Detailed Post-Wildfire Natural Hazard Risk Analysis
Teare Creek Fire (G30210)

Prepared for:

BC Wildfire Service
Attention: Brendan Miller (via email: Brendan.Miller@gov.bc.ca)

Prepared by:

Westrek Geotechnical Services Ltd.
100 - 1383 McGill Road
Kamloops, BC V2C 6K7
www.westrekgeotech.com

March 12, 2024
File No. 023-215

Table of Contents

1 Introduction and Scope

Westrek Geotechnical Services Ltd. (Westrek) was retained by the BC Ministry of Forests - BC Wildfire Service (BCWS) to complete a Detailed Post-Wildfire Natural Hazard[1] Risk Analysis (the Analysis) for the 2023 G30210 Teare Creek Fire (the Fire). The objective of this assignment[2] was to complete the Analysis for the four (4) watersheds and four face units[3] identified by the BC Ministry of Forests (the Ministry) within the Fire perimeter (Figure 1). The watersheds, from northwest to southeast, are named as follows:

- Rainbow Creek,
- Hagan Creek,
- Gort Creek, and
- Teare Creek.

For discussion purposes, we have numbered the face units sequentially from northwest to southeast, i.e., Face Unit 1 to Face Unit 4.

The scope of the Analysis, as defined by the Ministry, is to:

- Identify any elements at risk[4] from potential post-wildfire hazards;
- Identify potential post-wildfire natural slope hazards[5] which might affect the elements at risk. These hazards include landslides, rockfall, debris flows, debris floods, sediment-laden flows and clearwater flooding;
- Conduct a partial risk analysis for each element at risk; this should include, where relevant, the existing (i.e., pre-wildfire) risk and the increased risk due to the Fire; and
- Identify the need for risk mitigation and provide conceptual risk mitigation options, if required.

We understand that the intended use of the Analysis is to inform owners, agencies and stakeholders of the risk(s) from these hazards that may require immediate (i.e., emergency) mitigative action, or where more detailed assessments may be required.

The Analysis was completed in general conformance with the guidance provided in:

[1] The natural hazards considered for this assessment are slope hazards, i.e., landslides, only.
[2] Provided in an email from the Ministry of Forests, dated September 26, 2023.
[3] Face units consist of open slopes, sometimes dissected by numerous small draws or gullies; they are not considered to be of sufficient size to be designated as a watershed.
[4] Defined as residences or occupied public or private buildings, public transportation infrastructure, licenced domestic and community water intakes and infrastructure, and other values identified by the Ministry or local authorities.
[5] The Analysis did not consider other natural hazards, such as snow avalanches. There are also local site hazards, such as the stability of burned trees or cavities from burned out tree root balls, that have not been considered.

- Land Management Handbook (LMH) 69 – *Post-wildfire Natural Hazards Risk Analysis in British Columbia* (2015) by the BC Ministry of Forests, Lands, and Natural Resource Operations.

The services provided by Westrek are subject to the terms and conditions set out in the *General Services Agreement GS24WHQ0151* between the BCWS and Westrek, dated September 25, 2023. Where not specified in this contract, they are governed by those detailed in the *Interpretation and Use of Study and Report and Limitations* (Appendix A), incorporated herein by reference.

2 The Fire

The Fire is reported to have started in the lower reaches of the Teare Creek watershed on May 4, 2023. Overall, it burned 1,100 ha along the northeast side of the Robson Valley, near McBride, BC.

The burned slopes are located within the Regional District of Fraser-Fort George (RDFFG) boundary.

3 Burn Severity

Burn severity is an important factor in determining the potential for post-wildfire natural hazards to occur.

Burn severity is derived from:

- The vegetation burn severity mapping (Figure 2), which uses satellite images to process reflectance data and estimate the change to the vegetation cover[6], and
- The soil burn severity, which relies on field tests and observations of the effects of fire on soils to determine loss of ground cover, loss of soil structure and increases in water repellency (Curran et al 2006)[7].

Moderate and high burn severities correspond to a higher rate of vegetation consumption (i.e., loss of canopy, groundcover and organic soil layer) during a fire and the presence of typically stronger and more prevalent water repellency conditions. This is important because the hydrologic response (i.e., increased peak flows and runoff volumes) in a watershed following rainfall events can be significantly altered on slopes burned to these severities.

The Fire primarily burned the mid-elevation valley slopes above the Yellowhead Highway (the Highway; also known as the McBride Highway 16 E). Most of the burned slopes are mapped as high burn severity; moderate and low burn severity are generally limited to the lower slopes, but small areas are also scattered throughout the high burn severity areas.

[6] For this assessment, the satellite images compared were taken on July 26, 2022, and July 6, 2023.
[7] Curran, M.P., Chapman B., Hope G.D., and Scott D. 2006. *Large-scale Erosion and Flooding after Wildfires: Understanding the Soil Conditions,* BC Ministry of Forests and Range, Technical Report 030.

Using post-wildfire natural hazard research[8], Westrek adapted criteria to determine the likelihood of a post-wildfire slope hazard to occur, based on burn severity and slope steepness. Professional judgement gained from our experience completing post-wildfire natural hazard analyses in BC allowed for some flexibility in the application of this criteria.

Burn severity is considered to significantly affect the hydrologic response within a watershed or on a face unit slope when:

- Over 50% of the watershed/face unit burned, i.e., there is widespread loss of the tree canopy;
- Over 30% of the watershed/face unit burned to a high burn severity; and/or
- Over 40% of the watershed/face unit burned to at least a moderate burn severity.

Table 1 summarizes the total percentage area burned within each of the watersheds and on the face units, as well as the percentage area burned to a moderate and high severity:

Table 1: *Summary of percentages of burned area and burn severity in each watershed and face unit; the highlighting indicates a significant percentage was burned at a moderate or high severity.*

Watershed/Face Unit	% Burned	% Burned to a High Severity	% Burned to a Moderate Severity
Face Unit 1	34.5	28	2.4
Rainbow Creek	8.4	7.4	0.4
Face Unit 2	80.8	76.3	1.9
Hagan Creek	29	26	1.5
Gort Creek	25.9	23.1	1.4
Face Unit 3	78.5	72.7	2.4
Teare Creek	46.1	37.9	4.1
Face Unit 4	27.3	21.1	2.4

4 Post-Wildfire Slope Hazards

Wildfires can impact the initiation of potential slope hazards in several ways. Depending on the burn severity, wildfire-induced water repellency (i.e., hydrophobicity), which can reduce infiltration rates, may develop within the upper soil layers. This, combined with the loss of vegetative ground cover, results in a significant increase in the potential for runoff to develop during rainfall events, thereby creating a much faster hydrologic response (i.e., a “flashier” runoff regime). The effect of these conditions typically lessens as the vegetative ground cover re-establishes and the water repellency breaks down, returning to the pre-wildfire levels; this generally occurs within 2 to 5 years following a wildfire.

[8] The US Geological Survey (USGS) provides post-wildfire hazard research references to guide natural hazard screening-level assessments at: https://www.usgs.gov/programs/landslide-hazards/science/emergency-assessment-post-fire-debris-flow-hazards

Post-wildfire debris flows and debris floods generated from runoff are typically triggered within the first two (2) years following a wildfire (Cannon and Gartner 2005)[9].

Should these conditions exist following a wildfire, a short-term increase in the following hazards (see Appendix B for definitions) can be expected:

- Sediment-laden flows, which are mainly limited to face unit slopes; and
- Debris floods and debris flows, which are confined to creeks, gullies or draws; sediment-laden flows can also transition to debris floods or debris flows on converging slopes.

Over the long-term, increases in the potential for flooding (i.e., more clearwater flow) within a watershed can be expected until the canopy coverage returns to pre-wildfire levels.

The triggering of sediment-laden flows, debris floods and debris flows are related to the meteorological (i.e., rainfall) inputs. Research and experience suggest that these hazards are usually triggered by short-duration/high-intensity rainfall events, although, infrequently, they have also been triggered during longer duration periods of rainfall[10]. Cannon and Gartner (2005) note that the rainfall conditions required to trigger a post-wildfire debris flow can be at least an order of magnitude smaller than those required for debris flow generation in an unburned setting.

On slopes burned to a moderate and/or high severity, there is often substantial ash, sediment and woody debris available to be mobilized by runoff generated from short-duration/high-intensity rainfall. When these are mobilized by runoff, the flow becomes “bulked up” (i.e., more viscous) and erosional scour can occur on the slope surface and/or within gullies/draws.

When this occurs on face unit slopes, the resulting hazard is generally referred to as a sediment-laden flow. When the “bulked up” runoff becomes channelized in gullies and draws, debris flows or debris floods can be triggered. These events can travel farther than sediment-laden flows, extending across fan surfaces at the outlets of watersheds.

Research[11] suggests that once these events have been triggered from slopes burned by a wildfire, the likelihood of them occurring a second time from the same slopes is significantly reduced.

5 Methodology

The methodology adopted for the Analysis included the following:

1. Reviewing the readily available background information, including the geology and geomorphology, biogeoclimatic data and natural disturbance types, aerial photographs

---

[9] Cannon, S.H., and Gartner, J.E. 2005. *Wildfire-related debris flow from a hazards perspective*. In: Debris-flow Hazards and Related Phenomena. https://doi.org/10.1007/3-540-27129-5_15

[10] Beyond reporting debris floods/debris flows during these weather events, little to no research has been to understand the triggers for these hazards during these weather patterns.

[11] Rengers, F.K., McGuire, L.A., Oakley, N.S., Kean, J.W., Staley, D.M. and Tang, H. 2020. *Landslides after wildfire: initiation, magnitude, and mobility*. Landslides, DOI 10.1007/s10346-020-01506-3

and satellite imagery, LiDAR imagery, hydrometric data, local weather patterns, historic wildfire information and burn severity mapping.

2. Assessing the watershed morphometrics to determine the potential hydrogeomorphic hazards[12] that could be triggered within them. An analysis of the longitudinal profile of the mainstem creeks within the watersheds was also completed to identify reaches that may be prone to initiation, transport and deposition.

3. Modelling the slope hazard potential using the Staley et al (2016)[13] methodology (the Staley Model). This estimates the post-wildfire debris flow potential at both the watershed scale and in a spatially distributed manner along the drainage network[14] within each watershed and face unit. While the modelling refers to debris flow potential, we have assumed that it applies to debris floods and sediment-laden flows as well. The output provides a qualitative estimate of the likelihood of these hazards occurring as a result of the conditions created by the Fire.

   A more comprehensive description of the modelling is provided in Appendix C.

4. Fieldwork was then completed to confirm the burn severity, the hazard estimate developed from the modelling, the runout from historic landslides and the elements at risk. This was done to calibrate the modelling results and to identify areas where elements could be at risk should the design storm[15] occur.

   The following were also reviewed:

   - The terrain conditions, including identification of existing landslides, indicators of slope instability (i.e., open slope failures, rockfall and talus cones) and/or channel instability (i.e., evidence of previous debris flows, debris floods or floods).
   - The condition of the mainstem channels and riparian zones, including a review of the channel and floodplain characteristics and the extent of the riparian areas that burned.
   - The presence of roads and fireguards that could increase the potential of post-wildfire slope hazards occurring.

5. The background information review, modelling results and field observations were then compiled and analyzed.

[12] Hydrogeomorphic processes include debris floods and debris flows, which are hydraulically driven landslides on a spectrum regarding the sediment load being transported.
[13] Staley, D.M., Negri, J.A., Kean, J.W., Laber, J.L., Tillery, A.C., Youberg, A.M., 2016. *Updated Logistic Regression Equations for the Calculation of Post-Fire Debris Flow Likelihood in the Western United States*. U. S. Geological Survey Open-File Report 2016-1106, 13p. 10.3133/ofr20161106.
[14] That is geomorphic depressions, swales, draws and gullies.
[15] For the purpose of this Analysis, the design storm is defined as 4 mm of rainfall in 15 minutes, i.e., the equivalent of 16 mm/hour.

6. Based on the results of Item 5, the partial risk (i.e., encounter probability) was estimated for the identified elements at risk. A comprehensive discussion of the risk assessment methodology is provided in Appendix D.
7. The results of this work were then detailed in this report, addressing the scope and providing conceptual recommendations to reduce the post-wildfire natural hazard risk.

6 Background Information and Fieldwork

The following information was used in the Analysis:

- Historical aerial photographs, including:

  1958 – BC2511 #40-46, BC2512 #3-9;

  1973 – BC7505 #157-161, #218-222, BC7512 #47-51, 115-118;

  1987 – BC87027 #11-17, #99-102; and

  1996 – BC96067 #192-195.
- Google Earth Professional™ imagery dated 9/19/2022, 8/8/2022, 7/26/2021, 8/19/2019, 5/5/2014 and 12/31/2005, including relevant applications provided by DataBC Public Web Map Service (i.e., TRIM elevation contours and Freshwater Atlas).
- Campbell, R.B., Mountjoy, E.W., and Young, F.G., 1973. *Geology of the McBride map-area, British Columbia (93 H)*; Geological Survey of Canada, Paper 72-35 with Map 1356A, scale 1:250,000.
- Ferguson, C.A., and Ross, G.M., 2003. *Geology and structure cross-sections, McBride, British Columbia*; Geological Survey of Canada., Map 2004A, scale 1:50,000.
- Bedrock Geology spatial data obtained from the BC Data Catalog. Accessed from: https://catalogue.data.gov.bc.ca/dataset/ef8476ed-b02d-4f5c-b778-0d44c9126144.
- *Teare Creek (G30210) Post-Wildfire Risk Analysis - Preliminary Report* prepared by the Ministry and dated June 14, 2023.
- G30210 Teare Creek Fire burn severity mapping prepared by the Ministry and dated July 28, 2023. Based on imagery from June 26, 2022, and June 26, 2023.
- LiDAR – data was acquired by the Ministry for the lower slopes of the Fire in 2019 and on the upper slopes in 2020.
- Historic climate data obtained from the Pacific Climate Impacts Consortium online data portal. Accessed from: https://pacificclimate.org/data.
- Climate analysis using the 1971-2000 dataset from the ClimateBC website. Accessed from: http://www.climatebc.ca/.
- Land Management Handbook (LMH) 56 – *Landslide Risk Case Studies in Forest Development Planning and Operations,* 2004, BC Ministry of Forests.

Fieldwork for the Analysis was completed on October 11 and 12, 2023 by Tim Giles MSc PGeo, representing Westrek, and Brendan Miller MSc PGeo, representing the Ministry. The weather on both days was sunny and dry and no snow was present on the ground. Additionally, an overview helicopter flight was undertaken on October 11, 2023, to review the general slope conditions within the Fire perimeter and to identify existing landslides.

Information on the surficial sediments, slopes, soil drainage characteristics and geomorphological processes was obtained from site observations; no subsurface investigation (i.e., test pits, trenching or drilling) or laboratory testing was completed. Slope gradients were measured using a handheld clinometer, and relevant observations were recorded as waypoints using an iPad equipped with an in-built GPS, which typically has a horizontal accuracy of ±5 m.

7 Setting

The study area is located on southwest facing slopes in the Robson Valley, which is a wide, flat-floored, steep-walled valley that has been downcut by the Fraser River. The Rocky Mountain Range is located to the north and the Premier Range is located to the south.

The study watersheds drain to the southwest from a ridgeline, which extends from Mount Teare to McBride Peak. Teare, Gort and Hagan Creeks are all small, elongated watersheds, and have not eroded deep valleys. Rainbow Creek is a slightly larger watershed with a more deeply incised valley.

The face unit slopes are gentle to moderately steep, somewhat dissected and dominated by till-mantled bedrock slopes. Beach ridges (i.e., strand lines) which formed when a large glacial lake filled the Robson Valley over 10,000 years ago (Clague et al 2020)[16], form narrow benches across the study area. Broad, mid-slope alluvial fans or fan-deltas are also present; some have been developed into open pits for aggregate mining.

Lower on the slopes, the streams occupy moderate gradient gullies/draws, which lead onto a gently sloped bedrock terrace above the valley bottom; the terrace is most pronounced near Rainbow Creek and narrows towards the southeast. There is a moderately steep escarpment below the terrace.

8 Geology and Geomorphology

The Geological Survey of Canada completed geological mapping of the bedrock within the study area, originally by Campbell et al (1974) and subsequently revised by Ferguson and Ross (2004). The bedrock in the study area is mapped as the Windermere Supergroup, which was formed during the Upper Proterozoic as the western margin of North America craton experienced extensional tectonic activity during which siliciclastic sediments with minor carbonate and mafic volcanic rocks were deposited. Subsequently, thick sequences of

[16] Clague, J.J., Roberts, N.J., Miller, B., Menounos, B. and Goehring, B. 2020. *A huge flood in the Fraser River valley, British Columbia, near the Pleistocene Termination*. Geomorphology, 374. https://doi.org/10.1016/j.geomorph.2020.107473

siliciclastics (turbidites) were deposited during passive-margin sedimentation. The Windermere Supergroup sediments then experienced fold-and-thrust style deformation and greenschist-grade metamorphism.

As a result, the following rock types are mapped within the study area:

- East Twin Formation (Upper Proterozoic) – slate and silty argillite with sandstone and conglomerate. These rocks are moderately resistant to erosion and tend to weather to gravels, sands and silts.
- McNaughton Formation (Cambrian) - quartz arenite and minor quartz pebble conglomerate, with interbeds of mudstones. These rocks are strongly resistant to erosion and tend to weather to gravels, sands and silts with minor clay.

Within the Fire perimeter, the McNaughton Formation is mapped along the lower slopes and due to resistance to erosion, forms the prominent, low gradient terrace along the toe of the slope. The East Twin Formation is mapped higher on the slopes and is generally more steeply sloped.

The Robson Valley is part of the Southern Rocky Mountain Trench (SRMT), a 1,600 km long, 3 to 15 km wide valley stretching from Montana to the Yukon. The SRMT was created mainly by Cenozoic-aged extension with normal faulting and limited strike-slip movement. More recently during the Pleistocene, the SRMT was a conduit for glacial ice flow and has been carved into a U-shaped valley.

Surficial geology mapping is limited to generalized descriptions on the bedrock maps. The floor of the Robson Valley is identified as a combination of alluvial and lacustrine deposits. The alluvial deposits are primarily sands found along the floodplain of the Fraser River. The lacustrine deposits consist of clay-rich sediments which fill the valley base. Glacial Lake Fraser (Miller et al 2021[17]), into which these sediments were deposited, was over 400 m deep above the valley floor, as noted by strand lines high on the slopes to the north of McBride and within the Fire perimeter.

No terrain stability mapping was available for the study area. Review of the slopes indicates that the upper parts of the watersheds are glacially sculpted cirques and arêtes in steep bedrock, with rubbly colluvium. Gullying and rockfall are common, and the slopes are prone to snow avalanches. Rockfall and debris slides on the upper slopes are the dominant types of mass movement.

The mid-valley slopes consist of till veneers to blankets, with well-defined bedrock strata visible in areas of thin surficial cover. The lower slopes comprise till blankets with occasional mid-slope gravelly alluvial fan deposits. Beach ridges are more extensive on the lower slopes.

[17] Miller, B.G.N., Iverson, R.M., Clague J.J., Geertsema, M. and Roberts, N.J. 2021. *Channel-amphitheatre landforms resulting from liquefaction flow slides during rapid drawdown of Glacial Lake Fraser, British Columbia, Canada*. Geomorphology, 392. https://doi.org/10.1016/j.geomorph.2021.107898

9 Biogeoclimatic Zones and Natural Disturbance Types

The watersheds within the Fire perimeter extend to a maximum elevation of 2233 m above sea level (masl) along the ridgeline into the McKale River watershed to the north and the Holmes River watershed to the northeast. The following biogeoclimatic zones are mapped within the watersheds extending down to the floor of the Robson Valley:

- The upper slopes are mapped as the Raush variant of the moist, mild Engelmann Spruce – Subalpine Fir (ESSFmm1), between elevations 1380 and 1840 masl. This zone has higher precipitation and cooler temperatures than the zones downslope (Meidinger and Pojar 1991)[18]. These forest systems were historically even-aged, but extended post-fire regeneration periods have produced stands that are uneven-aged and possess multi-storeyed canopies. The forests of this zone are dominated by subalpine fir and Engelmann spruce. Hemlock, Douglas-fir, cedar and white pine are also common. The upper slopes transition into the alpine with "krummholz trees[19]" being common;
- The mid-slopes are mapped as the moist, mild Interior Cedar-Hemlock (ICHmm), between elevations 800 and 1380 masl. The ICHmm is quite dry, notably due to lower snow accumulation (Meidinger and Pojar 1991). This zone is dominated by cedar and hemlock with white spruce, subalpine fir, Douglas fir, lodgepole pine and aspen being quite common; and
- The lower slopes, in the base of the Robson Valley, are mapped as the McLennan variant of the dry, hot Sub-Boreal Spruce (SBSdh1), between elevations 720 and 800 masl. This zone is in the rainshadow of the Premier Range mountains to the west (Meidinger and Pojar 1991). This zone is dominated by lodgepole pine and Douglas-fir; white spruce and subalpine fir are also present but are rarely the dominant trees. Deciduous trees, including aspen, birch and cottonwood trees are also common.

Ecosystem mapping obtained from iMapBC[20] indicates that the upper and mid-slopes within the Fire perimeter are classified as Natural Disturbance Type (NDT) 2 (Ministry of Forests 1995)[21]. In the past, stand-destroying wildfires were often moderate in size (20 to 1000 ha) with patches of unburned due to higher site moisture and sheltering terrain features. Many larger wildfires occurred after periods of extended drought, but the landscape is dominated by extensive areas of mature forest surrounding patches of younger forest. Stand-initiating events have an approximate 200 year return cycle.

The lower slopes are classified as NDT 3 (Ministry of Forests 1995). Historically, these forest ecosystems experienced frequent stand-initiating wildfires that ranged in size from small spot fires to conflagrations that covered thousands of hectares. Natural burns usually contained

[18] Meidinger, D. and Pojar, J. 1991. *Ecosystems of British Columbia*. BC Ministry of Forests, Victoria, BC. 330pp.
[19] These are stunted or deformed trees encountered along the subalpine tree line, which are shaped by exposure to freezing winds.
[20] iMapBC is a BC Government application that allows users to view and analyze geographic datasets from the BC Geographic Warehouse; https://maps.gov.bc.ca/ess/hm/imap4m/
[21] BC Ministry of Forests. 1995. *Biodiversity Guidebook*. Forest Practices Code of British Columbia, 99 p.

unburned patches of mature forest that were missed by wildfire. Consequently, these forests produced a landscape mosaic of even-aged, regenerating stands ranging in size from hundreds to thousands of hectares with mature forest remnants embedded within. The frequency of stand-initiating disturbances is approximately 125 years.

10 Imagery Review

10.1 Aerial Photographs

Four sets of aerial photographs, i.e., 1958, 1973, 1987 and 1996, were reviewed to develop an understanding of the natural or post-wildfire landslides and wildfire history in the study area.

1. **1958 Images**: the strong imprint of the bedrock geology is visible across the slopes, in these images. Rainbow Road leaves the Robson Valley from the west side of the Rainbow Creek fluvial fan and rises through a series of switchbacks to a forest lookout tower on the peak of Mount McBride. No landslides, associated with the road construction, are visible. A small trail has been developed from the original highway alignment (i.e., present-day Mountain View Road) to the apex of the Rainbow Creek fluvial fan.

Scattered across the slope are numerous small and medium-sized wildfire scars, which appear to be limited by the absence of timber (i.e., fuel) in the upper elevations. Two large landslide scars are visible, one at mid-slope (elevation 1450 masl) southeast of Rainbow Creek and another 1500 m southeast of Teare Creek (outside of the Fire perimeter). The headscarps of the slides are arcuate in shape and both appear to be shallow failures in bedrock. Linear strips of even-aged trees or linear openings in the upper Rainbow Creek watershed indicate that avalanches, debris flows and rockfall are common. No channelized landslides were visible on the lower slopes within the study area.

Most watersheds have patchy vegetation cover due to sparse tree growth and complex wildfire history. There is limited evidence of logging on the northeast side of the Robson Valley; the southwest side of the valley has a much more productive forest. Forestry development is limited to small patch cuts and selective harvesting across the lower and mid -slope elevations. The Rainbow Creek watershed does not appear to have had any harvesting activity.

2. **1973 Images:** the new Highway alignment, which was completed in the late 1960s, is visible in these images. Rainbow Road has been widened. Residential development has commenced on the Rainbow Creek fan on both sides of Mountain View Road. An access road (the HG Road) has been constructed across the lower reaches of the Hagan and Gort Creek watersheds; HG Road leaves the Highway and switches back to the top of the escarpment.

3. **1987 Images:** logging on the terrace at the base of the slopes continues as selective patch cuts between Rainbow and Hagan Creeks and also in the Teare Creek watershed, is visible in this imagery. HG Road has been extended to access timber on the terrace.

4. **1996 Images:** continued forest regeneration, where previously open or sparsely treed slopes, are infilling with denser tree growth. None of the creeks show signs of recent channelized landslides lower in the watersheds, although there is evidence of continued rockfall, avalanche and landslide activity in the upper elevations of Rainbow Creek. HG Road has several new spurs accessing timber resources, but there are no signs of landslides associated with this forestry development.

10.2 Satellite Imagery

1. **2005 Google Earth Imagery:** clearcut logging has occurred on the terrace across all face units and within the Hagan, Gort and Teare Creek watersheds. No landslides were observed on this gently sloping ground. The original alignment of HG Road has been upgraded, i.e., a wider and straighter alignment, from the Highway to the top of the escarpment. More short spurs off HG Road have been developed to access timber.

2. **2014 Google Earth Imagery:** two small gravel pits are visible in the Hagan and Gort Creek watersheds. These pits are developed in the mid-slope alluvial fans or fan-deltas, which were formed into Glacial Lake Fraser. HG Road has been extended upslope to reach these resources; there are no signs of landslide activity associated with the road or gravel pits. The 2019, 2021 and 2022 imagery shows no appreciable change in the study area from a landslide hazard perspective.

10.3 LiDAR

LiDAR bare earth imagery was available for the study area (Figure 3) and was themed with slope gradients (Figure 4) to better understand the topography and likely slope processes to occur within the Fire perimeter. Review of the LiDAR-derived maps highlights the strong bedrock control across the slopes. Incised creek channels have dissected the slopes, but only the four study watersheds appear to have perennial flow. The two shallow bedrock landslides visible on the aerial images are more clearly defined in the LiDAR imagery.

Upper Rainbow Creek appears to have several large coalescent landslides, possibly rubbly earthflows or rock glaciers. The landslides seem to have arrested in the confined valley above 1000 masl elevation, outside of the Fire perimeter. Similar features are also visible in the headwaters of Hagan and Gort Creeks, as well as Sunbeam Creek to the northwest.

11 Weather

Data from the McBride North[22] weather station, located 9 km west of the Fire, was reviewed for this Analysis. This station closed in 2001 but has published climate normals based on historic data. Using the 1971 to 2000 dataset, Environment Canada estimates that the average annual precipitation is 679 mm. The greatest rainfall occurs between June and October; average monthly rainfall ranges from 8.9 mm in February to 73.5 mm in June. Of the total precipitation occurring at the weather station, only an equivalent of 189.3 mm (about 28%) falls as snow (Figure 5).

[22] McBride North, located at 53.37° N, -120.25° W. Environment Canada Station ID 1094955.

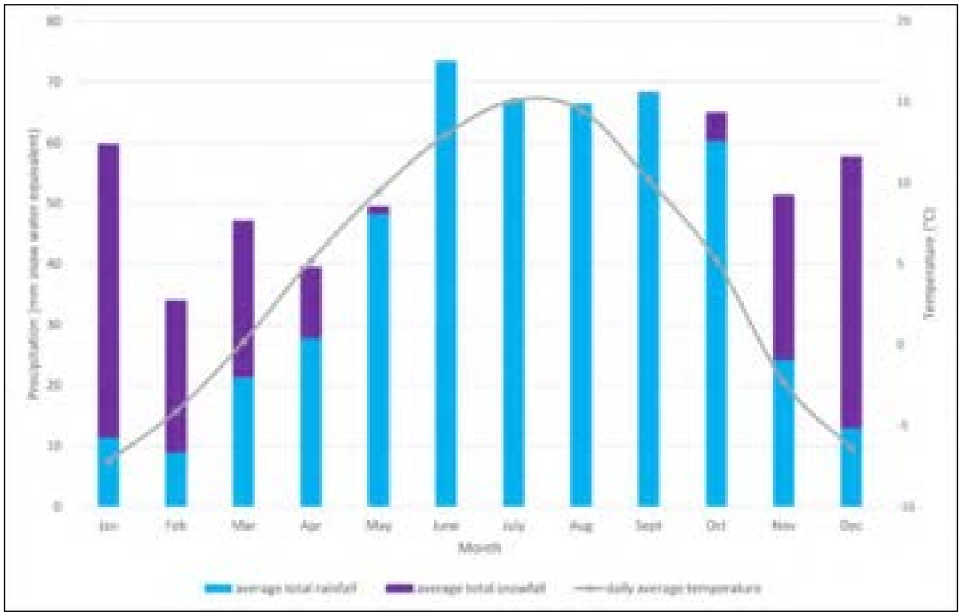


Figure 5: *Precipitation and temperature normals data for the McBride North weather station, from 1971 to 2000.*

Localized short-duration/high-intensity summer convective storms, which are the type of storm that is the most likely to trigger post-wildfire slope hazards, are not captured by the climate normals data; hourly precipitation data is required to gain insight of short-term rainfall intensities.

Analysis of the hourly data from the McBride North weather station shows that the peak 1-hour and 2-hour rainfall intensities generally occur between May and September. This is important, as the analysis from a previous Westrek study in the Lytton area[23], indicates that the time of concentration in small watersheds is on the order of 1 hour, and the highest peak flows generated are during short-duration/high-intensity rainfall events, such as those triggered by summer convective storms.

12 Wildfire History and Post-Wildfire Natural Hazards

Wildfires in the Robson Valley, between Prince George and Valemount, are not uncommon. Clearing of the land for agricultural development and construction of the Canadian National Railway through the valley is likely responsible for many of the older fires between 1915 and 1930.

The wildfires in this area tend to be small, usually under 1,000 ha. Although rare, they can be much larger, such as the Holmes River Fire in 1961, which was 14,780 ha. They typically burn mostly on the lower slopes as higher elevations are dominated by open rock with krummholz trees in alpine heaths and meadows.

[23] *Post-wildfire Natural Hazard Risk Assessment K70580 Nohomin Creek Fire Northwest of Lytton, BC* prepared by Westrek, and dated November 28, 2022.

Other notable wildfires in the Robson Valley include:

- Fire 1920-34 that occurred in 1920, south of Dunster (3,267 ha);
- Fire 1922-144 that occurred in 1922 in the Goat River watershed (2,091 ha); and
- Fire 1935-3A that occurred in 1935 in the Castle Creek watershed (1,642 ha).

No landslides, resulting from these fires, are known of in the Robson Valley.

Post-wildfire landslides are common throughout other parts of the BC southern interior, with notable events occurring after the 2003 Okanagan Mountain Park, Cedar Hills, Kuskonook and Ingersoll Fires; the 2007 Springer Fire; the 2009 Notch Hill, Glenrosa and Seton Portage Fires; the 2015 Cisco Road Fire; the 2017 Elephant Hill Fire; and the 2021 Lytton Creek Fire. All of these landslides were associated with short-duration/high-intensity convective storms and typically resulted in open slope sediment-laden flows, debris floods or debris flows; significant damage from these events occurred to residences, roads and infrastructure.

13 Existing Landslides Identified in the Area

A shallow bedrock landslide is present in the upper reaches of Face Unit 2 (Figure 3). The headscarp is an arcuate feature, approximately 500 m long, with a steep back slope in excess of 50%. The runout of the landslide debris appears to reach approximately 500 m downslope from the headscarp on slopes that range in gradient from 20% to 50%. Based on the available imagery, no landslide deposits are evident further downslope as the well-defined bedrock stratigraphy is unobscured.

Rainbow Creek has a wide headwater area with a large failure scarp that can be seen on the LiDAR bare earth imagery with what appears to be a rubbly earthflow, which may be influenced by periglacial[24] processes. The landslide headscarp extends for over 500 m across the southeast facing slope and the failure appears to be relatively shallow. Indications of flow can be seen in the landslide debris filling the base of the upper creek valley. There are several steeper headwater tributary creeks that experience avalanches, debris flows, debris slides and rockfall; these may introduce large volumes of sediment and woody debris to the mainstem channel. This sediment and woody debris is slowly moved downstream, normally during freshet floods, but also as storm-generated floods, through the mainstem creek.

Hagan and Gort Creek watersheds contain parallel creeks that share the same headwater area. LiDAR imagery shows a rubbly earthflow or rock glacier has initiated from a broad headscarp. The landslide deposits appears to be smaller than the volume expected to have been derived from the headscarp area. This suggests that the original landslide movement pre-dates glaciation and much of the landslide debris was removed by ice. Reactivation of the landslide has occurred since ice retreat.

[24] Periglacial describes a landscape that undergoes seasonal freezing and thawing, typically on the fringes of past and present glaciated regions.

About 2 km northwest of the study area, a debris flow occurred in Willox Creek on July 4, 2020 (Busslinger et al 2021)[25]. A small, shallow landslide initiated in the upper watershed (~1780 masl) and transitioned to a debris flow in the creek channel, which flowed 3.9 km to Mountain View Road. Additional debris flow surges occurred over the following days (i.e., from July 4 to 6, 2020). The average slope of the Willox Creek channel, through which the debris flow moved, was 26%. The cause of the landslide and subsequent debris flows was attributed to a very wet late spring and early summer and a temperature spike, which resulted in an increase in runoff and streamflow.

BGC (2021) modelled the 300 to 1000-year return period debris flow event and identified one residence as having a Very High partial risk. Consequently, a debris detention basin was constructed above Mountain View Road and two other buildings (a residence and a barn/outbuilding) were removed from the site.

Sunbeam Creek watershed, located to the northwest of the study area between Willox and Rainbow Creek, also has a large landslide feature in the upper reaches. Similar to the Rainbow Creek landslide, the headscarp is located on the southeast facing slope and the landslide appears to be shallow with some component of flow.

14 Watershed Analysis

A review of the watershed morphometrics and channel morphology was completed to provide an understanding of the likely hydrogeomorphic processes that could occur within them. Definitions of these processes are provided in Appendix B.

14.1 Morphometrics

Watershed morphometry involves the quantitative measurement and analysis of various parameters (i.e., elevation, slope, shape, topographic relief and watershed or stream length) that define a watershed, which provide insight to the hydrologic and hydrogeomorphic response in a watershed.

The Melton ratio[26] was calculated and used to differentiate flood-prone watersheds from debris flood/debris flow-prone watersheds (Wilford et al 2004)[27]. This ratio was then used in combination with watershed length to delineate watersheds prone to either debris floods or debris flows. The calculated morphometrics for the watersheds within the Fire perimeter are listed in Table 2.

[25] Busslinger, M., Collier-Pandya, B, Holm, K and Jakob, M. 2021. *Willox Creek, BGC slide presentation to the RDFFG Board Committee Meeting*, January 21, 2021.
[26] The Melton ratio is a dimensionless quotient of watershed relief and area that approximates the steepness of a watershed. It is calculated as relief (km) divided by the square root of the watershed area (km^2).
[27] Wilford, D.J., Sakals, M.E., Innes, J.L., Sidle, R.C., and Bergerud, W. 2004. *Recognition of debris flow, debris flood and flood hazard through watershed morphometrics.* Landslides, 1: 61-66.

When the Melton ratio is plotted against the watershed stream length and superimposed on data from Church and Jakob (2020)[28], larger watersheds are prone to floods and debris floods, while the smaller, steeper watersheds are more likely to develop debris flows (Figure 6).

Table 2: *Morphometric data for watersheds within the Fire perimeter.*

Watershed	Area Upstream from Fan Apex (ha)	Relief (m)	Watershed Length (km)	Melton Ratio using Fan Apex as the Point of Reference	Likely Hydrogeomorphic Process
Rainbow	474	1463	3.91	0.67	Debris flow/debris flood
Hagan	138	1388	3.83	1.18	Debris flow
Gort	147	1444	4.29	1.19	Debris flow
Teare	243	1395	4.23	0.90	Debris flow/debris flood

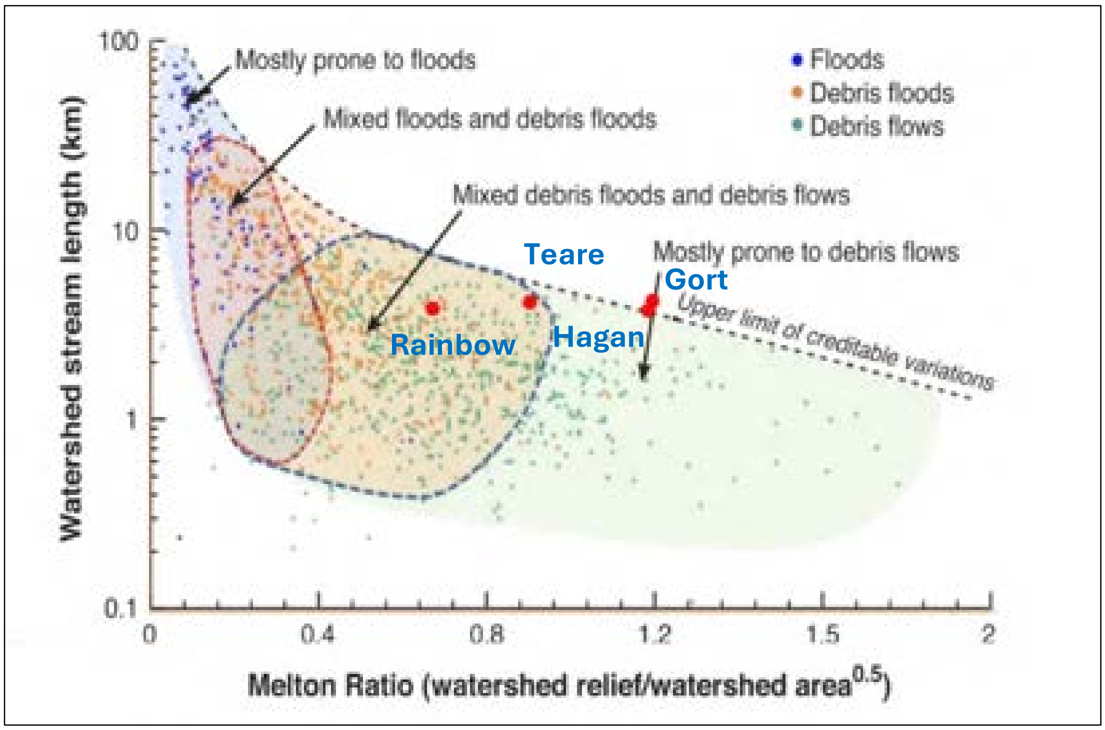


Figure 6: *Melton ratios for the watersheds within the Fire perimeter plotted on a graph developed by Church and Jakob (2020). The hydrogeomorphic process boundaries overlap and reflect the transitional nature of floods, debris floods and debris flows.*

[28] Church, M., and Jakob, M. 2020. *What is a debris flood?* Water Resources Research, 56, e2020WR027144. https://doi.org/10.1029/2020WR027144.

14.2 Longitudinal Profiles

A review of the watershed characteristics, with an understanding of the channel gradients and channel confinement, provides insight on whether the expected hydrogeomorphic processes could reach an element(s) at risk.

Longitudinal profiles were generated from the LiDAR to separate each creek into reaches based on channel gradients, and to understand the results of the watershed morphometrics.

Straight, confined channels that lack floodplain width tend to propagate channelized events and to maintain event momentum (i.e., transport). Channels with a wider floodplain (i.e., a lack of confinement) and a more irregular channel, tend to deposit sediment and debris.

14.3 Summary

Based on the longitudinal profiles, all of the watersheds are relatively small with high relief, and their elongate nature tends to elevate the Melton ratio. As a result, the Melton ratios generally tend to overclassify the expected hydrogeomorphic processes, i.e., debris flood-prone watersheds are classified as debris flow-prone.

Further analysis of the longitudinal profiles indicates that the channel gradients are predominantly moderate (i.e., ranging from 20% to 35%) on the mid to upper slopes and only the headwaters are steep. Confined creek channels with gradients over 25% are considered to be sufficient to maintain debris flow transport. Moving downslope, the creeks pass across a 300 to 1500 m wide, gently sloped terrace (i.e., ranging from 10% to 15%) before a short, steeper (i.e., ranging from 20% to 25%) decline from the escarpment down to the Robson Valley.

A waterfall is present in Rainbow Creek where it flows down the escarpment and descends to the Robson Valley. The creek drops 70 m over a 210 m distance across a series of cascades (i.e., overall gradient of 33%) to reach the apex of a broad fluvial fan. The mainstem channel gradients across the terrace and the fan are too low to maintain the momentum of coarse sediment, thus, the events expected to reach Mountain View Road will have typically transitioned to a flood.

Hagan and Gort Creeks descend the slope at very consistent gradients (i.e., ranging from 25% to 35%) for a channel length ranging from 2 to 3 km. These channels have sufficient confinement and gradient that any debris flows that initiate within them are likely to continue moving until they reach the terrace. The lower channel gradients and presence of roads are likely to cause the debris flows to overflow and disperse across the terrace. For more fluid landslides (i.e., debris floods), larger events are likely to overflow and disperse across the terrace; smaller debris floods or floods are likely to pass through culverts and remain confined within the creek draws.

The upper portion of Teare Creek watershed is located above the steep face slopes and the creek has a gradient of under 20% for over 1 km. It then increases steadily in grade as it drops into the gullied reach at the top of the steep slope; slope gradients are in excess of 50% for over 1 km. The grade of the channel on the lower slopes is consistently between 20% and 30%. The terrace and escarpment feature observed to the north blends into the slope moving to the southeast and the channel terminates on a broad gently sloped fluvial fan.

15 Face Unit Analysis

These slopes are generally located between the identified watersheds and are dissected by numerous small draws or gullies separated by uniform open slopes that are not considered to be of sufficient size to be designated as a watershed. Slope gradient maps generated from the LiDAR imagery were used to define the slope steepness and geometry across each face unit.

The post-wildfire natural hazard expected to occur on these slopes is typically a sediment-laden flow, which is a smaller-scale runoff process that entrains ash, soil and woody debris while it moves downslope; they are generally less damaging than debris floods and often considered to be nuisance events.

While these slopes were modelled using the Staley Model, the results were somewhat misleading. Where a moderate or high debris flow likelihood was identified on these slopes, the results were field checked to determine if this was geomorphically possible. This included a review of the slope morphology, burn severity and slope conditions, including the thickness of surficial materials and the presence of erosion (e.g., rilling).

16 The Staley Model

This modelling was developed and is currently used by the US Burned Area Emergency Response (BAER) program to assist in estimating the qualitative increase in debris flow[29] likelihood in a burned watershed (in the short-term). It describes the increased debris flow potential due to a wildfire and uses watershed characteristics and burn severity to quantify the elevated hazard. The following attributes are incorporated into the model:

- The terrain morphology;
- The vegetation burn severity;
- A soil erodibility factor; and
- A design rainfall event (i.e., the design storm).

At the watershed scale, a weighted-mean value was computed using the length and likelihood of all contained segments of the drainage network. At the drainage network scale, independent variable values were calculated for multiple locations along the network and summarized at the stream segment scale to obtain estimates of hazard likelihood.

[29] The Staley Model results are for debris flows, but equally express the potential for debris floods within channels. Debris floods are typically generated under similar climatic conditions but are more mobile and can travel farther than debris flows. They generally have less severe effects. On open slopes, or slopes where defined draws or gullies are not present, the modelling was used to identify the likelihood of sediment-laden flows.

A detailed description of the modelling methodology and the values used in this Analysis are presented in Appendix C.

Qualitatively, we have defined the hazard ratings from the modelling as follows:

- Low is defined as a less than 40% probability of a debris flow being triggered;
- Moderate is defined as a 40% to 60% probability of a debris flow being triggered; and
- High is defined as a greater than 60% probability of a debris flow being triggered.

The thresholds for our ratings are similar to those used by the USGS; however, we replaced their five (5) rating system with a three (3) rating system by combining their Very Low and Low as our Low and their High and Very High as our High.

LiDAR was used to create a digital elevation model (DEM) for the modelling. LiDAR generally has pixel size of 1 m x 1 m and detects small-scale slope or topographic changes and allows for the development of an accurate DEM.

To analyze the post-wildfire hazard likelihood on face units, LiDAR was used to delineate the locations of all drainage features (i.e., small creeks, gullies, draws and swales) and to provide an understanding of slope steepness and geometry. Using the weighted-mean value, the modelling identified the likelihood for sediment-laden flows within these features across the face units.

16.1 Results

The modelling results are presented in Appendix E; however, the following is a brief summary of the pertinent results.

Watersheds

The modelling results indicate that Rainbow and Teare Creek watersheds have a moderate likelihood for post-wildfire debris flows or debris floods occurring. The mainstem of Rainbow Creek indicates a low likelihood on Figure 2, but there are several short, steep tributary creek segments within the Fire perimeter, not visible on this figure, that elevate the weighted-mean rating to moderate.

Gort and Hagan Creek watersheds were identified as having a low likelihood for post-wildfire debris flow occurrence.

Face Unit Slopes

The modelling results indicate that Face Units 2 and 3 have a high likelihood for the initiation of a post-wildfire sediment-laden flow. Both face units are extensively burned (80.8% and 78.5%, respectively), with large areas of a high burn severity (76.3% and 72.7%, respectively).

Face Unit 4 is rated as a moderate likelihood for the initiation of a post-wildfire sediment-laden flow.

Face Unit 1 is rated as a low likelihood for the initiation of a post-wildfire sediment-laden flow.

16.2 Summary

Tables 3 and 4 summarize the Staley Model results for the watersheds and face units within the study area and the estimated hazard rating.

Table 3: *The watershed hazard rating based on the results of the Staley Model, the likely hydrogeomorphic process and field observations.*

Watershed	Modelling Result	Likely Hydrogeomorphic Process	Field Observations	Watershed Hazard Rating
Rainbow	Moderate	Debris flow / debris flood	Gentle to moderate, 2-3 m wide creek, boulder step pool morphology	Moderate
Hagan	Low	Debris flow	Gentle to moderate, 2 m wide creek, gravel cascade pool morphology	Low
Gort	Low	Debris flow	Gentle to moderate, 2 m wide creek, gravel cascade pool morphology	Low
Teare	Moderate	Debris flow / debris flood	Gentle to moderate	Moderate

Table 4: *The slope hazard rating for the face units within the study area based on the results of the Staley Model, slope gradients and field observations. The likely hydrogeomorphic process for all face units is a sediment-laden flow.*

Face Unit	Modelling Result	Slope Steepness	Field Observations	Slope Hazard Rating
1	Low	Gentle to Moderate	Wide lower terrace, moderate upper slope, two incised draws on upper slope	Low
2	High	Moderate	Wide lower terrace, moderate upper slope, occasional shallow draws, old landslide scar mid-slope	High
3	High	Moderate	Narrow lower terrace, several incised draws across moderate slopes	High
4	Moderate	Moderate	Several shallow incised draws across moderate slopes, large old landslide scar	Moderate

17 Field Observations

Field observations were primarily gathered along the base of the slope with access along Rainbow Road and HG Road.

The following information was collected:

- Select confirmation of the mapped burn severities was compared to the reviewed sites. Overall, the observed soil burn severities were generally classified lower than the satellite-derived vegetation burn severity mapping indicated.
- A review of each creek crossing, including the adjacent floodplain and riparian zone, was completed for each watershed. Basic channel information was gathered, i.e., channel gradient, width, depth, sediment size and condition, and presence of woody debris or logjams.

  Other relevant observations included the presence or absence of debris flow levees and/or lobes, and evidence of historic debris flood or flood deposits.
- On the face units, geomorphic hollows (such as swales and draws) were reviewed for signs of overland flow (i.e., erosional scour); information on the slope gradients and burn severity was also noted.
- Information (e.g., slope gradient, material size, headscarp depth, drainage) on open slope landslides, rockfall and talus cones was collected and recorded, where encountered.
- An aerial reconnaissance (by helicopter) of the burned slopes within the Fire perimeter was completed to assess the upper elevation slopes within the watersheds and on the face units.
- Photographs were collected for post-field review of the burned conditions within the watersheds and on the face unit slopes.

Detailed discussions of our field observations for each watershed and face unit are presented in Appendix E.

17.1 Comparison of Soil Burn Severity with Vegetation Burn Severity

As stated above, the observed soil burn severity within the Fire was generally lower than indicated by the vegetation burn severity mapping. Where the mapping indicated a high burn severity, our field observations indicated the soil burn severity was moderate; similarly, where the vegetation burn severity was indicated as moderate or low, our field observations indicated the soil burn severity was low.

The reasons for these discrepancies are thought to include the following:

- The Fire burned in May during which the ground was still moist from spring snowmelt. Review of Copernicus[30] satellite imagery shows the snowline along the upper margins of the burned ground on May 12, 2023. The Fire was able to burn and consume the tree

[30] Copernicus Data Space Ecosystem is an Earth observation initiative funded by the European Union which provides free imagery from seven dedicated Sentinel satellites at https://dataspace.copernicus.eu/

canopy and the upper leaf litter and shrub layer, but the deeper soil horizons were likely wet and burned poorly.

- The presence of different tree species. The lower and mid-slopes comprise mixed coniferous (e.g., lodgepole pine, Douglas-fir, cedar and hemlock) and deciduous (e.g., aspen, birch and cottonwood) trees, while the upper slopes are more continuous coniferous (e.g., subalpine fir and Engelmann spruce) trees. Coniferous trees have darker canopies that register lower normalized burn ratios than the deciduous trees, which have high contrast between the light green canopy and the burned trees. This makes forests with higher percentages of deciduous trees appear more burned in the satellite imagery used for burn severity mapping. In subsequent Copernicus imagery (i.e., later in 2023), the upper slopes appear much more burned throughout the year, while the lower and mid-slopes have rapid regrowth, which suggests they were less severely burned.

As such, the vegetation burn severity mapping (Figure 2) and the results of the Staley Model are likely conservative, particularly across low and mid-elevation slopes within the Fire perimeter. Due to the public safety risk from post-wildfire hazards, a conservative approach to risk management is considered appropriate.

18 Partial Risk Analysis

Partial risk is defined in LMH 56 as the product of the probability of occurrence of a specific hazardous landslide and the probability of that landslide reaching or otherwise affecting the site occupied by a specific element. That is,

$$P(HA) = P(H) \times P(S{:}H) \times P(T{:}S)$$

Where,

- *P(H)* is the probability (or when qualitative terms are used, the likelihood) of the hazard occurring. For this Analysis, the modelling results (after being calibrated with our fieldwork observations) determined the hazard likelihood.
- *P(S:H)* is the spatial probability, i.e., if the landslide occurs, will it reach the site where the element at risk is located.
- *P(T:S)* is the temporal probability, i.e., if the landslide occurs, will the element at risk occupy the site, if it is movable. For this assessment, the elements at risk are immovable, therefore, the temporal risk is assumed to be 1.

Partial risk analysis does not include an assessment of the vulnerability of the element at risk should the landslide impact it, i.e., it is an assessment of the encounter probability only.

A more detailed discussion on the partial risk is attached in Appendix D. This includes a discussion on what the different qualitative ratings for the hazard and spatial likelihoods mean. A matrix showing how these likelihoods are combined to produce the partial risk is also shown.

19 Elements at Risk

Elements at risk were preliminarily identified during the background imagery review. ESRI ArcMap was utilized as the GIS platform for the Analysis, leveraging its base map feature to identify and locate structures within the study area. This high-resolution imagery (captured on October 6th, 2022) confirmed the presence of the elements at risk. The status/condition of them was confirmed during fieldwork.

Identified elements at risk within and downslope from the Fire perimeter included:

- Occupied residences[31];
- Licenced water intakes; and
- Roads, including;
  - Rainbow Road,
  - HG Road, and
  - the Highway.

20 Post-Wildfire Partial Risk Results

The partial risk analyses results are summarized in Table 5 for the identified elements at risk, either within or adjacent to the individual watersheds and face unit slopes, where the risk is estimated to be moderate, high or very high; the very low and low partial risks are not reported in this table, although they are reported in the summary sheets in Appendix E.

Table 5: *Summary of Moderate, High and Very High Partial Risk for the watersheds and face unit slopes within the study area; the likely potential hazard is also listed.*

Element at Risk	Watershed or Face Unit	Hazard	P(H)	P(S:H)	Partial Risk
Rainbow Road	Face Unit 1	Sediment-laden flow	Low	High	Moderate
470 Mountain View Road	Rainbow Creek	Flood	Moderate	High	High
520 Mountain View Road		Flood	Moderate	High	High
385 Koeneman Road		Flood	Moderate	High	High
Mountain View Road		Flood	Moderate	High	High
Licensed Water Intakes		Flood	Moderate	High	High
HG Road	Face Unit 2	Sediment-laden flow	High	Moderate	High
Highway		Sediment-laden flow	High	Low	Moderate
3100 McBride Highway 16 E	Hagan Creek	Flood	Low	High	Moderate

[31] Structures that appeared abandoned were not assessed.

Element at Risk	Watershed or Face Unit	Hazard	P(H)	P(S:H)	Partial Risk
Licenced Water Intakes	Hagan Creek	Flood	Low	High	Moderate
HG Road		Flood	Low	High	Moderate
Highway		Flood	Low	High	Moderate
3192 McBride Highway 16 E	Gort Creek	Flood	Low	High	Moderate
Licenced Water Intakes		Debris flood	Low	High	Moderate
Licenced Water Intakes		Flood	Low	High	Moderate
HG Road		Flood	Low	High	Moderate
Highway		Flood	Low	High	Moderate
3270 McBride Highway 16 E	Face Unit 3	Sediment-laden flow	High	Low	Moderate
HG Road		Sediment-laden flow	High	Moderate	High
Licensed Water Intakes		Sediment-laden flow	High	Moderate	High
3496 Laing Road	Teare Creek	Flood	Moderate	Moderate	Moderate
Licenced Water Intake		Debris Flood	Moderate	Moderate	Moderate
Licenced Water Intake		Flood	Moderate	High	High

21 Risk Management

Management of landslide risk is generally based on whether the stakeholder finds the risk to be acceptable or unacceptable. Risk reduction (also known as mitigation) can be achieved in various ways, including a better understanding and/or monitoring of the landslide risk or the use of engineered structures.

For this assessment, we have adopted[32] the following risk management strategies:

- For Very Low and Low ratings, the risk is broadly considered acceptable, i.e., the risk is negligible and or adequately understood and controlled.
- A Moderate rating suggests that the risk may be tolerable depending on the risk acceptability/tolerability of the stakeholder, i.e., all avoidable risks shall be avoided, or risks shall be reduced wherever practicable. The risk may be tolerable as is or may require monitoring, treatment, further investigation or engineered solutions.
- A High rating indicates the risk is not acceptable without mitigation to reduce it, which will likely require an engineered solution for permanent structures.

[32] Australian Geomechanics Society, Sub-Committee on Landslide Risk Management, 2000. *Landslide Risk Management Concepts and Guidelines*, 44p.

- A Very High rating indicates that the risk is unacceptable and further investigation and/or engineering is required to reduce the risk.

The development of conceptual measures to mitigate the post-wildfire natural hazard risk within the burned watersheds and from the face units focuses on where the partial risk is moderate or greater. Westrek can provide conceptual risk mitigation measures if the Ministry's and/or the affected stakeholders' level of risk tolerability or acceptance dictates that a low or very low partial risk should also be addressed.

22 Conceptual Recommendations for Risk Mitigation

The recommended measures provide site level guidance for the element at risk, including signage, potential protection, inspection or maintenance, review and/or upgrade of existing infrastructure and hydrologic assessments. Where structures are required, detailed engineering design should be undertaken to size and locate them correctly. Westrek can assist with this, if required.

The following is a summary of the proposed risk mitigation measures for each watershed and face unit, where the partial risk dictates; the approximate locations of the mitigation measures are highlighted on figures included in Appendix E.

22.1 Face Unit 1

"No Stopping Due to Landslide Risk" signs should be posted at the start of Rainbow Road where it leaves Mountain View Road, to alert road users of the potential sediment-laden flow risk, especially during short-duration/high-intensity rainfall events.

All drainage infrastructure (i.e., culverts or ditches) along this road, within the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

22.2 Rainbow Creek Watershed

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

In the short-term, the owners of 470 and 520 Mountain View Road and 385 Koeneman Road should consider installing flood barriers, such as berms, uphill from their residences to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

"No Stopping Due to Flooding Risk" signs should be posted at the start of Mountain View Road, where it leaves the Highway, to alert road users of the potential flood risk.

All drainage structures along Mountain View Road, within the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

22.3 Face Unit 2

"No Stopping due to Landslide and Flooding Risk" signs should be posted:

- On the Highway, at both the east and west ends of the Fire, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

The owner of the outbuilding at 3100 McBride Highway 16 E should consider constructing a deflection berm to protect this structure.

22.4 Hagan Creek Watershed

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" should be posted:

- At both east and west ends of the Fire on the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

In the short-term, the owner of 3100 McBride Highway 16 E should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

22.5 Gort Creek Watershed

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" should be posted:

- At both east and west ends of the Fire on the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

In the short-term, the owner of 3192 McBride Highway 16 E should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

22.6 Face Unit 3

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" signs should be posted at the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along this road, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

In the short-term, the owner of 3270 McBride Highway 16 E should consider installing barriers, such as berms, uphill from their residence to deflect post-wildfire sediment-laden flows.

For the long-term, a landslide hazard assessment should be completed to determine whether protection/stabilization measures across the slope are necessary to mitigate the risk from landslides. If required, they should be installed.

22.7 Teare Creek Watershed

Consideration should be given to either building protective structures around the licensed water intake or developing contingency plans to provide an alternate source of water.

In the short-term, the owner of 3496 Laing Road should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

22.8 Face Unit 4

None required.

23 Increasing Public Awareness of Post-Wildfire Natural Hazards

The following are suggestions for the Ministry and the RDFFG to consider adopting to increase public awareness of post-wildfire natural hazards resulting from the Fire and future wildfires:

- Installation of information signs along the Highway and at the start of the HG and Rainbow Roads, such as the *Landslides and Flooding Risks Due to Wildfires* sign from the BC Government;
- Distribution of the *Landslides and Flooding Risks after Wildfires in British Columbia* brochure from the Ministry[33] to local government and stakeholders;
- Communication of the emergency response contacts and programs, i.e., Emergency Management BC; and
- Widespread distribution of this Post-Wildfire Natural Hazards Risk Analysis report to local government, stakeholders and the public.

24 Recommendations for Risk Mitigation - Existing Landslides

Several existing (i.e., pre-Fire) landslides, mainly rubbly earthflows, were identified within and immediately outside of the Fire perimeter (i.e., within Face Unit 2, Face Unit 4, Rainbow, Hagan and Gort Creek watersheds, as well as Sunbeam and Willox Creek watersheds).

As such, we recommend a detailed geohazard assessment be completed to:

[33] B.C. Ministry of Forests and Range. 2011. *Landslide and flooding risks after wildfires in British Columbia.* Wildfire Management Branch and Forest Science Program, Victoria, B.C.

- Characterize these (and any other) existing landslides,
- Determine the triggering mechanism(s) and the rate of movement of these landslides (if active), and
- Confirm whether risk mitigation measures are necessary to address the risk from these hazards.

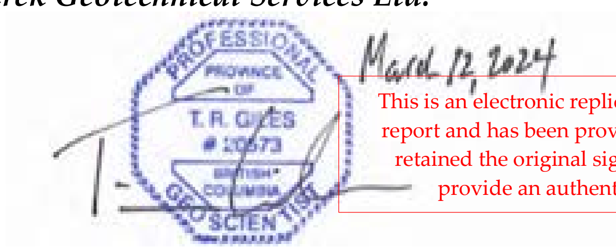
In addition to these points, a geohazard assessment should consider potential impacts from climate change and watershed-scale environmental changes, among other factors.

25 Closure

We trust that this report is complete for your present requirements. Please contact the undersigned if you have any questions.

Yours truly,

Westrek Geotechnical Services Ltd.



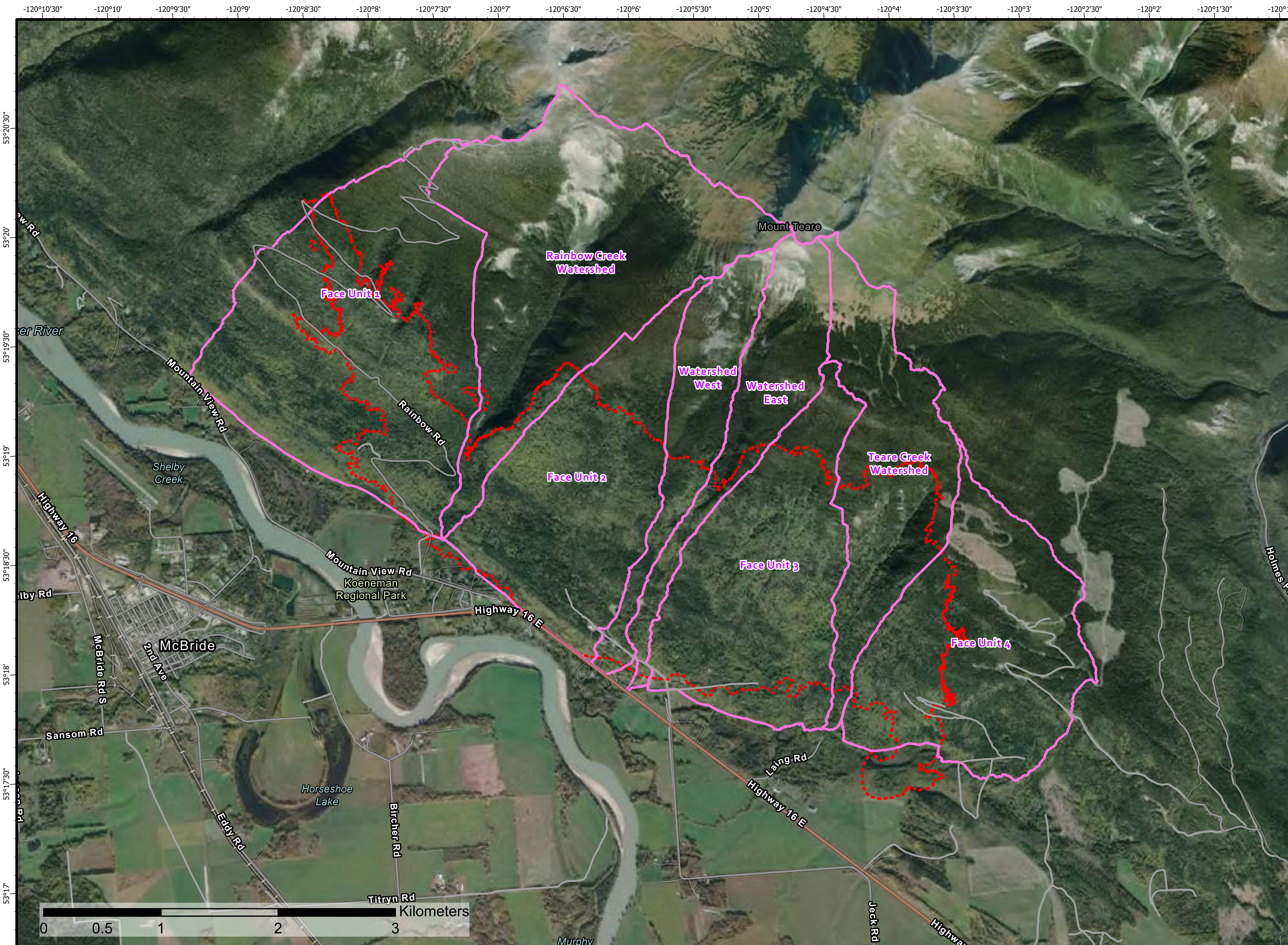
This is an electronic replica of the original signed and sealed report and has been provided for convenience. Westrek has retained the original signed/sealed report on file and can provide an authenticated document if required.

Tim Giles MSc, PGeo
Senior Geoscientist

Rev.: LM, 24-03-07

TS, 24-03-11

Permit #: 1002522



Post-Wildfire Natural Hazard Risk Analysis Overview

N

Fire Number: G30210

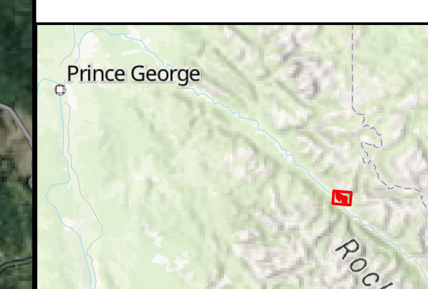
Date:2024-03-12
Projection: NAD83 BC Albers Conic

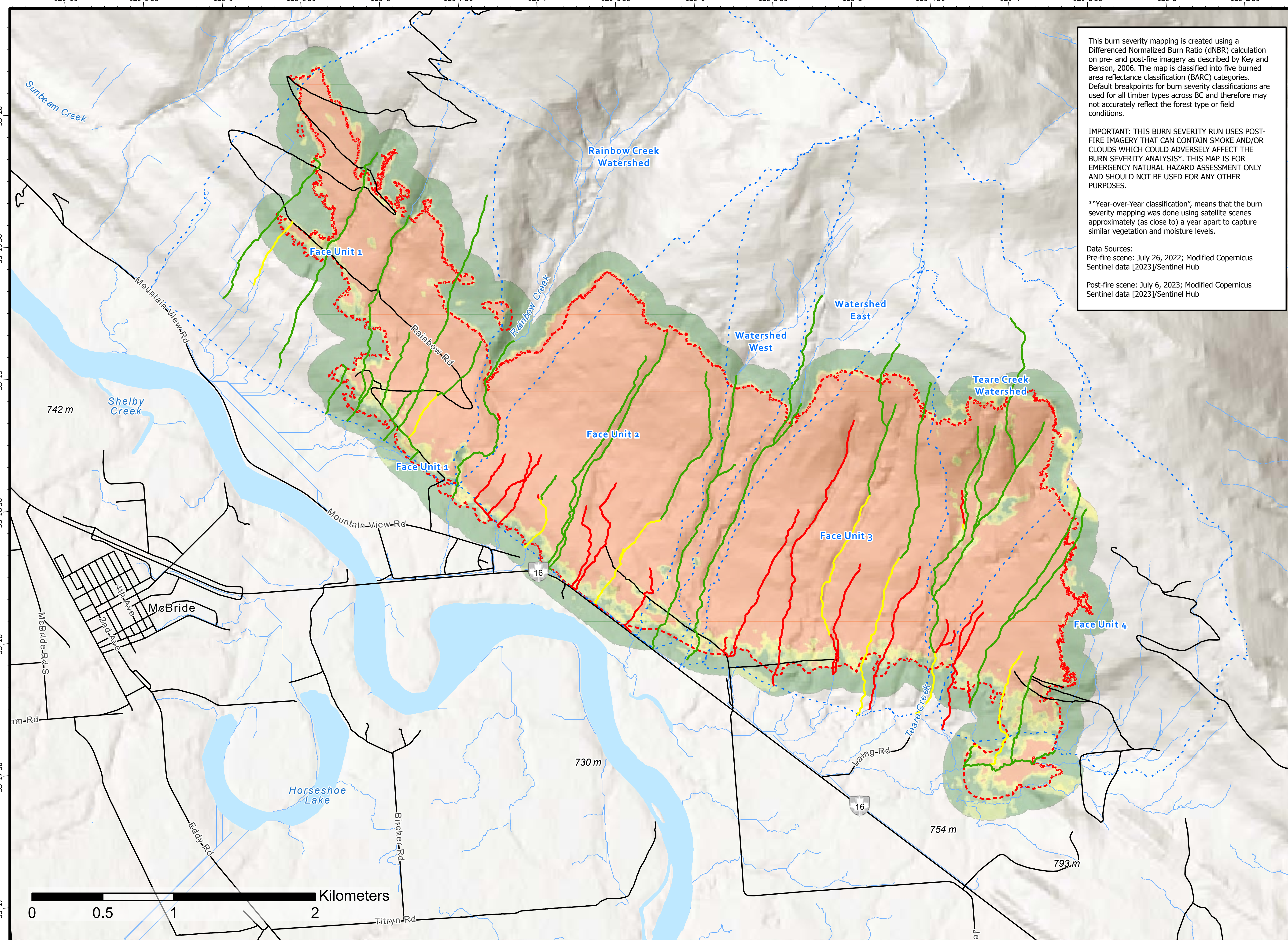
Watershed Boundary
G30210 Fire Perimeter
Roads

Scale: 1:30,000

Figure 1

westrek geotechnical services ltd.





Post-Wildfire Natural Hazard Risk Analysis Burn Severity Overview

Fire Number: G30210

Date:2024-03-12
Projection: NAD83 BC Albers Conic

N

- G30210 Fire Perimeter
- Watershed Boundary
- Stream Paths
- Road

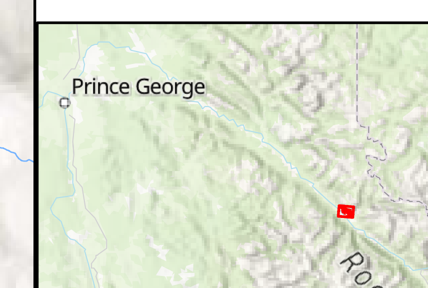
Staley et al. (2016) Model Result
- Low
- Moderate
- High

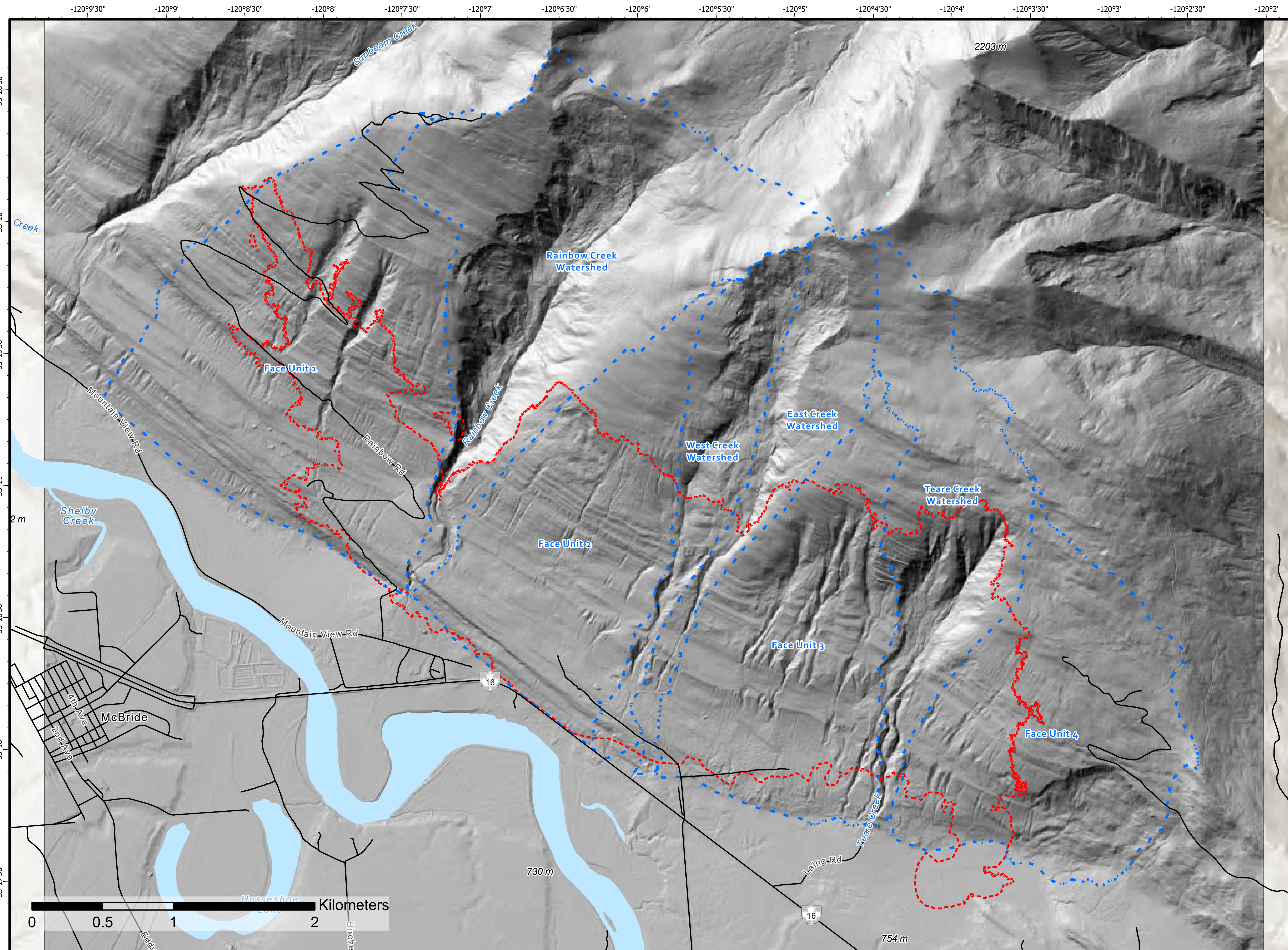
Burn Severity
- Unburned
- Low
- Moderate
- High

Scale: 1:25,000

Figure 2

westrek geotechnical services ltd.





Post-Wildfire Natural Hazard Risk Analysis LiDAR Bare Earth Overview

Fire Number: G30210

N

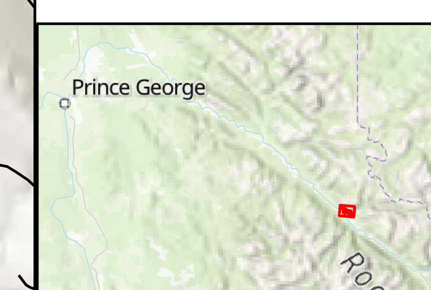
Date:2024-03-12
Projection: NAD83 BC Albers Conic

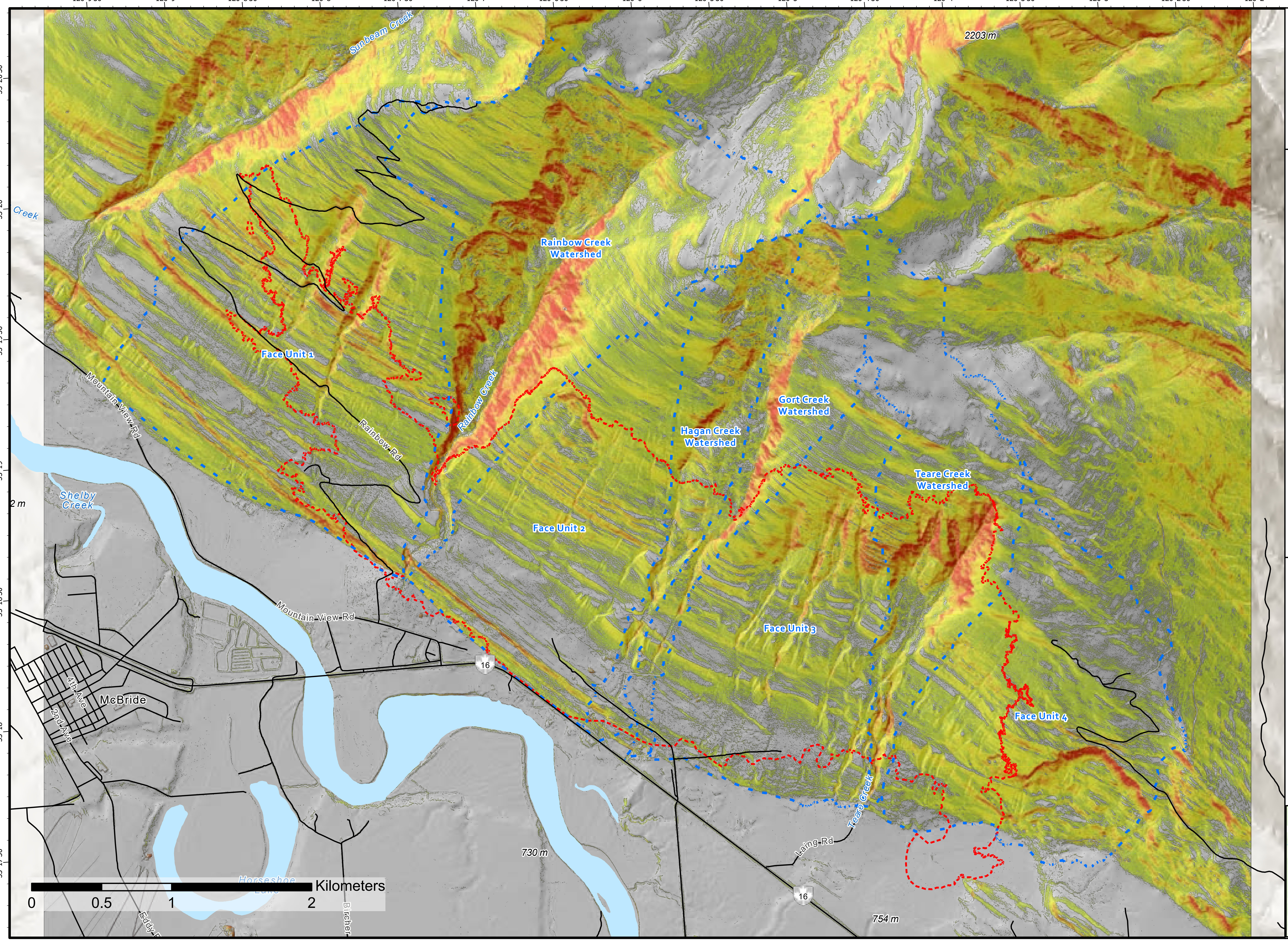
G30210 Fire Perimeter
Watershed Boundary
Road

Scale: 1:25,000

Figure 3

westrek geotechnical services ltd.





Post-Wildfire Natural Hazard Risk Analysis LiDAR Slope Overview

Fire Number: G30210

N

Date:2024-03-12

Projection: NAD83 BC Albers Conic

G30210 Fire Perimeter

Watershed Boundary

Road

Slope %

< 27

27 - 50

50 - 70

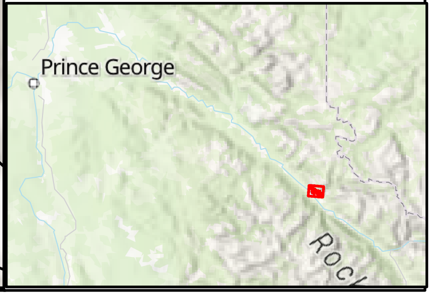
70 - 90

> 90

Scale: 1:25,000

Figure 4

westrek geotechnical services ltd.



APPENDIX A

Interpretation and Use of Study and Report and Limitations

APPENDIX A
INTERPRETATION AND USE OF STUDY AND REPORT AND LIMITATIONS

1. STANDARD OF CARE.

This study and Report have been prepared in accordance with generally accepted engineering and geoscience practices. No other warranty, express or implied, is made. Geological and geotechnical studies and reports do not include environmental consulting unless specifically stated in the report.

2. COMPLETE REPORT.

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF THE REPORT.

The Report has been prepared for the specific site, development, design objectives and purpose that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document are only valid to the extent that there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT.

The information and opinions expressed in the Report, or any document forming the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT. WE WILL CONSENT TO ANY REASONABLE REQUEST BY THE CLIENT TO APPROVE THE USE OF THIS REPORT BY OTHER PARTIES AS "APPROVED USERS". The contents of the Report remain our copyright property and we authorise only the Client and Approved Users to make copies of the Report only in such quantities as are reasonably necessary for the use of the Report by those parties. The Client and Approved Users may not give, lend, sell or otherwise make the Report or any portion thereof, available to any party without our written permission. Any uses, which a third party makes of the Report, or any portion of the Report, are the sole responsibility of such third parties. Westrek accepts no responsibility for damages suffered by any third party resulting from unauthorised use of the Report.

5. INTERPRETATION OF THE REPORT.

(i) Nature and Exactness of Soil and Description: Classification and identification of soils, rocks, geological units, and engineering estimates have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature and even comprehensive sampling and testing programs, implemented with the appropriate equipment by experienced personnel, may fail to locate some conditions. All investigations utilising the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarising such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and all persons making use of such documents or records should be aware of, and accept, this risk. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

(ii) Reliance on Provided information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations or fraudulent acts of any persons providing representations, information and instructions.

(iii) To avoid misunderstandings, Westrek should be retained to work with the other design professionals to explain relevant geotechnical findings and to review the adequacy of their plans and specifications relative to engineering issues. Further, Westrek should be retained to provide field reviews during the construction, consistent with generally accepted practices.

6. LIMITATIONS OF LIABILITY.

Westrek's liability will be limited as follows:

(a) In recognition of the relative risks and benefits of the Services to be provided to the Client by Westrek, the risks have been allocated such that the Client agrees, to the fullest extent permitted by law, to limit the liability of Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals for any and all claims, losses, costs, damages of any nature whatsoever or claims expenses from any cause or causes, whether arising in contract or tort including negligence, including legal fees and costs and disbursements (the "Claim"), so that the total aggregate liability of Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals:

   i. if the Claim is satisfied by the re-performance of the Services proven to be in error, shall not exceed and shall be limited to the cost to Westrek in re-performing such Services; or

   ii. if the Claim cannot be satisfied by the re-performance of the Services and:

      1. if Westrek's professional liability insurance does not apply to the Claim, shall not exceed and shall be limited to Westrek's total fee for services rendered for this matter, whichever is the lesser amount. The Client will indemnify and hold harmless Westrek from third party Claims that exceed such amount; or

      2. if Westrek's professional liability insurance applies to the Claim, shall be limited to the coverage amount available under Westrek's professional liability insurance at the time of the Claim. The Client will indemnify and hold harmless Westrek from third party Claims that exceed such coverage amount. Westrek shall maintain professional liability insurance in the amount of $2,000,000 per occurrence, $2,000,000 in the aggregate, for a period of two (2) years from the date of substantial performance of the Services or earlier termination of this Agreement. If the Client wishes to increase the amount of such insurance coverage or duration of such policy or obtain other special or increased insurance coverage, Westrek will cooperate with the Client to obtain such coverage at the Client's expense.

      It is intended that this limitation will apply to any and all liability or cause of action however alleged or arising, including negligence, unless otherwise prohibited by law. Notwithstanding the foregoing, it is expressly agreed that there shall be no claim whatsoever against Westrek, its officers, directors, partners, employees, shareholders, owners, subconsultants and principals for loss of income, profit or other consequential damages howsoever arising, including negligence, liability being limited to direct damages.

(b) Westrek is not responsible for any errors, omissions, mistakes or inaccuracies contained in information provided by the Client, including but not limited to the location of underground or buried services, and with respect to such information, Westrek may rely on it without having to verify or test that information. Further, Westrek is not responsible for any errors or omissions committed by persons, consultants or specialists retained directly by the Client and with respect to any information, documents or opinions provided by such persons, consultants or specialists, Westrek may rely on such information, documents or opinions without having to verify or test the same.

(c) Notwithstanding the provisions of the Limitation Act, R.S.B.C. 2012 c. 13, amendments thereto, or new legislation enacted in its place, Westrek's liability for any and all claims, including a Claim as defined herein, of the Client or any third party shall absolutely cease to exist after a period of two (2) years following the date of:

   i. Substantial performance of the Services,

   ii. Suspension or abandonment of the Services provided under this agreement, or

   iii. Termination of Westrek's Services under the agreement,

   whichever shall occur first, and following such period, the Client shall have no claim, including a Claim as defined herein, whatsoever against Westrek.

APPENDIX B

Definitions

APPENDIX B
DEFINITIONS

Landslides: Landslides are discrete geologic processes that predominantly occur on steeper terrain and involve rapid downslope movement of soil and/or rock that travels to areas downslope, usually terminating where slopes are less steep.

Risk: a measure of the probability of a specific landslide[1] event occurring and the consequence of that event.

Partial risk: the probability of occurrence of a specific hazardous landslide and the probability of it reaching or otherwise affecting the site occupied by a specific element (also known as an element at risk). Partial risk is also be referred to as the encounter probability.

Watershed length: the planimetric straight line distance from the fan apex to the highest, most distant point on the watershed boundary.

Watershed area: the area contributing to the creek above the fan.

Relief: the elevation difference between the highest and lowest points in a watershed.

Melton ratio: a dimensionless quotient of watershed relief and area that approximates the steepness of a watershed. It is calculated as relief (km) divided by the square root of the watershed area (km^2).

Hydrogeomorphic processes: include floods, debris floods and debris flows, and are hydraulically driven landslides on a spectrum based on the sediment load being transported (Figure 1).

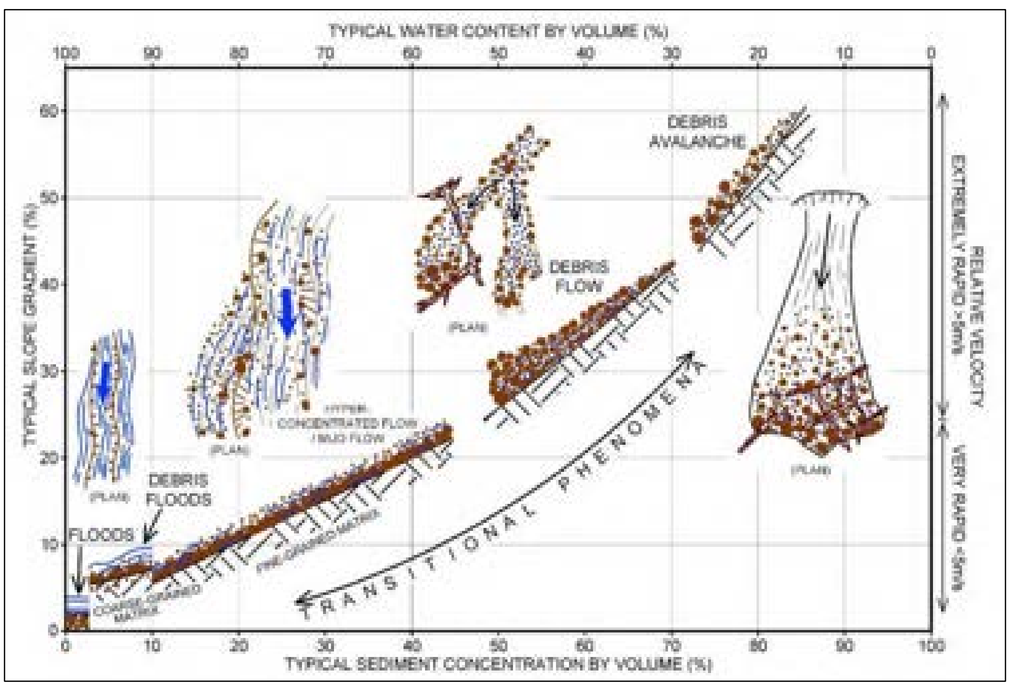


Figure 1: *Illustration of debris-transporting processes with variable slope gradients, water content, sediment concentrations, and flow velocities, copied from Lau 2017*[2].

[1] In the context of this assignment, this refers to a post-wildfire landslide or slope hazard.
[2] Lau, C.A. 2017. *Channel Scour on Temperate Alluvial Fans in British Columbia.* MSc Thesis, Simon Fraser University. Retrieved from http://summit.sfu.ca/files/iritems1/17564/etd10198_CLau.pdf.

The occurrence of these events is typically associated with the average channel gradient (as shown on the Y axis) combined with the typical sediment concentration by volume (as shown on the X axis). Hydrogeomorphic processes often transition seamlessly from one to another and different events may have different processes active, depending on rainfall and sediment inputs. Debris avalanches are primarily driven by water saturating the ground but are not associated with a confined channel.

Floods: river and lake flooding resulting from inundation due to an excess of clearwater discharge in a watercourse or body of water, such that land outside the natural or artificial banks, which is not normally under water, is submerged. While sometimes called "clearwater floods," such floods still transport sediment.

Debris flood: very rapid, sediment-charged flow of water with abundant fines in suspension and gravels, cobbles and boulders transported as bedload. A debris flow in the upper portion of a watershed may transition to a debris flood after saturated coarse debris is deposited and the watery tail continues down the channel. Debris floods may have instantaneous peak discharges up to 5 times that of a clearwater flood (Hungr et al., 2001[3]). Debris floods have increased sediment volumes but continue to be propelled by the tractive forces of water; objects impacted by debris floods are generally buried or surrounded by debris but are often undamaged or only slightly damaged.

Debris flow: very rapid to extremely rapid, surging flow of saturated non-plastic and sometimes organic debris in a steep channel; they commonly have the consistency of wet concrete and are very destructive. Debris flows initiate in the steep headwaters of a drainage and transport material along the channel (Hungr et al., 2014[4]). They can consist of bouldery fronts of up to 70% sediment by volume, followed by lower sediment concentration slurries. Flow velocities of up to 20 m/s can be attained and they may have instantaneous peak discharges up to 50 times greater than floods. Debris flows require a channel gradient in excess of 27% for prolonged transport (Takahashi 1991[5]). Transport continues at lower gradients (under 20%) but tends to lose momentum and begin deposition. In burned watersheds, the runoff process of progressive sediment bulking (Cannon 2001[6]), where overland flow concentrates rapidly into channels, readily eroding the bed, is common.

Sediment-laden flows: these events are hydrologic processes that are common on open slopes (also known as face units) following wildfire. They are a smaller-scale runoff process that transports ash, soil and woody debris downslope, and tend to be smaller, but can transition into debris floods or debris flows in channelized settings.

---

[3] Hungr, O., S.G. Evans, M. Bovis, and J.N. Hutchinson. 2001. *Review of the classification of landslides of the flow type*. Environmental and Engineering Geoscience 7 (3): 221-238.
[4] Hungr, O., Leroueil, S. and Picarelli, L. 2014. *The Varnes classification of landslide types, an update*. Landslides 11: 167-194.
[5] Takahashi, T. 1991. *Debris flow*: Monograph of IAHR, Balkema, Rotterdam: 1–165.
[6] Cannon, S.H. 2001. *Debris-flow generation from recently burned watersheds.* Environmental and Engineering Geoscience 7 (4):321-341.

APPENDIX C

Staley et al (2016) Post-Wildfire Slope Hazard Modelling

APPENDIX C

STALEY ET AL (2016) POST-WILDFIRE SLOPE HAZARD MODELLING

Methodology

This post-wildfire slope hazard modelling was undertaken utilizing the methodology set out by the USGS Landslide Hazards Program[1]. The post-wildfire hazard likelihood is estimated using the Staley et al (2016)[2] model at both the drainage basin (i.e., watershed/sub-basin) scale and in a spatially distributed manner along the drainage network within each basin. These authors state that the output is an estimate for the debris flow potential; however, it models the hazard likelihood within streams and on dissected slopes where the gradient is not sufficient for a debris flow to be triggered. We have, therefore, assumed that the output is an estimate on the debris flood and sediment-laden flow likelihood as well.

The specific characteristics of basins affected by the Fire (required for the model) were calculated using a geographic information system (GIS). The hazard likelihood was estimated for each basin outlet, as well as along the upstream drainage networks (where the contributing area to a specific pixel is greater than or equal to 0.02 km^2). At the basin scale, a weighted-mean value was computed using the length and likelihood of all contained segments of the drainage network. At the drainage network scale, independent variable values were calculated for multiple locations along the network and summarized at the stream segment scale to obtain estimates of hazard likelihood.

For cartographic clarity not all stream segments are displayed on the output maps. The lowest stream order segments are visually excluded, but these data values are included in the analysis.

The required input data includes:

- A difference normalized burned ratio image (dNBR);
- A soil erodibility index value (KF-Factor); and
- A design storm precipitation rate (measured in $mmhr^{-1}$, given a 15-minute duration).

Hazard Likelihood

The likelihood of a post-wildfire hazard occurring in response to a given peak 15-minute rainfall intensity are based upon a logistic regression approach, which combines the following two equations:

Debris Flow Likelihood (L)

$$X = -3.63 + (0.41 * PropHM23 *i15) + (0.67 x (dNBR / 1000) * i15) + (0.7 * KFFACT * i15)$$

and

$$L = exp(X) / (1 + exp(x))$$

[1] USGS Landslide Hazards Program: https://www.usgs.gov/programs/landslide-hazards/science/scientific-background

[2] Staley, D.M., Negri, J.A., Kean, J.W., Laber, J.L., Tillery, A.C., Youberg, A.M., 2016. Updated Logistic Regression Equations for the Calculation of Post-Fire Debris Flow Likelihood in the Western United States. U. S. Geological Survey Open-File Report 2016-1106, 13p. 10.3133/ofr20161106.

Where:

- *PropHM23* is the proportion of slope burned at high or moderate severity with gradient in excess of 23° (i.e., 42.5%);
- *dNBR/1000* is the average differenced normalized burn ratio (dNBR) divided by 1000;
- *KFFACT* is the soil erodibility index of the fine fraction of soils; and
- *i15* is the 15 minute rainfall intensity ($mmhr^{-1}$).

Burn Severity Modelling[3]

The burn severity data was compiled using Near Infrared (NIR) and Shortwave Infrared (SWIR) data from the Sentinel-2 satellite system. The raw data was accessed for NIR (Band 8a) and SWIR (Band 12) to perform a pre-fire versus post-fire classification and produce a difference Normalized Burn Ratio raster surface.

For this study, the pre-fire data was from July 6th, 2022, and post-fire data was taken from July 26th, 2023.

The resulting distribution of the dNBR raster (Figure 1) shows an average value of the High burn severity across the Fire.

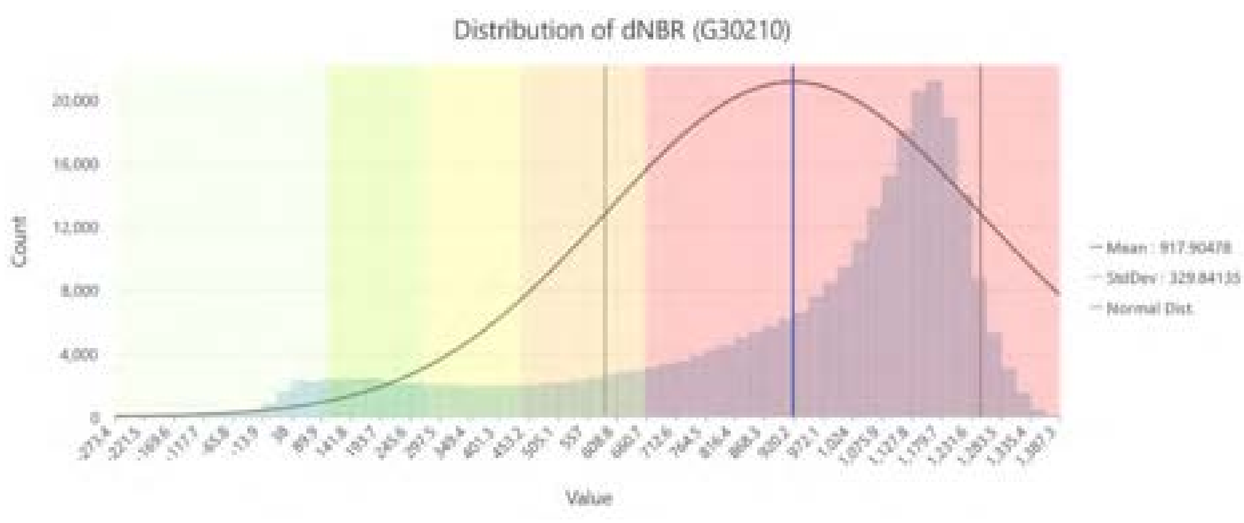


Figure 1: *Distribution of dNBR for the Teare Creek Fire (G30210).*

As advised by the USGS, in order to verify the results, an offset calculation was computed on an unburned area adjacent to the Fire. This indicates the level of change within the unburned areas, giving a confidence measure to the pre- and post-fire satellite data displaying similar

[3] Key, Carl & Benson, Nate. (2006). Landscape Assessment: Ground measure of severity, the Composite Burn Index; and Remote sensing of severity, the Normalized Burn Ratio.

forest conditions. The unburned offset test (Figure 2) produced a mean value well within acceptable variance (+/- 100).

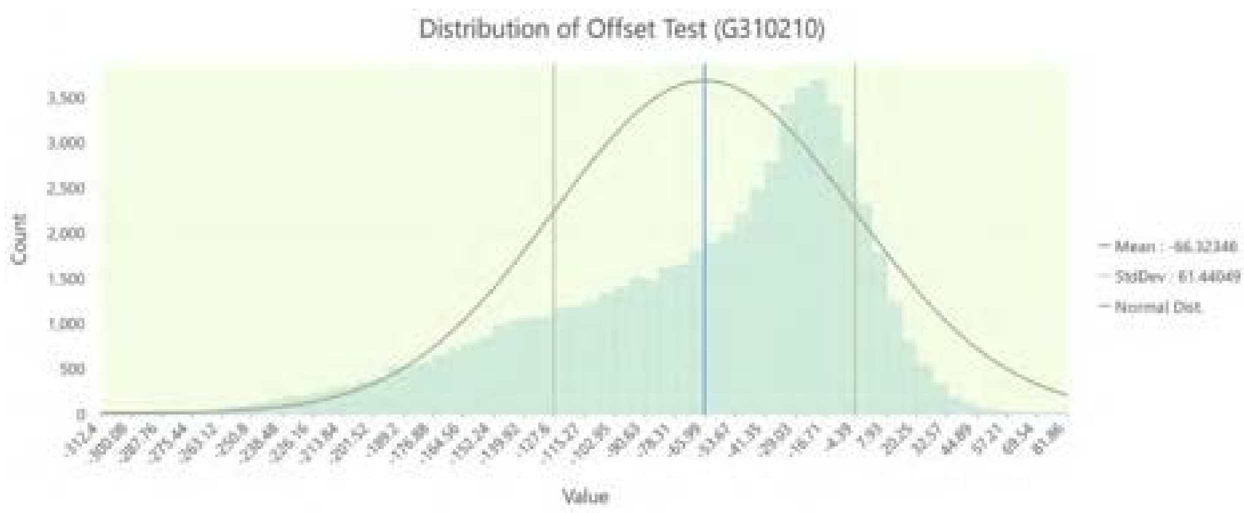


Figure 2: *Distribution of dNBR Offset Test for the Teare Creek Fire (G30210).*

Soil Erodibility Index (KF-Factor[4])

The Soil Erodibility Index was derived from the BC Soil Information Finder Tool – BC Soil Survey Polygons attribute data. Like characteristics, proximity and coverage of burn area were used to determine a representative value according to the textural classification and percentage of organic material. As a result, the dominant textural class was Sandy Loam with an assumed organic material percentage of approximately 2%; the resultant KF Factor was 0.24.

Design Storm Precipitation Rate

The design storm precipitation rate is measured in millimetres per hour ($mmhr^{-1}$) but applied at an interval of 15 minutes. To determine a value for 15-minute precipitation return rates the Intensity Duration Frequency (IDF) curves for a given station near the Fire were used (Figure 3). The station was chosen by proximity, elevation, and characteristics determined to be representative of climate patterns experienced within the Fire perimeter.

In this case, a return rate of approximately 2 years was selected to represent the time frame for increased likelihood of post-wildfire slope hazards.

[4] Stewart, B. A., Woolhiser, D. A., Wischmeier, W. H., Caro, J. H., Frere, M. H. (1975). Control of water pollution from cropland. 16 – 3.3b. USDA, EPA.

APPENDIX C
STALEY ET AL (2016) POST-WILDFIRE SLOPE HAZARD MODELLING

For this geographic region, the IDF data was taken from Environment Canada climate portal for the McBride North ECCC weather station (1094955)[5].

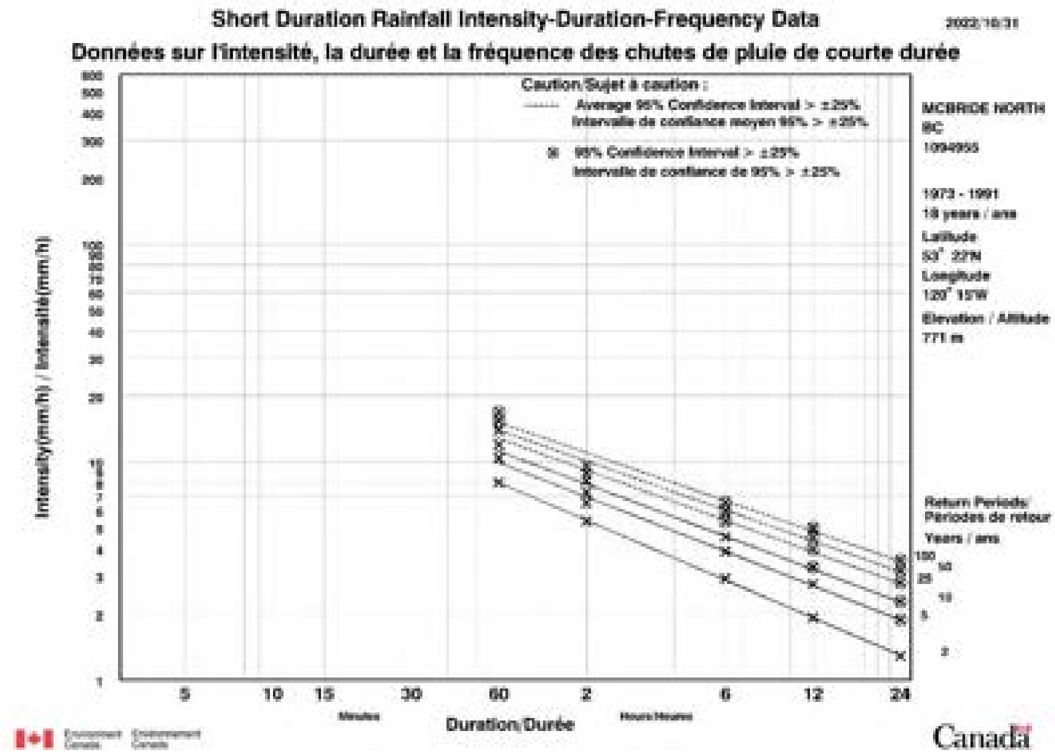


__Figure 3__: IDF data from McBride North (1094955) station near the Teare Creek Fire (G30210).

[5] Shephard, M.W., Mekis, E., Morris, R.J., Feng, Y., Zhang, X., Kilcup, K., and Fleetwood, R. 2014 *Trends in Canadian Short-Duration Extreme Rainfall: Including an Intensity-Duration-Frequency Perspective*, Atmosphere-Ocean, DOI: 10.1080/07055900.2014.969677

APPENDIX D

Partial Risk Assessment Methodology

APPENDIX D
PARTIAL RISK ASSESSMENT METHODOLOGY

Risk Assessment Methodology

Partial risk is defined as the probability (or likelihood) of a specific hazardous event affecting an element at risk and can be expressed as:

$$P(H{:}A) = P(H) \times P(S{:}H) \times P(T{:}S)$$

where:

- *P(H:A)* is the partial risk.
- *P(H)* is the likelihood of a hazardous event occurring.
- *P(S:H)* is the spatial likelihood that the hazardous event will reach the element at risk.
- *P(T:S)* is the temporal likelihood that the element at risk will be at the site if the hazardous event occurs.

For fixed structures, such as buildings and roads, the temporal probability is numerically 1. The partial risk then reduces to:

$$P(H{:}A) = P(H) \times P(S{:}H)$$

Effectively, the partial risk rating is an "encounter probability" and it does not include an assessment of the degree of damage (vulnerability), and assumes an encounter is undesirable.

Qualitative ratings, i.e., low, moderate, and high, are used to describe the hazard levels and spatial likelihood levels in this assessment. These ratings and the criteria used to determine each rating are defined in Tables 1 and 2 below.

The hazard and spatial likelihood ratings are then combined in a matrix (Table 3) to estimate the partial risk.

Likelihood of a Hazard Occurring [P(H)]

A hazardous event is one that has the opportunity to do harm. The type of post-wildfire natural hazards that could affect an element at risk depends on where they are located within a burned watershed; that is:

- Elements at risk adjacent to gullied streams or on fans downstream from the outlet of these streams could be at risk from hazards like floods, debris floods or debris flows.
- Elements at risk below face unit slopes could be at risk from sediment-laden flows.

For our assessment, the post-wildfire hazard level is rated based on the results of the Staley et al (2016) modelling, calibrated with our field observations. Table 1 below presents our hazard ratings and defines the criteria used to support the rating.

APPENDIX D
PARTIAL RISK ASSESSMENT METHODOLOGY

Table 1: *Post-wildfire Slope Hazard Likelihood (i.e., debris flow, debris flood and sediment-laden flow).*

Rating	Criteria
High	• The modelling estimates that the post-wildfire slope hazard is high, i.e., greater than 60% probability of a debris flow being triggered; and/or • There is observable evidence of previous events within the channel and/or fan, or face unit.
Moderate	• The modelling estimates that the post-wildfire slope hazard is moderate, i.e., 40% to 60% probability of a debris flow being triggered; and/or • There is possible evidence of previous events within the channel and/or fan, or face unit.
Low	• The modelling estimates that the post-wildfire slope hazard is low, i.e., less than 40% probability of a debris flow being triggered; and/or • There is no obvious evidence of previous events within the creek channel, or face unit.

Likelihood of a Spatial Interaction [P(S:H)]

To determine whether a post-wildfire slope hazard could interact with an identified element at risk, the following ratings with supporting rationale were used:

Table 2: *Likelihood of a Spatial Interaction should a Post-wildfire Slope Hazard Occur.*

Rating	Criteria
High	• The element at risk is within or immediately adjacent to a channel and/or it is within 50 m downstream of the fan apex; and • There are no natural barriers or risk mitigation measures installed to protect it. • The element at risk is located on a face-unit slope where gradients exceed 50%.
Moderate	• The element at risk is adjacent to a channel and/or is within 50 to 100 m downstream of the fan apex; and • There are no natural barriers or risk mitigation measures installed to protect it. • The element at risk is located on a face-unit slope where the gradients range from 30 to 50%.
Low	• The element at risk is either located away from the channel and/or is beyond 100 m downstream from the fan apex; or • There are sufficient natural barriers or risk mitigation measures installed to protect it. • The element at risk is located on a face-unit slope where the gradients range from 20 to 40%.

APPENDIX D
PARTIAL RISK ASSESSMENT METHODOLOGY

Partial Risk Analysis [P(HA)]

Combining the hazard likelihood with the likelihood of a spatial interaction in the following matrix (Table 3) defines the partial risk to the identified element at risk:

Table 3: *Post-wildfire Partial Risk Rating – P(HA).*

		Spatial Interaction P(S:H)		
		High	**Moderate**	**Low**
Hazard P(H)	**High**	Very High	High	Moderate
	Moderate	High	Moderate	Low
	Low	Moderate	Low	Very Low

The management implications for these partial risk ratings are provided in Table 4. These ratings assume a level of acceptability or risk tolerance, which is dependent upon the stakeholder (including owners, agencies responsible or affected, and government).

The risk ratings can also be used to prioritize management of the relative risks identified.

Table 4: *Risk Management Considerations.*

Risk Rating	Example of Management Implication
Very High	The risk is usually unacceptable and generally requires further investigation, research, planning engineering and implementation of mitigation options essential to reduce risk to acceptable levels; it may be too expensive or impractical to implement.
High	The risk is probably not acceptable, and mitigation options are likely required to reduce risk to acceptable levels. Further investment in engineering and construction required.
Moderate	The risk may or may not be tolerable, depending on the risk acceptability criteria of the stakeholder or decision maker. The risk may be tolerable as is, with or without further consideration, or with the understanding that the results will be monitored. The risk may be tolerable provided a treatment plan is implemented to minimize the influence of certain factors that contribute to the hazard. The risk may also require additional investigation prior to deciding to define the risk and/or assumptions used to define the risk in more certainty. The risk may involve consideration of additional or alternate treatment options, which may require more assessment and engineering.
Low	The risk is usually acceptable. Treatment requirements and responsibility may still be desired to mitigate the risk.
Very Low	The risk is usually acceptable.

APPENDIX E

Watershed and Face Unit Summaries

Face Unit 1

Observations (Figure E-1)

- Face Unit 1 has two well-defined draws on the upper slopes; the absence of any indications of significant flow or erosional scour suggests streamflow within both draws is ephemeral at the Rainbow Road crossings (Figure 3, Photo 1).
- There is a lower terrace which is gently sloped (i.e., ranging from 0% to 20%) and 200 to 400 m wide.
- Rainbow Road switches back as it crosses the slopes; the road appears to be poorly maintained with insufficient drainage management (i.e., culverts and ditches).
- Mountain View Road is constructed on the Fraser River floodplain below this unit and, due to the distance and gentle ground in between, will not be impacted by post-wildfire hazards initiating from this face unit.
- There are no residences at the toe of the face unit slopes that could be impacted by post-wildfire hazards.
- Two licenced water intakes (PD36386 and PD75863) are located at the toe of the slope.
- The Fire burned diagonally across the slope, rising from the south-southeast corner towards the north-northwest. The vegetation burn severity map indicates that about a third of the unit burned and most of that was high burn severity. Ground observations indicate that the soil burn severity across most of the face unit was mixed low to moderate severity (Photos 2 and 3). The leaf litter layer was consumed, but organic layers remained intact over mineral soil. Live roots were also found close to the surface and small and large woody debris was only partially consumed. Water repellency was consistently present, albeit as a thin and weak layer.

Face Unit Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	175	34.5%
High Burn Severity	142	28.0%
Moderate Burn Severity	12	2.4%
Low Burn Severity	21	4.1%
Unburned	332	65.5%
Total Watershed Area	507	

Results

Face Unit Morphometrics and Modelling Results	
Parameter	**Value**
Face Unit Area	507 ha
Elevation Range	1275 m
Likely Hydrogeomorphic Process	Sediment-laden flow
Staley Model Results	**Low**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire sediment-laden flow initiating from the burned slopes within this face unit in the short-term is estimated as low. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this face unit average 23% overall (i.e., 96% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 34.5% of this unit, with 2.4% and 28% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Sediment-laden flows initiating from the burned slopes on this face unit are likely to reach Rainbow Road due to the moderate gradient slopes; i.e., the P(S:H) is estimated as high.

Sediment-laden flows initiating from the burned slopes on this face unit are unlikely to reach the licensed water intakes due to the presence of the low gradient bench at the base of the slope which decouples them from the steeper upper slopes; i.e., the P(S:H) is estimated as low.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
Rainbow Road	Sediment-laden flow	Low	High	Moderate
Licensed Water Intakes	Sediment-laden flow	Low	Low	Very Low

Recommendations

"No Stopping Due to Landslide Risk" signs should be posted at the start of Rainbow Road where it leaves Mountain View Road, to alert road users of the potential sediment-laden flow risk, especially during short-duration/high-intensity rainfall events.

All drainage infrastructure (i.e., culverts or ditches) along this road, within the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

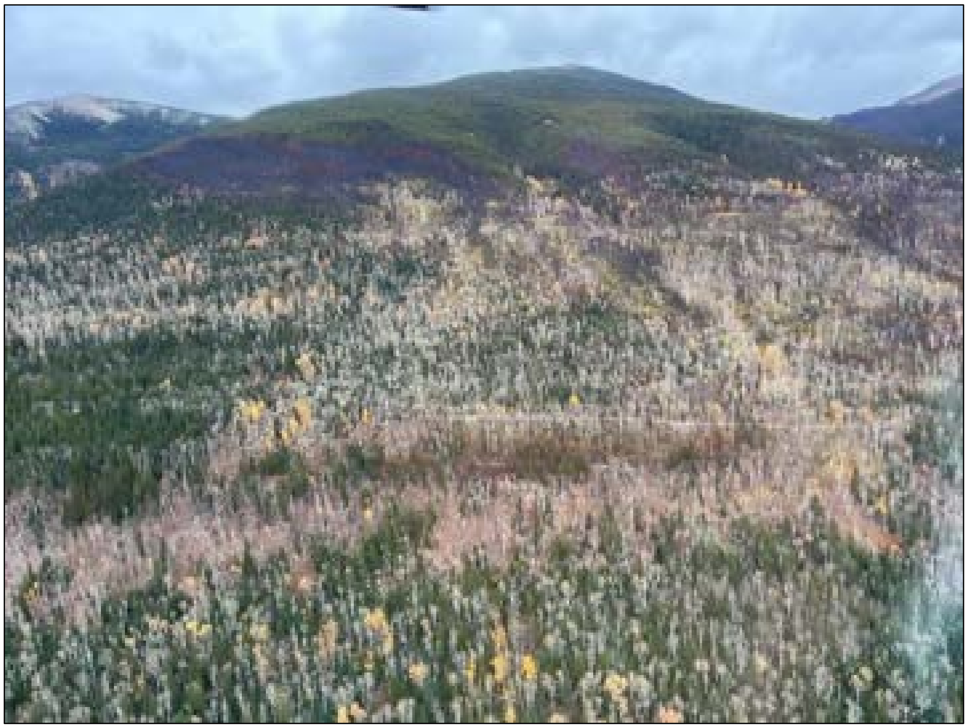
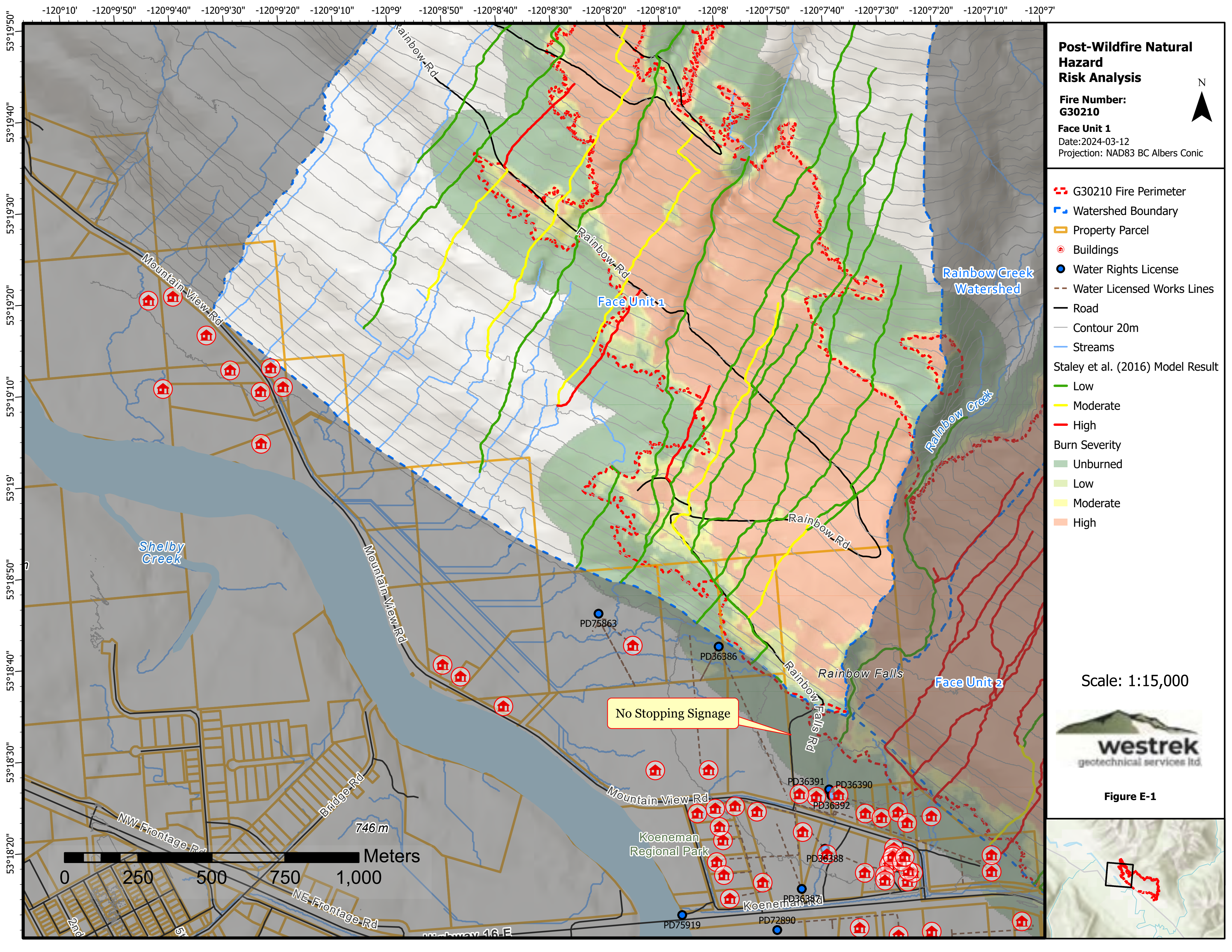


Photo 1: *View of Face Unit 1. The upper slopes appear to have burned more severely; this may reflect the dominance of coniferous trees in the stand, which tend to burn more intensely.*

Photo 2: *View looking northwest across the mid-slopes of Face Unit 1. Mixed deciduous and coniferous trees have lost their canopy, but many are only partially burned, suggesting the burn severity mapping may be conservative.*

Photo 3: *View looking southeast across the mid-slopes of Face Unit 1. Note the presence of organic material on and within the soil and the lack of fine ash on the ground; this site was observed to have low soil burn severity. Significant vegetative (shrub) regrowth has occurred since the Fire burned these slopes.*



Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Face Unit 1
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:15,000
westrek geotechnical services ltd.
Rainbow Creek Watershed
Rainbow Creek
Face Unit 1
Face Unit 2
Rainbow Rd
Rainbow Falls
Rainbow Falls Rd
Mountain View Rd
Shelby Creek
No Stopping Signage
Koeneman Regional Park
Koeneman Rd
NW Frontage Rd
NE Frontage Rd
Bridge Rd
746 m
PD75863
PD36386
PD36391
PD36390
PD36392
PD36388
PD36387
PD75919
PD72890
Meters
0
250
500
750
1,000

Figure E-1

Rainbow Creek Watershed

Observations (Figure E-2)

- Rainbow Creek has one main channel with several steep headwater tributary creeks. The watershed has a broad headwater area with a large, rubbly earthflow (rock glacier), which may be influenced by periglacial processes (Photo 4, Figure 3). Several of the tributary creeks have avalanches and debris flow tracks as well as rockfall (talus cones) and large debris slides.
- The moderate to low gradient section of the watershed that burned has a well-defined step-pool channel. Large bedrock slabs and blocks are embedded in the stream and the creek appears to be stable (Photo 5). The channel banks were only partially burned, with much of the root structure of the bank-stabilizing trees and shrubs likely to survive. The fire burned some of the large woody debris which helps stabilize the channel and moderate sediment movement.
- A waterfall is present where the creek flows over the escarpment and descends to the Robson Valley (Photo 6). The creek drops 70 m over a distance of 210 m across a series of cascades to reach the apex of a broad fluvial fan. The fan is large and gently graded between 5% and 10% and remains well treed despite being partially burned near the base of the escarpment. The channel is moderately incised into the gravelly fan surface (Photo 7)
- The vegetation burn severity map indicates that only a small portion of the watershed burned, but most of what burned was high burn severity. Ground observations indicate that the soil burn severity across most of the watershed was moderate. The leaf litter layer was consumed but organic layers remained over mineral soil, live roots were found close to the surface and small and large woody debris was only partially consumed. Water repellency was consistently present, albeit as a thin and weak layer.
- Three residences are located adjacent to the creek on the fluvial fan: 470 and 520 Mountain View Road (Photo 8)and 385 Koeneman Road (Photo 9). Anecdotal information provided by the resident at 520 Mountain View Road reported flooding had occurred during spring freshets in the recent past.
- Three licensed water intakes are located on the fan about 100 m upstream from Mountain View Road: PD36391, PD36390 and PD36392 (Photo 10).
- The creek passes through a 1000 mm diameter corrugated steel pipe culvert under Mountain View Road (Photo 11).

Watershed Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	40	8.4%

High Burn Severity	35	7.4%
Moderate Burn Severity	2	0.4%
Low Burn Severity	3	0.6%
Unburned	434	91.6%
Total Watershed Area	474	

Results

Watershed Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	474 ha
Channel Length	4402 m
Elevation Range	1463 m
Melton Ratio	0.672
Likely Hydrogeomorphic Process	Debris flow / debris flood
Staley Model Results	**Moderate**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire debris flow, debris flood or flood initiating from the burned slopes within this watershed in the short-term is estimated as moderate. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this face unit average 27% overall (i.e., 88% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 8.4% of this unit, with 0.4% and 7.4% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Debris flows or debris floods initiating from the burned slopes within this watershed are very unlikely to reach the residences, Mountain View Road, or licensed water intakes on the Rainbow Creek fan due to the low gradient channel; i.e., the P(S:H) is estimated as low.

Floods, however, are likely to reach the residences, Mountain View Road, and licensed water intakes on the fan; i.e., the P(S:H) is estimated as high.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire, natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
470 Mountain View Road	Debris flow/debris flood	Moderate	Low	Low
	Flood	Moderate	High	High
520 Mountain View Road	Debris flow/debris flood	Moderate	Low	Low
	Flood	Moderate	High	High
385 Koeneman Road	Debris flow/debris flood	Moderate	Low	Low
	Flood	Moderate	High	High
Mountain View Road	Debris flow/debris flood	Moderate	Low	Low
	Flood	Moderate	High	High
Licensed water intakes	Debris flow/debris flood	Moderate	Low	Low
	Flood	Moderate	High	High

Recommendations

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

In the short-term, the owners of 470 and 520 Mountain View Road and 385 Koeneman Road should consider installing flood barriers, such as berms, uphill from their residences to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

"No Stopping Due to Flooding Risk" signs should be posted at the start of Mountain View Road, where it leaves the Highway, to alert road users of the potential flood risk.

All drainage structures along Mountain View Road, within the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

Photo 4: *View of the upper reaches of Rainbow Creek watershed. A rubbly earthflow at right-centre of image is likely influenced by periglacial processes. Numerous other slump landslides in bedrock are visible in the headwaters.*

Photo 5: *View of Rainbow Creek on the lower bench above the falls. Note the presence of large boulders embedded in the base of the channel. This reach was identified as high burn severity, but ground observations indicate burn severity was moderate. The channel gradient was 10% to 15%.*

Photo 6: *View of Rainbow Creek including the fluvial fan at bottom right, the moderately steep escarpment with waterfall at centre, the low gradient bench above the escarpment, and the unburned and confined steep upper valley.*

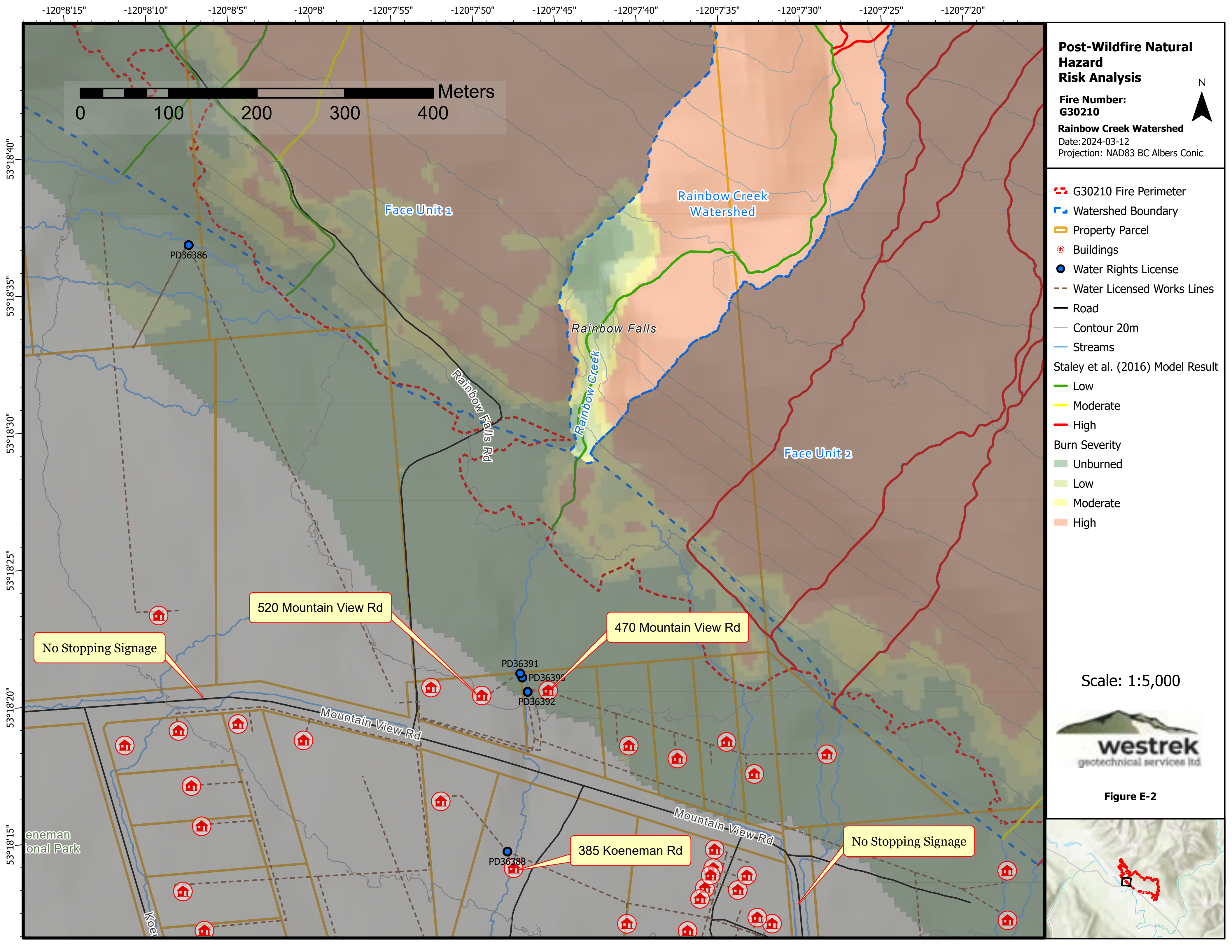
Photo 7: *View of Rainbow Creek on the fluvial fan surface. Bed grain size has diminished from the reach above the falls and the channel is less deeply incised; the channel gradient is between 6% and 10%.*

Photo 8: *View of the residential area on the Rainbow Creek fluvial fan. The larger, blue-roofed structure (circled at left) is the residence at 520 Mountain View Road. The grey-roofed structure in the trees at centre is a garage (circled) for the residence at 470 Mountain View Road, which is visible immediately to the right (circled).*

Photo 9: *View of Rainbow Creek fluvial fan. A barn (circled, left) and the residence (circled, right) at 385 Koeneman Road are located close to the creek channel. The blue line is the trace of Rainbow Creek.*

Photo 10: *View west of the licenced water pond and intake structure on Rainbow Creek. Structure is located on the property line between the properties at 520 and 470 Mountain View Road.*

Photo 11: *View of Rainbow Creek as it reaches Mountain View Road and passes under the road through a 1000 mm corrugated steel pipe culvert. Boulders are placed to armour the inlet.*



Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Rainbow Creek Watershed
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:5,000
westrek geotechnical services ltd.
Figure E-2
0 100 200 300 400 Meters
Face Unit 1
Face Unit 2
Rainbow Creek Watershed
Rainbow Falls
Rainbow Creek
Rainbow Falls Rd
Mountain View Rd
520 Mountain View Rd
470 Mountain View Rd
385 Koeneman Rd
No Stopping Signage
No Stopping Signage
PD36386
PD36391
PD36392
PD36388
-120°8'15" -120°8'10" -120°8'5" -120°8' -120°7'55" -120°7'50" -120°7'45" -120°7'40" -120°7'35" -120°7'30" -120°7'25" -120°7'20"
53°18'40" 53°18'35" 53°18'30" 53°18'25" 53°18'20" 53°18'15"

Face Unit 2

Observations (Figure E-3)

- Face Unit 2 is very uniformly graded, gradually steepening upslope (Photo 12, Figures 3 and 4). There are numerous narrow, shallow draws which have incised into the upper and mid-slopes, but these become less incised towards the base of the slope, indicating flow dispersion is occurring on the gentler slopes.
- Towards the base of the slope there is a gently sloped terrace (i.e., ranging from 5% to 15%) below which is a moderately sloped escarpment.
- There are several small creek draws within this unit, but none appear to have perennial flow.
- A large, scallop-shaped landslide feature is located within this unit. A steep headscarp in bedrock is clearly visible amongst the trees (Photo 13). This feature is also visible in the LiDAR bare earth imagery (Figure 3).
- Burn severity across this unit is rated as high, but ground observations suggest the soil burn severity is moderate.
- An outbuilding on the 3100 McBride Highway 16 E property is located in the southeast corner of this unit (Photo 14). The HG Road provides access to this building.
- The Highway crosses immediately downslope of this unit.
- Residences below the unit are located on the floor of the Robson Valley some distance from the slope toe and are not considered to be at risk from natural hazards occurring as a result of the Fire.

Face Unit Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	252	80.8%
High Burn Severity	238	76.3%
Moderate Burn Severity	6	1.9%
Low Burn Severity	8	2.6%
Unburned	60	19.2%
Total Watershed Area	312	

Results

Face Unit Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	312 ha

Elevation Range	1238 m
Likely Hydrogeomorphic Process	Sediment-laden flow
Staley Model Results	**High**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire sediment-laden flow initiating from the burned slopes within this face unit in the short-term is estimated as high. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which average 21% overall for this face unit (i.e., 98% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 80.8% of this unit, with 76.3% and 1.9% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Sediment-laden flows initiating from the burned slopes in this face unit might reach HG Road due to the moderate gradient slopes; i.e., the P(S:H) is estimated as moderate.

Sediment-laden flows initiating from the burned slopes in this face unit are unlikely to reach the Highway due to the low to moderate gradient slopes; i.e., the P(S:H) is estimated as low.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire, natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
HG Road	Sediment-laden flow	High	Moderate	High
Highway	Sediment-laden flow	High	Low	Moderate

Recommendations

"No Stopping due to Landslide and Flooding Risk" signs should be posted:

- On the Highway, at both the east and west ends of the Fire, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

The owner of the outbuilding at 3100 McBride Highway 16 E should consider constructing a deflection berm to protect this structure.

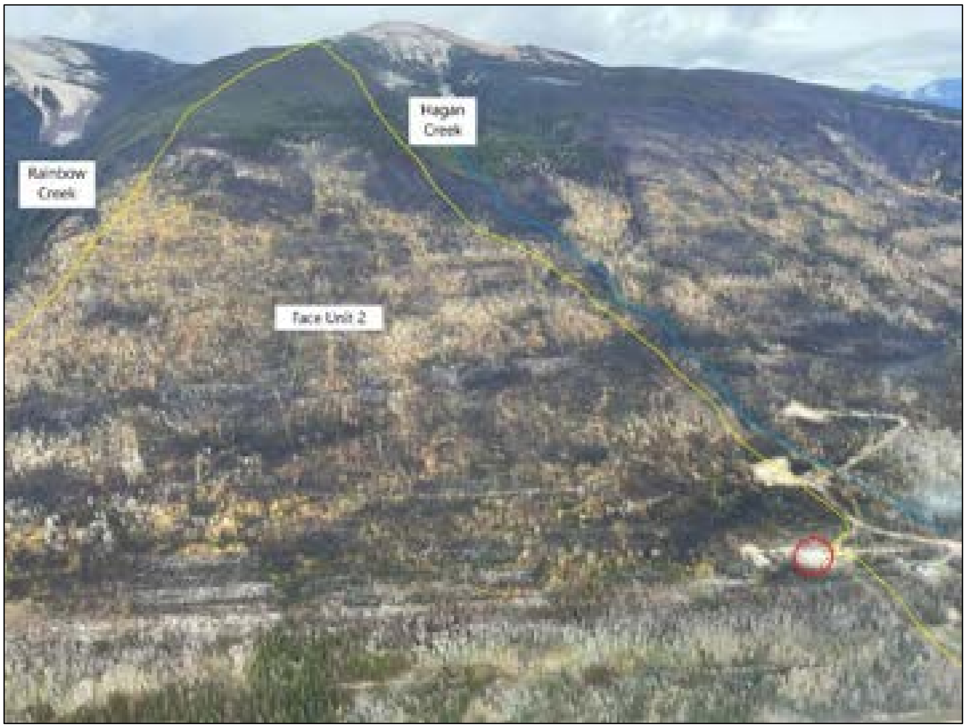


Photo 12: *Wide view of Face Unit 2, outlined in yellow. Upper Rainbow Creek watershed is at left of image; Hagan Creek is marked with a blue line at right centre. The shallow draws within Face Unit 2 are difficult to discern in the image due to color variation of the vegetation. The residence at bottom right of image is located within the Hagan Creek watershed. The large outbuilding (circled) is within Face Unit 2.*

Photo 13: *View of the upper end of Face Unit 2 with the large, shallow landslide outlined with exposed light brown bedrock in the headscarp at right centre on the open slope. Rainbow Creek, in the foreground, has several pre-existing, side-slope landslides leading into the main valley.*

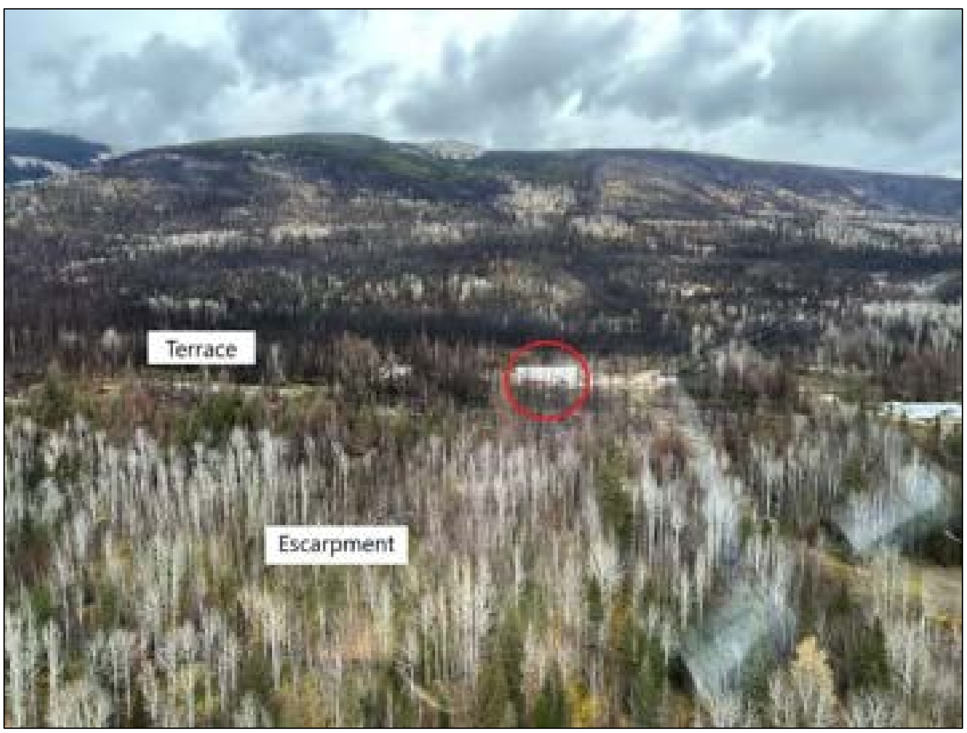


Photo 14: *View of the lower slope in Face Unit 2. The residence at bottom right is located in the Hagan Creek watershed. The large outbuilding at centre is accessed by HG Road from the right side of image. The building is on a wide, gently sloped bench immediately above the moderately steep escarpment face.*

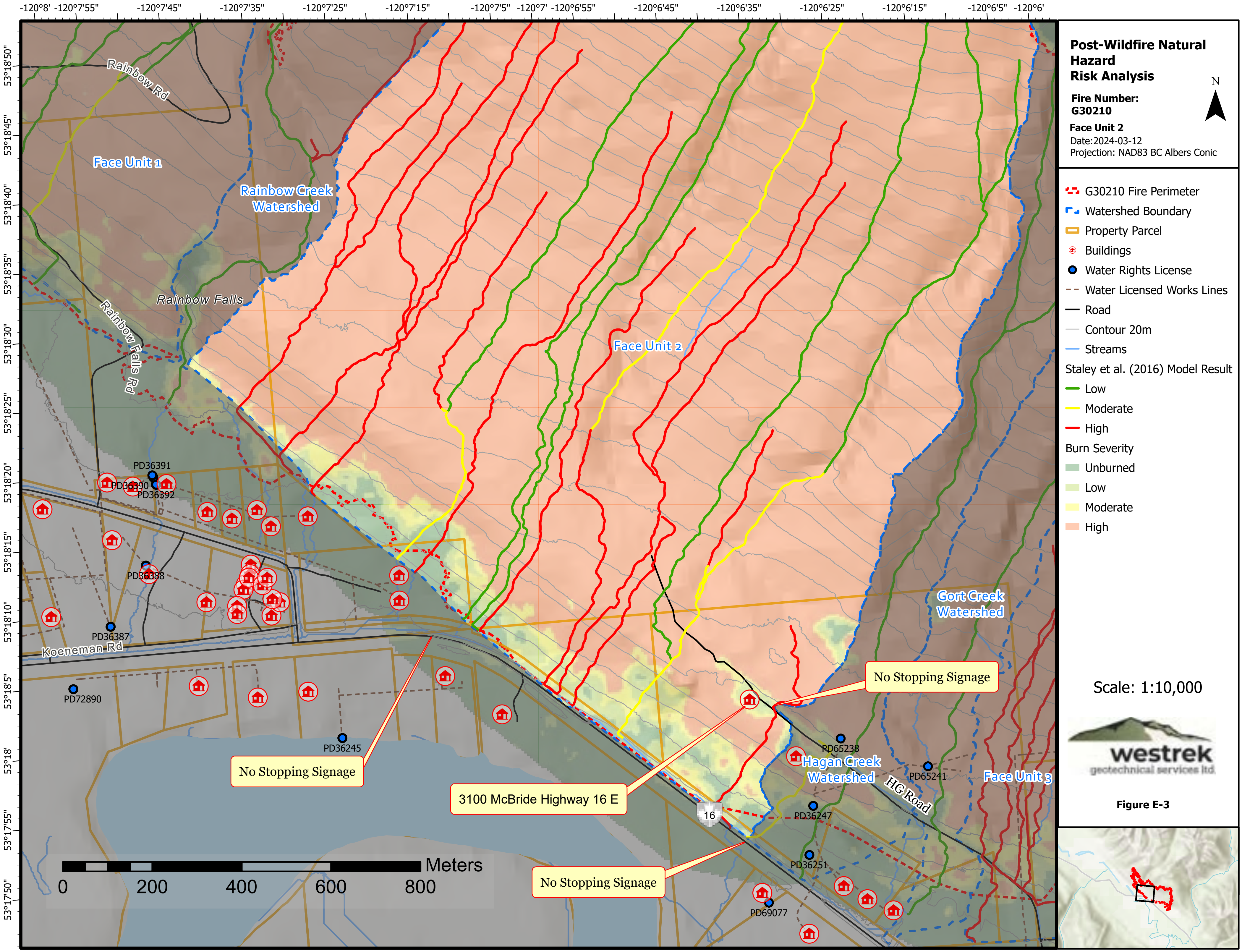

Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Face Unit 2
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:10,000
westrek
geotechnical services ltd.
Face Unit 1
Face Unit 2
Face Unit 3
Rainbow Creek Watershed
Gort Creek Watershed
Hagan Creek Watershed
Rainbow Rd
Rainbow Falls
Rainbow Falls Rd
Koeneman Rd
HG Road
16
No Stopping Signage
No Stopping Signage
No Stopping Signage
3100 McBride Highway 16 E
PD36391
PD36390
PD36392
PD36388
PD36387
PD72890
PD36245
PD65238
PD65241
PD36247
PD36251
PD69077
Meters
0
200
400
600
800

Figure E-3

Hagan Creek Watershed

Observations (Figure E-4)

- The Hagan Creek watershed is long and narrow; the creek channel rises at a steady grade between 25% and 35% for 3.5 km, with the exception of a 500 m long reach on the lower terrace that ranges from 5% to 15% (Figure 4).
- The upper watershed encompasses the southern flank of Mount Teare and there appears to be a landslide, possibly a rubbly earthflow (or rock glacier) with periglacial influence off the southern face of Mount Teare (Photo 15). Extensive tension cracks in the bedrock on Mount Teare indicate that there is potential for ongoing landslides (Figure 3). These areas were not burned by the Fire and, as such, existing landslides will not be affected by it.
- Lower on the slope, the creek crosses distinct bedrock benches capped with thicker deposits of till and glaciofluvial sediments into which it has incised a moderately deep channel (Photo 16). Mid-slope alluvial fans have been developed into aggregate quarries.
- On the lower terrace the channel is shallow and moderately confined as it flows across an alluvial fan surface. At least two channels can be seen on the LiDAR imagery (Figure 3).
- The residence at 3100 McBride Highway 16 E is located on the north side of the creek at the top of the lower escarpment (Photo 17). A second residence, at 3140 McBride Highway 16 E, is elevated 5 m above the creek immediately above the Highway.
- The HG Road comes off the Highway to the east and rises across the slope to provide access to the residence at 3100 McBride Highway 16 E. The road continues upslope and has been used for access for forest harvesting and gravel extraction. Hagan Creek passes through 5 culverts:
    - an 800 mm diameter culvert on the upper road;
    - a 1000 mm diameter culvert on HG Road;
    - an 800 mm diameter culvert on an older lower road;
    - an 800 mm diameter culvert on a second older lower road; and
    - a 600 mm diameter culvert underneath the Highway.
- Three licensed water intakes (PD66238, PD36247 and PD36251) are located within the Hagan Creek watershed above the Highway.

Watershed Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	40	29.0%
High Burn Severity	36	26.0%

Moderate Burn Severity	2	1.5%
Low Burn Severity	2	1.5%
Unburned	98	71.0%
Total Watershed Area	138	

Results

Watershed Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	138 ha
Channel Length	4104 m
Elevation Range	1388 m
Melton Ratio	1.182
Likely Hydrogeomorphic Process	Debris flow
Staley Model Results	**Low**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire debris flow, debris flood or flood initiating from the burned slopes within this watershed in the short-term is estimated as low. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this watershed average 24% overall (i.e., 95% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 29% of this unit, with 1.5% and 26% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Debris flows initiating from the burned slopes within this watershed are unlikely to reach the residences, HG Road, or the licensed water intakes due to the moderate gradient channel; i.e., the P(S:H) is estimated as low.

Debris floods initiating from the burned slopes within this watershed might reach the residence at 3100 McBride Highway 16 E, HG Road, or the licensed water intakes; i.e., the P(S:H) is estimated as moderate.

Debris floods initiating from the burned slopes within this watershed are unlikely to reach the residence at 3140 McBride Highway 16 E; i.e., the P(S:H) is estimated as low.

Floods initiating from the burned slopes within this watershed are likely to reach the residence at 3100 McBride Highway 16 E, HG Road, or the licensed water intakes; i.e., the P(S:H) is estimated as high.

Floods initiating from the burned slopes within this watershed are unlikely to reach the residence at 3140 McBride Highway 16 E; i.e., the P(S:H) is estimated as low.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire, natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
Residence at 3100 McBride Highway 16 E	Debris flow	Low	Low	Very Low
	Debris flood	Low	Moderate	Low
	Flood	Low	High	Moderate
Residence at 3140 McBride Highway 16 E	Debris flow	Low	Low	Very Low
	Debris flood	Low	Low	Very Low
	Flood	Low	Low	Very Low
Licenced Water Intakes	Debris flow	Low	Low	Very Low
	Debris flood	Low	Moderate	Low
	Flood	Low	High	Moderate
HG Road	Debris flow	Low	Low	Very Low
	Debris flood	Low	Moderate	Low
	Flood	Low	High	Moderate
Highway	Debris flow	Low	Low	Very Low
	Debris flood	Low	Moderate	Low
	Flood	Low	High	Moderate

Recommendations

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" should be posted:

- At both east and west ends of the Fire on the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

In the short-term, the owner of 3100 McBride Highway 16 E should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

Photo 15: *View of the Hagan Creek watershed. Landslides appear active in the upper watershed on the face of Mount Teare. The trace of Hagan Creek is marked in blue.*

Photo 16: *View of the Hagan Creek channel as it approaches the lower bench. The channel is deep and confined, but downslope from here, the creek loses confinement on the gentler slopes.*

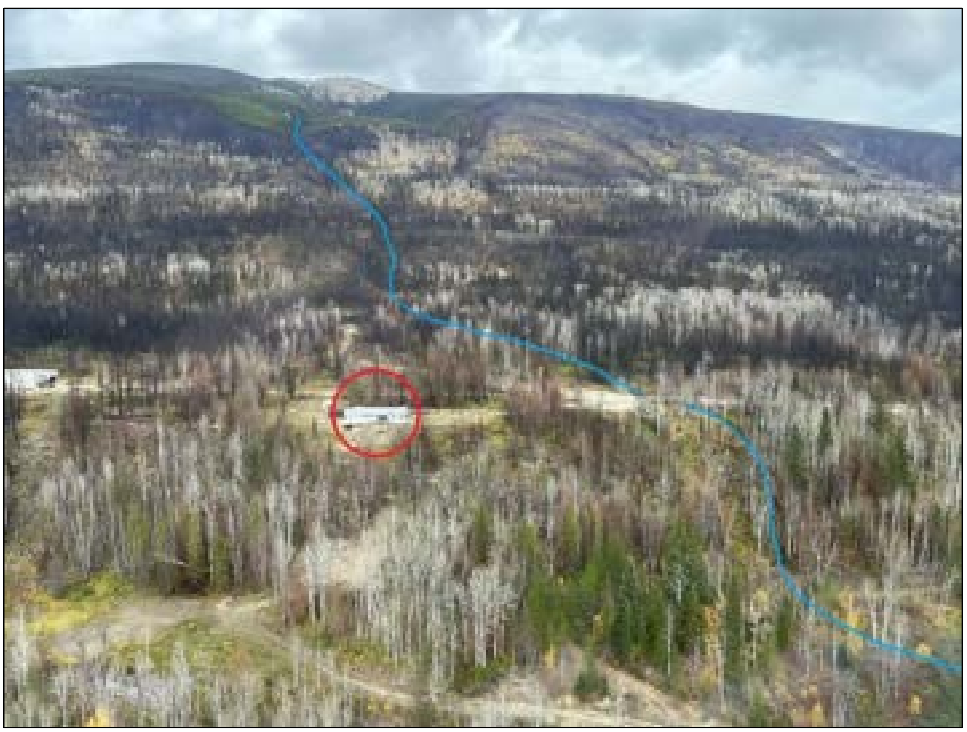
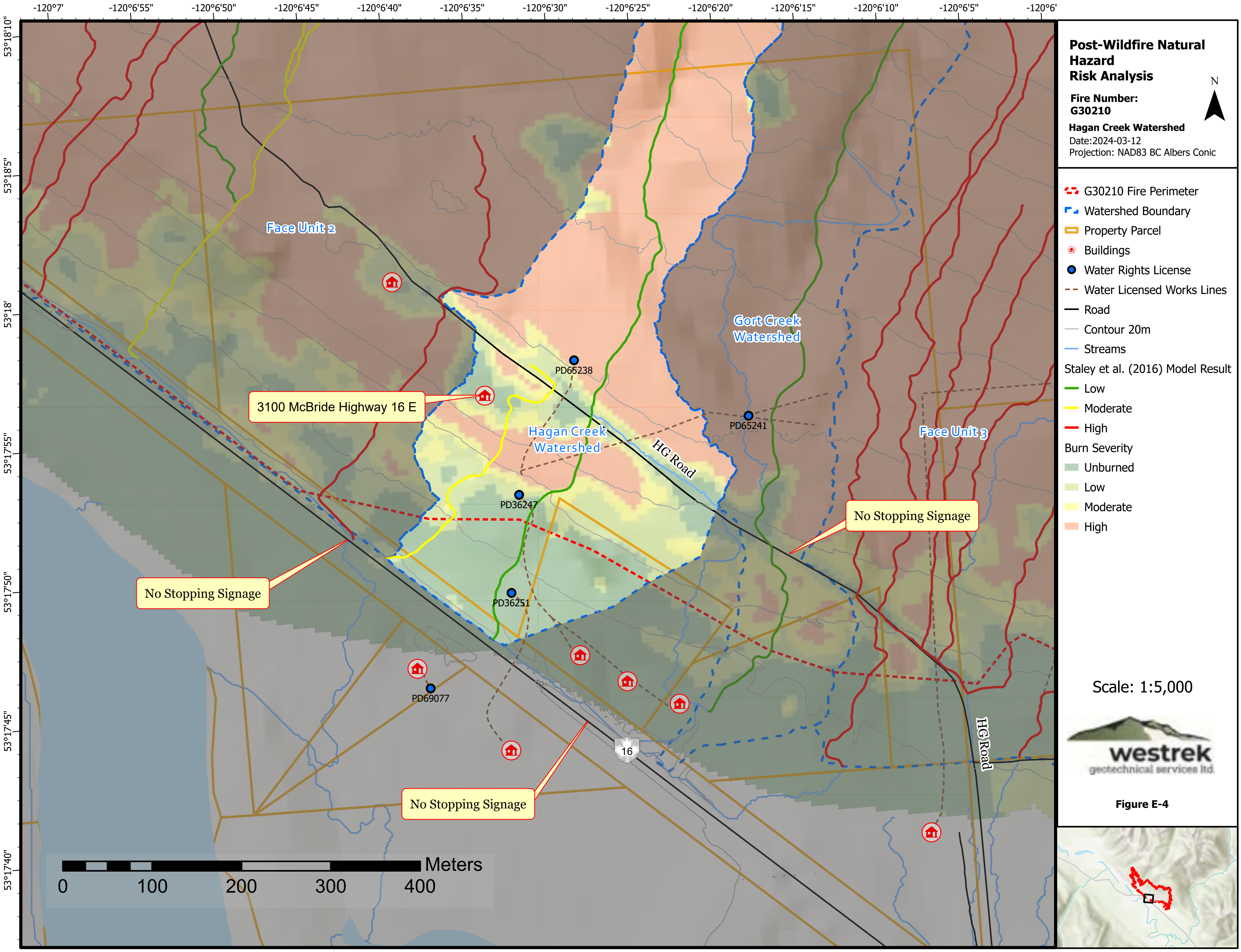


Photo 17: *View of the residence at 3100 McBride Highway 16 E (circled) on the north side of Hagan Creek. The creek channel crosses an upper road (not visible) and the HG Road through culverts. The creek has the potential to avulse and be diverted towards the residence.*



Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Hagan Creek Watershed
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:5,000
westrek
geotechnical services ltd.
Figure E-4
Face Unit 2
Face Unit 3
Gort Creek Watershed
Hagan Creek Watershed
HG Road
HG Road
3100 McBride Highway 16 E
No Stopping Signage
No Stopping Signage
No Stopping Signage
PD65238
PD65241
PD36247
PD36251
PD69077
16
Meters
0
100
200
300
400
-120°7'
-120°6'55"
-120°6'50"
-120°6'45"
-120°6'40"
-120°6'35"
-120°6'30"
-120°6'25"
-120°6'20"
-120°6'15"
-120°6'10"
-120°6'5"
-120°6'
53°18'10"
53°18'5"
53°18'
53°17'55"
53°17'50"
53°17'45"
53°17'40"

Gort Creek Watershed

Observations (Figure E-5)

- The Gort Creek watershed is long and narrow; the creek channel rises at a steady grade between 25% and 35% for 3 km, with the exception of a 500 m long reach on the lower terrace that ranges from 5% to 15% (Figure 4).
- The upper watershed encompasses the southern flank of Mount Teare and there appears to be a landslide, possibly a rubbly earthflow (or rock glacier) with periglacial influence off the southern face of Mount Teare (Photo 18, Figure 3). These areas were not burned by the Fire and, as such, the existing landslide will not be affected by it.
- Lower on the slope, the creek crosses distinct bedrock benches capped with thicker deposits of till and glaciofluvial sediments into which it has incised a moderately deep channel (Photo 19). Mid-slope alluvial fans have been developed as aggregate quarries.
- On the lower terrace, the channel is shallow and moderately confined as it flows across an old alluvial or fluvial fan surface. Several relict channels across the fan can be seen on the LiDAR bare earth imagery.
- The residence at 3192 McBride Highway 16 E is located on the north side of the creek, at the base of the lower escarpment.
- HG Road comes off the Highway to the east and rises across the slope to provide access to a residence in the Hagan Creek watershed. The road continues upslope and has been used for access for forest harvesting and gravel extraction. Gort Creek passes through 6 culverts:
    - two 800 mm diameter culverts on the upper road;
    - an 800 mm diameter culvert on HG Road;
    - an 800 mm diameter culvert on an older lower road;
    - a 1000 mm diameter culvert on the driveway to the residence at 3192 McBride Highway 16 E; and
    - a 600 mm diameter culvert underneath the Highway.
- One licensed water intake (PD65241) is located within the Gort Creek watershed above the Highway. A pond has been constructed about 100 m upstream from the Highway. Creek flow appears to be diverted below the main access road and into the pond (Photo 20). There are no records for this feature.

Watershed Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	38	25.9%
High Burn Severity	34	23.1%

Moderate Burn Severity	2	1.4%
Low Burn Severity	2	1.4%
Unburned	109	74.1%
Total Watershed Area	147	

Results

Watershed Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	147 ha
Channel Length	3649 m
Elevation Range	1444 m
Melton Ratio	1.191
Likely Hydrogeomorphic Process	Debris flow
Staley Model Results	**Low**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire debris flow, debris flood or flood initiating from the burned slopes within this watershed in the short-term is estimated as low. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this watershed average 23% overall (i.e., 93% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 25.9% of this unit, with 1.4% and 23.1% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Debris flows initiating from the burned slopes within this watershed are unlikely to reach the residence at 3192 McBride Highway 16 E, the licensed water intakes, the HG Road or the Highway due to the moderate gradient channel; i.e., the P(S:H) is estimated as low.

Debris floods initiating from the burned slopes within this watershed are likely to reach the licensed water intakes; i.e., the P(S:H) is estimated as high.

Debris floods initiating from the burned slopes within this watershed might reach HG Road; i.e., the P(S:H) is estimated as moderate.

Debris floods initiating from the burned slopes within this watershed are unlikely to reach the residence at 3192 McBride Highway 16 E or the Highway; i.e., the P(S:H) is estimated as low.

Floods initiating from the burned slopes within this watershed are likely to reach the residence at 3192 McBride Highway 16 E, the licensed water intakes, the HG Road and the Highway; i.e., the P(S:H) is estimated as high.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire, natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
3192 McBride Highway 16 E	Debris flow	Low	Low	Very Low
	Debris flood	Low	Low	Very Low
	Flood	Low	High	Moderate
Licenced Water Intakes	Debris flow	Low	Low	Very Low
	Debris flood	Low	High	Moderate
	Flood	Low	High	Moderate
HG Road	Debris flow	Low	Low	Very Low
	Debris flood	Low	Moderate	Low
	Flood	Low	High	Moderate
Highway	Debris flow	Low	Low	Very Low
	Debris flood	Low	Low	Very Low
	Flood	Low	High	Moderate

Recommendations

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" should be posted:

- At both east and west ends of the Fire on the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.
- At the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

All drainage structures along these roads, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

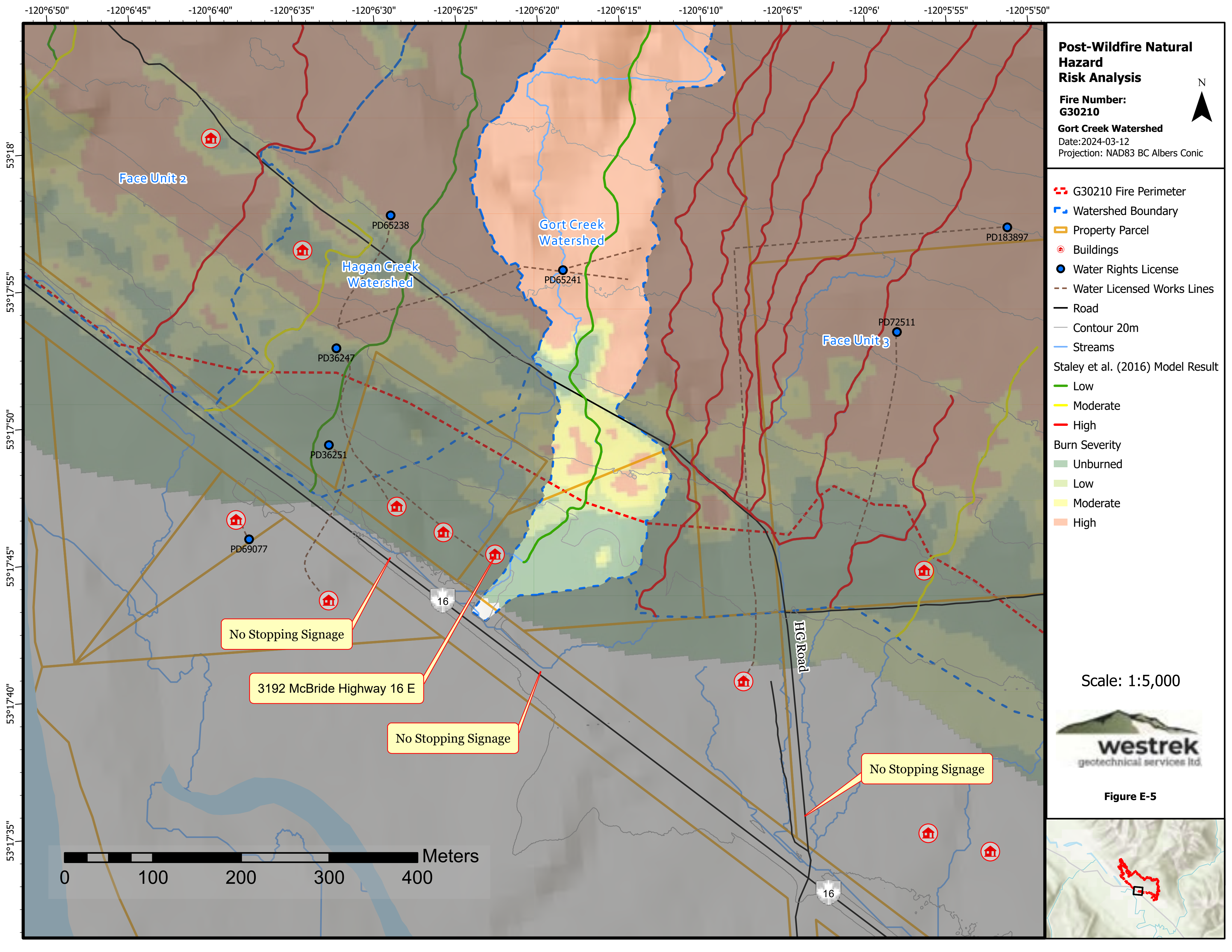
In the short-term, the owner of 3192 McBride Highway 16 E should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

Photo 18: *View of the upper reaches of the Gort Creek watershed. Landslides appear active in the upper watershed on the face of Mount Teare, but these are unlikely to move far downslope due to the moderate gradient slopes. The trace of Gort Creek is marked in blue.*

Photo 19: *View of Gort Creek channel above the upper access road. The creek is confined in a deep draw. The active channel has a coarse cobble-gravel base.*

Photo 20: *View of lower Gort Creek and the road system that crosses the lower watershed. The trace of lower Gort Creek is marked in blue. The diversion pond is visible at lower right. The residence at 3192 McBride Highway 16 E is out of image at bottom right.*



-120°6'50"
-120°6'45"
-120°6'40"
-120°6'35"
-120°6'30"
-120°6'25"
-120°6'20"
-120°6'15"
-120°6'10"
-120°6'5"
-120°6'
-120°5'55"
-120°5'50"
53°18'
53°17'55"
53°17'50"
53°17'45"
53°17'40"
53°17'35"
Face Unit 2
Face Unit 3
Gort Creek Watershed
Hagan Creek Watershed
PD65238
PD65241
PD36247
PD36251
PD69077
PD72511
PD183897
16
HG Road
No Stopping Signage
3192 McBride Highway 16 E
No Stopping Signage
No Stopping Signage
0
100
200
300
400
Meters
Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Gort Creek Watershed
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:5,000
westrek geotechnical services ltd.
Figure E-5

Face Unit 3

Observations (Figure E-6)

- This face unit is heavily dissected by draws on the moderately steep upper slopes (Figure 3, Photo 21). As the gradient decreases downslope, the draws become less incised and more indistinct.
- The lower half of the unit is gently to moderately sloped (Figure 4).
- No creeks were observed within Face Unit 3.
- The vegetation burn severity across this unit is mapped predominantly as high, but ground observations suggest the soil burn severity is moderate.
- A residence at 3270 McBride Highway 16 E, with two outbuildings, is located at the base of the slope (Photo 21) and one other outbuilding is located slightly further upslope to the northeast. The residence is accessed from the Highway by HG Road.
- Two licensed water intakes are located within the unit (PD72511 and PD183897).

Face Unit Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	256	78.5%
High Burn Severity	237	72.7%
Moderate Burn Severity	8	2.4%
Low Burn Severity	11	3.4%
Unburned	70	21.5%
Total Watershed Area	326	

Results

Face Unit Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	326 ha
Elevation Range	1087 m
Likely Hydrogeomorphic Process	Sediment-laden flow
Staley Model Results	**High**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire sediment-laden flow initiating from the burned slopes within this face unit in the short-term is estimated as high. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this face unit average 21% overall (i.e., 98% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 78.5% of this unit, with 2.4% and 72.7% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Sediment-laden flows initiating from the burned slopes in this face unit are likely to reach the licensed water intakes and the HG Road due to the moderate gradient slopes; i.e., the P(S:H) is estimated as moderate.

Sediment-laden flows initiating from the burned slopes in this face unit are unlikely to reach the residence at the base of the slope due to the low to moderate gradient slopes; i.e., the P(S:H) is estimated as low.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire, natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
Residence at 3270 McBride Highway 16 E	Sediment-laden flow	High	Low	Moderate
HG Road	Sediment-laden flow	High	Moderate	High
Licensed Water Intakes	Sediment-laden flow	High	Moderate	High

Recommendations

Consideration should be given to either building protective structures around the licensed water intakes or developing contingency plans to provide an alternate source of water.

"No Stopping due to Landslide and Flooding Risk" signs should be posted at the start of HG Road, where it leaves the Highway, to alert road users of the potential sediment-laden flow and flood risks, especially during short-duration/high-intensity rainfall events.

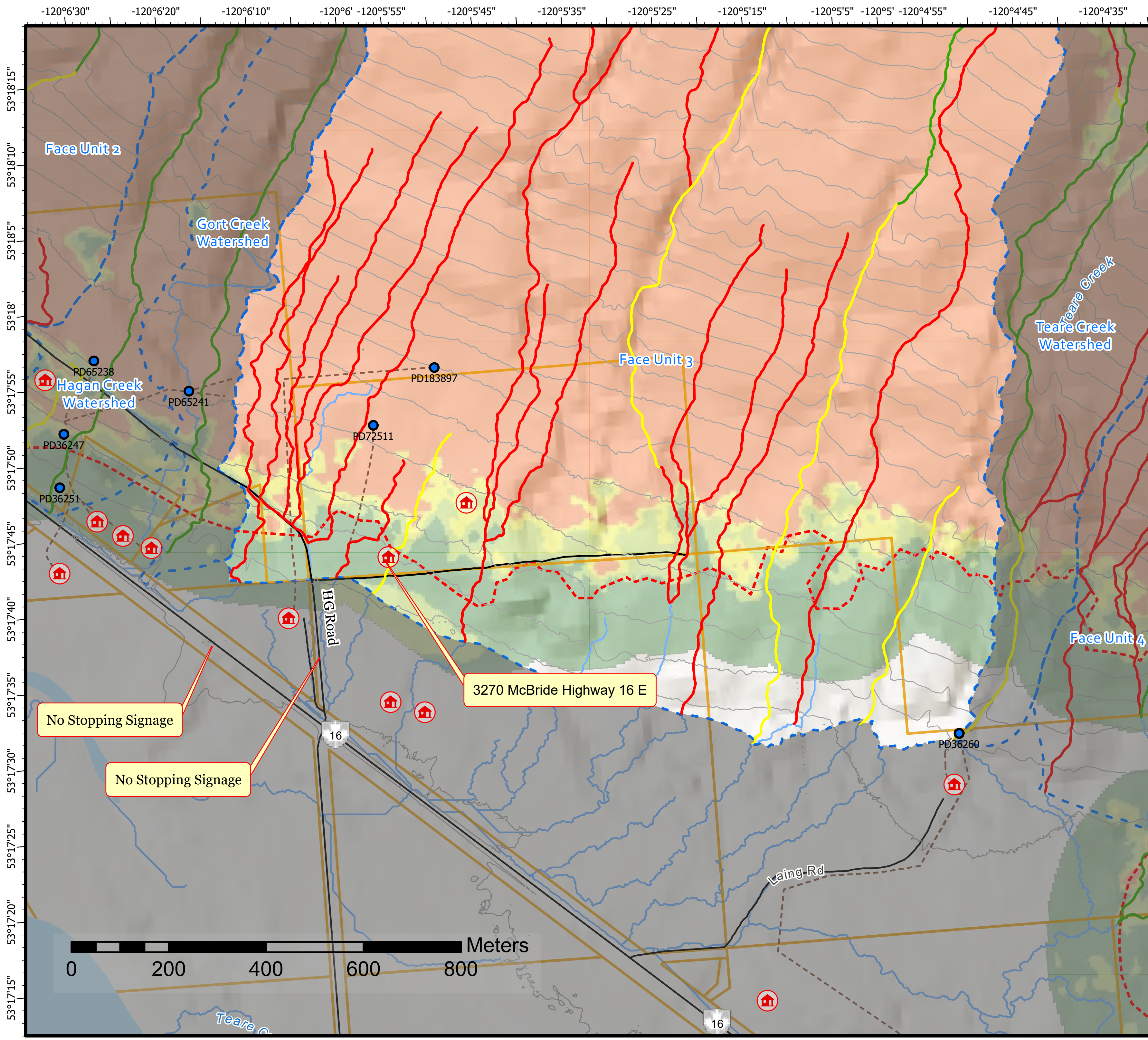
All drainage structures along this road, within and below the Fire perimeter, should be:

- Inspected and maintained at least annually for the next five years.
- Reviewed to determine the efficacy to be able to convey the post-wildfire flows.

In the short-term, the owner of 3270 McBride Highway 16 E should consider installing barriers, such as berms, uphill from their residence to deflect post-wildfire sediment-laden flows.

For the long-term, a landslide hazard assessment should be completed to determine whether protection/stabilization measures across the slope are necessary to mitigate the risk from landslides. If required, they should be installed.

Photo 21: *View looking north at Face Unit 3. The residence at 3270 McBride Highway 16 E is located at centre. Immediately upslope of the residence the slopes are mapped as having a low or moderate burn severity.*



Post-Wildfire Natural Hazard Risk Analysis

Fire Number: G30210

Face Unit 3

Date:2024-03-12

Projection: NAD83 BC Albers Conic

N

G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams

Staley et al. (2016) Model Result
Low
Moderate
High

Burn Severity
Unburned
Low
Moderate
High

Scale: 1:10,000

westrek geotechnical services ltd.

Figure E-6

Teare Creek Watershed

Observations (Figure E-7)

- The upper reaches of the Teare Creek watershed are gently to moderately sloped on the eastern flank of Mount Teare. There is a clear break in the slope, below which the slopes are moderately steep (i.e., >50%) and gullied for over a kilometre (Figures 3 and 4). Avalanche and debris flow paths are common, as are talus cones and open slope landslides (Photo 22).
- The gradient of the mainstem channel is over 50% in this upper gullied area and then decreases to between 25% and 30% for approximately 2 km to the base of the slope (Photo 23). The creek does not develop a well-defined channel until it reaches the mid-slopes where it has incised into the thicker till sediments and strand lines.
- On the edge of the Robson Valley floodplain, Teare Creek has formed a gently sloped (~10%) fluvial fan, which extends for 250 m from the fan apex to the distal margin on the valley floor. The channel has been directed to the east through an excavated ditch (Photo 24) and could be diverted into a catchment basin on the mid-fan, although this was not confirmed.
- A residence is located at 3496 Laing Road on the southern half of the fan.
- The creek has a licensed water intake (PD36260) in the confined draw near the fan apex (Photo 25); it consists of a vertical culvert installed in the centre of the creek channel and buried distribution pipes. Water is used for irrigation on the nearby agricultural developments and domestic water for the residence on the fan.

Watershed Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	112	46.1%
High Burn Severity	92	37.9%
Moderate Burn Severity	10	4.1%
Low Burn Severity	10	4.1%
Unburned	131	53.9%
Total Watershed Area	243	

Results

Watershed Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	243 ha
Channel Length	5500 m

Elevation Range	1395 m
Melton Ratio	0.90
Likely Hydrogeomorphic Process	Debris flow
Staley Model Results	**Moderate**

Risk Analysis

Hazard Likelihood P(H)

The likelihood of a post-wildfire debris flow, debris flood or flood initiating from the burned slopes within this watershed in the short-term is estimated as moderate. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this face unit average 22% overall (i.e., 92% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 46.1% of this unit, with 4.1% and 37.9% burned to a moderate and high burn severity respectively).

Spatial Interaction Likelihood P(S:H)

Debris flows initiating from the burned slopes within this watershed are very unlikely to reach the residence or licensed water intake on the Teare Creek fan due to the low to moderate gradient channel; i.e., the P(S:H) is estimated as low.

Debris floods initiating from the burned slopes within this watershed are unlikely to reach the residence on the Teare Creek fan; i.e., the P(S:H) is estimated as low.

Debris floods initiating from the burned slopes within this watershed might reach the licensed water intake on the Teare Creek fan; i.e., the P(S:H) is estimated as moderate.

Floods initiating from the burned slopes within this watershed might reach the residence on the Teare Creek fan; i.e., the P(S:H) is estimated as moderate.

Floods initiating from the burned slopes within this watershed are likely to reach the licensed water intake on the Teare Creek fan; i.e., the P(S:H) is estimated as high.

Partial Risk Assessment P(HA)

The following is a summary of the short-term, post-wildfire natural hazard partial risk:

Summary of Partial Risk Analysis				
Elements at Risk	**Hazard**	**P(H)**	**P(S:H)**	**Partial Risk**
Residence at 3496 Laing Road	Debris flow	Moderate	Low	Low
	Debris flood	Moderate	Low	Low
	Flood	Moderate	Moderate	Moderate
Licenced Water Intake	Debris flow	Moderate	Low	Low
	Debris flood	Moderate	Moderate	Moderate
	Flood	Moderate	High	High

Recommendations

Consideration should be given to either building protective structures around the licensed water intake or developing contingency plans to provide an alternate source of water.

In the short-term, the owner of 3496 Laing Road should consider installing flood barriers, such as berms, uphill from their residence to deflect post-wildfire floods.

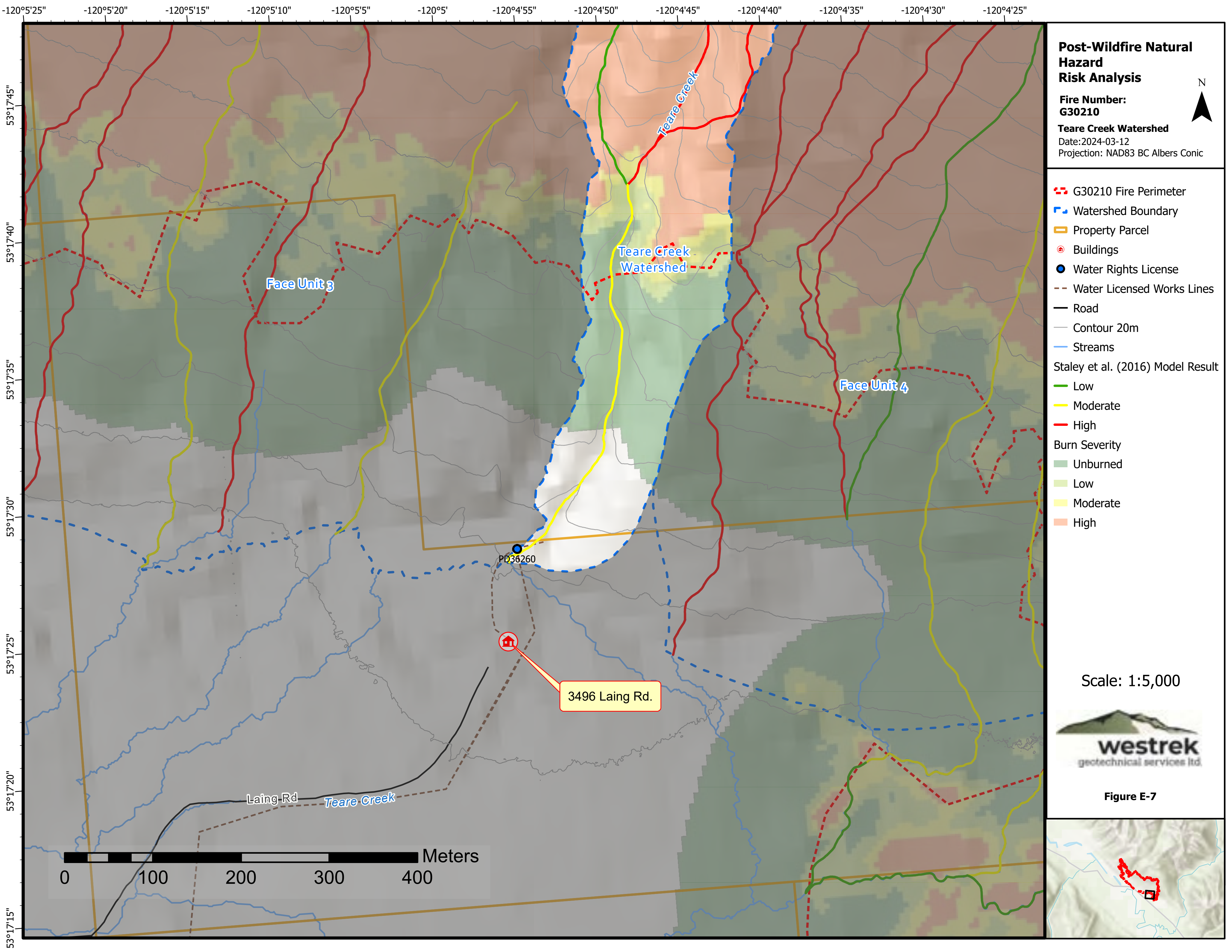
For the long-term, a flood hazard assessment should be completed to determine whether protection/stabilization measures along the creek channel are necessary to mitigate the risk from the increased magnitude of streamflow. If required, they should be installed.

Photo 22: *View of the steep gullied slopes in the upper part of the Teare Creek watershed. Avalanche and debris flow paths are common, as are talus cones and open slope landslides.*

Photo 23: *View of the Teare Creek watershed. The steep, gullied slopes of the upper watershed are visible at the top of the image. The residence at 3496 Laing Road is circled.*

Photo 24: *View of the licensed water intake structure located on the upper fan of Teare Creek.*

Photo 25: *View of Teare Creek on the fan at the base of the slope; flow has been diverted to the east in an excavated channel. During a flood, the creek could overtop its banks and flow downslope towards the residence.*



Post-Wildfire Natural Hazard Risk Analysis
Fire Number: G30210
Teare Creek Watershed
Date:2024-03-12
Projection: NAD83 BC Albers Conic
N
G30210 Fire Perimeter
Watershed Boundary
Property Parcel
Buildings
Water Rights License
Water Licensed Works Lines
Road
Contour 20m
Streams
Staley et al. (2016) Model Result
Low
Moderate
High
Burn Severity
Unburned
Low
Moderate
High
Scale: 1:5,000
westrek
geotechnical services ltd.
Figure E-7
Teare Creek
Teare Creek Watershed
Face Unit 3
Face Unit 4
PD36260
3496 Laing Rd.
Laing Rd
Teare Creek
Meters
0
100
200
300
400
-120°5'25"
-120°5'20"
-120°5'15"
-120°5'10"
-120°5'5"
-120°5'
-120°4'55"
-120°4'50"
-120°4'45"
-120°4'40"
-120°4'35"
-120°4'30"
-120°4'25"
53°17'45"
53°17'40"
53°17'35"
53°17'30"
53°17'25"
53°17'20"
53°17'15"

Face Unit 4

Observations (Figure E-8)

- This face unit is gently to moderately sloped at the base (Photo 25), moderately to steeply sloped though the mid-slope and gently sloped on the upper ridgeline which borders the Holmes River watershed (Figure 4).
- No buildings are located within or below this unit.
- One old logging road (overgrown) crosses the mid-slope within the Fire.
- An active logging road is constructed in the upper portion of this face unit but is located upslope and outside of the Fire perimeter.
- A large, steep, scallop-shaped landslide feature in bedrock is located within this unit, but outside of the Fire perimeter and will not be influenced by it (Figure 3).

Face Unit Burn Severity Summary		
Burn Severity Class	**Area (ha)**	**Percentage of Watershed**
Total Burned Area	93	27.3%
High Burn Severity	72	21.1%
Moderate Burn Severity	8	2.4%
Low Burn Severity	13	3.8%
Unburned	249	72.7%
Total Watershed Area	342	

Results

Face Unit Morphometrics and Modelling Results	
Parameter	**Value**
Watershed Area	342 ha
Elevation Range	1002 m
Likely Hydrogeomorphic Process	Sediment-laden flow
Staley Model Results	**Moderate**

Risk Analysis

Hazard Likelihood P(H)

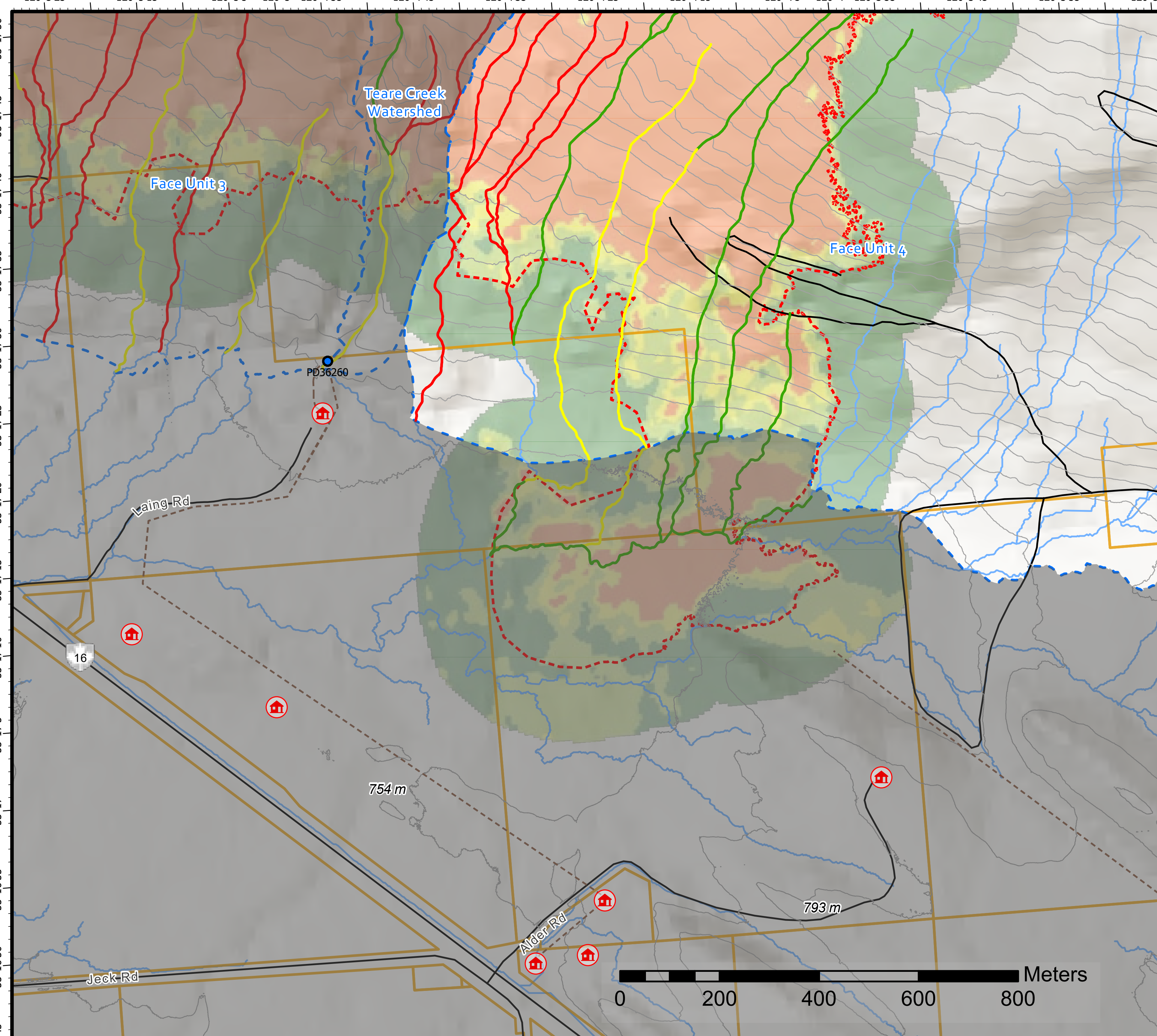
The likelihood of a post-wildfire sediment-laden flow initiating from the burned slopes within this face unit in the short-term is estimated as low. The rationale for this is based on the results of the Staley Model, which uses the following variables (amongst others) to determine the hazard rating based on the weighted mean:

- Slope gradients, which for this face unit average 21% overall (i.e., 97% of the slopes have a gradient less than 40%), and
- Burn severity (i.e., the Fire affected 27.3% of this unit, with 2.4% and 3.8% burned to a moderate and high burn severity respectively).

There are no elements at risk below this face unit.

Recommendations

None required.



Post-Wildfire Natural Hazard Risk Analysis

Fire Number: G30210

Face Unit 4

Date:2024-03-12

Projection: NAD83 BC Albers Conic

N

- G30210 Fire Perimeter
- Watershed Boundary
- Property Parcel
- Buildings
- Water Rights License
- Water Licensed Works Lines
- Road
- Contour 20m
- Streams

Staley et al. (2016) Model Result
- Low
- Moderate
- High

Burn Severity
- Unburned
- Low
- Moderate
- High

Scale: 1:10,000

westrek geotechnical services ltd.

Figure E-8