DATA REPORT

Water Quality and Stream Invertebrate Assessment

for Richards Creek, BC,

(Fall 2011)

Report prepared by:

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Table of Contents

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1. Background

This report documents a water quality and stream invertebrate assessment conducted on Richards Creek, BC, during October-November 2011.

This study was undertaken by 3rd year undergraduate students attending the Environmental Monitoring (RMOT 306) course at Vancouver Island University (VIU), offered as part of the Bachelor of Natural Resources Protection (Melissa Dorey, Greg Haider, Hayley McCabe and Heather McCubbin). 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 a student group report.

VIU students contributed approximately 125 student-hours to this project, including site visits, project proposal, field sampling, laboratory analyses, and oral and written presentations. Dr. Eric Demers contributed approximately 15 hours for project management and report compilation. Sarah Greenway provided 5 hours of laboratory support for this project.

Logistical support was provided by Fisheries and Oceans Canada (DFO). Funding for field expenses and analytical processing of water samples was provided by the Regional District of Nanaimo and Fisheries and Oceans Canada. ALS Laboratory (Burnaby, BC) provided reduced rates on its analytical services for this project.

2. Introduction

Richards Creek is located in the Somenos Basin, near the city of Duncan, B.C. It is approximately 9.2 km long and flows south-westerly from Crofton Lake to Somenos Lake. Richards Creek provides year round rearing and spawning habitat for salmonids. However, agricultural activities combined with low gradients and low summer flows in lower reaches of Richards Creek have contributed to elevated nutrient loads and hypoxic water conditions (Guimond and Sheng, 2005).

This report documents a water quality and stream invertebrate assessment conducted on Richards Creek during October-November 2011.

Specific objectives for this study of Richards Creek included:

- establish 4 water quality sampling stations;
- obtain field measurements of water quality at the 4 sampling stations during two sampling events (29 October and 20 November 2011);
- obtain water samples from each sampling station during two sampling events (29 October and 20 November 2011) for detailed laboratory analyses; and,
- collect stream invertebrate samples at 3 sampling stations during one sampling event (29 October 2011) for analysis at Vancouver Island University.

3. Methods

3.1. Study Site

This project was conducted on Richards Creek which is located northeast of the city of Duncan, BC (Figure 1). Richards Creek flows southeasterly from Crofton Lake to Richards Trail, then southwesterly, emptying into the northeast end of Somenos Lake. The upstream half of Richards Creek flows through residential areas and riparian forest, while the downstream half flows through agricultural lands. The Cowichan Valley Regional District (CVRD) regulates flow from the Crofton Lake reservoir into Richards Creek.

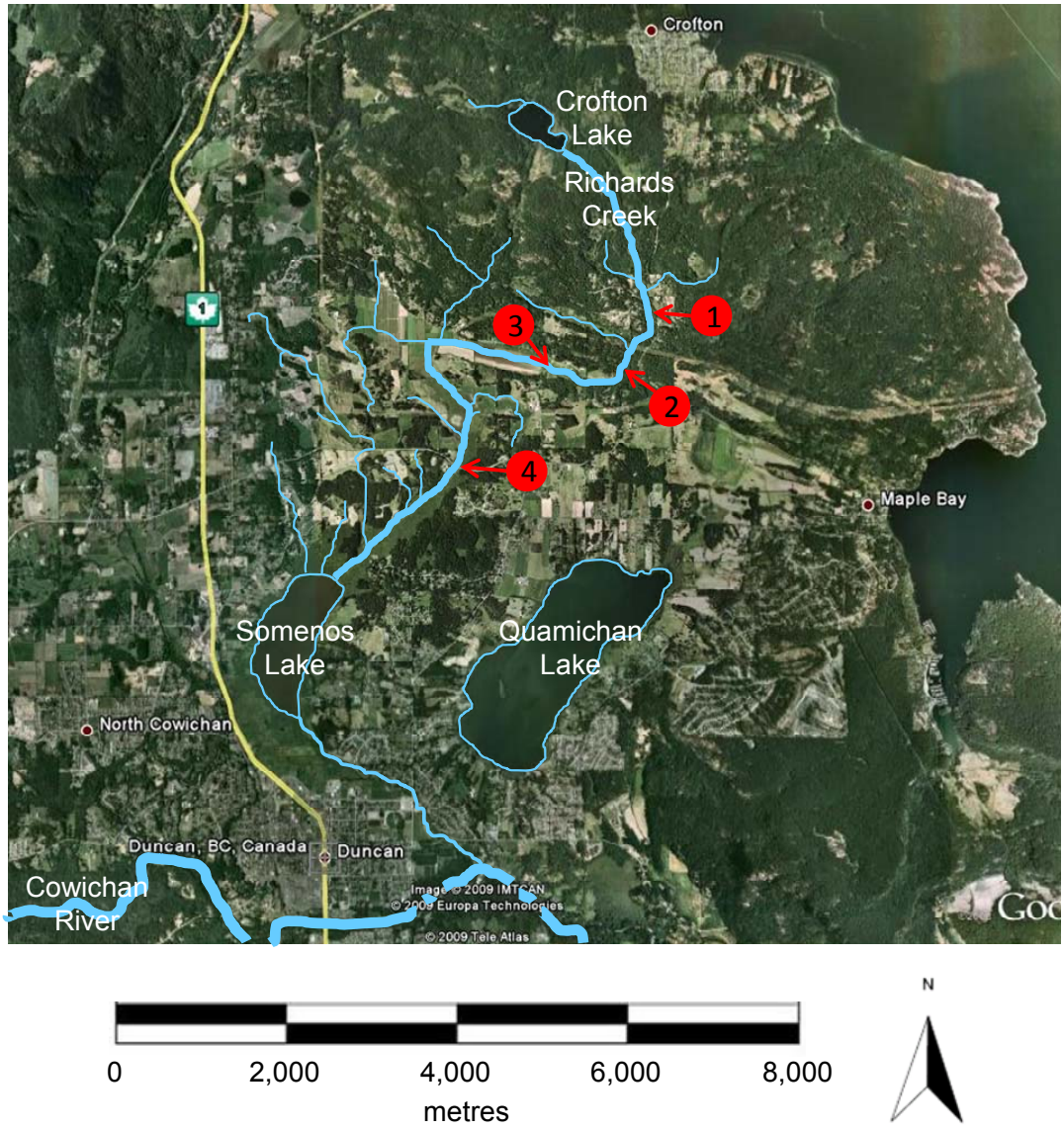

Figure 1. Approximate location of the sampling stations used for water quality and stream invertebrate assessments on Richards Creek during October-November 2011. Table 1 provides details of the specific location of each station. Table 2 details the sampling activities conducted at each station. This map was obtained from Google Earth. Map scale is approximated.

3.1.1. Sampling Stations

Four sampling stations were established on Richards Creek during October-November 2011 (Tables 1 and 2; Figure 1). The location of each station was chosen to provide adequate coverage for the length of the creek and to repeat sampling at stations previously used by DFO. Stations were numbered from upstream (Station 1) to downstream (Station 4). All stations were easily accessed via foot paths or road crossings. Station 1 was located at a culvert crossing on Escarpment Way, approximately 2.3 km downstream of Crofton Lake. Station 2 was located at the end of Rice Road on Innisvale Farm, and included a concrete weir and water depth gauge. Station 3 was located at a culvert crossing on Richards Trail, at the east corner of Pastula Farm. Station 4 was located at a road bridge on Herd Road, approximately 2.0 km upstream of Somenos Lake. Stations 1-3 consisted of shallow and gentle riffle sections, while station 4 was deep and steep-sided.

Table 1. Description of the sampling stations used for water quality and stream invertebrate assessments on Richards Creek during October-November 2011. All northing and easting coordinates are based on zone 10U.

Station	UTM Coordinates		Approximate Distance from Crofton Lake (km)	General Location
	Northing	Easting		
1	5409420	452560	2.3	Escarpment Way crossing
2	5408622	452083	3.5	End of Rice Road, weir and water depth gauge
3	5408795	451331	4.2	Richards Trail crossing
4	5407637	450282	7.2	Herd Road crossing

3.1.2. Sampling Schedule

Field sampling was conducted on 29 October and 20 November 2011. 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 October event. Photographs showing site conditions and sampling activities are included in Appendix 1.

3.2. Water Quality

3.2.1. Field Measurements

Water quality sampling events were conducted on 29 October and 20 November 2011. At each sampling station, field measurements of water temperature (to the nearest 0.01 ^{o}C), dissolved oxygen (to the nearest 0.01 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.

Basic hydrological measurements were taken at stations 1 and 2 during both sampling events. 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 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.

Table 2. Water quality and stream invertebrate sampling activities conducted at each station on Richards Creek during October-November 2011. The symbols "A" or "B" indicate whether samples / measurements were taken during the October or November sampling events, respectively.

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

Note: [1] Basic hydrological measurements were taken at stations 1 and 2 during both sampling events.

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). 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°C. Laboratory analyses were conducted at VIU within 48 hours of sampling.

Samples for analysis by ALS Laboratory were collected from stations 1, 3 and 4 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.

Table 3. Sampling containers and preservatives used for water quality samples taken from Richards Creek during October-November 2011. All containers and preservatives for analysis by ALS Laboratory were provided by ALS Laboratory, Burnaby, 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

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 0.01 NTU (Nephelometric Turbidity Units) using a HACH 2100 Potable Turbidimeter.

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.

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) (BCMWLAP 1998a, 1998b). These guidelines were applicable to all sampling stations.

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

Water samples for total and fecal coliform enumeration were collected from each sampling station on 29 October 2011 (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.

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. 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 1, 2 and 3 on 29 October 2011 (Table 1; Figure 1). The sampling stations were selected based on hydrological characteristics, apparent substrate uniformity, space available for replicate samples and site access. At the time of sampling, all stations consisted of shallow riffles (water depth ~10-25 cm), with water velocity of 0.25-0.75 m/s, and primarily sand and gravel substrate.

3.4.2. Invertebrate Sampling

At each station, four replicate samples were obtained using a Surber sampler as per the Pacific Streamkeepers procedures (Taccogna and Munro 1995). Each site was approached by walking from downstream. The Surber sampler was hand-pressed into the substrate to isolate a square 0.09-m^2 (30 cm x 30 cm) 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 replicate 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

The discharge measurements (Table 5) and field observations (see photographs in Appendix 1) for Richards Creek suggest that water level was not at bankfull during both sampling events. Discharge decreased at stations 1 and 2 between 29 October and 20 November 2011.

Average air temperature during the 10-day period prior to each sampling event was 7.5°C and 2.7 °C for the October and 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 October and November sampling events were 27 mm and 31 mm, respectively.

4.1. Water Quality

4.1.1. Field Measurements and VIU Laboratory Analyses

Water temperature averaged 7.1°C and 2.4°C during the October and November sampling events, respectively (Table 5). The decrease in water temperature between events reflected a similar decrease in air temperature between sampling events. During both sampling events, dissolved oxygen levels were above the minimum guideline of 9.0 mg/L for early fish life stages (RISC 1998). However, dissolved oxygen levels at station 3 during 29 October and at all stations during 20 November 2011 were well in excess of saturation (>130%). This was likely caused by equipment error or improper calibration. Nevertheless, dissolved oxygen levels at station 4 were lower than at the other stations during both sampling events. Similar results were found in previous studies conducted in 2008-2010 (VIU, 2009, 2010, 2011), where dissolved oxygen concentrations observed at station 4 suggested hypoxic conditions.

Mean conductivity increased from 133 to 184 µS/cm between the October and November sampling events. During both sampling events, there was an increase from upstream to downstream stations. Water pH was slightly acidic at most stations (range: 5.89-6.74). During both sampling events, the lowest pH was observed at station 1 and the highest pH was observed at station 2.

Total alkalinity averaged 27 and 36 mg/L during the October and November sampling events, respectively (Table 5). During both sampling events, there was a general increase from upstream to downstream stations. Overall, total alkalinity was above 20 mg/L during both sampling events, indicating "low acid sensitivity" as defined by RISC (1998).

Turbidity levels averaged 1.66 and 1.73 NTU during the October and November sampling events, respectively (Table 5). There was an increase in turbidity from upstream to downstream stations during both sampling events.

Table 5. Field measurements and laboratory results (VIU Laboratory) for water samples taken from four stations on Richards Creek during 29 October and 20 November 2011.

		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)**
			29 October 2011				
1	0.08	7.50	12.88	90	5.89	21.2	1.09
2	0.29	7.88	12.67	132	6.74	31.6	1.24
3		6.97	16.05	134	6.18	27.8	1.86
4		6.04	8.09	175	6.04	28.8	2.43
			20 November 2011				
1	0.03	2.04	21.63	118	6.18	25.5	0.78
2	0.10	2.45	21.10	164	6.60	32.6	0.92
3		1.72	21.44	176	6.30	34.5	1.27
4		3.31	18.00	276	6.44	50.1	3.93

4.1.2. ALS Laboratory Analyses

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

The conductivity measurements from ALS Laboratory were consistent with the field measurements obtained with the electronic probe and differed by ≤11%.

Total hardness followed similar trends as conductivity, namely an increase from upstream to downstream stations and an increase between sampling events. Total hardness averaged 49 and 66 mg/L during the October and November sampling events, respectively. Overall, total hardness was below or near 60 mg/L during both sampling events, indicating "soft water" as defined by RISC (1998).

Field measurements of pH (range: 5.89-6.74) were generally more variable than the ALS Laboratory results (range: 7.86-8.04). This discrepancy possibly reflects improper calibration, differences in air space content among sampling containers and/or time elapsed between sampling and laboratory analysis.

All nutrient levels were below applicable guidelines and/or below detection limits. During both sampling events, the highest ammonia concentrations were found at station 4 (0.236 mg/L during October and 0.317 mg/L during November). Nitrate concentrations ranged from 0.065 to 0.865 mg/L during this study. Nitrite levels were near or below detection limits (i.e., <0.002 mg/L), except at station 4 during both sampling events where nitrite levels were 0.013 and 0.018 mg/L during the October and November sampling events, respectively.

Orthophosphate were below detection limit (i.e., ≤0.001 mg/L) at station 1 during both sampling events, but not at stations 3 and 4. The highest orthophosphate levels occurred at station 4 during both sampling events (0.109 and 0.144 mg/L during the October and November sampling events, respectively). Total phosphorus followed a similar pattern as orthophosphate, with the highest levels of 0.154 and 0.212 mg/L observed at station 4 during the October and November sampling events, respectively. Overall, total phosphorus levels indicated "oligotrophic" conditions at station 1 (<0.010 mg/L), "mesotrophic" conditions at station 2 (0.010-0.025 mg/L), and "hypereutrophic" conditions (≥0.100 mg/L) at station 4 during both sampling events (as defined by RISC (1998)). Similar results were found in previous studies conducted in 2008-2010 (VIU, 2009, 2010, 2011).

With the exception of aluminium and zinc, all metals were below applicable guidelines. Total aluminium and zinc exceeded the applicable guidelines at station 4 during the November sampling event.

It should be noted that 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. The dissolved fraction of total metals in water is often lower than 100%.

Table 6. Laboratory results (ALS Laboratory) for water samples taken from 3 stations on Richards Creek during 29 October and 20 November 2011. 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]							
	BC Max	BC 30-day Mean	29 October 2011			20 November 2011		
Variable	mg/L	mg/L	1	3	4	1	3	4
General/Physical								
Conductivity (µS/cm)			90	131	165	129	196	279
Hardness, Total			33.7	49.1	55.2	48.9	77.1	98.7
pH (pH units)	6.5 - 9.0		7.90	8.00	7.90	7.87	8.04	7.86
Nutrients								
Ammonia-N	4.75 [b]	0.91 [b]	0.0071	0.0067	0.236	0.0246	0.0054	0.317
Nitrate (as N)	31.3	3	0.065	0.271	0.292	0.130	0.407	0.865
Nitrite (as N)	0.06 [c]	0.02 [c]	<0.0010	0.0066	0.0131	<0.0010	<0.0010	0.0180
Ortho Phosphate (as P)			<0.0010	0.0103	0.1090	<0.0010	0.0093	0.1440
Total Phosphorus			0.0087	0.0240	0.154	0.0054	0.0190	0.212
Total Metals								
Aluminum (Al) [m]	0.10 [d]	0.05 [d]	<0.20	<0.20	<0.20	<0.20	<0.20	0.28
Antimony (Sb) [m]	0.02		<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
Barium (Ba)	5	1	<0.010	<0.010	<0.010	<0.010	0.011	0.014
Berylium (Be)	0.0053		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bismuth (Bi)			<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
Cadmium (Cd) [m]	0.00001 [e]		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Calcium (Ca)			10.5	14.3	16.0	14.9	21.8	28.7
Chromium (Cr) [m]	0.001 [f]		<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
Copper (Cu) [m]	0.005 [g]	0.002 [g]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Iron (Fe)	1.0		0.288	0.303	0.493	0.311	0.200	0.650
Lead (Pb) [m]	0.020 [h]	0.004 [h]	<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
Magnesium (Mg)			1.82	3.26	3.68	2.84	5.49	6.58
Manganese (Mn)	0.911 [i]	0.753 [i]	0.026	0.016	0.105	0.077	0.011	0.117
Molybdenum (Mo)	2	1	<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
Phosphorus (P)			<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	3.9
Selenium (Se) [m]		0.002	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Silicon (Si)			3.12	5.19	5.07	4.62	7.82	7.78
Silver (Ag) [m]	0.0001 [k]	0.00005 [k]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium (Na)			3.9	5.8	8.7	6.2	9.1	16.5
Strontium (Sr)			0.031	0.050	0.063	0.047	0.084	0.130
Thallium (Tl) [m]	0.0003		<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
Titanium (Ti)	2		<0.010	<0.010	<0.010	<0.010	<0.010	0.017
Vanadium (V) [m]	0.006		<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Zinc (Zn)	0.033 [l]	0.0075 [l]	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0091

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.

4.2. Microbiology

All samples collected from Richards Creek contained some coliform bacteria (Table 7). Total coliform levels increased exponentially with distance downstream, and ranged from 184 CFU / 100 ml at station 1 to 1,236 CFU / 100 ml at station 4. The proportion of total coliform made up of *E. coli* bacteria generally decreased with distance downstream.

Table 7. Total coliform and *E. coli* counts from water samples taken at five stations on Richards Creek during 29 October 2011. All values are expressed as CFU (colony forming units) per 100 ml. No microbiology samples were collected on 20 November 2011.

Station	Total Coliform	*E. coli*	% *E. coli*
1	184	32	17.4%
2	316	76	24.1%
3	672	60	8.9%
4	1236	100	8.1%

4.3. Stream Invertebrates

A total of 492 stream invertebrates representing 9 broad taxonomic groups were counted at three stations on Richards Creek during 29 October 2011 (Table 8; Figure 2; Appendix 2). Animal density was similar at stations 1 and 3 (558-614 animals/m^2), but lower at station 2 (194 animals/m^2). Overall, mayfly nymphs were the most common taxonomic group at all three stations.

Site assessment ratings ranged from 2.75 to 3.50 suggesting "acceptable" invertebrate community abundance and diversity at all stations. The consistent representation of pollution-sensitive mayfly nymphs, stonefly nymphs and caddisfly larvae (EPT taxa: 60-80% of total abundance) also indicated generally "acceptable" environmental conditions at all stations.

Table 8. Abundance and density of stream invertebrates obtained from four replicate samples taken at three stations on Richards Creek on 29 October 2011. Overall site assessment ratings are also provided for each station (out of a maximum rating of 4.00). Invertebrate Survey Field Data Sheets are included in Appendix 2. No stream invertebrate samples were collected on 20 November 2011.

Pollution Tolerance	Invertebrate Taxa	Station 1	Station 2	Station 3
Category 1 Pollution Intolerant	Caddisfly Larva	2	0	44
	Mayfly Nymph	103	41	85
	Stonefly Nymph	15	15	11
Category 2 Somewhat Pollution Intolerant	Cranefly Larva	2	0	56
	Dragonfly Nymph	0	2	0
	Scud (Amphipod)	29	3	8
Category 3 Pollution Tolerant	Aquatic Worm (oligochaete)	16	3	16
	Blackfly Larva	18	5	0
	Midge Larva (chironomid)	16	1	1
	Total Abundance	201	70	221
	Density (number / m^2)	558	194	614
	Site Assessment Rating	3.25	2.75	3.50

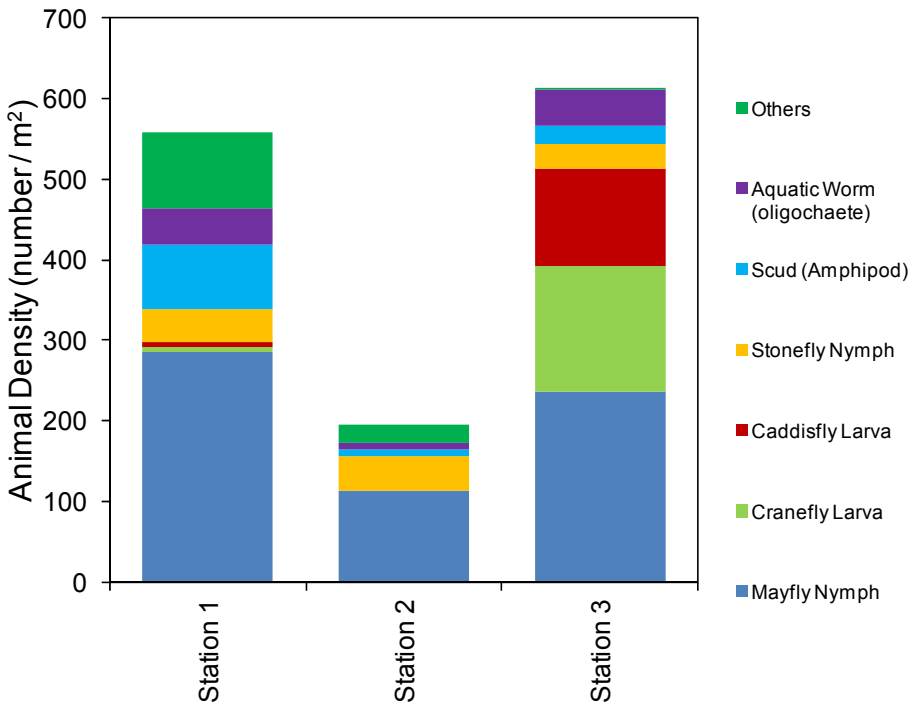

Figure 2. Density of stream invertebrates obtained from four replicate samples taken at three stations on Richards Creek during 29 October 2011. The "Other" category includes blackfly larva, midge larva (chironomid) and dragonfly nymph in decreasing order of abundance. Data are summarized in Table 8 and Invertebrate Survey Field Data Sheets are included in Appendix 2.

5. Acknowledgements

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7. Appendices

APPENDIX 1. Photographs showing site conditions on the Richards Creek taken on 29 October 2011.

Photo 1. Downstream view of Richards Creek at the Escarpment Way crossing (station 1).

Photo 2. Downstream view of Richards Creek at the end of Rice Road (station 2).

APPENDIX 1. (Continued)

Photo 3. Upstream view of Richards Creek at Richards Trail crossing (station 3).

Photo 4. Upstream view of Richards Creek at the Herd Road Bridge (station 4).

APPENDIX 2. Invertebrate Survey Field Data Sheet completed for replicate stream invertebrate samples collected at Stations 1, 2 and 3 on Richards Creek on 29 October 2011.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Richards Creek		Date:	29 October 2011
Station Name:	**Station 1**		Flow status:	Moderate
Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates		
Surber	4	0.09 x 4 =	0.36	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)	2	2
	Mayfly Nymph (EPT)	103	2
	Stonefly Nymph (EPT)	15	2
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		120	6
Category 2 **Somewhat Pollution Tolerant**	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	2	2
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Scud (amphipod)	29	1
	Watersnipe Larva		
Sub-Total		31	3
Category 3 **Pollution Tolerant**	Aquatic Worm (oligochaete)	16	1
	Blackfly Larva	18	1
	Leech		
	Midge Larva (chironomid)	16	1
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		50	3
TOTAL		201	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**: 201

DENSITY: Invertebrate density per square metre:

201 ÷ 0.36 = 558

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Mayfly Nymph (EPT)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 6 + 2 x 3 + 3 = 27

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

2 + 2 + 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

(2 + 103 + 15) / 201 = 0.60

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

103 / 201 = 0.51

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	3
Predominant Taxon Ratio	3

Average Rating
3.25

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Richards Creek		Date: 29 October 2011
Station Name: **Station 2**		Flow status: Moderate
Sampler Used: Surber	Number of replicates 4	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.09 x 4 = 0.36 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)	41	2
	Stonefly Nymph (EPT)	15	1
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		56	3
Category 2 Somewhat Pollution Tolerant	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva		
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva	2	1
	Fishfly Larva		
	Scud (amphipod)	3	1
	Watersnipe Larva		
Sub-Total		5	2
Category 3 Pollution Tolerant	Aquatic Worm (oligochaete)	3	1
	Blackfly Larva	5	1
	Leech		
	Midge Larva (chironomid)	1	1
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		9	3
TOTAL		70	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**: 70

DENSITY: Invertebrate density per square metre:

70 ÷ 0.36 = 194

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Mayfly Nymph (EPT)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 3 + 2 x 2 + 3 = 16

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

0 + 2 + 1 = 3

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 + 41 + 15) / 70 = 0.80

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

41 / 70 = 0.59

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	4
Predominant Taxon Ratio	3

Average Rating
2.75

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Richards Creek		Date:	29 October 2011
Station Name:	**Station 3**		Flow status:	Moderate
Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates		
Surber	4	0.09 x 4 = 0.36 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)	44	3
	Mayfly Nymph (EPT)	85	3
	Stonefly Nymph (EPT)	11	2
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		140	8
Category 2 **Somewhat Pollution Tolerant**	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	56	2
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Scud (amphipod)	8	1
	Watersnipe Larva		
Sub-Total		64	3
Category 3 **Pollution Tolerant**	Aquatic Worm (oligochaete)	16	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)	1	1
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		17	2
TOTAL		221	13

APPENDIX 2. (Continued)

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: 221

DENSITY: Invertebrate density per square metre:

221 ÷ 0.36 = 614

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (Col. C): Mayfly Nymph (EPT)

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 8 + 2 x 3 + 2 = 32

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

3 + 3 + 2 = 8

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

(44 + 85 + 11) / 221 = 0.63

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 13

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

85 / 221 = 0.38

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	3
Predominant Taxon Ratio	4

Average Rating
3.50