DATA REPORT

Water Quality and Stream Invertebrate Assessment

for the Millstone River, Nanaimo, BC,

(Fall 2010)

Report prepared by:

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1. Background

This report documents a water quality and stream invertebrate assessment conducted on the Millstone River, BC, during November 2010.

This study was undertaken by undergraduate students attending the Environmental Monitoring (RMOT 306) course at Vancouver Island University (VIU), offered as part of the Bachelor of Natural Resources Protection (Daniel Clark, Alysha Hile, Craig McCulloch). Students worked under the supervision of the course instructor, Dr. Eric Demers (Vancouver Island University). This report was compiled by Dr. Eric Demers based on student group reports.

VIU students contributed approximately 35 student-hours to this project, including site visits, project proposal, field sampling, laboratory analyses, and oral and written presentations. Dr. Eric Demers contributed approximately 10 hours for project management and report compilation.

Logistical support was provided by Fisheries and Oceans Canada (DFO). Funding for field expenses and analytical processing of water samples was provided by the Living Rivers - Georgia Basin / Vancouver Island program and Fisheries and Oceans Canada. ALS Laboratory (Vancouver, BC) provided reduced rates on their analytical services for this project.

2. Introduction

The Millstone River watershed encompasses an area of approximately 93 km^2 and is comprised of 26 km of streams, 16 tributaries and 8 lakes. The primary drainage network in the watershed consists of Benson Creek, Brannen Lake and the Millstone River. Benson Creek originates west of Mount Benson at Lucid Lake (elevation: 619 m), and flows in a northerly direction for approximately 12 km into Brannen Lake (elevation: 78 m). The Millstone River flows from Brannen Lake in a southeasterly direction for approximately 14 km to the Strait of Georgia at the Nanaimo Harbour.

During summer 2007, an 800-metre long bypass channel was constructed along the lower Millstone River in Bowen Park by the Nanaimo Fish and Game Protective Association, in partnership with Fisheries and Oceans Canada (DFO) and the City of Nanaimo. The bypass channel was built to provide anadromous salmonids with new spawning and juvenile rearing habitat, and access to the watershed above the Deadman Falls barrier in Bowen Park. Additional habitat restorations were conducted by DFO during 2008 and 2009 to provide summer flow augmentation to the Millstone River and bypass channel.

A need was identified for continued monitoring of water and habitat quality of the Millstone River and bypass channel. Therefore, this report documents a water quality and stream invertebrate assessment conducted on the Millstone River during November 2010.

Specific objectives for this study of the Millstone River included:

- establish 5 water quality sampling stations;

- obtain field measurements of water quality at the 5 sampling stations during two sampling events (early and late November 2010);
- obtain water samples from each sampling station during two sampling events (early and late November 2010) for detailed laboratory analyses; and,
- collect stream invertebrate samples at 3 sampling stations during one sampling event (early November 2010) for analysis at Vancouver Island University.

3. Methods

3.1. Study Site

This project was conducted on Benson Creek and the Millstone River located in the City of Nanaimo, BC (Figure 1).

3.1.1. Sampling Stations

Five sampling stations were established on Benson Creek and the Millstone River, during November 2010 (Tables 1 and 2; Figure 1). The location of each station was chosen to provide adequate coverage for the length of the Millstone River and to repeat sampling at some of the stations previously used by VIU. Stations were numbered from upstream to downstream (Station 1 on Benson Creek; Stations 2-5 on the Millstone River). All stations were easily accessed via foot paths or road crossings. Station 1 was located on Benson Creek at a crossing on Biggs Road. Stations 2 and 3 were located on the Millstone River at crossings on Biggs Road, and Durnin Road, respectively. Station 4 was located midway along the bypass channel in Bowen Park. Station 5 was located in Barsby Park, approximately 10 m upstream of the Millstone estuary. All stations consisted of shallow and gentle riffle sections.

3.1.2. Sampling Schedule

Field sampling was conducted on 3 and 24 November 2010. For this study, samples were collected for water quality analyses, microbiology and stream invertebrate assessment. Table 2 lists the specific activities conducted at each station during each sampling event. Microbiology and stream invertebrate assessments were only completed during the early November sampling event. Photographs showing site conditions are included in Appendix 1.

3.2. Water Quality

3.2.1. Field Measurements

Water quality sampling events were conducted on 3 and 24 November 2010. At each sampling station, field measurements of water temperature (to the nearest 0.1 ^{o}C), dissolved oxygen (to the nearest 0.1 mg/L), conductivity (to the nearest 1 µSiemens/cm) and pH (to the nearest 0.01 pH unit) were obtained with a YSI 556 MPS electronic probe. The electronic probe was placed directly in the channel water.

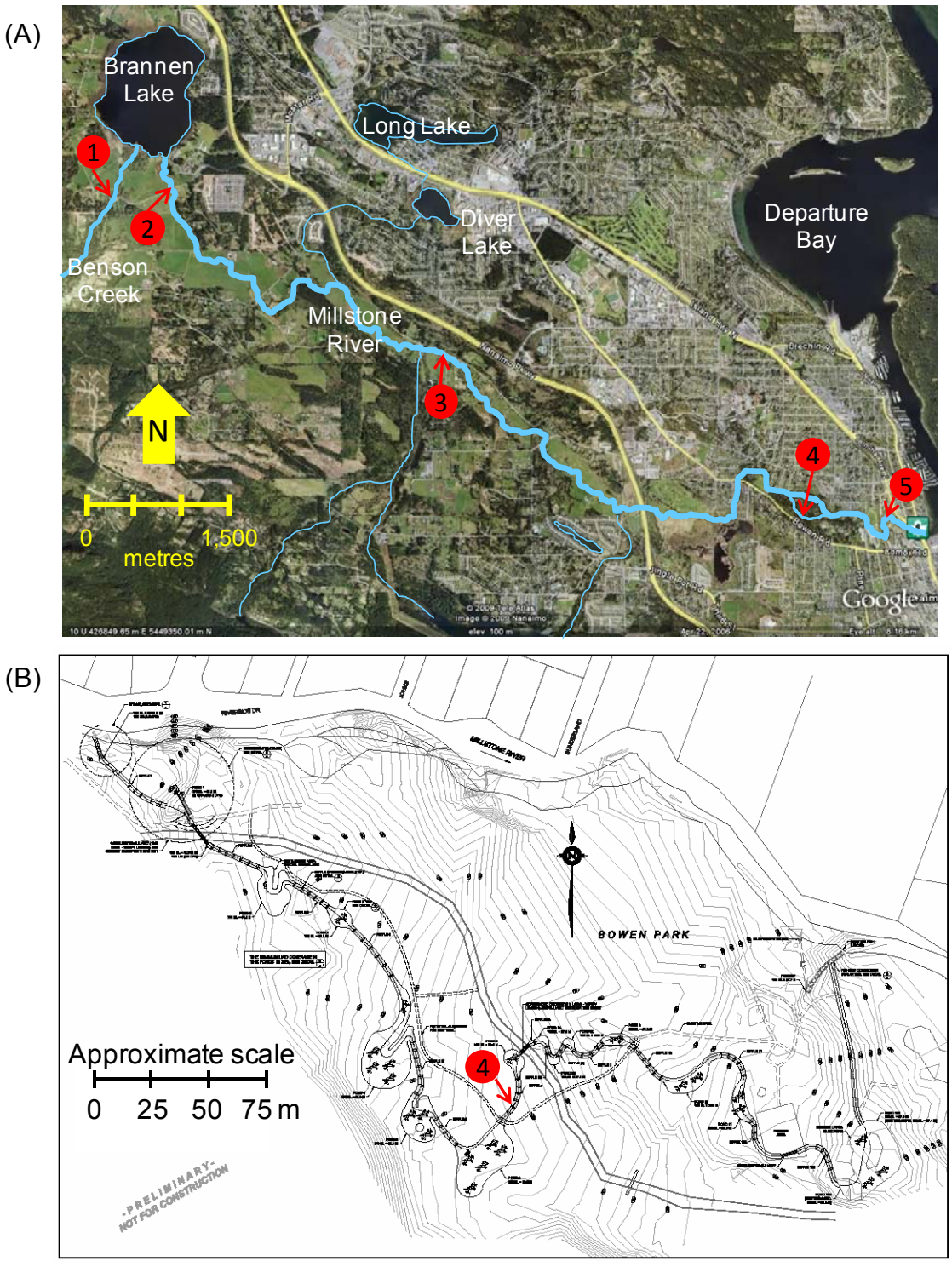

Figure 1. (A) Approximate location of the sampling stations used for water quality and stream invertebrate assessments on the Millstone River during November 2010. Station 1 was located on Benson Creek. This map was obtained from Google Earth. (B) Approximate location of sampling stations 4 along the Millstone River Bypass Channel. This map was obtained from Fisheries and Oceans Canada. Table 1 provides details of the specific location of each station. Table 2 details the sampling activities conducted at each station. Map scales are approximated.

Table 1. Description of the sampling stations used for water quality and stream invertebrate assessments on the Millstone River during November 2010. Station 1 was located on Benson Creek. All northing and easting coordinates are based on zone 10U and were approximated with Google Earth.

Station	UTM Coordinates		General Location
	Easting	Northing	
1	422736	5450704	Benson Creek, Biggs Road crossing
2	423348	5450814	Millstone River, Biggs Road crossing
3	426302	5448964	Durnin Road crossing
4	430047	5447279	Bypass channel, midway
5	431035	5447202	Barsby Park, 10-m of estuary

Table 2. Water quality and stream invertebrate sampling activities conducted at each station on the Millstone River during November 2010. The symbols "A" or "B" indicate whether samples / measurements were taken during the early or late November sampling events, respectively.

Station	Water Quality				Stream Invertebrates
	Field Measurements	VIU Analyses	ALS Lab Analyses	Microbiology	
1	A[1], B	A, B	---	A	---
2	A[1], B	A[2], B[2]	A, B	A	A
3	A[1], B	A, B	A, B	A	A
4	A[1], B	A, B	A, B	A	A
5	A, B	A, B	A, B	A	---

Note: [1] Basic hydrological measurements were only collected at stations 1-4 during the early November sampling event.

[2] A duplicate sample was collected at station 2 for analysis at the VIU Laboratory.

Basic hydrological measurements were taken at stations 1-4 on 3 November 2010. No measurements were taken at station 5 where flow conditions were unsafe for wading. Water velocity (in m/s) was measured along a 10-m stream length. A water-filled ping-pong ball was dropped slightly upstream of the stream length and allowed to float downstream through the stream length. A stopwatch was used to measure the travel time of the ball between the upstream and downstream ends of the stream length. The average travel time from 3-5 passes was used to calculate average water velocity.

Stream wetted widths were measured with a metered tape to the nearest 0.1 m, and wetted depths were measured (along the same wetted widths) with a meter stick to the nearest 0.01 m. Total cross-sectional areas (in m^2) were calculated as the sum of the areas of cross-section polygons. Stream discharge (in m^3/s) was obtained as the product of mean water column velocity and cross sectional area.

3.2.2. Water Sampling

During each sampling event, two sets of water samples were collected for laboratory analyses: one set was transported for analysis at Vancouver Island University (VIU), and another set was shipped for analysis by ALS Laboratory, in Vancouver, BC.

Water samples for analysis at VIU were collected from all stations (Table 2). At each station, a clean pre-labelled 500-ml plastic bottle was rinsed 3 times and then used to collect a water sample (Table 3). A duplicate sample was collected at station 2 during both sampling events for analysis at the VIU Laboratory. All water samples were obtained while standing on the stream bank or within the stream channel by immersing the containers just below the water surface while facing upstream. Care was taken not to disturb the bottom sediments. All water samples were kept in a cooler and stored at approximately 4^{o}C. Laboratory analyses were conducted at VIU within 48 hours of sampling.

Table 3. Sampling containers and preservatives used for water quality samples taken from the Millstone River during November 2010. All containers and preservatives for analysis by ALS Laboratory were provided by ALS Laboratory, Vancouver, BC.

Analytical Parameters	Container	Preservative	Analysed by
Total alkalinity, turbidity	500 ml plastic	None	VIU
Conductivity, pH, total hardness	1 L plastic	None	ALS Laboratory
Nutrients	250 ml amber glass	Sulphuric acid	ALS Laboratory
Total metals	250 ml plastic	Nitric acid	ALS Laboratory

Samples for analysis by ALS Laboratory were collected from all stations (except station 1) during both sampling events (Table 2). At each station, water samples were collected in three clean laboratory-supplied and pre-labelled sample containers (Table 3). All samples were obtained while standing on the stream bank or within the stream channel by directly immersing the containers just below the water surface while facing upstream. Care was taken not to disturb the bottom sediments. Samples for analysis of nutrients and total metals were preserved with laboratory-supplied sulphuric acid and nitric acid, respectively. Bottles with preservatives were inversed five times for adequate mixing. All water samples were stored in a cooler on site, and shipped with ice packs within 72 hours for laboratory analyses at ALS Laboratory.

3.2.3. VIU Laboratory Analyses

Water samples transported to Vancouver Island University were analysed for total alkalinity and turbidity. Total alkalinity (as $CaCO_3$) was measured to the nearest 0.1 mg/L using the HACH AL-DT digital titration method. Turbidity was measured to the nearest 1 FAU (Formazin attenuation units) using a HACH DR2000 Spectrophotometer (Method 8006).

3.2.4. ALS Laboratory Analyses

Water samples submitted for external analyses were processed as per ALS Laboratory standard analytical procedures. The analytes were: conductivity, total hardness, pH, nutrients (ammonia, nitrite, nitrate, orthophosphate and total phosphorus), and total metals (31 metals).

3.2.5. Quality Assurance / Quality Control

Throughout this study, measures were taken to ensure that potential contamination of water samples was minimized. This included using only clean and rinsed containers, preserving samples as prescribed by the analytical laboratory, and storing collected samples in well-labelled containers. Duplicate sampling provided an estimate of the overall precision associated with the field technique and laboratory analysis.

3.2.6. Data Analyses – Comparison with Applicable Guidelines

Water quality results were compared with the applicable provincial water quality guidelines for the protection of freshwater life. The BC Water Quality Guidelines are the maximum allowable concentration (for potential acute effects) and the 30-day average concentration (for potential chronic effects). All guidelines were obtained from the BC Ministry of Environment, Water Protection Division (http://www.env.gov.bc.ca/wat/wq/).

It is important to note that for some metal parameters, analytical detection limits were above applicable guidelines. These include aluminium, antimony, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, thallium and vanadium. For these metals, measured values reported to be below method detection limits cannot be assumed to be below the applicable guidelines.

3.3. Microbiology

3.3.1. Field Sampling

Water samples for total and fecal coliform enumeration were collected from each sampling station on 3 November 2010 (Table 2). At each station, a sterile pre-labelled 120-ml Whirl-Pak® bag was used to collect a 100-ml water sample by directly immersing the bag by hand just below the water surface while facing upstream. All samples were stored in a cooler with ice packs and transported within 48 hours to Vancouver Island University for laboratory analysis.

3.3.2. Laboratory Analyses

In the laboratory, water samples were tested for total coliform and fecal coliform (*Escherichia coli* or *E. coli*) using the m-coliBlue24 membrane filtration method (Millipore Corporation). A 25-ml volume of sample water was filtered through a 47-µm membrane filter (marked with 3-mm gridlines) using a vacuum pump. The filtration apparatus was then rinsed with approximately 5 ml of sterile water. A filtration blank was also completed with 25 ml of sterile water using the same filtration procedures. Each membrane filter (including the blank) was then

transferred to a Petri plate containing an absorbent pad saturated with m-ColiBlue24 broth. All membrane filters were incubated at 37°C for 20 hours (until bacterial colonies were clearly visible).

Upon completion of the incubation period, membrane filters were then examined for bacterial colonies under a dissection microscope (16X magnification). A red or blue colony represents a total coliform "positive" result (Table 4). A blue colony specifically represents an *E. coli* "positive" result. A clear or white colony represents a total coliform negative result.

All colonies present on a membrane filter were counted and expressed as CFU (colony forming units) per 100-ml of sample water.

Table 4. Possible outcomes of the m-coliBlue24 membrane filtration method.

Bacteria Type	Positive Result	Negative Result
Total coliform	Red or blue colony	Clear or white colony No colony
E. coli	Blue colony only	Non-blue colony

3.4. Stream Invertebrates

3.4.1. Sampling Stations

Stream invertebrate samples were collected from stations 2-4 on 3 November 2010 (Table 1; Figure 1). The sampling stations were selected based on hydrological characteristics, apparent substrate uniformity, space available for replicate samples, safety and site access. At the time of sampling, all stations consisted of shallow riffles (water depth ~10-25 cm), with water velocity of ~0.5-1.0 m/s, and primarily sand and gravel substrate.

3.4.2. Invertebrate Sampling

At each station, three replicate samples (triplicates) were obtained using a Hess sampler as per the Pacific Streamkeepers procedures (Taccogna and Munro 1995). Each site was approached by walking from downstream. The invertebrate sampler was hand-pressed into the substrate to isolate a 0.09-m^2 sampling area. All stones and debris 5 cm or larger within the sampling area were held under water in front of the collecting net and rubbed gently by hand to dislodge invertebrates. Cleaned stones and debris were then placed downstream of the sampling area. The streambed was then gently agitated to a depth of 5 cm to loosen any remaining invertebrates. The content of the collecting net was then transferred into a 125-ml plastic sample jar. The net was carefully inspected to ensure all contents were transferred into the sample jar. Samples were stored in a cooler and transported to Vancouver Island University, where laboratory analyses were completed within 48 hours of sampling.

3.4.3. VIU Laboratory Analyses

Laboratory procedures and identification also followed the Pacific Streamkeepers procedures (Taccogna and Munro 1995). The triplicate samples from each station were combined into a single composite sample per station. The contents of all invertebrate sample jars from a station were poured into a shallow white tray. Invertebrates were sorted into apparent taxonomic groups. Identification to the appropriate taxonomic level (as prescribed by the Pacific Streamkeepers procedures) was confirmed using a dissecting microscope. The number of invertebrates and the number of distinguishable subgroups within each broad taxonomic group were recorded on a Pacific Streamkeeper Invertebrate Survey Field Data Sheet. From these records, various useful metrics were calculated for each station, including: total density (number per m^2), total number of taxonomic groups, predominant taxonomic group, Pollution Tolerance Index, EPT (Ephemeroptera-Plecoptera-Trichoptera) Index, EPT to Total Ratio Index, Predominant Taxon Ratio Index, and overall Site Assessment Rating.

4. Results

Discharge measurements for the Millstone River suggest that water levels were near bankfull at the time of sampling in early November 2010 (Table 5). Discharge in Benson Creek was higher than in the Millstone River at Biggs Rd suggesting that the storage capacity of Brannen Lake (source of the Millstone River) had not yet been fully exceeded. The marked increase in discharge between stations 2 and 3 was possibly due to significant inflow from McGarrigle Creek, which enters the Millstone River approximately 350 m upstream of station 3.

Average air temperature during the 10-day period prior to each sampling event was 9.4^{o}C and 0.4 ^{o}C for the early and late November sampling events, respectively (data for Nanaimo Airport retrieved from http://climate.weatheroffice.gc.ca). Total rainfall during the 10-day period prior to the early November sampling event was 39 mm. Total precipitation during the 10-day period prior to the late November sampling event included 24 mm of rain and 32 cm of snow, with 24 cm of snow on 19 November 2010.

4.1. Water Quality

4.1.1. Field Measurements and VIU Laboratory Analyses

Water temperature averaged 9.5^{o}C and 3.6^{o}C during the early and late November sampling events, respectively (Table 5). The drop in water temperature between sampling events was related to the concurrent decline in air temperature. During late November, water temperature in the upper Millstone River was tempered by warmer water from Brannen Lake, but temperature gradually declined with distance downstream.

During both sampling events, all dissolved oxygen levels were above the minimum guideline of 9.0 mg/L for early fish life stages (RISC 1998). Overall, dissolved oxygen concentrations were at 83-130% saturation.

Table 5. Field measurements and laboratory results (VIU Laboratory) for water samples taken from five stations on the Millstone River during November 2010. Discharge measurements were only collected at stations 1-4 during the early November sampling event. VIU Laboratory results for station 4 during both sampling events represent the average of duplicate samples.

		Field Measurements				VIU Laboratory	
Station	Discharge (m^3/s)	Temperature (^oC)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	pH	Total Alkalinity (mg/L $CaCO_3$)	Turbidity (FAU)
			3 November 2010				
1	6.34	8.20	11.91	32	6.00	22.8	<1
2	4.38	9.43	11.41	72	6.47	21.4	2
3	7.83	10.28	10.80	77	6.61	23.6	3
4	0.32	9.70	11.32	92	6.85	31.6	9
5		9.90	10.76	91	7.02	24.8	9
			24 November 2010				
1		2.45	15.14	41	8.16	14.0	<1
2		6.43	16.01	70	7.59	21.6	3
3		4.11	13.43	89	8.88	30.0	2
4		3.02	11.08	110	9.52	47.2	3
5		2.14	16.81	120	9.37	35.2	3

Conductivity ranged from 32 to 120 µS/cm and increased as expected from upstream to downstream (Table 5). Conductivity increased by an average of 18% within station between sampling events. This pattern was opposite from observations in previous years (VIU 2009, 2010), when conductivity usually declined between sampling events due to dilution effect from the increased discharge.

Water pH ranged from 6.00 to 9.52 during this study, and there was an average increase of 2.1 pH units between sampling events. There was a general increasing trend in pH from upstream to downstream during both sampling events.

Total alkalinity ranged from 21.4 to 47.2 mg/L, and increased between the early and late November sampling events at all stations except Benson Creek (Table 5). There was a general increasing trend in alkalinity from upstream to downstream during both sampling events.

Overall, total alkalinity was above 20 mg/L during both sampling events, indicating "low acid sensitivity" as defined by RISC (1998).

Turbidity levels were at or below 3 FAU, except during early November at stations 4 and 5 when turbidity was 9 FAU.

A comparison of the water quality results from the duplicate samples taken at station 2 indicates that most values were within ±18% of each other.

4.1.2. ALS Laboratory Analyses

Water quality results from ALS Laboratories were compared to the BC Provincial water quality guidelines for the protection of aquatic life (Table 6).

The conductivity measurements from ALS Laboratories were consistent with the field measurements obtained with the electronic probe and differed by <4%. Both sets of conductivity results displayed consistent trends where conductivity increased from upstream to downstream stations, and generally increased between sampling events.

Total hardness ranged from 26.2 to 36.2 mg/L, and there was a general increase from upstream to downstream stations. Total hardness was below 60 mg/L during both sampling events, indicating "soft water" as defined by RISC (1998).

The pH measurements from ALS Laboratories span a narrower range of values (7.39-7.83) than the field measurements obtained with the electronic probe. This discrepancies possibly reflects improper probe calibration, differences in air space content among sampling containers and/or time elapsed between sampling and laboratory analysis. As with the field measurements, the ALS Laboratories results displayed a general increase between sampling events and with distance downstream. All pH levels were within or near the recommended range of 6.5-9.0 for aquatic life (RISC 1998).

All nutrient levels were below applicable guidelines and/or below detection limits. Total ammonia was below or near detection limit (i.e., <0.005 mg/L) during the early November sampling event, but increased during the late November sampling event when levels reached 0.011-0.023 mg/L. Nitrate concentrations generally increased from upstream to downstream, and averaged 0.148 and 0.164 mg/L during the early and late sampling events, respectively. Nitrite levels were below detection limit during this study (i.e., <0.001 mg/L).

Orthophosphate was below or near detection limit (i.e., <0.001 mg/L) during both sampling events. Total phosphorus ranged from 0.0085 and 0.0198 mg/L during the early November sampling event, and there was a general increase from upstream to downstream stations. During the late November sampling event, total phosphorus was relatively constant at stations 3-5 (range: 0.084-0.0096 mg/L), but reached 0.014 mg/L at station 2. Overall, total phosphorus levels were mainly within or near the moderate range of 0.010-0.025 mg/L typical of "mesotrophic" waters as defined by RISC (1998).

Table 6. Laboratory results (ALS Laboratory) for water samples taken from 4 stations on the Millstone River during 3 and 24 November 2010. All values are expressed in mg/L unless specified otherwise. The values enclosed in boxes exceeded at least one of the applicable water quality guidelines. See additional notes on the next page.

	BC Water Quality Guidelines [a]		3 November 2010				24 November 2010			
	BC Max	BC 30-day Mean								
Variable	mg/L	mg/L	2	3	4	5	2	3	4	5
General/Physical										
Conductivity (µS/cm)			70.0	75.8	90.2	89.0	67.8	88.8	112	122
Hardness, Total			29.5	28.2	32.4	32.5	26.2	31.6	36.2	36.0
pH (pH units)	6.5 - 9.0		7.39	7.42	7.54	7.56	7.53	7.72	7.83	7.83
Nutrients										
Ammonia-N	5.81 [b]	1.12 [b]	<0.0050	0.0055	0.0073	<0.0050	0.0227	0.0131	0.0110	0.0117
Nitrate (as N)	31.3	3	0.0098	0.1420	0.2180	0.2230	0.0800	0.1620	0.2010	0.2140
Nitrite (as N)	0.06 [c]	0.02 [c]	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Ortho Phosphate (as P)			<0.0010	<0.0010	0.0018	<0.0010	<0.0010	<0.0010	0.0011	0.0011
Total Phosphorus			0.0085	0.0137	0.0198	0.0167	0.0141	0.0085	0.0084	0.0096
Total Metals										
Aluminum (Al) [m]	0.10 [d]	0.05 [d]	<0.20	0.26	0.39	0.37	<0.20	<0.20	<0.20	<0.20
Antimony (Sb) [m]	0.02		<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Arsenic (As) [m]	0.005		<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Barium (Ba)	5	1	<0.010	<0.010	0.013	0.011	<0.010	<0.010	<0.010	<0.010
Berylium (Be)	0.0053		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Bismuth (Bi)			<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Boron (B)	1.2		<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium (Cd) [m]	0.00001 [e]		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Calcium (Ca)			7.93	7.73	9.00	9.01	7.16	8.85	10.20	10.20
Chromium (Cr) [m]	0.001 [f]		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Cobalt (Co) [m]	0.11	0.004	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Copper (Cu) [m]	0.004 [g]	0.002 [g]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Iron (Fe)	1.0		0.129	0.399	0.529	0.629	0.405	0.271	0.290	0.301
Lead (Pb) [m]	0.015 [h]	0.004 [h]	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Lithium (Li)	0.87	0.096	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Magnesium (Mg)			2.36	2.17	2.41	2.43	2.03	2.32	2.60	2.57
Manganese (Mn)	0.83 [i]	0.72 [i]	0.015	0.025	0.043	0.041	0.074	0.025	0.020	0.020
Molybdenum (Mo)	2	1	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Nickel (Ni) [m]	0.025 [j]		<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus (P)			<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)	373		<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Selenium (Se) [m]		0.002	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Silicon (Si)			3.28	3.48	3.84	3.97	3.76	3.79	3.94	3.90
Silver (Ag) [m]	0.0001 [k]	0.00005 [k]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium (Na)			3.2	4.1	6.0	5.9	3.0	5.0	8.2	9.6
Strontium (Sr)			0.031	0.051	0.060	0.059	0.029	0.073	0.074	0.074
Thallium (Tl) [m]	0.0003		<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Tin (Sn)			<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Titanium (Ti)	2		<0.010	0.016	0.018	0.023	<0.010	<0.010	<0.010	<0.010
Vanadium (V) [m]	0.006		<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Zinc (Zn)	0.033 [l]	0.0075 [l]	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Table 6. (Continued)

NOTES:

Results are expressed as mg/L except for pH and conductivity.
"<" means less than the detection limit.

[a] BC Water Quality Guidelines (WQG) compiled from
http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html
http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html

[b] Total ammonia guideline is dependent on water temperature and pH of tested water.

[c] Nitrite guideline is for chloride concentration < 2 mg/L.

[d] Aluminum guidelines for pH ≥ 6.5.

[e] The maximum cadmium guideline is $0.001 * 10^{\{0.86 [\log(\text{hardness})] - 3.2\}}$ mg/L.

[f] Chromium guideline is for the more toxic Chromium VI.

[g] The maximum copper guideline is 0.001 * [0.094(hardness) + 2] mg/L.
The 30-day mean copper guideline is for hardness < 50 mg/L.

[h] The maximum lead guideline is $0.001 * e^{\{1.273 [\ln(\text{hardness})] - 1.46\}}$ mg/L.
The 30-day mean lead guideline is $0.001 * [3.31 + e^{\{1.273 [\ln(\text{hardness})] - 4.704\}}]$ mg/L.

[i] The maximum manganese guideline is 0.01102 * (hardness) + 0.54 mg/L.
The 30-day mean manganese guideline is 0.0044 * (hardness) + 0.605 mg/L.

[j] Nickel guideline is for hardness < 60 mg/L.

[k] Silver guidelines are for hardness < 100 mg/L.

[l] Zinc guidelines are for hardness < 90 mg/L.

[m] Analytical detection limits were above applicable guidelines for these metals.

All metal concentrations were below the applicable water quality guidelines and/or below detection limits, except aluminium at stations 3-5 during the early November sampling event. Total metal analyses measure the combined amount of metals dissolved in water and bound to particles. In general, dissolved metals are more bio-available (hence toxicologically available) than metals that are bound to particles. It is unclear whether the observed elevated aluminium represented dissolved metals or metals bound to suspended particles.

4.2. Microbiology

All samples collected from the Millstone River contained some coliform bacteria (Table 7). Total coliform and *E. coli* levels generally increased from upstream to downstream, with the highest levels observed at station 5 (total coliform: 848 CFU / 100 ml; *E. coli*: 244 CFU / 100 ml). The proportion of total coliform made up of *E. coli* bacteria also increased from upstream to downstream, except at station 5.

The filtration blank completed with sterile water did not produce any bacterial colonies.

Table 7. Total coliform and *E. coli* counts from water samples taken at five stations on the Millstone River during 3 November 2010. All values are expressed as CFU (colony forming units) per 100 ml. No microbiology samples were collected during 24 November 2010.

Station	Total Coliform	*E. coli*	% *E. coli*
1	604	80	13.2%
2	240	80	33.3%
3	564	160	28.4%
4	772	444	57.5%
5	848	244	28.8%
Filtration blank	0	0	---

4.3. Stream Invertebrates

A total of 466 stream invertebrates representing 11 broad taxonomic groups were counted at three stations on the Millstone River during 3 November 2010 (Table 8; Figure 2; Appendix 2). Animal density was highly variable among stations, with the highest density observed at station 4 located along the bypass channel where density reached 1,170 animals/m^2. Amphipods (scud), mayfly nymphs and aquatic worms (oligochaetes) were the most common taxonomic group, although their abundance was highly variable among stations.

Site assessment ratings ranged from 1.75 to 3.25 suggesting “marginal” (stations 2 and 3) to “acceptable” (stations 4) invertebrate community abundance and diversity. The representation of

pollution-sensitive mayfly nymphs, stonefly nymphs and caddisfly larvae (EPT taxa) was highest at station 4, suggesting adequate invertebrate colonization since construction of the bypass channel in 2007.

Table 8. Abundance and density of stream invertebrates obtained from triplicate samples taken at three stations on the Millstone River during 3 November 2010. Overall site assessment ratings are also provided for each station (out of a possible range of 1.00-4.00). Invertebrate Survey Field Data Sheets are included in Appendix 2. No stream invertebrate samples were collected on 24 November 2010.

Pollution Tolerance	Invertebrate Taxa	Station 2	Station 3	Station 4
Category 1 Pollution Intolerant	Mayfly Nymph	0	5	94
	Stonefly Nymph	1	4	18
	Caddisfly Larva	1	0	3
	Dobsonfly (hellgrammite)	0	1	0
Category 2 Somewhat Pollution Intolerant	Scud (Amphipod)	3	117	122
	Cranefly Larva	6	0	0
	Clam, Mussel	0	0	3
	Alderfly Larva	0	0	2
	Crayfish	0	1	1
Category 3 Pollution Tolerant	Aquatic Worm (oligochaete)	4	5	73
	Water Mite	2	0	0
	Total Abundance	17	133	316
	Density (number / m^2)	63	493	1170
	Site Assessment Rating	2.25	1.75	3.25

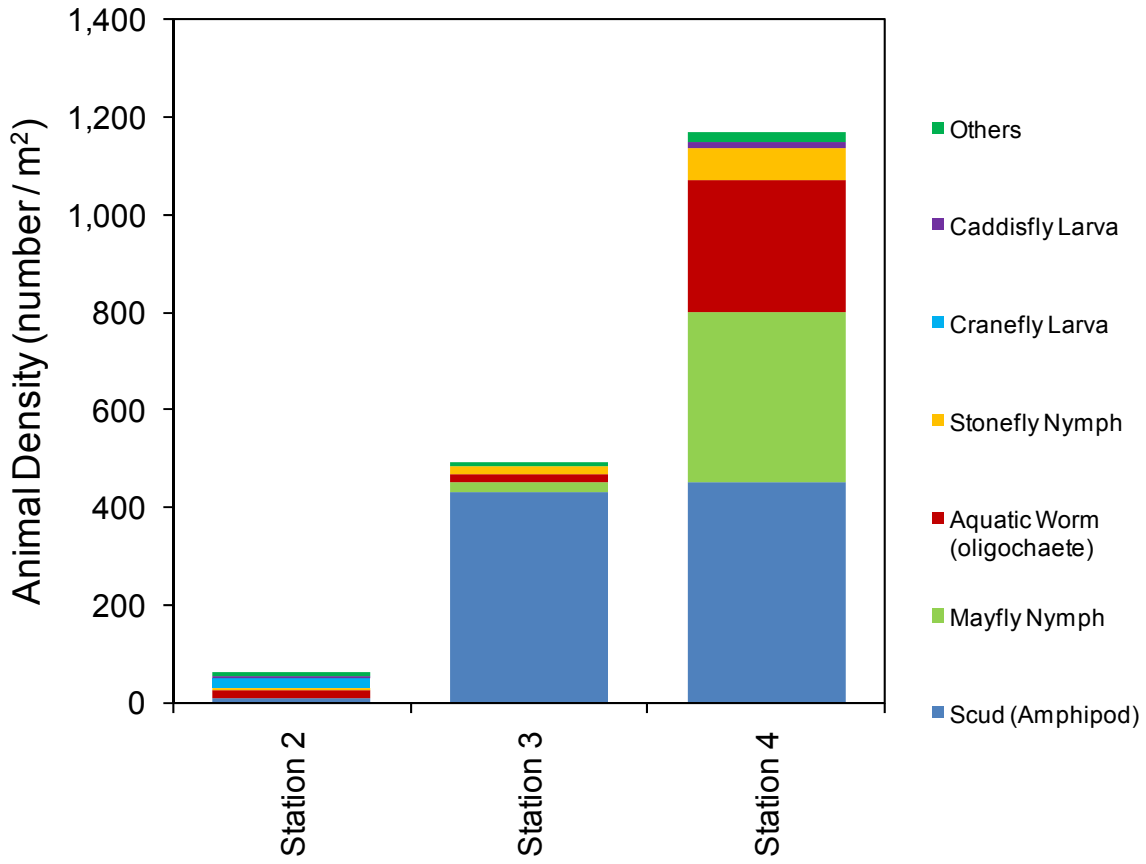

Figure 2. Density of stream invertebrates obtained from triplicate samples taken at three stations on the Millstone River during 3 November 2010. The "Other" category includes clam / mussel, alderfly larva, crayfish, water mite and dobsonfly larva (in decreasing order of overall density). Data are summarized in Table 8 and Invertebrate Survey Field Data Sheets are included in Appendix 2.

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7. Appendices

APPENDIX 1. Photographs showing site conditions at each sampling station on the Millstone River.

Photo 1. Benson Creek at the Biggs Road crossing on 20 October 2010 (station 1).

Photo 2. Millstone River at the Biggs Road crossing on 3 November 2010 (station 2).

APPENDIX 1. (Continued)

Photo 3. Millstone River at the Durnin Road crossing on 3 November 2010 (station 4).

Photo 4. Millstone bypass channel on 3 November 2010 (station 4).

APPENDIX 1. (Continued)

Photo 5. Millstone River in Barsby Park on 3 November 2010 (station 5).

APPENDIX 2. Invertebrate Survey Field Data Sheet completed for triplicate stream invertebrate samples collected at Stations 2-4 on the Millstone River during 3 November 2010.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Millstone River		Date:	3 November 2010
Station Name:	**Station 2**		Flow status:	Moderate
Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates		
Hess	3	0.09 x 3 = 0.27 m^2		

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1 **Pollution Intolerant**	Caddisfly Larva (EPT)	1	1
	Mayfly Nymph (EPT)		
	Stonefly Nymph (EPT)	1	1
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		2	2
Category 2 **Somewhat Pollution Tolerant**	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	6	1
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Scud (amphipod)	3	1
	Watersnipe Larva		
Sub-Total		9	2
Category 3 **Pollution Tolerant**	Aquatic Worm (oligochaete)	4	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite	2	1
Sub-Total		6	2
TOTAL		17	6

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 17

DENSITY: Invertebrate density per square metre:

17 ÷ 0.27 = 63

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Cranefly Larva

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x __2__ + 2 x __2__ + __2__ = 12

EPT INDEX: Total number of EPT taxa.

Good	Accpetable	Marginal	Poor
>8	5-8	2-5	0-1

EPT4 + EPT5 + EPT6

__1__ + __0__ + __1__ = 2

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

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

(EPT1 + EPT2 + EPT3) / CT

(1 + 0 + 1) / 17 = 0.12

SECTION 3 - DIVERSITY

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

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

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

Col. C for S3 / CT

__6__ / __17__ = 0.35

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
Accpetable	3
Marginal	2
Poor	1

Assessment	Rating
Pollution Tolerance Index	2
EPT Index	2
EPT To Total Ratio	1
Predominant Taxon Ratio	4

Average Rating
2.25

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Millstone River		Date: 3 November 2010
Station Name: **Station 3**		Flow status: Moderate
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.09 x 3 = 0.27 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1 Pollution Intolerant	Caddisfly Larva (EPT)		
	Mayfly Nymph (EPT)	5	2
	Stonefly Nymph (EPT)	4	2
	Dobsonfly (hellgrammite)	1	1
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		10	5
Category 2 Somewhat Pollution Tolerant	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva		
	Crayfish	1	1
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Scud (amphipod)	117	1
	Watersnipe Larva		
Sub-Total		118	2
Category 3 Pollution Tolerant	Aquatic Worm (oligochaete)	5	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		5	1
TOTAL		133	8

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 133

DENSITY: Invertebrate density per square metre:

133 ÷ 0.27 = 493

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Scud (amphipod)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x __5__ + 2 x __1__ + __1__ = 20

EPT INDEX: Total number of EPT taxa.

Good	Accpetable	Marginal	Poor
>8	5-8	2-5	0-1

EPT4 + EPT5 + EPT6

__0__ + __2__ + __2__ = 4

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

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

(EPT1 + EPT2 + EPT3) / CT

(0 + 5 + 4) / 133 = 0.07

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 8

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

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

Col. C for S3 / CT

117 / 133 = 0.88

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
Accpetable	3
Marginal	2
Poor	1

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

Average Rating
1.75

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Millstone River		Date: 3 November 2010
Station Name: **Station 4**		Flow status: Moderate
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.09 x 3 = 0.27 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1 Pollution Intolerant	Caddisfly Larva (EPT)	3	1
	Mayfly Nymph (EPT)	94	3
	Stonefly Nymph (EPT)	18	2
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		115	6
Category 2 Somewhat Pollution Tolerant	Alderfly Larva	2	1
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	3	1
	Cranefly Larva		
	Crayfish	1	1
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Scud (amphipod)	122	2
	Watersnipe Larva		
Sub-Total		128	5
Category 3 Pollution Tolerant	Aquatic Worm (oligochaete)	73	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		73	1
TOTAL		316	12

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 316

DENSITY: Invertebrate density per square metre:

316 ÷ 0.27 = 1170

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Scud (amphipod)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x __6__ + 2 x __5__ + __1__ = 29

EPT INDEX: Total number of EPT taxa.

Good	Accpetable	Marginal	Poor
>8	5-8	2-5	0-1

EPT4 + EPT5 + EPT6

__1__ + __3__ + __2__ = 6

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

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

(EPT1 + EPT2 + EPT3) / CT

(3 + 94 + 18) / 316 = 0.36

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 12

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

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

Col. C for S3 / CT

_122_ / _316_ = 0.39

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
Accpetable	3
Marginal	2
Poor	1

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

Average Rating
3.25