EXAMINING THE EFFECTS OF THE GARRISON LAKE FOREST FIRE OF 2021 ON THE SURFACE WATER QUALITY IN BELL CREEK'S WATERSHED

By

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Abstract

This study examined the effects of forest fire run-off on surface water quality by analyzing surface water samples taken from forest fire-affected Bell Creek watershed and comparing them against regulatory guidelines and an unburnt watershed control stream. Surface water sampling was performed at Bell Creek before precipitation events and snowmelt in March 2022. The results showed increased total metals and phosphorus levels compared to a nearby control stream. In addition, total organic carbon and turbidity were above regulatory guidelines. Precipitation will fall as rain, and snowmelt will occur as seasonal temperatures rise. The corresponding run-off of contaminants will increase stream loading. These results indicate possible post-fire water quality concerns for watersheds with similar physical characteristics and suggest a need to monitor water quality at Bell Creek further.

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1.0 Introduction

1.1 Background

Forest fires are a naturally destructive force and part of a forest ecosystem. Fires produce physical, chemical, and biological impacts on the downstream environments that affect surface water quality, water treatment systems, and aquatic life (Flannigan et al., 2005). In Western North America, forested headwaters supply 2/3s of the water supply to downstream populated regions. Unfortunately, this high-quality water is exceptionally vulnerable. Climate change has proliferated conditions conducive to natural disasters such as forest fires. Scientific modelling has shown that fire season length, severity, and area burned will increase by 74 to 118 percent by the end of this century (Westerling et al., 2011).

British Columbia's forested mountain water sources are becoming increasingly at risk of the effects of forest fires. There is a genuine need to understand these effects and quantify them. This study examined one particular watershed affected by the Garrison Lake Fire of 2021. The Garrison Lake fire started on July 20, 2021, and burned well into mid-September, covering 14,935 hectares (BC Wildfire Service, 2020). As the fire drew near, the small community of Eastgate had to evacuate their homes for weeks. Though their homes were ultimately spared from the fire, their drinking water source was not. When residents returned home, they did so under a boil water advisory due to turbidity from August to October 2021. The community of Eastgate draws its water from nearby Bell Creek, of which approximately 80% of its watershed burned. Their source water is pumped from the creek to a reservoir, filtered through gravel media, and treated with chlorine before being delivered to customers. The community of Eastgate's proximity to Bell Creek and the Garrison Lake fire can be shown in Figure 1

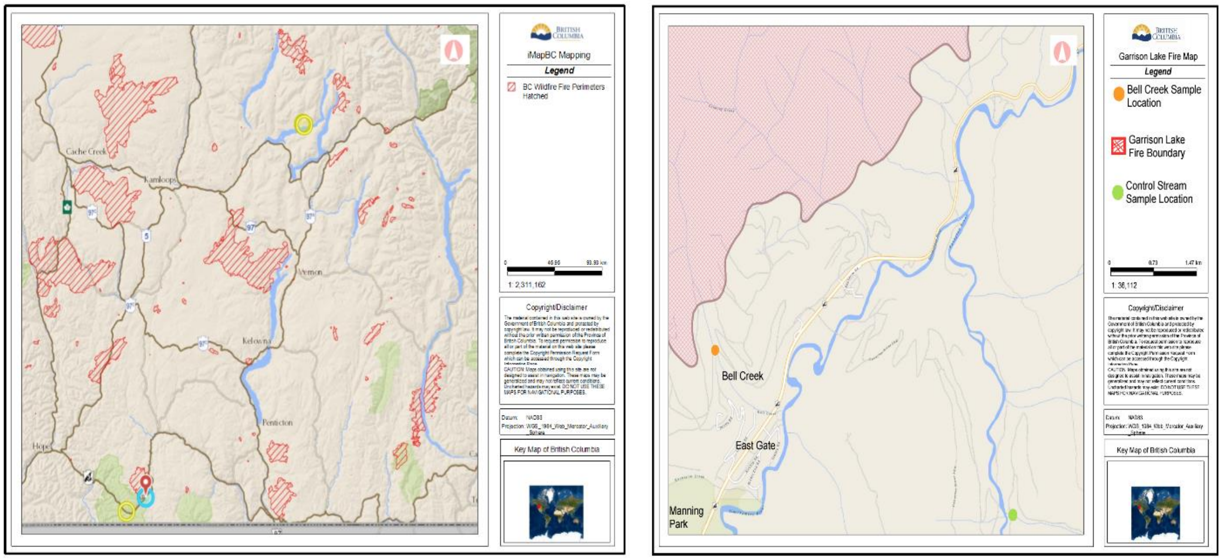

Figure 1: *Forest Fire Locations 2021 South Central BC*

Note. Map of fire boundaries South Central BC on the left, and zoomed-in map of the boundary of Garrison Lake fire denoting the Bell Creek sampling locations. Adapted from https://maps.gov.bc.ca/ess/hm/imap4m/

Figure 1 illustrates a large number of fires in the South Central BC region in 2021. The blue circle on the left picture is the location of East Gate.

1.2 Research Problem Statement

Studies have shown that deteriorating water quality post-wildfire can stress drinking water treatment facilities and, to a lesser extent, increase the concentrations of metals to a level harmful to aquatic life. As wildfires and extreme precipitation events are likely to increase in the future (Robinne et al., 2019), understanding surface run-off's effects on the local streams are essential. The degree of impact is a function of fire severity and geological and biological conditions. In addition to the increase of forest fires that comes with climate change comes the increase in drought. Just 20% of a watershed needs to burn to adversely affect downstream surface water quality, increasing pressure on water resources. By July of 2021, BC communities had already passed this threshold (Wilson, 2021). More data is needed to delineate which watersheds are at risk in BC and understand forest fires' associated effects on surface water quality.

1.3 Project Objectives

Healthy stream water quality is essential for the health of residents, the functionality of their water treatment station, and aquatic life. The primary objective of this study is to evaluate the effects of the Garrison Lake Forest fire on the Bell Creek watershed water quality. The community of Eastgate's water source and treatment facility is downstream of the forest fire-affected area. By delineating burn severity, watershed characteristics, and chemical analysis of water samples, the results could indicate the need for further monitoring of the watershed or serve as an indicator of watershed resilience to the effects of forest fires. Secondarily, the results could be used to examine if watersheds with similar features to Bell Creek would be at risk or not of water quality issues in the event of a wildfire in their catchment.

Coogan et al. (2019) conducted a thorough lit review in response to the World Scientist's Warning to Humanity: A Second Notice (Ripple et al., 2014). The response was a proposal of future recommendations for Canada, which included the need to further "understand the relationship between wildfire and hydrological function and develop a set of standardized guidelines to address the risk to water security." This study aims to build off that by taking a whole system approach and presenting data concerning watershed characteristics, burn severity, precipitation, and water quality. By presenting the data in a way that considers all the factors, we will be able to develop baseline models and, through further research, one day quantify a watershed risk and response to wildfire with accuracy. This study aims to be a step in that direction.

2.0 Literature Review

A thorough literature review was conducted to investigate published literature that showed the effects on surface water quality resulting from forest fires in a watershed catchment. The initial question was about the effects of forest fires on surface water quality. The investigation found no studies performed in the Nicola Thomson area, where the Garrison Lake fire occurred. Furthermore, the studies reviewed showed similarities and variances, which raised the question of what factors cause what type of effect? Moreover, are they consistent in watersheds that share similar characteristics? What became clear during this review was that scientists agree upon several factors that can affect the surface water quality after a fire. These factors include hydrological effects, burn severity, watershed characteristics and flooding and debris flow. Furthermore, studies indicated that these factors could affect water quality constituents such as; turbidity, total organic carbon (TOC), nutrients, trace elements, pH, temperature, and dissolved oxygen to a varying degree. Most of the reviewed studies focus on one factor and how it contributes to water quality. What became apparent was that multiple factors need to be taken into account, which raised the question can the results of one study be used as a reference for watersheds; with similar characteristics in the future? Ultimately, the findings from the literature reviewed provided a structure for designing a quantitative study of Bell Creek's surface water, examining the effect of the Garrison Lake forest fire, and discussing the correlation of results to the contributing factors.

2.1 Hydrological Effects

To properly examine wildfire's effects on a watershed, we must first understand the variables contributing to contaminant loading into receiving waters. In *Wildfires Alter Forest Watersheds and Threaten Drinking Water Quality* (2019), field data and works by authors and research teams were synthesized to examine the link between wildfire behaviours and their effect on soil conditions, water quality, and drinking water treatment facilities.   Hohner et al. (2019)thoroughly discuss how wildfires have a devastating impact on the vegetation structure and soil conditions. Numerous factors result in increased erosion and transport of sediment. First, the loss of foliage means there is less interception of precipitation and an increase in the volume of rainfall reaching ground level. Second, the loss of organic soil cover exposes the soil to rain, leading to significant sediment, nutrient, metal, and organic losses, contributing to an overall increase in erodibility. Third, precipitation run-off will transport the sediment downhill and into the receiving waters, affecting water quality and altering normal watershed processes that control streamflow, soil erosion, nutrient export, and downstream water chemistry.

Multiple studies have shown that the amount of rainfall must be considered when assessing the vulnerability of a watershed post-fire (Emmerton et al., 2020; Hohner et al., 2019; Murphy et al., 2016). In *The role of precipitation type, intensity, and spatial distribution in source water quality after wildfire* (2016), the effect of precipitation on run-off was examined post forest fire in the Southwestern US. It concluded that high-intensity rainfall was attributed to being the main driver behind increases in total suspended solids (TSS), nitrates (in particular NO_3-), manganese (Mn), with upstream snowmelt controlling the dissolved organic carbon (DOC) content.   Additionally, in *Severe western Canadian wildfire affects water quality even at large basin scales* (2020), the effects of the Fort McMurray fire in Alberta were assessed and observed the highest levels of variation of temperature, pH, specific conductivity, and dissolved oxygen (DO) during precipitation events. We know that precipitation affects the flux, as was determined by examining levels before and after rain events and snowmelts. The literature reviewed herein indicates that the best time to sample Bell Creek to observe fluxes resulting from the Garrison lake fire will be post-rain events or during significant snowmelt. However, studies focused solely on precipitation as the driver of contaminant flux negate considering other factors contributing to contaminant run-off and the effect on stream chemistry. Perhaps by examining burn severity, we can better understand the route cause of water quality fluctuations post-fire.

2.2 Burn Severity

Hohner et al. in the study titled *Wildfires Alter Forest Watersheds and Threaten Drinking Water Quality* (2019) Hohner et al. showed by comparing an unburnt watershed to a nearby burnt watershed that TOC, turbidity, total phosphorus (TP), and total nitrogen (TN) all reached high levels post-fire after a rain-storm event. Their research identified the correlation between the amount of organic matter consumed by a fire and the level of water quality response, but not the mechanisms of transport that lead to the organic matter being transported into the receiving waters. Furthermore, by comparing two watersheds, one with a burn rate of 45% and one with 10%, it was determined that "the magnitude of water quality responses often increases with the proportion of a watershed exposed to high severity wildfire" (Hohner et al., 2019, pg. 1237).

In *Spatial variability of soil hydrophobicity after wildfires in Montana and Colorado* (2007), Woods et al. conducted hydrophobicity measurements in moderate to high severity burnt forests in Colorado. Their results showed that burn severity plays a prominent role in the local water quality of run-off receiving water and moderate to severe fires. After a high severity fire, most, if not all, of the surface organic matter is burnt up, leaving the soil exposed to erosion. As raindrops fall on the exposed soil, infiltration reduces, and hydrophobicity increases, increasing overland flow. The effect of burn severity was affirmed in chapter 12 of *Water Quality and Forest Management: Compendium of Forest Hydrology and Geomorphology in British Columbia (2010),* a book providing a thorough synthesis of scientific knowledge of Hydrology in British Columbia. Pike et al. stated that In situations where burn severity is high and snow remains on the ground for 6-8 months a year, such as our subject area, there is minimal shading of the ground covering snow from sunlight when spring melt comes. Increased sunlight leads to a high melt rate, increased erosion, and sediment. The effect is that higher burn severity is likely to lead to more significant water quality effects due to increased consumption of organic material and corresponding increased soil erodibility. The result is that high burn severity increases hydrophobicity and erodibility, leading to increased sediment transport into surface waters when combined with precipitation and reduced interception by foliage.

2.3 Debris Flow and Sediment Transport

A 2012 study titled *Wildfire Impacts on the Processes That Generate Debris Flows in Burned Watersheds* determined that the more rugged a watershed is, the more susceptible it is to debris flow and flooding. Furthermore, Parise & Cannon found that watersheds with more than 65% moderate to high-intensity burn, coupled with steep slopes and sedimentary or metamorphic bedrock, are more susceptible. The watershed characteristics are important, but they also add that though intense rainfall can trigger flooding and debris flow, a debris flow does not need an extreme rainfall event to occur independently. Additionally, they found that most available debris material is eroded or transported within the first year and that debris flows are rare beyond the second year. These findings highlight the importance of testing during the first-year post-fire, with the most suitable time after intense rainfall. With this in mind, it is essential when collecting data to consider the slope, terrain, and burn severity. Though anecdotal on its own, by factoring watershed characteristics all into our dataset, the results could represent watersheds that share similar hydrological, geological, and terrestrial features. The results could indicate the need for sampling and water analysis at locations identified as similar.

A 2009 study *titled Climate Change and Water Resources: A Primer for Municipal Water Providers* revealed that forest fires decrease soil infiltration, leading to excessive erosion, higher run-off, and an increase in the chance of flooding and debris flow. Sediment and debris flow also can fill and disrupt reservoirs, infiltration basins, and treatment works. Furthermore, Miller and Yates examined a fire in the Strontia Springs Reservoir, a Denver water source, that led to the deposition of ten years of sediment into the reservoir. This fire and its subsequent debris flow clogged the water delivery system, shortening the reservoir's life by 30 years and leaving the water supply with a lingering turbidity problem. Because Bell Creek supplies water for 40 homes in the Eastgate Community, it is prudent to monitor the water quality and examine the watershed characteristics. With enough data, one day, we may be able to delineate watersheds at risk and avoid or prepare for a situation similar to the Strontia Springs Reservoir.

Horner et al. (2019) stressed a genuine need to design and conduct studies that couple the spatial variability of wildfire behaviour and its fuel consumption with chemical analysis. Their study revealed that forest fires contribute to the increased loading of nutrients and chemicals into streams, with the amount of loading being a function of fire severity and the factors mentioned above, such as geological features contributing to nutrient and sediment transport. These findings highlight the need to chemically study surface water in watersheds affected by forest fires to determine whether they are susceptible to contaminant loading and water quality issues.

2.4.0 Water Quality Issues and Characteristics

The transport of nutrients from soil and ash into the watershed elevates or alters several constituents' concertation, affecting water quality. Important parameters include; pH, turbidity, temperature, nutrients, total organic carbon, polycyclic aromatic hydrocarbons (PAHs), and some heavy metals. How much these parameters change depends on fire severity, duration, intensity, the slope and ruggedness of the terrain, soil erodibility, and the precipitation rate post-fire. Though the severity of the effects is most apparent immediately after a fire, during the first significant rainfall event or snowmelt, they have the potential to last for years (Burton et al., 2016). This increased loading of nutrients and sediments due to fire can alter the water quality chemistry of run-off receiving waters, presenting challenges to drinking water treatment and being harmful to aquatic life.

2.4.1 Turbidity

In 2013 the United States Environmental Protection Agency and the Water Research Foundation funded a study titled *Report on the Effects of Wildfire on Drinking Water Utilities and Effective Practices for Wildfire Risk Reduction and Mitigation.* In the report, Rook et al. identified several challenges that contaminant flux can cause for water treatment facilities downstream of fire-affected watersheds. Increased turbidity can require additional coagulants, resulting in shorter filter run time and an increased backwash rate. If the water treatment plant uses membrane filtration, a high turbidity load may be too excessive and facilitate a need to retrofit other filtration mechanisms. Additionally, in *Wildfire effects on water quality in forest catchments: A review with implications for water supply (2011),* Smith et al. reported that an increase in turbidity would require increased chlorination, resulting in the further formation of disinfection by-products (DBPs). The effect that turbidity can have on water treatment highlights the need to understand if a community's water source is susceptible to an increase in turbidity in the event of a fire in its watershed.

2.4.2 Total Organic Carbon

Another parameter of concern is elevated levels of organic carbon. Total organic carbon (TOC) to both particulate organic carbon (POC) and dissolved organic carbon (DOC). In *A Summary of the Scientific Literature on the Effects of Fire on the Concentration of Nutrients in Surface Waters (2004),* Renanali states that the literature supports that forest fire ash can have a high organic carbon content from burning organic matter. The subsequent deposition of the ash directly into surface water or via run-off, in conjunction with increased soil erodibility, may lead to elevated levels of POC. Water from precipitation and snowmelt percolates through ash, and burnt soil absorbs soluble carbon.

A study performed in 2012 titled *Impacts of Wildfire in Clear Creek Watershed on the City of Golden's Drinking Water Supply* showed a spike in TOC after first-run off and major precipitation event and elevated levels of DOC compared to reference unburnt watersheds persisting for 3-4 years. Additionally, research by Rooke et al. (2013) has provided evidence that high levels of TOC can affect coagulant dosing and oxidant demand leading to taste and odour problems. Furthermore, natural organic matter can react with chlorine and other disinfectants during the treatment processes, increasing the formation of Disinfectant By-Products (DPBs). Rook et al. add that organic carbon from fire is more humic and therefore more likely to form DPBs such as trihalomethanes and haloacetic acids, which have detrimental health effects. TOC is not the only organic compound of concern; nitrogen and phosphorus levels must also be examined.

2.4.3 Nutrients – Nitrogen and Phosphorus

In a study of the Crowsnest Pass wildfire titled *Wildfire impacts on nitrogen concentration and production from headwater streams in southern Alberta's Rocky Mountains* (2008)*,* Bradon et al. reported that the concentration of nitrogen in surface water in its various forms was between 1.5-6.0 times that of unburnt watersheds. The increase was most significant in the first-year post-fire and declined after that. The same study showed a similar increase in phosphorus, with concentration peaking in the 2nd year post-fire. In the *Effects of 2003 wildfires on stream chemistry in Glacier National Park, Montana* Mast and Clow (2008), nitrate concentrations were ten times higher than an unburnt control.

As carbon availability decreases in burnt soil, it likely leads to NO_3^- accumulation. The study *Wildfire Effects on Soil Gross Nitrogen Transformation Rates in Coniferous Forests of Central Idaho, USA (2010)* results indicated an increase in nitrate concentration in soils post-fire. Koyama et al. state that this is due to a reduction in nitrate uptake capacity. Additionally, as carbon availability decreases in burnt soil, it likely leads to nitrate accumulation. Furthermore, they argue that these effects are consistent due to soil properties in western North America. Elevated nitrate in the soils will likely be leached and transported to downslope surface water during the hydrological cycle.

An increase in nitrogen and phosphorus can lead to algae blooms which can become toxic to fish. It also has the potential of creating dead zones, an area with little or no dissolved oxygen, which many aquatic animals must leave to survive (*The Effects: Environment*, 2021). Elevated levels of dissolved nitrogen have also been found to contribute to an increase in DPBs. The study *Wildfire: Its Effects on Drinking Water Quality* (2021) stated that fire retardants have also contributed to an increase in nutrient levels. However, they were not used to combat the Garrison Lake fire and will not contribute to nutrient levels in Bell Creek. In addition, this study found that elevated levels of nutrients coincided with increases in trace element concentration.

2.4.4 Trace Elements

In *Wildfire effects on water quality in forest catchments: A review with implications for water supply,* a comprehensive review of a significant number of studies focused on stream chemistry post-fire, Smith et al. (2001) found that concentrations of Fe, Mn, As, Cr, Al, Ba and Pb were consistently found at elevated levels well over guideline values. Conversely, they reported that Cu, Zn, and Hg were recorded at less than or slightly above guideline values. Smith et al. noted that aquatic life and amphibian species are susceptible to high levels of trace elements. In elevated concentrations, trace elements can slow the growth and development of species, alter their behaviour, and be lethal. In addition, trace elements also can form complex compounds when they react with DOC, increasing their toxicity

In 2016 a study titled *Trace Elements in Stormflow, Ash, and Burned soil following the 2009 Station Fire in Southern California* performed water sampling and laboratory analysis of stream water before, during, and after a forest fire. Burton et al. found that Pb, Fe, Ni, Zn levels were detected in concentrations above aquatic criteria. They all tested above the Criteria Continuous Concentration (CCC) values; however, Pb and Zn measured above the Criteria Maximum Concentration (CMC) values. Their study revealed that trace element levels surge during and immediately after rain events, emphasizing sediment transport's role in trace element levels. Furthermore, trace elements can be affected by the pH of stream water.

2.4.5 pH

At higher pHs, trace elements can move to a more soluble form in which they become more bioavailable to aquatic life, increasing their toxicity (Burton et al., 2016). PH is an indicator of chemical equilibrium in a stream at a point in time and is an important parameter to measure when sampling. The deposition of ash and sedimentation can shift stream water to a higher pH. At higher pHs, acidic functional groups in organic carbon become ionized and more water-soluble, increasing the amount of DOC absorbed (Ranalli, 2004).

2.4.6 Temperature and Dissolved Oxygen

During their 2016 study, Burton et al. recorded temperature levels in the streams and noted that the natural shading effect is lost as the fires consume trees around watercourses. Intern, exposure to direct sunlight on surface water can lead to an increase in water temperature. Temperature can control the survival of specific flora and fauna. Burton et al. also stated that the reduction of DO due to rising water temperatures is the primary concern. An increase in temperature of 1-5 °C (at high altitudes such as Bell Creek) can lead to O_2 levels being less than 10ppm, which can have the ability to impair the survivability and sustainability of aquatic life and salmonoid fish in particular.

A study performed in Nicola Valley, BC, measured stream temperature in a watershed, pre and post logging over three years and showed that the maximum stream temperature increased by 1-2 degrees celsius. This temperature rise was attributed to the loss of shade and remained for two years (Rayne et al., 2018). Although the study was performed on a logged watershed and not a burned one, the cause of the stream temperature rising attributed to the loss of shade suggests that similar results can be expected from a burned watershed. Additionally, an increase in biological activity, coupled with an increase in nutrient loading, increases biological oxygen demand (BOD), leading to a further reduction in DO concentration. Therefore, an increase in temperature can also increase biological activity (EPA, 2019). Once measured, all the parameters mentioned above must be compared against regulatory criteria and background concentrations to delineate the effects of the Garrison Lake forest fire on the Bell Creek watershed.

2.5 Regulatory Criteria

2.5.1 BC Source Drinking Water Quality Guidelines

A review of BC'*s Source Drinking Water Quality Guidelines* found that they apply to ambient source drinking water before treatment (British Columbia Ministry of Environment and Climate Change Strategy, 2020). The report states that these guidelines do not supersede requirements established in the Drinking Water Protection Act. In addition, they are not enforceable under legislation like the Contaminated Sites Regulations. The guidelines are a conservative estimate of risk for chemical, physical, and biological attributes. The purpose is to reduce the risk to current and future water sources where there is a chance of human health being affected. These guidelines are to be used as a benchmark to assess and characterize raw drinking water sources before treatment and aid in resource management decisions. The guidelines apply to this study as Bell Creek is used as a drinking water source for the East Gate community, and our study will examine the water quality from the surface water of Bell Creek before treatment. In addition to being used as a source of drinking water, Bell Creek also sustains aquatic life and feeds into the Similkameen River, a salmonoid habitat, so aquatic life guidelines need to be observed.

2.5.2 British Columbia Approved Water Quality Guidelines: Aquatic Life

BC's Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture (2021) sets guidelines that represent safe levels of substances in surface water for aquatic life. Like the guidelines for Source Drinking Water, they are not enforceable, and the levels are meant to be considered in resource decision-making. The levels are meant to represent the background condition of the natural environment. The report discusses the difference between long-term chronic and short-term acute guidelines.

The long-term guidelines protect sensitive species from lethal and sub-lethal effects of indefinite exposure. The guidelines use an averaging approach over a specified period. The parameter can fluctuate above and below the guideline, but after the set amount of time, the average must not exceed the level set in the guideline. For example, the report states that if five samples are the minimum requirement over 30 days, the average of the five samples shall not exceed the guideline. The report states that the number of samples and the time frame set is arbitrary but must be followed as specified in the guidelines. In addition, the report emphasizes that if any of the individual samples exceeds the long-term guideline during sampling, it would indicate a need to increase the monitoring frequency. Furthermore, at no time shall the samples exceed the short term-term guidelines. The guidelines stipulate that short-term acute levels are set to protect sensitive species and life stages over a short-term period of time against lethal effects, usually 96 hours.

Additionally, there are five metals that the guidelines require an equation derived from experimental data that includes a parameter for ambient hardness. These metals are cadmium, fluoride, lead, manganese and zinc (British Columbia Ministry of Environment and Climate Change Strategy, 2021). In addition to comparing water samples to regulatory guidelines, Bell Creek samples should be compared to the regional background concentrations.

2.6 Background Concentrations and Control Sites

Once chemical and physical analysis has been performed on the fire-affected stream, it must be compared against something to examine the change in concentrations. If there is no pre-fire water quality data available for the selected sampling location, a control site should be sampled for comparison. In the paper, the *Effects of post-fire run-off on surface water quality: Development of a southern California regional monitoring program with management questions and implementation recommendations* (2019), control site selection criteria were discussed in detail. Brown & Stein state that the ideal control sites should have the following characteristics: nearby, unburnt, similar catchment size, similar land cover. By comparing the results to a control stream, local background concentrations can be delineated. In addition, the water quality continents should be compared to regulatory limits for drinking water and aquatic life to observe if any thresholds have been reached.

The interconnectivity of the water quality parameters discussed and the impact of forest fire on them stresses the need for further understanding of our local watersheds. This understanding can be achieved by chemical testing surface waters and monitoring fire-affected watersheds.

3.0 Methods

3.1 Design

The primary objective of this study was to evaluate the effects of forest fires on surface water quality. A quantitative experiment consisting of field measurements of water parameters, surface water sampling, and laboratory analysis was performed on the surface water of Bell Creek. First, the results were compared against British Columbia Approved Water Quality Guidelines for Drinking Water Sources and Aquatic life.

Secondarily, research was performed by examining Bell Creeks watershed characteristics. Online data and maps were consulted to determine the watershed size, slope, and vegetation. In addition, precipitation and weather data were used to select a control watershed that qualifies as similar. Hampton Creek was chosen as a suitable control stream. Hamptons Creek's surface water was sampled and analyzed at a lab, and the results were compared against Bell Creeks.

3.2 Site

The Garrison Lake fire of 2021 covered 14,935 hectares and was located in the northern Cascade Mountain range in South West British Columbia. The border of the fire and its severity can be seen below in Figure 2. Red are areas of high severity burn, orange mid severity, and yellow low. Bell Creek watershed supplies water to approximately 40 homes in the community of Eastgate and encompasses 3,444,934 m^2. The community of East Gates location is shown in yellow in Figure 2, and Bell Creek's watersheds boundary can be seen in blue.

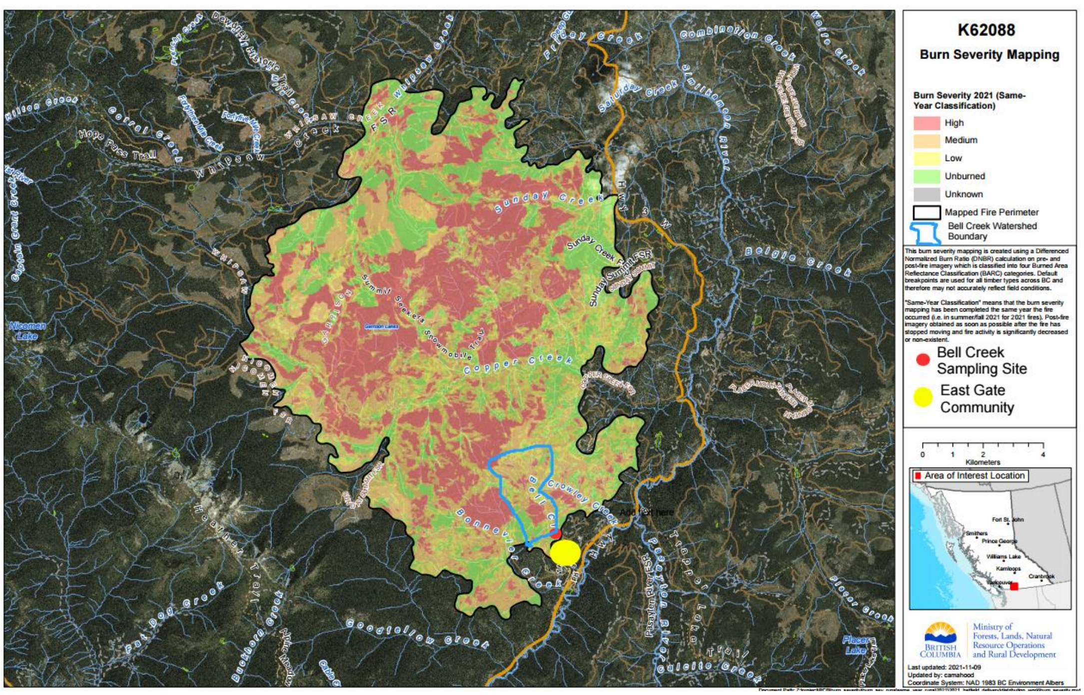

Figure 2: *Map of Garrison Lake Fire Burn Severity*

Note. Adapted from https://maps.gov.bc.ca/ess/hm/imap4m/

Through examining the burn severity map overlay, and the watershed boundary, it was approximated that the Bell Creeks watershed was 40% severely burned, 30% mid severity burned and 10% low burn severity for a total of 80% burn by area.

The region is classified as Cordilleran Montane Forest, and the landcover vegetation is primarily ponderosa pines, douglas furs, and to a lesser extent, jack and lodgepole pines. In March, the average temperature range is -4°C to 4°C approximately. Precipitation primarily falls as snow from November to April and rain from May to October.

3.2.1 Bell Creek Sampling **Site Description**

A sampling site was located on Bell Creek to conduct field measurements and surface water analysis. This site is considered a tier-one site for post-fire water quality monitoring for three reasons (Brown & Stein, 2009). First, the site is accessible year-round. Second, it is used as a drinking water source by local residences (40 connections), and third, its watershed had been burned with mid-to-high severity across approximately 80% of its area. The location of the sampling site can be seen in Figure 3, which shows the boundary of the community watershed and the fire. Access to the site required an approximate one-kilometre walk up a trail as the snow made it inaccessible by vehicle.

3.2.2 Control Site Description

A control site was chosen for comparison samples due to pre-wildfire water quality data unavailability. Hampton Creek was selected as the control site using the best practice guidelines for control streams; its proximity to Bell creek, similar size, slope, vegetation, and geological features (Brown & Stein, 2009). Hamptons Creek's location can be seen in Figure 3.

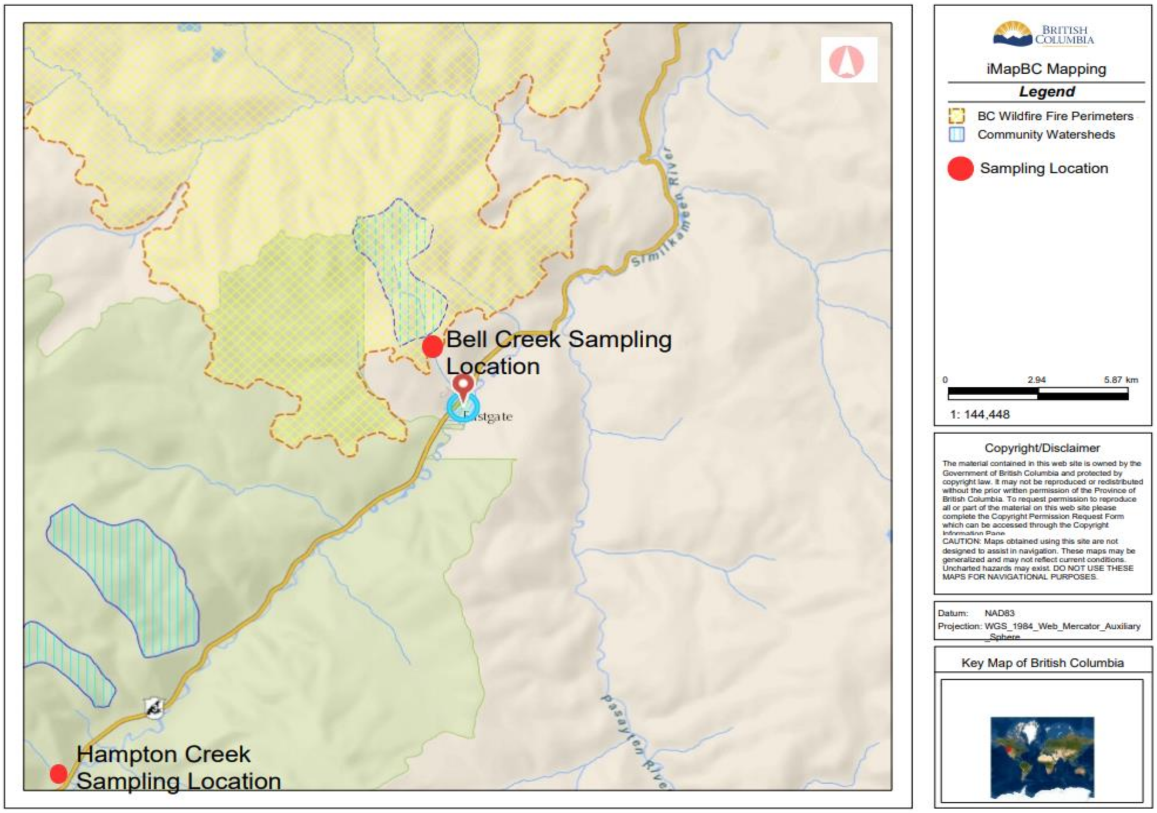

Figure 3: *Map of Sampling Locations*

Note. Adapted from https://maps.gov.bc.ca/ess/hm/imap4m/

The sampling site at Hampton Creek approximately fifteen kilometres from Bell Creek, and outside of the Garrison Lake fire's perimeter. This location was accessible from the highway with a short 100-metre walk upstream. The blue hatched area's are community watersheds. Hampton's Creeks water is not used for drinking water.

Though the ideal sampling conditions for post-fire water quality testing are during the first snowmelt and precipitation events (Emmerton et al., 2020; Hohner et al., 2019; Murphy et al., 2016), early March was chosen for the sample date to leave enough time to finish the project within the allotted timeframe. Performing surface water sampling at this time of year did pose some limitations.

3.3 Limitations

There were several limitations to this project. The first issue is the limited timeframe and the local weather. The data-gathering portion of this project had to happen on the weekend of March 4-6 for the following reasons.

1. The lab needs a week to analyze the sample and provide the results;
2. This leaves two weeks to complete the report's result analysis and discussion sections before submitting a draft of the report on March 31, 2022.

The ideal time to sample the water quality for fire-affected watersheds is post-rain events and during the snowmelt period. Historical weather patterns indicate that the rainy season begins in mid-April, with the ideal time to sample likely being in late May to June. Additionally, post-fire water quality monitoring ideally should occur over months or years to give a truly accurate representation of water quality. However, with the timeframe of this project, this was not possible.

Second, having water analysis performed at a lab is costly. Running two sets of samples and analyzing for the parameters; NO2/NO3, TN, TP, turbidity, PAHs, and a total metals scan costs $310. This cost covers the control stream and the sample site. The number of samples and sampling parameters was limited due to a limited budget for this project.

The third limitation was accessing the sampling sites. During this project's proposal phase, the floods in Southern BC in November 2021 led to landslides and closed roads. Highway access was not possible to the sampling locations, and this project was put on hold for a time. However, in late December 2021, the highways opened. Even with the highways open, access to the sites was difficult. One of the reasons the sample site chosen in Bell Creek was chosen is that a bridge crosses over the stream, allowing for year-round access. Access further upstream is challenging without the use of a snowmobile. In early March, there was lots of snow still on the ground during the sampling. The sampling site at Bell Creek could not be reached by vehicle and needed to be accessed by hiking with snowshoes for approximately one kilometre. In addition, the original location for the control site had to be changed due to the amount of snow on the ground and access not being possible. Maps of the area were consulted, and several other streams were noted that could be acceptable for a control stream. Hampton Creek was decided to be the safest to access during the sampling day and was chosen as the control stream.

3.4 Sampling Parameters

Measurements of temperature, DO, pH, oxidation-reduction potential (ORP) were performed in-situ as described in detail in the Procedure section and Appendix 1. Table 1 below lists the main parameters of concern and the rationale. In addition to what is listed in Table 1, a total metals scan was performed.

Table 1: *Parameters of Concern*

Water Quality Constituent	Reason for Choosing/Risk
Nitrate (NO_3^-)/ Nitrite (NO_2^-)	Nitrate reduces to nitrite, which is toxic
Total Nitrogen (TN.)	Can lead to algae blooms, cyanobacteria
Turbidity	Require increased chlorination, thereby contributing to DPB formation
Total Organic Carbon (TOC)	Contribute to DBP formation
Total phosphorus (TP.)	Can lead to algae blooms, cyanobacteria
Lead (Pb)	Toxic (can affect the nervous system)
Cu (Copper)	Poisonous at high concentrations, gastrointestinal symptoms
Polycyclic aromatic hydrocarbons (PAHs)	Carcinogen and mutagenic
Zinc (Zn)	Gastrointestinal effects at high concentrations

3.5 Procedure

The field measurements and the surface water sampling procedure were conducted on March 6, 2022, in accordance with the Field Sampling Manual (2013) Part E: Water and Wastewater Sampling of the BC. A detailed sampling procedure is provided in Appendix 1.

In-situ measurements of dissolved oxygen (DO), temperature, conductivity, pH, and oxidation-reduction potential (ORP) were performed with a YSI Probe supplied by BCIT. The instrument was pre-calibrated and used per the manufacturer's manual.

Grab water samples were taken in pre-labelled bottles supplied by Bureau Vistas Laboratories (BV Labs) and promptly secured and placed in a cooler filled with ice or ice packs for transport to the laboratory. Following sampling collection, a chain of custody form was filled out, and the samples were submitted to BV Labs for analysis the following day.

3.6 Observations During Sampling

The following observations were made during the sampling of Bell Creek on March 6, 2022:

- The sampling location could not be accessed by car due to heavy snow on the logging roads
- Required a snowshoe of approximately 1km up a trail accessed off of Thistle Road
- The time of sampling was approximately 1:00 PM
- It was a sunny day, with blue skies, scattered clouds and three degrees Celcius
- Bell Creek was flowing at approximately 6 inches deep and was free of debris
- The sampling site was located approximately 15m north of a bridge that had two signs, Hanna's Crossing and Bell Creek, as seen in Figure 4
- Sediment was observed in the sampling cups, as seen in Figure 5
- An invertebrate was observed in a sampling cup, as seen in Figure 5

Figure 4: *Picture of Bell Creek Sampling Location*

Note. The sampling location in Bell Creek is just to the left of the cooler, denoted by a red circle. The photo is taken from the south end of the bridge facing north

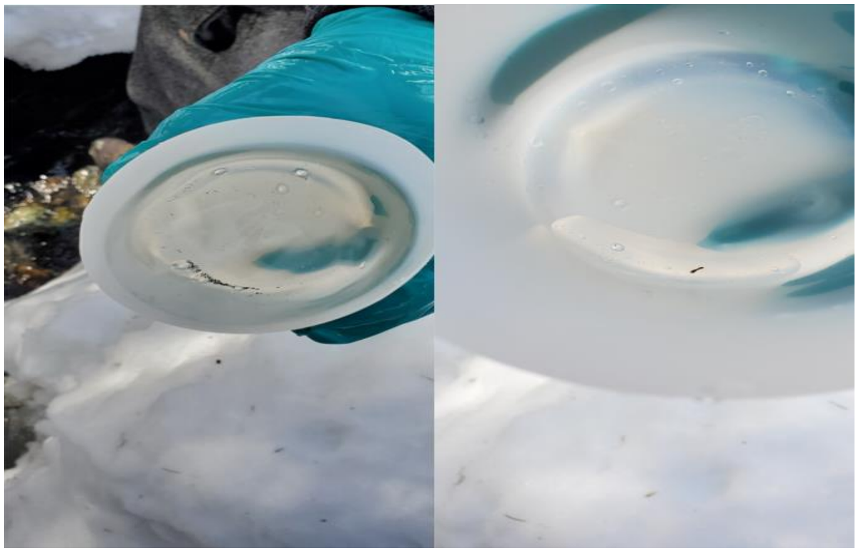

Figure 5: *Picture of Sampling Cups at Bell Creek*

Note. Side by side images of sampling cups with water from Bell Creek. The image on the left shows sediment, and the image on the right shows an invertebrate

The following observations were made while sampling at Hampton Creek on March 6, 2022:

- Sampling took place between 3:30 and 4:00 PM
- 4 degrees Celsius at the time of sampling
- The snow was soft, so snowshoes had to be worn for safe access to the creek
- The location was just off of Highway 3, approximately 40 meters upstream
- There was debris (sticks) in the creek that had to be removed before sampling, as seen in Figure 6
- For safety reasons, a rope was used to tie myself to a tree, as shown in Figure 7
- Less sediment in sampling cups was noted compared to Bell Creek

Figure 6: *Picture of Debris in Hampton Creek*

Figure 7: *Picture of Sampling Location at Hampton Creek*

Note. The picture was taken facing west, approximately 40 metres north upstream of Highway 3. The safety rope tie-off is circled in red.

3.7 Quality Control and Assurance

The quality of the data depends on the integrity of the sample. The quality assurance measures displayed in Figure 8 were integrated into the detailed procedures to protect samples from contamination and deterioration. The quality control methods were in place to assess and control any sample contamination and check the precision of the laboratory in the form of blank samples. These methods were chosen as best practices from the BC. Field Sampling Manual (2013).

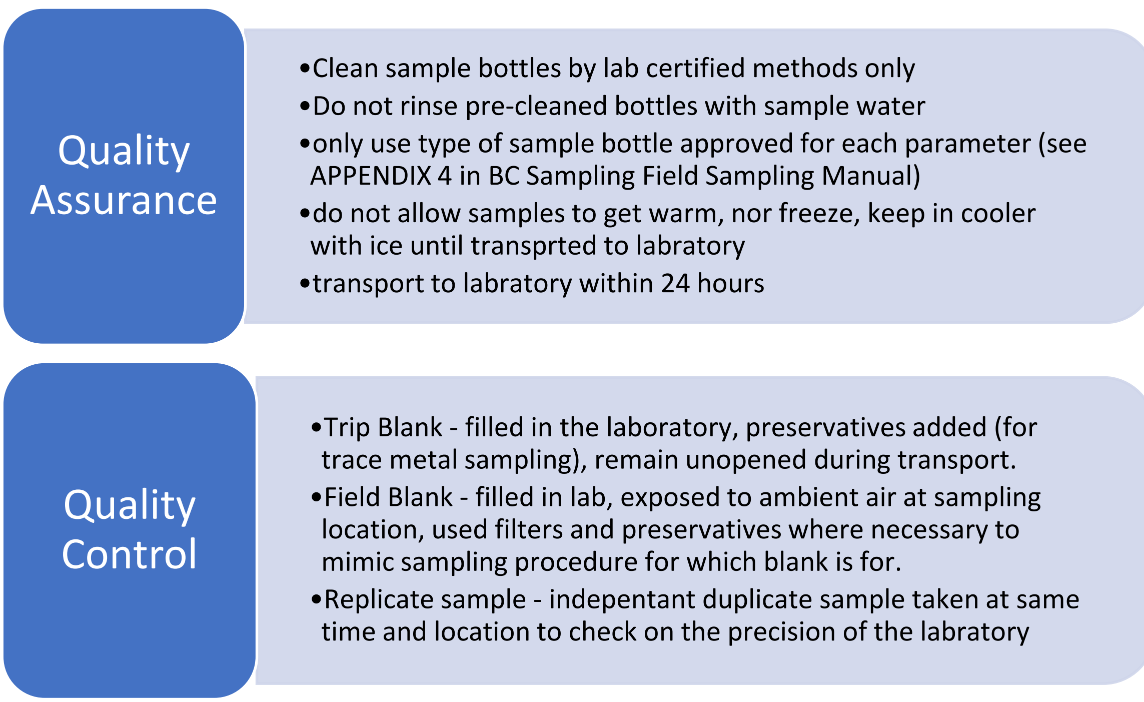

Figure 8: *Quality Control And Assurance Measures*

4.0 Results

The full detailed result results are saved in Appendix 3, Appendix 4, and Appendix 5. For ease of interpretation, the results have been split into four categories, as follows:

- YSI Probe In-situ Measurements -Table 2
- Anions and Nutrients – Table 3

- Total Metals - Table 4
- PAH Analysis – Appendix 5

The results were compared with British Columbia Approved Water Quality Guidelines for Freshwater Aquatic Life and British Columbia's Source Drinking Water Quality Guidelines. The regulatory levels for these guidelines are displayed in Tables 3 and Table 4. The parameters measured that do not have a set regulatory level display an NA under the Regulatory Limit. Where levels exceeded the regulatory limit, the measurement is highlighted in the colouring of the heading of the associated guideline that it exceeded.

Multiple studies refer to metals and nutrients' levels being X amount of times higher than the control stream of an unburnt watershed (Bladon et al., 2008; Mast & Clow, 2008). Relative change was used to relate the results of this study to the studied literature. Relative change was calculated for the values measured from Bell and the control using the following formula.

$$Relative\ Change\ \% = \frac{Bell\ Creek\ value -\ control\ stream\ value}{control\ stream\ value} * 100$$

The values of the control stream were subtracted from Bell Creek to display the difference in values for the analyzed constituents. A range was given for values in which either Bell Creek or the control did not reach an RDL. The relative change percentage could not be accurately calculated for these values where either the control or Bell Creek did not reach the RDL and was recorded as undetermined in Tables 3 and Table 4.

4.1 In-situ YSI Probe Measurements

Measurements were taken with the YSI Probe as described in Appendix 1. The results of these measurements can be seen in Table 2. The guidelines for temperature vary seasonally. There are no water quality guidelines for these parameters except for pH. The pH values are within the acceptable limit of 6.5-9 pH (British Columbia Ministry of Environment and Climate Change Strategy, 2021).

4.2 Anions and Nutrients

The chemical analysis was performed on the samples from Bell Creek and the control site. Bells creeks turbidity was measured at 1.2 NTU, which exceeds BC's Source Drinking Water Quality Guidelines for turbidity MAC of 1 NTU. In addition, the content of Total Organic Carbon in Bell Creek was found to be above the MAC as well as the Long Term Chronic for Aquatic Life. The long-term chronic guidelines for freshwater aquatic life state that TOC levels should be within 20% of the background median. Assuming the control group represents the background medium (cite), the following equation was used to determine the range of acceptable levels of TOC.

$$Upper\ limit = \frac{1.9mg}{L} * (100\% + 20\%) = \frac{2.28mg}{L}$$

$$Lower\ limit = \frac{1.9mg}{L} * (100\% - 20\%) = \frac{1.52mg}{L}$$

The measured TOC content in Bell Creek was 4.6 mg/L, approximately double the upper limit as per British Columbia Approved Water Quality Guidelines: Aquatic Life and 2.4 times higher than that of the control. Though there are currently no guidelines for total phosphorus values, it is important to note that the total phosphorus values measured in Bell Creek were over 14 times as high as measured in the control stream. In addition, nitrate values were higher in Bell Creek, though total nitrogen was measured higher in the control stream.

4.3 Total Metals

The analysis of Bell Creek and the control site showed that one value of total metal concentration values exceeded the guidelines for Source Drinking Water or Aquatic life. The measured amount of zinc in the control stream was 9.2 ug/L, and the long-term chronic limit for freshwater aquatic life under 2 degrees and < 90 mg/L for total hardness is 7.5 ug/L of Total zinc. Results from the total metals analysis are shown below in Table 3. Table 3 does not display the metals that did not meet the Reportable Detection Limit (RDL) in both samples. For complete results, refer to Appendix 3. For lead, manganese, and copper the long-term chronic and short-term acute water quality guidelines are dependent on water hardness and needed to be calculated using the equations as described in British Columbia Approved Water Quality Guidelines for Freshwater Aquatic Life (British Columbia Ministry of Environment and Climate Change Strategy, 2021).

Figure 9 graphically displays the measured total metals as a relative percentage change compared to the control. Though these levels are not above the water quality guidelines, there is a trend of the measured levels of total metals in Bell Creek being higher than that of the control stream. Of total metals measured in which both samples reached the RDL, 12 were higher in Bell Creek, and two were higher in the control stream. Including values in which one of either Bell Creek or the control reached the RDL 14 were higher in Bell Creek, and four were higher in the control stream.

Figure 9

Relative Change Percentage for Total Metals

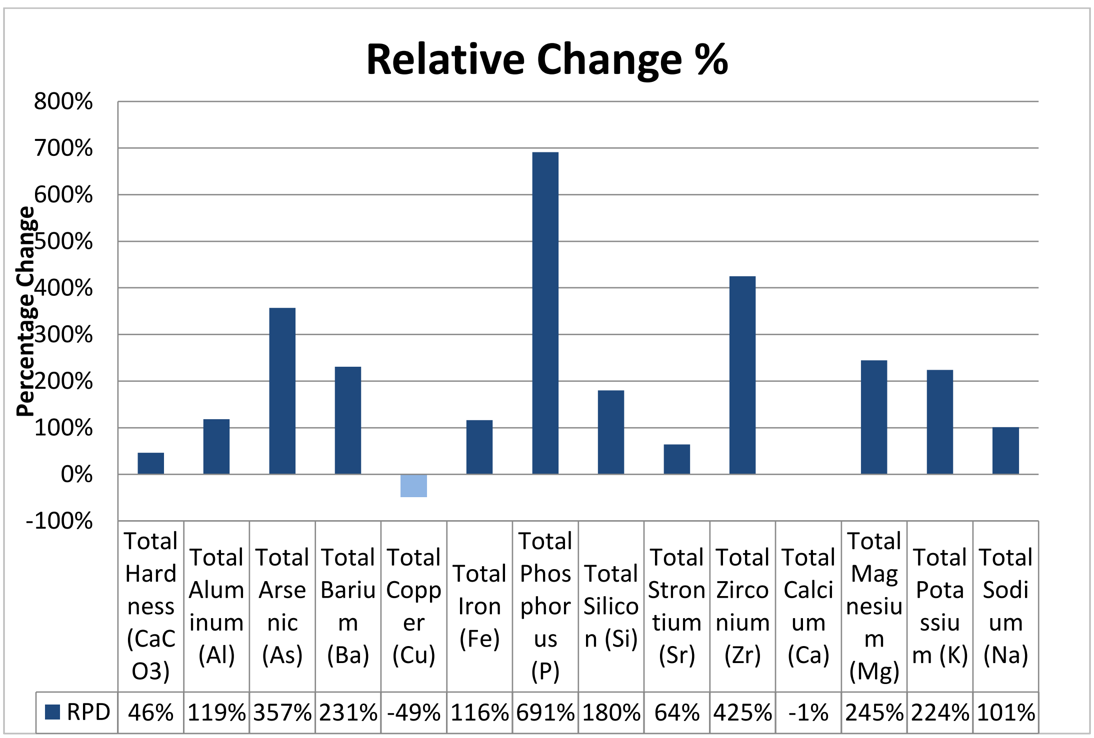

Figure 9: *Relative Change Percentage for Total Metals*

Note. Figure represents the Relative Change % of the concentrations of Bell Creek compared to the control stream (background concentration).

4.4 PAHs Results

None of the measured PAHs levels reached the RDL in Bell Creek or the control stream. The results table can be seen in Appendix 4.

5.0 Discussion

5.1 Turbidity

The turbidity levels measured in Bell Creek exceed the Maximum Allowable Concentration for source drinking water. An increase in turbidity levels will require increased chlorination, leading to the formation of disinfection by-products and presenting challenges for downstream water treatment facilities (Rooke et al. l, 2013.; Smith et al., 2011). Since the downstream water treatment plant is a gravel media filter and chlorination treatment, this could present difficulties in treatment for the East Gates water supply. On the sampling date, March 6, 2022, the daily high temperature was 3 degrees Celsius. In addition, precipitation was only falling as snow with little snowmelt due to low average temperatures. High-intensity rainfall and snowmelt have been observed as the primary driver of water quality degradation and contaminant flux post-fire (Murphy et al., 2016). As snowmelt increases and precipitation turns to rain, the turbidity levels in Bell Creek may increase more. A similar effect could be observed in nutrient concentrations.

5.2 Nutrients

Total phosphorus levels were measured to be approximately 14 times higher in the burnt watershed of Bell Creek than in the unburnt watershed control stream. Similar results were reported by Brandon et al. (2003), who reported increases in total phosphorus between 1.5-6 times that of unburnt watersheds. Brandon et al. also reported similar results for total nitrogen. Conversely, this study of Bell Creek showed a decrease in total nitrogen but an increase in nitrate concentration. Nitrate is the primary form of nitrogen of concern since it degrades into nitrite, which can be toxic. The increase in nitrate in the watershed may be due to the reduction of nitrate uptake capacity of the soils post-fire and soil properties in western North American coniferous forests (Koyama et al., 2010). As the hydrological cycle transports the soils into the stream, nitrate levels will likely increase. However, the results from Bell Creek are under the guidelines at the time of the performed sampling.

5.3 Total Organic Carbon

The measured levels of TOC in Bell Creek were well above the long-term chronic British Columbia Approved Water Quality Guidelines for freshwater aquatic life. The guideline states the TOC level should be within 20% of the background concentration, while the measured values were recorded and calculated to be 142% higher than the background. Rooke et al. (2013) provided evidence that high levels of TOC can affect water treatment and lead to taste and odour problems. In addition, they showed a spike in TOC after significant rain events. There has yet to be a significant rain event this year. The level of TOC in Bell Creek may spike during such an event. Rook et al. also showed that elevated levels of TOC can persist for three to four years post-fire compared to an unburnt watershed.

5.4 Total Metals

No metals in Bell Creek exceed the guideline values. However, zinc was measured to be over the long-term chronic guideline for freshwater aquatic life, indicating a high regional background concentration. There is a trend of higher metal concentrations in the burnt watershed of Bell Creek when compared to the unburnt control. However, these values do not exceed regulatory guidelines. There are many metals that BC does not have guidelines for, as shown in Table 3. Smith et al. (2001) reported concentrations at high values well above guidelines for Fe, Mn, As, Cr, Al, Ba, and Pb. These guidelines were not BC drinking water guidelines as the study area was in America. The results of the Bell Creek analysis do not indicate there is an issue with total metal concentrations. However, studies show the main driver of increased concentrations is high-intensity rainfall which flushes metals into the downstream water bodies (Murphy et al., 2016), which has not occurred this year as of the sampling date.

6.0 Conclusion

The results of the Bell Creeks surface water analysis compared to an unburnt control stream show some degradation of water quality. The most predominant effects are that of an increase in TOC and turbidity. Both of these levels are in exceedance of guidelines and can cause issues for the water quality treatment for East Gate. Though elevated in Bell Creek at the time of sampling, nutrient levels are below water quality guidelines. Total metal concentrations are below the guideline limits and, at the current time, do not pose a risk to aquatic life or water treatment. Previous studies indicate that contaminant flux is most predominant after the first snowmelt and subsequent high-intensity rainfall events. These conditions are likely to happen in April-June, leading to spikes in concentrations of many of the parameters measured.

Furthermore, studies have shown that wildfires' effect on surface water can last for up to 5 years post-fire. Given that some levels are in exceedance without rainfall events, it is likely that Bell Creek's water treatment facility will be stressed over the coming years and that continual monitoring will be required.

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Tables

Table 2: *YSI Probe In-situ Measurements*

Sampling Date		2022-03-07 13:00	2022-03-07 15:50		
	UNITS	**BELL CREEK**	**HAMPTON CREEK**	**Difference (Bell Creek - Hampton Creek)**	**Relative Change %**
Measured Parameters					
Temperature	Celsius	1.2	1.6	-0.4	-25
Dissolved Oxygen	mg/L	14.29	12.4	1.9	15
Specific Conductivity	dS/m	118.5	80.4	38.1	47
Total Dissolved Solids	ppm	0.077	0.0523	0.025	47
Salinity	ppt	0.05	0.03	0.02	67
PH	PH	9	7.73	1.3	16
Oxidation-Reduction Potential	mV	-25.2	105.4	-130.6	-124

Table 3: *Anions and Nutrients*

Sampling Date			Source Drinking Water Quality Guidelines	British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture		2022-03-07 13:00	2022-03-07 15:50	Difference (Bell Creek - Hampton Creek)	Relative Change %
	UNITS	RDL	MAXIMUM ALLOWABLE CONCENTRATION (MAC)	LONG TERM CHRONIC (less than 2C)	SHORT TERM ACUTE (less than 2C)	BELL CREEK	HAMPTON CREEK		
ANIONS									
Nitrite (N)	mg/L	0.0050	3	0.02	0.06	<0.0050	<0.0050	NA	NA
Calculated Parameters									
Nitrate (N)	mg/L	0.020	45	3	32.8	0.053	<0.020	.033 > .053	Undetermined
Misc. Inorganics									
Total Organic Carbon (C)	mg/L	0.50	4	Within 20% of the background median		4.6	1.9	2.7	242
Nutrients									
Total Phosphorus (P)	mg/L	0.0030	NA	NA for streams	NA	0.087	0.0055	0.082	1,582
Nitrate plus Nitrite (N)	mg/L	0.020	NA	3	32.8	0.053	<0.020	.033 > .053	Undetermined
Total Nitrogen (N)	mg/L	0.020	NA	NA	NA	0.194	0.288	-0.094	67
Physical Properties									
Turbidity	NTU	0.10	1 (without treatment for particulates)	Change from background of 8 NTU at any one time for a duration of 24 h in all waters during clear flows or in clear waters Change from background of 2 NTU at any one time for a duration of 30 d in all waters during clear flows or in clear waters		1.2	0.48	0.72	250.0

Table 4: *Total Metals*

Sampling Date			**Source Drinking Water Quality Guidelines**	**British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture**		2022-03-07 13:00	2022-03-07 15:50		
	UNITS	**RDL**	**MAXIMUM ALLOWABLE CONCENTRATION (MAC)**	**LONG TERM CHRONIC (less than 2C)**	**SHORT TERM ACUTE (less than 2C)**	**BELL CREEK**	**HAMPTON CREEK**	**Difference (Bell Creek - Hampton Creek)**	**Relative Change %**
Calculated Parameters									
Total Hardness (CaCO3)	mg/L	0.50	NA	100	50	51.8	35.4	16.4	46.3%
Elements									
Total Mercury (Hg)	ug/L	0.0019	1	NA	NA	<0.0019	0.0024	(0.0003) < (-0.0024)	undetermined
Total Metals by ICPMS									
Total Aluminum (Al)	ug/L	3.0	9500	5000	5000	96.0	43.9	52.1	119%
Total Arsenic (As)	ug/L	0.10	10	5	5	0.64	0.14	0.5	357%
Total Barium (Ba)	ug/L	1.0	NA	1000	NA	9.6	2.9	6.7	231%
Total Copper (Cu)	ug/L	0.50	2000	NA	NA	1.02	1.99	-1.0	-49%
Total Iron (Fe)	ug/L	10	NA	NA	1000	54	25	29.0	116%
Total Lead (Pb)	ug/L	0.20	5	4.7*	35.3*	<0.20	<0.20	NA	NA
Total Manganese (Mn)	ug/L	1.0	120	810*	596*	1.1	<1.0	0.1 > 1.1	undetermined
Total Phosphorus (P)	ug/L	10	NA	NA	NA	87	11	76.0	691%
Total Silicon (Si)	ug/L	100	NA	NA	NA	13000	4640	8,360.0	180%
Total Strontium (Sr)	ug/L	1.0	7000	NA	NA	83.5	50.8	32.7	64%

Total Zinc (Zn)	ug/L	5.0	3000	7.5	33	<5.0	9.2	(-4.2) < (-9.2)	undetermined
Total Zirconium (Zr)	ug/L	0.10	NA	NA	NA	0.63	0.12	0.5	425%
Total Calcium (Ca)	mg/L	0.050	NA	NA	NA	11.4	11.5	-0.1	-1%
Total Magnesium (Mg)	mg/L	0.050	NA	NA	NA	5.65	1.64	4.0	245%
Total Potassium (K)	mg/L	0.050	NA	NA	NA	1.68	0.518	1.2	224%
Total Sodium (Na)	mg/L	0.050	NA	NA	NA	4.55	2.26	2.3	101%
Total Sulphur (S)	mg/L	3.0	NA	NA	NA	3.8	<3.0	0.8 > 3.8	undetermined

Appendix 1

Surface Water Sampling Procedure

1) Locate sample site as per site plan.
2) Assess safety concerns – Is the flow of the river manageable? Is it icy? Is there debris? If everything is manageable continue on, if not try another day or time.
3) Identify preferred sampling location in-stream – should be midstream, not near the shore, take picture of the exact location, draw location in logbook
4) Turn on the D.O meter and calibrate as per the manufacturer's instructions.
5) Attach a safety line to the body.
6) Wade into the creek- start downstream and work your way upstream to the sample location
7) When sampling location is reached, stand perpendicular to flow and face upstream
8) Perform D.O, pH, conductivity, Temperature readings with YSI probe as per manual.
9) Travel downstream and exit the water.
10) Pick up a sample bottle
11) Remove the lid, taking care not to touch the inside. Place cap in a plastic bag and then in a pocket.
12) If a rinse of the bottle is required before sampling as per laboratory instructions, rinse 3 times in the creek.
13) Grasp the bottle below the neck, face the bottle downwards and plunge beneath the water surface. Then orient the bottle facing upstream. Avoid the surface of the stream. Aim for 6" below the surface.
14) Once full, remove the bottle by forcing it into the current and up and out of the water.
15) Replace the cap.
16) Travel downstream and exit the water.
17) Place sample bottle in cooler.
18) Repeat steps 5-13 until all samples have been taken.
19) Clean and decontaminated all equipment
20) Organize cooler so that samples without preservatives are closest to the ice
21) Fill out chain of custody form
22) Deliver to lab within 48 hours of sampling

Appendix 2

Anions and Nutrients Results

RESULTS OF CHEMICAL ANALYSES OF WATER

Bureau Veritas ID		APU353	APU354		
Sampling Date		2022-03-07 13:00	2022-03-07 15:50		
COC Number		658754-02-01	658754-02-01		
	UNITS	**BELL CREEK**	**HAMPTON CREEK**	**RDL**	**QC Batch**
ANIONS					
Nitrite (N)	mg/L	<0.0050	<0.0050	0.0050	A522337
Calculated Parameters					
Nitrate (N)	mg/L	0.053	<0.020	0.020	A520814
Misc. Inorganics					
Total Organic Carbon (C)	mg/L	4.6	1.9	0.50	A524440
Nutrients					
Total Phosphorus (P)	mg/L	0.087	0.0055	0.0030	A524721
Nitrate plus Nitrite (N)	mg/L	0.053	<0.020	0.020	A522335
Total Nitrogen (N)	mg/L	0.194	0.288	0.020	A522670
Physical Properties					
Turbidity	NTU	1.2	0.48	0.10	A521410

RDL = Reportable Detection Limit

Results relate only to the items tested.

Appendix 3

Total Metal Results

Bureau Veritas Job Number: C214770
Report Date: 2022/03/16

TOR GUTTRIDGE
Client Project #: FF2021 EFFECTS OF FOREST FIRES

Your PO #: FF2021
Sampler Initials: TG

CSR TOTAL METALS IN WATER WITH CV HG (WATER)

Bureau Veritas ID		APU353	APU354		
Sampling Date		2022-03-07 13:00	2022-03-07 15:50		
COC Number		658754-02-01	658754-02-01		
	UNITS	**BELL CREEK**	**HAMPTON CREEK**	**RDL**	**QC Batch**
Calculated Parameters					
Total Hardness (CaCO3)	mg/L	51.8	35.4	0.50	A520811
Elements					
Total Mercury (Hg)	ug/L	<0.0019	0.0024	0.0019	A523301
Total Metals by ICPMS					
Total Aluminum (Al)	ug/L	96.0	43.9	3.0	A521641
Total Antimony (Sb)	ug/L	<0.50	<0.50	0.50	A521641
Total Arsenic (As)	ug/L	0.64	0.14	0.10	A521641
Total Barium (Ba)	ug/L	9.6	2.9	1.0	A521641
Total Beryllium (Be)	ug/L	<0.10	<0.10	0.10	A521641
Total Bismuth (Bi)	ug/L	<1.0	<1.0	1.0	A521641
Total Boron (B)	ug/L	<50	<50	50	A521641
Total Cadmium (Cd)	ug/L	<0.010	<0.010	0.010	A521641
Total Chromium (Cr)	ug/L	<1.0	<1.0	1.0	A521641
Total Cobalt (Co)	ug/L	<0.20	<0.20	0.20	A521641
Total Copper (Cu)	ug/L	1.02	1.99	0.50	A521641
Total Iron (Fe)	ug/L	54	25	10	A521641
Total Lead (Pb)	ug/L	<0.20	<0.20	0.20	A521641
Total Lithium (Li)	ug/L	<2.0	<2.0	2.0	A521641
Total Manganese (Mn)	ug/L	1.1	<1.0	1.0	A521641
Total Molybdenum (Mo)	ug/L	<1.0	<1.0	1.0	A521641
Total Nickel (Ni)	ug/L	<1.0	<1.0	1.0	A521641
Total Phosphorus (P)	ug/L	87	11	10	A521641
Total Selenium (Se)	ug/L	<0.10	<0.10	0.10	A521641
Total Silicon (Si)	ug/L	13000	4640	100	A521641
Total Silver (Ag)	ug/L	<0.020	<0.020	0.020	A521641

Total Strontium (Sr)	ug/L	83.5	50.8	1.0	A521641
Total Thallium (Tl)	ug/L	<0.010	<0.010	0.010	A521641
Total Tin (Sn)	ug/L	<5.0	<5.0	5.0	A521641
Total Titanium (Ti)	ug/L	<5.0	<5.0	5.0	A521641
Total Uranium (U)	ug/L	<0.10	<0.10	0.10	A521641
Total Vanadium (V)	ug/L	<5.0	<5.0	5.0	A521641
Total Zinc (Zn)	ug/L	<5.0	9.2	5.0	A521641
Total Zirconium (Zr)	ug/L	0.63	0.12	0.10	A521641
Total Calcium (Ca)	mg/L	11.4	11.5	0.050	A521111
Total Magnesium (Mg)	mg/L	5.65	1.64	0.050	A521111
Total Potassium (K)	mg/L	1.68	0.518	0.050	A521111
Total Sodium (Na)	mg/L	4.55	2.26	0.050	A521111
Total Sulphur (S)	mg/L	3.8	<3.0	3.0	A521111

RDL = Reportable Detection Limit

Results relate only to the items tested.

Appendix 4

PAH Results

TOR GUTTRIDGE
Client Project #: FF2021 EFFECTS OF FOREST FIRES

Bureau Veritas Job Number: C214770
Report Date: 2022/03/16

Your PO #: FF2021
Sampler Initials: TG

CSR PAH IN WATER BY GC-MS (WATER)

Bureau Veritas ID		APU353	APU354		
Sampling Date		2022-03-07 13:00	2022-03-07 15:50		
COC Number		658754-02-01	658754-02-01		
	UNITS	**BELL CREEK**	**HAMPTON CREEK**	**RDL**	**QC Batch**
Calculated Parameters					
Low Molecular Weight PAH`s	ug/L	<0.10	<0.10	0.10	A520728
High Molecular Weight PAH`s	ug/L	<0.050	<0.050	0.050	A520728
Total PAH	ug/L	<0.10	<0.10	0.10	A520728
Polycyclic Aromatics					
Quinoline	ug/L	<0.020	<0.020	0.020	A524758
Naphthalene	ug/L	<0.10	<0.10	0.10	A524758
1-Methylnaphthalene	ug/L	<0.050	<0.050	0.050	A524758
2-Methylnaphthalene	ug/L	<0.10	<0.10	0.10	A524758
Acenaphthylene	ug/L	<0.050	<0.050	0.050	A524758
Acenaphthene	ug/L	<0.050	<0.050	0.050	A524758
Fluorene	ug/L	<0.050	<0.050	0.050	A524758
Phenanthrene	ug/L	<0.050	<0.050	0.050	A524758
Anthracene	ug/L	<0.010	<0.010	0.010	A524758
Acridine	ug/L	<0.050	<0.050	0.050	A524758
Fluoranthene	ug/L	<0.020	<0.020	0.020	A524758
Pyrene	ug/L	<0.020	<0.020	0.020	A524758
Benzo(a)anthracene	ug/L	<0.010	<0.010	0.010	A524758
Chrysene	ug/L	<0.020	<0.020	0.020	A524758
Benzo(b&j)fluoranthene	ug/L	<0.030	<0.030	0.030	A524758
Benzo(k)fluoranthene	ug/L	<0.050	<0.050	0.050	A524758
Benzo(a)pyrene	ug/L	<0.0050	<0.0050	0.0050	A524758
Indeno(1,2,3-cd)pyrene	ug/L	<0.050	<0.050	0.050	A524758
Dibenz(a,h)anthracene	ug/L	<0.0030	<0.0030	0.0030	A524758
Benzo(g,h,i)perylene	ug/L	<0.050	<0.050	0.050	A524758

Surrogate Recovery (%)					
D10-ANTHRACENE (sur.)	%	103	103		A524758
D8-ACENAPHTHYLENE (sur.)	%	88	86		A524758
D8-NAPHTHALENE (sur.)	%	81	74		A524758
TERPHENYL-D14 (sur.)	%	95	95		A524758

RDL = Reportable Detection Limit

Results relate only to the items tested.