WATER QUALITY AND INVERTEBRATE MONITORING OF BECK CREEK, NANAIMO BC

Fall 2018

Submitted to:

Dr. Eric Demers, Vancouver Island University

December 14, 2018

Ghislain de Laplante, Niki Gagne, Matthieu Soucy

Contents

List of Tables

List of Figures

1.0 Introduction and Background (Ghislain)

1.1 Project Overview

This document is issued in response to a Request for Proposals (RFP) in the context of Vancouver Island University's Environmental Monitoring class (RMOT 306), to propose water quality and habitat quality (via freshwater invertebrate monitoring) of Beck Creek in Nanaimo, BC. This project will aim to continue yearly monitoring of Beck Creek, begun in the fall of 2017 (also in the context of Vancouver Island University's RMOT 306 course) and with support from the City of Nanaimo, the Regional District of Nanaimo (RDN), Fisheries and Oceans Canada (DFO), and Snuneymuxw First Nation (SFN).

1.2 Location and Setting

Beck Creek is a short, ~5 km stream with Beck Lake (elevation 30 metres) situated at its headwaters (Figure 1). The lake as well as the upper 600 m of Beck Creek are lined to the west by agricultural properties, and to the east by the residential neighbourhood of South Wellington. Beck Creek then flows through second growth forest (<50 years) for ~1.5 km, flanked to the east-north-east by the defunct Esquimalt and Nanaimo rail line and the Trans Canada Highway (TCH). It then crosses under both transportation lines before flowing between residential neighbourhoods for its final ~2 km to the Nanaimo River estuary.

The total watershed area is 6.7 km, with one significant tributary (Richard Creek, center of Figure 1). Slope within the watershed is generally mild (5-10%), as is the average stream

gradient of 0.6%. The steepest gradient (2.0%) is reported from tidewater to Cedar Road (Irvine, et al., 1994), while the slower-moving sections above this are frequently dammed by beavers creating natural obstacles to fish migration. Flows within Beck Creek and its tributaries are highly seasonal, being nearly absent at the driest point during late summer and peaking with winter rains and aquifer recharge.

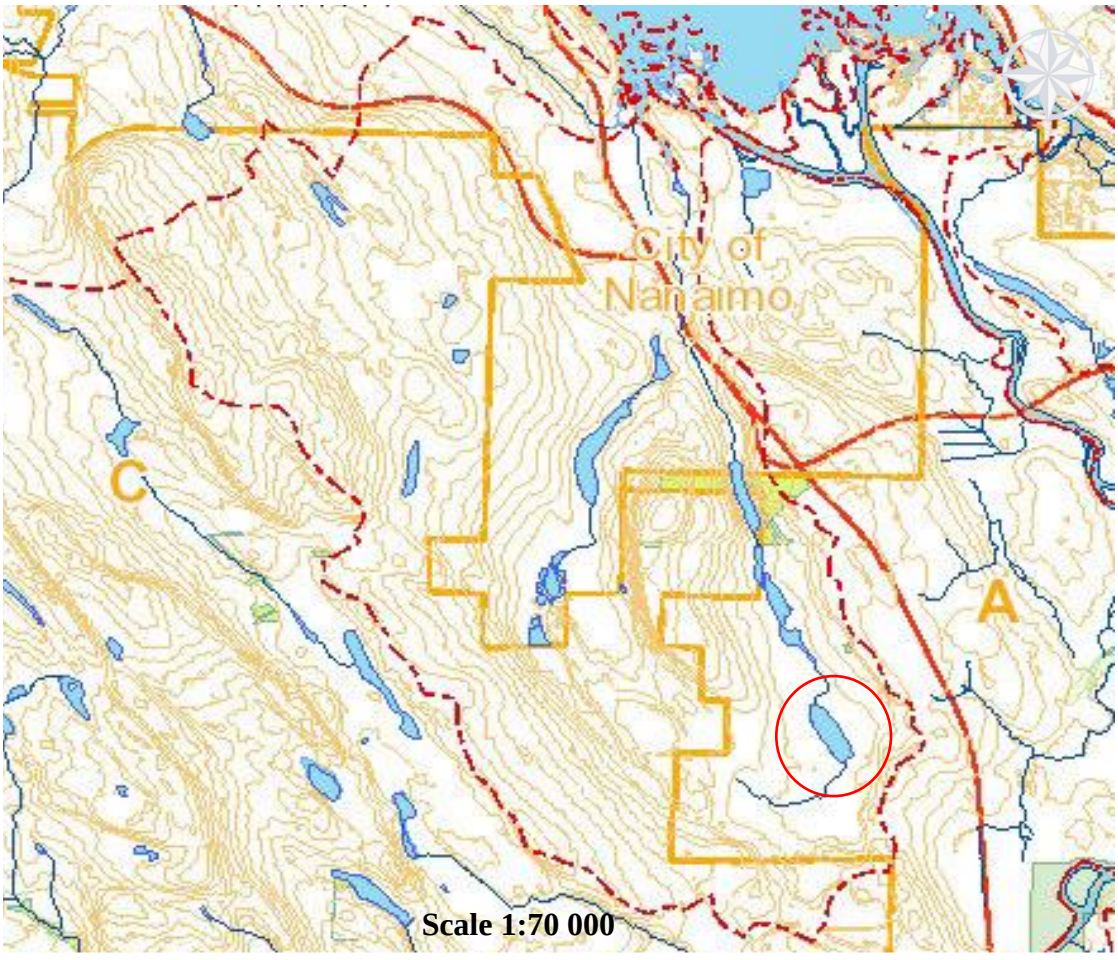


Figure 1: Beck Creek watershed (dashed line) represented with 10 m contours, municipal and electoral area boundaries. Beck lake is circled in red. Map generated through the Regional District of Nanaimo's web mapping application (Regional District of Nanaimo, 2018).

1.3 Hydrology

The catchment of Beck Creek (6.7 km^2) is generally of low slope (mostly 5-10%), low elevation, and receives the bulk of its annual ~1,140 mm of precipitation from October to March (Environment Canada, 2018).

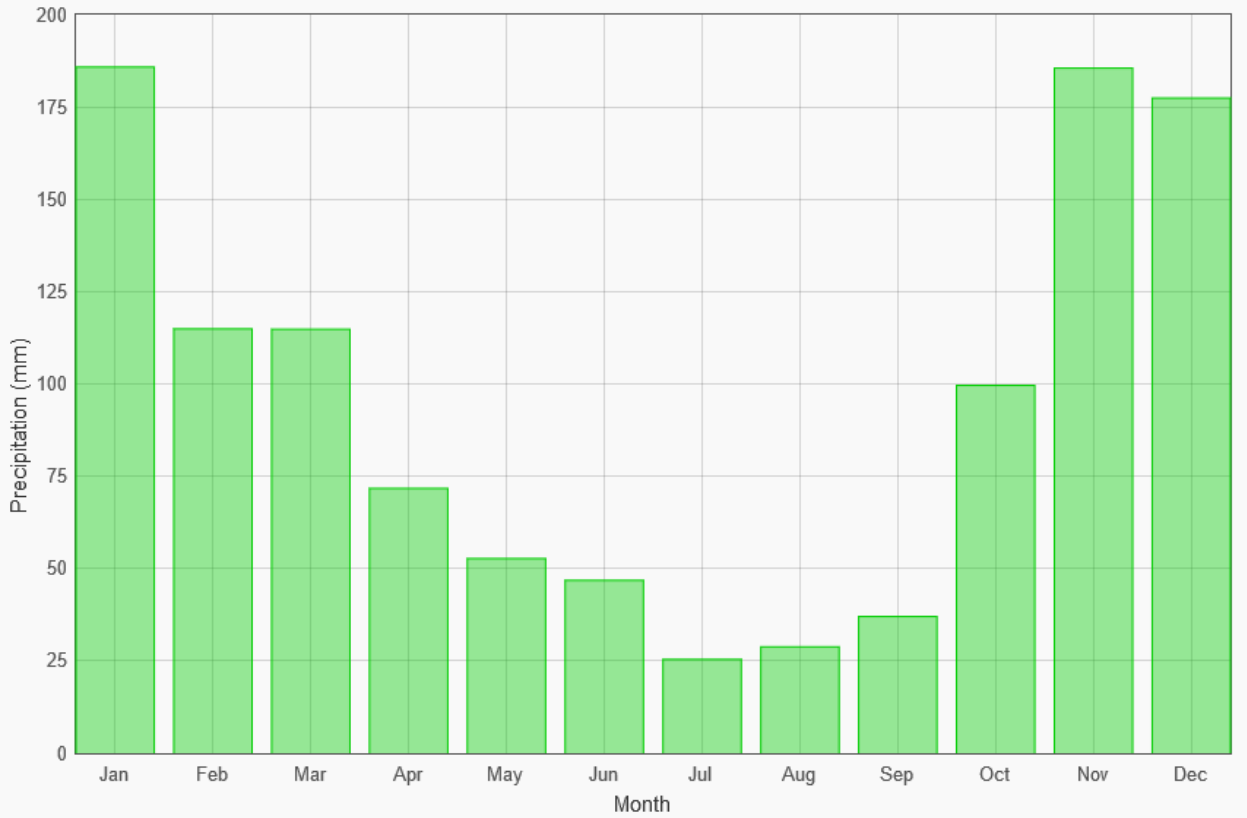


Figure 2: Annual precipitation (monthly averages 1981-2010) at Nanaimo City Yard (Environment Canada, 2018).

Beck Creek and Beck Lake are underlain by thin, discontinuous (0 to ~25 m thick) Quaternary alluvial and glacio-fluvial deposits (primarily sands and gravels with variable silt/clay content) and sporadic till overlying Nanaimo group sedimentary rocks. Quaternary soils in this area have good permeability, while till and sedimentary rocks act as aquitards, permitting only slow

infiltration of water (Bednarsky, 2015). Significant sediment cover is only mapped in the south-east quarter of the watershed (GeoBC, 2018), and this is mostly supported by ground observations.

Surface cover within the watershed consists of open fields, residential neighbourhoods, and patchy second-growth forests. This results in lower potential evapotranspiration (PE) compared to less developed environments. It is unclear at this time if storm water runoff is introduced directly into the creek, but it appears likely that runoff from roadways contributes in some ways to peak stream flows.

The result of heavy fall/winter precipitation, low PE, and storm water runoff coupled with poor groundwater flow capacity is significant overland flow into Beck lake, the wetlands which drain into Beck Creek and Beck Creek itself. Comparatively, zero flow conditions have been reported at the outlet of Beck Lake during the summer (Cook & Baldwin, 1994), with the underlying aquifer providing 100% of baseflow. Beck Creek is ungauged, but discharge estimates have been performed by Cook and Baldwin (1994) comparing precipitation, evaporation, and gradient to nearby gauged streams. **Error! Reference source not found.** illustrates this estimate.

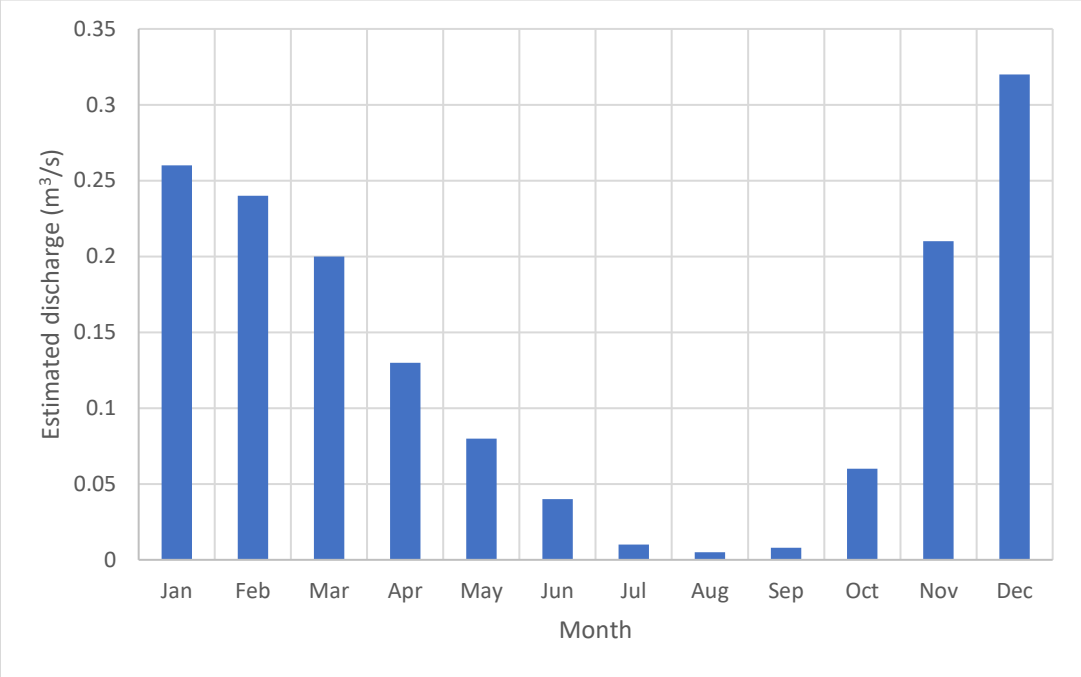


Figure 3: Estimated mean monthly discharge at Beck Creek (Cook & Baldwin, 1994).

1.4 Historical Review

Beck Creek is a locally important salmon spawning stream and may provide habitat for resident trout populations, but it has been subject to increasing agricultural, industrial and residential pressures since the industrialization of the Nanaimo region. Anadromous salmon migrate and spawn into Beck Creek and its tributaries, at times successfully migrating as far up as Beck Lake. Migration distance appears dependent on beaver activity: in some years beaver dams ~1 km upstream of the Trans-Canada Highway culvert prevent passage, but these are periodically washed away (Irvine, et al., 1994). Recent efforts have focussed on cleaning up detritus and garbage present within and on the banks of the creek, as well as improving spawning conditions through introduction of gravels and removal of upstream migration obstacles (Nanaimo News

Bulletin, 2012). These efforts are complemented by annual spawning return counts (though these counts are unpublished) spearheaded by the Harbour City River Stewards.

One study of the same scope as this proposal has previously been completed for VIU's RMOT 306 class (Miller, Keir, & Baildham, 2017). We plan to sample at the same locations as this study and to use identical methodology to enable comparative study of monitored parameters. Continued yearly studies of this watershed will aid in quantifying habitat quality and the impact of stream restoration efforts.

1.5 Current and Potential Environmental Concerns

The catchment of Beck Creek contains the mid-island's highest use transportation corridor (the TCH), agricultural land, some industrial land use sites, as well as significant and growing residential land use. In addition, the south end of the lake was once used to dispose of coal mining waste (Blackman, 1980). All of these are potential contributors to water contamination and resultant habitat degradation. This is exacerbated by the shallow soil and poorly permeable bedrock underlying the upper reaches of the watershed, resulting in significant overland flow and the potential for contaminant migration directly into the stream. Lastly, eutrophication is a significant concern for Beck Lake owing to agricultural and residential runoff directly into the lake, coupled with slow-moving to stagnant, shallow waters.

Future environmental degradation / disturbance (particularly affecting salmon and resident trout) is possible in many forms for this watershed. The following non-exhaustive list outlines several of the more common negative environmental impacts expected to be possible here:

- Additional surface runoff from residences and roadways
- Increased agricultural runoff
- Changes in agricultural land-use
- Industrial site runoff (from industrial subdivision along the TCH)
- Disturbance of coal mining waste within the lake
- Forestry practices resulting in changing flows and/or watercourse
- Diminished summertime flows due to dryer, warmer summers
- Residential waste deposited within or near the creek/lake
- Transportation incidents resulting in hazardous material spill
- Septic field and sanitary sewer inadvertent discharge from degraded infrastructure

2.0 Project Objectives (Niki)

This monitoring project aimed to describe the water quality parameters of Beck Creek at several sites along its reach, and at two different times and discharge rates during the onset of the rainy season. Additionally, it aims to describe and enumerate freshwater invertebrates found within the stream to provide a measure of stream health and to gather relevant data for future studies. There are four locations along Beck Creek that were tested for hydrology, water quality, microbiology,

and invertebrates. All stations that were used to gather data have been described in the 2017 report, and our descriptions are congruent. With the sample data collected, we were able to compare it to previous years of data and discovered trends within the health of the creek and the inhabitants within. Samples were sent to *Australian Laboratory Services (ALS)* in Vancouver, BC, to be assessed and analyzed. Following this, we obtained information regarding the overall health and condition of the stream and its invertebrate community.

3.0 Environmental Sampling and Analytical Procedures (Niki)

3.1 Sampling Program

3.1.1 Locations and Habitat Characteristics

Each location or site was numbered from one through four (beginning upstream) and had been used for previous data sampling and collection (Miller, Keir, & Baildham, 2017). As the information was being gathered regarding a specific area over a long-term study, the same methods and sites were used. This allows continuity of the assessment over time, allowing us, as well as future studies, to compare the same methods and sites per sampling period. To further maintain similarities to previous sampling, we used the same equipment, methods, and laboratory to gather and analyse samples.

All four sites used for Beck Creek had been chosen specifically and precisely. They take into consideration the location along the creek, the substrate within the creek, and the flow rate at which the creek is progressing. The four sites included in this environmental assessment were tested for hydrology, water quality, microbiology, and invertebrates, as requested by the RFP.

Every site was evaluated on October 17, 2018, to complete a necessary preliminary site assessment.

Figure 4: Predetermined site locations for the Beck Creek environmental assessment.

Site 1 is situated furthest upstream from the ocean, and slightly downstream of a beaver pond, at the approximate UTM coordinates 10U, 433603 E, 5440523 N (BC Albers). This site, along with the others, are used for this report in order for it to be compared to past reports. The water was moving relatively slowly in this reach, on either side of the culvert. Water depth was difficult to determine as the water was quite dark but was estimated at 30 cm deep. Depth of the water was expected to rise owing to the start of the rainy season. Above the culvert is a dirt road which seems to be accessible by vehicle, if needed. Access to the site is quite straightforward and is an

easy trek, but appropriate footwear is suggested. The grassy area surrounding the creek is uneven but of flat slope. Some spots are soft and would allow individuals to fall through, while others are firm and can hold body-weight.

Site 2 can be found around 500 m downstream of site 1, approximate UTM coordinates 10U, 433409 E, 5440990 N. This particular site has been used in the past along with the others, for research purposes. Using it for this report will continue its relevancy to the assessments. Movement or rate of water flow here was much quicker than that of site 1. The water is pouring quite steadily out of one large and one small culvert. Downstream a riffle can be seen, which we utilized for invertebrate sampling. If the weather quality decreased and heavy rains appeared, the riffle could be hidden below deep waters. Directly above the culvert of site 2 are rail road tracks, and directly across the creek behind a wall of trees is the Trans-Canada Highway. Access to this particular site is quite straightforward, as it is an undeviating walk from the end of Frames Road for approximately 300 m. A rather steep embankment with loose cobble and some garbage urges slight safety precautions to be taken when entering the area.

Site 3 is positioned across the highway from sites 1 and 2, around UTM coordinates 10U, 433346 E, 5441612 N. The water flow coming from the culvert here is quite rapid, but only approximately 10 cm deep before running into a large pool where depth is unknown. The water is retained in the pool by a large semicircle of cobble, which stops the water from overflowing downstream and creating an environmental hazard and/or disaster. Less than 10 m downstream of this cobble, a riffle is situated. This area acted as a good location for invertebrate sampling for

this project. Although, if heavy rains began, Beck Creek could also rise and make the pool a considerable danger. Accessibility to the riffle on the opposite side of the pool is dangerous. The individuals sampling are required to walk alongside a steep embankment to reach the riffle on the other side of the pool. There is possibility that an individual could fall down the embankment and into the unknown depth of water.

Site 4 is located near the Chase River Estuary on the north side of Maki Rd, with UTM coordinates 10U, 433289 E, 5442348 N. Water flow in this site is slow, and did not increase within the dates of the two sampling events. Beck Creek flows out of a large culvert which eventually leads to the Strait of Georgia. The water flows downstream through the Nanaimo River estuary before reaching the ocean. There are no riffles at site 4, which would make for a poor invertebrate sampling region. The single water sample will be taken from this site as water flows easily and accessibility is undemanding. If ocean tides were high, the site could be dangerous as the rocks are quite smooth and hard to keep a grip of. Also, the road this site is situated along is quite a high traffic area, between Rona and Living Forest Campground. The team must increase their precautions when taking samples.

Table 1: Preliminary Habitat Characteristic Assessment: October 19th, 2018. Modified from 2017 survey (Miller, Keir, & Baildham, 2017) to reflect 2018 conditions.

Site	Substrate Composition	Gradient	Canopy	Riparian Zone	Notes

1	Gravel 40% Fines 40% LWD 20%	<1%	Coverage 10% Big Leaf Maple (*Acer macrophyllum*) Western Red Cedar (*Thuja plicata*) Red alder (*Alnus rubra)*	Thimbleberry (*Rubus parviflorus*) Himalayan BlackBerry (*Rubus armeniacus*) Sword Fern (*Polystichum munitum*) Snowberry (*Symphoricarpos occidentalis*) Various Grasses	Sampling area directly downstream of culvert Substrate muddy/grassy Access: Easy
2	Cobble 30% Gravel 35% Fines 20% LWD 15%	2-3%	Coverage 80% Big Leaf Maple (*Acer macrophyllum*) Western Red Cedar (*Thuja plicata*) Red Alder (*Alnus rubra*)	Bracken Fern (*Pteridium*) Sword Fern (*Polysitchum munitum*)	Beaver dam 30m upstream of site 2, water depth (upstream side of the dam: 3m) Recent beaver activity observed upstream. Access: Easy
3	Cobble 40% Gravel 30% Fines 20% LWD 10%	2-3%	Coverage 80% Douglas Fir (*Pseudotsuga menziesii*) Big Leaf Maple (*Acer macrophyllum*) Western Red Cedar (*Thuja plicata*)	Dull Oregon Grape (*Mahonia nervosa*) Bracken Fern (*Pteridium*) Snowberry (*Symphoricarpos occidentalis*)	Riffle 10m downstream of culvert has good invertebrate sampling substrate. Access: Moderately steep bank.
4	Fines 70% Cobble 30% (upstream of culvert)	<1%	Coverage 30% Douglas Fir (*Pseudotsuga menziesii*) Western Red Cedar (*Thuja plicata*) Red Alder (*Alnus rubra*) Big Leaf Maple (*Acer macrophyllum*)	Ocean Spray (*Holodiscus discolor*) Thimbleberry (*Rubus parviflorus*) Various grasses	Not suitable for invertebrate sampling. Access: Steep bank to reach sampling site

3.1.2 Sampling Frequency and Timing

Sampling was performed twice during this project, once on October 31, 2018 and another on November 21, 2018. The sampling dates had been coordinated with all three of the students invested in the Beck Creek project, along with equipment available for use. Of the four locations indicated for sampling, microbiology and water quality were tested at all sites, while invertebrates were sampled at the middle two locations and hydrology measured at the furthest downstream location. Additionally, hydrology and water quality were tested during both sampling efforts, while microbiology and invertebrates were sampled only during the first sampling effort. Sampling took place on October 31st and on November 21st, 2018.

Table 2: Water and stream invertebrate sampling events conducted during October 31st and November 21st, 2018. Letters "A" and "B" are designated for October (A) and November (B).

Site	*Location (UTM 10U)*	*Hydrology*	*Water Quality*	*Microbiology*	*Invertebrates*
1	433603 E 5440523 N		A, B	A	-
2	433409 E 5440990 N		A, B	A	A
3	433346 E 5441612 N		A, B	A	A
4	433289 E 5442348 N	A, B	A, B	A	-

3.2 Hydrology (Ghislain)

The measurement of basic hydrological parameters such as flow velocity and total volume is essential to understanding a stream's population dynamics as well as response to precipitation events, Hydrology was measured at Site 4 (at tidewater) in order to capture the entirety of the

watershed's overland flow during both sampling events. As described under section 3.1.1, this site is characterized by Beck Creek's channeling through a large, circular culvert, creating the ideal location for measuring Beck Creek's discharge. This parameter is calculated by multiplying the stream channel with the average stream velocity: the former was calculated using the water depth and culvert diameter, while the later was obtained by measuring a floating object's velocity. Calculations are outlined in section 4.1.

3.3 Water Quality (Matt)

3.3.1 Field Measurements

Water quality measurements are an essential component of a complete stream assessment. Certain parameters are best obtained in the field (*in-situ*) as their quality may deteriorate/change and be time sensitive. As such, field measurements for water temperature and dissolved oxygen (DO) were obtained using an Oxyguard Handy Polaris electronic probe. These tests were performed at all 4 stations during two sampling events which took place on Octobers 31st, and subsequently November 21st, 2018.

3.3.2 Water Sample Collection

Water samples were obtained at the same time as field measurements. These samples consisted of a bottle filled at each of the four stations (for VIU laboratory analysis), as well as a single replicate sample taken at one of the stations to assess precision. Moreover, a trip blank (distilled water sample) was also brought to the field to assess for potential contamination in later analysis. For the purpose of third-party analysis by ALS laboratories in Vancouver, 3 water samples were

acquired each from station 1, 2, and 3; one with no additive, one buffered with nitric acid, and one buffered with sulphuric acid.

Both the provincial guidelines for designing and implementing a water quality monitoring experiment (BCMWLAP, 1997) and the ambient freshwater and effluent sampling methods (BCMWLAP, 2013) were followed to ensure best practice. Care was taken to begin sampling downstream at each of the station, systematically moving upstream in the thalweg as to not cross contaminate samples. A team member obtained samples from beneath the surface of the water to eliminate bias sampling from surface scum, after having rinsed the bottle 3 times. Samples were then transported from the field in a cooler packed with ice and analysed within a few hours that same day.

3.3.3 In-house Laboratory Analyses

Although certain experimental parameters are best obtained in the field, others require assessment under laboratory condition. Accordingly, a Vancouver Island University (VIU) lab was used within the allotted time period to test the samples taken during both sampling events. Turbidity, a measure of the total suspended solids (TSS), was acquired using a HACH 2100 Turbidimeter. Alkalinity was then measured using the HACH AL-DT digital titration method, hardness with HACH HA-4P test kit, and Phosphate and Nitrate using an HACH DR2800 Spectrophotometer using methods 8048 and 8192 respectively. Lastly, a measure of total coliform was assessed using the m-coliBlue24 membrane filtration method.

3.3.4 Sub-contracted Laboratory Analyses

As previously mentioned, further analyses were conducted by sending samples (from site 1, 2 and 3) to ALS Laboratories in Vancouver, a private-sector analytical laboratory. Because these advanced methods can be costly, consideration was given to shipping costs by sending the samples as a bulk order in conjunction with other samples from our firm. The analyses obtained were general water quality parameters, nutrient analyses, and a total metal scan of approximately 30 different metals. Measures where taken to liaise with ALS prior to sending the samples to guarantee compliance with their guidelines regarding transportation (mailing) protocols.

3.3.5 Quality Assurance/Quality Control

The methodology used in obtaining water quality samples is of the utmost importance. Attention was given to keeping all equipment clean and calibrated. Cross-contamination pathways such as previously used bottles and lids were mitigated by always rinsing equipment three times, or by using new bottles. When appropriate, sterile work practices were observed at all time including prior labeling to eliminate any mix up. Directions vis-à-vis water collection guidelines were adhered to with the inclusion of a trip blank and replicate samples during both sampling events. These considerations were extended to proper storage and transportation of all collected samples. In-field concerns included sampling from prior monitoring program locations to contribute to long-term data benefit, as well as utilizing the same in-stream sites during both sampling events.

3.3.6 Data Analysis, Comparison to Guidelines

Following our field data gathering phase we analysed our findings using provincial established guidelines. The Guidelines for Interpreting Water Quality Data in BC (BCMWLAP, 1997) were used to assess samples obtained from the VIU lab and ALS Laboratories to establish if the water quality parameters were within an acceptable range or if any exceeded or approached aquatic life threshold, indicating possible toxicity concerns.

3.3.7 Microbiology

In order to establish the presence (or absence) of fecal and non-fecal coliforms in our water samples, the m-coliBlue24 membrane filtration method – a test protocol devised by the U.S. Environmental Protection Agency – was used for testing. This test, if positive for fecal coliforms (i.e. creation of colony forming unit (CFU)) could indicate potential contamination from human or animal source, while non-fecal coliforms are expected from decomposition of organic material. Although the mere presence of fecal coliforms in of itself does not necessarily cause concerns, in sufficient number it may suggest the presence of more harmful bacteria. Water samples for this test were obtained during the first sampling event (October 31st, 2018), from all 4 stations including one replicate using sterile 100-ml Whirl-Pak plastic bags labelled prior to collection for ease and convenience in the field. Following field collection for microbiology, the samples were transported in an iced cooler to Vancouver Island University. The samples were then filtered through a 47-mm membrane (45 µm pore size) using standard sterile techniques. Next, this membrane was added to a 50-mm petri plate and saturated with the m-coliBlue24

broth in preparation for an incubation period of 24 hours at a temperature of 35^{o}C. Following incubation, the petri plate was visually inspected for the presence of red (non-fecal coliform) and blue colonies (fecal coliform or *E. coli*).

3.4 Stream Invertebrate Communities (Matt)

3.4.1 Invertebrate Sample Collection

Freshwater benthic macroinvertebrates are an important indicator of overall stream health. Benthos, as they are referred to, play a crucial role in the food chain and natural flow of energy and give dependable information on water quality and pollution past and present. For the purpose of this study, sampling occurred during our first sampling event (October 31st, 2018) and involved procuring data from station 2 and 3 only. It included 4 replicate samples form either sites for a total of 8 samples. A Hess Sampler was used to gather the inverts. Consideration was given to methodically sample moving upstream to obtain unbiased results. The procedures followed were those established in the Pacific Streamkeepers handbook (Department of Fisheries and Oceans, 2000).

3.4.2 Quality Assurance/Quality Control

As with the water quality procedures, rigorous practices ensure that the data obtained for the invertebrate sampling are accurate and free of interfering variables. Thus, quality assurances such as proper techniques were observed when working with the sampling gear ensuring that dislodged invertebrates were making their way into the collecting device. The site selection process also considered the type of substrate (ideally coarse gravels), and attention was given to

using similar substrates at each site. Furthermore, great care was taken when identifying the organisms contained in the samples in addition to being re-counted twice to ascertain the accuracy of the findings.

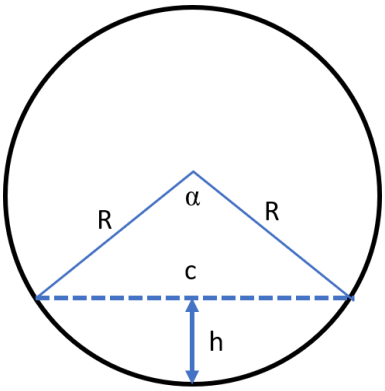
3.4.3 Data Analyses

The stream invertebrate collected were analysed at a VIU lab. The analysis entailed combining all the replicate samples from each separate site into two large samples. Identification and enumeration were aided by using a dissecting microscope and dichotomous keys, ensuring proper classification of the organisms within their respective taxonomic group. This analysis was conducted in accordance with the Pacific Streamkeepers procedures (Department of Fisheries and Oceans, 2000) resulting in abundance and density information, predominant taxon, diversity, and water quality assessment variables such as pollution tolerance index, EPT index, and EPT to total ratio index. In addition, the Shannon-Weiner Index was calculated to help in characterizing species diversity.

4.0 Results and Discussion

4.1 Hydrology (Ghislain)

Discharge measurements were performed at Site 4 as discussed in section 3.2. Flow was calculated using the culvert's radius, water height, and mean flow velocity; the latter was acquired using the floating object method over a 10-meter culvert length. To facilitate the completion of stream discharge measurements in the future, relevant measurements and equations used are represented below:



α = segment angle, calculated from c and R

c = chord length, (measured but not used in calculations)

R = culvert radius, 1.4 meters

v = stream velocity, measured using floating object method

h = height of water, (varies with flow volume)

The area below h is a *segment*, while the pie-shaped area within which the segment is, is a *sector*.

Figure 5: Culvert measurements for stream gauging purposes.

Area was calculated by subtracting the air-filled area of the *sector* from the sector's total area, yielding the *segment area* filled by water:

$$area\ of\ segment = area\ of\ sector - \ unfilled\ area\ of\ sector$$

$$area\ of\ segment = r^2 cos^{-1}(\frac{r-h}{r}) - (r-h)\sqrt{2rh-h^2}$$

Using the area thus obtained, volume was calculated by multiplying area and surface flow velocity, times a correction factor to account for the fact that a steam's fastest flow is at the surface. A correction factor of 0.90 (Michaud & Wierenga, 2005) was used on account of the smooth culvert bottom and the floating object penetrating to 2-5cm of the surface.

$$flow\ volume = wetted\ area * surface\ flow\ velocity\ at\ center * 0.90\ (correction\ factor)$$

The result of these calculations is represented in Table 3:

Table 3: Measured flow at Station 4.

	October 31, 2018	November 21, 2018
Wetted area	0.21 m^2	0.24 m^2
Flow velocity	1.14 m/s	1.05 m/s
Total discharge	0.22 m^3/s	0.23 m^3/s

As the previous year's discharge measurements were incomplete (including only wetted width and average depth for all sites *except* for Site 4), no comparison can be made at this time.

4.2 Water Quality (Matt)

4.2.1 Field Measurements

Field measurements were obtained during both sampling events at all sites for temperature and dissolved oxygen (DO) and are represented in Figure 6. The dissolved oxygen values were found to be ever increasing when comparing findings from Site 1 heading downstream towards Site 4 and the exiting of Beck Creek into the Nanaimo Estuary during both sampling events. A lowest value of 3.3 mg/L and highest of 9.4 mg/L where both found at Site 1 and 4 respectively during our second sampling event. It was found that when considering all sites, the average sample

mean was 6.8 mg/L (s±2.3) during the initial sampling, with a slight increase to 7.3 mg/L (s±2.8) in the following. These findings are congruent with the slow movement of poorly oxygenated water from eutrophic Beck Lake at the upstream sites, with increasing gradient resulting in oxygenation of the lower ones, resulting in higher DO from atmospheric diffusion and features such as riffles.

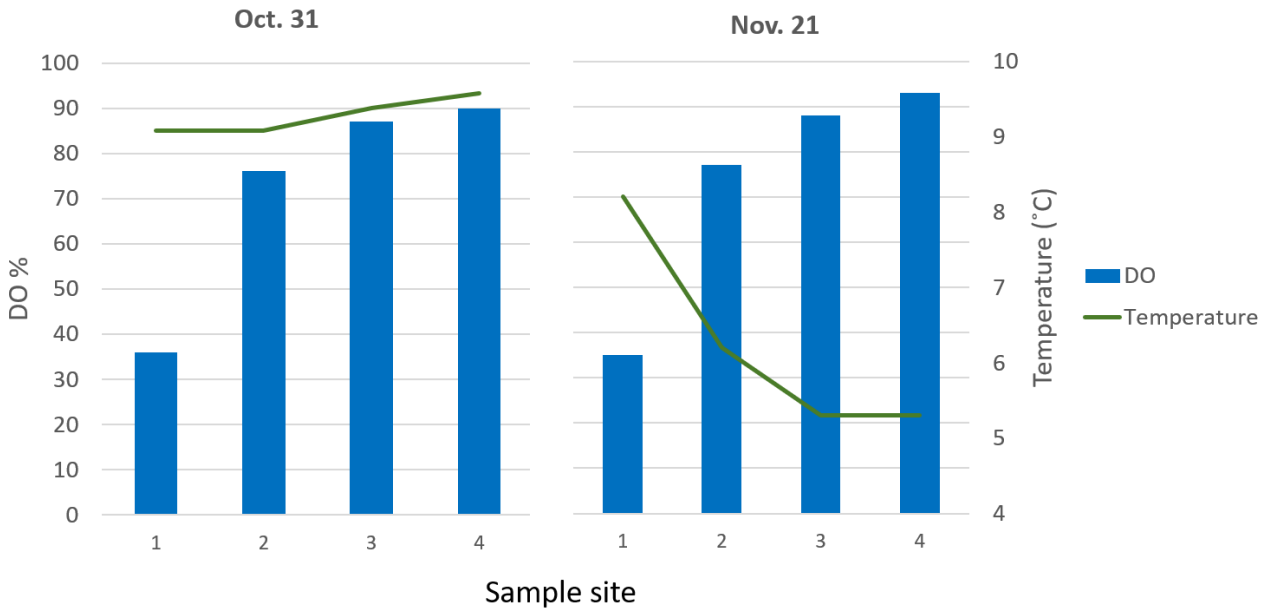


Figure 6: Temperature and dissolved oxygen (percent saturation) during both sampling events.

Although flow rates (refer to section 4.1) were similar during both events due to the fact that there was little in the way of meaningful rainfalls, the temperature of the water was found to have decreased between events with an average temperature of 9.3^{o} (s±0.2) on October 31st to 6.3^{o} (s±1.4) on November 21st, owing to a significant change in air temperatures prior to the second sampling event. Given these findings, although not exclusive of other influences, both field parameters showed a correlation between them as should be expected. The dissolved

oxygen increased as the water temperature declined, and in their sum, were found to be within a good range to support aquatic life (BCMWLAP, 1997).

4.2.2 Laboratory Analysis: VIU

The following section discusses the results that were obtained from the water analyses performed at Vancouver Island University lab on the same day as collection for both sampling events. In-text mentions, parameter explanations, and comparison to provincial guidelines have all been obtained from the British Columbia Water Quality Guidelines (BCMWLAP, 1997).

Turbidity, a relative measure of a liquid's clarity measured as Nephelometric Turbidity Units (NTU), is an important parameter to consider as increased levels (i.e. more suspended solids) give bacteria surface area on which to attach and grow from adversely affecting water quality. Our findings, as represented in Figure 7 were well within the provincial guidelines (max. increase 5 NTU if background ≤50 NTU) with our lowest result being 1.03 NTU at Site 1 during the second event, and 2.54 NTU at Site 4 during our October survey.

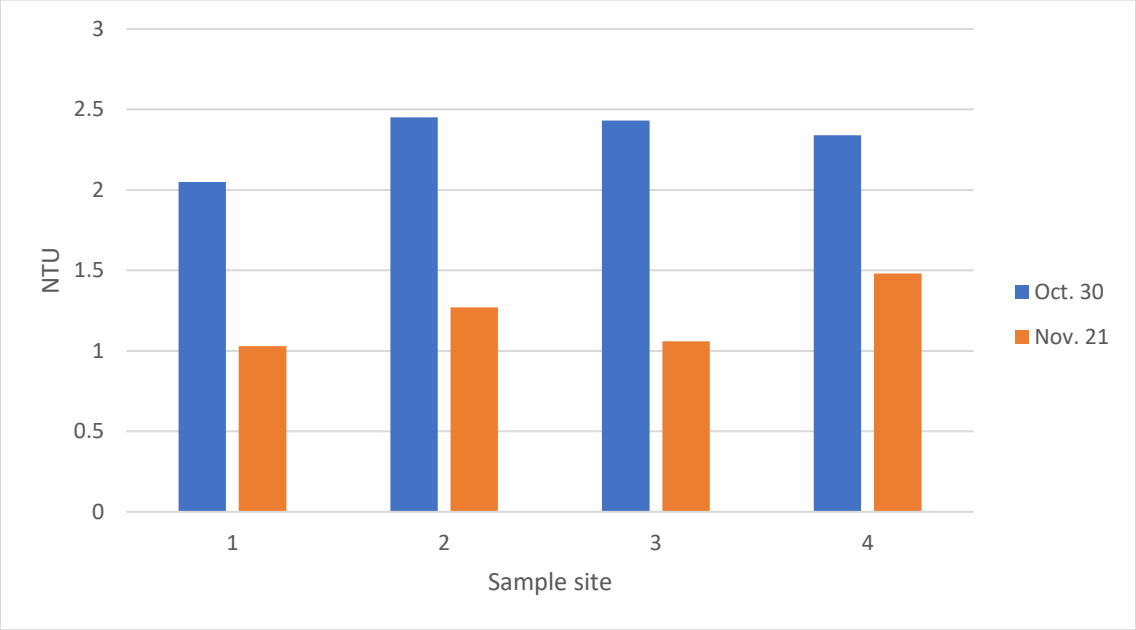


Figure 7: Turbidity at all sites for both sampling events.

On average, turbidity on October 31st was found to be 2.36 NTU (s±0.19) and 1.2 NTU (s±.018) on November 21st. This decrease in turbidity was marginal and overall water clarity adequate to sustain aquatic life. Our findings were also similar to the data collected in the 2017 Beck Creek water quality assessment conducted by the students of the RMOT 306 program (Miller, Keir, & Baildham, 2017). Viewed in conjunction with decreased water temperatures at the second sampling event, it seems likely that turbidity decreased due to decreased phytoplankton concentration.

Alkalinity, a measure of water's acid neutralizing capacity, is an important measure of a stream's ability to buffer acids. Typical values for coastal areas of this province are between 0 and 10 mg/L, with numbers reaching upwards of 100 mg/L for interior regions. Provincial guidelines stipulate that findings above 20 mg/L are indicative of water with low acid sensitivity

(little pH change with addition of acid), and as such act as a strong natural buffer system to watercourses against acidity induced issues. Our measurements, represented in Figure 8, showed numbers far above that low-sensitivity threshold with high (Site 1 Replicate) and low findings (Site 4) of 170 mg/L and 83.2 mg/L respectively during our second sampling effort more reflective of Interior lakes.

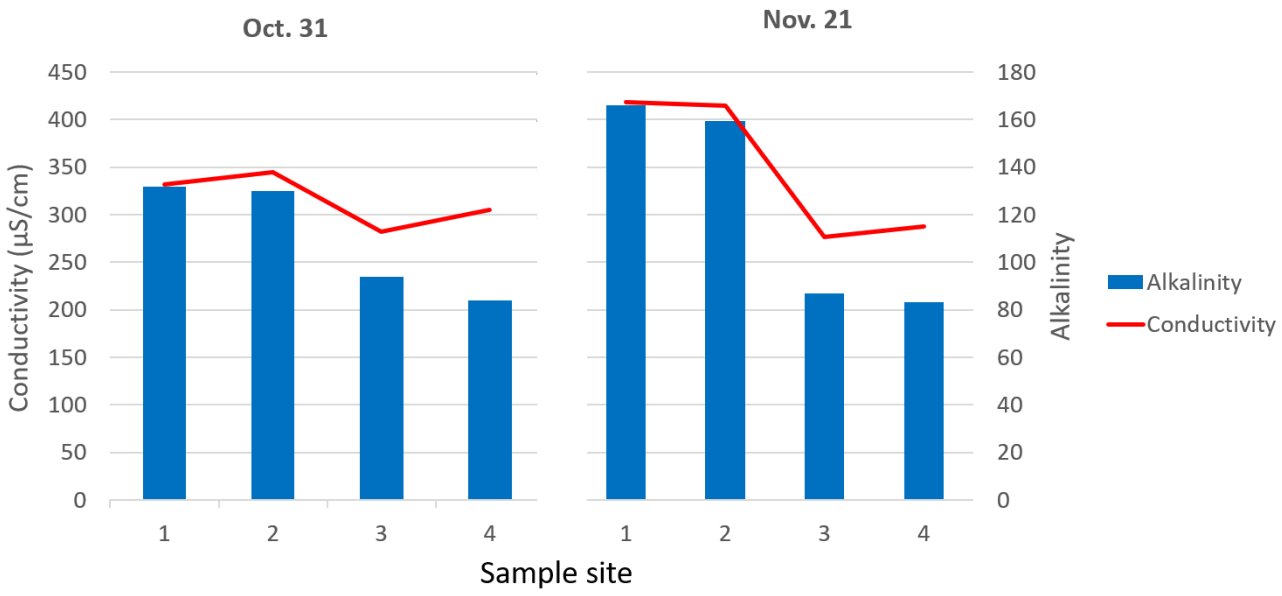


Figure 8: Alkalinity and conductivity values for all sites during both sampling events. Hardness, not represented, matched alkalinity perfectly, indicating that the two parameters are closely linked in Beck Creek.

The first and second sampling efforts yielded average alkalinities of 108 mg/L (s±21.77) and 133.12 (s±44.10) respectively. Last year's data (Miller, Keir, & Baildham, 2017) were found to be somewhat similar during their first sampling event, but noticeably lower (40-80.8 mg/L) during their November sampling likely due to rainfall events that were not observed this year in November.

Next, we conducted an analysis of the **hardness** of the water, a measure of divalent cations (mostly Ca^{2+} & Mg^{2+}), with our measurements all found to be within the provincial water quality guidelines between 60-120 mg/L. This is key as softer water (<60 mg/L) is conducive to making metals more toxic. In fact, hardness is used in conjunction with many metal counts for toxicity in aquatic life (e.g. Copper (Cu) — (0.094 x (hardness) + 2)/1000). Our efforts revealed hardness as low as 80 mg/L found twice at Site 4 during both events, and as high as 120 mg/L at Site 1 (and its replicate) and 2 during the November sampling. In their sum, the October sampling averaged 92 mg/L (s±12.96), while the later November one 104 mg/L (s±21.91) experiencing a slight increase in both average and variance. Hardness values are not represented graphically here as they mimic those of alkalinity; refer to Figure 8. All of our data for hardness was reasonably analogous to last year's findings (Miller, Keir, & Baildham, 2017).

We then turned our attention to **pH**, a measure of water's concentration of protons. pH is closely related to alkalinity, as the acid neutralizing capacity indicated by this parameter buffers against rises in proton concentrations (lowering pH). Low pH levels (<4.5) can be deadly to aquatic life by facilitating the dissolution of metals, while elevated values (>9) interfere with ionic processes. Values above neutral (pH 7) help to precipitate metals, forming salts, which sink rather than remain dissolved. Constant pH values are important as changes of one unit signifies a 10x increase in water's proton concentration.

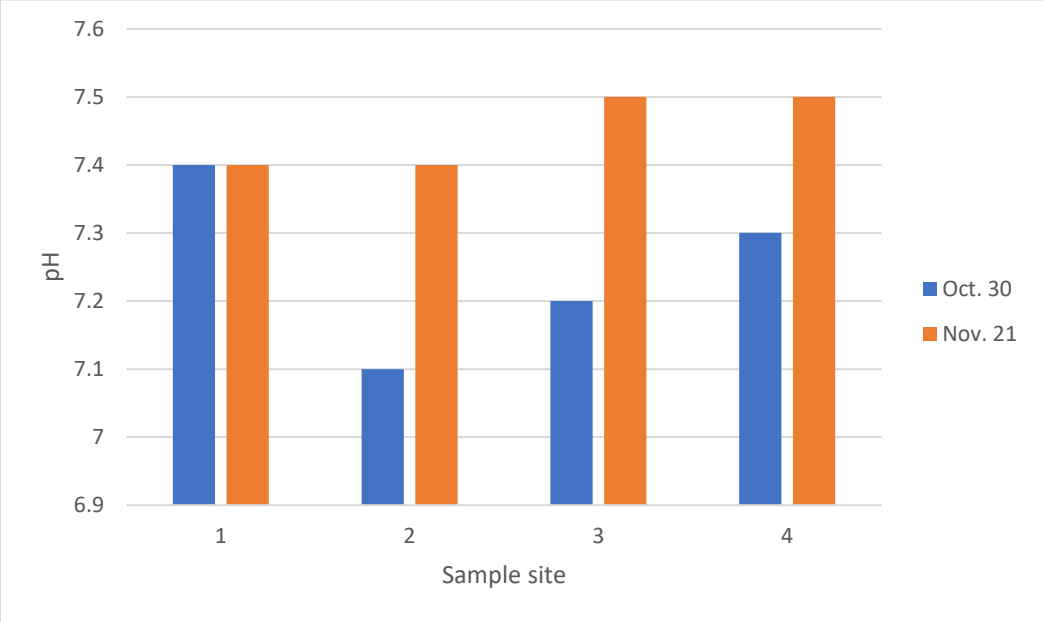


Figure 9: pH values for all sample sites during both sampling events.

Our findings across all sites during both dates averaged 7.4 pH (s±0.1) and were well within the desired provincial guidelines of pH 6.5-9 for aquatic life even conforming to drinking water standards (6.5-8.5 pH). Again, we found that our data was slightly above that expected of coastal water streams (5.5 to 6.5 pH), more closely resembling interior B.C lakes (>7 pH). Our findings corroborated last year's effort in documenting a pH level above typical values for coastal waterways (Miller, Keir, & Baildham, 2017).

Conductivity was then measured, and as with many of the parameters previously analysed, our conductivity findings (represented in Figure 8) were much higher than would be expected for a coastal stream. Even though natural waters are found to range widely between 50 to 1500 µS/cm, typical values for a coastal stream are equal or below to 100 micro Siemens. By way of contrast, our data were much higher even nearing high interior values (up to 500 µS/cm). Both our lowest

(277 µS/cm-Site 3) and highest (420 µS/cm-Site 1 replicate) recorded conductivity were obtained during the November sampling event. These high numbers mirrored last year's October sampling event as the state of the creek more closely resembled this year's low water level. Overall, the average specific conductivities were 315 µS/cm (s±25) and 364 µS/cm (s±74) respectively of our first and second sampling efforts, with the latter showing high variance amongst reflective of Site 1 and 3 large data gaps previously mentioned.

Lastly, **Nitrate (NO_3-) and Phosphate (PO_4^{3-})** measurements were obtained in the VIU lab. Nitrate and phosphate are the main form of nitrogen and phosphorus used by plants, and excessive levels of both can lead to eutrophication. Under optimal proportion, known as the Redfield Ratio of 16N:1P, plant growth is ideal. This ratio is often impeded by a lack of natural phosphorous unlike nitrate which can be found more readily in an ecosystem. Our results for nitrate were overall quite consistent with an average of 0.024 mg/L and almost no variance (s±0.01) well below any consideration for toxic level set at 200 mg/L (with an average of 40 mg/L) for aquatic life. Conversely, phosphate was found to be in high concentration averaging above eutrophic levels set at ≥0.025 mg/L under the British Columbia water quality guidelines with mean results of 0.09 mg/L (s±0.01) in October and 0.07 mg/L (s±0.03) in November.

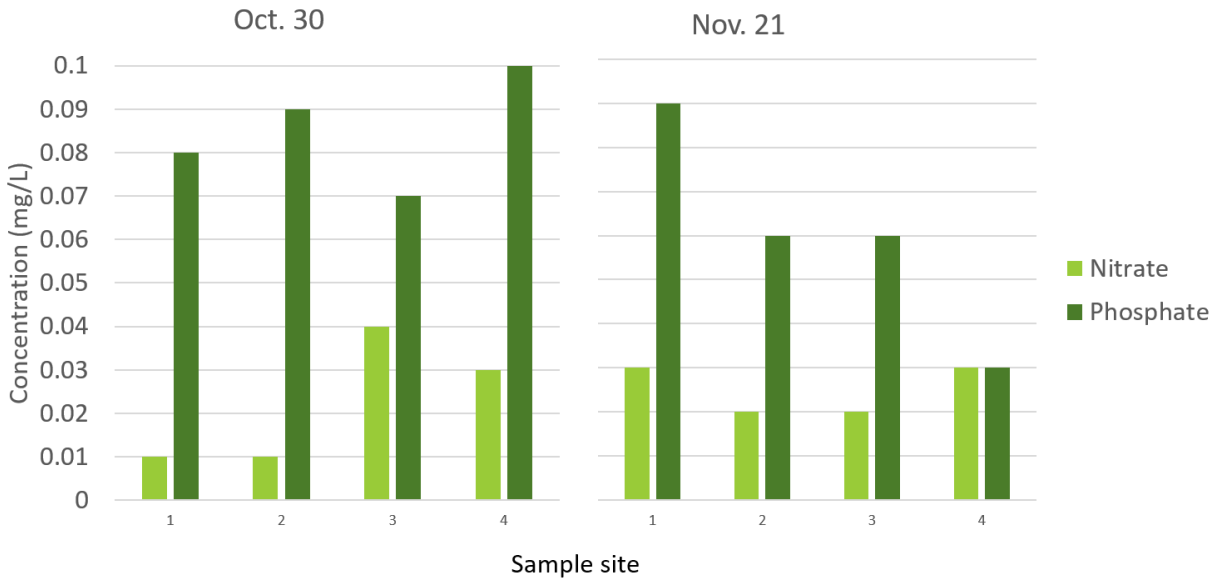


Figure 10: Nitrate and Phosphate concentrations measured at VIU for all sample sites and both sampling events. Total nitrogen:phosphate, as measured by ALS labs, are represented in Figure 11 and should take precedence over these results for nutrient analyses.

These results go against higher expected levels of nitrate as compared to phosphate under natural circumstances and is likely owed to the heavily mix-used setting of Beck Creek amidst agricultural and residential lands. Furthermore, it is important to mention that these analyses were not of total nitrate or phosphate, and in-lab errors may have also been produced inadvertently. As such, the ALS analyses will take precedent when compared, as their methodology and lower detection level (including accuracy) is greater.

4.2.3 Laboratory Analysis: ALS Labs

In addition to analysis efforts conducted at the VIU lab, samples from site 1 to 3 (from both sampling dates) were sent to ALS laboratory in Vancouver B.C., one of the largest environmental laboratory networks in the world with a 41,000 square-foot facility able to provide

analytical services with both organic and inorganic capabilities (ALS, 2018). A series of tests were conducted and then compared to the ones performed in-house. Of those, average conductivity was found to be similar to our results and consistently high for coastal streams, while average hardness was found ~20 mg/L lower in the ALS reports, but nonetheless within provincial guidelines (BCMWLAP, 1997). The pH results were also found to be in a comparable range, with the biggest discrepancy arising in the second sampling effort with a pH average of 8.11 (ALS) as compared to 7.43 (VIU).

Nutrient analyses beyond those performed at VIU were also requested, allowing for comparison with the addition of total ammonia (as N), nitrite (as N), as well as total nitrogen and phosphorus. October 31st results are represented in Figure 11: due to flow conditions reflecting the onset of fall rains prior to significant precipitation, these are presumed to accurately reflect Beck Lake's nutrient concentrations.

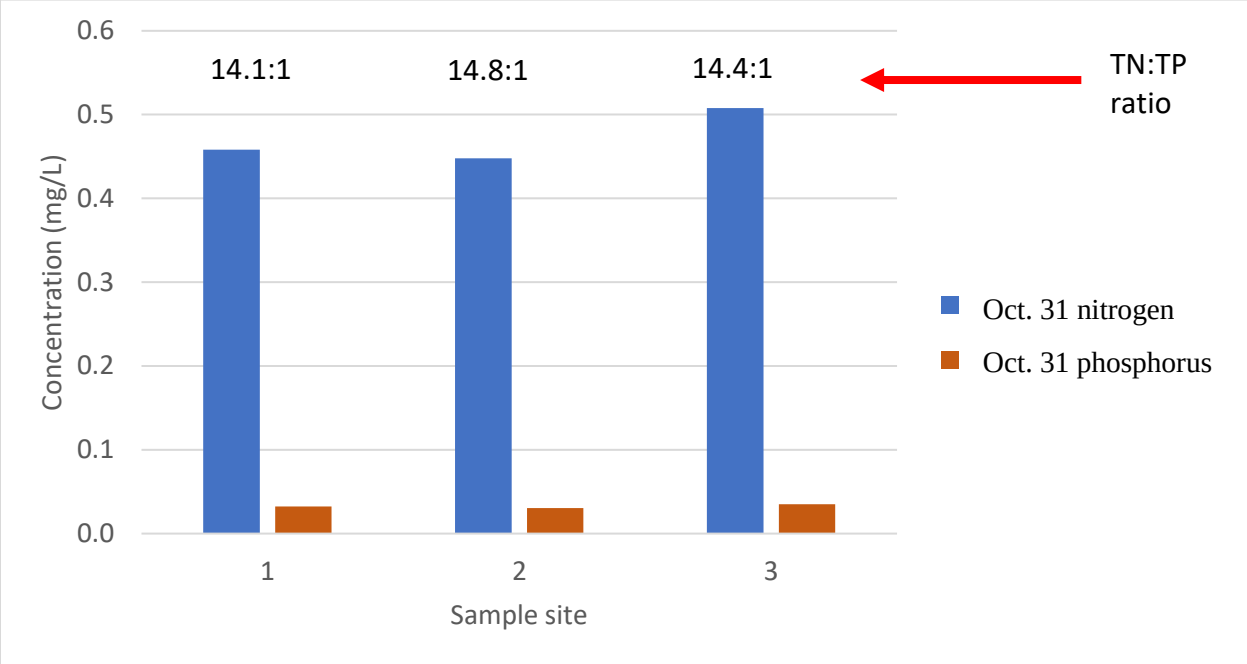


Figure 11: Total nitrogen to total phosphorus ratios at sites 1, 2, and 3 during October 31st sampling event. Results from ALS laboratory and are presumed to accurately reflect conditions within Beck Lake.

For both sampling events, ammonia and nitrite did not raise any concerns, but the average results for total phosphorus were high on both counts with levels exceeding the BCMWLAP aquatic life maximum threshold for aquatic life (15 µg/L) by 7 µg/L and 18 µg/L during sampling events 1 and 2, respectively. These results predict a eutrophic regime, corroborated by TN:TP ratios (as analyzed by ALS) all near the Redfield ratio of 16:1, ideal for algal growth and eutrophication.

ALS also performed an extensive review of dissolved metals. All-in-all, most were below minimum detection levels and thus of no concerns, while most detected were well below provincial guidelines. The exceptions is iron (Fe), found elevated during the October sampling event with a peak measure of 1.06 mg/L at Site 1 (BC aquatic life guidelines specify a short-term maximum of 0.35 mg/L (BCMWLAP, 2008)). Sodium (Na) levels were elevated but far below

threshold levels for adverse effects (BCMWLAP, 2003), averaging 52 mg/L in our samples. These elevated sodium levels are also a factor in the high conductivity values observed, and are likely present within Beck Lake/Creek from anthropogenic sources and/or from dissolution within the carbonate and sodium rich sedimentary rocks. Elevated iron levels may originate from the same source, but may also be due to the historical deposition of coal slag at the south end of the lake (see Background): coals are often iron rich, present as iron pyrite and highly mobile once exposed to oxygen.

4.2.4 Quality Assurance/Quality Control

All planned sampling, transportation, and lab methodologies were followed as per the proposal without deviation. The trip blanks did not indicate contamination in any meaningful way following analysis. The replicate sample size was in excess of the recommended minimum of 10%, and following careful analysis of the results, all were found well below the maximum reproducibility and accuracy 25% margin of error. The ALS samples were also sent, and results received, having maintained the chain-of-custody without any issues concerning continuity of evidence.

4.3 Microbiology (Niki)

4.3.1 Laboratory Analysis: VIU

For microbiology, all four stations mentioned previously were tested, with an additional replicate sample taken at Site 4. Samples were taken from the field only during our first visit, on October 31, 2018. Samples were collected using sterile 100 ml Whirl-Pak plastic bags filled below the

water surface. These bags were sterile, so it was not necessary to rinse prior to collection. Simply adding the water into the bag and twirling the top to close.

The samples were then taken to the laboratory at Vancouver Island University for analysis. To analyze the water samples for coliform, we used the m-coliBlue24 membrane filtration method (Hach Company, 2018) with a 24-hour incubation period. Firstly, we put the water through a filtered membrane, which then went through funnel that was operated with a vacuum pump. This was washed with sterile water before using. Secondly, a petri-dish with a wetted pad with the m-coliBlue 24 liquid on it was where the filtered membrane was then positioned on. The petri-dish with the membrane and m-coliBlue 24 liquid was then incubated for 24 hours in order to examine the amount of coliform in the water sample. The incubation period allows the coliform to grow on the membrane.

After incubation, we enumerated the colonies grown on the membranes. This method results in bacterial colonies of three colors: red, blue, and clear and/pink, shaped like small circles. The red colonies found on our membrane indicate coliform was found but does not express it is *E. coli*, while blue colonies specify the presence/abundance of *E. coli* within the water sample. Each dot is counted as one colony, and results reported as colony forming units/100 mL (CFU/100 ml). Coliform plate images can be found in the appendix of this report, and result represented below in Figure 12.

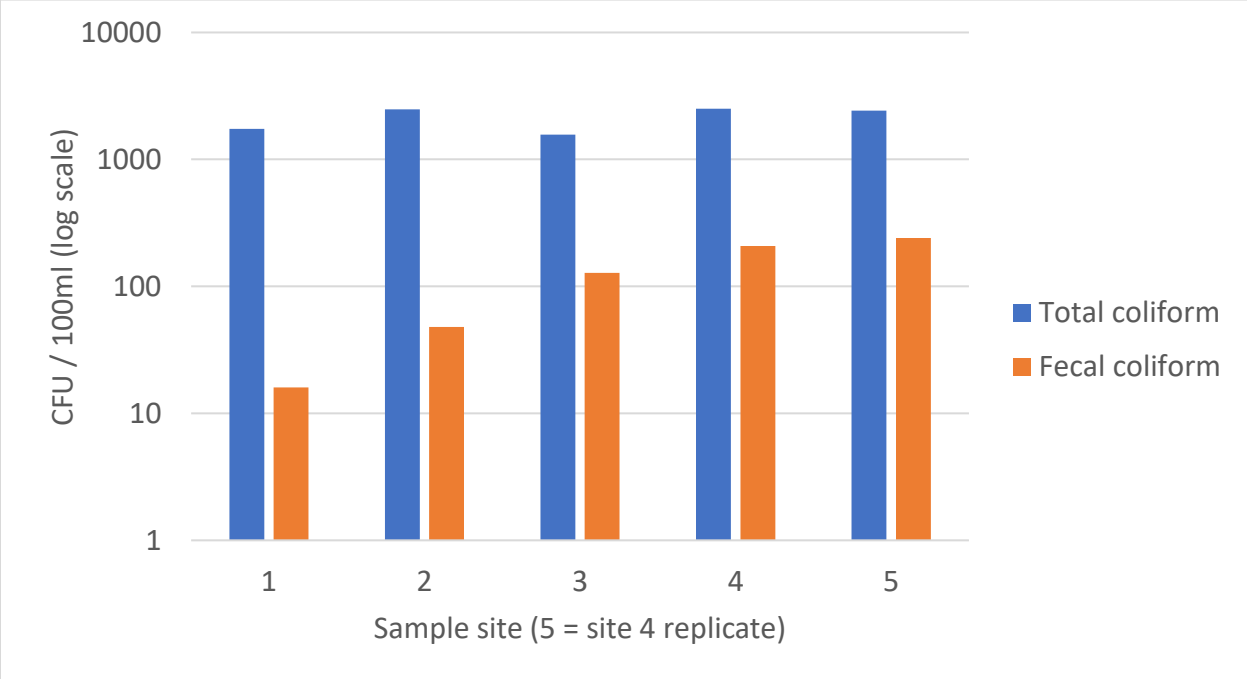


Figure 12: Total and fecal coliform counts for all sample sites, including Site 4 replicate (labelled as site 5 on graph). Note semi-log scale used.

4.3.2 Quality Assurance/Quality Control

Both quality assurance and quality control measures were ensured while both analyzing and collecting any samples in the laboratory and the field. Each element that was sampled and collected for this project had its own specific dates, locations, replicates, and bottles to prevent cross-contamination or sample mix-up. In order to guarantee quality assurance of the microbiology samples we collected, sterile While-Pak sample bags were, to make sure that the water we took from Beck Creek was non-contaminated. Bags were pre-labelled to indicate each site and reduce mix-up chance or confusion. The filled packs were then placed in a large cooler with other samples to keep them refrigerated until incubation.

4.4 Stream Invertebrate Communities (Niki)

4.4.1 Abundance, Diversity

Benthic, sentinel invertebrates are used to determine the number of stressors that are, or can be, present in aquatic environments. The invertebrates being sampled must be relatively sedentary, abundant, of acceptable size for chemical analysis of tissues, and have long life cycles (Eric Demers, class notes, 2018). Stream invertebrates are also useful because they are great bioindicators. Because their life cycles are commonly long, they bioaccumulate chemicals and stressors. The disadvantages of sampling invertebrates – their presence may be dependant on season and distribution is sporadic within a watercourse – should be considered, but do not outweigh their importance as health and biodiversity indicators. Although they are excellent habitat quality indicators, their presence in a stream can be variable as they lean toward specific habitat characteristics, such as riffles rather than pools or glides (Eric Demers, class notes, 2018).

Our group took invertebrate samples with a Hess Sampler at two sites only; Site 2 and Site 3. Samples were only taken during the first sampling event on October 31, 2018. Four replicate samples were taken at each site, for a total of eight samples. This ensured that we sampled a large enough area and enough times to collect a representative sample of invertebrates to analyze in the laboratory. Sampling was focussed on areas of the creek where the substrates and other habitat characteristics were similar. After each sampling event, the mesh of the sampler was rinsed and the remaining substrate/invertebrate sample was stored in pre-labelled containers to be taken back to Vancouver Island University to be analyzed.

Once the invertebrate samples reached the laboratory, the analyzing could continue. The organisms were placed into a larger white container where water was also poured into. This aided in finding the invertebrates by allowing them to swim or float throughout. The invertebrates were then taken out of the container with a plunger or tweezers and placed onto petri-dishes to be placed under a microscope. Placing them under the microscope allowed for a better visibility of the organisms. This made it substantially easier to identify the invertebrates and their taxa. This data was then filled onto an excel spreadsheet to determine the overall health of the stream.

Our samples produced an abundant number of invertebrates of different species and sizes. At our Site 2 sample we collected one hundred thirteen invertebrates from eight different groups/taxa. On the other hand, Site 3 samples were counted an even larger number of one hundred thirty invertebrates, from twelve groups/taxa. In both sampling sites we were able to observe a large diversity of invertebrates, including environmentally sensitive organisms such as stonefly nymphs and caddisfly, along with less sensitive amphipods and aquatic worms. The interpretation of the diversity and abundance of the invertebrate samples will be discussed in the following section.

4.4.2 Stream Health Analysis (Pacific Streamkeeper's Method)

The Pacific Streamkeeper's Method was used for the Beck Creek project because it is a straightforward, trouble-free method in comparison to other invertebrate analysis methods. This method involves using a spreadsheet along with calculations from abundance results to

determine the overall health of the stream. Using this method, we came to the conclusion that Site 2's predominant invertebrate were amphipods and that few environmentally sensitive taxa were found, with an overall Streamkeeper's site assessment rating of 1.75 (poor-marginal). The amphipod is a somewhat pollution tolerant organism, which is placed in category two. In Site 3, the most predominant invertebrate was the stonefly nymph, which was found alongside mayfly and caddisfly nymphs. The stonefly, in comparison to amphipods, is a category one organism, indicating that it is pollution intolerant. The stonefly, along with the mayfly and caddisfly, are the most intolerant invertebrates to pollution identified in the Streamkeeper' method. If these invertebrates are found in an aquatic ecosystem, they indicate that the ecosystem is rather healthy.

Stream health analysis was further quantified using the calculated Shannon-Weiner Index of each site sampled. The Shannon-Weiner Index can communicate to the researcher the balance of the diversity of the sample. In other words, it can tell us how even the amount of different species is compared to the number of organisms in the sample. For our Shannon-Weiner Index on Site 2, we received a number at 0.44, meaning the balance of diversity in the samples here are just under halfway even. At Site 3, our index number was calculated to be 0.48, which was slightly higher than that of Site 2, but still under 0.5. Both of these measures indicate a somewhat high degree of dominance by one/few species: numbers closer to 1indicate low species dominance, those approaching 0 indicate high dominance. All of the recording forms are to be found in the appendix.

4.4.2 Quality Assurance/Quality Control

Both quality assurance and quality control measures were taken when sampling the invertebrates both in the field and in the laboratory. All measures read throughout the project handouts were used in order to divert from possible issues that could arise. The proper measures were also used in order to keep continuity throughout to ensure the best samples were used for the project. All containers were pre-labelled in order to keep track of the samples per site. Each container with invertebrates were stored in a cooler after collection, to keep water cool and invertebrates alive. The replicates were taken to secure the diversity of samples in both Site 2 and 3.

5.0 Conclusions and Recommendations (Ghislain)

Overall Stream Habitat Quality Impressions

The health of Beck Creek and the quality of its aquatic environment overall was found to be acceptable for sustaining aquatic life; site quality assessment ratings ranged from Poor-marginal at Site 2 to Acceptable at Site 3 according to the Streamkeeper's method. Shannon-Weiner diversity indices of 0.44 and 0.48 indicate moderate dominance by a few species, with high prevalence of amphipods at Site 2 and stonefly nymphs at Site 3. These observations are only somewhat congruent with last year's survey (Miller, Keir, & Baildham, 2017), which found both higher species diversity – Shannon-Wiener indices of 0.55 for both sites – and lower Streamkeeper's site quality ratings of 1 for both streams.

Significant differences between sites was encountered with respect to stream temperature and dissolved oxygen concentrations, with Site 1 exhibiting warm temperatures and very low oxygen levels during both sampling events (3.x mg/L, too low for fish populations) and Site 2 still somewhat oxygen deficient. This oxygen deficiency at least partly explains the much lesser counts of environmentally sensitive taxa encountered at Site 2 compared to Site 3, and we suspect that sampling at Site 1 would reveal very few, low oxygen resistant taxa. This oxygen deficiency was also evident in the 2017 survey, though somewhat mitigated during the November sampling event due to precipitation flushing out poorly oxygenated water. This flushing did not happen to the same extent this year and both sampling events at Site 1 showed low oxygen concentrations.

We believe that the oxygen deficits encountered at sites 1 and 2 are directly attributable to upstream factors, namely the highly eutrophic conditions within Beck Lake. Supporting this, nutrient sample analyses reveal elevated nitrogen and phosphate levels, with phosphate levels particularly elevated compared to typical coastal natural conditions and a N:P ratio indicative of eutrophic conditions. Residential land use within the lake's catchment, which is densely inhabited for a rural area, as well as agricultural land uses are nearly certain to be the cause of this nutrient enrichment. Beck Creek's waters were also somewhat elevated in sodium, possibly due to road salting or to the presence of sodium within the surrounding sedimentary rocks; levels were not high enough to impair invertebrate or vertebrate aquatic life.

Recommendations for Future Improvements to Fish Habitat

Should the municipality or regional district desire, further improvements to fish spawning and rearing habitats could take three, non-exclusive forms: 1) improving water quality parameters with respect to oxygen, which would forcibly focus on improving conditions within Beck Lake; 2) further improvements to fish habitat in the lower half of the stream channel through side-channel construction, targeted introduction of coarse woody debris, and increasing the extent of gravel beds; and 3) removal or disruption of natural upstream migration barriers (beaver dams). It is important to note that estuarine conditions should also be examined to increase fish survival, as salmon fry spend significant time in this environment; however, this is beyond the scope of this study.

Recommendations Relating to Study Scope and Continuity

This study has clearly identified water exiting Beck Lake as an important, if not the most important, influence on sites within the upper half of the stream, but no data was found regarding water quality trends within the lake. Future studies would ideally sample Beck Lake, possibly during the onset of salmon migration to identify the extent to which water quality within the lake can impact fish habitat. As mentioned earlier, the estuarine environment could also be monitored due to its importance to salmon survival rates.

Large discrepancies were identified with respect to aquatic invertebrate communities between the two known studies of Beck Creek, performed last year (Miller, Keir, & Baildham, 2017) and

by us in 2018. Repeated sampling at the same sites is necessary to establish whether this is merely an artifact of poor sampling techniques during the 2017 study, a result of mis-matched insect hatching times, contamination which we failed to detect this year, or part of a larger trend of improving habitat quality. Closer monitoring of Beck Creek's hydrology could also be done relatively cheaply, which would help normalize invertebrate results against historically low or high flow prior to sampling. The culvert at Site 4 forms the ideal site to situate a constant-monitoring pressure transducer, which, combined with a few stream discharge measurements, would provide continuous discharge measures. Future studies could also incorporate testing for the presence of pesticides, herbicide and their residues, as well as non-natural organic pollutants such as hydrocarbons, all of which may be introduced from multiple sites within the watershed.

6.0 References

ALS. (2018). *ALS Vancouver Environmental*. Retrieved from ALS: https://www.alsglobal.com/ca/locations/americas/north-america/canada/british-columbia/vancouver-environmental

BCMWLAP. (1997). *Guidlines for Interpreting Water Quality Data.* Retrieved from https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/guidlines_for_interpreting_water_quality_data.pdf

BCMWLAP. (2003). Ambient water quality guidelines for chloride. Victoria, BC, Cananda: British Columbia Ministry of Environment. Retrieved from http://www.llbc.leg.bc.ca/public/PubDocs/bcdocs/366691/chloride.pdf

BCMWLAP. (2008). Ambiant Aquatic Life Guidelines for Iron. Victoria, BC, Canada: British Columbia Ministry of Environment. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/iron-or.pdf

BCMWLAP. (2013). *Ambient Freshwater and Effluent Sampling.* Retrieved from https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/part_e_water_and_wastewater_sampling_ambient_freshwater_and_effluent_sampling_simulate_template.pdf

Bednarsky, J. (2015). *Surficial Geology and Pleistocene stratigraphy from Deep Bay to Nanoose Harbour, Vancouver Island, British Columbia.* Geological Survey of Canada. doi:10.4095/295609

Blackman, R. (1980). *Lake Surveys: Nanaimo River Watershed.* Nanaimo: British Columbia Ministry of Environment. Retrieved from http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=33160

Cook, B., & Baldwin, J. (1994). *Chase to Nanoose Water Allocation Plan.* Nanaimo, BC: British Columbia Ministry of Environment, Lands, and Parks Vancouver Island Revion. Retrieved 10 22, 2018, from https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-planning/water_allocation_chase_nanoose.pdf

Department of Fisheries and Oceans. (2000). Module 4: Stream Invertebrate Survey. *The Streamkeepers Handbook and Modules*. (Pacific Streamkeepers Federation, Compiler)

North Vancouver, BC, Canada. Retrieved from https://www.pskf.ca/publications/Module04.pdf

Environment Canada. (2018). *Canadian Climate Normals 1981-2010.* Retrieved 07 20, 2018, from Environment Canada: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=189&autofwd=1

GeoBC. (2018). *iMapBC.* Victoria: British Columbia Provincial Government. Retrieved 2018, from https://maps.gov.bc.ca/ess/hm/imap4m/

Hach Company. (2018). Simultaneous Detection and Enumeration of Total Coliforms and Escherichia coli using m-ColiBlue24 Membrane Filtration Medium. *Hach Company Method 10029*. Loveland, Colorado, USA: Hach GmbH. Retrieved from https://www.hach.com/asset-get.download-en.jsa?id=53201915602

Irvine, J., Bailey, R., Imhof, D., Dalziel, F., Pennell, W., & Chestnut, C. (1994). *Coho Salmon (Oncorhynchus kisutch) Spawning Enumeration and Related Studies at Chase River and Beck Creek, Vancouver Island.* Nanaimo: Department of Fisheries and Oceans. Retrieved from http://www.dfo-mpo.gc.ca/Library/181095.pdf

Michaud, J. P., & Wierenga, M. (2005). *Estimating Discharge and Stream Flows.* Union Gap, Washington: Washington State Department of Ecology. Retrieved from https://fortress.wa.gov/ecy/publications/documents/0510070.pdf

Miller, J., Keir, A., & Baildham, A. (2017). *Water Quality and Stream Invertebrate Assessment for Beck Creek.* Nanaimo.

Miller, J., Keir, A., & Baildham, A. (2017). *Water Quality and Stream Invertebrate Assessment for Beck Creek, Nanaimo, BC.* Nanaimo: Vancouver Island University.

Nanaimo News Bulletin. (2012). River stewards spruce up Beck Creek. Nanaimo, BC.

Regional District of Nanaimo. (2018). *Regional District of Nanaimo WaterMap*. Retrieved from Regional District of Nanaimo: https://www.rdn.bc.ca/watermap

7.0 Appendix

Appendix A: Laboratory Results

Tables of VIU and ALS laboratory results

Table 4: VIU laboratory analysis of water samples for both sampling events.

	Site 1		Site 2		Site 3		Site 4		Site 4 replicate	Site 1 Replictae	Blanks					
	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd event	1st Event	2nd Event	1st event sample mean	2nd event sample mean	SD 1st event	SD 2nd event
time aquired	08:30		09:00		09:45		10:15		10:15		N/A					
time measured	14:00 to 17:00		14:00 to 17:00		14:00 to 17:00		14:00 to 17:00		14:00 to 17:00	14:00 to 17:00	14:00 to 17:00					
nitrate	0.01	0.03	0.01	0.02	0.04	0.02	0.03	0.03	0.04	0.01	0	0.02	0.03	0.02	0.02	0.01
phosphate	0.08	0.09	0.09	0.06	0.07	0.06	0.1	0.03	0.09	0.1	0.01	0	0.09	0.07	0.01	0.03
turbidity	2.05	1.03	2.45	1.27	2.43	1.06	2.34	1.48	2.54	1.17	0.16		2.36	1.20	0.19	0.18
hardness	108	120	104	120	84	80	80	80	84	120	0		92.00	104.00	12.96	21.91
alkalinity	132	166	130	159.6	94	86.8	84	83.2	100	170	4		108.00	133.12	21.77	44.10
pH	7.4	7.4	7.1	7.4	7.2	7.5	7.3	7.5	7.3	7.4	8		7.26	7.44	0.11	0.05
conductivity	332	418	345	415	282	277	305	288	310	420	0		314.80	363.60	24.51	74.16
coliform fecal/100ml	16		48		128		208		240				128.00		97.32	
total coliform/100ml	1744		2480		1568		2512		2416				2144.00		451.13	

Table 5: In-field measurements of oxygen and temperature for both sampling events.

	Site 1		Site 2		Site 3		Site 4	
	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event
time	08:30	08:40	09:00	09:00	09:45	09:45	10:15	09:20
DO %	36	35	76	77	87	88	90	93
DO mg/L	3.4	3.3	7.2	7.6	8.1	9	8.4	9.4
Temperature	9.1	8.2	9.1	6.2	9.4	5.3	9.6	5.3

	Ave. 1st	Ave. 2nd	SD 1st event	SD 2nd event
Mean DO	6.78	7.33	2.31	2.79
Mean Temp	9.30	6.25	0.24	1.37

Table 6: ALS water sample analyses for both sampling events.

Client Sample ID			BECK CREEK - STATION 1		BECK CREEK - STATION 2		BECK CREEK - STATION 3	
Date Sampled			31-Oct-18	21-Nov-18	31-Oct-18	21-Nov-18	31-Oct-18	21-Nov-18
Time Sampled			09:00	09:00	09:00	09:00	09:00	09:00
ALS Sample ID			L2190536-1	L2200252-1	L2190536-2	L2200252-2	L2190536-3	L2200252-3
Parameter	" Lowest De	Units	Water	Water	Water	Water	Water	Water
Physical Tests (Water)								
Conductivity	2	uS/cm	350	448	349	442	304	291
Hardness (as CaCO3)	0.5	mg/L	87.4	88.3	87.3	88.1	81.1	63.5
pH	0.1	pH	7.32	8	7.62	8.23	7.7	8.11
Anions and Nutrients (Water)								
Ammonia, Total (as N)	0.005	mg/L	0.0236	0.0553	0.0124	0.0337	0.0062	0.0116
Nitrate (as N)	0.005	mg/L	0.0056	0.0084	0.0096	0.0161	0.098	0.0421
Nitrite (as N)	0.001	mg/L	<0.0010	0.0012	<0.0010	0.002	0.0013	<0.0010
Total Nitrogen	0.03	mg/L	0.458	0.419	0.448	0.391	0.508	0.414
Orthophosphate-Dissolved (as P)	0.001	mg/L	0.0122	0.0153	0.0124	0.0113	0.0086	0.0056
Phosphorus (P)-Total	0.002	mg/L	0.0325	0.0284	0.0303	0.0229	0.0352	0.0153
N:P	N/A	N/A	14.1	14.8	14.8	17.1	14.4	27.1
Total Metals (Water)								
Aluminum (Al)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Antimony (Sb)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Arsenic (As)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Barium (Ba)-Total	0.01	mg/L	0.044	0.048	0.043	0.044	0.037	0.028
Beryllium (Be)-Total	0.005	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bismuth (Bi)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Boron (B)-Total	0.1	mg/L	0.1	0.13	<0.10	0.12	<0.10	<0.10
Cadmium (Cd)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Calcium (Ca)-Total	0.05	mg/L	25.8	26.1	25.8	26	23.6	18.2
Chromium (Cr)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Cobalt (Co)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Copper (Cu)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Iron (Fe)-Total	0.03	mg/L	1.06	0.558	0.854	0.457	0.917	0.371
Lead (Pb)-Total	0.05	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Lithium (Li)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Magnesium (Mg)-Total	0.1	mg/L	5.59	5.62	5.56	5.61	5.39	4.38
Manganese (Mn)-Total	0.005	mg/L	0.0833	0.096	0.0686	0.058	0.0773	0.0281
Molybdenum (Mo)-Total	0.03	mg/L	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Nickel (Ni)-Total	0.05	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus (P)-Total	0.3	mg/L	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium (K)-Total	2	mg/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Selenium (Se)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Silicon (Si)-Total	0.1	mg/L	8.42	7.15	8.25	7.11	6.88	5.16
Silver (Ag)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium (Na)-Total	2	mg/L	53.9	68.3	49.2	65.7	38.6	35.9
Strontium (Sr)-Total	0.005	mg/L	0.297	0.387	0.308	0.368	0.236	0.204
Thallium (Tl)-Total	0.2	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Tin (Sn)-Total	0.03	mg/L	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Titanium (Ti)-Total	0.01	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Vanadium (V)-Total	0.03	mg/L	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Zinc (Zn)-Total	0.005	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Qualifier Legend								
HTC	Hardness was calculated from Total Ca and/or Mg concentrations and may be biased high (dissolved Ca/Mg results unavailable).							

Table 7: Site 2 stream invertebrate sampling results.

Stream Name:	Beck Creek	Date:	Oct. 31 2018
Station Name:	Site 2	Flow status:	medium

Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates
Hess	4	0.36 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1 **Pollution Intolerant**	Caddisfly Larva (EPT)	2	1
	Mayfly Nymph (EPT)	8	1
	Stonefly Nymph (EPT)	9	2
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		19	4
Category 2 **Somewhat Pollution Tolerant**	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	6	1
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	71	1
	Watersnipe Larva		
Sub-Total		77	2
Category 3 **Pollution Tolerant**	Aquatic Worm (oligochaete)	17	2
	Blackfly Larva		
	Leech		
	Midge Larva (chironomid)		
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		17	2
TOTAL		113	8

Table 8: Site 3 stream invertebrate sampling results.

Stream Name:	Beck Creek	Date:	Oct. 31 2018
Station Name:	Site 3	Flow status:	medium

Sampler Used:	Number of replicates	Total area sampled (Hess, Surber = 0.09 m^2) x no. replicates
Hess	1	0.36 m^2

Column A Pollution Tolerance	Column B Common Name	Column C Number Counted	Column D Number of Taxa
Category 1 **Pollution Intolerant**	Caddisfly Larva (EPT)	7	2
	Mayfly Nymph (EPT)	21	1
	Stonefly Nymph (EPT)	41	3
	Dobsonfly (hellgrammite)		
	Gilled Snail		
	Riffle Beetle		
	Water Penny		
Sub-Total		69	6
Category 2 **Somewhat Pollution Tolerant**	Alderfly Larva		
	Aquatic Beetle		
	Aquatic Sowbug		
	Clam, Mussel		
	Cranefly Larva	1	1
	Crayfish		
	Damselfly Larva		
	Dragonfly Larva		
	Fishfly Larva		
	Amphipod (freshwater shrimp)	34	1
	Watersnipe Larva		
Sub-Total		35	2
Category 3 **Pollution Tolerant**	Aquatic Worm (oligochaete)	19	2
	Blackfly Larva	6	1
	Leech		
	Midge Larva (chironomid)	1	1
	Planarian (flatworm)		
	Pouch and Pond Snails		
	True Bug Adult		
	Water Mite		
Sub-Total		26	4
TOTAL		130	12

Incubated coliform bacterial plate images

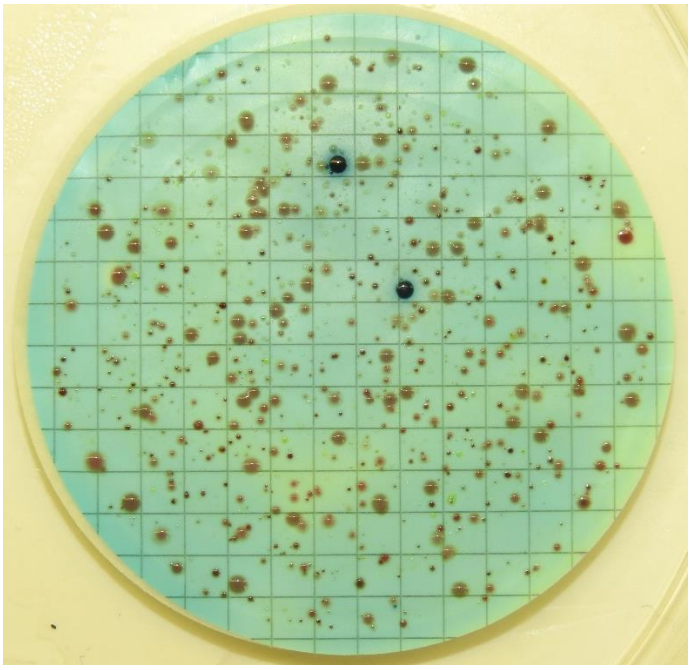


Figure 13: Site 1 bacterial plate

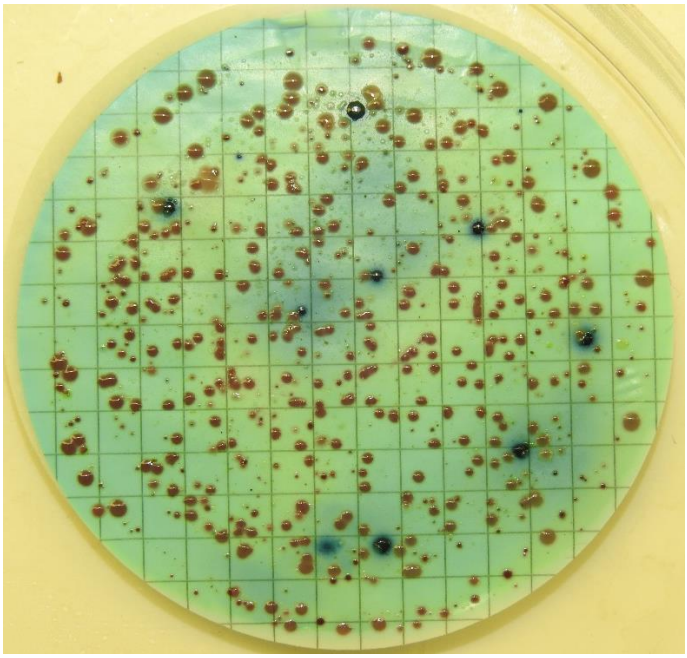


Figure 14: Site 2 bacterial plate.

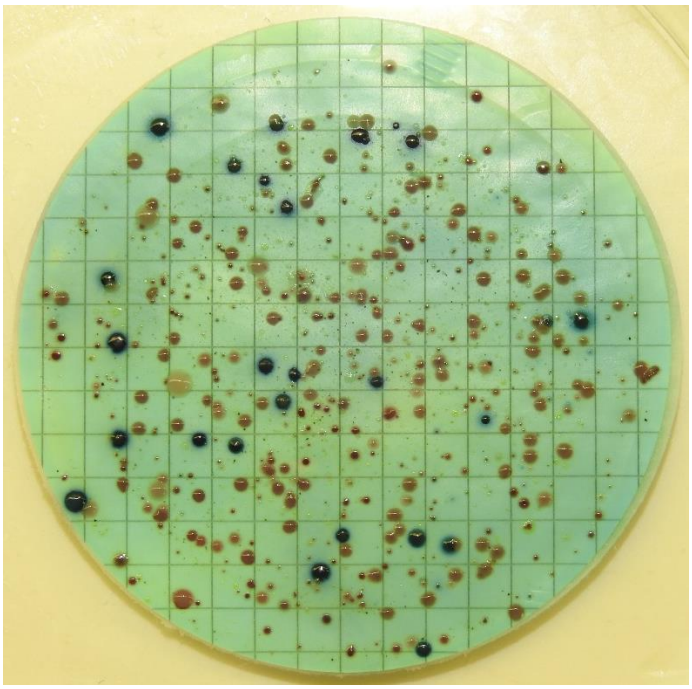


Figure 15: Site 3 bacterial plate.

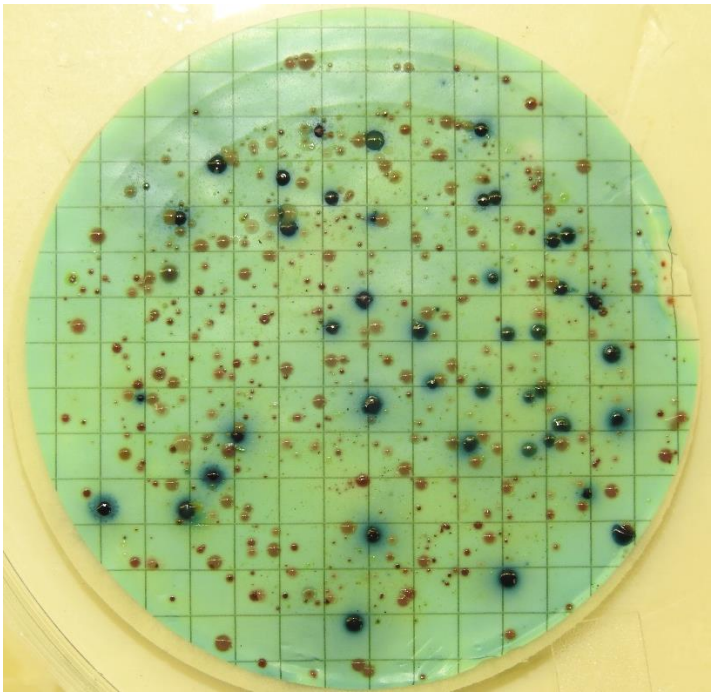


Figure 16: Site 4 bacterial plate.

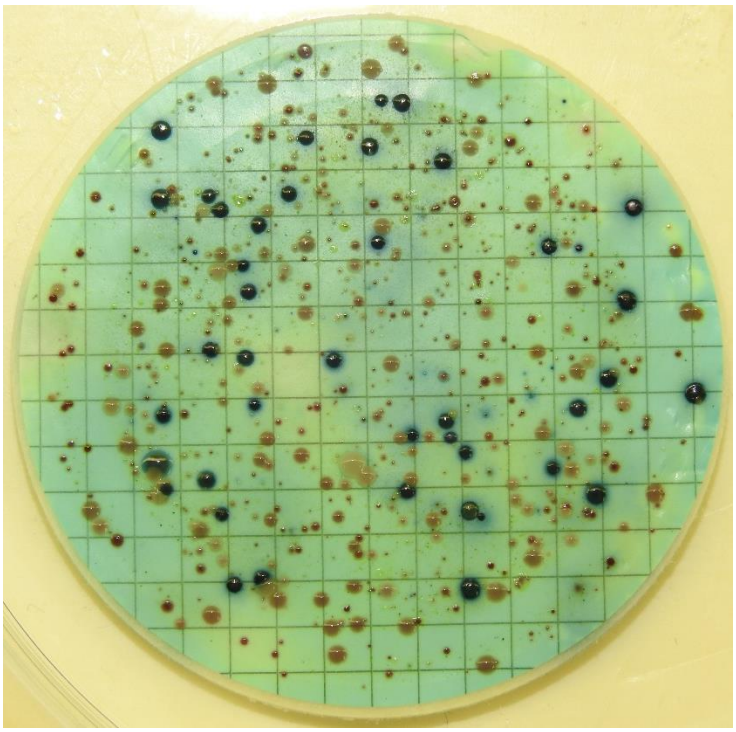


Figure 17: Site 4 replicate bacterial plate.

Appendix B: Preliminary Site Assessment, October 17th 2018

This section originally appeared in the Proposal for Water Quality and Invertebrate Monitoring of Beck Creek, Nanaimo BC submitted on October 22nd.

Site Safety and Hazard Assessment

Safety and cautionary arrangements must be discovered, assessed, and discussed prior to commencing the sampling portion of this project. The safety of the students is taken seriously, and many factors are taken into account. Before entering and departing the Beck Creek site, a text message must be sent to professor Eric Demers regarding who is accounted for to ensure all students are unharmed. For all the sites being used for this project, there are a number of concerns that must be addressed. These concerns comprise of: the accessibility of the site, traffic levels, various hazards, the depth and flow of the creek, and footing. Precautions are listed below in Table 9.

Table 9: Safety concerns for each of the four sites in Beck Creek, BC noted during preliminary inspection on October 17, 2018.

Site Location	1	2	3	4
Entrance	Easy/Medium	Easy	Easy	Easy/Medium (Tide Dependent)
Traffic	Little to None	Little to None	Little (Highway Nearby)	Very High
Hazards	- Culvert - Weather - Railroad	- Culvert - Glass/Garbage - Nearby Highway - Other Individuals	- Steep Slope - Large Culvert - Slippery Logs - Garbage - Loose Gravel	- Traffic - Large Culvert - Moving Tide - Parking on Road
Flow/Depth	Slow/Deep	Swift/Deep	Swift/Deep (In Areas)	Slow/Deep (In Areas)
Footing	Fair	Poor (Embankment)	Poor (Embankment)	Fair

Appendix C: Photos of all four sampling sites on Beck Creek in Nanaimo, B.C., on October 17, 2018.

Figure 18: Downstream of culvert at Site 1.

Figure 19: Downstream of culvert at Site 2.

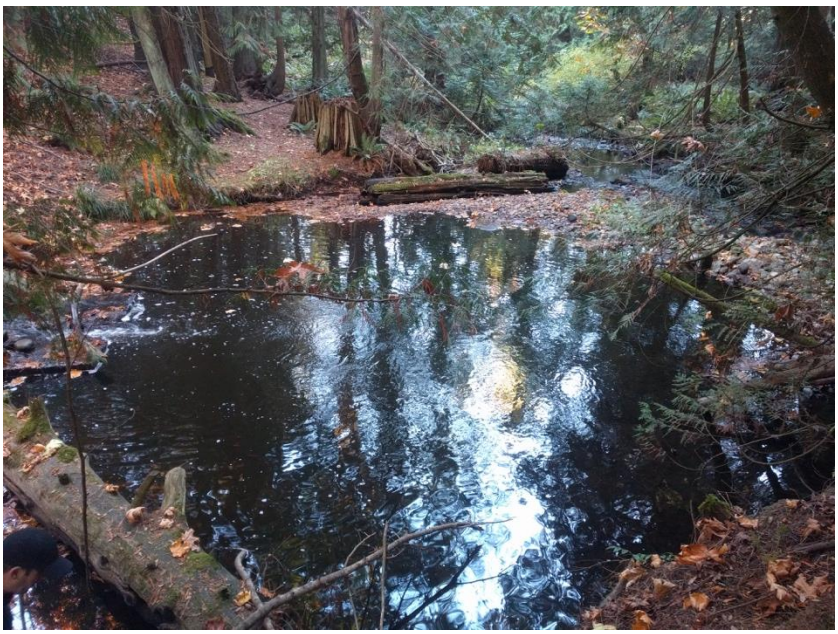


Figure 20: Pool and cobble below culvert at Site 3.

Figure 21: Downstream end of culvert at Site 4 (tidewater).