Water Quality and Stream Invertebrate Assessment on Richards Creek, North Cowichan, B.C.

Prepared by:

Richards, W. Bates, R. Izard, KC.

RMOT 306

Vancouver Island University

Nanaimo, BC

December 13th, 2021

Table of Contents

Tables and Figures

Executive Summary

An environmental monitoring project was conducted for the Natural Resource Protection Program at Vancouver Island University. The project includes 4 locations along Richards Creek which is located in the Cowichan Valley, BC. These sites were chosen from recommendations from previous sampling years. The data will be sent to the Department of Fisheries and Oceans and will be used to continue the assessment of the area that was concluded in previous years. Water samples were analyzed by VIU students, with the use of university laboratory equipment. As well as, sent away to ALS laboratory in Vancouver B.C. The results were then compared to the water quality guidelines for British Columbia. The objective of this environmental survey was to assess stream conditions and add to the existing data collected and thus compare and monitor the long-term stream health of Richards Creek. Sampling was conducted on October 20th, 2021, while low flow rates were observed and on November 23rd, 2021, after high flow rates. Microbiology and stream invertebrate samples were analyzed as well as, hydrology, and various water quality parameters. The invertebrate communities suggested that the stream is healthy but marginal with a decline in diversity when compared to previous sampling years. It was found that alkalinity was reduced substantially on the second sample date whereas Nitrite increased. The dissolved oxygen found in site 4 was low. Based on the results tested by ALS labs, Phosphorus, Phosphate, Aluminum, and Iron exceeded the BC guidelines recommendations for water quality. phosphorus and phosphate levels were also recorded to exceed recommendations when compared to the Vancouver Island University (VIU) lab analysis. phosphorus, from all sampling events and sites 2-4, and phosphate, from sampling event 1, sites 3 and 4. In sampling events, 1, sites 3-4, and sampling event 2, sites 1-3 Aluminum was above its water guideline. At low levels of pH, aluminum can cause deformities in fish embryos. The

construction along Richards Creek could be a contributing factor to these high aluminum levels. In sampling event 2, site 2, The level of iron exceeded that of the guideline. High concentrations of metals like iron can cause damage to the respiratory organs of aquatic animals.

1.0 Introduction

1.1 Project Overview

The project outlined in this report ran from October 20th, 2021, to November 23rd, 2021, and was confined to Richards Creek in North Cowichan, BC. With the direction of Vancouver Island University's (VIU's) environmental monitoring professor, Owen Hargrove. Three students from VIU conducted this environmental monitoring project to fulfill their bachelor's degree in natural resource protection. Richards Creek is a 10,092-meter-long creek in the Somenos basin, running from the Crofton reservoir southwest into Somenos Lake near Duncan. Richards Creek varies in width from 2-18 m and has a low overall gradient ranging between <0.1-5.0% (Lanarc Consultants Limited 1999). Our sample area consists of four locations along the creek. Escarpment Way Crossing, the end of Rice Road, Richards Trial Crossing, and Herd Road Crossing. This will make a length of 4.97km of the creek our area of focus. This report will consist of water quality monitoring, in the form of physical attributes such as flow, gradient, conductivity, dissolved oxygen levels, and turbidity, along with more chemical-based analyses such as alkalinity, Nitrate, and Phosphate testing, Hardness, and pH testing. Stream invertebrate samples will also be taken at three sites and analyzed to determine water habitat quality.

1.2 Historical Overview

Agriculture modifications have shaped Richards Creek; farmers have changed the flow patterns of the creek to maximize crip yields and benefit cattle farming which has also impacted the riparian vegetation along the creek bank. Cowichan Valley Regional District regulates the flow of water from the Crofton reservoir into Richards Creek and has been recorded that the lack of cooling groundwater during the summer months creates an abnormally high-water temperature being released from the Crofton reservoir into Richards Creek (Lanarc Consultants Limited 1999). In the past, over 700 Coho salmon (*Oncorhynchus kisutch*) have been recorded in Richards Creek, as well as coastal cutthroat (*Oncorhynchus clarkii*) and rainbow trout (*Oncorhynchus mykiss*). Their numbers have significantly decreased with a lack of spawning habitat (Madrone Environmental Services Limited 2015). Much of the lower-lying agricultural fields completely flood. Some areas have been modified to improve agricultural runoff and reduce flooding to improve drainage. A habitat restoration project was implemented in 1983 where a few properties above Richards Trail were fenced off to prevent livestock from accessing the creek directly and reduce access by livestock. Other less productive areas of Richards Creek were dredged to increase stream health. As a result, fish from lower Somenos lake seek refuge in this area during pour quality water events (Lanarc Consultants Limited 1999).

1.3 Environmental Concern

Most of the land used in the area is agricultural and urban areas. The use of water for agriculture and the constant flooding of fields has led to high nutrient runoff into Richards Creek. The lack of riparian vegetation and cattle grazing have also contributed to an increase in nutrient load. During the summer months, water usage from the Crofton reservoir has caused abnormally high-water temperatures and low dissolved oxygen content for productive salmon spawning habitats (Madrone Environmental Services Limited 2015). Urban areas have the potential to adversely affect stream health by improper disposal of household waste materials into Richards Creek. Garbage pickup locations are also close to the edge of the creek bank causing some waste materials to inadvertently end up in the creek.

2.0 Project Objectives

This report aims to accurately collect and compile stream health information for Richards Creek and contribute to the long-term assessment of the overall stream health. This information includes water quality assessments, both by VIU students and ALS labs in Vancouver BC. as well as invertebrate sampling to determine the environmental impact to Richards Creek from adjacent land use. Four sites were sampled along Richards Creek that best represent the overall characteristics of the creek. By completing this monitoring program, more information can be collected and compiled for The District of North Cowichan, The Department of Fisheries and Oceans, and the various agricultural landowners along Richards Creek.

3.0 Methods

3.1 Sampling Procedure and Frequency

All samples obtained from the 4 sites along Richards Creek were procured using standardized methods established before collection began. On October 20th, 2021, one sample for water quality analysis was taken from each site on behalf of the VIU laboratory. On the same day, three separate samples were taken from each site on behalf of the Australian Laboratory Services or ALS for analysis. To ensure quality assurance, all the bottles used for the VIU testing were rinsed out three times with water from the site where the sample was to be taken. This was done to prevent potential contamination within the sample bottles. Pre-rinsing was not done for the ALS sample collection because the bottles were pre-sterilized. Once at the site for testing, the seal on the bottle would be broken and the water sample would be collected. The ALS analysis would include general testing of water quality parameters, nutrient analysis, and a total metal scan which includes about 30 different metals. Sample collection was then replicated on November 24, 2021. Due to heavy rainfall the week before, site 4 was inaccessible for the second collection date. All samples that could be taken for the ALS and the VIU testing, were obtained carefully following the same procedures and methods as the first samples to maintain quality assurance.

3.2 Sampling procedures in Stream

Wetted depth was measured with a meter stick at the deepest part of the channel. The width was measured using a tape measure and stretching it along the top of the bankfull channel. It was important to make sure that the measuring tape is level and perpendicular to the flow of the stream.

Velocity was tested with a ping-pong ball and a timer. Set 3 meters apart and at the deepest section of the site, the ping-pong was timed for the duration it took to travel the 3 meters down the stream. This test was done 3 times at each site and the results were then averaged out to give a better representation of the velocity of the creek.

A YSI multimeter was used to measure water temperature and dissolved oxygen within each site. The probe was dipped into the creek for one minute to accurately gauge the temperature and dissolved oxygen to obtain an accurately reading.

A Hess sampler was used in sites 1, 2, and 3 for invertebrate captures. 3 samples were taken at each site. To ensure quality control, the Hess sampler was placed in the desired location for 1 minute for each sample. If any large debris or mollusks were collected during sampling, documentation would be made and then removed from the sampler. Once the samples were obtained, everything was preserved in a 70% concentration of ethanol.

3.3 Testing procedures in Lab

Phosphate - Phosphate was measured using the spectrophotometer with a pre-set program of procedures. The samples were carefully measured out into 3 match pairs of pre-rinsed square glass containers. PhosVer 3 reagent powder was added to one of each set of matched pairs with the other glass cell to be used as a blank. To allow for consistency in mixing the additive, a timer of 2 minutes was set. Once the 2 minutes had passed, we inserted the blank sample into the spectrophotometer and pressed the program start. This was repeated for all the prepared samples.

Conductivity - Each sample was measured for conductivity by measuring the level of electricity conducted by the water which is a product of ion concentration.

Alkalinity – Before testing alkalinity, PPE was donned, and all equipment was rinsed three times for quality assurance. Using the 0.1600 N sulphuric acid titration cartridge, we measured how many turns on the delivery knob it took to change the color. The concentration of sample water used is dependent on the level of conductivity recorded. The chemical additives, phenolphthalein indicator powder, and bromocresol green-methyl red indicator power were introduced to the water sample to initiate the colour change.

pH – pH was tested with a handheld pH tester in the VIU lab. The device was calibrated prior to testing.

Hardness – Harness was tested differently based on the conductivity of the sample being tested, based on the conductivity. 1ml of Harness 1 solution would be added to the sample, then two drops of Hardness 2 are added to the solution. Finally, Hardness 3 is introduced one drop at a time until the solution turns blue. The number of drops of harness 3 will be calculated to find out the hardness of the sample.

Turbidity - Turbidity tests are measuring the level of water clarity. The sample water is agitated and poured into a vile that is provided with the turbidity testing equipment. Next, the vile is agitated and placed in the correct orientation into the machine and tested.

3.4 Location Description

Richards Creek is in Duncan, B.C within the Somenos Basin. This creek is roughly 10 km from Crofton Lake to Somenos Lake. The samples will be collected from four different site locations within a 4.97km area of Richards Creek. These locations can be found on the site map (Figure 1) at the Escarpment Way Crossing (Site 1), the end of Rice Road (Site 2), Richards Trail Crossing (Site 3), and Herd Road Crossing (Site 4). It was observed that there was ongoing construction near the Escarpment Way Crossing and could lead to a possible source of contamination for Richards Creek.

Site 1 at the Escarpment Way Crossing is accessed along the banks just off the side of the road. There is a single pipe culvert that allows the creek to pass unobstructed underneath the road. The surrounding riparian area is densely packed with saplings and wild grasses that shade the area. The substrate within the site is sandy with deep pockets where root systems have grown.

Site 2 at the end of Rice Road is in a more isolated location with a dense riparian area showing more sword ferns and cedar tree coverage. The substrate of this site consists of cobble and sand within the stream bed with loamy soil along the banks. To access this site a 4-minute hiking trail was made from the road into the gully.

Site 3 at the Richard Trail Crossing is accessed along the banks beside the road. To allow the creek to run unobstructed, there is a large bridge culvert installed. There are several large agricultural practices alongside the banks, which is a potential concern for contamination. The surrounding riparian area consists of various brambles and small maples providing adequate shade. The substrate at this site is primarily stones and boulders with several pieces of large woody debris.

Site 4 at the Herd Road Crossing is located under the roadway accessed by foot on a steep gradient with dense English ivy and brambles blocking the access trail. This site is surrounded by a marshy riparian area, with a deep pool forming within the creek. Due to the unknown depth of the site, several tests were unable to be performed (invertebrates, velocity, wetted depth, wetted width), due to various safety concerns. During the second collection of samples, site 4 was completely inaccessible due to heavy flooding.

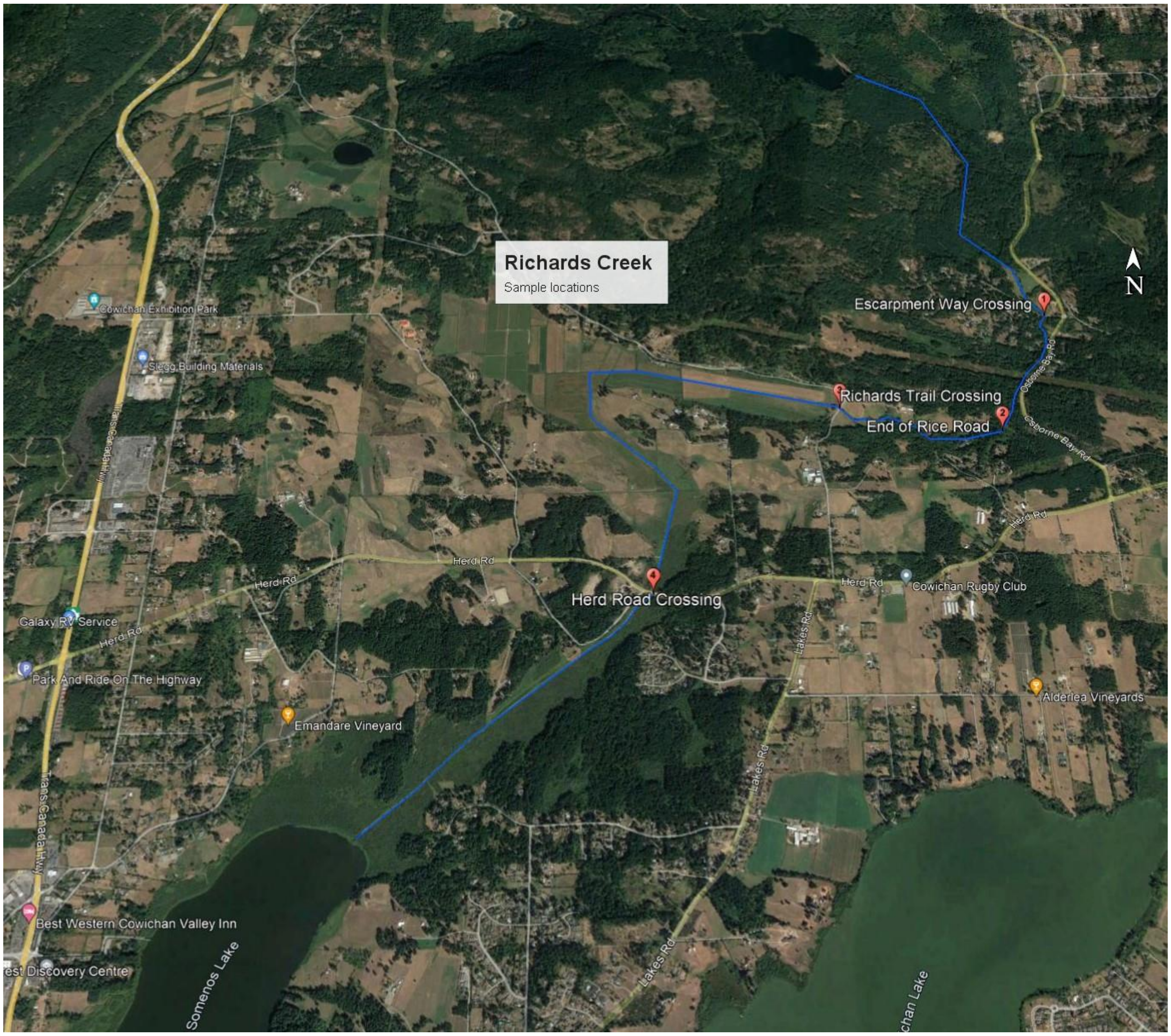

Figure 1: Sample sites located on Richards Creek that will be visited.

3.5 Quality Assurance and Quality Control

The samples were collected using the sampling equipment and the standardized procedures listed in the Streamkeepers Handbook (1995). To ensure quality control for each sample, the equipment used was cleaned in between collections at every site. The sample jars were rinsed three times prior to sample collection. Once the samples were collected, the jars were sealed and stored until the contents could be analyzed.

3.6 Sample Collection

The sample collection for the invertebrate samples was obtained during the first selection of sampling on October 20th, 2021. In a suitable substrate area, the sampler is placed so that it is resting on the bottom of the stream bed. The net portion of the Hess sampler was positioned downstream. Any adjustments were made by pushing down and rotating the sampler using the handles. Once in the correct position, the net was stretched out and the sample bucket was adjusted to have a horizontal flow of water. A timer of 1 minute was set in accordance with quality control. With the sampler in place, the cobble and substrate inside the sampler basin were then disrupted so that specimens can be carried by the current downstream and into the net and bucket. To ensure all organisms are dislodged, any large rocks or stones were hand-cleaned inside the sampler basin. After the larger debris has been dislodged and scraped for organisms, the remaining gravel and sand were stirred with a stick to collect the bottom-dwelling organisms. All mussels or snails that are not carried by the current into the net and sample bucket were removed by hand and recorded then returned to the water. Once the timer has finished, the Hess sampler was removed from the stream to end sample collection. The net will be rinsed down to collect any specimen stuck to the collection net. The Hess sampler is then rinsed off after each use to avoid potential contamination between sites. After the sample is extracted from the field, a concentration of 70% ethanol and 30% water is added to the sample container to preserve the invertebrates until analysis. These samples were then stored within the controlled environment of the VIU laboratory fridge. Reaching an average temperature of 4ºC. Analysis of the samples was performed on October 23, 2021.

4.0 Stream Invertebrates

All invertebrate samples taken from the field were tested within 3 days of being acquired to avoid complete disintegration of invertebrate specimens. Samples were only taken from Site 1, Site 2, and Site 3. The high waters at Site 4 made it impossible to acquire invertebrate samples as there were limitations of the personal equipment used. Each site sample was individually sorted and analyzed in the lab using a dissecting microscope. Any invertebrates found were identified and counted into a tally record modified from the Taccogna and Munro Streamkeepers Handbook (see Table 1).

Table 1: Total abundance, diversity and site assessment rating of invertebrates found in Richards Creek analyzed October 26, 2021.

Pollution Tolerance	Invertebrate Taxa	Station 1	Station 2	Station 3
Category 1 Pollution Intolerant	Caddisfly Larva	4	2	1
	Mayfly Nymph	6	1	7
	Stonefly Nymph	2	1	1
	Water Penny	1		
Category 2 Somewhat Pollution Intolerant	Clam, Mussel	1		
	Cranefly Larva	7	6	
	Damselfly Larva	2		
	Amphipod (Scud)	3	3	13
Category 3 Pollution Tolerant	Aquatic Worm (Oligochaete)	14	8	15
	Blackfly Larva	1	1	
	Midge Larva (Chironomid)	18	18	13
	Planarian (Flatworm)	5	6	
	Pouch and Pond Snails	2		
	True Adult Bug	1		2
	Water Mite	2		
	Total Abundance	69	46	52
	Density (number/m2)	255.55	170.4	192.6
	Site Assessment Rating	2.75	2.75	2.75

4.1 Invertebrate Diversity

The samples from Site 1 had captured 69 identified invertebrates. These invertebrates were divided into three categories. Category 1 represents pollution intolerant species, category 2 represents somewhat pollution intolerant species, and category 3 represents pollution tolerant species. Category 1 captured 13 invertebrates made up of 4 different species. Category 2 captured 13 invertebrates made up of 4 different species. Category 3 captured 43 invertebrates made up of 7 different species. These results show us that pollution tolerant species thrived predominantly make up the site population, with the most commonly found taxon being the midge larva (*chironomidae*). This would be an indicator of marginal overall stream health which is represented in the site assessment as a score of 2.75 (see Table 1).

The sample for Site 2 captured 46 invertebrates where 4 invertebrates were found, with 3 different species represented. Within this sample, there were only 2 different species identified as category 2. With 9 invertebrates making up the overall count. Category 3 had a large abundance of individuals captured, recording 33 invertebrates of which, there were only 4 different species. For Site 2, it was noted that the most abundant taxon observed was the midge larva. The Site 2 results show an indication of marginal stream health represented as a score of 2.75 (see Table 1). The sample for Site 3 yielded a total of 52 invertebrates, with 7 different species recorded. Within category 1, there is a total count of 9 individual invertebrates but only 3 different species. Category 2 only had 13 invertebrates, all of which were amphipods.

For Site 3, Category 3 once again displayed the most abundance over the other two categories, with 30 individuals captured representing 3 different species. In this site, the most abundant taxon was the aquatic worm (*oligochaeta*), which is considered pollution tolerant. Therefore, the tolerance index this once again calculated to be 2.75, which is suggesting that this site has marginal stream health. The results taken from Richards Creek show a trend when compared to previous years where sampling has been done. Figure 2 was created to better compare past studies from 2008 to 2017. In the report done in 2009 by Anderson et al. (2009), the site assessment rating for Site 1 was scored as a 2 with Site 2 and Site 3 scoring above a 3. The 2012 report done by Coopsie and Senkiw (2012) showed a variation in their site assessment score. Site 1 was scored 2.5 as marginal with Site 2 and 3 showing acceptable scores of 3. In 2015 the site assessment rating done by Der et al. (2015) shows Site 2 and Site 3 were scored as a 3 and 3.5 indicating acceptable levels of stream health, whereas Site 1 showed a lower score of 2.5. Even with several spikes in numbers for positive overall health, there has been a steady downward trend in stream health over the last 13 years. Although the reason behind the decline in stream health is unconfirmed at this time, it is highly likely to be attributed to agricultural runoff combined with the changes in weather and temperature due to climate change. However, it should be noted that the recorded data may have some margin of error because sampling and analysis are completed by different students every year rather than a consistent team.

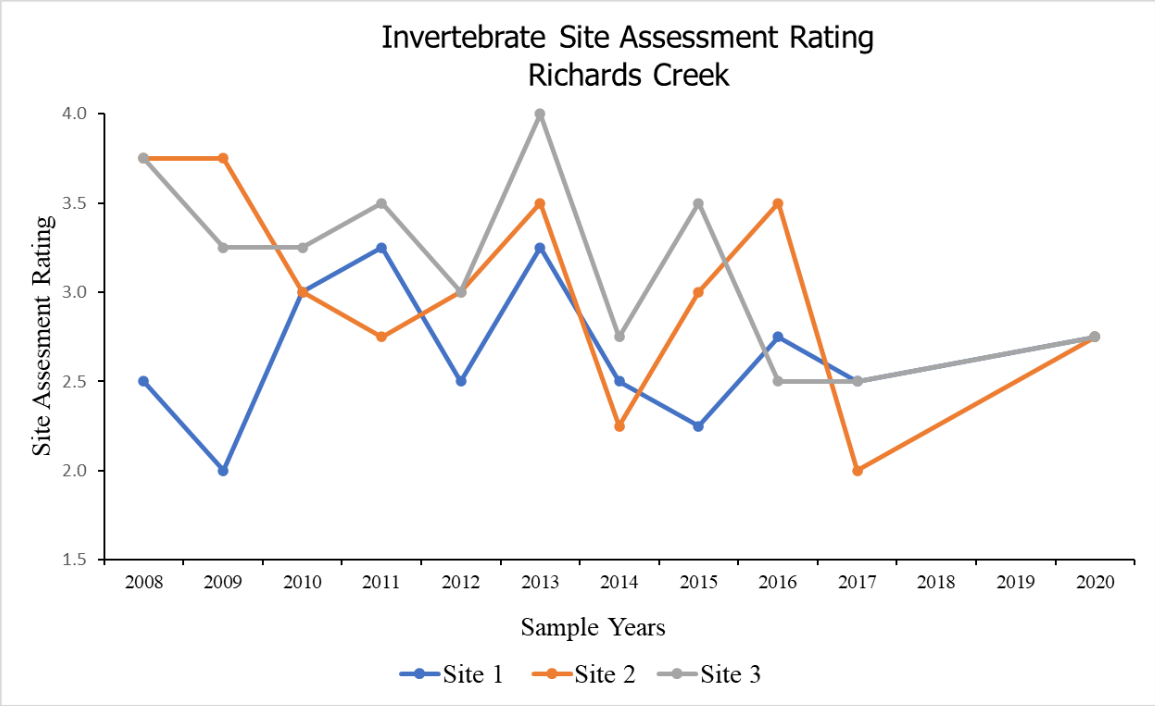

Figure 2: Data compiled from 2009 to 2020 representing the downward trends in stream health (Brown et al. 2008. Anderson et al. 2009. Brooks et al. 2010. Dorey et al. 2011. Dorey et al. 2012. Seibert et al. 2013. Aikman et al. 2014. Der et al. 2015. George et al. 2016. Bull et al. 2017).

5.0 Water Quality

5.1 Quality Assurance and Quality Control

To guarantee accurate data collection, Quality Assurance and Quality Control precautions were taken. The British Columbia Field Sampling Manual (2003) was followed. VIU sample bottles were rinsed three times, samples were taken facing upstream, samples were stored properly in a VIU cooler, and blank and replicate samples were taken for ALS, Covid safety protocols were followed, and the VIU safety plan was followed, and the proper equipment was used (see table 2).

Table 2: Water Quality Parameters

Parameter	Unit	Equipment	BC Water Quality Guideline
Conductivity	µS/cm	Pinpoint Conductivity Meter	n/a
pH	N/A	Oakton pH Tester 10 pH	6.5-9.0
Turbidity	NTU	HACH 2100 Portable Turbidimeter	<5
Alkalinity (CaCO3)	mg/L	HACH AL-DT digital titration method	>20
Hardness (CaCO3)	mg/L	HACH HA-4P test kit	n/a
Nitrate	mg/L	HACH DR2800 Spectrophotometer Method 8192	<200
Phosphate	mg/L	HACH DR2800 Spectrophotometer Method 8048	n/a

5.2 Field Measurements

Field measurements were taken at sites 1-4 during sampling event 1. These measurements include dissolved oxygen and temperature (see Table 3).

Table 3: Dissolved Oxygen and Temperature of Richards Creek

Site	Dissolved Oxygen (mg/L)	Temperature (°C)
1	10.0	9.9
2	10.5	9.8
3	10.2	10.2
4	1.0	11.0

5.2.1 Dissolved Oxygen

Dissolved Oxygen (DO) measures the amount of dissolved oxygen is available in an aquatic environment. This oxygen and its availability are essential to sustaining aquatic organisms. The increase or decrease of available dissolved oxygen in a water body over long periods of time can completely change an ecosystem through eutrophication (RISC 1998).

The Dissolved Oxygen of Richards Creek was measured in sites 1-4 during sampling event 1. According to the BC Fresh Water Guidelines sites 1-3 shows dissolved oxygen levels are high enough to support all life stages of fish within their water. Site 4 however, has drastically lower dissolved oxygen levels (see Table 3). This low level of Dissolved Oxygen in site 4 could cause fish mortality. As explained in BC Environment and Lands (1997) hypoxic stress in the aquatic environment is commonly cited as a factor in low salmonid survival rates. Anthropogenic sources that negatively affect dissolved oxygen levels are logging, pulp mills, sewage treatment effluent, industrial effluents, dams, and agriculture. The farmland on either side of Richards Creek could be causing the low levels of dissolved oxygen seen in site 4 through pesticides or fertilizer leaching downhill into the creek.

5.2.2 Water Temperature

Temperature measures the amount of heat stored in a volume of water. The temperature of water affects the solubility of chemical compounds within it. Hight temperatures increase the oxygen demand of organisms within it, while low temperatures increase energy loss in organisms. All the site's recorded temperatures were acceptable for spawning and incubating fish according to RISC (1998).

5.3 VIU laboratory Analysis

During sampling events 1 and 2 of Richards Creek, two sets of bottled samples were taken from the creek. One set of water samples were taken to be analyzed by Australian

Laboratory Services (ALS) to determine the levels of metals within the water. The other set of samples were taken for analysis in the Vancouver Island University (VIU) Laboratory to examine the creek's alkalinity, conductivity, hardness, nitrate levels, phosphate levels, pH, and turbidity (see Table 4).

Table 4: VIU Laboratory Analysis of Sampling Events 1 and 2

Sampling Event 1

Site	Conductivity (µS/cm)	pH	Turbidity (NTU)	Alkalinity (mg/L)	Hardness (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)
1	108	8.0	2.95	7.2	68	0.24	0.02
2	138	8.0	2.10	16.4	72	0.10	0.03
3	155	8.6	4.12	15.2	72	0.04	0.20
4	197	7.7	2.40	14.4	84	0.01	0.36

Sampling Event 2

Site	Conductivity (µS/cm)	pH	Turbidity (NTU)	Alkalinity (mg/L)	Hardness (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)
1	114	8.3	3.51	0.4	56	0.55	0.05
2	90	8.5	3.55	2	36	0.44	0.03
3	153	8.1	3.42	1.6	44	0.44	0.07

5.3.1 Conductivity

Conductivity measures the ability of water to conduct electric currents and can be used to measure the total ion concentration of the water body. Coastal streams of BC are known to have conductivities of ≤100 µS/cm (RISC 1998).

The conductivity of Richards Creek was recorded during sampling events 1 and 2. Sites 1-4 were sampled during sampling event 1 and sites 1, 2, and 3 were sampled during sampling event 2. The VIU and ALS laboratory analyses differ from one another, with ALS primarily showing greater levels of conductivity than measured by VIU. Sampling event 1 analyzed by VIU shows a steady increase in conductivity as you progress downstream ranging from 108 – 197 μS/cm. Sampling event 2 analyzed by VIU shows an increase from site 1 to site 3 from 114 – 153 μS/cm but also a significant drop in site 2 down to 90 μS/cm. The ALS analyses of sampling event 1 showed a gradual increase in conductivity as you progressed downstream just as VIU did but with a range of 117 – 213 μS/cm. The ALS analyses of sampling event 2 contradict the VIU results in that there is no sudden drop in conductivity at site 2. Instead, the conductivity gradually increases as you go downstream from 79 – 98 μS/cm. Anthropogenic sources known to affect conductivity are mining, roads, industrial and municipal effluents (see Table 4) (RISC 1998).

5.3.2 pH

pH measures the acidity of an aquatic environment. High pH levels facilitate the precipitation of metals and salts. Whereas low pH levels facilitate the dissolution of metals in an aquatic environment. (RISC1998)

Any pH <7 is considered acidic, >7 is basic, and 7 is neutral. The pH of Richards Creek was taken during sampling events 1 and 2. Sites 1-4 were sampled during sampling event 1 and sites 1-3 were sampled during sampling event 2. The ALS and VIU laboratory analyses varied on the measurements with ALS ranging from 7.19-7.65 and VIU ranging from 7.7-8.6. Despite the discrepancy, both ranges are within acceptable limits according to the BC Fresh Water Guidelines. Anthropogenic sources that affect pH in a water body are mining, agriculture, industrial effluents, and acid rain (RISC1998).

5.3.3 Turbidity

Turbidity measures the amount of suspended particulate matter in an aquatic environment. It affects the available surface area for bacteria to grow off and the depth of light penetration inside a waterbody. High turbidity hinders underwater vegetation growth but supports more are for bacteria. Low turbidity promotes photosynthesis and the development of underwater vegetation, aiding in the eutrophication of an aquatic environment (RISC 1998).

The Turbidity of Richards Creek was recorded during sampling events 1 and 2. Sites 1-4 were sampled during sampling event 1 and sites 1-3 were sampled during sampling event 2. The results from sampling event 1 range from 2.10 – 4.12 NTU, while the results from sampling event 2 are on average higher but do not reach as high with a range from 3.42-3.55 NTU. The values from both sampling events all fall within acceptable parameters according to the BC Fresh Water Guidelines. Anthropogenic sources known to affect turbidity are logging, agriculture, urban development, sewage treatment, mining, and industrial effluents (RISC1998). It is possible that the farms around Richards Creek could affect its turbidity.

5.3.4 Alkalinity

Alkalinity measures a water body's ability to neutralize acids within itself. High levels of alkalinity can lead to an increase in hardness and concentrations and depositions of metals. Whereas low alkalinity environments have little ability to buffer acids introduced to them making them sensitive to acidification.

The Alkalinity of Richards Creek was taken during sampling events 1 and 2. Sites 1-4 were sampled during sampling event 1 and sites 1-3 were sampled during sampling event 2. Both sampling events yielded low alkalinity results for all sites. With sampling event 1 yielding a range of 7.2 – 16.4 mg/L and sampling event 2 yielding 0.4 – 2 mg/L. As all our samples have alkalinity values of <20 and even <10 mg/L, this means that Richards Creek has Moderate to high acid sensitivity (see Table 4).

5.3.5 Hardness

In an aquatic environment, hardness is due to the presence of magnesium and calcium in the water. Water values of <60 mg/L are considered soft water and values >120 mg/L are considered Hard water. Water hardness can affect the toxicity of the aquatic environment, with hard water promoting metal deposition and soft water enabling corrosion (RISC 1998).

The Hardness of Richards Creek water was recorded during sampling events 1 and 2. Sites 1-4 were sampled during sampling event 1 and sites 1-3 were sampled during sampling event 2. During sampling event 1, hardness showed a gradual increase as you progressed downstream, ranging from 68-84 mg/L. Alternatively, sampling event 2 showed a decrease from upstream to downstream with a range of 56 – 44 mg/L, with a distinct drop at site 2 of 36 mg/L. Anthropogenic sources known to affect hardness are mining and industrial effluent (see Table 4) (RISC 1998).

5.3.6 Nitrate

Nitrate is the main source of nitrogen used by plants for growth. Excessive amounts of nitrogen in an aquatic ecosystem can lead to the excessive development of plants and the quickening of eutrophication (RISC 1998). Nitrate needs to be in a proper balance with Phosphate in an environment, in a ratio of 16N:1P is most optimal. This is the Redfield ratio and the results taken from Richards Creek show that the current ratio is lacking in nitrate (see Table 6).

From our ALS results, we found that Site 4 has an increased level of nitrogen as compared to every other site. Anthropogenic sources for nitrogen in an aquatic environment are usually sewage treatment effluent, agricultural runoff, urban development, industrial effluents, or mining (RISC 1998). Given its geographical location, the most likely source of this spike in nitrogen is from agricultural runoff coming from the nearby farmland. Pesticides and fertilizers are likely used and then run down the hills into the creek.

5.3.7 Phosphate

In an aquatic environment, phosphorus is the most limiting nutrient. Excessive amounts of phosphorus introduced into an aquatic environment can cause extrema algal blooms and plant growth leading to accelerated eutrophication of the water body(viu). The BC Water Quality Guidelines have laid out a standard for what yield of phosphorus in a water body is considered Oligotrophic, Mesotrophic, and Eutrophic (table 5).

Comparing to this guideline allows us to categorize each site of Richards Creek based off the phosphorus yield recorded. Site 1 had a phosphorus level of below or nearly equal to 0.01 mg/L making it most likely Oligotrophic. Sites 2,3, and 4 all had phosphorus levels greater than or close to 0.025 mg/l. Meaning, most of our samples from Richards Creek are considered eutrophic.

Anthropogenic sources for excessive phosphorus in an aquatic environment can be sewage plants, agriculture, development, detergents, and industrial effluents (risc1998). It is likely that like nitrogen, the farmlands along the majority of Richards Creek are the primary contributing source of this eutrophication. However, during our first and second sampling events, urban development was noted as construction was occurring near the creek. This could also be a cause of increased phosphorus in the creek.

Table 5: Trophic levels according to The BC Water Quality Guidelines

Trophic level	**Phosphorus Yield (mg/L)**
Oligotrophic	<0.01
Mesotrophic	0.01-0.025
Eutrophic	>0.025

Table 6: Redfield Ratio of Richards Creek

Sampling Event 1				**Sampling Event 2**			
Site	**Nitrate**	**Phosphate**	**Redfield Ratio 16N:1P**	**Site**	**Nitrate**	**Phosphate**	**Redfield Ratio 16N:1P**
1	0.24	0.02	0.750	1	0.55	0.05	0.688
2	0.10	0.03	0.208	2	0.44	0.03	0.917
3	0.04	0.20	0.013	3	0.44	0.07	0.393
4	0.01	0.36	0.002				

5.4 ALS Laboratory Analysis

Samples were taken from each site along Richards Creek during sampling events 1 and 2. These samples were taken and sent off to ALS labs to be analyzed. The results are then sent back to compare with the VIU's lab analysis. The ALS results from sampling event 1 and sampling event 2 respectively are found in Appendix D.

5.4.1 ALS Results

The only elements that exceeded the guidelines were Phosphorus and Phosphate, Aluminum, and Iron. Phosphorus and Phosphate were like VIU's analyzed results, with phosphorus and phosphate levels above their guideline parameters. Phosphorus, from all sampling events and sites 2-4, and phosphate, from sampling event 1, sites 3 and 4. This concurs with VIU's results showing a trend of eutrophication in Richards Creek. In sampling events, 1, sites 3-4, and sampling event 2, sites 1-3 Aluminum was above its water guideline. Aluminum may not be considered a risk to public health but when it comes to aquatic species it can be harmful. At low levels of pH, aluminum can cause deformities in fish embryos. Anthropogenic sources of high aluminum are usually industrial effluents or mine drainage (RISC1998). The construction along Richards Creek could be a contributing factor to these high aluminum levels. In sampling event 2, site 2, The level of iron exceeded that of the guideline. High concentrations of metals like iron can cause damage to the respiratory organs of aquatic animals within the waterbody. Additionally, high concentrations of iron can cause the fixation of essential elements required by plants. Anthropogenic sources that can affect iron levels in a water source are burning coal, acid mine drainage, and smelters.

5.5 Phosphorus Levels

Reviewing several years worth of past VIU creek water quality reports and examining the rise and fall of recorded phosphorus to determine the trophic level (graph) shows that even back to 2008, Richards Creek has been largely eutrophic. Looking at Figure 3, both 2010 and 2013 show a drastic increase in phosphorus levels of sites 3 and 4 but not 1 or 2. It can be inferred that an event occurred affecting those areas. Effluent spills, increased construction or most likely heavy rainfall resulting in agricultural runoff draining into those areas of the creek closest to them could be the cause of these abnormal spikes in phosphorus. The results taken in 2021 by our team show a gradual increase in phosphorus the further downstream testing is done which is more densely populated with agricultural farmland. Unfortunately, due to improperly recorded or absent data from 2018-2020, it is not possible to say whether there has been a gradual increase in phosphorus from 2016-present or if there were spikes previously and we are presently in decline. With future detailed recording, a gradual trend will be possible to graph.

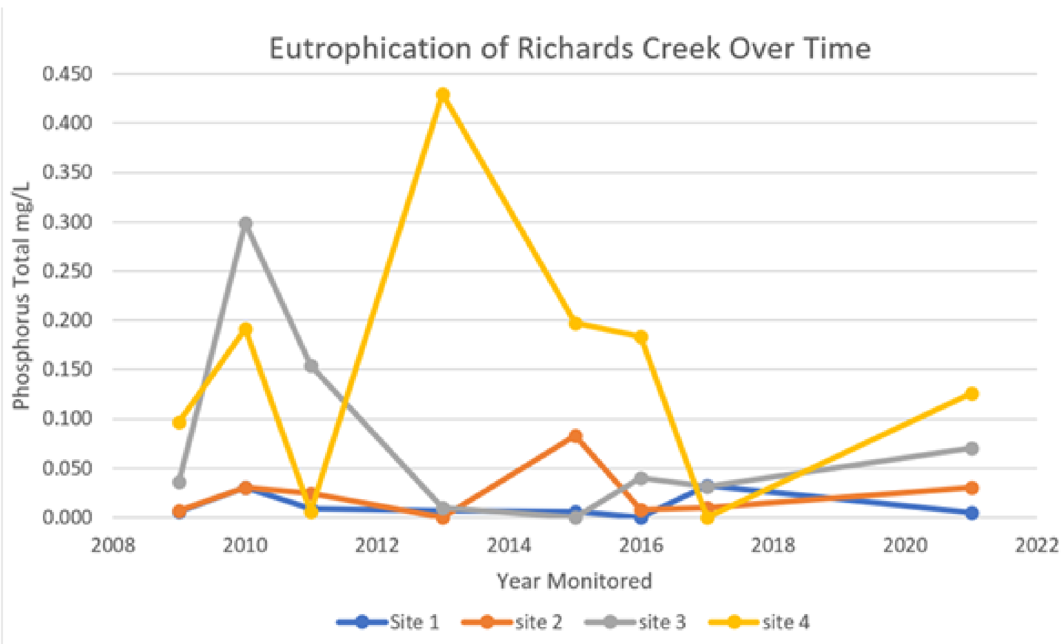

Figure 3: Phosphorus Levels in Richards Creek Showing Eutrophication Changes

6.0 Discussion

6.1 Conclusion

Assessing several year's worth of data collected from VIU, Richards Creek has been largely eutrophic. A drastic increase in phosphorus levels has been recorded since 2010.

Likely an event occurred affecting those areas around that time. Effluent spills, increased construction or most likely heavy rainfall resulting in agricultural runoff draining into those areas of the creek closest to them could be the cause of these abnormal spikes in phosphorus. The results taken by our team show a gradual increase in phosphorus where samples were taken adjacent to more densely populated agricultural practices. Because of a lack of data for several years in a row, it is not possible to get a more accurate picture of our findings. More care should be taken to collect data over the next few years to determine if the trend we are seeing is constant or varying.

6.2 Recommendation

More testing can be done to determine the exact cause for the increase in phosphorus levels found within Richards Creek. It would be beneficial to inform all agricultural practices that run alongside Richards Creek of the consistent decrease in stream health over the last 13 years. There may be alterations done within these agricultural practices that could assist in restoring previously recorded productivity within Richards Creek. One such alteration might be to put in place a large riparian zone around the creek. This might prevent runoff, flooding and further eutrophication. Another suggestion may include putting up proper fencing to prevent livestock from accessing the creek to lower contamination levels.

7.0 Acknowledgements

We would like to acknowledge Owen Hargrove and Mike Lester for their valuable input and instruction in the RMOT 306 environmental monitoring program. We would also like to acknowledge Vancouver Island University and sponsoring committees for providing the funding and the necessary facilities for this project to be successful.

8.0 Citations

Aikman T, Brophy C, Linza F. 2014. Fall 2014 water quality and stream invertebrate assessment of Richards Creek, Crofton, British Columbia. Prepared for Dr. Eric Demers: Vancouver Island University. 33 p.

Anderson M, Corbett M, Isbister B, Reaume K. 2009. Water quality and stream invertebrate assessment for Richards Creek and Somenos Creek, BC, (Fall 2009). Prepared for Dr. Eric Demers: Vancouver Island University. 28 p.

British Columbia Environment and Lands. 1997. Ambient Water Quality Criteria for Dissolved Oxygen. <https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/dissolvedoxygen-or.pdf> Accessed on 8 Dec 2021.

British Columbia Ministry of Environment and Climate Change Strategy. 2021. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture - Guideline Summary. Water Quality Guideline Series, WQG-20. Prov. B.C., Victoria B.C.

Brooks B, Godkin A, McNish J. 2010. Water quality and stream invertebrate assessment for Richards Creek, BC, (Fall 2010). Prepared for Dr. Eric Demers: Vancouver Island University. 25 p.

Brown L, McDonald T, Rochetta M. 2008. Water quality and stream invertebrate assessment for Richards Creek, BC, (Fall 2008). Prepared for Dr. Eric Demers: Vancouver Island University. 27 p.

Bull J, Farrugia P, Carlson J. 2017. Water quality and invertebrate analysis for Richards Creek, Duncan, BC, 2017. Prepared for Dr. Eric Demers: Vancouver Island University. 46 p.

Coopsie H and Senkiw S. 2012. Water quality, invertebrate and microbiology analysis for Richards Creek, Duncan, British Columbia. Prepared for John Morgan: Vancouver Island University R.M.O.T 306. 32 p.

Danielson K, Van Osch M, Wickham N. 2019. Water quality, microbiology, and invertebrate sampling in Richards Creek, Crofton, BC. Prepared for Dr. Eric Demers: Vancouver Island University RMOT 306. 53 p.

Der T, Govier S, Quist H, Richardson H. 2015. Water quality and stream invertebrate assessment on Richards Creek, North Cowichan (BC). Prepared for Dr. Eric Demers: Vancouver Island University Natural Resource Protection Dept. 30 p.

Dorey M, Haider G, McCabe H, McCubbin H. 2011. Water Quality and stream invertebrate assessment for Richards Creek, BC, (Fall 2022). Prepared for Dr. Eric Demers: Vancouver Island University. 25 p.

George D, Hepp C, Slyfor L. 2016. Annual environmental monitoring program: hydrology, water quality and invertebrate richness or Richards Creek. Prepared for Dr. Eric Demers: Vancouver Island University. 54 p.

Guimond E, and M. Sheng. 2005. A Summary of Water Quality Monitoring in the Somenos Basin 2003-2005. Prepared for the Pacific Salmon Commission by the Department of Fisheries and Oceans. 27 p.

Hargrove O. 2021. RMOT 306: Environmental Monitoring. <https://learn.viu.ca/d2l/le/content/178876/Home> Accessed Dec 8 2021.

Lanarc Consultants Limited. 1999. The Somenos-Quamichan Basin. Department of Fisheries and Oceans. Lake Cowichan, BC. 36 p.

Madrone Environmental Services Limited. 2015. Somenos Basin Coho Salmon Summer Habitat Assessment. Somenos Wildlife Society. Duncan, BC. 14 p.

Ministry of Environment & Climate Change Strategy. 1987. Second Report On Chemical Sensitivity Of BC Lakes To Acidic Inputs. <https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/monitoring-water-quality/second_report_on_chemical_sensitivity_of_bc_lakes_to_acidic_inputs.pdf> Accessed 8 Dec 2021.

Seibert C, Gregory S, Parker L, Demkiw M. 2013. Richards Creek VIU student monitoring program 2013. Prepared for Dr. Eric Demers: Vancouver Island University. 29 p.

Taccogna, G. and K. Munro (eds). 1995. The Streamkeepers Handbook: A Practical Guide to Stream and Wetland Care. Salmonid Enhancement Program, Dept. Fisheries and Oceans, Vancouver, BC.

Resources Information Standards Committee (RISC). 1998. Guidelines for interpreting water quality data. Version 1. <https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp/intrptoc.htm> Accessed on December 8th 2021.

Water, Air and Climate Change Branch Ministry of Water, Land and Air Protection Province of British Columbia. 2003. British Columbia Field Sampling Manual. <http://a100.gov.bc.ca/pub/eirs/finishDownloadDocument.do?subdocumentId=1629> Accessed 11 Dec 2021.

Appendix A

Table A: Invertebrate Survey Field Data Sheet completed for triplicate stream invertebrate samples collected at Site 1.

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Richards creek		Date: Oct 26 2021
Station Name: Station 1		Flow status:
Sampler Used: ~~[illegible]~~ 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 4	EPT4 1
	Mayfly Nymph (EPT)	EPT2 6	EPT5 1
	Stonefly Nymph (EPT)	EPT3 2	EPT6 1
Pollution Intolerant	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny	1	
Sub-Total		C1 13	D1 3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel	1	
	Cranefly Larva	7	2
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva	2	1
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	3	2
	Watersnipe Larva		
Sub-Total		C2 13	D2 5
Category 3	Aquatic Worm (oligochaete)	14	2
	Blackfly Larva	1	1
	Leech		
	Midge Larva (chironomid)	19	2
	Planarian (flatworm)	5	1
Pollution Tolerant	Pouch and Pond Snails	2	
	True Bug Adult	1	
	Water Mite	2	2
Sub-Total		C3 43	D3 8
TOTAL		CT 69	DT 16

Table A: (Continued)

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: CT 69

DENSITY: Invertebrate density per total area sampled.

69 ÷ From page 1 .27 m² = 255.55 / m²

PREDOMINANT TAXON:
Invertebrate group with the highest number counted (in Col. C): S1 Midge larva 18

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 3 + 2 x 5 + 8 = S2 27

EPT INDEX: Total number of EPT taxa

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

EPT4 + EPT5 + EPT6

1 + 1 + 1 = S3 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

(4 + 6 + 2) / 69 = S4 .174

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 16

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

18 / 69 = S5 .261

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	R1 4
EPT Index	R2 2
EPT To Total Ratio	R3 1
Predominant Taxon Ratio	R4 4

Average Rating
Average of R1, R2, R3, R4
2.75

Appendix B

Table B: Invertebrate Survey Field Data Sheet completed for triplicate stream invertebrate samples collected at Site 2

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Richards Creek		Date: Oct 26, 2021
Station Name: Station Site 2		Flow status:
Sampler Used: Hess Sample	Number of replicates: 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates: .27 m²

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	EPT1 ||	EPT4 |
	Mayfly Nymph (EPT)	EPT2 |	EPT5 |
	Stonefly Nymph (EPT)	EPT3 |	EPT6 |
Pollution Intolerant	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		C1 4	D1 3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	卌 |	|
	Crayfish		
Somewhat Pollution Tolerant	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	|||	|
	Watersnipe Larva		
Sub-Total		C2 9	D2 2
Category 3	Aquatic Worm (oligochaete)	卌 |||	||
	Blackfly Larva	|	|
	Leech		
	Midge Larva (chironomid)	|卌|| 卌 卌	||
	Planarian (flatworm)	卌 |	|||
Pollution Tolerant	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		C3 33	D3 8
TOTAL		CT 46	DT 13

Table B: (Continued)

Station 1
Richardscreek

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: CT 69

DENSITY: Invertebrate density per total area sampled.

69 ÷ (From page 1) .27 m^2 = 255.55 / m^2

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

S1 Midge larva 18

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 3 + 2 x 5 + 8 = S2 27

EPT INDEX: Total number of EPT taxa

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

EPT4 + EPT5 + EPT6
1 + 1 + 1 = S3 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
(4 + 6 + 2) / 69 = S4 .179

SECTION 3 - DIVERSITY

TOTAL NUMBER OF TAXA: Total number of taxa from cell **DT**: 16

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
18 / 69 = S5 .261

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	R1 4
EPT Index	R2 2
EPT To Total Ratio	R3 1
Predominant Taxon Ratio	R4 4

Average Rating
Average of R1, R2, R3, R4
2.75

Appendix C

Table C: Invertebrate Survey Field Data Sheet completed for triplicate stream invertebrate samples collected at Site 3

INVERTEBRATE SURVEY FIELD DATA SHEET (Page 1 of 2)

Stream Name: Richards creek		Date: Oct 26 201
Station Name: Station 3		Flow status: /
Sampler Used: Hess	Number of replicates 3	Total area sampled (Hess, Surber = 0.09 m²) x no. replicates 0.27 m²

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1	Caddisfly Larva (EPT)	EPT1 |	EPT4 |
	Mayfly Nymph (EPT)	EPT2 卌 ||	EPT5 |
	Stonefly Nymph (EPT)	EPT3 |	EPT6 /
Pollution Intolerant	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		C1 9	D1 3
Category 2	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva		
Somewhat Pollution Tolerant	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	卌 卌 |||	|||
	Watersnipe Larva		
Sub-Total		C2 13	D2 3
Category 3	Aquatic Worm (oligochaete)	卌 卌 卌	||||
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)	卌 卌 |||	|
Pollution Tolerant	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult	||	||
	Water Mite		
Sub-Total		C3 30	D3 7
TOTAL		CT 52	DT 13

Table C: (Continued)

Richards creek station 3

INVERTEBRATE SURVEY INTERPRETATION SHEET (Page 2 of 2)

SECTION 1 - ABUNDANCE AND DENSITY

ABUNDANCE: Total number of organisms from cell **CT**: CT 52

DENSITY: Invertebrate density per total area sampled:

52 ÷ (From page 1: .27 m² =) 192.6 / m²

PREDOMINANT TAXON:

Invertebrate group with the highest number counted (in Col. C): S1 Aquatic worm 15

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 3 + 2 x 3 + 7 = S2 22

EPT INDEX: Total number of EPT taxa.

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

EPT4 + EPT5 + EPT6: 1 + 1 + 1 = S3 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: (1 + 7 + 1) / 52 = S4 0.17

SECTION 3 - DIVERSITY

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

PREDOMINANT TAXON RATIO INDEX: Number of invertebrate in the **predominant taxon** (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: 22 / 52 = S5 0.42

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	R1 4
EPT Index	R2 2
EPT To Total Ratio	R3 1
Predominant Taxon Ratio	R4 4

Average Rating
Average of R1, R2, R3, R4
2.75

Appendix D

Table D: ALS Analysis from Sampling Event 1

Physical Tests (Matrix: Water)	Lowest Detection Limit	Units	Richards Creek Site 1 26-Oct-2021 11:45 VA21C4104-001 Sub-Matrix: Water	Richards Creek Site 3 26-Oct-2021 10:08 VA21C4104-002 Sub-Matrix: Water	Richards Creek Site 4 26-Oct-2021 10:36 VA21C4104-003 Sub-Matrix: Water	Guidelines
conductivity	2.0	µS/cm	117	172	213	n/a
hardness (as CaCO3), from total Ca/Mg	0.50	mg/L	45.0	60.3	80.9	n/a
pH	0.10	pH units	7.52	7.65	7.21	6.5-9.0
Anions and Nutrients (Matrix: Water)						
ammonia, total (as N)	0.0050	mg/L	0.0068	0.0092	0.0755	8.88
nitrate (as N)	0.0050	mg/L	0.524	0.407	0.0883	<200
nitrite (as N)	0.0010	mg/L	0.0011	<0.0010	0.0062	0.06
nitrogen, total	0.030	mg/L	0.732	0.761	1.04	n/a
phosphate, ortho-, dissolved (as P)	0.0010	mg/L	<0.0010	0.0491	0.0986	<0.01
phosphorus, total	0.0020	mg/L	0.0059	0.0700	0.126	0.005-0.015
Total Metals (Matrix: Water)						
aluminum, total	0.0030	mg/L	0.0857	0.218	0.108	≤0.1
antimony, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	0.02
arsenic, total	0.00010	mg/L	0.00023	0.00042	0.00058	0.006
barium, total	0.00010	mg/L	0.00964	0.0130	0.0193	5.00
beryllium, total	0.000020	mg/L	<0.000020	<0.000020	<0.000020	0.0053
bismuth, total	0.000050	mg/L	<0.000050	<0.000050	<0.000050	
boron, total	0.010	mg/L	0.016	0.018	0.037	1.2
cadmium, total	0.0000050	mg/L	0.0000072	0.0000096	0.0000222	0.00003
calcium, total	0.050	mg/L	14.0	17.4	24.5	
cesium, total	0.000010	mg/L	<0.000010	<0.000010	<0.000010	
chromium, total	0.00050	mg/L	<0.00050	0.00055	0.00053	0.001
cobalt, total	0.00010	mg/L	0.00012	0.00014	0.00038	0.11
copper, total	0.00050	mg/L	0.00131	0.00319	0.00343	0.008
iron, total	0.010	mg/L	0.329	0.380	0.610	1.00
lead, total	0.000050	mg/L	0.000053	0.000081	0.000111	0.031
lithium, total	0.0010	mg/L	<0.0010	<0.0010	<0.0010	0.087
magnesium, total	0.0050	mg/L	2.45	4.10	4.80	
manganese, total	0.00010	mg/L	0.0566	0.0159	0.116	0.71
molybdenum, total	0.000050	mg/L	0.000051	0.000123	0.000270	<2.0
nickel, total	0.00050	mg/L	<0.00050	0.00099	0.00112	0.03

Table D: (Continued)

phosphorus, total	0.050	mg/L	<0.050	0.073	0.164	
potassium, total	0.050	mg/L	0.543	0.961	1.16	373.00
rubidium, total	0.00020	mg/L	0.00068	0.00090	0.00137	
selenium, total	0.000050	mg/L	0.000081	0.000125	0.000119	0.005
silicon, total	0.10	mg/L	4.16	5.85	6.09	
silver, total	0.000010	mg/L	<0.000010	0.000010	<0.000010	<0.001
sodium, total	0.050	mg/L	6.03	8.15	10.0	
strontium, total	0.00020	mg/L	0.0446	0.0741	0.112	
sulfur, total	0.50	mg/L	3.91	6.93	10.3	
tellurium, total	0.00020	mg/L	<0.00020	<0.00020	<0.00020	
thallium, total	0.000010	mg/L	<0.000010	<0.000010	<0.000010	0.0003
thorium, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
tin, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
titanium, total	0.00030	mg/L	0.00451	0.00930	0.00460	2.00
tungsten, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
uranium, total	0.000010	mg/L	<0.000010	0.000016	0.000014	
vanadium, total	0.00050	mg/L	0.00055	0.00138	0.00148	0.006
zinc, total	0.0030	mg/L	<0.0030	<0.0030	0.0043	0.007
zirconium, total	0.00020	mg/L	<0.00020	<0.00020	<0.00020	

Appendix E

Table E: ALS Analysis of Sampling Event 2

Physical Tests (Matrix: Water)	Lowest Detection Limit	Units	Richards Creek Site 1 24-Nov-2021 12:40 VA21C6350-001 Sub-Matrix: Water	Richards Creek Site 2 24-Nov-2021 12:20 VA21C6350-002 Sub-Matrix: Water	Richards Creek Site 3 24-Nov-2021 12:15 VA21C6350-003 Sub-Matrix: Water	Guidelines
conductivity	2.0	µS/cm	79.9	93.7	98.4	n/a
hardness (as CaCO3), from total Ca/Mg	0.50	mg/L	28.0	34.1	35.2	n/a
pH	0.10	pH units	7.19	7.30	7.32	6.5-9.0
Anions and Nutrients (Matrix: Water)						
ammonia, total (as N)	0.0050	mg/L	0.0137	0.0121	0.0115	8.88
nitrate (as N)	0.0050	mg/L	0.277	0.319	0.361	<200
nitrite (as N)	0.0010	mg/L	<0.0010	<0.0010	<0.0010	0.06
nitrogen, total	0.030	mg/L	0.465	0.652	0.586	n/a
phosphate, ortho-, dissolved (as P)	0.0010	mg/L	0.0014	0.0020	0.0074	<0.01
phosphorus, total	0.0020	mg/L	0.0101	0.0374	0.0211	0.005-0.015
Total Metals (Matrix: Water)						
aluminum, total	0.0030	mg/L	0.184	1.04	0.353	≤0.1
antimony, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	0.02
arsenic, total	0.00010	mg/L	0.00017	0.00048	0.00029	0.006
barium, total	0.00010	mg/L	0.00818	0.0168	0.0110	5.00
beryllium, total	0.000020	mg/L	<0.000020	<0.000020	<0.000020	0.0053
bismuth, total	0.000050	mg/L	<0.000050	<0.000050	<0.000050	
boron, total	0.010	mg/L	0.011	0.012	0.012	1.2
cadmium, total	0.0000050	mg/L	0.0000080	0.0000290	0.0000102	0.00003
calcium, total	0.050	mg/L	8.77	10.6	10.9	
cesium, total	0.000010	mg/L	<0.000010	0.000042	0.000013	
chromium, total	0.00050	mg/L	<0.00050	0.00180	0.00067	0.001
cobalt, total	0.00010	mg/L	0.00014	0.00059	0.00023	0.11
copper, total	0.00050	mg/L	0.00174	0.00514	0.00332	0.008
iron, total	0.010	mg/L	0.233	1.18	0.409	1.00
lead, total	0.000050	mg/L	0.000070	0.000381	0.000132	0.031
lithium, total	0.0010	mg/L	<0.0010	<0.0010	<0.0010	0.087
magnesium, total	0.0050	mg/L	1.47	1.85	1.95	
manganese, total	0.00010	mg/L	0.0359	0.0591	0.0229	0.71
molybdenum, total	0.000050	mg/L	0.000052	0.000163	0.000129	<2.0
nickel, total	0.00050	mg/L	<0.00050	0.00197	0.00102	0.03

Table E: (Continued)

phosphorus, total	0.050	mg/L	<0.050	<0.050	<0.050	
potassium, total	0.050	mg/L	0.374	0.476	0.499	373.00
rubidium, total	0.00020	mg/L	0.00048	0.00084	0.00052	
selenium, total	0.000050	mg/L	<0.000050	0.000103	0.000120	0.005
silicon, total	0.10	mg/L	4.26	5.87	5.19	
silver, total	0.000010	mg/L	<0.000010	0.000012	<0.000010	<0.001
sodium, total	0.050	mg/L	4.06	4.75	4.76	
strontium, total	0.00020	mg/L	0.0270	0.0332	0.0379	
sulfur, total	0.50	mg/L	2.59	3.56	3.39	
tellurium, total	0.00020	mg/L	<0.00020	<0.00020	<0.00020	
thallium, total	0.000010	mg/L	<0.000010	<0.000010	<0.000010	0.0003
thorium, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
tin, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
titanium, total	0.00030	mg/L	0.00820	0.0475	0.0155	2.00
tungsten, total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	
uranium, total	0.000010	mg/L	<0.000010	0.000045	0.000018	
vanadium, total	0.00050	mg/L	0.00077	0.00351	0.00154	0.006
zinc, total	0.0030	mg/L	<0.0030	0.0049	<0.0030	<0.007
zirconium, total	0.00020	mg/L	<0.00020	<0.00020	<0.00020	

Appendix F

Photo of Sample Site 1, Escarpment Way, October 26th, 2021

Photo of Sample Site 2, Rice Road. October 26th, 2021

Photo of Sample Site 3, Richards Road. October 26th, 2021

Photo of Sample Site 3, Richards Road. October 26th, 2021

Photo of Sample Site 4, Herd Road. October 26th, 2021

Photo of Sample Site 1, Escarpment Way. October 26th, 2021