THURBER ENGINEERING LTD.

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Fine Peace Furry Creek Holdings Ltd.
545 - 1199 West Pender Street
Vancouver, BC V6E 2R1

Attention: Yang Jin, General Manager

OVERVIEW GEOHAZARD ASSESSMENT - FURRY CREEK LANDS (REV 1)
FURRY CREEK, BC

Dear Yang Jin:

This letter report presents the results of an updated overview geohazard assessment of the Furry Creek lands at Furry Creek, BC, further to the previous assessments completed by Thurber between 1990 and 1992. This study was commissioned by CREUS Engineering Ltd. (CREUS) on behalf of Fine Peace Furry Creek Holdings Ltd. (Fine Peace) and is intended to support Fine Peace's Comprehensive Development (CD) Zoning Application to the Squamish-Lillooet Regional District (SLRD) and the BC Ministry of Transportation and Infrastructure (MoTI). The limits of the both the study area and the Furry Creek lands are shown on Figure 1.

The scope of services for this updated study was outlined in our proposal letters to CREUS dated January 25, 2019 and July 21, 2020, and in subsequent e-mail correspondence with MoTI. In accordance with MoTI's geohazard acceptability criteria for large-scale developments, we have considered the potential for catastrophic landslides based on a probability of occurrence of 1:10,000 per annum (0.5% probability in a 50-year period) as discussed herein. We have also assessed the likelihood of potentially damaging geohazards based on a probability of 1:475 per annum (10% probability in a 50-year period), which is generally applied at an individual building site level. The results of this study, as they relate to potential catastrophic landslides with extremely low probabilities of occurrence (on the order of 1:10,000 per annum), are at the request of, and meant to guide, MoTI with their assessment of the proposed development.

As the overview geohazard assessment is regional in nature, this report does not address the relative safety of individual buildings or other infrastructure, nor does it include EGBC Landslide Assessment Assurance Statements. We understand from MoTI, however, that these statements will eventually be required to support any subdivision applications. Further, the SLRD Development Permit (DP) process will require review and assessment of geotechnical hazards by a qualified professional, design of mitigation works (if and where necessary), and submission of standard assurance statements. The results of this study are intended to support the eventual provision of these statements during the subdivision and building approval process. Thurber's comments on specific neighbourhoods and individual buildings have been provided to CREUS under separate cover and should be read in conjunction with this report.

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. PROJECT UNDERSTANDING

We understand from Fine Peace that the proposed development of the Furry Creek lands would accommodate up to 870 additional residential units, resort hospitality units, approximately 2,500 square metres of commercial floor space, a private marina, as well as a new fire hall and community facilities on the Furry Creek lands. Further details can be found in the CD Zoning application submitted to SLRD.

2. INFORMATION REVIEWED

The following background information was reviewed by Thurber as part of this study:

2.1 Reports and Drawings

- Thurber's project archives from the original Furry Creek development, including overview geotechnical/geohazard reports dated December 7, 1990 and February 27, 1992.
- Thurber Consultants Ltd. 1983. Debris Torrent and Flooding Hazards Highway 99, Howe Sound. Report to BC Ministry of Transportation and Highways, File No. 15-3-32.
- Civil base plan drawings and architectural renderings of the proposed developments, provided by CREUS.

2.2 Aerial Imagery and LiDAR

- Available historical aerial photographs (obtained from UBC Geography) of the Furry Creek area for the years 1957, 1969, 1976, 1979, 1982, 1987, 1990, 1994, and 2004.
- Bathymetry data covering the offshore portion of the Furry Creek fan, provided by CREUS.
- LiDAR data and orthoimagery of the Furry Creek lands (flown in 2006 & 2009), provided by CREUS.
- Orthoimagery and LiDAR data of the Furry Creek lands and adjacent up-valley areas along Furry Creek and Phyllis Creek (flown in 2020), provided CREUS.
- Available LiDAR data of the Furry Creek area (flown in 2018-2019), obtained from the LidarBC Open Data Portal (https://www2.gov.bc.ca/gov/content/data/geographic-data-services/lidarbc).
- LiDAR data covering the north side of the Furry Creek valley upstream of the Furry Creek lands (flown in 2012), obtained from McElhanney.
- Google Earth Pro aerial imagery.
- Sentinel-2 L2A multispectral satellite imagery of the Furry Creek area dated 07/29/2021, obtained from the Copernicus Open Access Hub (https://scihub.copernicus.eu/).

2.3 Published Maps and Data

- Available 1:20,000 scale TRIM topography and watercourse mapping.
- BC Ministry of Forests Biogeoclimatic Ecosystem Classification Mapping.
- Environment Canada Climate Normals or Averages for the period 1981-2010.
- Historical mineral exploration (MINFILE) records obtained from the BC Geological Survey.
- Annotated swath multibeam imagery of the Howe Sound seafloor (Jackson et al. 2008).
- 1:50,000 scale surficial geology and landslide mapping of the lower Sea to Sky corridor (Blais-Stevens 2008).
- Historical accounts of landslides and flooding events along the Sea to Sky corridor, British Columbia, from 1855-2007 (Blais-Stevens and Septer 2008).
- Landslide inventory and susceptibility mapping of the Sea to Sky corridor (Blais-Stevens and Hungr 2008).

3. SITE DESCRIPTION

3.1 General

Furry Creek is located along the east side of Howe Sound, approximately 30 km north of Horseshoe Bay. Howe Sound is the southernmost fjord in British Columbia and is situated within a larger physiographic region known as the Georgia Lowland, which extends along much of the Salish Sea and mainland coast (Holland 1976). These lowlands rise eastward and merge with the Coast Mountain Range at an elevation of approximately 1300 m above sea level.

The Furry Creek lands (the subject property) comprises approximately 419 ha to the north and south of Furry Creek, including approximately 57 ha to the west of Highway 99 with a total of 3.3 km of ocean frontage. Historical land uses at the site, as described in detail in the CD Zoning Application, mainly relate to resource extraction and include mining, logging, and gravel quarrying.

The subject property ranges in elevation from sea level to about 400 m above sea level. The proposed development areas are located within the rain-dominated elevation band (< 300 m), except for the Mountain Lands development area which is located in the transient elevation band (300 to 800 m) where rain-on-snow events predominate.

3.2 Existing Development

Development of the site began in 1991 and currently includes a golf course and associated facilities, single family subdivisions, duplex lots, and townhomes. Servicing for this development includes water supply by wells, a concrete water reservoir and drinking water treatment facility, wastewater treatment facility, propane tank farm, telecom switch station, hydro substation and park use.

The foreshore area, west of Highway 99, includes 56 existing townhomes as well as an engineered flood protection system along both the north and south sides of Furry Creek. This system was originally approved by the BC Ministry of Environment (MoE) but has since been turned over to the SLRD.

The existing railway, highway, and BC Hydro transmission lines have been present on the site prior to the start of the development in 1991.

3.3 Climate and Vegetation

The subject property is contained entirely within the "Coastal Western Hemlock – Dry Maritime" biogeoclimatic zone and experiences relatively warm, dry summers and mild, wet winters. Watercourses at the site typically experience their annual peak flow between October and February, coinciding with the autumn and winter rain and/or rain-on-snow storm events.

Environment Canada weather records from the nearest weather station at Squamish (period 1981 to 2010) indicate that mean annual precipitation is about 2000 mm. However, due to orographic uplift effects (the upward flow and cooling of air masses over mountains), precipitation amounts increase significantly with elevation. Climate statistics for various elevations at Furry Creek were estimated using the ClimateBC online tool (http://www.climatewna.com/ClimateBC_Map.aspx); the results are shown on Table 1.

TABLE 1 – CLIMATEBC[1] STATISTICS FOR FURRY CREEK (PERIOD 1981-2010)

Elevation (m asl)	Mean Annual Precipitation (mm)	Mean Winter Precipitation (mm)	Mean Annual Precipitation as Snow (mm water equivalent)	Mean Annual Number of Frost-Free Days
0	2030	1620	75	305
100	2180	1735	95	300
200	2315	1845	125	290
300	2420	1930	200	270
400	2525	2015	253	260
800	2940	2345	600	225
1200	3020	2410	1090	190

1. http://www.climatewna.com/ClimateBC_Map.aspx

It can be seen from Table 1 that annual snowfall accumulations increase rapidly with elevation at Furry Creek. In the transient elevation band (300 to 800 m), winter precipitation is driven by both rainfall and rain-on-snow activity.

3.3.1 Climate Change Considerations

According to the Pacific Climate Impacts Consortium Plan2Adapt web-based mapping tool (https://pacificclimate.org/analysis-tools/plan2adapt), the Squamish-Lillooet Regional District is projected to experience an approximate 6% increase in winter precipitation, a -12% decrease in summer precipitation, and a +1.7° C increase in annual mean temperature by the 2050s (compared to the 1961-1990 baseline period), although there is considerable uncertainty in these projections. Increases in winter precipitation, and precipitation intensities, are expected to increase the likelihood of shallow landslides in coastal BC (Jakob and Lambert 2009).

3.4 Bedrock Geology

According to British Columbia Geological Survey Open File 2017-8 (Cui et al. 2017), bedrock at the subject property comprises mid-Cretaceous granitic rocks of the Coast Plutonic Complex. The upper reaches of Furry Creek, upstream of about the 550 m elevation contour, are underlain by marine sedimentary and volcanic rocks of the lower Cretaceous Gambier Group along a faulted contact with the Coast Plutonic Complex. The nearest mapped fault is located approximately 4.5 km north of Furry Creek, at the descent of Highway 99 into Britannia Beach.

Bedrock has been deeply scoured by repeated glaciations over the Pleistocene time period (2.6 Million to 12 thousand years ago) to form a series of rounded knobs and depressions. The Coast Plutonic Complex rocks are generally massive except where cut by northwest-trending jointing and minor faults which have the potential to result in localized instabilities. Deep-seated bedrock instabilities seated in Gambier Group rocks are known at several locations in Howe Sound and along the Sea to Sky corridor including Bowen Island, Gambier Island, Lions Bay, and Jane Creek (Britannia Beach).

3.5 Surficial Geology

The current landscape and terrain features of the site were largely formed during the last (Fraser) glaciation, which ended approximately 12,000 ^{14}C years ago. Glacial ice flowed out of the Coast Mountains, then moved southwestward out of Howe Sound, depositing glacial sediments (till) over the scoured bedrock surface. However, substantial ice cover likely persisted in the Coast Mountains until about 9,500 ^{14}C years ago (Clague and James 2002). Therefore, glaciers in the upper headwaters of Furry Creek likely retreated to their current positions by about this time.

At the time when the area was de-glaciated, relative sea levels were approximately 220 m above the present datum due to glacio-isostatic depression of the earth’s crust by the weight of the ice sheet that covered most of British Columbia. At Furry Creek, a complex assemblage of glaciomarine, marine, ice-contact, and glaciofluvial outwash sediments were deposited into the high-level sea, forming an irregular surficial mantle over the till at present day elevations below about 220 m above sea level. These sediments have been subsequently reworked in post-glacial time by fluvial downcutting and mass-wasting processes (for example, in the form of modern stream channel deposits) as the earth’s crust rebounded and sea levels fell to the current datum.

1:50,000 scale surficial geology and landslide inventory mapping of the Furry Creek area completed by the Geological Survey of Canada (Blais-Stevens 2008) shows that the proposed development areas occupy glaciomarine and ice-contact terraces and areas of exposed bedrock in the uplands, and the post-glacial (Holocene) alluvial fan of Furry Creek in the lowlands. Soil cover is generally thin on steeper slope areas, and at the margins of the subject property, but is highly variable in thickness and character within the proposed development areas. In the Uplands South development area, for example, significant thicknesses of outwash sand and gravel remain near the abandoned gravel pits.

4. GEOHAZARD ASSESSMENT

4.1 Background

The Furry Creek area is subject to high volumes of precipitation and runoff driven by winter storm activity, which in combination with the steep terrain gives rise to various geohazards that have the potential to affect the community. These include mass-wasting (landslide) hazards, fluvial (creek) hazards, and coastal hazards. As described below, landslide hazards, which are the focus of this report, may originate in bedrock or soil and exhibit various modes of movement including falls, slides, and flows.

The Furry Creek area is also situated in a seismically active area. A seismic event may trigger rock falls, debris slides, or other landslide processes; however, in general, the seismic hazard for a specific property must be considered on a site-specific basis. In the case of a proposed development, this is generally captured under the jurisdiction of the British Columbia Building Code (BCBC 2018 or current version).

4.2 Hazard and Risk Acceptability Criteria

In British Columbia, geohazards have historically been managed using a hazard-based (rather than a risk-based) approach; for example, the 200-year return interval event adopted as the safety level for flooding hazards. At both the federal and provincial level, there is no legislated guidance for risk-based acceptability criteria to geohazards, and the term “safe” has not been defined.

We understand from CREUS that MoTI is the approving authority for residential development at Furry Creek. MoTI’s Guide for Rural Subdivision Approvals and the accompanying internal MoTI document entitled “Subdivision Preliminary Layout Review – Natural Hazard Risk” (2009; updated in 2013 and 2015) provide guidance on geohazard acceptability criteria for residential development, paraphrased as follows:

- “For a building site, unless otherwise specified, the qualified professional is to consider the potential for damaging landslides based on an annual hazard probability of 1:475 [10% probability in a 50-year period]”;
- “For a large-scale development, the qualified professional is to consider the potential for life-threatening or catastrophic landslides based on an annual hazard probability of 1:10,000 [0.5% probability in a 50-year period]”; and
- “Large-scale developments must also consider total risk and reference international standards”.

The probabilities described above are listed as probabilities of occurrence (defined as “P(H)”) in EGBC (2010); however, as noted in Porter and Morgenstern (2013), this is incorrect terminology; they should be considered as encounter probabilities. Encounter probability, also known as partial risk, is the probability of occurrence (“P(H)”) multiplied by the spatial probability (“P(S:H:)”) that the event reaches the development, i.e., P(H) x P(S:H).

The MoTI guidelines also state the method of geohazard assessment by a qualified professional should “determine if there is a hazard”, “determine extent of any hazard”, and “identify building sites free from hazard, or where risk could be rendered acceptable”. These guidelines, however, remain unpublished, and the terms “damaging”, “life-threatening”, “catastrophic”, “free from hazard”, and “where risk could be rendered acceptable” have not been fully defined.

4.3 Terminology

4.3.1 Landslide Hazards

Generally accepted landslide hazard terminology as referenced in this report is presented in Table 2. Diagrams of typical landslide processes are also shown on Figure A-1 in Appendix A.

TABLE 2 – LANDSLIDE HAZARD TERMINOLOGY

Mode of Movement[1]		Landslide Process and Material Type		
		Rock	Soil	
			Predominantly Coarse-Grained (“Debris”)[2]	Predominantly Fine-Grained (“Earth”)[3]
Falls		Rock Fall	Debris Fall	Earth Fall
Slides	Rotational	Rock Slump	Debris Slump	Earth Slump
	Translational	Rock Slide	Debris Slide	Earth Slide
Flows		Rock Flow	Debris Flow	Earth Flow
Avalanches		Rock Avalanche	Debris Avalanche	Earth Flow
Lateral Spreads		Rock Spread	Debris Spread	Earth Spread
Topples		Rock Topple	Debris Topple	Earth Topple
Creep		Rock Creep	Soil Creep	Soil Creep
Complex / Compound		Combinations in time and/or space of two or more modes of movement		

1. Table modified from Varnes (1978), Cruden & Varnes (1996), with terminology per Hutchinson (1988) and Hungr et al. (2001).
2. Soils with at least 20% of particles greater than 2 mm in diameter are classified as “Debris”.
3. Soils with at least 80% of particles smaller than 2 mm in diameter are classified as “Earth”.

4.3.2 Fluvial Hazards

Rivers, creeks and streams can experience different water flow (fluvial) processes, ranging from floods to debris floods to debris flows. Debris flows are normally treated as a landslide process (Table 2); however, they are discussed here as a continuum of fluvial processes. Distinction between fluvial hazard processes is important, as these processes differ in flow mechanics and potential consequences. Definitions of these processes are listed below:

- Debris Flow: A debris flow can be defined as “a very rapid to extremely rapid surging flow of saturated debris in a steep channel. Strong entrainment of material and water from the flow path” (Hungr et al. 2014). Debris flow material is typically saturated; however, the movement is colluvial (gravity transported) rather than fluvial (water transported). Hungr et al. (2001) suggest the use of peak discharge as the most reliable criterion to distinguish between debris floods and debris flows, with the latter having peak discharges up to 50 times higher than a flood due to the surging behaviour of these events (VanDine 1996).

Debris flows also typically require channel gradients more than 15° (27%) for transport over long distances (VanDine 1996) and have sediment concentrations of 50% to 60% (Jakob and Hungr 2005).

- Debris Flood: Debris floods can be defined as “a very rapid flow of water, heavily charged with debris, in a steep channel. Peak discharge comparable to that of a water flood” (Hungr et al. 2014). Debris floods typically occur on creeks with channel gradients between 3% and 30%. The term ‘debris flood’ is similar to the term ‘hyperconcentrated flow’, defined by Pierson (2005) as a “type of two-phase, non-Newtonian flow of sediment and water”, exhibiting transitional behaviour between debris flows and floods.
- Flood: For the purposes of this study, floods are defined as water flows with sediment concentrations of up to 10% by volume, transported as suspended load and bed load.

4.4 Methods

4.4.1 Desktop Mapping

Digital Elevation Models (DEMs) and slope gradient maps of the study area were created using GIS software based on the LiDAR “bare earth” imagery obtained from the information sources listed in Section 2.2. These maps were augmented with the results of the air photo interpretation and desktop review of the previously listed information sources to assist in the interpretation of the terrain conditions and slope stability in the study area. An overlay of the DEM showing the historical landslide events and key terrain features within the Furry Creek lands is presented on Sketch B-1 in Appendix B.

4.4.2 Ground Reconnaissance

A total of three days of ground reconnaissance fieldwork were completed in the spring of 2019 to verify the terrain features and landslide processes identified from the desktop mapping. No aerial reconnaissance was carried out. The fieldwork consisted of short foot traverses at selected stopping points within the proposed development areas, including steep slope areas, rock bluffs, creek crossings, and other areas of interest. Conditions in the upper headwaters of the major creeks (North Creek, Middle Creek, South Creek) and along the mountain ridgelines high upslope of the Furry Creek lands were not assessed.

Information gathered included visual assessment of the general topography, slope gradients, landforms, soil and bedrock exposures, hydrologic conditions, and vegetation. Detailed field notes and photographs were collected on a georeferenced map of the study area using a tablet computer. The location of field observation waypoints is shown on Sketch B-1 in Appendix B.

4.4.3 Aerial Reconnaissance

An aerial reconnaissance of the Furry Creek lands and adjacent up-valley areas was completed by helicopter on September 15, 2021. Drone surveys were also completed in the spring of 2022 to collect higher-resolution video and still imagery of areas of exposed bedrock along the southern flank of the Mountain Lands area, upslope of Sea View Drive. The GPS track of the September 2021 helicopter reconnaissance is shown on Sketch B-2 in Appendix B.

4.5 Hazards Identified

4.5.1 General

Landslide hazards which have the potential to locally impact the proposed developments are present at several locations in the Furry Creek lands as discussed in the subsections below. Selected photographs from the ground and aerial reconnaissance are also attached.

To put these findings in context, the type and extent of the identified hazards at Furry Creek are not uncommon to the Sea to Sky corridor and other mountainous areas of the SLRD. In fact, there is no mention of landslide hazards at Furry Creek in a 117-page compendium of historical landslides and flooding events along the Sea to Sky Corridor for the period 1855 to 2007 (Blais-Stevens and Septer 2008).

With respect to potentially damaging landslide hazards that could affect the proposed developments, we have based our assessment on an estimated probability of 1:475 per annum (10% in a 50-year period) as per the MoTI guidelines and previous development approvals at Furry Creek. In accordance with MoTI's guidelines for large-scale developments, we have also considered the potential for catastrophic landslides based on an estimated probability of 1:10,000 per annum (0.5% in a 50-year period). For the purposes of this study, catastrophic landsides are defined as rapid, large-scale releases of soil or rock that could affect multiple building lots within the Furry Creek lands. Examples of catastrophic landslides based on this definition include rock slides and rock avalanches.

<u>Development Permit Considerations</u>

Thurber has reviewed relevant background information, remote sensing data, and completed mapping and site reconnaissance. All of the identified hazards discussed below are within the mapped SLRD DP areas developed for the site. Many of the identified hazards have already been avoided as part of the planning process to date. Some hazards require more detailed assessment as they relate to proposed buildings and infrastructure; this work can only be carried out once site and building plans area further developed at a later stage of design. In accordance with the SLRD DP requirements, proposed developments located within the mapped hazard areas will require a specific, detailed hazard assessment and development of any necessary mitigation measures.

4.5.2 Rock Fall

Rock falls are rapid, potentially destructive failures of fragmental rock masses with individual blocks deposited downslope through a combination of rolling and bouncing. Typical causal mechanisms include freeze-thaw activity, heavy rainfall, and seismic activity. Disturbance to rock masses from wildfires, incautious blasting, or other construction disturbances can greatly increase the occurrence of rock falls. Rock falls can damage surface structures through direct impact and also impart cratering damage to buried facilities.

Rock fall is the dominant landslide hazard process observed within the Furry Creek lands. Rock fall hazards were identified at the following locations (see Photos 1 to 10, attached):

- Within the Northwest and Collector areas, where semi-detached rock masses with open (dilated) joints were observed along the margins of steep bedrock bluffs up to 50 m in height. Rock fall activity from these areas appears relatively infrequent, given the relative scarcity of debris at the base of the bluffs; however, localized detachments weighing from a few kilograms to several tonnes are certainly possible and difficult to predict. The development layouts appear to be relatively favourably sited with respect to rock fall in that the proposed buildings and roads generally follow the ridgelines; however, there may be isolated adverse occurrences requiring protective measures and/or slope treatments (i.e., scaling, shotcrete, rock bolting, trim blasting, etc.) to mitigate the risk.
- Within the Northeast area, where the proposed development footprint verges on steep bedrock-controlled terrain at the base of the Mountain Lands area with the potential for localized rock fall hazards.
- Upslope of Sea View Drive between the Collector and Uplands North areas, where an apparent rock fall scar is visible from Google Earth Pro aerial imagery dated July 13, 2021. The track is not visible on older Google Earth Pro imagery dated August 6, 2019, which provides some constraint as to when the rock fall occurred.
- Within the Uplands North area, where blocks of fallen rock up to 8 m in diameter were noted at scattered locations near the toe of the high mountain slopes at the eastern margin of the proposed development. These mountain slopes rise to a high alpine ridge at about the 1200 m elevation contour. As shown on Sketch B-1 in Appendix B, the observed blocks are clustered near the mouth of bedrock gullies/chutes extending up the mountain slopes, which suggests that rock fall activity may be concentrated within the steep gully sidewalls. Avoidance of this area is judged to be the only practical mitigation strategy given the massive size of these blocks and the potential seriousness of the hazard.
- Within the Uplands South area, where construction disturbance on the steep slopes leading down to Furry Creek could potentially dislodge cobbles and boulders within the coarse glaciofluvial outwash soils that underlie this area.
- Within the Upper Benchlands area, which is situated on steep bedrock slopes which rise approximately 75 to 100 m to a glacially scoured bedrock plateau located at about the 200 m elevation contour. Moderate to steep bedrock slopes continue upslope of this plateau to a ridgeline at about the 400 m elevation contour. The rock in this area of the site appears to be more heavily jointed, and, as can be seen from Sketch B-1 in Appendix B, exhibits a pronounced northeast-southwest trending structural “grain”. We interpret the latter to be the result of intense glacial scour along planes of weakness aligned with the pattern of bedrock jointing. Extensive rock fall deposits (talus) are present at the base of bedrock slopes within the southern half of the Upper Benchlands area, and in isolated pockets / patches within the northern half. Rock fall activity from these areas, however, appears relatively infrequent given the observed weathering of the exposed rock and the heavy moss cover blanketing the talus deposits. Nonetheless, localized

detachments weighing from a few kilograms to several tonnes are certainly possible and difficult to predict.

The development layout generally follows the bedrock plateaus located at about the 120 m and 200 m elevation contours, and in general appears to be favourably sited with respect to road grading and building construction. Rock fall hazards originating from the moderate to steep slopes between and upslope of the bedrock plateaus, however, pose a potential risk to the proposed development and its inhabitants. Construction disturbance (blasting, rock excavation, etc.) could also trigger localized rock fall which could potentially threaten the existing Benchlands development at the toe of the talus slope. Bearing in mind these issues, development of the Upper Benchlands will likely require protective measures and slope treatments, detailed construction practices, and very careful siting of the building lots to mitigate these risks in some areas. Such provisions may lead to a significant increase in construction costs and place constraints on the architectural design of the houses. Further geotechnical assessment of this area will be required as part of subdivision development to verify the scope and extent of these required provisions.

Areas of the Furry Creek lands which could be impacted by rock fall based on the results of screening-level rock fall runout analyses are further discussed in Section 5.1.

4.5.3 Rock Slides / Rock Avalanches

Rock slides involve the sudden failure of large bedrock masses, typically well over 1,000 cubic metres in volume, which remain semi-intact during sliding. In some cases, the failed mass can disintegrate into a rapidly flowing sheet of broken rock, termed a rock avalanche.

Based on our assessment, including review of the existing 1:50,000 scale surficial geology and landslide inventory mapping completed by the Geological Survey of Canada (Blais-Stevens 2008), there is no geological evidence of previous rock slides or rock avalanches within the Furry Creek lands. However, historical rock slides have occurred elsewhere along the Sea to Sky corridor, most recently at Porteau where a 16,000 cubic metre rock slide occurred in 2008, resulting in the closure of Highway 99 for several days. Potential rock avalanche hazards have also been identified along the western valley wall of the Jane Creek basin at Britannia Beach (Blais-Stevens and Hungr 2008). Given this regional context, the potential for such failures to impact the Furry Creek lands cannot be ruled out.

Potential rock slide / rock avalanche hazards were identified at the following locations:

- Upslope of Sea View Drive between the Collector and Uplands North areas, where a large semi-detached bedrock bluff was identified along the southern flank of the Mountain Lands during the September 2021 helicopter reconnaissance; this feature is herein referred to as ‘Area A’. The location of Area A is shown on Sketch B-2 in Appendix B. As shown on Photos 11 and 12, this feature consists of a relatively massive outcrop of granitic rock seated along a highly persistent joint plane dipping directly out of the slope at an angle of about 40 degrees. The in-situ volume of this feature is estimated to be approximately 35,000 cubic metres based on the measured area of disturbance from LIDAR and the estimated depth of the joint plane. The stability of the Area A feature with respect to catastrophic failure and implications for residential development are further discussed in Sections 5.2 and 5.3.

- Approximately 5 km upstream of from Highway 99 along the north valley wall of Furry Creek, an area of bedrock deformation seated in Gambier Group rocks was identified from the LiDAR imagery based on the presence of uphill facing scarps and linear tension cracks; this feature is herein referred to as 'Area B'. The location of Area B is shown on Sketches B-2 and B-3 in Appendix B. This feature has an estimated in-situ volume on the order of 1.5 million cubic metres based on the measured area of disturbance from LIDAR and an estimated failure thickness on the order of 30 m. The location and pattern of deformation at Area B suggests that this feature may be the result of slow gravitational deformation of the mountain ridgeline ("sackung"); however, the potential for this feature to catastrophically fail at some point in the future cannot be ruled out. Due to its remote location, this feature does not pose a direct hazard to the Furry Creek lands; however, were this area to fail, the resulting slide path could possibly inundate the channel of Furry Creek and form a landslide-impounded lake. In such a scenario, were the landslide dam to then be rapidly breached by the overtopping creek flows, the resulting outburst flooding on Furry Creek could potentially pose a risk to low-lying areas on the fan. The estimated likelihood of such a scenario at Area B is further discussed in Section 5.4.

As shown in Photos 13 and 14, there are several areas of exposed bedrock high upslope of the Uplands North area extending to the high alpine ridge at about the 1200 m elevation contour, including sheer bedrock cliffs of about 100 m to 150 m in height. Detailed examination of this area was not possible due to the extremely rugged terrain and dense tree cover; however, based on the conditions observed from the September 2021 helicopter reconnaissance, catastrophic landslides (in the form of rock slides or rock avalanches) do not appear to be kinematically feasible in this area based on photogrammetry analysis of high-resolution digital photographs and our engineering judgement.

4.5.4 Deep-Seated Bedrock Instability (Rock Slumps)

An area of deep-seated bedrock instability seated in Gambier Group rocks was identified from the LiDAR imagery along the north valley wall of Furry Creek approximately 4.5 km upstream from Highway 99, immediately to the west of Area B; this feature is herein referred to as 'Area C'. The location of Area C is shown on Sketch B-2 in Appendix B. As shown on Sketch B-4 in Appendix B, and in Photos 15 to 18, this area is delineated by an arcuate, downward-facing headscarp in glacial overburden along the crest of the slope and by large gullies incised into bedrock along the margins, defining a large, inferred slump feature measuring approximately 600 m in width and 1000 m in slope length. The total volume of the slump is estimated to be on the order of 10 to 30 million cubic metres based on the measured area of disturbance from LIDAR and the inferred thickness of the slump, which we estimate to be between 20 m and 60 m. The headscarp is approximately 25 m to 30 m in height based on LiDAR, which suggests that the slump has experienced significant deformation since the onset of movement.

The stability of both Area B and Area C have not been investigated as part of our assessment; however, these features do not appear to have experienced recent movement based on the following lines of evidence:

1. Preliminary review of archived ALOS-1 Interferometric Synthetic Aperture Radar (InSAR) satellite imagery by a third-party contractor does not show any evidence of measurable slope deformation within or near these features over the past several years.
2. LiDAR change detection analyses comparing the 2012 LiDAR (obtained from McElhanney) with the 2020 LiDAR (provided by CREUS) does not show any discernible pattern of deformation within or near these features; see Sketch B-5 In Appendix B.
3. No obvious physical indicators of active slope movement such as tension cracks, bent and tilted trees, seepage discharge, etc. were observed from the September 2021 helicopter reconnaissance.

Based on the above, the Area C slump feature is most likely an ancient landform resulting from glacial debuttressing of the valley walls of Furry Creek at the end of the last ice age (i.e., an early paraglacial feature). It is possible, however, that incision of the major gullies in post-glacial time has further debuttressed the north valley wall of Furry Creek and contributed to overall slope deformation. Mining-related disturbances are not considered a plausible trigger for the slump based on our review of the available MINFILE records for the Britannia Mine and other historical mine workings along Furry Creek, which are located 2 km to 5 km further up-valley.

Based on our interpretation of the surficial geology, the significant slope deformation which has already occurred at Area C (residual shear strengths having therefore likely developed along the failure plane), the relatively gentle gradient of the valley slope (25 to 30 degrees), and the lack of evidence indicating recent movement, we infer that the conditional probability of a catastrophic landslide from Area C that could affect the Furry Creek lands (in the form of landslide outburst flooding) is less than 1:10,000 per annum.

4.5.5 Debris Slides and Slumps

Debris slides are rapid, channelized or open-slope failures that involve the detachment of a thin sheet of mineral and organic soil from steep slopes and are perhaps the most common landslide type in British Columbia. Typical causal mechanisms include freeze-thaw activity, heavy rainfall, seismic activity, or changes to natural drainage patterns due to logging, road construction, or other disturbances. Areas underlain by thicker sediments can experience deeper rotational failures (slumps) rather than shallow translational failures (slides).

Debris slide / debris slump hazards were identified at the following locations (see Sketch B-1 in Appendix B and Photos 19 and 20, attached):

- Within the Mountain Lands area, where an inferred slide track was observed on the eastern flank of the mountain from the 1957 air photos, extending from the top of slope to about the present location of the Forest Service Road (FSR).

- Within the Uplands North area, where an inferred slide track was observed upslope (east) of the proposed developments on the 1994 air photos, extending to about the present location of the FSR.
- Within the Uplands South area, where several inferred slide tracks were observed from the 1957 and 1994 air photos on the steep slopes leading down to Furry Creek. There is also evidence from the LiDAR imagery of larger slump failures along the north (right) bank of Furry Creek, possibly caused by undercutting of the toe of the slope or changes to natural drainage patterns due to road construction and gravel pit development.
- Within the Uplands South area, along the steep soil slopes bordering the north and west perimeter of the abandoned gravel pit and adjacent slopes leading down to Middle Creek.
- Within the Collector area, where an inferred slump failure in glacial sediments was observed from the LiDAR imagery along the north bank of Middle Creek, approximately 125 m north of the club house building at the Furry Creek Golf & Country Club. The slump measures approximately 30 m high by 100 m in width based on LiDAR.
- Within the Upper Benchlands area, where the steep bedrock slopes are locally mantled by veneers of organic and mineral soil with observed seepage at the soil/rock interface.

4.5.6 Excavated Bedrock and Foundation Setback Hazards

Figure 2 shows several areas across the subject property with possible geotechnical hazards where proposed developments are located on or adjacent to steep bedrock slopes (also see Photos 1 to 12, attached). Within these areas, further, site-specific geotechnical assessments will be required to confirm the siting of individual buildings and associated foundation design and construction requirements per the SLRD DP requirements. Where the buildings cannot be adequately set back from the crest of these slopes, it will be necessary to construct the buildings with specially designed foundations, using carefully excavated platforms and rock anchors. These buildings will need to be very carefully sited and the building, its access and landscaping designed with input from both geotechnical and structural engineering disciplines. Protective measures may also be required at these locations to mitigate risks from rock fall.

The Northwest area is bisected by the CN Rail tunnel as shown on Sketch B-1 in Appendix B. We understand from CREUS that there will be restrictions on building development immediately above the tunnel alignment, per CN Rail requirements. Further discussion on this area is provided in Section 6.2 of the report.

4.5.7 Seismic Liquefaction Hazards

The alluvial sediments forming the fan of Furry Creek are potentially liquefiable under strong earthquake shaking. The potential consequences of liquefaction include differential vertical settlement, horizontal displacement (lateral spreading), and associated damage to buildings and buried facilities. Previous seismic analyses completed by Thurber indicate that liquefaction hazards on the Furry Creek fan are localized, rather than widespread; however, these hazards will need to be assessed on a site-specific basis in accordance with BCBC 2018.

4.5.8 Submarine Landslides

Based on our assessment, there is no geological evidence of significant submarine landslides originating from the Furry Creek fan or evidence of subaerial landslides that have deposited into Howe Sound from the Furry Creek lands; the available bathymetry is shown on Sketch B-6 in Appendix B. Jackson et al. (2008) describe minor localized slumps within the submarine fan of Furry Creek and broader slumps within the glacial and post-glacial sediments to the north of the fan; however, the adjacent seafloor of Howe Sound is relatively featureless.

4.5.9 Fluvial (Creek) Hazards

Furry Creek and the other named creeks (North Creek, Middle Creek, South Creek) draining the steep mountain slopes to the east of the subject property are subject to fluvial hazards including flooding and bank erosion. Previous studies by others have also identified that Furry Creek is subject to debris flood hazards.

Prior to the development of the existing 56-townhome development at Oliver's Landing, Delcan Corp. (now A Parsons Company) completed an engineering review of creek hazards along the foreshore area of the site north of Furry Creek. We understand that the designed and constructed flood protection measures were accepted by MoE / MoTI based on the identified creek hazards and associated flood levels estimated at that time.

The assessment of, and mitigation from, fluvial hazards is beyond the scope of this study but should be undertaken by a qualified hydrotechnical engineer / flood control engineer in accordance with EGBC's Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in BC (v 2.1, 2018). The requirements for this assessment prior to future development are laid out in recent DP guidelines jointly authored by Kerr Wood Leidal (KWL) and Thurber.

The morphology of the above-noted creek basins from LiDAR indicates the potential for debris floods in South Creek and debris floods or debris flows in North Creek based on respective Melton Ratios of approximately 0.5 and 0.75 upstream of Highway 99 (Wilford et al. 2004); however, no evidence of such hazards was identified in the field or from the desktop review. We attribute this discrepancy to the small drainage area of these creek basins and the relative absence of debris in the channels due to the generally massive nature of the exposed bedrock and the thin soil cover. Further comments on debris flow hazards at North Creek are provided in the following section.

4.5.10 Debris Flows – North Creek

Potential debris flow hazards at North Creek ("Unnamed Creek #9") are described in Thurber (1983), which recommended a design debris flow volume of 5,000 cubic metres based on a detailed aerial and ground reconnaissance of the creek completed at that time. The 1983 report notes, however, that no previous debris flows were recognized in this watershed; the probability of debris flow ("debris torrent") occurrence was also categorized as low.

Based on the topography and general character of the North Creek watershed from LiDAR, and our recent observations of this area via helicopter (see Photos 21 to 24), the debris flow design volume of 5,000 cubic metres from Thurber (1983) appears reasonable for the purposes of this overview study. We note that this design volume is not tied to a specific return period, but rather is based on engineering judgement estimates of debris volumes in the channel that could be mobilized by the creek and entrained into a debris flow.

Areas of the Furry Creek lands which could be impacted by debris flows from North Creek based on the results of preliminary runout analyses are further discussed in Section 5.5 of the report.

4.5.11 Coastal Hazards

Coastal hazards include flooding resulting from extreme tides, wave action, storm surge, global sea level rise (and combinations thereof), and the associated erosion of shoreline areas. Landslide or earthquake-induced tsunamis are another potential coastal hazard.

Similar to creek hazards as described above in Section 4.5.9, the flood protection works in the foreshore area that were constructed and approved provide a level of protection related to coastal hazards.

The alluvial fan of Furry Creek is potentially subject to coastal flooding and shoreline erosion hazards, in view of the local topography and erodibility of the fan deposits and imported fill materials on the fan. The assessment of, and mitigation from, coastal hazards is beyond the scope of this study but should be undertaken by a qualified hydrotechnical engineer / flood control engineer in accordance with EGBC's Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in BC (v 2.1, 2018). The requirements for this assessment prior to future development are laid out in recent DP guidelines jointly authored by KWL and Thurber.

With regards to tsunami hazards, previous studies by Clague and Orwin (2005) and others conclude that tsunamis triggered by a megathrust earthquake off the BC coast would attenuate to less than 2 m before reaching North and West Vancouver; they also conclude that there is no evidence for tsunamis induced by landslides or delta foreslope slumps (submarine failures) in Howe Sound within the past several thousand years. Nonetheless, the potential for a landslide-triggered tsunami in Howe Sound, while very small, cannot be ruled out. The height of such a tsunami at Furry Creek would depend on the location, size and character of the triggering landslide and the distance from the landslide source.

5. ANALYSIS

5.1 Rock Fall Runout Analysis – Furry Creek Lands

Preliminary rock fall runout analyses of the Furry Creek lands were completed using 3D commercial software (RocPro3D) as a screening-level tool to map areas of potential hazard. The models were developed based on the available LiDAR data and other background information sources referenced in Sections 2.1 to 2.3.

5.1.1 Input Parameters and Assumptions

Rock blocks with induvial volumes of up to 10 cubic metres were considered in the model based on our field observations. Rock fall source areas in the model were assumed to be from areas with slope angles greater than 50° based on site observations and engineering judgement. The modelled rock falls were released (“seeded”) from the slope with a small initial velocity (< 2 m/s) to account for strong earthquake shaking or potential construction-induced disturbances such as blasting that could cause large rock masses to be released from the slope. Trees were not explicitly considered in the model due to software limitations. The restitution coefficients assigned to different slope materials in the model are summarized in Table 3.

TABLE 3 – ASSIGNED VALUES FOR ROCK FALL RESTITUTION COEFFICIENTS

Surface Material	Overall Slope Angle	Trees and Vegetation on Slope?	Mean Normal Restitution(1), e_N	Mean Tangential Restitution(1), e_T	Friction Angle	
					Static	Dynamic
Hard Rock	> 50°	No	0.55 (σ = 0.05)	0.8 (σ = 0.05)	40°	38°
Talus Aprons	20° to 50°	Yes	0.33 (σ = 0.03)	0.7 (σ = 0.03)	38°	35°
Sand and Gravel	< 20°	Yes	0.25 (σ = 0.02)	0.6 (σ = 0.02)	35°	30°

The normal restitution coefficients in Table 3 were scaled based on the input velocity of the rock block using the equation provided in Pfeiffer and Bowen (1989). This factor reduces bounce heights in the model due to plastic deformation and crack propagation within the rock blocks at each impact. The scaled normal restitution is calculated as a function of the rock velocity immediately before the impact. Since velocity changes after every impact, the normal restitution also changes correspondingly.

5.1.2 Results

Sketch C-1 in Appendix C shows the modelled rock fall trajectories for the Furry Creek lands based on the above-noted input parameters, which are generally consistent with the distribution of rock blocks (talus) observed in the field in areas of rock fall deposition. The analysis results do not consider the mitigating effect of trees, which can significantly reduce the runout of individual rock blocks.

5.2 Limit-Equilibrium Slope Stability Analysis – Area A

Preliminary 2D limit-equilibrium slope stability analyses of the semi-detached bedrock bluff at Area A were completed using the computer program RocPlane to evaluate the likelihood of a catastrophic failure based on a probabilistic range of geotechnical parameters and failure plane angles as described below. The analyses were developed based on the available LiDAR data and other background information sources referenced in Sections 2.1 to 2.3.

5.2.1 Input Parameters and Assumptions

The modelled slope section based on LiDAR is shown in Appendix D. The analysis considered an approximately 35 m high rock slope inclined at 70° and a planar joint surface (failure surface) daylighting out of the slope at an inclination of between 30° and 50°. A vertical tension crack was included in the model for conservatism based on the observed bedrock conditions upslope. Due to the limited available information about the rock mass strength properties along the potential failure plane, the analysis considered a probabilistic range of Mohr-Coulomb drained shear strength parameters (φ' = 30° to 40°; c' = 0 kPa to 100 kPa) based on typical published values for similar rock types. The model included a pseudo-static horizontal seismic coefficient (k_h) of 0.3 g (equivalent to 100% of the Peak Ground Acceleration), based on 2475-year firm ground values obtained from the Earthquakes Canada National Building Code of Canada 2015 Seismic Hazard Calculator (https://earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/calc-en.php). A range of water pressures on both the joint plane and the tension crack (equivalent to 0% to 50% infilled) was also considered in the analysis in view of the high seasonal precipitation at the project site.

5.2.2 Results

The results of the analyses are presented in Appendix D. In brief, the results show that the Factor of Safety (FoS) of the semi-detached rock bluff at Area A with respect to planar failure is about 2.0 under pseudo-static loading using mean shear strength parameters (φ' = 35°; c' = 50 kPa; joint dip angle = 40°), and with water pressures set to 50% infilled.

The probabilistic analysis shows, however, that the probability of failure (FoS < 1) under pseudo-static loading is about 2% for the full range of shear strengths and failure plane dip angles considered in the model, with water pressures on the joint plane set to 50% infilled. Based on these results, we infer that the probability of a catastrophic failure at Area A, while very small, may be greater than 1:10,000 per annum.

5.3 Rock Avalanche Runout Analysis – Area A

Based on the results of the limit-equilibrium slope stability analysis, the runout path of a hypothetical 35,000 cubic metre rock slide / rock avalanche originating from Area A was analysed using the computer program RAMMS to map areas of potential hazard based on an estimated probability of 1:10,000 per annum. The model was developed based on the available LiDAR data and other background information sources referenced in Sections 2.1 to 2.3.

5.3.1 Input Parameters and Assumptions

The analysis was completed using material properties (i.e., rheological parameters) based on the Voellmy rheology with an assigned frictional coefficient (μ) of 0.3 to 0.4 and a turbulence coefficient (ξ) of 200 m/s^2 to 500 m/s^2 based on the character of the runout path and published values for similar case histories (Aaron and McDougall 2019). The event was modelled as in-situ failure mass of approximately 35,000 cubic metres released from Area A with entrainment of an additional 5,000 to 6,000 cubic metres from the path (to account for the erosion of path materials and bulking/swelling of the slide debris), resulting in a total volume of approximately 40,000 cubic metres at the point of deposition. Additional analysis runs were completed with a vertical deflection berm placed along the eastern property line of the proposed developments along Sea View Drive to evaluate this option as a potential mitigative solution.

5.3.2 Results

The analysis results are presented in Appendix E. The analysis shows that the runout path of a rock slide / rock avalanche from Area A could potentially reach the proposed developments along Sea View Drive based on the total event volume and range of rheological parameters considered. The analysis also shows, however, that an approximately 6 m high sub-vertical deflection berm located along eastern property line of the proposed developments would be sufficient to contain the slide debris based on a minimum freeboard of 1 m. Further geotechnical assessment will be required during preliminary/detailed design to confirm the layout and dimensions of the berm, which we expect could be constructed from locally sourced granular fill with a durable erosion-resistant facing (e.g., lock blocks, grouted riprap, or MSE wire baskets).

5.4 Rock Avalanche Runout Analysis – Area B

The runout path of a hypothetical 1.5 million cubic metre rock avalanche originating upstream of the Furry Creek lands at Area B was analysed using the computer program RAMMS to map areas of potential hazard assuming that a catastrophic failure from this location has a probability of occurrence of greater than 1:10,000 per annum. The model was developed based on the available LiDAR data and other background information sources referenced in Sections 2.1 to 2.3.

5.4.1 Input Parameters and Assumptions

The analysis was completed using rheological parameters based on the Voellmy rheology with an assigned frictional coefficient (μ) of 0.2 to 0.24 and a turbulence coefficient (ξ) of 400 m/s^2 to 600 m/s^2 based on the character of the runout path and published values for similar case histories (Aaron and McDougall 2019). The event was modelled as in-situ failure mass of approximately 1.5 million cubic metres released from Area B with entrainment of an additional 0.4 million cubic metres from the path (to account for the erosion of path materials and bulking/swelling of the slide debris), resulting in a total volume of approximately 1.9 million cubic metres at the point of deposition.

5.4.2 Results

The analysis results are presented in Appendix F. The analysis shows that the distal end of the runout path of a rock avalanche originating from Area B could potentially reach Furry Creek but would be unlikely to completely block the creek channel based on the total event volume and range of rheological parameters considered. Based on these results, we infer that the conditional probability of a catastrophic landslide from Area B that could affect the Furry Creek lands (in the form of landslide outburst flooding) is less than 1:10,000 per annum.

5.5 Debris Flow Runout Analysis – North Creek

The runout path of a hypothetical 5,000 cubic metre debris flow on North Creek was analysed using the computer program RAMMS as a screening-level tool to map areas of potential hazard adjacent to the creek. The model was developed based on the available LiDAR data and other background information sources referenced in Sections 2.1 to 2.3.

5.5.1 Input Parameters and Assumptions

The analysis was completed using typical rheological parameters for debris flows in coastal BC based on the Voellmy rheology, using a frictional coefficient (μ) of 0.1 and a turbulence coefficient (ξ) of 500 m/s^2. The event was modelled as a single surge with an initial failure of mass of approximately 2,500 cubic metres released from the upper headwaters of the creek with entrainment of an additional 2,500 cubic metres of debris from the flow path, resulting in a total volume of approximately 5,000 cubic metres at the point where the debris flow reaches the Furry Creek lands.

5.5.2 Results

Sketch G-1 in Appendix G shows the modelled debris flow runout where North Creek intersects the Furry Creek lands. It can be seen that most of the debris is confined to the existing channel upstream of Highway 99, with some minor avulsion of material out of the channel at an existing logging road bridge crossing. Based on these results, we infer that the areas of the Furry Creek lands at potential risk from debris flows on North Creek are limited to low-lying areas near the existing creek channel.

6. DISCUSSION AND RECOMMENDATIONS

6.1 Geohazard Polygons

Figure 2 shows the approximate extent of potentially damaging landslide hazards, mapped at 1:5,000 scale from the available LiDAR imagery. The hazard polygons shown on Figure 2 are based on an estimated encounter probability of 1:475 per annum (10% in a 50-year period). Symbols within each hazard polygon denote the primary hazard types identified.

Figure 3 shows the approximate extent of the runout path from a rock slide / rock avalanche originating at Area A for the unmitigated case (i.e., without the implementation of any stabilization measures or protective berms/barriers), based on a probability of 1:10,000 per annum. The runout path for the mitigated case (i.e., including the previously described 6 m high deflection berm) is shown in Appendix E.

The mapped hazards on Figures 2 and 3 are conditional which means they are subject to change pending further geotechnical assessment during preliminary/detailed design once the layout of the proposed roads, lots, and building footprints have been finalized. Unexpected determination of hazard may affect lots now judged to be hazard free.

6.2 Preliminary Geotechnical Recommendations for Subdivision Design

We offer the following comments to support the preliminary layout and design of the proposed roads, lots, and building footprints:

- Permanent, unsupported soil cuts in overburden should be cut no steeper than 1.5H:1V and preferably 2H:1V or flatter. Some ravelling and maintenance of slopes cut steeper than 2H:1V should be anticipated. Finer-gained soils, and areas where groundwater seepage is encountered, may require cutting at shallower slope angles to control sloughing. These slopes should be vegetated or provisioned with other durable erosion protection such as rock blanketing as soon as possible following completion of excavation. In this regard, the glaciofluvial soils exposed in the former gravel pits at the Uplands South area are more highly susceptible to surface erosion, particularly where concentrated surface runoff can discharge down the slope face. The relatively high erodibility of these soils should be carefully considered in the layout of road and lot grades and the design of the stormwater collection system.
- All steep, natural rock slopes above proposed building areas will require precautionary hand scaling. Removal of loose rock blocks, soil, and trees on and at the crests of rock slopes will be required for safety purposes. Additional details on this can be provided once lot/road layout and grading is completed.
- Design of temporary and permanent rock cuts should be undertaken per MoTI Technical Circular T-04/17 entitled “Geotechnical Design Criteria”. Preliminary design of bedrock cut slopes may assume a slope of 1H:4V (76 degrees) with no rock support. However, actual requirements for slope support can only be determined after excavation. Comprehensive machine and hand scaling will be required to remove loose rock blocks from crest of slope areas and final rock faces. All final cut slopes should be blasted using controlled blasting techniques. Specifically, a backline pre-shear and buffer row should be used to avoid damage to the face and minimize back-break. Blasting operations should be undertaken in accordance with MoTI Standard Specifications.

  Depending on the actual rock conditions encountered, and the effectiveness of the controlled blasting, rock slope stabilization including rock bolting, shotcrete, dental concrete and slope mesh may be required. All rock slopes should be inspected by a qualified geotechnical engineer during and on completion of blasting to identify zones of loose rock and/or unstable blocks and determine the requirement for scaling and rock bolting. All scaling and bolting should be carried out on an on-going basis while the blasting/rock slope stabilization contractor is on site and has access to the working face.

  We recommend a minimum 3 m wide zone of cleaned bedrock (i.e., remove all soil, loose rock vegetation, etc.) above all rock cuts and at the soil/rock interface in mixed overburden and rock cuts.
- As the development of the Northwest area may require a significant volume of blasting and rock excavation, it may be necessary to conduct pre-construction geotechnical surveys of the inside of the CN Rail tunnel, possibly including terrestrial LiDAR scans, to document the existing conditions. Controlled blasting techniques, supplemented by

ground displacement and vibration monitoring above or inside the tunnel, may also be required to satisfy CN Rail requirements.

- Fill slopes in coarse granular material or blasted rock fill should be tentatively planned at 1.5H:1V to 2H:1V, depending on the height of the slope, with careful attention to site preparation, fill placement and compaction. Additional details on this can be provided once lot/road layout and grading is completed. Geosynthetic reinforcement of higher fill slopes and embankments may be required to satisfy the minimum factors of safety for global stability per current MoTI standards. Given the relatively shallow depth to bedrock at the site, and the high volumes of winter precipitation and runoff, it may be necessary to incorporate robust drainage measures (e.g., French drains, drainage blankets, secondary culverts, etc.) into the base of fills and embankments across ephemeral creek channels and other naturally wet areas.
- The talus deposits, in addition to their potential susceptibility to rock fall from upslope, exhibit visible signs of creep (a common hillslope process involving the slow, downward movement of rock fragments due to gravity), and could be marginally stable in some areas. The development layouts appear to be relatively favourably sited with respect to avoiding areas of talus deposits. Construction of roads and buildings on talus is not recommended.

7. CONCLUSIONS

We provide the following conclusions based on the findings of our overview assessment:

Assessment of Potential Life-Threatening or Catastrophic Landslide Hazards (Probability of 1:10,000 per Annum)

1. Based on our assessment, there is no geological evidence of previous rock slides, rock avalanches, or other catastrophic landslides within the Furry Creek lands. There is also no geological evidence of significant submarine landslides originating from the Furry Creek fan or evidence of subaerial landslides that have deposited into Howe Sound from the Furry Creek lands.
2. The potential for a catastrophic failure of the semi-detached rock bluff at Area A may be greater than 1:10,000 per annum based on the results of our preliminary analyses. The analysis further shows, however, that an approximately 6 m high sub-vertical deflection berm located along eastern property line of the proposed developments along Sea View Drive would be sufficient to contain the slide debris based on a minimum 1 m freeboard. Detailed design work of this proposed mitigation measure must be completed. However, it is our opinion that a deflection berm could be feasibly designed and constructed to mitigate a potential large-scale rock slide from Area A.
3. In our opinion, the probability of the Furry Creek lands to be impacted by landslide outburst flooding from a catastrophic landslide originating upstream at Area B or Area C is estimated to be less than 1:10,000 per annum. We base this conclusion on the conditional probability of a catastrophic landslide occurring, the slide mass reaching and impounding Furry Creek, and the resulting landslide dam being rapidly breached by the overtopping creek flows.

Assessment of Potential Damaging Landslide Hazards (Probability of 1:475 per Annum)

4. The proposed developments should, where possible, avoid the geotechnical hazard areas shown on Figure 2. However, based on the referenced geohazard acceptability criteria, we expect that many of the proposed lots within the hazard areas can be rendered feasible for development with further, site-specific geotechnical assessment to verify lot siting and recommended provisions for protective works, slope and foundation treatments, and construction practices.
5. The type and extent of the identified hazards at Furry Creek (as described in the report and shown on Figure 2) are not uncommon to the Sea to Sky corridor and other mountainous areas of the SLRD. In fact, there is no mention of landslide hazards at Furry Creek in a 117-page compendium of historical landslides and flooding events along the Sea to Sky Corridor for the period 1855 to 2007 (Blais-Stevens and Septer 2008).
6. In certain areas of the subject property, a reduction in the number of currently proposed building lots is likely necessary to avoid locations of serious hazard. At this stage, based on the conditions described in Section 4.5.2 and the results of the rock fall runout analysis presented in Appendix C, it is our opinion that some of the currently proposed lots along the eastern and northern margins of the Uplands North area may not be safe for development unless substantial mitigation measures are implemented. Lots on these margins will require further study and analysis, and assessment of the potential to feasibly construct acceptable mitigation measures prior to development in accordance with the SLRD DP guidelines.

Assessment of Debris Flow Hazards (North Creek)

7. The debris flow runout analyses completed for North Creek suggest that areas of the Furry Creek lands at potential risk from debris flows are limited to low-lying areas near the existing creek channel, based on a total event volume of up to 5,000 cubic metres. However, as the conditions in the watershed have been disturbed by ongoing logging and resource road construction as shown on the attached photographs, further assessment should be undertaken during preliminary/detailed design to confirm debris volumes for the design return period event as required by the SLRD DP guidelines for this area.

8. CLOSURE

We trust the above provides the information you require at this time. If you have any questions regarding this letter, please contact either of the undersigned.

Yours truly,
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<u>Attachments</u>:

- Statement of Limitations and Conditions
- Photos 1 to 24
- Figure 1 – Study Area Limits
- Figure 2 – Geotechnical Hazard Areas
- Figure 3 – Catastrophic Landslide Hazard Zone - Area A
- Appendix A – Examples of Landslide Processes
- Appendix B – Landslide Inventory Mapping
- Appendix C – 3D Rock Fall Runout Analysis - Furry Creek Lands
- Appendix D – Limit-Equilibrium Slope Stability Analysis - Area A
- Appendix E – Rock Slide Runout Analysis - Area A
- Appendix F – Rock Avalanche Runout Analysis - Area B
- Appendix G – Debris Flow Runout Analysis - North Creek

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STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

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

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

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

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

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

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PHOTOGRAPHS

PHOTO 1: View of talus deposits in the Upper Benchlands area. (Photo taken by Thurber in May 2019).

PHOTO 2: View of rock bluffs high upslope (east) of the Uplands North area. Light-colored areas on the bluffs indicate where relatively recent rock fall has occurred. (Photo taken by Thurber in May 2019).

PHOTO 3: View of rock fall debris along the east side of Uplands North area, near the toe of the steep mountain slopes. Note the field notebook in centre of photo for scale. (Photo taken by Thurber in May 2019).

PHOTO 4: View of a fresh rock fall scar from the southern flank of the Mountain Lands area (indicated by yellow arrow) from Google Earth imagery dated July 2021. Inferred source area is circled in yellow.

PHOTO 5: View of steep rock bluffs upslope of the existing gravel road in the Collector area. (Photo taken by Thurber in May 2019).

PHOTO 6: View of steep bedrock bluffs in the Collector area, upslope of Clubhouse Road. (Photo taken by Thurber in May 2019).

PHOTO 7: View of steep bedrock bluffs within the Northwest area. Yellow polygon shows partially detached rock mass. (Photo taken by Thurber in May 2019).

PHOTO 8: View of steep bedrock bluffs within the Northwest area. Yellow arrow indicates unfavourably oriented fracture plane dipping out of the slope. (Photo taken by Thurber in May 2019.)

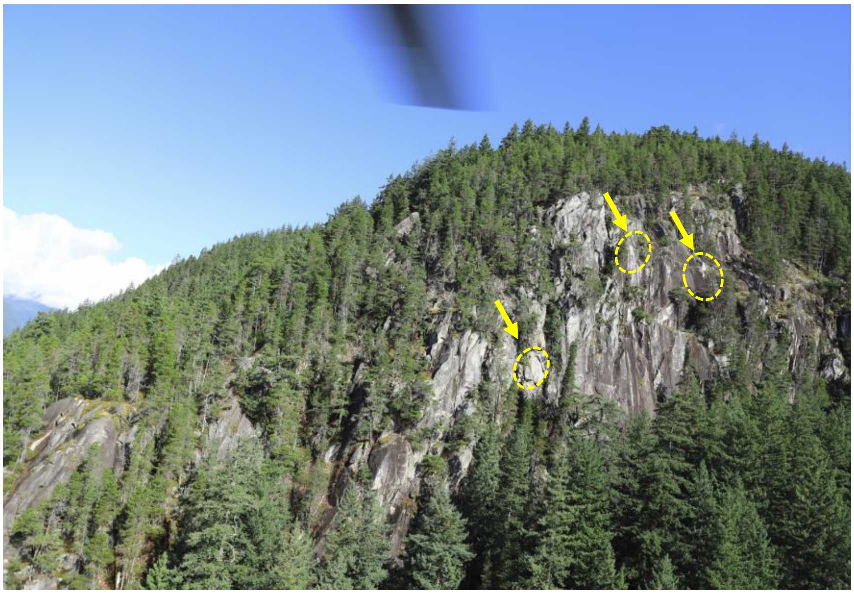

PHOTO 9: Aerial view of the Mountain Lands area, looking north. Yellow arrows show potential rock fall source areas from the more highly fractured areas of the bluff. (Photo taken by Thurber in September 2021).

PHOTO 10: Aerial view of the north valley wall of Furry Creek approximately 2.5 km upstream of Highway 99, looking north from an elevation of about 900 m above sea level. Yellow arrow shows location of recent rock fall. (Photo taken by Thurber in September 2021).

PHOTO 11: Aerial view of ‘Area A’ along the southern flank of the Mountain Lands area, looking northeast. Yellow dashed line shows limits of the potential large-scale rock instability. (Photo c/o Fine Peace, dated 04/2022).

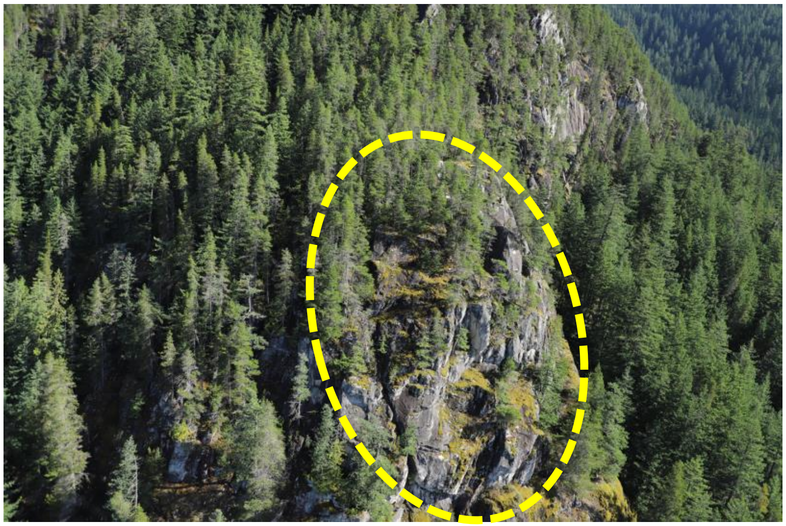

PHOTO 12: Aerial view of ‘Area A’ along the southern flank of the Mountain Lands area, looking east. Yellow dashed line shows limits of the potential large-scale rock instability. (Photo taken by Thurber in September 2021).

PHOTO 13: Aerial view of sheer bedrock cliffs along an alpine ridge high upslope of the northeastern portion of the Uplands North area, looking east from an elevation of about 1150 m above sea level. (Photo taken by Thurber in September 2021).

PHOTO 14: Aerial view of sheer bedrock cliffs along an alpine ridge high upslope of the southeastern portion of the Uplands North area, looking east from an elevation of about 750 m above sea level. (Photo taken by Thurber in September 2021).

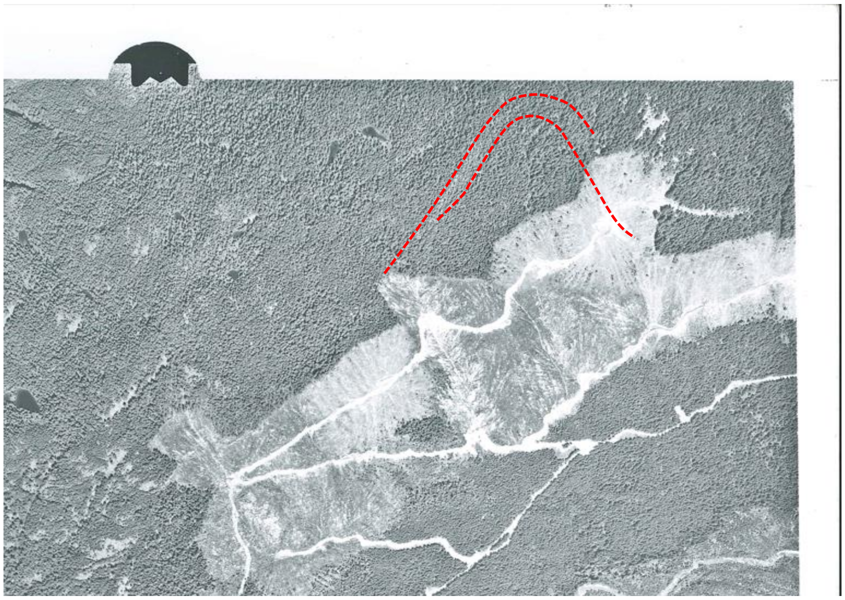

PHOTO 15: 1969 air photo of the north valley wall of Furry Creek at Area ‘C’, approx. 4.5 km upstream of Highway 99. Head scarp of inferred rock slump feature identified from LiDAR shown by red line.

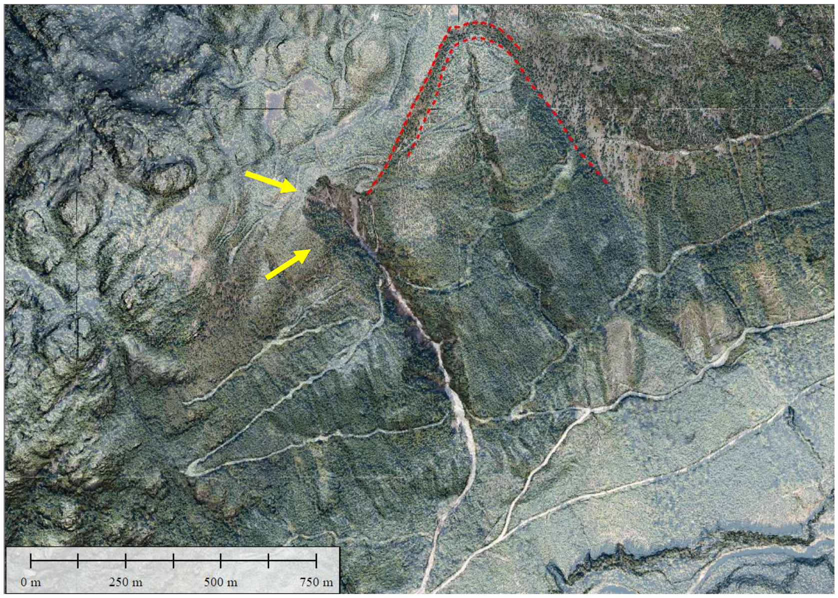

PHOTO 16: Overlay of 2020 LiDAR and orthoimagery of the north valley wall of Furry Creek at Area ‘C’, approx. 4.5 km upstream of Highway 99. Head scarp of inferred rock slump feature identified from LiDAR shown by red line. Yellow arrows show large gully feature which has retrogressed considerably since the 1960s.

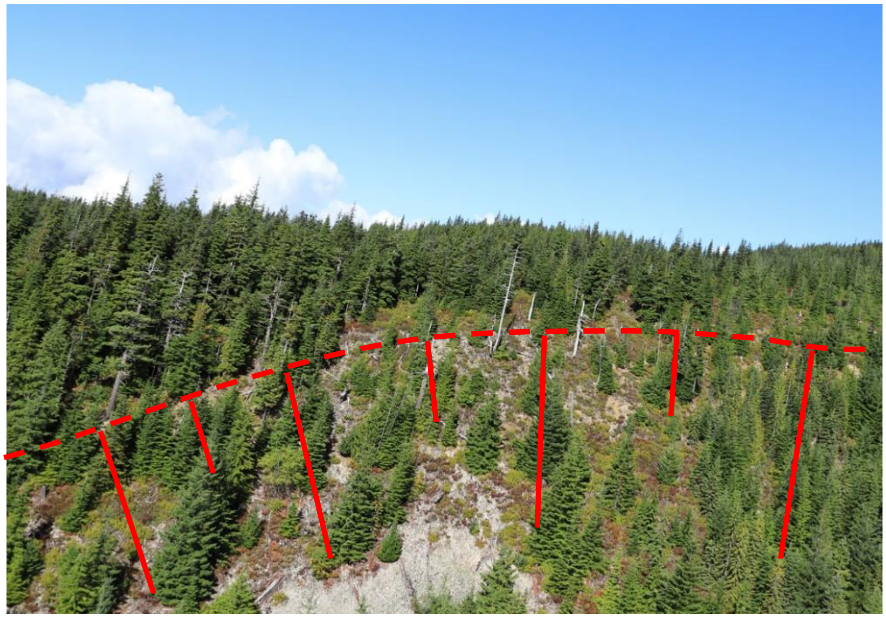

PHOTO 17: Aerial view of the head scarp of the inferred rock slump feature at Area ‘C’, approx. 4.5 km upstream of Highway 99. Note that this area has been disturbed by historical logging and resource road construction. (Photo taken by Thurber in September 2021).

PHOTO 18: Aerial view of the large retrogressing gully feature at Area ‘C’ along the north valley wall of Furry Creek, at the location shown on Photo 16. (Photo taken by Thurber in September 2021).

PHOTO 19: View of Upper Benchlands area showing shallow sloughing (indicated by hummocky ground and tilted trees) in overburden veneer over bedrock. (Photo taken by Thurber in May 2019).

PHOTO 20: View of inferred landslide tracks (shown by yellow arrows) from the 1994 air photo of the Uplands area.

PHOTO 21: Aerial view of the upper reaches of North Creek, looking northeast. Note recent logging activity along the lower half of the photo. No signs of water flow in channel; upper reaches of creek may be ephemeral. (Photo taken by Thurber in September 2021).

PHOTO 22: Aerial view of the middle reaches of North Creek, looking southeast. Note recent logging and resource road construction along the lower half of the photo. (Photo taken by Thurber in September 2021).

PHOTO 23: View of the lower reaches of the North Creek channel in the Northeast area of the Furry Creek lands, looking downstream. Note the old-growth stump with springboard notch visible in middle of photo. (Photo taken by Thurber in May 2019).

PHOTO 24: View of the lower reaches of the North Creek channel in the Northeast area of the Furry Creek lands, looking north. (Photo taken by Thurber in May 2019).

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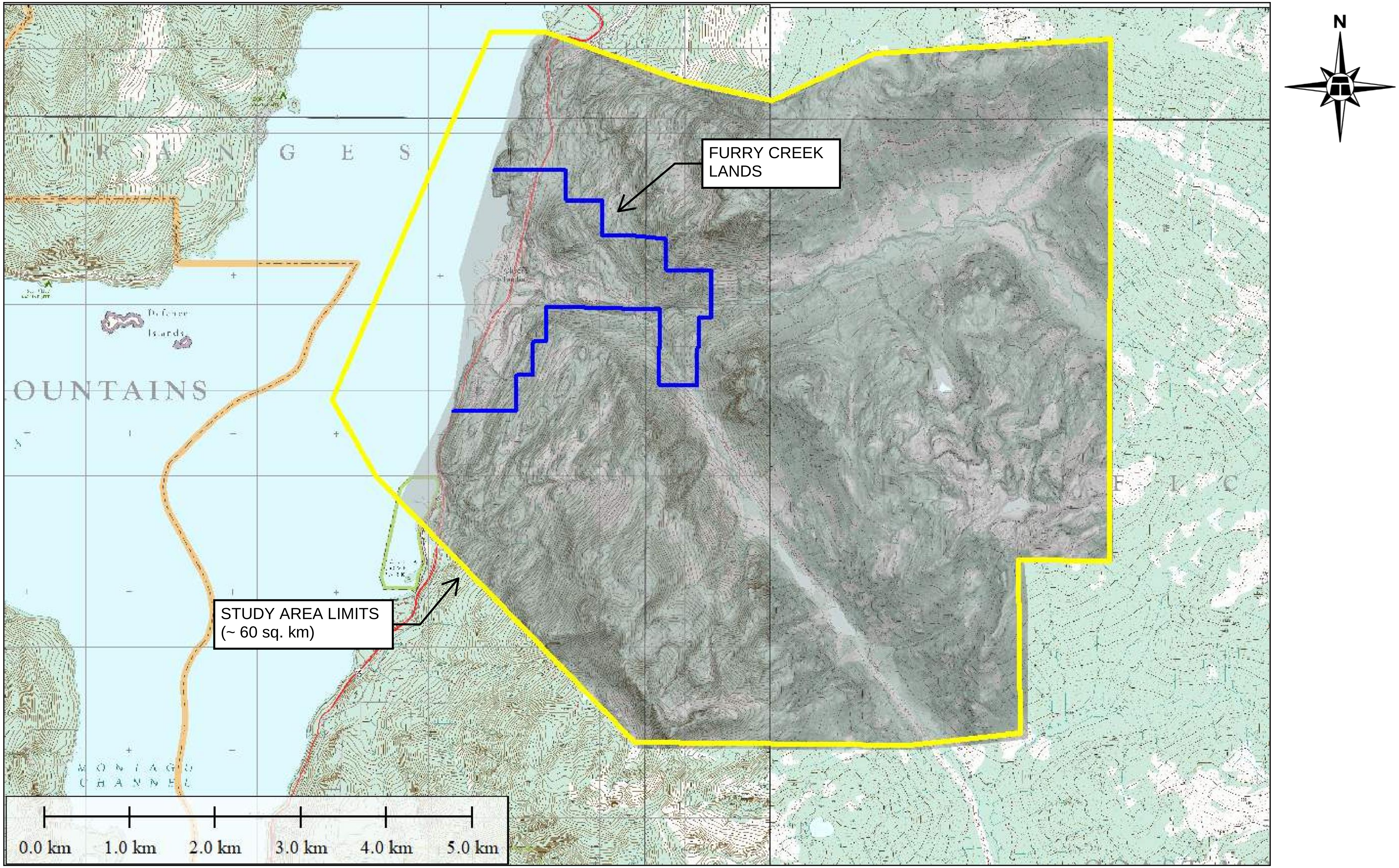
FIGURES



LEGEND:

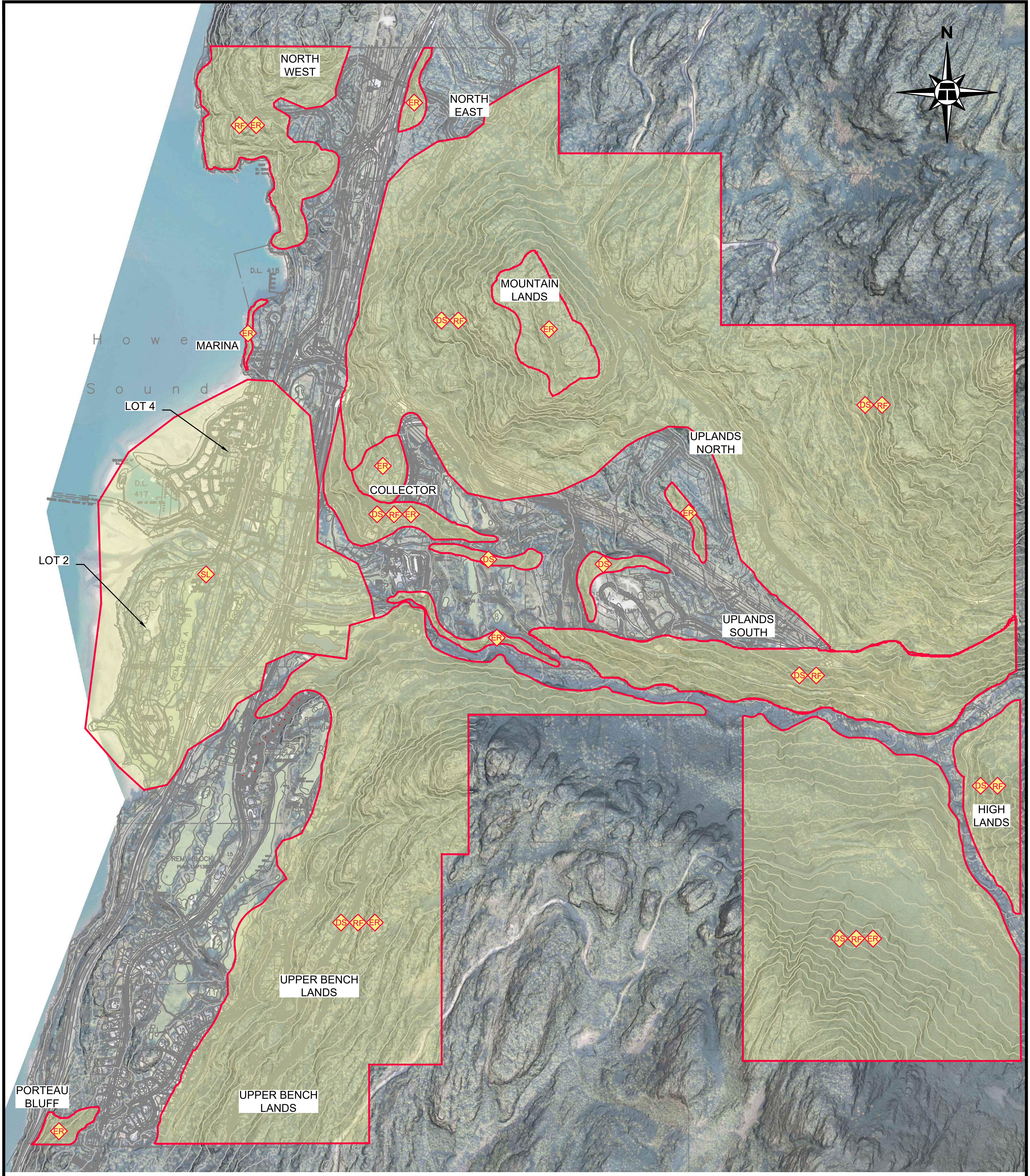
THURBER ENGINEERING LTD.

CLIENT	FINE PEACE FURRY CREEK HOLDINGS LTD.	DESIGNED JDP	DRAWN JDP	APPROVED DNR	
FIGURE TITLE	STUDY AREA LIMITS	DATE 08/12/2022		SCALE AS SHOWN	
PROJECT NAME LOCATION	OVERVIEW GEOHAZARDS STUDY FURRY CREEK DEVELOPMENT FURRY CREEK , BC	PROJECT No. 21452-30		FIG. No. 1	REV. 0

CANCEL PRINTS BEARING EARLIER NUMBER

S:\Data\BST Projects\21xxx\21452\06_Drafting\03_Working\21452-30_r1.dwg

Plotted: August 15, 2022



0 100 200 300 400 500m

NOTES:

1. THIS FIGURE IS TO BE USED IN CONJUNCTION WITH THURBER'S ACCOMPANYING GEOTECHNICAL REPORT (PROJECT #21452) DATED AUGUST, 2022.
2. HAZARD LINES DENOTE THE EXTENT OF POTENTIALLY DAMAGING GEOTECHNICAL HAZARDS BASED ON AN ESTIMATED ENCOUNTER PROBABILITY 10% IN 50 YEARS (1:475 ANNUAL PROBABILITY), MAPPED AT 1:5,000 SCALE. THESE LINES ARE CONDITIONAL AND ARE SUBJECT TO CHANGE PENDING FURTHER GEOTECHNICAL ASSESSMENT AS PART OF PRELIMINARY/DETAILED DESIGN.
3. THE BOUNDARIES OF THE GEOHAZARD MAPPING CORRESPOND TO LEGAL LOT LINES OF THE FURRY CREEK LANDS.
4. FLUVIAL AND COASTAL HAZARD LINES (FLOODING, BANK EROSION, ETC.) ARE NOT SHOWN.
5. CAD LINEWORK, LIDAR DATA AND ORTHOIMAGERY PROVIDED BY CREUS ENGINEERING LTD.
6. TOPOGRAPHIC CONTOUR INTERVAL 20 M.

LEGEND:

RF	POSSIBLE ROCK FALL HAZARDS (REPORT SECTION 4.5.2)
DS	POSSIBLE DEBRIS LANDSLIDE HAZARDS (REPORT SECTION 4.5.5)
ER	POSSIBLE EXCAVATED ROCK AND FOUNDATION SET BACK HAZARDS (REPORT SECTION 4.5.6)
SL	POSSIBLE SEISMIC LIQUEFACTION HAZARDS (REPORT SECTION 4.5.7)

THURBER ENGINEERING LTD.

CLIENT
FINE PEACE FURRY CREEK HOLDINGS LTD.

GEOTECHNICAL HAZARD AREAS

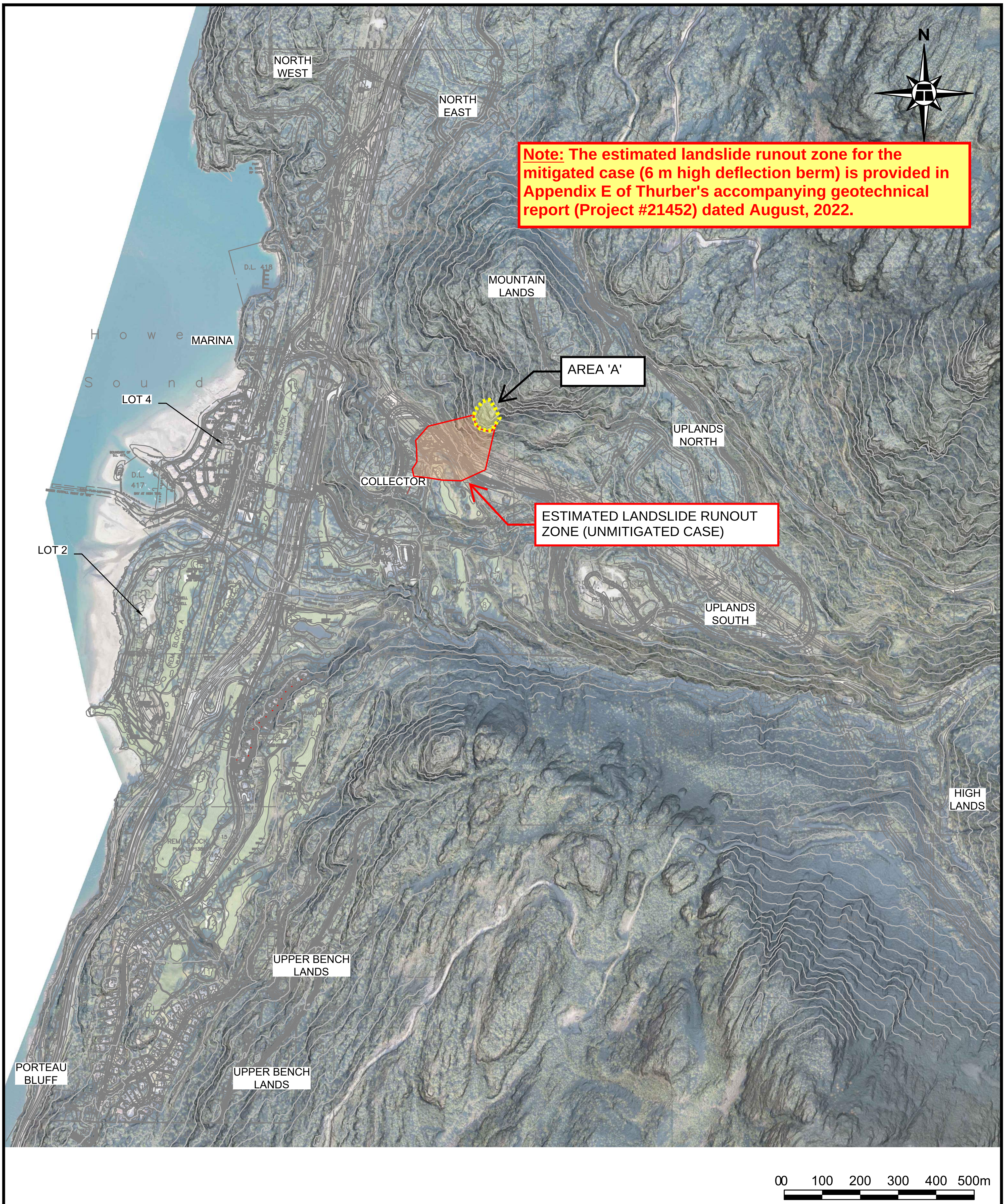
OVERVIEW GEOHAZARDS STUDY
FURRY CREEK DEVELOPMENT
FURRY CREEK, B.C.

DESIGNED	DRAWN	APPROVED
JDP	MOM/DRB	DNR

DATE	SCALE
AUGUST 12, 2022	1:10,000

PROJECT No.	FIG. No.	REV.
21452-30	2	1

CANCEL PRINTS BEARING EARLIER NUMBER



Note: The estimated landslide runout zone for the mitigated case (6 m high deflection berm) is provided in Appendix E of Thurber's accompanying geotechnical report (Project #21452) dated August, 2022.

NOTES:

1. THIS FIGURE IS TO BE USED IN CONJUNCTION WITH THURBER'S ACCOMPANYING GEOTECHNICAL REPORT (PROJECT #21452) DATED AUGUST, 2022.
2. HAZARD LINES DENOTE THE EXTENT OF POTENTIAL CATASTROPHIC LANDSLIDE HAZARDS FROM AREA 'A' BASED ON AN ANNUAL PROBABILITY OF 1:10,000 (0.5% IN 50 YEARS), MAPPED AT 1:5,000 SCALE. THESE LINES ARE CONDITIONAL AND SUBJECT TO CHANGE PENDING FURTHER GEOTECHNICAL ASSESSMENT AS PART OF PRELIMINARY/ DETAILED DEISGN.
3. CAD LINEWORK, LIDAR DATA AND ORTHOIMAGERY PROVIDED BY CREUS ENGINEERING LTD.
4. TOPOGRAPHIC CONTOUR INTERVAL 20 M.

CANCEL PRINTS BEARING EARLIER NUMBER

THURBER ENGINEERING LTD.

CLIENT
FINE PEACE FURRY CREEK HOLDINGS LTD.

CATASTROPHIC LANDSLIDE HAZARD ZONE - AREA A

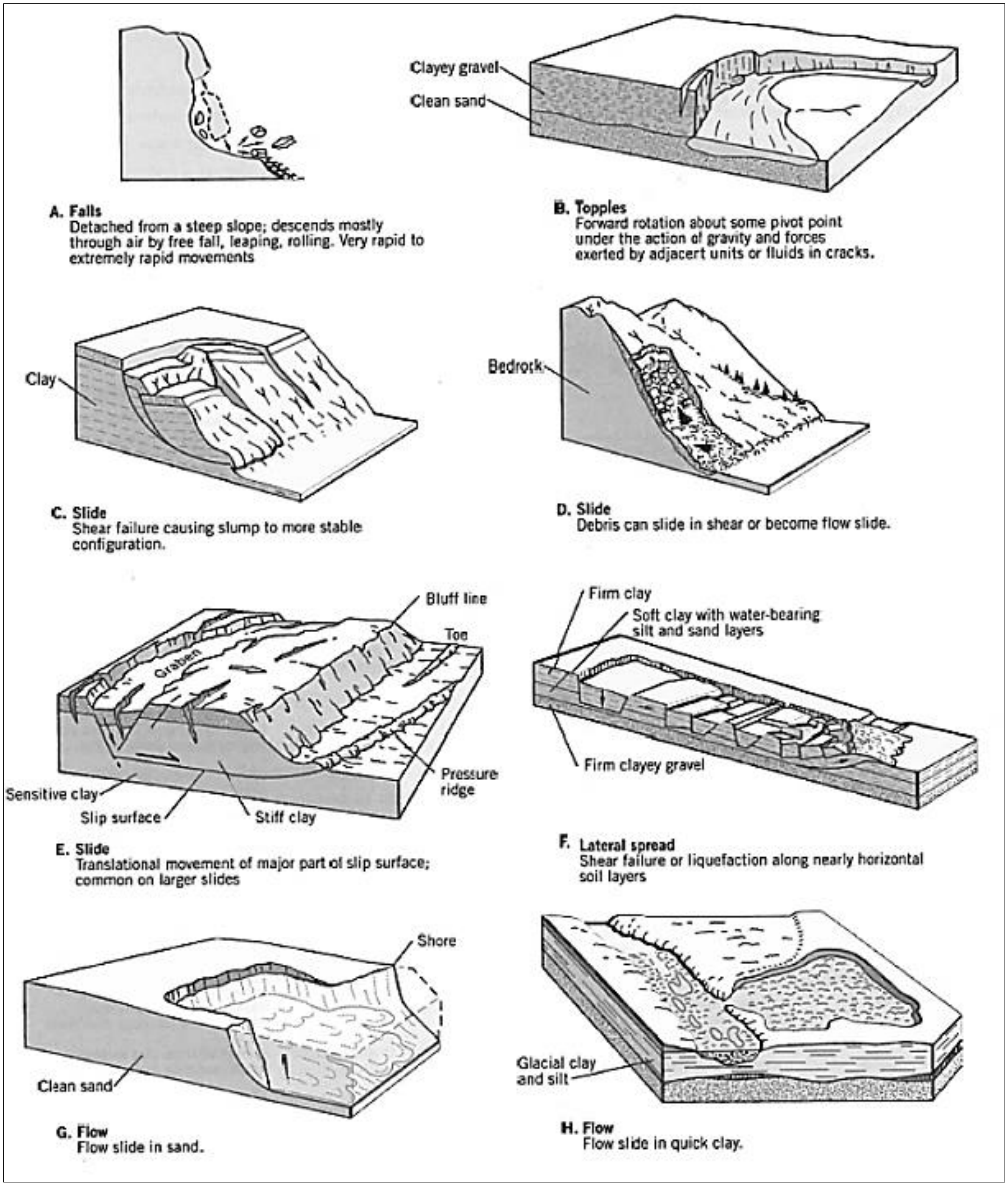
OVERVIEW GEOHAZARDS STUDY
FURRY CREEK DEVELOPMENT
FURRY CREEK, B.C.

DESIGNED	DRAWN	APPROVED
JDP	JDP	DNR

DATE	SCALE
AUGUST 16, 2022	1:10,000

PROJECT No.	FIG. No.	REV.
21452-30	3	0

APPENDIX A
EXAMPLES OF LANDSLIDE PROCESSES



A. Falls
Detached from a steep slope; descends mostly through air by free fall, leaping, rolling. Very rapid to extremely rapid movements

B. Topples
Forward rotation about some pivot point under the action of gravity and forces exerted by adjacent units or fluids in cracks.

C. Slide
Shear failure causing slump to more stable configuration.

D. Slide
Debris can slide in shear or become flow slide.

E. Slide
Translational movement of major part of slip surface; common on larger slides

F. Lateral spread
Shear failure or liquefaction along nearly horizontal soil layers

G. Flow
Flow slide in sand.

H. Flow
Flow slide in quick clay.

Figure A-1. Examples of Landslide Processes (after Varnes 1978 and Cornforth 2005).

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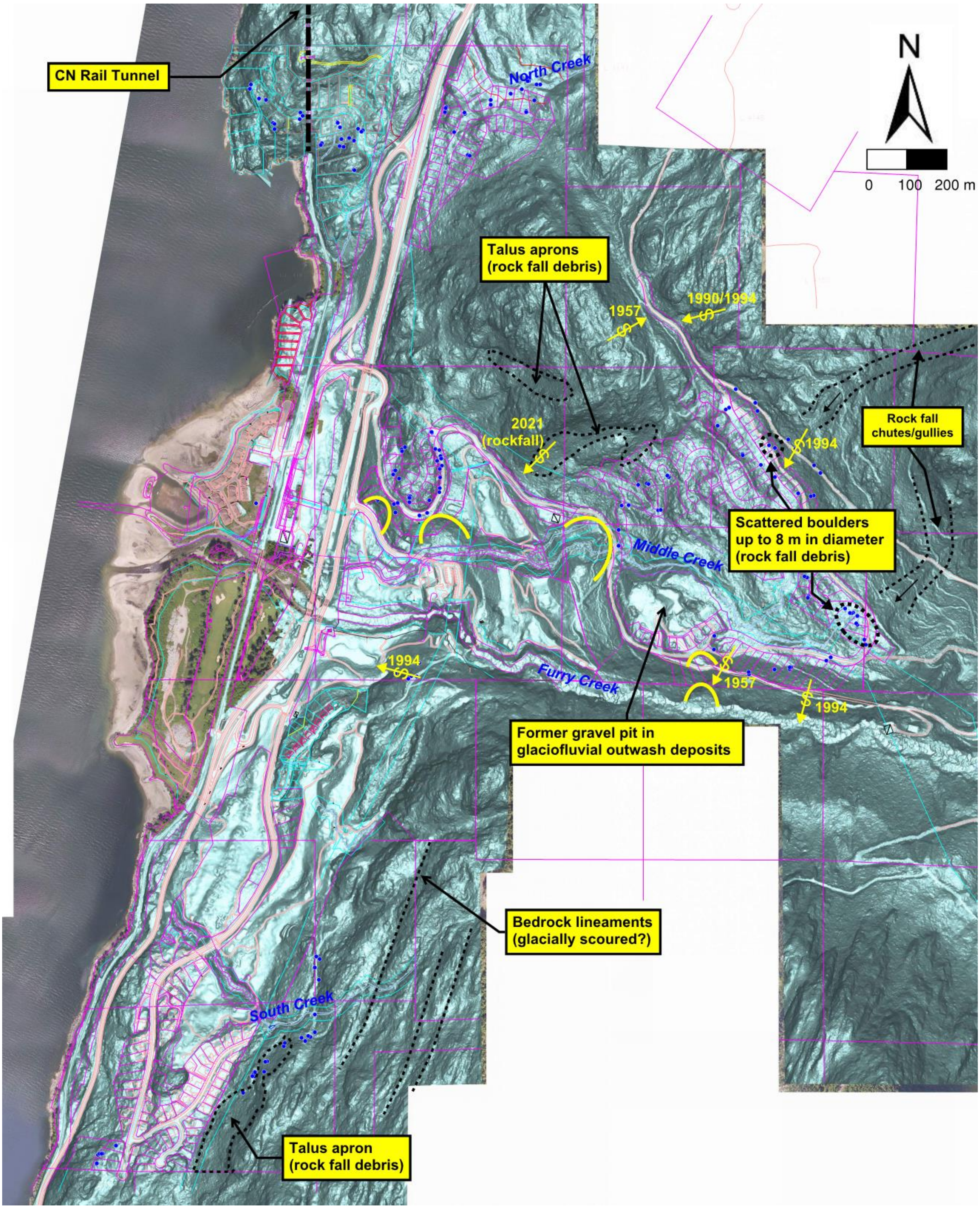
APPENDIX B
LANDSLIDE INVENTORY MAPPING

APPENDIX A

APPENDIX B



LEGEND:

● GPS Field Observation Waypoint (2019)

∩ Headwall (scarp)

$ Historical landslide / erosion track / rockfall track

⬚ Area or Feature of Interest

NOTES:

1. Identified terrain features are based on desktop review of the available LiDAR imagery and limited field checking.
2. The years noted on the figure correspond to the year of the historical aerial imagery where this feature was first observed.
3. CAD linework, LiDAR data, and orthophotos provided by CREUS Engineering.

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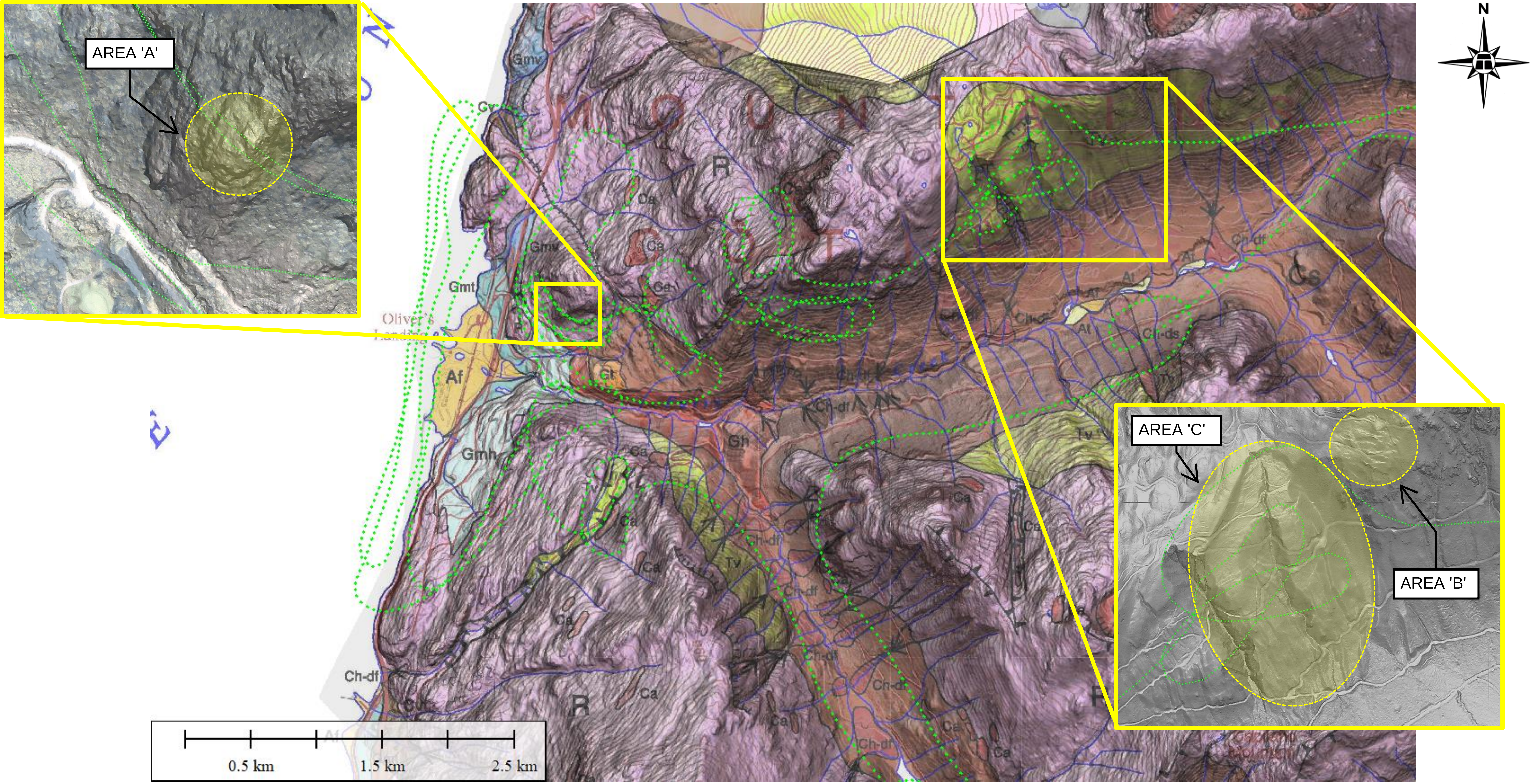
SKETCH B-1
LANDSLIDE INVENTORY MAPPING
FURRY CREEK LANDS



LEGEND:

Helicopter reconnaissance GPS track (09/15/2021)

Geohazard area of interest

NOTES:

1. LiDAR imagery provided by CREUS Engineering Ltd.
2. Base surficial geology and landslide inventory mapping modified from Geological Survey of Canada Open File 5322 (Blais-Stevens 2008), mapped at 1:50,000 scale.

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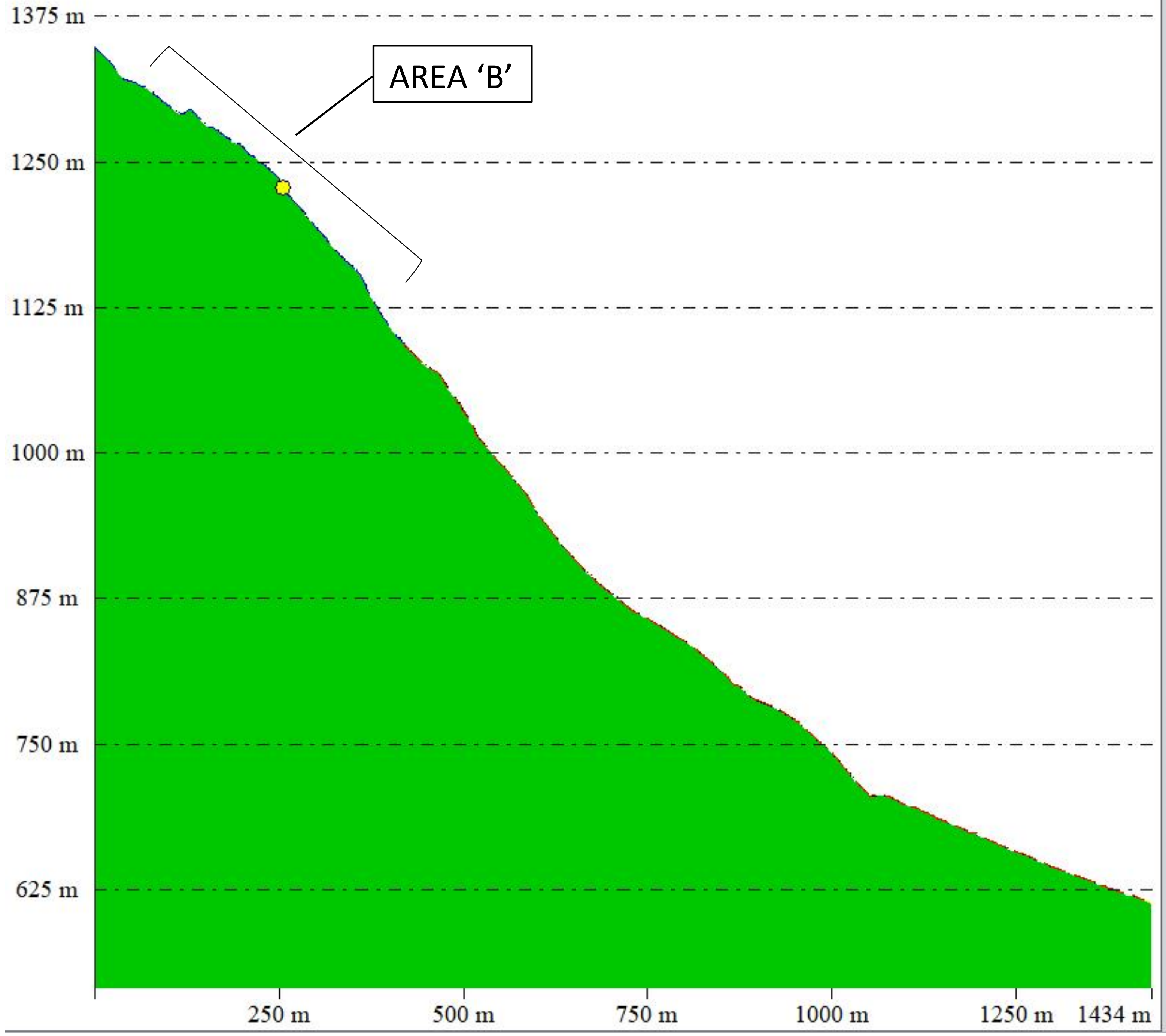
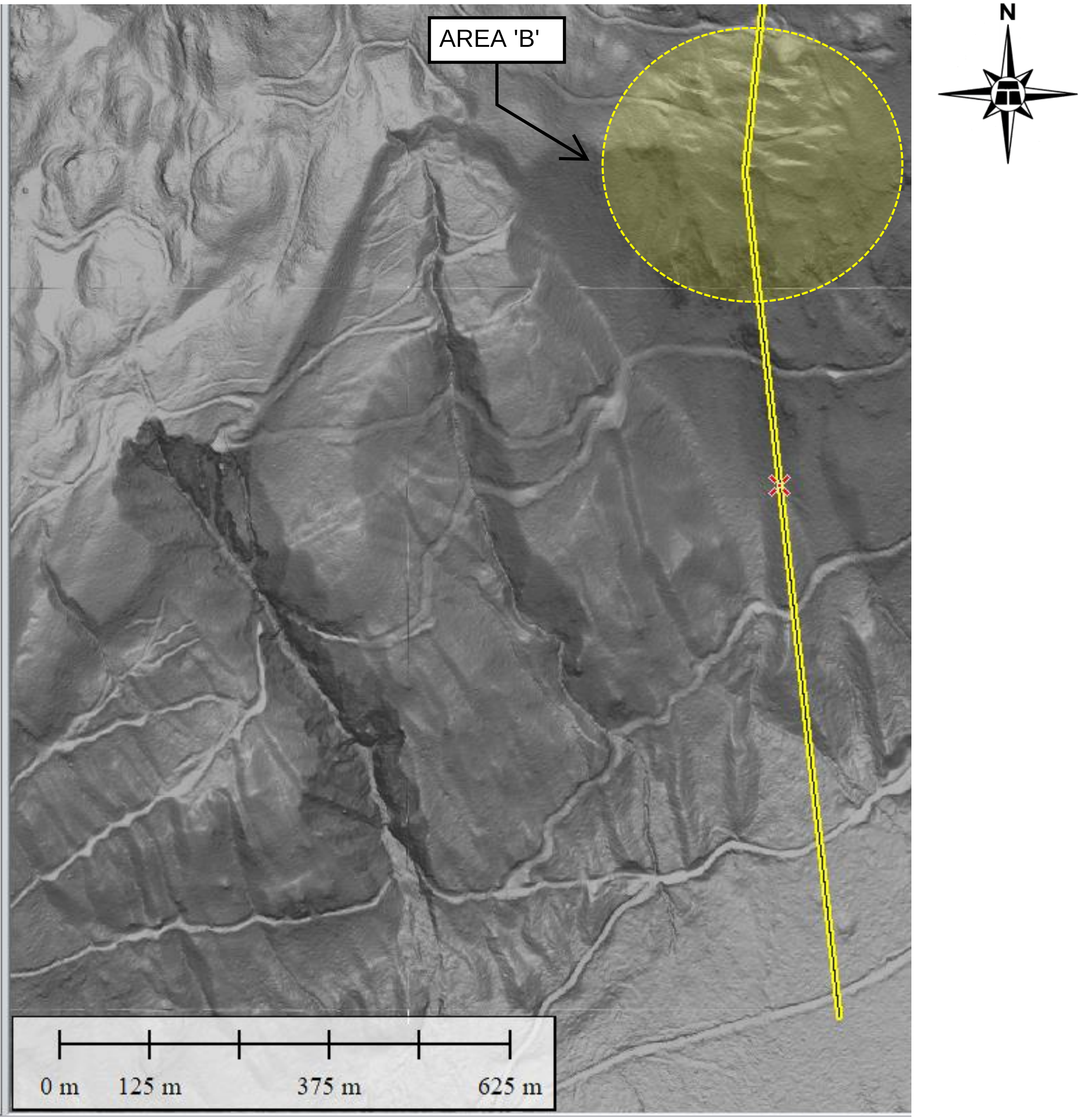
SKETCH B-2
LANDSLIDE INVENTORY MAPPING





LEGEND:

NOTES:

1. LiDAR imagery provided by CREUS Engineering Ltd.

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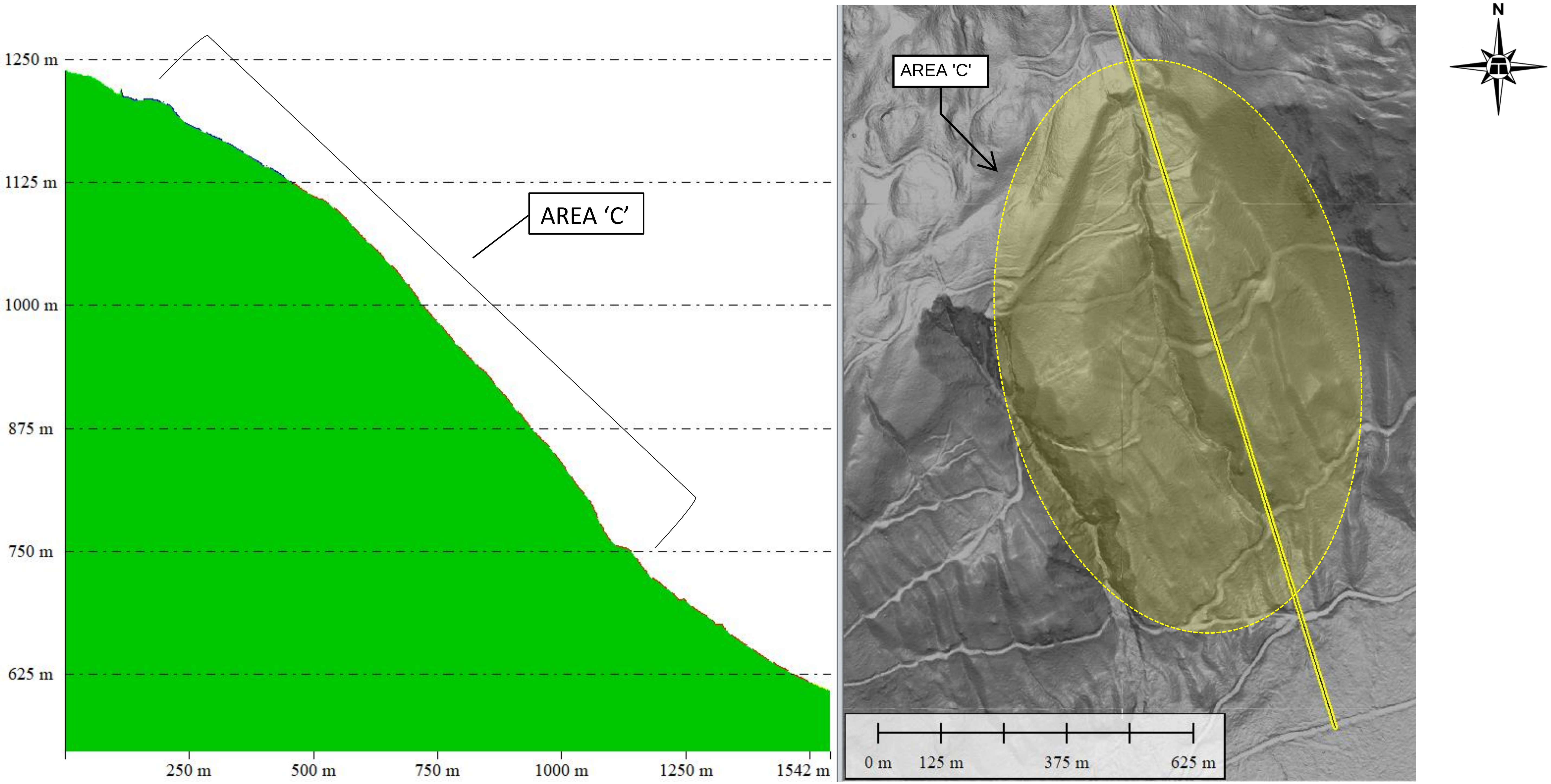
SKETCH B-3
AREA B – PLAN AND SECTION



LEGEND:

NOTES:

1. LiDAR imagery provided by CREUS Engineering Ltd.

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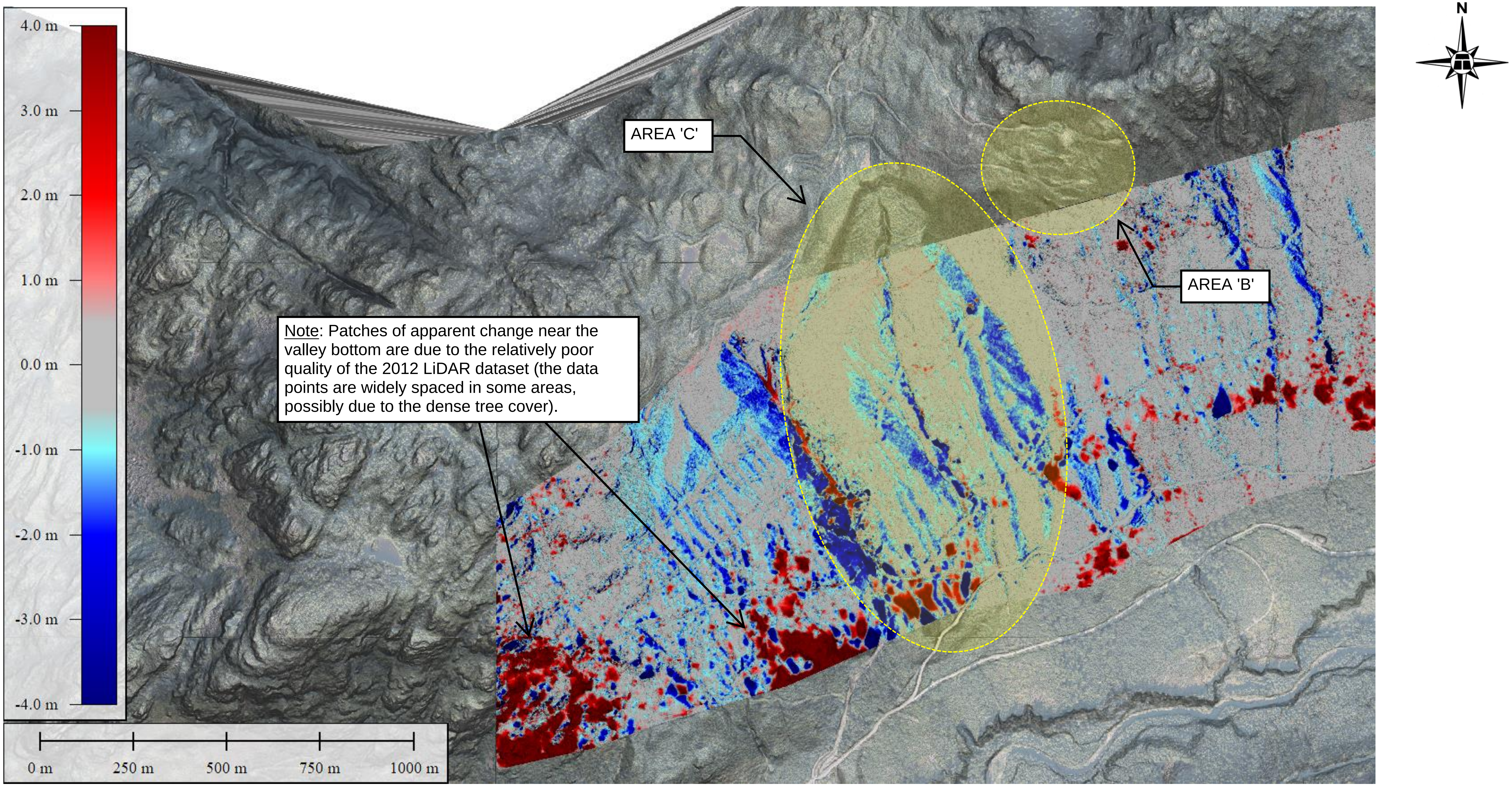
SKETCH B-4
AREA C – PLAN AND SECTION



Note: Patches of apparent change near the valley bottom are due to the relatively poor quality of the 2012 LiDAR dataset (the data points are widely spaced in some areas, possibly due to the dense tree cover).

LEGEND:

NOTES:

1. 2012 LiDAR imagery obtained from McElhanney; 2020 LiDAR imagery provided by CREUS Engineering Ltd.
2. Limit of Detection (LoD) = ±0.5 m due to the relatively poor quality of the 2012 LiDAR imagery.
3. Red shaded areas denote positive change (2012 ground surface is higher than 2020 ground surface); blue shaded areas denote negative change (2012 ground surface is lower than 2020 ground surface).

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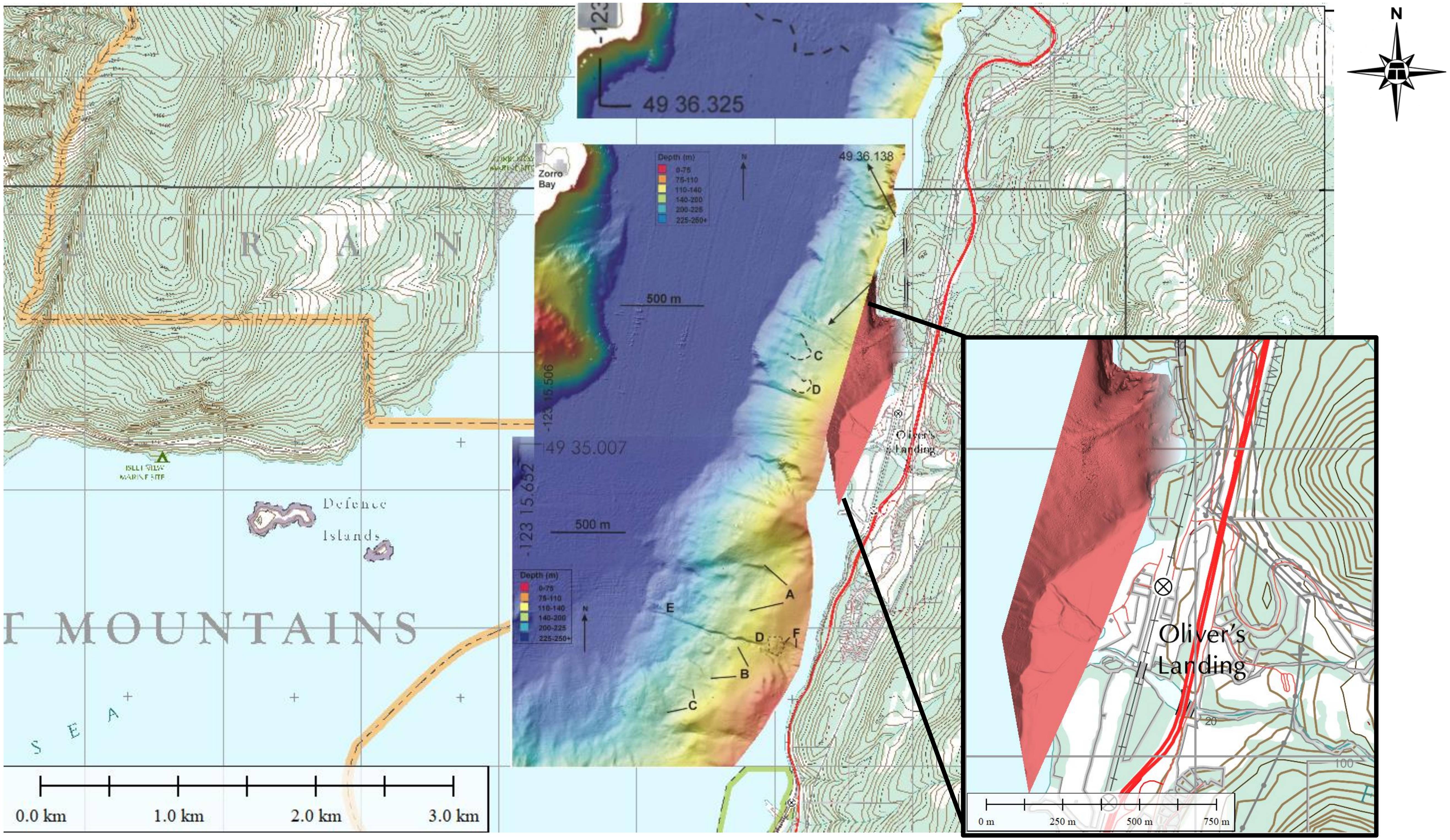
SKETCH B-5
LIDAR CHANGE DETECTION (2012 vs. 2020) – FURRY CREEK NORTH VALLEY WALL



LEGEND:

NOTES:

1. Nearshore bathymetry data provided by CREUS Engineering Ltd.; offshore bathymetry modified from Geological Survey of Canada Open File 5662 (Jackson et al. 2008).

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SKETCH B-6
BATHYMETRY DATA – FURRY CREEK

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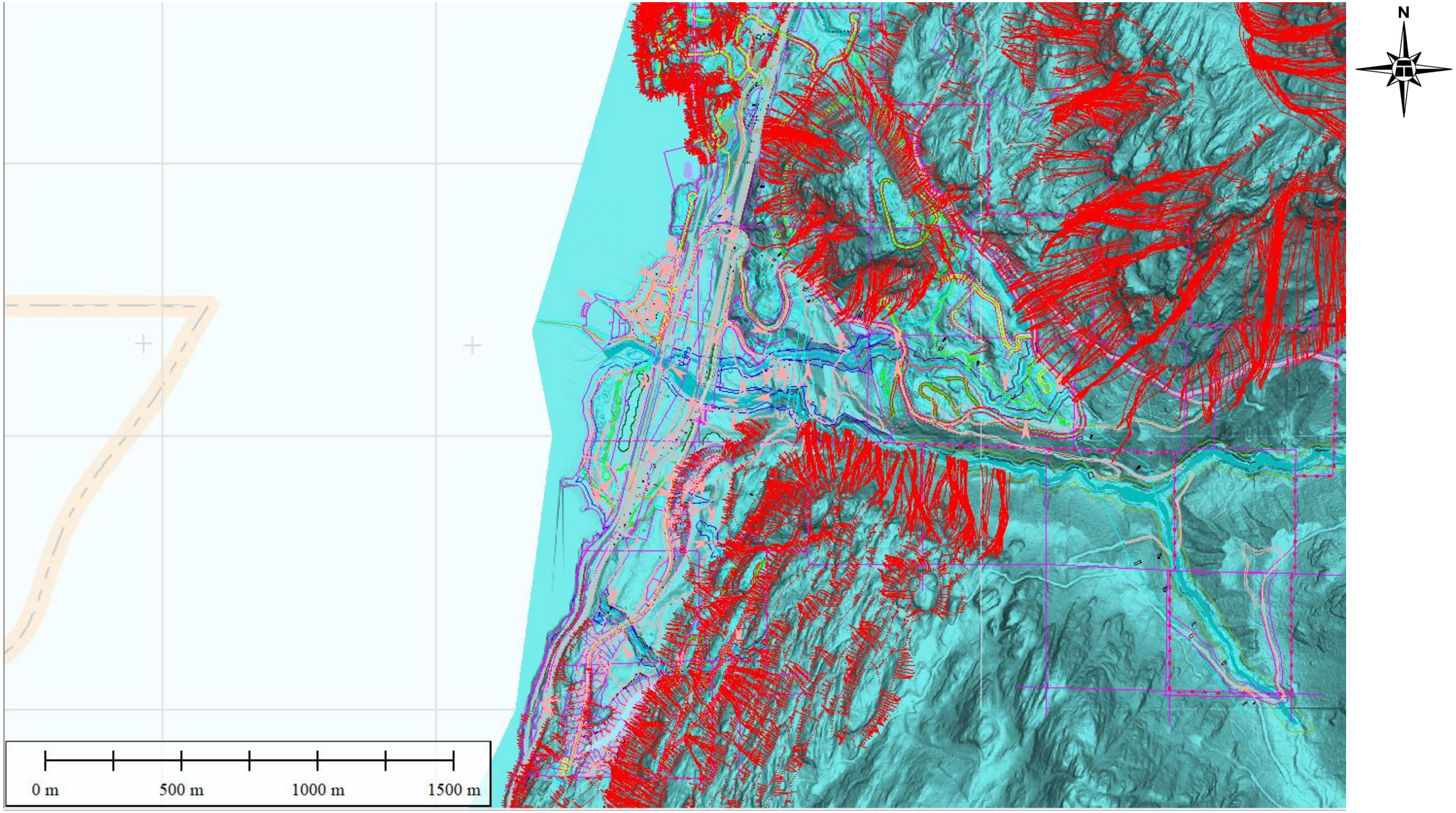
APPENDIX C
3D ROCK FALL RUNOUT ANALYSIS - FURRY CREEK LANDS



LEGEND:

Rock fall trajectory

NOTES:

1. Rock fall trajectories based on block sizes of up to 10 cubic metres and the normal/tangential restitution values provided in Table 3 of Thurber's August 2022 overview geohazard report.
2. Rock falls were sourced ("seeded") from areas with slope angles of greater than 50 degrees, with a small initial velocity of < 2 m/s.
3. CAD linework and LiDAR data provided by CREUS Engineering.

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SKETCH C-1
3D ROCK FALL RUNOUT ANALYSIS - FURRY CREEK LANDS

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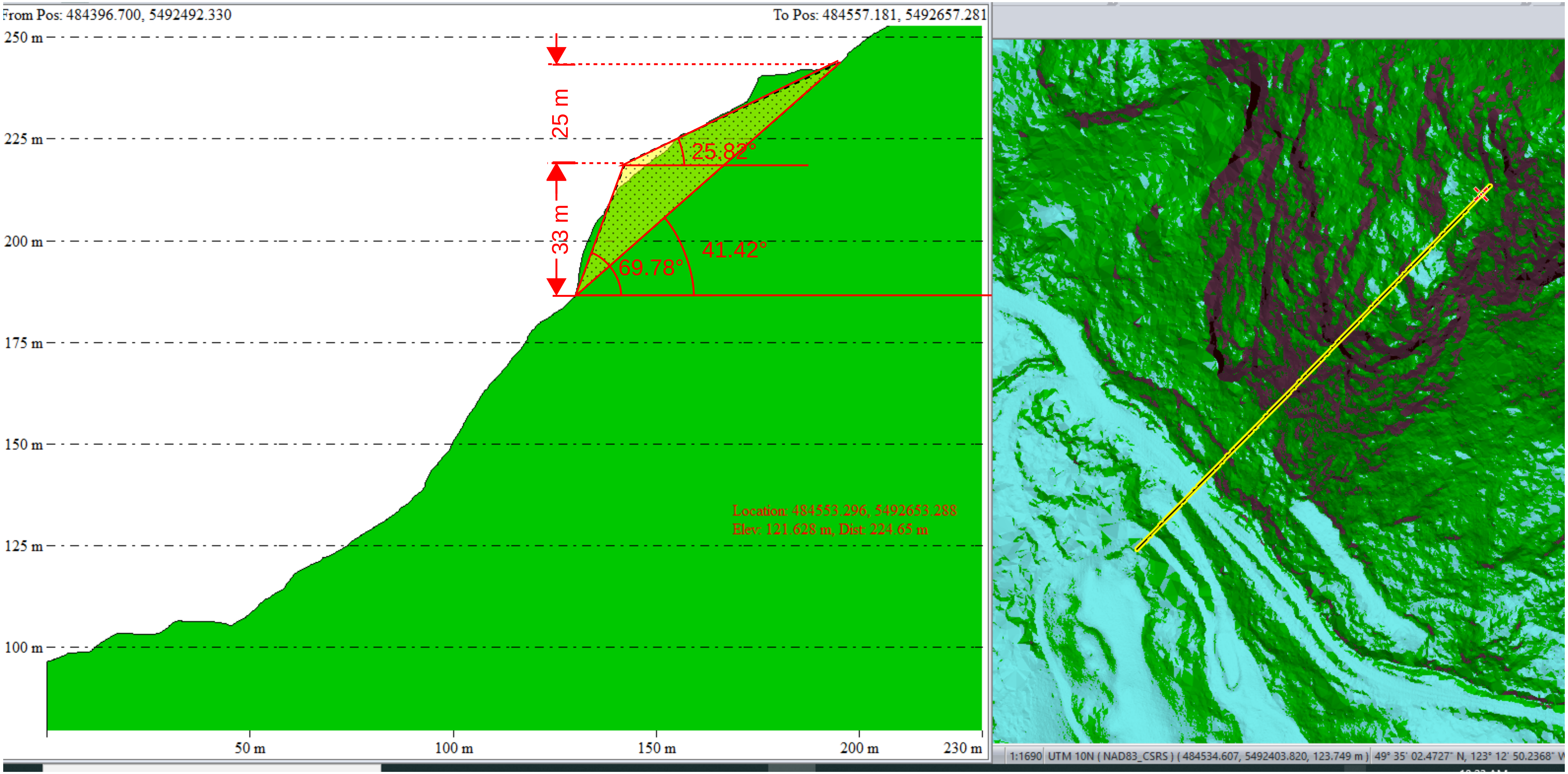
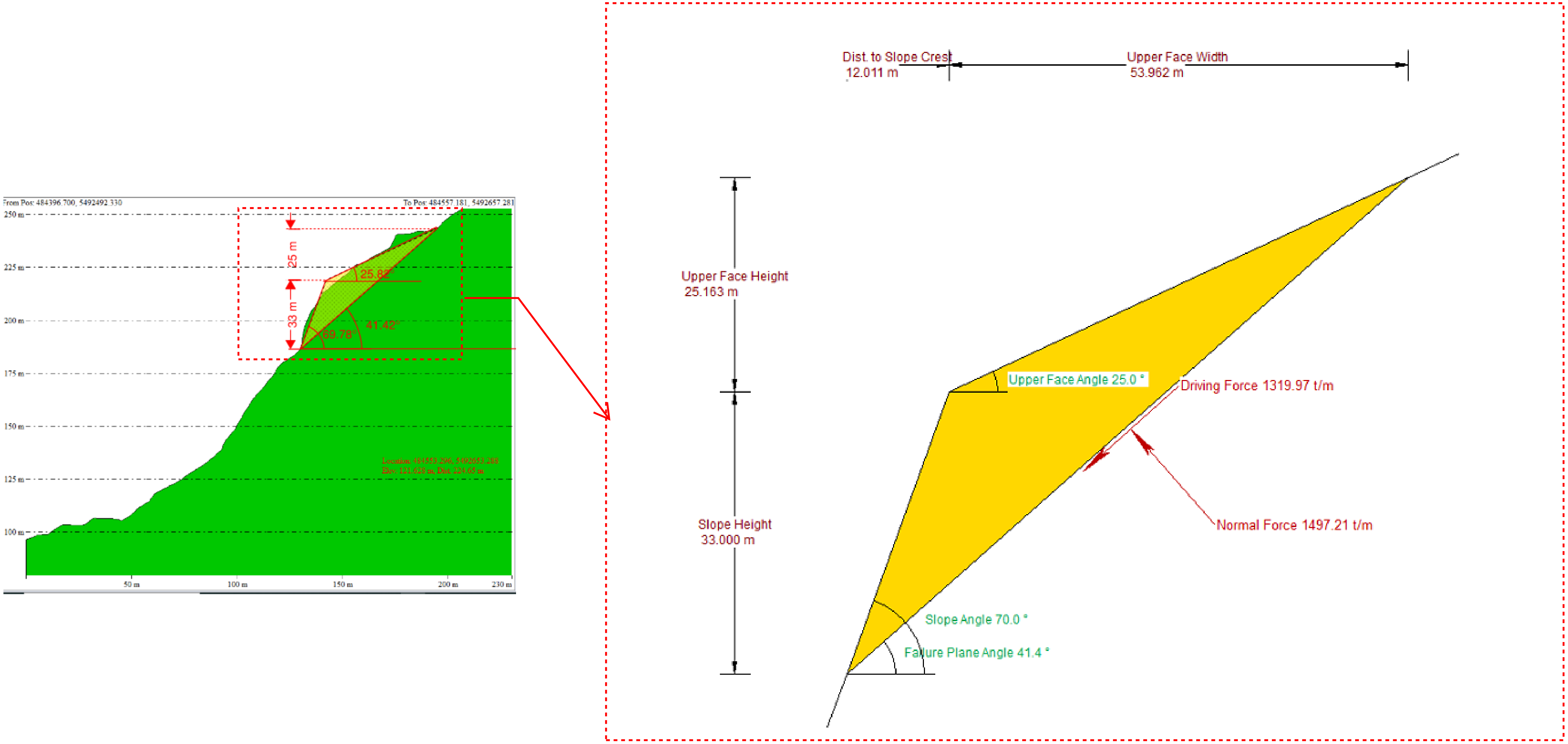
APPENDIX D
LIMIT-EQUILIBRIUM SLOPE STABILITY ANALYSIS - AREA A

APPENDIX A
APPENDIX B
APPENDIX C
APPENDIX D

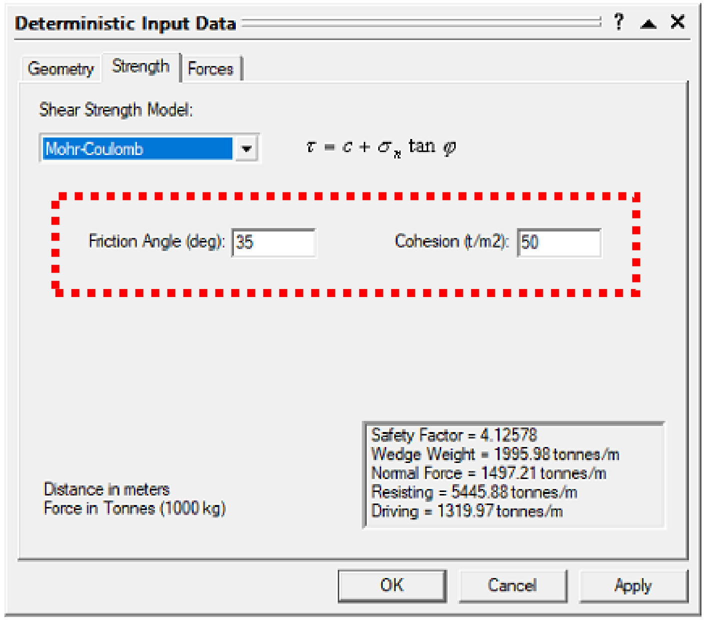
Plan and Section - Area A



Modeled failure extents - Area A (no tension crack)



Scenario 1: No tension crack; dry joint plane; static loading



Shear Strength Model: Mohr-Coulomb

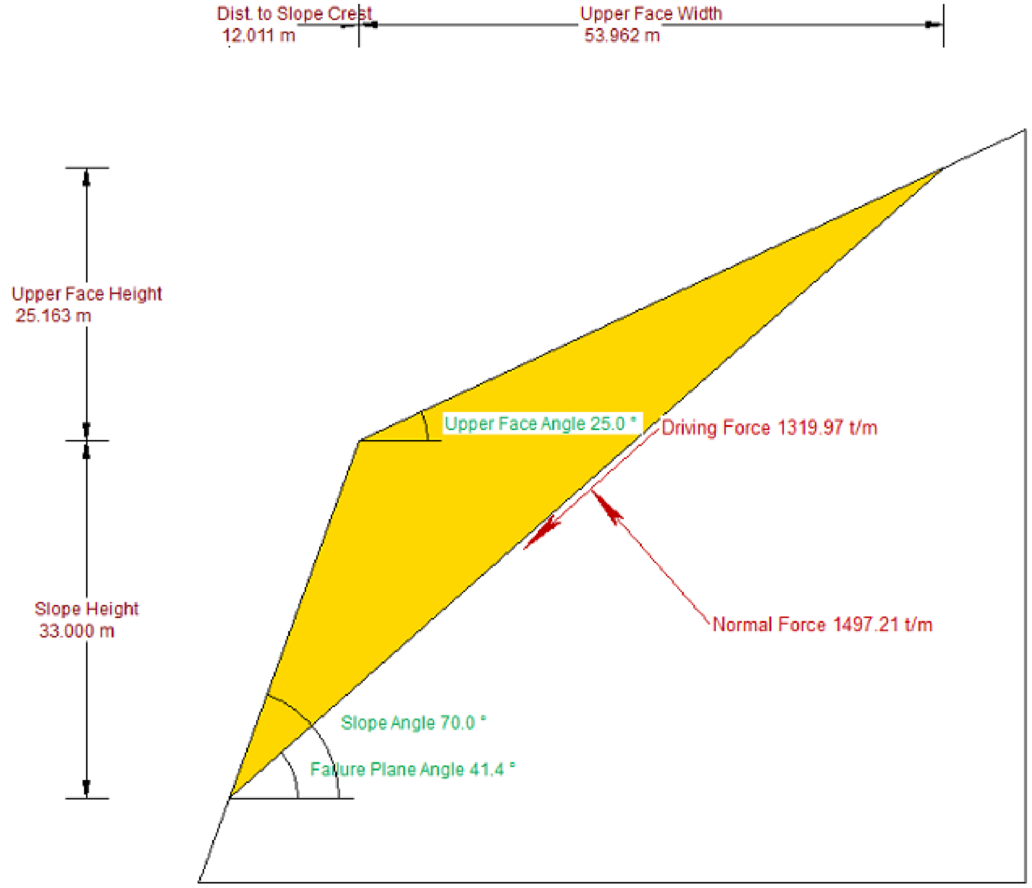
$\tau = c + \sigma_n \tan \varphi$

Friction Angle (deg): 35

Cohesion (t/m2): 50

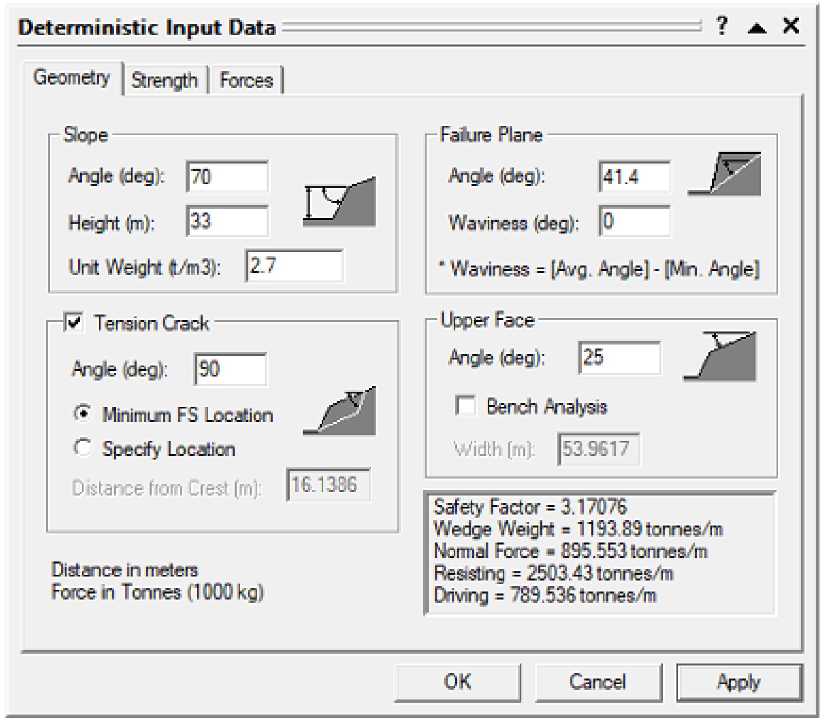
Safety Factor = 4.12578
Wedge Weight = 1995.98 tonnes/m
Normal Force = 1497.21 tonnes/m
Resisting = 5445.88 tonnes/m
Driving = 1319.97 tonnes/m

Distance in meters
Force in Tonnes (1000 kg)



Factor of Safety	4.13
Driving Force	1319.97t/m
Resisting Force	5445.88t/m
Wedge Weight	1995.98t/m
Wedge Volume	739.25m^3/m
Shear Strength	61.92t/m^2
Shear Resistance	5445.88t/m
Normal Force	1497.21t/m
Plane Waviness	0.0°

Scenario 2: With tension crack; dry joint planes; static loading



Deterministic Input Data

Slope
Angle (deg): 70
Height (m): 33
Unit Weight (t/m3): 2.7

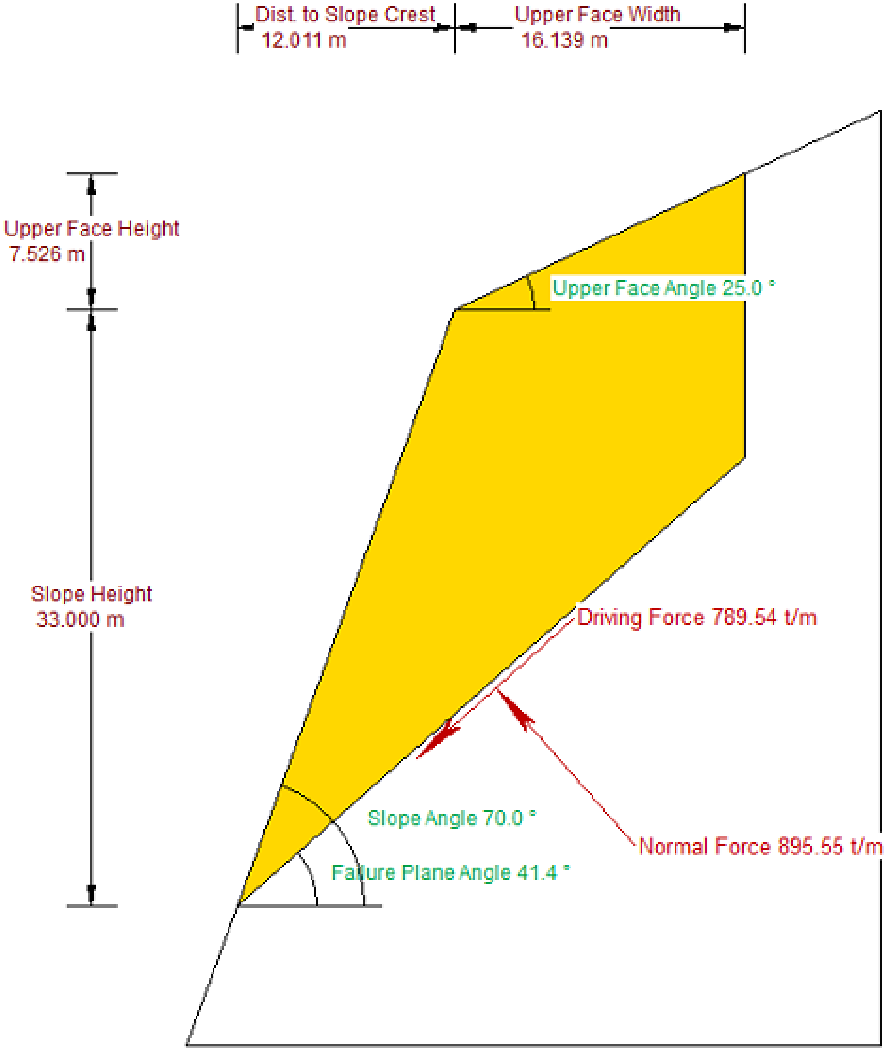
☑ Tension Crack
Angle (deg): 90
● Minimum FS Location
○ Specify Location
Distance from Crest (m): 16.1386

Failure Plane
Angle (deg): 41.4
Waviness (deg): 0
* Waviness = [Avg. Angle] - [Min. Angle]

Upper Face
Angle (deg): 25
☐ Bench Analysis
Width (m): 53.9617

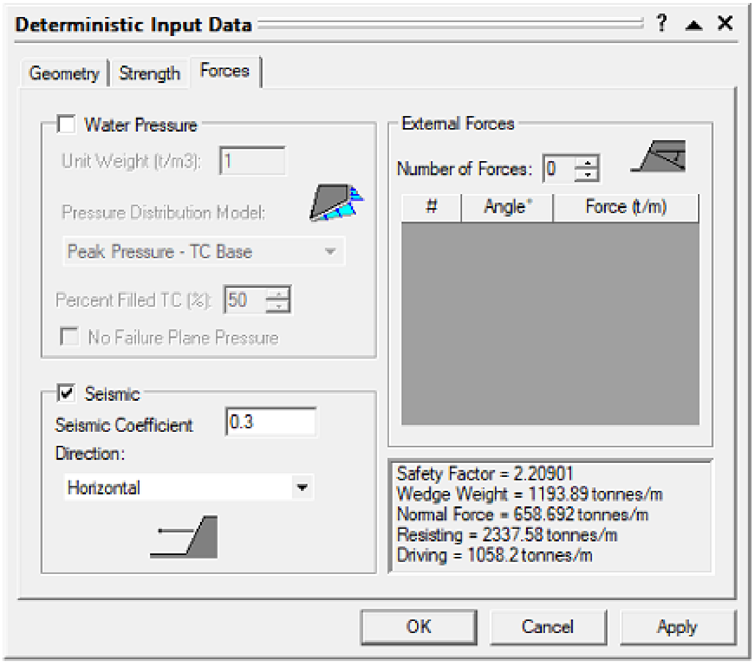
Safety Factor = 3.17076
Wedge Weight = 1193.89 tonnes/m
Normal Force = 895.553 tonnes/m
Resisting = 2503.43 tonnes/m
Driving = 789.536 tonnes/m

Distance in meters
Force in Tonnes (1000 kg)



Factor of Safety	3.17
Driving Force	789.54t/m
Resisting Force	2503.43t/m
Wedge Weight	1193.89t/m
Wedge Volume	442.18m^3/m
Shear Strength	66.71t/m^2
Shear Resistance	2503.43t/m
Normal Force	895.55t/m
Plane Waviness	0.0°

Scenario 3: With tension crack; dry joint planes; pseudo-static loading (kh = 0.3 g)



☐ Water Pressure

Unit Weight (t/m3): 1

Pressure Distribution Model: Peak Pressure - TC Base

Percent Filled TC (%): 50

☐ No Failure Plane Pressure

☑ Seismic

Seismic Coefficient: 0.3

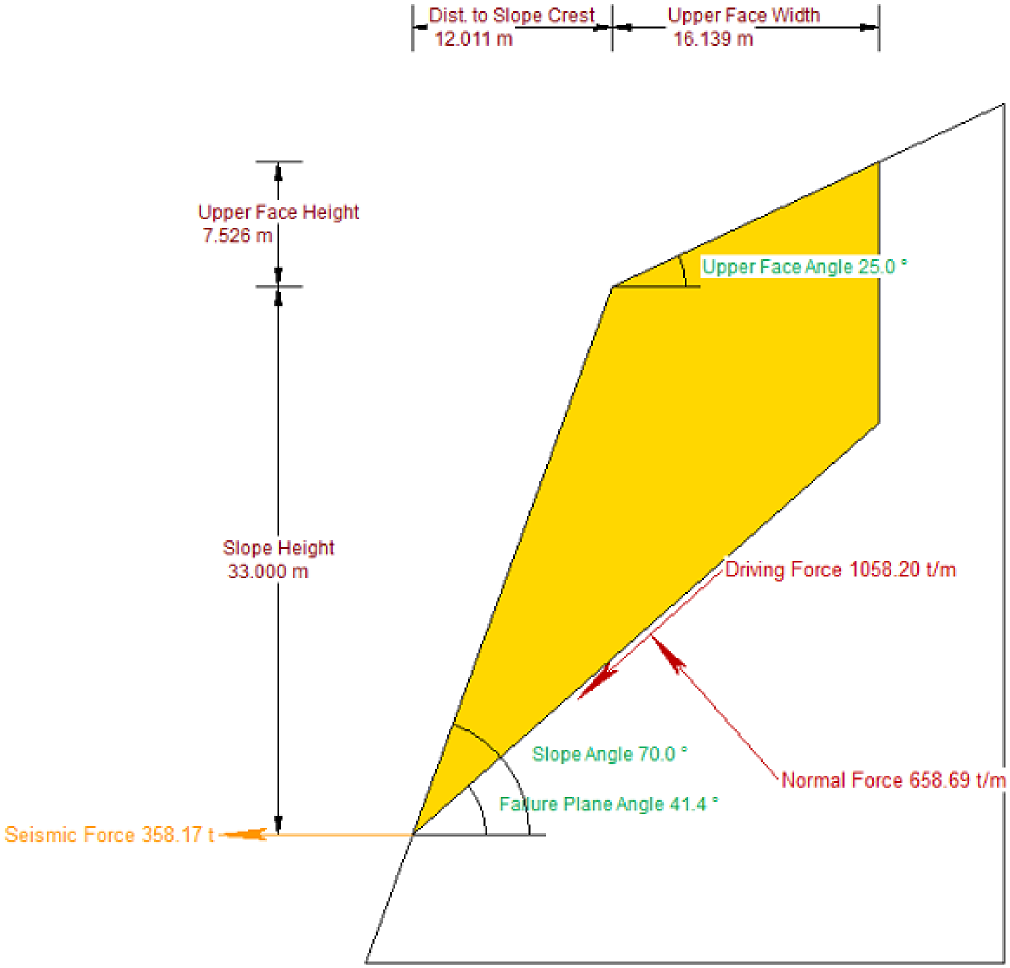
Direction: Horizontal

External Forces

Number of Forces: 0

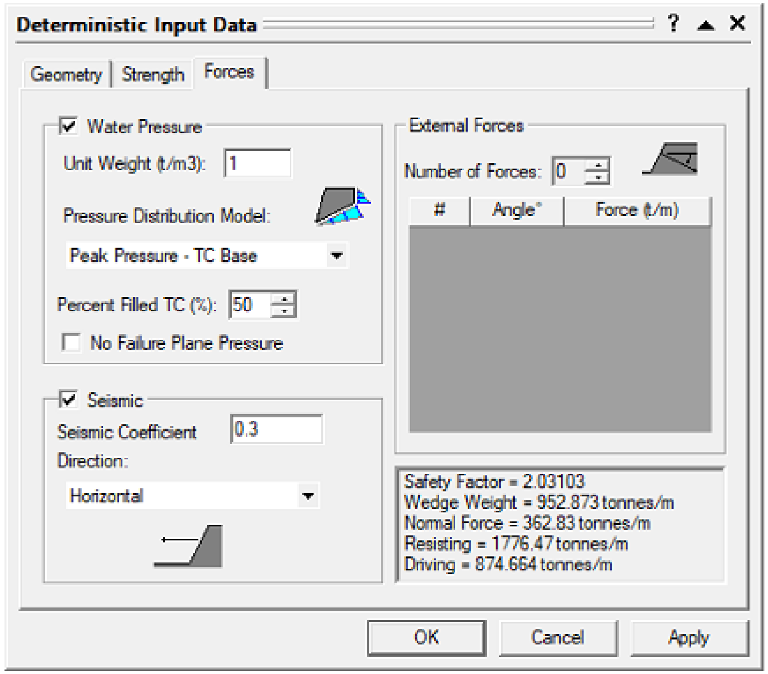
#	Angle°	Force (t/m)

```
Safety Factor = 2.20901
Wedge Weight = 1193.89 tonnes/m
Normal Force = 658.692 tonnes/m
Resisting = 2337.58 tonnes/m
Driving = 1058.2 tonnes/m
```



Factor of Safety	2.21
Driving Force	1058.20t/m
Resisting Force	2337.58t/m
Wedge Weight	1193.89t/m
Wedge Volume	442.18m^3/m
Shear Strength	62.29t/m^2
Shear Resistance	2337.58t/m
Normal Force	658.69t/m
Seismic Force	358.17t
Plane Waviness	0.0°

Scenario 4: With tension crack; joint planes 50% infilled with water; pseudo-static loading (kh = 0.3 g)



Deterministic Input Data

☑ Water Pressure

Unit Weight (t/m3): 1

Pressure Distribution Model: Peak Pressure - TC Base

Percent Filled TC (%): 50

☐ No Failure Plane Pressure

☑ Seismic

Seismic Coefficient 0.3

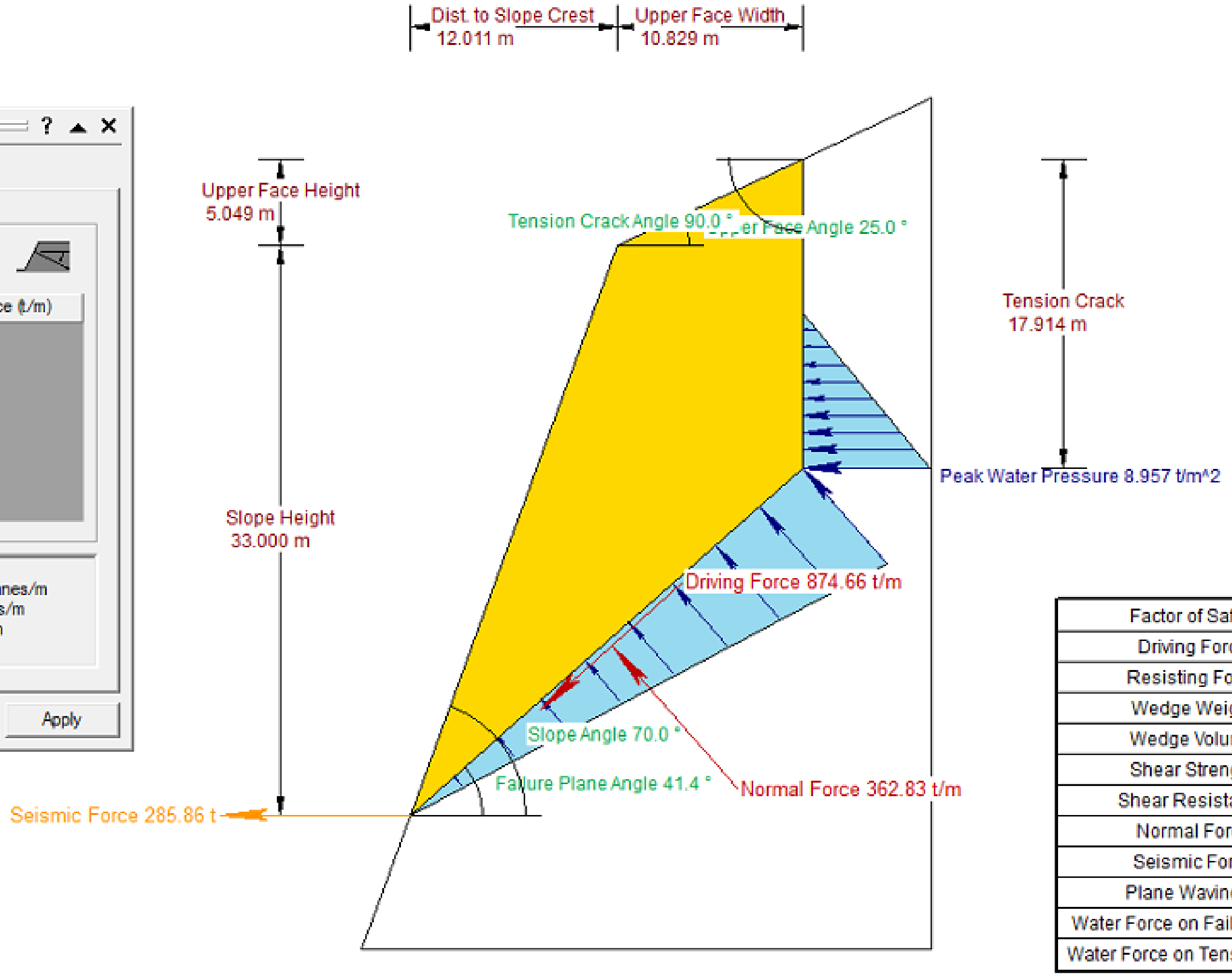
Direction: Horizontal

External Forces

Number of Forces: 0

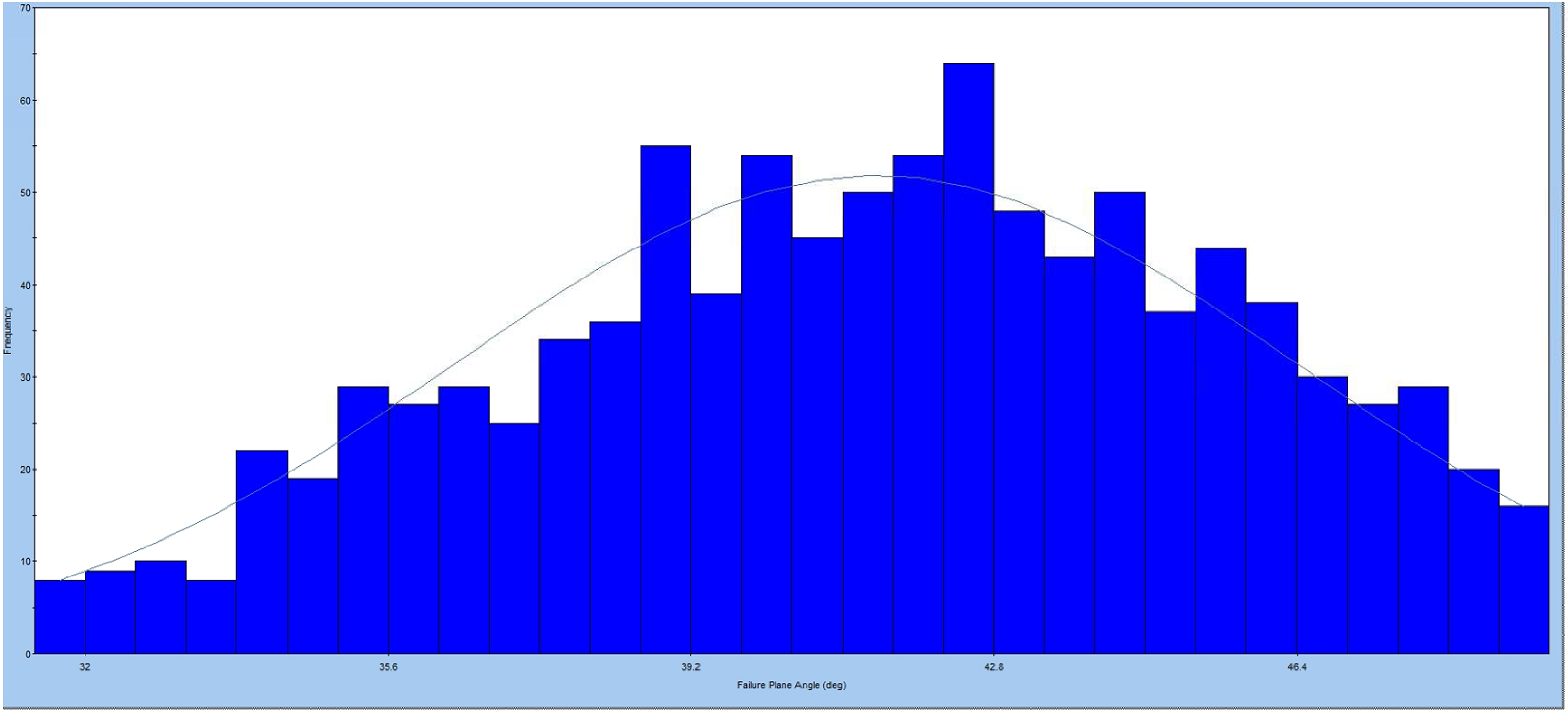
#	Angle°	Force (t/m)

Safety Factor = 2.03103
Wedge Weight = 952.873 tonnes/m
Normal Force = 362.83 tonnes/m
Resisting = 1776.47 tonnes/m
Driving = 874.664 tonnes/m



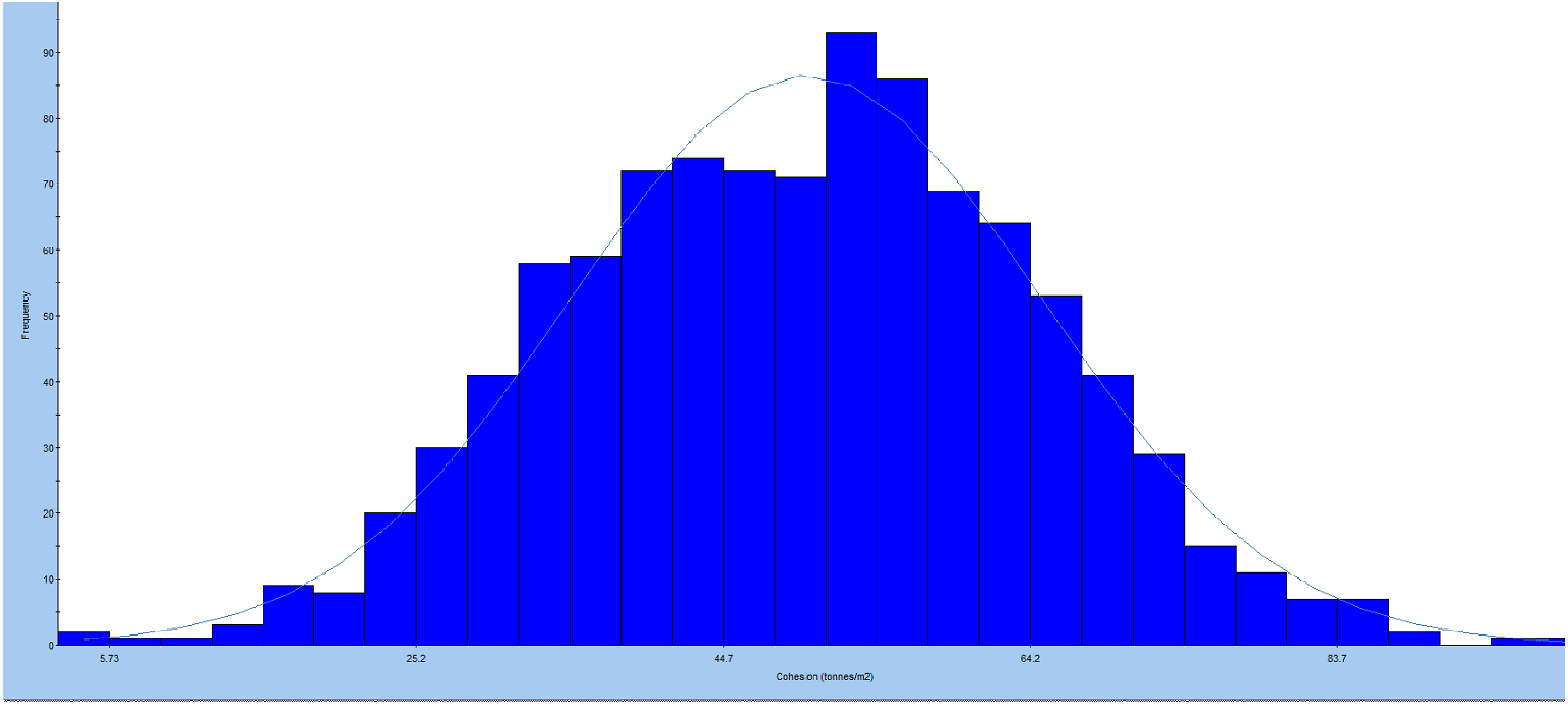
Factor of Safety	2.03
Driving Force	874.66t/m
Resisting Force	1776.47t/m
Wedge Weight	952.87t/m
Wedge Volume	352.92m^3/m
Shear Strength	58.34t/m^2
Shear Resistance	1776.47t/m
Normal Force	362.83t/m
Seismic Force	285.86t
Plane Waviness	0.0°
Water Force on Failure Plane	136.36t/m
Water Force on Tension Crack	40.11t/m

Plane failure inclination distribution



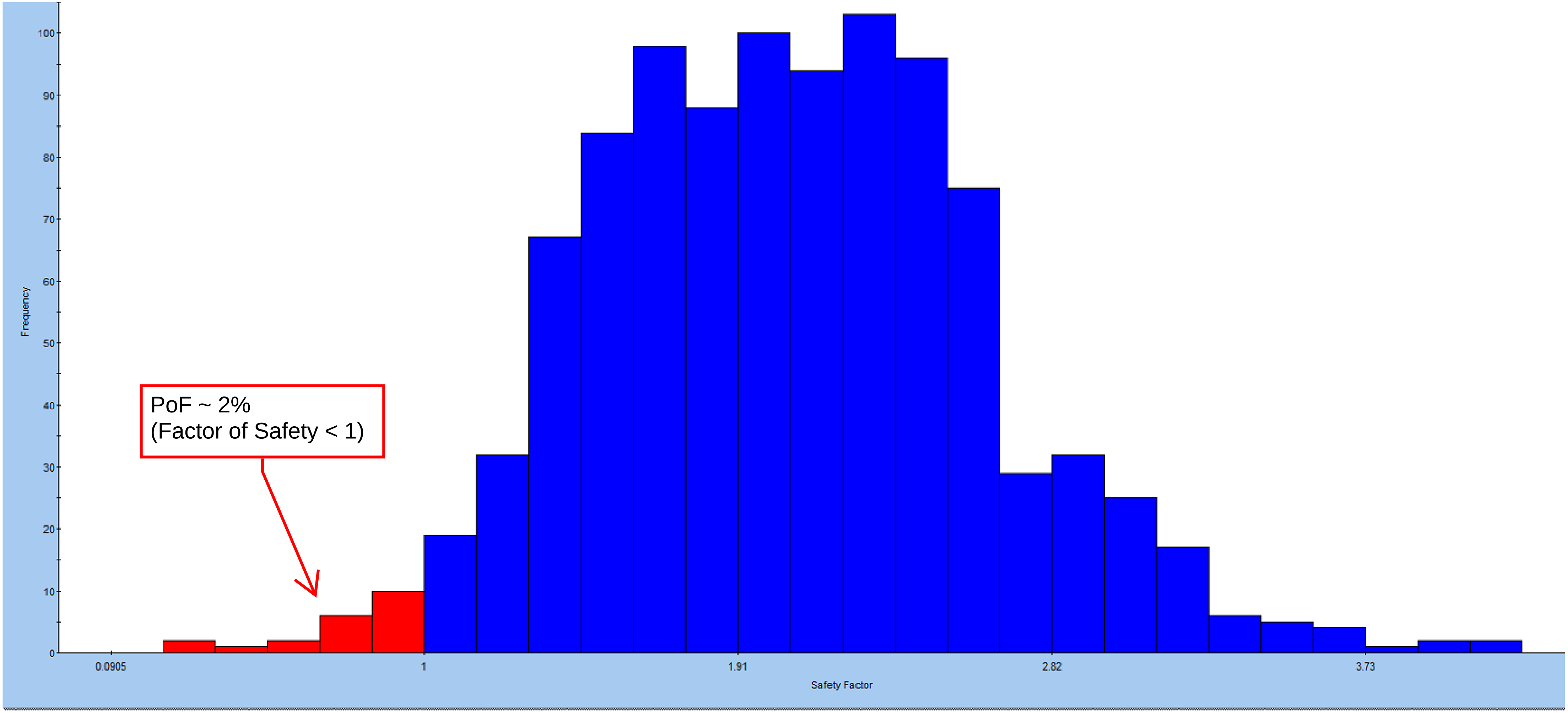
SAMPLED: mean=41.36 s.d.=4.143 min=31.42 max=49.39 PS=2.1 PF=2.1%
INPUT: NORMAL mean=41.4 s.d.=5 min=31.4 max=49.4

Cohesive strength distribution



SAMPLED: mean=49.71 s.d.=14.76 min=2.483 max=99.97 PS=2.1 PF=2.1%
INPUT: NORMAL mean=50 s.d.=15 min=0 max=100

Probability of failure (PoF) of the sliding rock block



PoF ~ 2%
(Factor of Safety < 1)

SAMPLED: mean=2.064 s.d.=0.5688 min=0.2432 max=4.156 PS=2.1 PF=2.1%

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APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

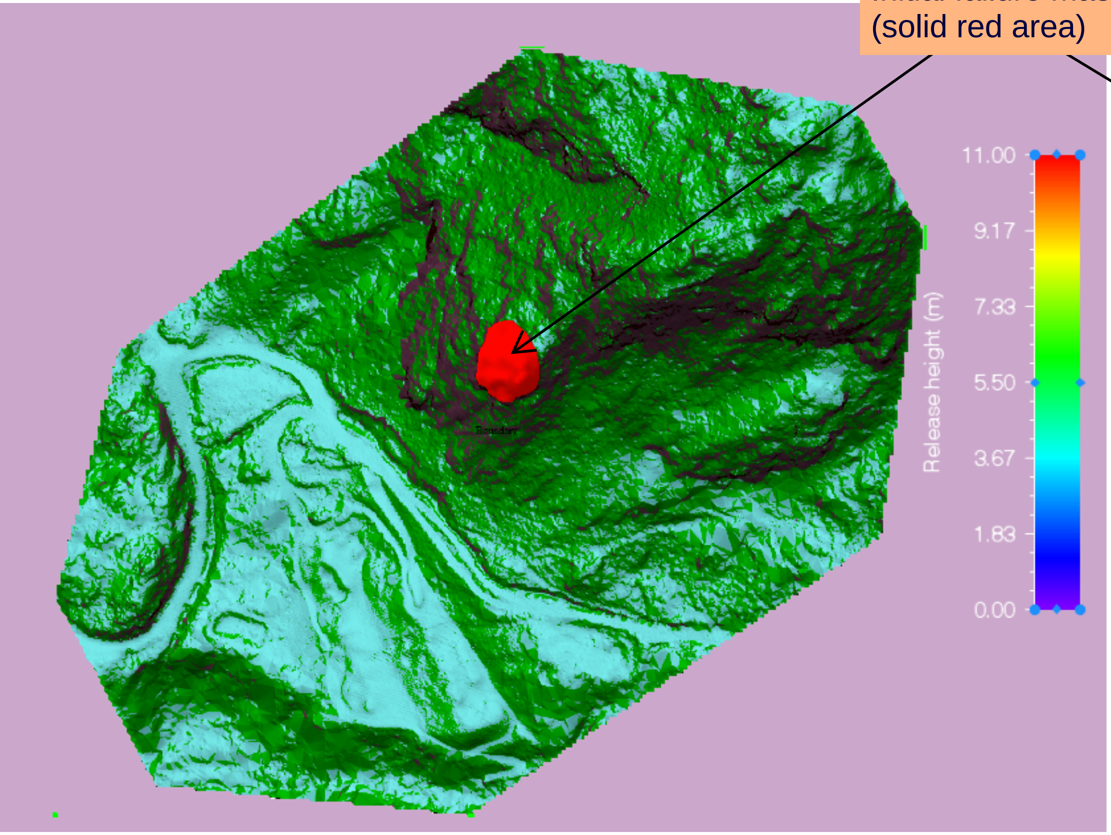
APPENDIX E

APPENDIX E
ROCK SLIDE RUNOUT ANALYSIS - AREA A

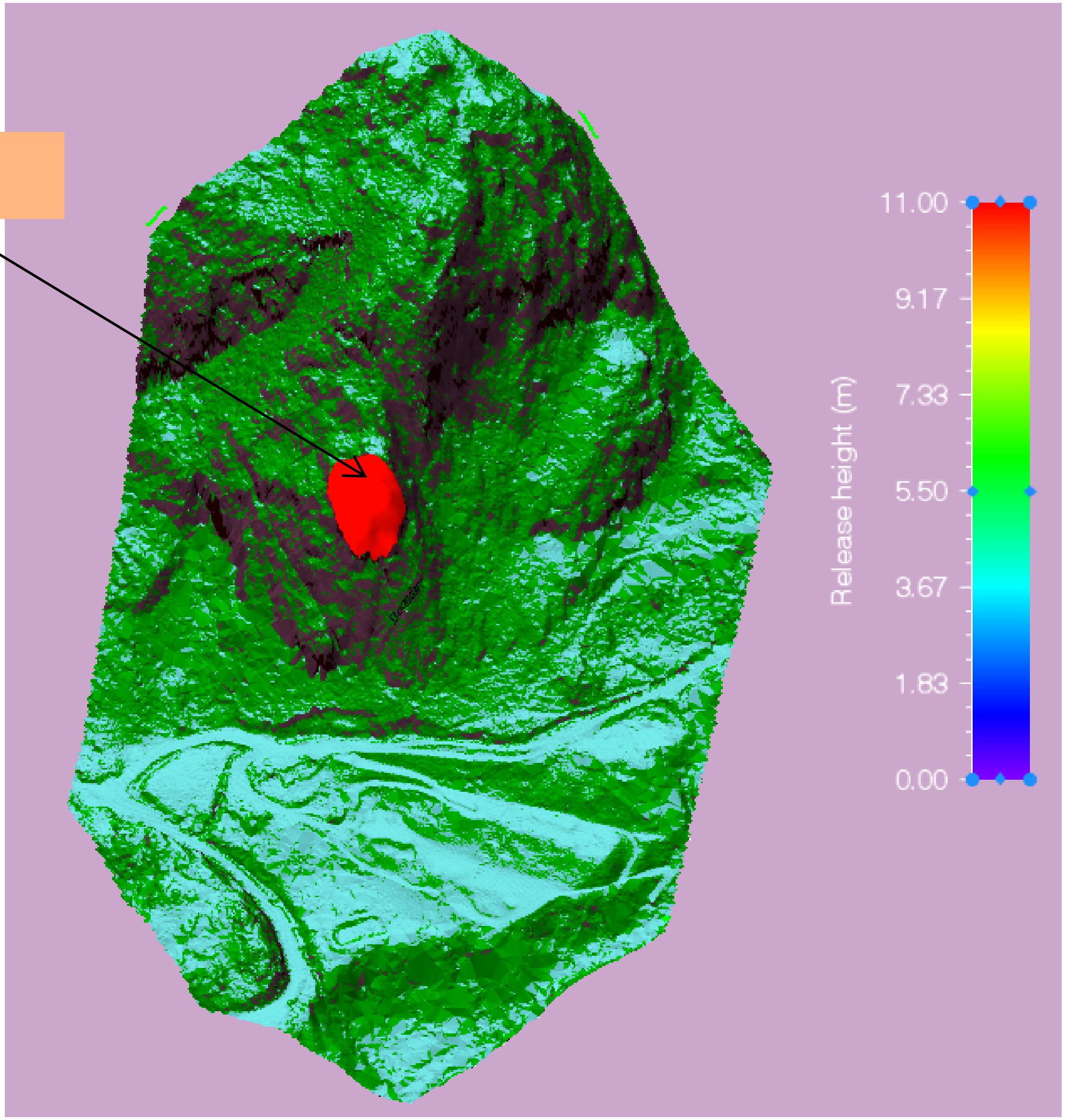
Area A - Rock Slide Runout Analysis
Case 1 - Existing Topography

Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 500 m/s^2
Friction coefficient: 0.3

Initial failure mass
(solid red area)



Plan view

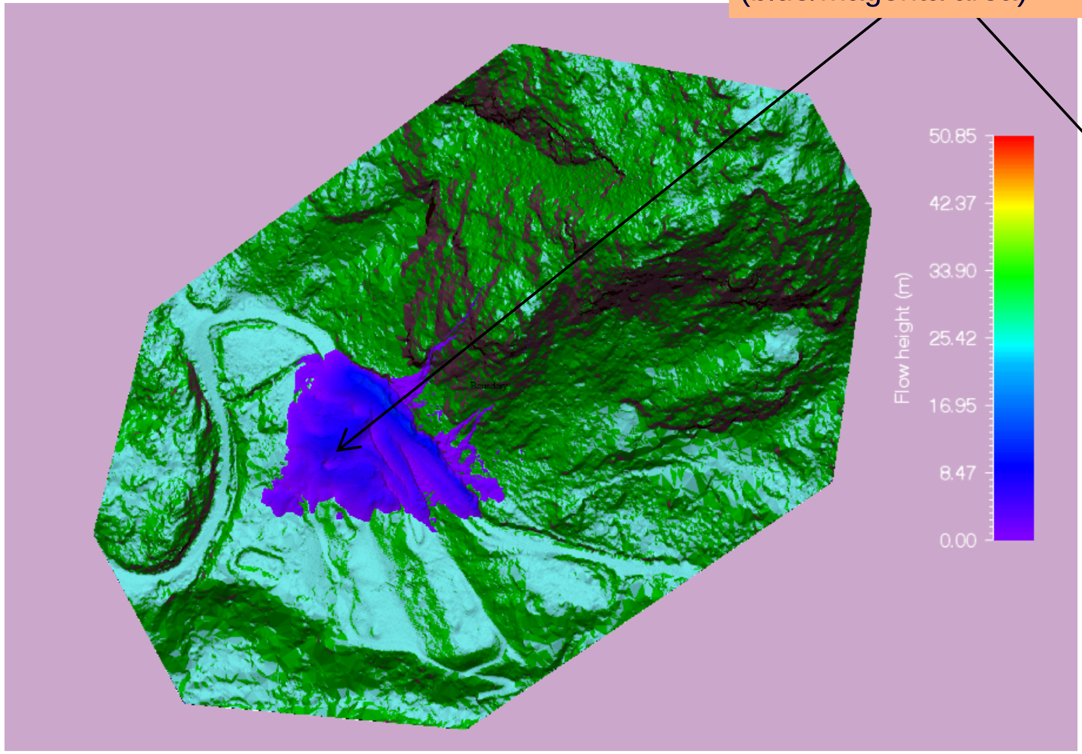


Isometric view

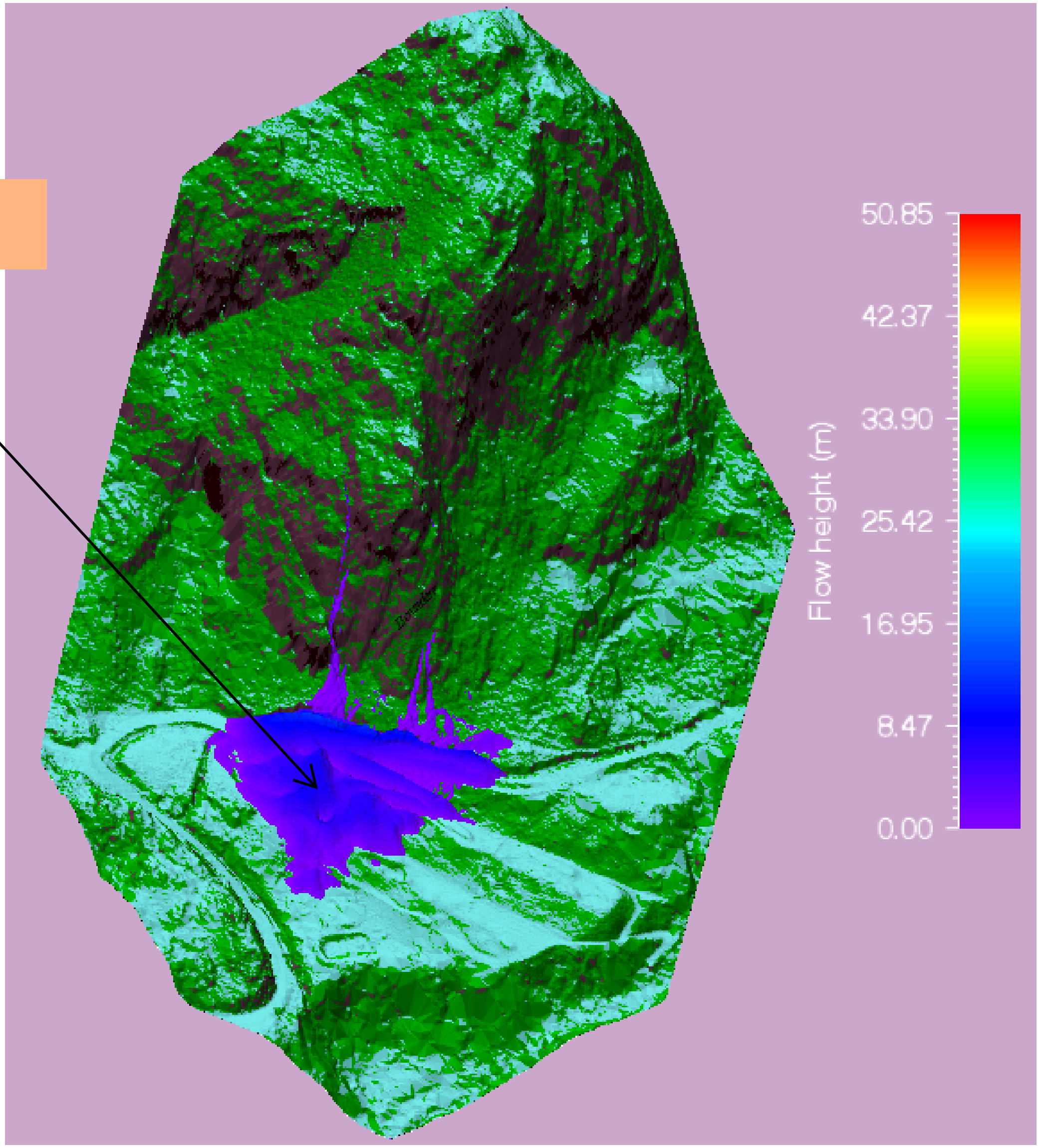
Area A - Rock Slide Runout Analysis
Case 1 - Existing Topography

Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 500 m/s^2
Friction coefficient: 0.3

Rock slide runout extents
(blue/magenta area)



Plan view

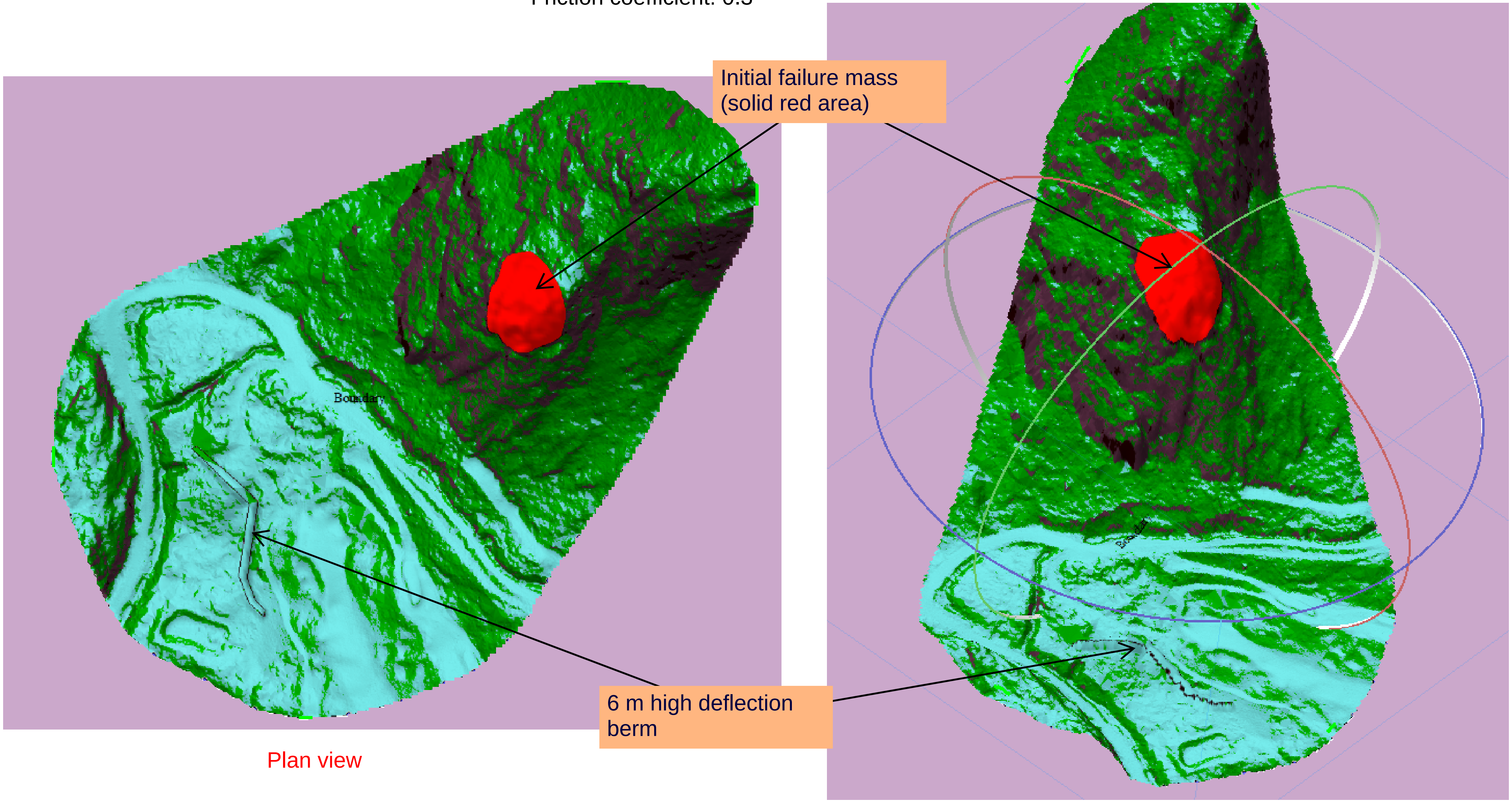


Isometric view

Area A - Rock Slide Runout Analysis

Case 2 - With 6 m high deflection bem

Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 500 m/s^2
Friction coefficient: 0.3



Initial failure mass (solid red area)

6 m high deflection berm

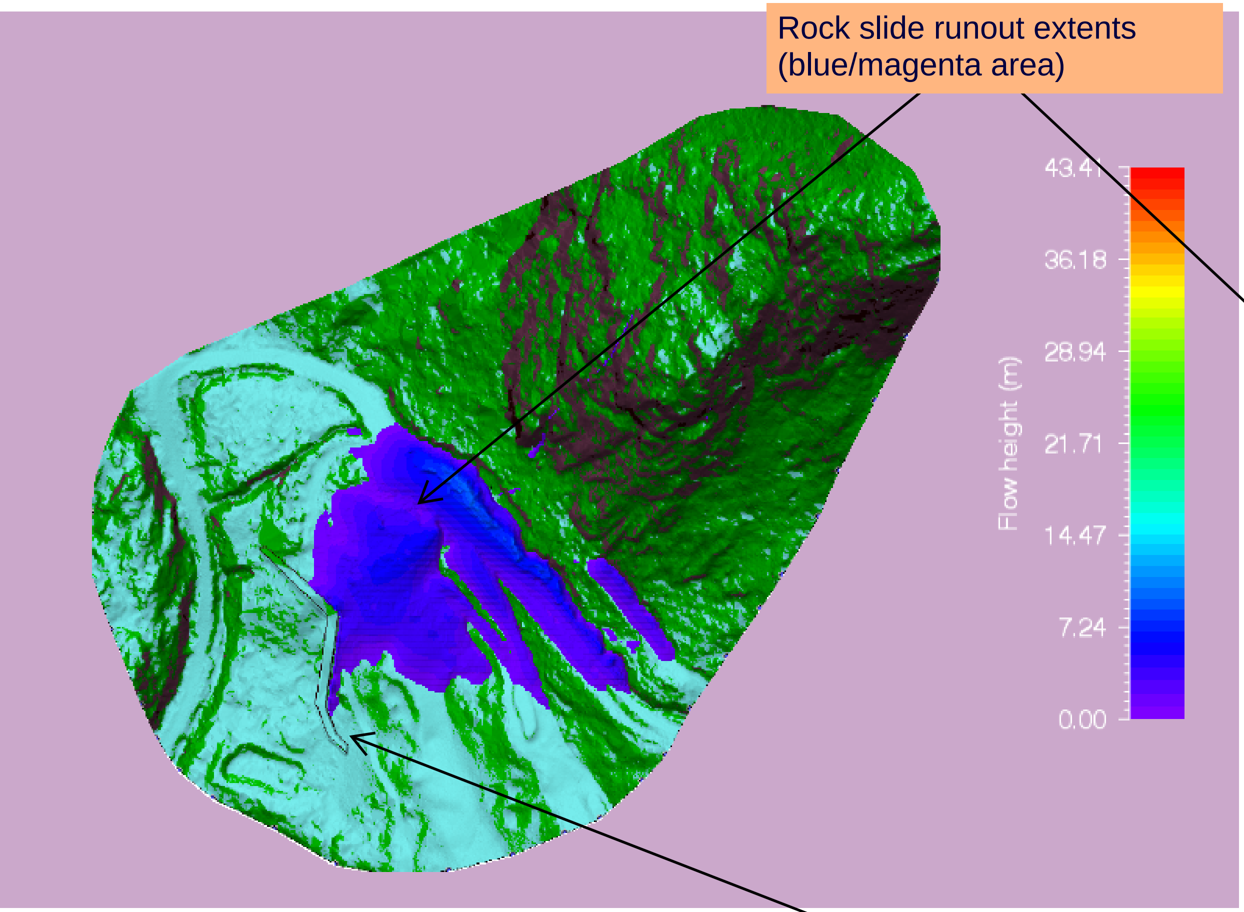
Plan view

Isometric view

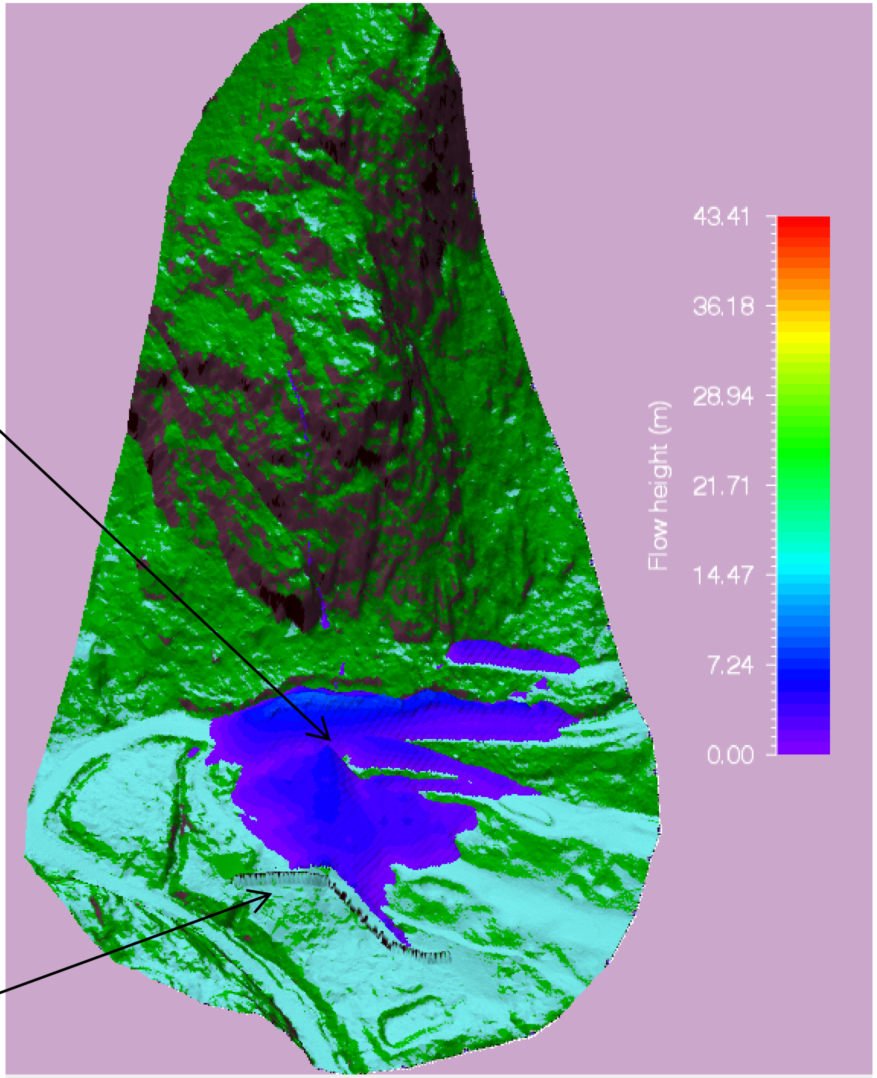
Area A - Rock Slide Runout Analysis
Case 2 - With 6 m high deflection bem
Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 500 m/s^2
Friction coefficient: 0.3

Rock slide runout extents (blue/magenta area)

6 m high deflection berm



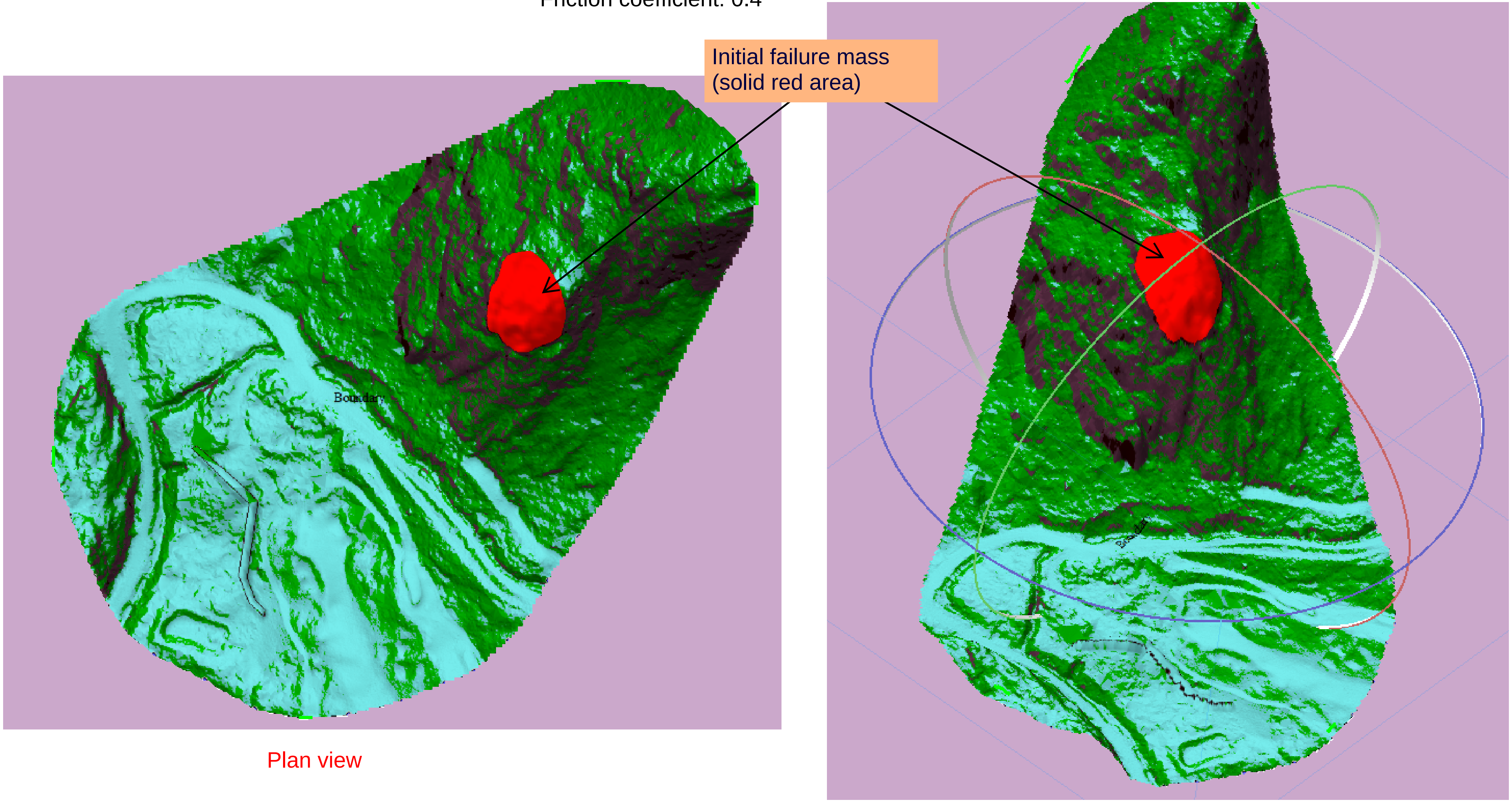
Plan view



Eye-bird view

Area A - Rock Slide Runout Analysis
Case 3 - With 6 m high deflection berm

Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 200 m/s^2
Friction coefficient: 0.4

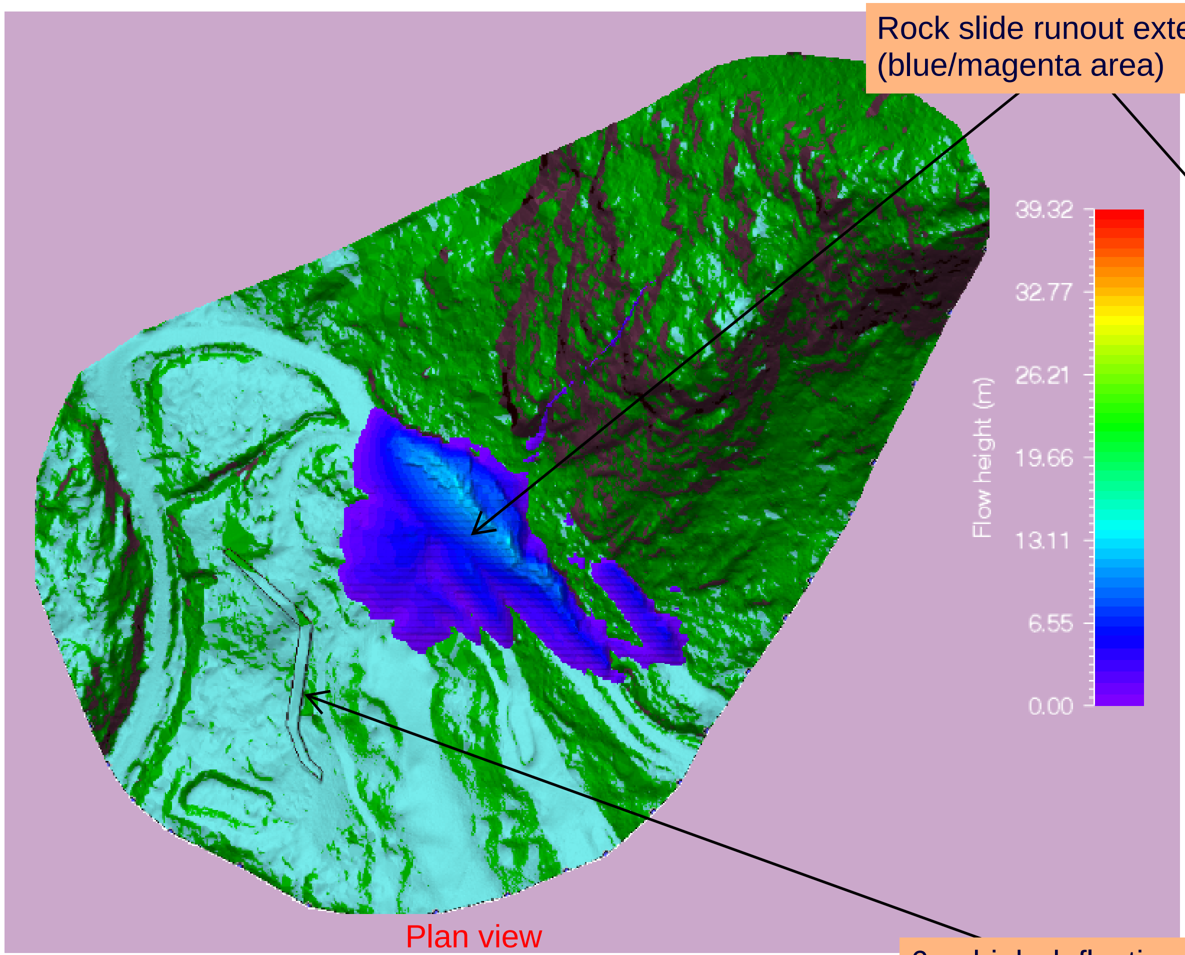


Plan view

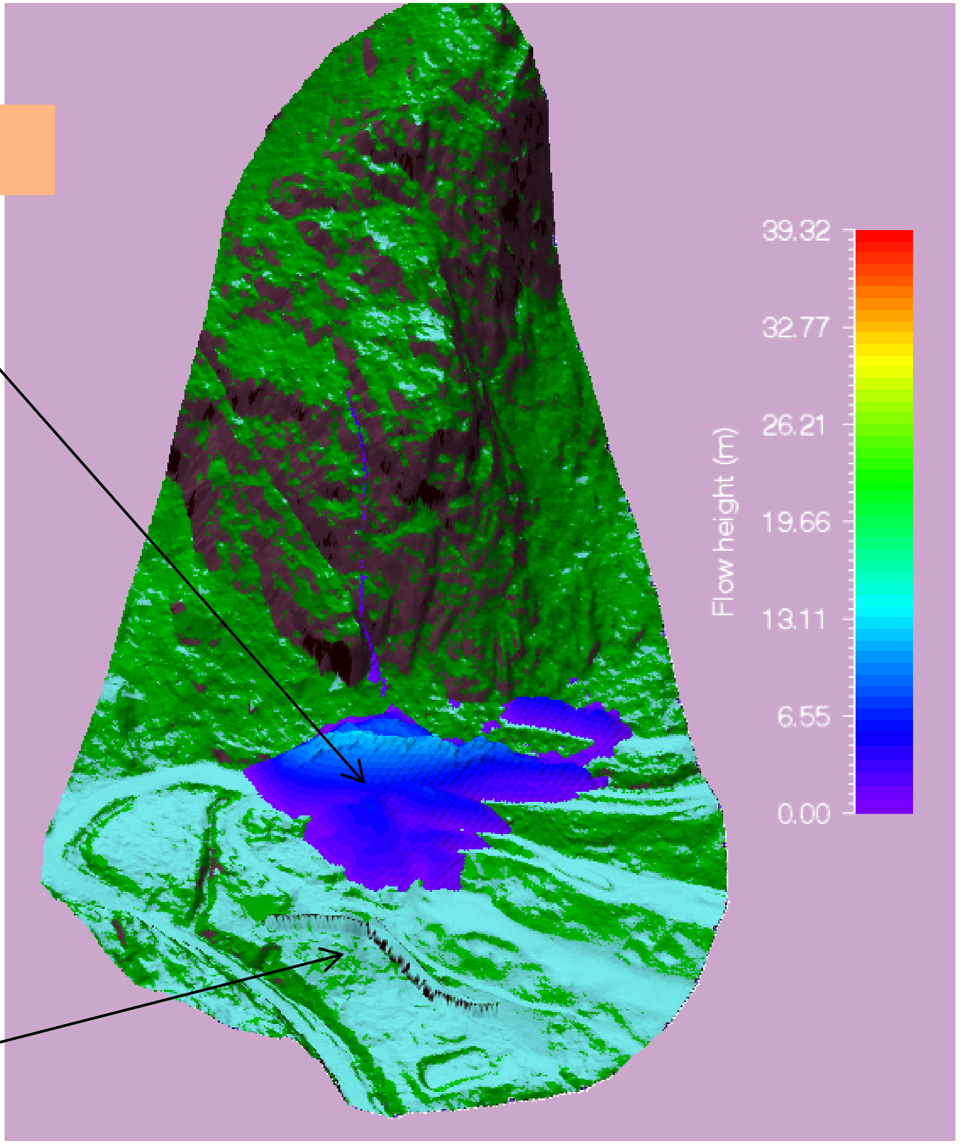
Isometric view

Area A - Rock Slide Runout Analysis
Case 3 - With 6 m high deflection berm

Rock slide initial volume: 35500 cubic meters
Eroded materials: 5850 cubic meters
(~15% bulking factor)
Turbulence factor : 200 m/s^2
Friction coefficient: 0.4



Plan view



Isometric view

Rock slide runout extents (blue/magenta area)

6 m high deflection berm

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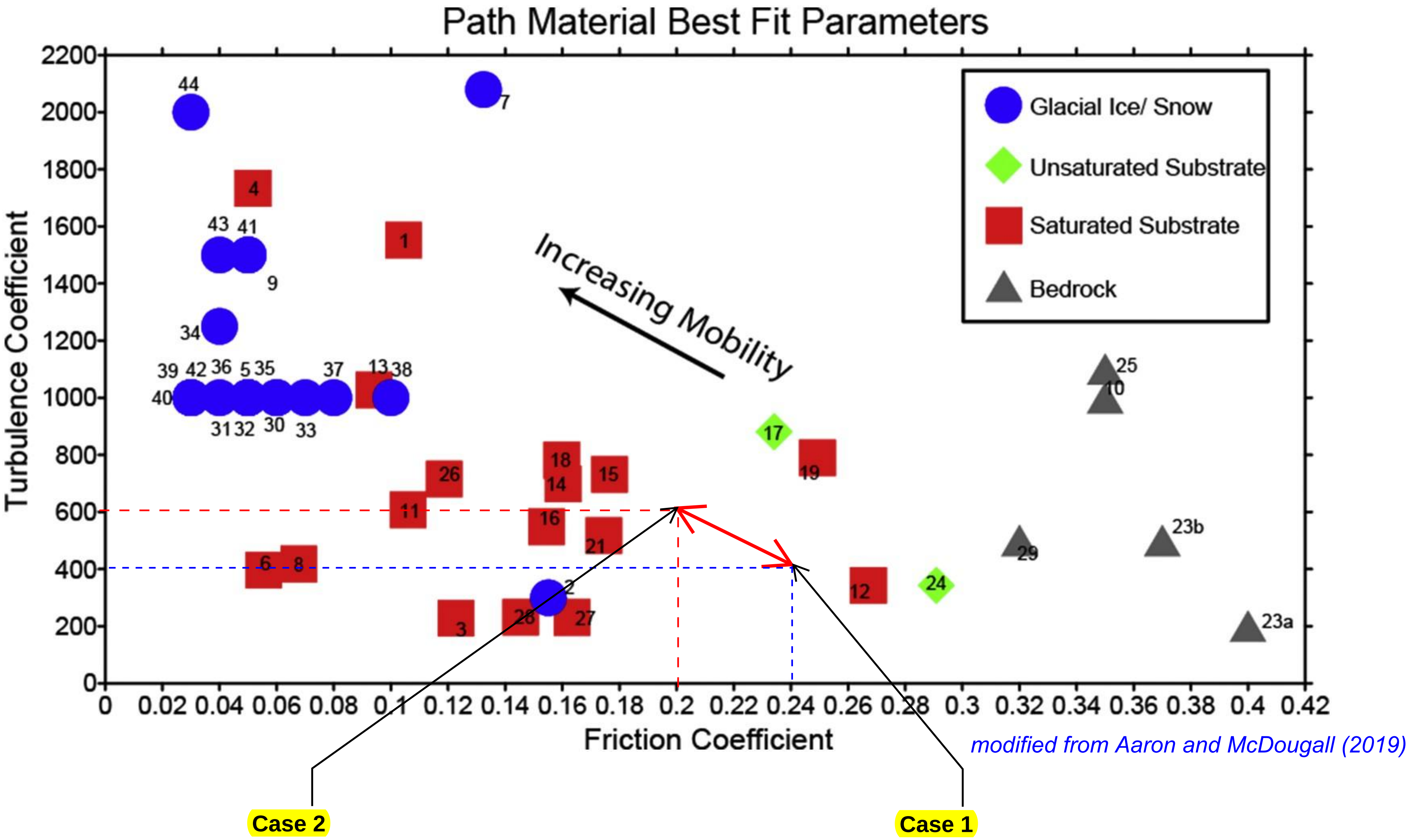
APPENDIX F
ROCK AVALANCHE RUNOUT ANALYSIS - AREA B

Area B - Rock Avalanche Runout Analysis
Selected Rheological Parameters

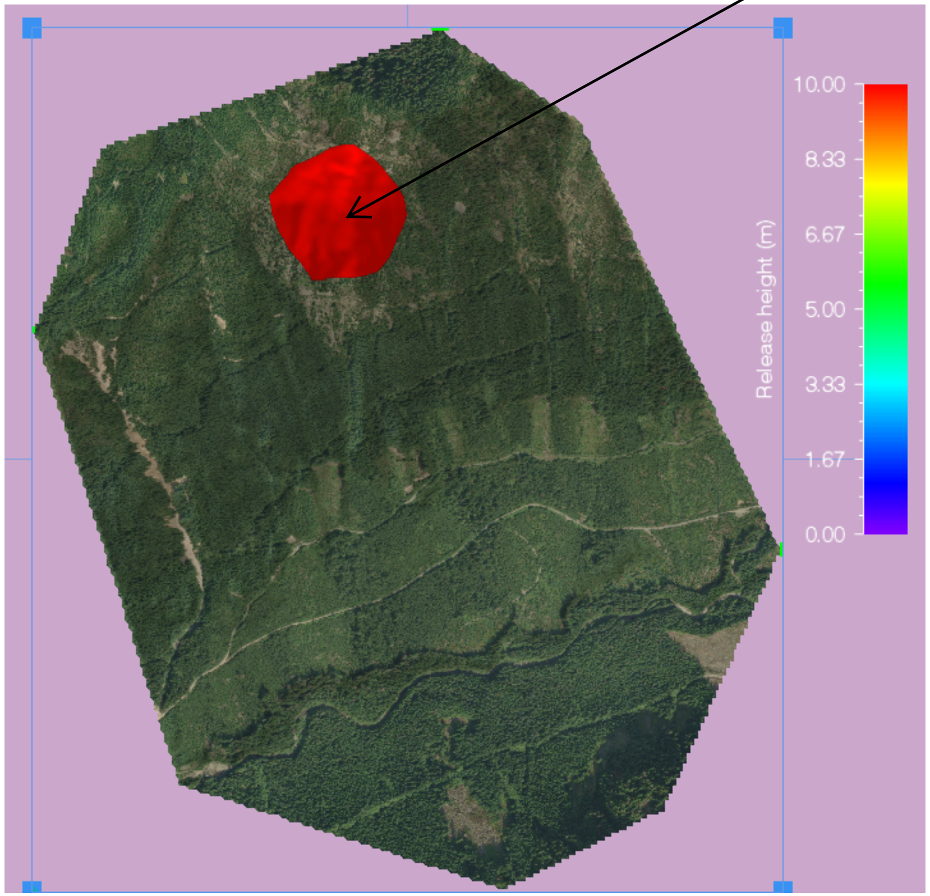


modified from Aaron and McDougall (2019)

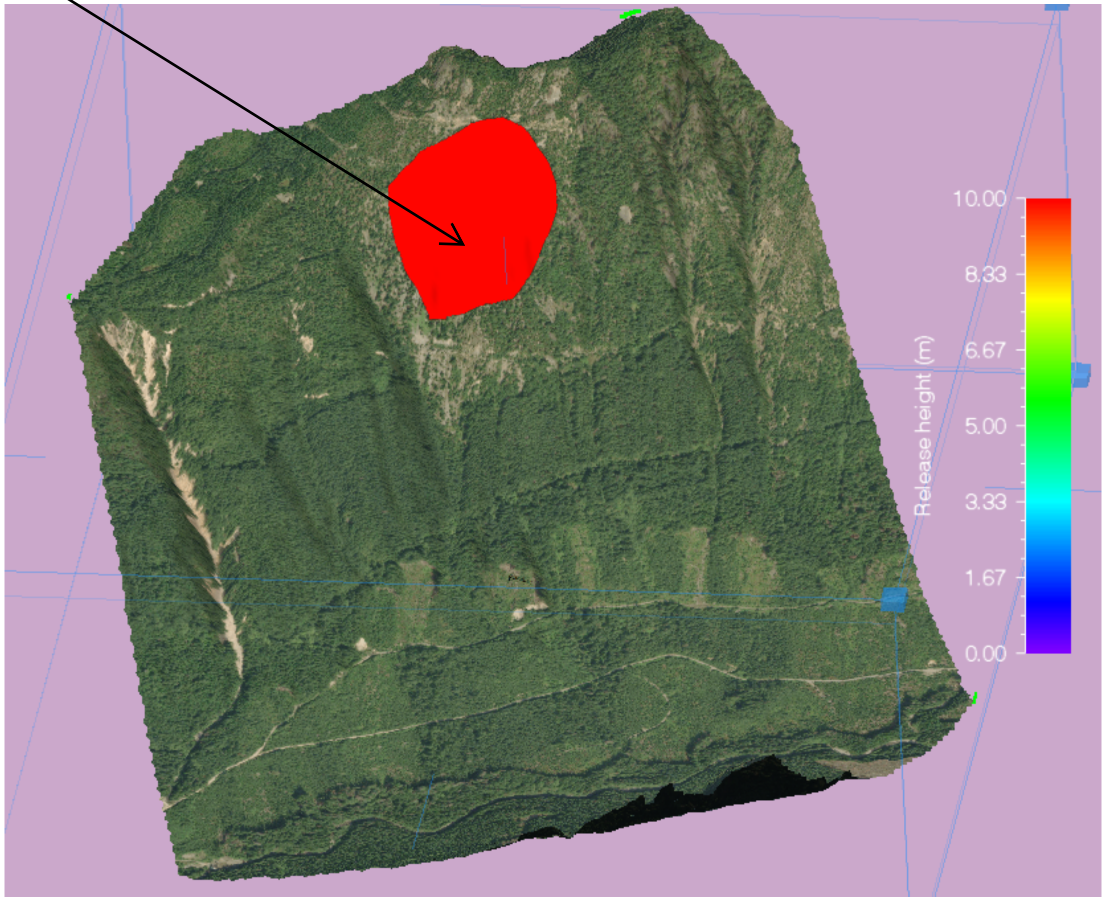
Area B - Rock Slide Runout Analysis - Case 1

Rock slide initial volume: 1,530,000 cubic meters
Eroded materials: 410,000 cubic meters
(~ 26% bulking factor)
Turbulence factor : 400 m/s^2
Friction coefficient: 0.24

Initial failure mass
(solid red area)



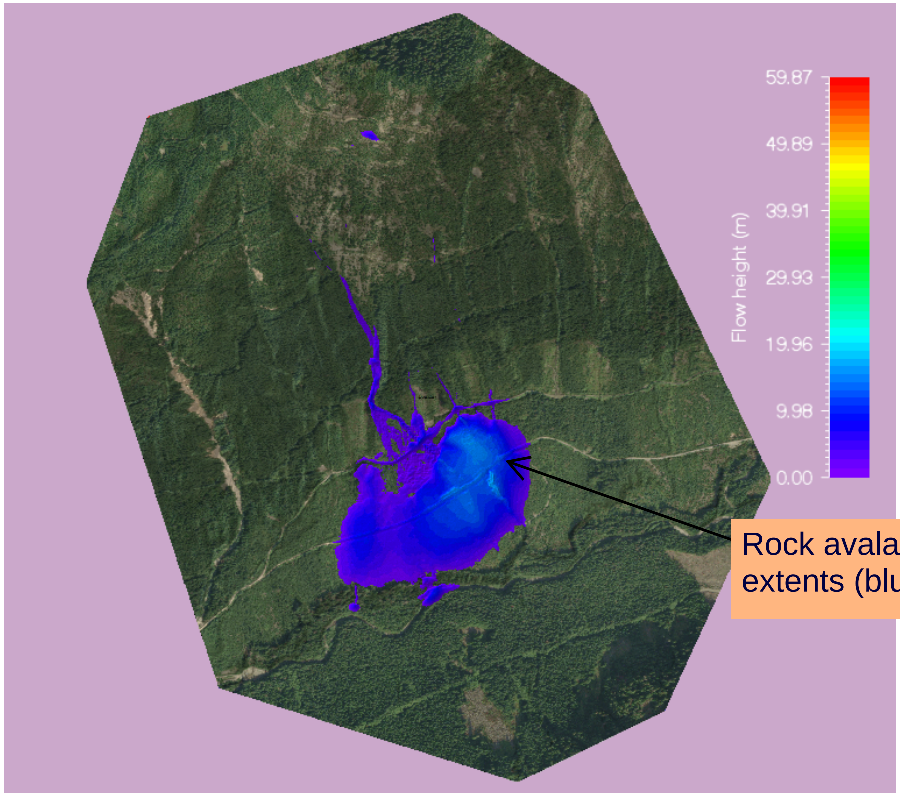
Plan view



Isometric view

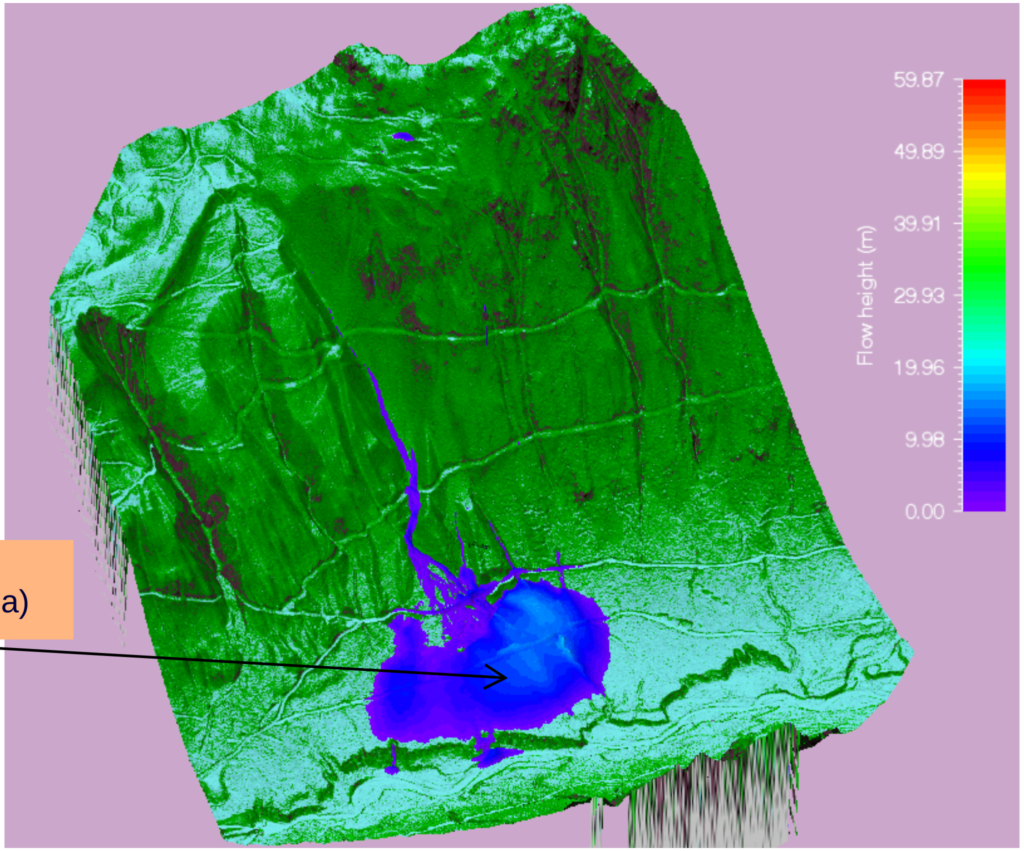
Area B - Rock Slide Runout Analysis - Case 1

Rock slide initial volume: 1,530,000 cubic meters
Eroded materials: 410,000 cubic meters
(~ 26% bulking factor)
Turbulence factor : 400 m/s^2
Friction coefficient: 0.24



Plan view

Rock avalanche runout extents (blue/magenta area)

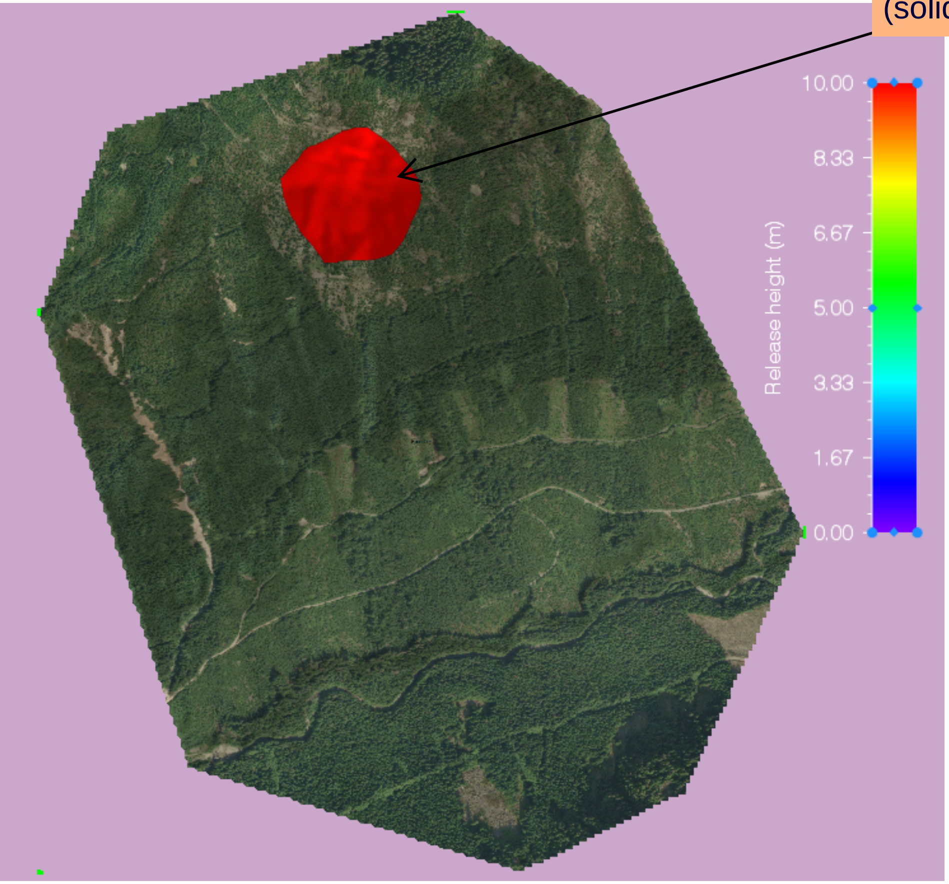


Isometric view

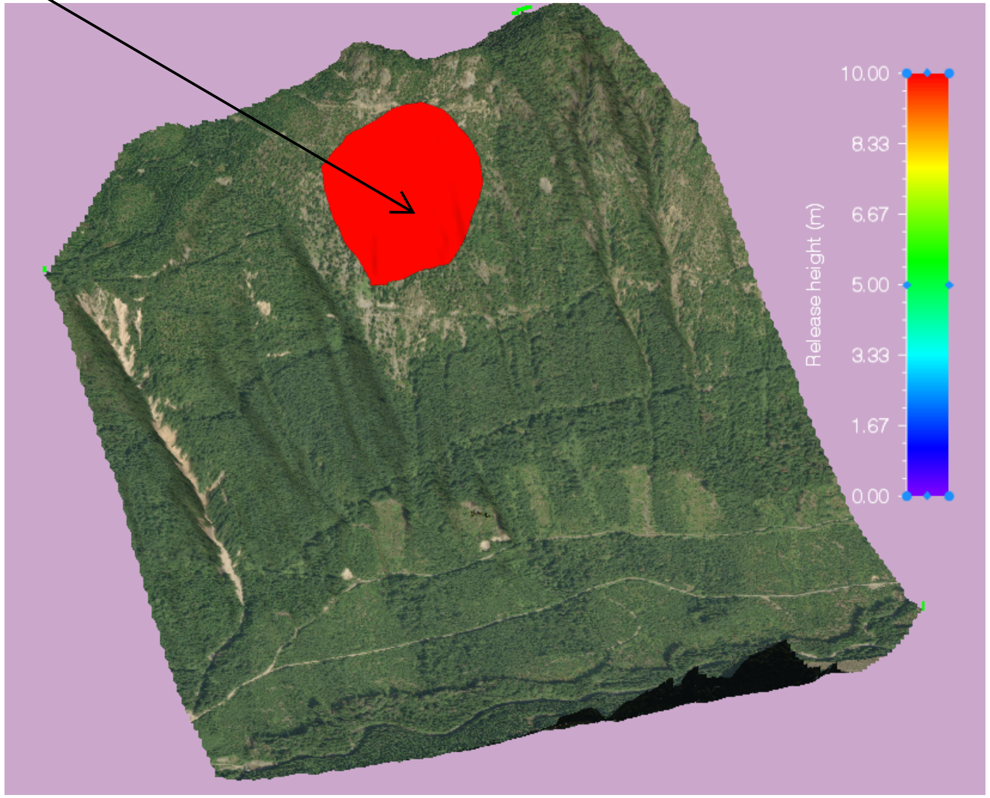
Area B - Rock Slide Runout Analysis - Case 2

Rock slide initial volume: 1,530,000 cubic meters
Eroded materials: 410,000 cubic meters
(~ 26% bulking factor)
Turbulence factor : 600 m/s^2
Friction coefficient: 0.2

Initial failure mass
(solid red area)



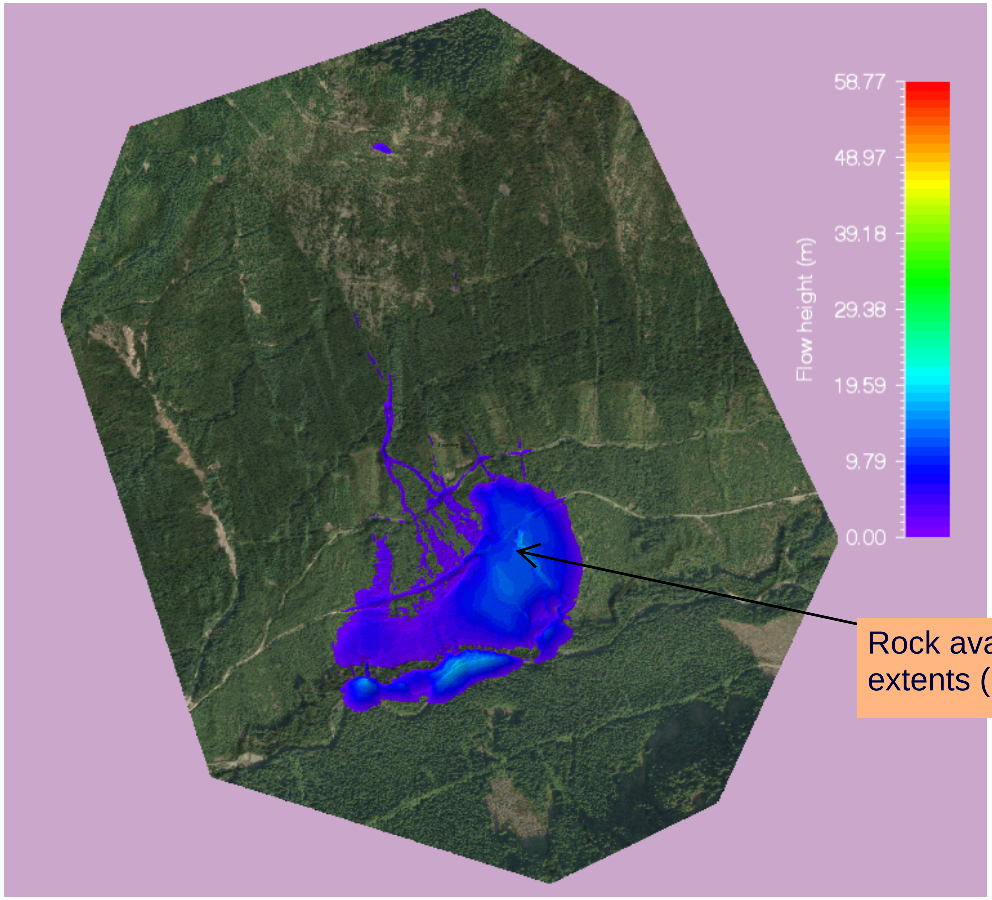
Plan view



Isometric view

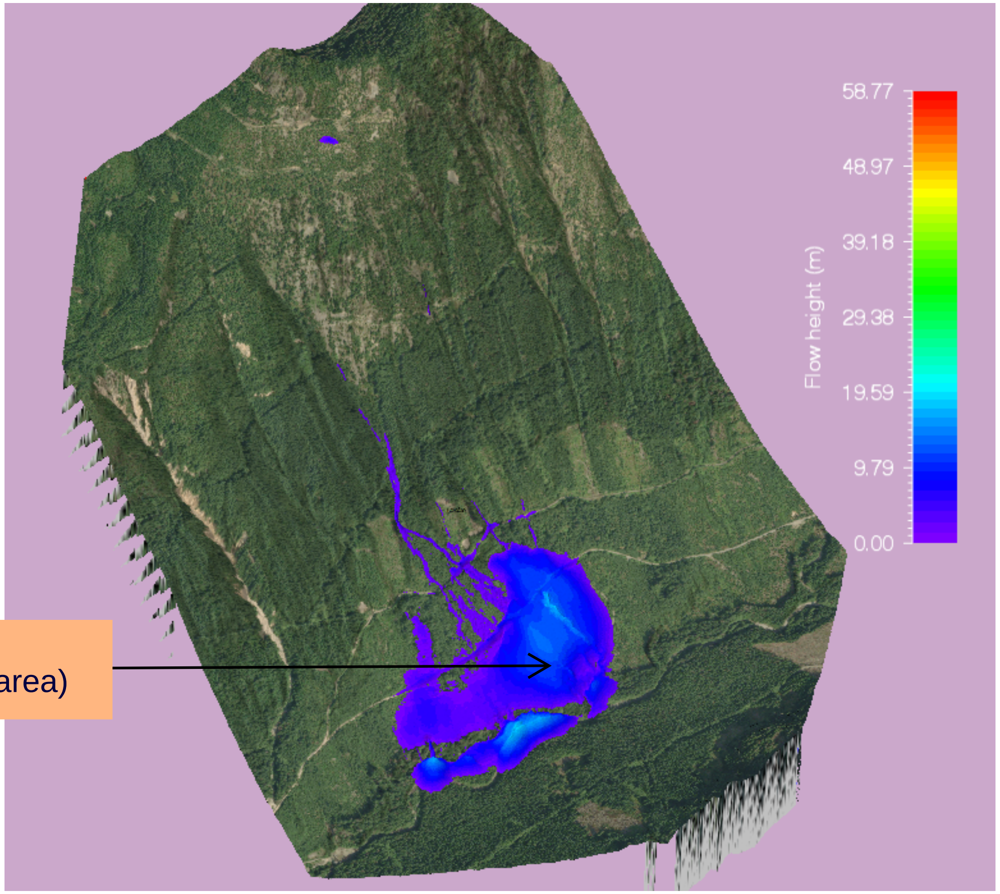
Area B - Rock Slide Runout Analysis - Case 2

Rock slide initial volume: 1,530,000 cubic meters
Eroded materials: 410,000 cubic meters
(~ 26% bulking factor)
Turbulence factor : 600 m/s^2
Friction coefficient: 0.2



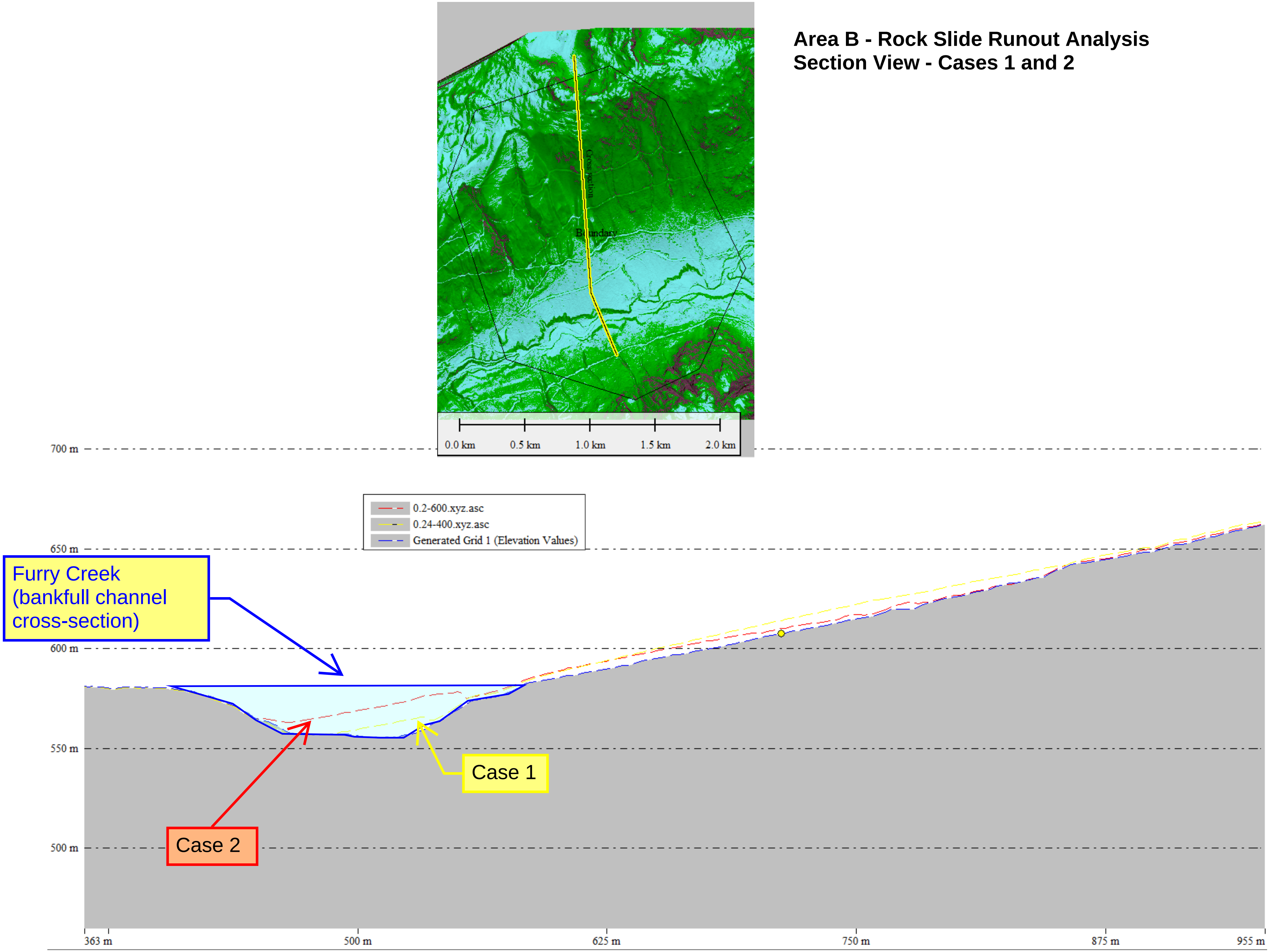
Plan view

Rock avalanche runout extents (blue/magenta area)



Eye-bird view

Area B - Rock Slide Runout Analysis
Section View - Cases 1 and 2



Furry Creek (bankfull channel cross-section)

Case 1

Case 2

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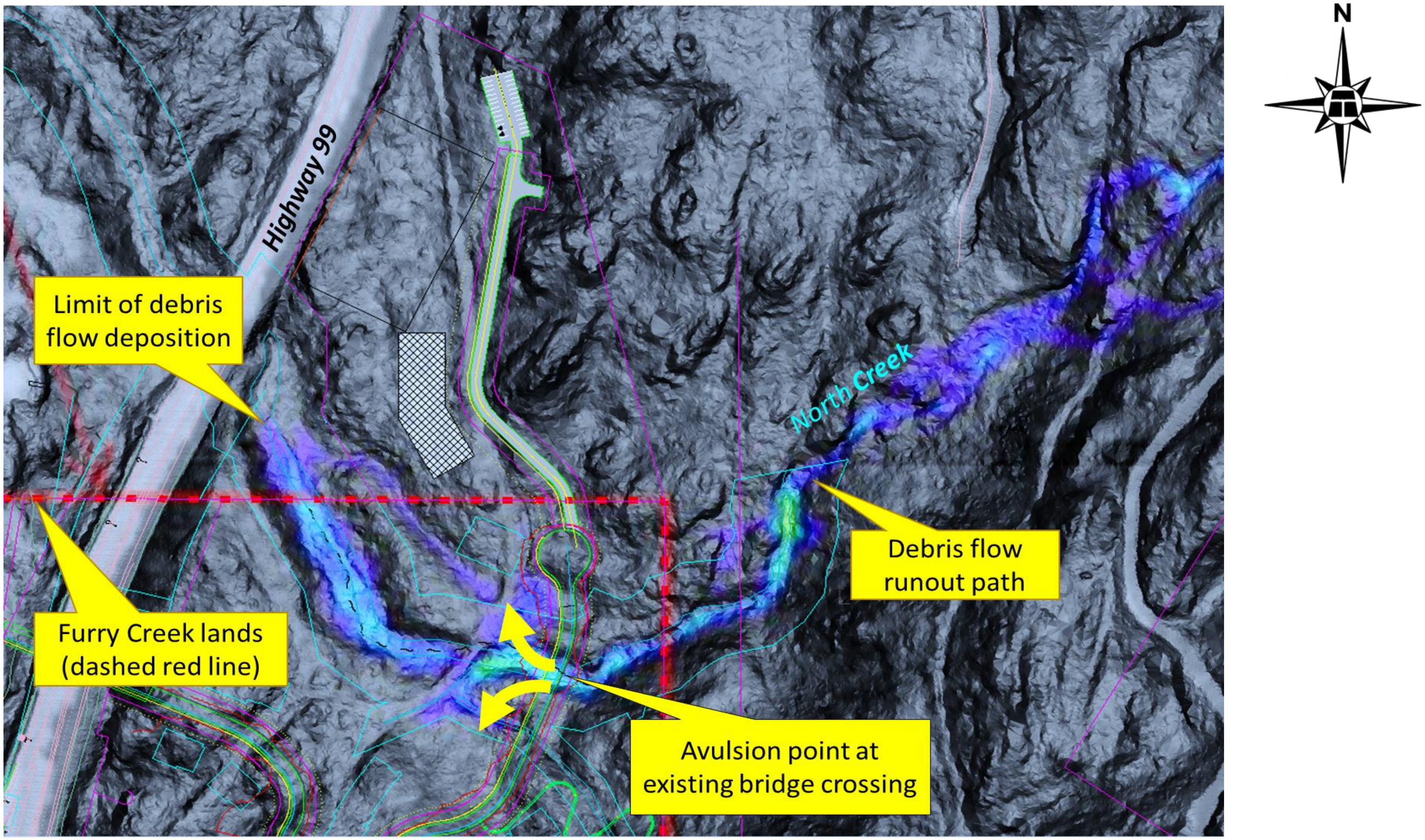
APPENDIX G
DEBRIS FLOW RUNOUT ANALYSIS - NORTH CREEK



LEGEND:

NOTES:

1. Debris flow runout path modelled with RAMMS software using the Voellmy rheology (μ = 0.1; ξ = 500 m/s^2).
2. Total event volume = 5,000 m^3 based on Thurber (1983).
3. CAD linework and LiDAR data provided by CREUS Engineering.

THURBER ENGINEERING LTD.

SKETCH G-1
DEBRIS FLOW RUNOUT ANALYSIS - NORTH CREEK