Battani Creek Hazard and Risk Assessment

Prepared by BGC Engineering Inc. for:

The Village of Lions Bay

October 1, 2025

Project 1791004

Rev. 0

Pioneering responsible solutions to complex earth science challenges

October 1, 2025 Project 1791004

The Village of Lions Bay
PO Box 141, 400 Centre Road
Lions Bay, BC V0N 2E0

Attention: Mr. Ross Blackwell, CAO

Battani Creek Hazard and Risk Assessment

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

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

Yours sincerely,

BGC Engineering Inc.
per:

Sophia Zubrycky, M.A.Sc., P.Eng.
Senior Geological Engineer

PLAIN LANGUAGE SUMMARY

On the morning of December 14, 2024, a landslide descended Battani Creek in Lions Bay, BC, stripping the hillside of dense forest, destroying a home, and spilling across Highway 99 and into Magnesia Creek. The event resulted in two fatalities inside the impacted building, temporary closure of Highway 99, and evacuation of multiple residences.

The Village of Lions Bay (the Village) retained BGC Engineering Inc. (BGC) to complete a hazard and risk assessment at Battani Creek. The goal of this work is to evaluate current risk levels and inform decisions related to future mitigation efforts. This work was funded by the BC Government as part of the emergency response following the December 14, 2024 landslide.

This study focusses on flow-type landslides that may originate within the Battani Creek watershed or from an access road (Battani Creek Road) and reservoir located in the lower parts of the watershed. BGC identify several hazard scenarios, including slope failures from steep terrain, rock mass failures below the reservoir, and road fill failures that could evolve into debris flows. While these scenarios may behave similarly to the December 14, 2024 landslide, they are expected to have smaller volumes due to the depletion of available debris following that event.

Due to the proximity of roads relative to Battani Creek and unstable source areas, many of the computer simulations show debris impacting roads, posing a life-safety risk to road users. Although the estimated risk level to a regular commuter from these hazards is relatively low compared to the general risk of traffic accidents, some scenarios could result in multiple fatalities on Highway 99. In addition to life-safety risks, emergency response costs, road closures, and intangible impacts such as reputational damage may justify mitigation efforts.

BGC estimates the life-safety risk to existing residences from flow-type landslides is negligible as none of the hazard scenarios are expected to directly impact building structures. This is largely due to the capacity and gradient of Battani Creek near 1 and 2 Goldenrod Avenue, which effectively conveys debris past these buildings. In extreme cases, debris flowing past these buildings may cause minor property damage, but is unlikely to pose a significant life-safety threat. Buildings along Crystal Falls Road and Brunswick Beach Road are not expected to be directly impacted by the assessed landslide scenarios due to insufficient debris volume and flow momentum; however, they may be vulnerable to flooding and debris flows from Magnesia Creek, which were not included in this study. Other out of scope hazards such as rock fall or falling trees from the road cuts and fill slopes may affect buildings at 1 and 2 Goldenrod Avenue and should be assessed separately.

There are several mitigation options available to reduce risk at Highway 99 and Battani Creek Road. These include upgrading or deactivating portions of Battani Creek Road, constructing an engineered deflection berm at Highway 99, and making information available to residents. BGC recommends a phased approach, beginning with the immediate removal of unstable fill and a deteriorating log crib structure located along Battani Creek Road directly above Highway 99, followed by additional mitigation measures. Furthermore, BGC recommends the property at 6 Glendale Avenue is not redeveloped.

TABLE OF REVISIONS

Date	Revision	Remarks
August 20, 2025	DRAFT	Draft issue for review.
October 1, 2025	Rev. 0	Final issue integrating review comments on behalf of Lions Bay.

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1.0 INTRODUCTION

1.1 General

Battani Creek is a small, steep tributary of Magnesia Creek in Lions Bay on the east side of Howe Sound, British Columbia (Drawing 01). At approximately 10:15 am PST on December 14, 2024, a debris flow descended Battani Creek destroying a residence at 6 Glendale Avenue and crossing Highway 99 before entering Magnesia Creek. This debris flow resulted in two fatalities at the 6 Glendale Avenue residence, temporary closure of Highway 99 in both travel directions, evacuation of multiple residences along Battani and Magnesia Creeks, and required the removal of several thousand cubic meters of soil and woody debris. The Village of Lions Bay (the Village) declared a state of local emergency on December 15, 2024.

In response to the December 14, 2024 debris flow, the Village retained BGC Engineering Inc. (BGC) to complete a hazard and risk assessment to quantify life-loss and limited aspects of economic risk from debris flows and debris avalanches that originate from the Battani Creek watershed or an access road within the watershed (Battani Creek Road). The purpose of this work is to compare life-loss risk estimates to risk tolerance criteria adopted in other jurisdictions in British Columbia, and to inform decisions about risk reduction strategies, as required.

1.2 Scope of Work

BGC's scope of work, as outlined in a proposal dated March 18, 2025, included:

- Desktop assessment, including a review of past reports, airphoto interpretation, lidar change detection, and geomorphic mapping
- Field assessment of the Battani Creek channel, watershed, roads, and reservoir
- Hazard assessment to estimate the frequency, magnitude, and impacts of debris-flow and debris-avalanche scenarios
- Risk assessment to quantify and evaluate life-safety and limited aspects of economic risk from the hazard scenarios
- Conceptual mitigation options development and comparison.

The Village, the BC Ministry of Forests (MoF), Ministry of Emergency Management and Climate Readiness, Ministry of Transportation and Transit (MoTT), and BGC defined the scope of work during virtual meetings on February 12, 2025 and March 14, 2025. The scope aligns with Engineers and Geoscientists of British Columbia (EGBC) best practice guidelines for landslide assessments (EGBC, 2023).

Work was carried out under the terms of the professional services agreement between the Village and BGC dated December 14, 2024.

1.3 Project Team

The project team includes qualified geohazard professionals from BGC, summarized in Table 1-1.

Table 1-1 Project team. Professional designations are for practice in British Columbia.

Project Role	Team Member
Project Manager and Technical Lead	Sophia Zubrycky, M.A.Sc., P.Eng.
Reviewer	Lauren Hutchinson, M.Sc., P.Eng. Dr. Alex Baumgard, P.Eng., P.Geo.
Project Engineer	Braeden Klassen, B.A.Sc., P.Eng. Lisa Tauskela, M.A.Sc. Gemma Ferland, B.A.Sc., EIT
Project Geomatics Technician	Celeste Melliship, B.A.

2.0 DATA SUMMARY

2.1 Available Reports

BGC reviewed the following reports and documents related to Battani Creek, listed in chronological order:

- Baumann Engineering. (1999, November 22). *Comments regarding your proposed house construction and Magnesia Creek (Lot 2, Block 6, D.L. 1815, Plan 3149 (Parcel Identifier 013-149-709)* [Report]. Prepared for Al MPhee.
- Higman, S. (2014, October 15). *Preliminary Geotechnical Assessment of the Alleged Trespass Road Associated with Water Licence C064497 on Battani Creek, Lions Bay, BC* [Report]. Prepared for Murray Watt, Sea to Sky District – Compliance and Enforcement Branch.
- Decision No. 2014-WAT-019(a). Environmental Appeal Board, September 30, 2014.
- Cordilleran Geoscience (2015, February 7). *Trespass Notices under Section 59 of the Land Act, dated September 4 & 5, 2014, issued by Murray Watt (MoFLNRO)* [Report]. Prepared for Steve Vestergaard.
- Cordilleran Geoscience. (2015, February 9). *Reservoir fillslope sign off* [Report]. Prepared for Steve Vestergaard.
- Higman, S. (2015, June 12). *Road Deactivation Plan for Alleged Trespass Road Associated with Water License C064497 on Battani Creek, Lions Bay, BC – Amended June 12, 2015 to include Deactivation Measures for Alleged Trespass Road on MOTI Property* [Report]. Prepared for Murray Watt, Sea to Sky District – Compliance and Enforcement Branch.
- Westrek Geotechnical Services Ltd. (2015, July 24). *Geotechnical Field Review of Four Sites Along the Access Road to Water License Intake on Battani Creek, Lions Bay, British Columbia* [Report]. Prepared for Steve Vestergaard.
- Cascade Environmental Resource Group Ltd. (2015, July 27). *Restoration Plan for DL 2935 Battani Creek, Lions Bay, BC* [Report]. Prepared for Steve Vestergaard.
- JCH Forestry Ltd. (2015, July 28). *Management Plan for Steven Vestergaard's License of Occupation Application #100137156* [Report]. Prepared for Steve Vestergaard.
- Cordilleran Geoscience (2018, June 25). *A Natural Hazards Assessment Area Strategy for Coastal, Creek and Hillslope Hazards* [Report]. Prepared for The Village of Lions Bay.

2.2 Lidar Data

A summary of the available lidar data is in Table 2-1. BGC completed lidar change detection between the GeoBC 2018-2019 and the MoTT February 3, 2025 lidar surveys (Figure 05).

Table 2-1 Lidar data summary.

Date	Owner	Bare Earth Lidar Density	Study Area Coverage
November 8, 2012	MoF (data collected by McElhanney)	Approximately 0.5 to 1 pulses/m^2	South-eastern half, all elevations
Collected between October 14, 2018 and October 1, 2019	Ministry of Water, Lands and Resource Stewardship - GeoBC	Target density of 8 pulses/m^2	Elevations up to approximately 770 m
February 3, 2025	MoTT (data collected by Terra Remote)	Approximately 3 to 10 pulses/m^2	Elevations up to approximately 400 m

2.3 Aerial Imagery

BGC reviewed historical airphotos, satellite imagery, and orthophotos of the study area to support terrain interpretation and to document changes in the landscape. A list of reviewed imagery is in Table 2-2. Airphotos are from the University of British Columbia Geographic Information Centre Airphoto Library and National Air Photo Library. Select aerial images are shown in Figure 04.

Table 2-2 Summary of aerial imagery covering the study area.

Date	Details	Approximate Scale
June 9, 1939	Airphoto #BC134-83,84,79,80	1:30,000
1946	Airphoto #A10398-114	1:30,000
October 14, 1952	Airphoto #BC1634-60,61	1:70,000
August 22, 1957	Airphoto #BC2348-82,83 Airphoto #BC2349-20,21	1:30,000
September 28, 1968	Airphoto #BC7117-215,216	1:15,000
1975	Airphoto #A40038-24,25	1:200,000
September 11, 1979	Airphoto #BC79194-61,62	1:20,000
September 17, 1982	Airphoto #BC82058-71,72	1:20,000
July 10, 1990	Airphoto #BCB90019-53,54	1:15,000
July 22, 1996	Airphoto #BCC96078-101,102	1:15,000
August 23, 1996	Airphoto #BCC96124-106,107	1:15,000
August 29, 2003	Google Earth satellite imagery	
September 4, 2003	Airphoto #BCC03039-41,42	1:15,000
August 18, 2004	Google Earth satellite imagery	
August 30, 2007	Airphoto #ME07464C-217,218	1:100,000
Approximately annually from 2009-2023	Google Earth satellite imagery	
December 15, 2024	Post-event drone orthomosaic of December 14, 2024 landslide path	
February 3, 2025	Orthophoto collected by Terra Remote during lidar collection	

2.4 Field Work

BGC collected field observations specifically related to this scope of work across the study area on April 30, June 1, and July 24, 2025. The field team consisted of Sophia Zubrycky, Braeden Klassen, and Lisa Tauskela on April 30 and May 1, 2025, and Sophia Zubrycky and Lauren Hutchinson on July 24, 2025. BGC field staff visited the lower Magnesia Creek channel, the main Battani Creek channel and landslide path, the Battani Creek Road and reservoir and surrounding slopes, and the upper Battani Creek watershed along the logging roads. Select field photographs are provided in the Photographs attachment. An annotated field map with reference locations is provided in Drawing 04.

2.5 Geohazard Inventory

BGC compiled an inventory of debris floods, debris flows, and debris avalanches (including logging road failures) along the Sea-to-Sky corridor from approximately Horseshoe Bay to Porteau Cove from past studies and airphoto review. Key references include:

- Thurber Consultants Inc. (April, 1983). *Debris Torrent and Flooding Hazards Highway 99, Howe Sound* [Report]. Prepared for the Ministry of Transportation and Highways.
- Eisbacher, G.H. (1983). *Slope stability and mountain torrents, Fraser lowland and southern Coast Mountains, British Columbia (Field trip guidebook, Trip 15)*. Victoria, BC: Geological Association of Canada.
- VanDine, D.F. (1984). Debris flows and debris torrents in the southern Canadian Cordillera. *Canadian Geotechnical Journal*, *22*, 44-68.
- Septer, D. (2007). *Flooding and landslide events: southern British Columbia, 1808-2006*. Victoria, British Columbia: Province of British Columbia, Ministry of Environment.
- Blais-Stevens, A. & Septer, D. (2008). *Historical Accounts of Landslides and Flooding Events along the Sea to Sky Corridor, British Columbia, from 1855-2007*. Geological Survey of Canada, Open File 5741.
- BGC Engineering Inc. (BGC) (2013, March 28). *Upper Bayview Road Debris Flow Hazard and Risk Assessment Update* [Report]. Prepared for BC Ministry of Forests, Lands and Natural Resource Operations (Sea to Sky District).

3.0 SITE CHARACTERIZATION

3.1 Terrain and Watershed

The Battani Creek watershed occupies approximately 0.7 km^2 of forested terrain on the valley sidewall of the Howe Sound fjord between Magnesia Creek and M (Yahoo) Creek (Drawing 01). The watershed extends from an elevation of approximately 30 m to 1,160 m above sea level. Less than 10% of the Battani Creek watershed is comprised of steep[2] slopes exceeding 35°. In contrast, the larger, more incised and rugged watersheds along Howe Sound, such as Magnesia Creek and M (Yahoo) Creek, have steep slopes accounting for approximately half of their total areas.

Within the Battani Creek watershed, slopes below an elevation of approximately 340 m (near the Battani reservoir, Drawing 01) tend to be steeper than those in the upper watershed (Figure 01). In this lower section, the Battani Creek channel is confined in a broad, bedrock-controlled draw. The stream gradient ranges from approximately 35% to 70% in this lower reach, until the confluence with Magnesia Creek upstream of Highway 99, where the Magnesia Creek stream gradient is approximately 13%. The December 14, 2024 landslide stripped this steep, lower reach of Battani Creek of vegetation and soil exposing bedrock. Baumann Engineering (November 22, 1999) reports that this lower section of Battani Creek was previously covered by old growth trees and old stumps, flowing through a well-established channel approximately 1.3 m wide and 0.3 m deep during yearly high flows. Baumann Engineering (November 22, 1999) suggests that water in Battani Creek originates from springs, based on the presence of precipitates in the channel indicating dissolved minerals.

Above the Battani Creek reservoir, the watershed slopes are mostly moderate to moderately steep (16 to 35°), interspersed with local gentle plateaus and isolated steep bedrock bluffs (Figure 01). These slopes are vegetated with mature conifers and the forest floor is littered with deadfall. Battani Creek is much less confined in the upper portions of the watershed, flowing through a distributed network of shallow V-shaped gullies (Drawing 02). The stream gradient of the upper channel reaches range from approximately 40% to 50%.

3.2 Bedrock Geology

Metamorphosed sedimentary rocks (argillite with minor conglomerate, limestone, schist) and volcanic rocks (andesite, rhyodacite) from the Lower Cretaceous-age Gambier Group underlie most of the study area (Roddick, Woodsworth, & Hutchinson, 1979; Armstrong, 1990). These rocks are sheared and fractured and have been intruded by igneous rocks (quartz diorite, granodiorite) from the Cretaceous-age Coast Plutonic Complex. BC Digital Geology (Cui et al., 2017) delineates a north-south trending contact between the Gambier and Coast Plutonic units in the upper reach of the Battani Creek watershed (Drawing 02). BGC observed both Gambier and Coast Plutonic rock types along road cuts on Battani Creek Road. Many of the rocks

[2] Slope classes are from the Forest Practices Code of British Columbia (August, 1999) Mapping and Assessing Terrain Stability Guidebook, see Figure 01.

exposed in the road cuts are heavily fractured and oxidized with some cuts exposing cross-cutting faults and shear zones (e.g., Photos 18, 28).

There are major north-west trending faults in Howe Sound (Armstrong, 1990). The closest mapped fault in BC Digital Geology (Cui et al., 2017) is in the upper Magnesia Creek watershed along a contact between the Coast Plutonic intrusive rocks and a roof pendant of the Gambier Group that forms Brunswick Mountain. Additionally, there is a long, linear feature trending northeast across the study area which BGC interprets to be a fault (Drawing 02). The interpreted fault crosses Battani Creek at approximately 230 m elevation, forming a drainage upslope and locally steep terrain on the upslope side of the fault.

3.3 Surficial Geology

Pleistocene-age glaciation and post-glacial erosional processes have played a major role in shaping the Howe Sound landscape. During the last glacial maxima approximately 17,500 years ago, Howe Sound was covered by glaciers except for a few high-elevation mountain peaks sticking up from the ice. Glacial erosion carved and widened the valley, while the immense weight of glacial ice depressed the land surface. Howe Sound became ice free approximately 12,500 years ago, and during deglaciation, sea level stood roughly 220 m higher than today (Cordilleran Geoscience, June 29, 2018). Major tributaries such as Magnesia Creek deposited glaciofluvial deltaic and glaciomarine sediments at the elevated sea shoreline before the ground rebounded with the weight of the ice removed. Remnants of these glacial deposits are present as raised fan-deltas along the coastline, such as the gravel quarry at Magnesia Creek. Within the study area, Blais-Stevens (2008) mapped glaciomarine sand and gravel deposits at the lower reaches of Battani Creek, below approximately 130 m elevation (Drawing 02). In the upper reaches of the Battani Creek watershed above approximately 400 to 500 m elevation, Blais Stevens (2008) mapped a discontinuous veneer of glacial till covering bedrock (Drawing 02).

After deglaciation, erosional processes such as flooding and landsliding rapidly denuded and reworked glacial sediments. Major tributaries carved into glacial deposits, forming modern inset alluvial fan-deltas at the shoreline, such as the alluvial fan at Magnesia Creek along Brunswick Beach Road (Drawing 02). Debris generated by hillslope erosion and landsliding accumulated within gullies and on adjacent slopes, with heavy rain and snowmelt periodically mobilizing this material downslope as debris floods or debris flows. Over time, these processes slowed, and by approximately 7,500 years ago, the landscape had stabilized into a form resembling its present-day condition (Cordilleran Geoscience, June 29, 2018). Although flooding and landsliding were far more active in the immediate post-glacial period, these processes are still active today (see Section 3.4).

3.4 Geohazards

3.4.1 Sea-to-Sky Corridor

The Sea-to-Sky Corridor, from Horseshoe Bay to Pemberton BC, has a well-documented history of landslides. This region accounts for over 18% of Canada's reported landslide-related fatalities (Blais-Stevens & Septer, 2008). Steep terrain and dynamic climate contribute to a range of geohazard types[3], including:

- **Clearwater flood:** When a watercourse receives more water than it can contain, causing overflow and inundation of normally dry land. Triggers: Heavy rain, rapid snow melt, rain-on-snow events.
- **Debris flood:** A flood on a steep creek characterized by high rates of sediment transport (Church & Jakob, 2020). Triggers: Heavy rain, rapid snow melt, rain-on-snow events, debris flows diluting into debris floods, dam breach causing outburst floods.
- **Debris flow:** A fast-flowing slurry of water mixed with debris (rock, soil, organics) that travels down steep channels. Triggers: Heavy rain, rapid snow melt, landslides (e.g., rock slide, debris avalanche) entering channels.
- **Debris avalanche:** A rapid flow of saturated or unsaturated debris on a steep slope without channel confinement that typically initiates as a sliding mass of soil. Triggers: Heavy or prolonged rain, rapid snowmelt, rain-on-snow events, melting permafrost, erosion, windthrow, impact from falling rocks, earthquakes.
- **Rock slide:** A mass of rock detaching, sliding, and fragmenting down a slope. Triggers: Heavy rain, rapid snow melt, freeze-thaw cycles, extreme heat, windthrow, earthquakes, human activities (e.g., road cuts, blasting).
- **Rock fall:** Pieces of rock that detach and fall, bounce, or roll down a slope. Triggers: Heavy rain, rapid snow melt, freeze-thaw cycles, extreme heat, windthrow, earthquakes, human activities (e.g., road cuts, blasting).
- **Rock avalanche:** An extremely rapid flow of a large volume (millions of m^3) of fragmented rock that detached from a mountainside. Triggers: Earthquakes, slope de-buttressing (e.g., a glacier retreating exposing a steep slope), melting permafrost, volcanic eruptions, freeze-thaw cycles, mining activities, progressive rock mass degradation through time, extreme and prolonged rainfall and snowmelt.

Among these geohazards, rock falls and debris flows are the most common in Lions Bay (Blais-Stevens & Septer, 2008).

The steep, rugged drainages along Howe Sound are susceptible to episodic debris flows. These systems are "supply-limited", meaning sediment must accumulate over time before a channel can generate a debris flow (Bovis & Jakob, 1999). Sediment recharge typically occurs through progressive soil erosion, rock falls, and debris avalanches. Coast Mountain debris flows are characterized by coarse-grained, bouldery surge fronts followed by a liquefied slurry with floating debris, and can reach velocities up to 5 to 10 m/s (Hungr et al., 1984; VanDine, 1984).

[3] Descriptions based on landslide classification by Hungr et al. (2014).

Based on a geohazard inventory from Horseshoe Bay to Porteau Cove (Section 2.5), most debris floods, debris flows, and debris avalanches occur from September through March spanning the rainy season (see climate summary in Section 3.5). The primary triggering factor is intense precipitation, followed by factors compounded by logging-related disturbances, such as road failures, disturbed drainage, and increased runoff following clearcutting. The most destructive period of debris flows occurred from the 1960s to 1980s, resulting in a total of 13 fatalities and the damage or destruction of many bridges and houses. The most active drainage in this area is Charles Creek (south of Lions Bay), with at least 20 recorded debris flows occurring since the 1960s.

In the mid 1980s, mitigation measures, including debris retention basins, channel improvements, and bridge reconstruction, were implemented at select creeks along Highway 99, such as the debris basin at Magnesia Creek. Many of these structures were designed to contain or convey a design event based on the “largest and most mobile debris torrent that could reasonably occur during the life of the structure” (Hungr et al., 1984).

3.4.2 Battani Creek Watershed

Cordilleran Geoscience’s (June 29, 2018) natural hazards assessment for the Village identifies potentially unstable terrain susceptible to open-slope landsliding (e.g., debris avalanches) in the Battani Creek watershed. The assessment included properties adjacent to Battani Creek and Magnesia Creek in the Natural Hazard Assessment Areas (NHAA) for debris fans of mitigated channels (NHAA 2A, Map 4), ravines (NHAA 2B, Map 6), and open-slope landslides (Map 7, NHAA 3A). This means that properties within the study area may be exposed to geohazards such as floods, debris floods, debris flows, ravine sidewall failures, and debris avalanches.

In a geotechnical report to the owners of 2 Goldenrod, Baumann (November 22, 1999) estimated “no rapid mass wastage events have affected this property in hundreds of years” given the lack of evidence of landslide activity, and that “no rapid mass wastage has likely occurred in thousands of years” given the presence of glacial soils. However, Baumann (November 22, 1999) indicates there is some residual risk of landsliding given the steep mountainous terrain.

Aside from the December 14, 2024 landslide, there are no documented occurrences of floods, debris flows, or debris avalanches originating from the Battani Creek watershed. BGC’s review of aerial imagery dating back to the earliest available airphoto from 1939 did not reveal evidence of recent geohazard activity, such as landslide scarps or debris tracks/paths (Figure 04). BGC’s field investigations and terrain mapping did not identify relict debris-flow or debris-avalanche deposits; however, given the steep mainstem of Battani Creek, debris from past events may have been transported downslope and into Magnesia Creek and Howe Sound.

Bedrock scarps identified in the lidar may represent historical rock slide release points (Drawing 02). Locally, rock fall has accumulated in the Battani Creek Road ditch and on slopes below the road from the blasted road cut and unravelling fill slopes (e.g., Photo 28).

The dominant hazard process type in a watershed can be correlated to watershed measurements such as the Melton ratio[4], watershed length, and fan slope (e.g., de Haas et al., 2024). Based on a global dataset compiled by de Haas et al. (2024) and BGC's watershed inventory, debris flows are the dominant hazard process type on Battani Creek (Figure 03).

3.4.3 December 14, 2024 Landslide

At approximately 10:15 am PST on December 14, 2024, a debris flow descended Battani Creek, crossing Glendale Avenue and Highway 99 before entering Magnesia Creek.

The debris flow originated as a small slope failure (landslide) with an estimated volume of approximately 100 m³ based on lidar change detection (Figure 05). The initial failure occurred directly downstream of the Battani Creek reservoir outlet at an elevation of approximately 330 m (Location 25 on Drawing 04). The landslide headscarp reveals a large, planar bedrock surface dipping approximately 60° to the northwest, which BGC interprets as a likely failure plane of the initiating mass (Photos 36, 38).

Upon failure, the initial mass entrained trees, soil, and fractured bedrock, transforming into a flowing mass of debris down Battani Creek. The debris flow stripped Battani Creek of soil and vegetation along a 15 to 25 m wide path in the channelized portion of the flow. In the steepest portions of the channel, BGC estimates the debris flow may have reached speeds[5] of up to 12 m/s (43 km/hour) with flow depths many meters thick. At approximately 450 m along the travel path downstream of the properties on Goldenrod Avenue, the debris flow lost confinement, avulsing toward Magnesia Creek and spreading debris across 6 Glendale Ave (Figure 05). Large woody debris from this avulsion amassed as a jam on the upstream side of the Glendale Avenue bridge on Magnesia Creek. The debris flow continued downslope of 6 Glendale Ave, crossing Highway 99 and entering Magnesia Creek where it stopped upstream of the CN Rail bridge. In total, the debris flow traveled approximately 710 m, descending approximately 320 m in elevation, resulting in a travel angle of approximately 24°/45% (Figure 05b).

The lidar change detection between 2025 and 2019 datasets indicates that the debris flow eroded approximately 10,000 m^3 of soil and rock along its path (Figure 05). The yield rate, or volume of eroded material per unit length, ranged from approximately 10 to 20 m^3/m, with erosion depths reaching up to 3 m. BGC estimates that the debris flow transported a total volume of approximately 15,000 m^3, including a large volume of trees[6].

[4] Melton ratio (index) describes the watershed ruggedness, with large values corresponding to a more rugged (steep) watershed. It is calculated by the watershed relief divided by the square root of the watershed area.

[5] Velocity back-calculated using empirical equations that use field-measured flow superelevation, channel gradient, and peak flow depth.

[6] BGC assumed a bulking factor of 50% to account for trees, organics, and pore water in the total debris-flow volume.

The landslide occurred during a period of high wind, with gusts reaching approximately 40 to 90 km/hour on the day of the event[7]. A total of 40 to 60 mm of rain accumulated on December 14, 2024, with maximum precipitation rates ranging from approximately 9 to 12 mm/hour leading up to the event. The week prior saw minimal rainfall, except for an accumulation of approximately 30 to 40 mm the day before the landslide on December 13, 2025.

The debris flow destroyed a residence at 6 Glendale Avenue, causing two fatalities at this location. Following the event, the Village placed residences at 1 and 2 Goldenrod, 1 and 14 Crystal Falls Road, and 57, 59, and 61 Brunswick Beach Road on evacuation order, with some changed to alert following initial emergency response actions. Highway 99 was closed in both travel directions for approximately 18 hours and several thousand cubic meters of soil and woody debris were removed. On the east shoulder of Highway 99, MoTT constructed a 1.5 m tall berm and basin from landslide debris, which directs Battani Creek into Magnesia Creek through an armoured culvert (Location 3 on Drawing 04; Photos 3, 4).

3.5 Climate

The climate of Howe Sound is characterized by mild, wet winters, and warm, relatively dry summers. The major climatic process bringing precipitation to the Coast Mountains are atmospheric rivers which come from the Pacific Ocean during the fall and winter months. Most precipitation occurs between October and January, with the driest months typically July and August (Figure 02a). From 1991 to 2020, the annual average precipitation at the Squamish airport was approximately 2,300 mm, including an extreme rainfall event of 164 mm in 24 hours on November 10, 1990. At the Environment Canada station in Lions Bay, annual precipitation between 1984 and 2003 ranged from 1,200 mm to 2,100 mm. Rainfall intensity varies significantly across the terrain due to orographic uplift, with much higher precipitation at the crest of Howe Sound compared to sea level (Cordilleran Geoscience, June 29, 2018). Localized storm cells are common, which can trigger high runoff in specific drainages while leaving adjacent areas unaffected.

The Howe Sound fjord funnels wind, with the prevailing wind direction from north to south (northerly) (Environment Canada, 2015). The more intense northerly outflow winds are typical in winter, while southerly inflow winds occur more frequently during the summer months.

Climate models[8] for Lions Bay project a slight increase in overall annual precipitation by the year 2100 (Figure 02b). The upper 90th percentile of the models show elevated extremes, suggesting increased uncertainty in model projections or a potential rise in extreme precipitation events. A study by Jakob and Owen (2021) on the nearby North Shore Mountains projects a threefold increase in the frequency of shallow landslides by the end of the century driven by more frequent and intense precipitation events. While debris flows and other landslides along

[7] Weather data from wunderground.com based on three stations in Lions Bay. There is a 1 to 1.5 hour gap in weather data on December 14, 2024 starting at approximately 8 am PST for all stations. As a result, the recorded wind speeds and precipitation may not accurately reflect the actual weather conditions leading up to the landslide.

[8] Climate models are from ClimateData.ca with Couple Model Intercomparison Project Phase 6 (CMIP6) global climate model data. The results reflect a ~10km x 6 km grid cell containing Lions Bay.

Howe Sound may become more frequent due to projected increases in extreme rainfall events, their individual event volumes may decrease (Stoffel et al., 2024). This is because sediment supply within these watersheds requires time to recharge following major events. In other words, even if triggering conditions become more common, the availability of unstable or entrainable material may limit the size of subsequent events.

The climate models also project a significant increase in both average and extreme temperatures. Under a worst-case emission scenario, the number of days with maximum temperature exceeding 25° could increase from approximately a few weeks annually to a few months annually by the end of the century. Increased temperatures may not significantly affect the frequency or magnitude of geohazards, particularly given the absence of glaciers and permafrost in the study area. However, thermal expansion of rock during hot days can contribute to increased rockfall activity, particularly on steep, exposed slopes. Repeated cycles of heating and cooling can cause fracturing and weakening of rock faces, making them more prone to failure over time. Warmer conditions could also lead to wildfires and beetle infestations, where the loss of vegetation could increase landslide susceptibility and high runoff.

3.6 Wildfire

According to BC Wildfire Service (2025), four wildfire incidents have occurred in the study area in 1986, 2009 (2), and 2012. Most were small, nuisance fires, with the largest wildfire occurring in 2012 and affecting an area of approximately 1 hectare (Figure 04). There have been no major wildfires in recent years that would suggest an elevated post-fire debris-flow hazard in the Battani Creek watershed.

3.7 Logging

Much of the Battani Creek watershed was clearcut in the 1920s and 1930s (Forest Analysis and Inventory Branch, 2025). In the 1960s, clearcutting occurred in parts of the Magnesia Creek watershed and the upper reaches of Battani Creek, requiring the construction of extensive logging roads across the hillside (Figure 04). These roads traverse the moderate to moderately steep slopes of the upper Battani Creek watershed and are since being used as popular hiking trails, providing access to Tunnel Bluffs and other routes in the area. While these roads are not currently being used for logging, BGC is unaware if they have been deactivated or who is inspecting/maintaining them.

3.8 Development History

The earliest airphotos from the 1930s and 1940s reveal a cleared hydro corridor across the study area, but no evidence of road access or development. Permanent development occurred in the late 1950s and 1960s following the opening of the railway in 1954 and the highway in 1958. In 1962, a large debris flow on Magnesia Creek destroyed both the highway and CN Rail bridge, and swept one building off its foundation (Thurber Consultants Inc., April, 1983). Logging in the 1960s resulted in the development of an extensive logging road network in the upper watersheds.

By the 1968 airphoto, development had occurred on Brunswick Beach Road and Crystal Falls Road. The residence at 6 Glendale Avenue was constructed in 1987 (BC Assessment). Also in 1987, Water License C064497 in Battani Creek was granted to S. Vestergaard, the owner of two lots north of the Battani Creek watershed (Drawing 03). Airphotos from 1996 show a small clearing on the bedrock bench of the Vestergaard property, along with the lower switchbacks of a road accessing Goldenrod Avenue. Buildings at 1 and 2 Goldenrod Avenue were constructed in 2000 and 2007, respectively (BC Assessment).

Google Earth imagery dated April 3, 2009 shows a large clearing on the Vestergaard property with road access developed to this location. By the July 8, 2009 imagery, additional clearing had occurred at the Vestergaard property, and road construction progressed through the adjacent MoTT property. Imagery from August 6, 2012 indicates a road had been advanced from the Vestergaard property to Battani Creek (Figure 04), providing access to the water license held by S. Vestergaard. The 2012 imagery also shows widening and surfacing of roads that access the Vestergaard property from below (Figure 04). A reservoir was blasted into bedrock sometime in 2013 or 2014 where the uppermost road intercepts Battani Creek (Photos 33, 34).

On September 4 and 5, 2014, M. Watt from the Ministry of Forests, Lands & Natural Resource Operations (FLNRO, now MoF) issued two trespass notices to S. Vestergaard. These notices cited unauthorized and unstable road and reservoir construction on Crown Land, raising concerns about public safety. A report authored by S. Higman from FLNRO on October 14, 2014 identified risks from unstable fill slopes, road drainage disturbance, reservoir seepage, and reservoir overtopping that could trigger debris flows. The report warned of potentially severe consequences from debris flows, including loss of life and damage to residential properties, Highway 99, and the CN Rail corridor. The report recommended remedial measures to be undertaken at the owner's expense before the onset of the rainy season, including fill slope stabilization and drainage improvements.

In September of 2014, S. Vestergaard retained Cordilleran Geoscience (Cordilleran) to review the non-compliance identified in the trespass notices and to develop prescriptions for remedial works (Cordilleran, February 7, 2015). Following FLNRO's review of Cordilleran's report, remedial work commenced in October of 2014. At this time, the remedial works were limited to pullbacks of the reservoir fill slopes, which were authorized by Cordilleran (February 9, 2015). Minor drainage measures and slope pullbacks along the road were also undertaken; however, Cordilleran (February 9, 2015) noted these measures were not completed to a level considered satisfactory. On November 9, 2014, Cordilleran submitted a drainage plan outlining a series of prescriptions for water management along the access road[9] (Cordilleran, February 7, 2015).

The remaining remedial measures outlined by Cordilleran (February 7, 2015) were not completed by the owner, and on June 12, 2015, S. Higman of FLNRO issued a road deactivation plan. This plan included decommissioning the reservoir and implementing slope pullbacks, with some prescriptions resulting in the loss of vehicle access.

[9] This access road is part of Battani Creek Road, as referred to throughout this report and on the Drawings.

S. Vestergaard retained Westrek Geotechnical Services Ltd. (Westrek) to conduct a geotechnical review of four sites along the access road (Westrek, July 24, 2015). The objective was to develop conceptual remedial measures that would preserve long-term vehicle access and reservoir use while mitigating downslope public safety risks. FLNRO advised Westrek that no subsurface investigations for detailed design could proceed until a license of occupation was granted to the owner.

To support this license of occupation application (#100137156), JCH Forestry Ltd. (July 28, 2015) prepared a management plan on behalf of S. Vestergaard. BGC is unaware whether the license of occupation was ultimately granted.

At this time, BGC does not have access to documentation confirming whether further site investigations or remedial works were completed and authorized along the access road. However, based on desktop and field review, BGC observed several features that appear to have been constructed since the summer of 2015. These include:

- A 50 m long segment of road pulled back from the slope and blasted into rock (Location 17 on Drawing 04; Photo 23)
- A 15 m long approximately 2.5 m tall rock fall net anchored to bedrock below the segment of road pull-back listed above (Location 16 on Drawing 04; Photo 22)
- A 70 m long ditch and berm in the benchland area below the reservoir access road (Location 18 on Drawing 04; Photo 24)
- A 10 m long concrete sill at the north side of the reservoir (Location 24 on Drawing 04; Photos 33, 34).

3.9 Field Observations

This section summarizes BGC's field observations. Reference locations and annotations are shown on the map in Drawing 04. Referenced field photos are included in the Photographs attachment.

3.9.1 Lower Battani Creek and Magnesia Creek

- The lower Battani Creek channel (downstream of the reservoir) is stripped of vegetation along a 15 to 25 m wide path following the December 14, 2024 landslide (e.g., Photos 40, 41). In many locations, the channel is scoured to bedrock (e.g., Photo 10) or glacial soils. Some fallen trees, woody debris, and soil remain in the channel (e.g., Photo 39).
- A large planar rock face dipping approximately 60° to the northwest is exposed in the left (south) flank of the Battani Creek landslide headscarp (Location 25; Photo 36). Locally, there is 0.5 to 1 m of soft, saturated, organic soil and cut stumps to the north of the headscarp (Photo 37). BGC observed seepage at the toe of exposed bedrock slopes below the left (south) flank of the headscarp (Photo 38).
- At the outlet of Battani Creek near Highway 99, Battani Creek turns 90° to the south toward Magnesia Creek, flowing along an approximately 1.5 m high and 25 m long berm constructed from landslide debris in the days following the December 14, 2024 landslide (Location 3; Photos 3, 4). The berm forms a small basin between Battani Creek and

Highway 99, which BGC estimates to have a capacity of approximately 100 to 200 m^3. At the south end of the berm, Battani Creek enters Magnesia Creek upstream of the Highway 99 bridge through a 30-inch steel culvert armoured with boulders.

- Near the Highway 99 bridge, Magnesia Creek flows through a deep and wide trapezoidal channel armoured with grouted riprap (Location 2; Photo 2).
- The CN bridge on Magnesia Creek is a concrete box culvert bridge with an approximately 8 m wide opening and a minimum clearance of 2.2 m on the upstream side (Location 1; Photo 1).
- The Glendale Avenue bridge on Magnesia Creek is a steel girder bridge with a maximum clearance of approximately 3.3 m at the channel thalweg in bedrock (Location 4, Photo 5).

3.9.2 Battani Creek Road and Reservoir

For the purposes of this report, Battani Creek Road refers to the roads beyond the Glendale Avenue Bridge that provide access to the Goldenrod Avenue properties, the Vestergaard properties, and the Battani Creek reservoir, and excludes driveways accessing the Goldenrod Avenue and Glendale Avenue properties (Drawing 03). The legal status of certain roadways in the area is uncertain. BGC will refer to roadways on the basis of what BGC understands to be names used in the community or otherwise, but in using those names, BGC is not implying they are lawfully established roads (e.g., Battani Creek Road).

- Battani Creek Road is of cut-and-fill construction. Fill slopes consist of angular shot rock sourced from blasting during road construction. Many of the fill slopes along the lower switchbacks are oversteepened[10], with maximum slope angles ranging from approximately 40 to 50° (e.g., Location 9; Photos 12, 13). Outside of the Village boundary between the edge of the MoTT property and the reservoir, fill slopes are less steep, with maximum slope angles ranging from approximately 35 to 37° (e.g., Location 20; Photo 27).
- The first switchback at Location 6 (Photo 8, 9) is supported by a steep rock-stack wall, which Cordilleran (February 7, 2015) identifies as engineered and signed-off by Baumann Engineering. The rock-stack wall appeared intact but logs and woody debris have been dumped over the edge.
- Open tension cracks are present in the road surface at Location 14 (Photo 20). Here, a small fill slope failure approximately 5 m wide has occurred.
- A larger fill slope failure, approximately 10 m wide, has occurred at the switchback at Location 10 (Photo 14). This failure likely coincided with the December 14, 2024 landslide, which possibly destabilized the toe of the fill.
- Deteriorating log crib structures that hold back fill are present along the road. At Location 11, one of the log cribs has snapped (Photo 15). At Location 12, a water tank, which was currently full and in operation at the time of BGC's July 24, 2025 site visit, rests on a concrete pad at the slope edge, supported by rotting log cribs (Photos 16, 17). At

[10] Forest Road Engineering Guidebook recommends fill slope angle of 33-38° for road fill composed of dumped angular rock (Forest Practices Code of British Columbia, June 2002).

Location 19, an approximately 1.5 m diameter boulder sits on top of fill supported by log cribs anchored to a leaning tree (Photo 25). At this location, fill has failed behind a portion of the log cribs, and there are fill boulders that have rolled down slope, coming to a rest on a local topographic bench.

- Logs and woody debris are present within and dumped on top of several fill slopes (e.g., Photos 9, 12, 13, 19).
- Most road cuts are blasted into heavily fractured and faulted bedrock (e.g., Photo 18). A recent rock wedge failure has occurred at Location 20 (Photo 28). BGC observed groundwater seepage emerging from several road cuts during the field visit at the end of April.
- Roadside ditches are largely unmaintained and partially obstructed by rockfall and vegetation overgrowth (e.g., Photo 31). BGC identified only three culverts along the road, two of which had partially blocked intakes. There were no cross ditches or swales, despite their inclusion in Cordilleran's November 9, 2014 drainage plan (Cordilleran, February 7, 2015).
- At the time of inspection, the reservoir had approximately 0.45 m of freeboard to the top of the concrete sill, with a total water depth of approximately 2 m along the concrete sill (Photo 33, 34). The concrete sill appeared intact. The reservoir outlet/spillway was overgrown with alders and measured approximately 0.45 m deep, with a bottom width of 1.6 m and top width of 3.5 m (Photo 35).

3.9.3 Upper Battani Creek Watershed

- Upstream of the reservoir, Battani Creek meanders through the underbrush and deadfall in weakly confined channels (Photo 32).
- Broad and densely forested V-shaped gullies show no signs of active sediment transport or recent debris-flow activity (Photo 42).
- The legacy logging roads that cross the upper Battani Creek watershed along-contour have poorly defined ditches and swales that direct flow over the edge of the road (Photo 43). BGC noted minor signs of settling in the road fill, but no major road failures or washouts within the watershed boundary.

4.0 HAZARD ASSESSMENT

4.1 Introduction

The purpose of the hazard assessment is to characterize the magnitude, probability of occurrence, and spatial impacts of hazard scenarios that could affect people and assets within the study area. The outcomes of the hazard assessment were used to inform the risk assessment (Section 5.0), hazard mapping (Section 6.0), and conceptual mitigation (Section 6.0).

This hazard assessment is limited to debris flows and debris avalanches occurring within the Battani Creek watershed or along the Battani Creek Road (Drawing 01), including those that initiate as debris slides, rock falls/slides, road failures, and reservoir failures. It excludes hazards such as local rock fall, snow avalanches, rock avalanches, earthquake-triggered landslides, post-wildfire debris flows, and debris flows or debris floods originating from the Magnesia Creek watershed.

4.2 Hazard Scenarios

BGC developed a suite of representative hazard scenarios to model the range of hazard frequencies and magnitudes that could affect the study area (Figure 06). Scenario development was informed by terrain interpretation, field observations, regional geohazard analogs, and site-specific observations from the December 14, 2024 landslide, as detailed in Section 3.0. The geohazard scenarios, labelled on Figure 06, are:

1. **Upper Watershed Open-Slope Landslide Transitioning to Debris Flow:** A landslide initiating on moderately steep terrain in the upper watershed as either a road fill failure, rock slope failure, or debris slide in the topsoil/glacial till, that transitions into a debris flow on Battani Creek. This scenario captures a relatively rare, but potentially high-volume debris flow due to the extended travel path and available entrainable material.
2. **Lower Watershed Open-Slope Landslide Transitioning to Debris Flow:** A landslide initiating on slopes previously identified as potentially unstable by Cordilleran (June 29, 2018), that transitions into a debris flow along a sub-drainage to Battani Creek. This scenario has the potential to bulk in volume as it becomes channelized down the sub-drainage, and is a scenario where flow could be oriented towards the Goldenrod Avenue properties where the sub-drainage joins with the main Battani Creek channel.
3. **Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow:** A rock slope failure occurring downslope of the Battani Creek reservoir, representing either an expansion of the December 14, 2024 landslide headscarp or a similar failure mechanism.
4. **Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow:** Road fill failure, caused by saturation of the fill slope and underlying organic soils due to poor drainage maintenance (e.g., blocked ditches and culverts) and/or collapse of buried log crib structures, directed toward Battani Creek and transitioning into a debris flow.
5. **Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche:** A structural failure of log crib retaining structures on the MoTT

property, resulting in a debris avalanche directed toward Highway 99. This scenario reflects a worst-case condition involving sudden collapse of a portion of the upslope structure, sustained momentum downslope, and entrainment of topsoil and debris along the steep slopes toward Highway 99. While not explicitly modelled as part of this scenario, BGC has also identified the potential rock fall from this location, discussed further in this report.

The defined scenarios emphasize sudden, rapid slope failures that evolve into flow-type landslides of similar nature to the December 14, 2024 event. The scenarios exclude localized slumping or minor roadbed failures, as well as secondary effects stemming from such failures, such as dislodged boulders rolling downslope or trees being toppled onto structures. This delineation ensures the focus remains on primary, high-consequence hazard processes rather than incidental or compound effects that fall outside the scope of the work.

4.3 Magnitude

BGC estimated total bulked volumes for each hazard scenario by combining initial failure volumes with additional material entrained along the flow path.

For failures initiating at roads, BGC assumed an initial volume of approximately 200 m^3, consistent with the observed road fill failure at the switchback at Location 10 (Photo 14). For open slope landslide scenarios, BGC assumed an initial volume of approximately 100 m^3 based on the estimated headscarp volume of the December 14, 2024 landslide. These assumptions are consistent with documented cases of small point-source landslides triggering large debris flows in the Sea-to-Sky corridor, such as the October 28, 1981 debris flow on M (Yahoo) Creek. That event was initiated by a small debris avalanche which ultimately mobilized a debris flow with an estimated total volume of 20,000 m^3 and causing nine fatalities (Hungr et al., 1984).

For the rock slope failure scenario (Scenario 3), BGC estimated three credible initial volumes based on field observations and geometric projection of failure planes through the rock mass located south of the existing headscarp.

To estimate volumes of sediment eroded and incorporated into debris flows, BGC applied yield rates, defined as the volume of eroded material per unit length of channel, based on terrain characteristics, debris availability, and back-calculated values from the December 14, 2024 landslide event (Figure 05). BGC assumed the following yield rates:

- 15 to 20 m^3/m along undisturbed, channelized reaches where steep, concentrated flow promote high entrainment
- 8 to 10 m^3/m along undisturbed, open-slope (unchannelized) terrain
- 5 m^3/m along the upper portion of the scoured Battani Creek landslide path where there is some material left behind by the landslide (e.g., Photo 39)
- 3 m^3/m along the lower portion of the scoured Battani Creek landslide path where there is limited material to entrain (e.g., Photo 10).

To account for the incorporation of soil/rock expansion, pore water, and the incorporation of organic material into the flow, BGC applied location-specific bulking factors to the volumes:

- 50% along densely forested areas, to account for abundant woody debris
- 20% for rock mass failures, to account for rock expansion
- 10% along the scoured Battani Creek landslide path, to account for trees that fall into the channel during or prior to a debris flow.

Final volume estimates are presented in Table 4-1. None of the scenarios exceed the total volume of the December 14, 2024 landslide, estimated at approximately 15,000 m^3. This is partly attributed to the depletion of erodible debris following that event, which scoured Battani Creek to bedrock. While larger, deeper-seated instabilities are possible, BGC judges these to be rare and likely beyond the return period recommended by EGBC (2023) for geohazard assessments at small subdivisions (up to a 1:1,000 year return period for <5 single family lots). As an additional check, BGC analyzed Thurber's (April 1983) estimates of maximum available debris for watersheds along the Sea-to-Sky corridor. When scaled by watershed area and total channel lengths, these data suggest that the Battani Creek watershed contains approximately 10,000 m^3 to 20,000 m^3 of available debris, representing an upper bound on credible event magnitudes.

The single volume values presented reflect best-approximation inputs for the purposes of numerical modeling. While these estimates are grounded in observed data and geomorphic reasoning, they carry substantial uncertainty. Actual volumes may reasonably vary from approximately 50% below to 100% above the stated values, but are not expected to change the outcomes of this assessment.

Table 4-1 Hazard scenario volumes.

Hazard Scenario	Initial Point Source Volume (m^3)	Entrained Sediment Volume (m^3)	Volume from Bulking (m^3)	Total Bulked Volume (m^3)
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	200	9,200	3,700	13,100
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	100	4,500	1,900	6,500
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	100 (small) 600 (moderate) 3,000 (large)	2,100 (small) 3,100 (moderate) 3,100 (large)	200 (small) 400 (moderate) 900 (large)	2,400 (small) 4,100 (moderate) 7,000 (large)
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	200	4,700	1,800	6,700
5. Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche	200	2,100	1,000	3,300

4.4 Probability of Occurrence

Hazard scenario probabilities, expressed as an average annual probability of occurrence, are summarized in Table 4-2.

In typical settings, hazard occurrence probabilities are informed by frequency estimates of past events. This involves developing a geochronology based on historical event records, airphoto interpretation, dendrochronology (e.g., dating impact scars on tree rings), test-pitting and radiocarbon dating of debris-flow deposits on alluvial fans, and other techniques. However, at Battani Creek, there are no alluvial fans for test pitting or applying regional empirical frequency-magnitude relationships (Jakob et al., 2020). Additionally, trees along the active channel that might have recorded episodic debris-flow impacts were destroyed during the December 14, 2024 event. Furthermore, due to the recent construction of the Battani Creek Road, the pre-construction historical record may no longer serve as a reliable indicator of future geohazard activity. Given the absence of conventional methods for reconstructing event chronologies and the possible changed geomorphic conditions in the watershed, there is substantial uncertainty in the probability estimates.

As a result, BGC assigned probability “ranges” to each scenario based on professional judgment and project

BGC took the following factors into consideration when assigning probabilities:

- **Historical Occurrence and Airphoto Evidence:** One landslide initiated near the Battani Creek reservoir on December 14, 2024, approximately 12 to 13 years after its

construction. Aside from this event, there is no evidence of floods, debris flows, or debris avalanches originating from the Battani Creek watershed dating back to the earliest airphoto record in 1939.

- **Road Infrastructure Observations:** Tension cracks, fill slope failure scarps, and failed portions of deteriorating log cribs structures indicate active slope instability along portions of Battani Creek Road (summary of field observations in Section 3.9). BGC noted minor settlement along logging roads in the upper watershed; however, no major road failures or washouts have occurred since their construction in the 1960s.
- **Slope and Terrain Characteristics:** The Battani Creek watershed is characterized by steep bedrock bluffs, bedrock plateaus, and moderately steep soil-mantled slopes (Figure 01, Drawing 02). However, it is much less steep, rugged, and incised compared to other watersheds along the Sea-to-Sky corridor with a history of landsliding. Most slopes in the upper watershed are below the “potentially active” threshold of >60% applied by Cordilleran (June 29, 2018), suggesting reduced landslide activity here.
- **Relative Age of Soil:** The upper watershed is mantled by a thin veneer of glacial till, indicating lower landslide frequency relative to nearby watersheds dominated by colluvial soils derived from active landslide processes (Blais-Stevens, 2008) (Drawing 02). Glacial soils exposed along Battani Creek suggest that, at these locations, a debris flow has not scoured to bedrock or deposited here in thousands of years.
- **Relative Age of Trees:** The age of logged stumps and standing timber in the upper watershed suggests that no debris flow or debris avalanche large enough to destroy tree stands has occurred in hundreds of years.
- **Average Regional Landslide Frequency-Density:** A compiled geohazard inventory along the Sea-to-Sky corridor (Section 2.5) indicates an overall landslide density-frequency of 0.0003 landslides/hectare/year. Studies by O’Loughlin (1972), Rood (1984), and Jakob (2000) report lower rates - approximately 0.0001 landslides/hectare/year - in natural, unlogged terrain across the Coast Mountains, Haida Gwaii, and Clayoquot Sound, BC. In contrast, data from Brardinoni & Church (2004) suggest much higher rates of 0.005 landslides/hectare/year in the Capilano Watershed east of the study area. Based on the terrain of the Battani Creek, BGC estimates a representative landslide density of 0.0001 landslides/hectare/year, equating to an average frequency 1 in 140 years for a landslide occurring anywhere in the watershed. The average landslide frequency-density from the hazard scenarios was checked against this number.
- **Average Regional Logging Road Failure Frequency-Density:** The logging road failure rate from the compiled landslide inventory along the Sea-to-Sky corridor (Section 2.5) is 0.03 per km/year. The coastal BC road failure data from Guthrie (2002) suggest 0.04 failures/km/year, while road failure data from Rood (1984) on Haida Gwaii suggest a higher rate of 0.18 failures/km/year. For any 100 m section of logging road, these rates suggest an average road failure frequency of approximately 1 in 50 to 1 in 100 years. However, given the Battani Creek Road fill is comprised of free-draining, angular blast-derived shot rock, BGC assumes the probability that a road failure transitions into a debris flow, per the scenario definitions, is likely lower.

Table 4-2 Hazard scenario probability estimates.

Hazard Scenario	Total Bulked Volume (m^3)	Annual Probability Range	Representative Annual Probability
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	13,100	1:300 to 1:1,000	1:500
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	6,500	1:300 to 1:1,000	1:500
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	2,400 (small) 4,100 (moderate) 7,000 (large)	1:10 to 1:30 1:30 to 1:100 1:300 to 1:1,000	1:20 1:50 1:500
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	6,700	1:100 to 1:300	1:200
5. Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche	3,300	1:100 to 1:300	1:200

4.5 Runout Assessment

4.5.1 Introduction

The purpose of the runout assessment is to estimate the runout extents and flow intensity of the hazard scenarios. BGC used the numerical model DAN3D to simulate landslide motion across the terrain. Figures showing the model results are provided in Appendix A.

4.5.2 Model Overview

DAN3D (McDougall & Hungr, 2004) is a commercially available and commonly used semi-empirical, depth-averaged model designed to simulate the motion of rapid landslides over complex three-dimensional terrain. It simulates landslide motion from initiation to deposition and is well-suited for processes like debris avalanches and debris flows. The model requires several key inputs: a digital elevation model (DEM) to define the sliding surface, the extent and thickness of the initiating landslide mass, the extent and thickness of erodible material along the potential flow path, a user-specified entrainment rate to simulate volumetric growth during motion, bulk density of the flowing material, and flow resistance parameters that govern landslide mobility (i.e., defining how far and how fast the landslide travels).

BGC used the Voellmy rheological model within DAN3D to define the basal shear resistance of the flowing mass. The Voellmy model is defined with two parameters: 1) a friction coefficient, f, which determines the slope angle at which material begins to deposit, and 2) a turbulence parameter, ξ, which introduces a velocity-dependent flow resistance that acts to limit flow speed.

4.5.3 Calibration

Using the calibration methodology described in Aaron et al. (2019), BGC selected flow resistance parameters to best match the estimated peak flow depths, velocities, and runout extents of the December 14, 2024 landslide (Section 3.4.3). Calibration results are provided in Figure A-1 of Appendix A. For the calibration, the sliding surface was derived from the 2019 lidar (pre-event topography), down-sampled to a 3 x 3 m grid and smoothed to improve numerical stability. BGC assumed an initial landslide volume of 100 m^3, a bulk density of 17 kN/m^3 to account for water and organic content in the flow, and set an entrainment rate such that the model reached a final volume of approximately 15,000 m^3. The resulting calibrated parameters were f of 0.25 and ξ of 700 m/s^2. For reference, GEO (2011) recommends a f of 0.20 and ξ of 500 m/s^2 for modelling saturated, channelized debris flows in Hong Kong. BGC also adopted the GEO (2011) parameters with the lower friction coefficient of 0.20 to reflect more mobile flow behaviour for select scenarios, described in the following section. As an additional check, BGC (March 28, 2013) previously applied f of 0.25 and ξ of 500 m/s^2 for modelling high-mobility debris flows with DAN3D at the Bayview Creek fan in Lions Bay.

4.5.4 Model Scenarios

BGC modelled scenarios with DAN3D as single release points at locations judged to be representative of broader areas where landslide initiation is plausible (Figure 06). BGC did not explicitly model a failure of the fill slope supporting the water tank (Location 12, Drawing 04), or retrogression of the fill slope failure at the switchback (Location 10, Drawing 04), as the total volume and expected downslope impacts are captured by other scenarios. However, these are potential hazard initiation points for which BGC has provided mitigation recommendations in Section 7.0.

BGC set entrainment rates and maximum erodible depths to achieve the bulked volumes defined in Section 4.3 and to match observed field conditions.

The sliding surface was derived from the 2025 lidar, down-sampled to a 3 x 3 m grid and smoothed to improve numerical stability.

BGC applied the calibrated Voellmy parameters f of 0.25 and ξ of 700 m/s^2 to simulate average mobility of landslides on Battani Creek. “High mobility” simulations with f of 0.20 and ξ of 500 m/s^2 were also used for select scenarios, such as models where flow stalled in the channel with the calibrated parameter set. Based on site conditions, BGC judges the high mobility scenario to be less likely, assigning it a conditional probability of 0.1. In contrast, the calibrated parameter set is judged to be more representative of expected flow behaviour, with a conditional probability of 0.9.

In Scenario 2 with high mobility parameters (Model 2B), modelled flow depths approached the estimated CN rail bridge capacity at Magnesia Creek (Photo 1). To reflect a possible flow obstruction and avulsion here, BGC manually modified the topography to simulate a bridge blockage. For all other scenarios, BGC did not simulate blocked bridges or force avulsions

through topographic changes. This decision was based on modelled flow behaviour, site conditions, and the absence of indicators suggesting likely blockage or redirection.

Key input parameters for each model are summarized in the tables included with the result figures in Appendix A.

4.5.5 Results and Discussion

Numerical modelling results are provided in Appendix A and summarized in Table 4-3.

Many of the models impact the Glendale section of Battani Creek Road and Highway 99. In the absence of mitigation, debris flows or debris avalanches may reach the Glendale section of Battani Creek Road with an upper-bound annual probability of 1:10 (Drawing 05). For Highway 99, debris flows descending Battani Creek may impact Highway 99 with an upper-bound annual probability of 1:30 (Drawing 05). Debris avalanches from the MoTT property may impact Highway 99 with an upper-bound annual probability of 1:100 (Drawing 05), however, individual rock blocks released from the log crib structure may have a higher likelihood of occurring and reaching the road[11]. The impact to life-safety of vehicle occupants and the service interruption is described in the risk assessment (Section 5.0).

None of the models show direct impacts to current building structures within the study area. While some of the modelled scenarios reach Magnesia Creek, they lack the volume and mobility required to directly impact buildings on Crystal Falls Road or Brunswick Beach Road. For a few scenarios, BGC estimates there may be damages to some properties from mudsplash, passing debris, and watery after-flows, but these do not pose a significant life-safety risk.

At 1 and 2 Goldenrod Avenue, Battani Creek is steep and deeply incised, promoting flow conveyance. The December 14, 2024 landslide incised the channel by approximately 2 to 3 m down to bedrock, resulting in a total maximum confinement depth of approximately 7 to 8 m directly upstream of the buildings (Figure 05; Photo 10). Based on a channel cross-section area of approximately 50 m^2 and assuming a debris-flow velocity of 10 m/s, a peak discharge of approximately 500 m^3/s would be required to exceed the channel capacity here. Applying an empirical formula relating peak discharge and sediment volume for granular debris flows in British Columbia (Bovis & Jakob, 1999), this corresponds to a sediment volume of approximately 28,000 m^3, exceeding volume estimates for the defined hazard scenarios (Table 4-1). Although the channel confinement will gradually decrease over time as it fills with organic debris and soil, full reversion to pre-landslide conditions will take many hundreds, possibly thousands, of years under natural conditions. In the short term, trees that fall into the channel are likely to be transported downstream by high-velocity flows and are unlikely to cause major avulsions in this section of the channel in a manner that directs flow toward existing properties.

[11] The potential runout and risk associated with rock falls are not included in this assessment. However, BGC estimates that rock fall from a collapse of the log crib structure on the MoTT property is very likely given the presence of large boulders supported by deteriorating log crib structures and observed rock fall blocks present down slope. From a preliminary estimate, a rock fall with sufficient momentum to reach Highway 99 likely falls in the probability class of 1:10 to 1:30 chance per year.

Table 4-3 Runout assessment results from numerical modelling with DAN3D (Appendix A). Table shading highlights relative increase in exposure (grey = no impact, yellows = impacts).

Hazard Scenario	Model Sub-Scenario	Model Impacts			
		Current Buildings[3]	Battani Creek Road[4]	Highway 99[4]	CN Rail[4]
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	1A. Calibrated Mobility	No direct impact	No direct impact	No direct impact	No direct impact
	1B. High Mobility	No direct impact	Direct impact (20 m flow width)	Direct impact, both lanes (30 m flow width)	Flow reaches bridge
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	2A. Calibrated Mobility	No direct impact	Direct impact (20 m wide)	Direct impact, both lanes (30 m flow width)	Flow reaches bridge
	2B. High Mobility, Blocked CN Rail Bridge	Possible damages[1] to 61 Brunswick Beach Rd.	Direct impact (20 m wide)	Direct impact, both lanes (30 m flow width)	Direct impact to tracks (30 m flow width)
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	3A. Small	No direct impact	Direct impact (10 m flow width)	No direct impact	No direct impact
	3B. Moderate	No direct impact	Direct impact (15 m flow width)	Direct impact, northbound lane (15 m flow width)	Flow reaches bridge
	3C. Large	Possible damages[2] to 2 Goldenrod Ave.	Direct impact (20 m flow width) Flow reaches water tank and Glendale Ave. bridge	Direct impact, northbound lane (20 m flow width)	Flow reaches bridge
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	4A. Calibrated Mobility	No direct impact	No direct impact	No direct impact	No direct impact
	4B. High Mobility	No direct impact	Direct impact (10 m flow width)	Direct impact, northbound lane (15 m flow width)	Flow reaches bridge
5. Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche	5. Calibrated Mobility	N/A	N/A	Direct impact, both lanes (60 m flow width)	Direct impact to tracks (50 m flow width)

Notes:

1. While DAN3D does not simulate debris directly impacting 61 Brunswick Beach Rd., there is potential for property damage resulting from watery after-flows if the CN Rail bridge is blocked and flow avulses the channel. Minor impacts could include flooding and sedimentation of the surrounding property, but flows are unlikely to enter the building.
2. While DAN3D does not simulate debris directly impacting 2 Goldenrod Avenue, there is potential for property damage resulting from passing debris or mud splash due to the proximity to the channel. Minor impacts could include damages to siding, windows, and external support structures at the southern side of the building.
3. Current buildings do not include the previous structure at 6 Glendale Avenue.
4. Reported flow widths represent the width of the main landslide surge, and do not include spreading or afterflow occurring after initial impact.

4.5.6 Uncertainties and Limitations

The results of the runout assessment should not be interpreted as precise predictions of future flow behaviour. They are derived from a numerical model that simplifies complex physical processes and relies on assumptions and input data that carry inherent uncertainty. Key limitations and sources of model uncertainty specific include:

- **Homogeneous Flow Assumption:** DAN3D treats the flow as a single-phase homogeneous fluid, combining water, sediment, and organic debris. It cannot simulate the complex interactions between fluid and solid phases (e.g., boulder transport, woody debris dynamics). Additionally, post-deposition processes such as flooding or sedimentation from dewatering (i.e., watery after-flows) are not explicitly modelled and must be interpreted from the results.
- **Simplified Erosion and Deposition:** While DAN3D allows for entrainment to simulate volumetric growth, it does not dynamically model erosion or deposition processes during flow. Consequently, changes to channel geometry, such as scour or channel plugs, must be defined a-priori and incorporated into the model topography rather than evolving during the simulation. Given the depth to bedrock at this site, BGC does not expect significant scour that could change flow trajectories. Besides the CN Rail bridge blockage scenario (2B), BGC does not expect channel plugs to develop during an event that significantly change flow behaviour in the steep and confined reaches of Battani Creek.
- **Static Topography:** The terrain used in the model is based on the 2025 lidar dataset, representing a single moment in time. Future landscape modifications (e.g., mitigation structures, road construction, erosion, channel migration, landslide deposits) may alter flow paths and thus the outcomes of the runout assessment.
- **Absence of Surface Structures:** The model does not incorporate three-dimensional natural (e.g., vegetation) or human-made (e.g., buildings, bridges) surface features. These elements can influence flow behaviour by restricting, concentrating, or redirecting flow.
- **Resolution Constraints:** The model uses a down-sampled and smoothed 3 × 3 m grid, which excludes topographic features smaller than this resolution that may affect local flow behaviour. Based on experience with similar-scale events, the influence of sub-grid terrain features is considered minor.

5.0 RISK ASSESSMENT

5.1 Introduction

Risk assessment is the process of characterizing the hazard, identifying elements at risk, and evaluating their vulnerability to potential losses. The purpose of this risk assessment is to evaluate risk levels to properties and roads given current conditions, compare risk levels against other risk tolerance criteria adopted in other jurisdictions in British Columbia, and inform decision-making regarding risk reduction measures.

The scope of the risk assessment is limited to:

- Life-safety risk of people inside buildings
- Life-safety risk of motorists on Highway 99 and Battani Creek Road
- Economic costs associated with emergency response
- Estimated service interruption durations for Highway 99.

The following are excluded from the risk assessment:

- Life-safety risk to people outside of buildings or vehicles (e.g., pedestrians, cyclists)
- Economic losses related to vehicle damage, business interruption, revenue or rental income loss, supply chain disruptions, CN rail service interruption, or litigation
- Intangible impacts, such as reputational damage and loss of public trust, effects on public health and quality of life, and disruptions to the environment or local ecosystems
- Risk from debris flows or debris floods that originate from the Magnesia Creek watershed or any other adjacent slope areas outside of the Battani Creek watershed.

Tables summarizing the risk calculations are provided in Appendix B.

5.2 Methods

As none of the assessed geohazards are expected to directly impact buildings (see Section 4.5.5 for discussion), the methods presented are specific to life-safety risk calculations for motorists. Accordingly, the risk level to people inside buildings was assessed to be negligible (see Section 5.4.1 for discussion).

5.2.1 Individual Risk

Individual risk evaluates the probability a person who spends the greatest proportion of time at a specific location is killed by a hazard. BGC calculated individual risk for motorists with Equation (1):

$$PDI = \sum_{i=1}^{n} h_i S_i T_i V_i \qquad \text{Eq. (1)}$$

Where:

- PDI is the annual probability of death of an individual (years^{-1})
- h_i is the annual probability of a hazard scenario (i) occurring (years^{-1})

- S_i is the conditional probability that scenario (i) reaches the road (i.e., spatial probability of impact)
- T_i is the conditional probability the individual is present during scenario (i) (i.e., temporal probability)
- V_i is the conditional probability of fatality given impact by the estimated scenario (i)'s intensity (i.e., vulnerability)
- n is the total number of scenarios (i) included in the assessment.

5.2.2 Group Risk

Group risk evaluates the number of people that could be killed by a scenario, considering all people exposed. BGC estimated the expected number of fatalities (N_i) for each scenario (i) with Equation (2):

$$N_i = E_i V_i \quad \text{Eq. (2)}$$

Where:

- E_i is the number of people exposed to scenario (i)
- V_i is the conditional probability of fatality given impact by the estimated scenario (i)'s intensity (i.e., vulnerability).

Group risk can be expressed as an annual probable life loss (PLL), which is the expected number of fatalities in a year, calculated with Equation (3):

$$PLL = \sum_{i=1}^{n} h_i S_i T_i N_i \quad \text{Eq. (3)}$$

PLL can also be expressed over a longer time frame, such as the expected number of fatalities accumulated over 100 years from all hazard scenarios. For clarity, the term 'expected' is a statistical measure of risk for the range of scenarios considered.

5.2.3 Risk Scenarios

A risk scenario represents a distinct set of conditions that may lead to different outcomes. It includes different hazard scenarios defined in Section 4.2, but also different exposure conditions, such as whether the landslide occurs during heavy traffic or not. For life-safety risk to road users, BGC included the following scenarios:

- Debris directly impacts vehicles during regular traffic (day and night)
- Vehicle collides with debris already deposited on the road (day and night)
- Debris directly impacts vehicles during standing traffic.

These scenarios are illustrated as risk chains in Figure 07. Separate branches for day and night account for differences in traffic volume, environmental conditions (e.g., sight lines), and driver behaviour. The standing traffic scenario represents a maximum probable exposure case, useful for bounding the upper end of fatality estimates. Based on observed road-use patterns along Battani Creek Road, BGC determined that the likelihood of standing traffic or a vehicle driving into debris after the event is negligible on Battani Creek Road, and excluded these scenarios from the risk chain.

5.2.4 Hazard Scenario Probability (h_i)

BGC based h_i on the average probability of occurrence in a given year, using the representative (best-estimate) in Table 4-2. For different sub-scenarios (e.g., high mobility vs. calibrated mobility; day vs. night), h_i was multiplied by the estimated conditional probability of the respective sub-scenario.

For the standing traffic scenario, BGC calculated its conditional probability based on the proportion of the year during which standing traffic is expected to occur. This was estimated based on the frequency of major traffic incidents in Lions Bay. Using crash statistics[12] from the Insurance Corporation of British Columbia (ICBC), which reports approximately 2.5 casualty-related crashes per year in the area, BGC assumed each incident results in a traffic disruption lasting roughly four hours. The assessment further assumes that only one direction of traffic is affected, and that there is a 50% chance the traffic queue aligns with the landslide path.

5.2.5 Spatial Impact Probability (S_i)

BGC derived the spatial impact probability from the results of the runout assessment (Section 4.5). A probability of 1 corresponds to scenarios with models that reach the road surface, and 0 with models showing debris stopping upslope of the road.

Other spatial factors, such as the spatial probability of a vehicle being in a section of roadway exposed to a hazard, are accounted for in other terms.

5.2.6 Exposure Length (L_i)

The exposure length refers to the length of road where a vehicle may be subject to consequences for a given scenario. It is used to calculate other terms in the risk equation.

For scenarios where debris directly impacts vehicles, exposure length is defined as the width of the flowing landslide at the point of road impact. These widths were estimated from numerical modelling results and are listed in Table 4-3.

For scenarios where vehicles impact debris, BGC assumed the exposure length to be the length of road where vehicles are within the estimated stopping sight distance (SSD). This is the distance required to perceive, react, and brake to a full stop. BGC assumed vehicles travelling within this distance are likely to impact debris during or shortly following the landslide. SSD was calculated with Equation (4) from Transport Canada's Geometric Design Guide Formula:

$$SSD = 0.278sv + \frac{v^2}{254f} \quad \text{Eq. (4)}$$

Where:

- SSD is the distance required to bring a vehicle to a stop (m)
- s is the reaction time (s)
- v is the maximum road operating speed (km/hour)

[12] Based on 10 reported crashes with casualties in Lions Bay between 2019 and 2023 (ICBC).

- f is the coefficient of friction between tires and the roadway.

Assuming an average reaction time of 1.5 seconds, posted speed limit within Lions Bay of 60 km/hour[13] on Highway 99, wet pavement corresponding to a friction coefficient of 0.33 for vehicles travelling at the posted speed limit, the SSD is approximately 68 m. The estimate does not account for factors such as road curvature, grade, lighting conditions, excessive speeding, or driver impairment.

5.2.7 Temporal Impact Probability (T_i)

For individual risk, BGC estimated the temporal probability as the proportion of time a hypothetical person spends within an exposure length (Section 5.3.3) over the course of a year given an average vehicle speed. This is calculated for the person "most at risk" (i.e., who spends the greatest proportion of time on the road). For Highway 99, this individual is assumed to commute five times per week, year-round, between Squamish and Vancouver, and travelling at the posted speed limit of 60 km/hour[13] in this section. For Battani Creek Road, the highest exposure is attributed to a resident of 1 or 2 Goldenrod Avenue who is assumed to make two return trips per day, year-round, travelling 10 km/hour along this road.

5.2.8 Exposed Population (E_i)

For regular traffic scenarios, BGC estimated the number of people exposed (E_i) in scenario (i) with Equation (5) modified from Nicolet et al. (2016):

$$E_i = \frac{t_i\,(L_v + L_i)\,n}{v} \qquad \text{Eq. (5)}$$

Where:

- t_i is the average traffic volume for scenario (i), expressed as the number of vehicles per unit time
- L_v is the average vehicle length
- L_i is the exposure road length for scenario (i)
- n is the average number of occupants per vehicle
- v is the average vehicle speed.

For scenarios where vehicles impact debris at night, BGC assumed one additional vehicle outside of the stopping sight distance impacts landslide debris on the road. Any following vehicles, or those during the daytime outside of the stopping sight distance, are assumed to slow down in time or avoid striking the landslide debris.

For scenarios where debris directly impacts standing traffic, the number of people exposed (E_i) in scenario (i) was estimated using Equation (6):

[13] Drivers may be travelling at speeds higher than the posted speed limit. The risk calculations are relatively insensitive to speeds within the typical range of 60 to 80 km/hour for regular traffic conditions along this section of Highway 99.

$$E_i = \frac{nlL_i}{L_v + L_s}$$ Eq. (6)

Where:

- n is the average number of occupants per vehicle
- l are the number of lanes
- L_i is the exposure road length for scenario (i)
- L_v is the average vehicle length
- L_s is the average space between vehicles in traffic.

Table 5-1 summarizes the values assumed for the terms in Equations (5) and (6).

Table 5-1 Assumed values for exposed population calculations.

Term	Highway 99	Battani Creek Road
Traffic volume (t_i)	1266 vehicles/hour (daytime)[1] 305 vehicles/hour (nighttime)[1]	0.3 vehicles/hour[2]
Vehicle length (L_v)	6 m	6 m
Exposure length (L_i)	See Section 5.3.3	See Section 5.3.3
Vehicle speed (v)	60 km/hour[3]	10 km/hour
Number of occupants per vehicle (n)	2	2
Number of lanes (l)	2 lanes/direction	N/A
Space between vehicles in traffic	2 m	N/A

Notes:

1. Average hourly counts for all lanes from January 2025 for daytime (7 am to 7 pm) and nighttime (7 pm to 7 am) from Eagle Ridge (P-99-01NS-N) station near Horseshoe Bay (MoTT Traffic Data Program). Only hourly counts for the month of January were available.
2. Equivalent to 8 vehicles/day, assuming two return trips per day for each of the two residences on Goldenrod Avenue.

5.2.9 Vulnerability ($V_{i,j}$)

A vulnerability function relates the expected degree of loss, where 0 is no loss and 1 is total loss, to a hazard intensity. BGC applied the vulnerability criteria in Table 5-2 based on the maximum modelled flow depth impacting the road. As there are no published vulnerability studies specific to vehicle occupants and landslide impacts, the criteria are based on project experience, relevant case histories, and vulnerability estimates in Finlay et al. (1999) and Brundl et al. (2009).

Table 5-2 Assumed vulnerability values for different impact scenarios.

Debris Depth (m)	Probability of Fatality Given Impact (Vulnerability)		
	Debris Impacts Moving Vehicle	Debris Impacts Stationary Vehicle	Moving Vehicle Impacts Debris
>2 m	0.99	0.99	0.1
1-2 m	0.5	0.5	0.1
0.4-1 m	0.2	0.1	0.05
<0.4 m	0.05	0	0

5.3 Risk Tolerance and Evaluation

Landslide risk evaluation involves comparing estimated risks to accepted risk thresholds, informed by perceptions of tolerable risk (Strouth & McDougall, 2021). The purpose of risk evaluation is to inform decisions on whether risk reduction measures are warranted, and to communicate risk assessment results by referencing to established benchmarks.

For this assessment, BGC applied individual risk tolerance criteria consistent with those adopted in other Canadian jurisdictions (e.g., District of North Vancouver, District of Squamish, Town of Canmore) which define acceptable risk levels for existing and future development in landslide-prone areas. These criteria are based on the principle that landslide risk should not significantly increase the overall background risk faced by an average individual.

In these jurisdictions, a commonly accepted threshold for involuntary[14] individual risk is a 1:10,000 annual chance of fatality, equivalent to 100 micromorts[15]/year. This level is similar to the background risk an average Canadian may experience during childhood, which is typically the lowest fatality risk experienced in a lifetime (Strouth & McDougall, 2022). This risk level is also similar to the average annual risk of death from everyday hazards such as motor vehicle travel. In these jurisdictions, risks exceeding a threshold of 100 micromorts/year are considered “unacceptable” and can trigger mitigation requirements. For new developments, a more conservative threshold of 1:100,000 annual chance of fatality (10 micromorts/year) is commonly applied to encourage hazard avoidance and to recognize increased opportunity for mitigation compared to existing developments. In these jurisdictions, individual risk levels less than 10 micromorts/year are considered ‘broadly acceptable’.

Some jurisdictions (e.g., District of Squamish) have also adopted group (societal) risk criteria. These criteria are defined using thresholds on an ‘FN diagram’, which plots the probability of N or more fatalities occurring for various hazard and exposure scenarios (Section 5.2.2). Group

[14] Voluntary risks are those individuals knowingly and willingly accept and are perceived to be within their control, often in the pursuit of benefit (e.g., recreational sports). Involuntary risks are imposed on individuals without their informed consent or direct benefit (e.g., contaminated water supply). Individuals are typically willing to accept greater voluntary risk compared to involuntary risk.

[15] A micromort is a unit used to communicate the risk of sudden death, equivalent to a one-in-a-million chance of fatality. Both micromorts and probabilities (expressed as odds) are provided to convey the same risk values in different formats.

risk curves are typically evaluated in site-specific assessments and where many fatalities could result from a single scenario (e.g., from a large rock avalanche or debris flow that impacts multiple buildings simultaneously). In this assessment, BGC communicates group risk as probable life loss, which is the expected number of fatalities over a period of time. While there are no formal risk tolerance criteria for probable life loss, this metric can be used to identify locations that disproportionately contribute to group risk, to compare risk levels across hazard types (e.g., comparing probable life loss from landslide hazards to traffic accidents along an equivalent segment of road), and to evaluate the effectiveness of mitigation measures.

5.4 Results and Discussion

5.4.1 Life-Safety Risk to Building Occupants

Life-safety risk to people in present buildings from the assessed hazard scenarios is estimated to be tolerable based on tolerance criteria adopted in other Canadian jurisdictions (<100 micromorts per year, or 1:10,000 annual probability of fatality, see Section 5.3). None of the numerical model simulations show direct impacts to building structures (see Section 4.5.5 for discussion), and life-safety risk is considered negligible for the current development. While there may be property damages arising from passing debris, mud splash, and watery after-flows not explicitly included in the modelling, these do not pose a significant life-safety risk. There is some, unquantified residual risk to properties on Crystal Falls and Brunswick Beach Road from debris flows and debris floods that occur on Magnesia Creek and overwhelm the Magnesia Creek basin, but these are out of the scope of this assessment.

Generalized life-safety risk levels across the study area from debris-flow and debris-avalanche impacts, assuming a building is present, are depicted on the hazard map in Drawing 05 and described in Section 6.0. Life-safety risk at the previous location of the residence at 6 Glendale Avenue is estimated to be unacceptable based on tolerance criteria adopted in other Canadian jurisdictions (>100 micromorts per year, or 1:10,000 annual probability of fatality).

5.4.2 Life-Safety Risk to Motorists

Life-safety risk estimates to motorists are summarized in Table 5-3, with detailed calculation tables in Appendix B.

For Highway 99, the life-safety risk to a frequent commuter from the assessed geohazards is relatively low. It has similar risk to that of traffic accidents occurring along an equivalent 200 m section of Highway 99 exposed to these same geohazards. When compared to the background risk of regularly driving Highway 99 from Horseshoe Bay to Squamish, these geohazard-related risks are multiple orders of magnitudes lower.

In the absence of mitigation measures, the expected number of fatalities on Highway 99 from the assessed geohazards is 1.9 over a 100-year period. The largest number of potential casualties arises from Scenario 5, in which up to 30 fatalities could occur if a large debris avalanche triggered by a log crib failure at the MoTT property descends the slope during a

period of standing traffic. However, the likelihood of this scenario coinciding with standing traffic is exceedingly low, estimated at less than 1 in 500,000 in a given year.

In contrast, risk to individuals regularly driving Battani Creek Road is relatively higher due to the increased frequency and intensity of landslide impacts, as well as the longer exposure time through the landslide path due to the lower driving speed. The individual risk level for a resident of 1 and 2 Glendale Avenue travelling on Battani Creek Road is approximately 12 micromorts per year (or 1:80,000 annual probability of fatality), which is slightly higher than the risk of undergoing anaesthesia (approximately 10 micromorts), and much less than the average risk of driving (approximately 100 micromorts per year). Since Battani Creek Road is a low-use road, the group risk remains very low, with effectively zero expected fatalities over a 100-year period.

The risk calculations do not include life-safety risk to people outside of buildings or vehicles, such as pedestrians and cyclists, but given their relatively low exposure time through the potential landslide paths, we estimate the risks from the assessed geohazards are also low.

Table 5-3 Life-safety risk to vehicle occupants.

Hazard	Location	Individual Risk[2] (Probability of Fatality)		Group Risk - Probable Life Loss[3] (Expected Fatalities)	
		Micromorts/ Year	Probability/ Year	/Year	/100 Years
Geohazards included in this assessment	Battani Creek Road	12	1:80,000	~0	~0
	Highway 99	0.8	1:1,300,000	0.02	1.9
Traffic Accidents (Comparison)[1]	Highway 99 – 200 m Geohazard Exposure Length	0.6	1:1,600,000	0.01	1.0
	Highway 99 – Total Trip from Horseshoe Bay to Squamish	132	1:8,000	2.0	200

Notes:

1. Risk estimates from traffic accidents are based on fatality statistics from ICBC (2019-2023) and Canadian Motor Vehicle Traffic Collision Statistics (2023) from Transport Canada along Highway 99 from Horseshoe Bay to Squamish.
2. Individual risk estimates are for a person who spends the greatest proportion of time on the road. For Highway 99, this individual is assumed to make 5 return trips per week, year-round, such as a frequent commuter. For Battani Creek Road, this individual is assumed to make two return trips per day, year-round.
3. The expected number of fatalities, or probable life loss, over a 100-year period may be overestimated since some of the assessed scenarios, such as log-crib failures, are single-occurrence events at a given location and cannot recur multiple times over a 100-year time period.

5.4.3 Highway 99 Service Interruption and Emergency Response Costs

A summary of the estimated debris clean-up volumes, service interruption, and emergency response costs for Highway 99 are provided in Table 5-4. The estimated average annualized service interruption from the assessed geohazards is approximately 0.28 hours per year, or 28 hours over a 100-year period. By contrast, assuming 2.5 casualty-related crashes per year on

Highway 99 in Lions Bay and an average of 4 hours of service disruption per incident, traffic accidents result in an estimated 10 hours of service interruption annually. This means the estimated service disruption risk from traffic accidents is nearly 30 times greater than from the geohazards included in this assessment.

The estimated average annualized cost of emergency response, including clean-up and recovery efforts, are $2,800/year (Table 5-4). The net present value (NPV)[16] of these costs, applied over a 75-year service life of a typical of a mitigation structure, is estimated at $109,000. NPV provides a useful measure of the long-term economic impacts of geohazards and can inform mitigation investment decisions. However, actual costs are likely to exceed those assumed in this assessment[17], and mitigation planning should also consider intangible factors such as reputational damage and loss of public trust.

[16] Net present value (NPV) is a financial metric that calculates the present value of a series of future cash flows, such as costs, losses, or revenues, discounted back to today's value using a specified rate. For the NPV calculation, BGC assumed a real discount rate of 2%.

[17] Economic losses do not include losses related to vehicle damage, business interruption, revenue or rental income loss, supply chain disruptions, CN rail service interruption, or litigation. They also do not include intangible impacts, such as reputational damage and loss of public trust, effects on public health and quality of life, and disruptions to the environment or local ecosystems.

Table 5-4 Summary of estimated service interruptions and emergency response costs for Highway 99.

Hazard Scenario	Model Sub-Scenario	Estimated Volume of Debris on Road[1]	Travel Directions Impacted	Estimated Service Interruption	Approximate Emergency Response Costs[2]
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	1A. Calibrated Mobility	-	-	-	-
	1B. High Mobility	1,500 m^3	North & South	12 hours	$120,000
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	2A. Calibrated Mobility	1,500 m^3	North & South	12 hours	$120,000
	2B. High Mobility, Blocked CN Rail Bridge	1,500 m^3	North & South	12 hours	$120,000
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	3A. Small Failure	-	-	-	-
	3B. Moderate Failure	<500 m^3	North	6 hours	$60,000
	3C. Large Failure	<500 m^3	North	6 hours	$60,000
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	4A. Calibrated Mobility	-	-	-	-
	4B. High Mobility	<500 m^3	North	6 hours	$60,000
5. Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche	5. Calibrated Mobility	3,000 m^3	North & South	24 hours	$240,000
			Annualized Total:	0.28 hours/year	$2,800/year
			Net Present Value (NPV) over 75 years Assuming 2% Discount Rate:		$109,000

Notes:

1. Debris volumes estimated from DAN3D deposit volumes from numerical modelling, rounded to the nearest 500 m^3.
2. BGC estimates emergency response costs at approximately $10,000 per hour of service interruption, based on its preliminary cost assessment of $150,000 incurred in response to the December 14, 2024 landslide. These costs assume incident management, search and rescue, hazard assessments, and debris removal. They do not include costs of opening emergency accommodations in nearby communities for extended closures, nor the economic impacts of a road closure which may significantly exceed the emergency response costs.

6.0 HAZARD MAP

A landslide hazard map illustrates the spatial distribution of hazard across an area based on the probability of occurrence and the expected intensity of impacts. From the results of the hazard assessment (Section 4.0), BGC developed a hazard map for debris flows and debris avalanches originating in the Battani Creek watershed or from Battani Creek Road (Drawing 05). The primary purpose of this hazard map is to communicate the results of the hazard assessment, highlighting how hazard levels vary across the study area. The hazard map can also be used as a resource for the Village in future land-use decision making, along with the Natural Hazard Assessment Areas identified by Cordilleran (June 25, 2018). The hazard map may need to be supplemented with additional assessment of hazards for site-specific development decisions.

BGC delineated the hazard zones in Drawing 05 using lidar topography, terrain interpretation, field observations, and risk calculations from the numerical modelling results. The core of the hazard zoning approach is the calculation of a risk index, which integrates both hazard intensity and probability across multiple hazard scenarios. The risk index is calculated by converting modelled hazard intensities into life-loss probabilities using a vulnerability function[18], multiplying these probabilities by the respective scenario likelihoods, and summing the results across all hazard scenarios. The resulting risk index reflects an average annual individual risk level across the model domain, assuming a person is present inside a typical building at the location 100% of the year. While a given location on the map may not be occupied with a dwelling, this method is a practical way to synthesize multiple hazard scenarios into a single composite map, and enables the definition of hazard zones tied to risk tolerance thresholds commonly applied in other Canadian jurisdictions for land-use decisions. BGC applied the risk index approach to guide hazard zone delineation and definition, as shown in Drawing 05.

For roads where risk levels related to inhabited buildings are not relevant, BGC delineated and labelled the frequency at which debris is estimated to reach the road based on the current conditions in the Battani Creek watershed (Drawing 05).

In addition to the assessed scenarios, the hazard map includes supplementary information on other hazard types not formally assessed, such as rockfall initiation zones above residential properties and driveways on Battani Creek Road.

The hazard map reflects current conditions. Changes to the landscape (e.g., mitigation structures, road construction, erosion, channel migration, landslide deposits) or hazard likelihood (e.g., road deactivation measures, occurrence of a hazard scenario removing potential source material) may may necessitate updates to the hazard map.

[18] BGC applied a vulnerability model developed through ongoing case study research (LeSueur et al., in press) relating impact pressures from rapid flow-type landslides to life-loss probability for individuals inside detached, wood-frame buildings.

7.0 CONCEPTUAL MITIGATION

7.1 Introduction

BGC developed conceptual mitigation options to facilitate high-level comparison between options and inform decisions on risk management at Battani Creek watershed. The identified options include both engineered works and non-engineered options such as monitoring and public awareness. Some of the mitigation options can be combined with others or constructed in a phased approach, as discussed in the recommendations in Section 7.4.

7.2 Objectives

The primary mitigation objective is to minimize life-safety risks to road users, cleanup and recovery costs, and service interruption. This can be achieved by reducing the likelihood of debris impacting Highway 99 and Battani Creek Road. Life-safety risk to present building occupants is assessed to be negligible and does not warrant intervention as the risk level is already within levels deemed tolerable by other Canadian jurisdictions for existing development. However, measures to reduce the likelihood of debris impacting Highway 99 and Battani Creek Road may also reduce life-safety and economic risk at specific properties, and to the community.

A secondary objective is to reduce maintenance costs and service interruption associated with geotechnical and hydrotechnical hazards at Battani Creek Road and reservoir, such as a collapse of the water tank foundation (Location 12, see discussion in Section 3.9) or a road washout. The mitigation recommendations are informed by the field review of existing conditions along Battani Creek Road, and not detailed site investigations.

7.3 Options

The following subsections present nine proposed mitigation options, each with a brief description, order-of-magnitude costs, key advantages, disadvantages, and BGC's recommendation. Recommendations include 'considered for further assessment' for feasible options to be advanced in future phases of design, or 'rejected' for options deemed unsuitable. The locations of the proposed options are depicted on Figure 08.

7.3.1 Option 1: Upgrade, Monitor, and Maintain Battani Creek Road and Reservoir

Description: Maintain road and reservoir access by improving geotechnical stability. Major items include:

- 1A – remove log-crib structures and replace with engineered retaining walls
- 1B – improve water tank foundation (Location 12), either by moving the tank away from the fill slope edge or onto a blasted bedrock bench, or replacing the log-crib structure with an engineered retaining wall (Option 1A)
- 1C – remove woody debris from fill and pull back select fill slopes (e.g., Location 9, Location 14)

- 1D – drain reservoir to inspect rock mass and line with concrete, as required and authorized by a qualified engineer
- 1E – implement improved drainage measures along road (clean ditches, install culverts, construct swales)
- 1F – scale, mesh, and/or bolt rock cuts
- 1G – conduct regular inspection of road, drainage measures, and reservoir.

Additional options and prescription details are provided in the Cordilleran (February 7, 2015) report and MoF's road deactivation plan (Higman, June 12, 2016).

Order-of-Magnitude Capital Cost: $2M (less for individual high-priority items).

Advantages: Reduces the likelihood of hazard scenarios related to road fill or reservoir-related failures. Reduces the overall costs of repairing or responding to geotechnical and hydrotechnical failures along the road. Can be completed in a phased approach for high-priority items. Maintains vehicle access for future road and reservoir inspections.

Disadvantages: High cost if all items are implemented. Will require continued, ongoing maintenance. Does not mitigate hazard scenarios that originate outside of the Battani Creek Road area.

Recommendation: Considered for further assessment. Complete in a phased approach, with sub-options 1A, 1B, and 1D recommended as high-priority items.

7.3.2 Option 2: Deactivate Battani Creek Road and Reservoir

Description: Improve geotechnical stability by fully decommissioning Battani Creek Road past 1 and 2 Goldenrod and decommissioning the reservoir. Major items include:

- 2A – remove log-crib structures and pull-back fill
- 2B – decommission water tank (Location 12), or move to a stable bench
- 2C – remove culverts and install cross-ditches and waterbars on intact roads, and re-establish drainage paths with armoured channels through roads in full pull-back
- 2D – decommission reservoir by either a) removing pond confinement by blasting rock and removing fill at the outlet to re-establish a channel, or b) filling the pond with a non-porous medium (e.g., concrete) and constructing a channel.

Additional options and prescription details are provided in the Cordilleran (February 7, 2015) report and MoF's road deactivation plan (Higman, June 12, 2016).

Order-of-Magnitude Capital Cost: $2M.

Advantages: Reduces the likelihood of hazard scenarios related to road fill or reservoir-related failures. If deactivation successful, no or very low long-term maintenance required.

Disadvantages: High costs. Removes vehicle access through some locations (foot or ATV access only). Blasting to decommission reservoir may reduce rock mass quality. Does not mitigate hazard scenarios that originate outside of the Battani Creek Road area.

Recommendation: Considered for further assessment.

7.3.3 Option 3: Engineered Deflection Berm at Highway 99

Description: An engineered earthfill berm adjacent to Highway 99 at the site of the existing Battani Creek berm and basin. Its primary function is to deflect debris flows away from the highway and redirect them into Magnesia Creek, while also providing some debris storage and energy dissipation beside the road. This berm would be approximately 30 m long with a height of 3 to 4 m and a 4 to 5 m wide crest. To maximize storage volume behind the berm, the upslope face should be steep (e.g., mechanically stabilized earth wall for a near-vertical profile, grouted riprap for 1H:1V slope), while the downslope face can consist of earthfill placed at a gentler slope. To enhance debris storage and flow conveyance, the channel behind the berm should be widened through excavation (excavated material may be reused as berm fill, subject to geotechnical suitability). The berm crest is to accommodate construction and maintenance traffic, with access ramps designed in subsequent phases.

Order-of-Magnitude Capital Cost: $0.3M.

Advantages: Effective mitigation technique that makes use of space in Magnesia Creek for temporary debris storage/conveyance. Relatively low costs. Potential cost savings from estimated cost depending on design decisions (e.g., berm height, layout, construction materials). Accessible for construction and maintenance from Highway 99.

Disadvantages: Temporary highway disruption during construction. Does not mitigate risk upstream to Battani Creek Road users.

Recommendation: Considered for further assessment.

7.3.4 Option 4: Debris Net at Highway 99

Description: Debris net adjacent to Highway 99 at the site of the existing Battani Creek berm and basin. Its primary function is to prevent debris from impacting the highway, and is an alternative to Option 3. BGC recommends using the Lambda Frame debris catcher system from Trumer Schutzbauten Canada Ltd. These systems can span long distances due to the self-supporting frames and can be made 4 to 7.5 m tall, providing more storage compared to typical debris nets. The steel frames are secured to concrete foundations with the open ends laterally anchored.

Order-of-Magnitude Capital Cost: $0.5M.

Advantages: Small footprint and large debris storage height, which could provide more storage compared to a berm depending on the net's alignment. Modular system that can be designed to fit site and loading conditions.

Disadvantages: Requires de-installation following an event to remove debris. Uncertainty in technical feasibility if unable to anchor south end of system. Temporary highway disruption during construction. Does not mitigate risk upstream to Battani Creek Road users.

Recommendation: Rejected, Option 3 is a more cost-effective alternative.

7.3.5 Option 5: Debris Barrier and Basin at 6 Glendale Avenue

Description: An earthfill debris barrier upslope of Highway 99 and the Battani Creek Road across Battani Creek and the 6 Glendale Avenue property. Its primary function is to retain debris upslope of the roads while allowing regular Battani Creek streamflow to pass through a culvert or opening in the structure. The debris barrier could be constructed from concrete, roller compacted concrete, or rockfill with a concrete face, similar to other debris-flow check dams in the area. BGC recommends the spillway be aligned toward the avulsion channel (Photo 6) south of the existing Battani Creek alignment such that over-flows are directed toward Magnesia Creek rather than directly at Highway 99.

Order-of-Magnitude Capital Cost: $5M.

Advantages: Debris storage and energy dissipation upstream of both Battani Creek Road and Highway 99. Reduces the likelihood of losing road access/egress to 1 and 2 Goldenrod Avenue following a debris flow.

Disadvantages: High cost. Requires construction on private property at 6 Glendale Avenue. Access disruption and significant disturbance to residents during construction. Inefficient debris storage relative to earthfill volume due to steep terrain.

Recommendation: Rejected due to high-cost relative to benefits.

7.3.6 Option 6: Battani Creek Channel Relocation

Description: A constructed channel south of the existing Battani Creek channel to direct streamflow and future debris flows into Magnesia Creek further upstream of Highway 99. This will involve excavating and blasting a large channel to maximize confinement and backfilling the existing channel with riprap. The channel will cross Battani Creek Road, or will be directed at the Glendale Avenue bridge, likely requiring new bridge construction.

Order-of-Magnitude Capital Cost: $5M.

Advantages: Does not require concrete or significant fill volumes as excavated material may be used to backfill existing channel. Makes use of space in the higher-capacity Magnesia Creek channel for temporary debris storage/conveyance.

Disadvantages: High cost. Possible risk transfer to properties on Crystal Falls Rd. Access disruption and significant disturbance to residents during construction. Performance risks as debris may avulse from or bypass channel upstream. Requires construction on private property at 6 Glendale Avenue. Requires bridge construction. May not mitigate risk to Battani Creek Road users.

Recommendation: Rejected due to performance uncertainty and high-cost relative to benefits.

7.3.7 Option 7: Flexible Debris Nets on Slopes Below MoTT Property

Description: A series of debris nets anchored to bedrock between the road along the MoTT property (Location 19) and Highway 99, similar to the one installed at Location 16 (Photo 22).

Order-of-Magnitude Capital Cost: $1M.

Advantages: Prevents rock fall and debris from reaching Highway 99 from other source areas. Provides protection to Highway 99 during road deactivation works on Battani Creek Road.

Disadvantages: Difficult construction and maintenance access along steep slopes. Highway 99 interruptions during construction. Individual nets may not retain debris volume from a large debris avalanche and could be damaged during this event.

Recommendation: Rejected due to high-cost relative to more cost-effective Option 1A/2A.

7.3.8 Option 8: Monitoring and Warning System on Battani Creek

Description: Monitoring and warning on Battani Creek, such as a radar system that detects passing debris and triggers a flashing traffic light on Highway 99 warning of debris on road. The system could also broadcast an alert to residents, Lions Bay, and Search and Rescue.

Order-of-Magnitude Capital Cost: $0.5M.

Advantages: Does not require major construction efforts or earthworks.

Disadvantages: High cost to implement and maintain system in the long-term. Risk of system failure, or failure of people to respond to the alarm. Given the proximity of Battani Creek channel to roads and speed of debris flows, detection system may not provide sufficient response times. Risk of false alarms causing traffic disruptions on Highway 99 or lead to additional accident risk. There is a lack of clear jurisdictional authority to manage and liability concerns. Does not reduce economic risk from clean-up and repair costs.

Recommendation: Rejected due to cost and effectiveness.

7.3.9 Option 9: Public Information and Awareness

In addition to the engineered mitigation options presented above, a passive mitigation strategy like improving awareness about geohazards may help reduce exposure to these hazards. At a minimum, this could involve making this report and supporting materials, such as the geohazard infographics in Appendix C, publicly available to residents and other stakeholders. Additional measures could include hosting community information sessions led by qualified geohazard professionals and installing signage at high-risk locations to promote hazard recognition and informed decision-making.

7.4 Recommendations

In the immediate term, prior to the 2025 rainy season (October), BGC recommends an excavator remove the boulder resting on the log crib structure on the MoTT property at Location 19 (Photo 25).

In the short term, ideally over the next year, BGC recommends the following risk-reduction actions be taken:

- Remove deteriorating log crib structures along Battani Creek Road, and either pull-back fill or replace with retaining walls (Option 1A/2A)
- Move the water tank at Location 12 (Photos 16, 17) away from the fill slope or onto a blasted bedrock bench (Option 1B/2B)
- Increase the berm height and basin storage at the Battani Creek berm and basin next to Highway 99 (Location 3), such that future debris flows are deflected into Magnesia Creek upstream of the bridge (Option 3)
- The Village make information about Battani Creek geohazards publicly available (Option 9) by posting this report and the infographics in Appendix C on the Village website, displaying printed copies of the infographics at the Village Town Hall, and announcing the availability of these resources during a Council Meeting.

In the longer term, ideally within the next few years, BGC recommends mitigation along the Battani Creek Road and reservoir through phased upgrades (Option 1), full deactivation (Option 2), or some combination of work items. Additional options and prescription details are provided in the Cordilleran (February 7, 2015) report and MoF's road deactivation plan (Higman, June 12, 2016).

Prior to progressing work plans related to the reservoir (Options 1D/2D), BGC recommends that a qualified professional assess the seepage and stability of the reservoir rock mass, including reviewing if any remedial works, such as lining or grouting the bottom of the pond, have already been undertaken. This may require draining the pond for inspection or obtaining as-built records and engineering reports, if they exist. BGC did not have access to any documentation regarding the initial construction of the reservoir or the subsequent construction of the concrete sill.

The mitigation works should be undertaken by a qualified professional. Given the high-risk nature of the proposed mitigation work on Battani Creek Road, such as removing log-crib structures that retain fill above roads, contractors and operators should have experience working on logging roads in steep terrain and experience constructing geohazard mitigation.

8.0 SUMMARY AND RECOMMENDATIONS

8.1 Hazard and Risk Summary

The Battani Creek watershed is a relatively small watershed with a lower proportion of steep terrain compared to other deeply-incised channels along Howe Sound that have experienced frequent and destructive debris flows. Aside from the December 14, 2024 event, there is no known history of debris flows in Battani Creek over the past century. Nevertheless, steep terrain in the lower watershed and potential climatic triggers make the area susceptible to future debris flows. Additionally, construction of Battani Creek Road and a reservoir has introduced new hazard mechanisms related to drainage pattern changes and geotechnical instability in fill slopes and fractured bedrock within blasted cuts.

BGC identified several hazard scenarios originating from the Battani Creek watershed or Battani Creek Road based on terrain analysis, historical aerial imagery, field observations, and regional geohazard analogues. The assessment focusses on geohazards that transition into flow-type landslides, similar in nature to the December 14, 2024 event. The hazard scenarios include debris flows and debris avalanches that initiate as open-slope landslides, rock slope failures below the reservoir, and failures of unstable fill slope (Figure 06). Estimated volumes range from approximately 2,400 to 13,100 m^3. These volumes are smaller than the 15,000 m^3 estimated for the December 14, 2024, primarily because of the depletion of material along Battani Creek.

BGC estimates an average annual probability of approximately 1:20 for the most likely scenario and 1:500 for the largest-volume event. The estimated frequency of these hazard scenarios is uncertain due to the limited historical data and changed conditions following the construction of the Battani Creek Road and the recent landslide.

Numerical modelling suggests that present building structures within the study area are not directly impacted by debris flows from the assessed hazard scenarios. This is primarily due to limited debris volumes and the existing channel's capacity to convey flow past 1 and 2 Goldenrod Avenue. While channel confinement will gradually decrease over time as it fills with organic debris and soil, full reversion to pre-landslide conditions will take many hundreds, possibly thousands, of years under natural conditions. In the short term, trees that fall into the channel are much more likely to be swept away by a future debris flow than redirect flow toward existing properties. While minor property damage from passing debris, mud splash, or watery after-flows may occur, these do not pose a significant life-safety risk. Accordingly, BGC estimates the life-safety risk to current residences in the study area is tolerable based on tolerance criteria adopted in other Canadian jurisdictions for existing development.

In contrast, many hazard scenarios impact Battani Creek Road and Highway 99, posing life-safety risks to road users, potential service interruptions, and economic costs from emergency response and cleanup. The estimated risk level is much lower compared to the background risk of traffic accidents along Highway 99 from Horseshoe Bay to Squamish. Nonetheless, BGC estimates 1.9 expected fatalities over a 100-year period on Highway 99 from the assessed geohazards. The highest fatality scenario involves a rapid failure of a log-crib structure on MoTT

property that transitions into a debris avalanche impacting stationary traffic on Highway 99, which could result in up to 30 fatalities. While the compounding factors of this scenario make it rare, individual rock blocks released from the log-crib structure could reach Highway 99 with a much higher probability. From this assessment, remedial works to eliminate this release source are recommended, along with other conceptual mitigation options described in Section 7.0 to reduce the probability of debris impacting roads.

Drawing 05 presents a hazard map depicting relative hazard levels across the study area, highlighting road segments exposed to debris impacts and estimated risk levels assuming the presence of inhabited structures. The map shows that life-safety risk at the previous location of the residence at 6 Glendale Avenue is unacceptable based on tolerance criteria adopted in other Canadian jurisdictions. The purpose of this map is to show what areas are affected by flow-type geohazards from the Battani Creek watershed, and to serve as a resource for the Village in future land-use decision making, along with the Natural Hazard Assessment Areas identified by Cordilleran (June 25, 2018). The hazard map may need to be supplemented with additional assessment of hazards for site-specific development decisions.

8.2 Recommendations

BGC recommends a phased mitigation approach, with specific recommendations highlighted for immediate and short-term action in Section 7.4. To summarize, BGC recommends the following key items are completed to manage geohazard risk from the Battani Creek watershed and Battani Creek Road:

- Remove deteriorating log crib structures and unstable fill along Battani Creek Road to reduce the risk of slope failure
- Increase debris storage and deflection capacity the Highway 99 outlet of Battani Creek to reduce the frequency and magnitude of debris reaching the road
- Engage a qualified professional to assess seepage and stability of the reservoir rock mass, and based on their findings, implement remedial measures such as lining the pond or removing it to restore the natural creek channel
- Upgrade or deactivate Battani Creek Road to restore natural drainage pathways and stabilize cut and fill slopes
- The Village share information with the public about Battani Creek geohazards.

Additionally, BGC recommends the Village:

- Coordinate with project partners to conduct a repeat lidar scan in 2026 following the upcoming rainy season and conduct a lidar change analysis to detect changes in the channels and slopes, particularly around the reservoir rock mass. Targeted survey areas may be completed through a drone-based lidar survey which is more cost-effective than typical aircraft-based lidar acquisition.
- Engage a qualified professional to conduct a rock fall hazard assessment for the road cuts along Battani Creek Road and surrounding cliff bands.
- Adopt development permit areas from the Natural Hazard Assessment Areas identified by Cordilleran (2018, June 25) to guide land-use decisions and consider life-safety risk-

tolerance criteria for development permit applications to improve consistency in hazard management.

- Apply for funding to complete a comprehensive geohazard risk assessment for all properties in Lions Bay, including the assessment of residual risk to properties on creeks with existing mitigation (e.g., Magnesia Creek). This assessment would reduce the burden on homeowners and developers, provide a consistent framework and technical resources for professionals conducting geohazard assessments, and serve as a public risk awareness tool. The assessment may screen properties that do not require further assessments, and/or identify properties with risk levels that warrant mitigation measures. For example, BGC's geohazard risk assessment at Upper Bayview Road (March 28, 2013) identified intolerable risk at two properties (545 and 540 Upper Bayview Road) and proposed four mitigation options to reduce risk to tolerable levels.
- Restrict future use of property at 6 Glendale Avenue without adequate mitigation in place; however, given the anticipated landslide intensity at this location, mitigation is unlikely to be technically nor economically feasible. Redevelopment is therefore not recommended.

8.3 Summary of Limitations

This assessment is limited to hazards from flow-type landslides originating within the Battani Creek watershed or along Battani Creek Road. It excludes other hazard types such as local rock fall, snow avalanches, rock avalanches, earthquake-triggered landslides, post-wildfire debris flows, and debris flows or debris floods from the Magnesia Creek watershed. Secondary effects stemming from localized slumping and minor roadbed failures, such as dislodged boulders rolling downslope or trees being toppled onto structures, are also excluded. While the hazard and risk level from these have not been quantified, rock fall source areas above buildings and driveways, as well as areas susceptible to slope or steep creek hazards, are identified in the Hazard Map (Drawing 05).

The greatest source of uncertainty lies in estimating the probability of future geohazard scenarios since the standard methods for reconstructing geohazard chronologies were not available for this site. Furthermore, landscape changes following the construction of Battani Creek Road and the recent landslide have reduced the reliability of historical records to inform future probabilities. In particular, the likelihood of a rock slope failure below the reservoir remains highly uncertain, and BGC recommends a repeat lidar scan and a seepage assessment of the reservoir to improve understanding. Nonetheless, BGC estimated probability ranges based on professional judgment and project experience, supported by field evidence and regional geohazard analogues.

As described in Section 4.5.6, the runout assessment is limited by numerical modelling that simplifies complex physical processes and relies on assumptions and input data with inherent uncertainty. BGC applied professional judgment in interpreting model results and delineating hazard boundaries.

The life-safety risk assessment is limited to people inside buildings or vehicles and does not account for the safety of people outdoors. Economic risk is restricted to high-level estimates of emergency response and cleanup costs and underestimates broader economic impacts such as supply chain disruptions and litigation costs. Furthermore, other intangible costs, such as reputational damage and loss of public trust is something that cannot be quantified.

The hazard map and risk calculations reflect current and static conditions. Risk levels are dynamic over time and may fluctuate seasonally or in response to landscape changes. For example, risk levels may increase as log crib structures deteriorate but will decrease immediately following their failure as the failure source is removed. Modifications to the landscape (e.g., mitigation structures, road construction, erosion, channel migration, landslide deposits) or changes to the hazard likelihood (e.g., road deactivation measures, occurrence of a hazard scenario removing potential source material) may necessitate updates to the hazard map.

9.0 CLOSURE

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

Yours sincerely,

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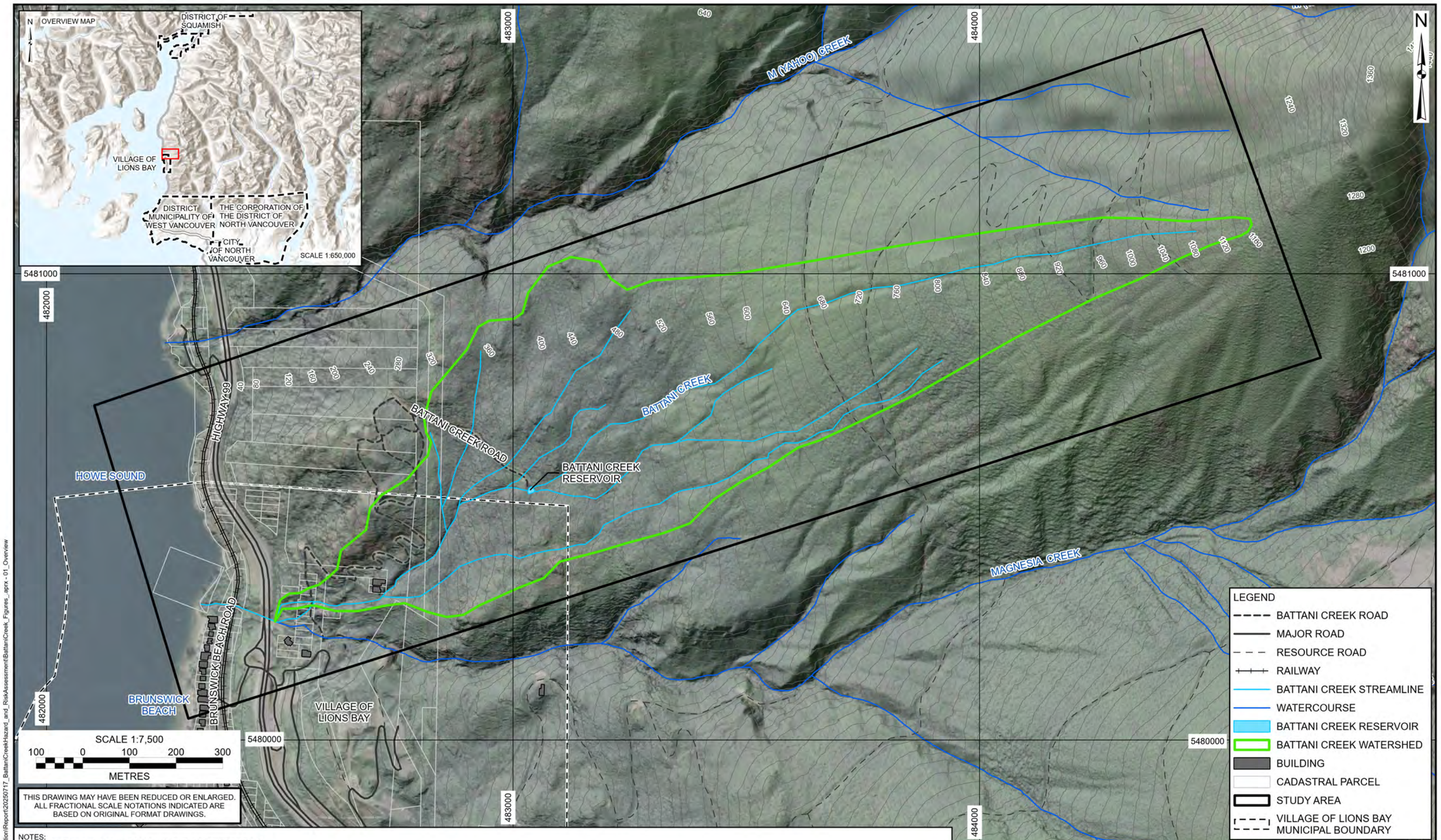
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NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "BATTANI CREEK HAZARD AND RISK ASSESSMENT", AND DATED OCTOBER 2025.
3. BASE TOPOGRAPHIC DATA IS BASED ON LIDAR PROVIDED BY MOTT (2025), GEOBC (2019), AND MCELHANNEY (2012), AND CDEM DATA FROM THE GOVERNMENT OF CANADA (2011). IMAGERY IS ESRI WORLD IMAGERY, AND IS DATED JULY 9, 2024. CONTOUR INTERVAL IS 20 m.
4. BATTANI STREAMLINES MAPPED FROM LIDAR AND FIELD OBSERVATIONS. WATERCOURSES ARE FROM THE BC FRESHWATER ATLAS, ROADS ARE FROM THE BC ROAD ATLAS AND CANVEC (GOVERNMENT OF CANADA) SERIES, PARCELS ARE FROM PARCEL MAP BC, AND BUILDINGS ARE FROM MICROSOFT OPEN BUILDING DATA AND MAPPED FROM ORTHOPHOTO PROVIDED BY MOTT (2025).
5. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N.
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DRAWN:	CM
REVIEW:	LH
APPROVED:	SZ

CLIENT: The Village of LIONS BAY

BGC

PROJECT: **BATTANI CREEK HAZARD AND RISK ASSESSMENT**

TITLE: **OVERVIEW MAP**

PROJECT No.:	DWG No:
1791004	01

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N

482000

483000

484000

5481000

5480000

HIGHWAY 99

M (YA'HOO) CREEK

BATTANI CREEK

BATTANI CREEK ROAD

BATTANI CREEK RESERVOIR

HOWE SOUND

BRUNSWICK BEACH ROAD

BRUNSWICK BEACH

VILLAGE OF LIONS BAY

GAMBIER ROCKS

COAST PLUTONIC ROCKS

MAGNESIA CREEK

SCALE 1:7,500

100 0 100 200 300

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

- BATTANI CREEK ROAD
- MAJOR ROAD
- RESOURCE ROAD
- RAILWAY
- BATTANI CREEK STREAMLINE
- BEDROCK GEOLOGY CONTACT
- BEDROCK SCARP
- INFERRED FAULT
- WATERCOURSE
- BATTANI CREEK RESERVOIR
- BATTANI CREEK WATERSHED
- BUILDING
- CADASTRAL PARCEL
- STUDY AREA
- VILLAGE OF LIONS BAY MUNICIPAL BOUNDARY

TERRAIN UNIT

- COLLUVIUM - VENEER
- ALLUVIAL FAN
- GLACIOMARINE - TERRACE
- GLACIOMARINE - ICE CONTACT
- TILL - VENEER, GULLIED
- BEDROCK - BENCHLAND
- BEDROCK - MODERATE SLOPES
- BEDROCK - STEEP SLOPES

NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "BATTANI CREEK HAZARD AND RISK ASSESSMENT", AND DATED OCTOBER 2025.
3. BASE TOPOGRAPHIC DATA IS BASED ON LIDAR PROVIDED BY MOTT (2025), GEOBC (2019), AND MCELHANNEY (2012), AND CDEM DATA FROM THE GOVERNMENT OF CANADA (2011). CONTOUR INTERVAL IS 20 m.
4. BATTANI STREAMLINES MAPPED FROM LIDAR AND FIELD OBSERVATIONS. WATERCOURSES ARE FROM THE BC FRESHWATER ATLAS, ROADS ARE FROM THE BC ROAD ATLAS AND CANVEC (GOVERNMENT OF CANDA) SERIES, PARCELS ARE FROM PARCEL MAP BC, AND BUILDINGS ARE FROM MICROSOFT OPEN BUILDING DATA AND MAPPED FROM ORTHOPHOTO PROVIDED BY MOTT (2025).
5. TERRAIN UNITS MODIFIED FROM SURFICIAL GEOLOGY MAP BY A. BLAIS-STEVENS, 2008. BEDROCK GEOLOGY CONTACT FROM BC DIGITAL GEOLOGY BY CUI ET AL., 2017.
6. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N.
7. BGC PREPARED THIS DRAWING FOR THE EXCLUSIVE USE OF BGC'S CLIENT IDENTIFIED ON THIS DRAWING. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING MUST NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE SPECIFIC PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES, INJURY, OR LOSS ARISING FROM ANY UNAUTHORIZED USE OR MODIFICATION OF THIS DRAWING. THIRD PARTIES USE OR RELY UPON THIS DRAWING AT THEIR OWN RISK.

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DATE:	OCT 2025
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REVIEW:	LH
APPROVED:	SZ

CLIENT: The Village of LIONS BAY

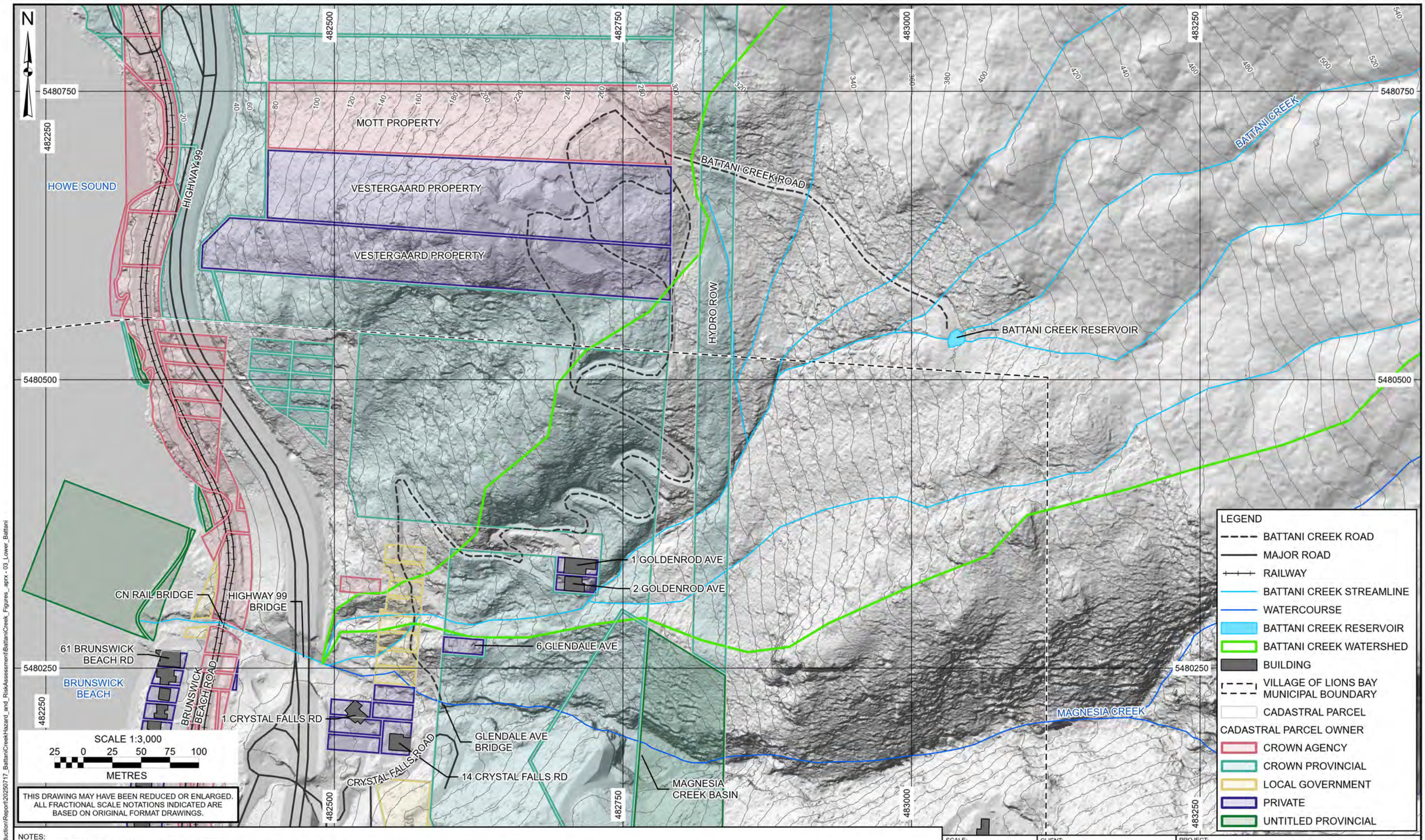
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PROJECT: BATTANI CREEK HAZARD AND RISK ASSESSMENT

TITLE: TERRAIN MAP

PROJECT No.:	DWG No:
1791004	02

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NOTES:
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3. BASE TOPOGRAPHIC DATA IS BASED ON LIDAR PROVIDED BY MOTT (2025) AND GEOBC (2019). CONTOUR INTERVAL IS 10 m.
4. BATTANI STREAMLINES MAPPED FROM LIDAR AND FIELD OBSERVATIONS. WATERCOURSES ARE FROM THE BC FRESHWATER ATLAS, ROADS ARE FROM THE BC ROAD ATLAS AND CANVEC (GOVERNMENT OF CANADA) SERIES, PARCELS ARE FROM PARCEL MAP BC, AND BUILDINGS ARE FROM MICROSOFT OPEN BUILDING DATA AND MAPPED FROM ORTHOPHOTO PROVIDED BY MOTT (2025).
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DATE:	OCT 2025
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REVIEW:	LH
APPROVED:	SZ

CLIENT: The Village of LIONS BAY

BGC

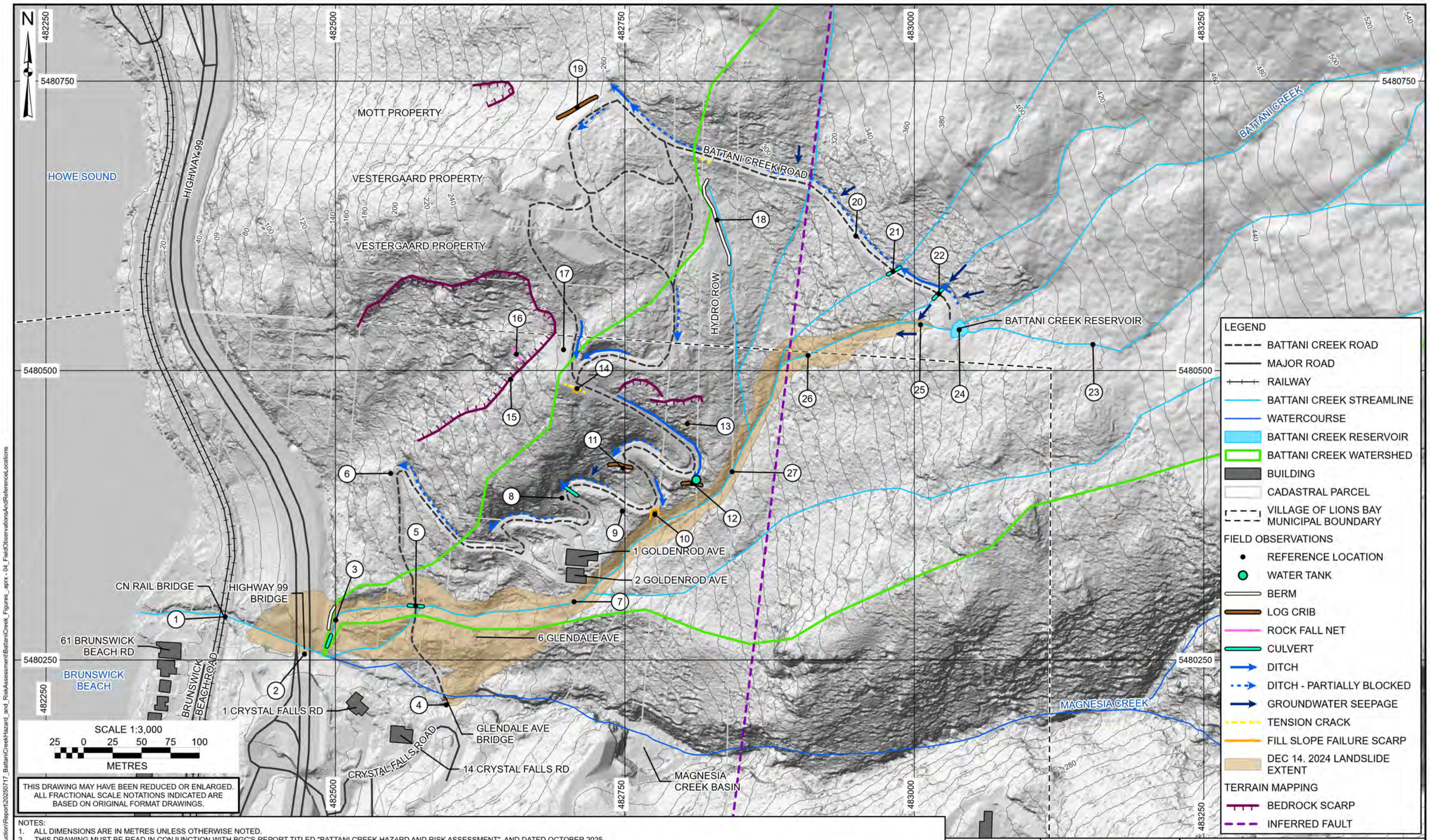
PROJECT: BATTANI CREEK HAZARD AND RISK ASSESSMENT

TITLE: LOWER BATTANI CREEK PROPERTY MAP

PROJECT No.: 1791004

DWG No: 03

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NOTES:
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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "BATTANI CREEK HAZARD AND RISK ASSESSMENT", AND DATED OCTOBER 2025.
3. BASE TOPOGRAPHIC DATA IS BASED ON LIDAR PROVIDED BY MOTT (2025) AND GEOBC (2019). CONTOUR INTERVAL IS 10 m.
4. BATTANI STREAMLINES MAPPED FROM LIDAR AND FIELD OBSERVATIONS. WATERCOURSES ARE FROM THE BC FRESHWATER ATLAS, ROADS ARE FROM THE BC ROAD ATLAS AND CANVEC (GOVERNMENT OF CANADA) SERIES, PARCELS ARE FROM PARCEL MAP BC, AND BUILDINGS ARE FROM MICROSOFT OPEN BUILDING DATA AND MAPPED FROM ORTHOPHOTO PROVIDED BY MOTT (2025).
5. FIELD OBSERVATIONS FROM APRIL 30, MAY 1, AND JULY 24, 2025.
6. PHOTOS AT REFERENCE LOCATIONS IN PHOTOGRAPHS ATTACHMENT.
7. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N.
8. BGC PREPARED THIS DRAWING FOR THE EXCLUSIVE USE OF BGC'S CLIENT IDENTIFIED ON THIS DRAWING. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING MUST NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE SPECIFIC PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES, INJURY, OR LOSS ARISING FROM ANY UNAUTHORIZED USE OR MODIFICATION OF THIS DRAWING. THIRD PARTIES USE OR RELY UPON THIS DRAWING AT THEIR OWN RISK.

SCALE:	1:3,000
DATE:	OCT 2025
DRAWN:	CM
REVIEW:	LH
APPROVED:	SZ

CLIENT: The Village of LIONS BAY

BGC

PROJECT: BATTANI CREEK HAZARD AND RISK ASSESSMENT

TITLE: FIELD OBSERVATIONS AND REFERENCE LOCATIONS MAP

PROJECT No.:	DWG No:
1791004	04

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Hazard Zone	Approximate Risk Level[1] (Annual Probability of Fatality)	General Description[2]	Application to Land-Use Planning in Other BC Jurisdictions
Very High	>1:1,000	Areas subject to frequent impacts by high intensity flow	Development typically unacceptable unless conditions or controls are applied
High	1:10,000 to 1:1,000	Areas possibly impacted by high intensity flow, or subject to frequent impacts by low intensity flow	
Moderate	1:100,000 to 1:10,000	Areas impacted by low intensity flow, or less frequent impacts by high intensity flow	Existing development typically acceptable, proposed new development may not be acceptable unless conditions or controls are applied
Low	<1:100,000	Areas impacted by low intensity flow and/or very rare impacts	Typically acceptable for all development

1. Note: Risk levels assume flowing debris impacting a fully occupied, detached, wood-frame building.
2. Note: High intensity flow may destroy buildings whereas low intensity flow may damage buildings.

N

5481000

5480500

5480000

482500

483000

483500

484000

M (YAHOO) CREEK

HOWE SOUND

1:10 TO 1:100, SEE NOTE 7

HIGHWAY 99

BATTANI CREEK ROAD

BATTANI CREEK

BATTANI CREEK RESERVOIR

1 GOLDENROD AVE

2 GOLDENROD AVE

6 GLENDALE AVE

CN RAIL BRIDGE

1:30

1:10

61 BRUNSWICK BEACH RD

HIGHWAY 99 BRIDGE

BRUNSWICK BEACH ROAD

CRYSTAL FALLS ROAD

GLENDALE AVE BRIDGE

14 CRYSTAL FALLS RD

1 CRYSTAL FALLS RD

MAGNESIA CREEK BASIN

BRUNSWICK BEACH

MAGNESIA

SCALE 1:5,000

50 0 50 100 150 200

METRES

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LEGEND

- BATTANI CREEK ROAD
- MAJOR ROAD
- RAILWAY
- BATTANI CREEK STREAMLINE
- WATERCOURSE
- BATTANI CREEK RESERVOIR
- BATTANI CREEK WATERSHED
- BUILDING
- CADASTRAL PARCEL
- STUDY AREA
- VILLAGE OF LIONS BAY MUNICIPAL BOUNDARY

HAZARD ZONE (DEBRIS FLOW, DEBRIS AVALANCHE)

- VERY HIGH
- HIGH
- MODERATE
- LOW
- MAXIMUM ESTIMATED ANNUAL PROBABILITY OF DEBRIS REACHING ROAD

HAZARD NOT ASSESSED

- ROCK FALL SOURCE AREA ABOVE BUILDING OR DRIVEWAY
- SLOPE & STEEP CREEK HAZARD
- SLOPE HAZARD

NOTES:
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5. THIS MAP REPRESENTS HAZARD ZONATION FOR DEBRIS-FLOW AND DEBRIS-AVALANCHE HAZARDS ORIGINATING IN THE BATTANI CREEK WATERSHED AND FROM BATTANI CREEK ROAD. THE HAZARD MAP DOES NOT INCLUDE OUT OF SCOPE HAZARDS, SUCH AS DEBRIS FLOWS OR DEBRIS FLOODS ON MAGNESIA CREEK, WHICH WOULD INCREASE HAZARD LEVELS DEPICTED ALONG MAGNESIA CREEK.
6. SIGNIFICANT MODIFICATIONS TO THE LANDSCAPE OR CHANGES TO THE HAZARD SOURCE AREAS (E.G., IF A HAZARD SCENARIO OCCURS AND REMOVES AVAILABLE DEBRIS) MAY WARRANT THE RE-MAPPING OF HAZARD ZONES.
7. WHILE THE ESTIMATED ANNUAL OCCURENCE PROBABILITY FOR A DEBRIS AVALANCHE IS BETWEEN 1:100 AND 1:300, ROCK FALL FROM THE FILL SLOPE MAY REACH THE ROAD WITH A HIGHER PROBABILITY, ESTIMATED TO BE 1:10.
8. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 10N.
9. BGC PREPARED THIS DRAWING FOR THE EXCLUSIVE USE OF BGC'S CLIENT IDENTIFIED ON THIS DRAWING. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING MUST NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE SPECIFIC PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES, INJURY, OR LOSS ARISING FROM ANY UNAUTHORIZED USE OR MODIFICATION OF THIS DRAWING. THIRD PARTIES USE OR RELY UPON THIS DRAWING AT THEIR OWN RISK.

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DATE:	OCT 2025
DRAWN:	CM
REVIEW:	LH
APPROVED:	SZ

CLIENT: The Village of LIONS BAY

BGC

PROJECT: BATTANI CREEK HAZARD AND RISK ASSESSMENT

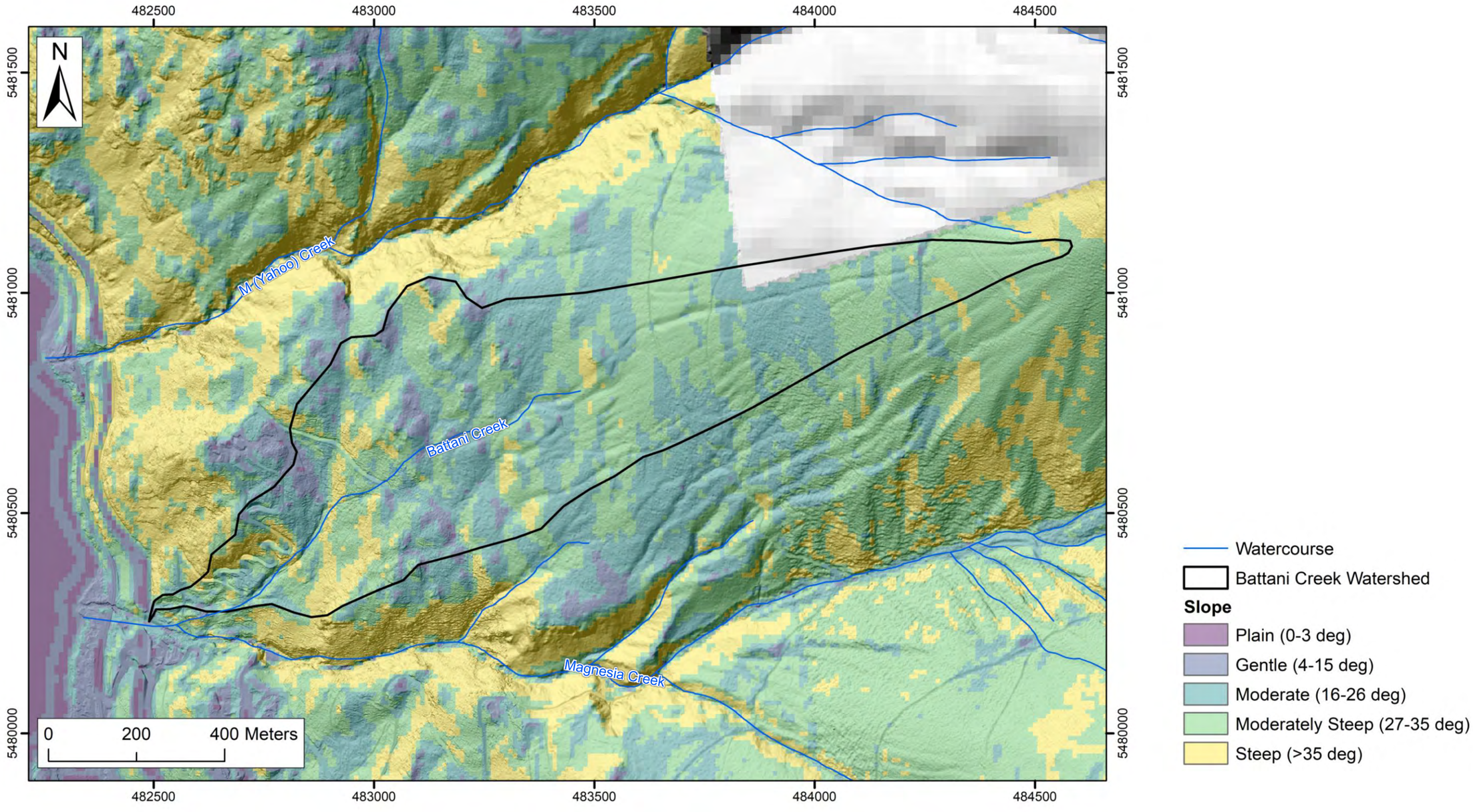
TITLE: HAZARD MAP

PROJECT No.: 1791004

DWG No: 05

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FIGURES

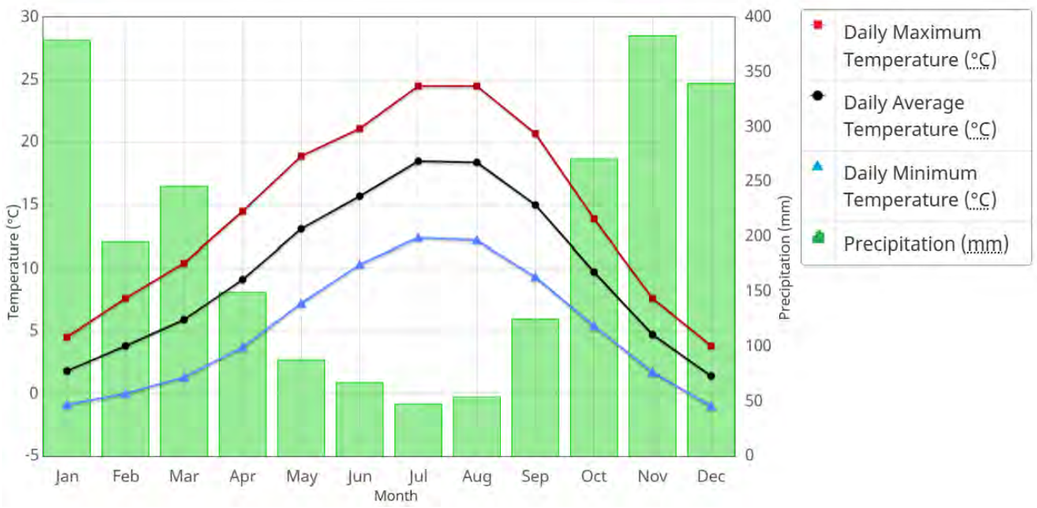


NOTES:

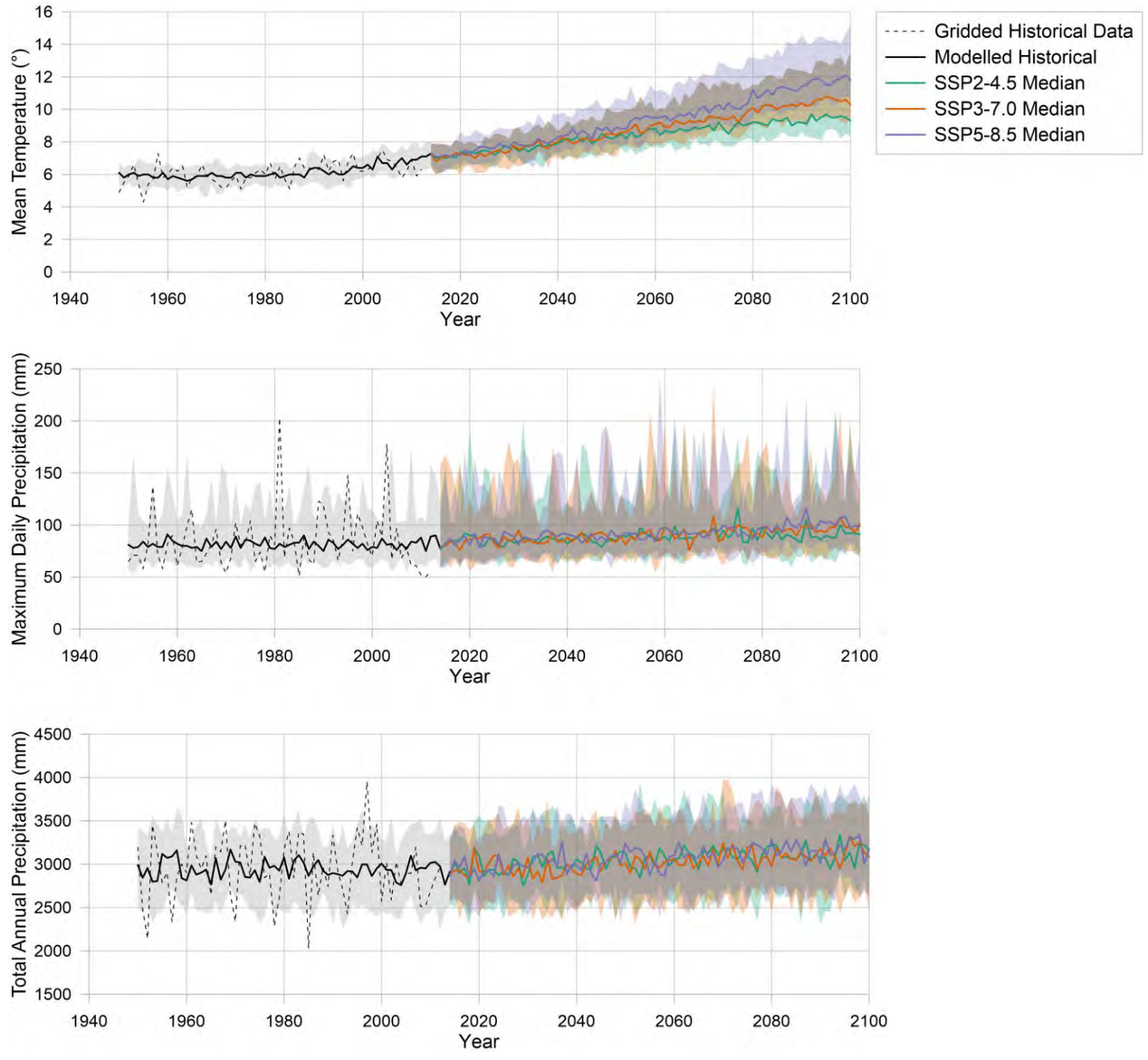
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Slope map derived from a 10 m DEM of lidar provided by MoTT (2025), GeoBC (2019), and McElhanney (2012). Slope classes are based on the Mapping and Assessing Terrain Stability Guidebook (Forest Practices Code of British Columbia, 1999).
3. Topographic hillshade is based on lidar provided by MoTT (2025), GeoBC (2019), and McElhanney (2012), and CDEM data from the Government of Canada (2011).
4. Watercourses are from the BC Freshwater Atlas.

PREPARED BY:	FIGURE TITLE:		
SZ	SLOPE MAP		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	AS SHOWN	1791004	01

a) Canadian Climate Normals for Squamish, British Columbia (1991-2020)



b) Climate models for Lion's Bay

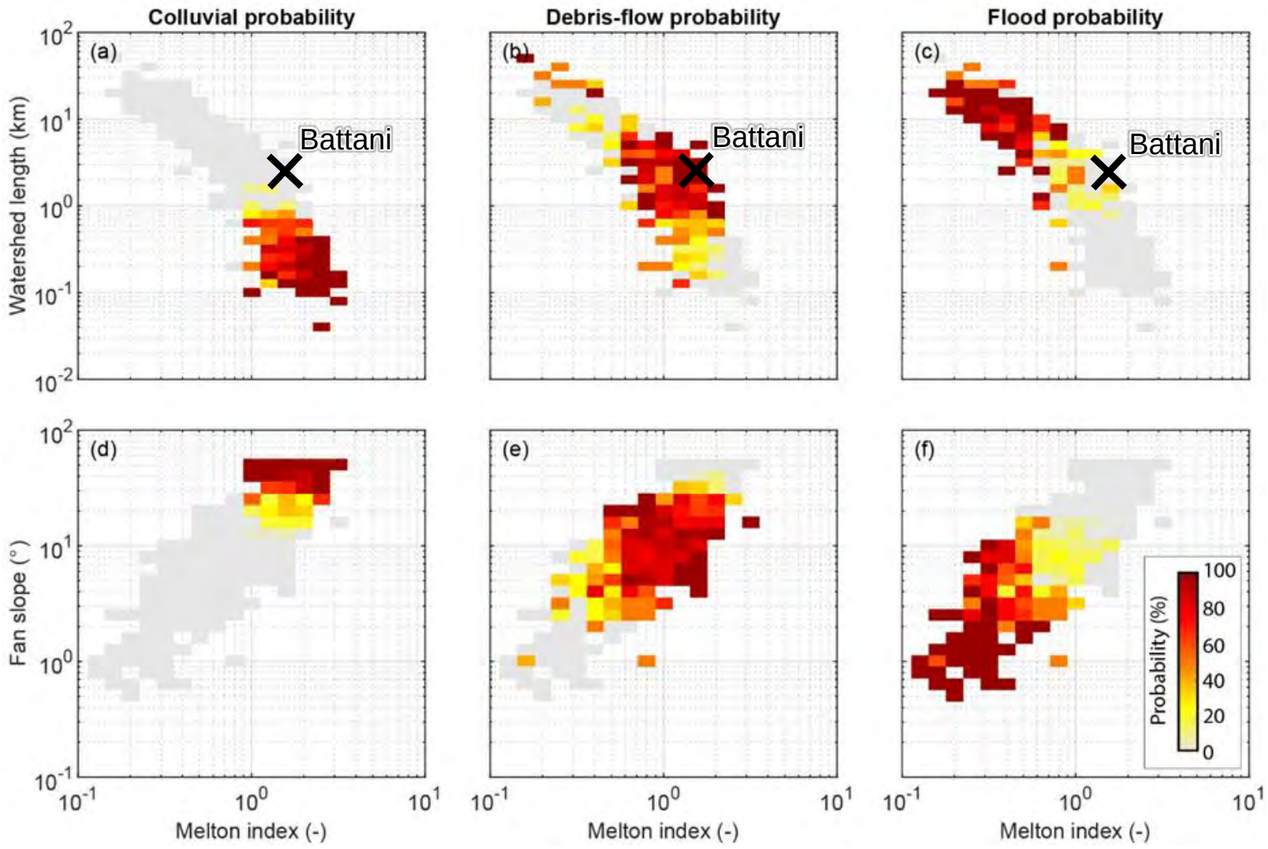


NOTES:

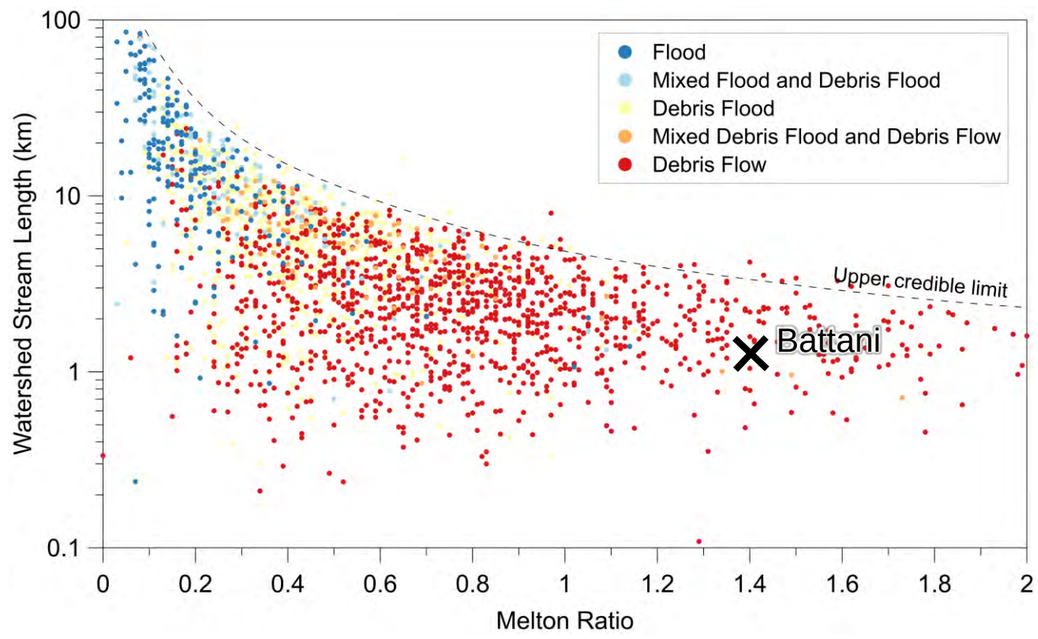
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Canadian Climate Normals (a) from Environment Canada (https://climate.weather.gc.ca/climate_normals/index_e.html) based on the Squamish Airport station at 53.7 m asl.
3. Climate models (b) are from ClimateData.ca with Couple Model Intercomparison Project Phase 6 (CMIP6) global climate model data. The results reflect a ~10km x 6 km grid cell containing Lion's Bay. Historical climate data pre-2014 are shown as modelled values from climate simulations (black solid line) and gridded values from the interpolation of weather station data (dashed black line). Post-2014, three climate models are shown for different emission scenarios, or share socioeconomic pathways (SSPs): SSP2-4.5 ("middle-of-the-road" scenario), SSP3-7 (high-emission scenario, with aerosols), and SSP5-8.5 (high-emission scenario). The bold lines indicate the median of the model results, meaning half the climate model results fall above and below this line. The shaded regions bound the 10th and 90th percentile of the model results, meaning 10% of the climate model results lie below and above this area.

PREPARED BY:	FIGURE TITLE:		
SZ	CLIMATE		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	-	1791004	02

a) Hazard process type probability from global dataset (de Haas et al., 2024)



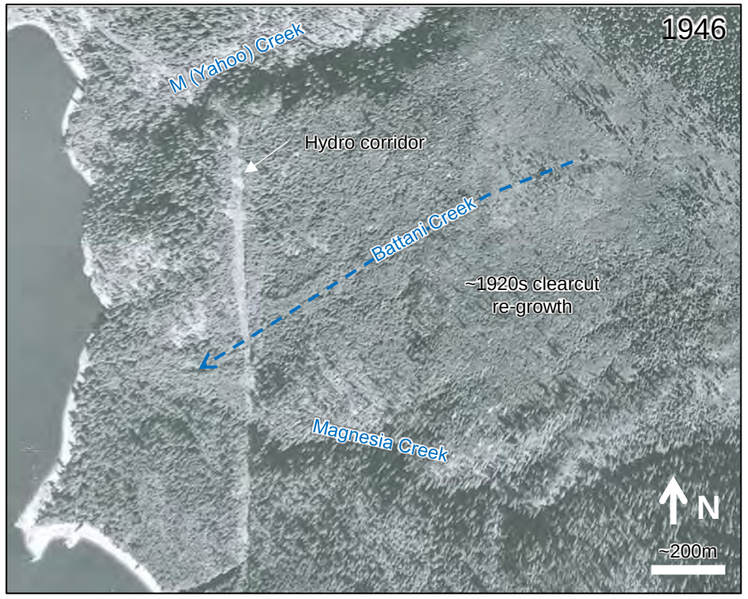
b) Hazard process types from BGC's watershed inventory

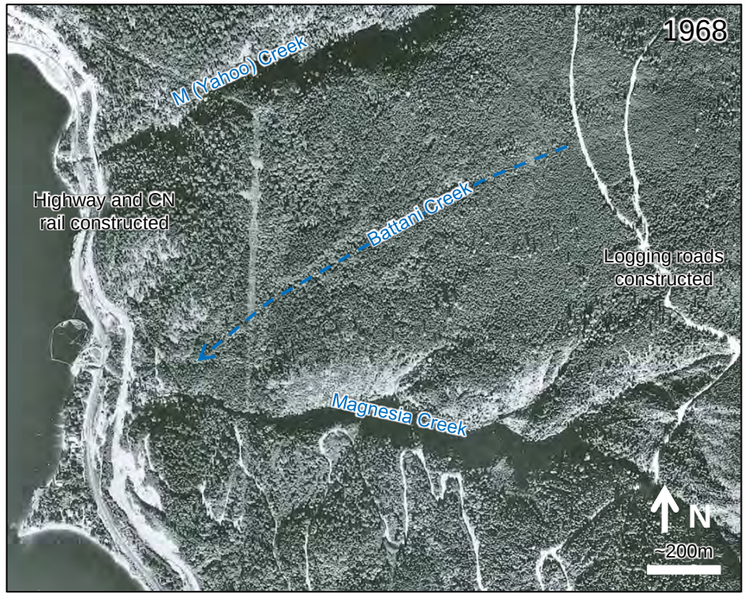


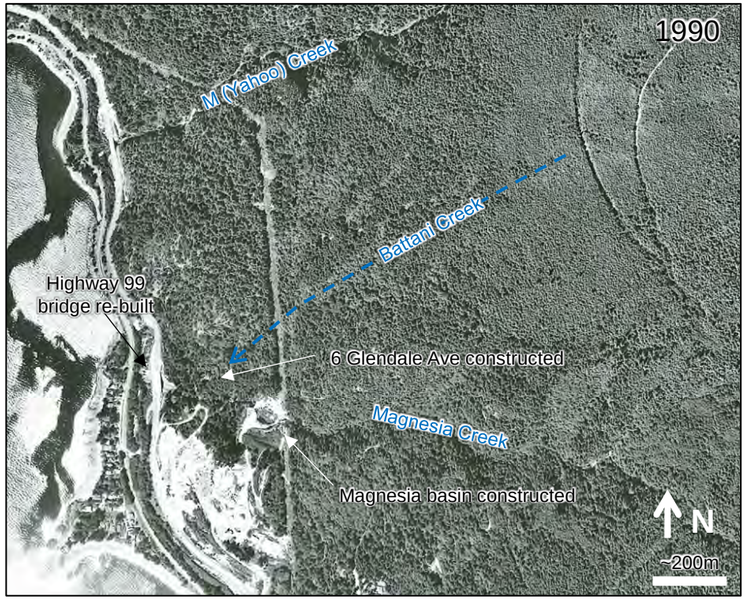
NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.

PREPARED BY: SZ	FIGURE TITLE: DOMINANT HAZARD PROCESS CLASSIFICATION		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: -	PROJECT NO: 1791004	FIGURE NO: 03

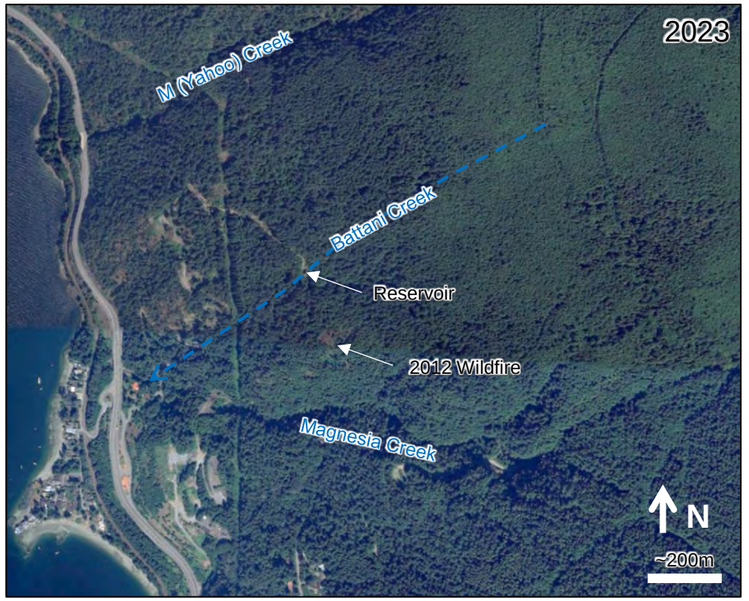










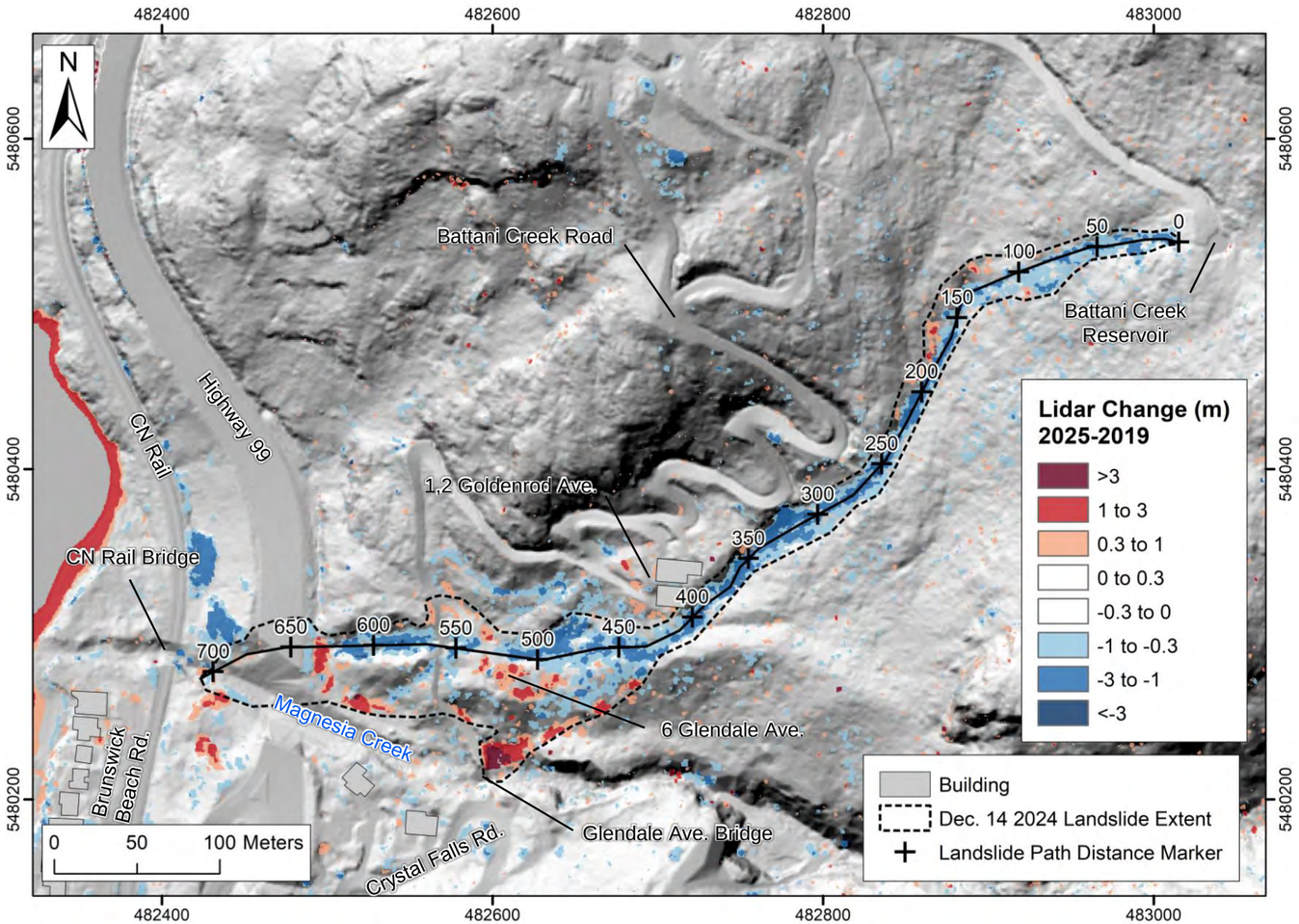


NOTES:

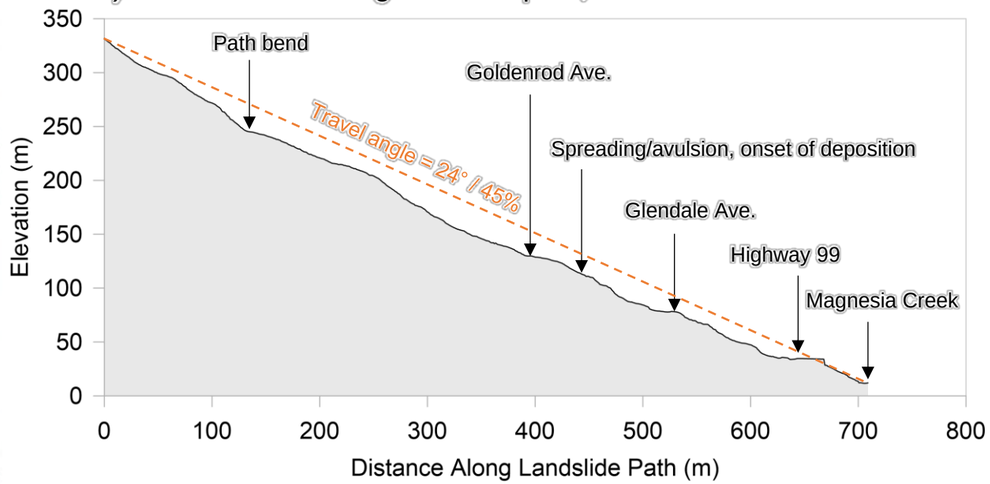
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Airphotos (1946: A10398-114; 1968: BC7117-215; 1990: BCB90019-54; 2003: BCC03039-42) from the University of British Columbia Geographic Information Centre.
3. Satellite imagery (August 6, 2012; June 25, 2023) from Google Earth.

PREPARED BY:	FIGURE TITLE:		
SZ	SELECT AERIAL IMAGE CHRONOLOGY		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	AS SHOWN	1791004	04

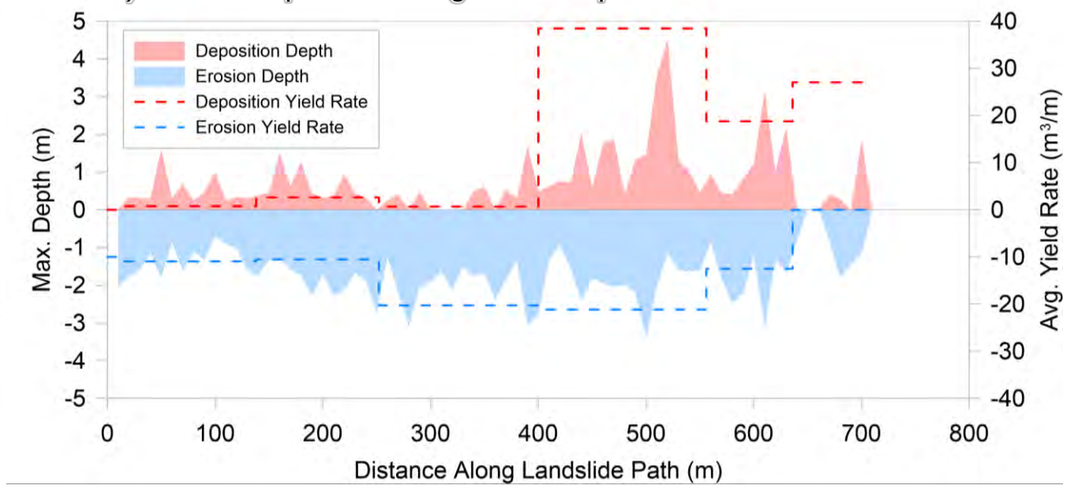
a) Lidar change map



b) Cross-section along landslide path, 2025 lidar



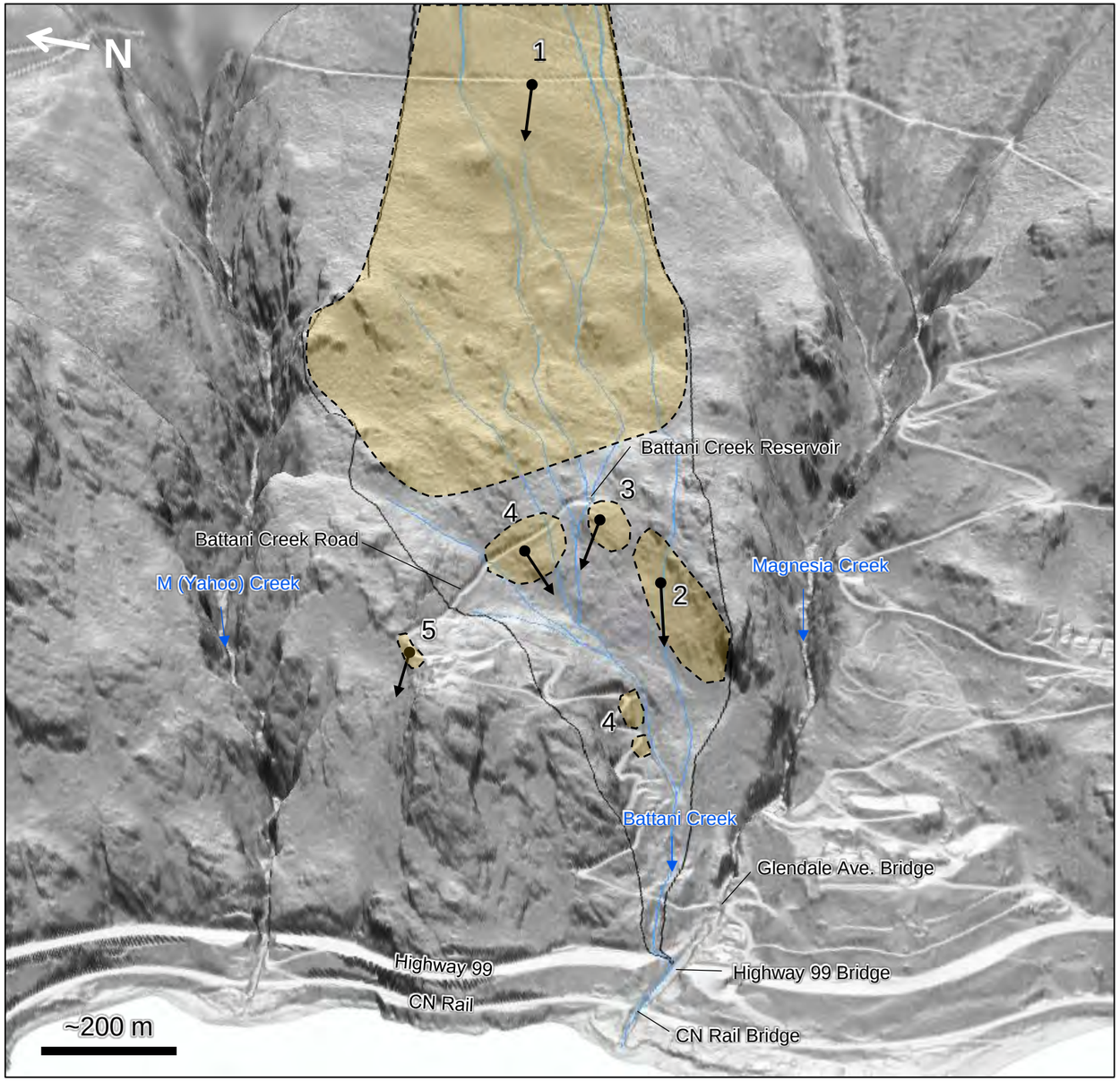
c) Erosion/deposition along landslide path



NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Change detection results between GeoBC (2019) and MoTT (2025-02-03) lidar surveys. Topographic hillshade shown is based on lidar provided by GeoBC (2019).
3. Landslide deposition downstream of approximately 500 m is not reflected in the lidar change due to clean-up and recovery efforts. Deposition yield rates shown in c) downstream of approximately 500 m are based on volume balance (from eroded volumes) and field observations.
4. Erosion and deposition depths plotted in c) are maximums from lidar change across the landslide extents perpendicular to the landslide path chainage markers.

PREPARED BY: SZ	FIGURE TITLE: LIDAR CHANGE ANALYSIS BETWEEN 2019 AND 2025		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: 05



Geohazard Scenario Area

Location of Modelled Point Source (Representative Scenario)

Battani Creek Watershed Streamline

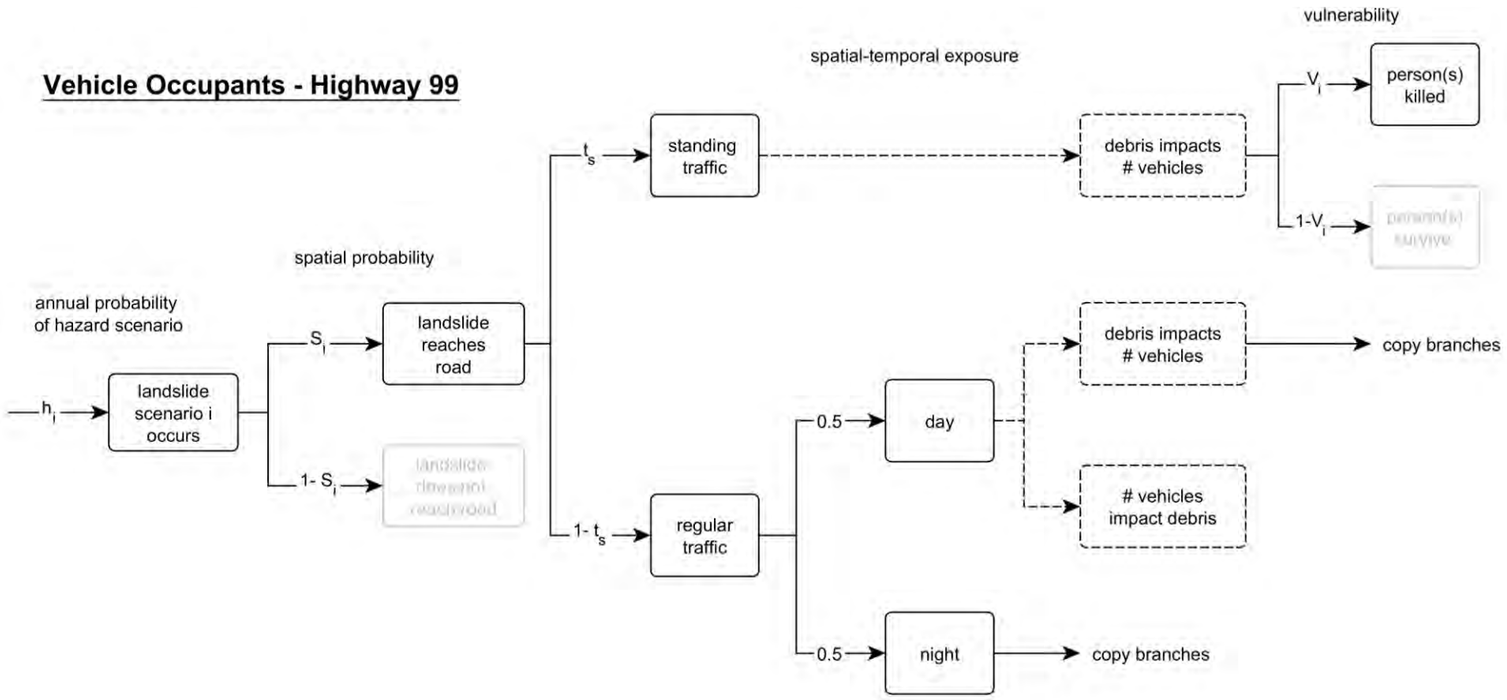
Battani Creek Watershed

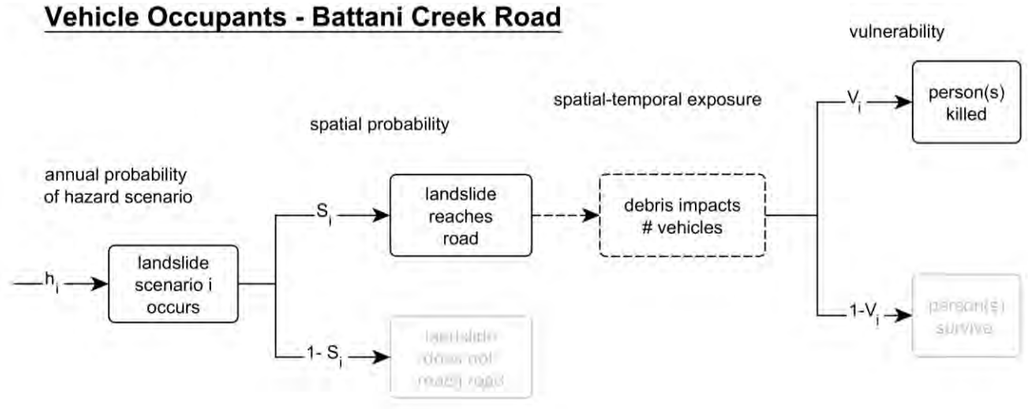
Hazard Scenarios	
1	Upper Watershed Open-Slope Landslide Transitioning to Debris Flow
2	Lower Watershed Open-Slope Landslide Transitioning to Debris Flow
3	Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow
4	Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow
5	Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche

NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Oblique view of topographic hillshade is based on lidar provided by MoTT (2025), GeoBC (2019), and McElhanney (2012), and CDEM data from the Government of Canada (2011).

PREPARED BY:	FIGURE TITLE:		
SZ	HAZARD SCENARIOS		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	AS SHOWN	1791004	06

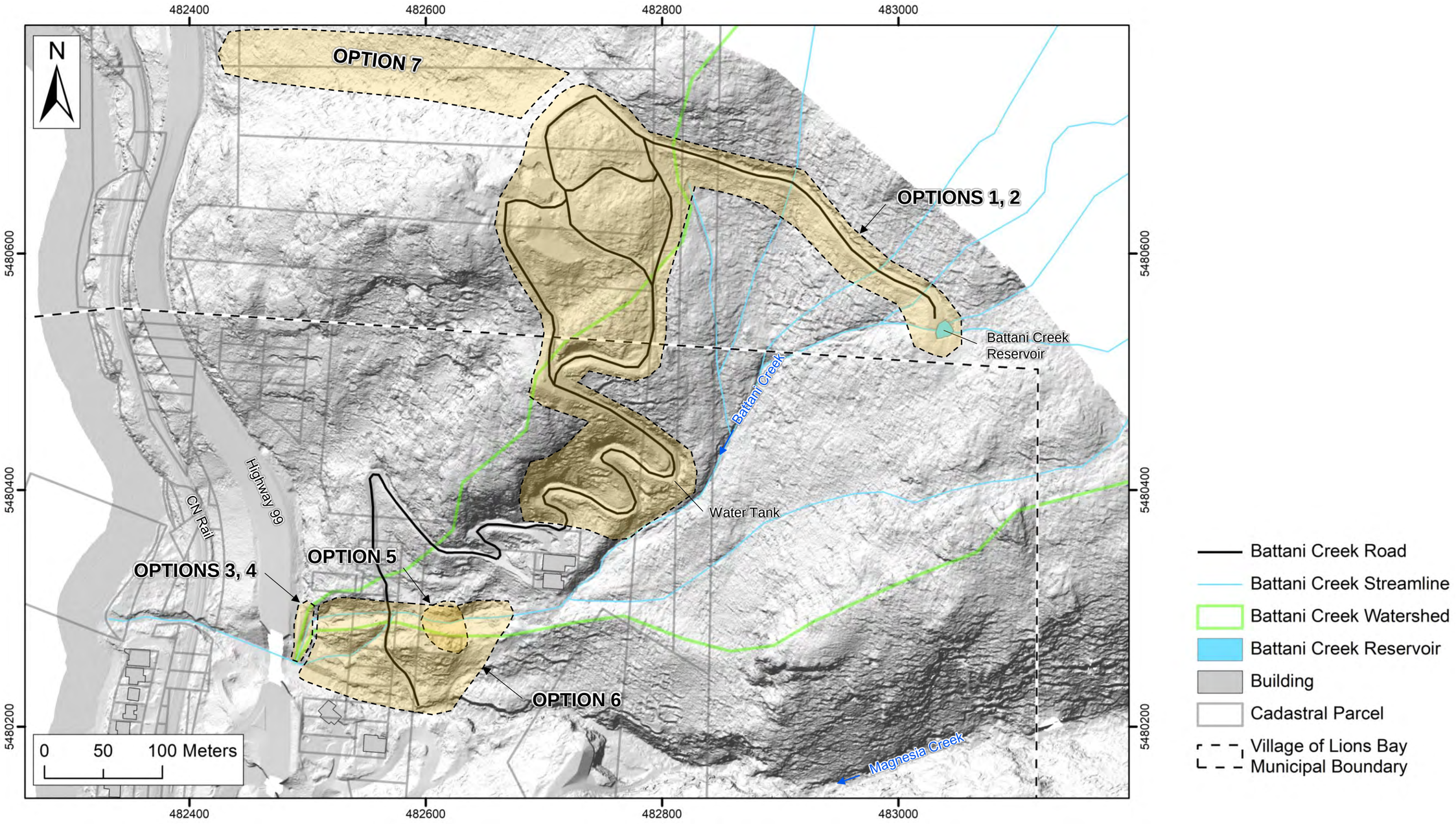




NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.

PREPARED BY:	FIGURE TITLE:		
SZ	RISK CHAINS		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	-	1791004	07



NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Topographic hillshade shown is based on lidar provided by GeoBC (2019).
3. Options 8 (monitoring and warning system) and 9 (public information and awareness) are not labelled on this map.

PREPARED BY:	FIGURE TITLE:		
SZ	MITIGATION OPTIONS		
CHECKED BY:	CLIENT:		
LCH	THE VILLAGE OF LIONS BAY		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SZ	AS SHOWN	1791004	08

BGC Engineering

PHOTOGRAPHS

Photo Reference Key:

Reference Location (Drawing 04)	Photo #s
1	1
2	2
3	3, 4
4	5
5	6, 7
6	8, 9
7	10
8	11
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19	25, 26
20	27, 28
21	29, 30
22	31
23	32
24	33, 34, 35
25	36, 37, 38
26	39
27	40, 41



Photo 1 **Looking upstream at CN bridge over Magnesia Creek (Location 1). Bridge opening is 8 m wide and 2.2 m to 2.8 m tall on the upstream side. Photo taken May 1, 2025.**



Photo 2 **Looking upstream at Highway 99 bridge at Magnesia Creek (Location 2). Photo taken May 1, 2025.**



Photo 3 **On Highway 99 berm and basin at Battani Creek (Location 3). Looking downstream toward culvert outlet and confluence with Magnesia Creek. Photo taken May 1, 2025.**



Photo 4 **Panorama of Highway 99 berm and basin at the outlet of Battani Creek (Location 3). Photo taken May 1, 2025.**



Photo 5 Looking downstream at the Glendale Ave. bridge on Magnesia Creek (Location 4). Maximum clearance is approximately 3.3 m. Photo taken May 1, 2025.



Photo 6 Looking downstream from Battani Creek Road at side-channel and landslide avulsion path south of Location 5. Photo taken April 30, 2025.



Photo 7 At culvert on Battani Creek Road, looking downstream along main landslide path toward Highway 99 (Location 5). Photo taken April 30, 2025.



Photo 8 Engineered rock stack wall at Battani Creek Road switchback (Location 6). Looking downslope toward Highway 99. Photo taken April 30, 2025.



Photo 9 At toe of engineered rock stack wall (Location 6) where logs and woody debris have been dumped. Photo taken July 24, 2025.



Photo 10 Looking upstream along the Battani Creek landslide path (Location 7). 2 Goldenrod Avenue is shown in the left of this photo. Photo taken April 30, 2025.



Photo 11 Switchback at Battani Creek Road (Location 8). Photo taken April 30, 2025.



Photo 12 Looking across Battani Creek Road fill slope (Location 9). Woody debris is scattered on shot rock fill slope. Photo taken July 24, 2025.



Photo 13 On Battani Creek Road looking down fill slope toward 1 and 2 Goldenrod Avenue (Location 9). Photo taken April 30, 2025.



Photo 14 Looking downslope at the scarp of a fill failure at a switchback on Battani Creek Road undermined by the landslide path (Location 10). Photo taken April 30, 2025.



Photo 15 Log cribs supporting Battani Creek Road fill (Location 11). Photo taken July 24, 2025.



Photo 16 Full and operating water tank at the edge of Battani Creek road on fill supported by log cribs adjacent to the landslide path (Location 12). Photo taken July 24, 2025.



Photo 17 Field book at location of rotting logs supporting fill slope beneath the water tank (Location 12). Photo taken July 24, 2025.



Photo 18 Battani Creek Road cut in fractured and faulted bedrock (Location 13). Photo taken July 24, 2025.



Photo 19 At toe of Battani Creek Road fill slope (Location 14). Shot rock is resting on top of woody debris. Photo taken July 24, 2025.



Photo 20 Slope-parallel tension cracks (red dashed) along the edge of Battani Creek Road (Location 14). Photo taken April 30, 2025.



Photo 21 Stepped bedrock slopes within a broader bedrock scarp facing Howe Sound (Location 15). Photo taken July 24, 2025.



Photo 22 Looking downslope at a 15 m wide, 2 m tall rock fall net anchored to bedrock downslope of Battani Creek Road (Location 16). Photo taken July 24, 2025.



Photo 23 Looking across slope (north) at an area of slope pull-back and re-alignment of Battani Creek Road (Location 17). Photo taken April 30, 2025.



Photo 24 Looking south along tributary of Battani Creek and 1.5 m tall berm to the right of the creek bed (Location 18). Photo taken April 30, 2025.



Photo 25 Log crib supporting fill at Battani Creek Road on MoTT property (Location 19). 1.5 m boulder is resting on log cribs supported by a leaning tree. Photo taken July 24, 2025.



Photo 26 Western end of log crib structures on the MoTT property where fill has failed from behind the logs (Location 19). Photo taken July 24, 2025.



Photo 27 Looking across fill slope (southeast) of Battani Creek Road (Location 20). Road fill slope is 37° and comprised of angular blast rock. Photo taken April 30, 2025.



Photo 28 Recent rock wedge failure from fractured cut slope on Battani Creek Road (Location 20). Wedge block is approximately 1 x 1 x 2 m. Photo taken April 30, 2025.



Photo 29 Inlet of 24-inch steel culvert at Battani Creek Road (Location 21). Photo taken April 30, 2025.



Photo 30 Looking across fill slope (southeast) of Battani Creek Road (Location 21). Road fill slope is 37° and comprised of angular blast rock. Photo taken April 30, 2025.



Photo 31 Battani Creek Road ditch (Location 22). Ditch is overgrown and inlet of 12-inch steel culvert (not shown) is partially blocked and ponding. Photo taken April 30, 2025.



Photo 32 Battani Creek upstream of reservoir (Location 23). Photo taken April 30, 2025.



Photo 33 Looking west toward the outlet of the Battani Creek reservoir along concrete sill on northern side of pond (Location 24). Photo taken April 30, 2025.



Photo 34 Looking upstream (southeast) at Battani Creek flowing into the reservoir (Location 24). Photo taken April 30, 2025.

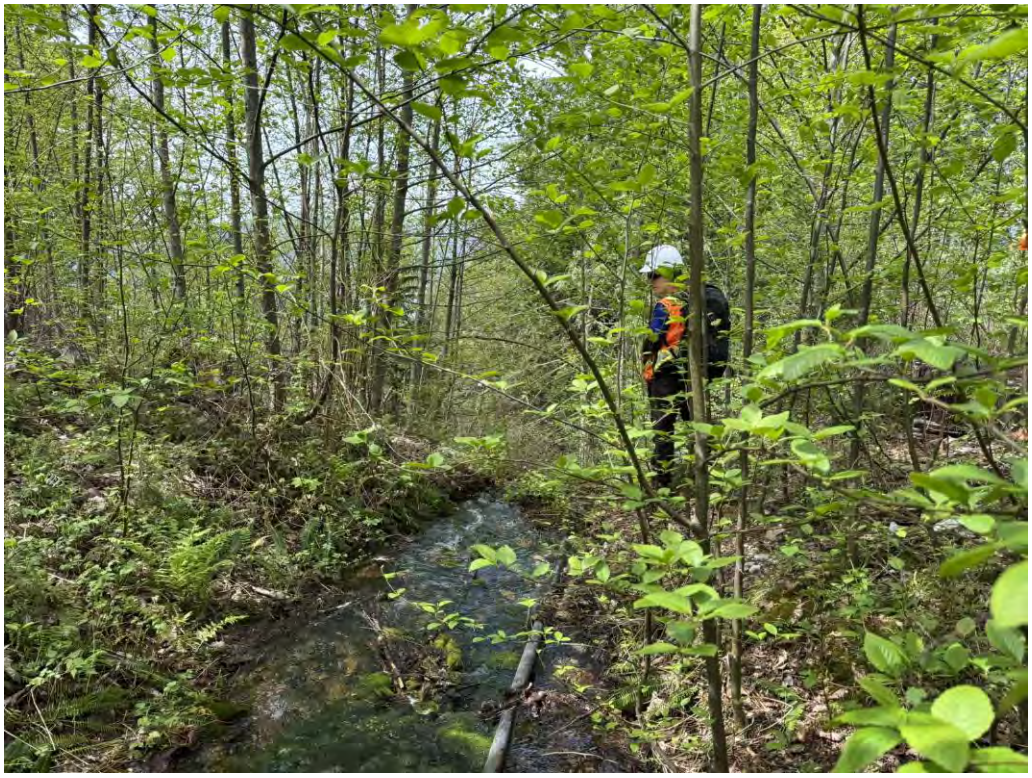


Photo 35 Outlet channel of the Battani Creek reservoir, upstream of the landslide headscarp (Location 24). Photo taken April 30, 2025.



Photo 36 Looking downstream at exposed bedrock in the Battani Creek landslide headscarp (Location 25). Photo taken April 30, 2025.



Photo 37 Soft organic soil and cut stumps directly to the north of the Battani Creek landslide headscarp (Location 25). Photo taken April 30, 2025.



Photo 38 Looking southeast toward bedrock slopes below Battani Creek landslide headscarp (Location 25). White arrows indicate bedrock seepage. Photo taken July 24, 2025.



Photo 39 Looking downstream along the Battani Creek landslide path (Location 26). Some woody debris left in channel from the landslide. Photo taken April 30, 2025.



Photo 40 Looking upstream along the Battani Creek landslide path (Location 27). Landslide has scoured 2-3 m to bedrock. Photo taken April 30, 2025.



Photo 41 Looking downstream toward Howe Sound along the Battani Creek landslide path (Location 27). Photo taken April 30, 2025.

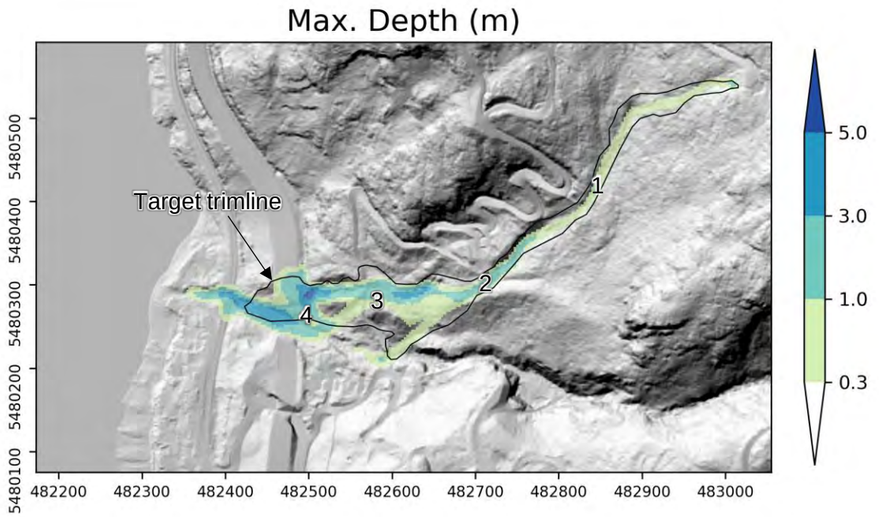


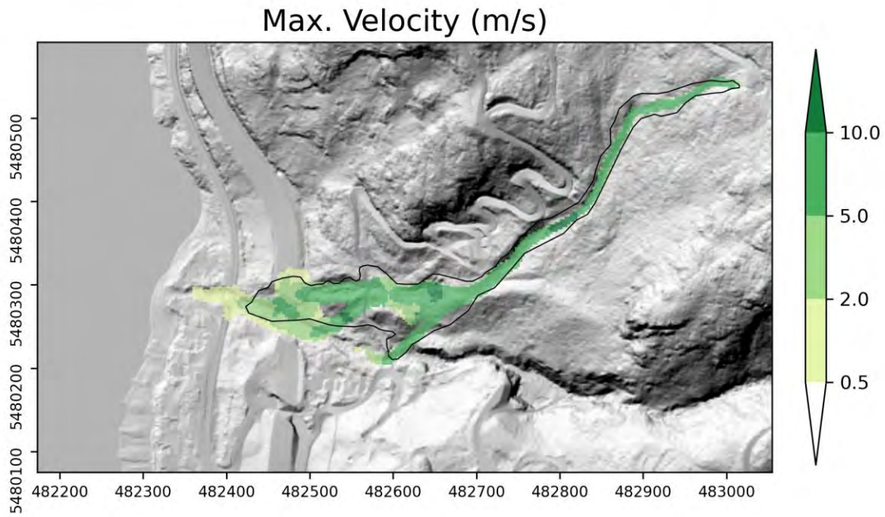
Photo 42 Looking upstream along a V-shaped gully that crosses the logging roads in the upper Battani Creek watershed at approximately 660 m elevation. Photo taken May 1, 2025.



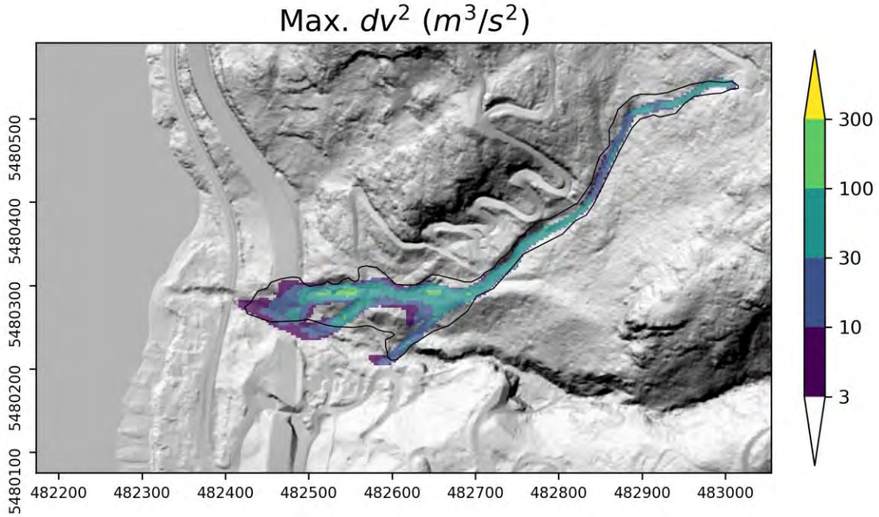
Photo 43 Looking north along the legacy logging road at the southern extent of the upper Battani Creek watershed. Ponding at the swale/cross-ditch. Photo taken May 1, 2025.

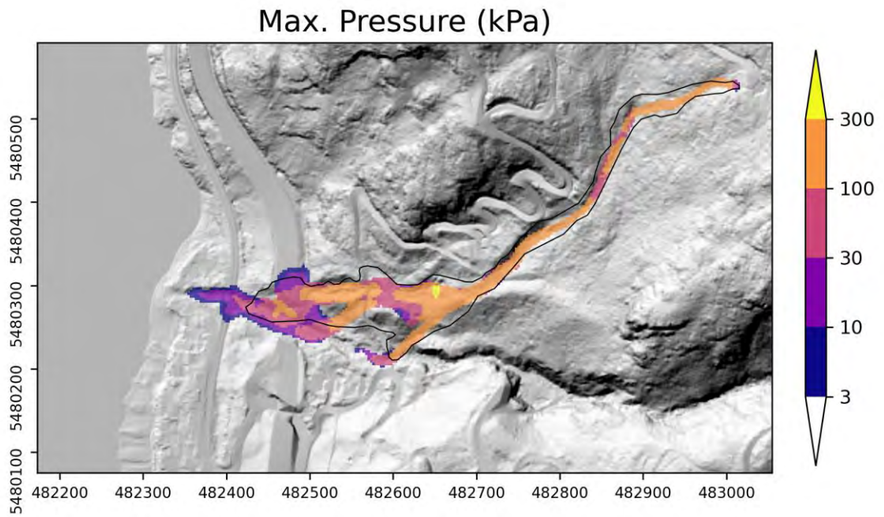
APPENDIX A
NUMERICAL RUNOUT MODELLING RESULTS





Calibration Location	Target	Model
1	3-5 m	0.9 m
2	5-12 m/s	8 m/s
3	2-3 m	0.6 m
4	2-2.5 m	2.4 m



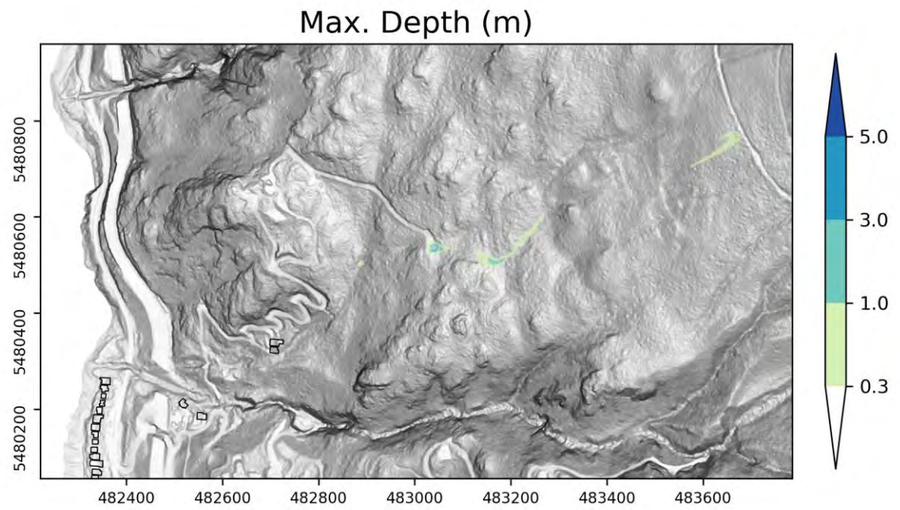


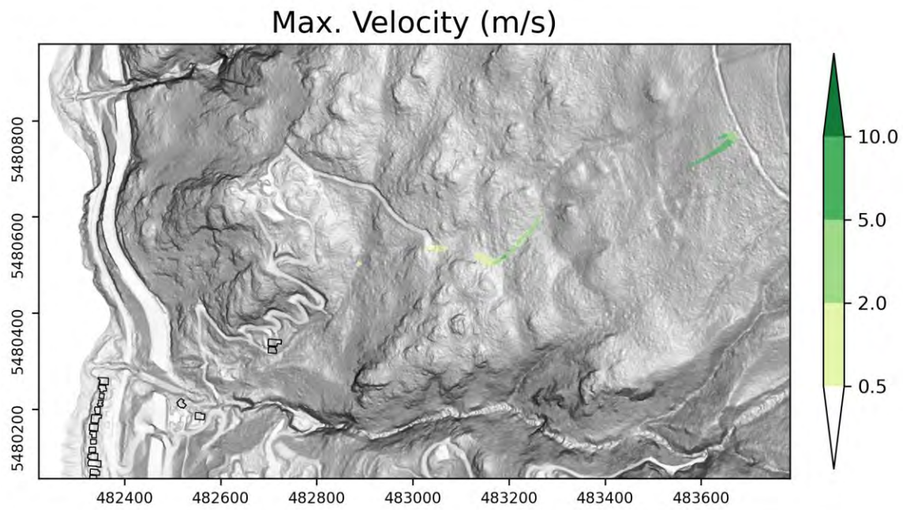
Scenario	December 14th 2024 Landslide Calibration
Initial Volume	100 m^3
Target Final Volume	15,000 m^3
Model Volume	15,500 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	17 kN/m^3
Topography	2019 lidar (3 m, smoothed)

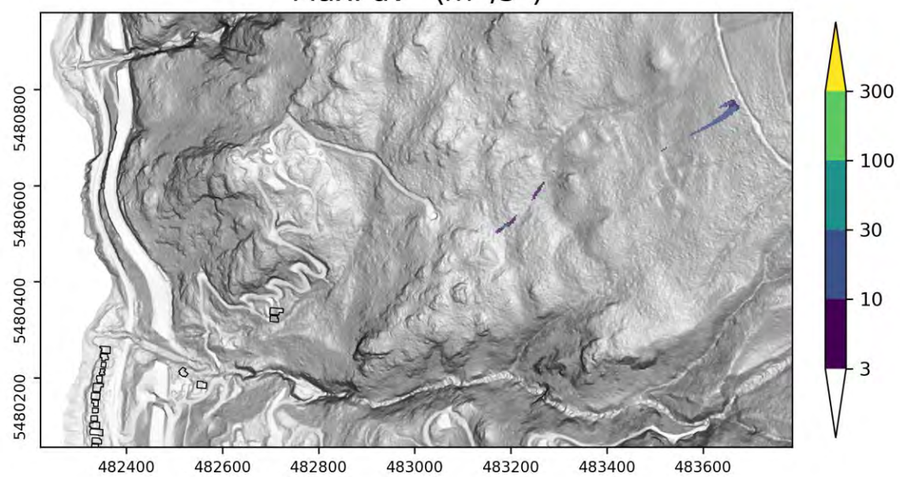
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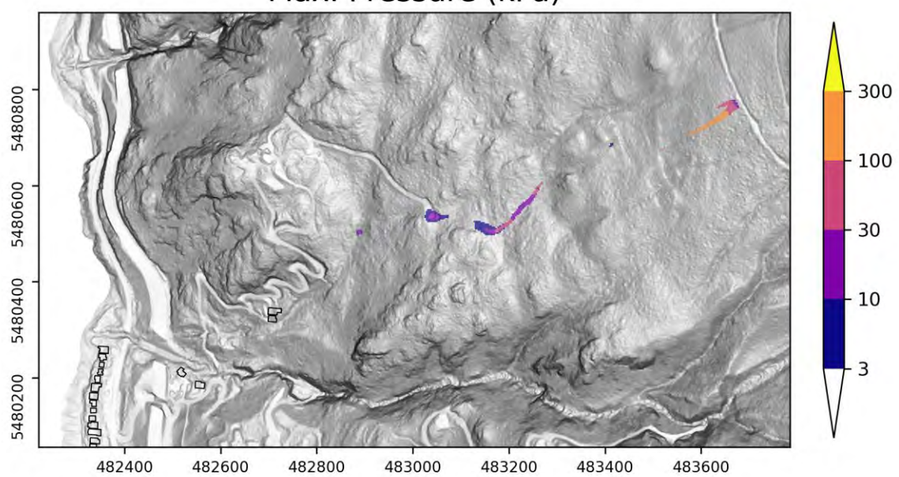
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019).
5. Calibrated parameters selected using methodology described in Aaron et al. (2019) to best match the estimated peak flow depths, velocities, and runout extents of the December 14, 2024 landslide. Model flow depths did not match observed flow depths along the upper parts of the channel for all tested parameter combinations.

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – CALIBRATION		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-1







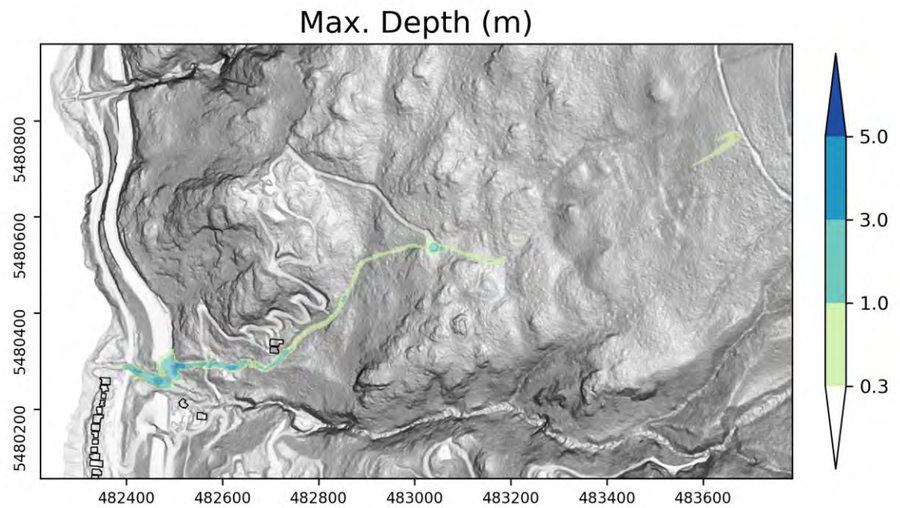


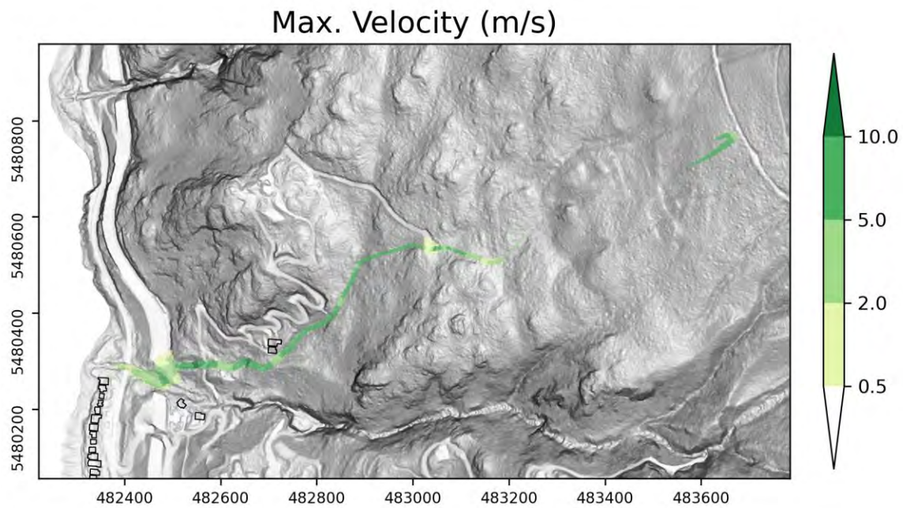
Scenario	Upper Watershed Open-Slope Landslide Transitioning to Debris Flow (1A)
Initial Volume	200 m^3
Target Final Volume	13,100 m^3
Model Volume	2,100 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar (3 m, smoothed)

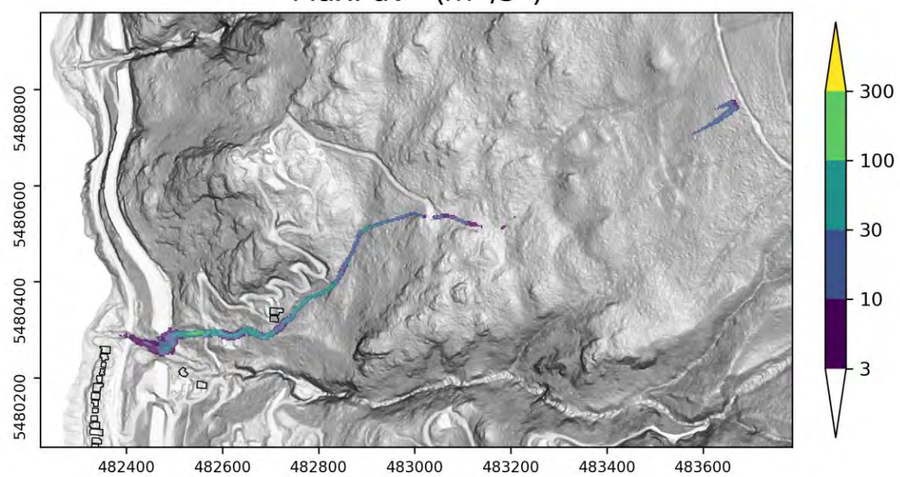
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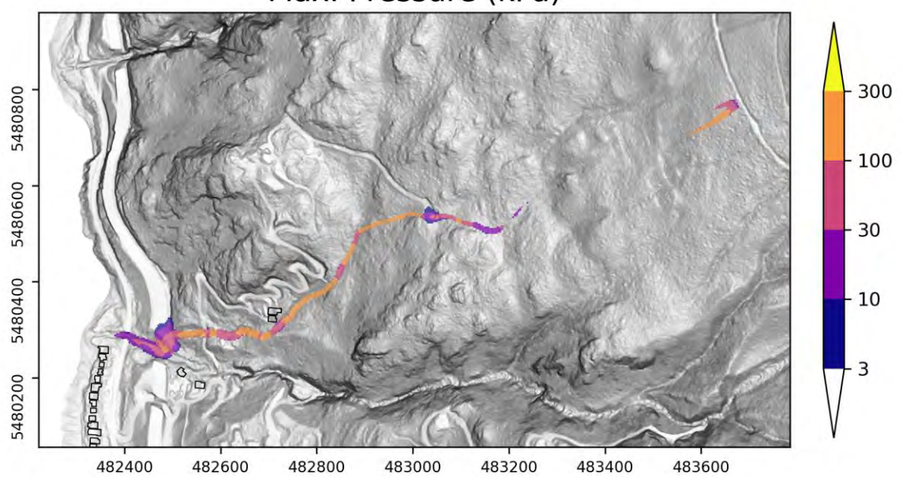
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).
5. Model volume did not reach target final volume since material stalled on the upper slopes and could not continue downslope to entrain material. A higher mobility scenario (1B) was included to reach target volume.

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 1A		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-2







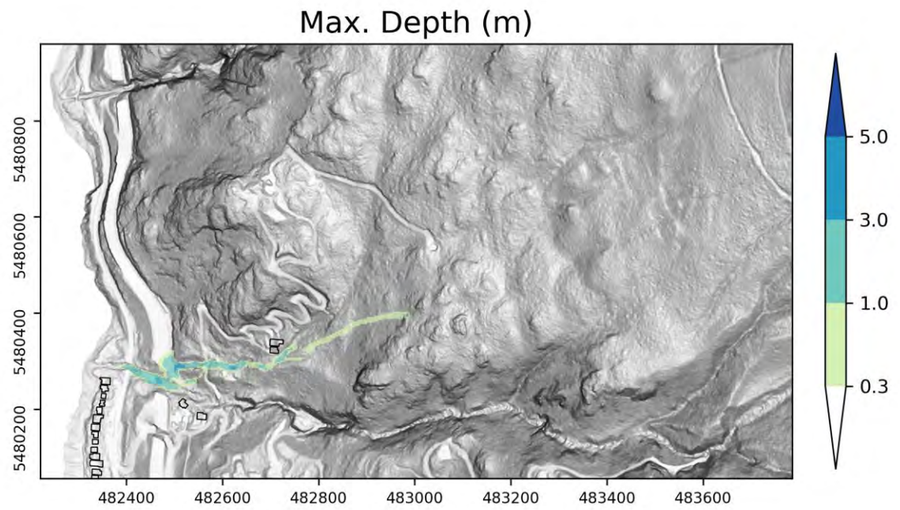


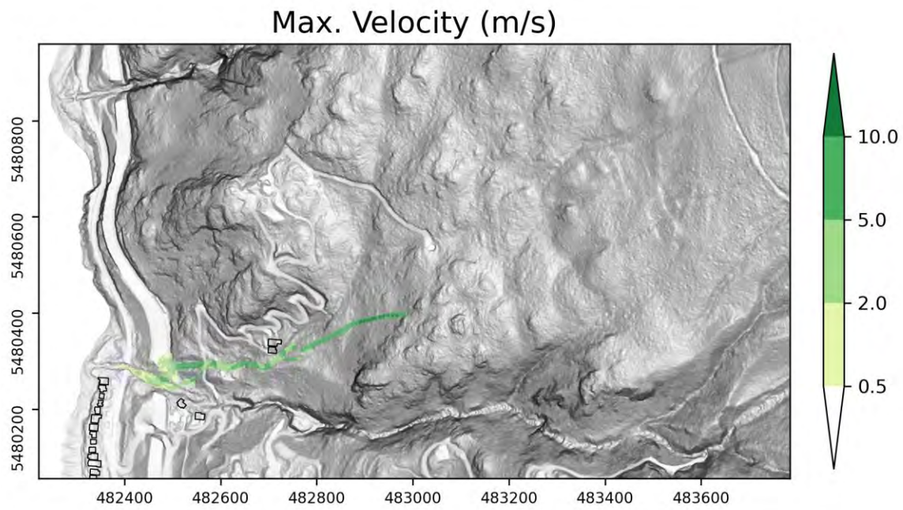
Scenario	Upper Watershed Open-Slope Landslide Transitioning to Debris Flow (1B)
Initial Volume	200 m^3
Target Final Volume	13,100 m^3
Model Volume	12,900 m^3
Numerical Model	DAN3D
Rheology	Voellmy – High Mobility (f=0.20, ξ=500 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar (3 m, smoothed)

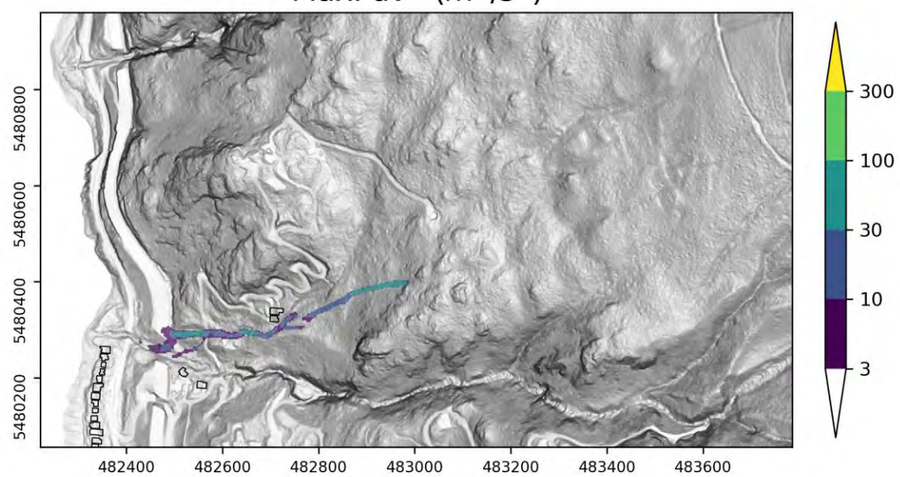
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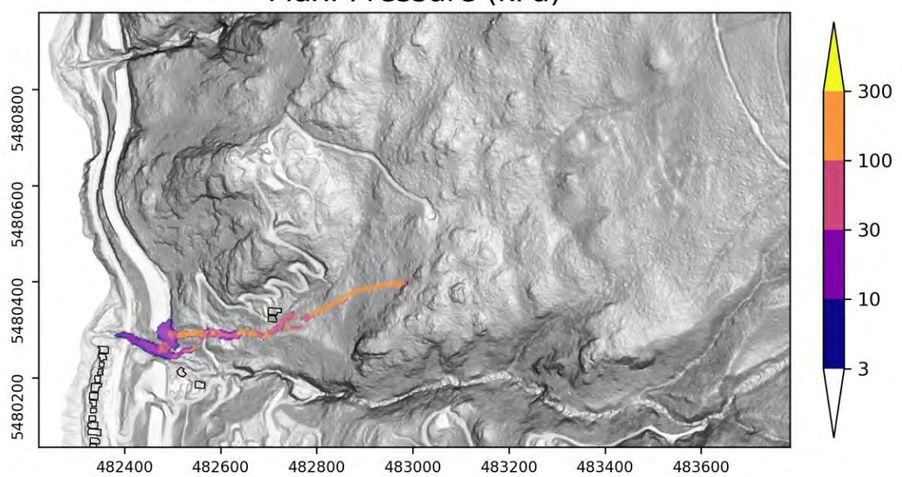
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 1B		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-3







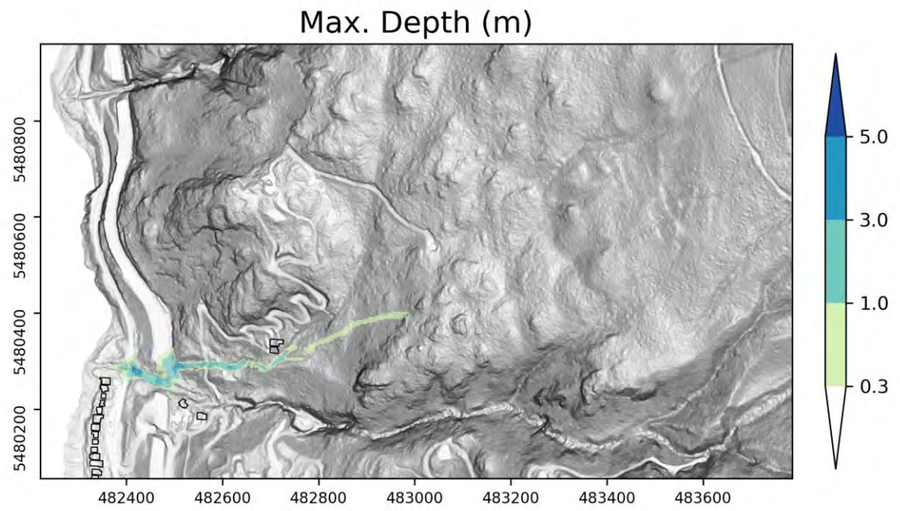


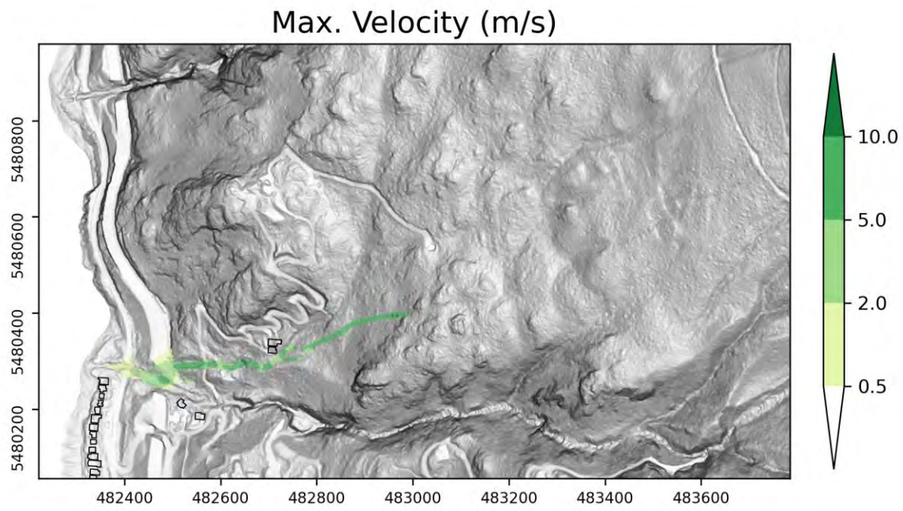
Scenario	Lower Watershed Open-Slope Landslide Transitioning to Debris Flow (2A)
Initial Volume	100 m^3
Target Final Volume	6,500 m^3
Model Volume	7,500 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar (3 m, smoothed)

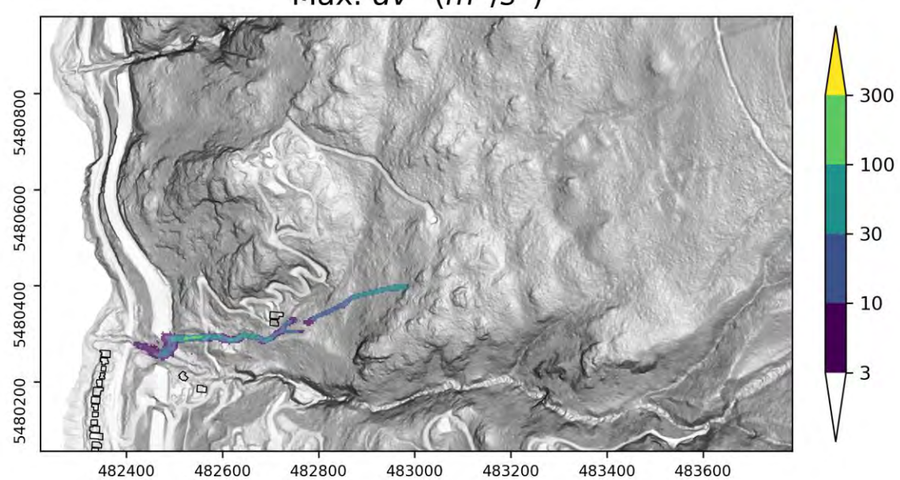
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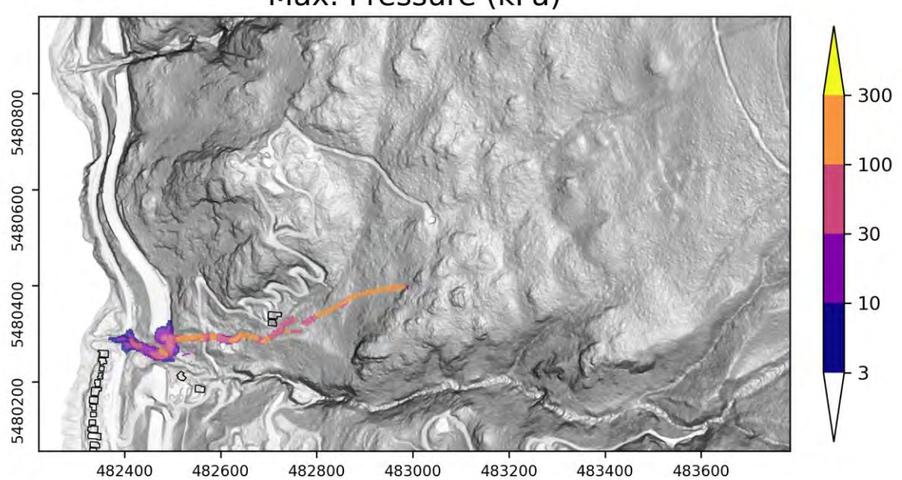
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 2A		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-4







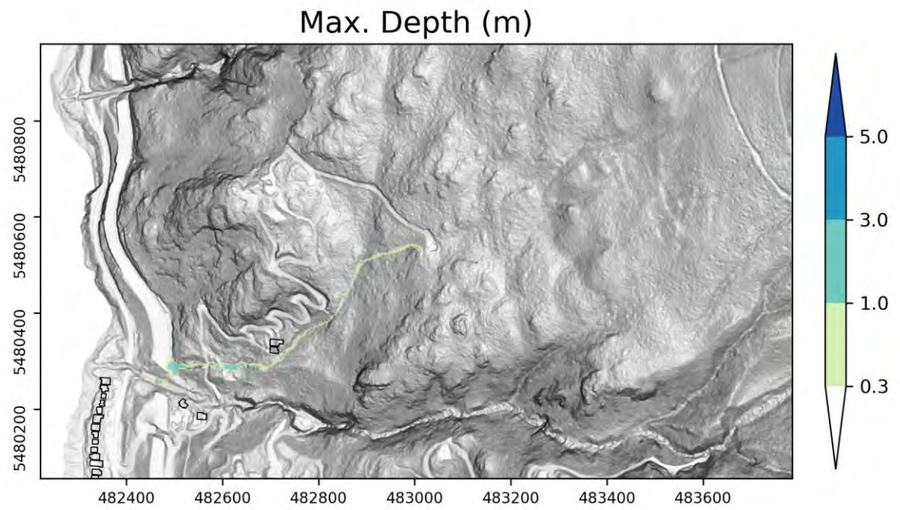


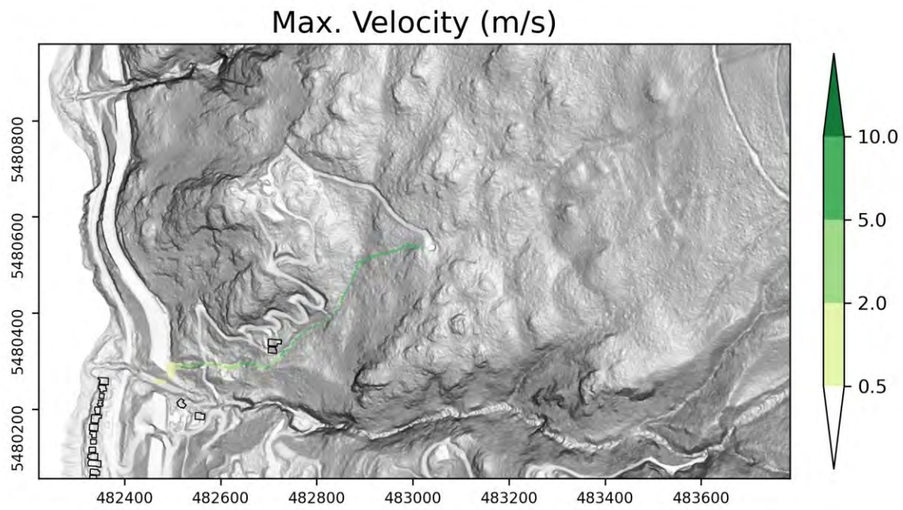
Scenario	Lower Watershed Open-Slope Landslide Transitioning to Debris Flow (2B)
Initial Volume	100 m^3
Target Final Volume	6,500 m^3
Model Volume	7,600 m^3
Numerical Model	DAN3D
Rheology	Voellmy – High Mobility (f=0.20, ξ=500 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar with CN Rail bridge blocked (3 m, smoothed)

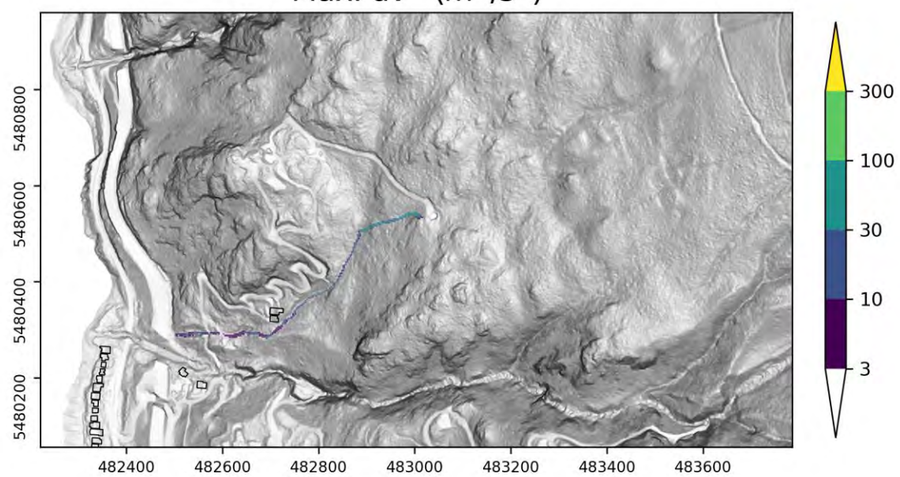
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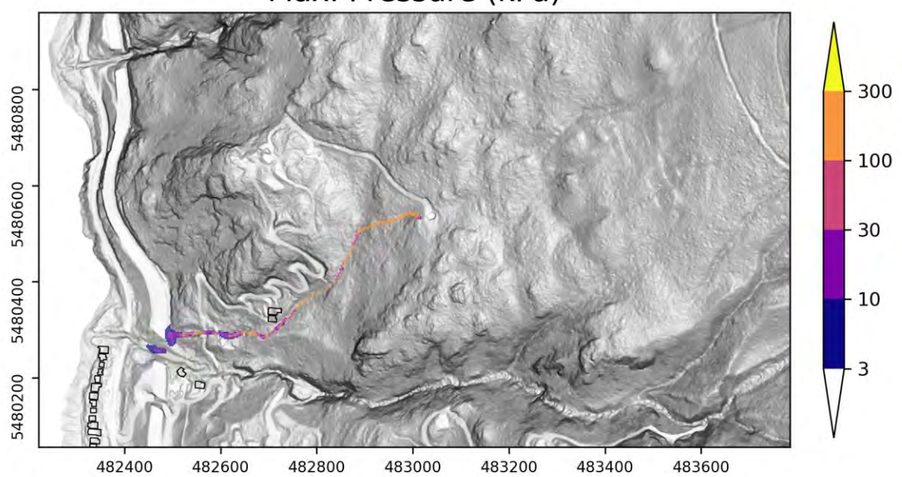
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 2B		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-5







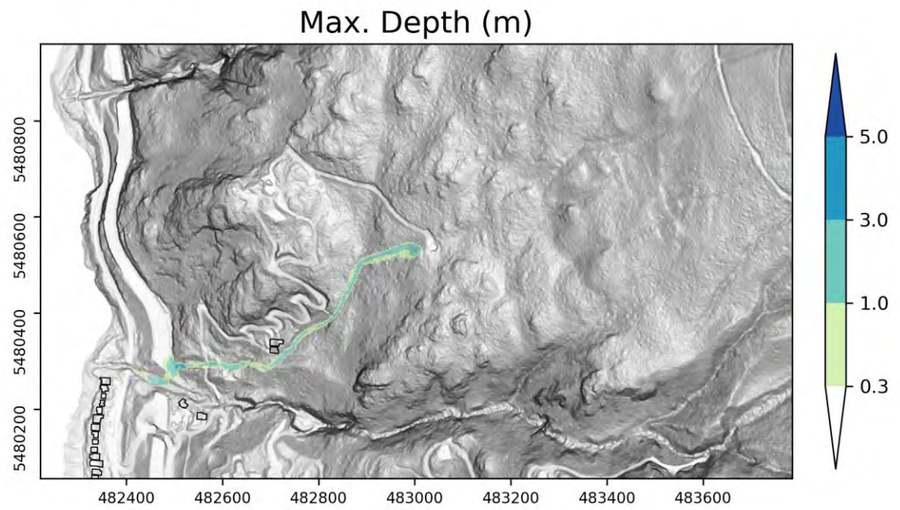


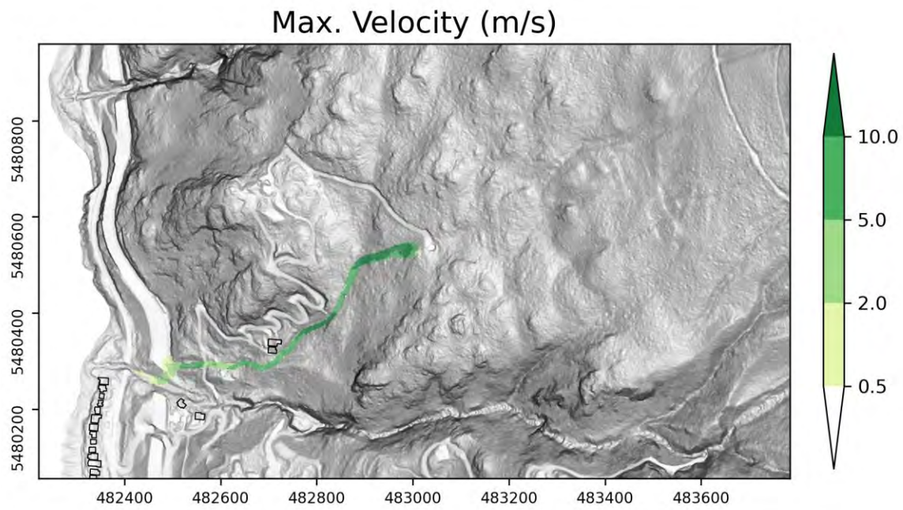
Scenario	Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow (3A)
Initial Volume	100 m^3
Target Final Volume	2,400 m^3
Model Volume	2,200 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	20 kN/m^3
Topography	2025 lidar (3 m, smoothed)

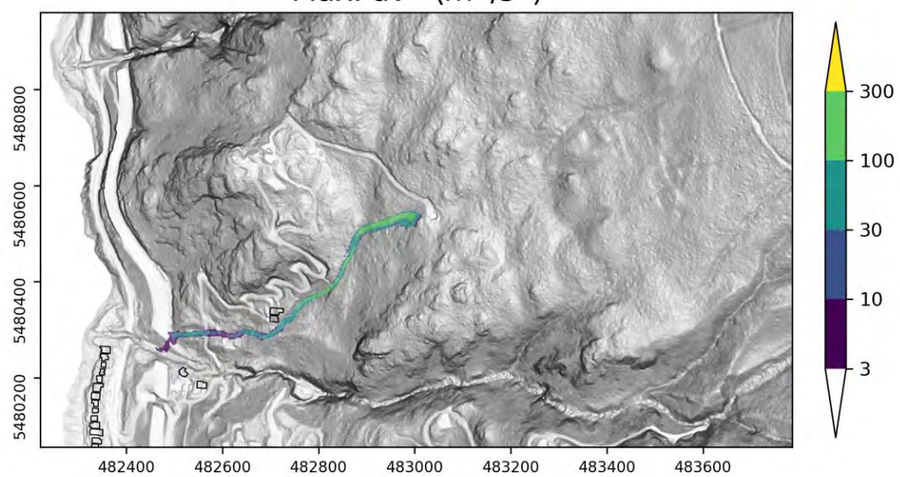
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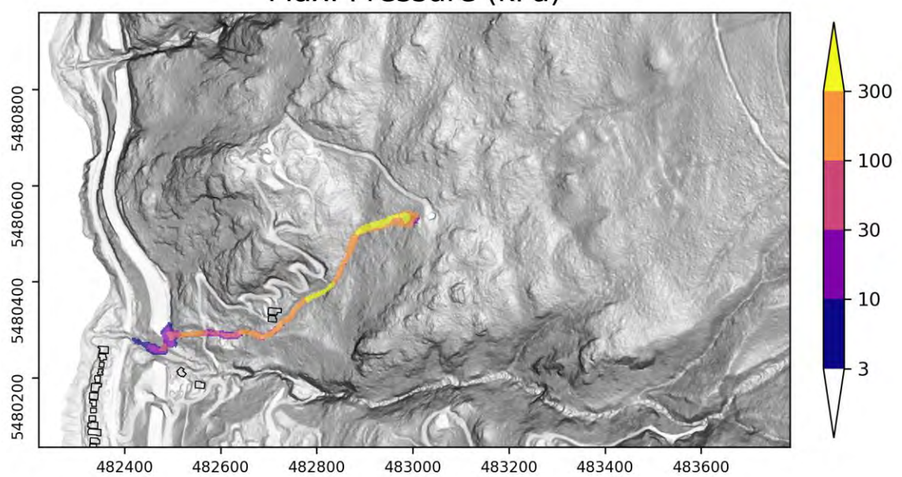
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 3A		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-6







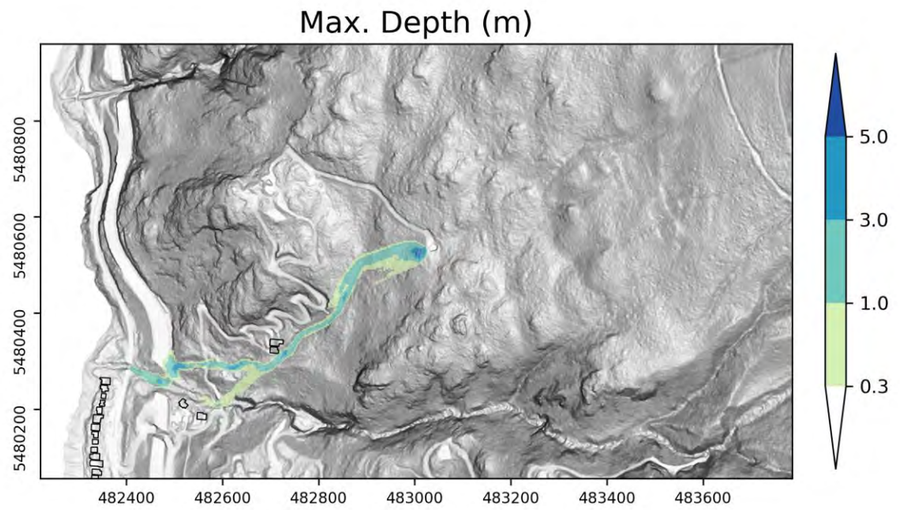


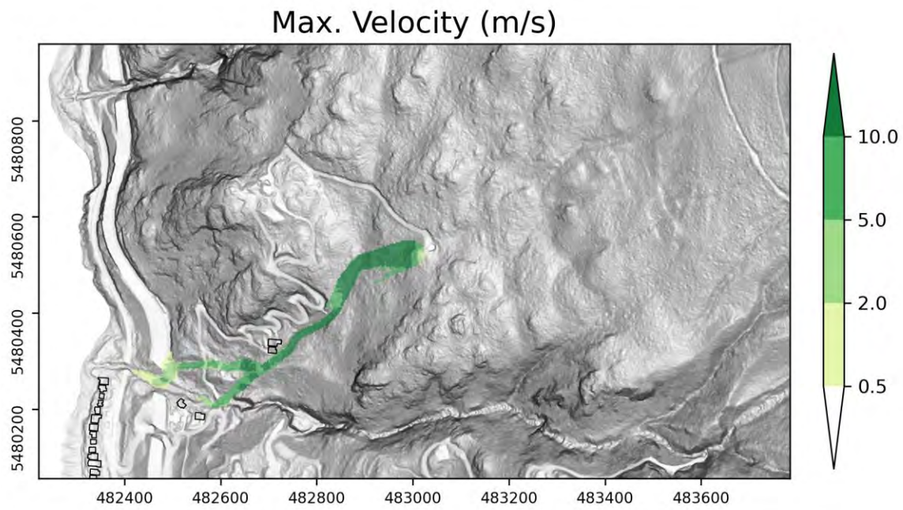
Scenario	Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow (3B)
Initial Volume	600 m^3
Target Final Volume	4,100 m^3
Model Volume	3,800 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	20 kN/m^3
Topography	2025 lidar (3 m, smoothed)

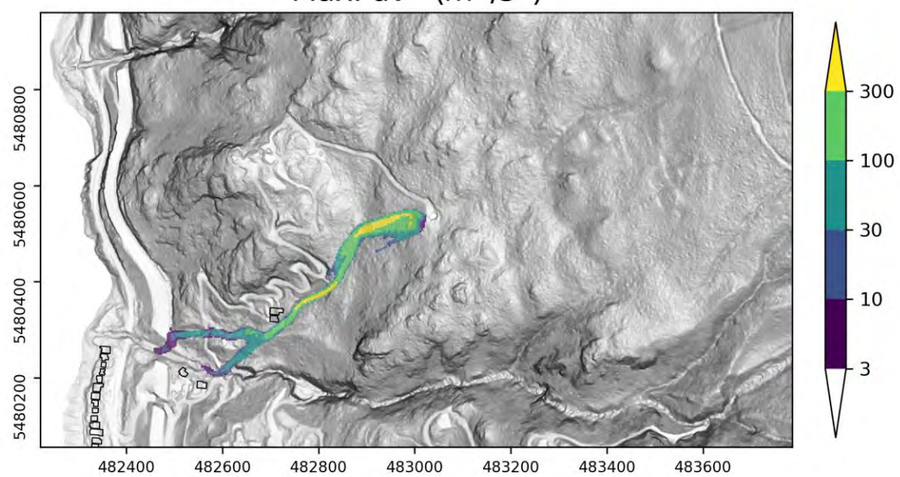
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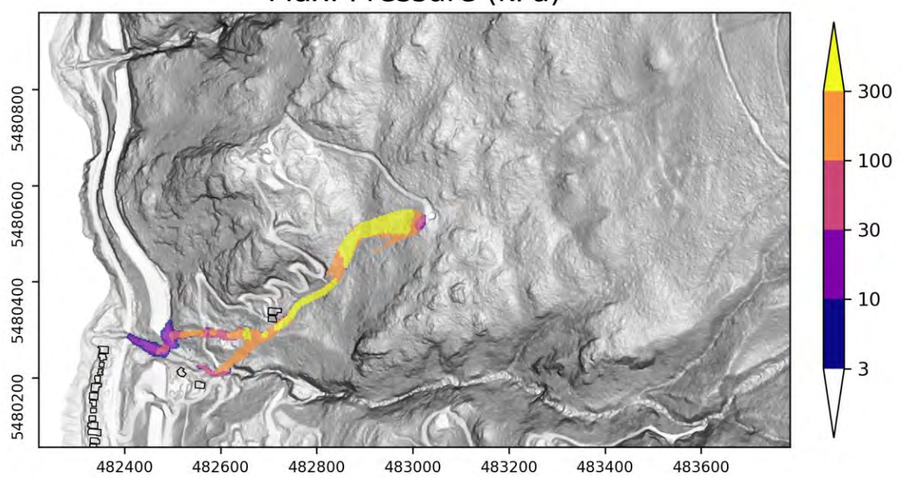
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 3B		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-7







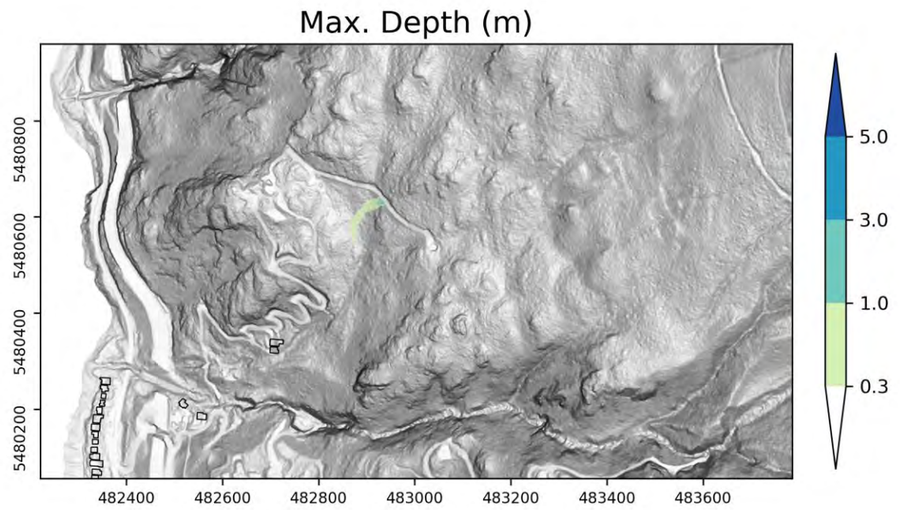


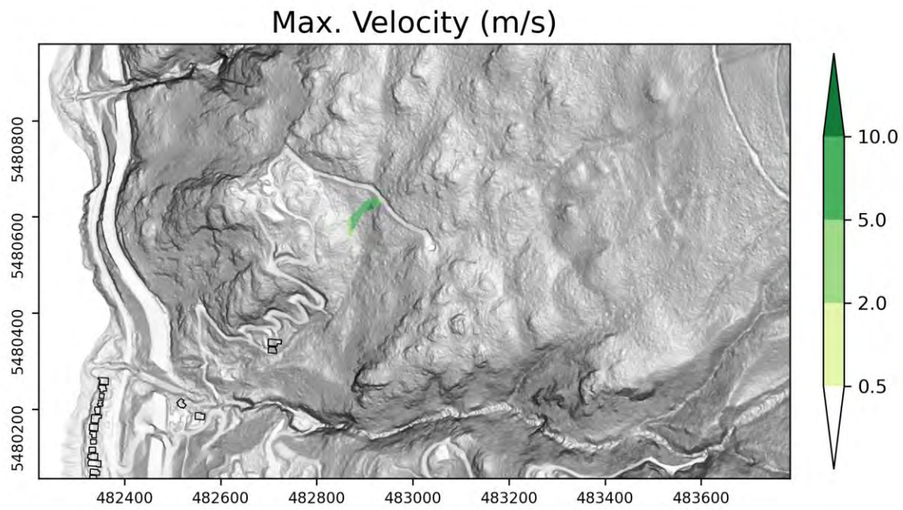
Scenario	Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow (3C)
Initial Volume	3,000 m^3
Target Final Volume	7,000 m^3
Model Volume	7,500 m^3
Numerical Model	DAN3D
Rheology	Voellmy – High Mobility (f=0.25, ξ=700 m/s^2)
Bulk Density	20 kN/m^3
Topography	2025 lidar (3 m, smoothed)

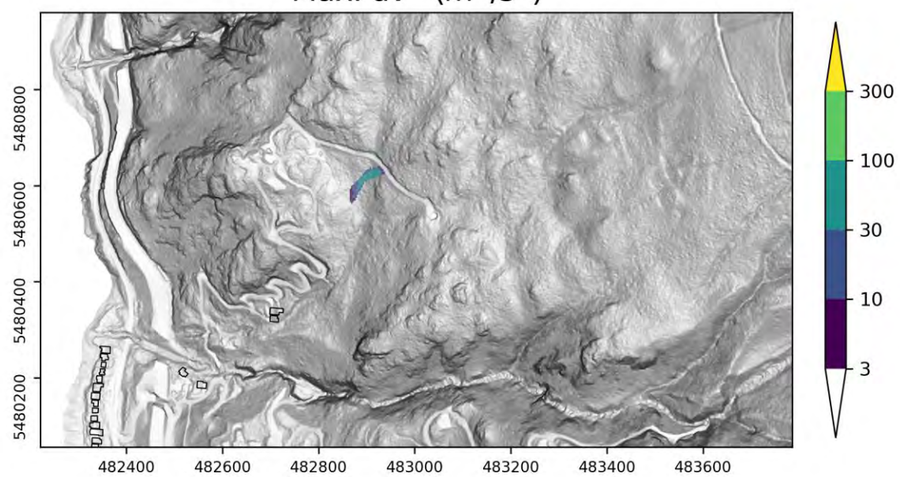
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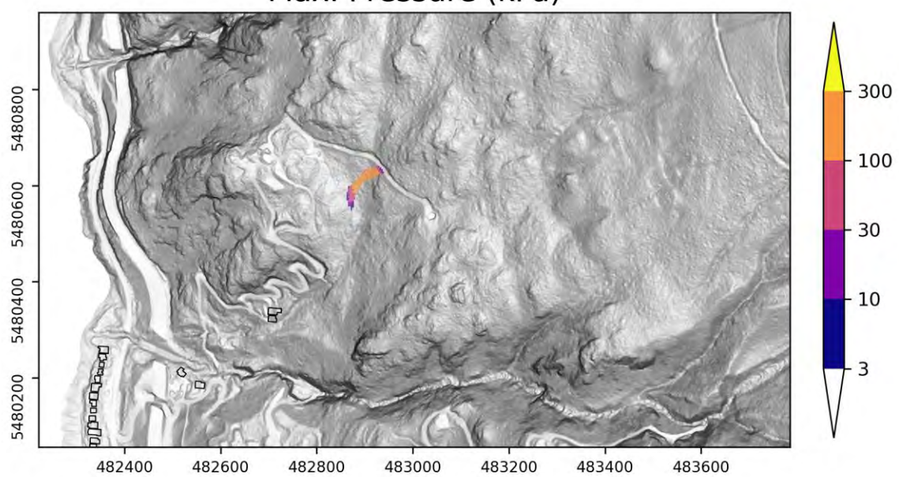
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 3C		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-8







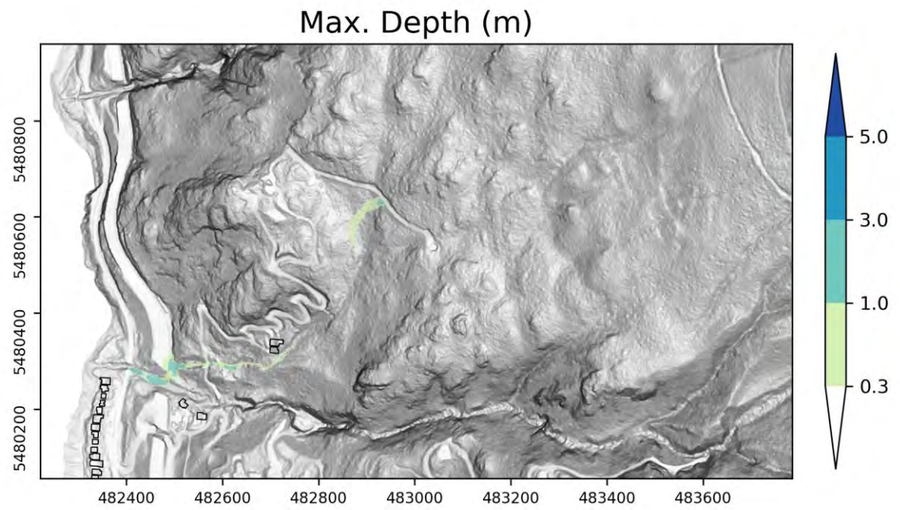


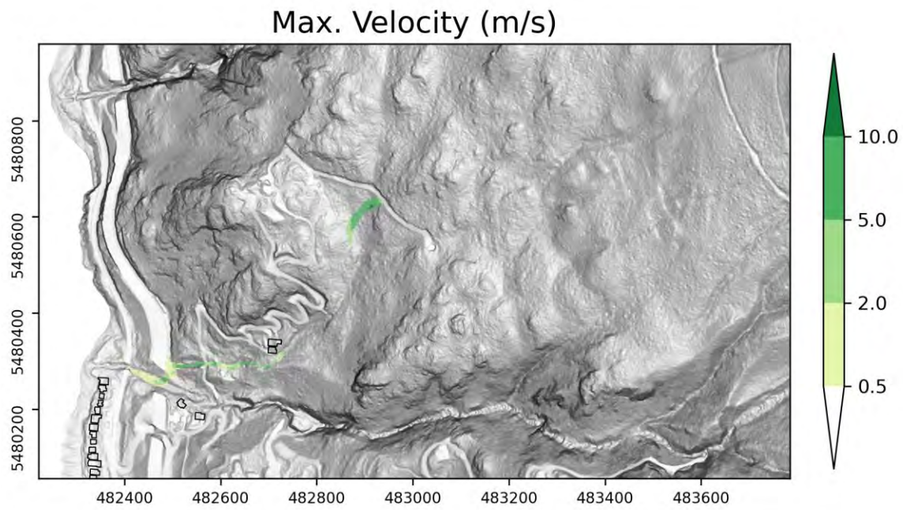
Scenario	Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow (4A)
Initial Volume	200 m^3
Target Final Volume	6,700 m^3
Model Volume	400 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar (3 m, smoothed)

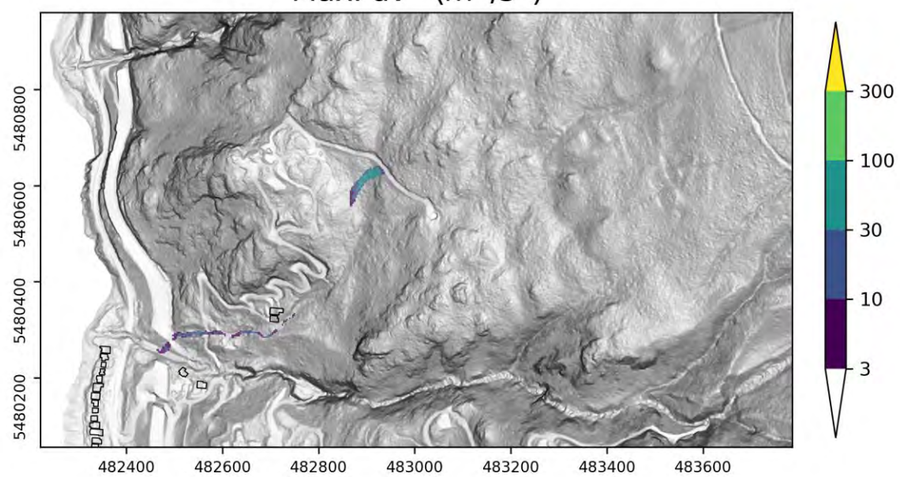
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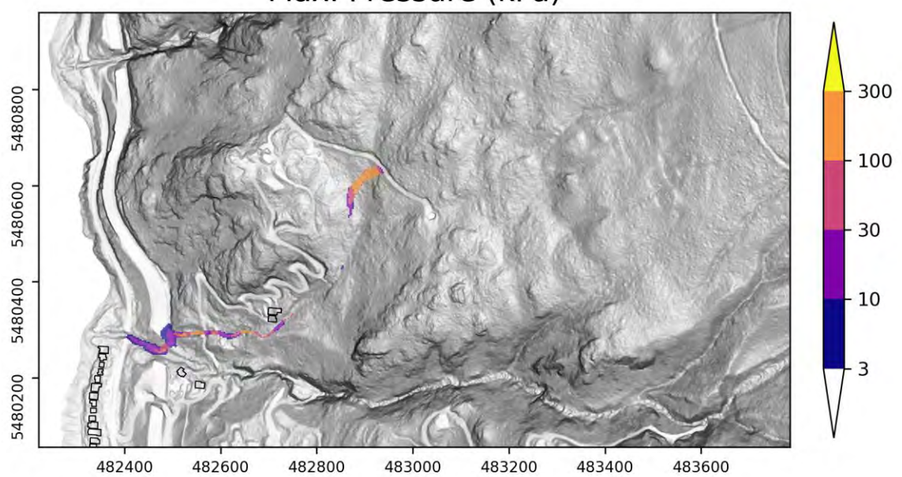
1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).
5. Model volume did not reach target final volume since material stalled on the upper slopes and could not continue downslope to entrain material. A higher mobility scenario (4B) was included to reach target volume.

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 4A		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-9







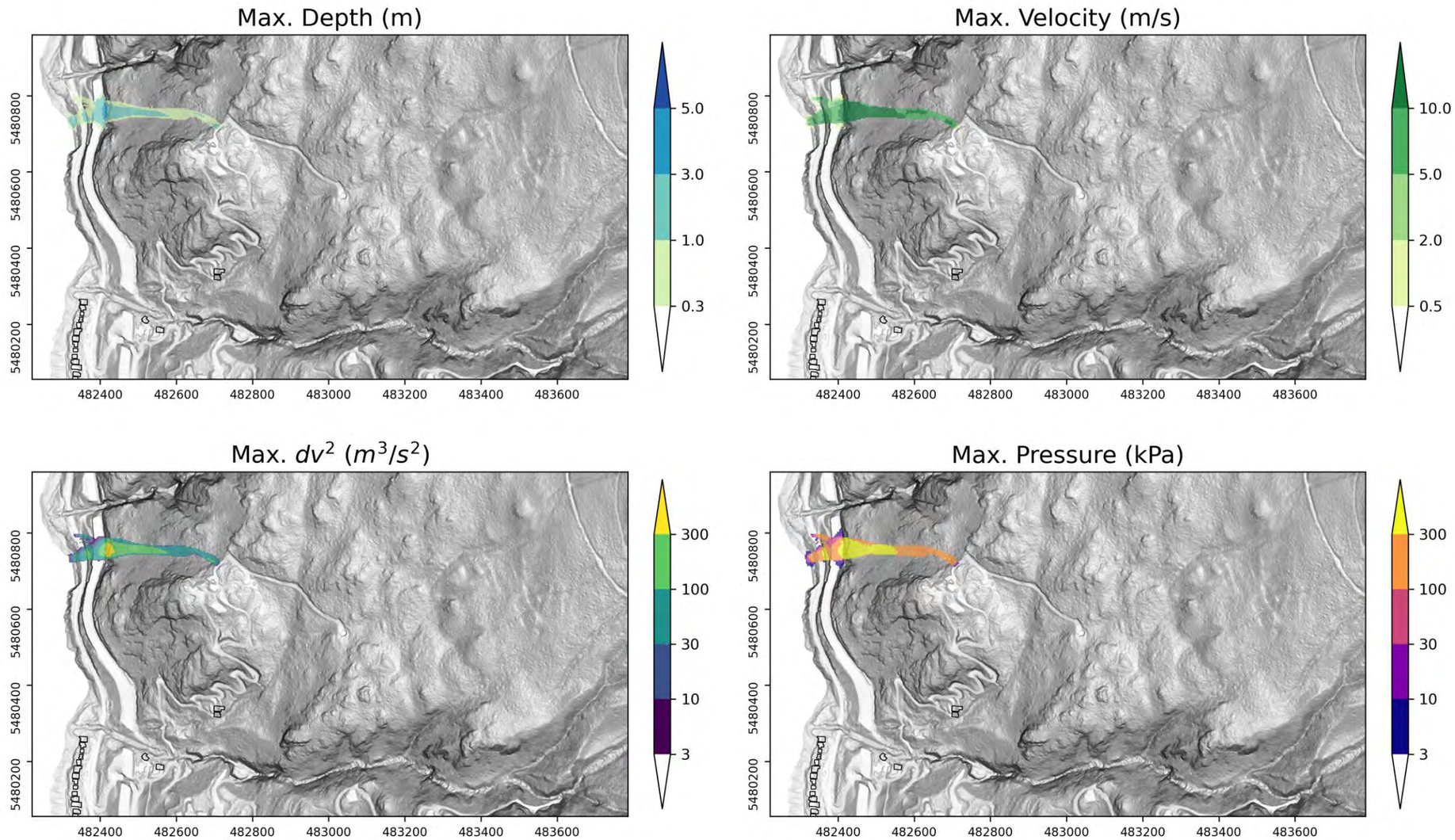


Scenario	Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow (4B)
Initial Volume	200 m^3
Target Final Volume	6,700 m^3
Model Volume	4,000 m^3
Numerical Model	DAN3D
Rheology	Voellmy – High Mobility (f=0.20, ξ=500 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 lidar (3 m, smoothed)

NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 4B		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-10



Scenario	Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche (5)
Initial Volume	200 m^3
Target Final Volume	3,300 m^3
Model Volume	5,500 m^3
Numerical Model	DAN3D
Rheology	Voellmy – Calibrated (f=0.25, ξ=700 m/s^2)
Bulk Density	17 kN/m^3
Topography	2025 (3 m, smoothed)

NOTES:

1. This Figure should be read in conjunction with BGC's report titled Battani Creek Hazard and Risk Assessment, and dated October 2025.
2. Results are filtered to exclude model flow depths <0.3 m.
3. Maximum impact pressure from calculations at 1 second time steps with flow depth and velocity outputs from DAN3D using the average pressure equation in Zanchetta et al. (2014) and assuming a dynamic impact coefficient of 1.5.
4. Topographic hillshade shown is based on lidar provided by GeoBC (2019). Buildings are mapped from orthophoto provided by MoTT (2025).

PREPARED BY: SZ	FIGURE TITLE: NUMERICAL RUNOUT MODELLING RESULTS – MODEL 5		
CHECKED BY: LCH	CLIENT: THE VILLAGE OF LIONS BAY		
APPROVED BY: SZ	SCALE: AS SHOWN	PROJECT NO: 1791004	FIGURE NO: A-11

APPENDIX B
RISK CALCULATION TABLES

Table B1. Life Safety Risk Calculations for Vehicle Occupants on Highway 99.

Hazard Scenario	Model Sub-Scenario	Exposure Scenario	Hazard Scenario Probability, h_i (/Year)	Conditional Probability - Model Scenario	Conditional Probability - Traffic Scenario	Conditional Probability - Day/Night Scenario	# Directions Impacted	Max. Debris Depth on Road (m)	Exposure Length, L_i (m)	Temporal Probability, Individual Most at Risk, T_i	Exposed Population, E_i	Vulnerability, V_i	Expected Number of Fatalities, N_i	Individual Risk, PDI_i (Micromorts/Year)	Group Risk - Probable Life Loss, PLL_i (/Year)	Group Risk - Probable Life Loss, PLL_i (/100 Years)
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	1B. High Mobility	Standing Traffic, Debris Impacts Vehicles	0.002	0.1	0.00028539	1	2	1.5	30	4.4E-05	15.00	0.5	7.50	1.3E-06	4.3E-07	4.3E-05
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.002	0.1	0.99971461	0.5	2	1.5	30	3.6E-05	1.52	0.5	0.76	1.8E-03	7.6E-05	7.6E-03
		Regular Traffic, Daytime, Vehicles Impact Debris	0.002	0.1	0.99971461	0.5	2	1.5	68	6.7E-05	3.12	0.1	0.31	6.7E-04	3.1E-05	3.1E-03
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.002	0.1	0.99971461	0.5	2	1.5	30	3.6E-05	0.37	0.5	0.18	1.8E-03	1.8E-05	1.8E-03
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.002	0.1	0.99971461	0.5	2	1.5	68	6.7E-05	2.75	0.1	0.28	6.7E-04	2.8E-05	2.8E-03
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	2A. Calibrated Mobility	Standing Traffic, Debris Impacts Vehicles	0.002	0.9	0.00028539	1	2	1.4	30	4.4E-05	15.00	0.5	7.50	1.1E-05	3.9E-06	3.9E-04
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.002	0.9	0.99971461	0.5	2	1.4	30	3.6E-05	1.52	0.5	0.76	1.6E-02	6.8E-04	6.8E-02
		Regular Traffic, Daytime, Vehicles Impact Debris	0.002	0.9	0.99971461	0.5	2	1.4	68	6.7E-05	3.12	0.1	0.31	6.1E-03	2.8E-04	2.8E-02
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.002	0.9	0.99971461	0.5	2	1.4	30	3.6E-05	0.37	0.5	0.18	1.6E-02	1.6E-04	1.6E-02
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.002	0.9	0.99971461	0.5	2	1.4	68	6.7E-05	2.75	0.1	0.28	6.1E-03	2.5E-04	2.5E-02
	2B. High Mobility, Blocked CN Rail Bridge	Standing Traffic, Debris Impacts Vehicles	0.002	0.1	0.00028539	1	2	1.4	30	4.4E-05	15.00	0.5	7.50	1.3E-06	4.3E-07	4.3E-05
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.002	0.1	0.99971461	0.5	2	1.4	30	3.6E-05	1.52	0.5	0.76	1.8E-03	7.6E-05	7.6E-03
		Regular Traffic, Daytime, Vehicles Impact Debris	0.002	0.1	0.99971461	0.5	2	1.4	68	6.7E-05	3.12	0.1	0.31	6.7E-04	3.1E-05	3.1E-03
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.002	0.1	0.99971461	0.5	2	1.4	30	3.6E-05	0.37	0.5	0.18	1.8E-03	1.8E-05	1.8E-03
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.002	0.1	0.99971461	0.5	2	1.4	68	6.7E-05	2.75	0.1	0.28	6.7E-04	2.8E-05	2.8E-03
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	3B. Moderate Failure	Standing Traffic, Debris Impacts Vehicles	0.02	1	0.00028539	1	1	1.1	15	2.2E-05	3.75	0.5	1.88	6.3E-05	1.1E-05	1.1E-03
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.02	1	0.99971461	0.5	1	1.1	15	2.1E-05	0.44	0.5	0.22	1.0E-01	2.2E-03	2.2E-01
		Regular Traffic, Daytime, Vehicles Impact Debris	0.02	1	0.99971461	0.5	1	1.1	68	6.7E-05	1.56	0.1	0.16	6.7E-02	1.6E-03	1.6E-01
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.02	1	0.99971461	0.5	1	1.1	15	2.1E-05	0.11	0.5	0.05	1.0E-01	5.3E-04	5.3E-02
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.02	1	0.99971461	0.5	1	1.1	68	6.7E-05	2.38	0.1	0.24	6.7E-02	2.4E-03	2.4E-01
	3C. Large Failure	Standing Traffic, Debris Impacts Vehicles	0.002	1	0.00028539	1	1	1.5	20	2.9E-05	5.00	0.5	2.50	8.3E-06	1.4E-06	1.4E-04
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.002	1	0.99971461	0.5	1	1.5	20	2.6E-05	0.55	0.5	0.27	1.3E-02	2.7E-04	2.7E-02
		Regular Traffic, Daytime, Vehicles Impact Debris	0.002	1	0.99971461	0.5	1	1.5	68	6.7E-05	1.56	0.1	0.16	6.7E-03	1.6E-04	1.6E-02
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.002	1	0.99971461	0.5	1	1.5	20	2.6E-05	0.13	0.5	0.07	1.3E-02	6.6E-05	6.6E-03
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.002	1	0.99971461	0.5	1	1.5	68	6.7E-05	2.38	0.1	0.24	6.7E-03	2.4E-04	2.4E-02
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	4B. High Mobility	Standing Traffic, Debris Impacts Vehicles	0.005	0.1	0.00028539	1	1	0.9	15	2.2E-05	3.75	0.1	0.38	3.1E-07	5.4E-08	5.4E-06
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.005	0.1	0.99971461	0.5	1	0.9	15	2.1E-05	0.44	0.2	0.09	1.0E-03	2.2E-05	2.2E-03
		Regular Traffic, Daytime, Vehicles Impact Debris	0.005	0.1	0.99971461	0.5	1	0.9	68	6.7E-05	1.56	0.05	0.08	8.4E-04	2.0E-05	2.0E-03
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.005	0.1	0.99971461	0.5	1	0.9	15	2.1E-05	0.11	0.2	0.02	1.0E-03	5.3E-06	5.3E-04
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.005	0.1	0.99971461	0.5	1	0.9	68	6.7E-05	2.38	0.05	0.12	8.4E-04	3.0E-05	3.0E-03
5. Log Crib Failure Along Battani Creek Road at MoTT Property Transitioning to Debris Avalanche	5. Calibrated Mobility	Standing Traffic, Debris Impacts Vehicles	0.005	1	0.00028539	1	2	3.0	60	8.8E-05	30.00	0.99	29.70	1.2E-04	4.2E-05	4.2E-03
		Regular Traffic, Daytime, Debris Impacts Vehicles	0.005	1	0.99971461	0.5	2	3.0	60	6.5E-05	2.79	0.99	2.76	1.6E-01	6.9E-03	6.9E-01
		Regular Traffic, Daytime, Vehicles Impact Debris	0.005	1	0.99971461	0.5	2	3.0	68	6.7E-05	3.12	0.1	0.31	1.7E-02	7.8E-04	7.8E-02
		Regular Traffic, Nighttime, Debris Impacts Vehicle	0.005	1	0.99971461	0.5	2	3.0	60	6.5E-05	0.67	0.99	0.66	1.6E-01	1.7E-03	1.7E-01
		Regular Traffic, Nighttime, Vehicles Impact Debris	0.005	1	0.99971461	0.5	2	3.0	68	6.7E-05	2.75	0.1	0.28	1.7E-02	6.9E-04	6.9E-02
													Sum (Total Risk)	**0.80**	**0.02**	**1.93**

Note: Model sub-scenarios 1A and 4A are not included in this table since models do not impact Highway 99 (spatial impact probability $S_i = 0$).

Table B2. Life Safety Risk Calculations for Vehicle Occupants on Battani Creek Road.

Hazard Scenario	Model Sub-Scenario	Exposure Scenario	Hazard Scenario Probability, h_i (/Year)	Conditional Probability - Model Scenario	Max. Debris Depth on Road (m)	Exposure Length, L_i (m)	Temporal Probability, Individual Most at Risk, T_i	Exposed Population, E_i	Vulnerability, V_i	Expected Number of Fatalities, N_i	Individual Risk, PDI_i (Micromorts/Year)	Group Risk - Probable Life Loss, PLL_i (/Year)	Group Risk - Probable Life Loss, PLL_i (/100 Years)
1. Upper Watershed Open-Slope Landslide Transitioning to Debris Flow	1B. High Mobility	Average traffic, debris impacts vehicle	0.002	0.1	2	20	0.000433333	0.001733333	0.5	0.0009	4.33E-02	1.73E-07	1.7E-05
2. Lower Watershed Open-Slope Landslide Transitioning to Debris Flow	2A. Calibrated Mobility	Average traffic, debris impacts vehicle	0.002	0.9	2.4	20	0.000433333	0.001733333	0.99	0.0017	7.72E-01	3.09E-06	3.1E-04
	2B. High Mobility	Average traffic, debris impacts vehicle	0.002	0.1	2.4	20	0.000433333	0.001733333	0.99	0.0017	8.58E-02	3.43E-07	3.4E-05
3. Rock Slope Failure Below Battani Creek Reservoir Transitioning to Debris Flow	1A. Small Failure	Average traffic, debris impacts vehicle	0.05	1	1.1	10	0.000266667	0.001066667	0.5	0.0005	6.67E+00	2.67E-05	2.7E-03
	1B. Moderate Failure	Average traffic, debris impacts vehicle	0.02	1	1.5	15	0.00035	0.0014	0.5	0.0007	3.50E+00	1.40E-05	1.4E-03
	1C. Large Failure	Average traffic, debris impacts vehicle	0.002	1	2.2	20	0.000433333	0.001733333	0.99	0.0017	8.58E-01	3.43E-06	3.4E-04
4. Road Fill Failure Along Battani Creek Road Transitioning to Debris Flow	4B. High Mobility	Average traffic, debris impacts vehicle	0.005	0.1	1.4	10	0.000266667	0.001066667	0.5	0.0005	6.67E-02	2.67E-07	2.7E-05
										Sum (Total Risk)	12.0	0.00005	0.005

APPENDIX C
GEOHAZARD INFOGRAPHICS

DEBRIS FLOODS

Floods that move large amounts of soil, rocks, and trees

Debris floods can be triggered by heavy rain, rain-on-snow events, and upstream hazards (debris flows, dam breaches)



Debris floods are more likely to occur after periods of prolonged rain or snowmelt, or in years following forest fires

Houses near mountain creeks are at greatest risk



Debris floods can occur over a long period of time (days) and can have several surges (pulses)



Debris floods can erode banks and undermine building foundations

Debris floods can burst their banks and flood houses far from the channel



Debris floods can sweep away or bury cars



Debris floods can destroy roads and bridges

PROTECT YOURSELF FROM

DEBRIS FLOODS

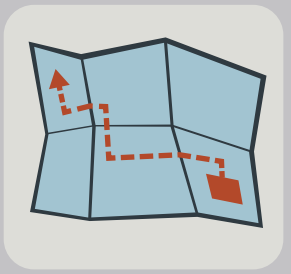
BEFORE

Stay informed



Keep updated with weather advisories, such as heavy rainfall warnings. Consult your local hazard map to learn where the flood hazard zones are located.

Prepare and plan



Prepare an emergency kit for your home, vehicle, and workplace. Know your local flood evacuation routes and emergency shelter locations.

Know the signs



Look/listen for an abrupt increase or decrease in water flow, unusually muddy water, and the sound of cracking trees and rolling boulders.

Protect your property



Store valuables in high places or water-tight containers. Consider flood-proofing measures, such as elevating the first floor, flood walls, erosion protection, sump pumps, etc.

DURING

DECISION: Evacuate



If it is safe to do so, take the flood evacuation route or go to higher ground. If you are able, shut off your gas/electricity and help others evacuate.

DECISION: Shelter



If you are unable or it is unsafe to evacuate, seek shelter on high ground. Avoid basements.

Build sandbag dikes



Sandbag dikes can prevent or lessen damage from overland flooding. Do not attempt to build if you are required to evacuate.

DO NOT go near the bank



Debris floods can quickly erode and undermine banks. If you are near the bank, you put yourself at risk of falling in and being swept away.

DO NOT cross bridges



Debris floods can erode bridge piers and cause bridges to collapse. Bridges affected by debris flooding must be avoided.

DO NOT cross flood waters



Moving water as little as 30 cm deep can quickly sweep you away. Do not attempt to drive or walk through water or debris.

AFTER

Obey road closures



Do not enter areas that are closed-off. There may be emergency repair efforts underway or flooded areas unsafe to the public.

Return only when safe



Do not return home until authorities say it is safe and they have cleared your home of structural, electrical, or other hazards.

Help each other



Floods are stressful and traumatic events. Offer and accept help if you are able. Communities are more resilient when they work together.

Clean up



If your home was flooded, dispose of mouldy items, open doors and windows, and scrub all washable surfaces with a household bleach solution.

NOTES

BGC Engineering Inc. (BGC) prepared this infographic with artwork by Sophia Zubrycky. This infographic depicts some measures that may help to lower but not eliminate certain kinds of risk associated with debris floods. Simply following the measures shown in this infographic does not make it safe to occupy areas at risk of debris floods. Even if the measures shown in this infographic are taken, debris floods may still cause serious personal injury (including death) or property damage. BGC provides no guarantee or warranty of any kind related to the information in this infographic. Persons and entities using or relying on this infographic do so at their own risk. BGC will not be responsible or liable for any loss or damage including any personal injury, death, or property damage that any person or entity may suffer or sustain as a result of the information in this document, or any use of or reliance on this document.

Information on flood preparedness is from PreparedBC's Flood Preparendess Guide.

Photo references:
[Top right] Wildfire. Photo: Shutterstock.
[Top left] Debris flood in Canmore, AB. Photo: THE CANADIAN PRESS/Jonathan Hayward.
[Middle right] Flood damaged homes along Cougar Creek in Canmore, AB. Photo: THE CANADIAN PRESS/Jeff McIntosh.
[Bottom left] Car swept away by debris on the Coquihalla Highway, Hope, BC. Photo: THE CANADIAN PRESS/Jonathan Hayward.
[Bottom right] Bridge damages from debris flood on Hwy. 1, Lytton, BC. Photo: TranBC.

DEBRIS FLOWS

A fast, flowing landslide comprised of mud, rocks, trees, and water

Debris flows are triggered by heavy bursts of rain or rain-on-snow events



Debris flows are more likely to occur after periods of prolonged rain or snowmelt, or in years following forest fires

Houses at the base of steep slopes with mountain creeks are at greatest risk



Debris flows begin in mountain creeks and grow in size as they travel down slope, usually in surges (pulses)

Debris can bury or destroy houses



Debris can flow faster than the fastest human can run

Debris can suddenly jump out of the channel

Debris can impact houses far from the channel



Debris can sweep away or crush cars



PROTECT YOURSELF FROM

DEBRIS FLOWS

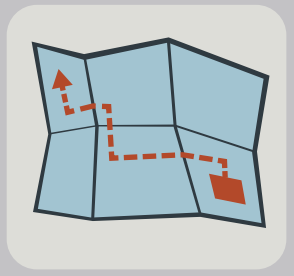
BEFORE

Stay informed



Keep updated with weather advisories, such as heavy rainfall warnings. Consult your local hazard map to learn where the slope hazard zones are located.

Prepare and plan



Prepare an emergency kit for your home, vehicle, and workplace. Plan a safe evacuation route and muster point. Know which rooms are safest if you have to shelter in place.

Know the signs



Look/listen for an abrupt increase or decrease in water flow, unusually muddy water, shaking ground, and a loud roar (sounds like a train or helicopter).

Safe home design



Put high occupancy rooms like bedrooms on the top floor and on the downhill side (away from slopes).

DURING

DECISION: evacuate



If you believe your life to be in imminent danger and you see a clear path to safety, evacuate. Get away and to higher ground as fast as you can.

DECISION: shelter



If it is unsafe to evacuate, shelter up and away. Climb to the top floor or on the roof. Shelter on the downhill side, away from the slope. Avoid basements.

Climb on top of furniture



Get on top of a bed or counter to avoid being swept away or buried. Do not hide behind or underneath heavy furniture as they can crush or pin you down.

Shelter in a closet



If you cannot escape vertically, small rooms like closets can offer additional protection from collapse if your home is buried.

DO NOT exit out of curiosity



Seek shelter instead of investigating the situation. Only go outside if you have to evacuate.

DO NOT cross flood waters



Moving water as little as 30 cm deep can quickly sweep you away. Do not attempt to drive or walk through water or debris.

AFTER

Assume more will come



Debris flows come in surges (pulses) and can continue for days. Subsequent pulses may be more severe than the previous.

Make noise if buried



Shout or tap on something so search and rescue can locate you faster.

If safe, help neighbours



Help evacuate your neighbours when it's safe to do so, and offer assistance to search and rescue personnel.

Obey closures



Evacuation orders and road closures must be taken seriously. Only return when local authorities declare it safe to do so.

NOTES

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Information on life loss risk reduction in case of debris flow impact is informed by Pollock, W., and Wartman, J. (2020) Human Vulnerability to Landslides. GeoHealth, 4, e2020GH000287. https://doi.org/10.1029/2020GH000287.

Photo references:
[Top right] Wildfire. Photo: Shutterstock.
[Middle left] Debris flow at Cataline Creek, BC. Photo: BGC.
[Middle right] Debris flow at Willox Creek, BC. Photo: BGC.
[Bottom left] Debris flow in the Austrian Alps. Photo: Shutterstock.
[Bottom right] Car swept away by debris on the Coquihalla Highway, Hope, BC. Photo: THE CANADIAN PRESS/Jonathan Hayward.

LANDSLIDES

Movements of earth, rocks, trees, and debris down a slope

Landslides can be triggered by rain, snowmelt, or earthquakes



Landslides are more likely to occur after periods of prolonged rain and snowmelt, or in years following forest fires

Landslides can be triggered by human-made land changes, such as roads, fill placement, or excavations

Landslides can occur with little warning

Landslides can bury or destroy houses



Houses on or near hillsides are at greatest risk

Landslides can reach speeds faster than cars



Landslides can impact areas far from their source

Landslides can sweep away or crush cars



PROTECT YOURSELF FROM

LAND-SLIDES

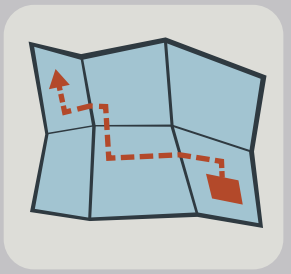
BEFORE

Stay informed



Keep updated with evacuation alerts, road closures, and weather advisories, such as heavy rainfall warnings.

Prepare and plan



Prepare an emergency kit for your home, vehicle, and workplace. Plan a safe evacuation route and muster point. Know which rooms are safest if you have to shelter in place.

Know the signs



Look/listen for fallen debris, moving and cracking trees, shaking ground, and a loud roar (sounds like a train or helicopter).

Safe home design



Put high occupancy rooms like bedrooms on the top floor and on the downhill side (away from slopes).

DURING

DECISION: evacuate



If you believe your life to be in imminent danger and you see a clear path to safety, evacuate. Get away and to higher ground as fast as you can.

DECISION: shelter



If it is unsafe to evacuate, shelter up and away. Climb to the top floor or on the roof. Shelter on the downhill side, away from the slope. Avoid basements.

Shelter in a closet



If you cannot escape vertically, small rooms like closets can offer additional protection from collapse if your home is buried.

Shelter in your vehicle



If you cannot drive away safely, shelter in your vehicle. Your vehicle may provide some protection from a landslide impact.

DO NOT exit out of curiosity



Seek shelter instead of investigating the situation. Only go outside if you have to evacuate.

DO NOT cross debris



Crossing fallen debris is very dangerous since more debris could come down. Take a route away from the slope and debris.

AFTER

Assume more will come



Debris may continue to slide since the slopes are unstable. Subsequent landslides may be more severe than the previous.

Make noise if buried



Shout or tap on something so search and rescue can locate you faster.

If safe, help neighbours



Help evacuate your neighbours when it's safe to do so, and offer assistance to search and rescue personnel.

Obey closures



Evacuation orders and road closures must be taken seriously. Only return when local authorities declare it safe to do so.

NOTES

BGC Engineering Inc. (BGC) prepared this infographic with artwork by Sophia Zubrycky. This infographic depicts some measures that may help to lower but not eliminate certain kinds of risk associated with landslides. Simply following the measures shown in this infographic does not make it safe to occupy areas at risk of landslides. Even if the measures shown in this infographic are taken, landslides may still cause serious personal injury (including death) or property damage. BGC provides no guarantee or warranty of any kind related to the information in this infographic. Persons and entities using or relying on this infographic do so at their own risk. BGC will not be responsible or liable for any loss or damage including any personal injury, death, or property damage that any person or entity may suffer or sustain as a result of the information in this document, or any use of or reliance on this document.

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Photo references:
[Top right] Wildfire. Photo: Shutterstock.
[Middle right] House buried by Johnsons Landing landslide, BC. Photo: CBC. Available from: https://www.cbc.ca/news/canada/british-columbia/johnsons-landing-evacuation-order-lifted-2-years-after-fatal-landslide-1.2723388
[Bottom left] Landsliding in Petropolis, Brazil. Photo: AP Photo/Silvia Izquierdo.
[Bottom right] Car swept away by debris on the Coquihalla Highway, Hope, BC. Photo: THE CANADIAN PRESS/Jonathan Hayward.

ROCKFALLS & ROCKSLIDES

Pieces of rock falling, bouncing, or rolling down a slope

Large masses of rock detaching, sliding, and breaking apart down a slope



Rocks can easily break through walls and roofs

Smaller rockfalls often precede larger rockfalls and rockslides



Rockslides can easily destroy roads, railways, and buildings

Houses at the base of steep slopes are at greatest risk

Events occur mostly during heavy rain, freeze/thaw cycles, or earthquakes

Rocks can reach speeds faster than cars



Boulders might be evidence of past rock-falls and rockslides

Rocks can bounce and roll long distances

Rocks can be larger than a truck



PROTECT YOURSELF FROM ROCKFALLS & ROCKSLIDES

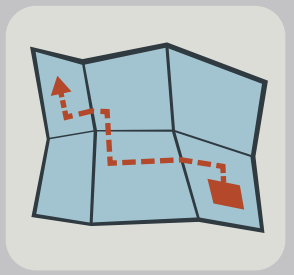
BEFORE

Stay informed



Keep updated with weather advisories, such as heavy rainfall warnings and repeated cycles of freeze/thaw.

Prepare and plan



Prepare an emergency kit for your home, vehicle, and workplace. Plan a safe evacuation route and muster point. Know which rooms are safest if you have to shelter in place.

Know the signs



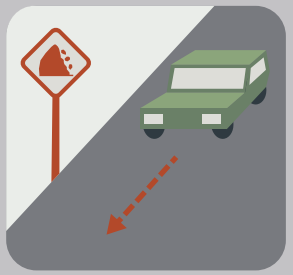
Look/listen for loud cracking, clouds of dust, and shaking ground (like an earthquake). Smaller rockfalls often come before larger ones.

Know the hazard zones



Consult your local hazard map to learn where the slope hazard zones are located.

Limit exposure



Limit time spent in the slope hazard zones. Do not park beneath steep slopes or rock cuts.

Safe home design



Put high occupancy rooms like bedrooms on the top floor and on the downhill side (away from slopes).

DURING

DECISION: evacuate



If you believe your life to be in imminent danger and you see a clear path to safety, evacuate. Get away from the slope as fast as you can.

DECISION: shelter



If it is unsafe to evacuate, shelter in a room on the downhill side of your house, preferably on the top floor.

DO NOT cross rock path



Crossing fallen debris is very dangerous since more rocks will likely fall here. Take a route away from the slope and debris.

DO NOT stay to watch



Rocks can bounce irregularly and roll long distances. Get away from the slope instead of watching or filming them.

AFTER

Assume more will fall



Rocks may continue to come down because the slope is unstable.

Notify authorities



Report any rockfalls and rockslides (big or small) to local authorities.

If safe, help neighbours



Help evacuate your neighbours when it's safe to do so, and offer assistance to search and rescue personnel.

Obey closures



Evacuation orders and road closures must be taken seriously. Only return when local authorities declare it safe to do so.

NOTES

BGC Engineering Inc. (BGC) prepared this infographic with artwork by Sophia Zubrycky. This infographic depicts some measures that may help to lower but not eliminate certain kinds of risk associated with rockfalls and rockslides. Simply following the measures shown in this infographic does not make it safe to occupy areas at risk of rockfalls and rockslides. Even if the measures shown in this infographic are taken, rockfalls and rockslides may still cause serious personal injury (including death) or property damage. BGC provides no guarantee or warranty of any kind related to the information in this infographic. Persons and entities using or relying on this infographic do so at their own risk. BGC will not be responsible or liable for any loss or damage including any personal injury, death, or property damage that any person or entity may suffer or sustain as a result of the information in this document, or any use of or reliance on this document.

Photo references:
[Top left] Rockfall damage from Christchurch, New Zealand earthquake. Photo: Julian Thomson.
[Top right] Rockslide blocking Sea-to-Sky highway near Porteau Cove, BC. Photo: THE CANADIAN PRESS/Jonathan Hayward.
[Bottom left] Site of rockfall tragedy in Rockville, Utah. Photo: Daily Mail U.K. Available from: https://www.dailymail.co.uk/news/article-2523067/Boulder-size-elephant-crushes-entire-house-instantly-kills-inhabitants-Utah-landslide.html
[Bottom right] Semi-truck smashed by boulder east of Spences Bridge, BC. Photo: Matt Ruscheinski. Available from: https://www.cbc.ca/news/canada/british-columbia/trans-canada-highway-rock-slide-semi-boulder-1.4502567