Water Quality & Stream Invertebrate Analysis for Beck Creek, Nanaimo, BC

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Report Submitted to:

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RMOT 306: Environmental Monitoring

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Executive Summary

This document is the compiled findings of an annual assessment on Beck Creek, located south of Nanaimo near Chase Creek in Nanaimo, BC. Two sampling events and multiple site visits took place from October 17th- November 26th with the purpose of data collection to establish long term trends as well to assess the overall health of the creek and surrounding catchment. During two separate sampling events tests including water quality, hydrology and stream invertebrates were conducted. The information that was gathered from both the sampling events and general site visits were analyzed in the field where appropriate, and at the VIU and ALS laboratory. Invertebrate density and relative abundance were analyzed between sampling sites. A greater diversity in species was recorded for the second sampling event, including a greater abundance in category 1 and 2 pollution-tolerant species. When comparing the averaged results of all sites between sampling events dissolved oxygen & conductivity had an increase of 37% and 18%, whereas temperature and pH decreased marginally showing no clear trend with position on stream and minimal variation between sites. Conductivity and dissolved oxygen concentrations were inversely related traveling downstream as expected. Hydrological data collected from sites 1, 2 & 3 showed increased water velocity consistent with the observed increase in water volume from high amounts of precipitation events between samplings. Blocked culvers of sites 1, 2 and 3 resulted in noticeable obstacles on flow patterns; additionally, they cause considerable disruptions in the migration paths for salmonid species. Increased agricultural/ anthropogenic input of nutrients, littering/garbage dumping and altered hydrology (flow patterns), currently pose considerable threat and have already resulted in some degree of degradation to the creek and surrounding environment. Remediation and restoration of bank integrity, substrate quality and removal of debris/litter would greatly benefit the overall health and stability of Beck Creek.

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1.0 INTRODUCTION

1.1 Project Overview

This document is the compiled findings of an annual assessment on Beck Creek, located south of Nanaimo near Chase Creek. Under the supervision of Dr.Phillip Morrison, 3 environmental monitoring students from Vancouver Island University have conducted a water quality and stream invertebrate analysis to continue monitoring the effects of environmental and anthropogenic activities on Beck Creek water course. Two sampling events took place between October 17th - November 26th, 2023. Sampling over two time periods allows better insight into potential flow rates and differing environmental conditions influencing the creek biota. Beck Creek acts as a potential spawning site to Coho Salmon (*Oncorhynchus kisutch*) and Chum Salmon (*Oncorhynchus keta*). Water quality and invertebrate monitoring has progressed annually from 2017-2020 and 2022-present day. The continuation of monitoring and assessment of Beck Creek will provide vital insight into potential agricultural impacts and impacts of development and land use influencing the surrounding watershed.

1.2 Background

1.2.1 Historical Review

Beck Creek, originally known as Hong Kong Creek, is one of four contributors of drainage into the west side of the Nanaimo River estuary along Maki Road (O'Regan et al. 2021). The creek has a total drainage area of 6.7 km^2 (Cook and Baldwin 1994). Flowing from Beck Lake the creek lines both agricultural and industrial land. The upper 600m of the creek flows parallel to agricultural land on the left bank and residential neighbourhoods on the right bank. In the 1900s, at least six coal mines were active within the watershed, with several adjacent to the stream along the Pacific railway. During this period there were multiple mineshaft explosions and floods that likely introduced contaminants into Beck Creek (Sifton et al. 2021). From 1995-1997 the Cedar Road Flyover was constructed to connect the Island Highway to the Nanaimo Parkway (Hwy 19) (Redlin et al. 1992). The construction of the off-ramp diverted the stream through several pipes and eventually underneath the Trans-Canada alignment through a 3 m culvert. This project was carried out with the consideration of the stream and was meant to allow uninterrupted passage of fish and enchanted spawning grounds. Additionally, gravel and boulders were added to the culvert to mimic natural habitat and about 2,000 fish were relocated during construction (Redlin et al. 1992). The increasing anthropogenic influence on the creek and surrounding habitat is a key element in the importance of continual monitoring, as the creek provides residence to local trout populations and is a spawning ground for local salmon populations.

In some years a beaver dam, historically found ~900 m above the Island Highway culvert, forms an impassable blockade for migrating salmon (Irvine et al. 1994). However, with high flow rates and flooding periods, the dam can be washed away, potentially allowing for migration events along the entire length of Beck Creek (Irvine et al. 1994). Roughly a 4-mile stretch upstream from the Nanaimo estuary is accessible to androgynous salmon species as spawning grounds (Aquatic Report Catalog, Accessed Oct 5, 2023). A presumably well-defined cutthroat run in fall and winter, resulting from a February spawning period leads to a congregation of juvenile cutthroat observed above the Island Highway. Halting the upstream progression of coho juveniles relatively near or just beyond where the creek flows underneath the Nanaimo parkway (Burns 1970). As a result of periodic heavy flow throughout the years large quantities of gravel have been washed downstream and deposited pools, predominantly seen at site 3, forming barriers for migrations; Further deteriorating the quality of spawning grounds for migrating salmonids. In July of 2012, 26 tons of custom mixed gravel was placed in Beck Creek channel, by The Harbour City River Stewards, to refresh the spawning grounds of migrating salmon (Nanaimo News Bulletin, 2012).

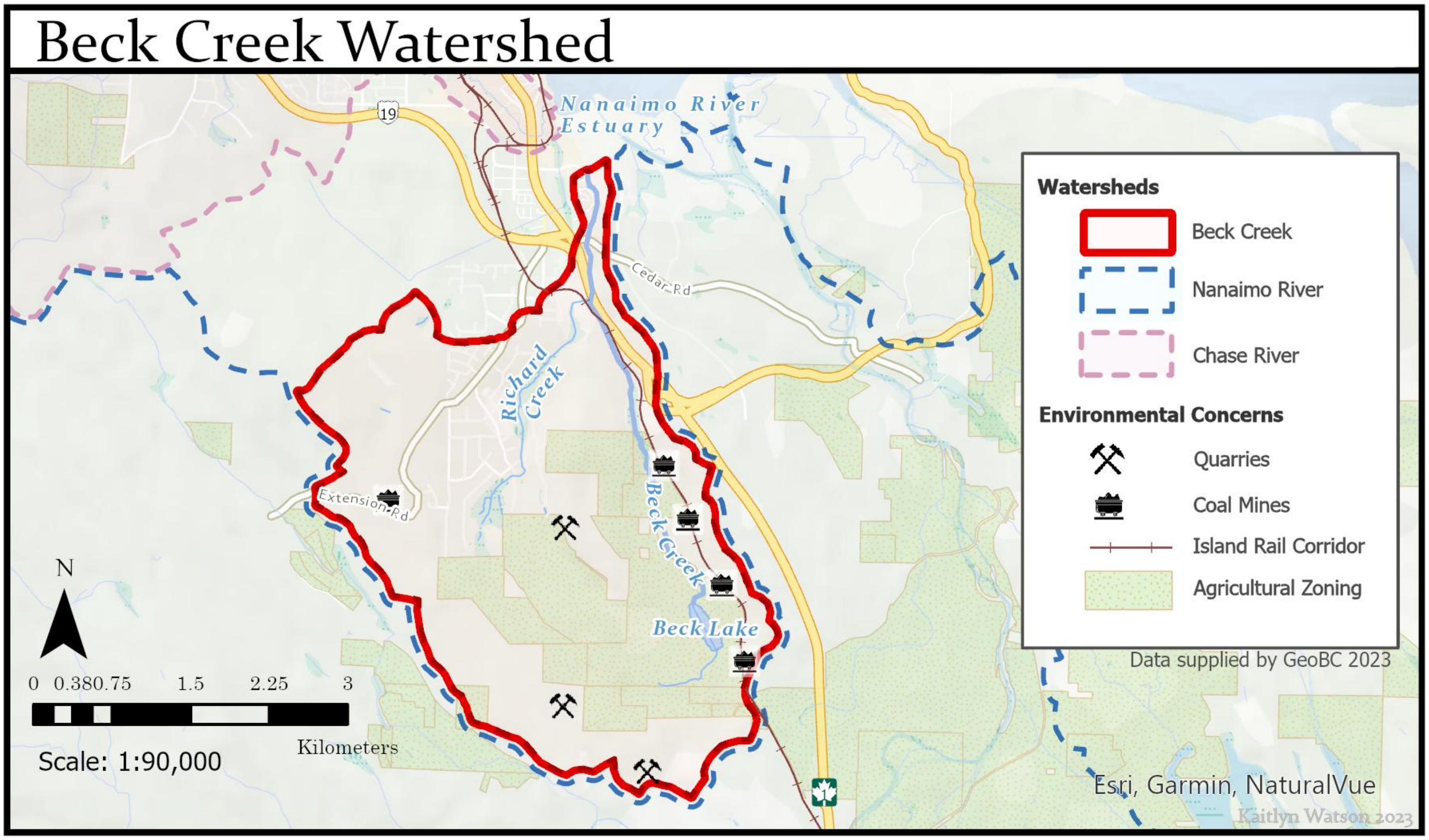

Figure 1: Beck Creek Watershed. Scale 1:90,000. Data layers: Freshwater Atlas (GeoBC 2023a), Nanaimo coal mines map (Sifton et al. 2021), Notice of Work (NoW) Spatial Locations (Government of British Columbia 2022), ALC Agricultural Land Reserve Lines (Hazaparu and Lambert 2020) [computer files]. Vancouver Island University BC: generated by Kaitlyn Watson, November 2023. Using ArcGIS Pro 3.1 [GIS].

1.2.3 Potential Environmental Concerns

Beck Creek's watershed encompasses a considerable region of agriculture, a growing residential area and industrial zoning. Beck Lake is enclosed within an agricultural area which can be a source of nutrient enrichment and increased stream temperatures due to the reduction of canopy cover. This leads to concern regarding the potential for harmful algal blooms and reduced dissolved oxygen (B.C. Ministry of Environment and Climate Change Strategy 2021). The mid-low sections of the stream are encompassed within a semi-urban area. This may cause more harm to the stream biota due to flow alterations, and the introduction of road salts and other contaminants (Waite et al. 2020). The stream’s flow has also been altered by a series of culverts running through the residential areas, underneath the Island Highway (Hwy 1) and the Island Railway (Figure 1). The resulting culverts force the stream to straighten and narrow in parts, altering numerous morphometric and environmental variables such as sediment transport, water velocity, gradient, and bank stability (Richardson et al. 2001). Additionally; the culverts are at risk of being blocked by debris; further altering habitats and restricting migration paths.

Climatic variables may be some of the biggest concerns for this stream and likely influence our results (Lawrence et al. 2010, Reynolds et al. 2015). The summer of 2023 preceding this project had above-average temperatures and low precipitation. The drought conditions for eastern Vancouver Island began in early June and increased to stage 5 starting in July, continuing until September. Lesser drought conditions continued until the end of October (GeoBC 2023b). To our knowledge, the drought level of the Beck Creek watershed is not directly recorded, however, nearby; the Millstone River watershed remained at drought level 2 until the end of November (GeoBC 2023c). Beck Creek is particularly vulnerable to drought conditions due to its small catchment area (Reynolds et al. 2015), making it susceptible to limited flow continuing into the fall.

Figure 2: Aerial view of Beck Creek sampling site 3 flowing adjacent to Island Highway 1 and 19 south end of Nanaimo parkway. Source; Walker K. 2010. Ramp between Highway 1 and Highway 19 at the south end of the Nanaimo Parkway. Available from: https://commons.wikimedia.org/wiki/File:CR_exit_Nanaimo.jpg.

1.3 Project Objectives

The objective of assessing Beck Creek in Nanaimo, BC is to understand the overall health and environmental conditions of this creek by measuring water quality parameters and collecting stream invertebrate samples. The findings will be available to compare with previous projects submitted by past VIU students who participated in RMOT 306-Environmental Monitoring. The water samples will be collected from 4 sites within the Beck Creek Watershed (Figure 1). Water samples will also be sent to ALS (Australian Laboratory Services) in Vancouver, BC. From these sites, we will test for water quality and stream invertebrates to help determine creek health. The water samples will be analyzed by the students assigned to Beck Creek at VIU and the results and summary will be provided in the following report.

2.0 METHODS

2.1 Sampling Program

2.1.1 Sampling Frequency

Table 1: Dates of Sampling Events.

Session	Measurements	Date
1	Water Quality (VIU & ALS)	October 24
	Field Measurements, Hydrology & Invertebrate Sampling	November 2
2	Water Quality (VIU & ALS)	November 21
	Field Measurements, Hydrology & Invertebrate Sampling	November 26

2.1.2 Locations

Beck Creek has been accessed by VIU students in the years 2018-2020 and 2022. To contribute to the continuity of this long-term monitoring program we have chosen our monitoring sites with reference to previous years. Sites 2-4 were surveyed in previous years (± ~50m), while site 1 was examined in 2022 and 2020. Our chosen sites cover the three strata described by Irvine et al. (1994). Sites 1 & 2 are within the U (upper) stratum upstream of where Richards Creek joins Beck Creek. Site 2 is within the lower portion of the M stratum; between the Island Highway and Cedar Road and Site 4 is in the lower stratum (L); approaching the tidal mudflats. We conducted site assessments and selection on October 4th, 2023 to evaluate stream conditions, riparian area vegetation and substrate composition (Table 2).

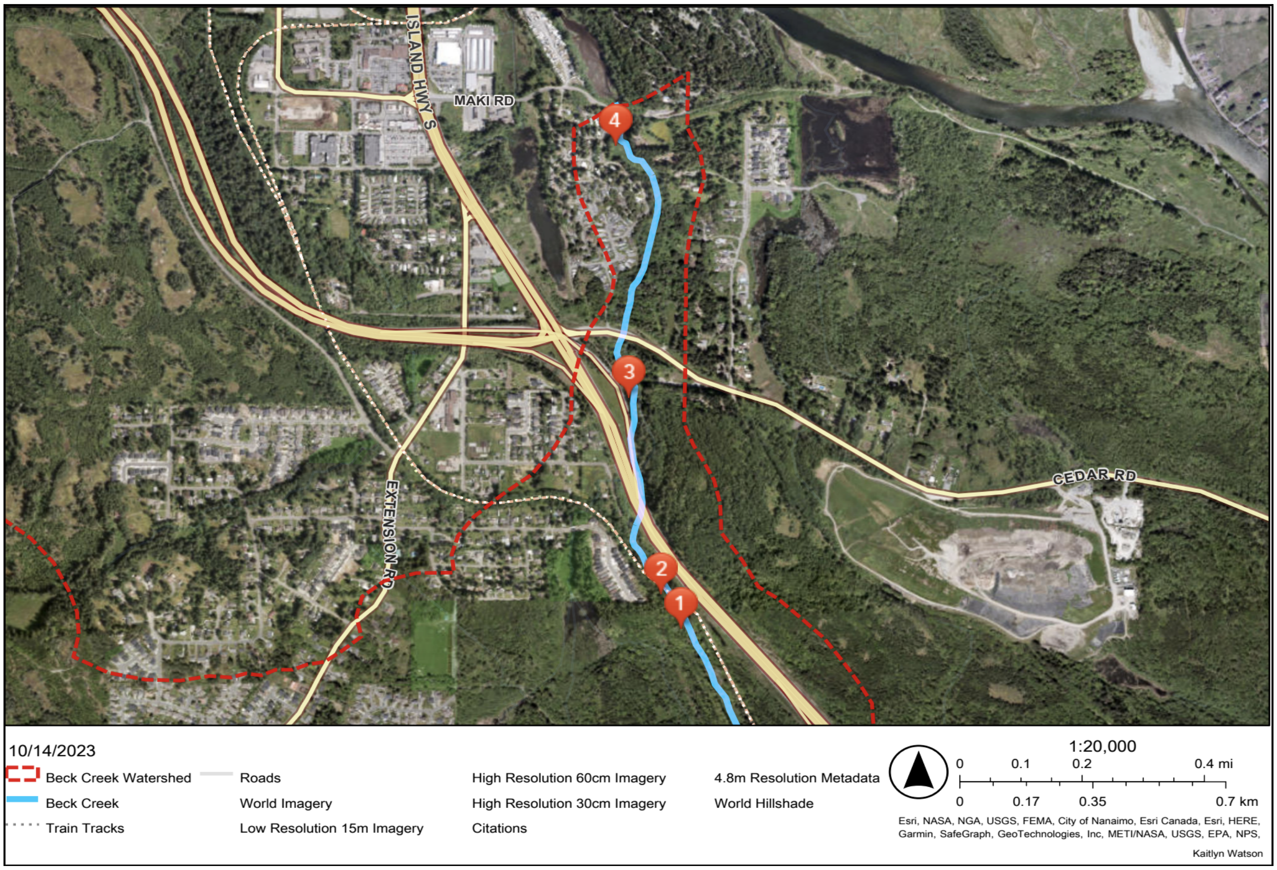

Figure 3: Sampling Locations for Beck Creek 2023. Scale 1:20,000. Data layers: Freshwater Atlas (GeoBC 2023a). Vancouver Island University BC: generated by Kaitlyn Watson, October 2023. Using ArcGIS Online [GIS].

Site #1 (UTM 10U 433443mE 5440924mN) is located upstream (west) of the culvert diverting the stream underneath the Vancouver Island rail line, approximately 3 km from Beck Lake. The site is about 60 meters from the Island Highway but is more accessible by following the train tracks from the end of Frames Road in Chase River. The site includes a pool flowing through a narrow section where woody debris creates a blockage, accompanied by an abrupt ~1 ft elevation drop and a short ~1 m-long riffle (Appendix 1). This obstruction leads to a reduction of flow into the lower shallow pool that precedes the culvert (Appendix 2).

Invertebrate sampling occurred in the 1 m riffle below the obstruction and in the pool just upstream. Water samples for laboratory analysis were collected from the lower pool, described in Table 2.

Site #2 (UTM 10U 433390mE 5441026mN) is located approximately 300 meters downstream of site 1. Sampling took place about 30m downstream of the culvert underneath the rail line (Appendix 3). The site is roughly 50 meters from the Island Highway, but like Site 1, it remains concealed by steep slopes and a stand of coniferous trees. Site 2 is characterized by entire riffles, primarily resulting from the stream narrowing and a steeper gradient. The same culvert at the downstream end of Site 1 is about 30 meters upstream of this site, with a large dead tree obstructing the smaller of the twin culverts. The tree was seemingly responsible for the accumulation of suds on the water's surface (Appendix 4).

Site #3, located in a forested area between the Highway 19 off-ramp and Cedar Road (UTM 10U 43331mE 5441595mN), is frequently evaluated primarily for its role as a spawning ground (Fukui 2022). Large substrate has additionally been introduced in this area to enhance the site's suitability for spawning (Nanaimo News Bulletin 2012 and Redlin et al. 1992). The construction of the off-ramp resulted in the site being situated in a deep depression, creating steep slopes in the riparian area. The culvert's flow forms a substantial deep pool, transitioning into riffles and depositing a cobble point bar (Appendix 5). Invertebrate samples were collected from the riffle habitat, while water samples were collected directly from the culvert outflow.

Site #4 (UTM 10U 433286mE 5442324mN) is located at the mouth of the stream as it enters the Nanaimo River Estuary through a culvert underneath Maki Rd. As the stream approaches the Estuary, the stream embankment widens and slows, creating a large pool (Appendix 6). Upstream of this site is a cattail

(*Typhaceae* spp.) marsh. Canopy coverage was thin overall, due to the width of the stream and the adjacent road; yet the presence of Bigleaf Maple (Acer *macrophyllum*), created an abundance of leaf litter.

2.1.3 Habitat Characteristics

Table 2: Summary of Habitat Characteristics for Water Sampling Locations October 4th 2023. Substrate percentages were visually estimated from shore using a simplified Krumbein phi scale where Boulder >256mm, Cobble 64-256mm, and Gravels 64-2mm. Substrate <2mm (Sand/Silt) are expected to make up the remaining percentages. Canopy Coverage was estimated using the Canopeo phone application. Gradient was estimated visually.

Site	**Dominant Habitat**	**Substrate Composition**	**Gradient (degrees)**	**Canopy (%)**	**Riparian Zone Vegetation**
1	Pool, Small Riffle	Cobbles >10% Gravels >15% Fine (Organic Silt) LWD	<1	<u>Coverage 70-80%</u> -Western Red Cedar (Thuja *plicata)* -Douglas Fir (Pseudotsuga *menziesii*)	-Sword Ferns (Polystichum *munitum*) -Bracken Ferns (Pteridium spp.) -Sedges (Cyperaceae spp.)
2	Riffles	Boulders <5% Cobbles < 40% Gravel >55% Fine	<5	<u>Coverage 70-80%</u> -Western Red Cedar (Thuja *plicata*) -Douglas Fir (Pseudotsuga *menziesii*)	-Sword Ferns (Polystichum *munitum*) -Bracken Ferns (Pteridium spp.) -Horsetails (Equisetum spp.)
3	Riffles, Pool	Boulders <5% Cobbles <50% Fine LWD	<5	<u>Coverage 80-90%</u> -Western Red Cedar (Thuja *plicata*) -Douglas Fir (Pseudotsuga *menziesii*) -Bigleaf Maple (A.*macrophyllum*)	-Sword Ferns (Polystichum *munitum*) -Bracken Ferns (Pteridium spp.)
4	Pool	Boulders <5% Cobbles >15% Gravels >10% Fine (Organic Silt) LWD	<1	<u>Coverage 5-10%</u> -Western Red Cedar (Thuja *plicata*) -Douglas Fir (Pseudotsuga *menziesii*) -Bigleaf Maple (A.*macrophyllum*)	-Ocean Spray (Holodiscus *discolor*) -Thimbleberry (Rubus *parviflorus*) -Daphne (Daphne *leorola*) -Sedges (Cyperaceae spp.)

*LWD = Large Woody Debris

2.2 Basic Hydrology

At all four sample sites, hydrology measurements were gathered. These measurements included: velocity, bankfull width, wetted width, wetted depth, and pool depth. Due to site access, substrate, and habitat types, some modifications to what measurements were recorded were made. The details of the hydrology parameters are outlined in detail in the results/discussion section. The surrounding riparian area to a stream plays a role in stream hydrology, therefore additional environmental features were recorded to supplement the hydrology parameters. This included the canopy cover percentage, riparian zone vegetation, substrate composition, and gradient. The combined habitat and hydrology provide an assessment of the overall health of the stream's habitat.

2.3 Water Quality

2.3.1 Field Measurements

During each invertebrate sampling period; electronic probes were used to measure pH, conductivity (μS/cm), temperature (C°), and dissolved oxygen (mg/L) near where invertebrate sampling took place. Oxygen saturation was not directly recorded but was converted using an online calculator for comparison purposes (U of MN Natural Resources Research Institute 2015); standardized to 1 atm and 0 m elevation.

2.3.2 Water Sample Collection

Water samples were collected from each site on October 24th and November 21st. For VIU analysis a single 1 L sample was taken from each site, in addition to a field blank (distilled water sample) which was filled and brought into the field at one of the four sites. An additional three samples were collected from Sites 2 and 3 during each sampling period, for third-party analysis. The three additional samples consisted of one bottle with no additive, one buffered with nitric acid, and the third buffered with sulphuric acid. Water samples were refrigerated within a few hours of collection and transported in coolers.

2.3.3 VIU Laboratory Analyses

Water samples were analyzed at the VIU laboratory within 48 hours of collection. HACH spectrometry was used to measure Nitrate (mg/L NO_3), phosphate concentration (mg/L PO_4^{3-}), and turbidity (NTU). Total hardness (mg/L $CaCO_3$) and alkalinity (mg/L $CaCO_3$) were found using HACH digital titration. Electronic probes were used to measure conductivity (μS/cm) and pH.

2.3.4 ALS Laboratory Analyses

Water samples collected from sites 2 and 3 were sent to ALS Laboratories, a private analytical lab located in Vancouver, BC. A total of 12 water samples (3 per site per sampling session) were collected over both the October and November sampling dates (Table 1). ALS provided more comprehensive water quality measurements including nutrient and heavy metal concentrations.

2.3.5 Quality Assurance / Quality Control

The Ambient Freshwater and Effluent Sampling Manual provided by the BC Government was used as a guide for sample collection. The manual provides comprehensive procedures for quality assurance/control, sample collection and preservation, field measurement, and equipment management. These measures include rinsing sampling bottles 3 times before collecting the final sample and avoiding cross-contamination between prepared sample bottles. Additionally, samples were collected from the same area at each site on both visits to ensure consistency of results.

2.3.6 Data Analyses, Comparison to Guidelines

Water quality parameters were compared to the most recent provincial guidelines for freshwater aquatic life. (B.C. and Ministry of Environment and Climate Change Strategy [B.ENV] 2023).

2.4 Stream Invertebrate Communities

2.4.4 Sample collection procedures -Moriah

Sites 2 and 3 were sampled in an identical method as both areas had similar substrate composition and aquatic habitat units that included a mixture of small riffles and glides. Some modifications to the sampling procedure were made for sites 1 and 4 due to accessibility. the fine sediment composition and pool habitats. Modifications to the sorting and storing procedures had to be made between the two sampling events due to shared equipment availability combined with lab availability.

For each sample event, the designated crew member would enter the water from the bank and take some steps upstream to ensure the sample area was not disturbed before the collection process. The rim of the Hess sampler would then be pushed down into the substrate until there were no gaps for invertebrates to escape. The net would be checked to make sure water flowed and there were no twists before proceeding. As per the streamkeeper's procedure, we scraped and removed large rocks and disturbed the substrate within the sampled area. Before repeating the procedure at the next site, crew members would thoroughly rinse the net and plankton trap and empty the contents into a tray or jar.

The collection procedure described above remained the same between the two sessions but the sorting and storing procedures were changed. During the first sampling session on October 24th, 2023, the 3 sample collections from the 4 sites were sorted through immediately at the site. This was done by carefully separating live inverts from organic material using tweezers and pipettes. Once the full sample was sorted through and inverts were gathered in a sample container, 70% ethanol was added to preserve the samples for 2 days before identification in the lab. During the second sampling session on November 25th, 2023, all samples were transferred directly into jars without separating organic debris. There was no ethanol available, therefore samples were refrigerated for 3 days before the lab was open for sorting. Invertebrate identification and counts were conducted at Vancouver Island University using dissection microscopes, following the Streamkeepers Module 4 (Taccogna and Munro 1995) guidelines for sorting into broad groups.

2.4.4 Data Analysis

To evaluate site health, we categorized each taxon into one of three pollution tolerance categories: Pollution Intolerant (1), Somewhat Pollution Tolerant (2), and Pollution Tolerant (3). The Pollution Tolerance Index was calculated based on the number of taxa in each category, with a higher weight given to more pollution-sensitive taxa. Within the pollution-intolerant group, mayflies, stoneflies, and caddisflies were further classified as EPT (Ephemeroptera, Plecoptera, and Trichoptera) species. EPT species, recognized for their sensitivity to environmental disturbances (Ab Hamid and Md Rawi 2017), were used to calculate the EPT and EPT to Total Ratio Indices. The overall site rating was established by assigning ratings from 1 (poor) to 4 (good) to Pollution Tolerance, EPT, EPT to Total Ratio, and Predominant Taxon Ratio Indices, according to guidelines from the Streamkeepers manual (Taccogna and Munro 1995). The average rating of these indices provided an overall site assessment rating.

To further quantify species diversity and equality, we computed the Shannon-Weiner Diversity Index (H) (equation 1) and the Shannon Equitability Index (E_H) (equation 2) for each site. The Shannon-Weiner Diversity Index is a widely used ecological metric because it considers both richness and diversity (Agrawal and Gopal 2012). Evenness was specifically assessed by the Shannon Equitability Index (EH), which ranges from 0 to 1, with 1 representing complete equality.

1) $H = -\sum_{i=1}^{S}(p_i \times \ln p_i)$

2) $E_H = \frac{H}{\ln S}$

Where: S =Total number of taxa, p_i =proportion of taxon i

3.0 RESULTS AND DISCUSSION

3.1 Hydrology

Basic hydrology measurements were recorded from sites 4,3,2,1 in that order to work our way upstream. Measurements were collected on November 2, 2023 and November 26th, 2023. Some modifications to the sampling process were made for safety and accessibility reasons at site 4 and site 1. Reaches within the sites were not determined however we did ensure that measurements were taken that included major characteristics of each site including habitat type (pool/riffle/glide), substrate, surrounding vegetation, and discharge. Precipitation was additionally observed throughout this project. Hydrological data collected from sites 1,2 & 3 showed increased water velocity consistent with the observed increase in water volume from high amounts of precipitation events between samplings (Figure 4).

The following field measurements are descriptions from site 3 and site 2. Velocity was measured by using a ping-pong ball and a stopwatch. One crew member stood downstream to catch the ball while another crew member stood 6.5m upstream with the ball and a timer. The crew members were in eyesight and earshot of each other to ensure there would be good communication to accurately record the times. The ball would be dropped three times, once near the right bank, the left bank, and the middle of the stream. The times were then averaged to give the sited velocity in m/sec. Bankfull width (Wb) and Wetted width (Ww) were recorded using a measuring tape (m) between two crew members on each side of the stream. Wetted depth (cm) was then measured at the .25 mark, .5 mark, and .75 mark along the wetted width line and calculating the average.

Site 4 velocity could not be recorded as the habitat was a pool with deep fine sediment that you could not wade through and there was no observable flow when we attempted the ping-pong ball method. We considered recording the discharge rate from the culvert at the site however after assessing the risk amongst the group it was unsafe due to the size, flow, and depth. Due to accessibility issues, bankfull width and Wetted width could not be recorded. Maximum pool depth (Dmax) was recorded by measuring the depth at three different points within the pool and calculating the average. Site 1 velocity was recorded by using the pipe/culvert discharge method. There was no culvert, however, there was a narrow step between the pool and slow glide. This measurement was taken by timing how long it took to fill a container from the steps discharge. The process was repeated 3 times and then averaged. The Bankfull width was recorded in the same way as sites 3 and 2 and the pool's depth was taken in the same way as site 4. Hydrology measurements can be viewed in Table 3.

Table 3: Hydrology data collected during sampling events in November 2023.

Date	***Hydrology Element***	***Site 1***	***Site 2***	***Site 3***	***Site 4***
November 2nd	Surface velocity (m/s)	N/R	3.44	1.39	N/R
	Bankfull width (m)	6.24	4.07	6.5	N/A
	Wetted width (m)	N/R	N/R	N/R	N/R
	Mean Water Depth (cm)	N/R	N/R	N/R	N/R
November 26th	Surface velocity (m/s)	2.74	8.61	2.7	N/R
	Bankfull width (m)	14.9	4.8	5.9	N/A
	Wetted width (m)	11.45	15.7	5.85	N/R
	Mean Water depth (cm)	81.7	15.7	14	74.7

N/R- Not Recorded

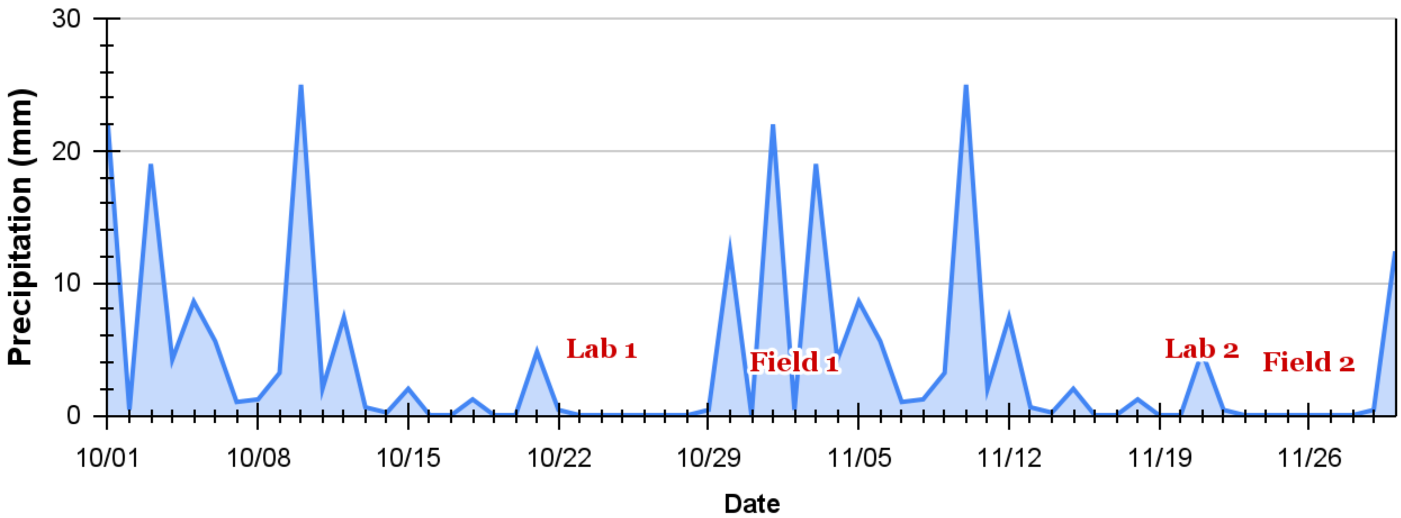

Figure 4: Precipitation preceding sampling events. Source: Environment and Climate Change Canada 2023

3.2 Water Quality

3.2.1 Field Measurements

We recorded basic water quality parameters during each invertebrate sampling event; near where invertebrate samples were collected. Collected data is available in Appendix 7.

3.2.1.1 Water Temperature

Temperature within the stream ranged from 8.6 to 9.6 °C during the first sampling session, with an average of 9.05 °C. Water temperature was an average of 3.0 degrees lower during the second sampling session (SD±0.51). The temperature decline was greatest at Sites 2 and 3 with declines of 3.2 and 3.6 °C respectively. In contrast, the temperature at sites 1 & 4 dropped by only 2.9 and 2.4 °C. Differences in water surface temperature within the stream are likely a consequence of differences in the riparian zones (Table 2), as opposed to position on the stream (Figure 4). Canopy coverage was thicker at sites 2 & 3 where field measurements were recorded and therefore the sites would be more buffered from temperature fluctuations.

3.2.1.2 Dissolved Oxygen

Reduced temperatures undoubtedly contributed to the 2.85 mg/L (SD±0.71) average increase in dissolved oxygen (DO) concentration between the sampling periods. During the first sampling session, the mean DO was 7.8 mg/L (SD ±1.1) (~68% saturation) compared to 10.65 mg/L (SD ±1.6) (~85% saturation) in the following session. In addition to being correlated with temperature, DO concentrations are influenced by turbulence, photosynthetic activity, and biological oxygen demand (Blaszczak et al. 2019). Furthermore, figure 3 shows a clear trend of increasing DO concentrations from upstream to downstream. This trend was apparent in both sampling periods, with site 4 having a 2.5 mg/L higher concentration than site 1 in the first session and 3.2 mg/L higher in the second session. These findings are promising and indicate that stream modifications in the lower 2 strata are not severely limiting productivity, which is a common side effect of channel modifications (Blaszczak et al. 2019). The lowest concentration was at site 1 during the first visit; where we recorded a concentration of 6.4 mg/L. This was within BC guidelines and would be sufficient for most aquatic species (B.ENV 2023). However, this corresponded to only 56% saturation; and may approach dangerously low concentrations in the warmer months, as has been reported in the lower stream by O'Regan and Forge (2021).

3.2.1.3 In-Field Conductivity

Conductivity showed the opposite spatial trend to DO; with values decreasing downstream during both sampling periods (Figure 3), likely due to dissolution. In-situ measurements revealed an average conductivity of 290.8 µS/cm (SD ±57.5) in the first session and 344.8 µS/cm (SD ±87.6) in the second session. It is unusual for conductivity to increase later in the fall considering decreased temperatures and increased flow both lower conductivity (Fukui 2022). However, Figure 4 shows that the 2nd field measurements were recorded following 2 weeks of relatively little rain.

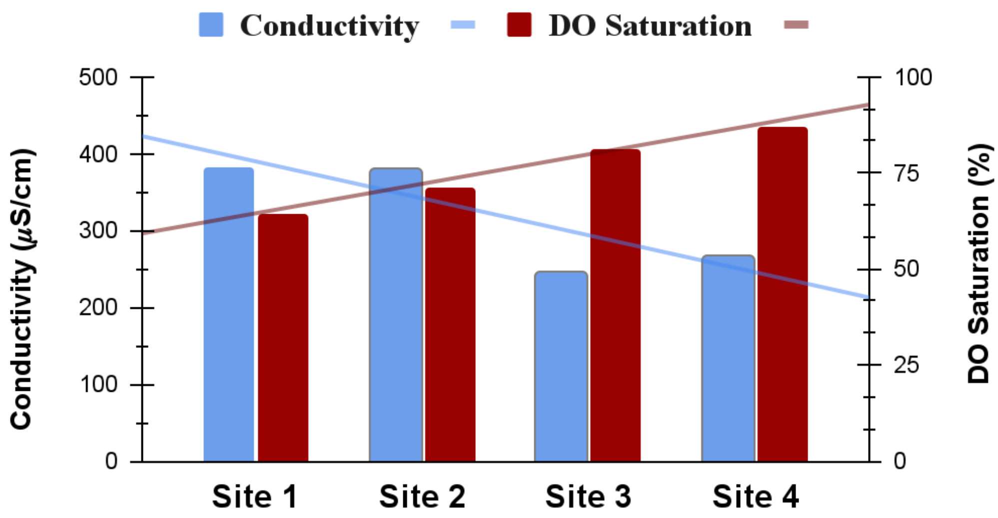

Figure 5: Conductivity and Dissolved Oxygen (DO) Saturation Spatial Trends. Measurements for each site were averaged between both sampling dates. Linear trendlines show that there was a strong correlation between stream position and both DO (%) and conductivity.

3.2.1.3 In-Field pH

In the field, pH readings averaged 7.8 (SD ±0.35) during the first visit and 7.45 (SD ±0.26) during the second visit. According to provincial and federal guidelines, these values fall within the acceptable range and are comparable to average readings for water bodies in the Nanaimo lowland area (mean = 7.6, n = 39, STD.DEV. = 0.8) (McKean and Nagpal 2021). Our readings were found to be slightly higher than has previously been found at Beck Creek with the average pH during 'fall flush' previously being recorded as 7.226 (Fukui 2022). During the second sampling session, field pH readings were, on average, 0.3 units lower (SD ±0.29).

3.2.2 VIU Laboratory Analyses

Laboratory analysis of basic water quality parameters was conducted at Vancouver Island University, Nanaimo campus. Water samples collected from all four sampling sites as well as an additional field blank were transported to VIU laboratory within 24-48 hours post-sampling.

Conductivity showed little variation between sampling events at sites 1 & 2, with an average of 1.4-2.4 percent difference. Comparatively, sites 3 & 4 showed a significant decrease in conductivity between sampling events with averages of -34.4 and -43.3 percent difference (Figure 6). Conductivity was lower than previous studies that found an average of 500 µs/cm (Plews et al. 2018).

Turbidity is an optical characteristic of water measuring the quantity of light scattered by suspended solids present (USGS 2023)(Water Science School 2018b). Turbidity is a valuable parameter for water quality as increased turbidity can be associated with increased bacterial activity/abundance, as well as adverse effects on the respiratory structures of aquatic animals. Beck Creek remained within the provincial guidelines as no change from background of 5 NTU (when background is ≤50 NTU) was recorded. Sample sites 1, 2 and 4 show increases in turbidity between samplings, with the exception of site 3 where a decrease of 1.2 NTU was recorded. Beck Creek at Cedar Road has been shown to exceed 2NTU in previous years (Ecoscape 2021). Fall turbidity has been shown to be positively correlated with rainfall in Beck Creek (2018), a negative association with conductivity due to dilution. (Done at Cedar Rd) (Plews et al. 2018)

Nitrates are essential nutrients used by plants in moderation, however in excess can have detrimental effects on water quality. The water quality guidelines for nitrate for freshwater aquatic life is a maximum concentration of 32.8 mg/L and a 30-day average concentration of 3.0 mg/L (Nordin and Pommen 2009)(B.ENV 2021a). Nitrate levels were measured within these guidelines on both sampling events. Results remain consistent with 2019 and 2017 monitoring events with an increase in nitrate concentration between October and November sampling dates.

Water quality guidelines indicate **phosphate** concentrations greater than 3 µg/L have the potential to cause deterioration in stream quality (B.C Ministry of Environment and Climate Change Strategy [B.ENV] 2021b). The increased levels of phosphate are consistent with water bodies influenced by surrounding agricultural and industrial land use. Levels remain relatively consistent with the 2022 and October sampling sessions of 2017 monitoring efforts, however unlike the November sampling session of 2017 phosphate appears to drop in the second sampling session of this report. A negative correlation can be observed in Figure 6 for sample sites 1, 2 and 4; except site 3 where no change was recorded. Fluxes in phosphate concentrations are closely associated with diminishing water quality. Increased concentrations may result in decreased oxygen availability and an increase in algae growth.

pH remained within water quality guidelines of 6.5-9.0 for freshwater environments for all four sites on both sampling occasions (Water Quality Guidelines. 2023).

Alkalinity was found to decrease between sampling events at sites 1, 3 and 4, except for site 2 where a slight increase was recorded. Provincial guidelines stipulate concentrations of > 20 mg/L indicate a low sensitivity to pH change with the addition of acid (US EPA, 2015). Alkalinity is dependent on the levels of carbonates present in a system influencing the acid-neutralizing capacity of a water body; high alkalinity is characteristic of a high neutralizing capacity.

Hardness is the measurement of divalent cations within a water body, consequently, this parameter is directly related to alkalinity and conductivity levels. The water quality guidelines for ambient hardness are based on an equation encompassing five metals, cadmium, fluoride, lead, magnesium and zinc. Measurements of 121-180 mg/L are considered hard water, containing high amounts of dissolved magnesium and calcium (Water Science School 2018a). All four sample sites were equal to or exceeded this limit during the October sampling session, consequently, a decrease in hardness was recorded in the November sampling session at all four sites. Water quality guidelines for freshwater aquatic life in streams are valid between 10-430 mg/L $CaCO_3$ (B.ENV 2023). all measurements were within this range for both sampling events, the highest recorded concentration being 136 mg/L $CaCO_3$. In addition, extensive analysis of metals was conducted by ALS for calcium and magnesium, both measurements were within water quality guidelines.

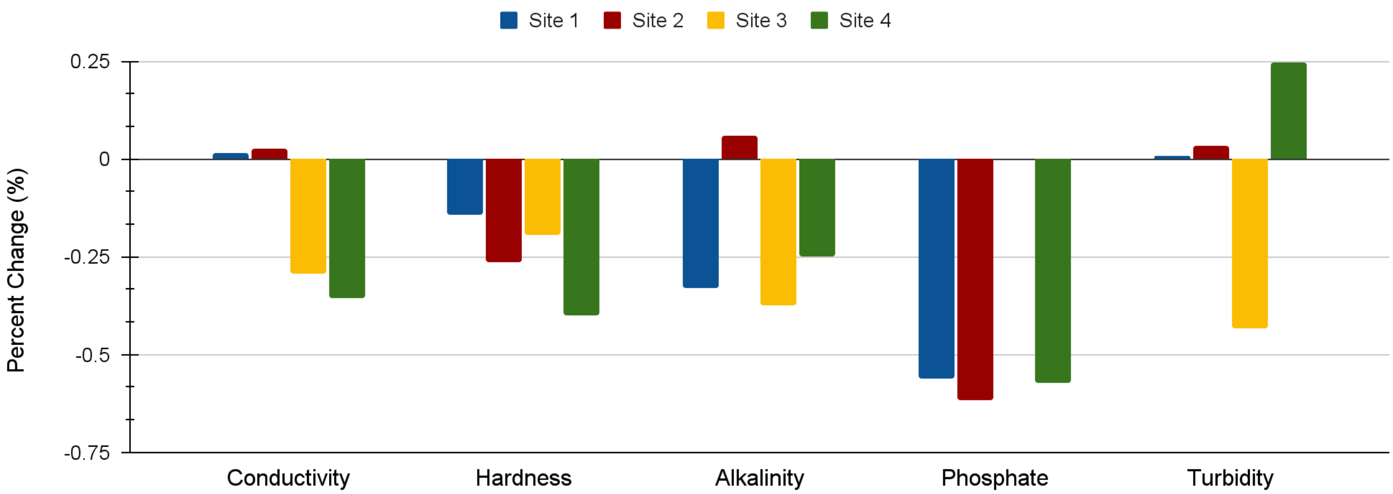

Figure 6: Percent change of water quality parameters between October and November sampling events.

3.2.3 ALS Laboratory Analyses

All measured parameters were within BC guidelines for freshwater environments.

Metal analyses, conducted by ALS laboratories, were found to be within BC guidelines or below the LDL.

A moderate decrease in conductivity of 121 mg/L (-30 %) was observed at site 3, consistent with VIU laboratory analysis (Figure 7). The decrease in conductivity from October to November is most likely the result of increased precipitation between sampling events resulting in a higher rate of dilution. Comparatively, an increase in conductivity of 3 mg/L (+0.7) is observed at site 2. Hardness showed a decreasing trend for sites 2 & 3, with a considerable reduction of 33 mg/L at site 3 (Figure 7). A positive correlation between decreasing conductivity and hardness would be expected as both parameters are dependent on the relative measure of cations present.

pH and hardness show minimal variation between ALS analysis and measurements obtained from VIU laboratories.

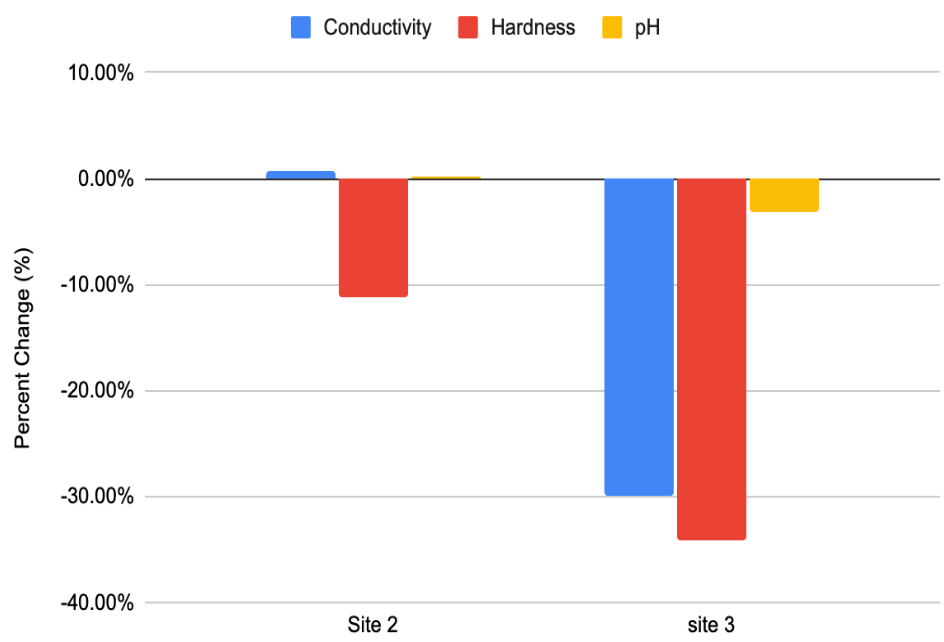

Figure 7: Percent change of water quality parameters between October and November sampling events, analyzed by ALS Laboratories.

The LDL archives by ALS laboratories from nitrates and phosphates were 0.0050 mg/L and 0.0010 mg/L respectively. Excluding nitrate concentration from site 2 during the October sampling event, all parameters were measured above the LDL for both sampling events. ALS provided further analysis of total nitrogen and total phosphorus levels. Visualized by Figure 8 below, an increase in the TN:TP ratios between sampling events was measured for both site 2 and 3. Comparisons can be made in reference to the redfield ratio for TN:TP of 16:1 as the optimal ratio for available nutrients (Savic et al. 2022).Variation from this ratio, in regards to Beck Creecs ratios being <16:1, indicated a nitrogen-limited environment. Increases in the TN:TP ratios across sampling events in sites 2 and 3 indicate a decrease in phosphorus availability relative to the amount of available nitrogen. N:P ratios vary in meaning depending on the environment they are collected in, in a river or stream, such as Beck Creek, the N:P ratio in water represents only a potential nutrient limitation rather than an actual limitation (B.ENV 2021b).

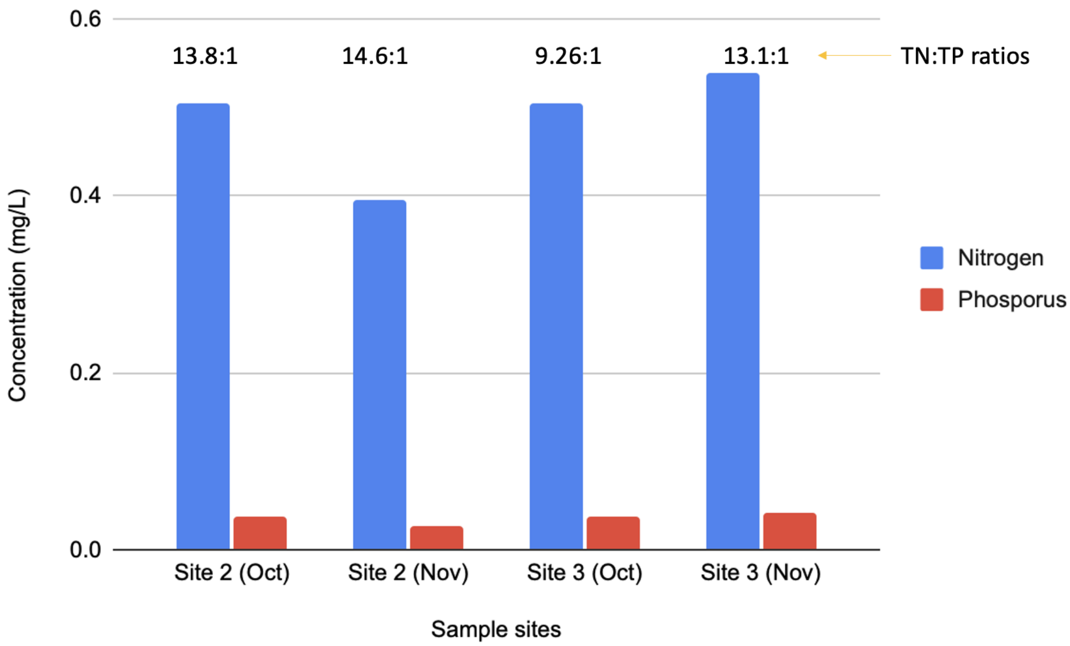

Figure 8: Total nitrogen to total phosphorus ratios of sites 2 and 3 from the October and November sampling events. Concentrations were received from ALS laboratory analysis.

3.3 Stream Invertebrate Communities

3.3.1 Abundance and Composition

Macroinvertebrates were sampled from each sampling location on November 2nd and 26th, with 3 replicates per sampling event; totalling 2.15 m^2 of search effort. We recorded a total of 555 invertebrates from 19 broad groups (Appendix 10). Amphipod spp. were the predominant group, constituting over 63% of the total recorded invertebrates. The density of invertebrates found at each site, categorized by pollution tolerance, is presented in Figures 9a & 9b. Overall, the combined density was higher during the second sampling event, because of a significant increase at sites 2 and 4. Conversely, density decreased at sites 1 and 3. The heightened density at site 2 may be attributed to increased water levels allowing water passage through the partially blocked upstream culvert at site 1 (Appendix 2). This blockage severely restricted downstream flow, likely delaying downstream drift. The observed increase at site 4 was likely aided by increased flow, with the most immediate upstream site (3) showing increased surface velocity (Table 3).

During the first sampling event, 66.5% of the total collected invertebrates fell under category 2, primarily due to the prevalence of amphipod species. Amphipod density peaked at site 1 with 322.2 m^2 and progressively decreased downstream to 40.7 m^2 at site 4. In the second sampling session, sites 1 and 2 exhibited identical amphipod densities of 255.6 m^2, while site 4 again had the lowest density of 48.1 m^2. The observed variations along the stream are likely a result of downstream predation rather than poor water quality, supported by the presence of pollution-intolerant taxa at the lower sites; which are often predators (Taccogna and Munro 1995). Additionally, historical records show chum (O. *keta*) and coho (O. *kisutch*) salmon spawning near site 3, along with more recent sightings of trout (*Oncorhynchus* spp.) and pumpkinseed fish (*Lepomis gibbosus*) (Munro and B.C. Gov 2023), all of which could prey on small invertebrate species.

The abundance and relative proportion of Category 1 taxa increased during the second sampling session (Figure 9a & 9b). The dominant group was the stonefly nymph with a total of 38 counted. The majority of stonefly nymphs were found at site 4; this is unusual, as the group is characteristic of large sediments and fast-flowing water (Waite et al., 2020). It is conceivable an upstream disturbance triggered a downstream increase; however, we cannot dismiss the possibility of a procedural error.

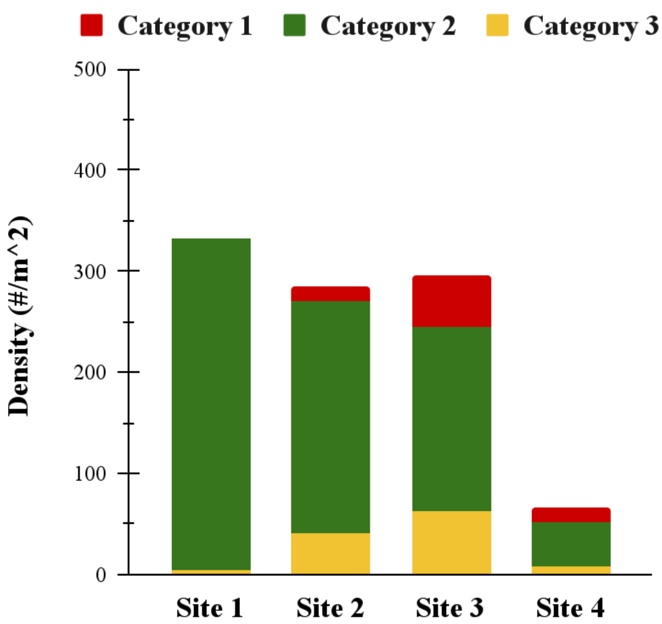

Figure 9a: Density of each pollution tolerance category per site November 2nd.

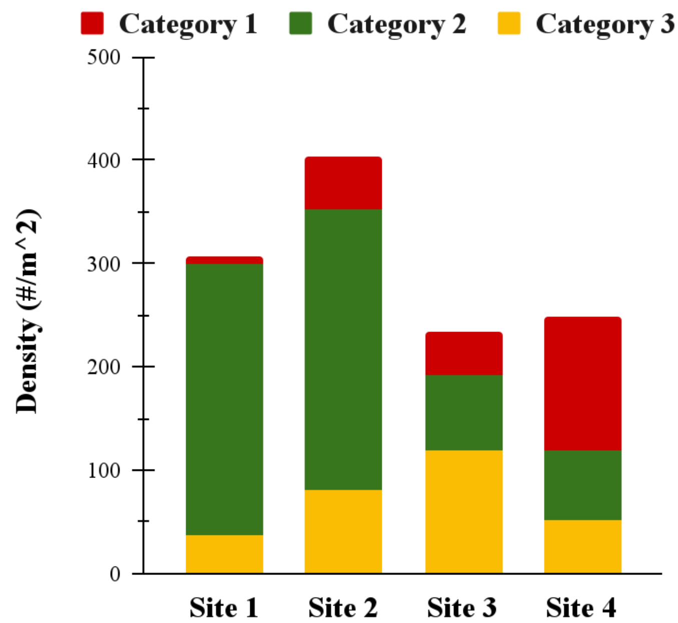

Figure 9b: Density of each pollution tolerance category per site November 26th.

3.3.2 Species Diversity & Equitability Indices

The Shannon-Weiner Diversity Index assesses the diversity and richness of species within a community. Higher values indicate a more diverse community. In the second session, the average index value decreased slightly from 0.890 (SD ±0.534) to 0.820 (SD ± 0.846). The variability was also higher in the second session since we recorded both the lowest rating at site 3 and the highest rating at site 4 (Figure 10) (Appendix 11).

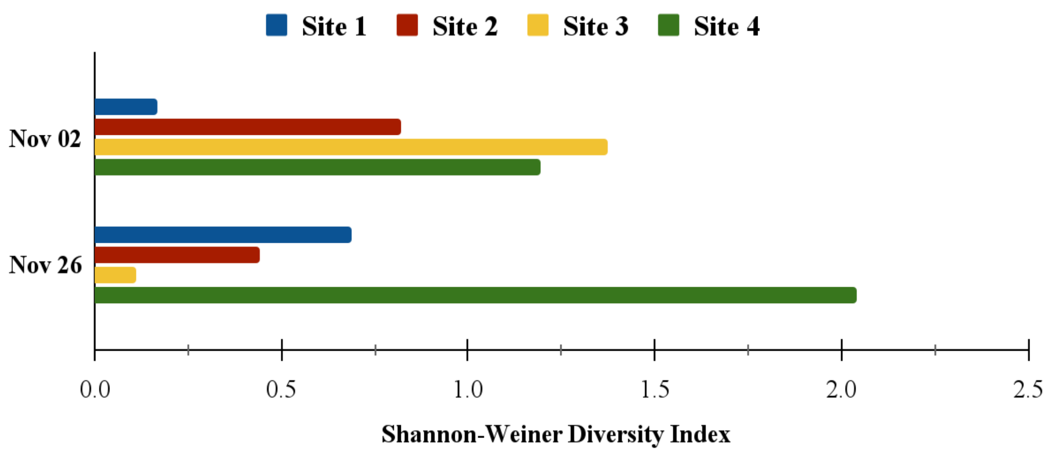

Figure 10: Shannon-Weiner Diversity Index Spatial and Temporal Trends.

The Shannon equitability index depicts the evenness of a community structure on a scale of 0 to 1. Higher values signify similar abundances among each group. As shown in Figure 11, during the first visit, the index values increased downstream and were relatively high overall, particularly at sites 2-4. However, during the second sampling event, the values dropped significantly at sites 2 and 3 but increased at sites 1 and 4, as was shown for the Shannon-Weiner Diversity Index (Figure 10).

The relative values between sites and sampling dates were nearly identical to the results of the Shannon diversity index; except for between sites 3 & 4 during the first sampling event. Site 3 had a higher diversity index but a smaller equality index relative to site 4. This is largely due to site 3 having a higher richness and abundance with taxa from 8 broad groups compared to only 5 at site 4. But at site 4; the abundance of each taxa was more similar.

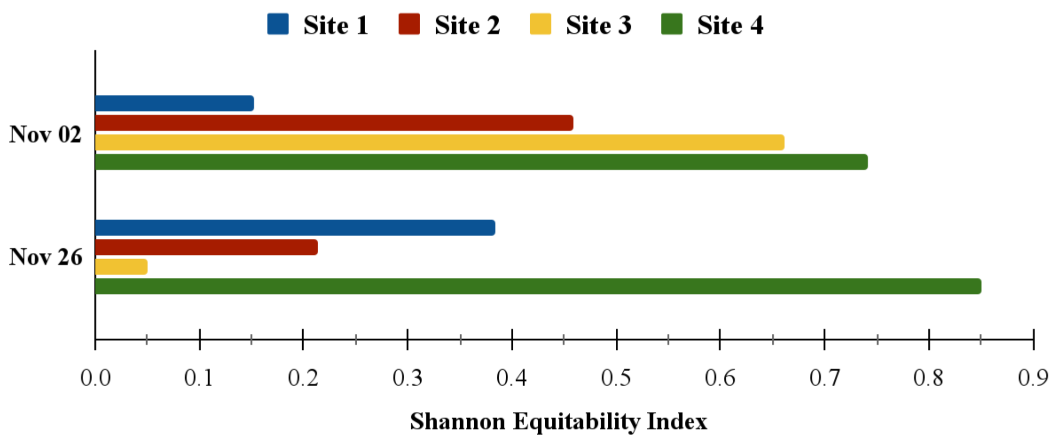

Figure 11: Shannon Equitability Index Spatial and Temporal Trends.

3.3.3 Biological Indices & Site Assessment

3.3.3.1 Site Assessment Ratings

The indices provided by the Streamkeepers Manual yielded site ratings ranging from 1.0 to 3.0 (Table 4). The Pollution Tolerance and Predominant Taxon Ratio indices returned the best ratings with averages across both dates of 2.63 (SD ±1.06) and 2.13 (SD ±0.99) respectively. Despite an increase in EPT species, the EPT to Total Ratio index yielded a maximum rating of 2; only for sites 3 & 4 in the second session. There were also relatively few taxa within the EPT groups. Consequently, the EPT indices also ranged from 1 to 2. However, the results of the EPT index and, therefore, the overall site rating, should be interpreted with caution due to the possibility of underreporting the number of individual taxa.

Table 4: Stream Keeper Invertebrate Survey Indices and Site Assessment Ratings.

Site	Visit	Pollution Tolerance		EPT		EPT to Total Ratio		Predominant Taxon Ratio		Site Assessment	
		Score	Rating	Score	Rating	Score	Rating	Score	Rating	Site Rating	Assigned
Site 1	1	7.0	1	0.0	1	0.00	1	0.97	1	1.0	Poor
	2	16.0	2	2.0	2	0.02	1	0.83	1	1.5	Poor

Site 2	1	12.0	2	1.0	1	0.05	1	0.78	2	2.3	Marginal
	2	56.0	4	2.0	2	0.13	1	0.63	2	1.5	Poor
Site 3	1	20.0	3	3.0	2	0.16	1	0.56	3	1.5	Poor
	2	18.0	3	4.0	2	0.35	2	0.74	2	2.3	Marginal
Site 4	1	11.0	2	1.0	1	0.11	1	0.61	2	2.3	Marginal
	2	32.0	4	3.0	2	0.39	2	0.27	4	3.0	Acceptable

3.3.3.2 Site Assessment Annual Trends

Our site assessment rating for site 3 was lower than in 2019, 2020 and 2022, but higher than ratings in 2017 & 2018. Our rating for site 2 was higher than all previous site evaluations except for 2019 (Vancouver Island University 2023). Figure 12 illustrates that the site ratings for sites 2 and 3 peaked in 2019 and have since fluctuated around an average of 2.1 (n=3 ± 0.18) and 1.8 (n=2 ±0.11), respectively. This decline following 2019 coincides with when the standard procedure changed from 4 replicates per event to 3. Thus, due to the nature of the stream keepers' indices favouring a broader number of taxa; and the inherent 'patchiness' of stream invertebrates; the decline in ratings does not necessarily indicate a decline in stream health. The site evaluations after 2019 have been relatively consistent and don't show a strong positive or negative trend (Figure 11). However, the most recent sampling events (2020 onwards) recorded higher average ratings than 2017/2018 resulting in a slight increase over time. This may suggest a gradual improvement in stream health, and 2019 was merely an anomaly. Taken together, the most frequently surveyed sites; 2 & 3 are on par with previous evaluations, and we found no clear signs of an environmental disturbance or decline since the last report. However, continuous monitoring would provide a better baseline to assess the health of these sites.

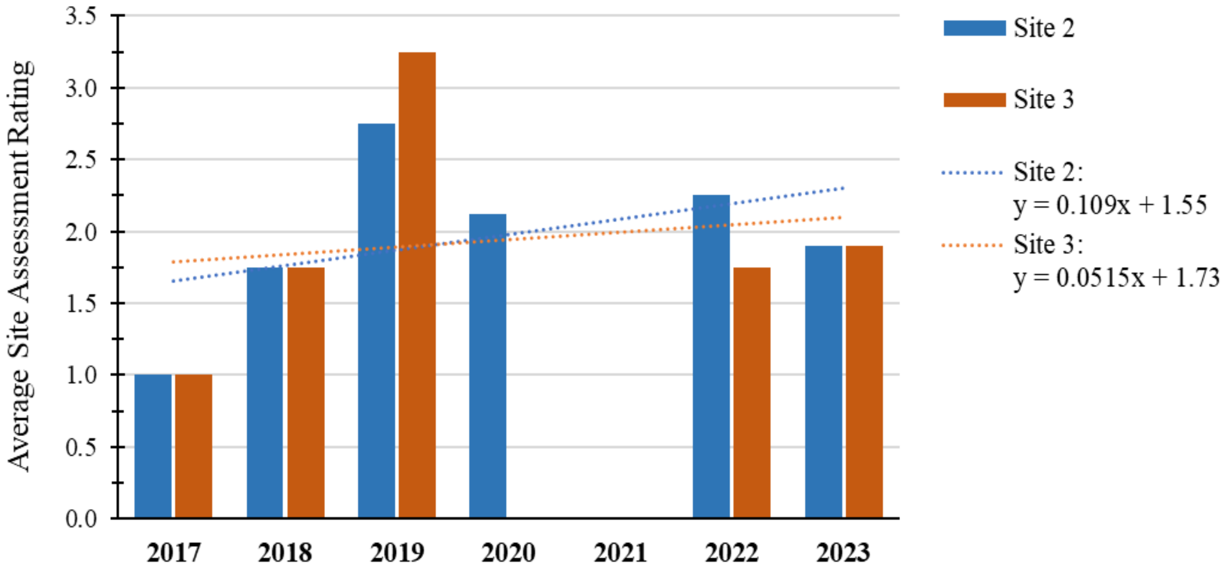

Figure 12: Annual Site Assessment Ratings for Sites 2 & 3. Ratings are averaged over two sampling periods. Site ratings show a slight increase over time. Linear trend lines show site rating (y) as a function of year (x). Low R^2 values suggest positive correlations were not statistically significant for either site (site 2; = 0.185, site 3 = 0.027).

4.0 CONCLUSIONS AND RECOMMENDATIONS

After multiple sampling sessions that tested for water quality, hydrology, and stream invertebrate abundance, our findings suggest that the environmental stressors present in the watershed are not severely impacting the water quality. Beck Creek is still a productive stream and appears to be in moderate health based on our sampling results.

The creek's gradual flow creates natural marshes and wetlands. Our biomonitoring, focused on faster-moving environments using a Hess sampler in ripples and pools, may have overlooked biodiversity within these wetland areas. Sites 1 & 4; downstream of these marshes were unideal habitats for a lot of stream invertebrates which may explain the low ratings. However, sites 2 and 3 were ideal habitats for most pollution intolerance invertebrates (Waite et al. 2020) and had only marginal ratings even after the ‘fall flush’. Since our site ratings for sites 2 & 3 were comparable to recent years; it is unlikely a recent disturbance has severely impacted invertebrate communities. However, without a reference before the most influential disturbances (agriculture, urbanization, stream re-routing) it is difficult to infer if the natural features of the stream or ongoing disturbances are the reason for the low ratings. There may also be dangerously high concentrations of contaminants that we did not measure such as mercury, herbicides, or pesticides.

Water quality, hydrology, and invertebrate assessments are important subjects for assessing overall stream health. These are the required parameters to be sampled for the RMOT 306 Environmental Monitoring course. Despite the previously mentioned parameters, our group discussed additional tests and monitoring ideas that would be beneficial in the future to help understand this creek's health. Some ideas included fish monitoring using minnow traps, additional assessments of habitats surrounding site 3, and more frequent assessments of culverts to prevent long-term blockages. For future RMOT 306 students who choose to monitor Beck Creek and to collect accurate data, we recommend selecting a new sample area for site 4.

Given that the health of Beck Creek is moderate, it would benefit from continuing the annual environmental monitoring projects conducted by RMOT students. Agriculture, illegal dumping, and altered stream hydrology all due to anthropogenic activities pose a risk to the health and productivity of this creek. Considering the current conditions of the watershed and climate change factors, it is important that the residents of Nanaimo work together to improve and protect this watershed.

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7.0 APPENDIX

Appendix 1. Woody debris limiting flow at site 1 invertebrate sampling location. October 4th 2023.

Appendix 2: Site 1 lower pool; water sampling collection location. October 4th 2023.

Appendix 3: Site 2 riffle habitat. October 4th 2023.

Appendix 4: Culvert upstream of site 2. November 2nd 2023.

Appendix 5: Site 3 pool and point bar; area habitat behind point bar became a more prominent riffle habitat when the water level rose. October 4th 2023.

Appendix 6: Site 4 Pool October 4th 2023.

Appendix 7: Field Water Quality Measurements. Recorded November 2nd (1) and November 26th (2) 2023.

	Site 1		**Site 2**		**Site 3**		**Site 4**	
Visit	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
DO (mg/L)	6.4	9.1	7.6	9.5	8.3	11.7	8.9	12.3
Temp (C°)	9.1	6.2	9.3	6.2	8.6	5	9.2	6.8
pH	8	7.3	7.4	7.2	7.5	7.5	8.1	7.8
Conductivity (μS/cm)	342	421	338	420	231	260	252	278

Appendix 8: VIU Water Quality Analysis Data.

	Site 1		**Site 2**		**Site 3**		**Site 4**		**Blank**	
Collection Date	**Oct 23**	**Nov 21**	**Oct 23**	**Nov 21**	**Oct 23**	**Nov 21**	**Oct 23**	**Nov 21**	**Oct 23**	**Nov 21**
Conductivity (μS/cm)	415	421	409	419	375	265	427	275	0	0.01
pH	7.2	7.6	6.9	7.3	7.5	7.5	7.3	7.3	8	9
Hardness (mg/L $CaCO_3$)	140	120	136	100	124	100	120	72	2	1
Alkalinity (mg/L $CaCO_3$)	241.6	161.6	168.4	178.6	147.6	92.4	138	103.6	3	2.2
Nitrate (mg/L NO_3)	0.02	0.1	0.01	0.5	0.01	0.08	0.01	0.1	0.02	0.1
Phosphate (mg/L PO_4^{3-})	0.25	0.11	0.13	0.05	0.19	0.19	0.14	0.06	0.02	0.1
Turbidity (NTU)	1.47	1.48	1.22	1.26	2.83	1.6	1.22	1.52	0.18	0.21

Appendix 9: ALS Results; water collected October 23rd and November 21st 2023.

	Lowest Detection Limit	Units	**October 23rd**	**November 21st**

Physical Tests (Matrix: Water)			Site 2	Site 3	Site 2	Site 3
Conductivity	2	µS/cm	439	403	442	282
Hardness (as CaCO3), from total Ca/Mg	0.5	mg/L	104	97.8	92.3	64.4
pH	0.1	pH units	7.67	7.85	7.69	7.6
Anions and Nutrients (Matrix: Water)						
Ammonia, total (as N)	0.005	mg/L	0.0263	0.0262	0.048	0.0221
Nitrate (as N)	0.005	mg/L	<0.0050	0.0167	0.0243	0.055
Nitrite (as N)	0.001	mg/L	<0.0010	0.0014	0.0028	0.0017
Nitrogen, total	0.03	mg/L	0.505	0.538	0.396	0.528
Phosphate, ortho-, dissolved (as P)	0.001	mg/L	0.0097	0.0094	0.0098	0.0035
Phosphorus, total	0.002	mg/L	0.0366	0.0365	0.0272	0.0412
Total Metals (Matrix: Water)						
Aluminum, total	0.003	mg/L	0.0194	0.065	0.0255	0.272
Antimony, total	0.0001	mg/L	<0.00010	<0.00010	<0.00010	<0.00010
Arsenic, total	0.0001	mg/L	0.00032	0.00034	0.00022	0.0003
Barium, total	0.0001	mg/L	0.0425	0.0394	0.0425	0.0311
Beryllium, total	0.00002	mg/L	<0.000020	<0.000020	<0.000020	<0.000020
Bismuth, total	0.00005	mg/L	<0.000050	<0.000050	<0.000050	<0.000050
Boron, total	0.01	mg/L	0.124	0.102	0.121	0.073
Cadmium, total	0.000005	mg/L	<0.0000050	<0.0000050	<0.0000050	0.0000069
Calcium, total	0.05	mg/L	30.2	28.3	27	18.9
Cesium, total	0.00001	mg/L	<0.000010	<0.000010	<0.000010	0.000016
Chromium, total	0.0005	mg/L	<0.00050	<0.00050	<0.00050	0.00068
Cobalt, total	0.0001	mg/L	0.00013	0.00015	<0.00010	0.0003
Copper, total	0.0005	mg/L	<0.00050	0.00066	<0.00050	0.00136
Iron, total	0.01	mg/L	0.657	0.669	0.436	0.768
Lead, total	0.00005	mg/L	<0.000050	0.000087	<0.000050	0.000368
Lithium, total	0.001	mg/L	0.0053	0.0046	0.0054	0.0033
Magnesium, total	0.005	mg/L	6.86	6.59	6.05	4.18
Manganese, total	0.0001	mg/L	0.0371	0.0792	0.0616	0.124
Molybdenum, total	0.00005	mg/L	0.000126	0.000122	0.000125	0.000082
Nickel, total	0.0005	mg/L	0.00091	0.00087	0.00072	0.00098
Phosphorus, total	0.05	mg/L	<0.050	<0.050	<0.050	<0.050
Potassium, total	0.05	mg/L	1.42	1.72	1.34	1.42
Rubidium, total	0.0002	mg/L	0.00154	0.00154	0.00118	0.00114

Selenium, total	0.00005	mg/L	0.000063	0.000068	0.000058	0.000055
Silicon, total	0.1	mg/L	7.83	7.48	6.58	5.66
Silver, total	0.00001	mg/L	<0.000010	<0.000010	<0.000010	<0.000010
Sodium, total	0.05	mg/L	58.2	49.2	64	35.6
Strontium, total	0.0002	mg/L	0.381	0.348	0.396	0.227
Sulfur, total	0.5	mg/L	5.96	5.96	8.08	4.81
Tellurium, total	0.0002	mg/L	<0.00020	<0.00020	<0.00020	<0.00020
Thallium, total	0.00001	mg/L	<0.000010	<0.000010	<0.000010	<0.000010
Thorium, total	0.0001	mg/L	<0.00010	<0.00010	<0.00010	<0.00010
Tin, total	0.0001	mg/L	<0.00010	<0.00010	<0.00010	<0.00010
Titanium, total	0.0003	mg/L	0.00129	0.00392	0.00145	0.0144
Tungsten, total	0.0001	mg/L	<0.00010	<0.00010	<0.00010	<0.00010
Uranium, total	0.00001	mg/L	0.000034	0.000027	0.000051	0.000028
Vanadium, total	0.0005	mg/L	<0.00050	0.00068	0.00053	0.00148
Zinc, total	0.003	mg/L	<0.0030	<0.0030	<0.0030	0.003
Zirconium, total	0.0002	mg/L	<0.00020	<0.00020	<0.00020	<0.00020

Appendix 10: Invertebrates Counts, from 3 replicates per site (Total Search Effort=0.27 m2). Unrecorded groups were excluded from the list.

Date		Nov 02				Nov 26			
Site		**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Category	**Taxa**								
Category 1	Caddisfly Larva (EPT)					1		2	6
	Mayfly Nymph (EPT)		4	9	2	1	2	1	2
	Stonefly Nymph (EPT)			4			12	8	18
	Gilled Snail								8
	Water Penny			1	2				1
Cat 1 Sub-Total		0	4	14	4	2	14	11	35
Category 2	Aquatic Beetle						1		
	Aquatic Sowbug	2	1						3
	Cranefly Larva			4	1		1		2
	Crayfish		1				1		
	Amphipod (freshwater shrimp)	87	60	45	11	69	69	20	13
	Watersnipe Larva					2	1		
Cat 2 Sub-Total		89	62	49	12	71	73	20	18
Category 3	Aquatic Worm (oligochaete)	1	8	14		5	6	23	3
	Blackfly Larva			2				2	
	Leech						16		
	Midge Larva (chironomid)		3			5		4	10
	Pouch and Pond Snails				2			2	
	Water Mite			1				1	1
Cat 3 Sub-Total		1	11	17	2	10	22		14
Total		90	77	80	18	83	109	63	67

Appendix 11: Shannon-Weiner Diversity Index Results. 3 Hess sampler replicates were taken per site per visit.

Date \ Site	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Nov 02	0.167	0.823	1.376	1.194
Nov 26	0.688	0.443	0.110	2.038

Appendix 12: Shannon Equitability Index Results. 3 Hess sampler replicates were taken per site per visit.

Date \ Site	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Nov 02	0.152	0.459	0.662	0.742
Nov 26	0.384	0.213	0.050	0.850