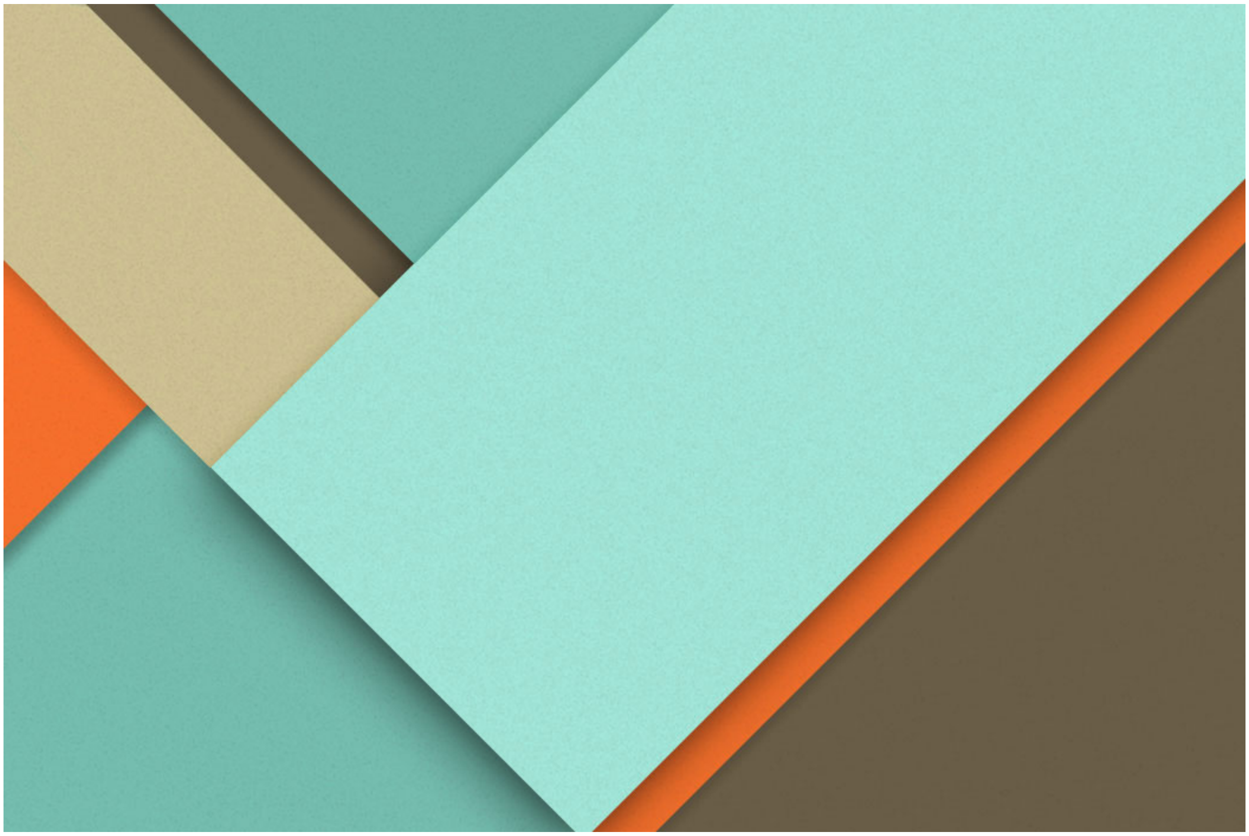

Cottle Creek Monitoring Project

12.09.2022

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EXECUTIVE SUMMARY

The purpose of this report is to share the findings from two field sampling events in October and November at 4 sites along Cottle Creek in Nanaimo, British Columbia. The reasoning for this sampling was to add to the cumulative archive of stream sampling data that RMOT 306 students have been engaged in for over a decade. This project is performed in tandem with the Department of Fisheries and Oceans Canada in order to add to their federal database of watershed health.

Throughout this process, the British Columbia's Water Quality Guidelines provided a framework to illustrate acceptable and safe levels of contaminants in a water supply. These guidelines provide the metrics against which the samples collected for this report were compared. The methodology for this project was a combination of field sampling and measurements, VIU Lab analysis of samples, and ALS Environmental Laboratory analysis. In addition to water quality parameters, invertebrates were also sampled at each site to measure density and calculate an overall numerical value for site health.

After compiling all the relevant data from all analytical avenues it was found that the stream contained elevated levels of three metals surpassing the water quality guidelines during the October sampling event at site 2. No sites were found to be eutrophic and all sites fell between the overall site rating of “acceptable” and “good”. In addition, when comparing the results to previous years there is a marked increase in invertebrate density for the samples contained within this report. At this time we are unable to discern exactly what could account for the cause of this dramatic increase in invertebrate density.

TABLE OF CONTENTS

1.0 INTRODUCTION/BACKGROUND

1.1 INTRODUCTION

Canada has remained the fastest growing among the G7 countries since 2016, with a population increase of 1.8 million. Today, roughly 27.3 million people live within the 41 large urban centers across the vast country (Statistics Canada 2022). With these populations increasing, a demand for housing and other urban spaces has pressured cities to grow and encroach on neighboring ecosystems. This encroachment on environments leads to habitat fragmentation, pollution, disruptions to natural cycles and movements, and the introduction of invasive species. Streams and other lotic water bodies are important environmental features to all ecosystems as they transport sediments and nutrients throughout the watershed and purify the water, while hydrating and creating habitat for a variety of plant and animal species.

Development and urbanization alters these natural processes and characteristics of water bodies through a multitude of different ways . One way effects are seen on these water bodies is through the inherent planning of modern construction. Many modern buildings and urban areas use vast amounts of concrete and other non-permeable materials, which prevents precipitation from entering the soils naturally. Instead, precipitation is collected via storm drains and culverts and directed towards these lotic systems, increasing the rate at which water enters these fluvial beds. This funneling of precipitation results in an increase of runoff, erosion and sediment loading while also altering stream morphology and the magnitudes of seasonal flow variability (Wemple et al. 2017). To better understand the impacts we have on these fluvial systems, numerous tests and surveys are performed by various groups and organizations to document and catalog the stream's characteristics. These procedures help the scientific community gain a greater understanding of alterations occurring within a watershed, while gaining insights to the possible sources causing them. Over time, a large data set can be compiled allowing users from various disciplines to view trends, changes, and current conditions of the stream to better plan and act according to the needs of the ecosystem. These greater principles reflect the intent of this report, to continue the study of the Cottle Creek Watershed as overseen by Vancouver Island University.

1.2 PROJECT LOCATIONS AND GEOGRAPHICAL DESCRIPTION

The Resource Management Officer Technology Program (RMOT) has been involved in a long standing partnership between the Department of Fisheries and Oceans (DFO), Vancouver Island University (VIU), and the City of Nanaimo to monitor local watersheds along the East Coast of Vancouver Island, particularly in the Nanaimo region. Our group was assigned to monitor the water quality, hydrological conditions, and stream invertebrate communities of Cottle Creek. This system has a total stream length of roughly 3.4 km (not including the length of Cottle Lake), stretching from just west of Linley Creek Park and flowing eastward until it meanders south and discharges into Departure Bay. The total watershed area covers about 4.5 km^2 and contains three main subunit reaches (Figure 1). The first reach is the Upper Cottle Creek which flows from its headwaters off Rutherford Road east to Cottle Lake. The second reach is the North Cottle Creek, which begins at Lost Lake and flows into Cottle Lake. Thirdly, the Lower Cottle Creek flows from the outflow of Cottle Lake until its end at Departure Bay (Ware & Rundel 2012). Cottle Creek's overall slope is mild with some variation and displays minimal flow rates due to its small size. The forests surrounding Cottle Creek are mainly secondary growth forests consisting of Douglas Firs (*Pseudotsuga menziesii*), Red Cedar (*Thuja plicata*), Western Hemlock (*Tsuga heterophylla*), Pacific Yew (*Taxus brevifolia*), and Arbutus trees (*Arbutus menziesii*). Low lying vegetation ranges from various fern and moss species to shrubs such as, Salal (*Gaultheria shallon*), evergreen huckleberries (*Vaccinium ovatum*), Salmonberry (*Rubus spectabilis*), and invasive Himalayan Blackberry (*Rubus armeniacus*). This stream also boasts a cutthroat trout (*Oncorhynchus clarkii clarkii*) population throughout the watershed. Due to a steep gradient at the outflow of Cottle Creek, no anadromous salmonids find their way residing in Cottle Creek. The project required us to collect two sets of data on two separate days; the first set of data was collected on October 26th, while the second set of data was collected on November 23rd. On each of these days, data regarding stream morphology parameters, water quality, and stream macroinvertebrate communities were collected at 4 designated sample locations. These 4 sites were located along Reach 1 and Reach 3 of the Cottle Creek watershed. The collected data was then measured in one of the Vancouver Island University labs on October 26th, November 23rd and November 30th.

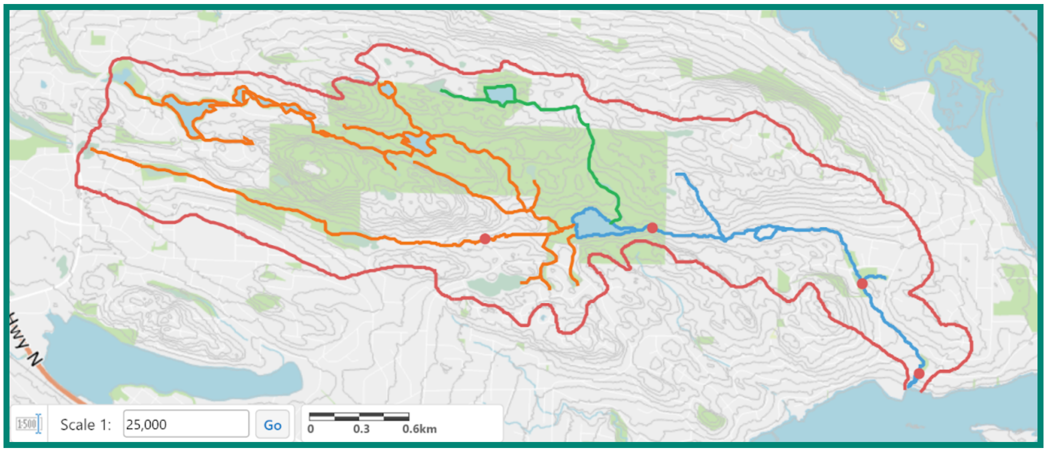

Figure 1. Overview of Cottle Creek Watershed (*sample locations*- red dots, *Upper Cottle Creek*- orange, *North Cottle Creek*- green, *Lower Cottle Creek*- blue)

1.3 HISTORICAL OVERVIEW

Nanaimo's change in natural history primarily lies in the effects of its rich coal deposits found right under today's downtown Nanaimo, it is these coal veins that brought upon large urban growth of the area. Coal was first discovered in the Nanaimo area in 1852 which then steered the Hudson's Bay Company to bring its miners down from Fort Rupert to a more productive area. (Leduc 2021). The first ship to leave with loaded coal happened in September 1852 which marked a point of 100 years of steady growth for Nanaimo fueled by the mining industry. (Nanaimo Museum). From there, the area saw substantial growth with families coming from several countries including England, Scotland, Croatia, Finland, Italy, and China. These new families brought more shops, housing and large urban development and it began to form into one of the dense urban centers of Vancouver Island (Nanaimo Museum). In the 1990s, development of the Cottle estate subdivision began and plans for Cottle Creek to be completely piped were in place. In response to this, a concerned boy went door to door across Nanaimo petitioning for the

Creek to be saved. This advocacy brought about collaboration with the city and concerned environmental groups to line up plans for a new park (Clough 2022). With that, a part of the stream was introduced into the protection of a new park in 2003, now known as the Linley Valley Cottle Lake Park (Bolland et al. 2013). With this history in mind, it is important that we take into consideration the current circumstances the stream is in and improve on past mistakes to advance the robustness of the Cottle Creek tributary system.

1.4 POTENTIAL ENVIRONMENTAL ISSUES

The environmental issues and concerns for Cottle Creek are considerably present and far reaching throughout the entire watershed. A significant portion of the creek's expanses run through residential areas, meaning anthropogenic impacts are of concern. These influences may include point source and nonpoint source pollution as seen through inputs from fertilizers coming from large scale and home run farms as well as other anthropogenic sources. Alterations to stream flow and direction may also occur directly from property owner intervention or residential and commercial development through large scale construction. Heavy foot traffic in urban areas and within the park can also lead to erosion of banks along the stream, and destruction of riparian and fish habitat. This heavy foot traffic is also often associated with an abundant number of dogs which could contribute to eutrophication due to an excess of dog fecal matter. Beyond these considerations, there is also the concern of increased sediment loading at culverts and road crossings as well as through neighboring construction sites.

2.0 PROJECT OBJECTIVES:

Knowing the location description, history, and environmental concerns of Cottle Creek, the main goal of this project is to continue the legacy of water quality and environmental site monitoring of this stream. This legacy at Cottle Creek with the students of the Resource Management Officer Technology Program (RMOT) has continued for 10 years starting in 2012 to monitor the important attributes associated with the waterbody. Through the monitoring and surveying of this year's proposed project, more data can be added to the growing collection obtained from Cottle Creek throughout the years. This successive data can then be used to observe the long term patterns and measurements at a site specific level and at a broad scale. This consecutive year project has been in large part due to the partnership between VIU and Department of Fisheries and Oceans (DFO). The partnership has allowed for the aid in gathering scientific data regarding Cottle Creek while also offering RMOT students the chance to experience field work related to stream sampling and monitoring.

3.0 SAMPLING AND ANALYTICAL PROCEDURE(S):

3.1 SAMPLING LOCATIONS:

3.1.1 Map Overview of Sampling Locations:

Figure 2. Satellite overview of Cottle Creek Watershed with included markers of sample locations.

3.1.2 Sampling Location 1 (Site 1):

Figure 3. Photo of the Site 1 location as part of the Cottle Creek watershed.

The first sampling location, titled Site 1, is located at the western part of the watershed (Figure 4). It is the only site that lies within Reach 1 of the greater tributary system (Upper Cottle Creek) and is located just upstream of Landalt road (Figure 1). The sample was taken in a small ravine as seen in Figure 3 with the location having minimal gradient and low water levels on both events, only revealing small riffles. Located just upstream of Site 1 was a large sieve/strainer for large woody debris to protect the entrance of the culvert. At the time of both our samplings it appeared that the sieve had not been cleaned out in a long time.

Figure 4. Satellite map showing the area surrounding sampling location Site 1.

3.1.3 Sampling Location 2 (Site 2):

Figure 5. Photo of the Site 2 location downstream of the beaver dam

The second sampling location, titled Site 2, is located just downstream of Cottle lake (Figure 7). This site lies within the upper part of Reach 3 (Lower Cottle Creek) as part of the larger Cottle Creek watershed (Figure 1). The sample was taken in a small windy gorge with a minor gradient allowing for small riffles to occur. At both sampling events there were multiple beaver dams causing problems with good waterflow, however this did not inhibit our ability to sample from the site (Figure 6).

Figure 6. Photo of one of the beaver dams bringing down the amount of flow in the nearby section of the Cottle Creek watershed.

Figure 7. Satellite map showing the area surrounding sampling location Site 2.

3.1.4 Sampling Location 3 (Site 3):

Figure 8. Photo of the Site 3 location as part of the larger Cottle Creek watershed.

The third sampling location, titled Site 3, is located just west of Cottle Creek Park and was easily accessible via a trail near the park (Figure 9). This site also lies within the third reach of the watershed (Lower Cottle Creek) roughly two thirds the way downstream from Cottle Lake to

Departure Bay (Figure 1). The sample was in a slightly wetter area with skunk cabbage growing in the vicinity; the gradient was minimal with small riffles forming.

Figure 9. Map showing the area surrounding sampling location Site 3.

3.1.5 Sampling Location 4 (Site 4):

Figure 10. Photo of the Site 4 location as part of the larger Cottle Creek watershed.

The fourth sampling location, titled Site 4, crosses Stephenson Point Road just where Ricker's Curve and Stephenson Point Road meet (Figure 11). This site lies at the tail end of Reach 3

(Lower Cottle Creek) just before the stream exits into Departure Bay (Figure 1). It was easily accessible from the pavement as the site sits below a large culvert that empties the stream into a large pool (Figure 10). This pool then meanders its way towards very steep, rocky terrain that acts as a barrier to anadromous fish.

Figure 11. Map showing the area surrounding sampling location Site 4.

3.2 SAMPLING FREQUENCY

For this year's monitoring project of Cottle Creek a frequency of two replicates was achieved. Due to the field time for processing and collecting samples being substantial and the limited time for the project, these methods ensured some assurance of sampling quality while at the same time fitting within the time constraints. In addition, lab time for stream invertebrate and water quality analysis took multiple hours to process for each site. Given this information, two replicates were sufficient for the goals of this monitoring project.

Table 1. Measurements and analyses completed for each sampling site for both sampling events. Site 3 was omitted from ALS analysis due to cost constraints as well as the fact that it was deemed to have the least unique environment, as it was nestled between sites and wasn't located near any unique points of interest such as ongoing construction, lakes, or the ocean.

Sampling Site	Hydrology Measurements	Water Quality Analysis (VIU lab)	Water Quality and Metal Analysis (ALS)	Stream Invertebrate Sampling
Site 1	Y	Y	Y	Y
Site 2	Y	Y	Y	Y
Site 3	Y	Y	N	Y
Site 4	Y	Y	Y	Y

3.3 HYDROLOGICAL MEASUREMENTS

For this project some basic hydrology measurements such as flow and discharge of the stream were measured to continue the legacy of data collected at this tributary system by the RMOT students.

3.3.1 Hydrological Measurement Method

The "float-method": This method entails measuring out a fixed length in a chosen section of the site. A floating object - in this case a ping pong ball - was placed at the upstream end of the fixed length measurement of one meter. As the floating object was placed in the water, a timer was started to measure the time it takes the floating object to reach the other end of the fixed length. This was replicated three times and the average time of the three trials was used as the stream velocity measurement. The ping pong ball was replaced by the use of a leaf for the second sampling event at Site 2, as the ball was misplaced on the way to the site.

Wetted width: Obtained by measuring the width of the streambed in with flowing water at an area of the site thought to be representative of the stream's average width at the sampling site. If the stream was broken into two or more channels, then the channel’s widths were measured individually and added together.

Wetted depth: Obtained by finding the deepest point of the stream and taking a reading on the length of a meter stick after being submerged in the streambed at that deepest point.

Bankfull width: Measured by placing one end of a measuring tape on the edge of where the channel may be filled before overflowing to the adjacent floodplain, and having another person take the other end of the tape to the other edge.

Bankfull depth: Measured by placing a meter stick at the deepest point of the channel, and measuring where that meter stick interacts with a taut measuring tape stretched over the bankfull width.

3.3.2 Sampling Criteria

3.3.2.1 Water Quality:

At each sampling site a regime of water quality analysis measurements were completed using sampling equipment provided by VIU. These field measurements completed included dissolved oxygen and temperature. When performing sampling methods in the VIU lab, appropriate PPE such as safety glasses and latex gloves were worn at all times. In the lab, the following measurements were obtained via laboratory analysis at the VIU Lab: Turbidity, alkalinity, nitrate levels, phosphate levels, pH and hardness. Separate from our VIU water quality analysis we also collected data to send to ALS laboratories to measure general water quality parameters, metal concentrations, and anion and nutrient levels.

Conductivity: Conductivity was measured by first rinsing the conductivity probe provided by the VIU Lab in distilled water. After this step the probe was placed into a water sample and left in the water for a minute while swirling in order to ensure that the reading had settled on a number. After the minute had passed the number on the display was recorded into our data tables.

Hardness: Calculating hardness required the use of a HACH Hardness Test Kit containing three reagent dropper bottles. The exact number of each drop necessary for the process was outlined in directions provided by VIU Lab staff. The water sample was placed in a flask with the appropriate amount of reagents from the first two droppers. The flask was then swirled constantly as each drop from the third dropper bottle was counted. Once the sample in the flask dramatically changed colour and was stable, the total number of drops from dropper bottle 3 was noted. This number was then plugged into an equation provided in the instructions in order to calculate total hardness. The equation that was chosen was dependent on the conductivity of our sample.

Alkalinity: Alkalinity was measured in the VIU lab by using a HACH Alkalinity Kit. This kit consisted of reagent/indicator powders and involved titrating an appropriate concentration of acid into a flask of our sample. The concentration was selected based on a corresponding table in the analysis directions provided by VIU Lab staff. The concentration is based on conductivity levels in the water sample. Eventually, once the appropriate amount of acid has been titrated into the sample the sample will turn a bright reddish pink. Once this colour has stabilized, the number of titrated drops is marked down, and plugged into a provided formula in the lab directions in order to discern the alkalinity of the sample.

Dissolved Oxygen: Dissolved oxygen was measured using a digital YSI probe on site at each sampling location on Cottle Creek. To use the probe, it was removed from its protective housing and powered on with the instrument end of the probe being fully submerged at each sampling site for a minute. After the minute had passed the level of dissolved oxygen was marked in our field notes. The DO was measured in % dissolved oxygen as well as mg/l.

Temperature: Temperature was measured using a digital YSI probe on site at each sampling location on Cottle Creek. To use the probe, it was removed from its protective housing and powered on with the instrument end of the probe being fully submerged at each sampling site for a minute. After the minute had passed the given temperature was marked in our field notes.

Turbidity: Turbidity was measured using a HACH Turbidity Meter in the VIU lab. The first step of the process was to use the calibration solutions to calibrate the turbidity meter followed by taking a sample of water and decanting it into a small test container. The exterior of the test container was then wiped with Kimwipes and placed into the turbidity meter. After running the meter the turbidity was displayed and the measurement was recorded in our lab notes.

Nitrate: Nitrate was measured in the VIU Lab using a DR 2800 HACH Spectrophotometer that had a pre-set program created by the VIU Lab staff loaded for analyzing nitrate in water samples. In order to see through the analysis of the nitrate, a blank jar and a sample jar were needed. Procedures had the sample prepared first. 100 ml of sample water was decanted into a plastic tube followed by a reagent being added and agitated for 30 seconds. After the 30 seconds was completed the solution was decanted into a small glass cell/jar specifically made to fit the mass spectrophotometer. A second reagent was added to the same solution and the jar was agitated for 5 minutes, once fully agitated, the sample solution had to sit for 15 minutes. While the sample solution was sitting, a blank was prepared in the meantime. A second small jar was filled with sample water. This sample blank jar would be placed in the machine first in order to "zero" the machine for reading the sample solution. Before placing either the blank or the sample into the machine the jars were thoroughly cleaned with Kimwipes so as not to skew the reading. After the machine had been zeroed with the blank jar, the sample jar was placed into the machine and analyzed. The nitrate value then displayed on the machine screen and was recorded in our lab notes. After notes had been recorded, all sample solution and blank sample liquids were disposed of in the designated waste receptacle bottle.

Phosphate: Phosphate was measured in the VIU Lab using a DR 2800 HACH Spectrophotometer. The device had a pre-set program created by the VIU Lab staff designed for analyzing phosphate in water samples. To successfully analyze the phosphate levels, a blank jar and a sample jar were needed. First the sample was prepared, 100 ml of sample water was decanted into a plastic tube followed by a reagent being added to the tube and agitated for 30 seconds. After the 30 seconds was completed the solution was decanted into a small glass jar/cell specifically made to fit the mass spectrophotometer. A second reagent was added to the solution and the jar was agitated for 5 minutes until completed at which the sample solution had to sit for 15 minutes. While the solution was sitting a blank was prepared by taking a second small jar and filling it with sample water. This sample blank jar would be placed in the machine first in order to "zero" the machine for reading the sample solution. Before placing either the blank or the sample into the machine the jars were thoroughly cleaned with Kimwipes so as not to skew the reading. After the machine had been zeroed with the blank jar, the sample jar was placed in and analyzed until the phosphate value displayed on the machine screen. Once the values had been recorded, all sample solution and blank sample liquids were disposed of in the designated waste receptacle bottle.

pH: pH was recorded both in the field and in the lab. In both instances a pen style probe was used to measure the water pH. Prior to taking any field or lab measurements the probe was calibrated at VIU with appropriate calibration liquid. In the field the probe was submerged at each sampling site for one minute in order to get a stabilized reading. It was deemed unreliable in the field due to the readings we were getting and it was decided that pH measurements would be taken in the lab. Once at the VIU lab, the same procedure was performed except the probe was submerged in each sample site bottle for one minute. The readings were then recorded in our respective field and lab notes.

It is important to note that during this process all instruments used during sampling were thoroughly inspected beforehand to ensure that they would perform adequately/reliably. With that being said, it was outside the scope of our knowledge and expertise if there was an internal calibrating issue with any of the equipment used.

ALS: To collect the ALS samples three different methods were applied. The first method was for general water quality. The bottles provided for this collection were sterilized bottles. Water was then decanted into two smaller containers. The first was an amber glass container for nutrient and anion analysis that had a preservative present already in the bottle. Once this bottle was filled it was placed in our cooler. The second container was a small plastic bottle for metals. Once this container had been filled a small vial of acid provided by ALS was used to preserve the metals for analysis. Following the addition of the acid this bottle was placed in the cooler. Finally the initial water quality sampling bottle was topped up with additional stream water and then placed in our cooler.

The above mentioned collection methods were implemented during the October sampling event. Unfortunately due to a miscommunication we did not receive our ALS bottles the morning of the November sampling event, thus the same field sampling procedure for ALS was not able to be applied in November. Instead, all ALS sample bottles were filled with our VIU Lab collected samples. Even though the field method was not applied, the methodology surrounding preservation of metals sample, anion and nutrient sample, and water quality sample remained unchanged.

3.3.2.2 Stream invertebrates:

Procedure: Stream invertebrates were collected at each site using a Hess Sampler. Three total samples were collected at each site in order to ensure a site representative sample. Stream invertebrates were collected during both sampling events both in October and November.

At each site the Hess Sampler was deployed to collect the invertebrates. After decanting the material from the sampler and removing all possible debris the invertebrates were preserved in a solution of 70% ethanol. These preserved samples were then transported back to the VIU lab for analysis.

Analysis: The first step to analyzing the invertebrates was to go through each sample and identify the invertebrates to order and family if possible. The number and species of all invertebrates would then be counted for each sample. This was done using petri-dishes, a magnifying glass, tweezers, a pipette, a microscope, and water for rinsing the sample. Using the tweezers and pipette both liquid and solid material from the sample was placed on a petri-dish. When all inverts in a petri-dish had been counted the materials from the dish were deposited in a waste receptacle bin.

Stream invertebrates can act as a good overall indicator of stream health. Using various indicator species of invertebrates it is possible to gain an overall image of stream health based on type, number and diversity of invertebrates. Certain species such as mayfly, stonefly, and caddisfly were used to calculate an EPT ratio which is a measure of ecosystem productivity/overall stream health. To calculate the EPT ratio the total number of aforementioned invertebrate specimens from a site was divided by the total number of all invertebrate specimens from the site. The three aforementioned species are all a common source of food for salmonids and they are also all non resilient to increased stream pollution. For both these reasons mayfly, stonefly, and caddisfly are good indicators of stream health.

4.0 RESULTS AND DISCUSSION

After collecting water and stream invertebrate samples from the four sampling locations, all the samples were taken back to the laboratory located in Building 370 on Vancouver Island University and sampled/measured. A second set of water samples was collected at three of the sampling locations and sent to ALS Environmental in Burnaby for additional cross-examination and additional testing for trace metals and water quality measurements. All results from these samples will be provided in this section with subsequent discussion of results.

4.1 HYDROLOGY MEASUREMENTS

All four locations were sampled for basic hydrological measurements, these measurements include surface velocity, wetted width and depth, and bankfull width and depth. These measurements are collected to give insight to conditions present at the time of sampling as well as seasonally, as bankfull measurements mark the maximum flow conditions present at the site. These changes in hydrological measurements can be used to explain water quality results and changes in stream macroinvertebrate communities.

4.1.1 Surface Velocity

At Site 1, the surface velocity was determined to be 0.29 m/s during the first sampling date (October 26th) and 0.49 m/s at the time of the second sampling date (November 16th). Sample Site 2, had a velocity of 0.13 m/s in October, which increased to 0.57 m/s in November. Site 3 had a velocity of 0.3 m/s in October, which increased to 0.43 m/s in November. Site 4's surface velocity increased from 0.1 m/s in October, to 1.6 m/s in November (Table 2).

4.1.2 Wetted and Bankfull Widths/Depths

As outlined in table 2, the wetted widths for our sites ranged from 1.25 meters at Site 2 to 3.27 meters at Site 4. In November, wetted widths increased, ranging from 1.4 meters (Site 2) to 3.3 meters (Site 4) for the sample locations. Wetted depths for the four sites were 0.06, 0.01, 0.02, 0.09 meters in October and were 0.07, 0.15, 0.7, and 0.15 meters in November. Bankfull widths and depths were determined to be 5.5 meters wide and 0.25 meters deep at Site 1. Site 2 had a bankfull width of 5.5 meter with a depth of 0.39 meters. Site 3 had the smallest bankfull width with 3.2 meters and a depth of 0.5 meters. Lastly, Site 4 had a bankfull width of 8.48 meters and a depth of 0.93 meters. The greatest wetted depth observed during the study period was that of Site 2 and Site 4 during the November sampling event, with a depth of 0.15 meters.

4.1.3 Hydrological Measurement Discussion

Overall, the sample locations showed very little variation in hydrological parameters due to the lack of precipitation during the study period. These low wetted width and depth values are the result of the record drought observed across British Columbia in 2022. For all of the sampling locations, we saw an increase in wetted depth, and surface velocity in November. This increase is directly associated with the precipitation which was observed between the sampling events. Site 1 and 3 did not increase in wetted width, due to established banks, as Site 1 had well established banks which contained the stream flow. Site 3 had rip rap boulders positioned along the banks which prevented widening. Bankfull widths and depths did not change over the sampling period as these measurements represent the highest discharge height and width observed in the creek, therefore it typically remains constant.

Table 2. Comparison of Cottle Creek Hydrological measurements from the four sampling sites in October and November.

Parameter	Site 1 (O/N)	Site 2 (O/N)	Site 3 (O/N)	Site 4 (O/N)
Flow Speed (m/s)	0.29/0.49	0.13/0.57	0.3/0.43	0.1/0.16
Wetted Width (m)	2.42/2.42	1.25/1.4	2.7/2.7	3.27/3.3
Wetted Depth(m)	0.06/0.07	0.01/0.15	0.02/0.7	0.09/0.15
Bankful Width(m)	5.5	5.5	3.2	8.48
Bankful Depth (m)	0.25	0.39	0.5	0.93

4.2 STREAM INVERTEBRATE COMMUNITIES

4.2.1 Stream Invertebrate Community Results

Over the four sample locations and two sampling events, 3040 invertebrates were sampled. Site 1 had the highest single count with 703 invertebrates during the October sampling event and subsequently had the lowest total count of the study in November with 142 total invertebrates (Figure 12). Site 2 saw total counts decrease from 549 in October to 342 in November. Site 3 had 365 invertebrates in October, which decreased to 281 in November. Lastly, Site 4 had a total of 320 invertebrates in October, which increased to 338 sampled invertebrates in November (Figure 12). After calculating the Shannon-Wiener species diversity indexes for all the site samples (appendix 10.2), site 1 had an index of 1.96 in October and 2.04 in November. Site 2 had an index of 1.99 in October and 1.36 in November. Site 3 had an index of 1.81 and 1.65 in November. Site 4 had an index of 1.91 in October and 1.90 in November (Figure 14).

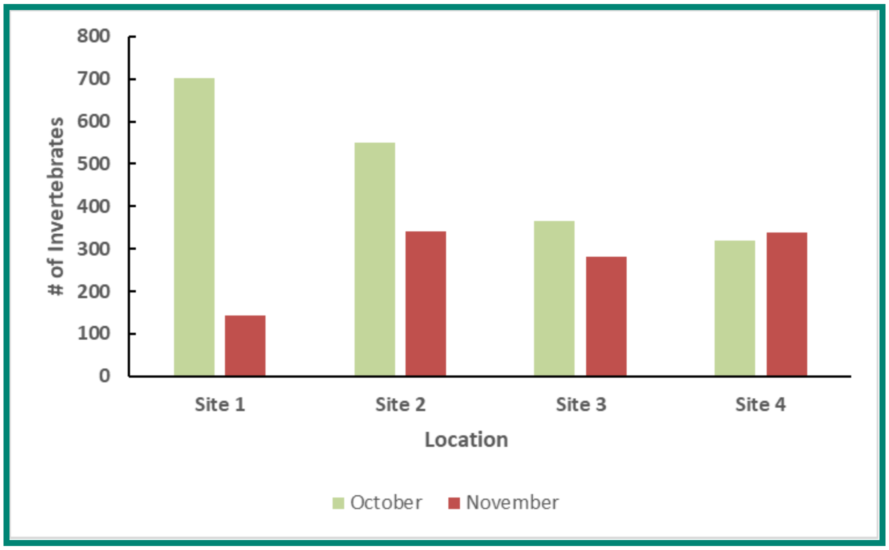

Figure 12. Comparison of total stream invertebrates counted across the four sample locations on Cottle Creek in October and November.

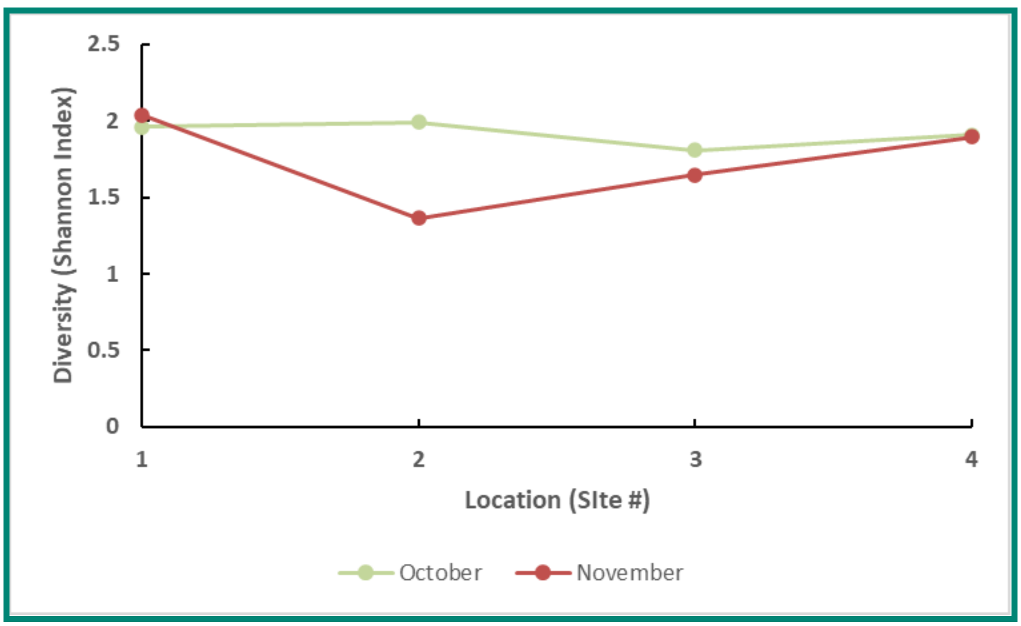

Figure 13. Seasonal change in diversity of stream invertebrates in Cottle Creek across four sampling locations.

Site 1 had a site assessment of 3.5 for both sampling events. Site 2 saw a decrease from a rating of 3.5 during the first sampling date to a rating of 3.25. Both Sites, 3 and 4, had a consistent rating of 3.25 for both sampling events. In terms of invertebrate category breakdown, Site 1 had the highest number of pollution tolerant and intolerant species with 313 category 1 (pollution intolerant) species and 344 category 3 (pollution tolerant) species. Site 2 was composed largely of category 2 species (O: 268, N:228), with category 3 (O: 127, N:82) species being the second largest group, and category 1 (O:154, N: 32) being the lowest group (Figure 14). Site 3 and 4 had little variation from the two sample dates with category 1 counts being 36 (October) and 27 (November) for Site 3, and 72 (October) and 67 (November) for site 4. Category 2 species remained level with counts of 150 (October) and 126 (November) at site 3 and 117 (October) and 128 (November) at Site 4. Lastly, category 3 species for Site 3 (O:117, N:128) and Site 4 (O:131, N:167) remained equal, which can be seen in Figure 14.

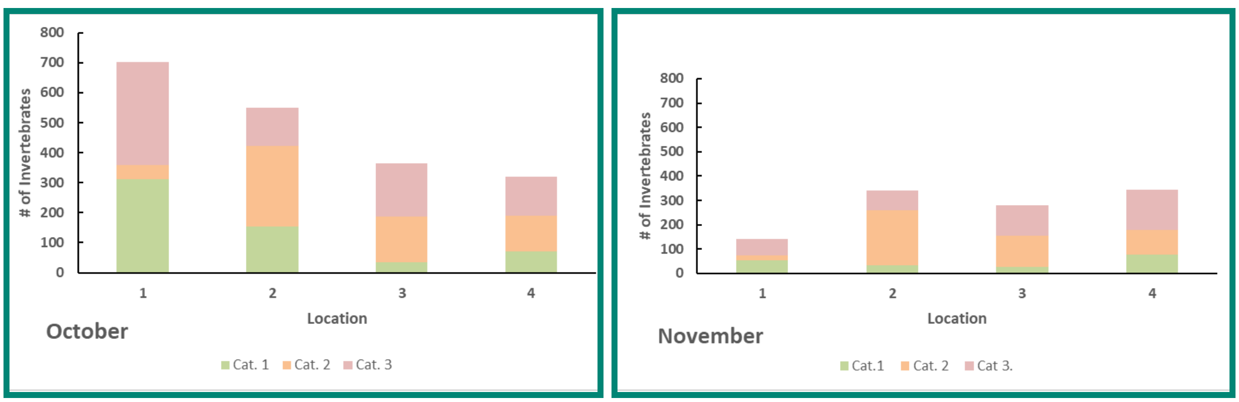

Figure 14. Comparison of pollution tolerant, somewhat-tolerant, and pollution intolerant stream invertebrates over the four sample sites in October (right) and November (left).

Table 3. Site assessment ratings of four sample locations on Cottle Creek.

Site Assessment Rating		
Location	October	November
Site 1	3.5	3.5
Site 2	3.5	3.25
Site 3	3.25	3.25
Site 4	3.25	3.25

4.2.2 Stream Invertebrate Community Discussion

Overall, the stream invertebrate communities located at Cottle Creek sample sites rated strong with a score range of 3.25-3.5, which was between the assessment scores of good (4) and acceptable (3) (Table 3). This means looking at the system solely through the context of pollution intolerant invertebrates, the stream's reaches are relatively healthy and boast diverse communities. When looking at the composition of tolerant/intolerant invertebrates, we can see a decrease of category 1 (pollution intolerant) invertebrates at Sites 1, 2, and 3, with Site 4 having an increase. Diversity wise, all the sites sampled in October were consistent with a difference range of 0.15, while November had a difference range of 0.48. This increase in index difference is due to site two, which saw a 0.63 index drop in diversity from October to November. This may be caused by lower quality water or deleterious materials being flushed downstream from Cottle Lake via the increased flow. Additionally, the increase in total invertebrates in Site 4 may be due to downstream drift associated with the increase in flow in the stream as invertebrates are uplifted due to increased velocity and then deposited in areas of low velocity.

When looking at the composition of category groups of invertebrates we saw that both site 3 and four effectively remained the same, while Sites 1 and 2 saw category 1 and 3 groups decrease from the first sampling event, while category 2 species numbers remained the same.

Comparison of averaged yearly invertebrate densities of the four sample locations (Figure 15), there is an increase in total density since 2019. Additionally, there appears to be a correlation between all site densities from 2017 to present date, why the sudden correlation may be the result of many influences ranging from variation in water quality, input of deleterious materials (heavy metals), or variation in a group's ability to properly use the hess sampler and/or ability to spot and identify invertebrates within the sample.

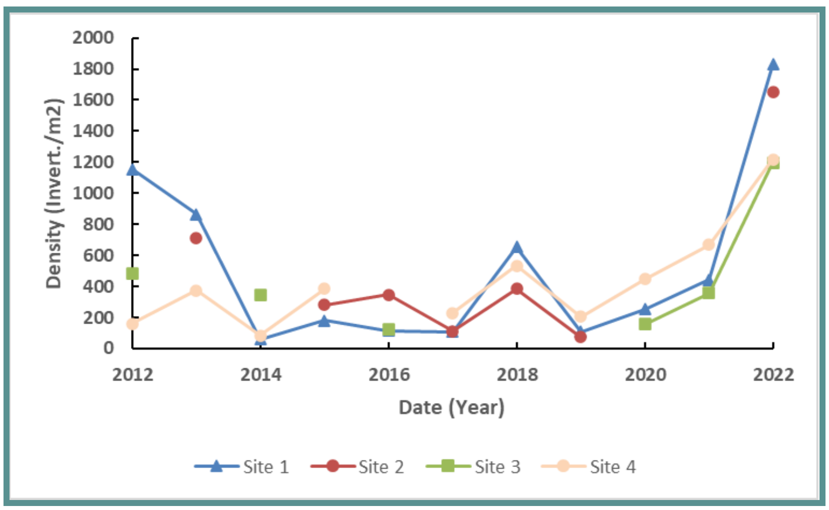

Figure 15. Temporal comparison of averaged yearly sample site locations stream invertebrate counts from 2012-2022.

4.3 WATER QUALITY

4.3.1 VIU Water Quality Results

At the VIU Laboratory, we measured a number of water quality parameters including hardness, alkalinity, pH, nitrates, phosphates, turbidity, conductivity, temperature, and dissolved oxygen. Hardness is the measure of divalent cations and is used to determine the toxicity of trace metals in streams. Water is considered soft with a concentration of less than 60 mg/L $CaCO_3$, and hard water being 120+ mg/L $CaCO_3$, our hardness values ranged from 76 to 104 mg/L $CaCO_3$ and are considered moderately hard (60-120 mg/L) (Table 4).

Alkalinity is the measure of carbonates in the water and used to measure the acid neutralizing capacity of a system, the lower the alkalinity the more susceptible a system is to changes in pH. BC coastal streams generally are <20 mg/L and are considered sensitive to pH changes, our samples found Cottle Creek to have a higher alkalinity with concentrations ranging from 52 mg/L to 80 mg/L (Table 4). pH is the concentration of hydrogen ions in a sample and are arranged in a logarithmic scale, meaning small changes in pH can result in large differences. Our samples demonstrated very little change with pH values ranging from 6.8 to 7.0 (Table 4).

Nitrates and phosphates are important nutrients in plant growth and when found in high concentrations at the correct ratio, can lead to eutrophication in aquatic environments. The optimal ratio for eutrophication (the Redfield ratio) is known to be 16N:1P. For nitrates, Site 4 had the highest overall concentration (0.45) in November and Site 2 had the highest concentration in October (0.26 mg/L). For phosphates, values ranged from 0.02 mg/L (Site 3 - November) to 0.26 mg/L (Site 4 - November). Site 1's readings are closest to the Redfield ratio

(10N:1P), but as the concentrations don't exceed guidelines, it would not be likely to lead to eutrophication. Turbidity is the relative clarity of a liquid and is measured in nephelometric turbidity units (NTUs), the higher the value, the greater the amount of particulates within a sample. The eight samples taken from the four sample locations on Cottle Creek had a range of 0.6 NTUs (Site 4 -Nov.) to 5.62 NTUs (Site 2 - Oct.). Conductivity is the measure of dissolved ions (e.g. chloride and sodium) within a sample and were measured in µS/cm. Our samples ranged in conductivity from 173 µS/cm (Site 2 - Oct.) to 239 µS/cm (Site 1 - Oct.). Lastly, temperature and dissolved oxygen (DO) are often measured together due to the correlation of temperature and DO, the lower the water temperature, the greater amount of DO that can be carried in the water. Temperatures ranged from a high of 10.1℃ (Site 3 - Oct.) to a low of 4.1℃ (Site 2 - Nov.) during the sampling period. Dissolved oxygen concentrations were 10.94 mg/L (93.9% sat.) in October and 12.35 mg/L (96.1% sat.) in November at Site 1. Site 2 had a DO concentration of 9.2 mg/L (78.7% sat.) during the first sampling event and a concentration of 11.46 (87.7% sat.) during the second sampling event. Site 3 had the lowest DO measured during the study with a concentration of 5.44 mg/L (48.8% sat.) in October, then a concentration of 11.24 mg/L (89.2% sat.) in November. Lastly, site 4 had a DO concentration of 11.42 (100.2% sat.) in October and a concentration of 12.71 mg/L (100.7% sat.) in November (Table 4).

Table 4. VIU laboratory water quality data from four sampling locations on Cottle Creek, during two sampling events (October 26, November 16, 2022).

Cottle Creek Water Quality Meaurements (VIU)										
Parameter	Site 1	Site 1	Site 2	Site 2	Site 3	Site 3	Site 4	Site 4	Trip Blank	Trip Blank
Hardness (mg/L CaCO3)	104	92	80	80	92	96	80	76	1	2
Alkalinity (mg/L CaCO3)	30.8	52	28.8	60	32	80	28.8	54	2	1.8
pH	7	6.8	6.9	6.8	7	6.8	7	6.8		
Nitrate (mg/L NO3)	0.3	0.07	0.26	0.11	0.17	0.15	0.22	0.45	0.09	0.01
Phosphate (mg/L PO4)	0.03	0.19	0.05	0.07	0.05	0.02	0.03	0.26	0.02	0.1
Turbidity(NTU)	1.48	1.5	5.62	5.4	2.92	0.8	1.18	0.6	0.31	0.3
Conductivity (µS)	239	192	173	188	196	179	192	190	0	0
Temperature (°C)	8.8	4.8	8.5	4.1	10.1	5.6	9.6	5.5		
Dissolved Oxygen (%)	93.9	96.1	78.7	87.7	48.4	89.2	100.2	100.7		
Dissolved Oxygen (mg/L)	10.94	12.35	9.2	11.46	5.44	11.24	11.42	12.71		

4.3.2 ALS Water Quality Results

We sent water samples from three sample locations to be tested for physical tests (conductivity, hardness, and pH), anions and nutrients (ammonia, nitrates, nitrites, total nitrogen, phosphates, and total phosphorus), and total metals. Not all of the anion and nutrient parameters (ammonia, nitrites, total nitrogen, total phosphorus) will be outlined in the results/discussion as they aren't the main focus of sampling but are good to include as they relate to parameters we will focus on. Only three sites were chosen due to budget restraints and we chose Site 1, Site 2, and Site 4 as we believed these sites gave us the most representative sample of our study area. Similarly to the VIU determined concentrations, hardness ranged from 68.7 to 100 mg/L $CaCO_3$ and is in the moderately hard range (60-120 mg/L $CaCO_3$). Conductivity was determined to be 205 (Oct.) and 248 µS/cm (Nov.) for Site 1, 198 (Oct.) and 179 µS/cm (Nov.) for Site 2, 193 (Oct.) and 193 µS/cm (Nov.) for Site 4. pH values for the October and November sampling event were determined to be 7.62 and 7.90 for Site 1 respectively (Table 5). Site 2 had pH values of 7.61 (Oct.) and 7.57 (Nov.), while Site 4 had values of 7.76 (Oct.) and 7.85 (Nov.)(Table 5). Site 1 had nitrate levels of 0.0736 (Oct.) and 0.133 mg/L (Nov.). Site 2 had an October nitrate concentration of 0.0711 mg/L and a concentration of 0.169 mg/L in November. Site 4 saw a nitrate concentration of 0.358 mg/L and 0.230 mg/L in October and November respectively. Lastly, phosphate concentrations ranged from <0.0010 mg/L (Site 2 -Oct.) to 0.0056 (Site 1 - Nov.) mg/L (Table 5). Table 6 outlines the metal concentrations determined by ALS Environmental and though individual concentrations will not be discussed in the results, the trends and concentration changes will be elaborated on in the discussion.

Table 5. ALS Environmental physical and anions/nutrients concentrations from three sample locations on Cottle Creek.

Physical Tests (Matrix: Water)			Site 1 (O.)	Site 1 (N.)	Site 2 (O.)	Site 2 (N.)	Site 4 (O.)	Site 4 (N.)
conductivity	2.0	µS/cm	205	248	198	179	193	193
hardness (as CaCO3), from total Ca/Mg	0.50	mg/L	71.3	100	71.1	70.5	68.7	73.7
pH	0.10	pH units	7.62	7.90	7.61	7.57	7.76	7.85
Anions and Nutrients (Matrix: Water)								
ammonia, total (as N)	0.0050	mg/L	0.0052	0.0121	0.0311	0.0846	<0.0050	0.0120
nitrate (as N)	0.0050	mg/L	0.0736	0.133	0.0711	0.169	0.358	0.230
nitrite (as N)	0.0010	mg/L	<0.0010	0.0022	0.0014	0.0058	0.0019	0.0018
nitrogen, total	0.030	mg/L	0.390	0.497	0.452	0.554	0.538	0.470
phosphate, ortho-, dissolved (as P)	0.0010	mg/L	0.0021	0.0056	<0.0010	0.0020	0.0013	0.0045
phosphorus, total	0.0020	mg/L	0.0110	0.0283	0.0110	0.0157	0.0061	0.0154

Table 6. ALS total metal concentrations from water samples taken at three sample locations on Cottle Creek during two sampling events (O.=October 26, N.=November 16, 2022)(highlighted concentrations exceed B.C. 's water quality guidelines).

Total Metals (Matrix: Water)	Site 1 (O.)	Site 1 (N.)	Site 2 (O.)	Site 2 (N.)	Site 4 (O.)	Site 4 (N.)
aluminum, total	0.0086	0.0247	0.221	0.0140	0.0259	0.0120
arsenic, total	0.00026	0.00020	0.00150	0.00028	0.00029	0.00022
barium, total	0.00267	0.00450	0.00885	0.00407	0.00302	0.00349
boron, total	0.054	0.033	0.076	0.057	0.126	0.090
cadmium, total	0.0000086	0.0000702	0.000844	0.00333	<0.0000050	0.000700
calcium, total	26.7	18.2	18.3	18.8	20.1	18.3
cesium, total	<0.000010	<0.000010	0.000012	<0.000010	<0.000010	<0.000010
chromium, total	<0.00050	<0.00050	0.00052	<0.00050	<0.00050	<0.00050
cobalt, total	0.00010	<0.00010	0.00082	<0.00010	<0.00010	<0.00010
copper, total	0.00138	0.00123	0.00101	0.00237	0.00187	0.00229
iron, total	0.253	0.484	2.74	0.363	0.312	0.133
lead, total	<0.000050	0.000080	0.000151	0.000151	<0.000050	<0.000050
magnesium, total	8.13	6.27	6.03	5.86	5.72	5.58
manganese, total	0.0305	0.0127	2.52	0.0763	0.0193	0.0142
molybdenum, total	0.000052	0.000059	0.000104	0.000091	0.000126	0.000065
nickel, total	0.00140	<0.00050	0.00053	<0.00050	<0.00050	<0.00050
phosphorus, total	<0.050	<0.050	0.065	<0.050	<0.050	<0.050
potassium, total	0.919	1.27	0.463	1.04	0.922	0.553
rubidium, total	0.00081	0.00099	0.00081	0.00120	0.00101	0.00055
selenium, total	<0.000050	<0.000050	<0.000050	<0.000050	0.000058	0.000054
silicon, total	9.62	7.08	3.56	3.56	6.26	5.24
sodium, total	12.7	11.1	10.2	11.6	11.5	11.1
strontium, total	0.101	0.0771	0.0743	0.0787	0.0763	0.0692
sulfur, total	<0.50	1.33	<0.50	<0.50	2.49	1.38
titanium, total	0.00031	0.00041	0.0145	0.00074	0.00163	0.00065
vanadium, total	<0.00050	<0.00050	0.00186	<0.00050	0.00052	<0.00050
zinc, total	0.0042	<0.0030	0.0041	<0.0030	0.0033	<0.0030

4.3.3 Water Quality Discussion

Looking at a water quality parameter that was determined in the field and not determined by the ALS Laboratory was dissolved oxygen (DO). Dissolved oxygen is the amount of oxygen molecules that are dissolved in water and available to aquatic life. The British Columbia water quality guidelines for dissolved oxygen is 8 mg/L for the long-term average for all life stages other than buried embryo/alevin and the instantaneous minimum being 5 mg/L (MOE 2018). When looking at our dissolved oxygen concentrations we can see that Site 3 in October came close to exceeding the minimum limit, while all other locations remained above the average

(Table 4). The cause for this decrease is hard to pinpoint as the temperature was not drastically different than any of the locations and may be caused by a variety of reasons. When we look at DO in the context of yearly averages, we can see that DO is highly variable on Cottle Creek with there being no correlation or pattern to results (Figure 16). Site 2 has had the greatest variability in terms of changes seasonally ranging from 9-12 mg/L, while Site 3 remained fairly consistent until this year where we see a large decrease in seasonal averages due to the October sample (Table 4, Figure 16).

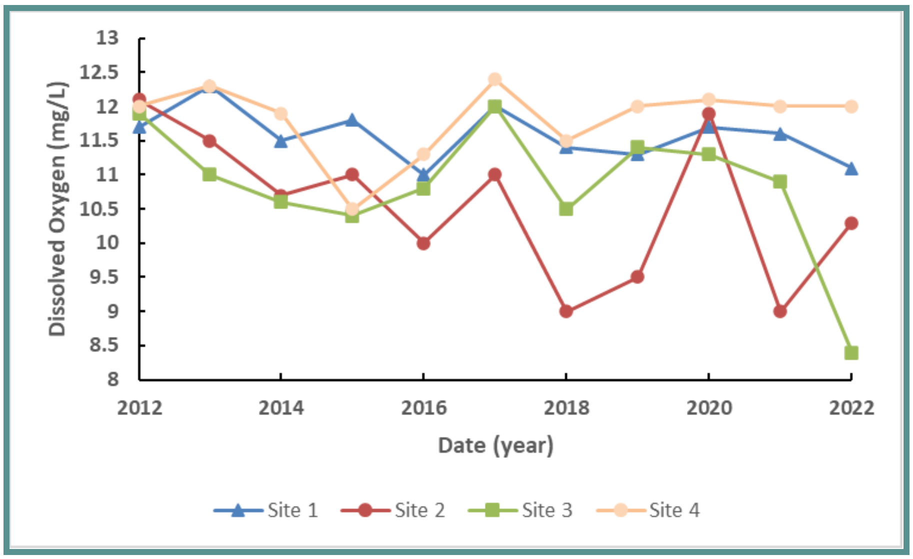

Figure 16. Temporal comparison of averaged dissolved oxygen concentrations (mg/L) at each site from 2012 to present.

As stated prior, we enlisted the expertise of ALS Environmental to analyze water samples from three of our sample locations to compare to our VIU Laboratory data and gain insight into the metal makeup of Cottle Creek. After analyzing the samples and taking each set of results and comparing them you can see some parameters had similar results, while others were very different. Water quality parameters that had similar values were that of water hardness, nitrates, and conductivity (Table 7). Parameters that had significant differences were pH and phosphate, this can be seen in table 7. For instance, for Site 2, the VIU measurement of pH came out to 6.9 and 6.8, while the ALS results for samples taken at the same time showed a pH of 7.57 and 7.61. This can also be seen for phosphates; we determined a concentration of 0.03 and 0.26 mg/L for Site 4, but ALS Environmental determined these concentrations to be 0.00045 and 0.0013 mg/L respectively. This can be caused by a variety of reasons ranging from user error when in lab, disturbance of sediments/material upstream of sampling location, accuracy/precision of instrument used, and/or miscalibration of measuring instruments prior to determination. For the case of phosphate, it is likely it is due to miss calibration or an issue with the mass spectrometer used as the results are consistently higher for all locations than the ALS data (Figure 7).

Parameters with concentrations or values with similar results were hardness, nitrates, and conductivity. This can be seen in Figure 17, where we see the results of both lab's concentrations for a single site are all very close to each other (conductivity graph- Figure 17), or a site with a high concentration sample is observed by both labs. Though the accuracy of the true value varies more than the second sample from the same site (nitrate graph - Figure 17). In terms of trends with the non-metal water quality – excluding DO – they are very minimal with nitrates being the only graph that might showcase a slight increase in concentration with distance downstream from the headwaters, as the VIU-Nov., ALS-Oct., and ALS-Nov. concentration points highlight this possible trend.

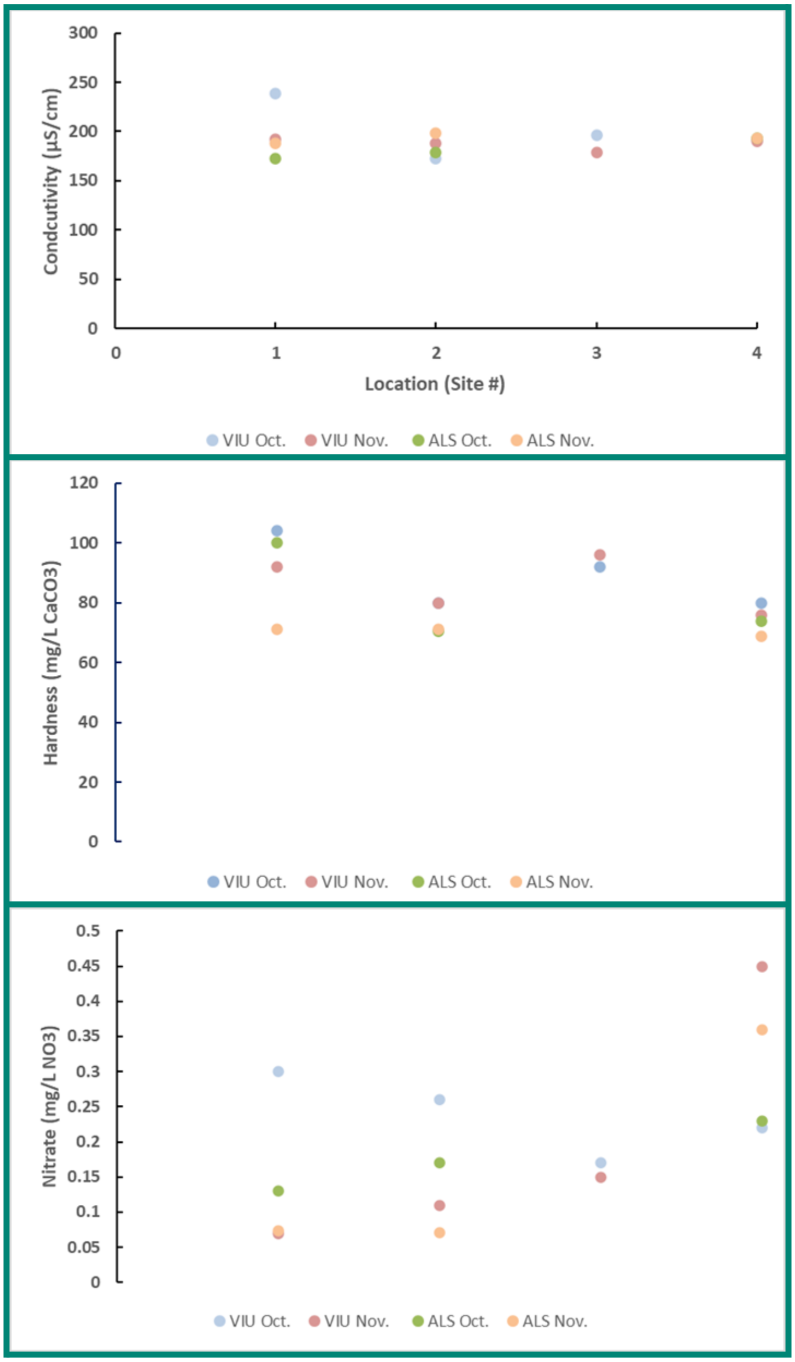

Figure 17. Comparison of nitrate, conductivity, and hardness of VIU and ALS results of water samples from four locations on Cottle Creek.

As stated prior, water quality samples were sent to ASL Environmental to use as a cross reference for the measurements we determined in the field or lab and allow us to gain a better idea of the metal composition found in Cottle Creek. After receiving the data, we compared results to that of British Columbia water quality guidelines and discovered that the guidelines for aluminum, iron, and manganese were all exceeded in the Site 2, October sample (Table 6). For aluminum, the guideline states that the concentration should not exceed 0.05 mg/L for a water with a pH ≥6.5, which site 2 (October) had a concentration of 0.221 mg/L (MOE 2018). For iron, the guideline states that for short-term maximum limit is 1 mg/L of iron where Site 2 (October) had a concentration of 2.74 mg/L which would be lethal to aquatic life (MOE 2018). For manganese, an equation uses hardness to determine the long-term and short-term maximum guideline concentration, this limit was determined to be 0.957 and 1.32 mg/L respectively, where the Site 2 (October) sample had a concentration of 2.52 mg/L (MOE 2018). The reasoning of why these concentrations were exceeded only once, at one location during the entirety of the study may be a result of the development occurring in the area. As stated earlier in the paper, Cottle Creek is and continues to be highly urbanized, this was seen during the time of sampling as rock blasting was occurring just south of Site 2. It may be possible that fines may have entered the system and be the result of these high concentrations of specific metals while other parameters do not change (Table 7, Table 8) . When looking at the other metals that did not exceed the guidelines, we can see that barium, cadmium, chromium, cobalt, arsenic and nickel are all higher concentrations than any of the other samples regardless of seasonality (Table 8). While zinc appears to have higher concentrations during October but drops below detectable limits so it is possible that zinc was diluted with the increase in water. Molybdenum had the highest concentrations in October at Site 2 and 4 but in November we see that the concentration is still the highest at Site 2, while the concentration halves at Site 4. This remaining high concentration may mean that there is an input for molybdenum at Site 2 and is the cause for the remaining high concentration.

Table 7. Comparison of VIU laboratory and ALS Environmental's nutrient and physical water quality measurements from three sample locations on Cottle Creek.

Cottle Creek Water Quality Statistics							
	Site 1 (O/N)		Site 2 (O/N)		Site 3 (O/N)	Site 4 (O/N)	
Parameter	**VIU**	**ALS**	**VIU**	**ALS**	**VIU**	**VIU**	**ALS**
Hardness (mg/L CaCO3)	104/92	100/71.3	80/80	70.5/71.1	92/96	80/76	73.7/68.7
pH	7/6.8	7.9/7.62	6.9/6.8	7.57/7.61	7/6.8	7/6.8	7.85/7.76
Nitrate (mg/L NO3)	0.3/0.07	0.13/0.074	0.26/0.11	0.169/0.071	0.17/0.15	0.22/0.45	0.23/0.358
Phosphate (mg/L PO4)	0.03/0.19	0.006/0.002	0.05/0.07	0.002/<0.001	0.05/0.02	0.03/0.26	0.00045/0.0013
Conductivity (µS)	239/192	248/205	173/188	179/198	196/179	192/190	193/193

Table 8. ALS total metal results from water samples taken at three sample locations over two events (October 26, November 16, 2022) (excludes metals below minimum detectable limit).

Total Metals (Matrix: Water)	Site 1 (O.)	Site 1 (N.)	Site 2 (O.)	Site 2 (N.)	Site 4 (O.)	Site 4 (N.)
aluminum, total	0.0086	0.0247	0.221	0.0140	0.0259	0.0120
arsenic, total	0.00026	0.00020	0.00150	0.00028	0.00029	0.00022
barium, total	0.00267	0.00450	0.00885	0.00407	0.00302	0.00349
boron, total	0.054	0.033	0.076	0.057	0.126	0.090
cadmium, total	0.0000086	0.0000702	0.000844	0.00333	<0.0000050	0.000700
calcium, total	26.7	18.2	18.3	18.8	20.1	18.3
cesium, total	<0.000010	<0.000010	0.000012	<0.000010	<0.000010	<0.000010
chromium, total	<0.00050	<0.00050	0.00052	<0.00050	<0.00050	<0.00050
cobalt, total	0.00010	<0.00010	0.00082	<0.00010	<0.00010	<0.00010
copper, total	0.00138	0.00123	0.00101	0.00237	0.00187	0.00229
iron, total	0.253	0.484	2.74	0.363	0.312	0.133
lead, total	<0.000050	0.000080	0.000151	0.000151	<0.000050	<0.000050
magnesium, total	8.13	6.27	6.03	5.86	5.72	5.58
manganese, total	0.0305	0.0127	2.52	0.0763	0.0193	0.0142
molybdenum, total	0.000052	0.000059	0.000104	0.000091	0.000126	0.000065
nickel, total	0.00140	<0.00050	0.00053	<0.00050	<0.00050	<0.00050
phosphorus, total	<0.050	<0.050	0.065	<0.050	<0.050	<0.050
potassium, total	0.919	1.27	0.463	1.04	0.922	0.553
rubidium, total	0.00081	0.00099	0.00081	0.00120	0.00101	0.00055
selenium, total	<0.000050	<0.000050	<0.000050	<0.000050	0.000058	0.000054
silicon, total	9.62	7.08	3.56	3.56	6.26	5.24
sodium, total	12.7	11.1	10.2	11.6	11.5	11.1
strontium, total	0.101	0.0771	0.0743	0.0787	0.0763	0.0692
sulfur, total	<0.50	1.33	<0.50	<0.50	2.49	1.38
titanium, total	0.00031	0.00041	0.0145	0.00074	0.00163	0.00065
vanadium, total	<0.00050	<0.00050	0.00186	<0.00050	0.00052	<0.00050
zinc, total	0.0042	<0.0030	0.0041	<0.0030	0.0033	<0.0030

5.0 RECOMMENDATIONS

The goal of this stream monitoring project is to strengthen the archive of stream health over the long term. With that in mind it is recommended that future groups in RMOT 306 continue to monitor at the same locations in order to add more data points for long term trend observations in stream health. In addition – if resources permit – it is recommended that additional sampling sites be established on Cottle Creek with a wider representative array of ecological areas being studied. In particular it would be beneficial to place sampling stations in proximity to where known commercial or residential development is taking place. This would provide valuable insight and data into how this particular stream' health responds to local development and could potentially help develop further solutions in order to mitigate any negative effects observed. In addition, it is recommended that special attention be paid when sampling again at Site 2 in order to see if elevated metals are present in a future October sampling event.

A secondary recommendation is that the culvert sieve at Site 1 be cleared. This sieve – which is illustrated in the figure below – is blocked with what appears to be years if not decades of woody debris. While this built up debris persists in the stream it acts as a barrier to fish passage which in turn could limit the dispersal and sustenance of healthy fish populations.

Figure 18. Woody debris culvert sieve acting as a fish passage barrier at Site 1.

6.0 ACKNOWLEDGEMENTS

This undertaking would not have been possible without the help of the Vancouver Island University, the Department of Fisheries and Oceans, ALS Environmental Laboratories, VIU Professor Owen Hargrove, and VIU Technician Mike Lester.

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8.0 APPENDIX

8.1 INVERTEBRATE FIELD SURVEY DATA SHEETS

Table 9. Invertebrate survey field data sheet: Site 1, October 26, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Cottle Creek		Date: October 26th	
Station Name: Sample Site 1		Flow status: Low	
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)	61	7
	Mayfly Nymph (EPT)	117	5
	Stonefly Nymph (EPT)	132	4
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle	3	1
	Water Penny		
Sub-Total		313	17
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	15	1
	Cranefly Larva	18	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva	5	1
	Fishfly Larva		
	Amphipod (feshwater shrimp)	5	1
	Watersnipe Larva	3	1
Sub-Total		46	5
Category 3	Aquatic Worm (oligochaete)	45	2
	Blackfly Larva	65	1
	Leech		
	Midge Larva (chironomid)	221	3
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails	2	1
	True Bug Adult		
	Water Mite	11	1
Sub-Total		344	8
TOTAL		703	30

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

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

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3

3 x 17 + 2 x 10 + 8 = 69 → **69**

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6

____ + ____ + ____ = **16**

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

(____ + ____ + ____) / ____ = **0.44**

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: **30**

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

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

Col. C for S1 / CT

____ / ____ = **0.314**

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment Rating	
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.5**

Table 10. Invertebrate survey field data sheet: Site 1, November 16, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	Nov. 16th
Station Name:	Sample Site 1	Flow status:	Low
Sampler Used: Hess	Number of replicates: 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates: 0.27 m²	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	9	3
	Mayfly Nymph (EPT)	17	5
	Stonefly Nymph (EPT)	26	6
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail	1	1
	Riffle Beetle		
	Water Penny		
Sub-Total		53	15
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	1	1
	Cranefly Larva	20	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)		
	Watersnipe Larva	1	1
Sub-Total		22	3
Category 3	Aquatic Worm (oligochaete)	15	2
	Blackfly Larva	20	1
	Leech		
	Midge Larva (chironomid)	29	3
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite	3	1
Sub-Total		67	7
TOTAL		142	25

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

DENSITY: Invertebrate density per total area sampled: ____ ÷ From page 1 ____ m² = ____ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = 58

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = 14

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: (____ + ____ + ____) / ____ = 0.36

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 25

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

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

Col. C for S1 / CT: ____ / ____ = 0.2

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.5**

Table 11. Invertebrate survey field data sheet: Site 2, October 26, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	October 26th
Station Name:	Sample Site 2	Flow status:	Low

Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates
Hess	3	0.27 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	77	4
	Mayfly Nymph (EPT)	27	2
	Stonefly Nymph (EPT)	31	3
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail	5	1
	Riffle Beetle	6	1
	Water Penny	8	1
Sub-Total		154	12
Category 2	Alderfly Larva		
	Aquatic Beetle	7	1
	Aquatic Sowbug		
	Clam, Mussel	33	2
	Cranefly Larva	4	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	216	2
	Watersnipe Larva	8	1
Sub-Total		268	7
Category 3	Aquatic Worm (oligochaete)	7	2
	Blackfly Larva	2	1
	Leech		
	Midge Larva (chironomid)	80	3
	Planarian (flatworm)	1	1
Pollution Tolerant	Pouch and Pond Snails	2	1
	True Bug Adult		
	Water Mite	35	1
Sub-Total		127	9
TOTAL		549	28

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: **25**

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

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = **69**

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = **9**

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: (____ + ____ + ____) / ____ = **0.25**

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: **28**

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

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

Col. C for S1 / CT: ____ / ____ = **0.39**

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.5**

Table 12. Invertebrate survey field data sheet: Site 2, November 16, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Cottle Creek		Date: Nov. 16
Station Name: Sample Site 2		Flow status: Low
Sampler Used: Hess	Number of replicates: 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates: 0.27 m²

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	20	5
	Mayfly Nymph (EPT)	7	4
	Stonefly Nymph (EPT)	3	2
Pollution Intolerant	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle	2	1
	Water Penny		
Sub-Total		32	12
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug	7	1
	Clam, Mussel	1	1
	Cranefly Larva	3	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva	1	1
	Fishfly Larva		
	Amphipod (freshwater shrimp)	216	1
	Watersnipe Larva		
Sub-Total		228	5
Category 3	Aquatic Worm (oligochaete)	30	2
	Blackfly Larva	7	1
	Leech		
	Midge Larva (chironomid)	41	3
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails	4	1
	True Bug Adult		
	Water Mite		
Sub-Total		82	7
TOTAL		342	24

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

DENSITY: Invertebrate density per total area sampled: ____ ÷ ____ (From page 1) m² = ____ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = 53

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = 11

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: (____ + ____ + ____) / ____ = 0.088

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 24

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

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

Col. C for S1 / CT: ____ / ____ = 0.62

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment Rating	
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.25**

Table 13. Invertebrate survey field data sheet: Site 3, October 26, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	October 26th
Station Name:	Sample Site 3	Flow status:	Low
Sampler Used: Hess	Number of replicates: 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates: 0.27 m²	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	13	3
	Mayfly Nymph (EPT)	12	4
	Stonefly Nymph (EPT)	9	3
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail	2	1
	Riffle Beetle		
	Water Penny		
Sub-Total		36	11
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	17	1
	Cranefly Larva	8	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva	5	1
	Fishfly Larva		
	Amphipod (freshwater shrimp)	115	1
	Watersnipe Larva	5	1
Sub-Total		150	5
Category 3	Aquatic Worm (oligochaete)	14	2
	Blackfly Larva	17	1
	Leech		
	Midge Larva (chironomid)	138	4
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails	7	2
	True Bug Adult		
	Water Mite	3	1
Sub-Total		179	10
TOTAL		365	26

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

DENSITY: Invertebrate density per total area sampled: ____ ÷ ____ (From page 1) m² = ____ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = 53

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = 10

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: (____ + ____ + ____) / ____ = 0.093

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 26

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

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

Col. C for S1 / CT: ____ / ____ = 0.38

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.25**

Table 14. Invertebrate survey field data sheet: Site 3, November 16, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	Nov. 16
Station Name:	Sample Site 3	Flow status:	Low
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m²	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	8	4
	Mayfly Nymph (EPT)	13	4
	Stonefly Nymph (EPT)	6	3
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		27	11
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	12	1
	Cranefly Larva	4	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	108	1
	Watersnipe Larva	2	1
Sub-Total		126	4
Category 3	Aquatic Worm (oligochaete)	38	1
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)	84	2
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails	5	1
	True Bug Adult		
	Water Mite	1	1
Sub-Total		128	5
TOTAL		281	20

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: **25**

DENSITY: Invertebrate density per total area sampled: ____ ÷ ____ (From page 1) m² = ____ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = **46**

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = **11**

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: (____ + ____ + ____) / ____ = **0.096**

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: **20**

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

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

Col. C for S1 / CT: ____ / ____ = **0.384**

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.25**

Table 15. Invertebrate Survey field data sheet: Site 4, October 26, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	October 26th
Station Name:	Sample Site 4	Flow status:	Low

Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates
Hess	3	0.27 m²

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	18	4
	Mayfly Nymph (EPT)	23	4
	Stonefly Nymph (EPT)	27	5
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle	4	1
	Water Penny		
Sub-Total		72	14
Category 2	Alderfly Larva	1	1
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	9	1
	Cranefly Larva	12	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	95	1
	Watersnipe Larva		
Sub-Total		117	4
Category 3	Aquatic Worm (oligochaete)	36	1
	Blackfly Larva	8	1
	Leech		
	Midge Larva (chironomid)	87	3
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		131	5
TOTAL		320	23

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

DENSITY: Invertebrate density per total area sampled: ____ ÷ From page 1 ____ m² = ____ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ____ + 2 x ____ + ____ = 55

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ____ + ____ + ____ = 13

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: (____ + ____ + ____) / ____ = 0.21

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 23

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

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

Col. C for S1 / CT: ____ / ____ = 0.3

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4)
3.25

Table 16. Invertebrate survey field data sheet: Site 4, November 16, 2022.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name:	Cottle Creek	Date:	Nov. 16
Station Name:	Sample Site 4	Flow status:	Low
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m²	

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	10	4
	Mayfly Nymph (EPT)	24	5
	Stonefly Nymph (EPT)	29	7
	Dobsonfly (hellgrammite)		
Pollution Intolerant	Gilled Snail		
	Riffle Beetle	4	1
	Water Penny	3	1
Sub-Total		70	18
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	9	2
	Cranefly Larva	4	1
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	88	1
	Watersnipe Larva		
Sub-Total		101	4
Category 3	Aquatic Worm (oligochaete)	56	2
	Blackfly Larva	16	1
	Leech		
	Midge Larva (chironomid)	95	4
	Planarian (flatworm)		
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		167	7
TOTAL		338	29

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell CT: 25

DENSITY: Invertebrate density per total area sampled: ___ ÷ From page 1 ___ m² = ___ / m²

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

SECTION 2 - WATER QUALITY ASSESSMENTS

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

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

3 x D1 + 2 x D2 + D3: 3 x ___ + 2 x ___ + ___ = 69

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: ___ + ___ + ___ = 16

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: (___ + ___ + ___) / ___ = 0.19

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell DT: 29

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

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

Col. C for S1 / CT: ___ / ___ = 0.281

SECTION 4 - OVERALL SITE ASSESSMENT RATING

SITE ASSESSMENT RATING: Assign a rating of 1-4 to each index (S2, S3, S4, S5), then calculate the average.

Assessment	Rating
Good	4
Acceptable	3
Marginal	2
Poor	1

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

Average Rating (Average of R1, R2, R3, R4): **3.25**

8.2 SHANNON-WEINER DIVERSITY INDEX TABLES

Table 17. Shannon Index calculation table of Site 1's October stream invertebrate sample.

Site 1 - Oct.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	61	0.0868	-2.444	-0.212
Mayfly Nymph (EPT)	117	0.1664	-1.793	-0.298
Stonefly Nymph (EPT)	132	0.1878	-1.673	-0.314
Riffle Beetle	3	0.0043	-5.457	-0.023
Clam, Mussel	15	0.0213	-3.847	-0.082
Cranefly Larva	18	0.0256	-3.665	-0.094
Dragonfly Larva	5	0.0071	-4.946	-0.035
Amphipod (freshwater shrimp)	5	0.0071	-4.946	-0.035
Watersnipe Larva	3	0.0043	-5.457	-0.023
Aquatic Worm (oligochaete)	45	0.0640	-2.749	-0.176
Blackfly Larva	65	0.0925	-2.381	-0.220
Midge Larva (chironomid)	221	0.3144	-1.157	-0.364
Pouch and Pond Snails	2	0.0028	-5.862	-0.017
Water Mite	11	0.0156	-4.157	-0.065
Total:	**703**	**1**	**Shannon Index:**	**1.959**

Table 18. Shannon Index calculation table of Site 1's November stream invertebrate sample.

Site 1 - Nov.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	9	0.063	-2.759	-0.175
Mayfly Nymph (EPT)	17	0.120	-2.123	-0.254
Stonefly Nymph (EPT)	26	0.183	-1.698	-0.311
Gilled Snail	1	0.007	-4.956	-0.035
Clam, Mussel	1	0.007	-4.956	-0.035
Cranefly Larva	20	0.141	-1.960	-0.276
Watersnipe Larva	1	0.007	-4.956	-0.035
Aquatic Worm (oligochaete)	15	0.106	-2.248	-0.237
Blackfly Larva	20	0.141	-1.960	-0.276
Midge Larva (chironomid)	29	0.204	-1.589	-0.324
Water Mite	3	0.021	-3.857	-0.081
Total:	**142**	**1**	**Shannon Index:**	**2.040**

Table 19. Shannon Index calculation table of Site 2's October stream invertebrate sample.

Site 2 - Oct.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	77	0.140	-1.964	-0.276
Mayfly Nymph (EPT)	27	0.049	-3.012	-0.148
Stonefly Nymph (EPT)	31	0.056	-2.874	-0.162
Gilled Snail	5	0.009	-4.699	-0.043
Riffle bettle	6	0.011	-4.516	-0.049
Water penny	8	0.015	-4.229	-0.062
Aquatic beetle	7	0.013	-4.362	-0.056
Clam, Mussel	33	0.060	-2.812	-0.169
Cranefly Larva	4	0.007	-4.922	-0.036
Amphipod (freshwater shrimp)	216	0.393	-0.933	-0.367
Watersnipe Larva	8	0.015	-4.229	-0.062
Aquatic Worm (oligochaete)	7	0.013	-4.362	-0.056
Blackfly Larva	2	0.004	-5.615	-0.020
Midge Larva (chironomid)	80	0.146	-1.926	-0.281
Planarian (flatworm)	1	0.002	-6.308	-0.011
Pouch and Pond Snails	2	0.004	-5.615	-0.020
Water Mite	35	0.064	-2.753	-0.175
Total:	**549**	**1**	**Shannon Index:**	**1.993**

Table 20. Shannon Index calculation table of Site 2's November stream invertebrate sample.

Site 2 - Nov				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	20	0.058	-2.839	-0.166
Mayfly Nymph (EPT)	7	0.020	-3.889	-0.080
Stonefly Nymph (EPT)	3	0.009	-4.736	-0.042
Water penny	2	0.006	-5.142	-0.030
Aquatic Sowbug	7	0.020	-3.889	-0.080
Clam, Mussel	1	0.003	-5.835	-0.017
Cranefly Larva	3	0.009	-4.736	-0.042
Amphipod (freshwater shrimp)	216	0.632	-0.460	-0.290
Dragonfly	1	0.003	-5.835	-0.017
Aquatic Worm (oligochaete)	30	0.088	-2.434	-0.213
Blackfly Larva	7	0.020	-3.889	-0.080
Midge Larva (chironomid)	41	0.120	-2.121	-0.254
Pouch and Pond Snails	4	0.012	-4.449	-0.052
Total:	**342**	**1**	**Shannon Index:**	**1.362**

Table 21. Shannon Index calculation table of Site 3's October stream invertebrate sample.

Site 3 - Oct.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	13	0.036	-3.335	-0.119
Mayfly Nymph (EPT)	12	0.033	-3.415	-0.112
Stonefly Nymph (EPT)	9	0.025	-3.703	-0.091
Gilled Snail	2	0.005	-5.207	-0.029
Dragonfly	5	0.014	-4.290	-0.059
Clam, Mussel	17	0.047	-3.067	-0.143
Cranefly Larva	8	0.022	-3.820	-0.084
Amphipod (freshwater shrimp)	115	0.315	-1.155	-0.364
Watersnipe Larva	5	0.014	-4.290	-0.059
Aquatic Worm (oligochaete)	14	0.038	-3.261	-0.125
Blackfly Larva	17	0.047	-3.067	-0.143
Midge Larva (chironomid)	138	0.378	-0.973	-0.368
Pouch and Pond Snails	7	0.019	-3.954	-0.076
Water Mite	3	0.008	-4.801	-0.039
Total:	**365**	**1**	**Shannon Index:**	**1.810**

Table 22. Shannon Index calculation table of Site 3's November stream invertebrate sample.

Site 3 - Nov.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	8	0.028	-3.559	-0.101
Mayfly Nymph (EPT)	13	0.046	-3.073	-0.142
Stonefly Nymph (EPT)	6	0.021	-3.847	-0.082
Clam, Mussel	12	0.043	-3.153	-0.135
Cranefly Larva	4	0.014	-4.252	-0.061
Amphipod (freshwater shrimp)	108	0.384	-0.956	-0.368
Watersnipe Larva	2	0.007	-4.945	-0.035
Aquatic Worm (oligochaete)	38	0.135	-2.001	-0.271
Midge Larva (chironomid)	84	0.299	-1.208	-0.361
Pouch and Pond Snails	5	0.018	-4.029	-0.072
Water Mite	1	0.004	-5.638	-0.020
Total:	**281**	**1**	**Shannon Index:**	**1.647**

Table 23. Shannon Index calculation table of Site 4's October stream invertebrate sample.

Site 4 - Oct.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	18	0.056	-2.878	-0.162
Mayfly Nymph (EPT)	23	0.072	-2.633	-0.189
Stonefly Nymph (EPT)	27	0.084	-2.472	-0.209
Riffle bettle	4	0.013	-4.382	-0.055
Alderfly	1	0.003	-5.768	-0.018
Clam, Mussel	9	0.028	-3.571	-0.100
Cranefly Larva	12	0.038	-3.283	-0.123
Amphipod (freshwater shrimp)	95	0.297	-1.214	-0.361
Aquatic Worm (oligochaete)	36	0.113	-2.185	-0.246
Blackfly Larva	8	0.025	-3.689	-0.092
Midge Larva (chironomid)	87	0.272	-1.302	-0.354
Total:	**320**	**1**	**Shannon Index:**	**1.909**

Table 24. Shannon Index calculation table of Site 4's November stream invertebrate sample.

Site 4 - Nov.				
Common Name	**Number Counted**	**Relative Abundance (pi)**	**ln(pi)**	**pi*ln(pi)**
Caddisfly Larva (EPT)	10	0.030	-3.520	-0.104
Mayfly Nymph (EPT)	24	0.071	-2.645	-0.188
Stonefly Nymph (EPT)	29	0.086	-2.456	-0.211
Riffle bettle	4	0.012	-4.437	-0.053
Water penny	3	0.009	-4.724	-0.042
Clam, Mussel	9	0.027	-3.626	-0.097
Cranefly Larva	4	0.012	-4.437	-0.053
Amphipod (freshwater shrimp)	88	0.260	-1.346	-0.350
Aquatic Worm (oligochaete)	56	0.166	-1.798	-0.298
Blackfly Larva	16	0.047	-3.050	-0.144
Midge Larva (chironomid)	95	0.281	-1.269	-0.357
Total:	**338**	**1**	**Shannon Index:**	**1.895**

8.3 ALS WATER QUALITY DATA SHEETS

Table 25. ALS Environmental total metal analysis of sample sites 1, 2, and 4 on Cottle Creek during two sampling events (October 26 and November 16, 2022).

		October 26, 2022			November 16, 2022		
Total Metals	**Minimum Detection Limit**	**Cottle Creek Site 1**	**Cottle Creek Site 2**	**Cottle Creek Site 4**	**Cottle Creek Site 1**	**Cottle Creek Site 2**	**Cottle Creek Site 4**
aluminum, total	0.003	0.0086	0.221	0.0259	0.0247	0.014	0.012
antimony, total	0.0001	<0.00010	<0.00010	<0.00010	0.00012	<0.00010	<0.00010
arsenic, total	0.0001	0.00026	0.0015	0.00029	0.0002	0.00028	0.00022
barium, total	0.0001	0.00267	0.00885	0.00302	0.0045	0.00407	0.00349
beryllium, total	0.00002	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
bismuth, total	0.00005	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
boron, total	0.01	0.054	0.076	0.126	0.033	0.057	0.09
cadmium, total	0.000005	0.0000086	0.000844	<0.0000050	0.0000702	0.00333	0.0007
calcium, total	0.05	26.7	18.3	20.1	18.2	18.8	18.3
cesium, total	0.00001	<0.000010	0.000012	<0.000010	<0.000010	<0.000010	<0.000010
chromium, total	0.0005	<0.00050	0.00052	<0.00050	<0.00050	<0.00050	<0.00050
cobalt, total	0.0001	0.0001	0.00082	<0.00010	<0.00010	<0.00010	<0.00010
copper, total	0.0005	0.00138	0.00101	0.00187	0.00123	0.00237	0.00229
iron, total	0.01	0.253	2.74	0.312	0.484	0.363	0.133
lead, total	0.00005	<0.000050	0.000151	<0.000050	0.00008	0.000151	<0.000050
lithium, total	0.001	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
magnesium, total	0.005	8.13	6.03	5.72	6.27	5.86	5.58
manganese, total	0.0001	0.0305	2.52	0.0193	0.0127	0.0763	0.0142
molybdenum, total	0.00005	0.000052	0.000104	0.000126	0.000059	0.000091	0.000065
nickel, total	0.0005	0.0014	0.00053	<0.00050	<0.00050	<0.00050	<0.00050
phosphorus, total	0.05	<0.050	0.065	<0.050	<0.050	<0.050	<0.050
potassium, total	0.05	0.919	0.463	0.922	1.27	1.04	0.553
rubidium, total	0.0002	0.00081	0.00081	0.00101	0.00099	0.0012	0.00055
selenium, total	0.00005	<0.000050	<0.000050	0.000058	<0.000050	<0.000050	0.000054
silicon, total	0.1	9.62	3.56	6.26	7.08	3.56	5.24
silver, total	0.00001	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
sodium, total	0.05	12.7	10.2	11.5	11.1	11.6	11.1
strontium, total	0.0002	0.101	0.0743	0.0763	0.0771	0.0787	0.0692
sulfur, total	0.5	<0.50	<0.50	2.49	1.33	<0.50	1.38
tellurium, total	0.0002	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020
thallium, total	0.00001	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
thorium, total	0.0001	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
tin, total	0.0001	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
titanium, total	0.0003	0.00031	0.0145	0.00163	0.00041	0.00074	0.00065
tungsten, total	0.0001	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
uranium, total	0.00001	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
vanadium, total	0.0005	<0.00050	0.00186	0.00052	<0.00050	<0.00050	<0.00050
zinc, total	0.003	0.0042	0.0041	0.0033	<0.0030	<0.0030	<0.0030
zirconium, total	0.0002	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020

8.4 IMAGES FROM STUDY

Figure 19. Woody Dam located upstream of Site 2.

Figure 20. Road Work on Rock City Road, October 12, 2022.

Figure 21. Cottle Creek, ecological area salmonid habitat sign.

Figure 22. Downstream view of Cottle Creek from Site 1 (October 26, 2022).

Figure 23. Image of upstream view of Cottle Creek from Site 1 (October 26, 2022).

Figure 24. Upstream view of Cottle Creek from Site 2 (October 26, 2022)..

Figure 25. Downstream View of Cottle Creek from Site 2 (October 26, 2022).

Figure 26. Image of downstream view of Cottle Creek from Site 2 (November 16, 2022).

Figure 27. Image of upstream view of Cottle Creek from Site 2 (November 16, 2022).

Figure 28. Image of downstream view of Cottle Creek (October 26, 2022).

Figure 29. Image of old vehicles upstream of Site 2 (October 26, 2022).

Figure 30. Image of Hess sampling Site 4 (October 26, 2022).

Figure 31. Image of tires in Cottle Creek downstream of Site 3 (October 26, 2022).