Cottle Creek Water Quality, Microbiology and Stream Invertebrate Assessment, 2016

RMOT 306

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EXECUTIVE SUMMARY

A complete stream ecosystem analysis was conducted by four Vancouver Island University students for Cottle Creek, located in Nanaimo BC. The environmental assessment involved monitoring the stream for water quality, microbiology and stream invertebrate conditions from October to November 2016. The purpose of this project was to assess the environmental conditions of four different sites located within Cottle Creek. Water quality samples and stream invertebrate samples were examined in the lab at the Vancouver Island University campus and water quality samples were also processed by a professional facility, ALS Laboratories in Burnaby, BC. Analysis of lab results concluded that Cottle Creek represents a moderately healthy stream ecosystem. Hydrology and water quality results were influenced by inclement weather on the first sampling day but overall the analysis revealed predictable results, a moderately healthy stream reflecting some environmental impacts from nearby construction and agriculture activity. It is recommended that local riparian zone bylaws are enforced and annual monitoring continues, in order to ensure the health of Cottle Creek.

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SECTION 1 & 2: INTRODUCTION AND ENVIRONMENTAL CONCERNS

This report documents an environmental monitoring project on Cottle Creek located in Nanaimo, BC. The project was undertaken from October to December 2016, with the final report submitted no later than December 16, 2016. We executed two field sampling dates for our project: the first on November 2, 2016, and the second November 23, 2016. Four undergraduate students currently enrolled in the course RMOT 306 offered by Dr. Eric Demers at Vancouver Island University conducted the planning, sampling, and analysis necessary for the completion of this environmental monitoring project. The main goal of this project was to investigate aspects of stream health including hydrology, water quality, microbiology, and invertebrate populations. The results obtained from the completion of this project augment currently existing reports on Cottle Creek that have been provided by Vancouver Island University students from previous years.

Cottle Creek originates upstream from Cottle Lake and runs through the Linley Valley through 3 main tributaries : Upper Cottle Creek (from Rutherford Road to Cottle Lake), North Cottle Creek (from Lost Lake to Cottle Lake), and Lower Cottle Creek (from Cottle Lake to Departure Bay). The total watershed covers about 4.5 km^2 (City of Nanaimo and NALT, 1999). The area was logged in the mid 1990’s and is now dominated by a second growth coastal Douglas fir ecosystem. The Nanaimo Area Land Trust (NALT) acquired Cottle Lake and its surrounding areas in 2003. NALT added 59 hectares of park reserve into the Nanaimo park system encompassing Cottle Lake and a portion of the three tributaries (VIU, 2013). In 1996, the City's’ Urban Containment Boundary

(UCB) was established in order to define areas where urban growth was expected and encouraged, offering protection to a large area of the Linley Valley. The UCB was disposed of in 2008, leaving areas for new roads and developments through the Linley Valley such as the construction of Linley Valley Drive which cuts through wetland areas behind Oliver Woods and over to Rock City Road (Mid-Island News, 2014). There is a city bylaw protecting a 15-metre wide riparian buffer on each side of the creek for habitat protection, as the creek supports steelhead and cutthroat trout populations (City of Nanaimo and NALT, 1999). Because the Cottle Creek system covers such a large amount of land, there are many land use aspects that may affect the watershed. While the park reserve area protected by NALT is relatively undisturbed, there has been a large amount of urban development in the last 20 years surrounding the rest of the creek system. In many places, including Station 1 at Landalt Road, there are housing developments currently under construction as well as recently completed housing all along Nottingham Drive, Station 3. At Station 3 there was also a project initiated in 2016 to beautify Cottle Creek Park, a previously unused area populated by invasive plants and garbage. VIU, the City of Nanaimo and residents are hoping to make the area a desirable, scenic setting with a playground, tables and benches by clearing the land with excavators and building the new green space. Construction of this park is currently under way (Nanaimo News Bulletin, 2016). Finally, the creek system also flows along agricultural areas as well, adding to the potential impacts on Cottle Creek's health.

The Cottle Creek system contains multiple types of sensitive ecosystems, all of which are under threat from multiple sources in the area. Potential environmental issues for Cottle Creek include point sources such as storm water and vehicle effluent from drains into the creek along roads, construction directly beside the creek in areas like the Landalt Road and Nottingham Drive stations, and construction of culverts to allow for road development. Non-point source influences include nearby construction runoff from multiple sites, agricultural runoff including fertilizer use from nearby farms, sedimentation and stream bank erosion. Previous studies of the creek have shown high phosphorus levels, likely from agricultural runoff (VIU, 2013), restriction of fish movement by culverts (City of Nanaimo and NALT, 1999), and fecal contamination from cattle and wildlife (VIU, 2015).

SECTION 3: PROJECT OBJECTIVES

The objectives for this project were to assess the environmental conditions at four different stations along Cottle Creek. Sampling and analysis were performed by our team to gather information regarding the hydrology, water quality, microbiology, and invertebrate populations of Cottle Creek. Four sampling sites were situated at locations along Cottle Creek, the first one above Cottle Lake at Landalt Road, the second at Cottle Lake, the third at Nottingham Drive and the last at Stephenson Point Road just before Cottle Creek meets the Strait of Georgia. This allowed our team to compare data between sites and determine where any environmental changes and/or impacts may have arisen along the watershed. The information obtained from this project, along with data from previous reports on Cottle Creek, will add to the ongoing environmental monitoring efforts of the area. The final report of this project will provide our client (Dr. Demers), as well as Fisheries and Oceans Canada, City of Nanaimo, Nanaimo Area

Land Trust, and British Columbia Conservation Foundation with valuable data to assist in the short and long-term understanding of Cottle Creek's overall stream health.

SECTION 4: METHODS

4.1: SAMPLING STATIONS AND HABITAT CHARACTERISTICS

We proposed four sites to be sampled for our environmental monitoring project (Figure 1). These sites were chosen as they have been assessed by previous RMOT 306 students, and therefore allowed us to compare our current results with past conditions present at the sites. Our sampling of the sites adds updated information on the current stream conditions of Cottle Creek. Our proposed sites were also chosen based on ease of access for safe and efficient fieldwork to be conducted.

Site 1 was located at Landalt Road where Cottle Creek flows downstream through a culvert beneath the road next to a residential area. The site was located in a small gully between two hills. There was construction occurring directly beside this site on a housing development up one slope and a small farm with chickens in a pen up the other slope. The banks of the creek were relatively steep slopes and populated by mostly large alder trees, blackberries and grasses. The stream bed was composed of mostly smaller rocks/gravel with a bit of silt. This site provided data on the most upstream conditions of the Cottle Creek watershed.

Site 2 was located at Linley Valley Park where Cottle Lake drains downstream. It was an approximately 10 minute hike to the sampling location on the east side of Cottle Lake and the location that sampling happened at was right after a foot bridge along the hiking trail. The banks were relatively flat but sloped on one side and populated by Douglas fir, red cedar, sword ferns, salal and salmonberry bushes. The stream bed was composed of large and small rocks with a bit of gravel in some places. This site provided information on the conditions of the discharge area from the lake. Site 3 is located at Nottingham Drive where Cottle Creek flows under a small bridge. A lot of rapid residential development has occurred in this area recently, including the construction of a playground directly beside the creek. The banks were flat, populated by grasses, blackberries and some large alder and maple trees. The ground was very saturated and muddy at this site compared to the other three, as was the stream bed, which was very deep mud with some gravel areas. Sampling here provided data on new potential environmental risks present from recent construction.

Site 4 was the furthest downstream sampling station, located where Cottle Creek flows beneath Stephenson Point Road. This site had medium sloped banks populated by Douglas fir, red cedar, sword ferns and salal. The stream bed was mostly slippery large rocks with some smaller rocks. This site provided important information on the environmental conditions of Cottle Creek as it flowed into the coastal marine ecosystem of Departure Bay.

Table 1: Latitude and longitude coordinates for each sampling location of the November 2016 Cottle Creek environmental monitoring assessment.

Site 1 (Landalt Road)	49° 13' 6.006" N, 123° 59' 22.340" W
Site 2 (Cottle Lake)	49° 13' 7.86" N, 123° 58' 35.7924" W
Site 3 (Nottingham Drive)	49° 13' 0.2064" N, 123° 57' 30.0348" W
Site 4 (Stephenson Point Road)	49° 12' 41.0328" N, 123° 57' 11.574" W

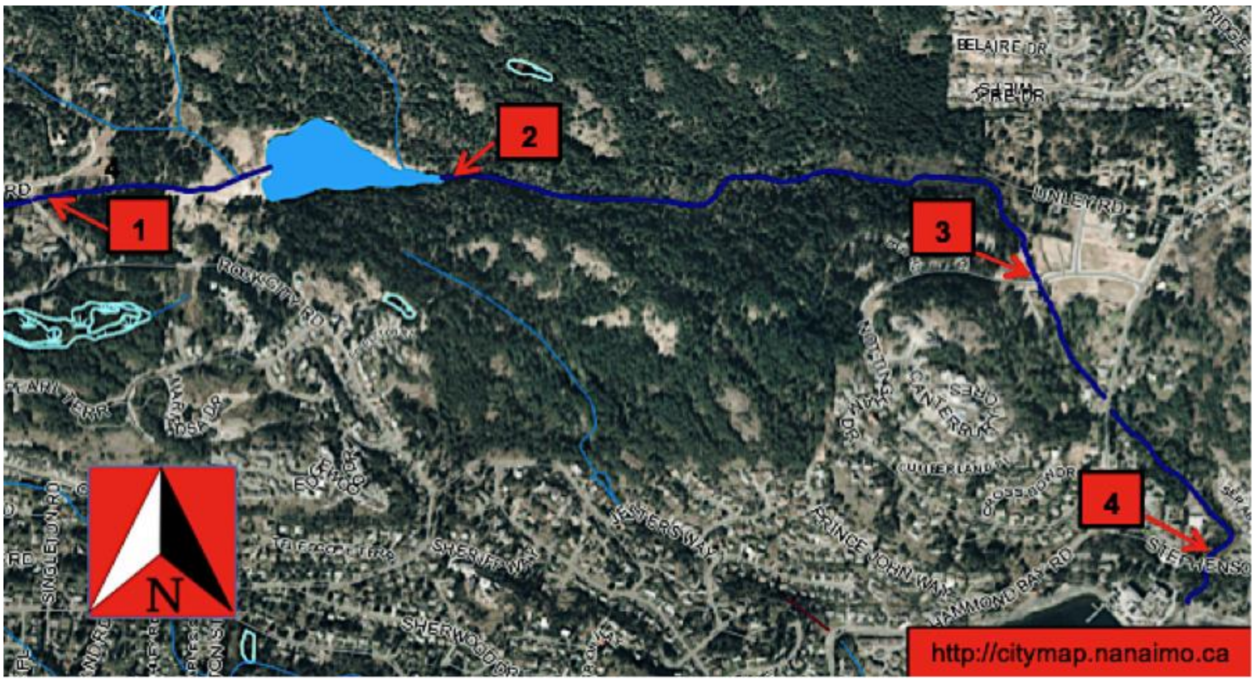

Figure 1: Map of Nanaimo, BC showing the Cottle Creek watershed area. The dark blue line outlines the main stream of Cottle Creek, and the light blue line outlines its tributaries. Each number indicates our proposed sampling stations. Site 1 is located furthest upstream, and Site 4 is located furthest downstream right before Cottle Creek meets Departure Bay in the Strait of Georgia.

4.2: SAMPLING FREQUENCY

The location and sampling frequency for each water parameter tested are summarized in Table 2. The parameter with the highest sampling frequency was water quality. The specific parameters that were tested for are discussed in further detail in Section 4.4

(Water Quality). The frequency of water quality sampling was dependent on the method of analysis. On-site water quality parameters were sampled during both sampling events, and at all four stations (as described in Section 4.1 – Sampling Stations). Water parameters that were analyzed in the laboratory facilities at Vancouver Island University (VIU), located in Nanaimo, B.C., were also sampled for during both events and at all four stations. The water quality parameters analyzed by the private analytical lab, ALS Environmental in Burnaby, B.C., were sampled during both sample events, at sites 1, 2 and 4 only. To test for water quality control, replicate samples were collected during each sampling event at site 4 only. Hydrology measurements were taken during both events at sites 2 and 3.

Sampling for microbiology and stream invertebrates took place during the first sampling event on November 2nd, 2016. Microbiology was tested for at each site. To ensure microbiology quality control, a replicate sample was also collected at site 4. Invertebrate sampling was scheduled to take place at sites 1, 2 and 4, however, due to unforeseen weather events leading to high river flow and unsafe conditions, invertebrate sampling was taken at sites 1, 2 and 3.

Table 2: Water quality, hydrology, microbiology and invertebrate sampling frequency during the November, 2016 environmental assessment of Cottle Creek, located in Nanaimo, B.C.

Sample Event	Site Number	Water Quality ON-SITE	Water Quality VIU LAB	ALS	Hydrology	Microbiology	Invertebrates (X3 samples)
1 (Nov 2)	1	•	•	•		•	•
1 (Nov 2)	2	•	•	•	•	•	•
1 (Nov 2)	3	•	•		•	•	•
1 (Nov 2)	4	•	•	•		•	
1 (Nov 2)	Replicate	•	•			•	
2 (Nov 23)	1	•	•	•			
2 (Nov 23)	2	•	•	•	•		
2 (Nov 23)	3	•	•		•		
2 (Nov 23)	4	•	•	•			
2 (Nov 23)	Replicate	•	•				

4.3: HYDROLOGY

Hydrology measurements of Cottle Creek were conducted on November 2nd and November 23rd, 2016. These measurements were taken at sites 2 and 3 during both sampling events. Wetted stream width, stream depth, water velocity, and discharge were the four hydrological aspects measured during our assessment. The results and discussion on the hydrology of Cottle Creek is further discussed in Section 5.1. Wetted stream width was measured in meters by stretching a measuring tape from one side of the stream to the other. Stream depth was measured with a meter stick at one meter intervals along the wetted width. Water velocity was measured by placing a meter stick level with the surface flow and recording the amount of time required for a hollow ping pong ball to flow down the length of the meter stick. Five trials of velocity measurements were conducted to obtain a more precise average of the water velocity in m/s. Stream discharge was then calculated using the equation Q = A x V. Q represents the stream discharge in m^3/s, A is the cross-sectional area in m^2 (wetted width x average depth), and V is the velocity in m/s.

4.4: WATER QUALITY

The spatial and temporal distributions for water quality parameters tested are outlined in section 4.2 (Sampling Frequency). Water quality samples were analyzed on-site, in the laboratory facilities at VIU, or by ALS Environmental. All samples were collected and analyzed per the *Ambient Freshwater and Effluent Sampling manual* (Ministry of Water, Land, and Air Protection, 2003).

Temperature (ºC) and dissolved oxygen content (mg/L) were measured on-site using an Oxyguard Handy Polaris electronic probe. VIU lab samples were collected using 1L plastic bottles, and the water collected was used to measure the following parameters: conductivity (µs/cm), pH, turbidity (NTU), total alkalinity (mg/L as $CaCO_3$), water hardness (mg/L as $CaCO_3$), nitrate (mg/L) and reactive phosphorus (orthophosphate (PO_4^{3-})) (mg/L) (Table 3). ALS lab samples were collected using several pre-rinsed bottles (1L plastic, 250mL plastic, & 250mL amber glass) and the following parameters were analyzed: general water quality parameters, nutrient content, and a comprehensive metal scan.

Table 3: Methods used during the November, 2016 environmental monitoring assessment for the VIU in-lab water quality analyses on Cottle Creek, Nanaimo, B.C.

Parameter	Method
Temperature, DO, % saturation (on-site)	OxyGuard Handy Polaris Probe
Alkalinity	HACH AL-DT Digital Titration
Hardness	HACH HA-71A Test Kit
Phosphate	HACH DR2800 Spectophotometer (method 8048)
Nitrate	HACH DR2800 Spectrophotometer (method 8192)
Turbidity	HACH 2100 Portable Turbidimeter

4.4.1: QUALITY CONTROL / QUALITY ASSURANCE

To ensure that water quality assurance and controls were being addressed during environmental sampling and analytical procedures, the methods outlined in the *Ambient Freshwater and Effluent Sampling manual* (Ministry of Water, Land, and Air Protection, 2003) were strictly adhered to. The outlined methods provided quality and consistency during data collection during the environmental surveys.

Sample integrity was achieved by following a series of quality assurance steps, procedures and practices. All precautions were taken to minimize contamination and deterioration of the samples. Some parameters of quality assurance included: using clean, sterile equipment; ensuring preservatives and reagents were certified and contaminant-free; properly labelling samples; and using techniques to safeguard sampling, handling, storing and shipping procedures (Ministry of Water, Land, and Air Protection, 2003). To avoid sample contamination during the collection process:

samplers were positioned downstream of water flow, containers were sealed immediately after being filled, VIU bottles were rinsed three times prior to filling, samples were handled with clean hands, and only specified containers were used. Samples were stored in a chilled cooler during transport and analyzed in the VIU lab the same day as collection. During laboratory analysis, gloves were worn and sampling glassware was rinsed three times prior to use.

Quality control measures aimed to quantify the quality of data, as well as assess any levels of sample contamination by using a series of trip blanks and replicate samples. Trip blanks were used to assess any possible contamination that may have occurred from equipment, during transport or storage, or from the surrounding environment (Ministry of Water, Land, and Air Protection, 2003). Trip blanks consisted of VIU bottles filled with distilled water, sealed prior to entering the field. One trip blank was used for each sampling event. Replicate samples were collected to establish reproducibility and precision of measurements (Ministry of Water, Land, and Air Protection, 2003). During both sampling events, a replicate sample was collected from site 4.

4.5: MICROBIOLOGY

Microbiology sampling took place at all four stations during the first sampling event on October 23rd, 2016. Analysis of the samples followed the *Total Coliform and E. coli Membrane Filtration Method (USEPA) (2003)*. Sampling was done to indicate coliform presence, checking for the presence of both non-fecal and fecal forms *(Escherichia coli (E. coli)*). This selective and differential technique checked for the growth of coliform colonies after a 24-hour period. The colony growth was documented in pictures by Dr. Demers so that they could be counted online. Presence of fecal and non-fecal coliforms potentially indicated the existence of other pathogens in the water source at the time of sampling. The results of coliforms observed are discussed in Section 5.3. Samples were collected using pre-labelled 100-ml Whirlpak bags and were prepared for incubation on the same day that samples were taken. Quality assurance and control was followed per the *Ambient Freshwater and Effluent Sampling Manual* (Ministry of Water, Land, and Air Protection, 2003), including a minimum 10% effort of blanks and replicate samples.

4.6: STREAM INVERTEBRATES

Invertebrate samples from sites 1, 2 and 3 were obtained in triplicate in order to determine the health of Cottle Creek on November 2, 2016. Invertebrate samples were not collected from site 4 due to high, fast flowing water levels that would be dangerous to sample in. A Hess sampler was used to collect samples which were stored in plastic containers with lids and transported back to Vancouver Island University for lab analysis. Invertebrates are an excellent indicator species because they are fairly sedentary, abundant and usually don’t move out of an area that is being affected by pollution because they cannot recolonize quickly. The presence or absence of certain aquatic insects will therefore help to determine the overall health of the steam. In order to maintain safety, the team made sure to only enter areas of the stream that were low flow and not slippery to avoid hidden drop offs or hazards at the sites.

4.6.1: QUALITY CONTROL / QUALITY ASSURANCE

In order to maintain quality assurance for invertebrate sampling, the team used clean containers to collect samples. There was no need to preserve and store invertebrate samples as they were analyzed the same day as collection. Triplicate samples at each site were taken to maintain quality control and the Hess sampler was faced upstream for each sample taken to avoid contamination. Once collection was complete, invertebrate samples were transported to Vancouver Island University for lab analysis under a dissection microscope. Triplicate samples from each site were combined so that there were three data sheets in total, one for each site sampled. Presence and abundance of all species found in our samples was recorded.

SECTION 5: RESULTS AND DISCUSSION

5.1: HYDROLOGY

Hydrological measurements were taken at sites 2 and 3 during both sampling events on November 2 and 23, 2016 (for methods see Section 4.3). The results obtained from our assessment are summarized in Table 4 and Figure 2. Site 2 showed an increase in discharge from sample event 1 to sample event 2 (figure 2A & C). Site 3 showed a decrease in discharge from sample event 1 to sample event 2 (figure 2B & D). Sample event 1 was predicted to have the highest discharge values due to the heavy amount of rain that Nanaimo had received on November 2, 2016. Site 3 followed this prediction with a discharge of 0.77 m^3/s during sample event 1, and a lower discharge of 0.41 m^3/s during sample event 2. Site 2 did not follow this prediction as it showed a discharge of 0.52 m^3/s during sample event 1, and a higher discharge of 0.69 m^3/s. Some possible causes of the increase may have been due to precipitation lag time of the watershed following the November 2nd heavy rainfall event. A hydrograph of the site over the month of November would have been required to further investigate the possibility of this speculation. Other possible causes of the discharge increase may have been a result of higher drainage of Cottle Lake into Cottle Creek during sample event 2, or sampling errors during data collection in the field (i.e. measuring velocity at stream surface rather than subsurface).It should also be noted that all discharge values observed during our 2016 Cottle Creek assessment were much higher than the discharge values reported in the 2015 assessment. This was due to higher precipitation received in November 2016 versus November 2015. Nanaimo, BC had a total rainfall of 111.1 mm in November 2015, and a total rainfall of 205.3 mm in November 2016 (Environment Canada, 2016). Average discharge of Cottle Creek at site 2 was 0.010 m^3/s in 2015, and 0.65 m^3/s this year. Average discharge at site 3 was 0.0007 m^3/s in 2015, and 0.55 m^3/s this year (VIU, 2015). Overall, it can be concluded that Cottle Creek is a small stream with relatively low discharge rates, even under high precipitation conditions.

Table 4: Hydrological results of Cottle Creek at sites 2 and 3 for both sampling events on November 2nd and 23rd, 2016.

Date	Site	Wetted Width (m)	Average Depth (m)	Average Velocity (m/s)	Discharge (m^3/s)
02-Nov	2	6.1	0.18	0.48	0.52
	3	4.3	0.51	0.35	0.77
23-Nov	2	5.1	0.11	1.29	0.69
	3	3.6	0.27	0.41	0.41

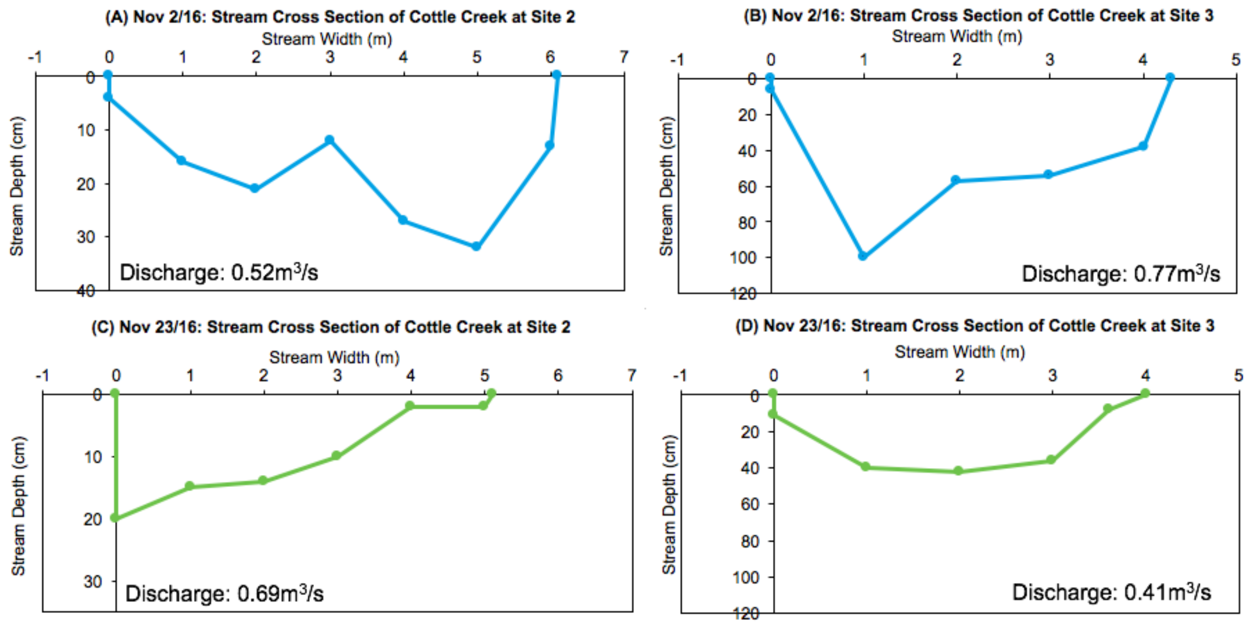

Figure 2: Stream cross sections and discharge of Cottle Creek measured during both sampling events (November 2nd and 23rd, 2016) at sites 2 and 3. Blue lines indicate measurements for sample event 1, and green lines indicate measurements for sample event 2. (A) Shows the stream cross section at site 2 for sample event 1. (B) Shows the stream cross section at site 3 for sample event 1. (C) Shows the stream cross section at site 2 for sample event 2. (D) Shows the stream cross section at site 3 for sample event 2.

5.2: WATER QUALITY

A thorough analysis of water quality parameters were measured during both sampling events from all sites of our Cottle Creek environmental monitoring assessment. On-site measurements of temperature, dissolved oxygen, and % saturation were recorded with an OxyGuard oxygen probe. Water samples from each site were collected and analyzed in-lab at Vancouver Island University by our team for: pH, alkalinity, hardness, conductivity, phosphates, nitrates, and turbidity. Water samples were also sent to the ALS Environmental lab in Burnaby, BC for a more accurate analysis of pH, hardness, conductivity, phosphates, nitrates, and 31 metals.

5.2.1: TEMPERATURE AND DISSOLVED OXYGEN

Temperature is shown in relation to dissolved oxygen in Figure 3 to better reflect the correlation between the two parameters and for trend analysis. Temperature was measured in degree Celsius (ºC) and dissolved oxygen (DO) in mg/L. As the temperature of water increases, gas solubility decreases (Shaw *et al.*, 2004). Therefore, as the water in Cottle Creek heats up, the less dissolved oxygen gas molecules the water can hold.

This expected trend was found when analyzing and comparing the parameters between each sample event. The first sampling event (Nov 2nd, 2016) had resulting higher temperatures and lower levels of DO when compared to the second sampling event (Nov 23rd, 2016), which had lower temperature levels and high levels of DO. Temperatures ranged from 10.3-11.2ºC (9.8-11.0 mg/L for DO) during the first sampling event and 8.8-10.0ºC (10.3-11.5 mg/L for DO) during the second sampling event (see Appendix A). Per the *Guidelines for Interpreting Water Quality Data* (Ministry of Water, Land, and Air Protection, 1998), the criteria for supporting all aquatic fish and invertebrates, DO levels must be a minimum of 9 mg/L. DO levels during both events were sufficient to support aquatic life with no detrimental effects.

Levels of DO and % saturation were lowest at site 2 during both events due to the site being the output for Cottle Lake (see Appendix A). The oxygenic photosynthetic organisms in and surrounding Cottle Lake utilized the DO during primary production, therefore slightly depleting levels in outflowing waters. Water temperatures were higher at site 3 during both events due to the site being relatively open. The dominant riparian trees at site 3 were deciduous alders that had lost most of their foliage, allowing for an open canopy and increased light penetration.

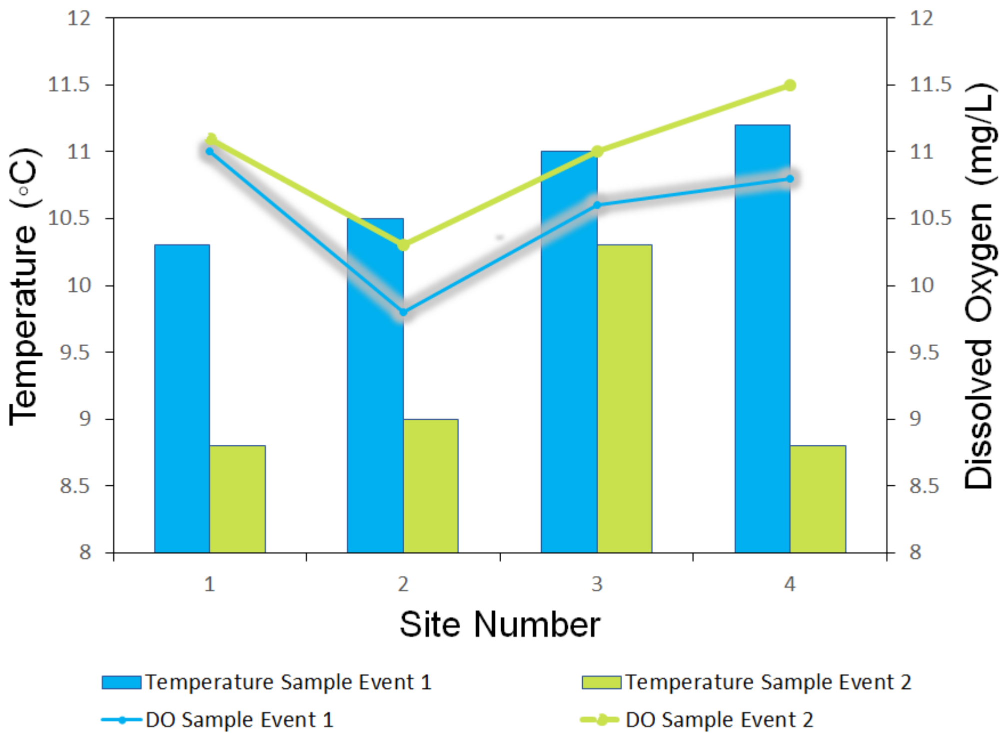

Figure 3: Temperature and dissolved oxygen levels for Sample Event 1 (November 2, 2016) and Sample Event 2 (November 23, 2016) for Cottle Creek, located in Nanaimo, B.C.

5.2.2: pH LEVELS

pH is a measurement of the concentration of hydrogen ions existing within a solution. This is an important parameter to consider when conducting an environmental monitoring program as it has a large influence on many biological reactions, and the potential toxicity of some metals (Shaw et al., 2004). From our VIU lab analysis for sample event 1, site 1 had a pH of 6.5 and site 4 had a pH of 6.8. For sample event 2, site 1 had a pH of 7.1 and site 4 had a pH of 7.6 (figure 4). There is some concern in the accuracy of our VIU results as there is a large deviation from the reported ALS pH values. This may have been a result of sampling error, or a faulty probe in the pH meter that was used for our measurements. Overall, there was a subtle increase in pH downstream from our VIU and ALS results during both sampling events. Although there were some differences between the VIU and ALS pH levels, all measurements fell within the BC water quality guideline (Ministry of Environment, LandData BC, and Geographic Data BC, 1998). Therefore, based on current conditions, acidification of Cottle Creek is not a concern.

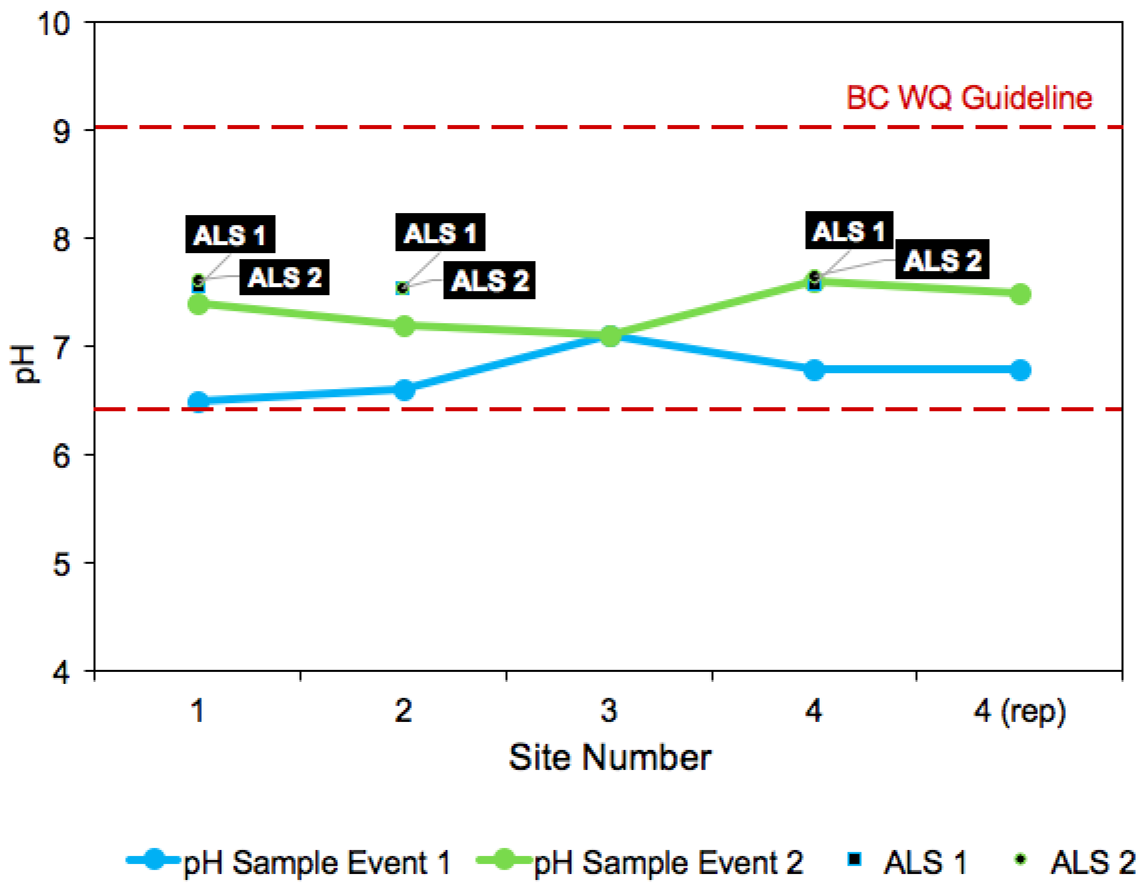

Figure 4: Change in pH moving downstream of Cottle Creek from site 1 to site 4. The blue line indicates pH levels obtained from sample event 1 (November 2nd, 2016), and the green line indicates pH levels obtained from sample event 2 (November 23rd, 2016). Site 4 (rep) indicates the results obtained from a replicate sample of site 4 for quality control. Black boxes indicate the pH results obtained from ALS. Dashed red lines indicate the range for the BC water quality guideline.

5.2.3: ALKALINITY

Alkalinity is a measure of the acid neutralizing capacity of a solution. It measures the concentration of carbonates (HCO_3^- and CO_3^{2-}) present in the solution. Higher concentrations of carbonates in a sample mean there will also be a higher alkalinity. It is an important water quality parameter to consider as it directly has an influence on the pH of the water (Shaw et al., 2004). From our VIU analysis for sample event 1, site 1 had an alkalinity value of 33.8 mg/L and site 4 had an average value of 26.5 mg/L (average of site 4 and site 4 rep. results). For sample event 2, site 1 had an alkalinity value of 27.6 mg/L and site 4 had an average value of 24.8 mg/L (figure 5). Overall, these results show a decreasing trend downstream. This may possibly be related to the high amount of surface runoff being received at site 1. Surface runoff causes erosion of the stream bank sediments, which may be rich in carbonate ions (Shaw et al., 2004). This would explain the higher alkalinity upstream at site 1. The decrease downstream may have been a result of dilution effects. The BC water quality guideline divides alkalinity into 3 categories: low, moderate, and high sensitivity to acidification (figure 5) (Ministry of Environment et al., 1998). All alkalinity results for Cottle Creek fall into the category of low acid sensitivity; meaning it has a high capacity to neutralize acids. Together, the pH and alkalinity results allow for the further conclusion that acidification of Cottle Creek is not currently a concern.

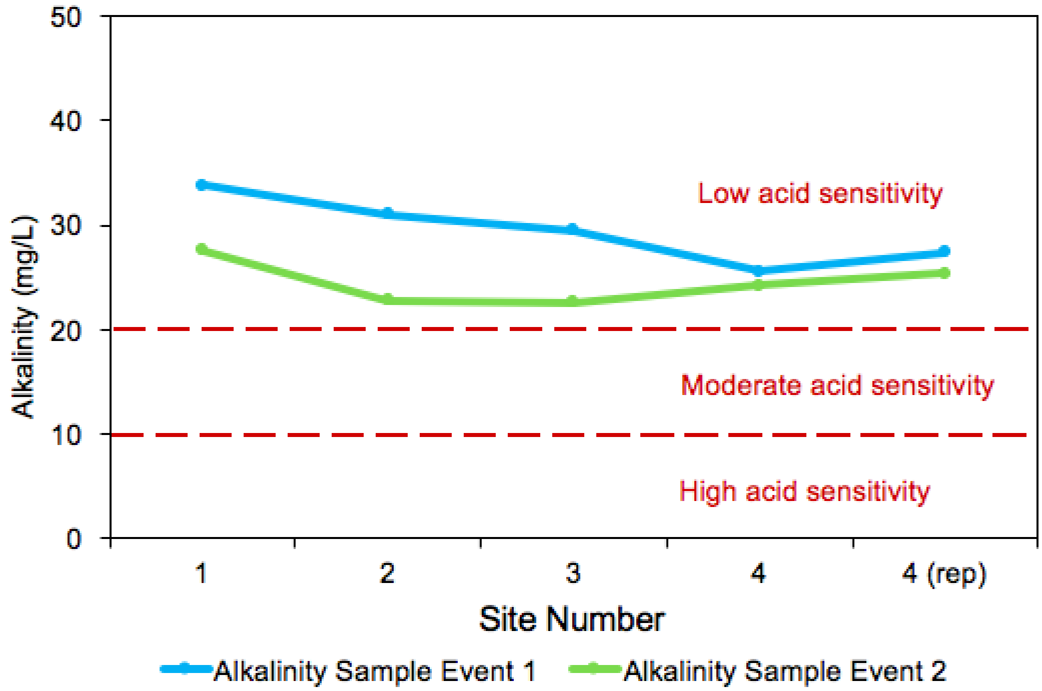

Figure 5: Change in alkalinity moving downstream of Cottle Creek from site 1 to site 4. The blue line indicates alkalinity in mg/L obtained from sample event 1 (November 2nd, 2016), and the green line indicates alkalinity obtained from sample event 2 (November 23rd, 2016). Site 4 (rep) indicates the results obtained from a replicate sample of site 4 for quality control. Dashed red lines indicate the BC water quality guideline for low, moderate, and high sensitivity to acidification.

5.2.4: HARDNESS

Hardness is a measure of the concentration of divalent cations present in a solution. The major cations that relate to hardness in a freshwater system are calcium (Ca^{2+}) and magnesium (Mg^{2+}). Higher concentrations of cations in a sample mean there will also be a higher hardness value (Shaw et al., 2004). Water samples containing <60 mg/L as $CaCO_3$ is considered soft water, and samples containing >120 mg/L as $CaCO_3$ is considered hard water (Ministry of Environment et al., 1998). Hardness is an important parameter to analyze for as it has an influence on the potential toxicity of metals to aquatic organisms. Metals become more toxic to aquatic organisms in soft water. Therefore, water quality guidelines for certain metals (i.e. copper) will vary based on hardness levels. From our VIU analysis for sample event 1, site 1 had a hardness value of 39 mg/L as $CaCO_3$ and site 4 had a value of 30 mg/L as $CaCO_3$. For sample event 2, site 1 had a hardness value of 40 mg/L as $CaCO_3$ and site 4 had a value of 36 mg/L as $CaCO_3$ (figure 6). Since hardness and alkalinity are theoretically correlated, a similar decreasing trend downstream was observed. The higher hardness concentration at site 1 during both sampling events may also be a result of the high surface runoff and erosion being received there. The VIU lab analysis results for hardness were similar to the ALS results received from our water samples, indicating that our hardness results were accurate. All hardness results were well below 60 mg/L as $CaCO_3$, meaning that Cottle Creek drains soft water from the watershed.

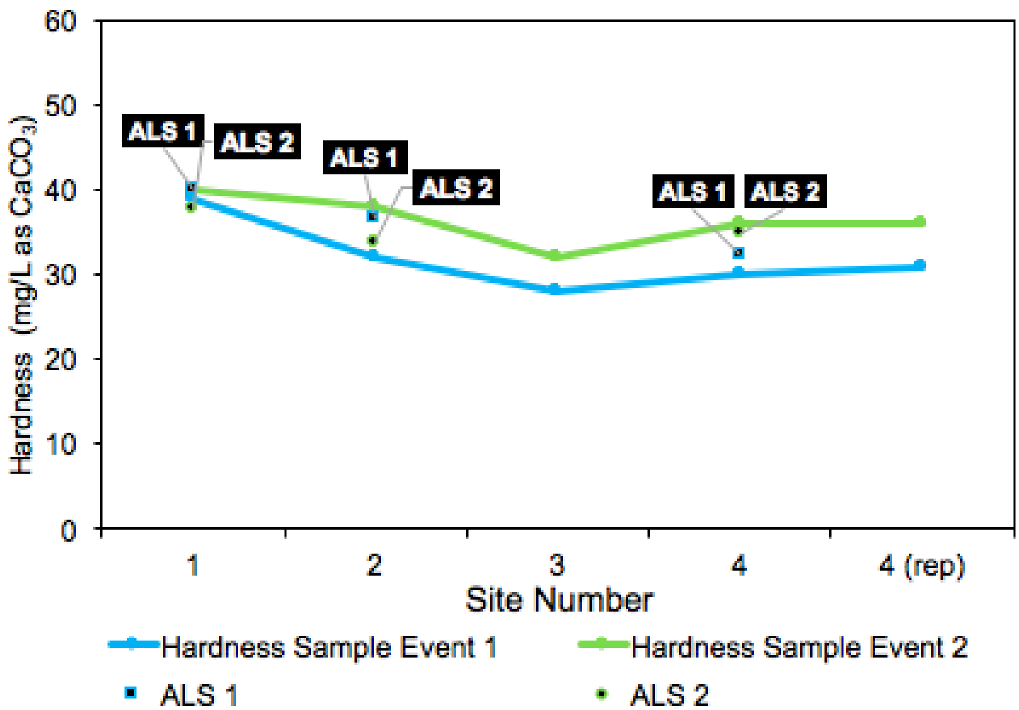

Figure 6: Change in hardness moving downstream of Cottle Creek from site 1 to site 4. The blue line indicates hardness obtained from sample event 1 (November 2nd, 2016), and the green line indicates hardness obtained from sample event 2 (November 23rd, 2016). Site 4 (rep) indicates the results obtained from a replicate sample of site 4 for quality control. Black boxes indicate the hardness results obtained from ALS.

5.2.5: CONDUCTIVITY

Conductivity is a measure of the amount of electricity that can be conducted within a solution. It is directly correlated with hardness because a higher concentration of dissolved ions causes an increased ability for water to conduct electricity (Shaw et al., 2004). There is no specific BC water quality guideline for conductivity as it can vary greatly depending on the ions present in the water (Ministry of Environment et al., 1998). However, it is also very valuable for identifying potential pollution sources from any industrial or residential effluents. From our VIU analysis for sample event 1, site 1 had a conductivity value of 81 μS/cm and site 4 had an average value of 66 μS/cm (average of site 4 and site 4 (rep) results). For sample event 2, site 1 had a conductivity value of 81 μS/cm and site 4 had an average conductivity of 75 μS/cm (figure 7). Since conductivity, hardness, and alkalinity are all theoretically correlated, the same decreasing trend downstream was also observed for conductivity. Again, the higher values at site 1 during both sampling events may have been caused by the increased surface runoff seen at the site. The VIU lab analysis results somewhat deviated from the ALS conductivity results, which may indicate reduced accuracy during our in lab measurements. Reduced accuracy of our conductivity measurements may possibly be caused by sampling errors in the lab (i.e. contamination with deionized water, or other group's samples), a weak conductivity probe, or different sample locations when bottles were filled in the field. Overall, the conductivity results remain as expected for typical coastal BC streams (<150 μS/cm). Therefore, effluent pollution in Cottle Creek is not a concern.

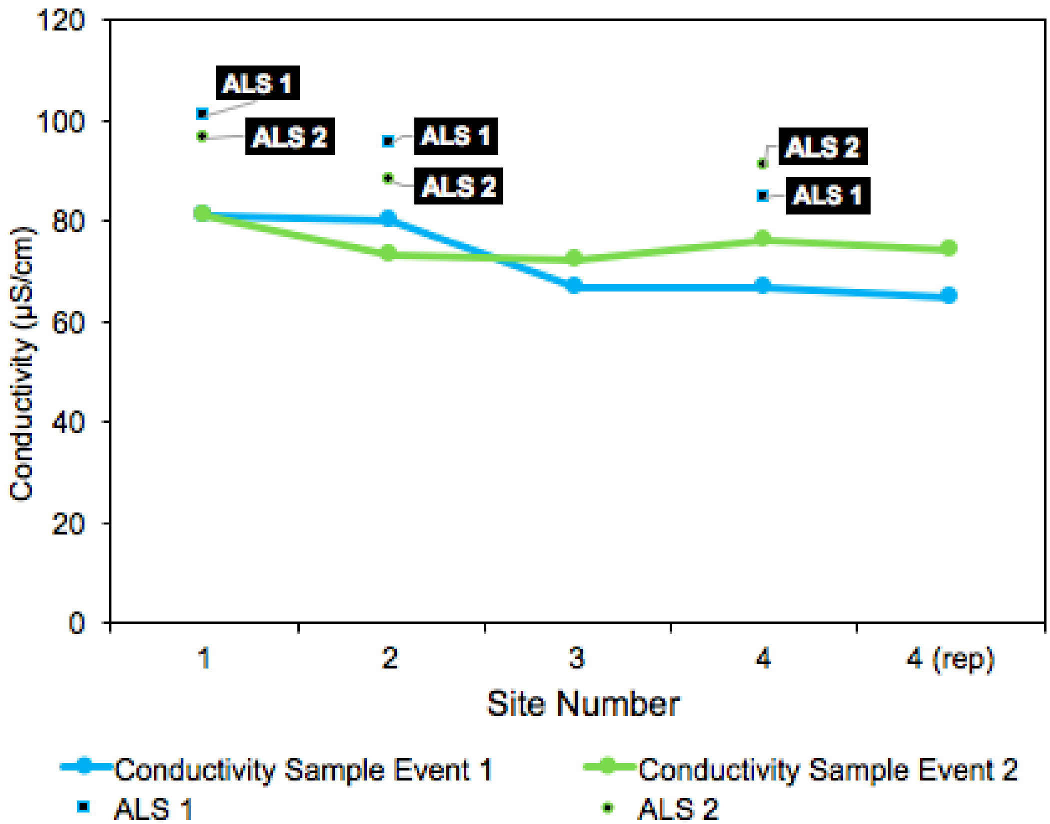

Figure 7: Change in conductivity moving downstream of Cottle Creek from site 1 to site 4. The blue line indicates conductivity obtained from sample event 1 (November 2nd, 2016), and the green line indicates conductivity obtained from sample event 2 (November 23rd, 2016). Site 4 (rep) indicates the results obtained from a replicate sample of site 4 for quality control. Black boxes indicate the conductivity results obtained from ALS.

5.2.6: PHOSPHATE

Phosphate is the most limiting nutrient in freshwater systems, yet is crucial to primary production, phytoplankton and macrophyte growth (Ministry of Water, Land, and Air Protection, 1998). Phosphate was measured in mg/L. Per the Guidelines for Interpreting Water Quality Data (Ministry of Water, Land, and Air Protection, 1998), the criteria for supporting all aquatic life (during spring turnover) is a range from 5-15µg/L (0.005-0.015 mg/L). During the first sampling event (Nov 2nd, 2016), VIU lab analyzed ranges between 0.10-0.24 mg/L (ALS range: 0.013-0.039 mg/L). During sampling event

2 (Nov 23rd, 2016), VIU lab analyzed ranged between 0.02-0.17 mg/L (ALS range: 0.010-0.015 mg/L) (see Appendix A).

Although it is not spring turnover, fall also represents a time when nutrients would be mixing and spread throughout the water column. The results from the VIU lab analysis shows levels way higher than the guidelines, and in the case of ALS, they are either too high or right on the cusp. This would indicate a trophic state from mesotrophic – eutrophic (Ministry of Water, Land, and Air Protection, 1998). High results of phosphate in the water are most likely due to anthropogenic inputs entering the system from the surrounding watershed. Phosphates are found in fertilizers and sewage runoff. The Cottle Creek sites run through urban neighborhoods and are impacted from agricultural and industrial inputs.

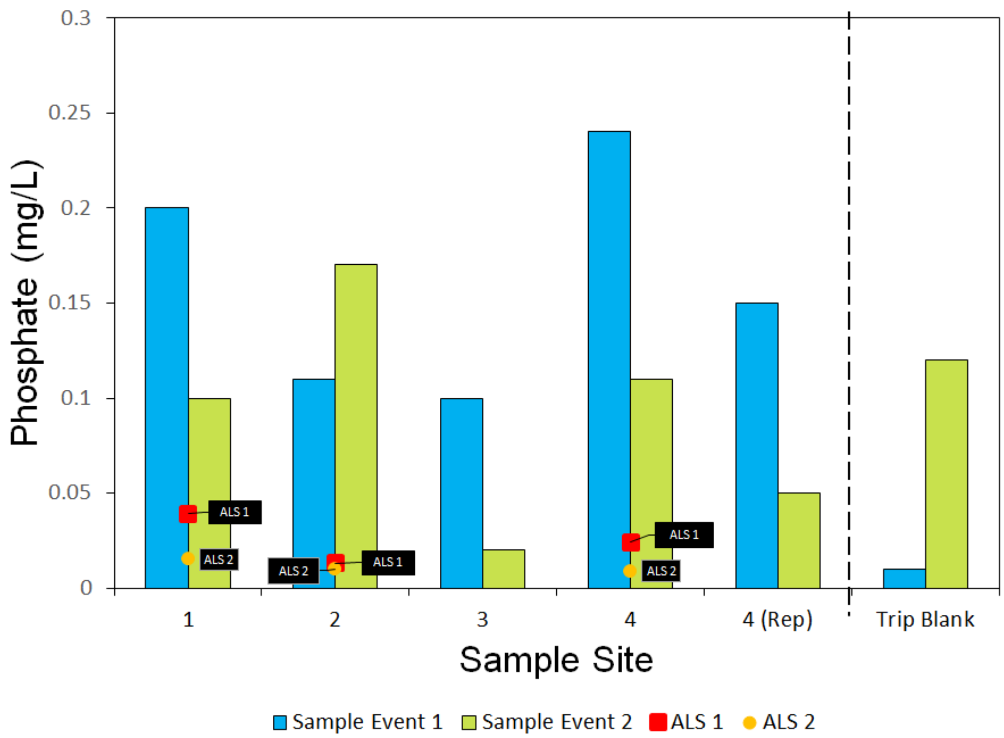

Figure 8: Comparison of phosphate levels from VIU and ALS laboratories for Sample Event 1 (November 2, 2016) and Sample Event 2 (November 23, 2016) for Cottle Creek, located in Nanaimo, B.C.

The results from the ALS lab were lower than those from VIU. The reason may be due to the high volume of students using the equipment at VIU, leaving room for possible vial contamination. This is evident in the trip blank in sampling event 2, as levels of phosphate were detected in a blank sample of distilled water. ALS is a private, analytical lab that most likely has stricter adherence to sanitization between sample analysis.

5.2.7: NITRATE

Nitrate is the main form of nitrogen used by primary producers and is a key nutrient in phytoplankton and macrophyte growth (Ministry of Water, Land, and Air Protection, 1998). Nitrate was measured in mg/L. Figure 9 summarizes nitrate levels found during both sampling events. Analysis from both the VIU and ALS labs are shown. For nitrate analysis at the VIU lab, water samples from each site, along with the replicate and trip blank, were measured. Nitrate analysis from the ALS lab included samples from sites 1,2 and 4. Results from both sampling events were within the limits of nitrate level guidelines to support aquatic life (200 mg/L) (Ministry of Water, Land, and Air Protection, 1998).

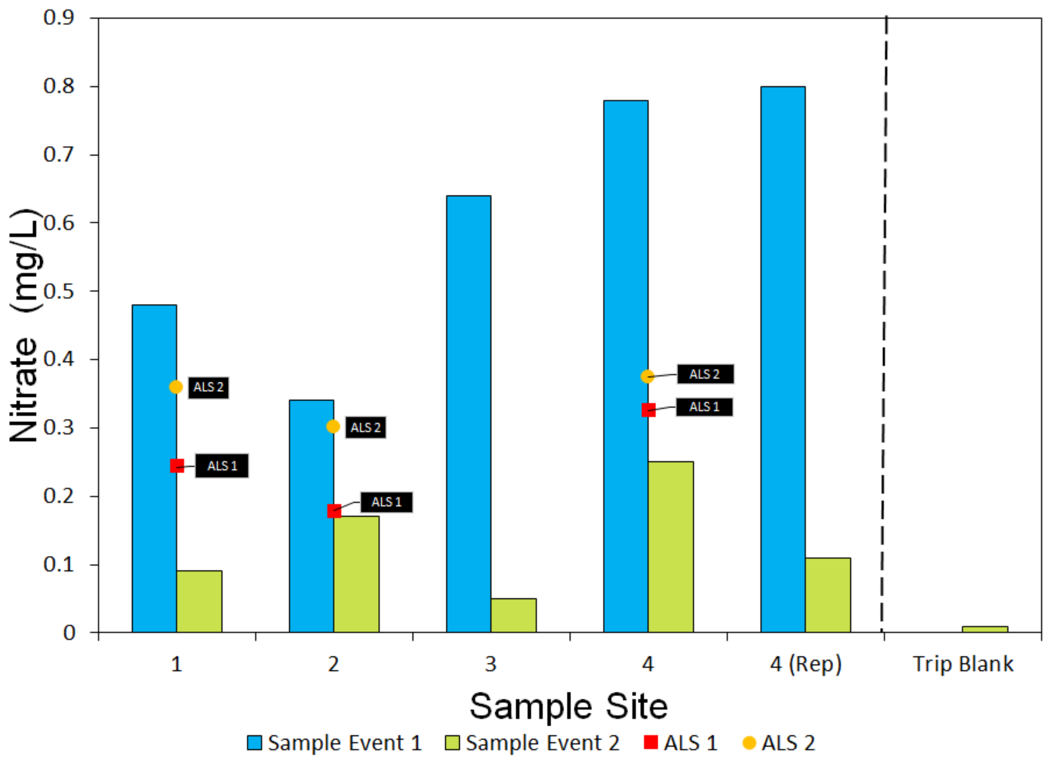

Figure 9: Comparison of nitrate levels from VIU and ALS laboratories for Sample Event 1 (November 2, 2016) and Sample Event 2 (November 23, 2016) for Cottle Creek, located in Nanaimo, B.C.

When comparing nitrate analysis between the two labs, the results show opposite and unexpected trends. VIU lab results show higher levels of nitrate at every site during the *first* sampling event, whereas ALS lab results show higher nitrate levels at every site during the *second* sampling event. The reason for this result is unknown, but may be due to the sensitivity of equipment used when analyzing. The lab at VIU had multiple groups taking turns using the measuring equipment beforehand, therefore, depending on which vials were used, it is possible that there was improper cleaning techniques and possible contamination. ALS is a private, professional analytical lab, which most likely has stricter enforcement for equipment sanitization.

In general, nitrate levels were lowest at site 2 due to the site being the output stream for the photosynthetically productive Cottle Lake. If higher levels of nitrate were truly present during sample event 1 (Nov 2), it may have been caused by increased allochthonous inputs from storm activity. However, if higher levels were truly present in sample event 2, the water column may have been more concentrated with less nitrate being washed out of the system.

5.2.8: ALS TOTAL METALS

Water samples from sites 1, 2, and 4 were collected during both sampling events, preserved with nitric acid (HNO_3), and sent to the ALS Environmental lab to be analyzed for 31 metals. Table 5 summarizes the 10 metals that were found in concentrations exceeding the minimum detection limits of ALS technology. Since Cottle Creek contains soft water, it was important to analyze the stream for possible metal contamination as soft water increases the potential toxicity of many metals. Most metals at Cottle Creek were present at relatively low concentrations, and do not pose any threat to the aquatic and riparian habitats. It is not unusual to find these 10 metals present in a stream, as most exist in many common minerals found within the surrounding geology. The metals are released due to erosional forces of precipitation and flowing water. It should also be noted that higher concentrations of these metals were present in the stream during the first sampling event on November 2nd, 2016 when Nanaimo received heavy rainfall. This was possibly a result of increased erosion occurring, and sediments containing the metals being released into the stream. Based on the total metals results obtained from ALS the only metal that poses some concern to Cottle Creek was aluminum. Aluminum concentrations were quite high during sample event 1 at 0.95 mg/L at site 1, and 0.82 mg/L at site 2. During sample event 2, aluminum concentrations were significantly lower being less than the 0.20 mg/L minimum detection limit of ALS. This means that during high precipitation events, Cottle Creek is receiving a high amount of aluminum from an unknown source. This may be of some concern as the BC water quality guideline indicates an average maximum dissolved aluminum concentration of 0.05 mg/L for aquatic life.

Table 5: ALS total metals results from both sampling events (November 2nd and 23rd, 2016) for site 1, 2, and 4 of Cottle Creek. ALS analyzed each sample for 31 metals; this data table only displays the 10 metals that were present above the detection limits of the inductively coupled plasma-optical emission spectrometer (ICP-OES) utilized for the total metals analysis at ALS Environmental.

Event	Total Metals (mg/L)	Site 1	Site 2	Site 4
1	Aluminum (Al)	0.95	<0.20	0.82
2		<0.20	0.27	<0.20
1	Calcium (Ca)	10.80	10.10	8.82
2		10.20	9.10	9.40
1	Iron (Fe)	2.06	0.93	1.54
2		0.40	0.58	0.39
1	Magnesium (Mg)	3.12	2.80	2.52
2		3.00	2.67	2.75
1	Manganese (Mn)	0.43	0.054	0.14
2		0.036	0.035	0.027
1	Silicon (Si)	6.29	5.45	5.60
2		5.21	5.64	5.83
1	Sodium (Na)	6.60	7.00	6.50
2		6.80	6.50	7.00
1	Strontium (Sr)	0.047	0.041	0.035
2		0.047	0.040	0.039
1	Titanium (Ti)	0.064	0.011	0.063
2		<0.010	0.018	0.011
1	Zinc (Zn)	0.0053	<0.0050	<0.0050
2		<0.0050	<0.0050	<0.0050

5.2.9: TURBIDITY

Turbidity, the relative clarity of a liquid, is measured by absorption and expressed in Nephelometric Turbidity Units (NTU). Water samples were collected in field, and turbidity measurements and analysis were performed in the VIU lab. Turbidity measurements were taken during both events, and at each sampling site, including the replicate samples at site 4.

As seen in Figure 10, the turbidity levels were higher during the first sampling event on November 2nd, then during the second sampling event on November 23rd. The results were consistent throughout each of the four sampling sites. Turbidity ranged between 10.5-38.7NTU during the first sampling event, and between 3.39-4.74NTU during the second sampling event (see Appendix A). Per the *Guidelines for Interpreting Water Quality Data* (Ministry of Water, Land, and Air Protection, 1998), the criteria for supporting aquatic life is: no more than a 10% increase in NTUs when the background is >50 NTU. As the results showed no levels above 50 NTU, turbidity levels during both sampling events were sufficient to support aquatic life.

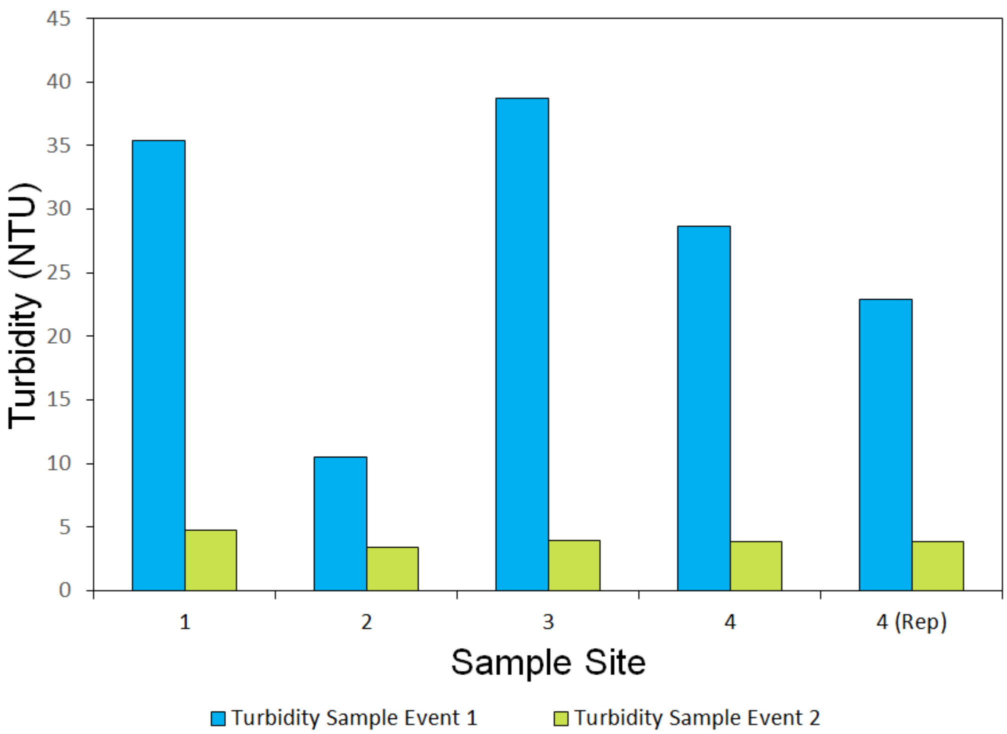

Figure 10: Turbidity levels for Sample Event 1 (November 2, 2016) and Sample Event 2 (November 23, 2016) for Cottle Creek, located in Nanaimo, B.C.

The low turbidity levels during the second sampling event most likely reflect the normal patterns in that area. The higher levels during the first sampling event were due to consistent rainstorm events contributing to an increase in atmospheric and watershed deposition. Heavy rainfall increased the allochthonous inputs to the creek. Heavy water inputs into the stream also increased the current velocity, increasing the shear stress and causing bank erosion. The resulting inputs into the creek caused a decrease in water clarity and an increase in turbidity levels. Site 2 had the lowest levels of turbidity following the storm events, as it is situated as an output stream to Cottle Lake. Cottle Lake and the riparian areas surrounding the lake serve as buffers to increased water flows and as an area for particulates in the water column to settle or be absorbed by macrophytes.

5.3: MICROBIOLOGY

FIELD SAMPLING

Fecal and non-fecal coliforms were analyzed from all four sites from the samples taken on November 2nd, 2016. All of the sites were positive for both fecal and non-fecal coliforms with higher total coliform counts than originally anticipated (Table 6). The inclement weather that occurred during the week before the sample date may have affected the coliform levels as turbidity was also very high at all sites for the first sample event (Table 6). Site 1 at Landalt Road had the highest fecal coliform percentage, 72%, which was expected due to the presence of construction as well as agricultural activity on both sides of the creek at this site. Site 2 at Cottle Lake had the lowest amount of total coliforms present as well as the smallest percentage of fecal coliforms, 7%, which may be because Cottle Lake acts as a filter, allowing some of the turbid material to settle in the lake before flowing downstream back into Cottle Creek. It was also the most remote of the sites and less exposed to anthropogenic sources that may influence coliform content such as agricultural waste. Sites 3 and 4 were comparable in total coliform amounts as well as % of fecal coliforms at 19 and 25% respectively, again likely due to higher than usual amount of water flowing through the stream, increasing turbidity and coliform content as well as their proximity to busy areas that humans and animals pass through regularly.

LAB ANALYSIS

Through lab analysis at the Vancouver Island University campus, we determined that all of the sites exceeded the maximum allowable limit of coliforms present outlined in the BC Water Quality Guidelines for untreated drinking water. The guidelines for untreated drinking water are 0 CFU fecal coliforms/ml and Sites 1, 3 and 4 were above the guideline for primary recreational contact, which is 50 CFU fecal coliforms/ 25ml (Ministry of Water, Land, and Air Protection, 1998).

Table 6: Microbiology analysis results from Cottle Creek, taken at 4 sites on November 2nd, 2016.

Site	Total Coliforms (CFU/25mL)	Fecal Coliforms (CFU/25mL)	Fecal Coliform (%)
1	323	232	72
2	249	7	3
3	474	91	19
4	443	111	25

5.4: STREAM INVERTEBRATES

5.4.1: TOTAL DENSITIES

The total invertebrate densities were calculated using an invertebrate survey data sheet. The total number of invertebrates recorded in a sample was divided by 0.27 m^2, the total area sampled within the Hess sampler. This number represents the total density per square meter of Cottle Creek. Invertebrate samples were taken at sites 1, 2 and 3 and were calculated to be 114.8/m^2 density at site 1, 348.0/m^2 density at site 2 and 129.6 m^2 invertebrate density at site 3. Tables 7, 8, and 9 show the taxon richness and diversity of invertebrates found at each of the sites sampled.

5.4.2: TAXON RICHNESS AND DIVERSITY

Table 7: Taxon Richness and Abundance of Invertebrates at Cottle Creek Site 1, November 2, 2016

Invertebrate Species	Number of Invertebrates Counted
Caddisfly Larva	3
Mayfly Nymph	2
Stonefly Nymph	3
Cranefly Larva	3
Freshwater Shrimp	6
Oligochaetes	12
Midge Larva	3

Table 8: Taxon Richness and Abundance of Invertebrates at Cottle Creek Site 2, November 2, 2016

Invertebrate Species	Number of Invertebrates Counted
Mayfly Nymph	2
Clam, Mussel	2
Freshwater Shrimp	32
Oligochaetes	58
Leech	2

Table 9: Taxon Richness and Abundance of Invertebrates at Cottle Creek Site 3, November 2, 2016

Invertebrate Species	Number of Invertebrates Counted
Caddisfly Larva	2
Mayfly Nymph	5
Stonefly Nymph	8
Cranefly Larva	5
Oligochaetes	14
Midge Larvae	1

The site assessment rating for each of the sites was calculated based on the presence or absence of certain invertebrates. This rating is used to indicate whether an ecosystem is in good or poor health by analyzing a number of factors including the number of pollution tolerant invertebrates present, the number of pollution intolerant invertebrates present and the predominant taxon ratio. The score is calculated on a scale of 1 to 4 with 1 meaning that the ecosystem is in poor health, and 4 meaning that the ecosystem is in good health. The overall site assessment rating of site 1 was 2.5, site 2 was 2 and site 3 was 2.5. In general, Cottle Creek scored in the Marginal to Acceptable, indicating that the aquatic stream ecosystem was in moderate health.

SECTION 6: CONCLUSIONS AND RECOMMENDATIONS

Considering the location of Cottle Creek near developing residential areas, the stream is moderately healthy. The first sampling event provided insight into the storm flow of the stream while the second sampling event was more representative of the base flow and general health of Cottle Creek. The water quality reflected the inclement weather that occurred but also revealed some impacts that the nearby construction and agricultural areas were having, especially on microbiological results. We recommend enforcing that the protected areas of the Linley Valley stay protected to avoid further impacts on the stream and watershed and the riparian buffer bylaw is also enforced. Furthermore, extra monitoring should be done before commencing any more construction projects as well as monitoring during and after completion of the projects so that appropriate mitigation can be taken to ensure any runoff isn't having detrimental impacts downstream. Finally, we recommend annual monitoring of the waterway to assess spatial and temporal trends as well as the impacts of anthropogenic stressors on the area.

SECTION 7: ACKNOWLEDGEMENTS

We would like to thank those that have assisted us in the execution and completion of this environmental monitoring project. First we would like to thank Dr. Eric Demers for his guidance in the conduction and compilation of an environmental monitoring survey; including providing materials for sampling and analysis in the field and also for his dedication to identification of any and all bird species in the area, regardless of relevance to the project at hand. Secondly we would like to thank Sarah Greenway for her assistance in the lab with set up and analysis. Thirdly we would like to thank Vancouver Island University and the RMOT program for the use of materials and laboratory space. We would also like to thank ALS Laboratories for the quick analysis and results provided which further enhanced our report.

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APPENDIX A:

Table A-1: Complete water quality data set for Cottle Creek, Nanaimo, B.C. (Nov, 2016)

Date	Sample Event	Time	Site	Temp. (ºC)	Dissolved Oxygen (mg/L)	% DO Sat	pH	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as CaCO3)	Turbidity (NTU)	Conductivity (µS/cm)	Nitrate (mg/L NO_3^-)	Phosphate (mg/L PO_4^{3-})
2-Nov	1	3:30 PM	1	10.3	11	100	6.5	39	33.8	35.4	81	0.48	0.2
		3:00 PM	2	10.5	9.8	88	6.6	32	31	10.5	80	0.34	0.11
		1:45 PM	3	11	10.6	97	7.1	28	29.5	38.7	67	0.64	0.10
		1:30 PM	4	11.2	10.8	100	6.8	30	25.6	28,7	67	0.78	0.24
		1:30 PM	4 (rep)				6.8	31	27.4	22.9	65	0.8	0.15
			Trip Blank									0	0.01
23-Nov	2	2:10 PM	1	8.8	11.1	97	7.4	40	27.6	4.74	81	0.09	0.1
		1:45 PM	2	9	10.3	90	7.2	38	22.8	3.39	73	0.17	0.17
		1:10 PM	3	10.3	11	100	7.1	32	22.6	3.9	72	0.05	0.02
		1:00 PM	4	8.8	11.5	99	7.6	36	24.2	3.88	76	0.25	0.11
		1:00 PM	4 (rep)				7.5	36	25.4	3.84	74	0.11	0.05
			Blank									0.01	0.12

Table A-2: ALS Environmental physical parameter and nutrient results for sample event 1 (November 2nd, 2016).

Client Sample ID			COTTLE CREEK-STATION 1	COTTLE CREEK-STATION 2	COTTLE CREEK-STATION 4
Date Sampled			2-Nov-2016	2-Nov-2016	2-Nov-2016
Time Sampled			15:00	15:00	15:00
ALS Sample ID			L1853599-4	L1853599-5	L1853599-6
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Physical Tests (Water)					
Conductivity	2.0	uS/cm	101	95.2	84.7
Hardness (as CaCO3)	0.50	mg/L	39.9	36.7	32.4
pH	0.10	pH	7.56	7.55	7.57
Anions and Nutrients (Water)					
Ammonia, Total (as N)	0.0050	mg/L	0.0187	0.0201	0.0116
Nitrate (as N)	0.0050	mg/L	0.244	0.179	0.326
Nitrite (as N)	0.0010	mg/L	0.0022	0.0042	0.0017
Total Nitrogen	0.030	mg/L	0.904	0.527	0.801
Orthophosphate-Dissolved	0.0010	mg/L	0.0045	0.0015	0.0030
Phosphorus (P)-Total	0.0020	mg/L	0.0391	0.0130	0.0243
N:P			23.1	40.5	33.0

Table A-3: ALS Environmental physical parameter and nutrient results for sample event 2 (November 23rd, 2016).

Client Sample ID			COTTLE CREEK - STATION 1	COTTLE CREEK - STATION 2	COTTLE CREEK - STATION 4
Date Sampled			23-Nov-2016	23-Nov-2016	23-Nov-2016
Time Sampled			13:00	13:00	13:00
ALS Sample ID			L1862835-4	L1862835-5	L1862835-6
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Physical Tests (Water)					
Conductivity	2.0	uS/cm	96.2	88.1	91.1
Hardness (as CaCO3)	0.50	mg/L	37.8	33.7	34.8
pH	0.10	pH	7.62	7.54	7.66
Anions and Nutrients (Water)					
Ammonia, Total (as N)	0.0050	mg/L	0.0074	0.0082	0.0069
Nitrate (as N)	0.0050	mg/L	0.359	0.301	0.375
Nitrite (as N)	0.0010	mg/L	<0.0010	0.0019	0.0010
Total Nitrogen	0.030	mg/L	0.751	0.556	0.615
Orthophosphate-Dissolve	0.0010	mg/L	0.0036	0.0014	0.0021
Phosphorus (P)-Total	0.0020	mg/L	0.0151	0.0099	0.0090
N:P	N/A	N/A	49.7	56.2	68.3

Table A-4: ALS Environmental total metals results for sample event 1 (November 2nd, 2016).

Client Sample ID			COTTLE CREEK-STATION 1	COTTLE CREEK-STATION 2	COTTLE CREEK-STATION 4
Date Sampled			2-Nov-2016	2-Nov-2016	2-Nov-2016
Time Sampled			15:00	15:00	15:00
ALS Sample ID			L1853599-4	L1853599-5	L1853599-6
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Total Metals (Water)					
Aluminum (Al)-Total	0.20	mg/L	0.95	<0.20	0.82
Antimony (Sb)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Arsenic (As)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Barium (Ba)-Total	0.010	mg/L	0.010	<0.010	<0.010
Beryllium (Be)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050
Bismuth (Bi)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Boron (B)-Total	0.10	mg/L	<0.10	<0.10	<0.10
Cadmium (Cd)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Calcium (Ca)-Total	0.050	mg/L	10.8	10.1	8.82
Chromium (Cr)-Total	0.010	mg/L	<0.010	<0.010	0.024
Cobalt (Co)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Copper (Cu)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Iron (Fe)-Total	0.030	mg/L	2.06	0.934	1.54
Lead (Pb)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Lithium (Li)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Magnesium (Mg)-Total	0.10	mg/L	3.12	2.80	2.52
Manganese (Mn)-Total	0.0050	mg/L	0.430	0.0542	0.144
Molybdenum (Mo)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Nickel (Ni)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Phosphorus (P)-Total	0.30	mg/L	<0.30	<0.30	<0.30
Potassium (K)-Total	2.0	mg/L	<2.0	<2.0	<2.0
Selenium (Se)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Silicon (Si)-Total	*0.050*	mg/L	6.29	5.45	5.60
Silver (Ag)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Sodium (Na)-Total	2.0	mg/L	6.6	7.0	6.5
Strontium (Sr)-Total	0.0050	mg/L	0.0469	0.0408	0.0348
Thallium (Tl)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Tin (Sn)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Titanium (Ti)-Total	0.010	mg/L	0.064	0.011	0.063
Vanadium (V)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Zinc (Zn)-Total	0.0050	mg/L	0.0053	<0.0050	<0.0050

Table A-5: ALS Environmental total metals results for sample event 2 (November 23rd, 2016).

Client Sample ID			COTTLE CREEK - STATION 1	COTTLE CREEK - STATION 2	COTTLE CREEK - STATION 4
Date Sampled			23-Nov-2016	23-Nov-2016	23-Nov-2016
Time Sampled			13:00	13:00	13:00
ALS Sample ID			L1862835-4	L1862835-5	L1862835-6
Parameter	Lowest Detection Limit	Units	Water	Water	Water
Total Metals (Water)					
Aluminum (Al)-Total	0.20	mg/L	<0.20	0.27	<0.20
Antimony (Sb)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Arsenic (As)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Barium (Ba)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Beryllium (Be)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050
Bismuth (Bi)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Boron (B)-Total	0.10	mg/L	<0.10	<0.10	<0.10
Cadmium (Cd)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Calcium (Ca)-Total	0.050	mg/L	10.2	9.10	9.40
Chromium (Cr)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Cobalt (Co)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Copper (Cu)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Iron (Fe)-Total	0.030	mg/L	0.399	0.585	0.391
Lead (Pb)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Lithium (Li)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Magnesium (Mg)-Total	0.10	mg/L	3.00	2.67	2.75
Manganese (Mn)-Total	0.0050	mg/L	0.0360	0.0353	0.0275
Molybdenum (Mo)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Nickel (Ni)-Total	0.050	mg/L	<0.050	<0.050	<0.050
Phosphorus (P)-Total	0.30	mg/L	<0.30	<0.30	<0.30
Potassium (K)-Total	2.0	mg/L	<2.0	<2.0	<2.0
Selenium (Se)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Silicon (Si)-Total	0.050	mg/L	5.21	5.64	5.83
Silver (Ag)-Total	0.010	mg/L	<0.010	<0.010	<0.010
Sodium (Na)-Total	2.0	mg/L	6.8	6.5	7.0
Strontium (Sr)-Total	0.0050	mg/L	0.0468	0.0400	0.0390
Thallium (Tl)-Total	0.20	mg/L	<0.20	<0.20	<0.20
Tin (Sn)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Titanium (Ti)-Total	0.010	mg/L	<0.010	0.018	0.011
Vanadium (V)-Total	0.030	mg/L	<0.030	<0.030	<0.030
Zinc (Zn)-Total	0.0050	mg/L	<0.0050	<0.0050	<0.0050

Figure A-1: Photo taken November 23rd, 2016 at Site 1 (Landalt Rd.) looking upstream.

Figure A-2: Photo taken November 23rd, 2016 at Site 2 (Cottle Lake) looking upstream.

Figure A-3: Photo taken November 23rd, 2016 at Site 3 (Nottingham Dr.) looking downstream.

Figure A-4: Photo taken November 23rd, 2016 at Site 4 (Stephenson Point Rd.) looking downstream.

APPENDIX B:

Please see attached Stream Invertebrate Survey Data Sheets

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Cottle Creek		Date: 2/11/2016	
Station Name: Station #1		Flow status: High	
Sampler Used: Hess Sampler	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.27 m^2	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	EPT1 3	EPT4 1
	Mayfly Nymph (EPT)	EPT2 1	EPT5 1
	Stonefly Nymph (EPT)	EPT3 3	EPT6 1
Pollution Intolerant	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		C1 7	D1 3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	3	1
Somewhat Pollution Tolerant	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	6	1
	Watersnipe Larva		
Sub-Total		C2 9	D2 2
Category 3	Aquatic Worm (oligochaete)	12	4
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)	3	1
Pollution Tolerant	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		C3 15	D3 5
TOTAL		CT 31	DT 10

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

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

S1: 31

DENSITY: Invertebrate density per total area sampled:

S1 31 ÷ 0.27 m^2 =

S2: 114.8 / m^2

PREDOMINANT TAXON:

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

S3: oligochaete

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 __3__ + 2 x __2__ + __5__ =

S4: 18

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

__1__ + __1__ + __1__ =

S5: 3

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

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

(EPT1 + EPT2 + EPT3) / CT

(__3__ + __1__ + __3__) / __31__=

S6: 0.226

SECTION 3 - DIVERSITY

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

S7: 10

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

_12_ / _31_ =

S8: 0.387

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 1
Predominant Taxon Ratio	R4 4

Average Rating

Average of R4, R5, R6, R8

2.5

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Cottle Creek		Date: 2/11/16
Station Name: Station #2		Flow status: High
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.27 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	EPT1	EPT4
	Mayfly Nymph (EPT)	EPT2 2	EPT5 2
	Stonefly Nymph (EPT)	EPT3	EPT6
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		C1 2	D1 2
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	2	1
	Cranefly Larva		
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	32	4
	Watersnipe Larva		
Sub-Total		C2 34	D2 5
Category 3	Aquatic Worm (oligochaete)	58	4
	Blackfly Larva		
	Leech	2	1
	Midge Larva (chironomid)		
Pollution Tolerant	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		C3 60	D3 5
TOTAL		CT 94	DT 12

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

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

S1: 94

DENSITY: Invertebrate density per total area sampled:

S1: 94 ÷ 0.27 m^2 = S2: 348 / m^2

PREDOMINANT TAXON:

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

S3: Oligochaete

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 5 + 5 =

S4: 21

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

0 + 2 + 0 =

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

(0 + 2 + 0) / 94 =

S6: .03

SECTION 3 - DIVERSITY

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

S7: 12

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

58 / 94 =

S8: 0.62

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 1
Predominant Taxon Ratio	R4 2

Average Rating
Average of R4, R5, R6, R8
2

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Cottle Creek		Date: 2/11/2016	
Station Name: Station #3		Flow status: High	
Sampler Used: Hess Sampler	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates 0.27 m^2	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	EPT1 2	EPT4 1
	Mayfly Nymph (EPT)	EPT2 5	EPT5 1
	Stonefly Nymph (EPT)	EPT3 8	EPT6 2
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		C1 15	D1 4
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	5	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)		
	Watersnipe Larva		
Sub-Total		C2 5	D2 1
Category 3	Aquatic Worm (oligochaete)	14	4
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)	1	1
Pollution Tolerant	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		C3 15	D3 5
TOTAL		CT 35	DT 10

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

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

S1: 35

DENSITY: Invertebrate density per total area sampled:

S1 35 ÷ $0.27\ m^2$ =

S2: 129.6 $/ m^2$

PREDOMINANT TAXON:

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

S3: oligochaete

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 __1__ + __5__ =

S4: 19

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

__1__ + __1__ + __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

(__2__ + __5__ + __8__) / __35__=

S6: 0.429

SECTION 3 - DIVERSITY

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

S7: 10

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

_14_ / _35_ =

S8: 0.4

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