# Bush Creek East Fire

# Post-Wildfire Geohazard Assessment for Emergency Decision Support

Prepared by BGC Engineering Inc. for:

COLUMBIA SHUSWAP REGIONAL DISTRICT

October 23, 2023

Project 1899009

Pioneering responsible solutions to complex earth science challenges

October 23, 2023 Project 1899009

Columbia Shuswap Regional District
555 Harbourfront Drive NE
Salmon Arm, BC, V1E 4P1

Attention: Derek Sutherland, Team Leader, Protective Services and Gerald Christie, Manager, Development Services

**Post-Wildfire Geohazard Assessment for Emergency Decision Support**

Please find the above referenced report attached. We appreciate the opportunity to collaborate with you on this challenging and impactful project.

Should you have any questions, please do not hesitate to contact the undersigned.

Yours sincerely,

**BGC Engineering Inc.**
**per:**

Hazel Wong, M.Eng., P.Geo. (BC)
Engineering Geologist

# EXECUTIVE SUMMARY

Since July 2023, the south Adams Lake and Shuswap Lake areas have been and continue to be impacted by Bush Creek East Fire (Drawing 01). The fire has caused widespread destruction across several communities. At the end of August 2023, over 3,700 properties were evacuated within the Columbia Shuswap Regional District (CSRD), with more evacuations in First Nations reserves and the Thompson-Nicola Regional District. The Bush Creek East Fire has burned mountainous slopes draining into Adams Lake, Shuswap Lake, and Little Shuswap Lake, and has impacted geohazard potential on populated alluvial fans and in areas below rock slopes.

BGC Engineering Inc. (BGC) was retained by the Columbia Shuswap Regional District (CSRD) to better understand the preliminary risk, posed by wildfire-related geohazards, to residents that are currently in the area or about to return home following the downgraded wildfire evacuation order. The assessments described in this report are intended to inform ongoing emergency response and support decision-making for preliminary recovery actions within the CSRD, and are not intended to replace detailed post-wildfire risk assessment implemented over a longer time horizon.

This report summarizes an emergency post-wildfire assessment of geohazards. Geohazards assessed include debris flow, debris flood, rockfall, and shallow landslide. Debris flow and debris flood are collectively referred to as steep creek hazards.

The Post-wildfire Steep Creek Hazard Assessment provides:

- Post-wildfire Hazard Likelihood ratings for 63 watersheds (Drawing 02)
- Post-wildfire Geohazard ratings describing the relative risk for 62 identified Potential Hazard Areas (PHAs) (Drawing 03). Fourteen of the PHAs were previously assessed in the Risk Prioritization Study completed for the CSRD (BGC, April 16, 2020)

The Post-wildfire Rockfall and Shallow Landslide Assessment (Drawing 04), provides estimates of the Change in Hazard ratings for 20 identified Areas of Interest (AOIs).

In the assessments, BGC focused on risk to areas with private property parcels within the CSRD. Assets at risk which are outside of the CSRD, including those belonging to Skwlāx te Secwepemcúl̓ecw and Adams Lake Indian Band, provincial parks, or belonging to the Thompson-Nicola Regional District, or assets which were non-structural or of cultural value were not assessed or focused on in this assessment.

Both steep creek hazards and rockfall and shallow landslide hazards were assessed using matrices. For steep creek hazards, Post-wildfire Geohazard Ratings were based on the Post-wildfire Hazard Likelihood of the upstream watershed and the Post-wildfire Impact Likelihood of the alluvial fan. Fifteen PHAs were rated as “Very High” Post-wildfire Geohazard Rating and 23 PHAs rated as “High”. For rockfall and shallow landslide hazard, “Type IV” is assigned to slopes where there is visible evidence that there has been a significant increase in hazard level due to burn conditions given the existing slope geometry or composition, and the asset is at or near the toe of the burned slope with no barriers present. Two AOIs were assessed as having “Type IV” change in hazard level for post-wildfire rockfall and shallow landslide hazards.

Since the geohazard types are different and used different methodologies for hazard estimation, Table E-1 is provided to illustrate how the hazard levels for the different assessments relate to each other.

**Table E-1 Relationship between different hazard levels assessed by this study for post-wildfire steep creek, rockfall and shallow landslide hazards.**

| Steep Creek Hazard | Rockfall and Shallow Landslide Hazard | Priority Level |
|---|---|---|
| **Post-wildfire Geohazard Rating** | **Change in Hazard Level Type** | |
| Very High | Type IV | Highest Priority |
| High | | |
| Moderate | Type III | |
| Low | Type II | |
| Very Low | | |
| N/A | Type I | Lowest Priority |

# TABLE OF REVISIONS

| Date | Revision | Remarks |
|---|---|---|
| October 5, 2023 | DRAFT | |
| October 20, 2023 | DRAFT | Updated based on feedback from CSRD |
| October 23, 2023 | FINAL | |
| | | |
| | | |

# CREDITS AND ACKNOWLEDGEMENTS

BGC would like to acknowledge the following contributors to this assessment:

- Hazel Wong, M.Eng., P.Geo., Engineering Geologist
- Kevin McCoy, Ph.D., PG (California), Project Scientist
- Natalia Skomorowski, M.Sc., P.Eng., Geological Engineer
- Gemma Ferland, B.A.Sc., EIT, Geological Engineer-in-Training
- Lucy Lee, B.A., GISP, GIS Analyst
- Matthew Buchanan, B.Sc., GISP, Senior GIS Analyst
- Corey Scheip, Ph.D., PG (North Carolina), Senior Geoscientist
- Joseph Gartner, Ph.D., P.Eng., Senior Geological Engineer
- Dave Gauthier, Ph.D., P.Eng., P.Geo., Senior Geological Engineer/Geoscientist
- Carie-Ann Lau, M.Sc., P.Geo., Senior Geoscientist
- Katherine Johnston, M.Sc., P.Eng., P.Geo., Principal Geological Engineer
- Kris Holm, M.Sc., P.Geo., Principal Geoscientist.

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# 1.0 INTRODUCTION

As requested by the Columbia Shuswap Regional District (CSRD, the District), BGC Engineering Inc. (BGC) performed emergency geological hazards (geohazards) assessment for steep creek (i.e., debris flow, debris flood), rockfall, and shallow landslides hazards, to support ongoing emergency management for the Bush Creek East Fire (K21633). The request for support was made via email and virtual meetings by Gerald Christie and Derek Sutherland on August 29, 2023. BGC submitted a proposal to the CSRD on September 1, 2023. Funding for this project was approved by BC Emergency Management and Climate Readiness on September 7, 2023. This work was performed under the existing Consulting and General Services Contract provided to the CSRD and dated November 17, 2021.

The Bush Creek East Fire was discovered on July 12, 2023 and had burned over 45,600 hectares of forested terrain by October 5, 2023 (BCWS, 2023). Several communities have been impacted by the fire, including Skwlāx te Secwepemcúl̓ecw and Adams Lake Indian Band, and the communities at Woolford Point and lower Adams Lake, Chase, Lee Creek, Scotch Creek, Celista, Magna Bay, Anglemont, Little River, Sorrento, and Notch Hill West. At the end of August, there were 10 fire-related evacuation orders for approximately 3,700 properties and three fire-related evacuation alerts for over 3,000 properties. At the time this report was issued, the fire is considered “Being Held” (BCWS, 2023) and there are no remaining evacuation orders or alerts (CSRD, 2023).

The CSRD requested this assessment to better understand the risk, posed by wildfire-related geohazards, to residents that are currently in the area or about to return home following downgraded wildfire evacuation orders. The assessments described in this report are intended to inform ongoing emergency response and support decision-making for preliminary recovery actions within the CSRD and are not intended to replace a detailed post-wildfire risk assessment.

## 1.1 Background

BGC previously completed a Regional Risk Prioritization Assessment for the CSRD (BGC, April 16, 2020). The primary objective of the 2020 study was to characterize and prioritize flood and steep creek hazards in the CSRD that could impact developed properties. The goal of the assessment was to support decisions that prevent or reduce injury or loss of life and economic loss due to geohazard events. However, the 2020 assessment does not account for the potential for increase in geohazard activity and intensity that may be a result of the Bush Creek East wildfire. In addition, the 2020 assessment was limited to clear-water flood and steep creek hazards and did not include rockfall hazard.

## 1.2 Scope of Work

The scope of work is to provide a screening-level hazard characterization and hazard exposure assessment for post-wildfire hazards from the Bush Creek East Fire. The following post-wildfire hazards and effects were identified by BGC to be relevant within the CSRD and characterized within this assessment:

1. Post-wildfire steep creek hazard assessment. This includes updating the hazard likelihoods for watersheds and impact likelihoods for alluvial fans previously identified and assessed in the 2020 study (BGC, April 16, 2020), which may have changed due to fire impacts in the upstream watersheds. In addition, burned watersheds with potential for steep creek hazards and fans and areas that may be impacted by these hazards, which were not identified during the 2020 study, were also assessed.
2. Post-wildfire rockfall and shallow landslide hazard assessment. Assessment of rockfall and shallow landslides were outside the scope of the 2020 study and therefore not assessed at that time. In the current assessment, BGC identified areas of interest (AOIs) for potential rockfalls and shallow landslides. The results of this hazard assessment provide a comparison of the change in hazard level of the pre-burn slopes to the post-wildfire conditions.
3. Wildfire situational awareness products consisting of satellite-imagery-derived vegetation burn severity maps, which were updated as new satellite imagery became available.

An interim technical memo was provided to the CSRD by BGC on September 14, 2023 to inform the District of the general hazard study areas and to provide a Burn Severity map from the August 2023 imagery (BGC, September 14, 2023). Since the memo, BGC generated updated burn severity data from September 2023 imagery, which is shown on Drawing 01 of this report.

A separate detailed post-wildfire hazard and risk assessment is currently in progress on the Bush Creek East Fire for the BC Ministry of Forests. That study includes fieldwork and collaboration with affected agencies including the CSRD and is being carried out over a longer timeframe. BGC is not involved with this detailed post-wildfire hazard and risk assessment for the Bush Creek East wildfire.

## 1.3 Assumptions and Limitations

BGC recognizes the following assumptions and limitations:

- Due to the screening-level scale and time-sensitivity of the assessment, to avoid interfering with active firefighting operations, and to reduce effort redundancy with the assessment requested by the BC Ministry of Forests, fieldwork was not included in the current scope of work. However, BGC considers fieldwork to be an important component of a detailed study. Should additional detailed studies be required, BGC would work with the CSRD to develop a fieldwork scope.
- This assessment focused on areas with property parcels within the CSRD, but included watersheds that may affected undeveloped areas or areas outside the District's jurisdiction (i.e., First Nations reserves). Other assets at risk (in addition to property parcels within the CSRD) are displayed on mapping deliverables. These assets were limited to those identified in public databases at the time of the assessment, such as provincial parks and public roads. BGC recognizes that there may be other assets, including new or temporary utilities, and those of physical and cultural value belonging to Skwlax te Secwepemculecw and the Adams Lake Indian Band, which may or may not be recorded and identified on public databases. Such assets were not included in this assessment.

## 2.0 BACKGROUND

Wildfires are well-documented to increase the likelihood and magnitude of geohazards (e.g., Cannon & Gartner, 2005). Effects can vary greatly but may include those listed in Table 2-1.

**Table 2-1 Potential effect of wildfires on geohazards in the CSRD resulting from the Bush Creek East Fire.**

| Hazard Type | Potential Effects from Wildfire |
|---|---|
| Steep Creek (debris flow, debris flood) | • Increase in frequency and potential magnitude of debris flood and debris flows due to the increased availability and mobility of sediment and increase in post-wildfire hydrologic discharge.<br>• Lower rainfall threshold for erosion and flooding, resulting in more frequent debris flow and debris flood initiation.<br>• Increase in landslide dam and outburst flood potential.<br>• Increased overland flooding and potential related erosion may occur on open slopes, outside of channelized areas. |
| Rockfall | • Increase in rockfall frequency due to loss of support from vegetation.<br>• Increase in potential rockfall sources due to heat-related rock spalling and boulder breaks during the fire.<br>• Increase in potential travel distance of rock-fall boulders due to loss of vegetative protection and related terrain roughness. |
| Earth and Debris Landslide | • Increase in post-wildfire frequency of debris avalanche, boulder fall, and shallow landslides due to loss of soil strength, loss of plant-root support, and mobilization of fine sediment.<br>• Increased groundwater levels due to a reduction in evapotranspiration.<br>• Increase landslide runout distance due to loss of protection and roughness from vegetation.<br>• Increase in soil erosion and dry ravel due to physical changes in the soil structure and loss of vegetative cover. |
| Washout of Culverts | • Increase in post-wildfire creek discharge due to loss of vegetation and/or development of hydrophobic soils.<br>• Increase in post-wildfire sediment and debris content in creeks draining burned watersheds. This includes trees and rocks that may fall and plug culverts.<br>• More rapid response in peak flow compared to unburned conditions. |
| Bank Erosion | • Increase in post-wildfire in bank erosion and avulsion in small (<1 $km^2$) and medium (1 to 10 $km^2$) size watercourses (e.g., Owen et al. 2013).<br>• Increase in erosion to riverbanks due to loss of vegetation.<br>• Increase flow due to higher surface runoff.<br>• Increased sediment load may lead to local and/or short-term channel aggradation, which can lead to localized channel widening and bank erosion. |

The likelihood of a future geohazard event varies with respect to the magnitude of the event with larger, more destructive events being less frequent than smaller, less destructive events. However, in the case of post-wildfire geohazards, the likelihood and magnitude subside with time, as vegetation re-establishes on hillslopes and soil stability is regained (Figure 2-1).

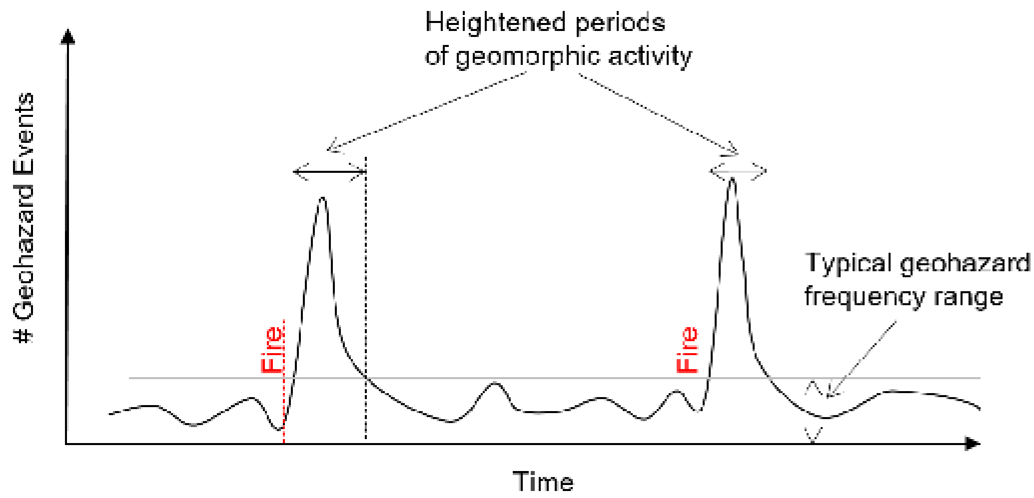


**Figure 2-1 Schematic diagram showing the temporary increase in geohazard activity following fire. Depending on the rate of watershed recovery, the peaks can last for one to ten years following the fire. Schematic prepared by BGC.**

Watersheds capable of generating steep creek hazards are prevalent in the study area. In susceptible watersheds, most post-wildfire debris floods and debris flows typically occur within the first two years following a fire (Cannon & Gartner, 2005; DeGraff et al., 2015), but can persist beyond that timeframe. For example, the 2017 Elephant Hill Fire located approximately 60 km north of the study area experienced post-wildfire debris-flow events most recently in February 2020, nearly three years after the fire.

# 3.0 METHODS

## 3.1 Burn Severity Mapping

The potential for post-wildfire response can be estimated by how severely the vegetation has burned using satellite imagery; this process produces a "Burn Severity Map". Burn severity is a relative measure of fire-induced ecological changes, typically reported as low, moderate, high, or a combination of these. The most common index used in estimating burn severity using multispectral satellite imagery relies on the normalized burn ratio (NBR), which is a normalized difference of the reflectance measured in the near-infrared and short-wave-infrared wavelengths. The difference in NBR between pre-fire imagery and post-fire imagery may be compared to identify burned areas and measure burn severity. The methodology and limitations in generating the burn severity is provided in Appendix A.

The burn severity data provided in Drawing 01 is based on the most recent available and suitable satellite imagery, which is from September 8 – 18, 2023 (6 images in total), compared to pre-fire imagery from September 8 – 18, 2022 (also 6 images in total). The fire perimeter was retrieved from the BC Wildfire Service on September 26, 2023. The burn severity data was subsequently clipped to the fire perimeter, as shown in Drawing 01. The Bush Creek East Fire is currently "Being Held" (as of October 2, 2023) and the burn severity and fire perimeter may change if fire activity changes. BGC will provide updated burn severity data as updated cloud-free satellite imagery becomes available and if the fire activity increases. BGC will provide up to two more burn severity data updates if needed.

## 3.2 Hazard and Risk Assessment

The workflow for hazard and risk assessments in this study is summarized for post-wildfire steep creek hazards (Figure 3-1) and post-wildfire rockfall and shallow landslide hazards (Figure 3-2). The methodology is further described in the following sections.

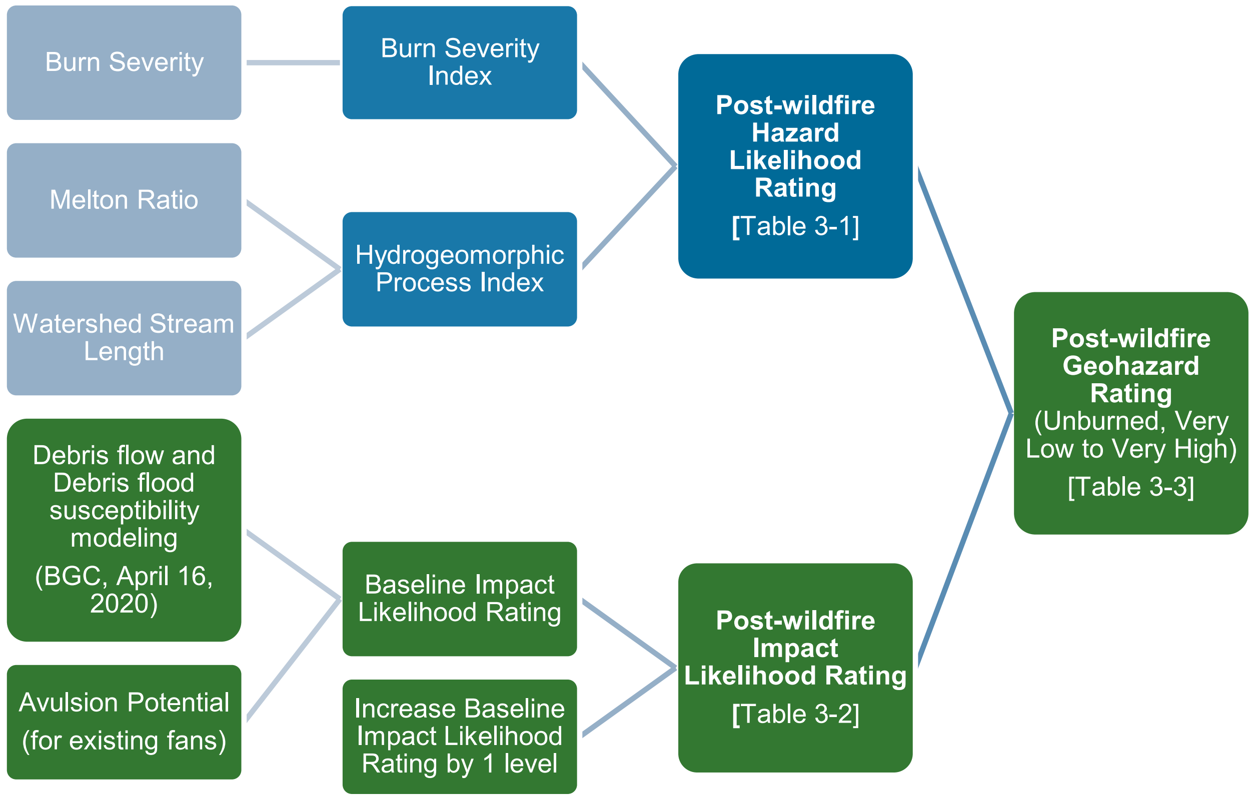


**Figure 3-1 Assessment workflow for post-wildfire steep creek hazards. Blue boxes indicate characteristics for delineated watersheds (Drawing 02). Green boxes indicate characteristics of delineated potential hazard area (Drawing 03).**

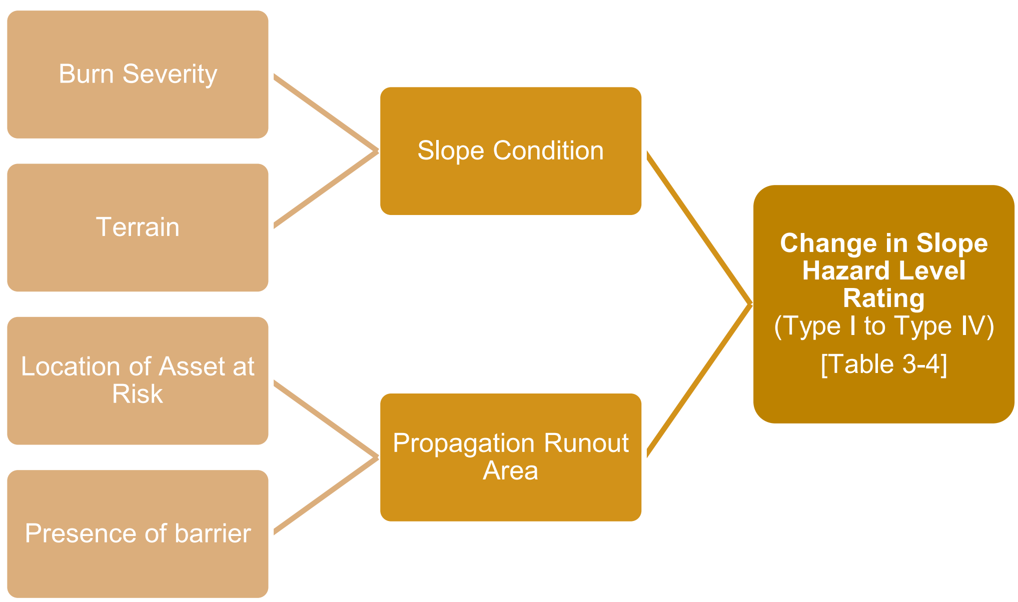


**Figure 3-2 Assessment workflow for post-wildfire rockfall and shallow landslide hazards (Drawing 04).**

### 3.2.1 Post-wildfire Steep Creek Hazard Assessment

The following methodology was used to assess post-wildfire steep creek hazard and risk (summarized in Figure 3-1):

1. Watershed characterization.
    a. Delineation: identified burned watersheds within the CSRD burned by the Bush Creek East Fire.
    b. Burn Severity Index: assessed the proportion of burn severity (unburned, low, moderate, high severity) for each watershed.
    c. Hydrogeomorphic Process Type Index: assessed the expected dominant hydrogeomorphic process (i.e., debris flow, debris flood, or clearwater flood) for each watershed.
    d. Post-wildfire Hazard Likelihood: Assigned relative ratings of likelihood for each watershed to produce post-wildfire debris flows and/or debris floods.
2. Potential Hazard Area (PHA) characterization.
    a. Delineation: used previously mapped fans (BGC, April 16, 2020) and also identified new hazard areas downstream of burned watersheds.
    b. Post-wildfire Impact Likelihood: assessed the likelihood of impact from post-wildfire steep creek hazards using previous debris flow and debris flood runout susceptibility modelling (BGC, April 16, 2020) for each PHA.
    c. Post-wildfire Geohazard: Assessed relative risk for spatially fixed assets within the CSRD (i.e., property parcels, assuming structures are located on parcels).

Exposure of infrastructure, people, pets, livestock, vehicles, and other non-fixed assets, and vulnerability (i.e., likelihood of injury, death, or financial loss, given event occurrence and impact) were not included in this assessment.

The following subsections describe methods of identifying watersheds and assessing potential hazard areas (PHAs) beyond the watershed outlets (i.e., fans and runout areas), assigning relative likelihood of occurrence ratings for post-wildfire steep creek hazards to each watershed, and assigning relative risk ratings to the PHAs (i.e., fans and runout areas) downstream of the watershed outlets.

#### 3.2.1.1 Identifying and Delineating Burned Watersheds for Assessment

Burned watersheds were visually identified by overlaying the classified satellite-based vegetation burn severity map (Section 3.1) with nominal 23-m-resolution Canadian Digital Elevation Data (CDED) data (CDED, 2015), aerial imagery, a digital stream network derived from the CDED data (using a minimum contributing area threshold of 0.1 $km^2$), previously mapped alluvial fans (BGC, April 16, 2020), and potential debris flow and/or debris flood hazard areas, which were previously identified based on runout susceptibility modeling (BGC, April 16, 2020). BGC identified watershed outlet points in a geographic information system (GIS) and generated digital watersheds using the CDED data for further analysis.

The following criteria were used when selecting watershed outlets:

1. The watershed is located within or discharges into the District.

2. The watershed intersects or is adjacent to the fire perimeter. Note that because the fire was not contained at the time the assessment began, adjacent watersheds which were not in the fire perimeter were included in case the fire were to spread to these areas over the course of the assessment.
3. The outlet is located at the apex of a previously mapped fan, or the mouth of a drainage outlet or gully that was previously shown to be a potential source for downstream debris flow or debris flood inundation based on the runout susceptibility modeling.

In some cases, a watershed outlet or fan head was located upstream of another, larger-scale watershed outlet (i.e., a sub-watershed within a larger watershed, which both may pose a hazard to developed areas near their respective outlets). In such cases, both the larger watershed and the sub-watershed were delineated for assessment.

#### 3.2.1.2 Post-wildfire Watershed Hazard Likelihood Rating

For each of the burned watersheds (Section 3.2.1.1), BGC characterized likelihood of post-wildfire debris flow or debris flood based on a "Burn Severity Index" and a "Hydrogeomorphic Process Index".

- The Burn Severity Index reflects the increase in likelihood of debris flow or debris flood occurrence at increasing burn severity and extent in each watershed.
- The Hydrogeomorphic Process Index characterizes the expected dominant process type (debris flow, debris flood, or clearwater flood) and is independent from occurrence or severity of a wildfire. The premise is that the geometry of a watershed gives an indication of what flood processes have formed it and are active currently. While storm-induced processes may vary by storm intensity and duration, BGC's likelihood ratings assume occurrence of a debris-flow triggering storm and are independent of design storm scenarios. It should be noted that while the hydrogeomorphic process type is assumed to be the dominant process governing landform development in the watershed, a given watershed may experience a range of hydrologic processes ranging from clear water flooding to debris flows depending on watershed-specific hydrologic and geologic conditions.

Post-wildfire hazard likelihood ratings were assigned to each watershed by combining the Burn Severity Index with the Hydrogeomorphic Process Index using a matrix (Table 3-1). The following subsections provide further explanation of Table 3-1 and describe BGC's methods for assessing Burn Severity Index and Hydrogeomorphic Process Index ratings.

For previously mapped fans (BGC, April 16, 2020), baseline hazard likelihood ratings were available; in such cases, BGC compared the post-wildfire hazard likelihood rating calculated using the methods described below to the baseline rating and adjusted the baseline rating as necessary to reflect post-wildfire conditions.

**Table 3-1 Post-wildfire hazard likelihood rating for steep creek hazards based on burn severity and coverage and watershed susceptibility to hydrogeomorphic processes.**

| Post-wildfire Hazard Likelihood | | Hydrogeomorphic Process Index | | | |
|---|---|---|---|---|---|
| | | Susceptible to Debris Floods only in rare storms | Somewhat susceptible to Debris Flows and Debris Floods in moderate to intense storms | Susceptible to Debris Flows and Debris Floods in moderate storms | Very susceptible to Debris Flows and Debris Floods in mild to moderate storms |
| **Burn Severity Index** | | **Process I** | **Process II** | **Process III** | **Process IV** |
| **Very High** | ≥ 40 | High | High | Very High | Very High |
| **High** | 30 to 40 | Moderate | High | High | Very High |
| **Moderate** | 20 to 30 | Low | Moderate | High | High |
| **Low** | 10 to 20 | Low | Low | Moderate | High |
| **Very Low** | < 10 | Very Low | Low | Low | Moderate |

## Burn Severity Index

The Burn Severity Index is calculated as the sum of watershed areas burned at each severity class (unburned, low, moderate, and high) (Table 3-1) multiplied by a weighting factor for each burn severity class (0.7 for high severity, 0.2 for moderate severity, 0.1 for low severity, and 0 for unburned terrain). Mathematically this can be expressed as:

$$I_{BS} = \sum_{i=1}^{n} W_{BS,i} A_{B,i} \quad \text{[Eq. 3]}$$

where $I_{BS,}$ is the Burn Severity Index, calculated as the summation of the product of the area burned at the ith burn severity class ($A_B, i$), and the burn severity weight for the $i^{\text{th}}$ class ($W_{BS,i}$). There are four burn severity classes (from i = 1 to i = 4) where i =1 is unburned, i = 2 is low burn severity, i = 3 is moderate burn severity, and i = 4 is high burn severity (in this case, n = 4). The weighting factors used in this study were selected by BGC during prior post-wildfire debris-flow hazard assessment work in BC, in which it was observed that the responses of watersheds to rainfall events varied greatly depending on the severity of burn, with areas of high burn severity having a much stronger effect in changing the hydrological response relative to baseline conditions as compared to areas of moderate or low burn severity. The weighting factors are therefore based on expert judgement and have been qualitatively validated through observation of subsequent post-wildfire debris-flow events in BC.

## Hydrogeomorphic Process Index

The Hydrogeomorphic Process Index characterizes the expected dominant process type in each watershed (ranging from clear water flooding to debris flows) and is independent from occurrence or severity of a wildfire. The premise is that the geometry of a watershed gives an indication of what flood processes have formed it and are active currently. This is estimated by plotting the watershed length and the Melton Ratio (watershed relief divided by square-root of watershed area) of a watershed and comparing against an empirical database of known process types to identify the dominant hydrogeomorphic process of the assessed watershed (e.g., Debris Flow, Debris Flood, Clearwater Flood). Watershed lengths were estimated using the Flow Length (upstream) tool. Watershed relief and area for the Melton Ratio calculation were estimated from the CDED data. Melton Ratio and watershed length values for the delineated watersheds are plotted on Figure 3-3. Occurrence of classified process types are conditional on the occurrence of a debris-flow triggering storm and presence of sufficient volumes of erodible material in the watershed.

The process-type classification is based on data compiled by BGC for records from western Canada. Other examples of using watershed morphometrics to identify process type else may be found in Church and Jakob (2020), Coe et al. (2003), Godt and Coe (2007), Holm et al. (2016), and Wilford et al., 2004.

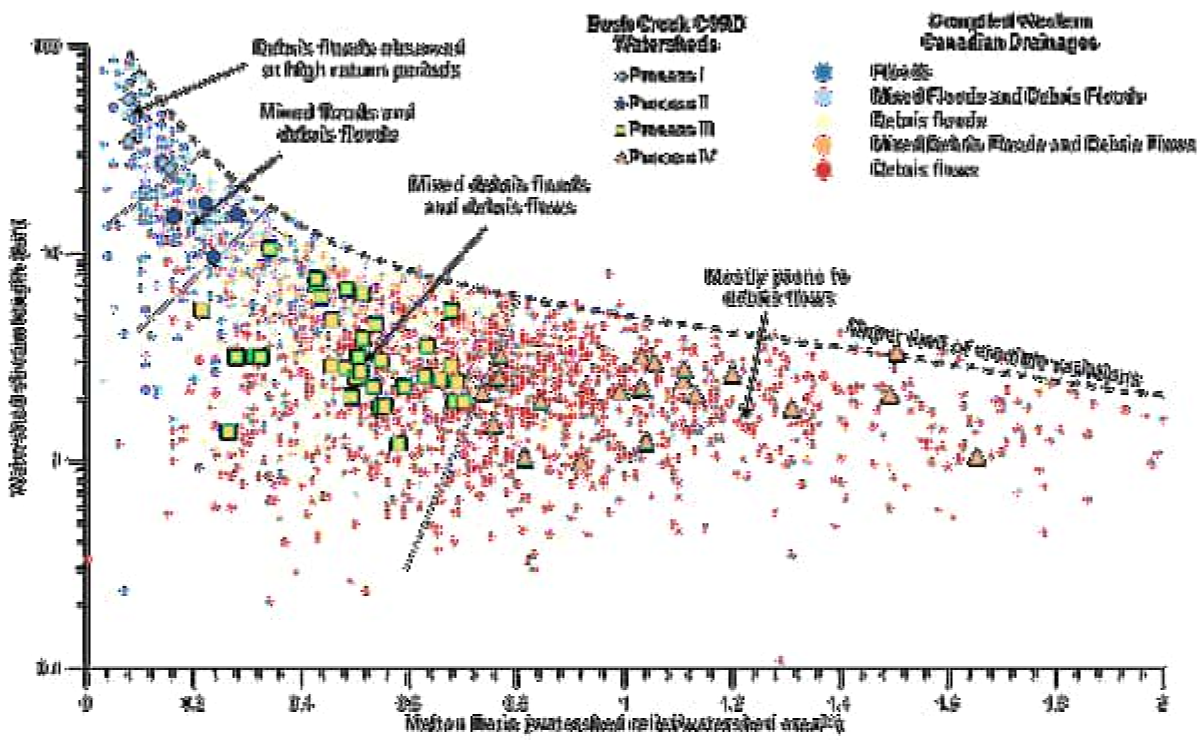


**Figure 3-3 Hydrogeomorphic process type classifications.**

### 3.2.1.3 Post-wildfire Potential Hazard Area (PHA) Geohazard Ratings

Potential Hazard Areas (PHAs) downstream of the watershed outlet were identified as previously mapped alluvial fans (BGC, April 16, 2020) and new hazard areas identified by this assessment. The newly mapped hazard areas were delineated based on the potential debris flow or debris flood inundation areas from the previous runout susceptibility modeling (BGC, April 16, 2020) and from terrain interpretation of alluvial fans using lidar, digital elevation models, and orthophotos.

For each PHA, a relative risk rating, called the “Geohazard Rating”, was assigned based on the post-wildfire hazard likelihood rating (Section 3.2.1.2) and an impact likelihood rating, which was estimated based on susceptibility modeling from the previous assessment (BGC, April 16, 2020). Where multiple watersheds direct flows to a single PHA, the watershed representing the worst-case likelihood rating was selected. The “Geohazard Rating” in this assessment is analogous to the “Geohazard Rating” assigned in the previous assessment (BGC, April 16, 2020).

Note that this assessment does not specifically characterize the spatial likelihood of the hazard reaching a specific element at risk. This assessment also does not include aspects of vulnerability or consequence, including estimates on loss of life or economic impacts.

The post-wildfire impact likelihood was assessed using the relative proportions of previous debris flow and debris flood susceptibility modeling and avulsion potential (BGC, April 16, 2020). The susceptibility modeling provides zones of “High”, “Moderate”, “Low”, and “Very Low” susceptibility to debris flow and debris flood hazard. BGC used the assessed Hydrogeomorphic Process Type (Section 3.2.1.2) of the upstream watershed to determine whether to use the debris flow or debris flood susceptibility modeling (BGC, April 16, 2020):

- For Process IV upstream watersheds, which are mostly prone to debris flow processes, both the debris flood and debris flow susceptibility modeling was used and the hazard type contributing to the higher impact likelihood rating (Table 3-2) was selected.
- For Process III upstream watersheds, which are prone to both debris flow and debris flood processes, and Process II watersheds, which are prone to both flood and debris flood processes, the debris flood susceptibility modeling was used since it covered a greater extent of the hazard area and therefore represents a worst-case scenario.
- For Process I upstream watersheds, which are mostly prone to flood processes, flood susceptibility mapping (BGC, April 16, 2020) was used to determine the proportion of previously mapped fans within a floodplain. The Impact Likelihood ratings for these mapped fans was used to calibrate ratings for unmapped hazard areas with Process I watersheds.

For previously mapped fans, baseline, or not post-wildfire, impact likelihood ratings were already available, and ratings also factored in avulsion potential (BGC, April 16, 2020). Unless a contributing watershed was not significantly burned (ie. less than 10% of watershed burned, and at low severity), BGC assigned new post-wildfire impact likelihood ratings to these fans by applying a rating increase of 1, which accounts for post-wildfire conditions of increased sediment load and discharge, which would increase avulsion potential relative to baseline conditions. For newly mapped PHAs, BGC evaluated an analogous “baseline” impact likelihood based on the previous assessment (BGC, April 16, 2020) but increased the rating by 1 to account for post-wildfire conditions (Table 3-2).

**Table 3-2 Post-wildfire Impact Likelihood Rating Criteria**

| Post-wildfire Impact Likelihood Rating | Criteria |
|---|---|
| **Very High** | Previously mapped fan with “High” (baseline) Impact Likelihood Rating OR newly mapped PHA contains >40% “High” susceptibility |
| **High** | Previously mapped fan with “Moderate” (baseline) Impact Likelihood Rating OR newly mapped PHA contains >5% “Moderate” or “High” susceptibility but <40% of PHA rated High susceptibility |
| **Moderate** | Previously mapped fan with “Low” (baseline) Impact Likelihood Rating OR newly mapped PHA contains <5% “Moderate” or “High” susceptibility |
| **Low** | Previously mapped fan with “Very Low” (baseline) Impact Likelihood Rating OR newly mapped PHA only contains “Very Low” or “Low” susceptibility |
| **Very Low** | Not used (previously rated fans were increased by a factor of 1) |

Post-wildfire Geohazard Ratings were then assigned to each PHA by combining the Post-wildfire Hazard Likelihood and Post-wildfire Impact Likelihood ratings using a matrix (Table 3-3).

**Table 3-3 Post-wildfire Geohazard Rating based on Post-wildfire Hazard Likelihood and Post-wildfire Impact Likelihood.**

| Post-Wildfire Geohazard Rating | | Post-wildfire Impact Likelihood Rating | | | | |
|---|---|---|---|---|---|---|
| | | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
| **Post-Wildfire Hazard Likelihood Rating** | **Very High** | Moderate | High | High | Very High | Very High |
| | **High** | Low | Moderate | High | High | Very High |
| | **Moderate** | Low | Low | Moderate | High | High |
| | **Low** | Very Low | Low | Low | Moderate | High |
| | **Very Low** | Very Low | Very Low | Low | Low | Moderate |

### 3.2.2 Post-wildfire Rockfall and Shallow Landslide Hazard Assessment

Rockfalls are defined as the release of rock fragments from natural or cut slopes. Boulder rollouts from glacial soil deposits on steep slopes are also included as rockfall hazards in this work. Rock may travel down a slope through a combination of bouncing, rolling or direct falls. Rockfalls can be triggered by a number of factors including freeze-thaw cycling, vegetation root jacking, erosion from rainfall, or high winds which lead to windfall of trees which then plucks rock from a slope.

A shallow landslide is defined as a moving mass of organics, soil or very weak rock that often moves primarily by sliding on a basal shear surface, potentially accompanied by internal deformation. Shallow landslides are generally smaller in magnitude than steep creek events. They may be triggered by high amounts of rain on steep slopes where the surficial material overlays shallow bedrock.

The wildfire has burned source areas (i.e., steep slopes where a hazard may initiate) and runout zones (i.e., where the rockfall or shallow landslide may move after initiation). Rockfall and shallow landslides may be more likely to occur and may be able to travel further after a fire due to a loss of vegetation, fire-induced hydrophobicity of the soil, and thermal damage to the source zone. BGC has defined hazard for this report as the likelihood of a geohazard event impacting an asset at risk in the post-wildfire environment.

BGC provided initial delineations of areas of interest (AOIs) for potential rockfalls and shallow landslides for CSRD (BGC, September 14, 2023). The preliminary identification of AOIs was completed on a large scale (kilometer-scale) with the intention to refine the AOIs to smaller specific hazard areas (decameter-scale) with further review. BGC outlined areas where a hazard may exist based on the following criteria:

- The area is below or on a burned slope and contains potential assets at risk, as visible in Google Earth.
- The geology is likely shallow till or colluvium deposits or near surface bedrock based on photographs, surficial geology maps of the area, and topography.
- The slope is 25° or steeper from toe to crest of the slope (NASA et al., 2019).

The extents of the AOIs were refined and classified based on further review of photographs taken by the BC Ministry of Forests on September 1, 2023, burn severity data generated by BGC (Section 3.1), geological maps, topography, and property boundary and asset maps provided by the CSRD. The slopes above and within the modified AOIs were reviewed to determine if there could be a credible rockfall or landslide source present, and if the likelihood of events occurring and interacting with assets had changed due to the burn severity.

BGC developed a qualitative scheme to compare the change in hazard level of the pre-burn slopes to the post-wildfire conditions. The assessment uses a 6 x 4 matrix based on characteristics of the source area including burn severity, geology and geometry of the slope, and on the characteristics of the runout zone between the toe of the slope and assets. Each area is assigned a designation which is defined below:

Type I is assigned to slopes where there is no visible evidence to suggest a change in hazard level, or no geohazard credibly exists based on the current information. The slope may be unburned or the infrastructure may be outside of a feasible runout distance of rocks and shallow landslides.

Type II is assigned to slopes where there is visible evidence to suggest there has been an increase in hazard level due to some amount of burning and/or slope geometry and composition, however for cases where the burn is moderate or higher, there are barriers or partial barriers protecting the infrastructure from geohazard activity. These barriers may include unburnt or burnt trees, roads, gullies, large ditches, or swells in the topography.

Type III is assigned to slopes where there is visible evidence to support a significant increase in hazard level due to burn levels, however the geometry of the slope or the presence of partial barriers may prevent the assets from being impacted by debris. Alternatively, the assets may not be protected by a partial barrier but there is some distance between the toe of the slope and the structures.

Type IV is assigned to slopes where there is visible evidence that there has been a significant increase in hazard level due to burn conditions and slope geometry or composition, and there are no barriers, and the asset is at or near the toe of the burned slope.

Table 3-4 shows the matrix used to assess the change in slope hazard level to the subsections of the AOIs.

**Table 3-4 Rockfall and shallow landslide hazard matrix.**

| Slope Conditions[1] | Change in Slope Hazard Level | | | |
|---|---|---|---|---|
| High burn and steep or rocky | Type I | Type II | Type IV | Type IV |
| High burn | Type I | Type II | Type III | Type IV |
| Moderate burn and steep or rocky | Type I | Type II | Type III | Type IV |
| Moderate burn | Type I | Type II | Type II | Type III |
| Low burn | Type I | Type II | Type II | Type II |
| Unburned | Type I | Type I | Type I | Type I |
| **Runout Area** | Asset is outside of feasible runout zone of rocks and shallow landslides | Asset is within feasible runout zone and barrier present between slope and asset (trees, topography) | Asset is within feasible runout zone and partial barrier present between slope and asset (burnt trees, road)<br>OR<br>No barrier and assets are not at the toe of the slope | No partial barriers and the assets are at the toe of the slope |

Note:
1. Appendix A provides detailed descriptions of high, moderate, and low burn classifications.

### 3.2.3 Limitations to the Work

Limitations to this assessment are as follows:

- The hazard study area polygons denote areas evaluated to have a potential of being impacted by post-wildfire hazards. These areas do not denote hazard extents (i.e., runout zones of a debris flow or rockfall), and further analysis may identify areas within the study areas which are free from hazards.
- The scale of the assessment encompassed areas with multiple parcels. PHAs were assessed on a fan-scale for post-wildfire steep creek hazards (ranging from 0.01 $km^2$ to 6.5 $km^2$) and AOIs ranged from 0.04 $km^2$ to 3.9 $km^2$. This assessment did not account for parcel-scale considerations.
- The study areas were limited to areas that could have an impact on the CSRD. Areas of Interest identified in the initial memo by BGC have been excluded based on the area limits

of the study. No specific scenarios or specific property addresses were examined in the course of this study.

- The selection of hazard study areas is based on the fire perimeter generated from imagery dated September 26, 2023 and burn severity data generated from September 8 – 18, 2023 (Drawing 01) and photographs taken by the BC Ministry of Forests on September 1, 2023. Any changes to conditions since those data were collected are not reflected in our study area selection.
- The Potential Hazard Area (steep creeks) polygons included the mapped fans from the regional prioritization study (BGC, April 16, 2020), with additional areas delineated based on lidar and digital elevation model data and the susceptibility modeling from the previous study (BGC, April 16, 2020). The potential hazard areas associated with these watersheds were assumed to be generally similar to the potential inundation areas delineated through debris-flow and debris-flood susceptibility modelling completed during the 2020 study.
- The Area of Interest (rockfall and shallow landslide) polygons were delineated based on visual observations of Google Earth imagery and photographs from the BC Ministry of Forests or mapped fans from the regional prioritization study (BGC, April 16, 2020). There may be other assets at risk outside of the study area polygons. The photographs provided by the BC Ministry of Forests do not cover all burned areas; therefore, BGC is unable to confirm the presence of other assets at risk in some areas.
- No detailed assessments such as frequency magnitude assessments or consequence ratings were completed.
- The assessment for rockfall and shallow landslide hazards only considers the change in hazard to general areas from pre-wildfire conditions to post-wildfire conditions.
- Ground conditions and modeling have not been verified from fieldwork. The hazard ratings have been assigned based on a desktop study only.

# 4.0 RESULTS

The following section provides a summary of the results of the assessment. Full results for each watershed, PHA, and AOI are provided in Appendix B.

## 4.1 Post-Wildfire Steep Creek Hazard Assessment

A total of 63 watersheds were assessed to be impacted by the Bush Creek East Fire with potential to impact the District. Using the methodology outlined in Section 3.2.1, the following plots summarize the profile across the assessed watersheds of Burn Severity Index (Figure 4-1), Hydrogeomorphic Process Index (Figure 4-2), and resultant Post-wildfire (Steep Creek) Hazard Likelihood (Figure 4-3). Drawing 02 provides the Post-wildfire Hazard Likelihood ratings for each watershed.

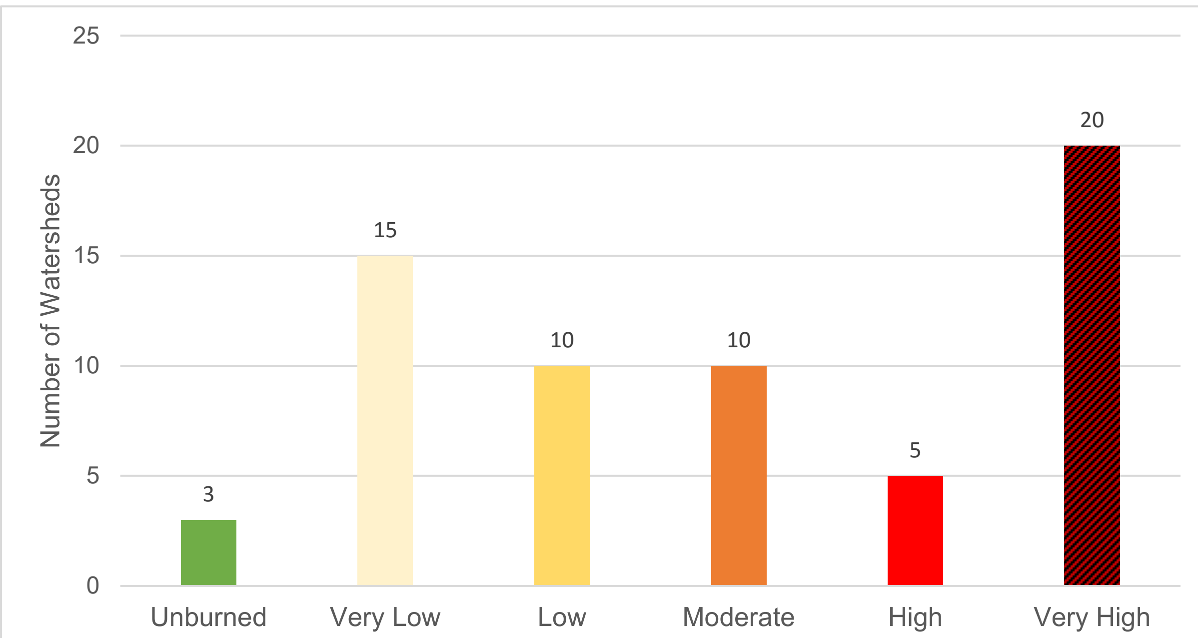


**Figure 4-1 Burn Severity Index ratings for all watersheds, with number of watersheds per rating.**

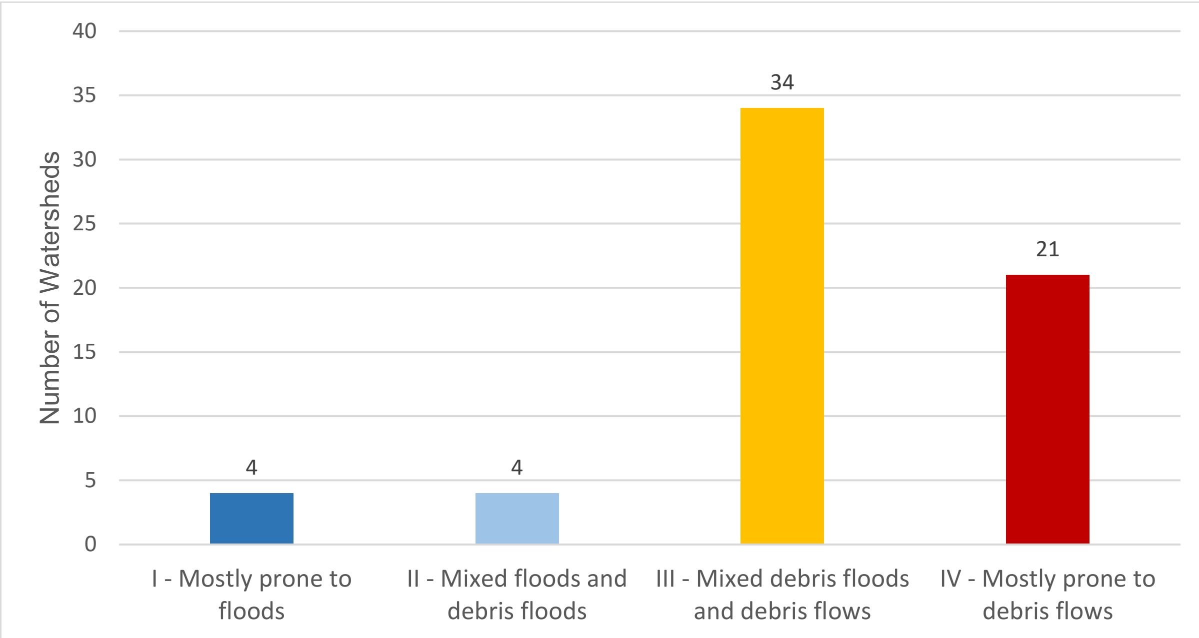


**Figure 4-2 Hydrogeomorphic Process Index ratings for all watersheds, with number of watersheds per rating.**

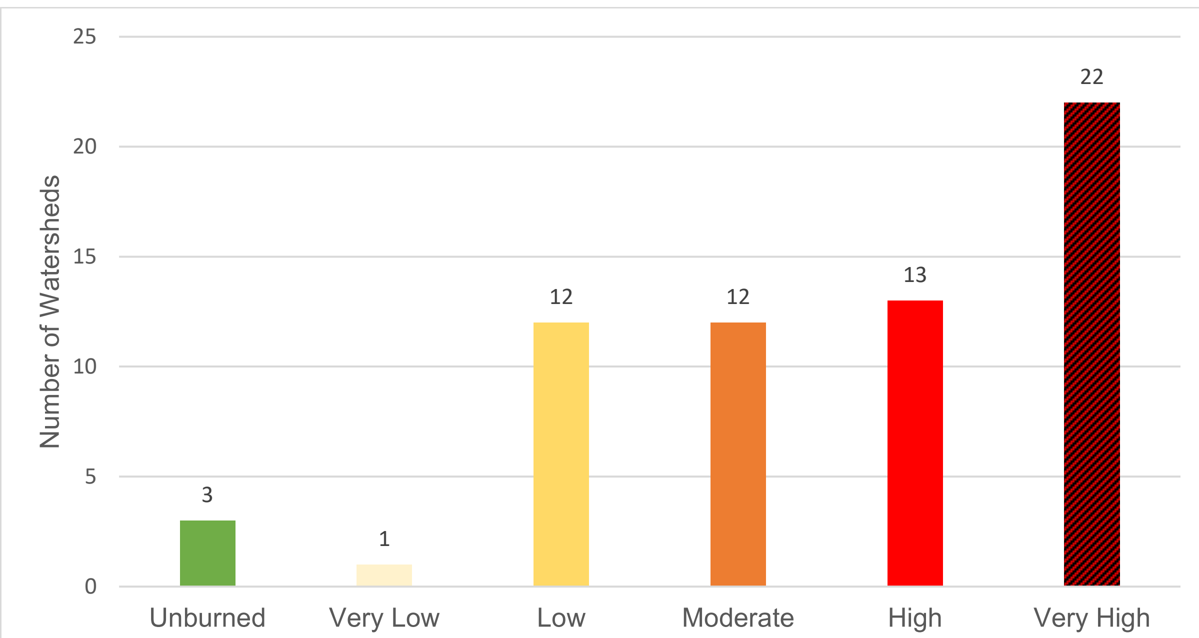


**Figure 4-3 Post-wildfire (steep creek) Hazard Likelihood ratings for all watersheds, with number of watersheds per rating.**

The watersheds rated High to Very High post-wildfire hazard likelihood were generally characterized as severely burned watersheds which are mostly prone to debris flows. These were assessed to be located throughout the study area, including above Woolford Point, west of Scotch Creek, in the upper watersheds above Celista, above Quaaout 1 I.R., and above Highway 1 close to the Squilax-Anglemont Road bridge crossing.

A total of 62 Potential Hazard Areas (PHAs) were identified, including 14 alluvial fans which were included in the previous study (BGC, April 16, 2020) and 48 PHAs which were newly delineated in the current study. The distribution of Post-wildfire Impact Likelihood ratings across all watersheds is provided in Figure 4-4. This rating combines with the Post-wildfire Hazard Likelihood rating (Figure 4-3) to estimate Post-wildfire Geohazard Rating from steep creek hazards (Figure 4-5).

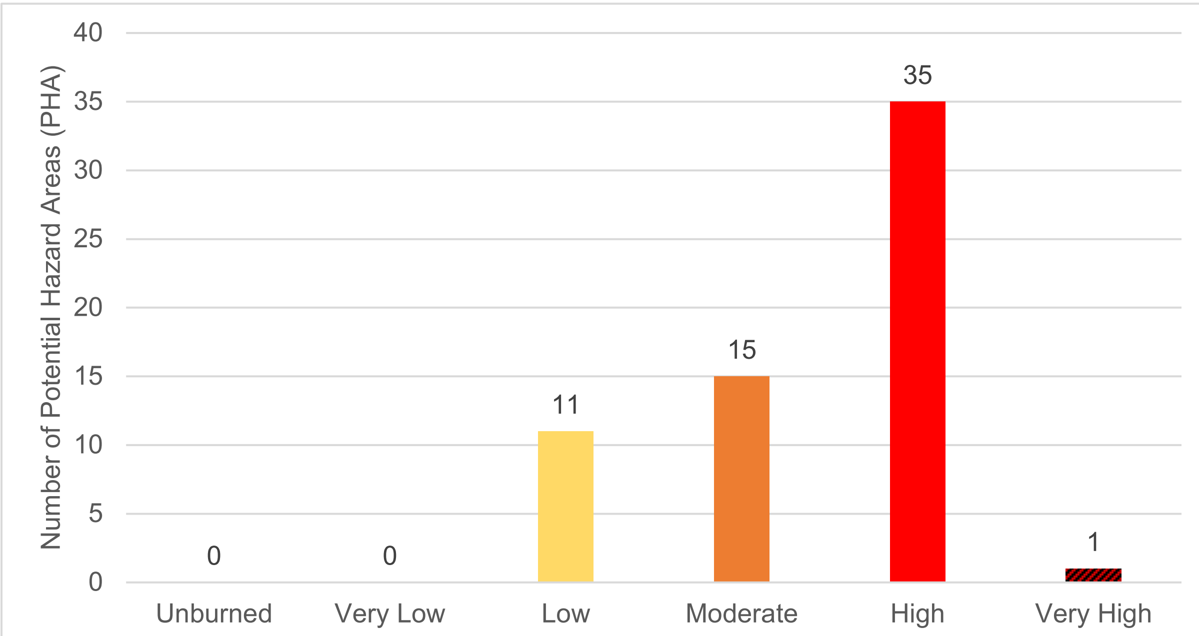


**Figure 4-4 Post-wildfire Impact Likelihood ratings for all watersheds, with number of watersheds per rating.**

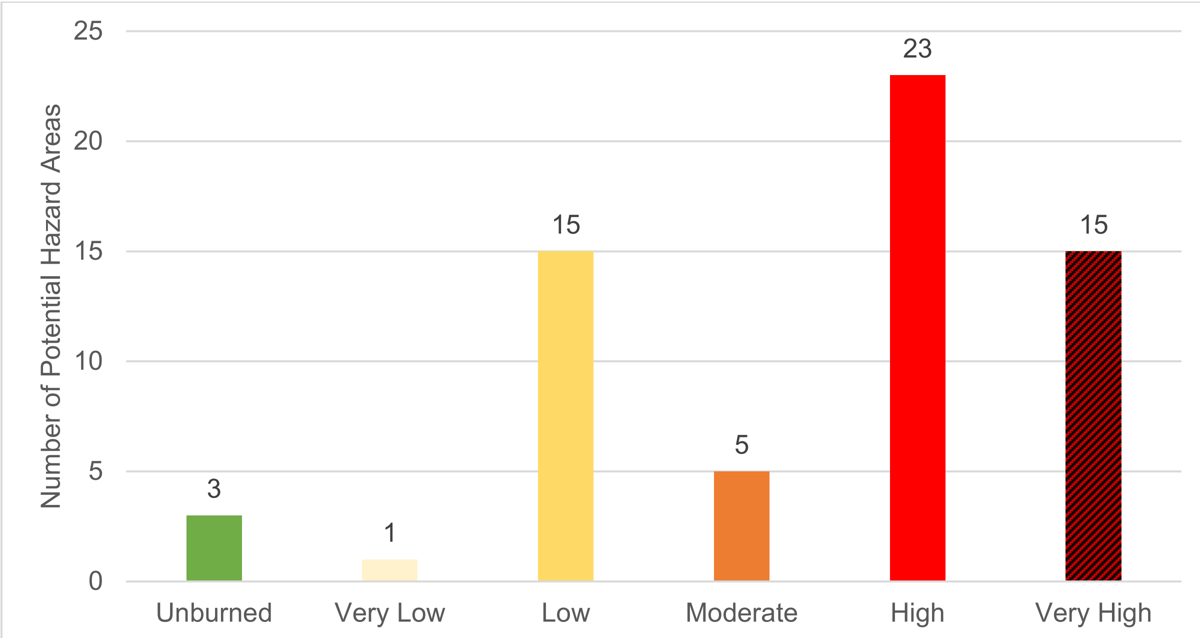


**Figure 4-5 Post-wildfire Steep Creek Geohazard Ratings for all watersheds, with number of watersheds per rating.**

There are 15 PHAs rated as “Very High” and 23 rated as “High” Post-wildfire Geohazard Rating to steep creek hazards. These include all identified areas along south Adams Lake, fans within the Adams River valley and the Adams River fan by Lee Creek, areas at Quaaout 1, PHAs at the outlet of watersheds west of Scotch Creek, smaller areas between Scotch Creek and Celista, and between Celista and Magna Bay, areas in the plateau above Celista, and watershed outlets above Highway 1 along the south shore of Shuswap Lake.

## 4.2 Post-Wildfire Rockfall and Shallow Landslide Assessment

A total of 20 Areas of Interest (AOI) have been identified and assessed in this report. The distribution of the assigned ratings is presented in Figure 4-6.

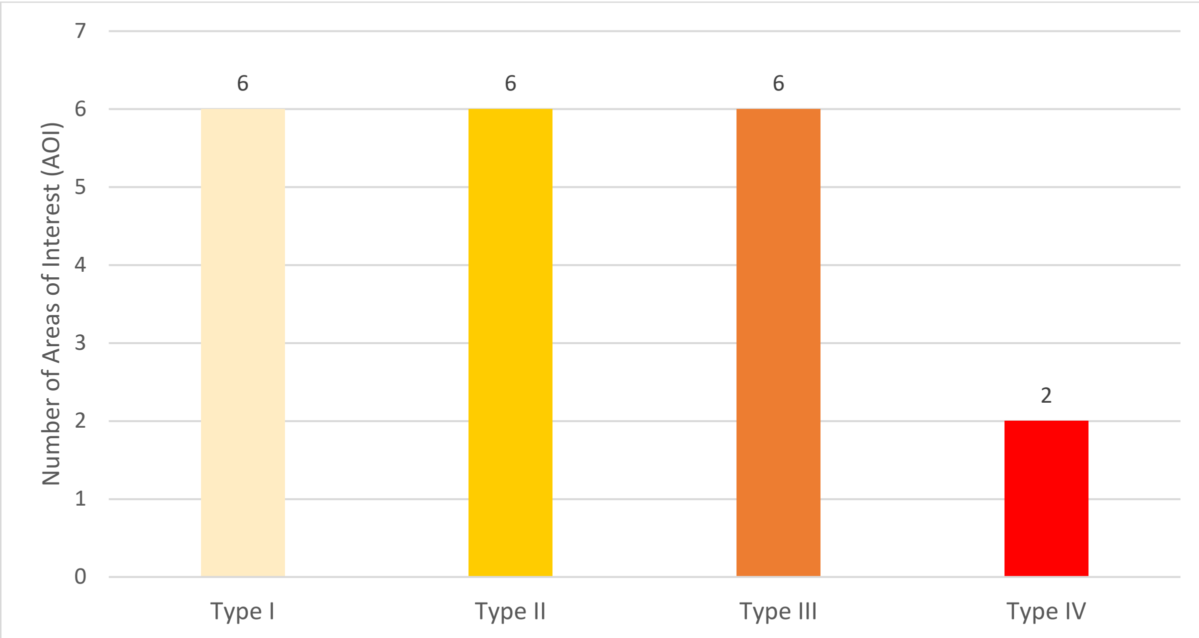


**Figure 4-6 Change in Hazard ratings for post-wildfire rockfall and shallow landslides for all Areas of Interest, with the number of areas per rating.**

Two areas have been designated as Type IV areas. AOI8-c and AOI8-d are located between Scotch Creek and Celista. The photos show sparse vegetation and soil over shallow bedrock outcrops. The infrastructure is at the toe of the slope with very little runout distance to infrastructure.

Six areas have been designated as Type III areas. These locations are below moderately to severely burned slopes. There are either partial barriers or no barriers between the toe of the slope and the infrastructure. Debris from the slope may fall but it is not likely to reach infrastructure due to slope geometry, partial barriers, or distance from the toe of the slope to the structures.

Six areas have been designated as Type II areas. These locations have barriers or partial barriers between the slope and infrastructure. The risk of a rockfall or shallow landslide occurring has increased however due to the characteristics of the propagation area, the debris are unlikely to reach buildings.

The remaining areas are assigned a Type I classification and do not require further study. The slope is either unburned or mildly burned, or the propagation area is such that it is highly unlikely debris would reach infrastructure.

Table 4-1 lists the results of the hazard assessment for rockfalls and shallow landslides. The results are also provided in Appendix B.

**Table 4-1 Results of hazard assessment for rockfall and shallow landslides.**

| Area of Interest | Location | Slope Condition[1] | Runout Area[2] | Change in Hazard |
|---|---|---|---|---|
| AOI1-a | Adams Lake East McLeod Point North | Moderate burn | Outside rollout zone | Type I |
| AOI1-b | Adams Lake East McLeod Point Upper | Moderate burn and steep/rocky | Partial barrier | Type III |
| AOI1-c | Adams Lake East McLeod Point Lower | Moderate burn and steep/rocky | Barrier | Type II |
| AOI1-d | Adams Lake East Between McLeod Point and Woolford Point | Moderate burn and steep/rocky | Partial barrier | Type III |
| AOI1-e | Adams Lake East Woolford Point | Low burn | Outside rollout zone | Type I |
| AOI1-f | Adams Lake East Hustalen Creek | Unburned | Barrier | Type I |
| AOI3-a | Adams River South | High burn | Partial barrier | Type III |
| AOI3-b | Adams River South | Low burn | Barrier | Type II |
| AOI5-a | Lee Creek Drive West | Moderate burn | Barrier | Type II |
| AOI5-b | Lee Creek Drive Lower | Moderate burn | Outside rollout zone | Type I |
| AOI8-a | Between Scotch Creek and Celista West Upper | Moderate burn | No barrier / at toe of slope | Type III |
| AOI8-b | Between Scotch Creek and Celista West Lower | Moderate burn | Partial barrier | Type II |
| AOI8-c | Between Scotch Creek and Celista | High burn and steep/rocky | Partial barrier | Type IV |
| AOI8-d | Between Scotch Creek and Celista East | High burn and steep/rocky | Partial barrier or no barrier / at toe of slope | Type IV |
| AOI9-a | Mount Riley | High burn | Partial barrier | Type III |
| AOI9-b | Mount Riley | High burn | Outside rollout zone | Type I |
| AOI10 | Little River Boatworld | Low burn | Outside rollout zone | Type I |
| AOI11 | North of Celista | Severe burn | Partial barrier | Type III |
| AOI12 | Scotch Creek North | Severe burn | Barrier | Type II |
| AOI16 | Lee Creek Drive Upper | High burn | Partial barrier | Type II |

Notes:

1. Refer to Table 3-4 for definitions of slope conditions.
2. Refer to Table 3-4 for full definitions of propagation area.
3. Refer to Section 6.0 for recommendations associated with change in hazard level.

# 5.0 DISCUSSION

This work is a screening-level assessment and may be used to support urgent decision making. It is emphasized that the current study is an emergency assessment to evaluate (1) steep creek geohazard levels and (2) a change in hazard level at sites which may be subject to rockfall and shallow landslide hazard that is applicable in the aftermath of the Bush Creek East Fire. The ratings provided are averaged across areas (PHAs and AOIs) and hazard levels at specific locations within the areas may vary. This study also does not include a quantitative risk assessment to evaluate risk to loss of life. Additionally, this screening-level assessment is an interim deliverable and may be superseded by detailed assessments.

Since the geohazard types are different and used different methodologies for hazard estimation, Table 5-1 is provided to illustrate how the hazard levels for the different assessments relate to each other.

**Table 5-1 Relationship between different hazard levels assessed by this study for post-wildfire steep creek, rockfall and shallow landslide hazards.**

| Steep Creek Hazard | Rockfall and Shallow Landslide Hazard | Priority Level |
|---|---|---|
| **Post-wildfire Geohazard Rating** | **Change in Hazard Level Type** | |
| Very High | Type IV | Highest Priority |
| High | | |
| Moderate | Type III | |
| Low | Type II | |
| Very Low | | |
| N/A | Type I | Lowest Priority |

Due to uncertainty in this desktop-based assessment, parties interested in determining if an area has a tolerable risk level may consider completing detailed risk-based, localized (e.g. parcel-scale) studies to reduce the uncertainty. It should also be noted that areas mapped within hazard areas (PHAs and AOIs), with the exception of Type I AOIs, are considered potentially hazardous unless a more detailed assessment proves otherwise. Additionally, detailed investigations that include fieldwork may identify other hazard areas that are outside of assessed watersheds and hazard areas.

For rockfall and shallow landslide hazards, the hazard change classifications should be updated as further studies are completed or more information is gathered in the potential hazard areas. Note that some areas within the fire perimeter were not assessed in this study due to a lack of photographs. The CSRD can use the matrix presented in Section 3.2.2 to conduct a preliminary change in hazard assessment on these areas:

- The west side of Celista (east portion of AOI8),
- The area west of Mount Riley (west portion of AOI9),
- Northwest of Celista (AOI13), and
- Northeast of Squalix Mountain (AOI15).

Additionally, several areas referenced in the technical memorandum provided to the CSRD (BGC, September 14, 2023) were not included in the assessment as they are outside of CSRD jurisdiction (AOI2, AOI4, AOI6, AOI7, and AOI14).

## 6.0 RECOMMENDATIONS

BGC has compiled a list of preliminary recommendations for the CSRD based on the emergency work that may be superseded by forthcoming recommendations from the MOF or other detailed hazard studies. BGC understands that the MOF will be completing a detailed assessment of the area by the end of 2023. The preliminary recommendations provided below are meant to provide guidance around prioritization of land use and/or future assessments in the area until the MOF study has been released.

The CSRD may wish to implement interim building permit guidance for the aftermath of the wildfire that is similar to policy P-26 that was issued after the Geohazard Risk Prioritization study (BGC, April 16, 2020) was completed. This guidance could be based on the prioritization provided in Table 5-1 applied to the results of the assessment (Appendix B). BGC recommends using the results of this study on an interim basis until a more detailed assessment is available and/or the increased geohazard activity following the fire has subsided.

The results of the assessment (Appendix B) and Table 5-1 may also be used for prioritization of areas for emergency response and detailed assessments for emergency mitigation measures. In addition to the results of this assessment (Appendix B), CSRD may wish to also consider population density, number of re-occupied homes, presence of critical infrastructure, asset values, and asset types. For instance, PHAs rated as High and Very High and AOIs rated as Type IV slopes may be prioritized for further assessments in areas with high population design and presence of critical infrastructure.

## 7.0 CLOSURE

This report contains sections under the supervision of different individuals. Hazel Wong is the responsible author for the Introduction (Section 1.0), Background (Section 2.0), Burn Severity Methods (Section 3.1), Steep Creek Hazard Methods (Section 3.2.1), and Post-wildfire steep creek hazard assessment results (Section 4.1). Natalia Skomorowski is the responsible author for Rockfall and Shallow Landslide Hazard Methods (Section 3.2.2) and Post-wildfire rockfall and shallow landslides results (Section 4.2). Hazel Wong and Natalia Skomorowski jointly authored the Limitations to the Work (Section 3.2.3) and Discussion (Section 5.0) and Recommendations (Section 0).

We trust the above satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

**BGC Engineering Inc.**
**per:**

Hazel Wong, M.Eng., P.Geo.
Engineering Geologist

Natalia Skomorowski, M.Sc., P.Eng.
Geological Engineer

Reviewed by:

Joseph Gartner, Ph.D., P.Eng.
Senior Geological Engineer

Dave Gauthier, Ph.D., P.Eng., P.Geo.
Senior Geological Engineer/Geoscientist

HW/JG/DG/ksj/mm

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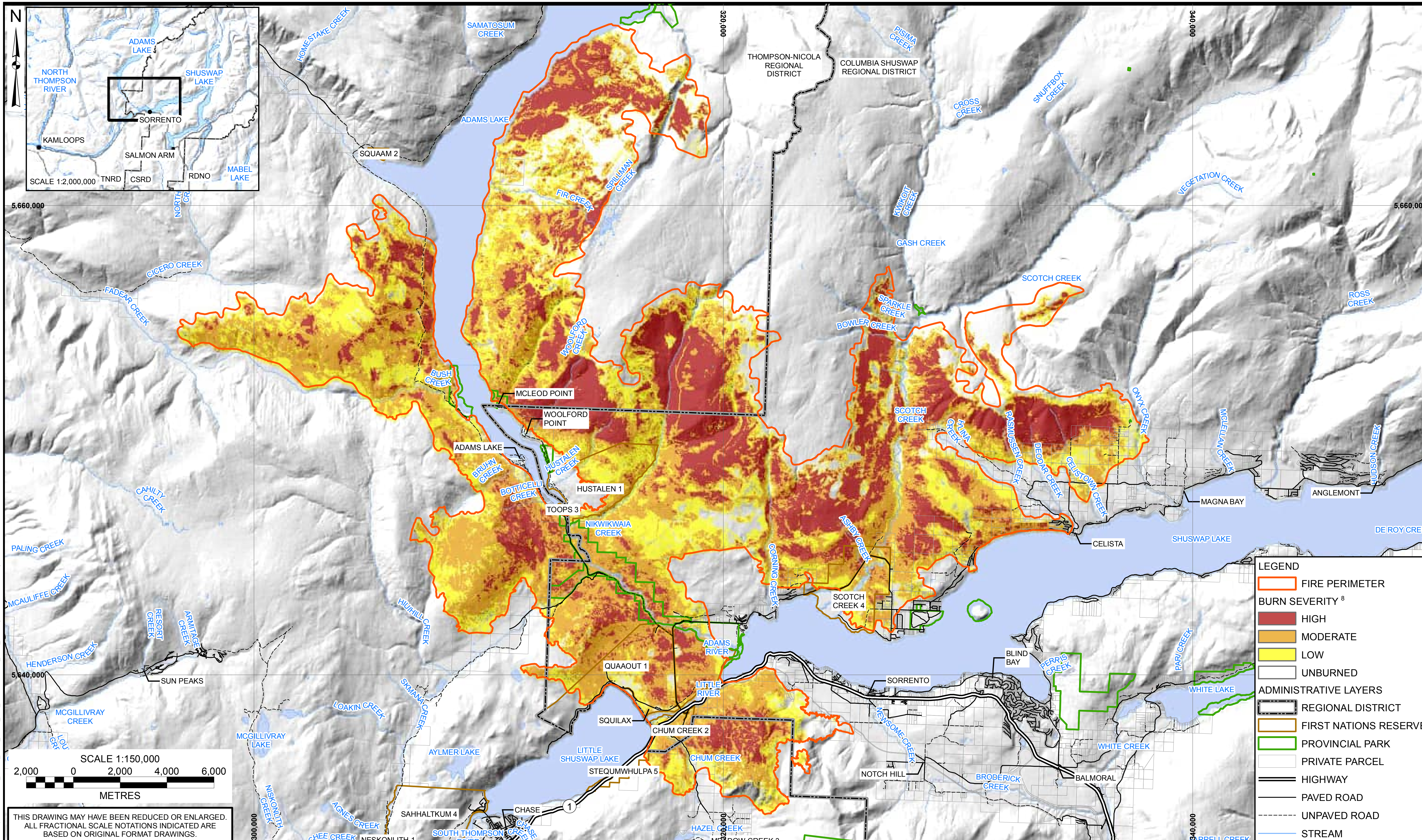
# DRAWINGS




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "BUSH CREEK EAST FIRE - POST-WILDFIRE GEOHAZARD ASSESSMENT FOR EMERGENCY DECISION SUPPORT" AND DATED OCTOBER 2023.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM NDMP, DATED 2019. CONTOUR INTERVAL IS 10 m.
4. PARCEL DATA IS PARCELMAP BC (2021) FROM ICI SOCIETY.
5. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
6. HYDRO FEATURES FROM CANVEC. ONLY NAMED FEATURES ARE SHOWN.
7. REGIONAL DISTRICTS, MUNICIPALITIES AND ROADS FROM GEO BC.
8. BURN SEVERITY DATA BASED ON IMAGERY FROM SEPT 8 TO 18, 2023.
9. MAPPED GEOHAZARD STUDY AREAS ONLY INCLUDE AREAS WITHIN OR WHICH MAY IMPACT THE CSRD.
10. FIRE PERIMETER RETRIEVED FROM THE BCWS ON SEPTEMBER 26, 2023.
11. BGC PREPARED THIS DRAWING FOR THE EXCLUSIVE USE OF BGC'S CLIENT IDENTIFIED ON THIS DRAWING. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING MUST NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE SPECIFIC PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES, INJURY, OR LOSS ARISING FROM ANY UNAUTHORIZED USE OR MODIFICATION OF THIS DRAWING. THIRD PARTIES USE OR RELY UPON THIS DRAWING AT THEIR OWN RISK.

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| SCALE: | 1:150,000 |
| DATE: | OCT 2023 |
| DRAWN: | MIB |
| REVIEW: | JG |
| APPROVED: | HW |

CLIENT: CSRD

BGC

PROJECT: BUSH CREEK EAST FIRE - POST-WILDFIRE GEOHAZARD ASSESSMENT FOR EMERGENCY DECISION SUPPORT

TITLE: BURN SEVERITY

PROJECT No.: 1899009

DWG No: 01

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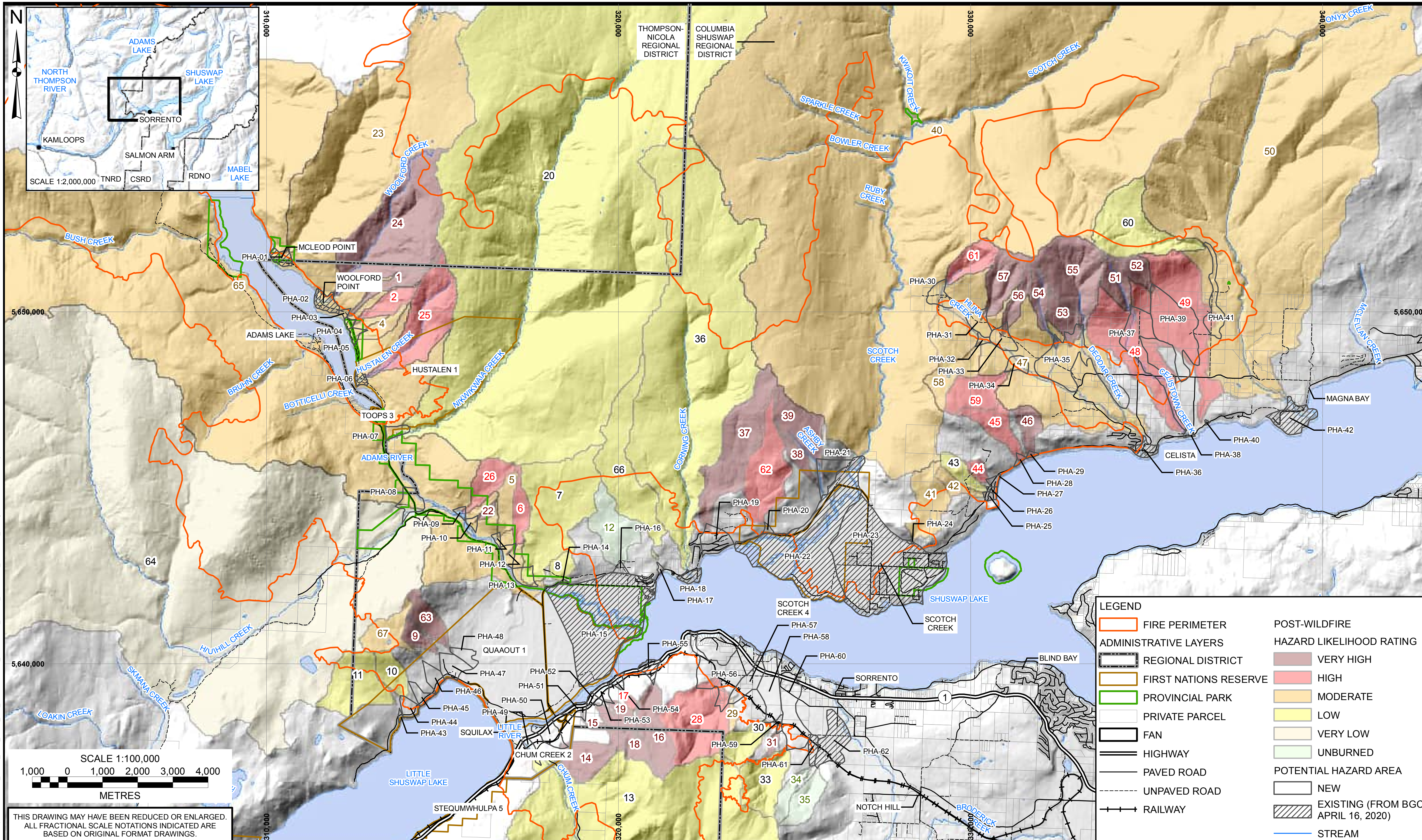


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3. BASE TOPOGRAPHIC DATA BASED ON CANADIAN DIGITAL ELEVATION DATA (CDED).
4. PARCEL DATA IS PARCELMAP BC (2021) FROM ICI SOCIETY.
5. PROJECTION IS NAD 1983 UTM ZONE 11N.
6. HYDRO FEATURES FROM CANVEC. ONLY NAMED FEATURES ARE SHOWN.
7. REGIONAL DISTRICTS, MUNICIPALITIES AND ROADS FROM GEO BC.
8. FIRE PERIMETER RETRIEVED FROM THE BCWS ON SEPTEMBER 26, 2023.
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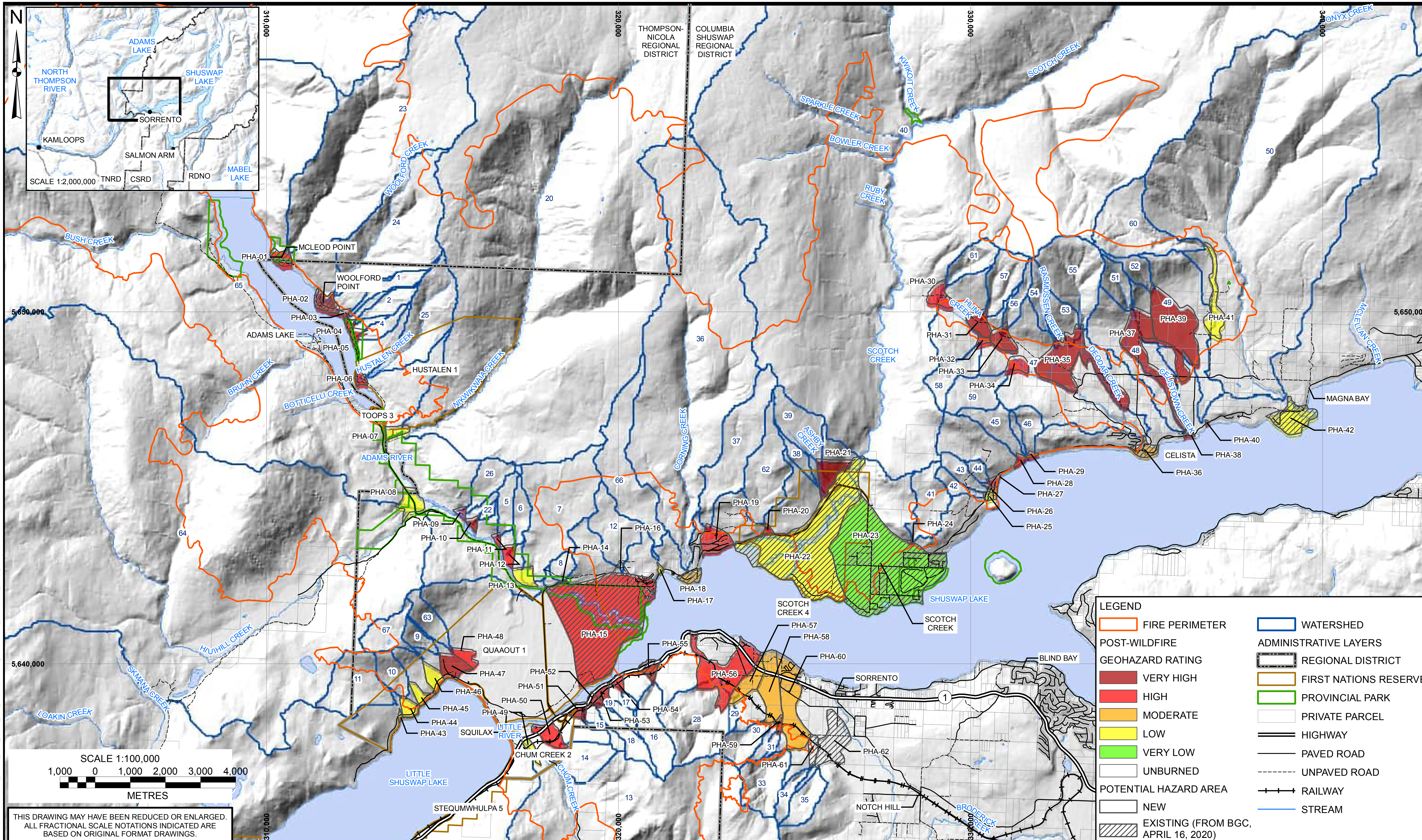
BGC

PROJECT: BUSH CREEK EAST FIRE - POST-WILDFIRE GEOHAZARD ASSESSMENT FOR EMERGENCY DECISION SUPPORT

TITLE: POST-WILDFIRE HAZARD LIKELIHOOD RATINGS (STEEP CREEK)

PROJECT No.: 1899009

DWG No: 02

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PROJECT: BUSH CREEK EAST FIRE - POST-WILDFIRE GEOHAZARD ASSESSMENT FOR EMERGENCY DECISION SUPPORT

TITLE: POST-WILDFIRE GEOHAZARD RATINGS (STEEP CREEK)

PROJECT No.: 1899009

DWG No: 03

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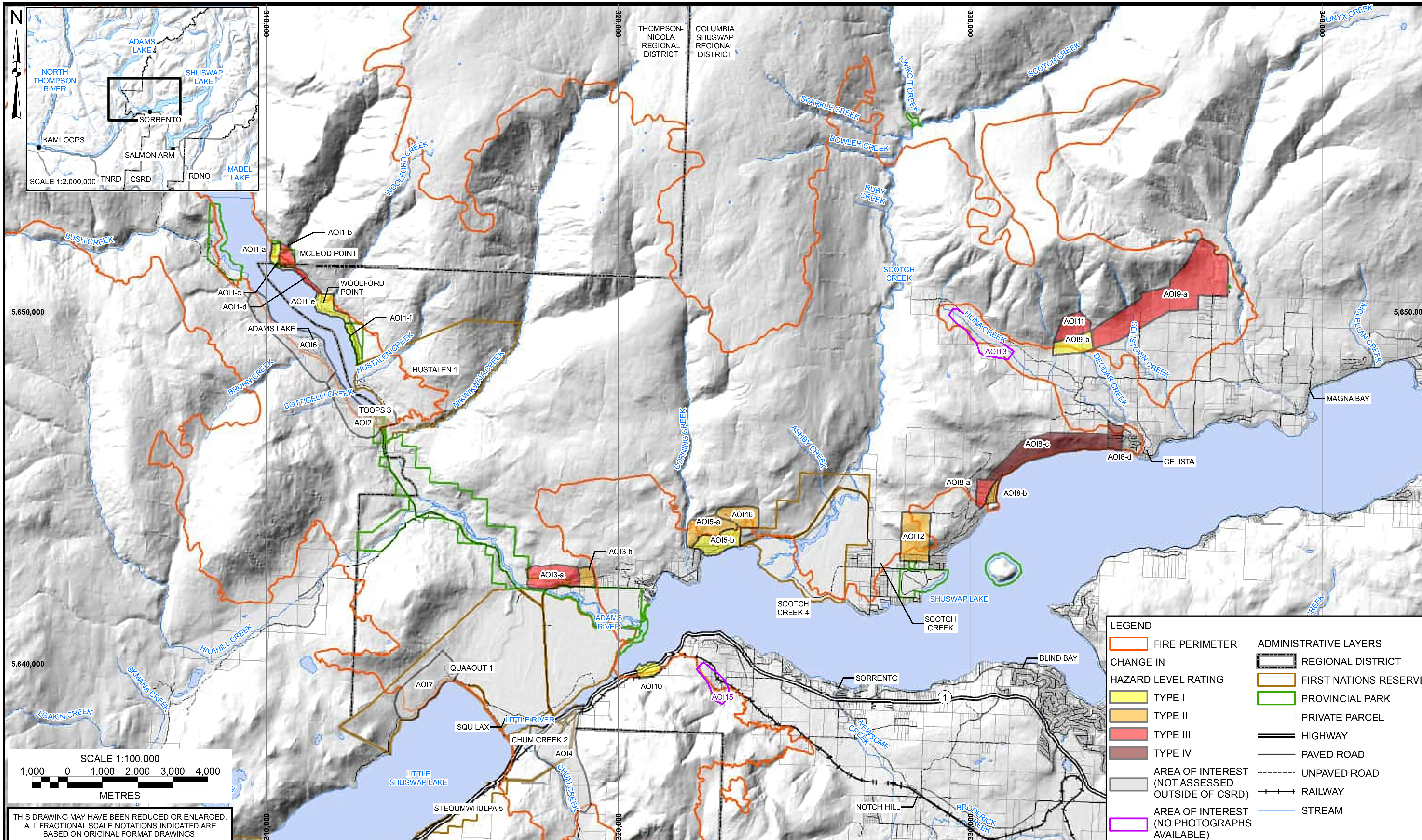


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3. BASE TOPOGRAPHIC DATA BASED ON CANADIAN DIGITAL ELEVATION DATA (CDED).
4. PARCEL DATA IS PARCELMAP BC (2021) FROM ICI SOCIETY.
5. PROJECTION IS NAD 1983 UTM ZONE 11N.
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7. REGIONAL DISTRICTS, MUNICIPALITIES AND ROADS FROM GEO BC.
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| APPROVED: | NS |

CLIENT: CSRD

BGC

PROJECT: BUSH CREEK EAST FIRE - POST-WILDFIRE GEOHAZARD ASSESSMENT FOR EMERGENCY DECISION SUPPORT

TITLE: POST-WILDFIRE CHANGE IN HAZARD LEVEL RATINGS (ROCKFALL AND SHALLOW LANDSLIDE)

PROJECT No.: 1899009

DWG No: 04

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# APPENDIX A
## BURN SEVERITY METHODOLOGY AND LIMITATIONS

## A-1 METHODOLOGY

Burn severity is a relative measure of fire-induced ecological changes, typically reported as low, moderate, high, or a combination of these. Examples of vegetation changes associated with the different burn severity indices for high density mixed conifer forests, which is similar vegetation to the Shuswap and Adams Lake area, are provided in the Field Guide for Mapping Post-Fire Soil Burn Severity (Parson et al, 2010).

Since at least the 1990s, the wildland fire community has been using multispectral satellite imagery (MSI) to estimate burn severity (Key and Benson, 2006). A remote sensing approach to burn severity mapping has the advantage of being able to characterize the spatial heterogeneity inherent in a post-fire landscape and assess many fires or large fires more efficiently than exclusively field-based methods.

The most common radiometric index used in estimating burn severity from MSI relies on the normalized burn ratio (NBR), which is a normalized difference of the reflectance measured in the near-infrared (NIR) and short-wave-infrared (SWIR) wavelengths. NBR highlights characteristics of vegetation presence and health. Pre- and post-fire NBR values may be compared to identify burned areas and provide a measure of burn severity.

$$\mathrm{NBR} = \frac{(NIR - SWIR)}{(NIR + SWIR)} \qquad \text{[Eq. 1]}$$

NBR is typically computed for conditions prior to, and following, the fire. Most commonly, the delta NBR (dNBR) is computed as the difference of pre- and post-fire datasets (Eq. 2), though some authors have evaluated a relative delta NBR (Miller and Thode, 2007) and relativized burn ratio (Parks et al., 2014) for comparing changes in areas that had very different amounts of vegetation prior to the fire.

$$\mathrm{dNBR} = NBR_{pre} - NBR_{post} \qquad \text{[Eq. 2]}$$

Differences between pre- and post-fire NBR are specifically related to vegetation changes and do not account for fire-related changes in soil properties; however, in the absence of field observations, NBR has been used as a proxy for overall burn severity (Hudak et al., 2004; Keeley, 2009).

BGC used satellite images from 2022 and 2023 to compute dNBR for the Bush Creek East fire. We performed our analysis in Google Earth Engine (GEE; Gorelick et al., 2017) utilizing atmospherically corrected Sentinel-2 imagery. BGC classified the dNBR results into unburned, low, moderate, and high burn severity classes using thresholds shown in Table A-1 for the calculation of the Burn Severity Index. The dates of the imagery used in the analysis are shown in Table A-2.

**Table A-1 Burn severity classification thresholds for dNBR data (from Lutes et al., 2006).**

| dNBR Values | Burn Severity Class |
|---|---|
| <0.10 | Unburned |

| | |
|---|---|
| 0.10 to 0.27 | Low |
| 0.27 to 0.66 | Moderate |
| >0.66 | High |

**Table A-2 Imagery acquisition dates used by BGC for dNBR calculation.**

| Image | Date Acquired |
|---|---|
| Pre-fire | All images from September 8 – 18, 2022 (6 total images) |
| Post-fire | All images from September 8 – 18, 2023 (6 total images) |

## A-2 LIMITATIONS TO THE WORK

BGC used values of dNBR to estimate burn severity classes across the wildfire area (Table A-1). These values are based on published literature (Lutes et al., 2006) and have not yet been calibrated to local and actual vegetation or soil burn severity categories. Ground inspections, not currently part of the scope of work, will be required to verify the burn severity index estimated by remote sensing methods.

Differences between pre- and post-fire NBR illustrate wildfire-induced vegetation changes and have not yet been related to changes in risk level of burned geohazard sites in the CSRD.

BGC has assumed that the data provided by satellite imagery is accurate, complete, and reliable. BGC is not responsible for any deficiency, misstatement, or inaccuracy in this document due to errors or omissions in information collected from remote sensing methods.

The CSRD is solely responsible for determining what action (if any) to take based on the burn severity estimates.

# APPENDIX B
## ASSESSMENT RESULTS

## B-1 POST-WILDFIRE STEEP CREEK HAZARD

| Location | | | Watershed Hazard Characterization | | | | Potential Hazard Area Relative Risk Characterization[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| Potential Hazard Area ID | Description | Existing[2] or New Hazard Area? | Watershed ID | Process Type | Burn Severity Index | Post-wildfire Hazard Likelihood | "Baseline" Impact Likelihood | Post-wildfire Impact Likelihood | Post-wildfire Geohazard Rating |
| PHA-01 | McLeod Point | Existing | 23 | III | Low | Moderate | Moderate | High | High |
| PHA-02 | Woolford Point, Woolford Creek | Existing | 24 | III | Very High | Very High | Moderate | High | Very High |
| PHA-03 | South of Woolford Point | New | 1 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-04 | South of Woolford Point | New | 2 | IV | Low | High | Moderate | High | High |
| PHA-05 | South of Woolford Point | New | 4 | IV | Very Low | Moderate | Moderate | High | High |
| PHA-06 | Hustalen Creek, Hustalen 1 | Existing | 25 | III | Moderate | High | Moderate | High | High |
| PHA-07 | Nikwikwaia Creek, Hustalen 1 | New | 20 | I | Low | Low | Very Low | Low | Low |
| PHA-08 | Hiuihill Creek, Roderick Haig-Brown Provincial Park | New | 64 | I | Very Low | Very Low | Low | Moderate | Low |
| PHA-09 | Roderick Haig-Brown Provincial Park | New | 26 | III | Moderate | High | Moderate | High | High |
| PHA-10 | Roderick Haig-Brown Provincial Park | New | 22 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-11 | Roderick Haig-Brown Provincial Park | New | 5 | III | Low | Moderate | Moderate | High | High |
| PHA-12 | Roderick Haig-Brown Provincial Park | New | 6 | III | Moderate | High | Low | Moderate | High |
| PHA-13 | Roderick Haig-Brown Provincial Park | New | 7 | III | Very Low | Low | Low | Moderate | Low |
| PHA-14 | Roderick Haig-Brown Provincial Park | New | 8 | III | Very Low | Low | Very Low | Low | Low |
| PHA-15 | Adams River / Lee Creek | Existing | 65 | I | Low | Moderate | High | Very High | High |
| PHA-16 | Lee Creek community | New | 12 | III | Omit - Unburned | Omit - Unburned | Very Low | Low | Unburned |
| PHA-17 | Mackay Bay | New | 66 | III | Very Low | Low | Very Low | Low | Low |

[1] Where multiple watersheds drain onto a single Potential Hazard Area, the watershed with the highest Post-wildfire Hazard Likelihood rating (if different) was used to calculate the Geohazard Rating.
[2] "Existing" Hazard Area refers to a fan was mapped and characterized in the previous assessment (BGC, April 16, 2020).

| Location | | | Watershed Hazard Characterization | | | | Potential Hazard Area Relative Risk Characterization[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| Potential Hazard Area ID | Description | Existing[2] or New Hazard Area? | Watershed ID | Process Type | Burn Severity Index | Post-wildfire Hazard Likelihood | "Baseline" Impact Likelihood | Post-wildfire Impact Likelihood | Post-wildfire Geohazard Rating |
| PHA-18 | Corning Creek | Existing | 36 | II | Low | Low | Moderate | High | Moderate |
| PHA-19 | Indigo Bay | New | 37 | III | Very High | Very High | Low | Moderate | High |
| PHA-20 | Scotch Creek 4 | New | 62 | III | High | High | Moderate | High | High |
| PHA-21 | Scotch Creek 4 (north) | New | 38 | IV | Very High | Very High | Moderate | High | Very High |
| | | | 39 | III | Very High | Very High | | | |
| PHA-22 | Scotch Creek 4 | Existing | 40 | I | Very Low | Very Low | Moderate | High | Low |
| PHA-23 | Scotch Creek community | Existing | 40 | I | Very Low | Very Low | Very Low | Low | Very Low |
| PHA-24 | Scotch Creek community (north) | New | 41 | III | Low | Moderate | Moderate | High | High |
| PHA-25 | Between Scotch Creek and Celista | New | 42 | III | Low | Moderate | Very Low | Low | Low |
| PHA-26 | Between Scotch Creek and Celista | New | 43 | III | Very Low | Low | Low | Moderate | Low |
| PHA-27 | Between Scotch Creek and Celista | New | 44 | III | High | High | Low | Moderate | High |
| PHA-28 | Between Scotch Creek and Celista | New | 45 | III | Moderate | High | Moderate | High | High |
| PHA-29 | Between Scotch Creek and Celista | New | 46 | III | Very High | Very High | Low | Moderate | High |
| PHA-30 | Hilna Creek Valley (Meadow Creek Road) | New | 61 | IV | Moderate | High | Moderate | High | High |
| PHA-31 | Hilna Creek Valley (Meadow Creek Road) | New | 57 | IV | High | Very High | Moderate | High | Very High |
| PHA-32 | Hilna Creek Valley (Meadow Creek Road) | New | 58 | III | Low | Moderate | Moderate | High | High |
| PHA-33 | Hilna Creek Valley (Meadow Creek Road) | New | 56 | IV | High | Very High | Moderate | High | Very High |
| PHA-34 | Hilna Creek Valley (Meadow Creek Road) | New | 59 | III | Moderate | High | Moderate | High | High |
| PHA-35 | | New | 53 | III | Very High | Very High | Moderate | High | Very High |

| Location | | | Watershed Hazard Characterization | | | | Potential Hazard Area Relative Risk Characterization[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| Potential Hazard Area ID | Description | Existing[2] or New Hazard Area? | Watershed ID | Process Type | Burn Severity Index | Post-wildfire Hazard Likelihood | "Baseline" Impact Likelihood | Post-wildfire Impact Likelihood | Post-wildfire Geohazard Rating |
| | Deodar Creek area, west of Evans Road | | 54 | IV | Very High | Very High | | | |
| | | | 55 | III | Very High | Very High | | | |
| PHA-36 | Celista | Existing | 47 | II | Moderate | Moderate | Low | Moderate | Moderate |
| PHA-37 | Celistown Creek | New | 51 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-38 | Between Celista and Blake Point | Existing | 48 | III | Moderate | High | Low | Moderate | High |
| PHA-39 | Between Evans Road and Garland Road | New | 52 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-40 | Between Celista and Blake Point | Existing | 49 | III | High | High | Low | Moderate | High |
| PHA-41 | East of Garland Road | New | 60 | III | Very Low | Low | Low | Moderate | Low |
| PHA-42 | Onyx Creek, Magna Bay at Blake Point | Existing | 50 | II | Very Low | Moderate | Low | Low | Low |
| PHA-43 | Quaaout 1 | New | 11 | III | Very Low | Low | Low | Moderate | Low |
| PHA-44 | Quaaout 1 | New | 10 | III | Very Low | Low | Low | Moderate | Low |
| PHA-45 | Quaaout 1 | New | 10 | III | Very Low | Low | Very Low | Low | Low |
| PHA-46 | Quaaout 1 | New | 67 | III | Low | Moderate | Very Low | Low | Low |
| PHA-47 | Quaaout 1 | New | 9 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-48 | Quaaout 1 | New | 63 | III | Very High | Very High | Very Low | Low | High |
| PHA-49 | Chum Creek, Chum Creek 2 | New | 13 | II | Very Low | Low | Low | Moderate | Low |
| PHA-50 | Chum Creek 2 | New | 14 | III | Very High | Very High | Very Low | Low | High |
| PHA-51 | Hwy 1 between Little River Bridge and Cruikshank Point | New | 15 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-52 | Hwy 1 between Little River Bridge and Cruikshank Point | New | 18 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-53 | Hwy 1 between Little River Bridge and Cruikshank Point | New | 19 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-54 | Hwy 1 between Little River Bridge and Cruikshank Point | New | 17 | IV | Moderate | High | Moderate | High | High |

| Location | | | Watershed Hazard Characterization | | | | Potential Hazard Area Relative Risk Characterization[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| Potential Hazard Area ID | Description | Existing[2] or New Hazard Area? | Watershed ID | Process Type | Burn Severity Index | Post-wildfire Hazard Likelihood | "Baseline" Impact Likelihood | Post-wildfire Impact Likelihood | Post-wildfire Geohazard Rating |
| PHA-55 | Hwy 1 between Little River Bridge and Cruikshank Point | Existing | 16 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-56 | Elson and Cruikshank Point | New | 28 | III | Moderate | High | Moderate | High | High |
| PHA-57 | Between Elson and Sorrento | New | 29 | IV | Very Low | Moderate | Low | Moderate | Moderate |
| PHA-58 | Between Elson and Sorrento | New | 30 | III | Very Low | Low | Moderate | High | Moderate |
| PHA-59 | Between Elson and Sorrento | New | 31 | IV | Very High | Very High | Moderate | High | Very High |
| PHA-60 | Between Elson and Sorrento | New | 33 | III | Very Low | Low | Moderate | High | Moderate |
| PHA-61 | Sorrento (south) | Existing | 34 | IV | Omit - Unburned | Omit - Unburned | Moderate | High | Unburned |
| PHA-62 | Sorrento (south) | Existing | 35 | IV | Omit - Unburned | Omit - Unburned | Moderate | High | Unburned |

## B-2 POST-WILDFIRE ROCKFALL AND SHALLOW LANDSLIDE HAZARD

| Area of Interest | Location | Slope Condition | Propagation Area | Change in Hazard Level Type |
|---|---|---|---|---|
| AOI1-a | Adams Lake East McLeod Point North | Moderate burn | Outside rollout zone | Type I |
| AOI1-b | Adams Lake East McLeod Point Upper | Moderate burn and steep/rocky | Partial barrier | Type III |
| AOI1-c | Adams Lake East McLeod Point Lower | Moderate burn and steep/rocky | Barrier | Type II |
| AOI1-d | Adams Lake East Between McLeod Point and Woolford Point | Moderate burn and steep/rocky | Partial barrier | Type III |
| AOI1-e | Adams Lake East Woolford Point | Mild burn | Outside rollout zone | Type I |
| AOI1-f | Adams Lake East Hustalen Creek | Unburned | Barrier | Type I |
| AOI3-a | Adams River South | Severe burn | Partial barrier | Type III |
| AOI3-b | Adams River South | Mild burn | Barrier | Type II |
| AOI5-a | Lee Creek Drive West | Moderate burn | Barrier | Type II |
| AOI5-b | Lee Creek Drive Lower | Moderate burn | Outside rollout zone | Type I |
| AOI8-a | Between Scotch Creek and Celista West Upper | Moderate burn | No barrier / at toe of slope | Type III |
| AOI8-b | Between Scotch Creek and Celista West Lower | Moderate burn | Partial barrier | Type II |
| AOI8-c | Between Scotch Creek and Celista | Severe burn and steep/rocky | Partial barrier | Type IV |
| AOI8-d | Between Scotch Creek and Celista East | Severe burn and steep/rocky | Partial barrier or no barrier / at toe of slope | Type IV |
| AOI9-a | Mount Riley | Severe burn | Partial barrier | Type III |
| AOI9-b | Mount Riley | Severe burn | Outside rollout zone | Type I |
| AOI10 | Little River Boatworld | Mild burn | Outside rollout zone | Type I |
| AOI11 | North of Celista | Severe burn | Partial barrier | Type III |
| AOI12 | Scotch Creek North | Severe burn | Barrier | Type II |
| AOI16 | Lee Creek Drive Upper | Moderate burn | Partial barrier | Type II |