Water Quality and Flow of
Elk/Beaver Lake Tributaries and Outflow
From 2014 to 2021

Coastal Collaborative Sciences

a Division of World Fisheries Trust

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December 29, 2021

Executive Summary

Elk/Beaver Lake is the principal recreational lake in the Capital Regional District of Victoria, BC, Canada. It has had ongoing water quality issues with eutrophication for decades, contributing to increased blue-green algal blooms. There are several government and stewardship groups involved in attempting to improve water quality in the lake, but there has not been a consolidated summary of historical water quality for its tributaries. This report aims to summarize this existing data and serve as a baseline to assess the effectiveness of future mitigative measures.

There are four main inputs into Elk/Beaver Lake: O'Donnell Creek, Haliburton Brook, Hamsterly Creek, and Linnet Creek. The main contributor of both water and nutrients to the Lake is O'Donnell Creek, while the outflow is Colquitz River.

Internal and external nutrient loading in Elk/Beaver Lake is the primary cause of water quality problems, with as much as 30% of nutrients brought in from inflowing streams. This report compares all publicly accessible water quality data from May 2014 to Oct 2021 for the streams flowing into and out of Elk/Beaver Lake. Water quality monitoring and subsequent data has been sporadic, with the most robust data coming from the Peninsula Streams Society in 2014 and 2015. The British Columbia Ministry of Environment, the Capital Regional District, and the Beaver Elk Environmental Stewards all contributed more recent data.

Data in this report were compared to BC Ministry of Environment and Climate Change Strategy Water Quality Guidelines for the protection of aquatic life, except for the use of *E. coli* guidelines for human health in recreational water. Nutrients, including nitrite and phosphorus, as well as *E. coli*, were found to be above water quality guidelines, with phosphorus being the most problematic and above water quality objectives for Vancouver Island in every sample. Phosphorus has also been the biggest water quality problem in Elk/Beaver Lake, as it is likely responsible for blue-green algal blooms. O'Donnell Creek was found to be the largest contributor of phosphorus amongst the four inflowing streams. Colquitz River also showed elevated levels of phosphorus, well above Vancouver Island water quality objectives. Water quality of Elk/Beaver Lake may be negatively impacting downstream habitats.

The water quality measures of special concern in the Elk/Beaver tributaries are the following:

- *E. coli* – exceedances of 5-10- and 3-4-times guideline maximums in Haliburton Brook and O'Donnell Creek, respectively. *E. coli* in streams indicates fecal contamination.
- Nitrite – above guidelines in Haliburton in fall/winter months of 2014/2015, all other streams data were limited to one or two samples – more data are needed. Nitrite impacts sensitive fish fry.
- Phosphorus – well above Vancouver Island water quality objectives in every sample from every year in Haliburton Brook, O'Donnell Creek, Hamsterly Creek, and Colquitz River. High phosphorus levels contribute to poor water quality and promote the growth of blue-green algae

Increasing monitoring resources, capacities and coordination between the various organizations stewarding the Elk/Beaver Lake watershed, including community groups and non-governmental organizations, is recommended as the first step to improving water quality in Elk/Beaver Lake, its tributaries and outflow. Key specific recommendations identified by the current data summary include:

1. Design a directed water quality monitoring program to identify and inform the resolution of key problems. For example, phosphorus sampling should happen during peak agricultural activity, 5/30 sampling and investigative source tracing should be carried out upstream to determine high E. coli, nitrite and phosphorus origins.
2. Standardize methodologies and parameters being measured between stewardship groups. Phosphorus, in particular, requires a cost-effective standard approach.
3. Monitor throughout the year, rather than only in the summer, as is currently recommended in the Capital Regional District's Elk/Beaver Lake watershed management plan.

4. Other water quality parameters that should be regularly monitored are: dissolved oxygen, dissolved organic carbon, pH, conductivity, turbidity, temperature, total nitrogen, ammonia, and metals. Monitoring for 6PPD-quinone, a recently discovered toxicant from tire wear, should also be considered due to its toxicity to coho salmon and the proximity of the highway to Elk/Beaver Lake.

Effective watershed management and stream restoration are mitigative tools that can improve water quality in the Elk/Beaver Lake watershed. Water quality monitoring is therefore essential for identifying problems and trends, as well as assessing the effectiveness of mitigation measures. Engagement with and the education of landowners is likely to play a key role in the success of any mitigative plans and actions. The contribution and/or leadership of NGOs and community stewardship groups will be essential for effective implementation of mitigative efforts to face the challenges within the Elk/Beaver Lake watershed.

Acknowledgements

Stewardship and water quality management of the tributaries and outgoing stream for Elk/Beaver Lake are shared by many groups and individuals, including: the Beaver Elk Environmental Stewards (BEES), the British Columbia Ministry of Environment and Climate Change (BC ENV), the Capital Regional District (CRD), Coastal Collaborative Sciences (a Division of World Fisheries Trust), the Victoria Golden Rods and Reels (VGRR), and the Peninsula Streams Society (PSS). All data in this report were gathered by Mick Collins of the VGRR, and his guidance and support made this report possible. CRD data was provided by Barri Rudolph. PSS data and support were provided by Brian Koval, Kyle Armstrong and Katrina Adams. BEES data and support were provided by Jamie Disbrow. Neil Goeller of BC's Ministry of Forest Lands Natural Resource Operations and Rural Development (FLNROD) provided flow data for this report. Thanks to Heather Wright of Coastal Collaborative Sciences, and Ania Javorski of POLIS for their editorial support. Special thanks to Sara Stallard of Fish Kissing Weasels Environmental and Yogi Carolsfeld and Pradnya Sawant from World Fisheries Trust for their expertise and guidance.

This report was commissioned by Coastal Collaborative Sciences, a Division of World Fisheries Trust. Coastal Collaborative Sciences acknowledges and respects the Songhees, Esquimalt, T'Sou-ke, WSANEC and other First Nations peoples on whose traditional and unceded territories we work and whose historical relationships with the land continue to this day.

Coastal Collaborative Sciences, a Division of World Fisheries Trust, acknowledges the financial support from the Province of British Columbia and the Habitat Conservation Trust Foundation to this project through the Conservation Economic Stimulus Initiative.

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List of Abbreviations

Abbreviation	Definition
6PPD	6-*p*-phenylenediamine
BC ENV	British Columbia Ministry of Environment and Climate Change Strategy
BEES	Beaver Elk Environmental Stewards
CCME	Canadian Council of Ministers of the Environment
CFU	Colony Forming Units
CO_3	Carbonate
CRD	Capital Regional District
CTV	Canadian Television Network
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOI	Digital Object Identifier
EMS	Environmental Management System
EPt	Environmental Professional in Training
FLNROD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
ID	Identification
NGO	Non-Governmental Organization
NH_3	Ammonia
NH_4	Ammonium
NO_2	Nitrite
NO_3	Nitrate
NTU	Nephelometric Turbidity Unit
PCR	Polymerase Chain Reaction
PNAS	Proceedings of the National Academy of Sciences
PO4	Phosphate
PSS	Peninsula Streams Society
QA/QC	Quality Assurance/Quality Control
SC	Specific Conductivity
T	Temperature
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United States Geological Survey
USU	Utah State University
VGRR	Victoria Golden Rods and Reels
VI	Vancouver Island
WMP	Watershed Management Plan
WQG	Water Quality Guideline
WQO	Water Quality Objective
WRWC	Water Research Watershed Center

1 Introduction

1.1 Background

Elk/Beaver Lake Regional Park, located in the Capital Regional District (CRD) (*Fig.1*), is a popular visitor destination that offers recreational activities including boating, swimming, horseback riding, hiking and fishing. Historically the lake naturally contained coho and cutthroat, but currently it is stocked with rainbow trout, and also contains yellow perch, largemouth bass, bullhead, smallmouth bass, and pumpkinseed (Hemmera, 2017).

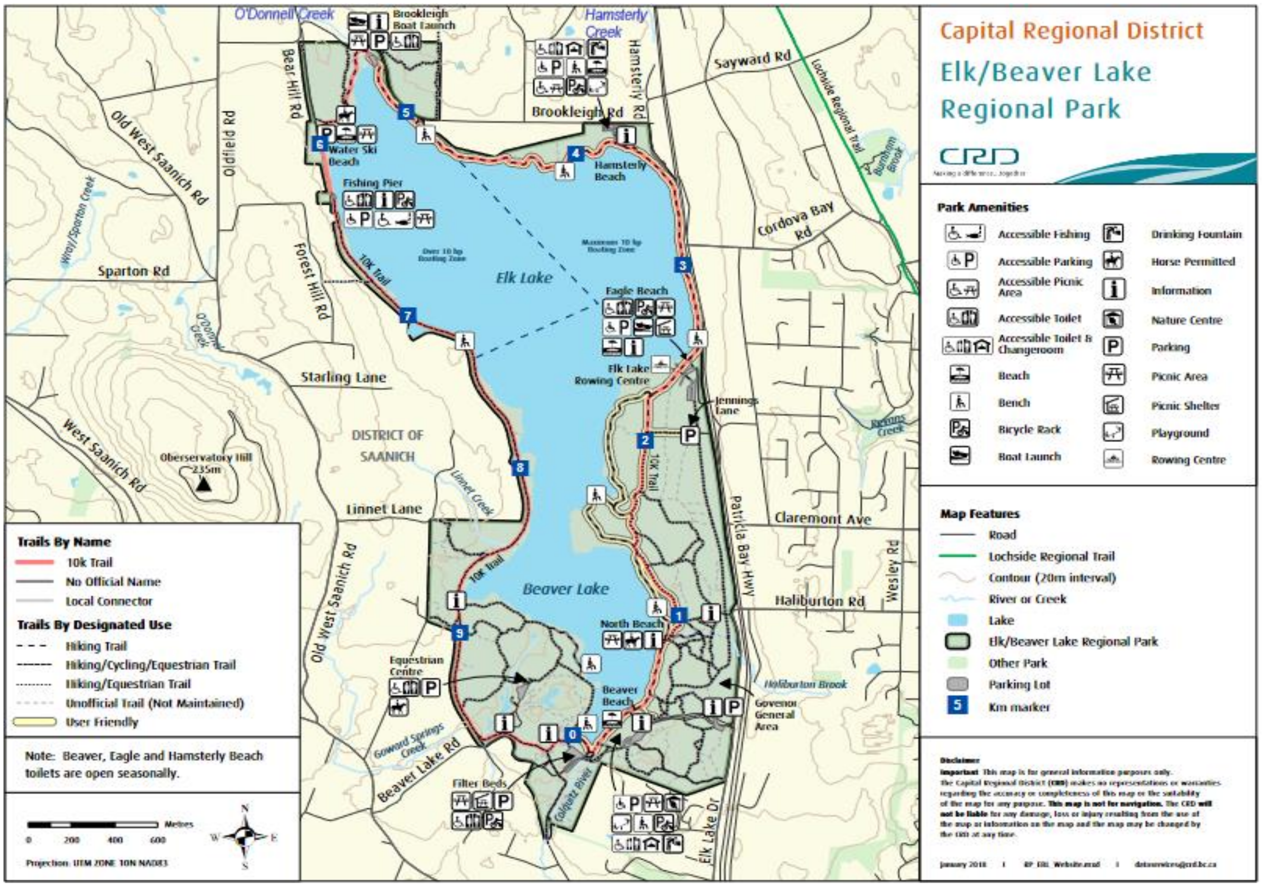

Figure 1: Map of Elk/Beaver Lake Regional Park

The lake is subject to elevated nutrient levels from external sources and internal loading which have resulted in eutrophication and an increase in blue/green algal blooms (CRD, 2020). Currently a project is underway to improve water quality within the lake, and a watershed management plan has been implemented by the CRD including a comprehensive sampling plan shown in Appendix A of this report.

The purpose of this report was to evaluate and present available water quality data of the tributaries flowing into Elk/Beaver Lake, with the intention of understanding their contributions to water quality within the lake, and to make recommendations for improvements to water quality monitoring.

There are four tributaries flowing into Elk/Beaver Lake: Haliburton Brook, O'Donnell Creek, Hamsterly Creek, and Linnet Creek, and a single outflow, Colquitz River. O'Donnell Creek is the main input for Elk/Beaver Lake, while Haliburton, Hamsterly and Linnet Creeks are seasonal streams that flow into the lake during the rainy seasons. See *Table 1* below for sample site descriptions and identification (ID) numbers.

Table 1: Sample Locations and Identifications of Elk/Beaver Tributaries

Tributary	Sample Site	BC ENV EMS ID	CRD ID
Haliburton Brook	See Figure 2 (multiple locations)	E297792	SW0690D-12
O'Donnell Creek	Near mouth of creek, D/S of Brookleigh Bridge	E207351	SW0690D-17
Hamsterly Creek	Mouth of creek that discharges to Hamsterly Beach	E297790	SW0690D-15
Linnet Creek	10 K trail, access off Linnet Lane	Not available	SW0690D-23
Colquitz River	At outlet of Elk/Beaver Lake below weir	E207361	SW0690D-8

All four creeks feeding Elk/Beaver Lake were analyzed for metals and contaminants, including nutrients, in 1987 and 2019 by the CRD. Results showed that metals in all four creeks were within BC Guidelines for the protection of aquatic life. However, nutrient levels were above the recommended guidelines, and therefore subsequent water quality testing has focused on nutrient levels in these creeks. There are also several storm drains that flow into Elk/Beaver Lake along the Patricia Bay Highway, but this report does not cover the data from these storm drains. Monitoring these may become of greater importance with the recent discovery of the toxic compound 6PPD-quinone from tire wear, likely present on the roads and highway within the watershed (Tian, et al., 2021).

1.2 Sources and Presentation of Data

There are many groups involved in stewardship of Elk/Beaver Lake, including water quality monitoring of the incoming tributaries and outflowing stream. Data for this report came from four of these groups: the Capital Regional District (CRD), British Columbia Ministry of Environment and Climate Change Strategy (BC ENV), Peninsula Streams Society (PSS), and the Beaver Elk Environmental Stewards (BEES). All readily available data sets were gathered by Mick Collins of the Victoria Golden Rods and Reels (VGRR), amalgamated by the author and presented in this report. See *Appendix B* for a complete list of data sources, sampling dates, and parameters tested.

Most of the data in this report were provided by PSS from May 2014 to February 2015, and included: 37 samples for Haliburton Brook, 47 samples for O'Donnell Creek, 10 samples for Hamsterly Creek, and 37 samples for Colquitz River. Many of these samples were duplicates, and data over this time period were robust and reliable, however testing was limited to four parameters: *E.coli*, total phosphorus, total phosphates and turbidity. Chemical analysis for PSS water samples was provided by M.B. Laboratories Ltd (MB Labs).

Data from the BC ENV were very limited, and could only be accessed by the author through the Surface Water Quality Monitoring Sites Map from the BC ENV Environmental Monitoring System (EMS) (BC ENV, 2021). Further EMS data could not be accessed by the author through the BC ENV website. Data for each stream (excluding Linnet Creek) consisted of turbidity and total phosphorus from one sample per creek in April 2015.

CRD data included a complete water quality profile including metals and nutrients for each creek in November and December of 2019, which were analyzed by Maxxam Labs (now Bureau Veritas). Additional data provided by the CRD included: one sample in 2016 and five samples in 2017 for Haliburton Creek, one sample in 2016 and six samples in 2017 for O'Donnell Creek, one additional sample in 2016 for Hamsterly Creek, and one additional sample in 2017 for Colquitz River.

Data provided by the BEES were limited to Haliburton Brook, consisting of monthly samples from October 2020 to October 2021. BEES water samples were handled by PSS and analyzed by MB Labs.

Flow data for 2014-2015 were provided by Neil Goeller of the Government of BC's Ministry of Forest, Lands, Natural Resources Operations and Rural Development (FLNROD). Flow data for O'Donnell Creek and Colquitz River were measured in real time and included precipitation variations within the dataset. Flow data for Haliburton and Hamsterly Creeks were interpolated from in stream flow measurements taken at weekly, biweekly or monthly intervals, so does not include precipitation events. No other flow data were available for this report.

Due to the variety of sources and formats of the data, and for ease of comparison, multi-year graphs of monthly data were constructed for each creek. All available data were standardized for consistency of units, and is contained in appendices C through H at the end of this report.

1.3 Water Quality Parameters, Guidelines and Objectives

Water quality in freshwater streams and lakes is important for the protection and development of the organisms that depend on and live in the water, as well as human health. There are many factors that influence water quality, but for the purpose of understanding nutrients loading into Elk/Beaver Lake, this report focuses on water flow (volume), bacteria, turbidity, nitrogen (nitrates, nitrites, ammonia) and phosphorus. Other water quality parameters tested are discussed briefly along with relevant water quality guidelines (WQGs).

BC ENV WQGs are based on tolerances by the most sensitive aquatic animal species and consideration of human health. They are categorized based on water uses, including: drinking water, recreation, aquatic life, wildlife and agriculture (BC ENV, 2019). Elk/Beaver Lake and its tributaries are subject to WQGs for the protection of aquatic life, in addition to bacteria guidelines for the protection of human health (CRD, n.d.)

WQGs used in this report come from the British Columbia Ministry of Environment and Climate Change Strategy (BC ENV), Vancouver Island Water Quality Objectives (VI WQOs) and Canadian Council of Ministers of the Environment (CCME). Most of these guidelines came from the Colquitz Guidelines provided by the CRD, for the protection of aquatic life, except bacterial (*E. coli*) guidelines that are protective of human health (CRD, n.d.).

Table 2: WQGs for Aquatic Life (and E. coli guidelines for Human Health)

WQGs for the Protection of Aquatic Life	
Parameter	BC ENV WQGs
Ammonia	8.18 mg/L (acute), 1.57mg/L (chronic)[1]
Dissolved Oxygen	Minimum: 5 mg/L
Dissolved Organic Carbon	Long-term median within 20% of background median
E. coli (guideline for the protection of human health)[2]	Geometric mean (min 5 samples): 200 CFU/100 mL Single sample maximum: 400 CFU/100 mL
Nitrate	32.8 mg/L (acute), 3.0 mg/L (chronic)
Nitrite	0.06 mg/L (acute), 0.02 mg/L (chronic)
pH	6.5-9.0
Phosphorus (VI objective)	May-Sept Avg: 0.005 mg/L, Max: 0.01 mg/L
Temperature	Maximum: 17 °C
Turbidity	Average: 3 NTU, Maximum: 9 NTU[3]

[1] These are average guidelines based on the average pH and temperature readings in Haliburton Brook for 2021. BC ENV WQGs for ammonia are based on field pH and temperature readings taken during sampling. Refer to (BC ENV, 2009) for more information.

[2] Recreational waters primary contact guideline (BC ENV, 2019)

[3] This turbidity guideline is based on a background turbidity of 1 NTU and comes from the CRD's Colquitz guidelines which are based on BC ENV WQGs (CRD, n.d.)

WQGs are often divided into long-term (chronic) averages, and short-term (acute) maximums. Long-term averages are based on a 5/30 sampling program, where 5 weekly samples are taken in 30 days and the average is compared to the guideline (BC ENV, 2016). This allows for fluctuations above and below the long-term guideline, but requires that the averages stay below the guideline. Long-term WQGs are meant to protect the most sensitive aquatic animal species or life-cycle stages against chronic toxic effects, but are also recommended for use "where water quality parameters are being influenced by ongoing anthropogenic activities" (BC ENV, 2016). Short-term (acute) WQGs refer to levels that should never be exceeded in order to protect the most sensitive species or life-stages against toxic effects, and these limits were created to inform water quality decisions in situations where spills or other issues cause abnormal levels (BC ENV, 2016). Data provided by the PSS from 2014-2015 included several 5/30 samples, but none of the following years or other data sources contained a 5/30 sampling protocol.

Since aquatic life in healthy ecosystems tend to include extremely sensitive species and life stages, ensuring that the appropriate WQGs are used for water quality monitoring is imperative. If less sensitive guidelines than appropriate are used to report on water quality in aquatic systems, problematic water quality may remain undetected. For example, WQGs for agriculture were created for the needs of large animals that are not as sensitive to compounds like nitrates or nitrites, so the WQG for nitrates in livestock water is 100 mg/L N, and for nitrite alone the WQG is 10 mg/L. Compare this to the WQG for aquatic life, which is 3.0 mg/L N for nitrates and 0.02mg/L N for nitrite, and it becomes apparent that using the correct WQG is incredibly important for the protection of the most sensitive species in the system being tested.

1.3.1 Dissolved Organic Carbon

Dissolved organic carbon (DOC) and total organic carbon (TOC) are important water quality parameters that refer to the amount of organic matter dissolved or suspended in water. Microbes, including bacteria and algae, feed on organic carbon, potentially using up significant amounts of oxygen and increasing nutrient levels. The more organic matter there is in water, the less available oxygen there may be due to increased microbial activity. Nevertheless, some aquatic systems, such as those in wooded areas, will naturally have high DOC.

The BC WQG for DOC is based on variation from background levels that are determined with a 5/30 sampling program. Once the background levels are determined, the WQGs for protection of aquatic life require that DOC remains within 20% of the background levels (BC ENV, 2018).

1.3.2 Dissolved Oxygen

Dissolved oxygen refers to the amount of oxygen in water. Oxygen comes from aquatic plants and the atmosphere, and turbulent water (such as that in moving streams) generally has higher dissolved oxygen than still water (such as in lakes or ponds). Oxygen is also more soluble in cold water, so temperature can impact oxygen levels. Most aquatic animal life requires adequate levels of dissolved oxygen. The BC WQG for dissolved oxygen is a minimum guideline of 5 mg/L.

1.3.3 E. coli

Escherichia coli (*E. coli*) is a bacterium found in the digestive tract of warm-blooded animals, and is an indicator of fecal contamination when found in surface water (USGS, n.d.). BC WQGs for *E. coli* are from Health Canada's WQGs and are based on correlations between *E. coli* concentrations in water and gastrointestinal illness observed in swimmers (BC ENV, 2019). *E. coli* concentrations are measured in colony forming units per 100 millilitres (CFU/100 mL). The BC WQG for E. coli for the protection of human health is a geometric mean (minimum 5 samples) of 200 CFU/100 mL, or for a single sample the maximum is 400 CFU/100 mL. In this report, there was not enough consecutive data to calculate a geometric mean for *E. coli* in the Elk/Beaver tributaries, except for

Haliburton Creek in the spring of 2014. Colquitz River was tested more frequently for *E. coli*, and data contained two sets of 5 samples where geographic means could be calculated.

1.3.4 Dissolved Metals

Dissolved metals refer to any metal that is dissolved in solution. Please refer to *Appendix C* for metal guidelines and analysis. All metals were tested by the CRD in 2019 in the tributaries and outflow for Elk/Beaver Lake.

1.3.5 Nitrogen

Nitrogen is an essential nutrient for aquatic life, particularly plant growth, but excess nitrogen can lead to algae blooms and poor water quality. Nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) are the major inorganic nitrogenous compounds that occur in surface waters (BC ENV, 2009). The forms and concentrations of nitrogen found in water fluctuate due to bacteria and plant uptake, and are influenced by other water quality parameters such as pH and temperature.

1.3.5.1 Nitrate

Of the three most common nitrogenous compounds found in freshwater systems, nitrates are the least toxic to aquatic animals, and therefore have the highest permissible level in the WQGs. The BC WQG for nitrate is: maximum short-term (acute) concentration of 32.8 mg/L N, and long-term (chronic) concentration of 3.0 mg/L N (BC ENV, 2019).

Available nitrate data for the Elk/Beaver tributaries and outflow were limited, and did not consist of enough data to assess compliance with long-term (chronic) guidelines, however, where water quality parameters are influenced by ongoing anthropogenic activities, chronic guidelines should be considered the maximum allowable level (see previous discussion). Therefore, this report uses the more sensitive chronic WQG of 3.0 mg/L N as the appropriate guideline for the protection of aquatic life.

1.3.5.2 Nitrite

Nitrite is the intermediate oxidation state between nitrate and ammonia, and can be problematic to fish as it competes with haemoglobin for oxygen and can disrupt blood oxygen levels, chloride and potassium levels (Jensen, 2003). In healthy ecosystems, nitrite is short-lived due to microbial action.

CCME Guidelines for the protection of aquatic life suggest a maximum long-term (chronic) nitrite concentration of 60 ug/L (=0.06 mg/L) (CCME, 2021b). There are no CCME guidelines for short-term nitrite concentration.

The BC ENV WQGs for the protection of aquatic life suggest a maximum short-term (acute) nitrite concentration of 0.06 mg/L N, and a maximum long-term (chronic) concentration of 0.02 mg/L N (BC ENV, 2019).

1.3.5.3 Ammonia

Ammonia in water can exist in two different forms, NH_3 (unionized-ammonia) and NH_4^+ (ammonium), with NH_3 being the more toxic form (WRWC, 2020). Ammonia is the excretory compound of most aquatic animals. In well-balanced ecosystems, bacteria generally convert ammonia quickly to nitrites and, subsequently, to nitrates. The form of ammonia in water changes with temperature and pH, with toxicity increasing as pH and temperature increase.

Animals are more sensitive to ammonia than plants, and different species have different tolerances. Trout are one of the more sensitive species to ammonia toxicity, and can only tolerate levels of up to about 0.2 mg/L (WRWC, 2020). Salmon fry are susceptible to bacterial gill disease when chronically exposed to ammonia levels as low as 0.002 mg/L for six weeks (WRWC, 2020).

BC ENV provides tables to determine acceptable ammonia concentrations for the protection of aquatic life based on temperature and pH of the water taken in the field during sampling (BC ENV, 2009). For example, a sample with a pH of 7.8 and temperature of 11°C would have an acute WQG of 8.18 mg/L NH_3 and a chronic WQG of 1.57 mg/L NH_3. Each ammonia result in this report was checked against the appropriate field pH and temperature for that sample to determine specific guidelines for each sample.

1.3.6 Phosphorus

Phosphorus is an essential nutrient, like nitrogen, and is usually the limiting nutrient in freshwater systems. This means that normal phosphorus levels are usually quite low, and when elevated they are a key trigger of eutrophication (Shindler, 2008) and can cause excessive algal blooms. Such algal blooms can result in low oxygen as the algal cells decompose, and, in the case of blue-green algal blooms, can be toxic. When phosphorus is disproportionately high relative to nitrates, blue-green algae are favoured, compared with the less toxic green algae (Merrill, 2015). Blue green algal blooms have become more frequent throughout the world, possibly due to higher temperatures and increased phosphates in run-off from more frequent and intense rain events (Merrill, 2015).

Elk/Beaver Lake also has a problem with increased frequency of blue/green algae blooms, attributed to high phosphorus levels. While mobilization of phosphorus from historical sediments is currently considered the primary reason for increased algal blooms (Nordin, 2015), evidence indicates that understanding and controlling surface contributions of this nutrient to the lake is also crucial to controlling algal blooms and improving water quality.

Phosphorus can take many forms, including: inorganic phosphate (ortho-phosphate), organic particulate phosphate, and organic dissolved phosphate, as well as total phosphorus (TP) which includes all of the above. The only form that can be compared to guidelines is total phosphorus (TP) and is generally recommended as the most meaningful measurement of phosphorus in surface waters (CCME, 2021a).

Where analysis costs are a concern, ortho-phosphate can be measured with a handheld meter, and may serve as an adequate estimate for trends of available phosphorus if used consistently for monitoring purposes. There is no water quality guideline or objective for ortho-phosphate, with chlorophyll concentrations often used as a surrogate indicator of nutrient enrichment impacts in streams (BC ENV, 2014).

The Canadian Council of Ministers of the Environment provide a Canadian Guidance Framework for long term total phosphorus levels in freshwater, for the protection of aquatic life. Their framework shows water quality impacts of the following levels of total phosphorus:

Oligotrophic 4-10 ug/L phosphorus (low nutrients, good water quality)
Mesotrophic 10-20 ug/L phosphorus (some nutrients, fair water quality)
Meso-eutrophic 20-35 ug/L phosphorus (nutrients available, fair water quality)
Eutrophic 35-100 ug/L phosphorus (high nutrients, poor water quality) (CCME, 2021a)

The BC ENV has developed water quality objectives (WQOs) specific to Vancouver Island (VI), and the phosphorus objective for total phosphorus in streams is: May-Sept Average (samples collected monthly) 0.005 mg/L (5 ug/L), and any one sample should not exceed a maximum of 0.01 mg/L (10 ug/L) (BC ENV, 2014). Where data were available, May-September averages were calculated and compared to the VI phosphorous objective.

1.3.7 pH

Water pH refers to how acidic or basic the water is, and is measured in pH units (a measure of free hydrogen ions). Aquatic life can generally tolerate a pH range of 6.5 to 9 without adverse affects. If water pH goes below 6.5, it becomes too acidic for aquatic life, and if it exceeds a pH of 9 the water becomes too alkaline (basic) for aquatic life. Therefore, the BC WQG for pH is 6.5-9.

1.3.8 Temperature

Water temperatures in streams fluctuate seasonally, and temperature changes can affect aquatic life by changing other water quality parameters, such as nitrogen and dissolved oxygen. If temperatures get too high, oxygen levels can be greatly depleted, and aquatic life suffers. The BC WQG for temperature is based on known fish species and their temperature requirements. The WQG for temperature in Colquitz River, which contains similar species to the other Elk/Beaver tributaries, is below 17°C for protection of aquatic life. Guidelines also state that temperatures should not change more than 1°C/hour for protection of aquatic life. Temperatures will likely increase with climate change, and shading by riparian vegetation will become increasingly important.

1.3.9 Turbidity

Water clarity or transparency is measured in nephelometric turbidity units (NTUs) that indicate the reflection of light by suspended particles in the water (Fondriest, 2014). Suspended particles, and their sedimentation, can negatively impact aquatic life by clogging and abrading gills, reducing egg survival rates, impacting feeding and movement, and degrading streambeds and spawning habitats. Turbidity can also reduce water oxygenation and impact gas exchange of fish eggs and larvae (CCME, 1999). High turbidity can be caused by erosion, urban runoff during heavy rains, chemicals, algae blooms and other disturbances. The WQG of 9 NTU used in this report comes from the CRD Colquitz Guidelines and is based on a background of 1 NTU. Background turbidity is determined by hourly or daily sampling, and background levels were not available for the inflowing Elk/Beaver tributaries.

1.4 Water Flow

Water flow and volume can impact water quality parameters, and these data may help better understand water quality issues. When water flow is high, turbidity and oxygen levels can increase, and nutrient concentrations may decrease due to dilution factors. When water levels are low, oxygen levels can decrease, which can negatively impact aquatic life, and can also increase other water quality degradation. Being able to compare flow data with corresponding water quality data can give a more robust understanding of the dynamics of water quality problems and nutrient loading.

The only water flow data available for this report came from Neil Goeller, and covered Haliburton Brook, O'Donnell Creek, Hamsterly Creek and Colquitz River from May 2014 to April 2015. O'Donnell Creek and Colquitz River were both equipped with flow meters for constant flow measurements. Haliburton Brook and Hamsterly Creek had flows measured manually at weekly, bi-monthly or monthly intervals, and daily flow measurements were interpolated from those measurements.

3 Water Quality Results

3.1 Haliburton Brook

Haliburton Brook collects runoff from the Haliburton Watershed and carries water underneath the Patricia Bay Highway through Elk/Beaver Lake Park to the lake *(Fig. 2).* The upper reaches of the brook dry out in the summer, while the lower reaches closest to the lake maintain water flow year-round, though levels slow to a trickle in August and September. Haliburton Brook has several issues affecting water quality, including urban run-off and bank destabilization caused in part by invasive plant species impacting native riparian vegetation. Available water quality data for Haliburton Brook are shown in Appendix C and Appendix D.

The data indicates that metals, ammonia, dissolved oxygen, and pH were all within BC WQGs for the protection of aquatic life, therefore, these parameters are not discussed further. Parameters that exceeded WQGs, or did not have enough data, are discussed throughout this chapter.

Haliburton Brook is being tested monthly by volunteers from the BEES, with *Figure 2* indicating sampling sites.

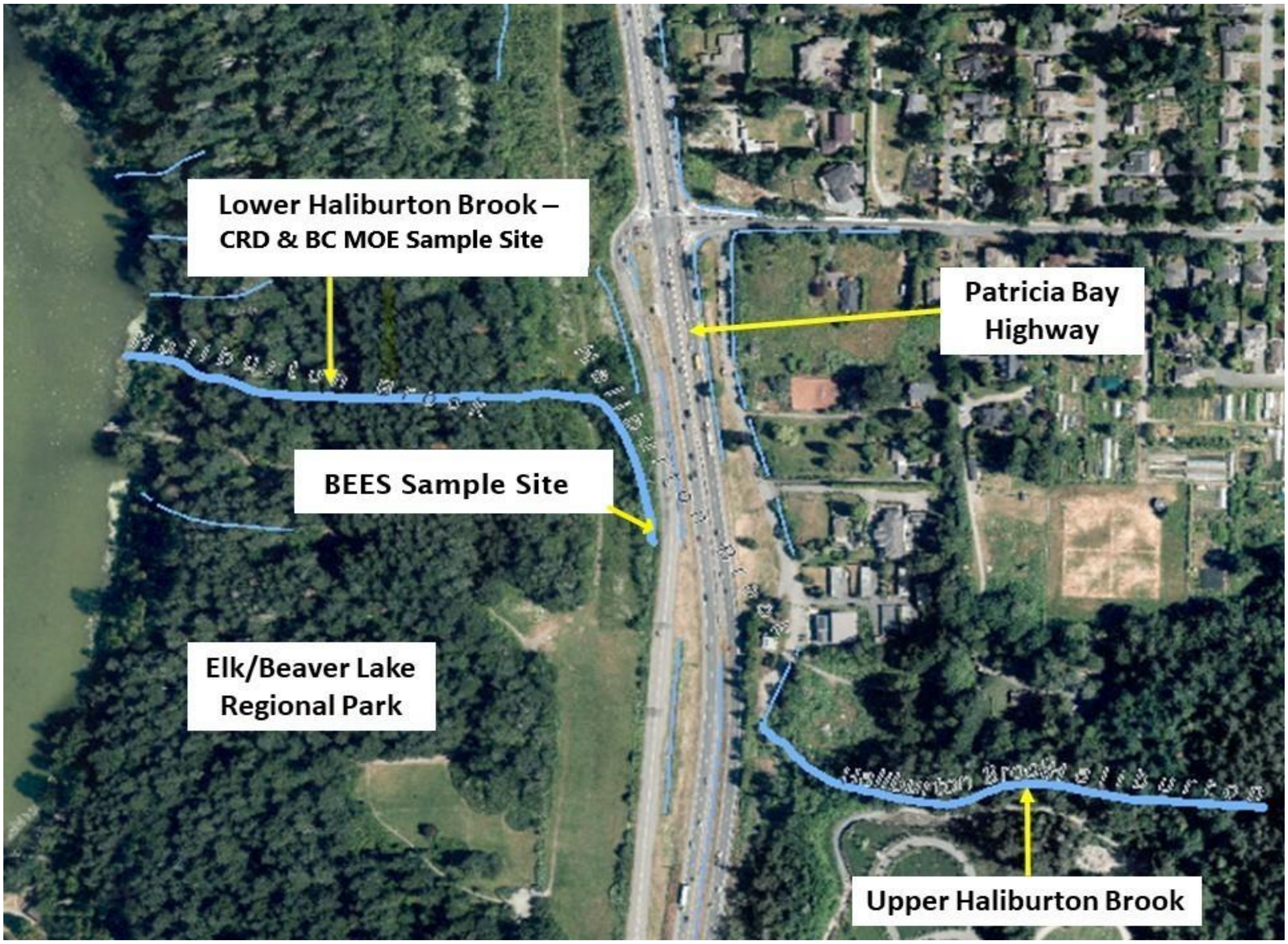

Figure 2: Sampling Locations for Haliburton Brook (Locations are approximate) (BEES, 2021)

Note that the sampling site used by the BC ENV and the CRD is slightly downstream of the BEES Sampling location. Upper Haliburton Brook is not currently being monitored for water quality.

3.1.1 Dissolved Organic Carbon

Haliburton Brook has not had enough dissolved organic carbon testing to create a background level to use for a guideline. *Table 3* shows available DOC data. To create a background level for a water quality guideline of 20% background, 5 samples must be taken within one month.

Table 3: Dissolved Organic Carbon in Haliburton Brook

Dissolved Organic Carbon in Haliburton Brook from 2016-2019		
Sample Date	Data Source	DOC (mg/L)
2016-10-20	CRD	8.04
2017-02-24	CRD	4.17
2017-02-24	CRD	4.37
2017-02-24	CRD	4.76
2019-11-28	CRD	7.2
2019-12-11	CRD	6.3

3.1.2 E. coli

Figure 3 shows very limited *E. coli* measurements recorded for Haliburton Brook, but readings in August 2014 and November 2019 show *E. coli* measurements well above BC WQG maximum of 400 CFU/100 mL for protection of human health. There were not enough data to calculate the geometric mean WQG of 200 CFU/100 mL.

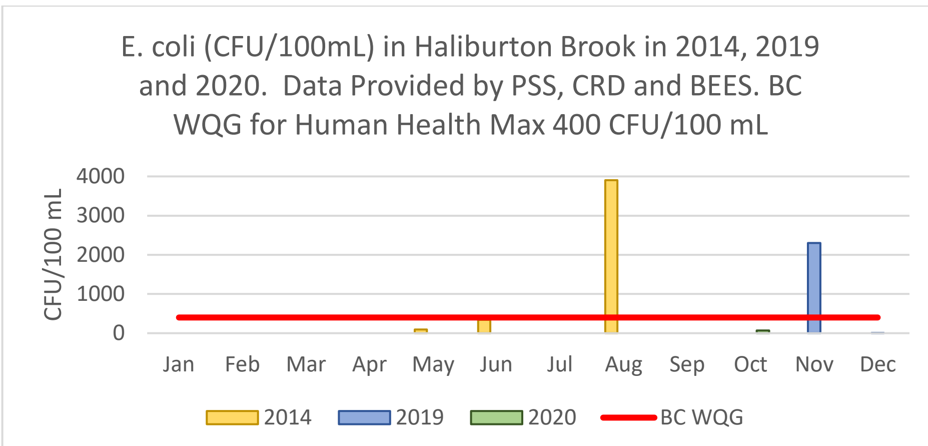

Figure 3: E. coli in Haliburton Brook in 2014, 2019 and 2020

Key Findings: High *E. coli* measurements in Haliburton Brook indicate fecal contamination. More testing is needed.

High *E. coli* levels in creeks indicate fecal contamination, which may come from various sources, including: septic systems, farm animals, pet feces, and hyper-abundant wildlife (such as Canadian geese) (CRD, 2020).

3.1.3 Nitrogen

Nitrogen data in Haliburton Brook were very limited, with only nine samples analyzed for nitrates, nitrites and ammonia out of the 53 samples from 2014 to 2021. Nitrates and ammonia were found to be within WQGs, but nitrites were above guidelines during the rainy season. More data are needed to understand nitrogen loading in Haliburton Creek, particularly for nitrites.

3.1.3.1 Nitrate

Figure 4 shows monthly nitrate levels in Haliburton Brook for the spring, fall and winter months from 2019 to 2021. The short-term BC WQG for nitrate is maximum 32.8 mg/L NO_3, with a long-term WQG of an average of 3 mg/L. There were not enough data to create an average long-term concentration, however; as per BC ENV recommendations, the continuous anthropogenic source of nitrogen in Haliburton Brook warrants the use of the long-term guideline. Most nitrate measurements were well below both long-term and short-term guidelines, except in July and August of 2021, nitrates exceeded the long-term maximum guideline of 3.0 mg/L.

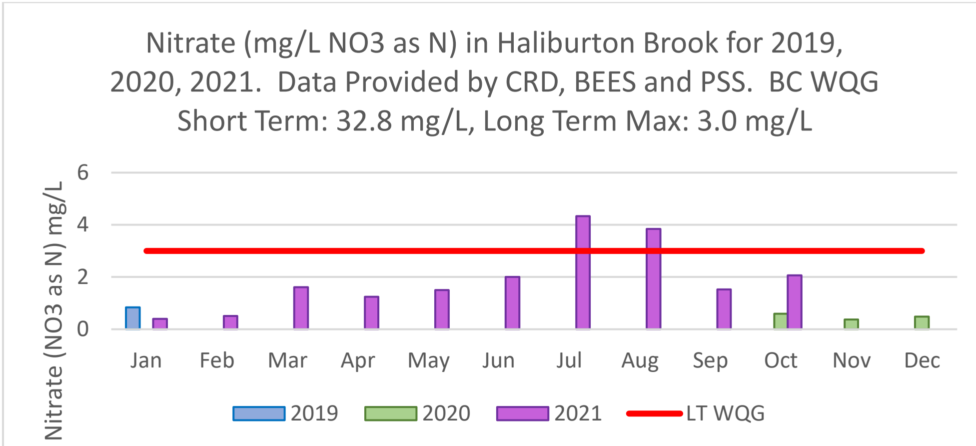

Figure 4: Nitrate in Haliburton Brook in 2019, 2020 and 2021

Key Findings: Nitrate levels were below short and long-term guidelines except in July and August 2021, when they exceeded the long-term maximum guideline.

3.1.3.2 Nitrite

Figure 5 shows Nitrite measurements in Haliburton Brook from 2019 to 2021. Almost all measurements exceeded the long-term WQG of 0.02 mg/L, with exceedances of short-term and long-term readings in October and December of 2020, and January of 2021, and one extremely high reading in July 2021.

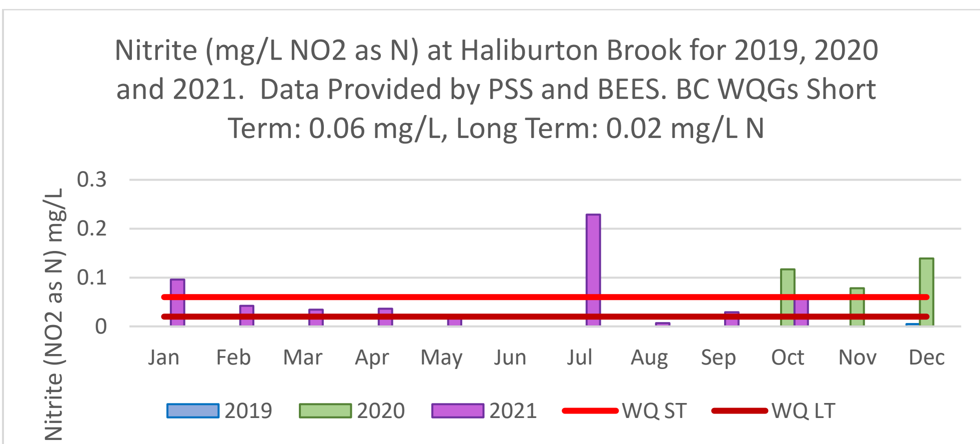

Figure 5: Nitrite in Haliburton Brook in 2019, 2020 and 2021

Key Findings: Nitrite levels were above short-term BC WQGs in winter 2019/2020, and above long-term BC WQGs in winter, spring and summer 2020/2021.

3.1.4 Phosphorus

Available phosphorus data for Haliburton Brook were measured in different forms by different groups, including ortho-phosphate, total-phosphate, and total phosphorus, with a comprehensive table of data available in

Appendix I. Further discussion is included later in this report. Total phosphorus is the only measurement that can be compared to guidelines, and therefore is the only measurement shown in *Figure 6*.

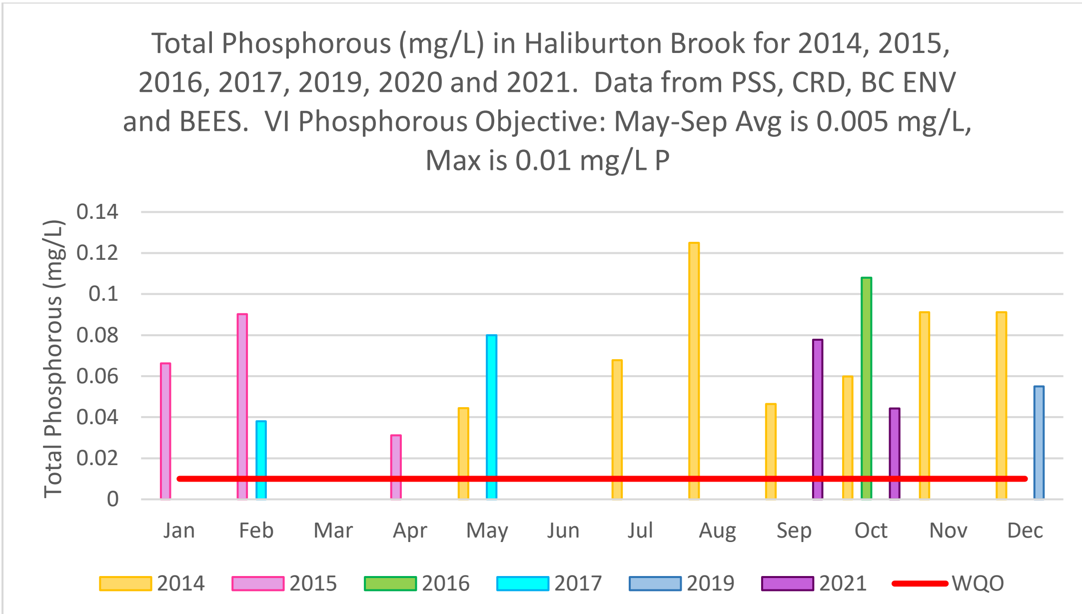

Figure 6: Total Phosphorus in Haliburton Brook

Key Findings: Total Phosphorus in Haliburton Brook significantly exceeded Vancouver Island objectives on all sample dates.

Figure 6 shows that total phosphorus measurements taken in Haliburton Brook between 2014 and 2019 all exceeded the VI phosphorous objective for protection of aquatic life. In months with more than one phosphorus measurement, the higher phosphorus measurement was used for this graph, however all measurements were above objectives.

3.1.5 Temperature

Temperature in Haliburton Brook (*Figure 7*) remained under the WQG for most samples, except during June, July and August 2021 when Vancouver Island experienced extremely high temperatures in an event known as the "heat dome" (CTV News, 2021). Temperature data were very limited, and there were not enough data to determine if an annual upwards trend is occurring. More data are needed.

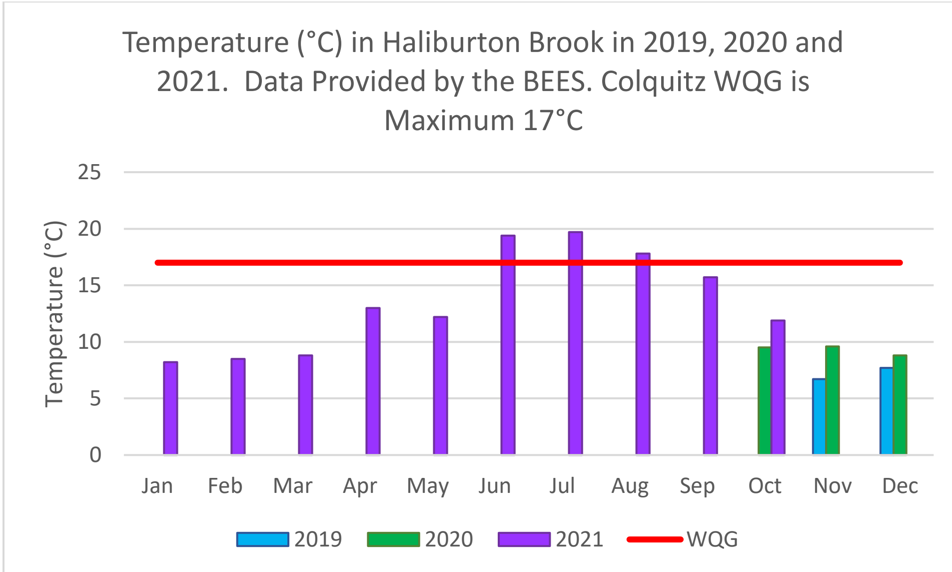

Figure 7: Temperature in Haliburton Brook

Key Findings: Temperature in Haliburton Brook exceeded WQGs in June, July and August of 2021 during the "heat dome."

3.1.6 Turbidity

Turbidity in Haliburton Brook remained under the BC WQG of 9 NTU for most months in most years, but showed elevated levels in fall and winter of 2014, 2020 and 2021. Turbidity data for 2020 and 2021, provided by the BEES, are estimates and were converted from centimeters to NTUs using a Turbidity Tube Conversion Chart (USU, 2016). See *Figure 8* below for turbidity in Haliburton Brook.

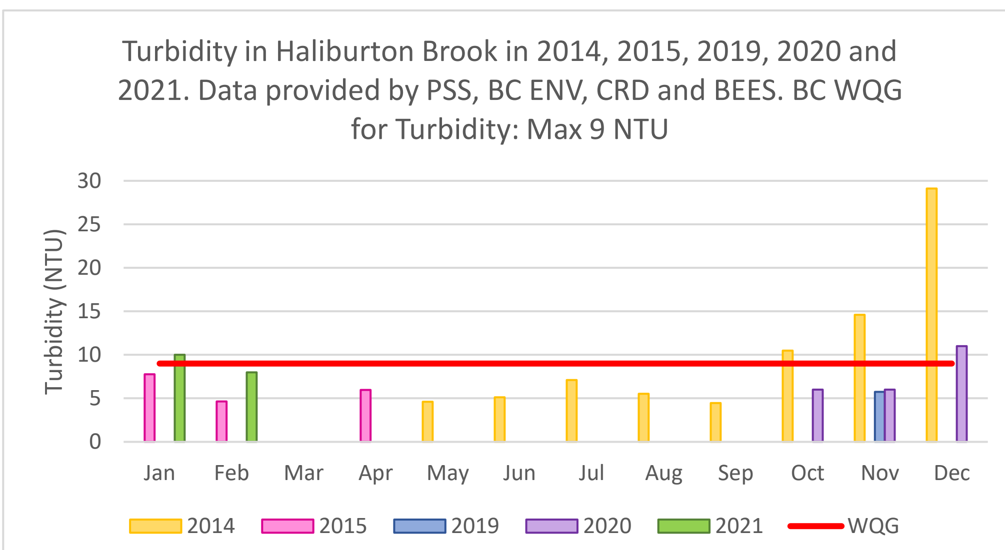

Figure 8: Turbidity in Haliburton Brook

Key Findings: Turbidity remained under guidelines except in Oct, Nov, Dec 2014, Dec 2020 and Jan 2021.

3.2 O'Donnell Creek

O'Donnell Creek is the main inflowing creek for Elk/Beaver Lake, located in the North-West corner of the lake, and contributes a significant amount of water and nutrients into the lake. The surrounding watershed is mostly agricultural, with some small farms and low-density rural residential lots (CRD, 2020). Some reaches of the creek underwent restoration by the Golden Rods and Reels in the 1990s, and some portions were diverted into drainage ditches to accommodate development (CRD, 2020).

Water Quality monitoring in O'Donnell Creek was carried out extensively by the Peninsula Streams Society in 2014 and 2015, and further testing was carried out by the CRD in 2017 and 2019, including metals. Metals, dissolved oxygen, ammonia, pH and temperature were all within guidelines, however, *E. coli* and nutrients exceeded guidelines on many occasions.

3.2.1 E. Coli

Figure 9 shows *E. coli* measurements in O'Donnell Creek. While most measurements were below the WQG for human health, there were samples in August and September of 2014 that were three and four times the maximum guideline. Measurements in November of 2014 and March of 2017 also exceeded the guideline. These numbers indicate fecal contamination in all seasons, during low and high water flows. There were insufficient data to determine geometric means, which require five samples within one month.

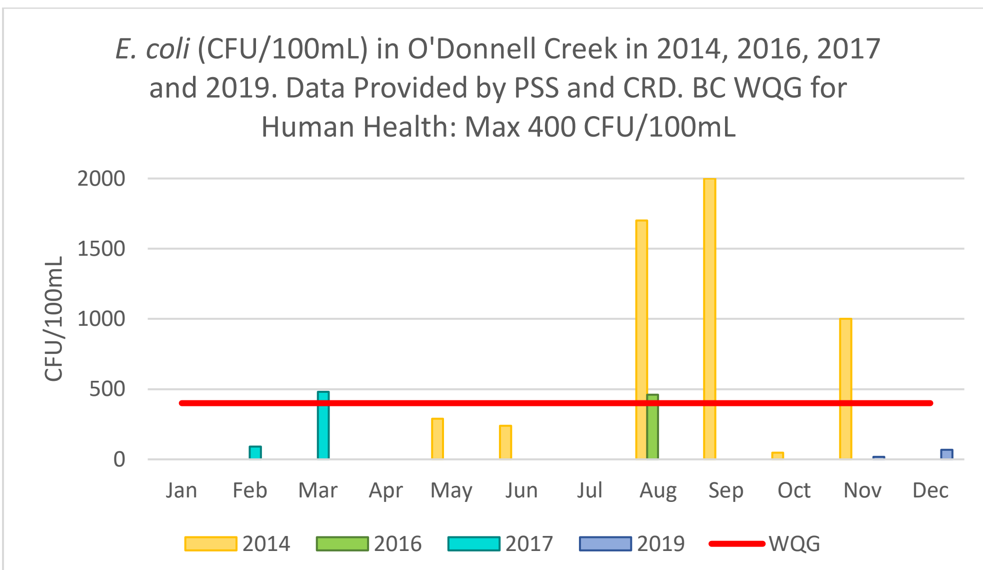

Figure 9: E. coli in O'Donnell Creek

Key Findings: In August and September 2014, *E. coli* measurements were four times the maximum limit.

3.2.2 Phosphorus

Phosphorus loading in O'Donnell Creek appears to be a significant problem, as can be seen in *Figure 10* below. This is likely due to the agricultural nature of the watershed. Every sample tested for total phosphorus exceeded the objective for Vancouver Island streams. The May-Sept average in 2014 was 0.131 mg/L P, the total average of all samples was 0.158 mg/L P.

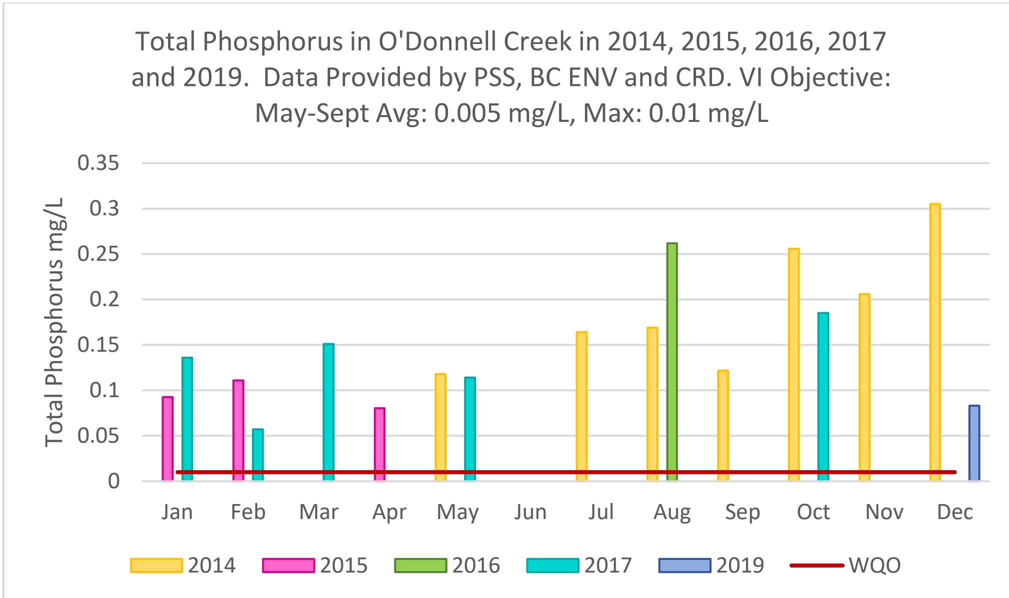

Figure 10: Total Phosphorus in O'Donnell Creek

Key Findings: Total phosphorus levels were above VI Objectives in all samples for every year.

3.2.3 Turbidity

Turbidity in O'Donnell Creek is shown below in *Figure 11*. Turbidity levels were all below WQGs except on three occasions, in June, November and December of 2014, however turbidity data were limited.

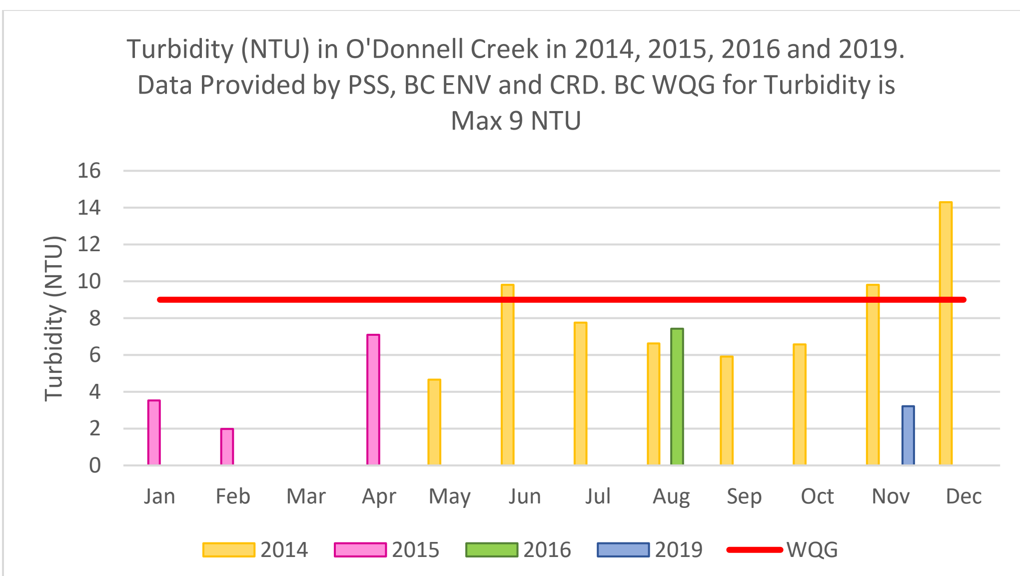

Figure 11: Turbidity in O'Donnell Creek

Key Findings: Turbidity in O'Donnell Creek remained within WQGs, except on 3 occasions in 2014.

3.3 Hamsterly Creek

Hamsterly Creek, also known as Whiskey Creek, is a low flow, seasonal creek that runs into the North-East corner of Elk/Beaver Lake. Much of the creek is ditched, and it dries out in the summer, likely contributing limited water and nutrients to Elk/Beaver Lake (CRD, 2020).

Water quality data for Hamsterly Creek were limited to 10 samples in 2014 and 2015 from the Peninsula Streams Society, and 3 samples from the CRD in October 2016 and November and December 2019. Metals, dissolved oxygen, *E. coli*, ammonia, nitrates, nitrites, pH and temperature were all within BC WQGs, however, total phosphorus and turbidity exceeded guidelines. There were not enough data to create a background level to determine a WQG for dissolved organic carbon. Turbidity and phosphorus are discussed below.

3.3.1 Phosphorus

Total phosphorus in Hamsterly Creek (*Figure* 12) was limited to seven samples from 2014 to 2019, and all samples exceeded the BC WQO for Vancouver Island. Total phosphorus was particularly high in October 2016, but this was the only sample for 2016, so there were not enough data to determine if this is an outlier. There were no phosphorus data from May to September, likely due to the stream drying in the summer months.

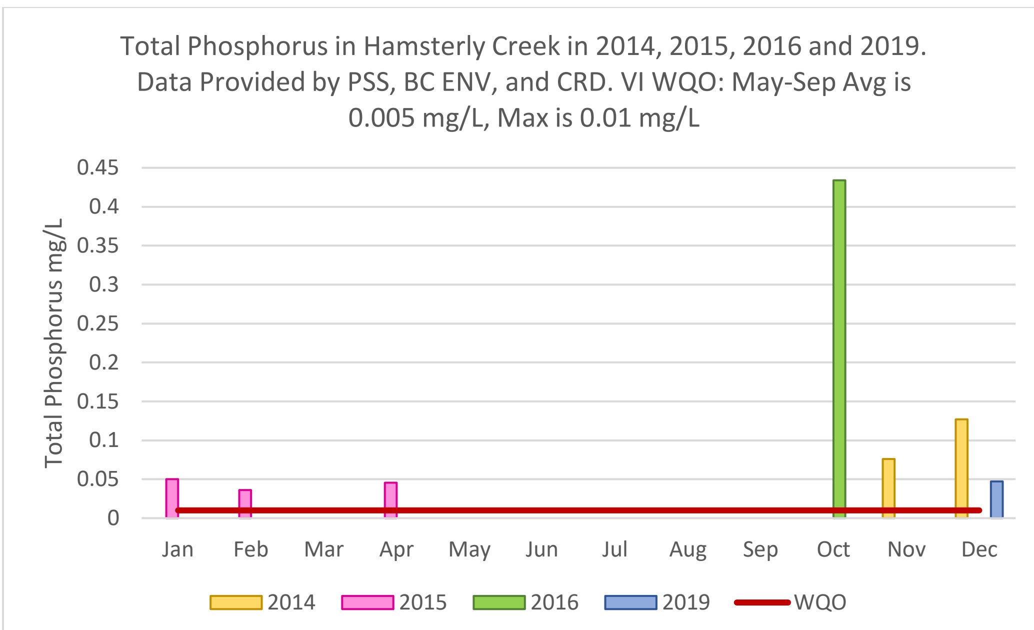

Figure 12: Total Phosphorus in Hamsterly Creek

Key Findings: Total phosphorus exceeded WQOs in all seven samples.

3.3.2 Turbidity

Turbidity data in Hamsterly Creek was limited to six samples between 2014 and 2019, as shown in *Figure* 13 below. Turbidity was below WQGs except in December of 2014, when it was extremely high, this was the only measurement in December in any year.

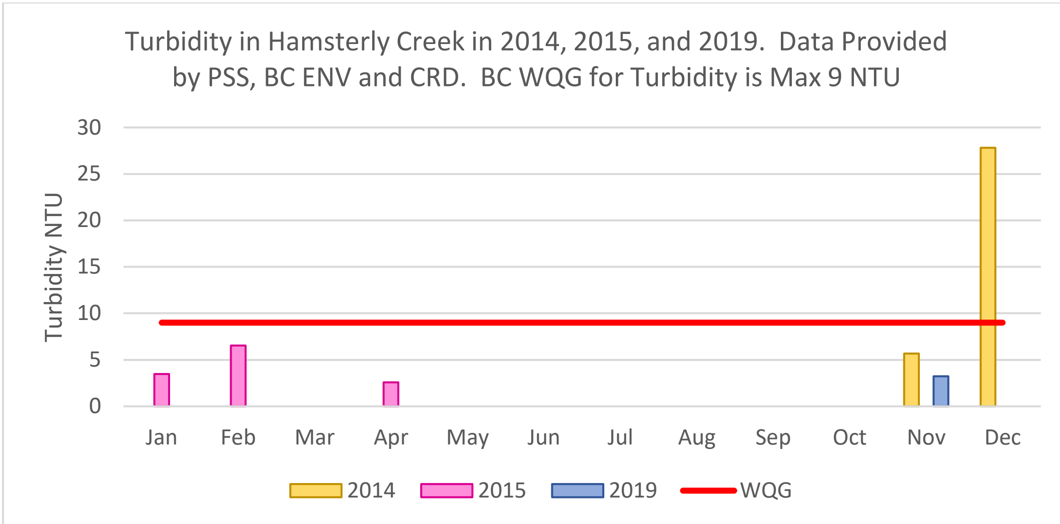

Figure 13: Turbidity in Hamsterly Creek

Key Findings: Turbidity data for Hamsterly Creek was very limited, one out of six samples exceeded guidelines.

3.4 Linnet Creek

Linnet Creek is a small stream that flows into the South-West side of the Beaver Lake portion of Elk/Beaver Lake. Water flow and nutrients are very low, which explains why data for Linnet Creek were so limited. There are only two sample dates for water quality monitoring, carried out by the CRD in November and December of 2019. All parameters were within WQGs. Total phosphorus was not analyzed in either sample.

3.5 Colquitz River

Colquitz River is the outflow for water and nutrients in Elk/Beaver Lake, and flows over a dam at the South end of Beaver Lake. Colquitz River flows out to the ocean at Portage Inlet, and collects water and nutrients from various tributaries throughout Central Saanich and Saanich (CRD, 2020). Colquitz River is a fish-bearing stream; therefore, maintaining excellent water quality is important for the health of downstream ecosystems.

Water quality in Colquitz River is monitored at various locations down the length of the stream, however, this report just focused on the sample point immediately below the outflow at the Beaver Lake dam. Water quality monitoring was carried out in 2014 and 2015 by Peninsula Streams Society, but only *E. coli*, total phosphorus and turbidity were measured during this time period. CRD monitoring was carried out in November of 2017, and November and December of 2019 for metals, nutrients, and all other parameters. All parameters, including *E. coli*, were within WQGs except for total phosphorus and turbidity.

3.5.1 Phosphorus

Total phosphorus levels in Colquitz River are shown below in *Figure 14*. All samples except one exceeded the VI WQO, indicating that phosphorus issues in Elk/Beaver Lake are continuing downstream. Total phosphorus was particularly high in August 2014, at 0.08 mg/L P. The May to September average in 2014 was 0.044 mg/L P. The total average for all measurements was 0.032 mg/L P.

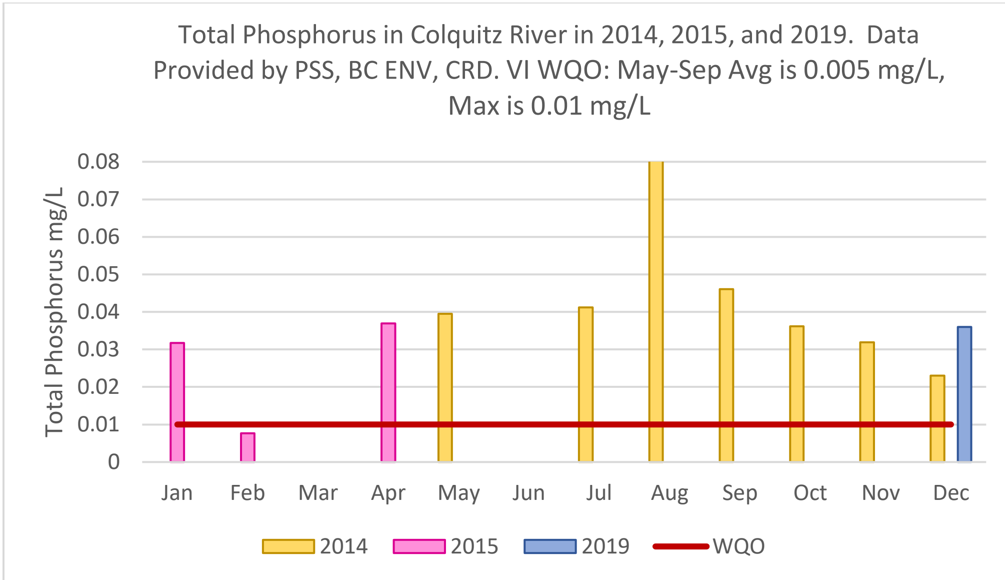

Figure 14: Total Phosphorus in Colquitz River

Key Findings: Total phosphorus levels in Colquitz River all exceeded WQOs except one.

3.5.2 Turbidity

Turbidity data for Colquitz River are shown in *Figure 15* below. Turbidity remained below WQGs for most samples, except for three exceedances in June, August and October of 2014. The turbidity exceedances did not appear to be sustained, as samples taken between these exceedances show low turbidity levels, so these exceedances may have been caused by algal blooms.

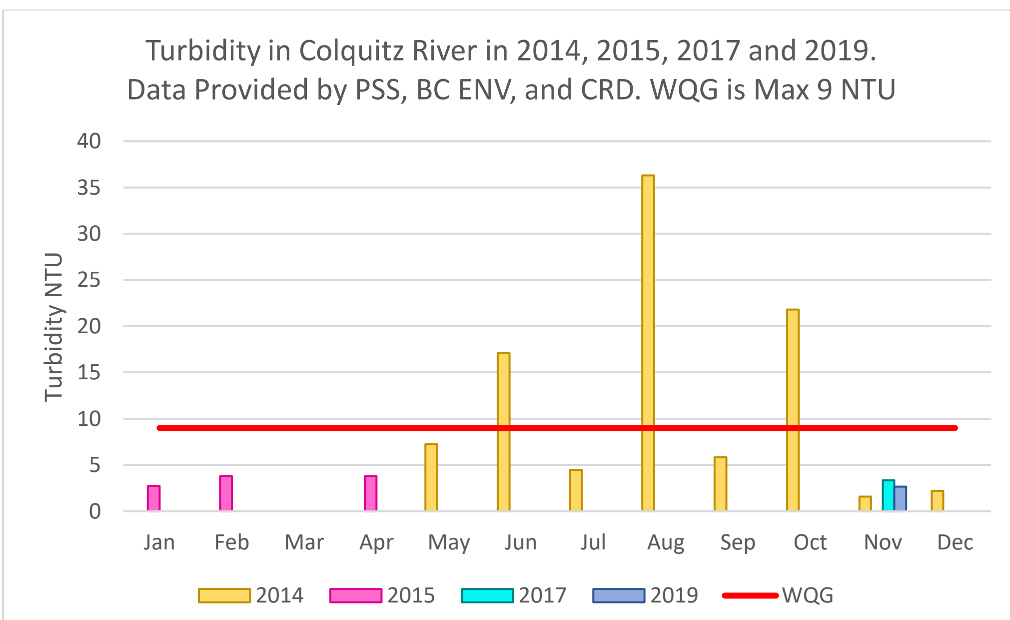

Figure 15: Turbidity in Colquitz River

Key Findings: Turbidity in Colquitz River remained below WQGs except in June, August and October of 2014.

3.6 Water Flow

O'Donnell Creek and Colquitz River data presented in *Figure 16* shows real-time flow data, including variations from precipitation events. Haliburton Brook and Hamsterly Creek data presented in *Figure 16* are interpolated, only showing the general average flows based on less robust sampling, and therefore does not include precipitation events.

Figure 16 below shows flow data by creek from May 2014 to April 2015. O'Donnell Creek (purple) significantly increased in volume during the winter months, and contributed the majority of the water flowing into Elk/Beaver Lake. The peaks and valleys of the flow data for O'Donnell Creek show changes in volume from precipitation events through the winter months. O'Donnell and Haliburton (red) Creeks both had very little flow in the summer months. Hamsterly Creek (green) dried up and had no water flow from June 9th to October 22nd of 2014. Colquitz River (yellow) is the outflow of Elk/Beaver Lake, and shows steady water levels for most of the year, with slightly lower volumes through August and September, and higher volumes in February and March. Colquitz River flows over a dam at the South end of the Beaver Lake portion of Elk/Beaver Lake, and levels are managed by the CRD.

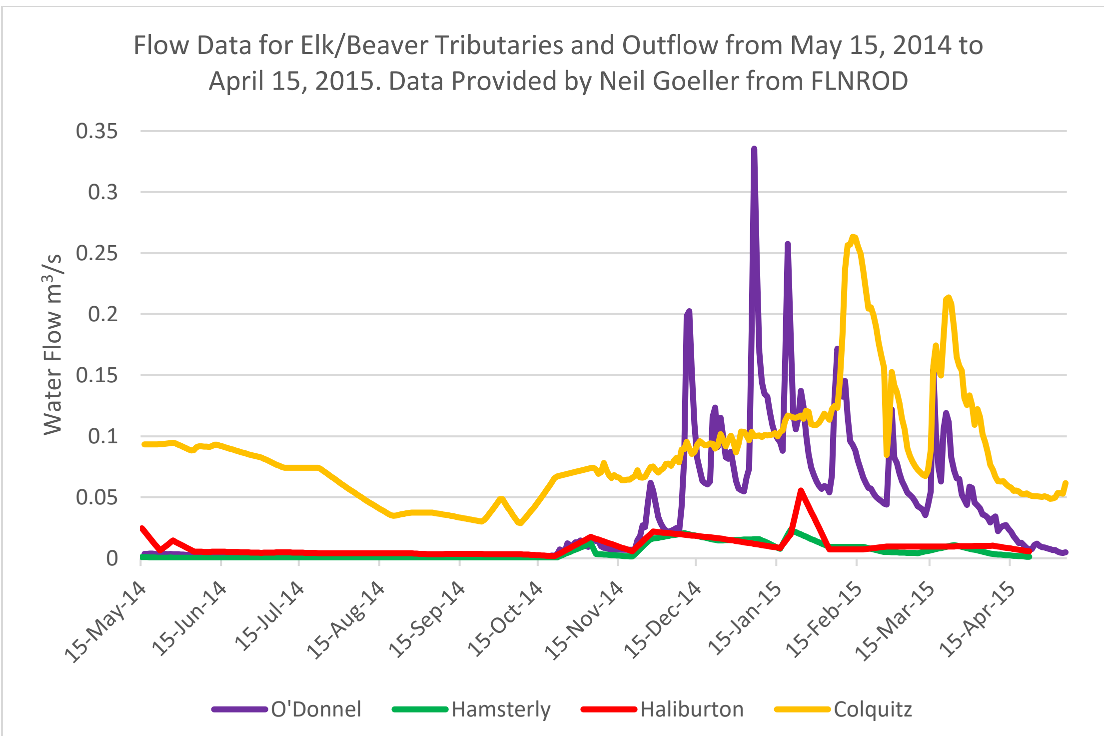

Figure 16: Flow Data for Elk/Beaver Tributaries and Outflow

Key Findings: All three tributaries flowing into Elk/Beaver Lake contribute most of their volume from November to April, with O'Donnell being the most significant contributor.

Table 4 below shows estimates of total water volume carried by the Elk/Beaver tributaries and Colquitz River in one year, based on the data provided by Neil Goeller. The flow volumes for O'Donnell Creek and Colquitz River are based on instream flow meters and are more accurate than the interpolated estimates for Haliburton Brook and Hamsterly Creek.

Table 4: Estimated Annual Water Flows in 2014/2015

Estimated Water Flow Volumes from May 15/14 to May 6/15 in Cubic Meters (m^3)			
Haliburton Brook	O'Donnell Creek	Hamsterly Creek	Colquitz River
284,134	1,053,177	156,796	2,592,742

Based on the water flow volume estimates presented in *Table 4*, O'Donnell Creek contributes approximately three times the volume as Haliburton Brook, and five times the volume of Hamsterly Creek, to Elk/Beaver Lake.

4 Discussion

Most water quality parameters analyzed in the Elk/Beaver Lake tributaries and outflow were within WQGs for the protection of aquatic life and human health. However, due to the semi-rural and agricultural nature of the watershed, all streams have the common issue of nutrient loading and bacterial contamination, including increased levels of *E. coli*, nitrogen and phosphorus, with phosphorus being the biggest concern.

Water quality monitoring of nutrients in all four creeks was not consistent enough to properly compare between parameters or streams. The 2014-2015 PSS data provided the best snapshot of water quality issues in the Elk/Beaver tributaries and outflow, however, even that data only contained a few samples of the various nutrients in the streams. There were not enough data for *E. coli*, dissolved organic carbon, nitrates, nitrites or ammonia to meet the 5 samples required for average or long-term guidelines.

4.1 E. coli

Haliburton Brook and O'Donnell Creek both showed elevated *E. coli* measurements on several sampling occasions, however, *E. coli* testing and data were extremely limited. Haliburton Brook was only tested for *E. coli* on 14 out of 53 dates, and significantly exceeded guidelines on three of those dates, in both summer and winter months. O'Donnell Creek was tested for *E. coli* on 24 out of 53 dates, with exceedances on eight of those dates, in both summer and winter months. Both streams experience fecal contamination, which loads into Elk/Beaver Lake, further contributing to nutrient loading and eutrophication. This contamination may come from malfunctioning septic fields, wildlife (especially geese or racoons) or dogs. More sophisticated tests could distinguish some of these potential sources.

4.2 Nitrogen

Nitrogen data were very limited for most of the creeks. Haliburton Brook had the most robust nitrogen data from recent monitoring by the BEES. In Haliburton Brook, nine samples out of 53 were tested for nitrogenous compounds, and while nitrates and ammonia were below WQGs, nitrites exceeded guidelines in half of the samples. As nitrites should be reduced to nitrate fairly quickly in a healthy ecosystem, the reason for this imbalance should be investigated. The other creeks going into and out of Elk/Beaver Lake only had one or two samples analyzed for nitrogen. Nitrogen contamination may come from the same sources as *E. coli*, as sewage and decomposition are amongst the primary sources of aquatic nitrogenous compounds. The overabundance of the transient nitrite form of nitrogen suggests that the source may be fairly close to the sampling site.

4.3 Phosphorus

The nutrient of greatest concern is phosphorus, as this is the limiting nutrient in most freshwater systems, and was above water quality objectives in every stream flowing into and out of Elk/Beaver Lake. Phosphorus has also been identified as responsible for the increase in blue-green algal blooms in the Lake. While most of the phosphorus loading in Elk/Beaver Lake is believed to be internal, external sources are also contributing to the problem and may be more influenced by climate change.

Phosphorus testing was inconsistent between different sampling groups, as shown in Appendix I. PSS analyzed 17 samples for total phosphorus, and one sample for ortho-phosphate. The BC ENV tested one sample for total phosphorus. CRD tested samples for both ortho-phosphate and total phosphorus, but data were limited to three samples. The BEES tested samples for total-phosphate, but not ortho-phosphate or total phosphorus, so results cannot be compared to CRD or PSS data. These discrepancies show an opportunity for improvement and coordination in testing between the various groups collaborating on water quality monitoring in the Elk/Beaver watershed.

5 Recommendations

Recommendations come from the CRD's Elk/Beaver Lake Watershed Management Plan, and the BC ENV's Phosphorus Management in Vancouver Island Streams document, as well the author's observations made during data amalgamation and creation of this report.

5.1 Water Quality Monitoring

The first recommendation is to design and implement an investigative water quality monitoring protocol to identify and track sources of pollution. This requires a different approach than monitoring to confirm that water quality entering the lake is of adequate quality. Water quality affecting aquatic life in Elk/Beaver Lake requires monitoring streams for water quality parameters/nutrients (including flow) near the stream outflow (into the lake), to determine how much nutrient/contaminant is entering the lake (all recommended parameters). This needs to be regular and ongoing monitoring, and should include a 5/30 sampling program during summer low flow periods, and fall first flush. A spring monitoring program could capture fertilizer or manure applications at this time.

Investigating where nutrients/contaminants are entering the streams requires monitoring at multiple locations along the length of each stream to identify differences in water quality contaminants (*E. coli*, total phosphorus, dissolved oxygen). This may identify source points along the creeks that could be managed to reduce contaminants entering the stream. This investigative process could be more concentrated and discrete, with specific parameters, though monitoring of identified sources would require on-going regular sampling. Due to the intensive sampling requirements of source tracking, an ortho-phosphate meter is recommended for regular monitoring along streams to detect fluctuations and estimate phosphorus levels. Regular lab analysis for total phosphorus is still recommended for water quality monitoring of water flowing into Elk/Beaver Lake.

The water quality parameters of concern in the Elk/Beaver tributaries are the following:

- *E. coli* – 5/30 sampling for *E. coli* is recommended due to increased levels. *E. coli* in streams indicates fecal contamination. PCR testing could indicate if the source is human or otherwise, facilitating source tracking.
- Nitrite – measured above WQGs and requires 5/30 sampling. This parameter is closely linked to nitrate and ammonia levels, which would require similar investigative monitoring.
- Phosphorus – BC ENV recommendations for streams with phosphorus levels under WQO is monthly from May-Sept, all Elk/Beaver streams are severely over total phosphorus WQOs, so more rigorous sampling is recommended. **<u>Total phosphorus</u> is the recommended parameter[4].**

[4] BC ENV, 2014 (WQO page 6, sampling page 9)

Other water quality parameters that should be monitored (recommended by CRD WMP[5], BC ENV):

- Dissolved Oxygen – indicates general stream health, with handheld meters making sampling simple and cost effective. This measure may change on a diurnal basis, which needs to be considered for more refined data needs.
- Dissolved organic carbon (DOC) – initially requires 5/30 sampling to determine a background, which has not been done for any Elk/Beaver tributaries. WQG is 20% of background level DOC. Increase in DOC contributes to eutrophication.
- pH, conductivity, turbidity, temperature – indicate general stream health, handheld meters make sampling easy. Diurnal changes need to be taken into account.
- Total nitrogen (including: nitrate, nitrite, ammonia) – less of a concern in Elk/Beaver tributaries compared to total phosphorus, still contribute to poor water quality/eutrophication.
- Metals – historically metals in the tributaries have all been within WQGs (based on samples from 1987, 2019). Nevertheless, regular monitoring of sediments on an annual or multi-annual basis is likely warranted
- 6PPD-quinone – an emerging contaminant of concern. Further investigation is needed.

The CRD Elk/Beaver Lake WMP recommends monthly sampling from May to September, however, exceedances shown in this report have occurred throughout winter months as well, so monitoring should be carried out year-round until parameters are within recommended guidelines.

Sampling for total phosphorus on a bi-monthly or even weekly basis would increase reliability of data, show more robust trends, and if sampled along with water flow, allow for calculations of phosphorus loading into Elk/Beaver Lake. Associated costs of total phosphorus monitoring at this scale may be prohibitive, as determination requires lab analysis. Using handheld ortho-phosphate and flow meters could at least estimate changes in phosphate levels and scales of loading, and would be better than no monitoring or sporadic monitoring. Comparative sampling of free orthophosphate and total phosphate could create a site-specific understanding of the relationship between the two, which could be useful for correlating free orthophosphate measures with likely total phosphorus. This approach could also be used to help investigate the likely source of the phosphates.

Isotopic analysis of phosphates could be a particularly powerful investigative tool to understand the contribution of surface waters to the lakes' phosphate load, or even the specific phosphate being used by an algal bloom. For example, Elsebury et al. (2009) estimated the proportionate contribution of rivers to phosphate loading in Erie Lake using this approach. The technique has subsequently been considerably refined. As it works by virtue of differences in oxygen isotopes, baseline data would be needed before oxygenation of the lake proceeds.

Confirming that the various groups conducting water quality monitoring are all following the same sampling protocols and carrying out analysis of the same parameters is just as important as regular monitoring. Water quality data are only valuable if they are trustworthy and robust. Collaborating on sampling techniques and carrying out QA/QC protocols would confirm that data collected between groups can be confidently compared, a substantial challenge for this report.

An emerging contaminant of concern that has shown acute toxicity to coho salmon is 6PPD quinone (Tian et al, 2021). While this compound has not been analyzed in the Elk/Beaver watershed before, new evidence suggests that this toxic compound is likely present on roadways, and due to the urban nature of the watershed, and the

[5] CRD, 2020 (appendix E, page 4)

proximity of Elk/Beaver Lake to the Patricia Bay Highway, it is recommended that 6PPD quinone should be added to the list of contaminants to be regularly monitored. Further investigation into this compound and monitoring protocols is needed.

5.2 Watershed Management

Watershed management to minimize run-off of nutrients and contaminants into the streams and lake requires a multi-faceted approach, including educating landowners and farmers about the impacts and guidelines for managing manure, fertilizers, lawns, and septic systems, and implementing control measures to make sure residents are compliant and proactive. The CRD's Elk/Beaver Lake Watershed Management Plan includes control measures for rural and urban landowners to reduce phosphorus inputs into the watersheds (CRD, 2020). The CRD's goal is to contact 90% of landowners within the watershed within the next five years, to increase education and management practices for reduction of Phosphorus inputs.

A review of 35 eutrophic lakes, by D. Schindler (2012), found that decreasing external phosphorus loading resulted in reduced in-lake levels of phosphorus and phytoplankton chlorophyl α, and increased water clarity. Lakes where phosphorus inputs had been reduced usually took 10-15 years to reach a new steady state, due to internal phosphate loading (as observed in Elk/Beaver Lake), and phosphates in sediments (Schindler, 2012). Schindler's study looked at other managements practices for reducing phosphorus in eutrophic lakes, and found that "the only method that has had proven success in reducing the eutrophication of lakes is reducing inputs of phosphorus (Schindler, 2012). While monitoring is an important aspect of phosphorus management in Elk/Beaver tributaries and lake, perhaps the more important effort is control and reduction of phosphorus inputs within the watershed. Stream monitoring will likely show phosphorus reduction long before Elk/Beaver Lake will, so continued monitoring is still an integral part of the reduction and management of phosphorus within the watershed.

5.3 Stream Restoration

Another approach to phosphorus reduction is to increase nutrient capacity of the creeks by increasing vegetation growing in and along the banks, maintaining open and vegetative drainage ditches, and increasing vegetation buffers between the creeks and surrounding neighborhoods and farms. Plants utilize nutrients effectively so creating these buffers will increase the capacity of the creeks to reduce phosphorus levels naturally. Plant buffers along banks will also slow erosion of soil and reduce phosphorus release from the sediment.

6 Conclusion

External nutrient loading into Elk/Beaver Lake is primarily phosphorus, with the majority of the nutrients coming from O'Donnell Creek. Haliburton Brook and Hamsterly Creek are also contributing nutrients on a smaller scale. *E. coli* contamination is also a concern, and indicates that some of the nutrients may be coming from septic systems or animal manure. Continuous water quality and flow monitoring should be carried out until nutrient levels loading into Elk/Beaver Lake are under control and within guidelines. An additional toxic contaminant of concern, 6PPD quinone, should be added to the water quality monitoring regimen. Watershed management and stream restoration will help reduce phosphorus, nitrogen and *E. coli* contamination in the Elk/Beaver tributaries, and over time may help reduce phosphorus levels and algal blooms in Elk/Beaver Lake. Reducing phosphorus loading in Elk/Beaver Lake is important because it is currently flowing downstream through the Colquitz River and may be impacting other ecosystems.

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Appendix A: Stormwater (SW) Sampling from Appendix E of Elk/Beaver Watershed Management Plan (CRD, 2020)

Water Quality Parameters

Physical Parameters	**Chemical Samples**
Dissolved Oxygen	Total Phosphorus
Temperature	Ortho-Phosphorus
pH	Total Nitrogen, Nitrite, Nitrate, Ammonia
Conductivity	Dissolved Organic Carbon
Water Clarity	Dissolved Metals

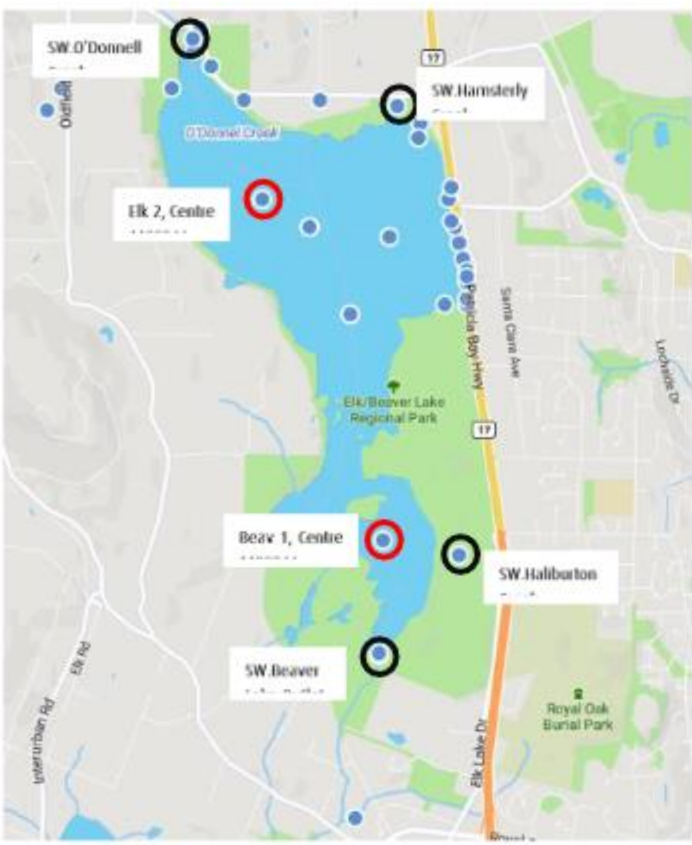
Data Collection

- All parameters every four weeks (August-October)

Sampling Locations

a. Inflow: O'Donnell Creek, Haliburton Brook, Hamsterly Creek
b. Outflow: Sampling the head of Colquitz River to monitor outflows

Sampling Map



Appendix B: Data Sources, Sampling Dates, and Parameters Tested, by Creek

Data Sources, Sampling Dates, and Parameters Tested, by Creek

Date	Source	Parameters	Source	Parameters	Source	Parameters	Source	Parameters	Source	Parameters
	Haliburton Brook		**O'Donnell Creek**		**Hamsterley Creek**		**Linnet Creek**		**Colquitz Creek**	
2014-05-15	PSS	E. coli, P-T, Turb	PSS	E. coli, P-T, Turb					PSS	E. coli, P-T, Turb
2014-05-21	PSS	E. coli, P-T, Turb	PSS	E. coli	PSS	E. coli,			PSS	E. coli
2014-05-27	PSS	E. coli, P-T, Turb	PSS	E. coli, P-T, Turb					PSS	E. coli, P-T, Turb
2014-06-03	PSS	E. coli, P-T, Turb	PSS	E. coli					PSS	E. coli
2014-06-10	PSS	P-T, Turb	PSS	PO4-O					PSS	PO4-O, Turb
2014-06-12	PSS	E. coli, P-T, Turb	PSS	E. coli					PSS	E. coli
2014-07-08	PSS	P-T, Turb	PSS	P-T, Turb					PSS	P-T, Turb
2014-07-22	PSS	P-T, Turb	PSS	P-T, Turb					PSS	P-T, Turb
2014-08-06	PSS	E. coli, P-T, Turb	PSS	P-T, Turb					PSS	P-T, Turb
2014-08-14	PSS	E. coli, P-T, Turb	PSS	E. coli					PSS	E. coli
2014-08-19	PSS	E. coli, P-T, Turb	PSS	P-T, Turb					PSS	E. coli, P-T, Turb
2014-08-26	PSS	P-T, Turb	PSS	E. coli					PSS	E. coli
2014-09-03	PSS	P-T, Turb	PSS	E. coli					PSS	E. coli
2014-09-09	PSS	P-T, Turb	PSS	E. coli, P-T, Turb					PSS	E. coli
2014-09-23	PSS	P-T, Turb	PSS	P-T, Turb					PSS	P-T, Turb
2014-10-07	PSS	P-T, Turb	PSS	P-T, Turb					PSS	Turb
2014-10-21	PSS	P-T, Turb	PSS	P-T, Turb					PSS	P-T, Turb
2014-10-28			PSS	E. coli						
2014-11-04	PSS	P-T, Turb	PSS	E. coli	PSS	P-T, Turb			PSS	P-T, Turb
2014-11-12			PSS	E. coli, P-T, Turb						
2014-11-19	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turb
2014-11-26			PSS	P-T, Turb						
2014-12-09	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turb
2014-12-23	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turbidity
2015-01-07	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turbidity
2015-01-20	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turbidity
2015-02-03	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turbidity
2015-02-17	PSS	P-T, Turb	PSS	P-T, Turb	PSS	P-T, Turb			PSS	P-T, Turb
2015-04-21	MOE	P-T, Turb	MOE	P-T, Turb	MOE	P-T, Turb			MOE	P-T, Turb
2016-08-19			CRD	DOC, E. coli, P-T NO_2, NO_3, PO_4-O						
2016-10-20	CRD	DOC, PO_4-T NO_2+NO_3								
2017-01-17							CRD	DOC, E. coli, fecal, PO_4-O NO_2+NO_3, P-T		
2017-02-17			CRD	DOC, E. coli, fecal, PO_4-O NO_2+NO_3, P-T						
2017-02-24	CRD	DOC, PO_4-O, PO_4-T								
2017-03-17			CRD	E. coli, fecal, P-T						
2017-05-17	CRD	PO_4-O, PO_4-T	CRD	PO_4-O, P-T						
2017-10-17			CRD	NO_2+NO_3, PO_4-O, P-T						

Date	Source	Parameter	Source	Parameter	Source	Parameter	Source	Parameter	Source	Parameter
	Haliburton Creek		**O'Donnell Creek**		**Hamsterley Creek**		**Linnet Creek**		**Colquitz Creek**	
2017-11-15									CRD	DO, E. coli, metals, NO_2 NO_3, pH, T, TSS, Turb
2019-11-22					CRD	DOC, PO_4-O NO_2+NO_3, P-T				
2019-11-28	CRD	DO, DOC, pH E.coli, metals, SC, NH_4, T, Turb	CRD	DO, DOC, E.coli, metals, pH, SC, T, Turb					CRD	DO, DOC, T E.coli, Turb, metals, pH,
2019-12-11	CRD	DO, DOC, E. coli, metals, NH_3, NO_2, NO_3, PO_4-O, PO_4-T, pH, SC, T	CRD	DO, DOC, E. coli, metals, NH_3, NO_2, NO_3, PO_4-O, PO_4-T, pH, P-T, SC, T	CRD	DO, DOC, E. coli, metals, pH, SC, T, Turb			CRD	DO, DOC, E. coli, NH_3 metals, NO_2 NO_3, PO_4-O pH, P-T, T
2020-10-25	PSS/ BEES	As, Cu, DO, E. coli, Fe, fecal, Hg, Mn, NH_3, NO_2, NO_3, Pb, PO_4-T, pH, SP, T					CRD	DO, DOC, metals, pH, SC, T, Turb		
2020-11-20	BEES	DO, fecal, NH_3, NO_2, NO_3, PO_4-T, pH,			CRD	DO, DOC, E. coli, metals, NH_3, NO_2, NO_3, PO_4-O, pH, P-T, SC, T, Turb	CRD	DO, DOC, E. coli, metals, NH_3, NO_2, NO_3, PO_4-O, PO_4-T, pH, SC, T		
2020-12-18	BEES	DO, NH_3, NO_2, NO_3, PO_4-T, pH, T								
2021-01-15	BEES	DO, NH_3, NO_2, NO_3, PO_4-T, pH, T								
2021-02-28	BEES/ PSS	DO, fecal, NH_3, NO_2, NO_3, PO_4-T, pH,								
2021-03-29	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-04-29	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-05-24	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-06-29	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-07-30	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-08-30	BEES/ PSS	NH_3, NO_2, NO_3, PO_4-T, pH, T, Turb, SC, DO_2								
2021-09-27	BEES/ PSS	NH_3, NO_2, NO_3, P-T, pH, T, Turb, SC, DO_2								
2021-10-29	BEES/ PSS	NH_3, NO_2, NO_3, P-T, pH, T, Turb, SC, DO_2								

Abbreviations for Appendix B:

DO	Dissolved Oxygen	NH_3	Ammonia	NH_4	Ammonium	NO_2	Nitrite
NO_3	Nitrate	PO_4-O	Ortho Phosphate	PO_4-T	Total Phosphate	P-T	Total Phosphorus
SC	Specific Conductivity	T	Temperature (°C)	TSS	Total Suspended Solids	Turb	Turbidity

Appendix C: Metals in Creeks Flowing in and out of Elk/Beaver Lake (Source – CRD)

Parameter (total state unless specified ** dissolved)	Unit	Guideline*	Haliburton		O'Donnell		Hamsterley		Linnet		Colquitz		
			2019-11-28	2019-12-11	2019-11-28	2019-12-11	2019-11-22	2019-12-11	2019-11-28	2019-12-11	2017-11-15	2019-11-28	2019-12-11
Aluminum	µg/L	Max 100[1]	4.32	5.39	24.3	29.8	28.9	30.2	17.5	15.4	43.6** 5.43	1.66	1.1
Antimony	µg/L	Max 20	0.139	0.096	0.064	0.076	0.092	0.124	0.03	0.03	0.131	0.091	0.102
Arsenic	µg/L	Max 5	0.544	0.459	0.419	0.512	0.327	0.344	0.16	0.146	1.13	0.852	0.802
Barium	µg/L	Max 5,000[2]	12.4	11.4	16.4	19.1	17.6	18.4	6.13	6.78	13.8	10.8	11
Beryllium	µg/L	Max 5.3[2]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bismuth	µg/L		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Boron	µg/L	Max 1,200	70	45	28	32	15	16	21	21	22	22	22
Cadmium	µg/L	Max 0.05-0.39[3]	0.0053	0.005	<0.005	0.0058	0.0057	0.0059	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Calcium **	mg/L		79.8	52.7	38.9	42.4	26.7	25.6	25.3	28.4	20	19.2	20.7
Chromium	µg/L	Max 1/9[IV/III, 2]	0.19	0.14	0.31	0.32	0.31	0.32	0.12	0.11	< 0.1	< 0.1	< 0.1
Cobalt	µg/L	Max 110	0.205	0.0921	0.332	0.294	0.332	0.294	0.0513	0.0509	0.0313	0.0227	0.022
Copper	µg/L	Max 2.8-8.2[5]	2.51	1.51	1.41	1.44	1.82	1.94	0.753	0.705	0.335	0.213	0.216
Hardness $CaCO_3$	mg/L		299	203	130	141	87.3	84.3	81.2	91.5	69.5	67.1	71.6
Iron	µg/L	Max 1000	61.9	22.1	137	200	438	487	33	33.5	48.7	11.5	11.4
Lead	µg/L	Max 3.7-48.4[7]	0.0245	0.0097	0.028	0.0377	0.183	0.178	0.0061	0.0065	0.0256	0.0069	0.0067
Lithium	µg/L	Max 870[2]	0.56	0.77	<0.5	<0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Magnesium	mg/L		24.2	17.4	7.9	8.5	5.01	4.93	4.34	5	4.75	4.68	4.85
Manganese	µg/L	Max 637-1271[9]	234	19	31.2	30.5	114	89.4	7.75	13.3	60.6** 35.3	1.76	8.01
Molybdenum	µg/L	Max 2000	0.421	0.342	0.583	0.585	0.328	0.349	0.137	0.125	0.408	0.387	0.383
Nickel	µg/L	Max 25-110[2, 11]	1.22	0.84	1.16	1.31	1.01	1.06	0.186	0.162	0.242	0.221	0.234
Potassium	µg/L	Max 373,000-432,000	2.54	1.8	3.74	3.6	1.74	1.64	1.25	1.28	1.7	1.75	1.78
Selenium	µg/L	Max 2	0.114	0.073	0.078	0.089	0.064	0.056	0.07	0.069	< 0.04	< 0.04	< 0.04
Silicon	mg/L		8460	8260	7050	7400	7530	8000	6210	6680	514	235	116
Silver	µg/L	Max 0.1[13]	<0.005	<0.005	<0.005	<0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Sodium	µg/L		27.5	26.1	12.5	13.2	18.5	21.2	9.06	10.6	9.62	9.45	9.94
Strontium	µg/L		335	232	163	180	116	106	84.9	95.6	78.9	78.8	82.5
Sulphur **	µg/L		9.1	6.9	8	9.4	5.9	4.1	4.4	4.7		< 3	< 3
Thallium	µg/L		< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.0024	< 0.002	< 0.002	< 0.002
Tin	µg/L		< 0.2	< 0.2	< 0.02	< 0.02	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Titanium	µg/L	Max 2,000[2]	< 0.05	< 0.05	0.86	1.23	0.86	1.23	< 0.5	0.72	< 0.05	< 0.05	< 0.05
Uranium	µg/L	Max 8.5[2]	0.261	0.156	0.0555	0.0527	0.0567	0.0427	0.0153	0.0161	0.0085	0.008	0.0077
Vanadium	µg/L		0.41	0.46	1.12	1.23	0.61	0.64	0.49	0.58	0.31	0.31	0.24
Zinc	µg/L	Max 33[16]	1.96	0.39	2.67	2.97	7.67	6.97	0.24	0.14	0.87	0.38	0.78
Zirconium	µg/L		0.11	0.1	0.17	0.21	0.19	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

*BC ENV WQGs for the protection of aquatic life

[1] dissolved aluminum if pH > or = 6.5

[2] BC working water quality guideline

[3] max: e[1.03 * ln(Hss) – 5.274]; average: e[0.736 * ln(Hss) – 4.943], µg/L dissolved Cd

[4] no guideline; background levels

[5] (0.094(hardness)+2) µg/L and 2 µg/L if hardness is < or = 50 mg/L $CaCO_3$; otherwise 0.04 (mean hardness) µg/L total Cu

[6] dissolved oxygen is a minimum guideline

[7] if hardness > 8 mg/L : e(1.273 ln (hardness) – 1.460; if hardness < 8 mg/L : 3 µg/L total lead

[8] if mean hardnesss > 8 mg/L CaCO3 then, 3.31 + e(1.273 ln (mean hardness) – 4.704) µg/L total lead

[9] 0.01102 hardness + 0.54 maximµm mg/L total Mn

[10] 0.0044 hardness + 0.605 average mg/L total Mn

[11] 25 µg/L total Ni if hardness is < or = 60 mg/L CaCO3, 110 µg/L Ni at hardness > 60 to 180 mg/L as CaCO3, 150 µg/L Ni at hardness of 120 to 180 mg/L as CaCO3

[12] draft Vancoµver Island Objective, applies to monthly 5/30 samples collected June to September

[13] 0.1 µg/L Ag max, 0.05 µg/L Ag ave if hardness is <=100mg/L; otherwise 3 mg/L Ag max, 1.5 mg/L Ag ave

[16] Max: 33 µg/L total Zn if hardness is < 90mg/L CaCO3; otherwise 33+0.75(hardness-90)µg/L; Ave.: 7.5 µg/L total Zn if hardness is <= 90mg/L CaCO3; otherwise 7.5 +0.75 (hardness – 90) µg/L

Appendix D: Water Quality Data for Haliburton Brook

Water Quality Monitoring of Haliburton Brook from 2014 to 2021, Data Provided by PSS, BC ENV, CRD and BEES

Date	Parameter	DO	DOC	E. coli	Fecal	NH_3-N	NO_2-N	NO_3-N	pH	PO_4-O	PO_4-T	P-T	SC	T	Turb
	Unit	mg/L	mg/L	CFU/ 100mL	CFU/ 100mL	mg/L	mg/L	mg/L	pH	mg/L	mg/L	mg/L	µS/cm	°C	NTU
	WQG	5	>6.5	400	200	1.57	0.06	33	6.5-9			0.01	80	<19	
2014-05-15				69								0.0363			4.61
2014-05-21				93											
2014-05-27				44								0.0444			3.99
2014-06-03				50											
2014-06-10										0.027					5.12
2014-06-12				340											
2014-07-08												0.0609			7.1
2014-07-22												0.0678			4.67
2014-08-06				3900								0.104			4.43
2014-08-14				3000											
2014-08-19				160								0.125			5.51
2014-09-09												0.0465			1.91
2014-09-23												0.0451			4.46
2014-10-07												0.0598			10.5
2014-10-21															4.74
2014-11-04												0.0912			14.6
2014-11-19												0.0345			2.38
2014-12-09												0.0911			29.1
2014-12-23												0.071			7.33
2015-01-07												0.0663			7.42
2015-01-20												0.0412			7.75
2015-02-03												0.0903			4.65
2015-02-17												0.0227			4.34
2015-04-21												0.312			5.98
2016-10-20			8.04					3.360			0.108				
2017-02-24			4.76							0.026	0.035				
2017-05-17										0.065	0.080				
2019-11-28		8.21	7.2	2300					7.37				709.4	6.7	5.74
2019-12-11		10.6	6.3	2		0.015	0.005	0.845	8.22	0.047		0.055	552.2	7.7	
2020-10-25		10.4		72	72	0.097	0.117	0.592	7.30		0.074			9.5	6
2020-11-20		11.1			126	0.104	0.078	0.372	7.30		0.06			9.6	6
2020-12-18		10.4				0.086	0.139	0.487	7.85		0.023			8.8	11
2021-01-15		10.9				0.028	0.096	0.397	7.95		0.03			8.2	10
2021-02-28		10.4			12	0.054	0.042	0.505	7.78		0.022			8.5	8
2021-03-29		11.5				0.021	0.034	1.610	7.93		0.0308		523	8.8	9.9
2021-04-29		9.70				0.0127	0.036	1.240	7.98		0.0325		784	13.0	12.0
2021-05-24		9.86				0.0199	0.0194	1.500	7.60		0.0502		400	12.2	<6
2021-06-29		7.88						2.010	7.83		0.0392		548	19.4	19
2021-07-30		8.30					0.2290	4.330	7.85		0.1090		427	19.7	10
2021-08-30		8.61					0.0068	3.840	8.11		0.2130		546	17.8	10
2021-09-27		9.21				0.0248	0.0293	1.530	7.90			0.0778	675	15.7	9.21
2021-10-29		11.6				0.0443	0.0599	2.060	7.80			0.0443	697	11.9	12.2

Abbreviations for Appendix D:

DO	Dissolved Oxygen	DOC	Dissolved Organic Carbon	NH_3-N	Ammonia (as Nitrogen)
NO_2-N	Nitrite (as Nitrogen)	NO_3-N	Nitrate (as Nitrogen)	PO_4-O	Ortho Phosphate
PO_4-T	Total Phosphate	P-T	Total Phosphorus	SC	Specific Conductivity
T	Temperature	Turb	Turbidity		

Appendix E: Water Quality Data for O'Donnell Creek

Water Quality Monitoring of O'Donnell Creek from 2014 to 2019, Data Provided by PSS, BC ENV and CRD

Date	Parameter	DO	DOC	E. coli	Fecal	NH_3-N	NO_2-N	NO_3-N	pH	PO_4-O	PO_4-T	P-T	SC	T	Turb
	Unit	mg/L	mg/L	CFU/ 100mL	CFU/ 100mL	mg/L	mg/L	mg/L	pH	mg/L	mg/L	mg/L	µS/cm	°C	NTU
	WQG	5	>6.5	400	200	1.57	0.06	33	6.5-9			0.01	80	<19	
2014-05-15				81								0.118			3.44
2014-05-21				140											
2014-05-27				290								0.106			4.66
2014-06-03				140											
2014-06-10										0.11					9.8
2014-06-12				240											
2014-07-08												0.140			
2014-07-22												0.164			7.76
2014-08-06												0.169			6.63
2014-08-14				1300											
2014-08-19				560								0.138			6.01
2014-08-26				1700											
2014-09-03				2000											
2014-09-09				290								0.122			3.99
2014-09-23												0.127			5.91
2014-10-07												0.143			6.57
2014-10-21												0.256			5.46
2014-10-28				48								0.168			3.12
2014-11-04				1000								0.206			5.91
2014-11-12				32								0.091			9.8
2014-11-19												0.095			7.83
2014-11-26				250								0.170			4.37
2014-12-09												0.305			14.3
2014-12-23												0.081			1.9
2015-01-07												0.092			3.17
2015-01-20												0.093			3.53
2015-02-03												0.111			
2015-02-17												0.047			7.09
2015-04-21												0.802			7.42
2016-08-19			3.72	460			0.0082	0.198		0.17		0.262			
2017-01-17			5.51	< 10	10					0.066		0.136			
2017-02-17			2.54	90	60					0.028		0.057			
2017-03-17				480	460							0.151			
2017-05-17										0.061		0.144			
2017-10-17										0.153		0.185			
2019-11-28		11.9	8.2	18					8.11				348.7	2.4	3.22
2019-12-11		9.11	10	68		0.21	0.0216	1.77	7.84	0.07	0.083		376.2	6.6	

Abbreviations for Appendix E:

DO	Dissolved Oxygen	DOC	Dissolved Organic Carbon	NH_3-N	Ammonia (as Nitrogen)
NO_2-N	Nitrite (as Nitrogen)	NO_3-N	Nitrate (as Nitrogen)	PO_4-O	Ortho Phosphate
PO_4-T	Total Phosphate	P-T	Total Phosphorus	SC	Specific Conductivity
T	Temperature	Turb	Turbidity		

Appendix F: Water Quality Data for Hamsterly Creek

Water Quality Monitoring of Hamsterly Creek from 2014 to 2019, Data Provided by PSS, BC ENV, and CRD

Date	Parameter	DO	DOC	E. coli	Fecal	NH_3-N	NO_2-N	NO_3-N	pH	PO_4-O	PO_4-T	P-T	SC	T	Turb
	Unit	mg/L	mg/L	CFU/ 100mL	CFU/ 100mL	mg/L	mg/L	mg/L	pH	mg/L	mg/L	mg/L	µS/cm	°C	NTU
	WQG	5	>6.5	400	200	1.57	0.06	33	6.5-9			0.01	80	<19	
2014-05-21				20											
2014-11-04												0.076			5.69
2014-11-19												0.037			1.58
2014-12-09												0.127			27.8
2014-12-23												0.053			20.5
2015-01-07												0.050			3.17
2015-01-20												0.019			3.46
2015-02-03												0.033			4.09
2015-02-17												0.036			6.55
2015-04-21												0.046			2.58
2017-10-17			14.2							0.053		0.434			
2019-11-22		8.61	6.8	3					7.68				281.1	5.4	3.22
2019-12-11		7.42	7.7	13		0.076	< 0.005	0.081	7.58	0.026		0.047	303.1	8	

Abbreviations for Appendix F:

DO	Dissolved Oxygen	DOC	Dissolved Organic Carbon	NH_3-N	Ammonia (as Nitrogen)
NO_2-N	Nitrite (as Nitrogen)	NO_3-N	Nitrate (as Nitrogen)	PO_4-O	Ortho Phosphate
PO_4-T	Total Phosphate	P-T	Total Phosphorus	SC	Specific Conductivity
T	Temperature	Turb	Turbidity		

Appendix G: Water Quality Data for Linnet Creek

Water Quality Monitoring of Linnet Creek in 2019, Data Provided by CRD														
Date	Parameter	DO	DOC	E. coli	Fecal	NH_3-N	NO_2-N	NO_3-N	pH	PO_4-O	PO_4-T	P-T	SC	T	Turb
	Unit	mg/L	mg/L	CFU/ 100mL	CFU/ 100mL	mg/L	mg/L	mg/L	pH	mg/L	mg/L	mg/L	µS/cm	°C	NTU
	WQG	5	>6.5	400	200	1.57	0.06	33	6.5-9			0.01	80	<19	
2019-11-28		11.62	5.1						7.78				189.2	5.6	2.96
2019-12-11		10.49	4.4	6		0.032	< 0.005	0.569	7.72	0.0052	0.03		257.8	7.2	

Abbreviations for Appendix G:

DO	Dissolved Oxygen	DOC	Dissolved Organic Carbon	NH_3-N	Ammonia (as Nitrogen)
NO_2-N	Nitrite (as Nitrogen)	NO_3-N	Nitrate (as Nitrogen)	PO_4-O	Ortho Phosphate
PO_4-T	Total Phosphate	P-T	Total Phosphorus	SC	Specific Conductivity
T	Temperature	Turb	Turbidity		

Appendix H: Water Quality Data for Colquitz River

Water Quality Monitoring of Colquitz Creek from 2014 to 2019. Data Provided by PSS, BC ENV, and CRD

Date	Parameter	DO	DOC	E. coli	NH_3-N	NO_2-N	NO_3-N	pH	PO_4-O	PO_4-T	P-T	SC	T	Turb
	Unit	mg/L	mg/L	CFU/ 100mL	mg/L	mg/L	mg/L	pH	mg/L	mg/L	mg/L	µS/cm	°C	NTU
	WQG	5	>6.5	400	1.57	0.06	33	6.5-9			0.01	80	<19	
2014-05-15				5							0.0323			7.26
2014-05-21				4										
2014-05-27				6							0.0395			5.26
2014-06-03				5										
2014-06-10									0.0016					17.1
2014-06-12				1										
2014-07-08											0.0406			4.45
2014-07-22											0.0412			3.09
2014-08-06											0.0804			36.3
2014-08-14				15										
2014-08-19				4							0.037			4.58
2014-08-26				4										
2014-09-03				20										
2014-09-09				3							0.0323			2.21
2014-09-23											0.0461			5.85
2014-10-07														21.8
2014-10-21											0.0362			3.34
2014-11-04											0.0319			1.57
2014-11-19											0.0257			1.53
2014-12-09											0.023			1.41
2014-12-23											0.0051			2.19
2015-01-07											0.0172			2.72
2015-01-20											0.0317			2.09
2015-02-03											0.0077			2.12
2015-02-17											0.0069			3.78
2015-04-21											0.0369			3.81
2017-11-15		10.24		10		0.0067	0.119	7.44				215	7.4	3.34
2019-11-28		12.33	5.4	2				7.57				194.5	3.3	2.65
2019-12-11		10.46	6.1	1	0.054	0.005	0.02	7.63	0.0046		0.036	208.7	5.6	

Abbreviations for Appendix H:

DO	Dissolved Oxygen	DOC	Dissolved Organic Carbon	NH_3-N	Ammonia (as Nitrogen)
NO_2-N	Nitrite (as Nitrogen)	NO_3-N	Nitrate (as Nitrogen)	PO_4-O	Ortho Phosphate
PO_4-T	Total Phosphate	P-T	Total Phosphorus	SC	Specific Conductivity
T	Temperature	Turb	Turbidity		

Appendix I: Phosphorus and Phosphate in Haliburton Brook

Phosphorus and Phosphate Measurements in Haliburton Brook from 2014 to 2021				
Date	Source	Ortho-Phosphate (PO_4-O as P) (mg/L)	Total-Phosphate (PO_4-T as P) (mg/L)	Total Phosphorus (TP) (mg/L)
2014-05-15	PSS			0.0363
2014-05-27	PSS			0.0444
2014-06-10	PSS	0.0270		
2014-07-08	PSS			0.0609
2014-07-22	PSS			0.0678
2014-08-06	PSS			0.1040
2014-08-19	PSS			0.1250
2014-09-09	PSS			0.0465
2014-09-23	PSS			0.0451
2014-10-07	PSS			0.0598
2014-11-04	PSS			0.0912
2014-11-19	PSS			0.0345
2014-12-09	PSS			0.0911
2014-12-23	PSS			0.0710
2015-01-07	PSS			0.0663
2015-01-20	PSS			0.0412
2015-02-03	PSS			0.0903
2015-02-17	PSS			0.0227
2015-04-21	BC ENV			0.0312
2016-10-20	CRD			0.1080
2017-02-24	CRD	0.0300		0.0350
2017-05-17	CRD	0.0650		0.0800
2019-12-11	CRD	0.0470		0.0550
2020-10-25	BEES/PSS		0.0740	
2020-11-20	BEES/PSS		0.0600	
2020-12-18	BEES/PSS		0.0230	
2021-01-15	BEES/PSS		0.0300	
2021-02-28	BEES/PSS		0.0220	
2021-03-29	BEES/PSS		0.0308	
2021-04-29	BEES/PSS		0.0325	
2021-05-24	BEES/PSS		0.0502	
2021-06-29	BEES/PSS		0.0392	
2021-07-30	BEES/PSS		0.1090	
2021-08-30	BEES/PSS		0.2130	
2021-09-27	BEES/PSS			0.0778
2021-10-29	BEES/PSS			0.0443