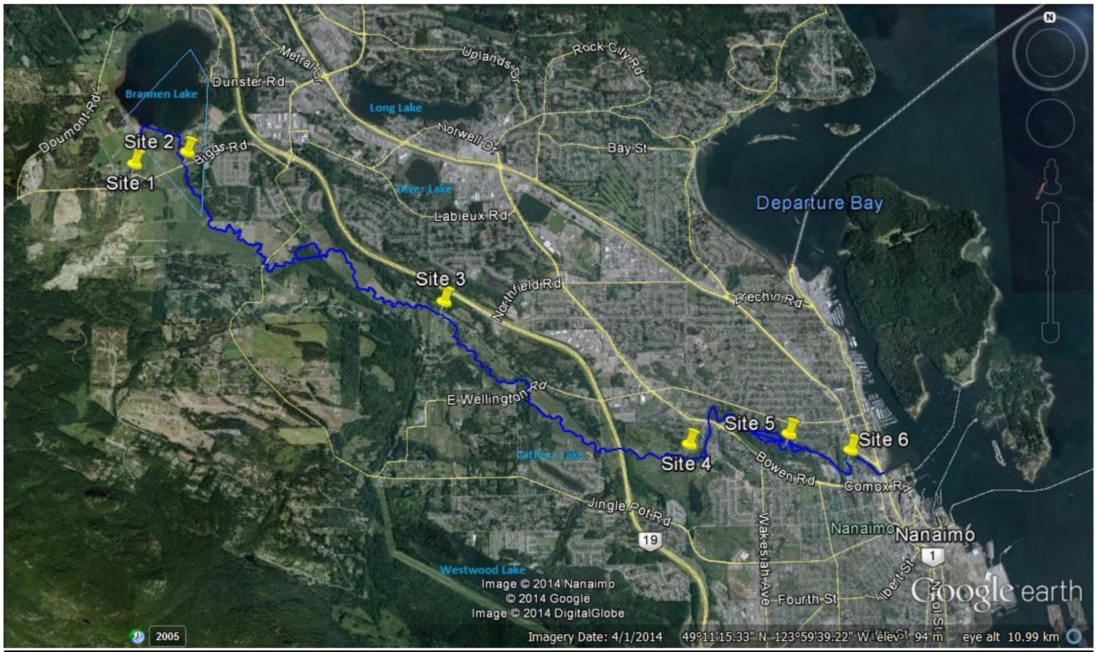


**Figure 6** – Sampling area of the Millstone River, Nanaimo, BC showing locations of all 6 sites (Google Earth 2014, edited by authors)


**Figure 7** – Site 1 overhead view with flow going north (Google Earth 2014, edited by authors)

**Figure 8 –** Site 1 from street level with flow going from right to left (Photo by authors)

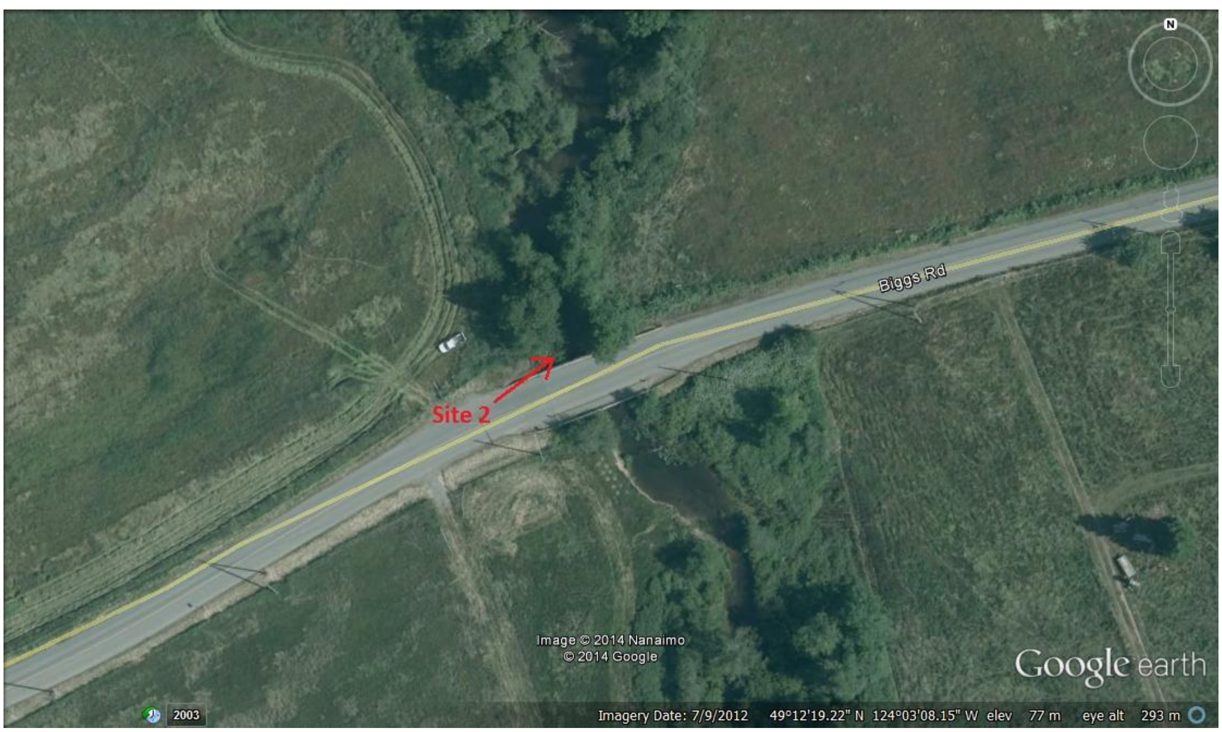


**Figure 9 –** Site 2 overhead view with flow going south (Google Earth 2014, edited by authors)

**Figure 10 –** Site 2 from street level with flow going from left to right (Photo by authors)


**Figure 11 –** Site 3 overhead view with flow going southeast (Google Earth 2014, edited by authors)

**Figure 12** – Site 3 from below bridge with flow going from right to left (Photo by authors)

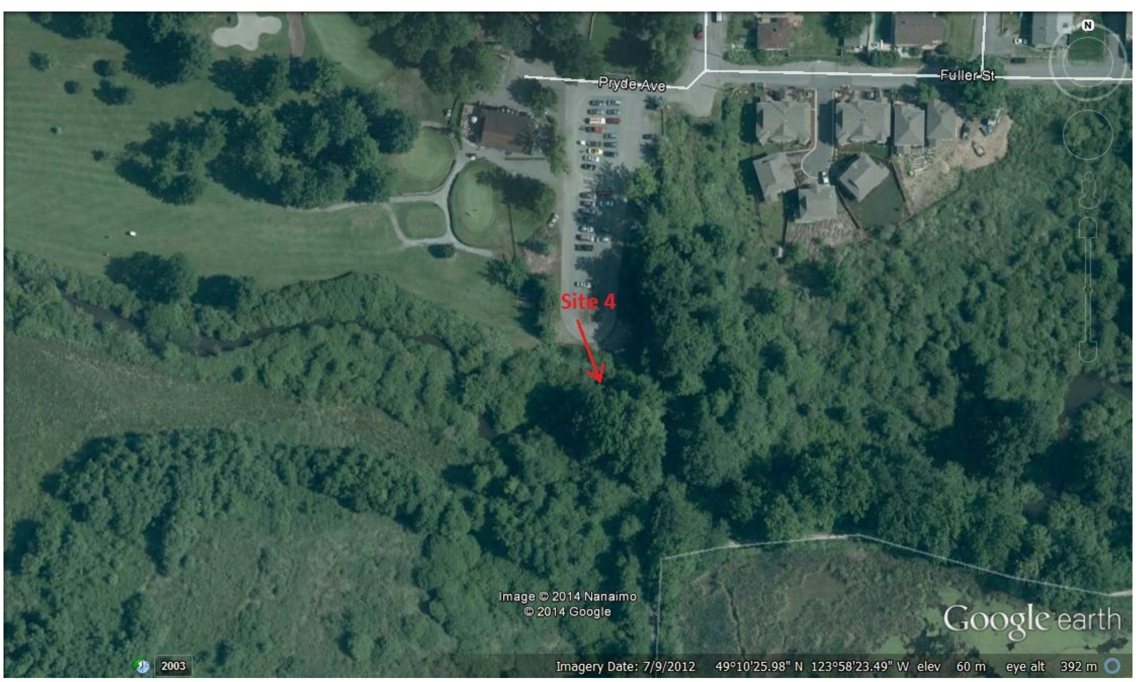


**Figure 13** – Site 4 overhead view with flow going east (Google Earth 2014, edited by authors)

**Figure 14 –** Site 4 from stream bank looking upstream (Photo by authors)


**Figure 15 –** Site 5 overhead view with flow going north out of duck pond (Google Earth 2014, edited by authors)

**Figure 16** – Site 5 from stream bank looking upstream towards duck pond (Photo by authors)


**Figure 17** – Site 6 overhead view with flow going north (Google Earth 2014, edited by authors)

**Figure 18 –** Site 6 from stream bank looking downstream (Photo by authors)

## 9.2 Tables

**Table 6**: Field measurements and VIU Laboratory results for water samples taken from 6 sites on the Millstone River during October 26-29/14.

| Field Measurements and VIU Laboratory Results<br>First Sample Event – October 26/14 | | | | | | | | | VIU Analysis October 29/14 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Station | Surface Velocity (m/s) | Discharge ($m^3/s$) | Temperature (°C) | Dissolved Oxygen (mg/L) | Conductivity (µS/cm) | pH | Alkalinity (mg/L $CaCO_3$) | Turbidity (NTU) | Nitrate mg/L | Orthophosphate (mg/L) |
| 1 | | | 9.7 | 11.3 | 38 | 7.84 | 13.2 | 2.12 | 0.17 | 0.17 |
| 2 | 0.7 | 2.27 | 12.6 | 9 | 59 | 7.75 | 29.2 | 3.51 | 0.05 | 0.08 |
| 3 | | | 12.3 | 9.8 | 77 | 7.55 | 29.6 | 5.33 | 0.43 | 0.06 |
| 4 | | | 11.6 | 9.8 | 90 | 7.57 | 33.2 | 9.77 | 0.5 | 0.05 |
| 5 | 0.6 | 0.22 | 11.4 | 10.6 | 101 | 7.68 | 34 | 6.67 | 0.48 | 0.08 |
| 6 | | | 11.4 | 11 | 99 | 7.85 | 35.6 | 14.7 | 0.49 | 0.07 |

(Table by authors)

**Table 7**: Field measurements and VIU Laboratory results for water samples taken from 6 sites on the Millstone River during November 16-19/14.

| Field Measurements and VIU Laboratory Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Second Sample Event – November 16/14 | | | | | | | | VIU Analysis November19/14 | | |
| Station | Surface Velocity (m/s) | Discharge ($m^3/s$) | Temperature (°C) | Dissolved Oxygen (mg/L) | Conductivity (μS/cm) | pH | Alkalinity (mg/L $CaCO_3$) | Turbidity (NTU) | Nitrate mg/L | Orthophosphate (mg/L) |
| 1 | | | 5.4 | 13.1 | 35 | 7.46 | 14.4 | 1.35 | 0.13 | 0.13 |
| 2 | 0.53 | 1.17 | 8.3 | 9.6 | 54 | 7.24 | 27.6 | 1.09 | 0.06 | 0.09 |
| 3 | | | 6.4 | 11.7 | 70 | 7.19 | 34 | 2.54 | 0.06 | 0.08 |
| 4 | | | 5.5 | 12 | 83 | 7.24 | 35.6 | 2.74 | 0.09 | 0.11 |
| 5 | 0.6 | 0.26 | 5.6 | 12.9 | 89 | 7.29 | 38.4 | 2.92 | 0.19 | 0.07 |
| 6 | | | 5.1 | 13.1 | 90 | 7.41 | 42 | 1.67 | 0.07 | 0.11 |

(Table by authors)

**Table 8**: VIU Laboratory results for coliform counted on bacterial plates to determine the total coliform, fecal coliform and % fecal coliform from samples taken from 6 sites on the Millstone River during October 26/14.

| VIU Laboratory Analysis Results for Coliform | | | |
|---|---|---|---|
| First Sample Event – October 26/14 | | | VIU Analysis |
| Station number | Total Coliform (CFU/100mL) | Fecal Coliform (CFU/100mL) | % Fecal Coliform |
| 1 | 204 | 8 | 3.9 |
| 2 | 144 | 80 | 56 |
| 3 | 4,156 | 404 | 9.7 |
| 4 | 3,832 | 604 | 15.8 |
| 5 | 4,076 | 564 | 13.8 |
| 6 | 4,196 | 444 | 10.6 |

(Table by authors)

**Table 9**: Results from samples taken at sites on the Millstone River on October 26/14 and November 16/14 Analyzed by ALS Laboratory.

| ALS Laboratory Results | Event 1 | | 10/26/14 | Event 2 | | 11/16/14 |
|---|---|---|---|---|---|---|
| | Station 1 | Station 2 | Station 5 | Station 1 | Station 2 | Station 5 |
| **Physical Tests** | | | | | | |
| Conductivity | 33.0 | 81.3 | 119 | 44.3 | 72.4 | 106 |
| Hardness (as CaCO3) | 13.7 | 31.9 | 40.5 | 18.3 | 29.1 | 39.5 |
| pH | 7.16 | 7.60 | 7.66 | 7.42 | 7.52 | 7.73 |
| **Anions and Nutrients** | | | | | | |
| Ammonia, Total (as N) | <0.0050 | <0.0050 | 0.0168 | <0.0050 | 0.0055 | 0.0076 |
| Nitrate (as N) | 0.446 | 0.0118 | 0.726 | 0.188 | 0.134 | 0.279 |
| Nitrite (as N) | <0.0010 | <0.0010 | 0.0031 | <0.0010 | <0.0010 | 0.0012 |
| Total Nitrogen | 0.588 | 0.215 | 1.05 | 0.276 | 0.323 | 0.464 |
| Orthophosphate-Dissolved (as P) | <0.0010 | <0.0010 | 0.0073 | <0.0010 | <0.0010 | 0.0029 |
| Phosphorus (P)-Total | 0.0058 | 0.0063 | 0.0353 | <0.0020 | 0.0053 | 0.0113 |
| TN:TP | 101 | 34 | 30 | 138.0 | 60.9 | 41.1 |
| **Total Metals** | | | | | | |
| Aluminum (Al)-Total | <0.20 | <0.20 | 0.72 | <0.20 | <0.20 | <0.20 |
| Antimony (Sb)-Total | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic (As)-Total | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Barium (Ba)-Total | <0.010 | <0.010 | 0.021 | <0.010 | <0.010 | 0.010 |
| Beryllium (Be)-Total | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth (Bi)-Total | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron (B)-Total | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium (Cd)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Calcium (Ca)-Total | 3.78 | 8.50 | 11.4 | 5.15 | 7.96 | 11.1 |
| Chromium (Cr)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt (Co)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Copper (Cu)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Iron (Fe)-Total | 0.142 | 0.118 | 1.16 | <0.030 | 0.173 | 0.326 |
| Lead (Pb)-Total | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lithium (Li)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Magnesium (Mg)-Total | 1.03 | 2.59 | 2.91 | 1.33 | 2.25 | 2.84 |
| Manganese (Mn)-Total | <0.0050 | 0.0123 | 0.0963 | <0.0050 | 0.0226 | 0.0224 |
| Molybdenum (Mo)-Total | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel (Ni)-Total | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| Phosphorus (P)-Total | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium (K)-Total | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| Selenium (Se)-Total | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon (Si)-Total | 3.69 | 2.61 | 4.59 | 3.79 | 3.35 | 3.92 |
| Silver (Ag)-Total | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium (Na)-Total | <2.0 | 4.0 | 8.8 | <2.0 | 3.6 | 7.3 |
| Strontium (Sr)-Total | 0.0129 | 0.0297 | 0.0671 | 0.0199 | 0.0310 | 0.0771 |
| Thallium (Tl)-Total | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin (Sn)-Total | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium (Ti)-Total | <0.010 | <0.010 | 0.038 | <0.010 | <0.010 | <0.010 |
| Vanadium (V)-Total | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc (Zn)-Total | <0.0050 | <0.0050 | 0.0075 | <0.0050 | <0.0050 | <0.0050 |

**Table 10**: Site 1 invertebrate survey field data sheet

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

| | | |
|---|---|---|
| Stream Name: Millstone River | | Date: October 28, 2014 |
| Station Name: Site 1 | | Flow status: high |
| Sampler Used: Hess | Number of replicates 3 | Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m² |

| Column A Pollution Tolerance | Column B Common Name | Column C Number Counted | Column D Number of Taxa |
|---|---|---|---|
| Category 1 | Caddisfly Larva (EPT) | EPT1 1 | EPT4 1 |
| | Mayfly Nymph (EPT) | EPT2 | EPT5 |
| | Stonefly Nymph (EPT) | EPT3 6 | EPT6 1 |
| | Dobsonfly (hellgrammite) | | |
| Pollution Intolerant | Gilled Snail | | |
| | Riffle Beetle | | |
| | Water Penny | | |
| Sub-Total | | C1 7 | D1 2 |
| Category 2 | Alderfly Larva | | |
| | Aquatic Beetle | | |
| | Aquatic Sowbug | 1 | 1 |
| | Clam, Mussel | | |
| | Cranefly Larva | 5 | 2 |
| | Crayfish | | |
| Somewhat Pollution Tolerant | Damselfly Larva | | |
| | Dragonfly Larva | | |
| | Fishfly Larva | | |
| | Amphipod (freshwater shrimp) | | |
| | Watersnipe Larva | | |
| Sub-Total | | C2 6 | D2 3 |
| Category 3 | Aquatic Worm (oligochaete) | 170 | 2 |
| | Blackfly Larva | | |
| | Leech | | |
| | Midge Larva (chironomid) | 2 | 1 |
| | Planarian (flatworm) | | |
| Pollution Tolerant | Pouch and Pond Snails | | |
| | True Bug Adult | | |
| | Water Mite | 1 | 1 |
| Sub-Total | | C3 173 | D3 4 |
| TOTAL | | CT 186 | DT 9 |

**Figure 19:** Site 1 invertebrate survey interpretation sheet

## INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

### SECTION 1 - ABUNDANCE AND DENSITY

**ABUNDANCE:** Total number of organisms from cell CT: S1 186

**DENSITY:** Invertebrate density per total area sampled:

S1 186 ÷ 0.27 $m^2$ = S2 689 / $m^2$

**PREDOMINANT TAXON:**
Invertebrate group with the highest number counted (Col. C) S3 170 (aquatic worm)

### SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 2 + 2 x 3 + 4 = S4 16

**EPT INDEX:** Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

1 + - + 1 = S5 2

**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

( 1 + - + 6 ) / 186 = S6 0.04

### SECTION 3 - DIVERSITY

**TOTAL NUMBER OF TAXA:** Total number of taxa from cell DT: S7 9

**PREDOMINANT TAXON RATIO INDEX:** Number of invertebrate in the **predominant taxon** (S3) divided by CT.

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

Col. C for S3 / CT

170 / 186 = S8 0.91

### SECTION 4 - OVERALL SITE ASSESSMENT RATING

**SITE ASSESSMENT RATING:** Assign a rating of 1-4 to each index (S4, S5, S6, S8), then calculate the average.

| Assessment Rating | |
|---|---|
| Good | 4 |
| Acceptable | 3 |
| Marginal | 2 |
| Poor | 1 |

| Assessment | Rating |
|---|---|
| Pollution Tolerance Index | R1 2 |
| EPT Index | R2 2 |
| EPT To Total Ratio | R3 1 |
| Predominant Taxon Ratio | R4 1 |

| Average Rating |
|---|
| Average of R4, R5, R6, R8 |
| 1.5 |

**Table 11**: Site 2 invertebrate survey field data sheet

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

| | | |
|---|---|---|
| Stream Name: Millstone River | | Date: October 28, 2014 |
| Station Name: Site 2 | | Flow status: high |
| Sampler Used: Hess | Number of replicates 3 | Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m² |

| Column A Pollution Tolerance | Column B Common Name | Column C Number Counted | Column D Number of Taxa |
|---|---|---|---|
| Category 1 | Caddisfly Larva (EPT) | EPT1 13 | EPT4 2 |
| | Mayfly Nymph (EPT) | EPT2 | EPT5 |
| | Stonefly Nymph (EPT) | EPT3 | EPT6 |
| | Dobsonfly (hellgrammite) | | |
| Pollution Intolerant | Gilled Snail | | |
| | Riffle Beetle | | |
| | Water Penny | | |
| **Sub-Total** | | C1 13 | D1 2 |
| Category 2 | Alderfly Larva | 1 | 1 |
| | Aquatic Beetle | | |
| | Aquatic Sowbug | | |
| | Clam, Mussel | | |
| | Cranefly Larva | | |
| | Crayfish | | |
| Somewhat Pollution Tolerant | Damselfly Larva | | |
| | Dragonfly Larva | | |
| | Fishfly Larva | | |
| | Amphipod (freshwater shrimp) | 170 | 1 |
| | Watersnipe Larva | | |
| **Sub-Total** | | C2 171 | D2 2 |
| Category 3 | Aquatic Worm (oligochaete) | 83 | 2 |
| | Blackfly Larva | | |
| | Leech | | |
| | Midge Larva (chironomid) | | |
| Pollution Tolerant | Planarian (flatworm) | | |
| | Pouch and Pond Snails | | |
| | True Bug Adult | | |
| | Water Mite | | |
| **Sub-Total** | | C3 83 | D3 2 |
| **TOTAL** | | CT 267 | DT 6 |

**Figure 20:** Site 2 invertebrate survey interpretation sheet

## INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

### SECTION 1 - ABUNDANCE AND DENSITY

**ABUNDANCE:** Total number of organisms from cell CT: S1 267

**DENSITY:** Invertebrate density per total area sampled:

S1 267 ÷ 0.27 $m^2$ = S2 989 / $m^2$

**PREDOMINANT TAXON:** Invertebrate group with the highest number counted (Col. C) S3 170 (amphipod)

### SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 2 + 2 x 2 + 2 = S4 12

**EPT INDEX:** Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

2 + - + - = S5 2

**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

( 13 + - + - ) / 267 = S6 0.05

### SECTION 3 - DIVERSITY

**TOTAL NUMBER OF TAXA:** Total number of taxa from cell DT: S7 6

**PREDOMINANT TAXON RATIO INDEX:** Number of invertebrate in the **predominant taxon** (S3) divided by CT.

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

Col. C for S3 / CT

170 / 267 = S8 0.64

### SECTION 4 - OVERALL SITE ASSESSMENT RATING

**SITE ASSESSMENT RATING:** Assign a rating of 1-4 to each index (S4, S5, S6, S8), then calculate the average.

| Assessment Rating | |
|---|---|
| Good | 4 |
| Acceptable | 3 |
| Marginal | 2 |
| Poor | 1 |

| Assessment | Rating |
|---|---|
| Pollution Tolerance Index | R1 2 |
| EPT Index | R2 2 |
| EPT To Total Ratio | R3 1 |
| Predominant Taxon Ratio | R4 2 |

| Average Rating |
|---|
| Average of R4, R5, R6, R8 |
| 1.75 |

**Table 12**: Site 5 invertebrate survey field data sheets

## INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

| | | |
|---|---|---|
| Stream Name: Millstone River | | Date: October 28, 2014 |
| Station Name: Site 5 | | Flow status: high |
| Sampler Used: Hess | Number of replicates 3 | Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m² |

| Column A Pollution Tolerance | Column B Common Name | Column C Number Counted | Column D Number of Taxa |
|---|---|---|---|
| Category 1 | Caddisfly Larva (EPT) | EPT1 22 | EPT4 2 |
| | Mayfly Nymph (EPT) | EPT2 | EPT5 |
| | Stonefly Nymph (EPT) | EPT3 370 | EPT6 2 |
| | Dobsonfly (hellgrammite) | | |
| Pollution Intolerant | Gilled Snail | | |
| | Riffle Beetle | | |
| | Water Penny | | |
| Sub-Total | | C1 392 | D1 4 |
| Category 2 | Alderfly Larva | 1 | 1 |
| | Aquatic Beetle | | |
| | Aquatic Sowbug | 3 | 1 |
| | Clam, Mussel | | |
| | Cranefly Larva | | |
| | Crayfish | | |
| Somewhat Pollution Tolerant | Damselfly Larva | | |
| | Dragonfly Larva | | |
| | Fishfly Larva | | |
| | Amphipod (freshwater shrimp) | 413 | 1 |
| | Watersnipe Larva | | |
| Sub-Total | | C2 417 | D2 2 |
| Category 3 | Aquatic Worm (oligochaete) | 70 | 2 |
| | Blackfly Larva | | |
| | Leech | 2 | 2 |
| | Midge Larva (chironomid) | 11 | 1 |
| Pollution Tolerant | Planarian (flatworm) | | |
| | Pouch and Pond Snails | | |
| | True Bug Adult | | |
| | Water Mite | | |
| Sub-Total | | C3 83 | D3 5 |
| TOTAL | | CT 892 | DT 11 |

**Figure 21:** Site 5 invertebrate survey interpretation sheet

## INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

### SECTION 1 - ABUNDANCE AND DENSITY

**ABUNDANCE:** Total number of organisms from cell CT: S1 892

**DENSITY:** Invertebrate density per total area sampled:

S1 892 ÷ 0.27 $m^2$ = S2 3,304 / $m^2$

**PREDOMINANT TAXON:**
Invertebrate group with the highest number counted (Col. C) S3 413 (amphipod)

### SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 4 + 2 x 2 + 5 = S4 21

**EPT INDEX:** Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

2 + - + 2 = S5 4

**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

( 22 + - + 370 ) / 892 = S6 0.44

### SECTION 3 - DIVERSITY

**TOTAL NUMBER OF TAXA:** Total number of taxa from cell DT: S7 11

**PREDOMINANT TAXON RATIO INDEX:** Number of invertebrate in the predominant taxon (S3) divided by CT.

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

Col. C for S3 / CT

413 / 892 = S8 0.46

### SECTION 4 - OVERALL SITE ASSESSMENT RATING

**SITE ASSESSMENT RATING:** Assign a rating of 1-4 to each index (S4, S5, S6, S8), then calculate the average.

| Assessment Rating | |
|---|---|
| Good | 4 |
| Acceptable | 3 |
| Marginal | 2 |
| Poor | 1 |

| Assessment | Rating |
|---|---|
| Pollution Tolerance Index | R1 3 |
| EPT Index | R2 2 |
| EPT To Total Ratio | R3 2 |
| Predominant Taxon Ratio | R4 3 |

| Average Rating |
|---|
| Average of R4, R5, R6, R8 |
| 2.5 |

**Table 13**: Site 1 Shannon-Weiner diversity index

| Common Name | Column C | $p_i$(C/T) | Ln($p_i$) | $p_i$ * ln ($p_i$) |
|---|---|---|---|---|
| Caddisfly Larva | 1 | 0.005 | -5.29 | -0.026 |
| Stonefly Nymph | 6 | 0.03 | -3.51 | -0.105 |
| Aquatic Sowbug | 1 | 0.005 | -5.29 | -0.026 |
| Cranefly Larva | 5 | 0.026 | -3.65 | -0.095 |
| Aquatic Worm | 170 | 0.91 | -0.09 | -0.082 |
| Midge Larva | 2 | 0.01 | -4.61 | -0.046 |
| Water Mite | 1 | 0.005 | -5.29 | -0.026 |
| **Total** | **186** | **1.0** | **---** | **-0.406** |

Shannon-Weiner: (Table by authors)
-(-0.406)/ln(7)
= -(-0.406)/1.946
= **0.208**

**Table 14**: Site 2 Shannon-Weiner diversity index

| Common Name | Column C | $p_i$ (C/T) | Ln($p_i$) | $p_i$ * ln ($p_i$) |
|---|---|---|---|---|
| Caddisfly Larva | 13 | 0.048 | -3.036 | -0.146 |
| Alderfly Larva | 1 | 0.004 | -5.521 | -0.022 |
| Amphipod | 170 | 0.637 | -0.451 | -0.287 |
| Aquatic Worm | 83 | 0.311 | -1.168 | -0.363 |
| **Total** | **267** | **1.0** | **---** | **-0.818** |

Shannon-Weiner: (Table by authors)
-(-0.818)/ln(4)
= -(-0.818)/1.386
= **0.590**

**Table 15**: Site 5 Shannon-Weiner diversity index

| Common Name | Column C | $p_i$ (C/T) | Ln($p_i$) | $p_i$ * ln ($p_i$) |
|---|---|---|---|---|
| Caddisfly Larva | 22 | 0.024 | -3.729 | -0.089 |
| Stonefly Nymph | 370 | 0.415 | -0.879 | -0.365 |
| Alderfly Larva | 1 | 0.001 | -6.908 | -0.007 |
| Aquatic Sowbug | 3 | 0.003 | -5.809 | -0.017 |
| Amphipod | 413 | 0.463 | -0.770 | -0.356 |
| Aquatic Worm | 70 | 0.078 | -2.551 | -0.199 |
| Leech | 2 | 0.002 | -6.214 | -0.012 |
| Midge Larva | 11 | 0.012 | -4.423 | -0.053 |
| **Total** | **892** | **1.0** | **---** | **-1.098** |

(Table by authors)

Shannon-Weiner:
-(-1.098)/ln(8)
= -(-1.098)/2.079
= **0.528**