BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

SQUAMISH-LILLOOET REGIONAL DISTRICT

CATILINE CREEK

DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

FINAL

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January 22, 2015
Project No: 1358001

Ryan Wainwright
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Dear Mr. Wainwright,

Re: Catiline Creek debris-flow hazard and risk assessment – FINAL

Please find enclosed a copy of our above referenced report for your review and comment. We trust this meets your current requirements. We have appreciated the opportunity to work on such an interesting and challenging project.

Yours sincerely,

BGC ENGINEERING INC.
per:

ISSUED AS A DIGITAL DOCUMENT, SIGNED RECORD COPY ON FILE WITH BGC ENGINEERING INC.

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Senior Geoscientist

EXECUTIVE SUMMARY

BGC Engineering Inc. (BGC) was retained by the Squamish-Lillooet Regional District (SLRD) as agent for Emergency Management BC (EMBC) to assess debris-flow hazards and risks on Catiline Creek on the north side of Lillooet Lake. The primary objectives of this assessment were to:

- Assess geohazard safety risk for residential development located at the outlet of the Catiline Creek drainage
- Develop conceptual debris-flow risk reduction options and costs.

BGC assessed risk for four debris flow scenarios representing a range in debris-flow return periods from 5 - 30 to 3000 - 10,000 years. Debris flows were numerically simulated for each scenario at volumes ranging from 6000 m^3 for the smallest event to 300,000 m^3 for the largest event. The risk assessment involved estimating the probability that debris flows will impact residential dwellings and cause loss of life. It considered the existing channel configuration and conservatively assumed that no evacuation is possible during the event.

This assessment used two different metrics to estimate safety risk: individual risk and group risk. Individual risk evaluates the chance that a specific individual (the person judged to be most at risk) will be affected by the hazard. Group risk, also known as societal risk, evaluates the chance that any people present in the area will be affected by the hazard.

Results were compared to quantitative risk tolerance or risk acceptance criteria to help guide the development of options to reduce risk to tolerable levels. Such criteria have not been defined for British Columbia by formal legislation. For this study, estimated risks were compared with individual risk tolerance criteria formally adopted by the District of North Vancouver, British Columbia (DNV 2009), and with group risk tolerance criteria formally adopted in Hong Kong (GEO 1998) and previously applied by DNV. The DNV criteria for individual landslide risk tolerance are as follows (DNV 2009):

- Maximum 1/10,000 (10-4) risk of fatality per year for existing developments
- Maximum 1/100,000 (10-5) risk of fatality per year for new developments.

In summary, BGC's best-estimate of individual risk exceeded 1:10,000 risk of fatality per year for 76 of the 114 occupied, residential-classed lots within the study area. Of these, 18 lots exceeded 1:1,000 annual risk of fatality, more than one order of magnitude above the DNV individual risk tolerance threshold. Estimated group safety risk also fell entirely into the "Unacceptable" range when compared to the above risk tolerance standards.

Table E-1 summarizes mitigation options and estimated costs. Each option was developed for 100,000 m^3 and 300,000 m^3 design volumes, which correspond to approximately 1000 – year and 10,000 year return period events, respectively. The estimated cost of mitigation for the smaller design volume is about half that of the larger option, primarily due to lower earthworks requirements.

The larger design volume is intended to reduce risk to tolerable levels according to DNV standards (e.g. tolerable residual risk). Preliminary analyses suggest that mitigation of the smaller design volume may reduce individual safety risk but not group risk to tolerable levels according to DNV criteria. This is subject to confirmation during detailed mitigation design. While risks other than safety were not quantified in this assessment, the mitigation options listed in Table E-1 would also reduce risk for a broad spectrum of other elements on Catiline fan including roads, utilities, and water and power transmission.

Table E-1. Mitigation Options and Costs.

Risk Reduction Option		Description	Design Volume	Conceptual Level Cost Estimate1
1	Increase capacity of existing channel	Widen, deepen, and straighten the existing channel to increase the peak flow rate that the channel is able to convey.	100,000 m^3	$ 4.0 M
			300,000 m^3	$ 9.1 M
2	Diversion structure at fan apex	Excavate a diversion channel that captures debris flows at the fan apex and directs flow along the undeveloped land on the east margin of the fan, across the forest service road to Lillooet Lake.	100,000 m^3	$ 4.7 M
			300,000 m^3	$ 8.1 M
3	Retention barrier at fan apex	Construct a debris retention barrier on the fan near the fan apex to capture debris during a debris flow event.	100,000 m^3	$ 17.9 M
			300,000 m^3	$ 31.2 M

Note:
1) Cost estimates are 'conceptual level', associated with an accuracy of roughly -50% to +100%, and intended for comparison purposes only.

Of the options above, Options 1 and 2 provide the greatest level of risk reduction for the estimated cost. The estimated costs for Options 1 and 2 include replacement of the FSR bridge. Alterations to the BC Hydro line or purchase of private land adjacent to the existing channel may also be required, but have not been included in the cost estimate. Ongoing maintenance costs to maintain channel capacity are also not included. Option 3 is the highest cost option, requires a larger structural footprint, and provides less storage potential.

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LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Squamish-Lillooet Regional District (SLRD) as agent for Emergency Management BC (EMBC). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document of any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made of actions based on this document.

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1.0 INTRODUCTION

1.1. General

Catiline Creek is located on the north side of Lillooet Lake in the Squamish-Lillooet Regional District (SLRD), British Columbia (Drawing 1). A 14° steep fan, as well as abundant boulder lobes and levees on the fan and upstream from the fan apex, indicate previous debris-flow activity. Debris-flow hazard translates into a potential risk to existing residential buildings and residents, roads, and utilities infrastructure within Heather Jean Properties (HJP) and Lillooet Lake Estates (LLE), both partially located on Catiline Creek fan (Drawing 2). Note that while the creek is locally known as 'Cataline Creek', the official spelling has been used in this report.

Since proposed subdivision development in the early 1970s, Catiline Creek has been the subject of several geotechnical assessments to characterize and mitigate landslide hazards affecting the fan. The first study was completed by Piteau Gatsby Macleod Ltd. (PGM 1976), followed by later technical reports and completion of channel excavation works following debris-flows. At that time, the available topographic mapping was poor quality (1:50,000 scale), and the hazard characterization and risk evaluation was based almost solely on expert judgment. During the last 40 years, standards of hazard characterization and risk assessment have improved to include detailed hazard frequency-magnitude assessment, high resolution LiDAR topographic mapping, computer assisted runout modeling, risk analysis, and evaluation of risk against socially accepted standards.

These newer methods and tools were applied in this assessment to improve the understanding of debris-flow risks and risk reduction options for Catiline Creek in a transparent and repeatable manner and to put Catiline Creek debris-flow risks in perspective to risks observed elsewhere. The primary objectives of this assessment are to:

- Complete a geohazard safety risk assessment for residential development located at the outlet of the Catiline Creek drainage
- Develop conceptual level debris-flow risk reduction options and costs.

The report is organized as follows:

- Section 1.0: Scope of work, terminology and risk assessment framework
- Section 2.0: Study area physiography, geology, climate and hydrology
- Section 3.0: Hazard characterization based on desktop study and field investigations
- Section 4.0: Methodology used to estimate the frequency and magnitude of debris-flow events
- Section 5.0: Debris-flow modelling approach and results
- Section 6.0: Methodology used to assess risk and presents the results of the risk assessment
- Section 7.0: Conceptual risk mitigation options.

1.2. Scope of Work

Elements at risk considered in this assessment include persons within residential dwellings on Catiline Creek fan. The assessment thus excludes people outside of buildings by foot or in vehicles. Assessment of development other than residential dwellings was limited to identifying their location on drawings in relation to debris-flow hazard areas. However, risk mitigation decisions based on this assessment will also reduce risk for a broader spectrum of elements in protected areas than those explicitly considered.

Geohazards considered include landslides with the potential to impact Catiline creek fan. Geohazard types other than landslides (e.g. earthquakes) were not considered.

Of the 180 residential-classed lots within LLE or HJP, 155 lots are located at least partially within the study area boundary shown on Drawing 2. A remaining 25 lots are located northwest and west of Cataline Creek fan, outside the study area for this assessment. Note that the northwest corner of LLE and HJP, while not on Catiline fan, is located on the fan of an unnamed basin between Catiline Creek and McCullock Creek and possibly the southeast corner of McCullock Creek fan (Drawing 1). BGC also noted landforms on upper bedrock slopes adjacent to these basins (uphill facing scarps) that indicate deep-seated bedrock instability. Assessment of this unnamed basin or McCullock Creek are outside the scope of this report and any additional geohazard risk to HJE or LLE associated with these basins are not considered in this report.

Table 1-1 describes the work required to meet the assessment objectives. The work was completed under the terms of a consulting agreement between SLRD as agent for EMBC and BGC dated March 21, 2014. Tasks listed in Table 1-1 follow BGC's December 18, 2013 proposal and subsequent discussion in an April 23 project kickoff meeting with the steering committee, consisting of Ryan Wainwright and Kristen Clark from SLRD, Andrew Morrison and John Oakley from Emergency Management BC, and Gary Young from Lillooet Lake Estates.

For this assessment, BGC and SLRD have chosen a quantitative risk assessment (QRA) approach. This is compatible with the APEGBC Guidelines for Legislated Landslide Risk Assessments for Proposed Residential Developments in B.C. (2010). It is also consistent with Canadian and international guidelines for risk management (CAN/CSA Q850-97) and the Canadian Landslide Assessment Guidelines in that it provides a transparent, repeatable method to assess risk, define thresholds for risk tolerance, evaluates potential debris-flow mitigation alternatives, and describes uncertainties. Other jurisdictions where risk assessment is a more established standard of practice, such as Hong Kong and Australia, use similar frameworks.

Table 1-1. Work tasks.

Task	Work Items and Deliverables
1. Project Management and Steering Committee Meetings	• Initial Steering Committee meeting • Discuss landslide risk tolerance criteria with the steering committee, including whether SLRD wishes to set a threshold for tolerable landslide risk in their jurisdiction • Discuss practical limitations to risk reduction based on level of existing development and past experience with decisions by the provincial government to fund design and construction of structural risk reduction measures • Interim Steering Committee meeting • Project Administration.
2. Desktop Study	• Review existing reports, geology, terrain, landslide, and hydrologic information • Compile remotely-sensed (LiDAR, Airphoto) and basemap data in GIS format • Complete initial landslide inventory maps and transfer to GIS format.
3. Field Work	• Channel and fan traverses and test pitting • Dendrochronology • Inspection of elements at risk • Inspection of existing protective works.
4. Hazard and Risk Analyses	• Numerical modelling of debris-flow runout • Quantitative and semi-quantitative risk analysis based on results of field work and hazard analysis.
5. Evaluation of Mitigation Options	• Compare existing protective works to the 1976 Land Use Contract (LUC) governing the original Lillooet Lake Estates development, and recommendations in a 1976 Piteau Gadsby Macleod Ltd. (PGM) Report cited within the LUC • Describe structural and non-structural risk reduction options.
6. Draft and Final Reports	• Describe methods and results of risk assessment including comparison of risk results to tolerance thresholds • Provide maps showing identified hazards, elements at risk, and the location of existing and proposed risk reduction measures • Recommend further work required for detailed design of risk reduction measures.
7. Public Meeting	• Presentation of results to stakeholders at a public forum.

1.3. Terminology

The appropriate use of this assessment requires some understanding of hazard and risk terminology. In particular, the following key terms are used in this assessment:

Hydro-geomorphic event: General term to describe earth-surface processes whose dominant driver is water, with varying concentrations with respect to sediment.

Debris Flow:	Very rapid to extremely rapid surging flow of saturated, non-plastic debris in a steep channel (Hungr et al., 2012). Debris generally consists of a mixture of poorly sorted sediments, organic material and water. In contrast, debris avalanches occur in an unconfined area, and debris floods are dominated by water, as opposed to solids.
Rock Avalanche:	Extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rock fall (Hungr et al., 2012).
Hazard:	Process with the potential to result in some type of undesirable outcome. For example, the hazard could include a debris-flow runout area intersecting the footprint of a building. The term hazard refers to the specific nature of the process (type, frequency, magnitude), but not the consequences. Hazards are described in terms of *scenarios*, which are specific debris-flow events of a particular frequency and magnitude.
Element at Risk:	Anything considered of value in the area potentially affected by hazards.
Consequence:	The outcomes for elements at risk, given impact by a debris flow. In this report, consequences considered include potential loss of life, and potential damage to buildings and infrastructure.
Risk:	Likelihood of a debris-flow hazard scenario occurring and resulting in a particular severity of consequence. In this report, risk is defined in terms of safety or damage level. For example, this could include the likelihood of debris-flow impact to a building resulting in destruction of the building.

1.4. Risk Assessment Framework

Risk is a measure of the probability and severity of an adverse effect to health, property or the environment, and is estimated by the product of hazard probability (or likelihood) and consequences (Australian Geotechnical Society (AGS) 2007).

Debris-flow risk assessment involves estimation of the likelihood that a debris flow will occur, impact elements at risk, and cause particular types and severities of consequences.

Each of these components are estimated separately and then combined analytically. The objective is to provide a systematic, repeatable assessment with an appropriate level of detail for the information available.

The geographic area considered for a geohazard risk assessment is known as the "consultation zone", which is defined as, "all proposed and existing development in a zone defined by the approving authority that contains the largest credible area affected by landslides, and where fatalities arising from one or more concurrent landslides would be viewed as a single catastrophic loss" (original use by the Hong Kong Geotechnical Engineering Office (GEO) 1998, defined as above by Porter et al. 2009 and Porter and Morgenstern, 2013). Definition of this zone is particularly important to assess group safety risk, which is proportional to the number of persons exposed to a hazard. The consultation zone in this assessment spans the extent of Catiline Creek fan as shown on Drawing 1.

Geohazard risk assessment is part of the larger framework of geohazard risk management, which encompasses initial hazard identification through risk analysis and optimization of risk reduction and monitoring measures.

Figure 1-1 provides an overview of a risk management framework, after Canadian Standards Association (CSA 1997), AGS (2007), and ISO 31000:2009. This report includes the first 4 phases and the first part of the 5th phase, identification of risk control options.

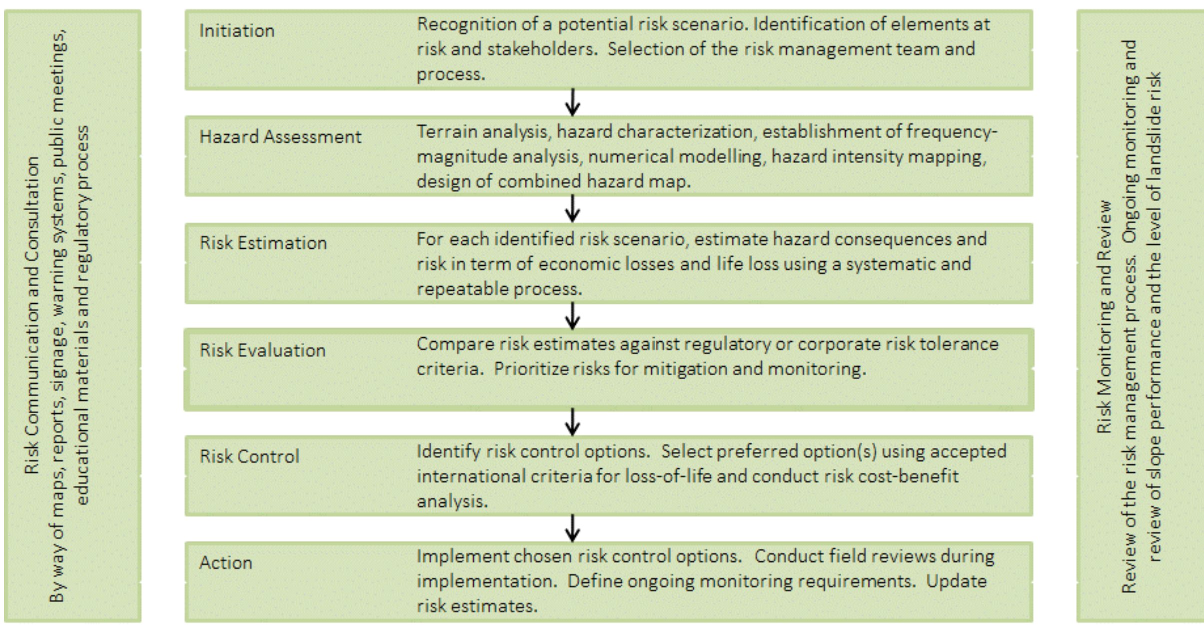

Figure 1-1. Risk management framework (adopted after CSA 1997, AGS 2007, and ISO 31000:2009).

While based on the best data available, it is important to note that each step in this risk assessment is subject to uncertainties. These uncertainties are noted where relevant in the report and should be considered when making risk management decisions. Additional description of risk assessment methodology is provided in Section 6.0.

2.0 STUDY AREA DESCRIPTION

2.1. Physiography

The project site is located on Catiline Creek, a south-facing watershed on the north shore of Lillooet Lake about 21 km east of Pemberton, within the southern British Columbia Coast Mountains (Holland 1976), (Drawing 1).

The Coast Mountains have been glaciated several times during the last two million years. The main valley glacier flowed down Lillooet Lake, scouring the valley sides leaving a U-shaped valley profile. The last, or Fraser glaciation, reached its maximum extent about 14,500 years ago, and the area was ice-free by about 10,500 years ago (Friele and Clague, 2002). As a result of glacial action, the upper slopes are steep and rocky, while lower slopes may be mantled by glacial debris including till and glaciofluvial materials. Post glacial processes have included bedrock erosion and instability leading to rock fall and landslide activity, and the reworking of glacial drift by landsliding and stream action. These post glacial process have led to the formation of colluvial aprons at the base of steep slopes and alluvial fans at the mouths of steep basins like Catiline Creek.

In the deglacial and early post glacial period, glacial sediments and bedrock were destabilized by the removal of ice support. The erosion and reworking of surficial material was initially very rapid, and colluvial aprons and alluvial fans formed within a few thousand years after complete deglaciation. Subsequently, the sediment supply declined exponentially, and fan activity diminished considerably. This dramatic decline in sediment yield characteristic of formerly glaciated regions is termed the paraglacial paradigm (Church and Ryder, 1972). The paraglacial paradigm was applied to justify safe use at Catiline Creek by Piteau Gadsby Macleod Ltd. (PGM 1976). However, since that time it has been recognized that, while sediment yield was indeed much reduced, landslides still happened and the “normal” geomorphic realm is still periodically punctuated by catastrophic events (Jordan and Slaymaker, 1991; Dadson and Church, 2005; Friele and Clague, 2009).

The Catiline Creek watershed encompasses an area of approximately 4 km^2, rising from 500 m at the fan apex to 2130 m at the summit of Lone Goat Peak. The basin is extensively gullied and steep, with a Melton Ratio[1] of 82%, indicating debris-flow activity is expected at the fan apex and beyond (Wilford et al. 2004). No glaciers exist in Catiline Creek basin. Between 600 to 1000 m elevation there are five main converging gullies, each having multiple source gullies in their upper reaches. In total 18 km of the channel are gullied, with reaches ranging from 500 to 3000 m in length. These gullies are steep-sided and sidewalls are prone to rock fall, slumping and dry ravel. The central part of the basin rises to the ridge capped by Lone Goat Peak, and the gullies support numerous fresh scars and landslide tracks. While still gullied, the western and southern sides are less subject to erosion and landslides based on the greater presence of forest cover. Between 500 to 600 m acts as a zone of debris accumulation for

[1] Watershed relief divided by the square root of watershed area.

smaller tributary debris flows and rock fall, but may become a sediment source through material entrainment increasing debris volumes.

Catiline Creek fan has an area of about 1 km^2. The main channel on the fan is incised several metres and appears to have been in its present location since at least 1948. Several assessments have identified boulders in the creek channel blocking or constricting the creek channel (Photograph 1; Appendix C). PGM (1976) identified a 200 to 300 foot (61 to 91 m) section of the creek channel above the Forest Service Road that had low freeboard and observed several abandoned channels on the adjacent fan surface. The 2010 debris flow avulsed on the left bank in this area and a lobe affected the fan surface locally. Subsequent remediation works have increased the channel capacity by excavation.

The fan surface profile is concave: at the apex a 375 m long reach has average slopes of 35%; the middle part of the fan above the FSR has 25% slopes; while the lower fan has 20% slopes. The steeper apex area supports a 100 m wide belt of largely deciduous vegetation which is indicative of snow avalanche activity. Fresh debris tracks on several airphotos appear to terminate in this zone.

Historic debris-flow events in 1986, 2004, 2010 and 2013 demonstrated that the fan slope is sufficiently steep to support debris flows mobility to Lillooet Lake. The channel has a somewhat less concave gradient as it attempts to achieve an equilibrium slope to the base level (Lillooet Lake). This results in a condition whereby at the apex the channel is more deeply entrenched than on the middle and lower fan. The point where the fan surface and channel gradients converge is called the intersection point (Drawing 6; Blair and McPherson, 1994), and this marks the point below which avulsions are more likely. Surficial materials are bouldery, and the surface expression is irregularly lobed and channeled with local relief of several metres. The surface expression is derived from overlapping boulder lobes and discontinuous abandoned channels.

2.2. History of Development on the Fan

The Catiline Creek fan area was logged between 1949 and 1952 (PGM 1976). Airphotos from 1969 indicate the entire fan complex was logged with the exception of a few old-growth Douglas fir trees in the upper fan areas and the ridge ("kame terrace") located on the east side of the fan (Drawing 5). PGM (1976) notes that the tributary valley and upper reaches of the creek have not been logged. Recommendations to ban logging activities in or on the fan were proposed by Piteau (1986), as forest may act to reduce debris-flow intensity or arrest flows (Guthrie et al. 2010),

Airphotos from 1969 show a recently constructed hydro right-of-way and access road. Early construction works of the subdivision began between 1969 and 1973 with construction of an access road below the FSR. Several more subdivision access roads are noted in the 1977 airphotos and a road up to the top of the subdivision is observed in airphotos from 1981.

Land Use Contract (LUC) Authorization By-law No. 88, 1976 was formally adopted by the SLRD in 1977 (SLRD 1977). For reference the LUC is included in Appendix A of this report. The LUC contains clauses for managing flood and debris-flow hazards. Clause 24D (b) of the LUC dictates the following flood hazard management requirements:

- No buildings or mobile structures permitted within 200 feet (61 m)[2] of the main or active watercourse of the two alluvial fans.
- No buildings or mobile structures permitted within 50 feet (15 m) of any other watercourse or side of auxiliary channels to the alluvial fan watercourses.

For debris-flow hazard management, the LUC establishes two creek protection corridors along Catiline Creek:

- Creek Protection Corridor No. 1 is defined as the area of land and land covered by water, coloured red on the Schedule "B" Site Plan (Appendix A)
- Creek Protection Corridor No. 2 is defined by the area hatched with red lines on Schedule "B" Site Plan (Appendix A).

Clause 24F of the by-law also requires suitably designed training walls (berms) be constructed at the fan apex to prevent channel avulsions. "Suitably designed" is defined by the LUC as designed by a professional engineer competent in river channel hydraulics and engineering.

The permitted uses and standards and restrictions for the Creek Protection Corridors are outlined in Schedule C clause V and VIII of the LUC. For Creek Protection Corridor No. 1, the permitted use is recreation only. The standards and restrictions state no permanent structures, and no tree cutting or disturbance of the ground (unless required for access to the creek). For Creek Protection Corridor No. 2, the permitted use is equivalent to uses for "common sites"[3]. The standards and restrictions state no construction is permitted until the recommendations on page 7, item 4 of the PGM (1976) report have been acted upon and completed as certified by a geotechnical consultant. BGC interprets clause VIII (2) to include all recommendations a) to f) listed in item 4 of the report (i.e. on page 7 to 9). The 1976 PGM report is summarized in Section 3.2.1.

In this context, the term "corridor" is interpreted as the width of land on both sides of Catiline Creek. The creek protection corridors illustrated in Schedule B Site Plan (Appendix A) are hand drawn and show minor variation in width along the channel. At a scale of 1:400, Creek Protection Corridor No.1 and No. 2 measure approximately 50 to 70 feet (15 to 21 m) wide and 300 feet (91 m), respectively. These measured widths are narrower than the 300 feet (91 m) and 800 feet (244 m) recommended by PGM (1976). The Schedule B Site Plan drawing scale

[2] To be consistent with previous reports, all corridor measurements in this report are stated in imperial units first and followed by metric units in brackets. Other measurements (e.g. volumes) are stated in metric units first and followed by imperial units in brackets.
[3] The use of land, buildings and structures on Common Sites is restricted to: Community or Recreation Halls or Buildings; Parks and Playgrounds; Churches, Hospitals, Libraries and other similar uses; Accessory Buildings for the structures listed above are also permitted.

has been manually changed to 1:400. The reason and timing for the change in scale are unknown (pers. comm. Kristen Clark, SLRD).

PGM (1976) notes “that although the terms of reference for our work apply to the area above the forestry road, it should be recognized that the potential of flooding damage exists below the road as well. It is advisable therefore to complete the corrective work on the creek to minimize the possibility of damage below the road”. BGC notes the creek protection corridors illustrated on Schedule “B” Site Plan (Appendix A) do not extend below the road.

A more recent map Plan of Heather-Jean Development Lot 4901, Lillooet District dated May 2, 2007 shows two protection corridors with widths of 400 feet (122 m) and 800 feet (244 m) respectively. Based on discussions with SLRD, BGC understands the 800 foot (244 m) protection corridor corresponds to the 800 foot (244 m) corridor recommended by PGM (1976) and the 400 foot (122 m) corridor corresponds to LUC clause 24D which restricts construction along all watercourses.

Drawing 2 shows 800 foot (244 m), 400 foot (122 m), and 300 foot (91 m) corridors . The corridors are shown as setback lines on either side of the creek (i.e. the 800 foot corridor corresponds to the two 400 foot setback lines) and were measured using GIS as the distance from the stream channel. As such they may differ slightly from hand-drawn corridors on older drawings by others. There are 60 residential-classed lots partially or wholly within the 800 foot corridor, of which 45 were classified as “occupied” (see Section 6.5.2). Of these, 26 residential lots are at least partially wthin the 400 foot corridor (18 occupied), and 21 at least partially within the 300 foot corridor (14 occupied).

2.3. Geology

2.3.1. Bedrock Geology

Catiline Creek is underlain by granodiorite, with regional geology mapping indicating steeply dipping (60 to 80^0) foliation[4] with one set trending E/W to NW/SE and another trending NE/SW (Roddick and Hutchison, 1973). Tension cracks on pre-existing joint planes were identified at the crest of the mountain slope by PGM (1976). On the southeast wall of the tributary valley, PGM (1976) identified one shallow, tabular slide although the specific site was not shown on maps. Along the east side of the basin aligned NNE/SSW there is a bedrock lineation exploited by a south flowing creek; the projection of this lineation extends through a zone of tension cracking identified by Cordilleran (2010, 2013) (Drawing 6). About 400 to 500 m west within the basin there is a series of fresh tracks and large rock fall scars that align along a similar trend. These lineations may be related to the regional structure, suggesting there may be structural control on rock fall contributing sediment and acting as a trigger for debris flows.

[4] Repetitive layering

2.3.2. Surficial Geology

In the basin, surficial materials consist of bedrock and rock fall derived colluvium. Colluvial debris mantles steep rock slopes and may form thicker (several metres) blankets along channel sections where it collects between periodic channel scouring events. Along the feeder channels there are thick deposits of colluvium that are a debris source for channel entrainment. In the forested parts of the basin there may be a thin veneer of morainal material on rock. At the mouth of the basin, along the flanks of the south facing valley walls on either side of the creek mouth, blocky talus slopes bound the alluvial fan. PGM (1976) described fan materials as fine grained unsorted debris interpreted as debris-flow and/or ‘mud flow’ deposits. Debris lobes have variable texture, ranging from these unsorted sandy boulder gravels to openwork boulder lobes. Boulders everywhere on the fan may be found up to 3 m in diameter. Near the apex on the east side of the fan there is an area that consists of large angular clasts apparently derived from rock slide or rock avalanche of unknown date.

2.4. Climate

The online ClimateBC map hosted by the Department of Forest Science at the University of British Columbia, reports an average precipitation of 1244 mm/year over the period of record from 1951 to 2009 from an elevation of 1900 m (Wang et al. 2006; Wang et al. 2014). Most precipitation occurs during fall and winter. Approximately 30% of precipitation falls as rain, and 70% as snow, with a higher proportion of snowfall at upper elevations (Wang et al. 2014).

Summer months are warm (mean temperature of 10°C) and generally dry (~140 mm of precipitation). During spring and fall mean temperatures are around 0°C with moderate precipitation. Winters are cold (mean temperature of -10°C) and wet (~530 mm of precipitation).

2.5. Hydrology

With a small, steep and rocky basin, Catiline Creek has a “flashy” discharge, meaning that creek flow will respond quickly to rainfall and snowmelt. Primary flood generating mechanisms include rain, rain on snow and snowmelt freshet. Rain-generated flood events occur in summer related to thunderstorm activity and late summer and fall related to cyclonic storms. The largest floods are related to rain and rain on snow events. In spring the snowmelt freshet produces a longer, more sustained highwater.

3.0 HAZARD CHARACTERIZATION

3.1. Debris-Flow Phenomenon

Debris flows typically occur in creeks with slopes between 15 and 35°, with watershed areas between 0.1 and 10 km^2 (i.e. Jakob 2005). Catiline Creek is a typical example, with slopes in the above range and a watershed area of 4 km^2. The most significant contributor to debris-flow occurrence is a supply of readily erodible material, often created by rock falls and landslides. If a system has a large supply of erodible material, a debris flow may occur once a hydrodynamic threshold (e.g. specific antecedent rainfall) has been reached (Bovis and Jakob, 1999). If a system has a limited supply of erodible material, such as Catiline Creek, the creek bed must gradually recharge with debris until there is sufficient material for a debris flow to occur (Jakob 1996). The process of gradual recharge helps explain why debris-flow occurrence can be intermittent, and not necessarily correlated with significant rainfall events (Jakob et al. 2005).

A debris flow is typically initiated by a mass movement in the upper reaches of a creek. Mechanical weathering, especially during freeze-thaw cycles in the spring and fall generate rock fall, which supplies debris to the channel areas and may be a trigger in itself. Rain and rain on snow is a potential trigger for debris flows, particularly in November and December before the snowpack is of sufficient thickness to absorb rainfall before releasing it to the underlying ground (Jakob and Weatherly, 2003; Jakob et al. 2011). Some cases of in-channel triggering through exceedance of a critical creek discharge are known. For example, this type of event occurred in 2009 on Spidery Creek in the headwaters of Lillooet River, resulting in destruction of a bridge on a Forest Service Road (Cordilleran 2009). Other landslide triggers include seismic activity, or simply progressive weakening and accumulation of gravitational stress.

Debris flows have three general stages: initiation, transportation and deposition. However, as the debris-flow process itself is transient (it can dilute into debris floods), transportation reaches can also be subject to some deposition while deposition zones can, under some circumstances, be subject to additional debris entrainment. For example, at Catiline Creek the lower feeder channel and upper fan apex areas are deposition zones for small frequent (yearly) rock fall and debris-flow events, but rarer (> 10 year return period) debris flows may entrain debris from these areas.

Once initiated, debris flows typically travel down a confined channel, overrunning streamflow thus sustaining mobility and momentum. Debris flows can cause complete scour in the transportation zone. Scoured materials are entrained in the debris flow, increasing its volume and flow velocity if sufficient water is available. Debris flows reach their maximum velocity in the transport zone. Flow velocity is dependent on channel gradient, debris-flow volume and the grain size of the transported materials, but will not increase indefinitely due to flow resistance inherent in its flow mechanics. Debris flows have flow velocities exceeding several metres per second, on the order of 3 to 10 m/s for Catiline Creek.

Debris deposition occurs either when the channel becomes unconfined, or where the channel gradient becomes too shallow to sustain continued flow. Debris flows typically deposit on a fan, which is often formed over thousands of years from multiple debris-flow deposits. The extent of debris-flow runout on a fan primarily depends on the debris-flow magnitude, velocity and debris texture, as well as the topography of the deposition area. For bouldery debris, Hungr et al. (1984) reported that most debris will begin to deposit in confined channels on slopes less than about 8 to 12° and in unconfined channels on slopes of 10 to 14°. Based on these values, confined or unconfined debris flows on Catiline Creek fan could reach Lillooet Lake.

While most debris flows deposit material on fans, it is also possible for debris flows to scour material from the fan and increase in size. A debris flow in 1995 on Hope Creek, BC, obtained 90% of its material through scour of the existing fan (Jakob et al. 1997). This may occur during times with elevated phreatic (ground water level) surfaces and preferentially in pre-existing (paleo) channels. Debris flow science has not advanced to a point where the likelihood or location of fan scour can be predicted with any degree of confidence.

Debris flows can cause severe building and infrastructure damage in the deposition zone due to high impact forces. Debris deposition can also block or divert existing creek channels causing localized flooding, scour, erosion and debris re-deposition that is difficult to predict, preventing precise delineation of potential impact zones.

3.2. Desktop Study

3.2.1. Previous Geohazard Studies

Previous geotechnical and geohazards studies completed at Catiline Creek are summarized in Appendix B, including studies completed for the development and for individual lots. This section summarizes previous studies pertaining to debris-flow hazard assessment, remediation recommendations, and previously completed channel works. Information on who commissioned the study is listed in the “Client” column of Appendix B.

In 1976 Heather Jean Properties retained PGM to complete an assessment of the proposed development on the Catiline Creek fan. This assessment reviewed bedrock, overburden and creek channel conditions and provided a series of recommendations with respect to development on the fan. The key report recommendations were:

- Implementation of a temporary no building zone within an 800 foot (244 m) wide corridor until completion of in-channel works to further constrain the channel
- Implementation of a permanent no building zone within a 300 foot (91 m) wide corridor upon completion of in-channel works to further constrain the channel.

The term “corridor” refers to the width of land on both sides of Catiline Creek (e.g. 400 feet on either side of the Catiline Creek for a total corridor width of 800 feet). Recommended in-channel works included removal of large blocks at the crest, in the bed, or on the banks of the channel that could form possible obstructions, channel deepening and channel straightening.

Drainage improvements near the FSR and drainage provisions on proposed residential access roads were also recommended as was a ban on logging activities. The scope of this report was for the area above the FSR; however, flood potential below the FSR was also noted.

Following a debris flow event in 1986, Piteau Associates (Piteau) completed a geotechnical assessment of the Heather Jean Property No. 2[5] at the request of Heather Jean Property No. 2. The 1986 assessment noted that few, if any, of the 1976 recommendations were implemented. It was uncertain whether in-channel works to further constrain the channel were undertaken and thus, the 800 foot (244 m) corridor was considered applicable. Buildings constructed within the 800 foot (244 m) and the 300 foot wide corridors were observed. This report summarized the 1986 debris-flow characteristics (see Section 4.4.1) and identified 1150 m^3 of remaining material near and above the fan apex. The 1986 report recommended implementation of the recommendations outlined in the 1976 report (i.e. no building within 800 foot (244 m) and 300 foot (91 m) corridors and various in-channel works). To reduce the likelihood of debris obstructing the existing FSR bridge, construction of either a debris basin upstream of the FSR, or a bridge with much greater clearance and regular annual inspection of all active creek channels from the fan apex to the lake was recommended by Piteau (1986).

In 1989, SLRD retained Piteau to review the site conditions and re-assess the previously recommended mitigation measures (Piteau 1989a). Site conditions were unchanged from the previous inspection (July 1987), with the exception of additional debris noted near the upper water tower intake. Channel improvements (entrenchment, straightening, construction of a levee and a deflection channel on the right bank) in the 100 m downstream of the FSR bridge were observed. Based on their assessment, Piteau recommended the following measures:

- Breaking of large boulders along the upper portion of the channel with the potential to block the channel (using portable hand held equipment – Photograph 1; Appendix C)
- Channel realignment and entrenchment, removal of loose debris in the channel, and construction of levees in the vicinity of the upper water tower intake
- Cleaning, straightening and side slope trimming at specific locations along the channel (totaling 400 m)
- Realignment of approximately 170 m of the channel (exact requirements not specified)
- Construction of a debris check dam/containment basin (Photograph 2; Appendix C)
- Straightening, entrenchment, cleaning and trimming below the debris check dam to the log trash racks immediately above the FSR
- Removing debris partially obstructing the FSR bridge clearance
- Potential realignment of channel below the FSR considering proposed development footprint.

[5] Heather Jean Property No. 1, No. 2, and No. 3 were the three trust indentures referenced in Schedule A of the Land Use Contract. Heather Jean Property No. 2 encompasses at total of 60 lots in two groups: (1) 15 lots located below the FSR, northwest of Catiline Creek, and (2) 45 lots above the FSR, southeast of Catiline Creek. Heather Jean Properties No.1 to No. 3 are currently referred to as Lillooet Lake Estates.

Previously recommended remedial measures at the fan apex were eliminated based on the opinion of Piteau that they would be costly and would only provide limited benefit.

Based on review of site conditions outlined above and in Piteau (1989a), in a letter to Squamish – Lillooet Regional District, Piteau re-affirmed the previous recommendation to implement a no building zone within an 800 foot (244 m) wide corridor until completion of remedial measures (Piteau 1989b). Piteau (1989a) also noted that the only other active stream on the fan located in the northwest corner of the property (the unnamed creek between Catiline and McCullock Creeks – Drawing 1) may also have potential to produce debris flows. Review of development plans and additional investigation to characterize the hazards were recommended. In a letter to SLRD, Piteau (1989b) suggested a similar restricted development corridor be established along the creek pending clarification of development plans and hazard assessment. BGC's understanding is that a hazard assessment has not been completed for this unnamed creek and such an assessment is outside the scope of this report.

Further clarification of the recommended remedial works were summarized in Piteau's response to a letter from Heather Jean Estates (no copy provided). The estimated containment volume for the proposed debris check dam and catchment basin was estimated as 3,000 to 6,000 m^3 (Piteau 1990). The check dam design incorporated gabion baskets, artificial levees constructed from excavated material, a controlled outlet/spillway to decant ponded water, a stepped downstream face, and erosion control measures downstream of the dam. Piteau (1990) noted that the debris basin would require ongoing maintenance and periodic removal of sediment.

Additional channel works were undertaken by a local contractor in the winter of 1991/1992 (Piteau 1992). Piteau were not involved in these works; however they reviewed the completed works and re-evaluated the debris-flow hazard on behalf of SLRD (Piteau 1992). The inspection concluded that substantial mitigation works were completed above the FSR and although the mitigation works fell short of the recommendations outlined in Piteau (1990), the completed works "significantly" decreased the level of debris-flow hazard above the FSR. No mitigation works were undertaken below the FSR, and since the upstream debris containment basin was not constructed as per design (undersized and no check dam at the basin outlet), Piteau assessed the level of debris-flow hazard downstream of the FSR as unchanged. Piteau recommended the following additional mitigation:

- Limited amount of channel maintenance, trimming and straightening, ideally under the supervision of a qualified geotechnical engineer
- Annual inspection of the remedial works and the creek (to look for blockages).

In 1998, following a site assessment of Lot 92 (Piteau 1998a), Piteau prepared a letter to the SLRD which noted that based on their site inspection on April 9, 1998 it did not appear that any of the additional remedial measures outlined in Piteau's letter to SLRD dated August 19, 1992 (Piteau 1992) had been implemented (Piteau 1998b). The letter also stated that "to our knowledge, it would appear that the recommended annual geotechnical inspections of the creek have not been conducted" (Piteau 1998b). Piteau notes that "substantial" development of the Heather Jean property has occurred since their previous assessment, and that at least some of that development occurred within the restricted zone. Finally, Piteau reiterated that in the absence of mitigating factors, any development within the restricted zone may be subject to an “unacceptable” (not formally quantified) level of risk (Piteau 1998b).

On May 22, 2003, Piteau completed a site assessment on behalf of the owner of Lot 166 (Piteau 2003a). In a letter to the Lot owner, Piteau reiterated that the completion of remedial measures outlined in their letter dated August 19, 1992 (Piteau 1992), and some possible additional channel modification and enhancements, would provide additional risk mitigation to several lots within the development (Piteau 2003a). Annual geotechnical inspection of the creek by a qualified professional geotechnical engineer was once again recommended (Piteau 2003a).

In 2004, following a debris-flow event the evening of July 6/7, the area was inspected on behalf of the Ministry of Forests (MoF) (Bartle 2004). The FSR and bridge was repaired following the event. The MoF observed an abundance of loose debris in the channel and noted in letters to the SLRD (MoF 2004a) and to Heather Jean Estates (MoF 2004b) that the effectiveness of existing protective measures along the creek were likely reduced following the event. The MoF recommended inspection of the existing protective measures by a Qualified Professional. It is unknown if such an inspection occurred or if repair works outside the jurisdiction of the MoF were undertaken; however local residents do not recall any mitigation works being completed following the 2004 event (pers. comm. Gary Young). Recommended remedial works within MoF jurisdiction included maintaining historical flood control measures on the FSR, maintaining the catchment basin above the FSR, and debris removal below the FSR bridge (Bartle 2004).

In 2005 the SLRD retained Baumann Engineering to complete a brief helicopter reconnaissance to identify any obvious geological hazards posing an imminent threat to residents in light of a major storm system affecting the area (Baumann Engineering 2005). No immediate threat was identified; however it was noted that the main road was impassable due to thick ice that would hamper evacuation should it be necessary.

On September 28, 2010 a debris flow blocked the FSR at Catiline Creek and prompted an emergency assessment by Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO) (Cordilleran 2010). Cordilleran mapped the affected area on the fan, estimated the debris volume and described damages. The event partially avulsed above the FSR depositing a lobe on the left bank fan surface, with flood water travelling down road to reach the FSR. The main lobe crossed the FSR and buried a truck parked outside a house on the right bank. To restore FSR access the following work plan was recommended to the MoF (Cordilleran 2010):

- Follow operational shutdown guidelines when working near the channel
- Clear the road, clear the bridge opening, replace guardrails and eroded abutment fill, perform a structural inspection of the bridge

- Clear the debris plugs above and below the FSR and re-establish the creek into the main channel.

Recommendations for the Lillooet Lake Estates property were beyond the scope of the Cordilleran memo (2010). In July 2011, Kerr Wood Leidal Associates (KWL) reviewed the site and provided short-term recommendations to LLE for limited works on Catiline Creek. Short term recommendations to re-establish hydraulic capacity included the following measures (KWL 2011):

- Excavation of areas with locally elevated bed levels to reduce the likelihood of avulsion
- Excavation of select sections of Catiline Creek.

KWL recommended the above works be designed and the construction reviewed by a Qualified Professional. It was recommended that works be completed in a timely manner (in advance of the fall rainy season). Emergency management BC allocated SLRD funding to complete this work (KWL 2011). Finally, KWL noted that any hazard mitigation works should be aware of and consider in their design “transfer of risk” issues to adjacent or downstream areas.

Long term recommendations included:

- Review of the flood and debris-flow hazards be conducted as a first step in preparing a comprehensive long-term debris-flow mitigation plan
- Develop and Implement an Emergency Response Plan.

On August 30, 2013 at 1:30 AM, another debris flow occurred at Catiline Creek. On behalf of the MoFLNRO, Cordilleran completed a site assessment, mapped the deposit, estimated the volume and described damages (Cordilleran 2013). The following key recommendations were made to MoFLNRO:

- Clear the debris from the road and re-establish the catchment basin
- Complete an engineering inspection of the bridge once debris is cleared and prior to allowing regular traffic to resume
- Clean the channel between the lake and the fan apex again
- Reconsider the completed works below the road as they were overwhelmed by the 2013 event
- Complete a Quantitative Landslide Risk Assessment for Lillooet Lake Estates
- Based on the findings of the risk assessment, develop and implement a landslide risk mitigation plan.

For works outside the MoFLNRO scope, SLRD obtained up to $250,000 funding from Emergency Management BC to re-establish the previous creek channel and bank alignment to restore the site. Project costs totaled $197,793 for construction, engineering and environmental costs. Construction work was completed under the supervision of Kerr Wood Leidal from September 6 to 18, 2013. Debris removal/restoration work included the following measures (KWL 2013):

- Restoration and debris removal within the small debris basin upstream of the FSR bridge

- Restoration and debris removal of the creek downstream of the FSR bridge including re-construction of the eroded right creek bank at the avulsion location
- Removal of debris from the avulsion deposition area below the FSR bridge.

The creek channel was restored but no mitigative works were constructed and KWL concluded that the debris-flow hazard had not been reduced from the pre-event condition.

In addition to the above fan-wide studies and channel work, assessments have also been completed for individual lots. Prior to issuing a building permit, the SLRD requires that as per Section 56[6] of the Community Charter, "a professional engineer with experience in geotechnical engineering determines and certifies that the land may be used safely for the use intended, subject to conditions contained in the engineer's report" (Piteau 2003b, SLRD 2014a).

Individual lot assessments were completed for lot nos. 5, 6, 13, 16, and 166, as well as the water treatment facility approximately 520 m upstream of Lot 166 (GVH 2013; P.K. Read 2008a, 2008b, 2009a; GVH 2012; P.K. Read 2009b; Piteau 2003a, 2003b). The lot numbers are illustrated in Drawing 2, and conclusions of these reports are listed in Appendix B. Note that conclusions of the individual lot assessments are described for reference, but were not "relied upon" to form conclusions in this assessment.

Piteau (2003b) also notified the SLRD that a dwelling on Lot 165 had been constructed in a location within the restricted development corridor that was "unacceptable" from a geohazard risk perspective in that it appeared to have been constructed in an old channel. BGC understands the SLRD informed the resident of Lot 165 in a letter dated July 2003, but based on the SLRD's understanding and BGC's fieldwork, the residence is still there and appears occupied (SLRD 2014b).

3.2.2. Anecdotal information

Mr. Young provided some old photos and archival information collected by the Hills family, previous owners of the A-frame in Lot 42, below the FSR. These materials were reviewed and select photos scanned (Appendix C). Anecdotal information about debris-flow frequency and a 1987 debris flow was also gathered from Mr. Klassen. He described a stay at their cabin during the summer after the documented 1986 debris flow. During the day their kids were playing in and around Catiline Creek near the FSR bridge. One hour after being called in for dinner, a debris flow impacted the FSR crossing where the kids had been playing. A picture of the kids on the fresh debris was provided (Photograph 3; Appendix C). The event was attributed to a localized thunderstorm. Mr. Klassen also described how frequent small events in the upper basin are: in any given year distinct periods of loud rumbling would be noted "10s" of times, but the rumbling did not appear to coincide with a similar number of events reaching the fan apex. Mr. Klassen interpreted this to mean that frequent small rock fall fills

[6] Section 56 of the Community Charter supersedes Section 699 (5) of the Local Government Act (Piteau 2003b) and Section 734 (2) of the B.C. Municipal Amendment Act (Bill 62, 1985) (Piteau 1998a).

the feeder channels and less frequent events scour this material and deliver it to the fan. Another resident, Horst Joost, suggested that there were more than the recorded number of debris flows reaching the feeder channel and/or fan apex area, but that they escaped notice due to their small size and confinement to the proximal fan.

3.2.3. Incidents of floods, landslides and rock fall around Pemberton, 1808-2006

Septer (2006) data-mined newspaper and published literature to create a provincial record of flooding and landslide activity. This data catalogue was reviewed to develop a record of event generating storms affecting the Pemberton area, as these storms are candidate storms for triggering landslides on Catiline Creek.

For Pemberton, the first record is the Meager Creek 1931 debris flow related to October rains. Other significant events are major flooding on Lillooet River in October 1940, 1984 and 2003, and events in 1981 and 1991 that destroyed bridge crossings on Rutherford Creek. The incidents of flood, rock fall or landslides around Pemberton are listed below:

- October 1931 (Meager)
- January 20-27, 1935
- October 27-29, 1937
- October 19-20, 1939
- October 17-20, 1940 (flood of record since July 19, 1918)
- July 13-15, 1946
- November 27-December 4, 1951
- December 1-3 1955
- September 5-6 1957
- April 29-30, 1959
- January 8-17, 1961
- November 20-25, 1966
- October 30-November 1, 1967
- January 12-20, 1968
- October 29, 1968
- July 22, 1975 (Devastation)
- October 29-November 6, 1975
- December 23-27, 1980
- October 27-31, 1981
- January 1-4, 1984
- October 6-12, 1984 (Preacher’s quote: the biggest one since 1940)
- October 4, 1990
- November 6-13, 1990
- November 16-24, 1990
- August 7-9, 1991
- August 27-31, 1991

- October 23-24, 1992
- March 17-26, 1997
- May 31-June 1, 1997 (Gowan)
- June-July 1999
- October 16-22, 2003
- January 16-31, 2005.

In summary, Septer records 32 event storms affecting the Pemberton area between 1930 and 2006, or one every 2 to 3 years. The record is likely incomplete for the period before development in the 1970s and more local, non-regional event storms have triggered events at Catiline (e.g. 2004). As such these averages should be interpreted with caution. Moreover, debris flows do not occur on Catiline Creek every time threshold rainfall conditions are exceeded, as some time is needed between events to recharge the channels with debris. This is a common phenomenon in debris-flow channels (Church and Miles, 1987, Jakob et al. 2005) that increases uncertainty in debris flow volume and frequency prediction.

3.2.4. LiDAR Data

Light Detection and Ranging (LiDAR) is a remote sensing technology used to examine the earth's surface and make high-resolution maps. It measures distance by illuminating a target with a laser and analyzing the reflected light, The technology uses ultraviolet, visible, or near infrared light to image objects, and wavelengths are varied to suit the target, including for example, non-metallic objects, rocks, trees, houses, rain and cloud.

For this project, airborne LiDAR was used to collect high-resolution imagery of the ground surface. The data collection was scheduled for June 30th and July 1st, 2014, with a cloud free sky (McElhanney 2014). The watershed was snow free, except for a small amount of residual snow on parts of the ridge crest. Two main map products were derived from the LiDAR: a 5 m contour interval map base and a hillshade relief image. Additionally, McElhanney was asked to identify house locations where possible.

The high resolution LiDAR images are very useful for illuminating details of the land's surface expression. The hillshade model defines slope aspect changes very well, and is especially useful for delineating ridges and linear features. Surface texture may also be useful for discriminating different landform types, such as irregular rocky slopes versus smoother colluvial deposits. The LiDAR imagery was used to create geomorphic maps of the basin and fan (Drawings 5 and 6).

In the lower reaches of the basin along the feeder channel, substantial volumes of debris has collected and is available for entrainment, forming a significant sediment source in the watershed. Scarps and channels in these gully fills indicate past erosion and entrainment of these materials.

A most distinct feature in the watershed are structural lineaments in bedrock. These are well defined and are comprised of several sets (E/W, NE, ESE and SE) consistent with the bedrock structure reported by regional mapping and observed by airphoto.

Along Lillooet Lake the LiDAR allowed for precise delineation of several distinct geomorphic features, including:

- Talus cones and aprons formed along the base of the steep, rocky, mountain front, and confining the edge of the Catiline Creek fan
- Raised, kame terrace features on the east side of Catiline Creek fan, and a matching surface remnant to the west above Unnamed Creek fan
- Abandoned channels bounded by boulder levees
- Lobate forms on the upstream or downstream ends of abandoned channels.

The interrelationship of these features can be used to deduce relative age and activity of the various landform elements. Based on geomorphic inferences from LiDAR, the Catiline Creek fan area has been divided into several zones:

- The northwest sector lying to the north of a prominent abandoned channel and south of the Unnamed Creek fan.
- The central sector lying between this prominent paleochannel and the west flank of the kame terrace. The central sector is further divided into a proximal zone extending down to about the 260 m contour, and distal zones on the lower fan on the north and south sides of the creek.
- The northeast sector inset into the upslope end of the kame.

The kame was formed at the waning stages of the last ice age (10-12 ka; Friele and Clague, 2002). The surface of the kame displays a ridge perpendicular to the fall line and this is interpreted as a till ridge. West of the till ridge are lobate forms that overlie the kame surface, suggesting that debris flows have and may overrun the kame terrace surface. Thus, although incised by the east and central sectors of the fan, areas of the kame surface not yet impacted by debris flows could possibly be overrun by a rare, large event.

Along the north side of the northwest fan margin there is a debris track that is partially obscured by talus encroachment. This indicates that talus formation postdates channel formation, and suggests that the NW channel is relatively old (i.e. thousands versus hundreds of years). This suggests the NW-most fan sector is relatively less active than the central fan sectors.

The east portion of the fan at the apex overlies or is inset in the kame, and appears to be a series of two sequentially inset surfaces. On the older, higher surface there is an abandoned channel plugged by a lobe at its upstream end. Overlying this is a large blocky deposit 125 m wide by 150 m long. The surface of the blocky deposit consists of 1 to 4 m diameter angular blocks, and may be derived from a rockslide onto the fan. At the fan apex, this deposit is incised up to 15 m by the modern channel, and it appears to confine modern, high to moderate frequency debris-flow events.

The central portion of the fan is inset into the northwest and east sectors, and displays an irregular, undulating to channeled surface expression. In the proximal zone, aside from the modern channel and the abandoned channel defining the north edge, the lack of abandoned channel forms suggests that debris deposition dominates. In the distal zones, short abandoned channel reaches are evident, indicating primarily debris transport through this reach.

The northwest fan sector is considered the least active; while the central fan sector is most active.

3.3. Field Investigation

The primary objectives of fieldwork were to collect field evidence in support of the following work:

- Hazard assessment: field estimates of debris-flow hazard extent, frequency and magnitude based on surface mapping, stratigraphic mapping in test pits, and tree core samples for dendrogeomorphic analysis.
- Vulnerability estimation: field observations supporting estimates of vulnerability of residential buildings to debris-flow impact.
- Mitigation assessment: field observations of existing mitigation works and supporting development of debris-flow risk reduction options.

Fieldwork was completed in three separate visits on June 15-18, July 24-25, and September 8, 2014.

The June 15-18 fieldwork was completed by Matthias Jakob, P.Geo. and Kris Holm, P.Geo. of BGC, and Pierre Friele, P.Geo. of Cordilleran Geosciences. This work focused on hazard characterization and included traverses and surface mapping of the fan, a low level helicopter overview flight of Catiline Creek basin, and a ridge top traverse at the head of the basin. Field observations on the fan surface include landform mapping, location and geometry of abandoned channels and debris lobes, description of grain size and roundness, identification of signs of recent (e.g. 0 to 200 yr BP) debris impact including stem burial and scarring. Field observations in the basin included identification and inspection of potentially unstable areas within the basin, and inspection of lineaments and tension crack features at the slope crest. On June 16 Mr. Friele directed backhoe test pitting, using a machine supplied by Lizzie Bay Logging Ltd. A total of 8 test pits, 3 to 5 m deep were excavated and described (Appendix D). All test pits were backfilled immediately after they were logged.

The July 24-25 fieldwork was completed by Matthias Jakob, P.Geo. and Emily Moase, E.I.T. of BGC, and included dendrochronology sampling of trees on the Catiline Cree fan.

The September 8 fieldwork was completed by Alex Strouth, P.Eng. and Kris Holm, P.Geo. of BGC, and included a site reconnaissance to assess potential mitigation options.

The results of fieldwork are described as part of the frequency-magnitude analysis (Section 4.0) and risk reduction options assessment (Section 7.0).

4.0 FREQUENCY – MAGNITUDE ANALYSIS

4.1. Introduction

Frequency-magnitude (F-M) relations are defined as volumes or peak discharges of landslides related to specific return periods (or annual frequencies) of their occurrence. This relation forms the core of any hazard assessment because it combines the findings from frequency and magnitude analyses in a logical format suitable for numerical analysis.

Any frequency-magnitude calculation that spans time scales of millennia necessarily includes some judgment and assumptions, both of which are subject to uncertainty. BGC has used multiple approaches to characterize hazards and estimate their magnitude and frequency of occurrence, as described in Section 3.0 and below. Each approach provides partial insight that, taken together, gives the best possible estimate with the data available. Uncertainty can further be addressed by building in redundancies and freeboard in engineering measures.

This section uses the terms “frequency”, “hazard probability” and “return period” interchangeably, depending on the context. Frequency is numerically equivalent to hazard probability, and is defined as the annual probability of occurrence of a hazard scenario. Return period is the inverse of frequency, and is defined as the average recurrence interval (in years) of a hazard scenario. For example, an annual frequency of 0.01 corresponds to a 100 year return period.

4.2. Frequency-Magnitude Model

There are no commonly applicable rules in Canada to define the range of hazard event frequencies or return periods that should be considered in an assessment. However, regulatory guidance and/or legislation worldwide mandate a range from several tens of years up to 10,000 year return periods. For example, in British Columbia, Canada, the current guidance to Ministry of Transportation approving officers is that a 10,000 year return period be considered for all life threatening landslide processes (MoTI 2009). This guidance contrasts with a more structured approach developed for the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC 2012) “Guidelines for Legislated Flood Assessments in a Changing Climate”. In these guidelines, the scale of future (and existing) development to be protected guides the return periods to be considered. For example, for very high loss potential sites, which would apply to Catiline Creek, the APEGBC guidelines stipulate that an event up to 2,500 year return period be considered. Lastly, hazard tolerance criteria developed by Cave (1992) suggest consideration of up to a 10,000 year return period for new subdivisions.

These relatively high return period ranges are more conservative than the present standard of practice in Austria and Switzerland, where return periods of up to 150 years and 300 years are considered, respectively and, in the case of Switzerland, consider residual risk for return period exceeding 300 years (Hübel, pers. comm.). In Switzerland, hazard maps are then based on a combination between debris-flow intensity and the occurrence probability. Rudolf-Miklau et al.

(2011) provide an overview of the hazard and risk assessment guidelines in various European nations.

Once events have been documented and their age and volume estimated, return periods need to be assigned to individual events that allow extrapolation and interpolation into annual probabilities beyond those extracted from the physical record. Such record extension is necessary to develop scenarios across the return period range under consideration. These scenarios then form the basis for debris-flow modelling and risk analysis (e.g. Sections 5.0 and 6.0).

In this context, judgement is required to assign magnitudes for very long return periods (thousands of years) and the degree of error is proportional to the length of the return period. This high degree of uncertainty can be addressed through secondary lines of defense or contingency plans should the channel aggrade significantly over time.

4.3. Uncertainties

While based on the best available data, estimates of landslide frequency and magnitude span time scales of millennia and require judgment and assumptions that are subject to uncertainty.

Uncertainties include:

- Older events are covered by new ones, thus obliterating evidence
- For very old events, organic material is often not found in test trenches
- Trees are not always scarred by debris flows, or reaction wood is not formed due to deposition of sediment around the tree, and thus do not necessarily leave sufficient evidence for dendrochronologic dating
- Tree scars can be misleading, as scars are often formed by trees falling on trees, animal scratching, frost scars, fire scars and scars from trail blazing
- Debris-flow layers discovered in only one or two test pits cannot be correlated across the entire fan to yield reliable volumes
- Test trench soil stratigraphic information may be ambiguous
- Airphotos may not show small debris flows that flow through forested areas without creating visible swaths of damaged vegetation and deposits
- Access constrictions (e.g. housing development) or budget limitations do not allow test trenching equally distributed over the fan.

Assumptions include:

- The probability of occurrence of debris flows during a time interval is low and the probability of two or more simultaneous events is negligible in the same main channel (see McClung 1999 who describes this for snow avalanches).
- The premise of stationarity over time (no long term trend in the frequency of debris flows), and that they underlie an ergodic (independence from initial conditions) stochastic process.

Both of the above assumptions can be questioned. For example, extrapolation of high return periods from the initial record length is done with only limited information on how climatic or geomorphic watershed conditions may have changed during this time. Changes in vegetation cover, wildfire suppression, changes in the frequency and/or magnitude of hydroclimatic events and the occurrence of cataclysmic events such as large landslides will influence levels of hazard and associated risk.

Despite these limitations, a combination of field and analytical techniques, as well as geomorphic reasoning, can reduce uncertainty and allow the derivation of a plausible debris-flow frequency-volume relationship. The key is to view frequency–volume estimates as credible proxies for true events rather than precise estimates. These estimates are then used to determine key consequences and risks that support risk reduction decision-making.

4.4. Frequency Analysis

Debris-flow frequencies were estimated by three direct dating methods: airphoto interpretation of photos dating back to 1948; dendrochronology; and test trenching with visual classification of soils.

4.4.1. Recorded Debris Flow Events

Documented debris-flow events at Catiline Creek occurred in 2013, 2010, 2004, 1987 and 1986. The August 1987 event was reported by residents (pers. comm. Ed Klassen) but no written documentation for the event was identified (Photograph 3; Appendix C). A 1990 or 1991 event (possible several events) was identified in discussions with local residents (pers. comm. LLE residents) (KWL 2011), but again no written records exist. However, in 1990-1992 there were six storm events that caused landslide/flood events in the Pemberton area (Septer 2006), so it is possible that a small event reached the fan without causing sufficient harm to alert authorities (i.e. no damage to FSR, or avulsion onto the fan surface affecting property or houses).

The October 26, 1986 debris flow initiated above the fan apex and below the intersection of the two main tributaries (Piteau 1986). The source material was stated to be rock and soil debris that accumulated over several years due to minor slope failures originating from higher elevations. The debris flow travelled down the channel, entraining additional material in the channel. At an unknown distance below the fan apex, debris levees were observed and the channel varied from narrow and well entrenched to wide and poorly defined with limited to no entrenchment. Fresh and historic debris levees were observed on both sides of the channel. Further downstream, fresh and remnant debris levees were observed but the creek appeared relatively well entrenched. Debris flow deposits plugged the culverts beneath the FSR, inundated the road and avulsed to the north before flowing downslope to Lillooet Lake (Photograph 1; Appendix C). Photographs provided to BGC indicate that the event affected the Hills A-Frame residence, enveloping the foundation posts in mud without damaging them (Photograph 2; Appendix C). No evidence of recent debris-flow activity was observed below the FSR in the existing channel. The estimated volume of the 1986 debris flow was 2,700 m^3 (Piteau 1986).

Bartle (2004) reports that the July 6/7, 2004 debris flow initiated from an elevation of approximately 1920 m in the east tributary of the watershed (sub-basin 3b, Drawing 6). Airphotos from 2004 indicate fresh appearing tracks in several other gullies as well (Drawing 4). Local residents reported an intense rainstorm the evening of July 6/7 that likely triggered the event. Debris-flow deposits were observed at the FSR bridge with some debris flowing beneath the bridge to the lake (MoF 2004a). A small cabin on the left bank close to the FSR bridge had debris "at its doorstep", but was not damaged (Bartle 2004). This cabin is still existing and in use. The volume of the 2004 debris flow is unknown.

The September 28, 2010 debris flow initiated from an elevation of approximately 1930 m in the east side of the basin (sub-basin 3b, Drawing 6). The Pemberton Firebase weather station recorded 21.4 mm of precipitation between September 27 at 2200 hrs and September 28 at 0600 hrs, with a peak hourly intensity of 8 mm/hr at 0400 hrs. The Meager Creek weather station recorded 54.2 mm of precipitation between September 27 at 0900 hrs and September 28 at 0700 hrs (peak hourly intensity of 5.4 mm/hr was recorded at 0100 hrs). Thus, local high intensity rainfall was likely the trigger for the event (Cordilleran 2010). The initial debris-flow lobe remained confined, crossed the FSR and plugged the channel immediately downslope. At this point two smaller lobes avulsed to the north and south, each reaching Lillooet Lake. The north lobe buried a truck parked outside the A-frame residence. A second lobe plugged the channel near the upper part of the subdivision and avulsed to the left (facing downstream). Most of the debris was deposited within the 80 m of the main channel, but a small lobe and afterflow material traveled through the subdivision, following roads and shallow gullies just missed another vehicle, damaged a small shed and narrowly missed several houses, blocked several subdivision roads, and just missed the canoe rack at the boat launch (Photos 6 to 12; Appendix C). The estimated volume of the 2010 debris flow was 15,000 to 20,000 m^3 (Cordilleran 2010).

The August 30, 2013 debris flow initiated from the upper part of the watershed in the same gully system that produced the 2004 and 2010 events (sub-basin 3b, Drawing 6). A short, intense rainfall event resulting from thunderstorm activity with peak intensities around midnight was identified as the event trigger (Cordilleran 2013). The debris flow remained confined along the ~900 m length of channel to the debris basin immediately upstream of the FSR, filled the basin, deposited 4 to 5 m of debris on the FSR, and then continued down the channel. A large debris lobe was deposited on the south bank, plugging the channel at a footbridge crossing. The flow then avulsed north, overrunning the boat launch and reaching the beach. The north lobe swept over the driveway of an A-frame house, pushed the same pickup that was buried in 2010 into the lake and destroyed a boat rack full of boats (Photo 7; Appendix C). The estimated volume of the 2013 debris flow is 10,000 to 25,000 m^3 (Cordilleran 2013). Note that several buildings along the creek corridor narrowly escaped being struck by debris (KWL 2013).

The 2010 and 2013 Cordilleran assessments noted an area of tension cracks at the crest of the slope in sub-basin 3b and a potential rock fall source with an estimated volume of 7,000 to 10,000 m^3. These are noted as “tension cracks” and “slope distress features” on Drawing 6.

In summary, records and anecdotal information suggest debris flows have occurred in 1986, 1987, 2004, 2010 and 2013, 5 events since about 1970, or one every 9 years. These are events ranging in size from 5,000 to 30,000 m^3.

4.4.2. Airphoto Interpretation (API)

Airphoto were interpreted for photos dated 1948, 1951, 1969, 1973, 1977, 1981, 1987, 1993, 1997, 2004 and 2004. For each year, bright or fresh scars, debris tracks and areas of disturbance on the fan were identified and plotted onto a 1:20,000 scale TRIM map base. Observations are summarized in Table 4-1. Select airphotos are shown in Drawing 4 and Figure 4-1 and Figure 4-2. Drawing 3 shows channel numbers that are referenced in the descriptions below.

Limitations on API included moderate to poor image quality. Tones were typically muddy, and some sets supported strong shadows that prevented good observation of channels in the steep basin. Some photos were overexposed and more than 50% of the airphoto series were of small scale (1:30,000 to 1:70,000). Due to variations in exposure, shading and scale, it was difficult to confidently determine differences between photo years and identify fresh scars and tracks.

Due to the above limitations, airphotos were of limited use to identify individual events. To the list of historic events developed from background material, we add one event sometime just prior to 1948, possibly related to an October 1940 flood-generating storm, although this event is speculative.

Historic airphotos were of greater use to observe bedrock structure, characterize sediment sources and identify the most active gullies. Channels 1 to 5 are active channels visible as early as 1948, and channels 3 to 4 are the most active with fresh tracks converging towards and reaching the fan apex (Drawing 3). It appears that frequent (on the order of annual or more frequent) rock fall events in the upper basin provide sediment to the feeder channel. Thus the headwater gullies and the feeder channel are sediment sources and debris flows may increase in volume by entrainment of this material.

On the east side of the basin there is a NNE/SSW trending lineation followed by a south draining creek; this lineation cuts across the head of channel 3b where previous assessments (Cordilleran 2010, 2013) identified gaping tension cracks and the potential for future rock fall activity. A second sub-parallel lineation was noted about 400 to 500 m west in the central part of the basin; this feature lines up with a large rock fall scarp in channel 3b, and a fresh debris track in channel 4a. These lineations may align with regional structures (foliation) shown on bedrock maps (Roddick and Hutchison, 1973) and represent a structural control on rock fall.

In summary, debris flows reaching the fan apex have varied sediment sources including dry ravel, rock fall and rockslides from gully sidewalls and headwalls, and channel sediment entrainment along the lower feeder channel. Debris flows in the main channel may involve a single channel or multiple channels that converge upstream of the fan apex.

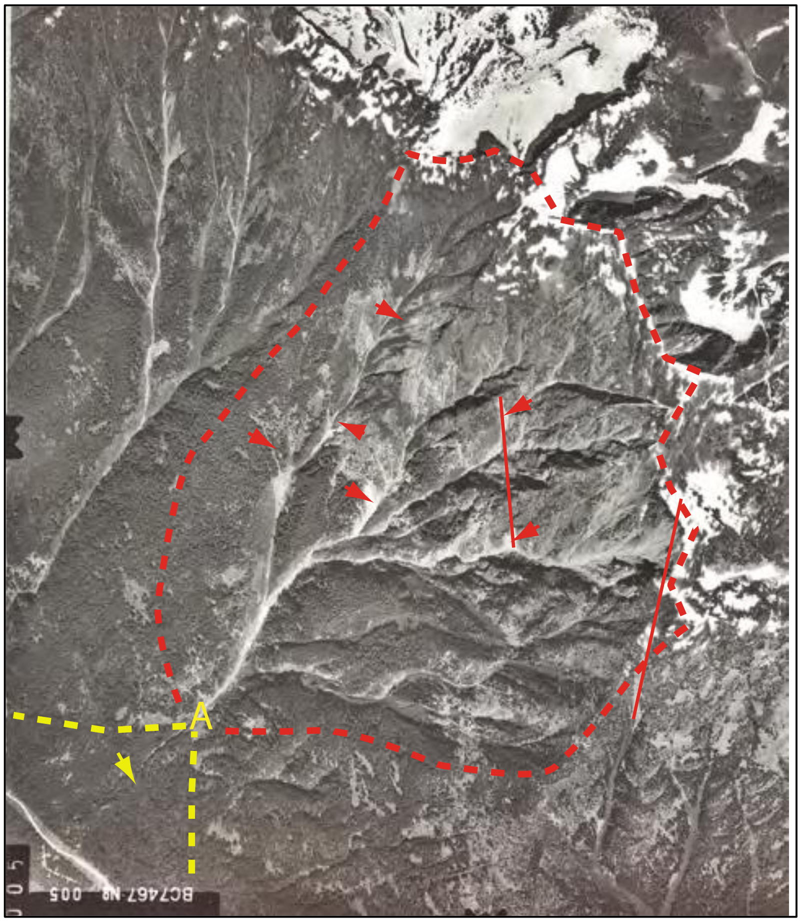

Figure 4-1. View of Catiline Creek basin (red dashed line) and fan (yellow dashed line, A is fan apex) from 1973 airphotos BC7467:4-6 (original scale 1:15,000).

Note fresh scars (red arrows) and bright (whitest) track areas. Disturbance reaches to upper third of fan (yellow arrow). Red lines are bedrock lineations.

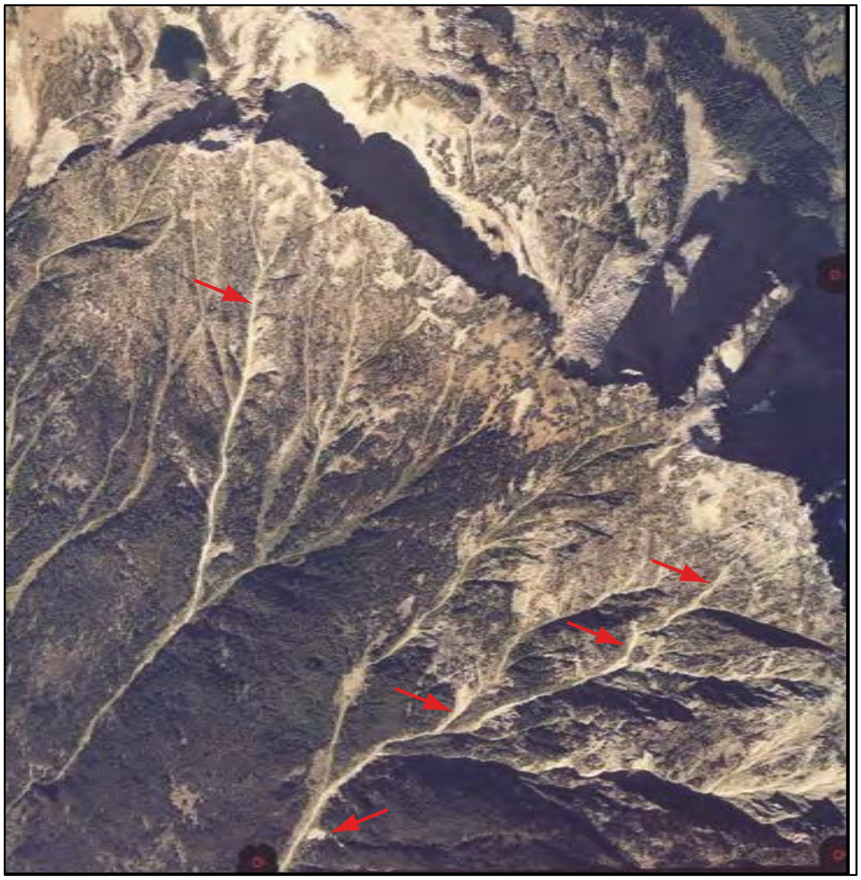

Figure 4-2. Stereo airphoto from October 4, 2004. Debris flow was in July 2004 (see Section 4.4.1).

Red arrows indicate initiation sites. A new rock fall scar appeared near the mouth of channel 2. Due to shading it is difficult to assess whether channel 3 contributed to this event. Note a small event also occurred in the basin to the west, but did not reach the fan.

Due to the dense tree canopy, the incised channel, and perhaps relatively small historic events, debris flows reaching the fan were not visible on the fan. This is best illustrated by viewing the 2005 photos that show the fan area, with no clear disturbance related to the 2004 event although it is known to have reached the FSR.

Table 4-1. Observations from airphoto interpretation, Catiline Creek 1948-2005.

Series	#s	Year	Scale	Observations
BC497	26-27	1948	1:64,000	Strong shading obscures east side of basin. No logging; Fresh appearing tracks in channels 3, 4b & 5a 3; fresh debris reaching apex. Channel is in same position as today.
A13249	83-84	1951	1:70,000	Dark, shaded photos make API difficult. Shore based logging on lower fan; cannot assess tracks in basin; possible disturbance on upper 1/3 of fan.
BC5340	121-122	1969	1:45,000	Well exposed photos. Entire fan complex logged, except eastern, kame ridge of Catiline fan. Hydro RoW and access road recently constructed. Fresh track on unnamed basin to west reaches apex. In Catiline several fresh appearing tracks, similar to 1948, and disturbance reaches apex; on the fan, the channel is more visible because of recent logging.
BC7467	4-6	1973	1:15,000	Excellent exposure, scale & visibility. Subdivision started with access road below FSR. Several tracks appear fresh, similar to 1948, with disturbance reaching apex.
BR77063	6-7	1977	1:35,000	Medium quality photo. Several more subdivision roads built. No new tracks in basin; no disturbance on fan.
30BC81114	137-139	1981	1:20,000	Medium quality photo. Subdivision road built to apex of fan. Possible fresh track from channel 4c; disturbance reaches fan apex.
15BC87098	71-72	1987	1:70,000	Upper basin overexposed. Channels not clearly defined. No apparent disturbance on fan.
30BCC93095	54-55	1993	1:15,000	Coverage for only central part of basin and feeder channel. Apparent fresh tracks in channels 3, 4b, 4c & 5a, and along feeder channel.
15BCB97027	111-112	1997	1:40,000	Good exposure of basin and fan. No new tracks.
30BCC04052	125-126	2004	1:15,000	Photos only cover part of basin and feeder channel, but not the fan. Taken October 4, so July 2004 event is recorded. Fresh track in unnamed basin to west, but does not reach fan apex. In Cataline, fresh track in channel 1 reaches fan, fresh track in channel 2 does not reach apex, and fresh rock fall at mouth of channel 6.
30BCC05086	87-89	2005	1:15,000	Upper basin truncated, but entire fan visible. 2004 track is visible to apex, with bright area near FSR indicating deposit there.

Historic airphotos dating to 1948 were useful to make regional observations on bedrock structure, characterize sediment sources and identify the relatively most active gullies. However, moderate to poor image quality limited their use to identify individual events. To the list of historic events developed from background material, we tentatively add about 5 events reaching at least the fan apex since sometime just prior to 1948.

4.4.3. Test Trenching and Fan Surface Observations

Trenches were excavated to explore fan sedimentary stratigraphy in an attempt to distinguish different debris-flow deposits. Test pit (TP) descriptive logs and photographs are included in Appendix D.

The principal objectives of the test trenching into the fan deposits were:

- To examine the stratigraphy of the test pits and determine the likely origin of the materials in question (for example, glacial till, debris-flow diamicton, rock fall debris)
- To search for, and obtain organic materials that would allow radiocarbon dating which would allow the designation of ages to overlying debris flow units
- To allow the measurement of the thickness of debris-flow deposits and thus support an estimate of specific debris-flow volumes.

In test pits TP1, TP6 and TP7 there are interbedded sandy gravel and unsorted massive debris, indicating fluvial action between successive debris-flow events. At test pits TP4 and TP5 there is a surface unit >6 m thick, of unsorted massive debris deposits with little or surface soil development. At TP2, TP3 and TP8 there are several stacked unsorted, massive debris units, revealing debris thicknesses on the order of 100 to 200 cm. Well-developed podzols (which typically indicate soil development over a period of millenia) were not observed anywhere in test pits.

There are no direct records of moderately frequent events (e.g. those with return periods of at least decades). The units all displayed a lack of well-developed podzolic soil horizons, suggesting that the interval between successive events is less than 1,000 to 2,000 years. In many areas burial of the lower stems of logged stumps was noted (e.g. Photograph 19; Appendix C), implying debris flows affected the forest that existed prior to logging (~50 years ago). This would indicate debris flows affected portions of the southern distal fan at various times between 50 to 500 years ago.

In the east sector at the apex is a 100 wide by 200 m long deposit formed of blocky debris, with angular blocks up to 4 m diameter. The deposit is entrenched by the central fan. This deposit indicates that large rockslides (>100,000 m^3) have affected the fan apex at least once since deglaciation. Only one discrete deposit was identified which is eroded and inset by the younger, more active central fan. This suggests that large rockslide events occur rarely, with a return period on the order of thousands of years.

4.4.4. Dendrochronology

Dendrochronology is an absolute dating method where annually distinct tree rings are used to determine the age of a tree. Dendrogeomorphology, a sub-discipline of dendrochronology, focuses on geomorphological processes that influence tree growth. It is used to date geomorphic events such as debris flows and debris floods.

Depending on the ages of trees along the mainstem channel of a creek, dendrogeomorphology can extend the frequency record of debris floods past the airphotograph record. Depending on the quality of data sampled, dendrogeomorphology can potentially be precise to the nearest year in dating growth disturbances, and in some cases, even the seasonal timing of growth disturbance can be deciphered (Stoffel and Bollschweiler, 2008).

Dendrogeomorphological analysis does not allow a clear designation of process type; thus, the dated events may have been debris flows or other natural hazards. However, sampled trees were selected specifically to avoid possible influence from other processes. Not all noted historical events are preserved in the tree ring record, as some trees have been destroyed or transported by large debris flows, or removed during fan development.

Cores from 25 coniferous trees were sampled on July 24, 2014 (Drawing 7). Two species were sampled: Douglas fir (*pseudotsuga menziesii*) and Western Red Cedar (*thuja plicata*). The growth rings in these samples were analyzed to identify anomalies that may be associated with debris-flow events. Appendix E outlines the processes of dendrogeomorphological analysis in further detail.

Six dates were observed in the dendrogeomorphology samples that are interpreted to show debris-flow-related growth reactions. Drawing 7 shows the location of all sampled trees as well as the dates and extents of observed growth disturbances. Event dates are summarized in Table 4-2, along with corresponding dates from airphoto interpretation and recorded events. Given limitations of sampling, Table 4-2 should be considered a partial record of event dates and impacted areas.

Table 4-2. Debris-flow event dates inferred from dendrochronology.

Inferred Debris-Flow Date	Date(s) From Sample(s)	Number of Affected Samples	Corresponding Data
1905	1905 to 1908	3, 2 scars	
1951	1951 to 1955	7, 2 scars	API1 1948 to 1951 event
1964	1964 to 1968	3	API 1951 to 1969 event
1980	1980 to 1985	4	API 1977 to 1981 event
1991	1990 to 1996	10, 4 scars	1990/1991 recorded event, and API 1993

Note: [1]Airphoto Interpretation (API)

The dendrochronological analysis did not permit the delineation of previous flows on the fan, largely because the fan has been logged and most trees postdate debris flows which would have led to growth reactions. Nonetheless, the analysis confirmed known events as well as provided new event dates that were previously unknown.

4.4.5. Summary

Table 4-3 lists the years with known debris-flow events. Airphoto, stratigraphic, geomorphic, and dendrochronological evidence support the following conclusions:

- The lower subaerial (above the water) fan has been impacted by debris flows for over 10,000 years.
- At least 11 debris flows have reached the fan in the past 66 years, which implies an average return period of six years. It is likely that some debris flows were missed in the older air photograph record or were counted as a single event even though more than one event actually occurred. As such, the true return period of any debris flow is likely higher, perhaps five years. The events of 1986, 1987, 2004, 2010, 2013 all reached Lillooet Lake.
- While the most recent recorded debris flows occurred in the late summer or fall, debris flow may occur any time between spring and late fall. It is unlikely that debris flows will occur when the upper basin is covered in a thick winter snowpack.
- Very rare debris flows are conceivable if associated with a large rockslide originating at Twin Goat Peak. The frequency of such event is unknown but conservatively estimated to be associated with a 10,000 year return period. A single rock slope failure of a dilated rock mass at Twin Goat Peak plus a maximum yield rate in the channel sections below would results in the largest conceivable event magnitude (see Section 4.2). Rockslides can occur at any time of the year (e.g. it is not possible to exclude the potential for occurring in winter) but would require sufficient streamflow water to evolve into debris flows.

**Table 4-3. List of debris-flow event years.
Ranges are given when the exact year is not known.**

Inferred Debris-Flow Date (Range)	Data Source
Pre-1948	API, Dendrochronology
1948-1951	API, Dendrochronology
1951-1969	API, Dendrochronology
1969-1973	API
1977-1981	API, Dendrochronology
1986	Recorded
1987	Recorded

Inferred Debris-Flow Date (Range)	Data Source
1990-1991	Recorded, API
2004	Recorded, API
2010	Recorded
2013	Recorded

4.5. Magnitude Analysis

4.5.1. Introduction

Magnitude analysis involves remote-sensed and field interpretations of landslide source zones, estimation of the potential range of debris-flow volumes and peak discharges that could be generated by entrainment of debris within the channel, and estimation of the volume of deposits identified on the fan.

The following sections describes multiple approaches to estimate debris-flow magnitudes on Catiline fan. Each approach provides partial insight into the range of expected events, from small debris flows just reaching the fan apex to the largest credible scenarios. Together, these investigations provide input parameters and calibration for a frequency-magnitude relationship and the debris-flow modelling described in Section 5.0.

4.5.2. Historical Volume Estimates

The following volumes were estimated by previous investigators:

- Piteau (1976) estimated volumes of the smallest debris flow as around 3,000 m^3. Based on the results of the hazard characterization (Section 3.0), BGC estimates that this corresponds to a return period of approximately 5 years and may range up to 6,000 m^3 for this return period class.
- Events recorded in 2010 and 2013 were estimated by Cordilleran Geoscience (2013) as averaging of 17,500 m^3 for the portion depositing on the fan. Accounting for some loss into Lillooet Lake, this may rise to an average of approximately 20,000 m^3. Given two such events in the last 66 years, a return period of approximately 30 years can be associated with events of this magnitude.

4.5.3. Landslide Point Source Input Volumes

Point source input volume is estimated as the volume of landslide material into the channel that triggers a debris-flow event. Volume ranges were assigned based on LiDAR interpretation, helicopter-based inspection of potential failure zones in inaccessible areas, and field observations. Recent debris slide and rockslide scars on sub-basin sidewalls indicate failure volumes of about 300 to 50,000 m^3.

Areas of distressed slope and evidence of a rockslide deposit on the fan suggest larger rock fall and rockslides on the order of 30,000 to 400,000 m^3 could also affect the basin and fan. Twin Goat Peak appears to be the source for the largest potential rockslide volumes, which would be larger than the maximum credible rainfall/rock fall-triggered debris flows.

Several extensive areas of distressed rock were identified (see Drawing 6 and Photograph 20; Appendix C). On Twin Goat Peak, on the subbasin4a-4b divide, there is an area of gaping tension cracks revealing a topple/slide failure mode. The distressed area is about 200 m across the slope, 100 m along the fall line and perhaps 15 m thick, or about 400,000 m^3. Structural measurements indicate a joint controlled failure plane dipping at 35^o slope parallel into the basin. This site is labeled the Twin Goat topple/slide (Drawing 6). A second smaller area of distress was noted on the subbasin 4a ridge, at about 1650 m elevation. The area is about 70 m long along the ridge, 25 m wide and perhaps 10 m thick, or 17,500 m^3. Also within subbasin 4, on the south side of subbasin 4a at 1250 m elevation, there is an area with gaping tension cracking and leaning trees. This area is 50 m by 100 m by perhaps 10 m thick, or 50,000 m^3. At the crest of subbasin 3b there is an area of distressed ground first noted first in 2010. This area is 70 m along the ridge, 30 m wide and 20 m thick, or 42,000 m^3. There are structurally bound convexities visible across basin headwalls that suggest bedrock failures of about 10,000 to 500,000 m^3 have occurred in the past.

4.5.4. Channel Sediment Entrainment Volumes

The basin can be divided into a lower feeder channel joined by five sub-basins, which have been numbered counterclockwise from the mouth. Sub-basins 1 and 3 to 5 all divide into smaller sub-basins, so that in sub-basin 1 for example, there is a confluent reach 1 and two sub-basin reaches, 1a and 1b. The arrangement of channels is shown in Drawing 3 and Drawing 6.

Entrainment is calculated as the product of *Effective Channel Length* and *Yield Rate* in cubic meter per meter channel length. Effective Channel Length is estimated as the length of channel exceeding 12° gradient, considered a minimum threshold gradient for debris entrainment in granular debris-flow channels (Hungr et al. 1984). All Catiline Creek basin channels are steeper than this threshold.

Yield Rate is estimated for each reach by:

- Plotting typical cross sections for various reaches as measured using a mapping program, Global Mapper
- Estimating the volume of the erodible materials within each channel profile based on the shape of the cross-channel profile and airphoto interpretation
- Estimating potential source area volumes by delineating possible landslide areas, including minimum and maximum areas, and plotting longitudinal (downslope) profiles and fitting conceivable failure planes to the profiles.

Total debris yield was then calculated by summing point source landslides and individual channel yields from the intercept of the point source failure with the nearest channel to the fan apex, assuming full entrainment of all available channel debris.

These values were compared to estimates from visual observation from the low level helicopter flight and values reported from the literature (Table 4-4). The headwater gullies are largely rocky and sidewall failures and erosion through the trunk channel[7] will likely contribute the greatest proportion of sediment as it is the widest and has the highest debris yields. As such, lower entrainment rates were typically assigned to the gullies and higher entrainment rates were assigned to the trunk channels (Table 4-5).

Table 4-4. Debris entrainment rates from BC literature (Hungr et al. 2005).

Reference	Location	No. of events	Yield rate (m^3/m)
Hungr et al. 1984	BC Coast	5	6-18
Jakob et al. 1997	BC Coast	2	23
Fannin and Rollerson, 1993	Haida Gwaii	253 196	12.6 24
Jakob et al. 2000	BC Interior	1	28

Table 4-5 lists estimated yield rates and volumes for each channel in Catiline Creek basin. Drawing 3 shows the location of each reach listed in the table.

Channel entrainment scenarios for events reaching the fan apex were estimated by selecting a combination of reach lengths to represent a potential scenario, and considering several scenarios, each with variation in the yield rate assigned to individual reaches. This method places bounds on a potential entrainment volume. Table 4-6 combines point source and channel yield estimates into nine scenarios representing a spectrum of debris-flow events that could occur in the upper basin. Volumes of the different scenarios range from about 13,000 to 120,000 m^3 for “conventional” debris flows, and about 200,000 to 500,000 m^3 for one scenario involving a larger rockslide. These estimates were considered in the frequency-magnitude relationship outlined in Section 4.6.

Several factors introduce uncertainty to the method outlined above. Point source volumes may be highly variable. Without detailed bedrock structural measurements, which is outside the scope of this work, a greater confidence in the source zone volumes cannot be achieved. Debris flows may occur in single channels, simultaneously in multiple channels, and from different starting points (or multiple points) within the channel. Yield rates also depend on the time since the last debris in a given gully (Jakob et al. 2005). The more time has passed since the last debris flow, the higher the potential debris yield. These factors influence the volume of materials contributed or entrained by the flow and result in a large range of potential debris-

[7] A trunk channel is defined as the lowermost channel portion upstream of the fan apex into which side channels discharge.

flow volumes. Given these uncertainties, the estimated values are reported as ranges. Judgment and some simplification are also required to apply estimates to a frequency-magnitude relationship, as described in Section 4.6.

Table 4-5. Estimated yield rates and volumes for channel reaches in Catiline Creek basin. For channel reach locations see Drawing 3.

Channel Reach	Length[1] (m)	Yield Rate (minimum) (m^3/m)	Yield Rate (maximum) (m^3/m)	Volume (minimum) (m^3)	Volume (maximum) (m^3)
1	878	2	5	1800	4400
1A	965	1	7	970	6800
1B	921	1	8	920	7400
2	1251	1	5	1300	6300
3	433	14	40	6000	1700
3A	1226	1	7	1200	8600
3B	1319	2	5	2600	6600
4	321	2	8	640	2600
4A	777	4	7	3100	5400
4B	1378	2	11	2800	15,000
4C	832	0	1	0	800
4D	492	0.5	3	250	1500
4E	747	0	1	0	750
5	692	2	8	1400	5500
5A	1585	1	5	1600	7900
5B	614	0	1	0	600
F[2]1	223	6	42	1300	9400
F1 to F2	205	4	54	800	11,000
F2 to 5	333	5	76	1700	25,000
F5 to F3/4	156	6	30	900	4700

Notes:
1. Length calculated from slope distances
2. F refers to Feeder

Table 4-6. Landslide scenarios used to generate representative debris-flow volumes, Catiline Creek fan.
For channel reach locations see Drawing 3.

Scenarios	Channel Reaches		Point Source		Total (Channel Reach + Point Source)	
	Volume (min.) (m^3)	Volume (max.) (m^3)	Volume (min.) (m^3)	Volume (max.) (m^3)	Volume (min.) (m^3)	Volume (max.) (m^3)
3B+3+Trunk	4,000	74,000	9,000	9,000	13,000	83,000
3A+3+Trunk	6,000	59,000	30,000	60,000	36,000	119,000
1B+1+Trunk	7,000	62,000	40,000	40,000	47,000	102,000
1A+1+Trunk	6,000	54,000	40,000	40,000	46,000	94,000
4B+4+Trunk	6,000	31,000	25,000	50,000	31,000	81,000
4E+4+Trunk	5,000	24,000	15,000	30,000	20,000	54,000
4B+4C+4+Trunk	8,000	66,000	200,000	450,000	208,000	516,000
4D+4+Trunk	6,000	54,000	6,000	12,000	12,000	66,000
5A+5+Trunk	8,000	64,000	24,000	48,000	32,000	112,000

4.5.5. Test Trenching and Fan Surface Observation

The distal (furthest) south sector of the fan contains a series of short abandoned channel reaches and lobate topography, including several unvegetated openwork boulder lobes. Several identified lobes (Drawing 5) have areas of 500 to 5,000 m^2.

BGC applied a relationship between debris-flow volume and area calibrated to a large global dataset (Griswold and Iverson 2008). The relationship is as follows:

$$B = 20V^{2/3} \quad [4\text{-}1]$$

where B is the planimetric area and V is the volume of the debris-flow deposit.

According to this relationship, the volumes corresponding to 500 and 5000 m^2 lobe areas are 140 m^3 to 4,000 m^3. These values appear low, and suggest mean lobe thicknesses of 0.3 to 0.8 m. Test pits suggested thicknesses of 1 to 2 m which would result in debris volumes of 500 to 10,000 m^3.

An event large enough to have lobes avulse on the lower fan likely also experienced avulsion on the proximal fan. Thus, these moderate frequency debris flows may have larger volumes (e.g. volume ranges somewhat exceeding 50,000 m^3).

4.5.6. Peak Discharge

Measurements along the active channel indicate it is trapezoidal, 14 to 16 m wide crest to crest and 6 to 8 m deep. BGC observed debris-flow run-up marks extending 100 to 130 cm up a cottonwood tree on the right bank of Catiline Creek in the south proximal fan sector. These were interpreted as being from the 2010 event. This runup height would require flow velocities of about 3 m/s, based on the gravity head equation of Chow (1959). Based on this geometry, estimated velocities of 3 to 8 m/s, and Bovis and Jakob's (1999) equation for bouldery flows (Figure 4-3), channel filling debris flows have estimated peak discharges of 170 to 600 m^3/s. This corresponds to volumes of 8,000 to 34,000 m^3, which are in reasonable agreement with the estimated volumes reported by Cordilleran (2010, 2013).

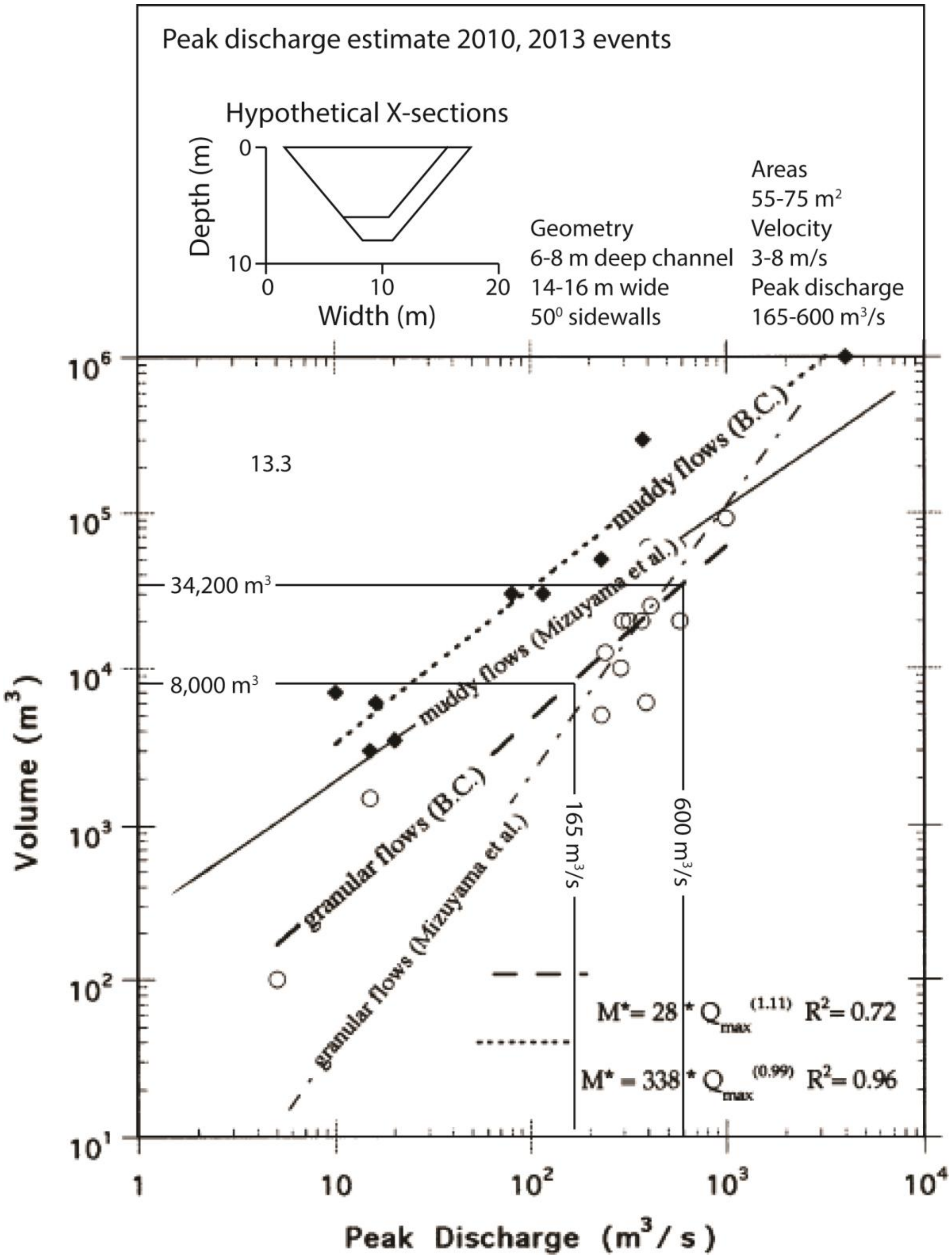

Figure 4-3. Peak discharge-volume estimate for small channelised debris flows on the Catiline Creek fan. Source: Bovis and Jakob (1999).

4.5.7. Maximum Credible Debris flow Volume

The estimated maximum credible landslide volume assumes rapid failure of a large structural instability in the upper basin, such as the Twin Goat topple/slide. Based on a rough area/volume estimate (100 m x 200 m x 20 m), the distressed slope has a volume of approximately 500,000 m^3. Structural discontinuities suggest 500,000 m^3 is a reasonable credible maximum for a rockslide failure in the watershed.

4.5.8. Summary

Debris-flow magnitudes were assessed using a combination of methods including test trenching, debris yield rate and landslide point source estimates. Each method provides partial insight into the range of possible landslide volumes.

BGC's "best" estimates of event magnitude are based on judgment and consider the data available at the time of assessment. They are presented in the next section as 3 volume classes and corresponding frequencies that serve as "anchors" for a frequency-magnitude relationship curve. The largest volume ranges are more uncertain given their rarity of occurrence.

4.6. Frequency-Magnitude Relationship

Sections 4.4 and 4.5 described assessment of debris-flow frequency (expressed as return period or annual probability of occurrence) and magnitude (expressed as volume and peak discharge).

In summary, BGC makes the following conclusions regarding landslide frequency and magnitude at Catiline Creek:

- High frequency events (return period approximately 5 years) are likely to range from 1,000 m^3 to 6000 m^3.
- Moderate frequency events (return period of approximately 30 years) are likely to range from 6,000 m^3 to 40,000 m^3.
- Very Low frequency events (return period of 10,000 years or larger) are likely to range from 100,000 m^3 to 500,000 m^3. This size range would require a large bedrock failure in the upper basin, such as the failure of potentially unstable slopes in the vicinity of Twin Goat peak. The lower bound of this range is considered the largest credible volume for "conventional" debris flows on Catiline Creek.

4.6.1. F-M Relationship

The frequency-magnitude model for Catiline Creek is developed based on applying judgment to the data presented in Sections 4.4 and 4.5. The bounds of the relationship are the 10,000 years of the Holocene Epoch and volumes ranging from 3,000 to 500,000 m^3.

Table 4-7 provides estimated debris-flow volumes that serve as "anchor" points for the F-M curve (Figure 4-4). Debris-flow volumes are presented as a range to reflect the uncertainty in the estimates with the "best" estimate at the midpoint. The frequency categories are logarithmic and the F-M curve is shown on a log-log plot.

Values interpolated from the best-estimate curve form the basis for the debris-flow modelling and risk analyses described in Sections 5.0 and 6.0, respectively. The interpolated line is dotted on Figure 4-4 above 100,000 m^3. The dotted line emphasizes the higher uncertainty in estimating the largest landslide volumes, and that rock avalanches form a different population of failure modes than the smaller events.

Table 4-7. F-M Model – estimated debris-flow volumes for different return periods.

Return Period (T) (years)	Annual Probability (1/T)	Probability in a lifetime[1] (%)	Volume Lower Bound (m^3)	Volume Best Estimate (m^3)	Volume Upper Bound (m^3)	Dominant Process
5	0.1	~100	1,000	3,000	6,000	Rock fall-triggered debris flow
30	0.01	55	6,000	20,000	40,000	Rock fall-triggered debris flow
10,000	10,000	1	150,000	300,000	500,000	Rockslide or Rock Avalanche and debris flow

Note:
1. 80 years lifetime used as reference

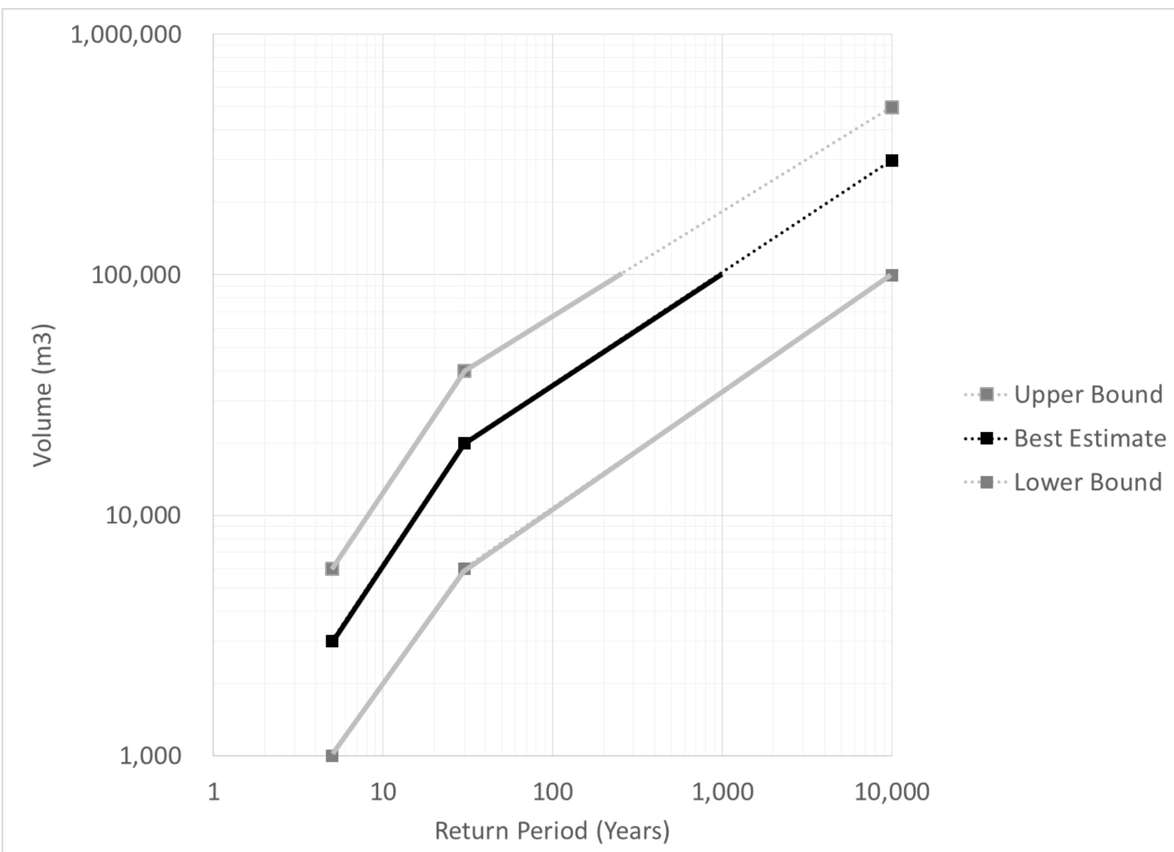

Figure 4-4. Frequency-Magnitude relationship for Catiline Creek.

4.6.2. Possible Effects of Climate Change on Frequency-Magnitude Relationships

Several limitations to the F-M analysis have been discussed. These are primarily based on the uncertainties related to the available analytical techniques as well as time-dependent changes in geomorphic activity as a function of their geological legacy and climate change, and the lack of a rigorous way to cross-check the results. In this section, the specific issue of climate change is revisited because mitigation measures proposed for Catiline Creek would be designed to last several decades or longer, and should thus consider changes in the climate.

It is now scientifically accepted that humans have measurably altered Earth's thermal climate over the past 50 to 60 years (IPCC 2014). The relevance of climate change with regard to Catiline Creek debris-flow risks is that the predicted warming of the troposphere will very likely[8] increase the intensity of the hydrological cycle in many regions worldwide. Due to more intensive energy exchanges in the vertical air column, as well as the projected intensification of air mass exchange between the low and high latitudes, it is expected that extreme precipitation events will increase in frequency and severity (SREX 2011; IPCC 2014). If this prediction were to materialize or has already commenced, this could result in several undesirable outcomes with respect to mountain creek hazards. In general (regional) terms these include:

- The frequency of flooding and debris flows may increase, especially should the timing of extreme storms coincide with the snowmelt season. Over the long term, however, some increases in extreme rainfall may be offset by lesser snowpack thickness due to projected temperature increases. For Catiline Creek, snow contribution may be minor given that most debris flows occur during summer or early fall.
- In sediment supply-limited watersheds in which channel debris is being exhausted by debris floods or debris flows and needs to recharge following an event (as is the case for Catiline Creek), an increase in the intensity or frequency of hydroclimatic events would not necessarily lead to an increase in debris-flow frequency. However, depending on changes in vegetation type and density covering adjacent slopes, the sediment recharge rates to the main channel could increase. Given the very rapid sediment recharge rates at Catiline Creek, it is likely that debris-flow frequency will increase.
- If the design of mitigation measures is based on purely stationary hydroclimatic conditions, they may, in time, be overwhelmed by events that had not been predicted, or by events whose return period has been reduced over time due to observed trends in hydroclimatic extremes. At Catiline Creek an increased debris-flow frequency would necessitate more frequent channel or basin clean outs which would be associated with higher costs.

[8] See IPCC (2014) for a definition of "very likely" in the context of that report

- In summary, the expected changes in hydroclimate are likely to lead to more, although not necessarily larger debris flows at Catiline Creek, necessitating more frequent clean outs and maintenance of existing or future mitigation works.

5.0 DEBRIS-FLOW MODELLING

5.1. Introduction

Numerical modelling of debris flows provided the basis for the estimation of spatial impact probabilities and corresponding debris-flow intensities, which serve as inputs to the quantitative risk assessment (QRA) described in Section 6.0. This section describes the debris-flow modelling approach, input and results.

5.2. Modelling Approach and Input

Debris-flow modelling was carried out using the three-dimensional numerical model *DAN3D* (McDougall and Hungr, 2004). *DAN3D* was developed specifically for the analysis of rapid landslide motion across complex 3D terrain and is well-suited to the simulation of coarse debris flows that deposit on relatively steep slopes, like Catiline Creek fan. BGC has used *DAN3D* for the same purposes on other recent projects.

The model simulates landslide motion from initiation to deposition and requires the following inputs, as described in detail below:

- A digital elevation model (DEM) of the topography in the study area, which defines the sliding surface across which the simulated landslide travels
- A corresponding DEM that delineates the extent and thickness of the initial landslide
- A corresponding DEM that delineates the extent and thickness of erodible material along the path that could be entrained by the landslide as it passes
- A user-specified entrainment rate that determines how much of the available erodible material is picked up by the landslide
- User-specified flow resistance parameters that control how fast and how far the simulated landslide travels.

5.2.1. Sliding Surface

The sliding surface that was used for debris-flow modelling was based on the bare earth LiDAR DEM provided by McElhanney (Section 3.2.4). The LiDAR data, which were collected about two elevation points per square metre, were resampled to 5 x 5 m grid spacing and smoothed to reduce surface roughness and improve numerical model stability. Resampling to 5 x 5 m spacing is standard procedure for debris-flow analyses at this scale to ensure that the model input parameter values that are selected are comparable with previous similar analyses. This generalization results in some loss of topographic details (e.g. large boulders or channel constrictions that could locally affect the flow path and flow depth) but does not substantively affect the debris-flow modelling results.

5.2.2. Debris Flow Volumes and Source Locations

Debris-flow modelling was based on the 'best estimate' frequency-magnitude curve described in Section 4.6 and shown in Figure 4-4. Four debris-flow volume classes were modelled corresponding to 10 year, 100 year, 1,000 year and 10,000 year return period events, with sub-scenarios modelled within each volume class as described below. For the 10 year and 100 year events, a source volume of 3,000 m^3 was used in the model, representing a relatively small triggering rock fall event. For the 1,000 year and 10,000 year events, source volumes of 40,000 m^3 and 230,000 m^3 were used, respectively, representing progressively larger triggering rockslide events. In all four cases, constant entrainment rates were specified between the source area and the fan apex to achieve the desired final 'best estimate' volumes based on Figure 4-4. The initial and final debris-flow volumes that were modelled are summarized in Table 5-1.

Table 5-1. Summary of modelled debris flow volumes.

Return Period (year)	Modelled Initial Volume (m^3)	Modelled Final Volume Reaching Fan[1] (m^3)
10	3,000	6,000
100	3,000	40,000
1,000	40,000	100,000
10,000	230,000	300,000

Note:

1. Final volumes are based on the 'best estimate' frequency-magnitude curve shown in Figure 4-4.

The steep slopes below Twin Goat Peak near the crest of subbasins 4a and 4b (Drawing 6) were used as the sources of the simulated debris flows. As described in Section 4.5.3, this area exhibits slope distress and is a potential source of future debris flows, including large rockslide-triggered debris flows.

Sensitivity model runs were carried out to investigate the sensitivity of the model results to the selected source locations, source volumes and entrainment rates. The sensitivity analysis results are discussed in Section 5.3.1.

All debris flows were modelled as single events (as opposed to events involving multiple source failures and/or surges that result in the same total event volume). This approach likely results in relatively conservative estimates of flow depth and velocity, and in turn vulnerability.

5.2.3. Resistance Parameters

To simulate debris flows on Catiline Creek, the Voellmy's (1995) flow resistance model was used. The Voellmy model is governed by two parameters: 1) a friction coefficient, f, which determines the slope angle on which material begins to deposit (i.e. if the friction coefficient is higher than the local slope gradient, material will decelerate and begin to deposit); and 2) a turbulence parameter, ξ, which produces a velocity-dependent resistance that tends to limit flow velocities (similar to air drag acting on a falling object).

To help constrain the resistance parameters, the 2010 and 2013 debris flows on Catiline Creek were back-analysed. Both of these events initiated in subbasin 3b, reached volumes of up to

20,000 to 25,000 m^3 and ran out to the lake (Section 4.4.1). The best simulations of these two events, in terms of runout distance and the distribution of deposits, were achieved using a friction coefficient ranging between 0.20 and 0.25, with the turbulence parameter set to 500 m/s^2 to limit the modelled flow velocities to a range that is typical of debris flows in southwestern B.C.

For predictive model runs, a range of parameter values was used to simulate the potential mobility range of debris flows reaching Catiline Creek fan. Each parameter combination was subjectively associated with a runout exceedance probability (the probability that an actual event will travel farther than the simulated event). The selected input parameter values are summarized in Table 5-2.

Table 5-2. Summary of *DAN3D* flow resistance parameter values and associated runout exceedance probabilities.

Parameter Combination	Friction Coefficient	Turbulence Parameter (m/s^2)	Runout Exceedance Probability
1	0.30	500	0.9
2	0.25	500	0.7
3	0.20	500	0.5

The selected friction coefficients 0.30, 0.25 and 0.20 approximate the gradients of the upper, middle and lower thirds of Catiline Creek fan, respectively. Parameter combination 1 was intended to simulate relatively 'low mobility' events on Catiline Creek fan. In this case, the selected friction coefficient 0.30 results in modelled deposition predominantly on the upper fan. A runout exceedance probability of 0.9 was assigned to the 'low mobility' results (i.e. there is a 90% expected chance that future debris flows of a given volume will travel farther than the modelled 'low mobility' debris flows). This is in accordance with observations that even small debris flows which typically have lower mobility have travelled well past the mid fan in the past. Parameter combination 3 was intended to simulate relatively 'high mobility' events on Catiline Creek fan. In this case, the selected friction coefficient 0.20 results in modelled deposition predominantly on the lower fan and discharge into Lillooet Lake. A runout exceedance probability of 0.5 was conservatively assigned to these 'high mobility' results (i.e. there is a 50% expected chance that future debris flows of a given volume will travel farther than the modelled 'high mobility' debris flows). This exceedance probability estimate is based largely on the observed behavior of the recent 2010 and 2013 debris flows, which both reached the lake and suggest that such high mobility events are relatively common on Catiline Creek fan. Parameter combination 2 was used as an intermediate case to facilitate interpolation between the results of combinations 1 and 3.

In all cases, the turbulence parameter was set to 500 m/s^2. This value generally limits the simulated flow velocities on the fan to less than 10 m/s, which is in the range of peak velocities that have been estimated for local historical debris flows (Thurber 1983).

For comparison, GEO (2011) recommends using a friction coefficient of 0.20 and a turbulence parameter of 500 m/s^2 to model typical saturated, channelized debris flows in Hong Kong. Similar input parameter combinations to those summarized in Table 5-2 have been used by BGC on other recent projects in BC.

5.2.4. Avulsion Scenarios

Flow avulsions out of the active creek channel can be caused by obstructions that develop during a debris-flow event, for example, due to tree jams, deposition of coarse debris lobes and levees, or channel bank collapses. These processes cannot be simulated automatically in *DAN3D*. Potential avulsion scenarios were therefore simulated manually by adjusting the local elevation of the sliding surface to mimic channel blockages.

Due to the limited bridge clearance and history of avulsions at the FSR location, a blockage of the channel at the FSR was simulated in all of the debris flow simulations described in this report.

In addition to the simulated blockage of the FSR, two main avulsion scenarios were simulated for each debris-flow volume class using the ‘high mobility’ parameter combination described in Section 5.2.3 (f = 0.20 and ξ = 500 m/s^2). The results were used as proxies to delineate the runout exceedance probability contours and hazard intensity zones described in Sections 5.3.2 and 5.3.3, respectively.

Under existing conditions, the two most likely locations upstream of the FSR for avulsions to occur during future events, denoted A1 and A2 on Figure 5-1, were identified using LiDAR imagery and verified during field reconnaissance. The A2 location corresponds closely with the avulsions that occurred during the 2010 debris flow (Drawing 5), and the A1 location corresponds to where partial channel plugging was observed in the field. A channel blockage at location A1 would likely cause an avulsion to the north of the active creek channel, whereas a blockage at location A2 would likely cause and avulsion to the south.

Figure 5-1. Simulated flow avulsion locations A1 and A2 (on shaded slope LiDAR image).

5.2.5. Summary of Debris Flow Model Scenarios

The debris-flow model scenarios described in the preceding sections are summarized in Table 5-3.

Table 5-3. Summary of debris-flow model scenarios.

Return Period (year)	Modelled Final Volume Reaching Fan (m^3)	Resistance Parameters f, ξ (m/s^2)	Forced Avulsion
10	6,000	0.30, 500	No
		0.25, 500	No
		0.20, 500	No
			Yes, A1
			Yes, A2
100	40,000	0.30, 500	No
		0.25, 500	No
		0.20, 500	No
			Yes, A1
			Yes, A2

Return Period (year)	Modelled Final Volume Reaching Fan (m^3)	Resistance Parameters f, ξ (m/s^2)	Forced Avulsion
1,000	100,000	0.30, 500	No
		0.25, 500	No
		0.20, 500	No
			Yes, A1
			Yes, A2
10,000	300,000	0.30, 500	No
		0.25, 500	No
		0.20, 500	No
			Yes, A1
			Yes, A2

5.3. Modelling Results

5.3.1. Raw Model Results

The raw DAN3D results for the model scenarios summarized in Table 5-3 are shown in Appendix F. The results in Appendix F show the maximum simulated debris-flow intensity index (Jakob et al. 2011) within the modelled inundation area on the fan in each case. This index indicates the simulated destructive potential of a flow, calculated as flow depth multiplied by the square of flow velocity.

In general, for a given flow resistance parameter combination, larger modelled flow volumes resulted in longer modelled runout distances, larger modelled inundation areas and higher modelled intensities. The largest, highest mobility event that was modelled (10,000 year event volume of 300,000 m^3 with resistance parameters f = 0.20 and ξ = 500 m/s^2) resulted in inundation of most of the fan surface.

Sensitivity analyses showed that the selected source location had some influence on the model results. Modelled debris flows that initiated in subbasin 3b (similar to the 2010 and 2013 debris flows) impacted the main creek channel at an oblique angle, which caused some 'sloshing' (runup due to the high mobility of the landslide) of the flow near the fan apex and resulted in more extensive avulsions on the upper portion of the fan. Similarly, the model results were somewhat sensitive to the assumed initial flow volumes and entrainment rates. In general, larger modelled initial volumes resulted in higher modelled intensities on the upper portion of the fan. These model sensitivities were subjectively accounted for when delineating the runout exceedance probability contours and hazard intensity zones described in Sections 5.3.2 and 5.3.3, respectively.

5.3.2. Interpreted Runout Exceedance Probability Contours

The raw model results shown in Appendix F and their associated runout exceedance probabilities (Table 5-2) were used to delineate runout exceedance probability contour lines for Catiline Creek fan (isolines associated with a certain conditional probability that debris flows of a given volume class will travel beyond the position of the line, somewhere along the length of the line). The interpreted contour lines for each of the four modelled debris-flow volume classes are shown in Appendix G.

Judgment was used to extrapolate the raw model results across the fan surface to account for potential flow avulsion scenarios that were not explicitly modelled. In general, debris that leaves the active creek channel and spreads out on the fan surface is unlikely to travel as far as debris that remains confined within the active creek channel. This occurs because unconfined debris flows are characterized by lower flow depths and faster water drainage from the debris mass, both of which increase frictional resistance which tends to decelerate the debris flow. At the same time, debris that avulses to the north near point A1 (Figure 5-1) is unlikely to travel as far as debris that remains confined for a longer distance and avulses to the south near point A2. Re-channelization of debris by abandoned paleochannels (Section 3.2.4) occurred in the *DAN3D* model runs so the influence of these paleochannels on the mobility of avulsed flows was therefore explicitly accounted for in the delineation of the runout exceedance probability contours.

5.3.3. Interpreted Hazard Intensity Zones

The raw model results shown in Appendix F were also used to delineate uniform hazard intensity zones for Catiline Creek fan (representing the order-of-magnitude debris-flow intensity that would be expected at a given location if a debris flow of a given volume class reaches or travels beyond that location). The interpreted hazard intensity zones for each of the four modelled debris-flow volume classes are shown in Appendix G.

Judgment was again used to extrapolate the raw model results. In general, larger debris flows are associated with higher hazard intensities. Within each volume class, the hazard intensity is expected to decrease with distance from the fan apex.

Note that the raw modelled intensities shown in Appendix F are based on simulations of coarse debris-flows using *DAN3D* (Section 5.2). *DAN3D* does not simulate the finer, more fluid afterflow phase that typically follows coarse debris-flow surges and often travels beyond the limit of the coarse debris deposits. The afterflow phase is represented on the interpreted hazard intensity maps (Appendix G) by areas of lower flow intensity extending further than the raw modelled results.

6.0 RISK ANALYSIS

6.1. General

Risk assessment involves estimation of the likelihood that a debris-flow scenario will occur, impact elements at risk, and cause particular types and severities of consequences. In this study, the assessment involves estimating the risk that debris flows will impact residential buildings and cause loss of life.

The primary objective of the risk assessment is to support risk management decision making. Importantly, the assessment does not consider all possible risks that could be associated with a debris flow. Rather, the risk assessment considers key risks that can be systematically estimated, compared to risk tolerance standards, and then used to optimize mitigation strategies. These mitigation strategies, once implemented, would also reduce relative levels risk for a broader spectrum of elements than those explicitly considered in this report. Debris-flow impact and resulting consequences are determined by relating the characteristics of debris-flow scenarios (flow velocity and depth) to impacted elements at risk at a given location.

This assessment uses two different metrics to estimate safety risk: individual risk and group risk. Individual risk evaluates the chance that a specific individual (the person judged to be most at risk) will be affected by the hazard. For example, an assessment of individual risk evaluates the chance that a specific person living in a dwelling would be affected by the hazard. Individual risk is independent of the number of people exposed to the hazard, as it focusses on a single individual.

Group risk, also known as societal risk, evaluates the chance that any people present in the area will be affected by the hazard. A low-frequency, high magnitude event might result in a very small, tolerable risk to an individual, but the same event may be considered intolerable if a large number of people are affected. Group risk assessments are completed in addition to individual risk assessments because society is less tolerant of events that affect multiple people. In a given home, the probability of any individual being affected (group risk) will be at least as high as the probability of a specific individual being affected (individual risk).

This risk assessment considers the existing channel configuration and does not consider any additional debris-flow mitigation. This approach provides a baseline estimation of risk to facilitate comparison of different debris-flow risk reduction options, as described in Section 7.0. BGC conservatively assumes that no evacuation of persons is possible during the event.

Lastly, this assessment was done at a building lot level of detail, where the likelihood of debris-flow impact is based on the location of a given lot in relation to hazard areas. The presence of dwellings within a lot were used to identify a lot as “occupied” to estimate safety risk, but the specific location of a dwelling within a lot does not otherwise factor into the risk estimation. This approach is considered reasonable given the available data and use of the assessment for risk reduction and land use planning.

6.2. Debris-Flow Scenarios

This risk analysis is based on debris-flow scenarios, which are defined as debris-flow events with particular volumes and likelihoods of occurrence.

Four main scenarios were chosen to represent the spectrum of possible event magnitudes, from the smallest and most frequent to the largest credible. These are listed in Table 6-1 and result from the hazard modelling described in Section 5.0. Drawings G-1 to G-4 show runout exceedance probability and hazard intensity zones for each scenario listed in Table 6-1. Methods to develop these maps were described in Section 5.3.

Each main scenario contains multiple sub-scenarios. These are defined based on the runout exceedance probability contours shown on Drawings G-1 to G-4 and represent the spectrum of estimated runout extents for each volume class.

Table 6-1. Debris-flow scenarios.

Main Scenario (Annual Return Period Range)	Representative Volume (m^3)	Representative Hazard Intensity Map (Drawing Reference, Appendix G)
Scenario 1: 5-30	6,000	G-1
Scenario 2: 30-300	40,000	G-2
Scenario 3: 300-3000	100,000	G-3
Scenario 4: >3000	300,000	G-4

6.3. Quantitative Risk Assessment (QRA)

Risk (P_E) was estimated using the following equation:

$$P_E = \sum_{i=1}^{n} P(H)_i P(T:H)_i P(S:H)_i P(T:S)_i \, N \qquad [6\text{-}1]$$

where:

$P(H)_i$ is the annual hazard (debris flow) probability for event scenario i of n total scenarios

$P(T:H)_i$ is the temporal probability that a debris flow will occur in a defined season

$P(S:H)_i$ is the spatial probability that the debris flow will reach the element at risk

$P(T:S)_i$ is the temporal probability that the individual will be present within the footprint of the hazard at the time of hazard occurrence

$N = V_i E_i$ describes the consequences. [6-2]

where:

V_i is vulnerability, the probability elements at risk will suffer consequences given debris-flow impact with a certain severity of destructive power

E_i is a measure of the element at risk, quantifying the severity of potential consequences (e.g. number of persons, building value).

Risk is estimated separately for individuals and groups (societal) risk. Estimated risk for combined debris-flow scenarios is calculated by summing the risk quantified for each individual debris-flow scenario.

Individual risk is reported as the annual Probability of Death of an Individual (PDI). As noted in Section 6.1, individual risk levels are independent of the number of persons exposed to risk.

Group risk is represented graphically on an F-N curve, as shown in Figure 6-2. The Y-axis shows the annual cumulative frequency, f_i, of each hazard scenario, and the X-axis shows the estimated number of fatalities, N_i, where:

$$f_i = \sum_{i=1}^{n} P(H)_i P(S:H)_i P(T:S)_i \qquad [6\text{-}3]$$

and N_i is represented by equation [2] (see Section 6.9)

For example, a point on the graph can be read as the estimated frequency of at least a certain number of fatalities. Zones on the graph define generally accepted risk tolerance thresholds (see Section 6.4). Comparison of results to these thresholds helps guide risk reduction decision making.

6.4. Risk Tolerance Criteria

Quantitative risk tolerance or risk acceptance criteria for landslides have not been defined for British Columbia by formal legislation. Instead, land-use decisions in areas with recognized landslide hazards have historically been made by considering hazard frequency only. The decisions have not been based on explicit consideration of risk, which includes both hazard and consequences. However, APEGBC guidelines on Legislated Landslide Assessments for Proposed Residential Developments (2010) encourage the use of quantitative risk assessments in the decision making process.

For this study, estimated risks have been compared with individual risk tolerance criteria formally adopted by the District of North Vancouver (DNV), British Columbia (DNV 2009), and with group risk tolerance criteria formally adopted in Hong Kong (GEO 1998) and previously applied by DNV. The Hong Kong landslide group risk criteria are similar to group risk criteria adopted for dam safety by the USBR (2003), ANCOLD (2003), NSW DSC (2006) and CDA (2007), and have been informally applied to previous landslide risk assessments in Australia (AGS 2007) and the DNV.

The DNV criteria for individual landslide risk tolerance are as follows (DNV 2009):

- Maximum 1/10,000 (10^{-4}) risk of fatality per year for existing developments
- Maximum 1/100,000 (10^{-5}) risk of fatality per year for new developments.

For illustration purposes, these tolerance criteria are shown on Figure 6-1 compared with Canadian mortality rates for the year 2008 (Statistics Canada 2013). Figure 6-1 shows that the DNV risk tolerance threshold of 10^{-4} (1/10,000) for existing development is comparable to the lowest background risks that Canadians face throughout their lives. This tolerance threshold is also similar to the average Canadian's annual risk of death due to motor vehicle accidents, 1/12,500, for the year 2008 (Statistics Canada 2013).

Appendix I provides additional context on risk tolerance criteria including reference to debris flow and debris flood studies completed elsewhere in British Columbia and Alberta.

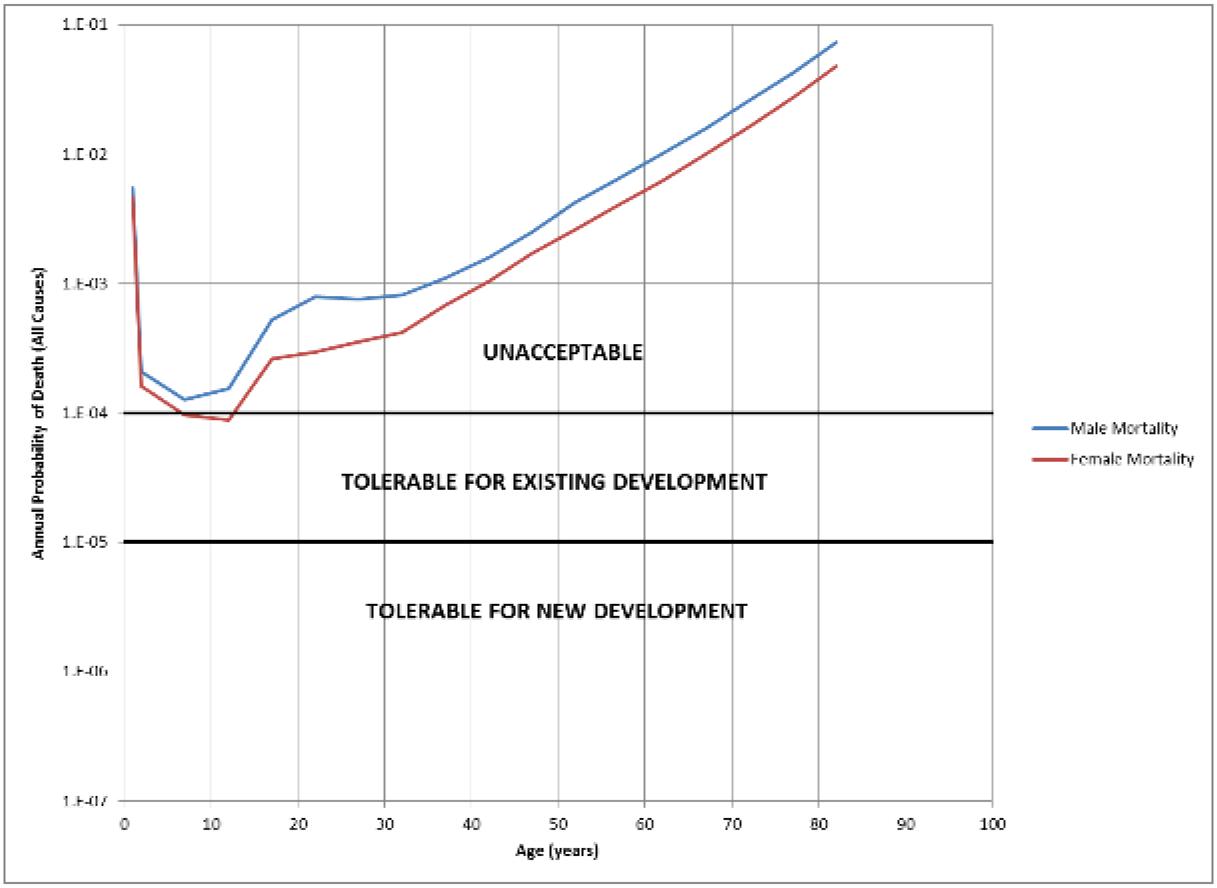

Figure 6-1. DNV individual risk tolerance criteria for landslides compared with Canadian mortality rates in 2008.

Group risk tolerance criteria reflect society's general intolerance of incidents that cause multiple fatalities. Group risk tolerance thresholds based on criteria adopted in Hong Kong (GEO 1998) are shown on Figure 6-2. Three zones can be defined as follows:

- Unacceptable – where risks are generally considered unacceptable by society and require mitigation
- As Low as Reasonably Practicable (ALARP) – where risks are generally considered tolerable by society only if risk reduction is not feasible or if the costs of risk reduction measures are grossly disproportionate to the improvement gained (this is referred to as the ALARP principle)
- Acceptable – where risks are considered broadly acceptable by society and do not require mitigation.

In addition to the above thresholds, an "intense scrutiny zone" may be added where the potential for fatalities exceeds 1000. This zone is not considered applicable to Catiline Creek.

Although not formally contained in legislation, DNV policy is that development approvals and building permits must demonstrate that natural hazards risks are reduced to As Low as Reasonably Practicable (ALARP) (DNV, 2009b).

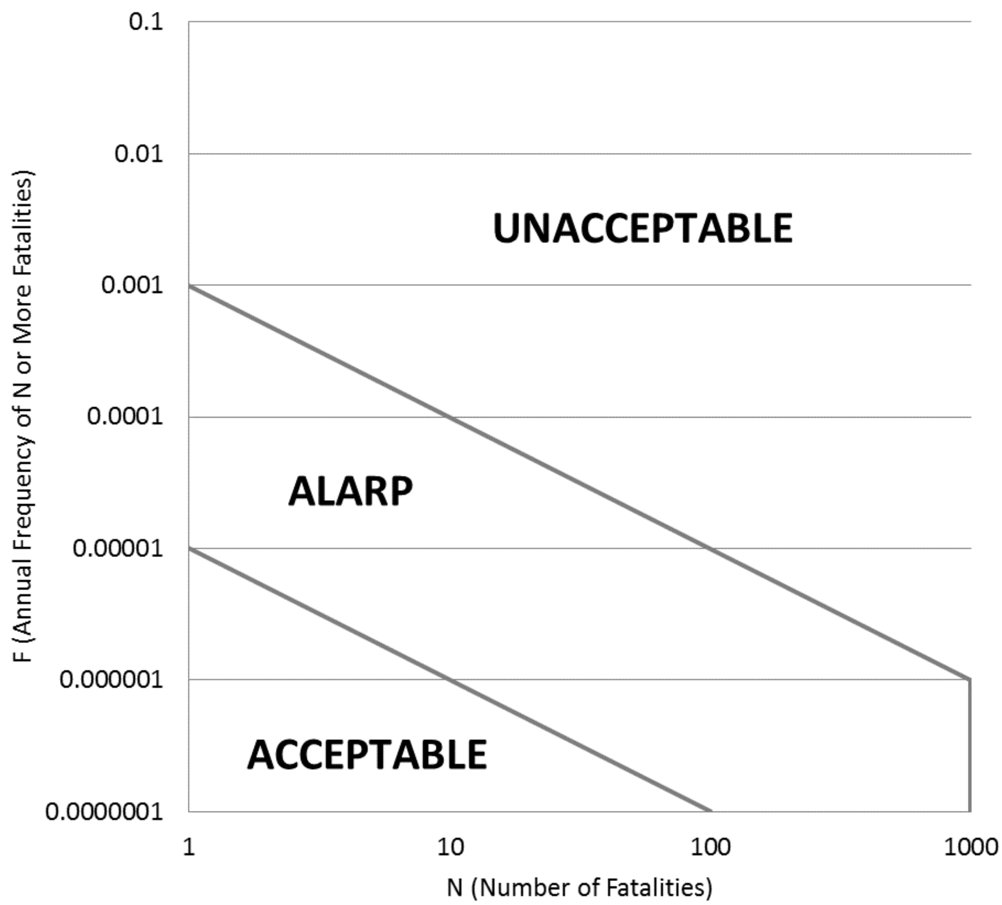

Figure 6-2. Group risk tolerance criteria as defined by GEO (1998).

6.5. Elements at Risk

Elements at risk considered in this assessment include persons within residential dwellings on Catiline Creek fan.

Assessment of elements other than residential dwellings was limited to identifying their location on drawings in relation to debris-flow hazard areas. As such, this assessment does not consider the full spectrum of possible risks due to debris flows. However, risk mitigation decisions based on safety risk will also reduce risk for a broader spectrum of elements in protected areas than those explicitly considered.

The assessment focuses on safety risk due to direct debris-flow impact to dwellings. The following text describes how dwellings and persons within them were characterized.

6.5.1. Dwellings

Information on dwelling locations within the study area was provided within data compiled for each lot. The locations of dwellings (dwelling footprints) were digitized by McElhanney from orthophotos acquired during the July 2014 LiDAR survey. This data was supplemented with data from 2009 and 2012 ground survey data from SLRD and BC Assessment (BCA) data. The source for building locations illustrated on Drawing 2 are as follows:

- *Building or Trailer* – Digitized from the July 2014 LiDAR survey (McElhanney 2014).
- *Building or Trailer (Uncertain)* - Cases where a dwelling exists (based on BCA data or SLRD's survey) at a location determined from image interpretation, but where the interpretation is uncertain due to dense forest cover.
- *Building or Trailer (Inferred)* - Cases where no building is visible based on image interpretation, but BC Assessment improvement values are non-zero, or SLRD or online residential survey results implied the presence of an occupied building or trailer. In this case, a point at the centroid of the lot was used to identify the location of an uncertain or inferred building or trailer. These data were used in the risk analysis to identify location(s) of buildings within lots that could be impacted by debris-flow scenarios.

While uncertainties in some building locations exist, note that these do not affect the results of the risk analysis as this was completed at a building lot level of detail due to uncertainties in debris flow runout modelling.

Building types on the fan include single family (sometimes more than one story), wood construction dwellings, and trailers or mobile homes.

In summary, 114 of the 155 residential-classed lots within the study area were identified as containing at least one dwelling and defined as "occupied" with a number of persons estimated as described below.

6.5.2. Persons

Estimates of the number of persons within residential dwellings is based on responses to an online survey of study area residents. This survey was prepared by BGC in June 2014 and issued via Gary Young of LLE. The survey questions were:

1. What is your lot number?
2. How many residents occupy your lot?
3. Is your residence occupied full-time or part-time?
4. If your residence is occupied part-time, what is the approximate time spent at the residence? Average number of days per month? Approximate time of year (months or seasons)?

Table 6-2 summarizes the results of the survey. BGC received only 32 responses out of the 114 lots classified as "occupied", and Table 6-2 thus underestimates the total population of the study area. BGC assumed 2 persons per lot with unknown occupancy, based on the average of the survey results, with total part- or full-time occupancy of LLE and HJP estimated as 267 persons.

Table 6-2. Summary of study area resident survey responses.

Total Responses	32
Full-Time Lots	3
Part-Time Lots	29
Total Residents	60
Full-Time Residents	6
Part-Time Residents	54
Average number of days per month	8
Average number of months per year (part-time residents only), typically occupied in Spring to Fall months	6
Average number of residents per lot	2

Occupancy of the remaining lots is unknown, and it was not possible to calibrate estimates based on, for example, Census information, because LLE and HJP occupies only a small proportion of the finest resolution of Census data available. Moreover, occupancy varies seasonally and likely also from year to year, and will also change over time due to changes in ownership.

Given the above uncertainties, population estimates should not be considered exact. Rather, they are a proxy to estimate baseline risk in support of land use decision-making, which would typically be based on a longer time frame than short-term population variations.

Differences between predicted and actual occupancy levels would affect estimation of group risk but not individual risk, because only the former scales with the number of persons exposed to hazard. For group risk, it is important to note that the population estimate is a snapshot based on the current level of development. Development of additional lots would increase the population, while abandonment of lots would decrease the population. Therefore group risk is calculated for current population estimates.

For planning purposes, BGC also estimated individual risk for every residential-classed lot irrespective of current occupancy (e.g. assuming full build-out of the development). However, note that DNV risk tolerance criteria for proposed future development are more conservative than for existing development (see Section 6.4).

6.6. Hazard Probability, $P(H)$

Hazard probability, $P(H)_i$, corresponds to the annual probability of occurrence of each hazard scenario, which are defined in Table 5-3 as annual frequency ranges. The bounds of a given range are exceedance probabilities. For example, the 10-100 year scenario represents the probability that the event will be larger than the 10-year event but not larger than the 100-year event.

Given a scenario with the annual exceedance probability range P_{min} to P_{max}, the probability of events within this range corresponds to:

$$P(H)_i = P_{min} - P_{max} \quad [4]$$

For example, for the 1:10 – 1:100 year range, this would correspond to:

$$P(H)_i = \frac{1}{10} - \frac{1}{100} = \frac{1}{11} \quad [5]$$

The upper and lower bounds of each range were used in the risk analysis as approximate upper and lower uncertainty bounds for each frequency range.

6.7. Spatial Probability

Spatial probability estimates for a given lot were based on the product of three factors. The first factor, avulsion probability, considers the probability that flows will avulse out of one or both sides of the channel for a given volume class, in addition to some flow remaining in the channel. Values used in the analysis are shown in Table 6-3. They are based on judgment guided by field observation and the results of modelling.

Table 6-3. Avulsion Probability

Fan Sector	Scenario			
	5-30	30-300	300-3,000	3,000-10,000
Avulsion into FSR Avulsion sectors (North and South)	1	1	1	1
Avulsion into sectors on northwest side of channel	0.2	0.5	1	1
Avulsion into fan sectors on southeast side of channel	0.4	0.8	1	1

The second factor, runout exceedance probability, considers the probability flows will exceed a certain runout extent whether they stay in the channel or avulse out of the channel. Values used in the analysis are shown by the runout exceedance probability isolines on Drawings 8 to 11. This factor addresses the question, “given avulsion, what is the chance that a flow will extend at least as far as a given dwelling?”

The third factor considers lateral impact probability. This was estimated for each volume class based on the typical width of a simulated flow path in relation to the possible corridor through which it might travel. This factor addresses the question, “what is the chance that a flow will follow a particular trajectory that results in impact to a building (as opposed to travelling past but missing a dwelling)?” Values used in the analysis are shown in Table 6-4. They vary by fan sector and are based on judgment guided by field observation and the results of modelling.

Table 6-4. Lateral Impact Probability

Fan Sector	$P(S{:}H)_3$_1	$P(S{:}H)_3$_2	$P(S{:}H)_3$_3	$P(S{:}H)_3$_4
FSR Avulsion (North and South)	0.3	0.5	0.7	0.9
Sectors on northwest side of channel (except FSR Avulsion sectors)	0.1	0.2	0.3	0.5
South Distal	0.1	0.2	0.3	0.5
South Proximal	0.2	0.3	0.5	0.7

6.8. Temporal Probability

Temporal probability considers the proportion of time residents spend within their dwelling. All else being equal, safety risk is directly proportional to the time residents spend at home (e.g. a resident who is rarely home has less chance of being struck by a debris flow).

There is strong variation in the proportion of time residents spend on Catiline fan, from occasional cabin users to full time occupants. There is also seasonal variation and likely variations from year to year. Survey responses suggest that most part-time residents use their dwellings about half the year, mostly between spring and fall, with a smaller population present during the winter. Based on anecdotal information from LLE, BGC understands that there are at least 15 full-time owner-residents and perhaps an additional number of full-time renters, but there is no formal record of full versus part-time occupancy.

Such variations are difficult to account for in baseline risk estimation supporting risk reduction and land use planning because unlike permitted development, variations in usage are not generally controlled or monitored. The only exception would be commercial developments with defined periods of operation, such as campgrounds or seasonal businesses, which is not the case at Catiline Creek.

Given the above variations and uncertainties, BGC assumed full-time occupancy to assess baseline risk for land use planning and permitting. This is particularly valid in areas that tend to evolve, over time, from part time to full time use as may be the case for some lots in LLE and HJP. “Full-time” is defined in this report as occupancy about 50% of the time on average, 365 days/year. No seasonal adjustment was made given that the debris-flow “season” approximately coincides with the spring-fall period when residents are more likely to be present.

6.9. Vulnerability

Vulnerability is defined as the likelihood of a fatality occurring given impact by the hazard in question. A vulnerability of 1 implies certainty of a fatality, while a vulnerability of 0.1 implies a 10 % chance of a fatality given hazard impact.

Vulnerability estimates were based on the debris-flow hazard intensity zones shown on Drawings 8 to 11. As described in Section 5.3.3, the hazard intensity zones were interpreted from modelled debris-flow intensity index values. Debris flow intensity index, I_{DF}, are defined according to Jakob et al. (2011) as the square of the flow velocity times the flow depth at a given location. As such, the index is a proxy for dynamic impact pressure.

Vulnerability of building occupants is difficult to estimate because fatalities are most commonly an indirect consequence of building damage or collapse. However, using data from 68 published debris-flow events, Jakob et al. (2011) demonstrated that the intensity index could be correlated with observed building damage, ranging from some sedimentation (I_{DF} < 1) to complete destruction (I_{DF} > 100). No fatalities were reported in any of the events involving I_{DF} estimates less than 1, equivalent to a 1 m deep flow traveling at 1 m/s.

Table 6-5 shows the vulnerability ratings used for both individual and group risk analysis. These values are based on judgement with reference to Jakob et al. (2011). They contain uncertainty, and may be expected to vary from assumed values by approximately +/- 0.1 to 0.2.

Table 6-5. Summary of estimated vulnerabilities as a function of modelled debris-flow intensity index.

Intensity Index	Damage Level	Vulnerability		
		Lower Bound	Best Estimate	Upper Bound
< 1	Some sedimentation	-01	~0	~0
1 - 10	Some damage	~0	0.2	0.4
10 - 100	Major damage	0.4	0.6	0.8
> 100	Destruction	0.8	0.9	1

Note:
"~0" represents "negligible"

6.10. Results

As described in Section 6.1, safety risk is estimated separately for individuals and groups (societal risk). The results presented are the combined annual risk from all debris-flow scenarios, given that some parcels may be impacted by more than one scenario.

To account for uncertainty, the results are reported as a best-estimate bounded by ranges determined from the vulnerability criteria described in Section 6.9.

6.10.1. Individual Risk

Table 6-6 lists the number of lots where estimated individual risk exceeds 1:1,000, 1:10,000 and 1:100,000 risk of fatality per year for occupied residential lots. Table 6-8 lists the number of lots estimated to exceed the same thresholds if every residential-classed lot was occupied.

Individual risk results for each lot are provided in Appendix J. Note that lot counts in Table 6-6 are also included in higher thresholds: for example if a dwelling exceeds a 1:1,000 individual risk threshold it will also be counted as exceeding the 1:10,000 and 1:100,000 thresholds.

In summary, BGC's best-estimate of individual risk exceeded the DNV risk tolerance standard of 1:10,000 risk of fatality per year for 76 of the 114 occupied, residential-classed lots within the study area. 18 lots exceeded 1:1,000 annual risk of fatality, one order of magnitude above the DNV individual risk tolerance threshold. A list of lots exceeding risk tolerance thresholds is provided in Appendix J.

Table 6-6. Summary of individual risk results for occupied residential lots.

Tolerance Threshold (Annual PDI)	Number of Lots Exceeding Threshold		
	Lower Bound	Best-Estimate	Upper Bound
1:1,000	4	18	20
1:10,000	56	76	84
1:100,000	93	94	96

Table 6-7. Summary of individual risk results for all residential lots (assuming full build-out).

Tolerance Threshold (Annual PDI)	Number of Lots Exceeding Threshold		
	Lower Bound	Best-Estimate	Upper Bound
1:1,000	5	26	31
1:10,000	74	99	107
1:100,000	122	123	125

Drawing 8 shows residential lots where BGC's best-estimate of individual risk (PDI) exceeds 1:1,000, 1:10,000 and 1:100,000 risk of fatality per year assuming full-time occupancy. Lots not hatched did not exceed PDI=1:100,000. Drawing 8 also shows shaded zones for individual risk. These are based on risk levels assigned to individual lots as well as geomorphic boundaries within the study area. For example, the eastern boundaries of the PDI>1:1,000 and PDI>1:10,000 zones follow the eastern fan boundary. Lots crossing two zones are conservatively hatched with the higher risk rating.

6.10.2. Group Risk

Figure 6-3 is BGC's "best estimate" for occupied residential lots. Upper and lower dashed lines are based on the upper and lower ranges in vulnerability estimates (see Section 6.9).

Estimated overall group debris-flood risk for Catiline Creek fan plots well into the unacceptable range when compared to the international risk tolerance standards described in Section 6.4. This is likely to be the case, even if all part time users were to be included in the analysis instead of the full-time use assumption.

Table 6-8 lists the range of expected fatalities for each main debris flow scenario. Values in the table above 5 are rounded to the nearest 5 to reflect uncertainties. Similarly to the F-N curve, the table shows lower, best, and upper estimates based on ranges in vulnerability estimates. The values in each column are also shown as ranges. These ranges reflect the spectrum of different runout extents possible for a given volume class (e.g. for a given volume class, a longer runout event is less likely, but would impact more buildings and result in higher expected fatalities). It is important to note that the debris-flow return periods listed in Table 6-8 indicate the recurrence interval of the scenario, not the likelihood of fatalities (which is lower, as shown on Figure 6-3).

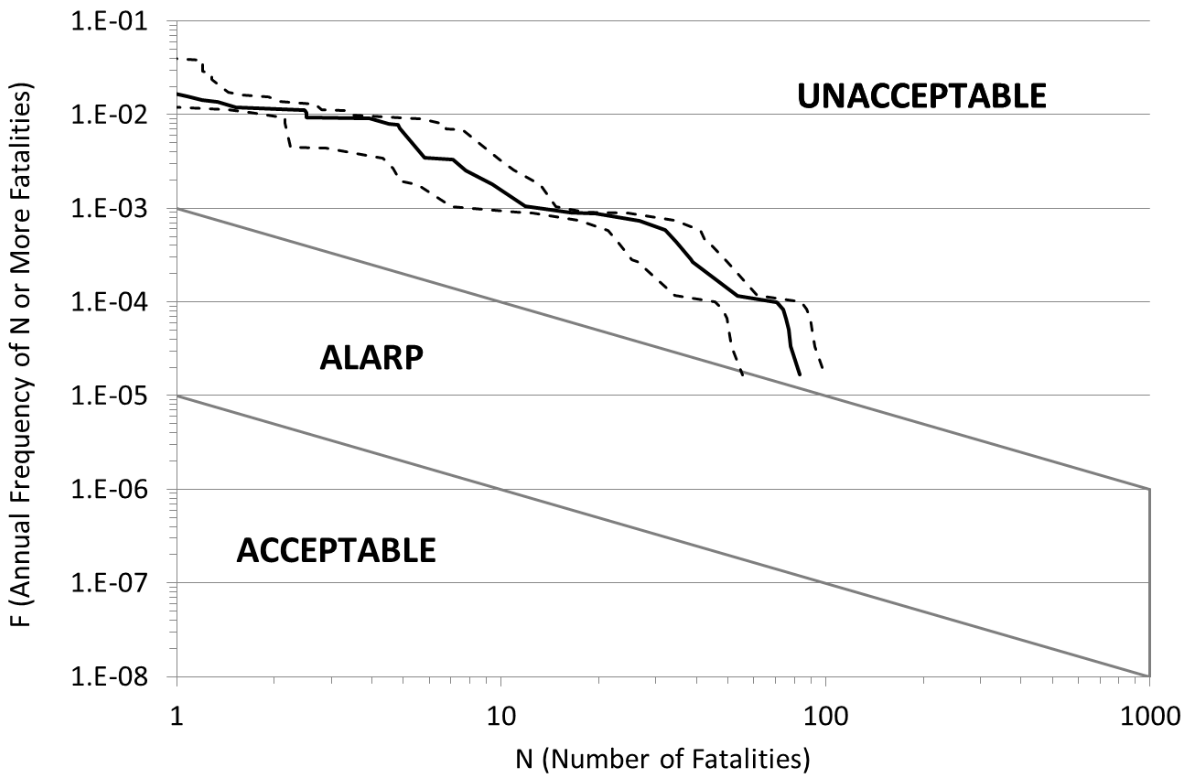

Figure 6-3. F-N curve showing the results of the Catiline Creek risk analysis for groups.

Table 6-8. Estimated life loss for each scenario.

Main Scenario (Annual Return Period Range)	Estimated Number of Fatalities (Lower Bound)	Estimated Number of Fatalities (Best Estimate)	Estimated Number of Fatalities (Upper Bound)
5-30	0	0 - 2	0 – 3
30-300	0 – 6	0 – 9	1 – 13
300-3000	2 – 25	2 – 38	2 – 48
>3000	13 - 56	16 – 80	17 - 97

6.11. Summary

This risk assessment estimated individual and group safety risk for persons within dwellings on Catiline Fan. While uncertainties exist, estimated individual and group risk fall well within the unacceptable range when compared to international risk tolerance thresholds including those adopted by the DNV.

For groups, the estimated annual frequency of at least 1 fatality is about 1:70, or near-certain within an average lifetime. This is about an order of magnitude higher than the upper group risk tolerance threshold of 1:1000 for fatality of at least one person. For individuals, approximately 76 lots have estimated annual risk exceeding 1:10,000, with 18 lots exceeding 1:1,000 (Appendix J). For comparison, the average annual risk of fatality faced by an automobile driver in Canada is approximately 1:12,500 (Stats Canada, 2013). Although no fatalities have occurred since the start of development on Catiline fan, these estimates are considered credible given the near-misses that have occurred during previous debris flow events (Section 4.4.1).

As noted in Section 6.2, large variations exist in possible outcomes for different debris-flow events, and many factors influence vulnerability to life loss that cannot be considered, such as the actions of neighbors to rescue impacted persons, or the risks faced by those rescuers. In addition, the nature of bedrock instability in the upper watershed is currently poorly understood, which influences estimates of landslide volume and source locations for the largest potential events. For these reasons, differences will likely exist between simulated debris-flow scenarios and actual events. However, but the simulated scenarios can be considered a credible proxy for debris-flow risk estimation and evaluation.

In addition, BGC has assumed "full-time" (average 50% of the time, 365 days/year) occupancy of lots containing dwellings as discussed in Section 6.8, even though many buildings are actually occupied part-time. This assumption is considered reasonable for the purpose of long-term risk reduction planning, especially given that part-time occupancy rates are not known, cannot be monitored, and likely vary over time. However, actual risk will be lower for residents using their dwelling a smaller proportion of time than assumed in this assessment.

7.0 RISK REDUCTION OPTIONS ASSESSMENT

7.1. General

Table 7-1 summarizes general methods for reducing debris-flow risk, and the applicability of each method at the Catiline Creek fan. Not all of the methods described in Table 7-1 are considered to be feasible alternatives at Catiline Creek fan. Technically feasible risk reduction options for debris-flow risk reduction at Catiline Creek considered in this assessment include:

- Option 1: Increase capacity of existing channel
- Option 2: Diversion structure at fan apex
- Option 3: Retention barrier at fan apex.

The proposed mitigation options assume the current development layout. Risk reduction through property acquisitions and land sterilization has not been assessed in this report but may be considered as an alternative risk management strategy.

Table 7-1. Possible methods of debris flow risk reduction.

Method	Description	Application at Catiline Creek
Prevent debris flow initiation	Prevent debris flow initiation by stabilizing and preventing entrainment of debris in the watershed.	This method is not considered to be feasible at Catiline Creek due to abundant loose material in the large and steep initiation zone.
Convey or divert debris flow away from elements at risk	Allow debris flows to occur, but limit the spatial impact of the flow to a corridor or area that does not contain elements at risk.	This method could be achieved by increasing the capacity of the existing channel to convey debris flows through the community without overtopping the channel (Option 1), or diverting the flow away from the developed fan areas (Option 2).
Capture debris before it reaches elements at risk	Build a debris retention structure upstream of the elements at risk designed to capture coarse sediment and to allow water flow to pass.	This method could be achieved by constructing a debris-flow barrier near the Catiline Creek fan apex (Option 3).
Temporarily remove elements at risk	Warning systems, including rainfall threshold systems or debris-flow alarms, are used to alert and evacuate people from the debris-flow hazard zone during periods of elevated debris-flow hazard.	This is not expected to be a feasible method for reducing risks to tolerable levels. Alarms are not effective because debris flows travel from the fan apex to developed areas within minutes. Rainfall threshold would have to be calibrated with a rain gauge in the upper watershed which does not exist. Therefore, calibration to previous events is not possible.
Permanently remove elements at risk	Remove people and homes from the debris-flow hazard zones.	This method could be achieved through property acquisition. However, it should be noted that future (mostly large) debris flows, can change the hazard zones on the fan, then possibly requiring further property acquisitions.

7.2. Design Considerations

The conceptual risk mitigation options have been developed in consideration of the items that are summarized below. These design considerations describe the basis and constraints of the current design stage, and in many cases were used to weigh and compare the technically feasible risk mitigation options.

7.2.1. Risk Reduction Targets

The debris-flow risk assessment has shown that the current debris-flow risk levels at Catiline Creek are unacceptable when compared to individual and group risk thresholds that have been adopted in other jurisdictions (See Section 6.4). Although SLRD has not formally adopted tolerable risk thresholds, the following target risk levels have been established for the conceptual risk mitigation designs.

- For individual risk, the target is a maximum best estimate of 1/10,000 (1E-04) annual probability of death for an individual for all existing homes on Catiline Creek fan, based on landslide risk tolerance criteria adopted by the DNV.
- For group risk, the target is a shift of the best estimate curve into the ALARP zone (according to the ALARP principle) based on group landslide risk tolerance criteria adopted in Hong Kong.

At the detailed design stage, debris-flow risk would be re-analyzed with consideration of the selected mitigation measures, to estimate the level of "residual risk" following completion of mitigation measures. This analysis helps optimize the mitigation design to reduce risk to within tolerable levels without being unnecessarily conservative and costly. Such analyses are outside the scope of this current assessment.

However, as a preliminary step to guide development of conceptual mitigation options, BGC examined the existing risk profile at each debris flow scenario to identify the scenarios that contribute most to the overall risk level. Figure 7-1 shows group risk best-estimates for the following groups of debris flow scenarios:

- <u>Black line</u> - All debris flow scenarios.
- <u>Orange line</u> – Debris flow scenarios 1, 2, and 3 only, representing debris flows up to 100,000 m^3 event volume. The largest debris flow scenario (scenario 4) is excluded.
- <u>Red line</u> – Debris flow scenarios 1 and 2 only, representing relatively small, frequent debris flows up to 40,000 m^3 event volume. The largest two debris flow scenarios (scenarios 3 and 4) are excluded.

In summary, excluding the largest scenarios from the analysis reduces the maximum number of expected fatalities, but F-N curve moves only slightly towards the uppermost tolerance threshold. In terms of individual risk, the number of occupied residential lots exceeding the DNV risk tolerance standard of 1:10,000 risk of fatality does not change if Scenario 4 is excluded from the analysis, and is reduced by only 8 lots if both Scenarios 3 and 4 are excluded.

This indicates that reducing risk for the smaller events will provide the greatest risk reduction cost-benefit. It does not imply that mitigation targeting only the smaller events (e.g. Scenarios 1 and 2) would reduce risk to tolerable levels according to international standards. However, this may guide discussion on the level of residual risk to accept if risk reduction to tolerable levels according to international standards is not practicable.

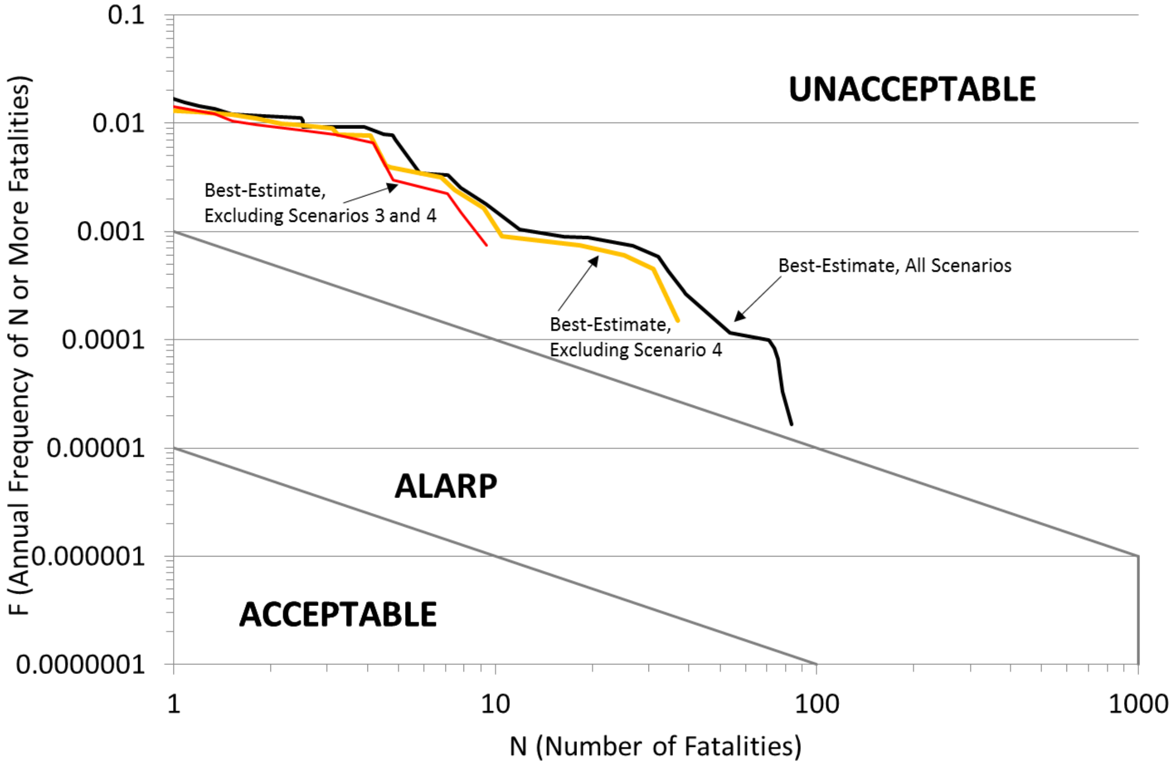

Figure 7-1. Group risk for different groups of scenarios

As a second step to establish risk reduction targets, BGC re-analyzed risk based on inputs from the existing baseline study and two levels of assumed mitigation, termed "Large" and "Small".

The "large" dimension and higher cost variant of each mitigation option presented is designed to manage the largest magnitude event expected at Catiline Creek (300,000 m^3 total volume, approximately 10,000-year return period event). The "small" variant of each mitigation option was designed to manage the portion of risk associated with the most frequent debris flows similar to those that have occurred during historical times (up to 100,000 m^3 total volume, approximately 1,000-year return period event).

Table 7-2 lists assumptions used for the preliminary risk evaluation. No new modelling was completed for "mitigated" conditions. Instead, smaller baseline debris-flow scenarios were used to represent "mitigated" conditions for larger scenarios. This approach is considered reasonable to guide development of conceptual mitigation options, but is not sufficient for detailed design.

Table 7-2. Preliminary risk evaluation assumptions.

Mitigation Level	Assumptions
Small	• 100,000 m^3 scenario reduced to the equivalent of the 6,000 m^3 baseline scenario • 300,000 m^3 scenario reduced to the equivalent of the 100,000 m^3 baseline scenario • All smaller scenarios fully mitigated (e.g. no channel avulsion).
Large	• 300,000 m^3 scenario reduced to the equivalent of the 6,000 m^3 baseline scenario • All smaller scenarios fully mitigated (e.g. no channel avulsion).

Based on the assumptions listed in Table 7-2, both the small and large mitigation levels would reduce individual risk at all properties to within tolerable levels (PDI <1:10,000).

Figure 7-2 shows group risk best-estimates. Estimated group risk falls within the “ALARP” zone for the larger mitigation level (see Section 6.4), but still falls within the unacceptable zone for the small upgrade level.

These estimates should be interpreted with caution. In reality, mitigation will not reduce residual risk to exactly zero for smaller scenarios, as assumed in Table 7-2. Scenarios involving large rockslides (e.g. the 300,000 m^3 scenario) are still poorly understood. These factors would be refined during detailed mitigation design. The estimates also assume that the mitigation works function successfully and do not fail during an event. While this is possible from an engineering point of view, it requires diligent maintenance of the structure, particularly after any debris flows.

Risk tolerance thresholds cited in this report have also not been formally adopted by SLRD or elsewhere in British Columbia except the DNV (for individual risk), and costs of the larger mitigation level may be prohibitively expensive. As such, mitigation options for both the lower and higher levels are discussed in the following sections.

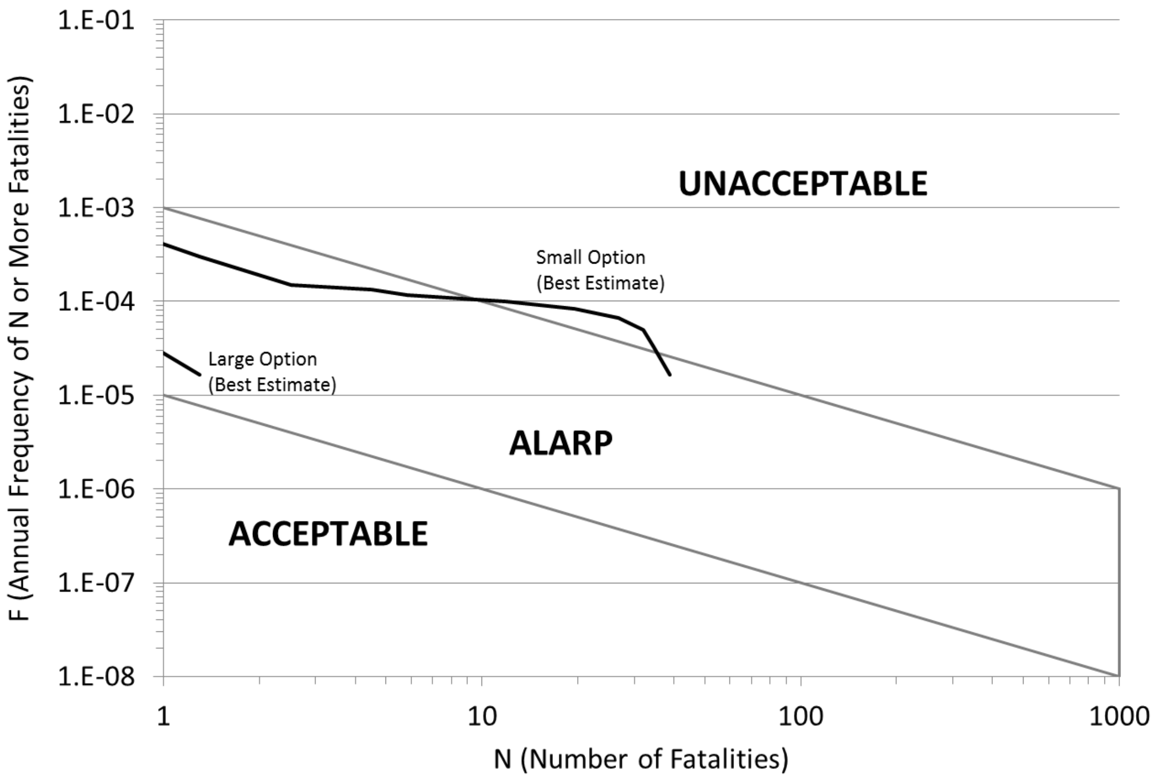

Figure 7-2. Preliminary best-estimate of group risk for small and large upgrade levels of mitigation. This estimate is subject to change during detailed design.

7.2.2. Conceptual Design Level

All proposed designs are considered to be at a conceptual level. The intent of the conceptual design stage is to present technically feasible design options that are capable of meeting the project design criteria and risk reduction targets. Design options have been developed only to a stage that allows the technical merit and relative costs of different options to be compared. Details of the design options, including final dimensioning and layout of design elements and budgetary level cost estimates, are beyond the scope of this conceptual design phase.

7.2.3. Exclusions

Mitigation measures considered in this study only address the debris-flow risk on Catiline Creek. The measures would also reduce other background geohazard risks to some degree, such as rock fall, rock avalanche and flood risks on Catiline Creek, but these other risks have not been specifically evaluated.

7.2.4. Risk Transfer

Mitigation measures should seek to not increase the debris-flow risk to any of the homes on Catiline Creek fan, or any other homes outside of the study area.

7.2.5. Environmental and Social Impact

Environmental and social impact is a factor considered in comparing the feasible mitigation options. Environmental and social impact would be reduced by:

- Minimizing vegetation removal and the overall footprint of physical protection structures as much as possible, while still achieving risk reduction targets
- Minimizing the volume of aggregate and other materials that need to be imported onto the fan for construction of the physical protection structures
- Using existing roads and right of ways for construction.

7.2.6. Site Access

It has been assumed for the conceptual design that existing roads can be used to access construction areas, and that there are no restrictions on constructing new construction access roads, if and where required.

7.2.7. Design Life

Design elements are considered to be permanent structures with a design life of at least several decades. The design life will depend on the performance of different system components, which may need to be replaced in isolation or as part of a complete structural upgrade.

7.2.8. Maintenance and Post-Event Restoration

Specific maintenance requirements have not been defined at this conceptual stage, however it is assumed that structures will be visually inspected annually and after every debris-flow event that is suspected or reported. Routine visual inspections are expected to be completed within one day but will need to be carried out by a professional engineer with the appropriate qualifications.

Restoration of the debris-flow mitigation structures following debris-flow events will be required, including disposal of debris retained by structures or deposited in channels, and repair to structures and erosion protection, if needed. Plans for this restoration have not been developed at this conceptual stage. Resources, including funding, equipment, and debris disposal plans, should be in place for post-event restoration and maintenance for the full life of the structures. Cost estimates for this maintenance work have not yet been determined.

7.2.9. Cost

At this conceptual design stage, cost estimates are rough order of magnitude estimates for design and construction, with expected variance from approximately –50 % to +100 %. The costs do not include a contingency, but are a best estimate that includes engineering design, material supply, and installation. These costs are developed to support a comparison between alternatives, and should not be used to set budgets for the mitigation works.

Each cost estimate is based on estimated quantities (e.g. volume of earthworks) and an assumed unit cost. More detailed cost estimates should be developed at the next stage of design, based on updated quantities determined for the selected alternatives, and improved unit cost estimates. Costs associated with operations and maintenance of the mitigation options are discussed qualitatively for each option, but have not been estimated. Costs may change due to market constraints, demand and supply of various materials and the availability of appropriate machinery.

Further development of the designs, which is beyond the scope of this study, would be required to reduce the uncertainty in the cost estimates. Improvement of the cost estimate for the selected risk reduction alternative(s) would typically be a primary objective of the next design stage.

7.2.10. Geotechnical and Topographic Design Parameters

Geotechnical design parameters are assumed based on surface observations and terrain interpretation. No subsurface investigation or material testing has been carried out as part of this assessment which would be required for detailed design. It is assumed that soils everywhere are granular sand, gravel, and cobbles with some large boulders, and that the water table is typically below the deepest portion of all proposed channel options. Bedrock is assumed to be deep (> 30 m) below the fan surface, except at the fan apex, and both bedrock and groundwater are assumed to have no bearing on the proposed designs, at this stage.

Position coordinates, areas, alignments, and volumes are estimated based on the currently available, July 2014 LiDAR topography, and hand measurements made in the field.

Further site investigations and surveying will be required to complete final designs.

7.3. Design Methods

This section describes the methods used to estimate debris-flow channel capacity, debris-flow discharge for different event magnitudes, and debris-flow storage volume behind barriers. These parameters determine the dimensions, and therefore the estimated cost, of the conceptual mitigation options.

Channel conveyance capacity, defined here as the volumetric flow rate (m^3/s) that the channel can carry without overtopping, has been estimated by multiplying the cross-sectional area of the channel by the estimated velocity of the debris flow. Various methods were used (on file with BGC) to estimate debris-flow velocity, including those summarized in Hungr et al. (1984), Rickenmann (1999), and Prochaska (2008). Velocity of the debris flows varies depending on sediment concentration and sediment composition, but is expected to be in the range of 3 m/s to 10 m/s, with the lower end of the range being associated with small volume, lower flow depth events, and the upper end being associated with larger volume events with greater flow depth and higher mobility. Empirical data on debris flows (e.g. Hungr et al. 1984) indicates a strong dependence of velocity on flow depth, which suggests that channel conveyance capacity can be maximized by using a deeper, narrower channel cross-section to maximize flow depth if the channel is steep enough to convey debris flows. The lower end of this velocity range was used for conceptual design, as it results in a more conservative channel area.

The peak debris-flow discharge (peak volumetric flow rate) at different event magnitudes (total debris-flow volume) was estimated based on empirical correlations between these same parameters summarized in Hungr et al. (1984), Rickenmann (1999), and Mizuyama et al. (1992). As described by these authors, debris flows have an unsteady, pulsating character. The discharge considered for conceptual design was the maximum (or peak) discharge, typically associated with a short duration flow surge near the start of the event. The empirical data shows that the peak discharge can vary widely for a given debris-flow magnitude. For conceptual design, correlations presented by all of the referenced authors were considered, but more weight was given to data collected at debris flows in western Canada (e.g. Hungr et al. 1984), which are assumed to have a similar character as debris flows at Catiline Creek.

The estimated storage volume of debris retained by a debris barrier is strongly affected by the slope of the surface of the deposited debris. As a rule of thumb, the deposition angle of debris captured by a barrier is assumed to be one-half of the fan slope. At Catiline Creek, the fan slope is 12° on average, and a debris deposition angle of 6° has been assumed for conceptual design.

Further work is needed for detailed design to refine and confirm the design methods that are used to design the selected debris-flow mitigation option.

7.4. Option 1: Increase Capacity of Existing Channel

Debris-flow risk could be reduced by increasing the capacity of the existing channel to convey larger debris flows from the fan apex to Lillooet Lake (Drawing 9). The intent of increasing the channel capacity is to force debris to travel completely to the lake without allowing flow avulsions out of the channel or debris deposition in the channel above the lake level. This could be achieved by deepening and widening the existing channel and straightening the channel where possible. The larger cross-sectional area of the channel would be constructed by excavating material from the base and sides of the existing channel, and using this material to construct berms along the top of the channel.

The gradient of the existing channel, and the typical fan gradient, is approximately 12° (21%). Historical events at Catiline Creek suggest that debris flows that remain in the channel are likely to be conveyed, in majority, to Lillooet Lake. These events correlate well with data and recommendations presented by Hungr et al. (1984), which suggest that confined debris flows are likely to travel, without deposition, at slope angles of 12° or steeper. It is not feasible to significantly increase the overall gradient of the existing channel, although local undulations in the channel gradient should be smoothed and steepened, where possible. The existing channel gradient is, however, expected to be capable of conveying debris flows to the lake, as long as confinement of the flow is maintained.

Table 7-3 summarizes the average cross-sectional area, channel conveyance capacity, and the estimated debris-flow event magnitude that could be conveyed by the existing channel and the proposed upgraded channels. Channel upgrade designs have been developed to a conceptual level only, and channel areas required for each event volume should be reviewed, and updated if necessary, during future design stages.

Table 7-3. Channel capacity summary estimated for conceptual design.

Channel	Avg. Cross-Sectional Area (m^2)	Est. Conveyance Capacity (m^3/s)	Est. Debris Flow Event Volume (m^3)	Best Estimate Return Period (years)
Existing	45	300	20,000	30
Small Upgrade	120	1,000	100,000	1,000
Large Upgrade	300	2,600	300,000	10,000

The “Large Upgrade” channel, intended to convey up to the largest expected event volumes, is illustrated in Drawing 9. For conceptual design, a 7 m base width and 1.5H:1V slopes have been adopted, because a relatively deep, narrow channel maximizes confinement and flow velocity, which maximizes conveyance capacity and reduces potential for debris to deposit in the channel. Design cross-sectional areas shown in Table 7-3 include approximately 1 m to 2 m height of free-board above the estimated, required flow area. This freeboard is provided to account for uncertainties in the flow velocity, and to allow for minor deposition in the channel, and super-elevation of the flow at channel bends.

Although not explicitly shown in the conceptual design, detailed designs of the channel should consider super-elevation of the flow at channel bends, by increasing the height of berms at the outside of curves. Super-elevation of the flow may be in the range of 2 m to 3 m for the “Small Upgrade” channel, and potentially up to 5 m at the “Large Upgrade” channel according to methods described in Prochaska et al. (2008). Straightening the channel to maximize the radius of curvature of channel bends will reduce the potential super-elevation of flow and associated risk of channel avulsion.

Although not shown in the conceptual design drawing (Drawing 9), access ramps to the base of the channel would need to be constructed at multiple locations to permit transportation of material excavated from the base of the channel to the berms on the channel sides. For the cost estimate it has been assumed that all material excavated from the channel will be placed as a berm above the channel, and that no excavated material will need to be transported from, or disposed of, off-site.

Widening of the channel and construction of raised berms along the edge of the channel may create conflicts with existing infrastructure, including:

- Lillooet West FSR bridge will need to be replaced to span the widened channel and berms. BC Ministry of Forests, Lands and Natural Resource Operations has provided an approximate cost estimate for replacing this bridge, which has been incorporated into the cost estimate provided in this report. The channel would need to be protected from erosion in the vicinity of the bridge abutments.

- BC Hydro transmission lines located next to the FSR bridge must maintain a minimum clearance between the transmission line conductors and the ground or vehicles on the bridge or bridge approach. If channel berms and the bridge are raised, the BC Hydro lines may need to be re-located or raised. This is expected to be costly to achieve, although the costs are unknown at this time and have not been incorporated into this assessment. It is also not known if these costs will be borne by BC Hydro or others.
- The channel access roads, channel berms, and the channel itself may overlap onto private property or roads, which may require negotiation with landowners and re-alignment of roads. Costs for purchasing land and road re-alignment of roads have not been included in the option cost estimate.

For conceptual design it is assumed that the channel is not lined with riprap, concrete or other erosion protection materials, except for in small extents around critical areas, such as bridge crossings and channel bends. Adding an erosion protection lining to the full channel length would greatly increase the capital cost of this option (potentially doubling the cost of the option), but would also reduce channel erosion, reduce potential for channel bank instability, and reduce potential for entrainment of channel bank materials into the flow. The most likely consequence of these phenomena are increased channel maintenance costs, but may also include channel slope retrogression, and bulking of the debris discharge during a flow, which would decrease the channel capacity below the design event. At this conceptual design stage the channel lining has been omitted due to its high cost because the consequences described are considered to be tolerable given that the cost, challenging site access, and the necessity of importing the erosion protection materials from elsewhere. Necessity of including the channel lining in the design should be further evaluated if this option is selected in future design stages.

It is important to note that deepening and widening the existing channel, which is already partly modified, substantially changes its flow behavior compared to a “natural” (unmodified) channel. These changes include lower avulsion potential, higher flow depth and higher flow velocity. Due to higher flow depths and velocities, increased scour will occur. This in turn will lead to oversteepening of the channel side slopes and instability of channel sideslopes through raveling and slumping. This will tend to fill in the channel over time.

The ultimate result will be a wider channel bottom with high aggradation rates and near-vertical lower side slope angles subject to undercutting by high flows. An unprotected channel such as proposed herein will be maintenance intensive to assure design conveyance. Regular inspections along key cross-sections will need to be carried out and an operation and maintenance manual will need to be created to specify at what changes in the channel cross-section geometry, renewed work will be required.

This method assumes that the slope of the ground topography at the proximal area of Lillooet Lake (below the water line) is as steep as (or steeper than) the portion of the fan that is currently visible above the lake level (12°), and that the full volume of debris conveyed by the channel can be dispersed into the lake without causing deposition in the channel. There is some maximum volume limit that can be accepted by the lake without causing debris deposition on the fan above the lake level (e.g. fan build-out into the lake), and this volume is determined primarily by the topography of the fan surface beneath Lillooet Lake. This maximum volume is currently unknown, but it is assumed to be greater than the maximum debris-flow event volume considered in the risk assessment. If this option is selected, a bathymetric survey of the lake bottom in the vicinity of the channel outlet and modeling of debris-flow runout into the lake is recommended to verify this assumption.

Also, it should be recognized that this mitigation method assumes that large event magnitudes, which are expected to be triggered by rock avalanches in the upper watershed, have a similar rheology as the frequent debris flows observed in historical times, which would allow them to flow in the channel completely to Lillooet Lake, without depositing in the channel. There is considerable uncertainty in this assumption, and events associated with rock avalanches may be more likely to deposit due to lower water content, and then avulse from the channel, than the more 'conventional', frequent debris flows. Resolving this uncertainty and its effect on residual risk following mitigation would require more detailed investigation of bedrock instability in the upper basin, as noted in BGC's recommendations (Section 8.0).

The principal advantage of increasing the existing channel capacity is that it is likely to be the least costly option, if the channel is not lined (as has been assumed in this conceptual design), and excluding land negotiation costs and BC Hydro line adjustment costs. Similarly, an additional advantage is that smaller upgrades to the existing channel than shown in this conceptual design can be implemented (with associated greater residual risk) as funds become available. As mitigation works are confined to the existing channel, the environmental impacts to currently undeveloped land is minimized, and the potential for debris-flow risk transfer to buildings located far from the channel is minimized compared to other structural mitigation options.

The principal disadvantage of this debris-flow mitigation option is that it is uncertain if the channel will function as intended, particularly for large magnitude events. There is greater uncertainty in residual risks estimated for this option. Therefore, the residual risks may be greater than shown. Additionally, frequent channel maintenance and cleaning will be required to maintain flow capacity, adding to the overall costs. These costs have not been quantified at this stage. Also, because the channel bisects the existing community, conflicts with existing infrastructure are expected to be more common and more costly than for the other structural mitigation options.

The cost of this mitigation option has been estimated assuming that material excavated from the base and sides of the channel will be placed as berms adjacent to the top of the channel, and that the cut and fill on site will be balanced. Erosion protection lining has been omitted from the cost estimate, as described above. Channel lining would greatly increase the capital cost above that is shown (potentially doubling the cost). An additional cost item that has been included is replacement of the FSR bridge. Alterations to the BC Hydro line, and purchase of private land adjacent to the existing channel may also be required, but have not been included in the cost estimate. Details of the cost estimate are provided in Appendix H.

7.5. Option 2: Diversion Structure at Fan Apex

The second risk reduction option considered is to construct a diversion ditch and berm at the fan apex that directs debris flows out of the main channel towards undeveloped land on the east margin of Catiline Creek fan which is naturally incised (Drawing 10, Figure 7-2). This could be achieved by constructing a large barrier in the existing channel to a height that is above the existing channel crest and which would account for flow superelevation as it is being deflected away from a straight line The barrier would be oriented oblique to the existing channel to direct debris flows towards a 500 m long diversion channel oriented north-south and connecting the fan apex to an undeveloped gully created by the eastern edge of the Kame Terrace (Drawing 5). The diversion channel would be constructed by excavating a trench at the margin of the Catiline Creek fan, and placing the excavated material as an engineered berm on the west side of the trench. The berm would increase the channel capacity, and be sized to prevent flow avulsion toward developed portions of Catiline Creek fan and the Kame Terrace. The conceptual design assumes that the diversion channel would end at the head of the Kame Terrace gully, and flow would continue uncontrolled down the gully some 500 m slope distance (180 m in elevation) to Lillooet Lake.

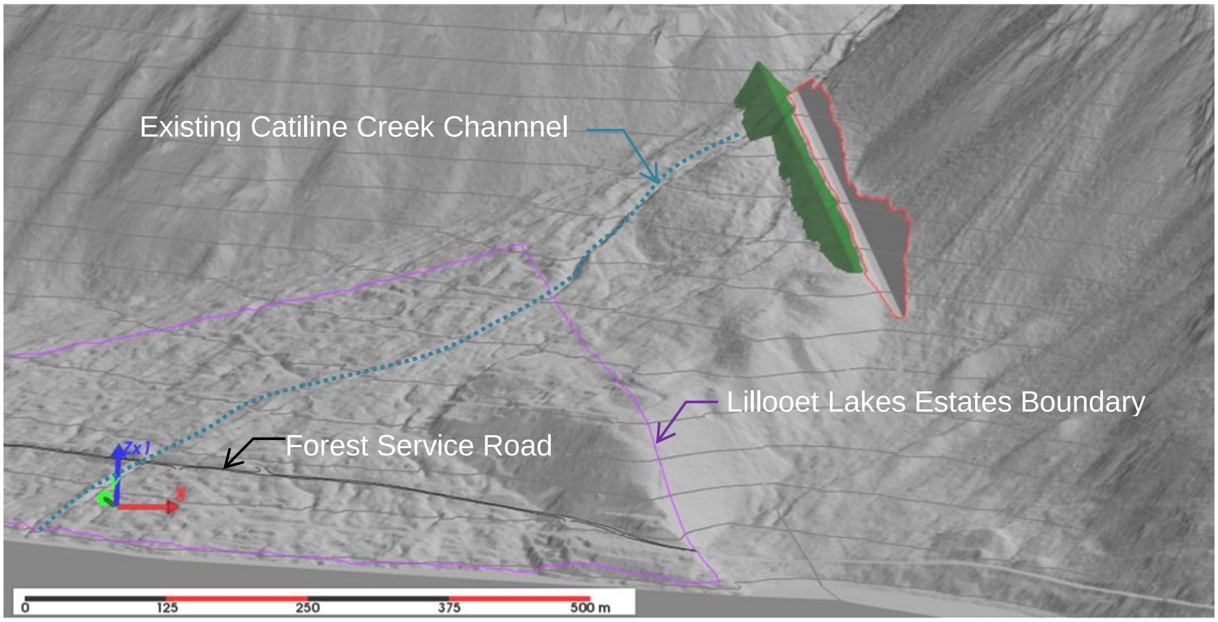

Figure 7-2. Three-dimensional model of the proposed diversion structure that is sized for 300,000 m^3 event associated with 10,000 year return period.

The size of the diversion channel, channel conveyance capacity, and associated event magnitude would be the same as needed for increasing the capacity of the existing channel (Option 1), and these parameters are summarized in Table 7-3. As described for Option 1, the conceptual design assumes that the majority of the diversion channel is not lined with riprap, concrete or other erosion protection measures. The height of the barrier within the existing channel would be chosen to minimize the amount of debris that runs up and over the barrier crest due to run-up and super-elevation at the curve into the diversion channel. The crest of the barrier should include a ‘spill-way’ that forces any debris-flow material that overtops the barrier into the existing channel. Both the upstream and downstream face of this barrier, and the spillway, should include suitably designed erosion protection, and erosion protection of this zone has been included in the conceptual level cost estimate. Use of an open slot, or steel grillage, outlet structure through the barrier at the existing channel was considered, as this would in theory allow Catiline Creek to remain in its existing channel and normal stream flow to follow the channel. This idea was abandoned at this stage because the outlet structure adds significant capital and maintenance costs, and is likely to be frequently plugged by small events, which would result in routine diversion of the creek to the diversion channel. This idea should be further evaluated if this option is selected for future design stages.

The gradient of the diversion channel would be between 14° and 15° (~26%), which is steeper than the existing channel (12°), and is expected to be capable of conveying debris flows to the Kame Terrace gully. The gradient of the upper two-thirds of the gully is approximately 20°, and the gradient decreases to about 10° in the bottom 30 m of elevation above Lillooet Lake. The conceptual design assumes that a channel would be constructed beneath the Lillooet West FSR, and a raised bridge with protected abutments would be constructed across the channel. The channel in the vicinity of the bridge would need to be erosion protected, and would extend up the gully far enough to funnel debris in the gully beneath the bridge. It is likely that some debris would deposit on the 10° slope, in the vicinity of the bridge, as this slope gradient is transitional between sediment transport and deposition. The conceptual design assumes that most debris would continue to travel at this gradient because it is channelized and traveling at a high initial velocity due to the steeper gully gradient above. This assumption should be further investigated during future design stages, if this mitigation option is selected.

The principal advantage of debris-flow mitigation Option 2 is that diversion of the debris flow away from the existing channel, and developed portions of the fan, is likely to result in greater total risk reduction, with less uncertainty related to the channel's ability to convey flow without flow avulsions. Additionally, this option minimizes modifications and environmental impacts in developed areas, and potential conflicts with existing infrastructure.

The principal disadvantage of diverting the debris flow is that debris-flow risk could be transferred to buildings on and below the Kame Terrace, where current debris-flow risk is relatively low. Houses on Lillooet Lake adjacent to the outlet channel (Parcel No. 1, primarily) would be most affected, and may be at risk from most debris-flow magnitudes conveyed by the channel. Although not quantified in the risk assessment, homes on the Kame Terrace (where current risk is relatively low) could be affected by debris flows if the diversion channel does not perform as intended, and flows avulse from the channel. Prevension of flow avulsion from the diversion channel should be a primary objective of detailed channel design, if this mitigation option is selected. Additionally, the overall environmental impact of this option may be greater than for modifications to the existing channel, because construction of the diversion channel would be concentrated in areas of the fan that are currently undeveloped, and Catiline Creek would be diverted to a new channel. Furthermore, this option would divert the creek out of its existing creek, which is typically difficult to permit, due to environmental concerns. Access roads in these undeveloped fan areas would be required for construction and maintenance.

Frequent diversion channel cleaning and maintenance would be required to maintain the design flow capacity, as is the case for all of the proposed risk reduction options.

The cost of this mitigation option has been estimated assuming that material excavated from the base and sides of the diversion channel will be placed as a berm, and that the overall cut and fill on site will be balanced. Erosion protection lining costs have been included for the surface of the proposed barrier and spillway at the existing channel, as well as for the areas around the proposed road bridge channel. Erosion protection lining has been omitted from the cost estimate for all other areas of the diversion channel. However, given the relatively steep channel inclination and transition to an even steeper natural gully, the potential for downcutting and requirements for additional erosion protection measures should be further investigated during future design stages, if this mitigation option is selected.

Construction of a new raised bridge and channel at the FSR has been included in the cost estimate. The cost estimate assumes that no other modifications to existing infrastructure or land purchase would be needed. Details of the cost estimate are provided in Appendix H.

7.6. Option 3: Retention Barrier at Fan Apex

The third risk reduction option considered is a large debris retention barrier located on the fan, near the fan apex (Drawing 11, Figure 7-3). The intent of the barrier is to capture debris during a debris flow before it reaches developed portions of the fan. The barrier would include an outlet slot or grillage structure in the existing channel that allows annual water flood flow to pass the barrier under typical conditions, but traps coarse sediment and debris during the initial surge of a debris flow. The outlet structure would also act as a spillway that would contain any debris that overtops the structure and direct it towards the existing channel. Access to the debris storage area on the upslope side of the barrier would need to be maintained to allow for removal of debris following debris flow and flood events. It is expected that frequent maintenance and debris removal would be required to maintain the design debris storage volume, and to ensure that the outlet structure remains open for typical stream flows.

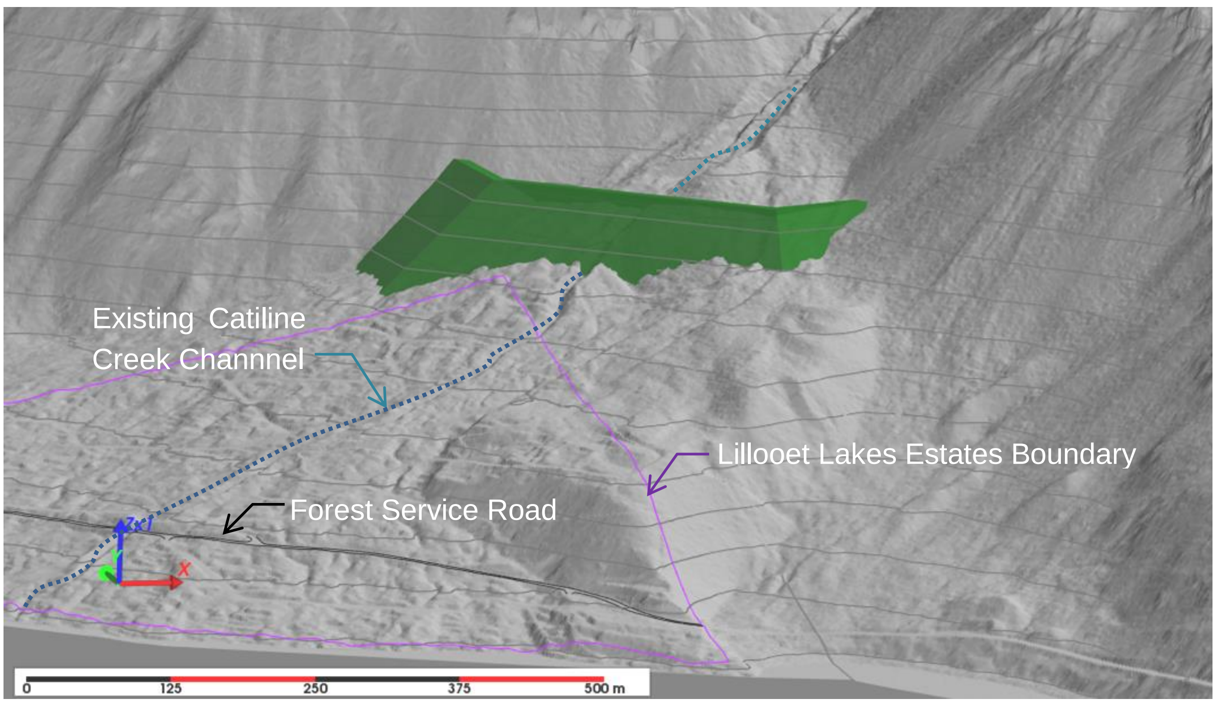

Figure 7-3. Three-dimensional model of the proposed retention barrier structure that is sized for 300,000 m^3 event associated with 10,000 year return period.

The conceptual design assumes that the debris barrier would be composed of earth fill with an erosion protected shell, where appropriate. It may be possible to construct a barrier out of concrete resulting in a relatively smaller barrier footprint, but earth fill was selected for conceptual design because it facilitated the cost estimate and comparison with the other options. As the volume of earth fill required to construct the barrier would be substantially more than the volume that could be cut from the existing fan surface, it is assumed that the majority of the earth fill would need to be imported to the site. The source for this material has not been explored at this conceptual level.

The gradient of the channel at the fan apex is steep (approximately 19°), and the width of the confined gully above the fan apex (approximately 40 m) is relatively narrow. Therefore the storage potential of the fan apex and gully is very poor. Table 7-4 summarizes the approximate barrier height (defined as the height of the barrier centerline crest above the existing channel centerline), barrier fill volume required, and retention volume for two return period events. As shown in the table, the fill volume required to construct the barrier is two to four times the volume of debris that could be stored. This is considered to be a highly inefficient design, but no alternative configuration that offers a more favorable ratio of barrier storage potential to required fill volume was identified. The footprint of the "Large" barrier alternative and conceptual design location is shown on Drawing 11.

Table 7-4. Debris barrier conceptual design summary.

Barrier Size	Barrier Height (m)	Fill Volume to Construct Barrier (m^3)	Barrier Storage Capacity (m^3)	Best Estimate Return Period (years)
Small	15	420,000	100,000	1,000
Large	27	720,000	300,000	10,000

The principal advantage of the debris retention barrier option is that the risk transfer issues described for the other structural mitigation options are minimized because a debris flow is stopped before it reaches developed areas of the fan. Similarly, because this option does not require debris to be conveyed to Lillooet Lake, uncertainties about the potential for the flow to deposit and avulse a channel can be disregarded, and therefore uncertainty in the residual risk level is relatively less than other options. Additionally, as with option 2, this option minimizes modifications and environmental impacts in developed areas, and potential conflicts with existing infrastructure.

The principal disadvantages of the debris retention barrier option are the high cost, large structural footprint, and poor storage potential relative to the other structural mitigation options. The large fill volume required to construct the barrier would need to be imported to site, which causes the construction footprint to extend well beyond the fan boundaries. Only a small percentage of the required fill volume could be sourced from upstream of the barrier, in the storage basin area. Additionally, frequent maintenance and removal and disposal of debris would be required to maintain the design storage potential, and costs for this maintenance are expected to be relatively higher than the other options, although they have not been quantified.

The cost of this mitigation option has been estimated assuming that the barrier is constructed primarily of imported earth fill, and that there is a concrete and steel outlet structure that extends to the full height of the barrier. The cost of the outlet structure has been estimated by extrapolating the costs of outlet structures constructed on previous projects that were one-third to one-half the height of the proposed structure at Catiline Creek. The cost estimate also includes an allowance for erosion protection, composed of large diameter riprap and concrete, on the upstream barrier face and over the spillway into the existing channel. The cost estimate uncertainty associated with this option is relatively higher than the other mitigation options, but it is considered likely that this option will be significantly more expensive than the other options that are presented. Details of the cost estimate are provided in Appendix H.

7.7. Comparative Analysis

A comparison of the three risk mitigation options is provided in Table 7-5.

Table 7-5. Summary comparison of the debris flow risk mitigation options considered at Catiline Creek fan.

Risk Reduction Option		Description	Advantages	Disadvantages	Risk Reduction Level	Conceptual Level Cost Estimate1
1	Increase capacity of existing channel	Widen, deepen, and straighten the existing channel to increase the peak flow rate that the channel is able to convey. For conceptual design, a base channel width of 7 m and 1.5H:1V side slopes has been selected. Material excavated from the existing channel would be used to construct berms adjacent to the channel. The cost estimate assumes the channel is not lined or protected from erosion.	- Lowest cost structural protection option. - Minimizes potential for debris flow risk transfer compared to other structural protection options. - Simple to explain to the public. - Minimizes environmental impacts on undeveloped land. - Can be implemented in stages as funds become available.	- Residual risk may be relatively high, and uncertain. Plugging of the channel during a debris flow, leading to flow avulsion, is possible and difficult to quantify. - Frequent channel cleaning and maintenance will be required to maintain the design flow capacity and manage risk of avulsions. - Footprint may conflict with existing infrastructure such as property boundaries, roads, buildings, and powerlines.	- Convey up to the largest conventional debris flow, which is the 1,000 year return period event; 100,000 m^3 debris volume; 120 m^2 channel area. - Residual risk likely to exceed risk reduction targets.	$ 4.0 M
					- Convey up to the largest debris flow event considered in the risk assessment, which is the 10,000 year return period event; 300,000 m^3 debris volume; 300 m^2 channel area. - Residual risk likely to be tolerable.	$ 9.1 M
2	Diversion structure at fan apex	Excavate a diversion channel that captures debris flows at the fan apex and directs flow along the undeveloped land on the east margin of the fan, across the forest service road to Lillooet Lake. Material excavated from the channel would be used to construct a berm along the downhill side of the diversion to increase the flow capacity, and to construct a barrier across the existing channel.	- Greater risk reduction potential than Option 1 for most residents. - Minimizes visual impact, environmental impacts, and modifications to the existing channel in the developed areas of the fan.	- Potential risk transfer to homes on the east side of the fan, particularly homes on and below the kame terrace that have acceptable existing risk. - Greater environmental impact to currently undeveloped areas of the fan than Option 1. - Frequent channel cleaning and maintenance will be required to maintain the design flow capacity.	- Convey up to the largest conventional debris flow, which is the 1,000 year return period event; 100,000 m^3 debris volume; 120 m^2 channel area.. - Residual risk likely to exceed risk reduction targets.	$ 4.7 M
					- Convey up to the largest debris flow event considered in the risk assessment, which is the 10,000 year return period event; 300,000 m^3 debris volume; 300 m^2 channel area. - Residual risk likely to be tolerable.	$ 8.1 M
3	Retention barrier at fan apex	Construct a debris retention barrier on the fan near the fan apex to capture debris during a debris flow event. Barrier constructed of earthfill is proposed. The steep fan topography and narrow canyon width results in very poor potential storage volume.	- Minimizes visual impact, environmental impacts, and modifications to the existing channel in the developed areas of the fan. - Less risk transfer potential than other structural options. - Potentially less residual risk than other structural options, which require flow to be conveyed to the lake.	- Largest environmental impact, concentrated in undeveloped fan areas. - Largest cost and environmental footprint. - Frequent clean out of debris storage basin required to maintain capacity. - Large volume of barrier construction materials would need to be imported to site.	- Retain the largest conventional debris flow, which is the 1,000 year return period event; 100,000 m^3 debris volume; 15 m barrier height at centerline. - Residual risk likely to exceed risk reduction targets.	$ 17.9 M
					- Retain up to the largest debris flow event considered in the risk assessment, which is the 10,000 year return period event; 300,000 m^3 debris volume; 27 m barrier height at centerline. - Residual risk likely to be tolerable.	$ 31.2 M

Notes:
1) Cost estimates are 'conceptual level', associated with an accuracy of roughly -50% to +100%, and intended for comparison purposes only.

8.0 CONCLUSIONS

In this report, debris-flow safety risk was assessed for persons inside dwellings on Catiline Fan. Three conceptual risk reduction options were developed.

8.1. Safety Risk

BGC's best-estimate of individual risk given full time occupancy, exceeded 1:10,000 risk of fatality per year for 76 of the 114 occupied, residential-classed lots within the study area. Of these, 18 lots exceeded 1:1,000 annual risk of fatality, exceeding the DNV individual risk tolerance threshold by more than one order of magnitude. Estimated group safety risk also fell entirely into the "Unacceptable safety risk" range when compared to the above risk tolerance standards.

8.2. Risk Reduction Measures

Debris-flow risk reduction options include:

- Increasing the capacity of the existing channel
- Constructing a diversion channel along undeveloped land on the east margin of the fan
- Constructing a debris-flow retention barrier at the fan apex.

These options were each described at two size levels for comparison of their estimated cost to preliminary estimates of the level of risk reduction achieved.

The larger variant was designed to manage the largest magnitude event expected at Catiline Creek, estimated as 300,000 m^3 total volume which corresponds to a return period of approximately 10,000 years. The smaller variant was designed to manage the portion of risk associated with the most frequent debris flows similar to those that have occurred during historical times, up to 100,000 m^3 total volume. This corresponds to a return period of approximately 1000 years. Preliminary analyses suggest that mitigation of the smaller design volume may reduce individual safety risk but not group risk to tolerable levels according to DNV risk tolerance criteria. This is subject to confirmation during detailed mitigation design.

Estimated mitigation construction costs ranged from $4M - $9.1 M for improved channelization or diversion, with barrier construction estimated to cost about $17.9-$31.2 M. The smaller and larger mitigation levels correspond with the lower and higher ends of these cost ranges, respectively. These estimates exclude the cost of long-term maintenance such as debris removal from the channel or the debris basin, which would be critical to ensure that the measures perform as intended.

8.3. Limitations

This risk assessment is based on the current number of dwellings and observed geomorphological conditions in the Catiline Creek watershed. Estimated risk levels assume constant conditions. Debris fans and the processes in their watersheds are dynamic, and hazard and risk will change to some degree when floods or debris flows avulse out of the existing channel or erode new channels. Similarly, any man-made alterations of the landscape through fill placements, cutslopes or road constructions may change the distribution and intensity of debris flow and flood hazards and thus change the fan's risk profile. Modifications to development will also change the risk by changing the number and location of persons exposed to hazard. As such, to assure consistency of this report with current conditions, BGC recommends that the risk assessment be updated following debris flows or changes to the existing development. Any landscape alterations should require permits from the SLRD and be reviewed by professionals with appropriate training in light of this risk assessment.

It is important to note that the nature of bedrock instability in the upper watershed is not yet sufficiently characterized for a full understanding of large landslide failure modes, volumes, and source locations. Such detailed assessment was outside the current scope of work. This uncertainty could be reduced through additional field investigation during snow-free conditions, more detailed measurement of source zone volumes, kinematic analysis of failure modes, and on-site or satellite-based monitoring to detect slope movement.

Finally, the northwest corner of LLE and HJP, while not on Catiline fan, is located on the fan of an unnamed basin between Catiline Creek and McCullock Creek and possibly the southeast corner of McCullock Creek fan (Drawing 1). BGC also noted landforms on upper bedrock slopes adjacent to these basins (uphill facing scarps or so-called antislope scarps) that indicate deep-seated bedrock instability. As such, estimated risks to HJP or the western-most portion of LLE should be considered as minimums until these areas are further assessed.

9.0 CLOSURE

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

Yours sincerely,

BGC ENGINEERING INC.
per:

ISSUED AS A DIGITAL DOCUMENT,
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APPENDIX A
LAND USE CONTRACT NO. 88

SQUAMISH-LILLOOET REGIONAL DISTRICT

BY-LAW NO. 88, 1976

A by-law to authorize the entering into of a Land Use Contract.

WHEREAS pursuant to the provisions of Subsection 1 of Section 798A of the Municipal Act, and the provisions of Section 702A of the Municipal Act, the Regional Board may by by-law, enter into a Land Use Contract containing such terms and conditions for the use and development of the land as may be mutually agreed upon;

AND WHEREAS a Public Hearing as required pursuant to Section 702A has been held;

AND WHEREAS this By-law has been approved by the Lieutenant-Governor-in-Council;

NOW THEREFORE the Regional Board of the Squamish-Lillooet Regional District in open meeting assembled, enacts as follows:

1. The Squamish-Lillooet Regional District is hereby authorized and empowered to enter into a Land Use Contract with the Canada Trust Company, H. J. Developments Ltd., Heather Jean Estates Ltd., Heather Jean Estates No. 2 Ltd., Heather Jean Estates No. 3 Ltd., and Heather Jean Properties Ltd., in accordance with the form of contract designated as Schedule A attached hereto and forming part of this by-law;

2. The Chairman and Secretary of the Squamish-Lillooet Regional District are hereby authorized and empowered to execute the said Land Use Contract with the Canada Trust Company, H. J. Developments Ltd., Heather Jean Estates Ltd., Heather Jean Estates No. 2 Ltd., Heather Jean Estates No. 3 Ltd., and Heather Jean Properties Ltd., and to register the said Land Use Contract at the Land Registry Office, and to do all things necessary in relation thereto;

3. This by-law may be cited as "Land Use Contract Authorization By-law No. 88, 1976".

READ A FIRST TIME this 23rd day of December, 1976.

READ A SECOND TIME this 23rd day of December, 1976.

READ A THIRD TIME this 23rd day of December, 1976.

APPROVED BY THE LIEUTENANT-GOVERNOR-IN-COUNCIL this 3rd day of March, 1977.

RECONSIDERED, FINALLY PASSED AND ADOPTED this 28th day of March, 1977.

T. B. M. Fougberg
Chairman

I. R. Knowles
Secretary-Treasurer

I hereby certify the foregoing to be a true and correct copy of By-law No. 88, 1976, cited as "Land Use Contract Authorization By-law No. 88, 1976" as at third reading.

Dated at Pemberton, B.C. this 1st day of April, 1977.

Secretary-Treasurer

This is Schedule "A" to Land
Use Contract Authorization
By-law No. 88, 1976

THIS AGREEMENT made the 17th day of June, 1976.

BETWEEN:

SQUAMISH-LILLOOET REGIONAL DISTRICT, a regional district incorporated under the laws of the Province of British Columbia, with offices at Pemberton, in the Province of British Columbia;
(hereinafter called the "District")

OF THE FIRST PART

AND:

THE CANADA TRUST COMPANY, a trust company duly incorporated under the laws of the Dominion of Canada, having an office at 901 West Pender Street, in the City of Vancouver, Province of British Columbia;
(hereinafter called the "Trustee")

OF THE SECOND PART

AND:

H.J. DEVELOPMENTS LTD., a company duly incorporated under the laws of the Province of British Columbia, having an office at the Village of Pemberton, Province of British Columbia;

OF THE THIRD PART

AND:

HEATHER JEAN ESTATES LTD., a company duly incorporated under the laws of the Province of British Columbia, having an office at the Village of Pemberton, Province of British Columbia;

OF THE FOURTH PART

AND:

HEATHER JEAN ESTATES NO.2 LTD., a company duly incorporated under the laws of the Province of British Columbia, having an office at the Village of Pemberton, Province of British Columbia;

OF THE FIFTH PART

AND:

HEATHER JEAN ESTATES NO. 3 LTD., a company duly incorporated under the laws of the Province of British Columbia, having an office at the Village of Pemberton, Province of British Columbia;

OF THE SIXTH PART

AND:

HEATHER JEAN PROPERTIES LTD., a company duly incorporated under the laws of the Province of British Columbia, having an office at the Village of Pemberton, Province of British Columbia;

OF THE SEVENTH PART

(H.J. Developments Ltd., Heather Jean Estates Ltd., Heather Jean Estates No. 2 Ltd., Heather Jean Estates No. 3 Ltd., and Heather Jean Properties Ltd., shall be hereinafter jointly called the "Developer" and/or :Beneficial Owners".)

.............2

WHEREAS the District, pursuant to Sections 702A and 798(1) of the "Municipal Act", may, notwithstanding any By-law of the District, or Sections 712 or 713 of the "Municipal Act" upon the application of an owner of land within a development area designated as such by By-law of the District, enter into a Land Use Contract containing such terms and conditions for the use and development of the land as may be mutually agreed upon and thereafter the use and development of that land shall be in accordance with such Land Use Contract;

AND WHEREAS the "Municipal Act" requires that the Regional Board, in exercising the powers given by Section 702A shall have due regard to the considerations set out in Section 702(2) and Section 702A(1) in arriving at the use and development permitted by any land development contract and the terms, conditions and considerations thereof;

AND WHEREAS the Developer and Trustee has presented to the District a scheme of use and development of the within described lands and premises and has made application to the District to enter into this Land Use Contract under the terms, conditions and for the consideration hereinafter set forth;

AND WHEREAS the Board of the District having given due regard to the considerations set forth in Sections 702(2) and 702A(1) of the "Municipal Act" has agreed to the terms, conditions and considerations herein contained;

AND WHEREAS the Developer acknowledges that it is fully aware of the provisions and limitations of Section 702A of the "Municipal Act" and the District and the Developer mutually acknowledge and agree that the Board of the District cannot enter into this contract until the Board has held a public hearing thereon, in the manner prescribed by law, has duly considered the representations made and the opinions expressed at such hearing, and unless at least two-thirds of all of the members of the Board vote in favour of the District entering into this contract;

...3.

AND WHEREAS the Trustee is the registered owner of the below described lands subject to certain trust agreements in favour of the Beneficial Owners dated the 13th day of September, 1973 (as to Heather Jean Estates Ltd. and the properties therein described), the 11th day of October, 1974 (as to Heather Jean Estates No. 2 Ltd. and the lands therein described), and the 11th day of October, 1974 (as to Heather Jean Estates No. 3 Ltd. and the lands therein described), a copy of each such trust agreements being annexed hereto jointly as Schedule "A" and being hereinafter jointly called the "Trust Agreement".

AND WHEREAS the Developer wishes to develop the below described land in accordance with the provisions of this Land Use Contract and the Trust Agreement;

NOW THEREFORE this contract witnesseth that in consideration of the premises and the conditions and covenants hereinafter set forth, the District and the Developer covenant and agree as follows:

1. Definitions

In this contract unless the context otherwise requires:

"Accessory Building" shall be construed to mean and include a building customarily incidental and subordinate to the principal building on the same Site.

"Building Inspector" shall be construed to mean and include the Building Inspector for the District and his duly authorized assistants or such consultants as may be appointed to act for the District.

"Commercial Site(s)" shall mean any or all of the Sites numbered 71, 72, 73, 93, 152, 153 and 154, as shown shaded yellow on the Site Plan.

"Common Site(s)" shall mean any or all of the Sites numbered 27, 28A, 34 and 59, as shown shaded orange on the Site Plan.

"Creek Protection Corridor No. 1" shall mean that area of land and land covered by water coloured solid red on the Schedule "B" Site Plan.

...4.

"Creek Protection Corridor No.2" shall mean that area hatched with red lines on Schedule "B" Site Plan.

"Greenbelt Area" shall mean that portion or portions of the Land shown shaded dark green on the Site Plan.

"Lodge Area" shall mean the area designated as Lodge Area and coloured red on the Site Plan.

"Private Site(s)" shall mean any or all building sites or lots as shown on Schedule "B" annexed hereto except for Commercial Sites, Common Sites, Greenbelt Area, Lodge Area and Works Area.

"Regional Administrator" shall mean and include the Regional Administrator for the District and his duly authorized assistants.

"Regional Board" shall mean and include the Regional Board of the District.

"Regional Zoning By-law" shall mean and include Zoning By-law No. 29-1972 of the District and all amendments as of the date hereof.

"Site" shall mean any one of the building areas or lots shown on the Site Plan inclusive of all Greenbelt Area, Lodge Area, Works Area, Commercial Sites, Private Sites and Common Sites, but exclusive of any road and/or right-of-way.

"Site Plan" shall mean the Plan attached hereto as Schedule "B".

"Works Area" shall mean the area designated as Works Area and coloured blue on the Site Plan.

H 52306F

2. Owner

The Trustee is the registered owner of an estate in fee simple and ALL AND SINGULAR that Certain parcel or tract of land and premises situate, lying and being in the Lillooet Assessment District, more particularly known and described as: FIRSTLY: District Lot 4901, Lillooet

District, except that part included in Plan 11938.

SECONDLY: PARCEL "A", DISTRICT LOT 4901, LILLOOET DISTRICT PLAN 11938, LILLOOET ASSESSMENT DISTRICT.

K20359F

(hereinafter called the "Land")

3. **Consents**

The Developer has obtained the consent of all persons holding any registered interest in the land as set out in the Consents to the use and development set forth herein, which Consents are attached hereto, (a list of such Consents being attached hereto as Schedule "D").

4. **Uses and Building Permits**

The Land and any Site and any and all buildings, Accessory Buildings, structures and improvements erected thereon, thereover or therein shall be used for the purposes specified in Schedule "C" hereto and for no other purposes. A separate Building Permit and fee shall be required by the District for each building erected on any Site, and for all alterations or renovations to Existing Buildings on any Site, as if each Site were a separate lot or parcel existing under the provisions of the British Columbia Land Registry Act. All proposed buildings must comply with the Building By-law of the District and all other appropriate Regional By-laws.

5. **District Restrictions**

The Sites shall be subject to and all buildings erected shall comply with the restrictions set forth in Schedule "C" hereto.

6. **Design on Sites**

The design of all buildings and Accessory Buildings on the Site(s) shall be subject to the approval of the Developer as set forth in the Trust Agreement. The sole responsibility for design approval and control shall vest in the Developer and the District shall not be bound to inquire as to whether or not any plans for buildings or Accessory Buildings on the Sites have been so approved prior to granting any Building Permit for the same and shall not be liable for any failure so to do.

7. Greenbelt Areas

The Greenbelt Area shall not be used for any purposes inconsistent with their use and retention as natural unimproved areas. To the extent that it is reasonably practical the Greenbelt Area shall be kept in its natural state, provided always that underground services may be installed under, and pedestrian pathways be constructed through, the Greenbelt Area.

8. Services

The District and the Developer acknowledge and agree that all utilities including street lighting, water, sewers, gas, cablevision, telephone and electricity on the Land are private utilities. The responsibility for the construction and installation, maintenance and repair of any or all such utilities shall be at the sole discretion of the Developer, and the Developer shall have the sole responsibility for the provision of any or all such services to the Land and to any individual Site. It is expressly understood by the Developer and the Developer hereby acknowledges and agrees that the District shall be under no obligation to provide any connection to a regional system for any or all such utilities and that any utilities installed by the Developer shall be self-contained within the Land. Save as specifically provided in this agreement, all utilities shall conform to all appropriate District, Provincial and Federal by-laws and/or statutes and regulations pertaining thereto. The Developer shall have the sole responsibility of obtaining any necessary permits for any such services from the appropriate authority.

8A Port Douglas - Pemberton Access Road

The Developer acknowledges that the present access road to the land being the Port Douglas - Pemberton Road (hereinafter called the "access road"), is an industrial road operated by the British Columbia Forest Services and the British Columbia Department of Highways. The Developer covenants and agrees:

(a) That the access road shall be kept clear of any and all obstructions including parked vehicles and/or

...7.

equipment at all times;

(b) That the use of the access road by the Developer shall not in any manner interfere with logging truck traffic engaged in the hauling of timber along the access road;

(c) That the British Columbia Forest Service and/or the British Columbia Department of Highways will not in any manner be responsible for road maintenance, snow plowing, and/or any other road improvement work for the access road now or in the future, and further that the British Columbia Forest Service and/or the British Columbia Department of Highways shall not in any manner be obliged by the Developer or any purchaser of any private site to make any improvements, or do any maintenance or snow plow the access road;

(d) That the British Columbia Forest Service and/or the British Columbia Department of Highways may close the access road at any time such closure is deemed necessary as a result of fire hazard, flooding, spring breakup, or any other reason, whether of the type enumerated before or otherwise. In the event the access road is closed, access to and from the land along the access road, by the Developer, or any owner of any Private Site, or any other person, shall be subject to the prior approval of the Forest Ranger or Department of Highways Foreman responsible for the territory covered by the access road. The Developer covenants and agrees not to use or permit the use of the access road during any period of closure without the approval of the Forest Ranger or Department of Highways Foreman for the territory first had and obtained.

(e) That the Developer shall engineer and install any junctions or intersection between roadways on the land and the access road to the satisfaction of the British Columbia Forest Service and/or British Columbia Department of Highways. The Developer shall provide

...8.

to the British Columbia Forest Service and British Columbia Department of Highways, all engineering drawings required for any such junction or intersection, and shall obtain the approval of the British Columbia Forest Service District Forester and the Department of Highways Foreman responsible for the territory prior to the installation or development of any such junction or intersection;

(f) That the Developer shall not use or permit any person to use the access road other than in compliance with any regulation established by the British Columbia Hydro and Power Authority with respect to non interference with power line towers, poles, or other installations, and the regulations maintaining safe distances from and under such structures and the power lines;

(g) That the Developer, on behalf of the Developer and any owner of any Private Site, hereby expressly waive any right or rights to demand petition or otherwise request the conversion of the access road from an industrial road to a public highway. It is expressly understood by the Developer, and the Developer hereby acknowledges and agrees, that neither the British Columbia Forest Service nor the British Columbia Department of Highways shall be under any obligation to provide, improve, or maintain the access road or to connect the land with any road or roads presently developed by the District and/or the British Columbia Department of Highways either at this time or in the future. Notwithstanding the waiver hereinbefore set forth, the Developer further covenants and agrees that if as a result of any development on the land, a public highway is necessary to connect the land with any other road or roads, the Developer shall pay all costs of installing and maintaining any such highway.

(h) That the Developer covenants and agrees to save harmless and effectually indemnify the District, the British

Columbia Forest Service, the British Columbia Department of Highways, and/or the British Columbia Hydro and Power Authority, their officers and employees and/or agents, against all actions and proceedings, costs, damages, expenses, claims, and demands whatsoever and by whomsoever brought by reason of use by the Developer and/or any owner of any Private Site, their respective agents, servants, employees, invitees, guests, or other persons of the access road; and

(i) That the Developer, as security for the due and proper performance of the covenants and agreements, contained in this paragraph, shall deposit with the District a bond in a form and amount satisfactory to the Regional Board to cover the covenants of the Developer as set forth in this paragraph.

9. Roadways

The access roads and cul-de-sac driveways shall be located substantially as shown on the Site Plan. The District and the Developer acknowledge and agree that the access roads and the cul-de-sac driveways are private roads and driveways, the responsibility for which remains with the Developer and the owners from time to time of the Sites. It is expressly understood by the Developer and the Developer hereby acknowledges and agrees that the District shall be under no obligation to provide, improve, or maintain any road or roads to connect the Land with any road or roads presently developed by the District either at this time or in the future, and that if any such connecting road or roads are hereafter requested by the Developer, the Developer shall pay all costs of installing and maintaining any such road or roads.

10. Garbage Facilities and Sanitary Landfill

The Developer shall provide one or more Sites for the purpose of a garbage dump and/or sanitary landfill and shall operate the same for the benefit of the individual site owners. It is acknowledged by the parties hereto that the District shall have no obligation to provide garbage collection facilities for the Land or any individual site, and that such garbage collection facilities shall be the sole responsibility of the Developer. The Developer shall be responsible for obtaining approvals of all appropriate authorities with regard to the operation of the garbage dump and/or sanitary landfill.

11. Indemnity for Subsequent Works

The Developer hereby covenants and agrees that any costs or expenses incurred by the District in respect of providing any services or maintaining or repairing any services provided by the Developer, or any steps that the District is obliged or forced to take to provide services or roads to the Land shall be paid by the Developer or upon default shall be added to and collectible as taxes against the Land or any constituent parts thereof in accordance with the provisions of Section 377 of the "Municipal Act".

12. Partition

The Land shall be divided into Sites substantially in compliance with and according to the Site Plan. It is acknowledged by the parties hereto that the Land will not be subject of a sub-division as such term is defined in the Land Registry Act, R.S.B.C. 1960 and all amendments as of the date hereof.

13. Changes in Schedule "B"

The District and the Developer agree that while the Site Plan shows the general location and sizes of the Sites, roads and other parts of the Land, the exact location and size of the Sites may vary slightly from Schedule "B" so long as no significant or substantial change is made. The Developer shall submit to the District for approval a revised Site Plan showing the final delineation of all Sites on the Land in as many copies as may be reasonably required by the District. In the event of any subsequent consolidation of any Sites (as set forth in Part VII of Schedule "C"), the Developer agrees to forthwith forward to the District such revised maps or plans as may be reasonably required by the District.

14. Inspection by Building Inspector

Notwithstanding that the services are private, the Building Inspector shall have the right, but not the obligation, from time to time to enter upon the Land for the purpose of inspecting the installation of all services and connections to individual Sites which service connections must comply with the applicable Regional by-laws. The Building Inspector shall be entitled to charge and receive the appropriate fees for inspections and approvals.

15. Prospectus to be Delivered to Purchasers

The Developer shall prepare a form of prospectus (herein called the "Prospectus") satisfactory to the Regional Administrator which shall incorporate the following:

(a) a description of the development;

(b) a summary of the provisions of this Land Use Contract; and

(c) a description of the procedure to be followed by each owner of a Site in order to obtain a Building Permit for the Site.

The Developer agrees that at or before the time the purchaser enters into an agreement to purchase a Site he will deliver to each purchaser of a Site, a true copy of the Prospectus and will afford that purchaser the right to read the Prospectus.

16. Payments by Developer

The Developer agrees:

(a) To pay all arrears of taxes outstanding against the property herein described before the execution by the District of this Land Use Contract;

(b) To pay all current taxes levied or to be levied on the said Land on the basis and in accordance with the assessment and collector's roll entries;

(c) To pay to the District all inspection fees, administration fees, engineering fees and legal costs in connection with this Land Use Contract.

17. Indemnity by Developer

The Developer covenants to save harmless and effectually indemnify the District, its officers, employees and/or agents against:

(a) All actions and proceedings, costs, damages, expenses, claims and demands whatsoever and by whomsoever brought by reason of the execution of this Land Use Contract;

...12.

(b) All expenses and costs which may be incurred by reason of the execution of the said works on the Land resulting in damage to any property owned in whole or in part by the District or which the District by duty or custom is obliged, directly or indirectly, in any way or to any degree, to construct, repair or maintain; and

(c) All expenses and costs which may be incurred by reason of liens for non-payment of labour or materials, workers' compensation assessments, unemployment insurance, Federal or Provincial Tax, check-off and for encroachments owing to mistakes in survey.

18. Development

The District hereby covenants and agrees with the Developer to permit the Developer to proceed with the development herein contemplated on the said Land and to issue Building Permits for each of the Sites subject to the terms and conditions herein contained.

19. No Other Terms

It is understood and agreed that the District has made no representations, covenants, warranties, guarantees, promises or agreements, (verbal or otherwise) with the Developer other than those in this contract.

20. Restrictive Covenant

This contract shall have the force and effect of a restrictive covenant running with the Land and shall be registered in the Land Registry Office by the District pursuant to the provisions of Section 702A(4) of the "Municipal Act".

21. Gender

Wherever the singular or masculine is used herein, the same shall be construed as meaning the plural, feminine or body corporate or politic where the contract or the parties so require.

22 Schedules Part of Contract

Schedules "A" to "D" hereinbefore referred to are hereby incorporated into and made part of this contract.

23. Compliance with By-laws

Except as permitted by this contract, the within works and the development herein shall comply with all the By-laws of the District.

...13.

24. Non-Assignability

The Developer may not assign this contract without the written consent of the District first had and obtained, such consent not to be unreasonably withheld. The Developer shall forthwith notify the District of any modifications or amendments to the Trust Agreement.

24A. Trustee

The parties hereto acknowledge that the Trusteee is joined as party to this Land Use Contract solely in its capacity as registered owner of the lands pursuant to the terms and conditions of the Trust Agreement and further that the Trustee's liability (if any) under this Land Use Contract shall be as set forth in the Trust Agreement.

24B. The construction of firebreaks and other measures for the protection of structures and their occupants shall meet the requirements of the National Fire Code and the B.C. Forest Service but in any event shall include a small pumper unit and water barrels.

24C. For the purposes of this section, the following definitions shall apply:

"Natural Boundary" means the visible highwater mark of any lake, river, stream, or other body of water where the presence and action of the water are so common and usual, and so long continued in all ordinary years, as to mark upon the soil of the bed of the lake, river, stream, or other body of water, a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself.

"Watercourse" is any natural or man-made depression with well-defined banks and a bed two feet or more below the surrounding land serving to give direction to a current of water at least six months of the year or having a drainage area of one square mile or more or as required by a designated Water Resources Official of the Province of British Columbia.

24D. Notwithstanding any other provisions of this Land Use Contract, no building or part thereof shall be constructed, altered, moved, or extended, nor shall any mobile home, mobile unit or structure be located;

(a) with the underside of the floor system of any area used for habitation, business, or storage of goods damageable by floodwaters, or in the case of a mobile home the ground level on which it is located, lower than five (5) feet above the natural boundary of any nearby watercourse nor lower than 659.5 feet (Geodetic Survey of Canada datum), whichever elevation is the higher.

(b) within two hundred(200) feet of the main or active watercourse on each of the two alluvial fans, nor within fifty (50) feet of any other watercourse or side of auxiliary channels to the alluvian fan watercourses, nor within twenty-five (25) feet of the natural boundary of Lillooet Lake.

24E. Where landfill is used to achieve the required elevations of Section 24D(a) no portion of the landfill slope shall be closer than the distances required in Section 24D(b) from the natural boundary and the face of the landfill slope must be adequately protected against erosion from floodwaters. The area raised by landfill shall have a border, exclusive of any side slope, of not less than fifteen (15) feet measured perpendicular from the outside edge of the building. Any structural erection shall be accomplished by construction of reinforced concrete bearing walls.

24F. In Addition to the above requirements, suitably designed training walls at the head of the alluvian fans are to be constructed to prevent watercourse from breaking out of present channel. By "suitably designed" it is meant designed by a professional engineer competent in river channel hydraulics and engineering. The Developer will be responsible for the construction and the maintenance of the training walls, and for obtaining any rights-of-way necessary for said construction and maintenance.

25. Binding Effect

This contract shall endure to the benefit of and be binding upon the parties hereto and their respective heirs, executors, administrators, successors and assigns.

26. Joint and Several

The covenants, undertakings, agreements and obligations of the Developer are joint and several.

A Public Hearing on this Agreement was held on the 14th day of June, 1976.

IN WITNESS WHEREOF the Parties hereto have duly executed this Agreement this 5 day of ______, 1976.

The Corporate Seal of the SQUAMISH-LILLOOET REGIONAL DISTRICT was hereunto affixed in the presence of:

____

____

APPROVED AS TO FORM AND CONTENT ....

The Corporate Seal of THE CANADA TRUST COMPANY was hereunto affixed in the presence of:

____

MANAGER, PERSONAL TRUST DEPT.
VANCOUVER BRANCH

____

TRUST OFFICER, VANCOUVER BRANCH

The Corporate Seal of H.J. DEVELOPMENTS LTD. was hereunto affixed in the presence of:

____

PRESIDENT

____

The Corporate Seal of HEATHER JEAN ESTATES LTD. was hereunto affixed in the presence of:

____
SECRETARY

____

The Corporate Seal of HEATHER JEAN ESTATES NO. 2 LTD. was hereunto affixed in the presence of:

____
PRESIDENT.

____

The Corporate Seal of HEATHER JEAN ESTATES NO. 3 LTD. was hereunto affixed in the presence of:

____
PRESIDENT.

____

The Corporate Seal of HEATHER JEAN PROPERTIES LTD. was hereunto affixed in the presence of:

____
PRESIDENT.

____

ACKNOWLEDGMENT OF OFFICER OF CORPORATION

I HEREBY CERTIFY that,

on the 31 day of May 19 76

at Pemberton

in the Province of British Columbia,

Louis H. Potvin

(~~whose identity has been proven by the evidence of oath of~~

who is) personally known to me, appeared before me and acknowledged to me that he is the President

of Heather Jean Estates No. 3 Ltd.

and that he is the person who subscribed his name to the annexed instrument as President

of the said Company

and affixed the seal of the Company

to the said instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY WHEREOF
I have hereunto set my hand and seal of office,
at Pemberton
in the Province of British Columbia, this
31 day of May , 19 76

A ~~Notary Public in and for the Province of British Columbia~~
A Commissioner for taking Affidavits for British Columbia

NOTE — Where the person making the acknowledgment is personally known to the officer taking the same, strike out the words in parenthesis.

MACK PRINTERS AND STATIONERS LTD., VANCOUVER, B.C. ©
LAW AND COMMERCIAL STATIONERS FORM No. 92

Acknowledgment of Officer of a Corporation

I HEREBY CERTIFY that, on the 5th day of June , 19 76 , at City of Vancouver , in the Province of British Columbia, ~~oath of~~ IVO JACK BROWN ~~(whose identity has been proved by the evidence on~~ , who is) personally known to me, appeared before me and acknowledged to me that he is the TRUST OFFICER, VANCOUVER BRANCH of THE CANADA TRUST COMPANY , and that he is the person who subscribed his name to the annexed instrument as TRUST OFFICER, VANCOUVER BRANCH of the said THE CANADA TRUST COMPANY and affixed the seal of ~~the~~ THE CANADA TRUST COMPANY to the said Instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said Instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY whereof I have hereunto set my Hand ~~and Seal of Office~~, at City of Vancouver, in the Province of British Columbia, this 5th day of June one thousand nine hundred and seventy -six.

~~A Notary Public in and for the Province of British Columbia.~~

ACKNOWLEDGMENT OF OFFICER OF CORPORATION

I HEREBY CERTIFY that,

on the 31 day of May 19 76

at Pemberton

in the Province of British Columbia,

Louis H. Potvin

(~~whose identity has been proven by the evidence of oath of~~

who is) personally known to me, appeared before me and acknowledged to me that he is the President

of H.J. Developments Ltd.

and that he is the person who subscribed his name to the annexed instrument as President

of the said Company

and affixed the seal of the Company

to the said instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY WHEREOF
I have hereunto set my hand and seal of office,
at Pemberton
in the Province of British Columbia, this
31 day of May , 19 76

A Notary Public in and for the Province ~~of British Columbia~~
A Commissioner for taking Affidavits for British Columbia

NOTE — Where the person making the acknowledgment is personally known to the officer taking the same, strike out the words in parenthesis.

ACKNOWLEDGMENT OF OFFICER OF CORPORATION

I HEREBY CERTIFY that,

on the 31 day of May 19 76

at Pemberton

in the Province of British Columbia,

Louis H. Potvin

(~~whose identity has been proven by the evidence of oath of~~

who is) personally known to me, appeared before me and acknowledged to me that he is the President

of Heather Jean EstatesLtd.

and that he is the person who subscribed his name to the annexed instrument as President

of the said Company

and affixed the seal of the Company

to the said instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY WHEREOF
I have hereunto set my hand and seal of office,
at Pemberton
in the Province of British Columbia, this
31 day of May , 19 76

A ~~Notary Public in and for the Province~~ of British Columbia
A Commissioner for taking Affidavits for British Columbia

NOTE — Where the person making the acknowledgment is personally known to the officer taking the same, strike out the words in parenthesis.

ACKNOWLEDGMENT OF OFFICER OF CORPORATION

I HEREBY CERTIFY that,

on the 31 day of May 19 76

at Pemberton

in the Province of British Columbia,

Louis H. Potvin

(~~whose identity has been proven by the evidence of oath of~~

who is) personally known to me, appeared before me and acknowledged to me that he is the President

of Heather Jean Properties Ltd.

and that he is the person who subscribed his name to the annexed instrument as President

of the said Company

and affixed the seal of the Company

to the said instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY WHEREOF
I have hereunto set my hand and seal of office,
at Pemberton
in the Province of British Columbia, this
31 day of May , 19 76

[signature]

A ~~Notary Public in and for the Province of British Columbia~~
A Commissioner for taking Affidavits for British Columbia

NOTE — Where the person making the acknowledgment is personally known to the officer taking the same, strike out the words in parenthesis.

ACKNOWLEDGMENT OF OFFICER OF CORPORATION

I HEREBY CERTIFY that,

on the 31 day of May 19 76

at Pemberton

in the Province of British Columbia,

Louis H. Potvin

(~~whose identity has been proven by the evidence of oath of~~

who is) personally known to me, appeared before me and acknowledged to me that he is the President

of Heather Jean Estates No. 2 Ltd

and that he is the person who subscribed his name to the annexed instrument as President

of the said Company

and affixed the seal of the Company

to the said instrument, that he was first duly authorized to subscribe his name as aforesaid, and affix the said seal to the said instrument, and that such corporation is legally entitled to hold and dispose of land in the Province of British Columbia.

IN TESTIMONY WHEREOF
I have hereunto set my hand and seal of office,
at Pemberton
in the Province of British Columbia, this
31 day of May , 19 76

[signature]

A ~~Notary Public in and for the Province of British Columbia~~
A Commissioner for taking Affidavits for British Columbia

NOTE — Where the person making the acknowledgment is personally known to the officer taking the same, strike out the words in parenthesis.

SCHEDULE "A"

1. Trust Agreement between Beneficial Owners and Trustee dated September 13, 1973.

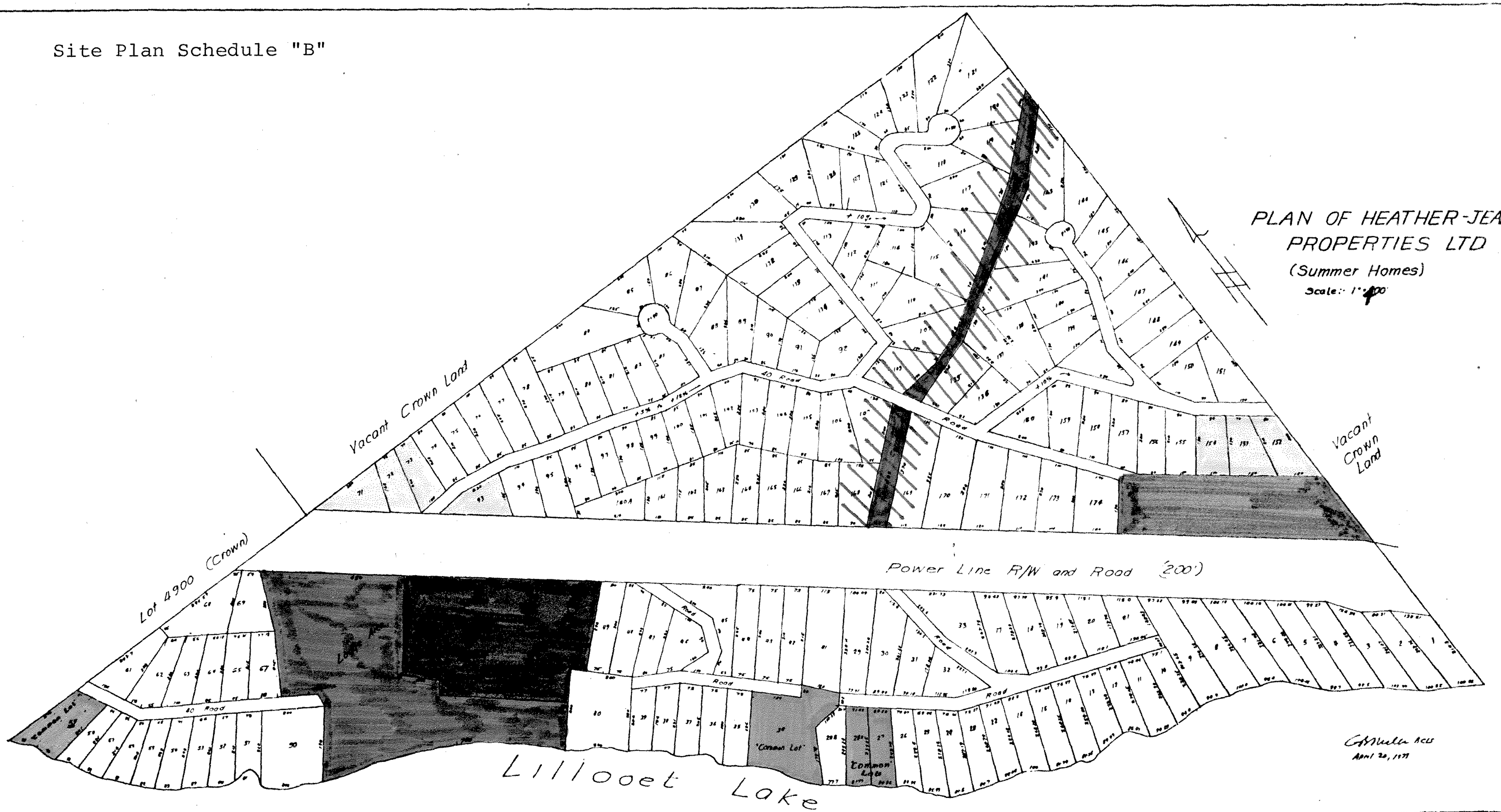
2. Trust Agreement between Beneficial Owners and Trustee dated October 11, 1974.

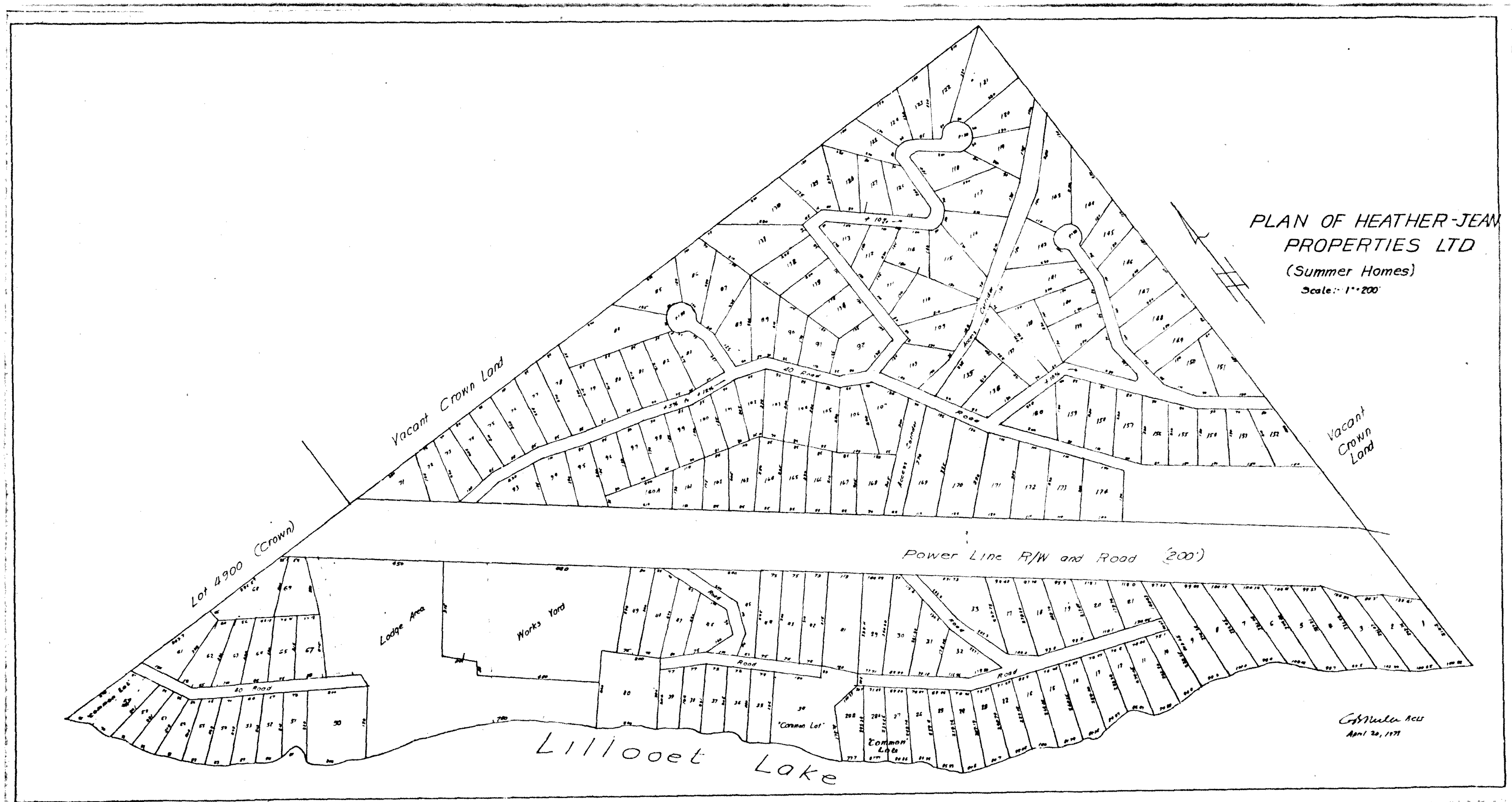
3. Trust Agreement between Beneficial Owners and Trustee dated October 11, 1974.

SCHEDULE "B"

Site Plan attached.

Site Plan Schedule "B"




PLAN OF HEATHER-JEAN
PROPERTIES LTD
(Summer Homes)
Scale:- 1" = 200'
Vacant Crown Land
Vacant Crown Land
Lot 4900 (Crown)
Power Line R/W and Road (200')
Lodge Area
Works Yard
"Common Lot"
"Common" Lots
Common Lot
Access Corridor
40 Road
Road
Lillooet Lake
April 20, 1971

SCHEDULE "C"

USES AND RESTRICTIONS

I. Commercial Sites

1. Permitted Uses

Use of Land, buildings and structures on Commercial Sites is restricted to:

(a) Retail Stores;

(b) Business and Professional Offices;

(c) Banks;

(d) Post Offices;

(e) Medical and Dental Clinics;

(f) Restaurants;

(g) Bakeshops or Confectioneries whose products are sold retail on the premises;

(h) Personal Service Establishments including barbershops, beauty parlours, shoe repair shops, electric and electronic shops, launderettes, laundry and dry-cleaning shops, florist shops, tailor or dressmaking shops, and similar uses;

(i) Theatres;

(j) Gasoline Service Stations;

(k) Any of the above uses together with residential use;

(l) Any Accessory Buildings and Structures accessory to the uses permitted in clauses (a) to (k) inclusive;

2. Standards and Restrictions

Every use of Land and every building or structure permitted on a Commercial Site shall conform with the provisions of Sections 2.4.2 to 2.4.9 inclusive of the Regional Zoning By-law.

3. Any person who acquires an interest in any Commercial Site and who alleges that the enforcement of regulations as to siting, size or shape of any building or structure would cause him undue hardship may apply to the Regional Board which may, to the extent necessary to give effect to its determination, exempt such person and subsequent persons having an interest in such Commercial Site from the applicable regulation or regulations as to siting, size or shape. The Beneficial Owners or any one of them shall be a

necessary party and deemed to be a co-applicant in any such application to the Regional Board. The decision of the Regional Board shall be final.

4. Change of Use

The Developer may, by written notice to the District, specify that any Commercial Site shall change in use to a Common Site, Greenbelt Area, or Private Site. Any such notice must be given prior to the commencement of any construction on the Site for which such notice is given and, subsequent to such notice, such Site shall be used and conform to the regulations pertaining to the type of Site designated.

II. Common Sites

1. Permitted Uses

The use of Land, buildings and structures on Common Sites is restricted to:

(a) Community or Recreation Halls or Buildings;

(b) Parks and Playgrounds;

(c) Churches, Hospitals, Libraries and other similar uses;

(d) Accessory Buildings and Structures accessory to the uses permitted in clauses (a) to (c) inclusive;

2. Standards and Restrictions

Every use of Land and every building or structure permitted on a Common Site shall conform with the provisions of Sections 2.5.2 to 2.5.9 inclusive of the Regional Zoning By-law.

3. If the Developer alleges that the enforcement of regulations as to siting, size or shape of any building or structure would cause him undue hardship, he may apply to the Regional Board which may, to the extent necessary to give effect to its determination, exempt the Developer and subsequent persons having an interest in such Common Site from the applicable regulation or regulations as to siting, size or shape. The decision of the Regional Board shall be final.

...3.

III. Greenbelt Area

1. Permitted Uses

The Greenbelt Area shall not be used for any purpose inconsistent with their use and retention as natural, unimproved areas. No buildings of any nature shall be permitted. To the extent that it is reasonably practical, the Greenbelt Area shall be kept in its natural state, provided always that underground services may be installed under, and pedestrian pathways may be constructed, through the Greenbelt Area.

IV. Lodge Area

1. Permitted Uses

The use of Land, buildings and structures in the Lodge Area is restricted to:

(a) One (1) Single-Family Dwelling;

(b) A Lodge, Motel or Hotel, together with such commercial uses as are normally included in the operation of a Lodge, Motel or Hotel;

(c) Accessory Buildings and Structures accessory to the uses permitted in clauses (a) and (b) above.

2. Standards and Restrictions

(a) In the event that the Lodge Area is used for Single-Family Residential purposes, every use of Land and every building or structure shall conform with the provisions of Sections 2.2.2. to 2.2.13 inclusive of the Regional Zoning By-law.

(b) In the event that the Lodge Area is used for the purposes of a Lodge, Motel or Hotel, every use of Land, building or structure permitted shall conform with the provisions of Section 2.5.2 to 2.5.9 inclusive of the Regional Zoning By-law.

..........4.

3. Any person who acquires an interest in any Lodge Area and who alleges that the enforcement of regulations as to siting, size or shape of any building or structure would cause him undue hardship may apply to the Regional Board which may, to the extent necessary to give effect to its determination, exempt such person and subsequent persons having an interest in such Lodge Area from the applicable regulation or regulations as to siting, size or shape. The Beneficial Owners or any one of them shall be a necessary party and deemed to be a co-applicant in any such application to the Regional Board. The decision of the Regional Board shall be final.

V. Private Sites

1. Permitted Uses

The use of Land, buildings and structures on any Private Site is restricted to:

(a) Single-Family and Two-Family Dwellings, excluding Mobile Homes;

(b) Individual Mobile Homes on individual parcels;

(c) Professional Practice, Home Craft or Occupation; provided that the use is conducted by the Resident, excluding Boarder, and is confined to the interior of a dwelling and does not (i) create a nuisance by reason of sound, sight or smell; (ii) involve storage exterior to the dwelling of any materials used directly or indirectly in the processing or resulting from the processing of any product of such craft or occupation; or (iii) involve material or products that produce inflammable or explosive vapours or gases under ordinary temperatures;

(d) Public Utility Buildings or Structures;

(e) Accessory Buildings and structures accessory to the uses permitted in clauses (a) to (d) inclusive.

2. Standards and Restrictions

Every use of Land and every building or structure permitted on any Private Site shall conform to the provisions of Sections 2.2.2 to 2.2.13 (excluding Section 2.2.3) inclusive of the Regional Zoning By-law, subject as therein provided.

3. Any person who acquires an interest in any Private Site and who alleges that the enforcement of regulations as to siting, size or shape of any building or structure would cause him undue hardship may apply to the Regional Board which may, to the extent necessary to give effect to its determination, exempt such person and subsequent persons having an interest in such Private Site from the applicable regulation or regulations as to siting, size or shape. The Beneficial Owners or any one of them shall be a necessary party and deemed to be a co-applicant in any such application to the Regional Board. The decision of the Regional Board shall be final.

VI. Works Area

1. Permitted Uses

The use of Land, buildings and structures in the Works Area is restricted to:

(a) Sawmills;

(b) Building Supply and Lumber Yards;

(c) Plumbing and Sheet Metal Workshops;

(d) Welding Shops;

(e) Machine Shop and Parts Manufacturing;

(f) Septic Tank Service;

(g) Public Utility Buildings or Structures inclusive of facilities for exterior storage of supplies and materials and garages for the repair and maintenance of equipment;

(h) Accessory Buildings and structures accessory to the uses permitted in clauses (a) to (g) inclusive.

...6.

2. Standards and Restrictions

   Every use of Land and every building or structure permitted in the Works Area shall conform with the provisions of Section 2.7.2 to 2.7.10 inclusive of the Regional Zoning By-law.

3. Any person who acquires an interest in the Works Area and who alleges that the enforcement of regulations as to siting, size or shape of any building or structure would cause him undue hardship may apply to the Regional Board which may, to the extent necessary to give effect to its determination, exempt such person and subsequent persons having an interest in such Works Area from the applicable regulation or regulations as to siting, size or shape. The Beneficial Owners or any one of them shall be a necessary party and deemed to be a co-applicant in any such application to the Regional Board. The decision of the Regional Board shall be final.

4. Change of Use and Partition

   The Developer may, by written notice to the District, specify that the Works Area shall change in use to Lodge Area. Subsequent to such notice, such Area shall be used and conform to the regulations pertaining to the Lodge Area. The Developer shall be permitted to partition the Works Area prior to making any such application for change in use and to designate any portion of the Works Area as Lodge Area and to leave the remainder of the Works Area designated as such for the uses set forth in this section.

VII. Creek Protection Corridor No.1

1. Permitted Uses

   The use of Land in the Creek Protection Corridor No.1 is restricted to:

   (a) Recreation uses.

2. Standards and Restrictions

   (a) Nothing shall be constructed so as to be permanently fixed to the Land or land covered by water;

   (b) There shall be no tree cutting, nor a disturbance of the ground other than that which may be necessary to maintain the required creek access.

VIII. Creek Protection Corridor No.2

1. Permitted Uses

The use of Land, buildings and structures in the Creek Protection Corridor No.2 is restricted to the uses permitted for the Common Sites.

2. Standards and Restrictions

No construction shall be permitted until the recommendations of the Piteau Gadsby Macleod Limited report of April 2, 1976 on page 7, item 4, have been acted upon and completed as certified by a geotechnical consultant retained by the Developer at the Developer's expense.

IX. General

1. Consolidation

In the event any person should acquire an interest in any two or more adjoining Sites of the same classification and such person wishes to develop such Sites as one Site, such person shall solicit the consent of the Developer. Upon approving any such consolidation of the Sites the Developer shall forthwith notify the District of such consolidation and forward to the District a map or plan showing the new configuration of such consolidated lot and its proper dimensions. Such map or plan shall be in a form acceptable to the District. Any such consolidated Site shall be treated as one Site for the purposes of Parts I to VI of this Schedule.

SCHEDULE "D"

SCHEDULE OF PERSONS HOLDING ANY REGISTERED INTEREST IN THE LAND AFFECTED AND WHOSE CONSENTS ARE REQUIRED.

FULL NAME	ADDRESS	OCCUPATION	NATURE OF CHARGE

day of , 1976

AGREEMENT

BETWEEN:

SQUAMISH-LILLOOET
REGIONAL DISTRICT

AND:

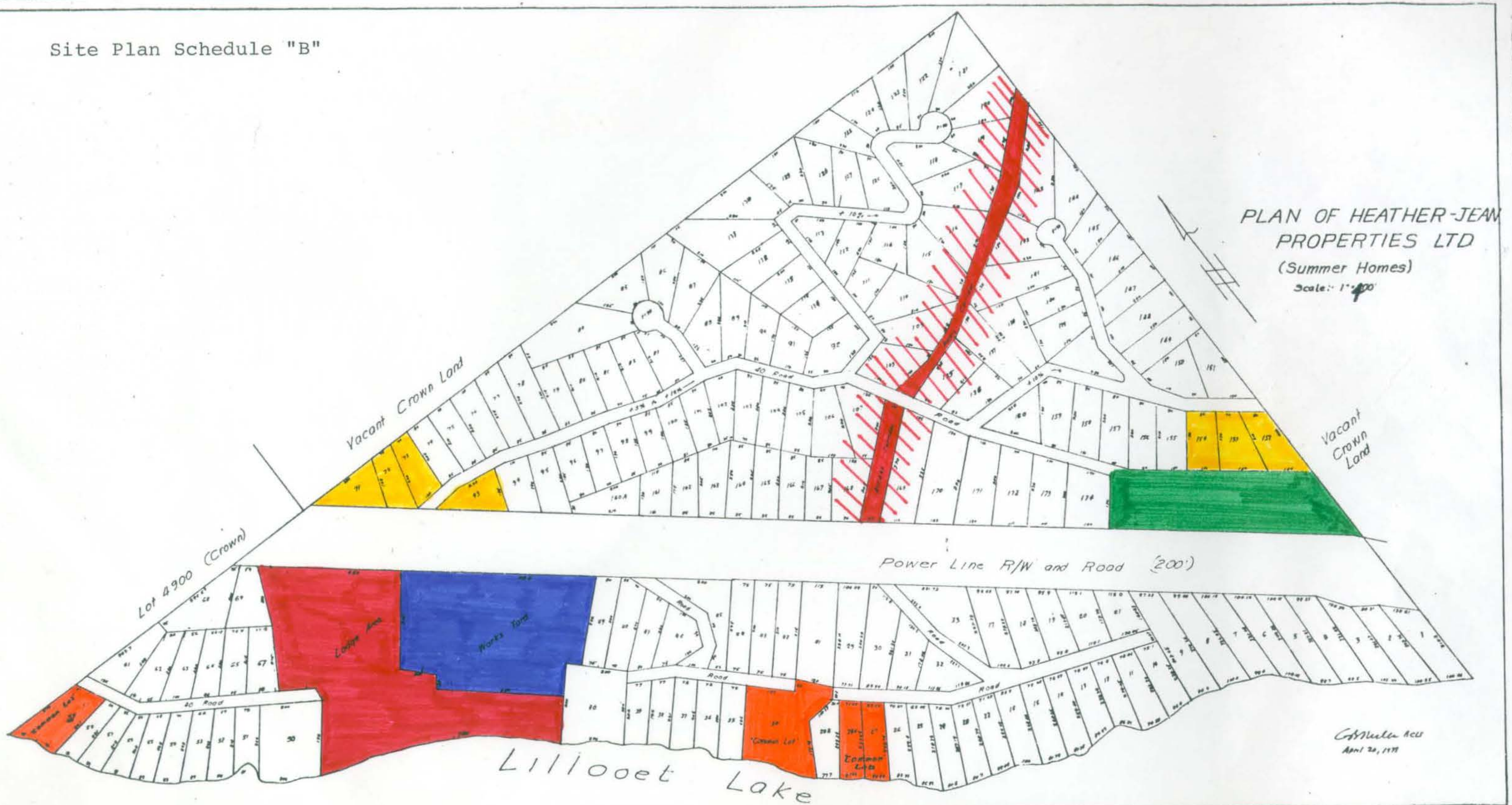
THE CANADA TRUST COMPANY

AND:

H.J. DEVELOPMENTS LTD.
HEATHER JEAN ESTATES LTD.
HEATHER JEAN ESTATES NO. 2 LTD.
HEATHER JEAN ESTATES NO. 3 LTD.
HEATHER JEAN PROPERTIES LTD.

W.P. Orobko, Esq.
Barrister & Solicitor
#217 - 2438 Marine Drive
West Vancouver B.C.

Site Plan Schedule "B"



SQUAMISH-LILLOOET REGIONAL DISTRICT

BYLAW NO. 820-2003

A bylaw of the Squamish-Lillooet Regional District to amend Squamish-Lillooet Regional District Bylaw No. 88-1976, Lillooet Lake Estates Land Use Contract.

The Board of Directors of the Squamish-Lillooet Regional District, in open meeting assembled, enacts as follows:

1. This by-law may be cited for all purposes as the "Squamish-Lillooet Regional District Bylaw No. 88-1976, Land Use Contract Amendment Bylaw No. 820-2003".

2. The Squamish-Lillooet Regional District Bylaw 820-2003, is amended as follows:

   (a) That the Official Site Plan, Schedule B, Bylaw No. 88-1976, is amended by reconfiguring the lot line alignments within the area outlined in heavy black lines on Schedule B, Plan of Heather-Jean Development, Lot 4901, Lillooet Land District, August 24, 1990, which is attached as Appendix 1 and forms part of this bylaw.

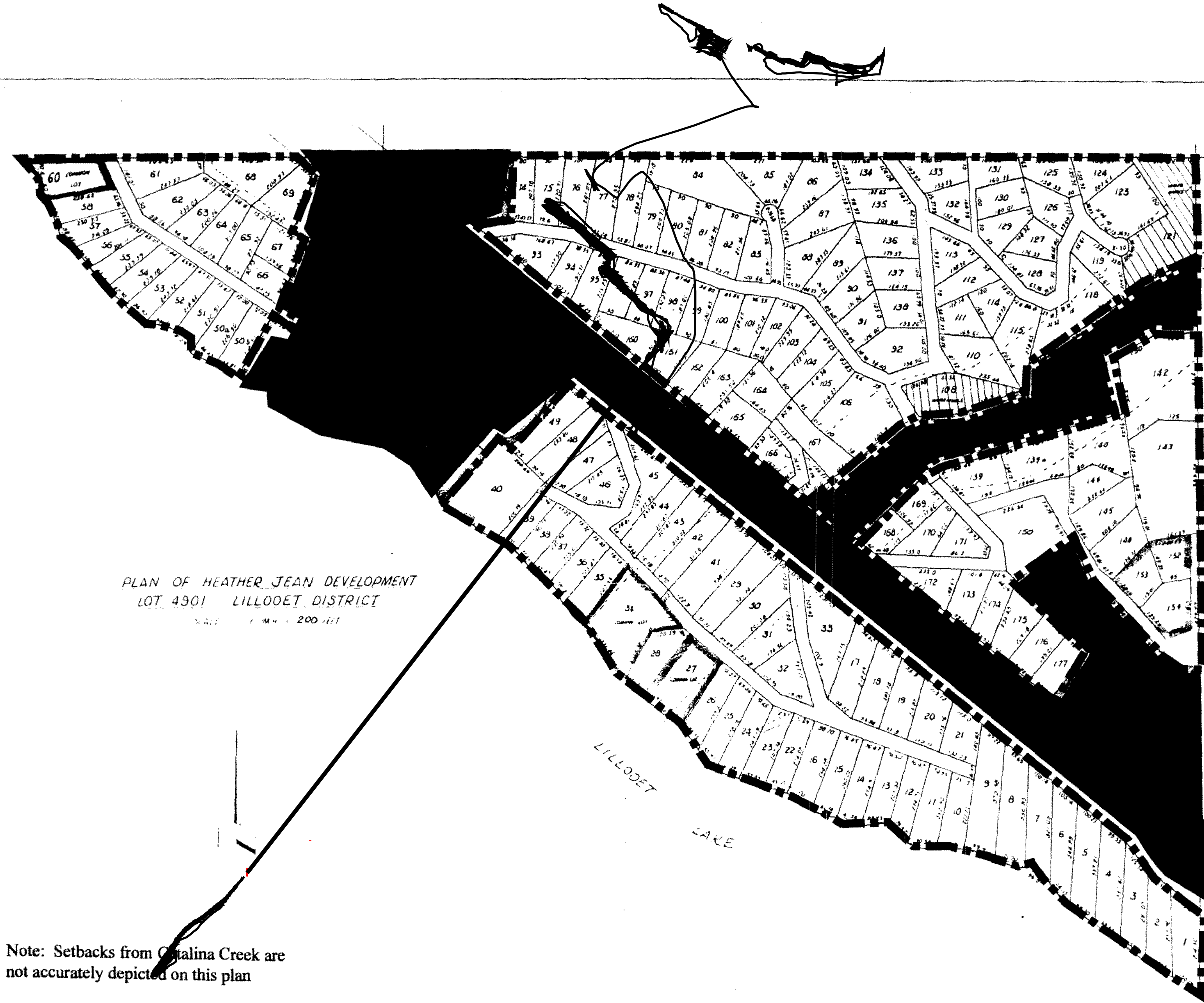
READ A FIRST TIME this	26th	day of	May,	2003
READ A SECOND TIME AS AMENDED this	28th	day of	April,	2008.
A PUBLIC HEARING WAS HELD, PURSUANT TO SECTION 890 OF THE *LOCAL GOVERNMENT ACT*, ON THE	15th	day of	May,	2008
READ A THIRD TIME this	23rd	day of	June,	2008
APPROVED BY THE MINISTER OF COMMUNITY DEVELOPMENT THIS	22nd	day of	October,	2008
ADOPTED this	27th	day of	October,	2008

Russ Oakley
Chair

Paul R. Edgington
Chief Administrative Officer

I hereby certify this to be a true and correct copy of "Squamish-Lillooet Regional District Bylaw No. 88-1976, Land Use Contract Amendment Bylaw No. 820-2003".

Paul R. Edgington
Chief Administrative Officer



Note: Setbacks from Catalina Creek are not accurately depicted on this plan

Appendix 1 to Bylaw 820

SQUAMISH-LILLOOET REGIONAL DISTRICT

BYLAW NO. 1106-2008

A bylaw of the Squamish-Lillooet Regional District to amend Land Use Contract Authorization Bylaw No. 88, 1976 (Lillooet Lake Estates Land Use Contract)

The Board of Directors of the Squamish-Lillooet Regional District, in open meeting assembled, enacts as follows:

1. This bylaw may be cited for all purposes as the "Land Use Contract Authorization Bylaw No. 88, 1976, Amendment Bylaw No. 1106-2008".

2. The Land Use Contract Authorization Bylaw No. 88, 1976, is amended as follows:

   (a) That the Official Site Plan, Schedule B, Bylaw No. 88,1976, is amended by reconfiguring the lot line alignments within the area outlined in heavy lines on Plan of Heather-Jean Development, Lot 4901, Lillooet Land District, prepared by G.B. Miller, BCLS on June 18, 2008, which is attached as Appendix 1 and forms part of this bylaw.

   (b) That the sites within the area outlined in heavy lines on Appendix 2 to this Bylaw be designated as follows:

      a. Sites 2A, 3B, 4C, 5D, 6E, 7F, 8G, 9I, 10J, 11K , 12L 13M, 14N, 15O, and 16 are designated residential
      b. Site 50d is designated office – residence
      c. Site 9H is designated shop/recreation site.

READ A FIRST TIME this	29th	day of	September, 2008
READ A SECOND TIME as amended this	16th	day of	December, 2008
A PUBLIC HEARING WAS HELD, PURSUANT TO SECTION 890 OF THE *LOCAL GOVERNMENT ACT*, ON THE	26th	day of	January, 2009
READ A THIRD TIME this	9th	day of	March, 2009
ADOPTED this	26th	day of	March, 2012

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Susan Gimse
Chair

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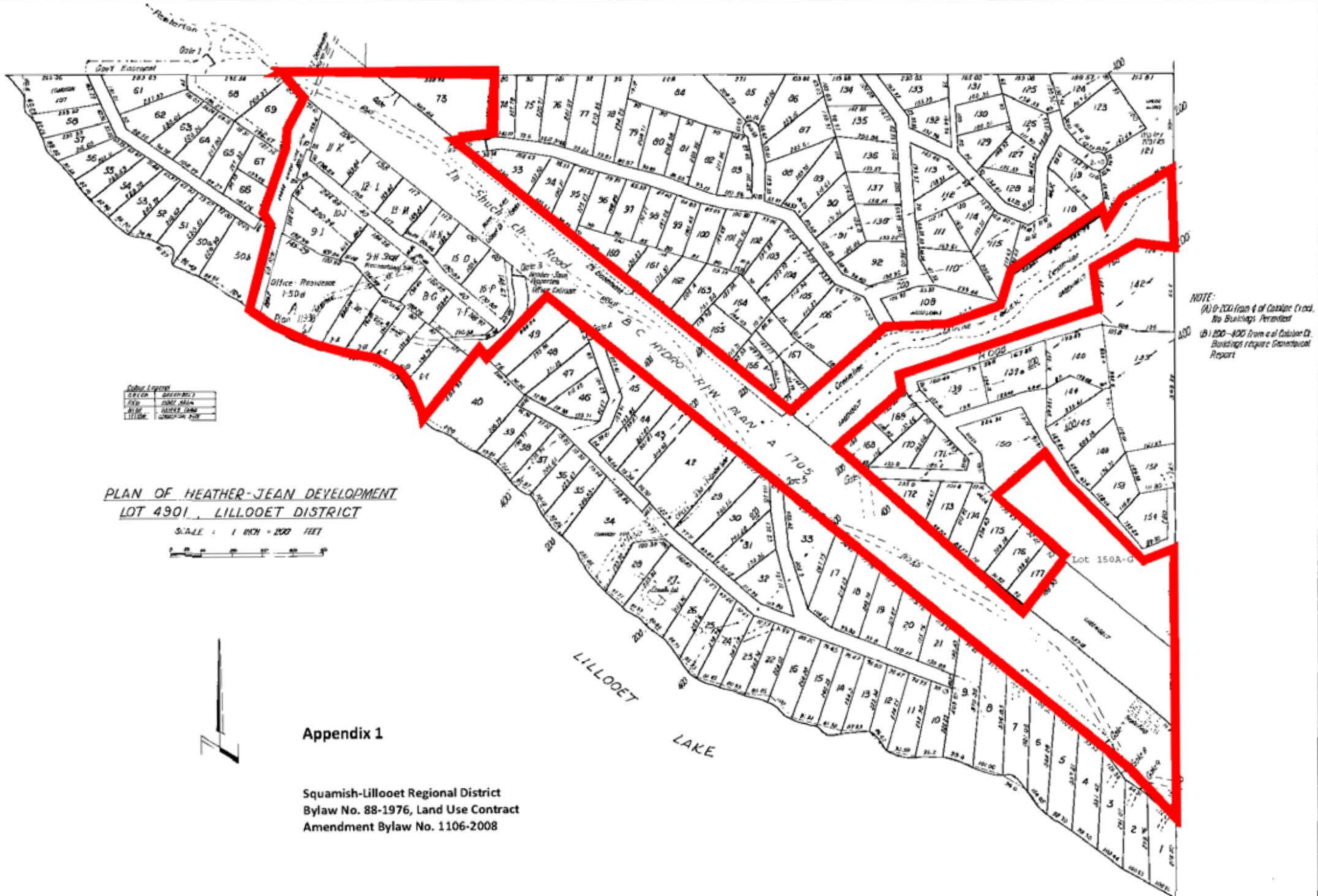
Peter DeJong
Secretary

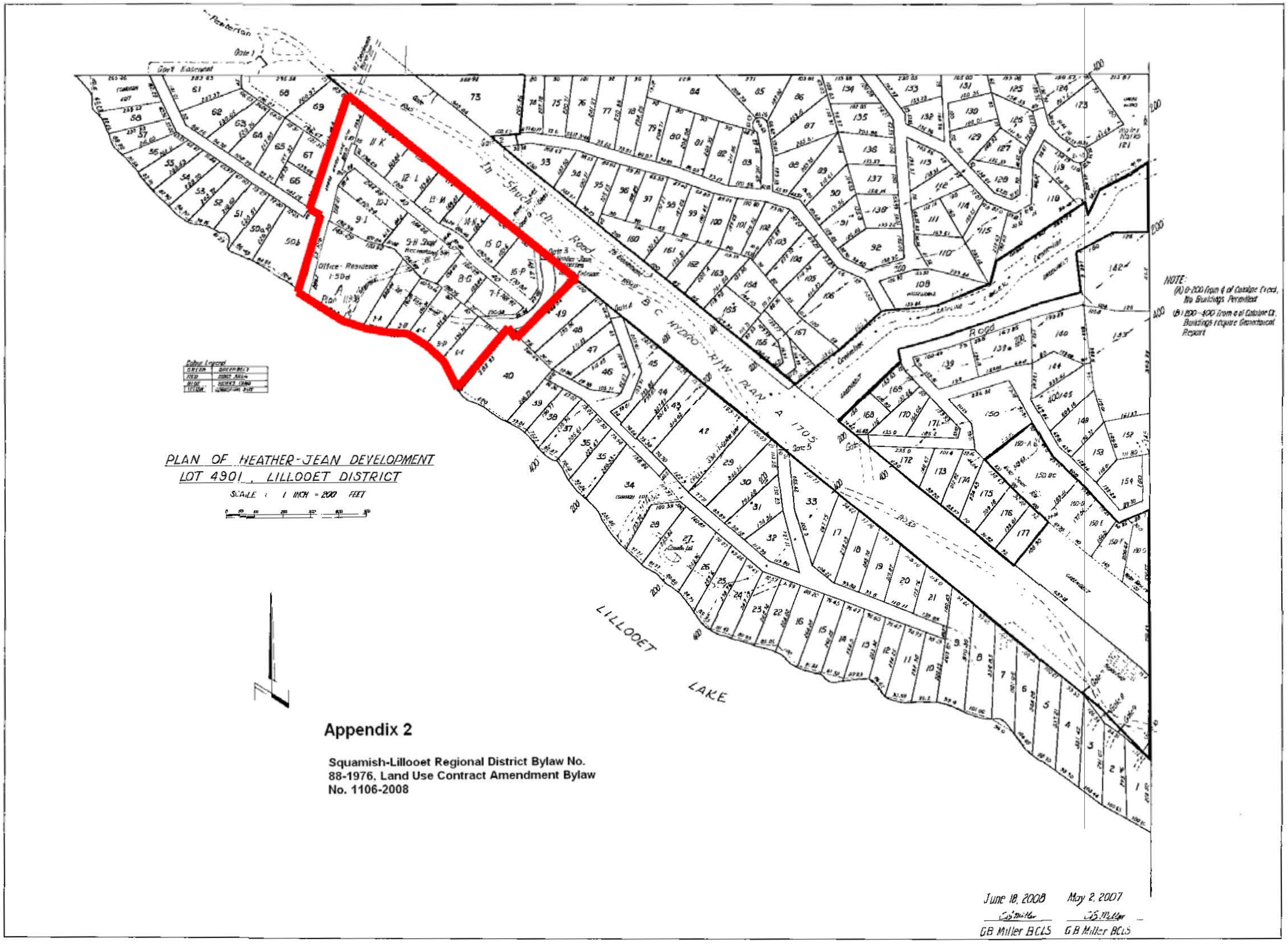


Appendix 1

Squamish-Lillooet Regional District
Bylaw No. 88-1976, Land Use Contract
Amendment Bylaw No. 1106-2008

June 18, 2008 — GB Miller BCLS

May 2, 2007 — GB Miller BCLS



Appendix 2

Squamish-Lillooet Regional District Bylaw No. 88-1976, Land Use Contract Amendment Bylaw No. 1106-2008

APPENDIX B
TABULAR SUMMARY OF PREVIOUS WORK

Date	Author	Title	Client	Document Type	Report Content	Recorded Debris Flow?	Assessment	Recommendations	Maps	Photos
5-Jan-73	Piteau Gadsby MacLeod Limited	Unknown - referenced in April 2, 1976 report	Lou Potvin / Heather Jean Properties	Unknown	Geotechnical/Geohazards Assessment, Proposed Development	No	Asked to comment on the "possibility of hazardous rockfalls or landslides occurring in the area". Piteau responded "that the possibility of your proposed property development below the road being jeopardized by either massive deep-seated landslides or rockfalls resulting from normal static loads is remote".	n/a	n/a	n/a
2-Apr-76	Piteau Gadsby MacLeod Limited	Proposed Development on the Northeast Shore of Lillooet Lake above the Forestry Road	Lou Potvin / Heather Jean Properties	Letter Report	Geotechnical/Geohazards Assessment Proposed Development	No	Identified Catiline Creek Fan as an "alluvial fan". Interpret that most fan development was immediately post-glacial with substantial decrease in activity since then. Note that the area was almost completely logged between 1949 and 1952. Note that the main creek flow has been in the same location since 1948. Note that flood potential exists below the Forestry road as well, although assessment of this hazard was outside the work scope. Description of bedrock, overburden and creek channel conditions.	No building development within an "800 foot" (270 m) wide corridor until completion of in-channel works to further constrain the channel (per Figure 2 in report, not provided for review) Following completion of channel works, maintain a permanent 300-foot (100 m) wide corridor (50 m either channel side) where no residential buildings are allowed. Provide adequate drainage for access roads and minimize tree removal. No logging on or immediately above the fan.	N	N
5-Dec-86	Piteau Associates	HJE No. 2 Property - Geotechnical Assessment of Catiline Creek	John Mitchell / Heather Jean Estates No. 2	Letter Report	Geotechnical/Geohazards Assessment, Event Forensics	Refers to recent event but no date is provided.	Note that few recommendations in April 1976 report were carried out and dwellings appear to have been constructed within 300 foot (100 m) wide corridor. Recommendation to ban logging in or on the fan appears to have been carried out. Air photo interpretation (1969, 1977, 1980 and 1982) did not identify debris flows of similar size to recent debris flows. Note that logging in the early 1950's may have altered the surface of the fan. Note that a significant portion of flow in Catiline Creek appeared to be lost into the fan. Note that the recent debris flow initiation zone was located above the apex of the fan and below the intersection of the 2 main tributaries. Accumulation of debris is attributed to a change in channel gradient from 19° to >25° (upslope) and a bedrock nose constricting part of the channel. Runout of the recent event occurred outside the channel about 30 to 60 feet (10 to 20 m) north of the creek. Runout reached the forestry road and continued to Lillooet Lake. The main flow was 10 to 20 feet (3 to 6 m) wide with 3 distinct lobes. Note that ~3500 yds3 (2700 m^3) of debris were mobilized during the recent event. Note that an additional ~1500 yds^3 (1150 m^3)of debris was not mobilized and remains at the apex of the fan.	No building development within an 800 foot (270 m) wide corridor if no remedial works are undertaken - particularly for the portion of the creek below the forestry road. Following completion of channel works, maintain a permanent 300-foot (100 m) wide corridor (50 m either channel side) where no residential buildings are allowed. Recommended measures to keep debris flows within the channel, including: remove constrictions in the channel, remove large blocks from channel crest, deepen channel, straighten channel. Near the forestry road consider creating a debris basin or install a bridge with greater clearance. Regular (annual) inspection of all active creek channels.	N	N
22-Aug-89	Piteau Associates	Geotechnical Assessments - Heather Jean Estates	Ivan Knowles / Squamish-Lillooet Regional District	Letter Report	Geotechnical/Geohazards Assessment, Remedial Measures	No	Review of current site conditions and reassessment of requirements for remedial measures. No evidence of debris flows since Summer of 1987 (previous site visit). Evidence of recent debris accumulation in the channel and unstable debris remaining from previous events. Observed implementation of some remedial measures, particularly immediately downstream of the forestry road bridge. Note that remedial works at the fan apex are no long proposed as most recent site investigation suggests the bulk of future debris flows would likely be contained within the existing channel. Note that channel improvements, including entrenchment, straightening and construction of a levee and deflection channel on the right bank appear to have been carried out 100 m downstream of the bridge. Brief recon of the lower portion of the other active stream on the fan (northwest corner of the property): observed relatively gentle gradient and no evidence of recent debris flow activity (although apparent that debris flows were active processes at one stage of fan development).	Cleaning, straightening and side slope trimming along 400 m of channel, ~170 m of channel realignment, construction of a debris check dam/containment basin and construction of levees and deflection berms. See report for specific locations for recommended measures. Detailed surveys of specific portions of the channel are recommended to support detailed design of proposed remedial work. If further development is proposed near the stream on the northwest corner of the property, additional investigation and possible remedial measures are recommended.	N	N
25-Aug-89	Piteau Associates	Geotechnical Assessments - Heather Jean Estates	Ivan Knowles / Squamish-Lillooet Regional District	Letter	Geotechnical/Geohazards Assessment, Remedial Measures	No	Review of recommendation to restrict building development within 800 foot wide corridor of channel. Based on August 1989 field inspection, there is no reason to modify this recommendation. Note that existing properties within this corridor remain at risk.	Recommend implementation of remedial works described in letter dated Aug. 22, 1989. Suggest a similar corridor be established along the other creek at the north end of the property (pending clarification of development plans and further hazard evaluation).	N	N
18-Jun-90	Piteau Associates	Heather Jean Estates - Remedial Measures for Catalina Creek	Ivan Knowles / Squamish-Lillooet Regional District	Letter	Remedial Measures	No	Response to Mr. Potvin's letter dated June 7, 1990 (copy not provided). Clarification of single basin, not multiple basins. Note that report author agrees that the check dam/containment basin will require ongoing maintenance and removal of accumulated sediment. Report author addresses concerns regarding ponding water and plugging voids in gabion check dam with clarification that the controlled outlet/spillway was designed to decant ponded water and direct outflows. Measures to dissipate hydraulic energy downstream of the check dam are also included in the design. Author concurs that a clear span bridge at the forestry road would help reduce risk to properties below the road, however remedial works above and below the road would still be required. Preliminary bridge recommendations: minimum clearance of 4 to 6m, span of 15 to 20 m and extensive excavation, filling and channel training immediately upstream and downstream. Such a bridge is considered to be cost prohibitive.	Recommend debris check dam is constructed in conjunction with debris basin to provide positive containment for 3,000 to 6,000 m3 of debris. Contractual recommendations provided for remedial works. Recommend implementation of remedial works outlined in letter from Aug. 22, 1989 and May 1, 1990. Acknowledge that these remedial works will require long term maintenance. Recommend timely implementation of remedial measures.	N	N
19-Aug-92	Piteau Associates	Heather Jean Estates - Inspection of Remedial Work on Catalina Creek	Ivan Knowles / Squamish-Lillooet Regional District	Letter Report	Review remedial works	No	Review of construction activities undertaken by a local contractors (not supervised by Piteau) in Winter 1991/1992 and evaluation of current level of debris flow hazard mitigation. Minor straightening and trimming of the channel in Zone 2 (immediately upstream of FSR bridge) completed. Channel side slopes in Zone 2 are steep and subject to raveling and shallow instability. Small debris catchment basin in the lower reaches of Zone 3 (500 to 1300 feet upstream of the FSR) was constructed but no check dam was built. Significant amount of channel straightening and entrenchment completed in middle reaches of Zone 3 near the intake for the lower water system - channel slopes are 4 to 5 m high and appear stable at 1.5H:1V. Substantial work completed in Zone 4 (1300 feet upstream of FSR to fan apex) to realign channel. Work in zone 4 falls short of recommendations but is a significant improvement over previous conditions. No significant construction activities observed in Zone 1A/1B (downstream of the FSR bridge to Lillooet Lake). Debris flow hazard in Zone 1A/1B remains essentially unchanged from previous inspection.	In Zone 2, recommend removal of vegetation and debris in Zone 2 channel and ongoing maintenance as required. In Zone 4, recommend that the levee which forms the right bank of the realigned channel (looking downstream) is extended 50 feet downstream to improve channel entrenchment near the intake for the upper water system. Also recommend minor training and cleaning of channel along Zone 4. Loose debris excavated for remedial works is a possible rockfall hazard and should be stabilized. Remaining remedial works should be completed under the supervision of a QP. Once work is complete, consideration could be given to reducing the width of the restricted development corridor along the portion of the creek above the FSR. Periodic inspections and maintenance recommended to review condition of debris in or near channel.	Y	Y

Date	Author	Title	Client	Document Type	Report Content	Recorded Debris Flow?	Assessment	Recommendations	Maps	Photos
20-Apr-98	Piteau Associates	Lot 92 - Heather Jean Estates, Lillooet Lake, BC	T. Trand/ Unknown	Letter report	Geotechnical/geohazard assessment	Refers to debris flow in 1986.	Site inspection on April 9, 1998 to evaluate potential risk to the subject property from debris flow hazard. Note that Lot 92 is within restricted development zone adjacent to Catiline Creek and SLRD requires a report certified by a P.Eng. that the land may be used safely for the use intended prior to issuing a building permit. The report describes the channel conditions observed at the time of the inspection, including debris accumulation, channel entrenchment, low spots with potential for avulsion). No significant change in creek morphology above the forestry road since previous Piteau inspection in 1992 (no significant debris flow events, or remedial works). Observed that a small wooden bridge had been replaced by a precast concrete bridge with concrete abutments (10 m span with ~1.5m clearance). While the bridge is a significant improvement over the old bridge, it is doubtful that this bridge would be able to pass a debris flow of the magnitude experienced in 1986. Note that a makeshift intake for a small hydroelectric generator has been constructed approximately 310 m upstream from the bridge in an area where debris accumulation may occur. This location is also where Piteau (1989) recommended construction of a debris containment basin. Construction of a new water storage treatment system is noted on the right bank approximately 600 m upstream from the bridge. Piteau suggests that the access ramp to the intake is a potential avulsion point due to the locally flatter gradient and change in channel alignment at this location. Overall, the potential for recurrent debris torrent activity on Catiline Creek is considered high, however, the amount of debris at the time of the inspection was low, and the likelihood of a large debris torrent occurring given the channel conditions at the time of the inspection was evaluated as relatively low.	Based on the current level of debris loading in the creek, location of the lot with respect to the creek, position of the access road, morphology of the terrain between the lot and the creek, and proposed location and size of the dwelling on the lot, the author considers that the overall risk of such an occurrence is very low and is within acceptable limits. In this context, Lot 92 is safe for the use intended. Recommendations from Piteau's letter of August 1992 are reiterated with possibly additional channel modifications and enhancements. Ongoing maintenance and annual inspections of the creek by a qualified professional geotechnical engineer are recommended again.	Y	N
20-Apr-98	Piteau Associates	Heather Jean Estates, Lillooet Lake	Mr. Barry Chilowski, Building Inspector, SLRD	Letter	Hazard Assessment	No	Letter to SLRD describing recent site visit to Catiline Creek for review of Lot 92. Refers to Lot 92 report for a description of the inspection and relevant observations since Piteau's last inspection in 1992. Notes that it does not appear that any of the additional remedial measures referred to in Piteau's letter dated 19-Aug-92 have been implemented and that no annual geotechnical inspection of the creek have been conducted. Note extensive development of the Heather Jean property, and that at least some of that development has occurred within the restricted zone. State that in the absence of mitigating factors, such as those noted for Lot 92, that any development within the restricted zone may be subject to an unacceptable level of risk.	No new recommendations.	N	N
3-Jun-03	Piteau Associates	Lot 166 - Lillooet Lake Estates, Lillooet Lake, B.C.	Larry Pretty	Report	Hazard Assessment	No	Summarizes history of development on the fan and previous geotechnical/geohazard work by Piteau dating back to 1976. Note that in general, there does not appear to have been any significant change in the morphology of the creek above the FSR since 1998. Also note, that there does not appear to have been any additional improvements to the channel alignment or construction of any additional mitigative works. Completed traverse of Catiline Creek between Lot 166 and the water treatment facility located about 520 m upstream of Lot 166. Observations suggest the channel is reasonable well entrenched with a few local low spots in the levee that forms the right bank (looking downstream) and one low spot in the levee on the left bank. At these low spots it is possible for the channel to avulse. Two narrow points in the channel were identified as locations of possible debris accumulation. A new water storage and treatment facility was observed on the right bank, the intake for this system is located midstream in a well entrenched section of the channel on a graded ramp that could possibly divert debris out of the channel during a large debris "torrent" event. Lot 166 is located within the restricted development corridor. However, an "Allowable Building Area" was delineated for Lot 166 based on a ridge-like topographical feature that would tend to deflect any surface flows. The potential for recurrent debris torrent activity is considered high. Note that at the time of writing the amount of debris within the channel is relatively low and the likelihood of a large debris torrent occurring given the present channel conditions is considered relatively low. The overall risk of a debris torrent event impacting the "Allowable Building Area" on Lot 166 is very low and within acceptable limits and therefore the lot is considered safe for the intended use.	Recommend additional channel training, shaping and armouring in the area of the water treatment facility intake pipe. Recommend completion of remedial works from letter of August 1992 and possible some additional channel modifications and enhancements. Recommend ongoing maintenance and annual inspections of the Creek by a qualified professional geotechnical engineer.	Y	N
6-Jun-03	Piteau Associates	Heather Jean Estates Lot 165, Lillooet Lake	Mr. Marvin Friesen, Building Inspector, SLRD	Letter	Hazard Assessment	No	During inspection Lot 166, Piteau observed a dwelling/cottage constructed in an unacceptable location within the 800 foot restricted development corridor. BGC understands the SLRD sent the resident of Lot 165 a letter in July 2003, but based on the SLRD's understanding and BGC's fieldwork, the residence is still there and appears occupied (pers. comm. Kristen Clark, SLRD).	Advises SLRD that the dwelling on Lot 165 has been constructed in an unacceptable location within the restricted development corridor.	N	N
26-Aug-04	Ministry of Forests	-	SLRD	Letter	Site-assessment following debris flow	July 6 and 7, 2004	Site inspection by MoF staff on July 7 and 8, 2004 to assure worker safety and public safety during emergency repairs of the bridge (approximately Km 8.5 of the In-Shuck-Ch FSR). The recent slide may have reduced the effectiveness of existing protective measures along the creek. Slide initiated at an elevation of ~6300 feet. Deposition of debris observed at bridge with some debris flowing beneath the bridge to the lake. Note that the MoF intends to "complete the repairs of the FSR in the days and weeks ahead".	Recommend the creek and existing protective measures along the creek be reviewed by a QRP with debris flow and flood expertise.	N	Y
27-Aug-04	Ministry of Forests	-	Lou Potvin / Heather Jean Properties	Letter	Site-assessment following debris flow	July 6 and 7, 2004	Identical to Aug. 26, 2004 letter to SLRD.	See above.	N	N
8-Sep-04	Hardy Bartle / Ministry of Forests	July 6/7, 2004 debris flow at Catiline Creek, km 8.5 of In-Shuck-Ch FSR	Mick McKechnie / Squamish Forest District	Memo	Site-assessment following debris flow, recommend maintenance works	July 6 and 7, 2004	Site inspections (July 7 and July 29) by MoF Geotechnical Engineer to document debris flow occurrence, site visits, and recommend completion of maintenance work. Note that residents reported intense rainfall (localized) around midnight the evening of July 6/7 that likely triggered the event. Fresh snow on mountain tops reported at ~5500 feet (1675 m) the morning after the slide. No evidence that the slide was related to forestry operations. Note that the Ministry's objective for the site was to return it to approximately its original (pre debris flow) level of risk. Assessment of private property outside the scope of this memo, but notes "what appears to be the deliberate direction of debris flows towards a public use road". Findings include past channel modifications to increase confinement and promote extra long runout behavior resulting in increased risk to FSR. Noted several historic measures, including: protective berm and flood control dike below FSR, deliberately out sloped FSR near bridge for flood control in the event of creek avulsion, and a deflection berm and catch basin upslope of FSR. Observed bridge capacity was significantly reduced by the 2004 event resulting in increased probability of plugging and avulsion at the bridge. Comments on safety of homes above and below FSR.	1) Maintain historical flood control measures along the FSR. 2) Maintain catch basin above FSR (remove debris and widen). 3) Remove debris from beneath the bridge. Complete the work before onset of fall rains. See memo for specific recommendations regarding geometry (gradient, depth, width, length) of catchment structure. Maintenance inspections of the stream banks an channel are recommended.	N	Y

Date	Author	Title	Client	Document Type	Report Content	Recorded Debris Flow?	Assessment	Recommendations	Maps	Photos
20-Jan-05	Baumann Engineering	Geologic hazard assessment of the Catiline Creek area…	SLRD	Letter	Hazard Assessment, In-Shuck-Ch FSR	No	Aerial review completed January 19, 2005 to assess "obvious safety concerns with regard to natural hazards during this time of unusual warm and wet weather". Note that the exact location of hazardous areas remains poorly defined, and a number of buildings appear to have been constructed without a building permit (and within the 800 foot wide corridor). Note that Catiline Creek was confined to its normal channel at the time of the review and did not appear to have had any unusual discharge or debris flow activity. The berms that contain the creek appear to be intact, and there was no indication of the FSR bridge being affected by a high water event. Note that snow avalanches have come down from the headwaters of Catiline and McCulloch creeks (stopping well short of the community). Note that the FSR is covered with thick ice and unsafe for travel.	No need for special alert or evacuation of residents. Snow avalanche debris in upper reaches of Catiline and McCullock creeks may melt during warm weather and add water to the discharge of the creeks. Residents should monitor water levels in the creeks. Provision to ensure that lack of road access does not present an undue burden to the community.	N	N
28-Jan-08	P.K. Read Engineering Ltd.	Lot 6 Lillooet Lake Estates Geotechnical Review HAZARD ASSESSMENT	Releppak Lemke Kraftwords c/o Mr. & Mrs. Rempel	Report	Hazard Assessment	No	Geotechnical report for proposed 2 story, 28 by 48 foot structure to be build into the slope of the east lot boundary. Note that lot is 1500 feet from the present creek, and this section of the fan shows evidence of being inactive from frequent (1/300 year) debris flows. Notes relatively recent "Debris lobes" above the fan apex - suggests these are annual events. Suggests that larger "high energy" events are in the range of 10 to 50 years. Describes a glaciocolluvial feature (gently sloping bench) on the east side of the fan above Lot 6 and the hydro ROW. Site map but no map showing location on fan.	From a geotechnical hazard viewpoint the site is considered safe for the use intended.	Y	N
7-Feb-08	P.K. Read Engineering Ltd.	Lot 6 Lillooet Lake Estates Geotechnical Review BUILDING CRITERIA	Releppak Lemke Kraftwords c/o Mr. & Mrs. Rempel	Report	Geotechnical report	No	Similar to previous report dated 28-Jan-08 but includes building and development recommendations.	No natural hazard related recommendations.	Y	N
2-Mar-09	P.K. Read Engineering Ltd.	Lillooet Lake Estates Lot 6 Re: Geotechnical Compliance and Information on Retaining walls.	Doug Rempel	Report	Geotechnical report	No	Documents review during construction of retaining walls. Includes several photos of the retaining walls.	No natural hazard related recommendations.	N	Y
15-Apr-09	P.K. Read Engineering Ltd.	Lot 16 Lillooet Lake Estates. Gate #5 Geotechnical Review & HAZARD ASSESSMENT	Darwin George & Lisadawn Shackleford	Report	Geotechnical report and Hazard Assessment	No	Geotechnical report and hazard assessment for proposed 36 by 32 foot structure (lot plan map provided) located 500 feet from Catiline Creek. The author identifies an ongoing debris flow hazard that could affect the lot "with an estimated probability of a debris flow impacting the lot of 1 in 1,000". The report identifies an old gulley with the potential for a future debris flow event to direct flow to the east past the proposed building site. A natural debris flow levee provides adequate mitigation to the proposed house location from natural hazards. Finally, PK Read (2009b) recommends that "the possible (1 in 1000 year) flow path adjacent to the west side of the lot driveway is kept free from obstructions".	Recommended that the possible (1 in 1000 year) flow path adjacent to the west side of the lot driveway is kept free from obstructions.	Y	Y
29-Sep-10	Cordilleran Geoscience	Catiline Creek emergency debris flow assessment	Malcolm Schulz / Ministry of Forests and Range	Report	Site assessment following debris flow	Sept. 28, 2010	Site assessment following debris flow to assess the situation and develop a workplan for reopening the FSR. Note that previous events occurred in July 2004, Summer 1987, and between 1982-1986. Rainfall trigger: 21.4mm in 9 hours (peak intensity 8mm/hr) at Pemberton Firebase weather station and 54.2 mm in 23 hours (peak intensity 5.4 mm/hr) at Meager Creek weather station. Note that the headscarp was in the southeast crown of the source basin. the source basin consists of a rock gully complex with about 6 individual source gullies. Note that the initial debris flow lobe remained confined, crossed the FSR and plugged the channel immediately downslope. At this point two smaller lobes avulsed to the north and south, each reaching Lillooet Lake. A second lobe plugged the channel near the upper part of the subdivision to the left. Most of the debris was deposited within the 80m of the main channel. See report for detailed runout characteristics. Total estimated debris flow volume was 15,000-20,000m3. Steep rock headwall observed at the 2010 head scarp that could yield a debris flow of 7,000-10,000m3 or larger if debris is entrained along the channel. Noted abundance of loose debris in the stream channel above the FSR that will likely wash downstream towards the bridge in the weeks and months following the debris flow.	Recommended work plan to clear the road and re-establish flow along the main channel: (1) Follow operational shutdown guidelines with modified thresholds of 25 mm/12 hrs and 50 mm/24 hrs. (2) Clear the road (~300 m^3), clear the bridge opening, conduct a bridge structural review, replace guardrails and fix other issues (eroded abutment fill) identified by bridge engineer. (3) Clean the debris plug below the FSR (5,000-7,000 m^3). (4) Clean the upper debris plus (8,000-10,000 m^3) and re-establish creek into main channel.	N	N
17-Aug-11	Kerr Wood Leidal	Site Review - September 2010 Debris Flow Remediation	Robie Thorn, Gary Young / Lillooet Lake Estates	Technical Memo	Site review and mitigation recommendations	Sept. 28, 2010	Short-term recommendations for limited work on Catiline Creek to re-establish hydraulic capacity and reduce the particularly high risk caused by the recent debris flow. Note that the Land Use Contract Authorization By-law No. 88, 1976 dictates flood hazard management requirements for LLE: no buildings within 200 feet (61m) of the 2 creeks and buildings be at least 5 feet (1.5m) above the natural boundary of the creeks. By-law also requires suitable designed training walls (berms) be constructed at the fan apex to prevent channel avulsions. Note previous events in: 1986, ~1990 (resident reference), 2004 and 2010. Note that the 2010 event size was reported as 50,000 m^3 (typo?). Remedial works completed since the event included: clearing the underside of the bridge and reconstructing the debris basin upstream of the bridge, and removal of some material and large boulders blocking the channel in a few locations. Note that the creek bed remains elevated above pre-2010 event levels by up to 6 m in some locations. Also note, that the material excavated from the creek was placed along the banks and not transported away from the creek. Note that new debris basin is ~400 m^2. Note that the bridge is ~1.5 m above the creek bed and has insufficient capacity below to convey debris flows on Catiline Creek. Identified 3 sections on the creek susceptible to avulsion as a result of the 2010 event: (1) perched creek bed just downstream of the bridge - buildings are located on the left and right bank. (2) downstream of the Catiline Creek intake, avulsion point of 2010 event, perched. (3) Right bank near the existing water crossing where the channel was partially blocked by a large rock in the 2010 event. Noted absence of engineered training berms at the fan apex.	Short term: excavate the areas with elevated bed levels to reduce risk of avulsion. - see report for specific details for Sections 1 to 3. Works should be designed and the construction reviewed by a QP. Works be completed in a timely manner (in advance of the fall rainy season). Any hazard mitigation works consider the potential to increase risk to adjacent or downstream areas. Long term: review of the flood and debris flow hazards be conducted as a first step in preparing a comprehensive long-term debris flow mitigation plan. Develop and Implement an Emergency Response Plan.	Y	Y
3-Jun-12	GVH Consulting Ltd.	Proposed Residence, Lot 13, DL 4901 Lillooet District Except Plan 11938	Tony Lago c/o Michael Henry	Report	Geotechnical report	No	Purpose of report is to provide subsoil information and recommendations pertaining to site preparation, foundation design, sub drainage and backfill. Risk mitigation from "debris torrents" is outside the scope of this report.	No natural hazards other than debris torrents on Catiline Creek were identified. The author deems the site safe for the intended use as pertaining to natural hazards "provided that the recommendations (by others) pertaining to debris torrent mitigation and on-going maintenance of the stream channel and other mitigation works are followed".	Y	N

Date	Author	Title	Client	Document Type	Report Content	Recorded Debris Flow?	Assessment	Recommendations	Maps	Photos
30-Aug-13	Cordilleran Geoscience	Catalina Creek debris flow, August 30, 2013	Malcolm Schulz / Ministry of Forests and Range	Letter Report	Site assessment following debris flow	Aug. 30, 2013	Debris flow occurred at 1:30 am on Aug. 30, 2013. The flow remained confined along the ~900 m length of channel to the debris basin, filled the basin, deposited 4-5 m of debris on the FSR then continued down the channel. A large lobe was deposited on the south bank, plugging the channel at a footbridge crossing; and avulsed north, overrunning the boat launch and reaching the beach. The north lobe swept over the driveway of the A-frame house, pushed a small pickup truck into the lake and destroyed a boat rack full of boats. The total volume is est. at 10,000-25,000 m^3. Initiation zone located in the upper part of the watershed in an eastern bedrock gully system (same gully that produced the 2010 event). Area of tension cracking at the crest of the slope noted in Cordilleran (2010) remains a potential rockfall source. Trigger was a short, but intense rainfall event resulting from thunderstorm activity with peak intensities around midnight (Pemberton and Meager Creek climate stations may not be representative of Catiline Creek). FSR cleanup work was completed under operational safety plan which included a spotter near the fan apex and following the BCTS wet weather safety shutdown guidelines. A rain gauge was installed to monitor rainfall at the site. The FSR Bridge was damaged but did not appear to be shifted by the debris flow. One-lane of traffic was restored to the road by late afternoon of Aug. 30.	Engineering inspection of the bridge once debris is cleared and prior to allowing regular traffic to resume. Clean the channel between the lake and the fan apex again. Reconstruct the catchment basin above the FSR. Works below the road need to be reconsidered as they were overwhelmed by the 2013 event. A Quantitative Landslide Risk Assessment is recommended for Lillooet Lake Estates. Based on the findings of the risk assessment, a Landslide Risk Mitigation Plan should be developed and implemented.	N	Y
4-Sep-13	GVH Consulting Ltd.	Proposed Residence, Site 5 DL 4901 Lillooet District Except Plan 11938 & EPP10321 Lillooet Lake Estates Geotechnical Report	Neil Thompson	Report	Geotechnical report	No	Purpose of report is to provide subsoil information and recommendations pertaining to site preparation, foundation design, sub drainage and backfill. Note the site is about 2000 feet from the active channel of Catiline Creek.	No natural hazards other than debris torrents on Catiline Creek were identified. The author deems the site safe for the intended use as pertaining to natural hazards since it is distanced about 2000 feet from the active channel of Catiline Creek.	Y	N
28-Nov-13	Kerr Wood Leidal	Catiline Creek 2013 Debris Flow Restoration	SLRD	Report	Construction completion report	Aug. 30, 2013	Emergency Management BC allocated SLRD up to $250,000 to re-establish the previous creek channel and bank alignment to restore the site. Project costs totaled $189,300.65 for construction, engineering and environmental costs. Construction work was completed from September 6-18, 2013. Note that MoFLNRO completed the assessment and debris removal for FSR bridge. Downstream of FSR bridge, the channel avulsed and caused a large amount of debris deposition adjacent to the house on LLE lot 42 and downslope through the LLE common lot 34 where the boat launch is located. Note that several buildings along the creek corridor narrowly escaped being struck by debris. Debris removal/restoration work included: (1) restoration and debris removal within the small debris basin upstream of the FSR bridge; (2) restoration and debris removal of the creek downstream of the FSR bridge including re-construction of the eroded right creek bank at the avulsion location; (3) removal of debris from the avulsion deposition area below the FSR bridge. See report for more details. Note that the creek channel were restored but no mitigative works were undertaken, therefore the debris flow hazard has not been reduced from the pre-event condition.	Remove debris from debris basin to re-establish capacity. Review of the flood and debris flow hazards be conducted as a first step in preparing a comprehensive long-term debris flow mitigation plan. Develop an emergency response plan if one does not yet exist.	Y	Y

APPENDIX C
PHOTOGRAPHS

Photograph 1. Breaking of large boulders along the upper portion of Catiline Creek following 1986 debris flow event. Photograph taken by the Hills Family provided by Gary Young dated July 25, 1987.

Photograph 2. Looking downstream at debris check dam constructed of wood (no longer existing). Photograph taken by the Hills family, provided by Gary Young dated November 12, 1986.

Photograph 3. Debris lobe at boat launch area at Lillooet Lake following 1986 event. Photograph taken by Gary Young dated October 26, 1986.

Photograph 4. Debris affecting A-frame house. Photograph taken by the Hills family and provided by Gary Young dated October 26, 1986.

Photograph 5. August 1987 debris flow deposits. Photo provided by the Klassen family. The logs are likely the remains of the check dam shown in Photo 2.

Photograph 6. Looking upstream at Catiline Creek channel showing large boulder on left bank. Photograph provided by the Hills family dated July 25, 1987.

Photograph 7. Estimated 20 tonne boulder in Catiline Creek channel. Photograph provided by the Hills family dated July 30, 1987.

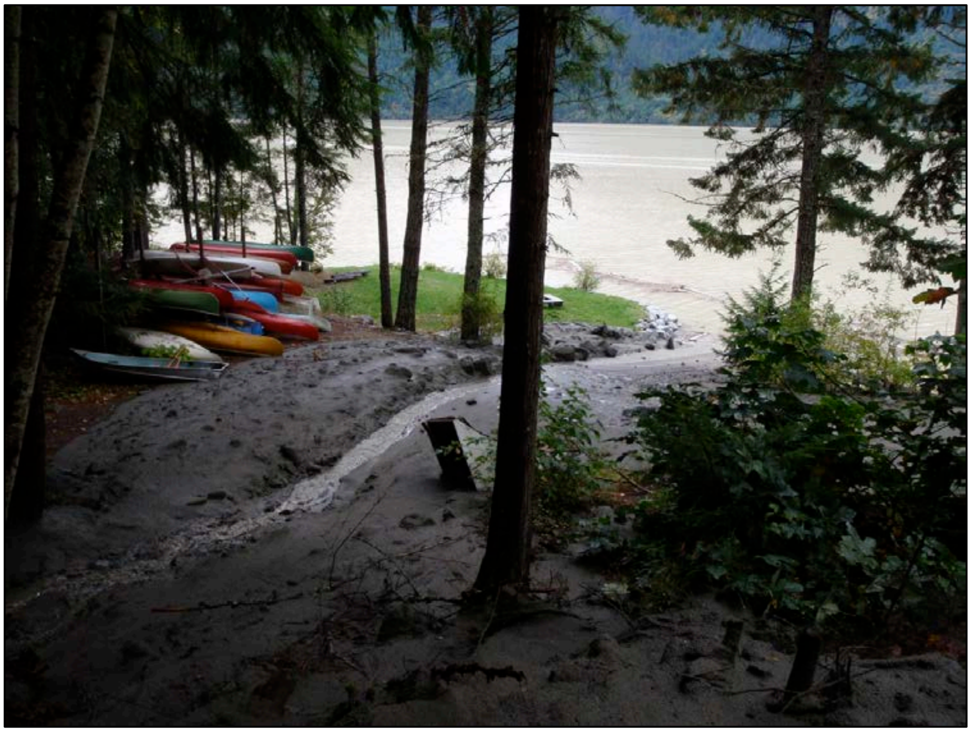
Photograph 8. Lower fan left lobe from 2010 debris flow.

Photograph 9. Lower fan left lobe from 2010 debris flow.

Photograph 10. 2010. Yard of A-Frame house just downstream of FSR on right bank. Truck partially buried in 2010. This same truck was destroyed in 2013.

Photograph 11. Left bank avulsion lobe from 2010 debris flow just misses vehicle.

Photograph 12. Debris from 2010 debris flow event that narrowly missed a guest house.



Photograph 13. Canoe rack narrowly missed by debris from 2010 debris flow event.

Photograph 14. Looking east at structural features in subbasin 3 (P617092 on Drawing 7). Photograph taken by Pierre Friele dated June 17, 2014.

Photograph 15. Looking northeast at channel downstream of the FSR, showing the area of avulsion in October 2013. Photograph taken by Matthias Jakob dated June 17, 2014.

Photograph 16. Looking downstream at "basin" immediately upstream of the FSR. Photograph taken by Matthias Jakob dated June 18, 2014.

Photograph 17. Looking downstream at the channel section immediately upstream of the FSR. Photograph taken by Matthias Jakob dated June 18, 2014.

Photograph 18. Looking downstream at a plugged channel section at about 420 m elevation, marked as "AV" (potential avulsion) on Drawing 6. The potential avulsion point to the right (northwest) channel is noted with a blue dashed arrow. Photograph taken by Matthias Jakob dated June 18, 2014.

Photograph 19. **Logged (1949-1952) tree stump impacted by debris flows, southeast fan sector (adjacent to Test Pit No. 5, Drawing 6). Photograph taken by Matthias Jakob dated June 18, 2014**

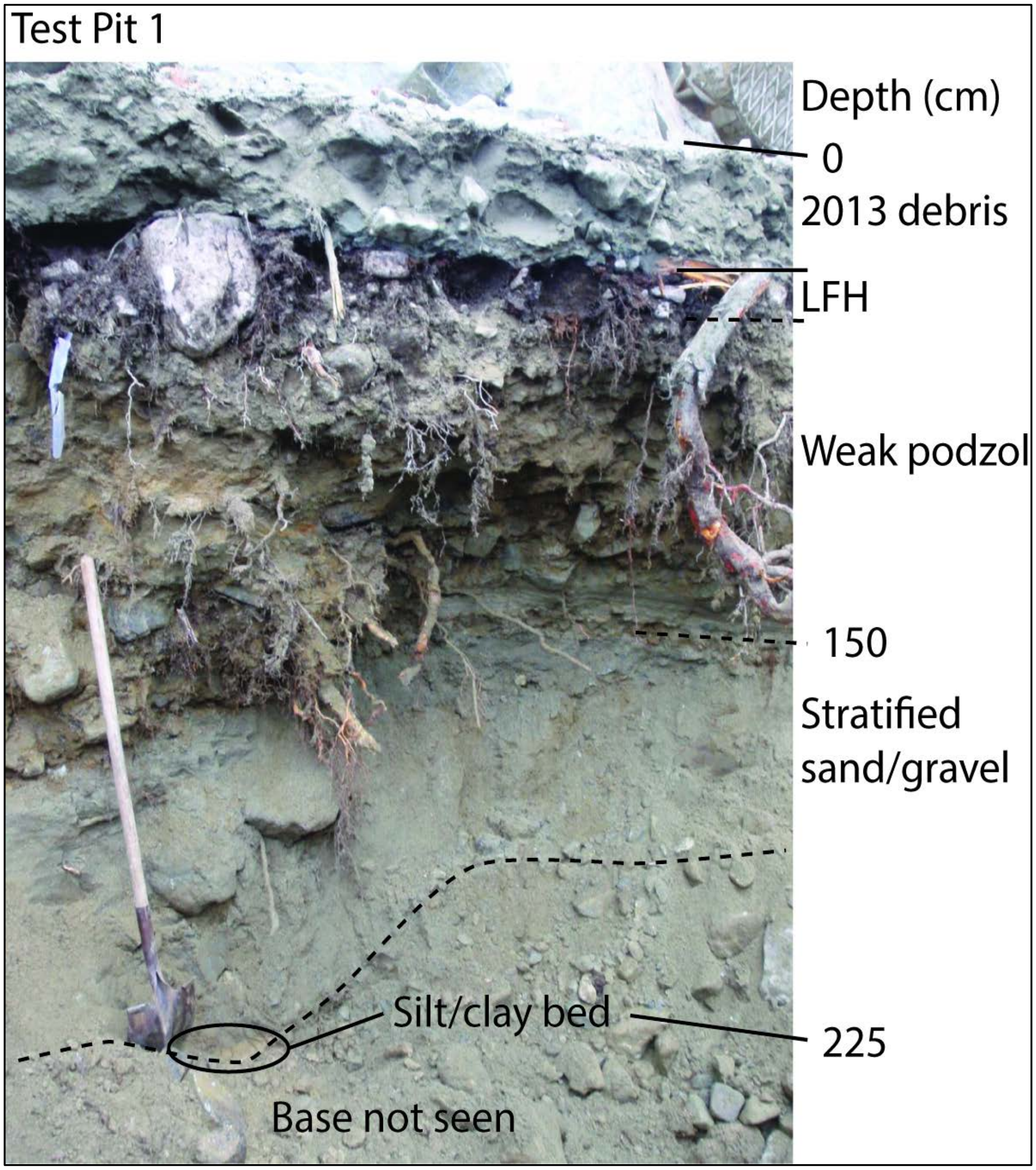
Photograph 20. **Annotated photos showing potential landslide sources in upper basin area. White arrows show the location of the photos taken. Upper left: potential rock slide source on Lone Goat Peak. Upper right. Tension cracks on ridge crest. Lower center: toppling trees and tension cracks (arrowed) showing bedrock instability in the mid-basin area. Photograph taken by Matthias Jakob dated June 18, 2014**

APPENDIX D
TEST PIT LOGS

Test Pit 1

Photos: P6170258, P6170259

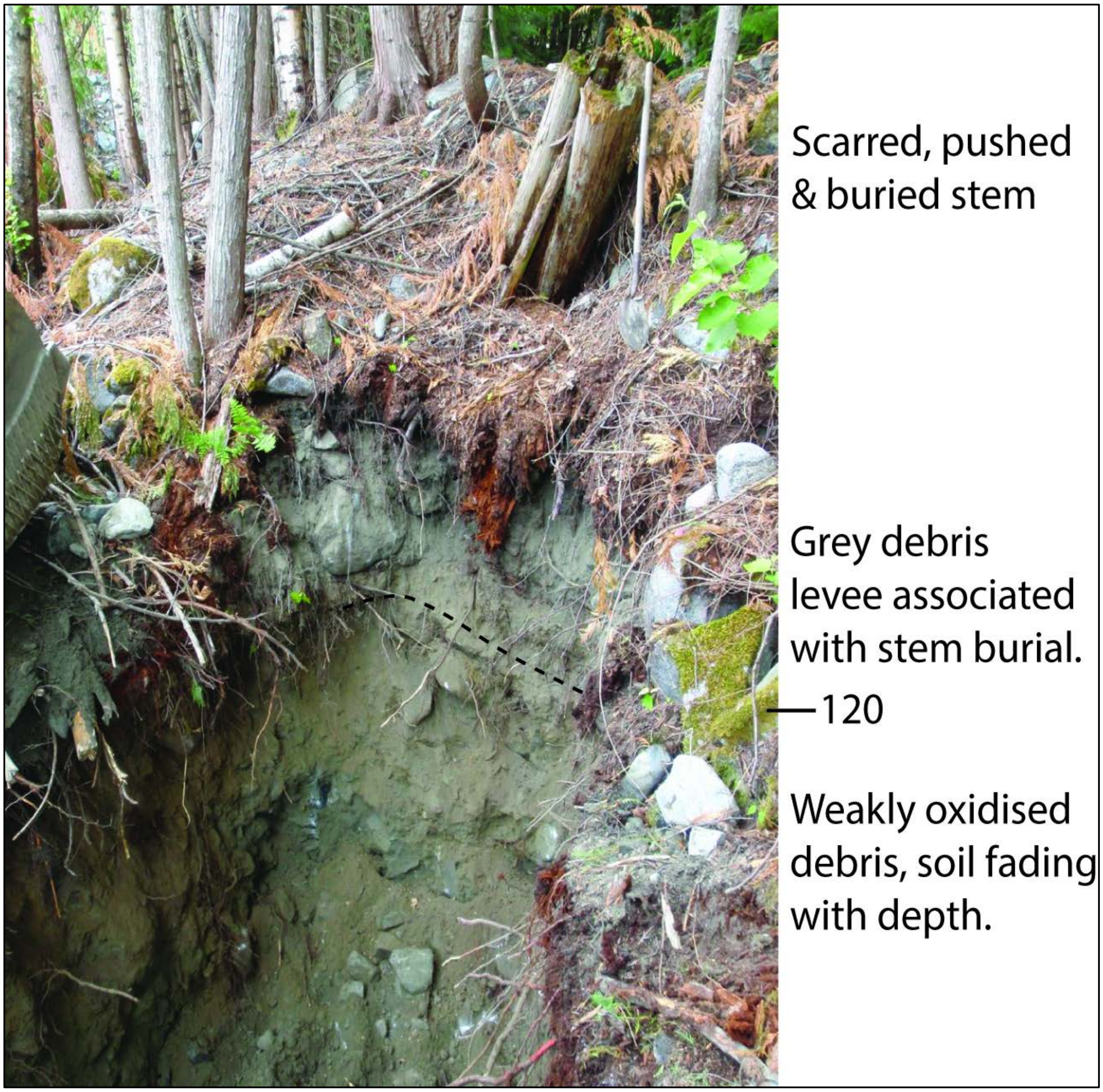
Depth (cm)	Observations
0-40	2013 debris
40-80	Fill
80-150	Stratified sand and cobble. Oxidized, with roots.
150-225	Stratified sand and cobble. No soil development.
225-235	Silt clay bed draped on boulders. Water table.
235	Base not seen.



Test Pit 2

Photos: P6170260, P6170261

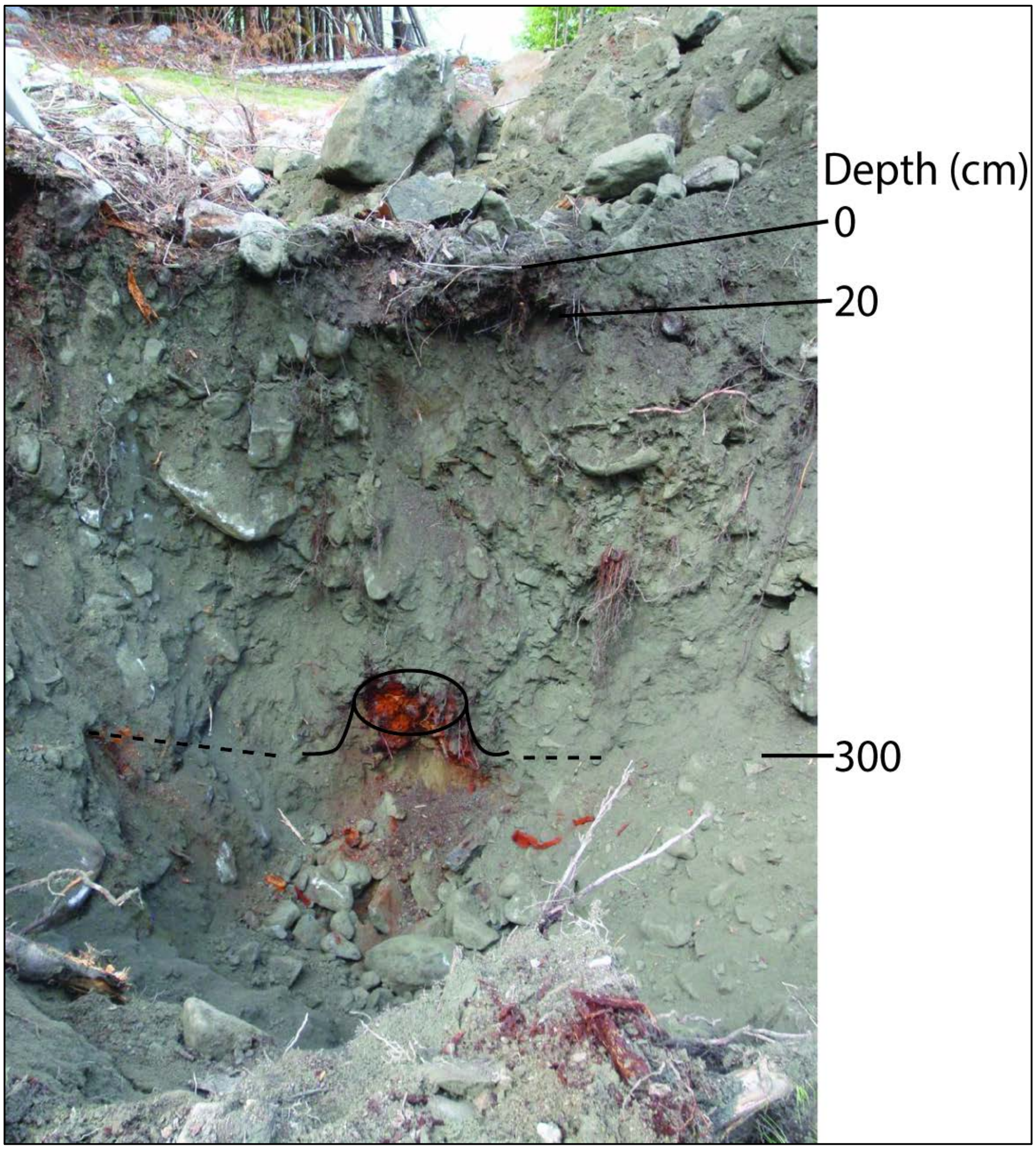
Depth (cm)	Observations
0-120	Historic debris levee with buried & scarred cedar stem.
120-300	Diamicton, massive, matrix supported. Weak soil development at top and fading with depth.
300	Base not seen.



Test Pit 3

Photos: P6170262, P6170263

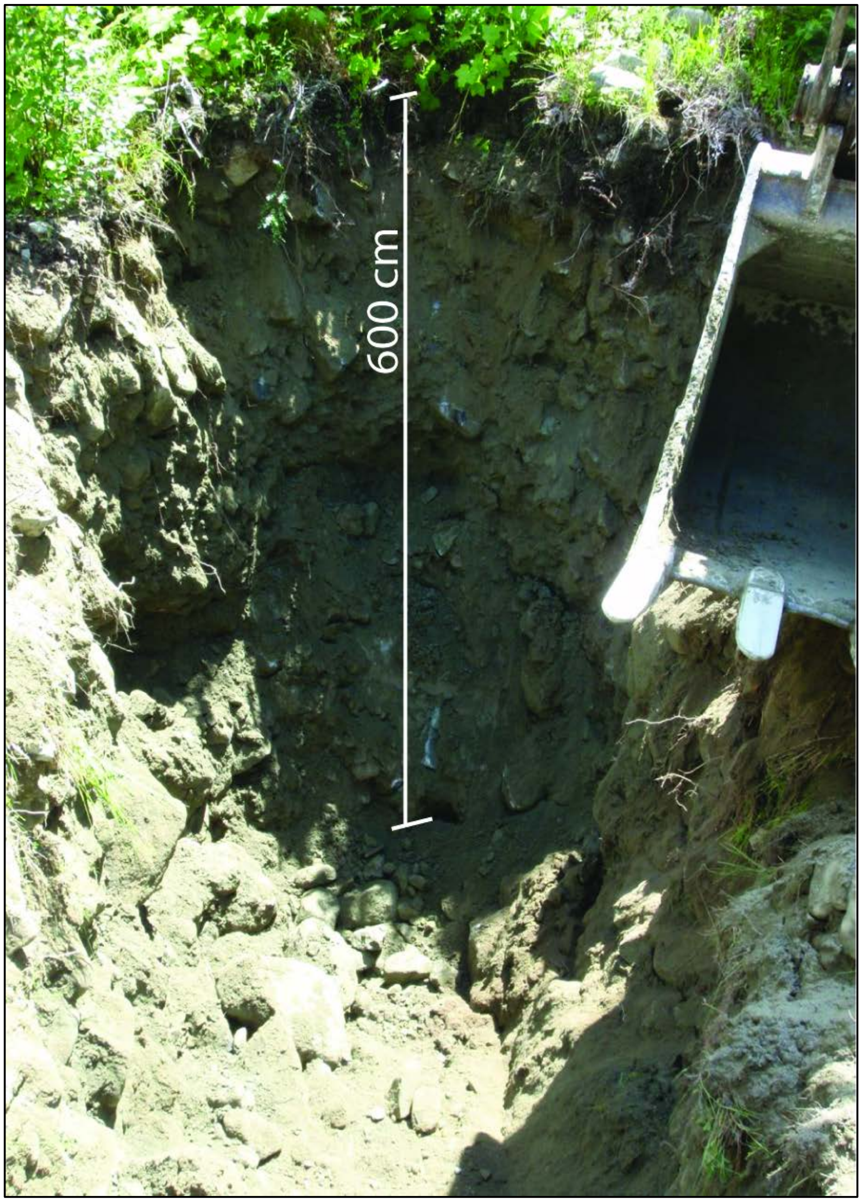
Depth (cm)	Observations
0-20	Organic horizon.
20-300	Diamicton, massive, matrix supported. No apparent soil development.
300-310	Paleosol with stump. Radiocarbon sample. No point dating because obviously recent.
310-400	Diamicton, massive, matrix supported. Weak soil development at top and fading with depth.
400	Base not seen.



Test Pit 4

Photos: P6180264, P6180265, P6180266, P6180267, P6180268, P6180269, P6180270

Depth (cm)	Observations
0-600	Diamicton, massive, matrix supported. Boulders to 1.5 m diameter.
600	Base not seen.



Test Pit 5

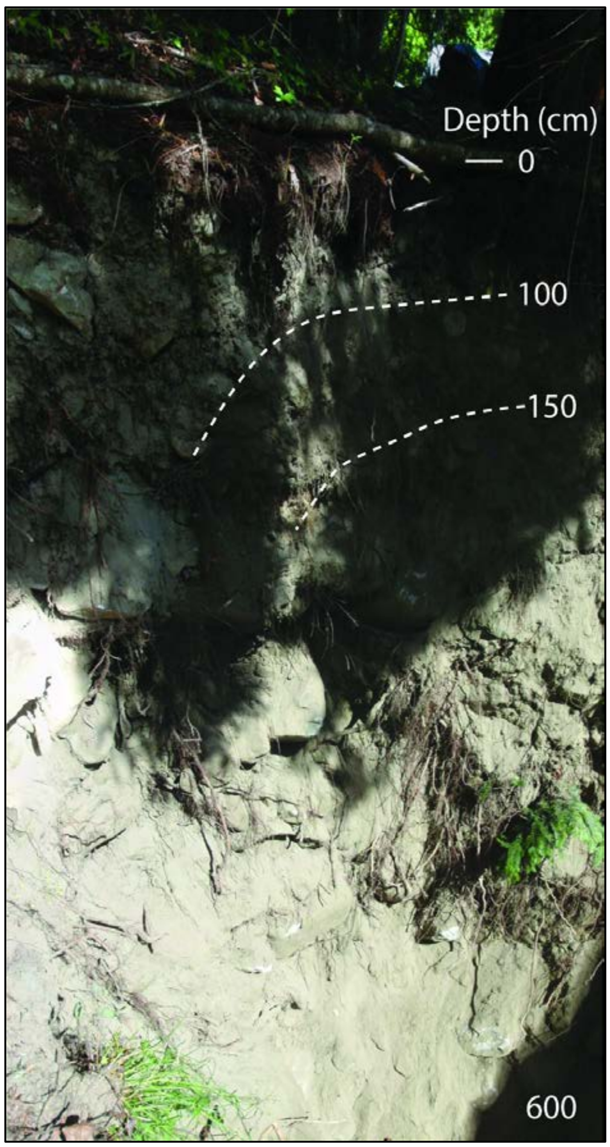
Photos: P6180271, P6180272, P6180273, P6180274

Depth (cm)	Observations
0-600	Diamicton, massive, matrix supported. Boulders to 2.0 m diameter. Wood fragment found at 4.5 m depth is 10 cm by 5 cm by 40 cm long. Clearly a broken log and not a root. Sampled for radiocarbon dating. No point dating because appears recent.
600	Base not seen.

Test Pit 6

Photos: P6180275, P6180276

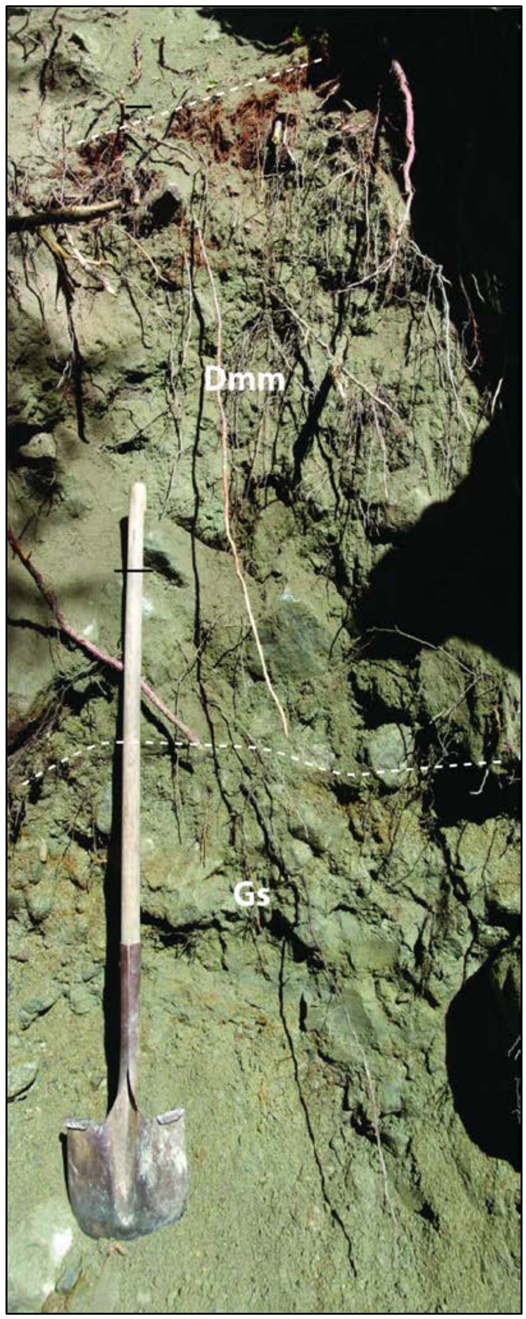
Depth (cm)	Observations
0-10	Organic horizon.
10-100	Diamicton, massive, matrix supported. Cobble to fine boulder.
100-125	Sandy pebble gravel.
125-150	Medium to fine gravel, slightly oxidized with humic layer. Bulk organic sampled for radiocarbon dating.
150-600	Diamicton, massive, matrix supported. Large boulders. At 5 m wood fragment sampled for radiocarbon.
600	Base not seen.



Test Pit 7

Photos: P6180277, P6180278

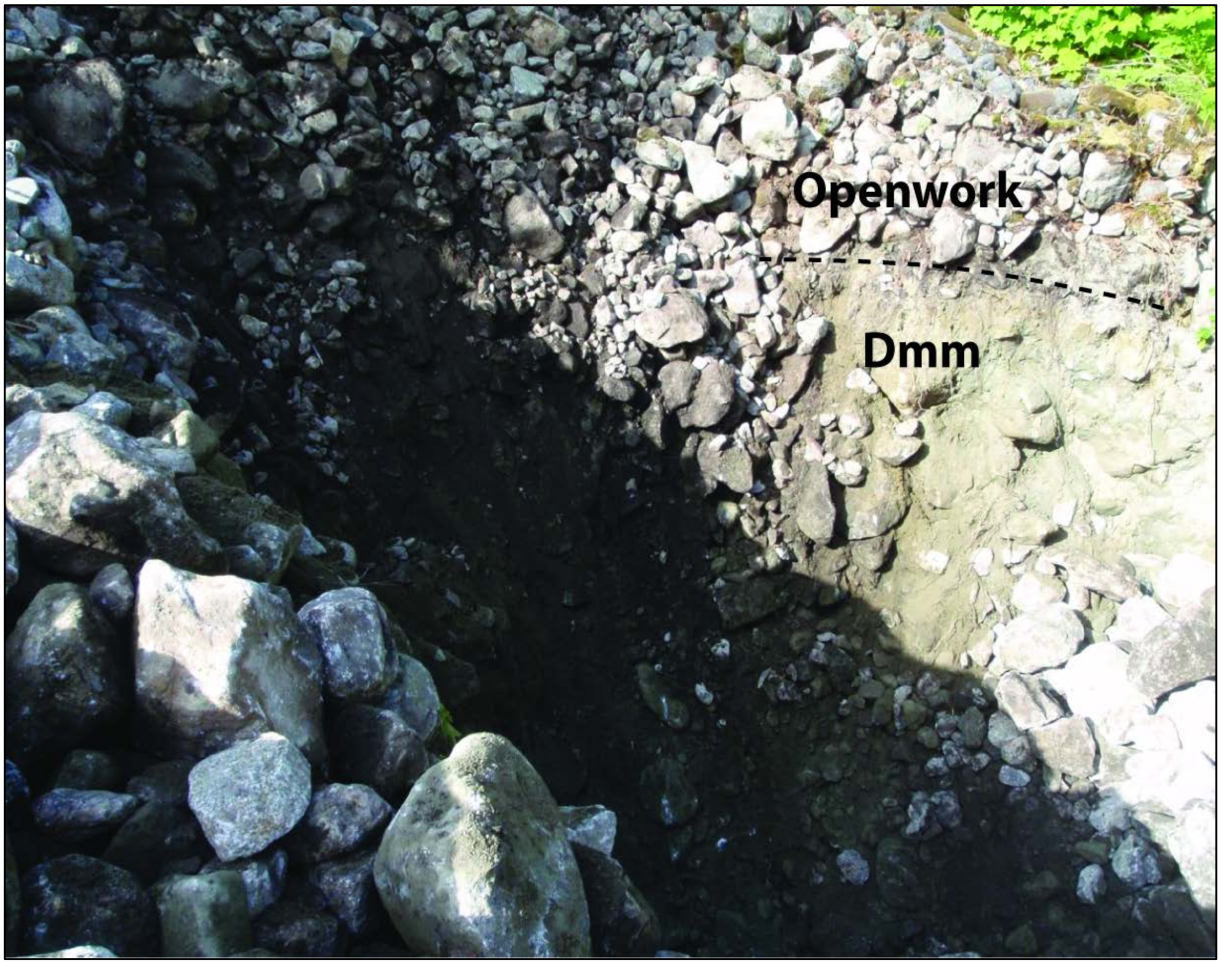
Depth (cm)	Observations
0-100	Diamicton, massive, matrix supported. Cobble to fine boulder.
100-120	Medium to coarse sand, massive.
120-400	Sandy gravel.
400	Base not seen.



Test Pit 8

Photos: P6180279, P6180280, P6180281

Depth (cm)	Observations
0-200	Openwork subround cobbles and boulders.
200-600	Diamicton, massive, matrix supported. Cobble to fine boulder.
600	Base not seen.



APPENDIX E
DENDROGEOMORPHOLOGY

APPENDIX E
DENDROGEOMORPHOLOGICAL ANALYSIS PROCEDURES

E.1. CATILINE CREEK DENDROGEOMORPHOLOGY

E.1.1. Introduction

Dendrochronology is an absolute dating method in which annually distinct tree rings are used to determine the age of a tree.

Dendrogeomorphology, a sub discipline of dendrochronology, focuses on geomorphological processes that influence tree growth. Depending on the ages of trees along the main stem channel of a creek, and the history of disturbing geomorphic events, dendrogeomorphology can extend the frequency record of debris flows well past the air photograph record and may close the time gap between air photograph interpretation (several decades) and radiocarbon dating (century to millennia). Unlike the other two methods, dendrogeomorphology can also be precise to the nearest year in dating growth disturbances, and in some cases, even the seasonal timing of growth disturbance can be deciphered (Stoffel and Bollschweiler, 2008).

Dendrogeomorphological methods have been applied specifically to debris flow which can influence regular tree growth in different ways (Alestalo, 1971; Stoffel and Bollschweiler, 2008).

- Trees may be damaged due to impact by large boulders or logs transported by a debris flow, producing scars or shearing the tree off above the stump in extreme cases (decapitation).
- Some trees species will produce tangential traumatic resin ducts (TRDs) when scarred or decapitated[1]
- Tree growth may be reduced or increased in years following a debris-flow event due to changes in resource (water/nutrients) access.
- Growth pattern may also change when a tree is tilted and produces denser (and thus darker) reaction wood to regain vertical alignment.

Because trees produce a new layer of radial growth each year, these events can be accurately dated by studying the tree's growth ring series.

E.1.2. Method

25 trees were sampled on July 24, 2014 from coniferous trees along Catiline Creek. Two species were sampled: Douglas fir (*pseudotsuga menziesii*) and Western Red Cedar (*thuja plicata*). One to three cores per tree were extracted from living trees using a 4 mm increment borer. Coring is a non-destructive sampling technique and is thus preferred to felling the tree.

[1] When a spruce or fir tree is wounded, the tree forms aligned rows of resin ducts, known as tangential TRDs. TRD formation is a defense mechanism that allows the tree to compartmentalize the damaged wood. By contrast, resin ducts in pine trees do not align after damage.

Retrieved samples were sanded to a high finish using 120 grit sand paper and scanned using a calibrated Epson scanner at 1600 dots per inch (dpi). The tree ring widths were measured using Regent Instruments' WinDENDRO 2012 software package (Regent Instruments Inc., 2012). WinDENDRO is a semi-automatic image analysis program, which identifies tree rings and measures the width of the yearly growth. The user inputs the outer ring year (2014, in this case), and the program counts inwards from the bark along a user-defined path. The operator is also able to review and correct the ring assignments as necessary. WinDENDRO can be superior to manual dating techniques because it facilitates verification; when errors are found, measurement image files can be easily opened, adjusted and re-saved.

Once the cores were measured, the first step in the analysis was to identify the event response features shown on each sample, for each year. The following response features were documented: tangential traumatic resin ducts (TRDs); reaction wood; and impact scars. This process was known as feature identification, and 91 features were identified.

The second step in the analysis was to identify the growth variations in each sample. Standard practice is to identify growth variations visually, either directly from the samples (Bollschweiler et. al., 2010) or using growth curves (Stoffel, 2010). For Catiline Creek samples, the latter option was selected. Tree ring widths were plotted graphically, and the tree ring series was visually inspected to identify growth accelerations or reductions. This process identified 11 growth accelerations and 13 growth reductions.

The third step involved combining the feature identification and growth variation identification results into a spreadsheet, on file at BGC. The spreadsheet was processed to produce a Global Mapper workspace with a number of map layers: one for each year of the dendrogeomorphological record on the Catiline Creek fan (Blue Marble Geographics, 2014). In this workspace, each tree sample appeared as a coloured dot, with different colours corresponding to different tree reactions, or combinations of reactions. For example, a bright red dot indicated that tree had been scarred in the given year.

In conjunction with the historical air photos, these map layers were used to identify event years, and to delineate event extents. The following criteria were used to identify an event on the Catiline Creek fan:

- At least one tree showing unambiguous scarring, and/or at least three trees showing TRDs or reaction wood.
- Presence of trees showing growth reduction with dates that match scarring or TRDs.

E.1.3. Limitations

It is important to note the high degree of uncertainty associated with the Catiline Creek dendrogeomorphology results. Due to logging on the fan in the 1950s and development in the intervening years, limited old growth trees were available for sampling. The use of tree cores to identify scar dates is also highly subjective, because the wood around a scar is distorted, and rings may be missing. For this reason, all scar dates obtained are assumed to be minimums; the scarring event may have occurred earlier, possibly by as many as 10 years. There is also uncertainty associated with TRD, reaction wood and growth variation dates, because the tree ring series were not crossdated[2] to check measurement errors. Although crossdating would have allowed greater confidence in the feature dates, the additional time and budget requirements would have more than outweighed any potential benefits.

[2] Crossdating is a process in which the ring-width variability among tree ring series is compared visually (list method) and statistically using the program COFECHA (Holmes, 1983), in order to identify measurement errors.

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Stoffel, M. (2010). Frequency-Magnitude Relationships, Seasonality and Spread of Debris Flows on a Forested Cone. *Tree Rings and Natural Hazards*. Springer, London, p. 211-226.

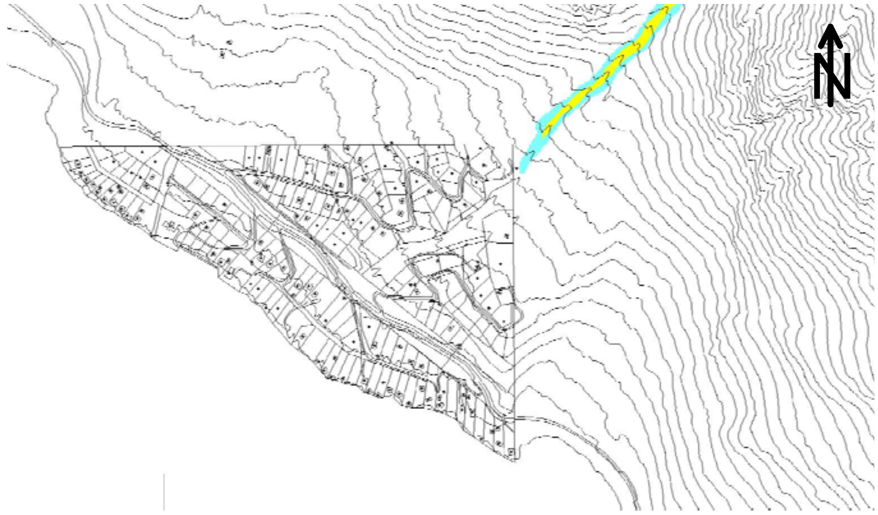
APPENDIX F
DEBRIS FLOW MODELLING

VOLUME: 6,000 m^3
PARAMETER COMBINATION 1
FRICTION COEFFICIENT: 0.30
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

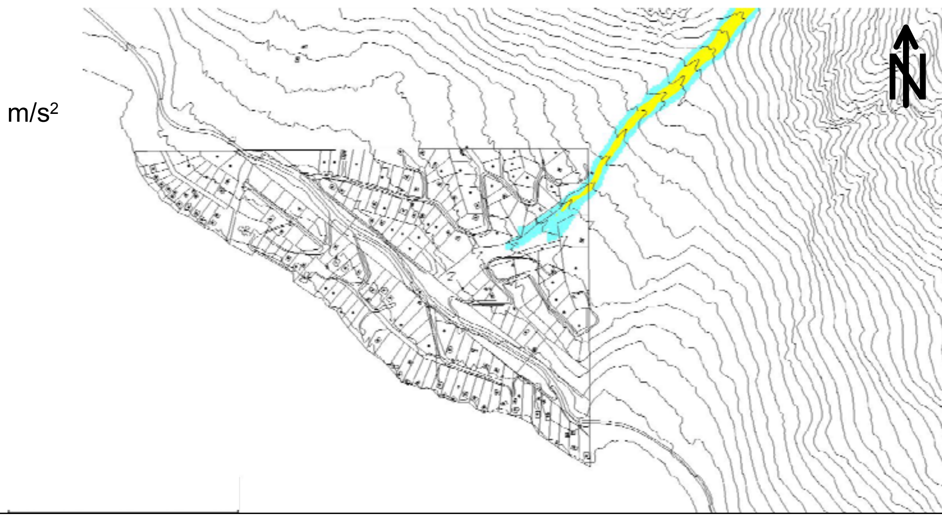


VOLUME: 6,000 m^3
PARAMETER COMBINATION 2
FRICTION COEFFICIENT: 0.25
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

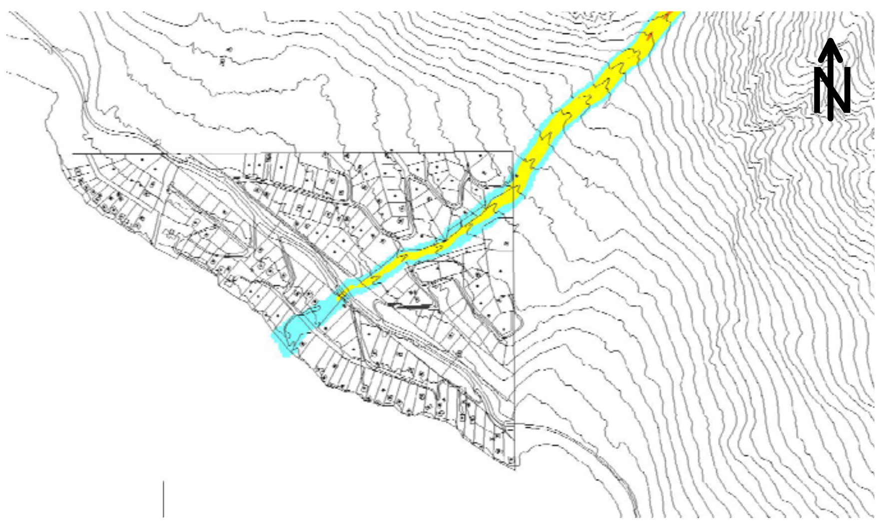


VOLUME: 6,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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SCALE:	AS SHOWN	DESIGNED:	SJK
DATE:	JAN 2015	CHECKED:	SDM
DRAWN:	SJK	APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS
FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
6,000 m^3 EVENT SCENARIO - NO FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-1	

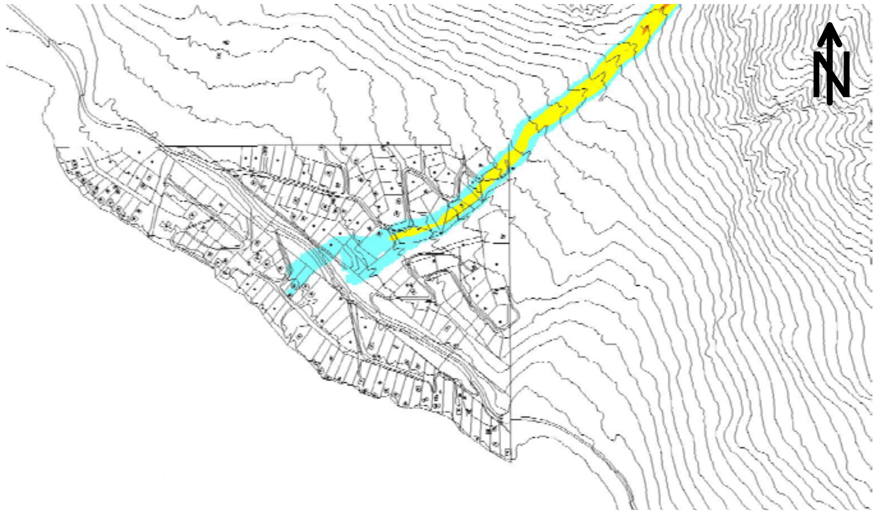
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 6,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NORTH FORCED AVULSION AT A1

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

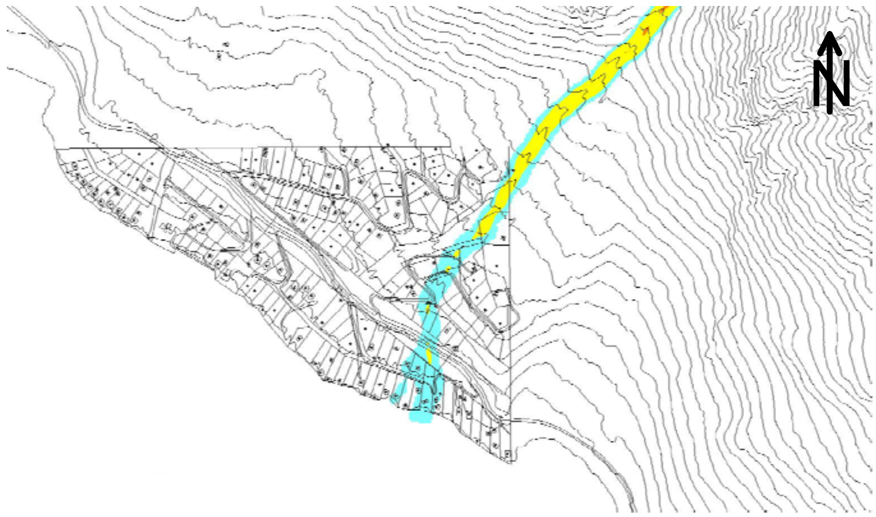


VOLUME: 6,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
SOUTH FORCED AVULSION AT A2

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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DATE:	JAN 2015	CHECKED:	SDM
DRAWN:	SJK	APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS
FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
6,000 m^3 EVENT SCENARIO - WITH FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-2	

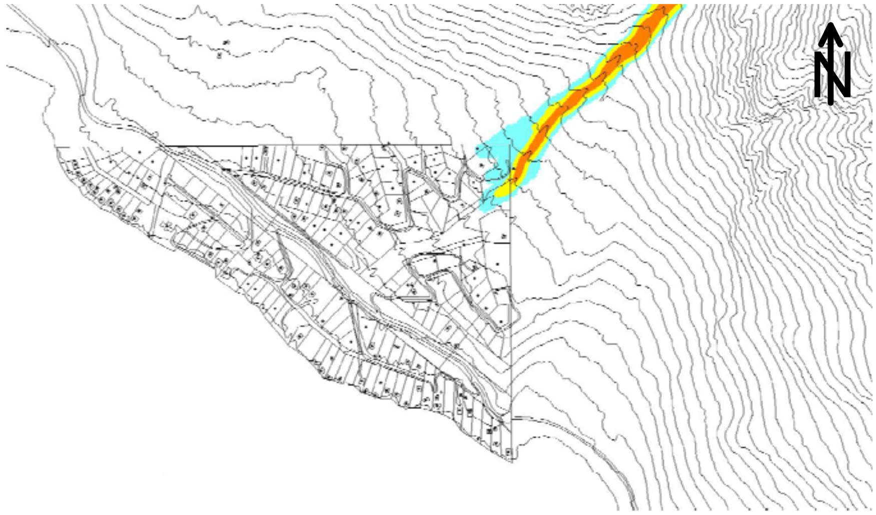
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 40,000 m^3
PARAMETER COMBINATION 1
FRICTION COEFFICIENT: 0.30
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

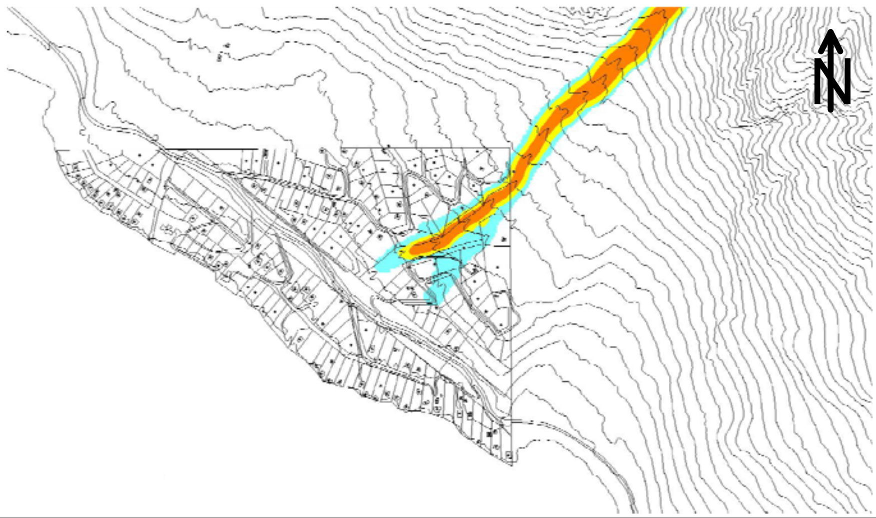


VOLUME: 40,000 m^3
PARAMETER COMBINATION 2
FRICTION COEFFICIENT: 0.25
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

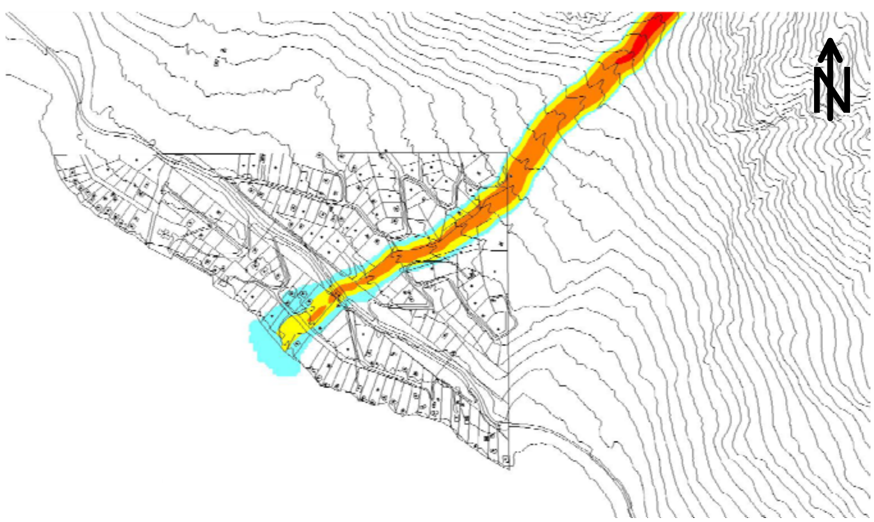


VOLUME: 40,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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DATE:	JAN 2015	CHECKED:	SDM
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PROJECT:
CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
40,000 m^3 EVENT SCENARIO - NO FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-3	

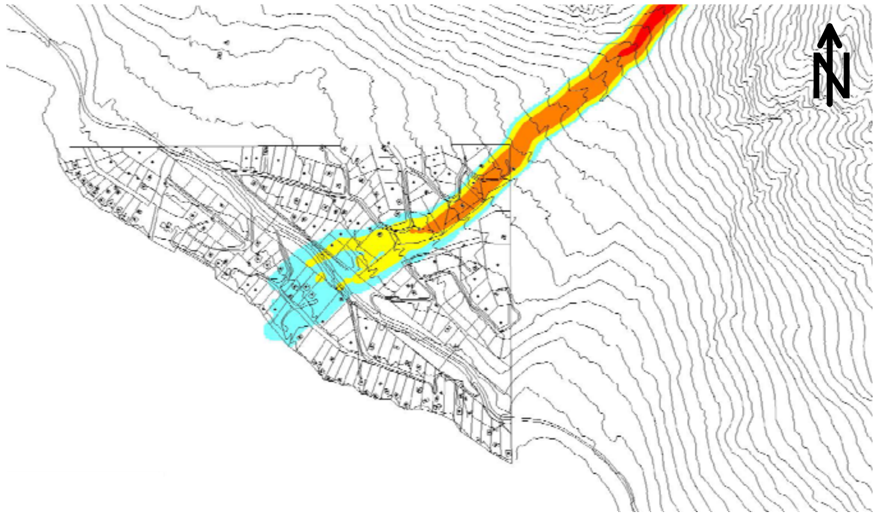
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 40,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NORTH FORCED AVULSION AT A1

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

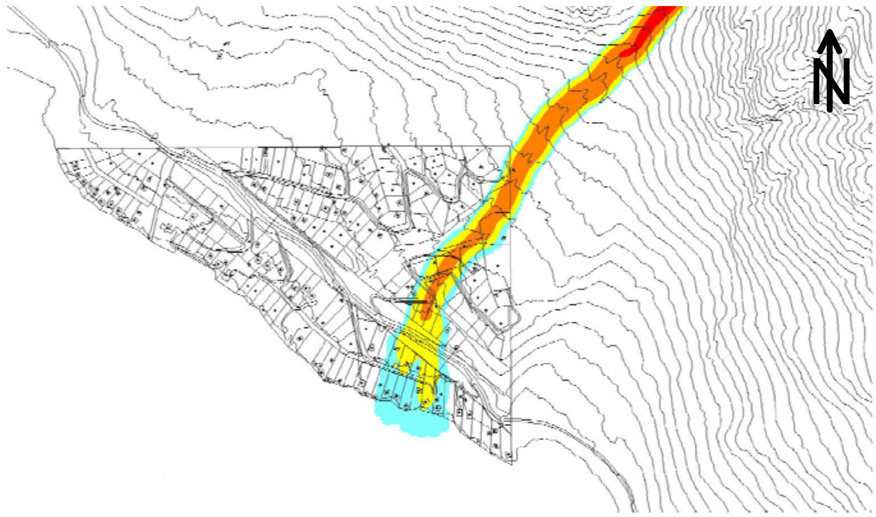


VOLUME: 40,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
SOUTH FORCED AVULSION AT A2

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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SCALE:	AS SHOWN	DESIGNED:	SJK
DATE:	JAN 2015	CHECKED:	SDM
DRAWN:	SJK	APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
40,000 m^3 EVENT SCENARIO - WITH FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-4	

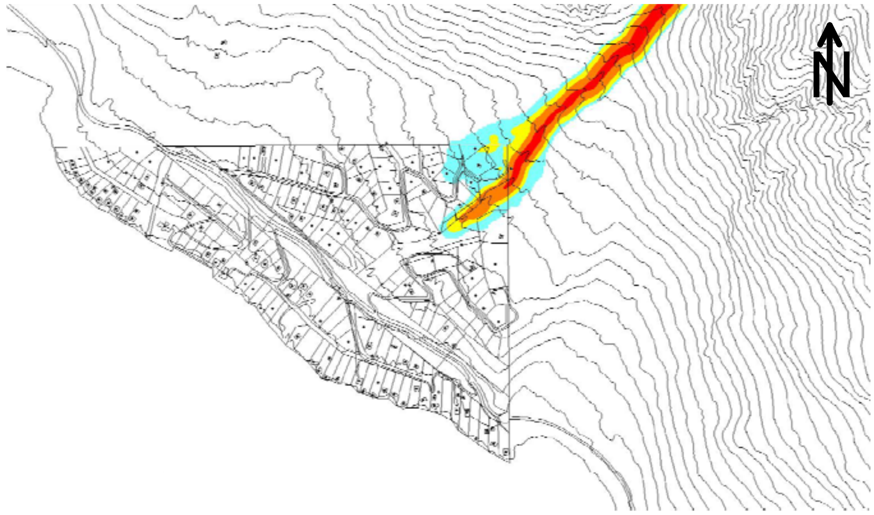
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 100,000 m^3
PARAMETER COMBINATION 1
FRICTION COEFFICIENT: 0.30
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

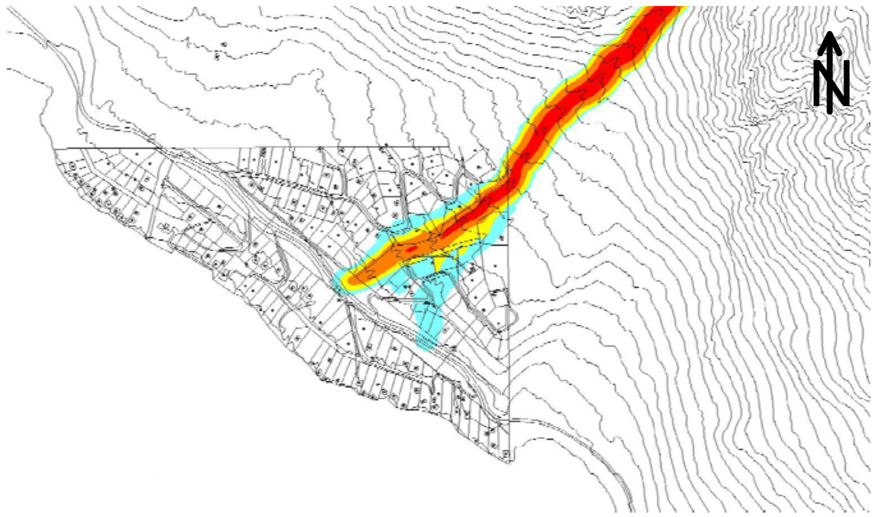


VOLUME: 100,000 m^3
PARAMETER COMBINATION 2
FRICTION COEFFICIENT: 0.25
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

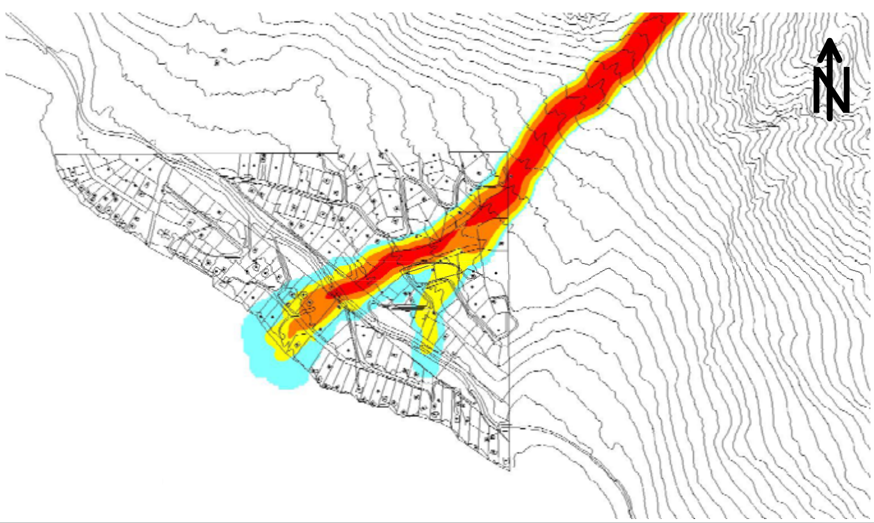


VOLUME: 100,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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DATE:	JAN 2015	CHECKED:	SDM
DRAWN:	SJK	APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
100,000 m^3 EVENT SCENARIO - NO FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-5	

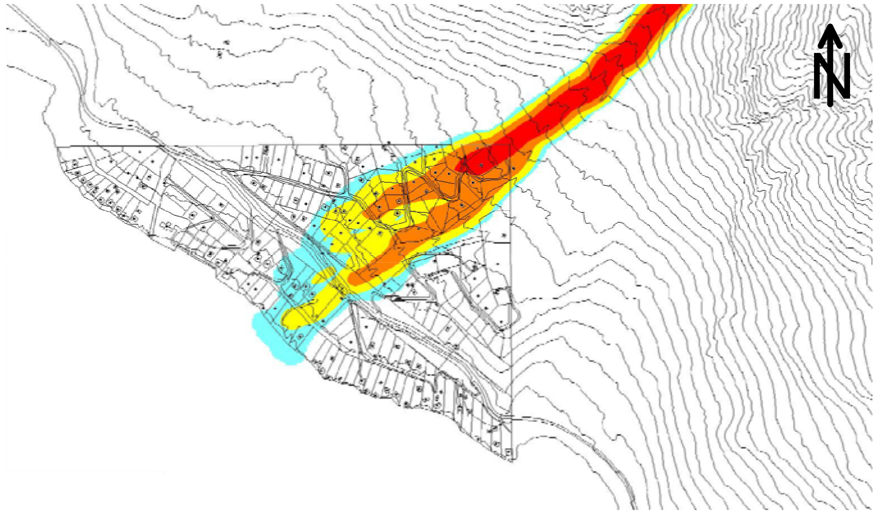
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 100,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NORTH FORCED AVULSION AT A1

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

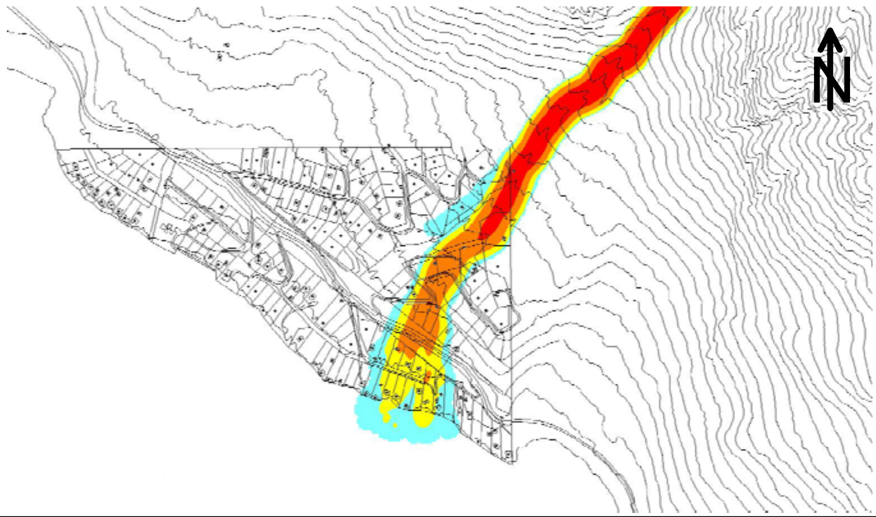


VOLUME: 100,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
SOUTH FORCED AVULSION AT A2

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT

TITLE:
DEBRIS FLOW MODEL OUTPUT
100,000 m^3 EVENT SCENARIO - WITH FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-6	

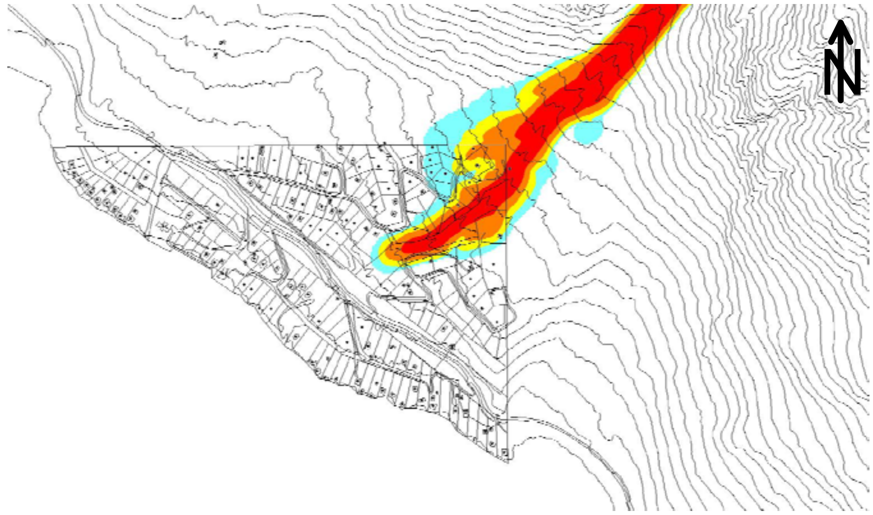
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 300,000 m³
PARAMETER COMBINATION 1
FRICTION COEFFICIENT: 0.30
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

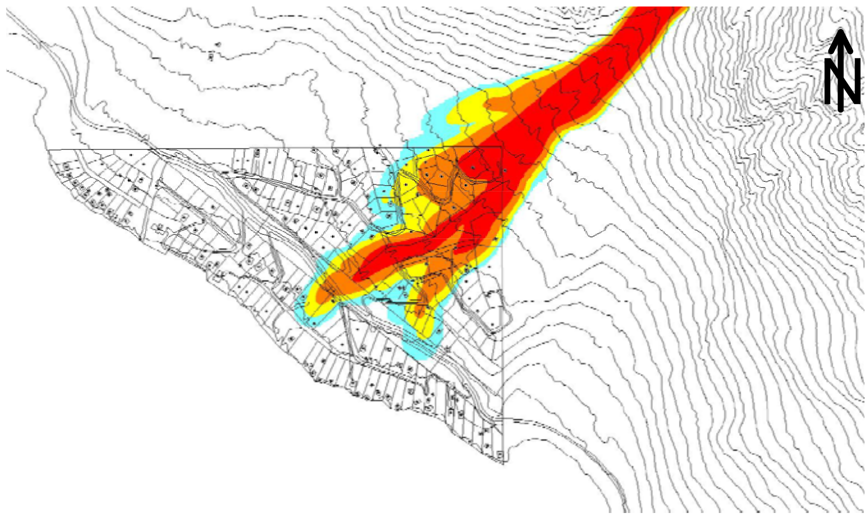


VOLUME: 300,000 m³
PARAMETER COMBINATION 2
FRICTION COEFFICIENT: 0.25
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

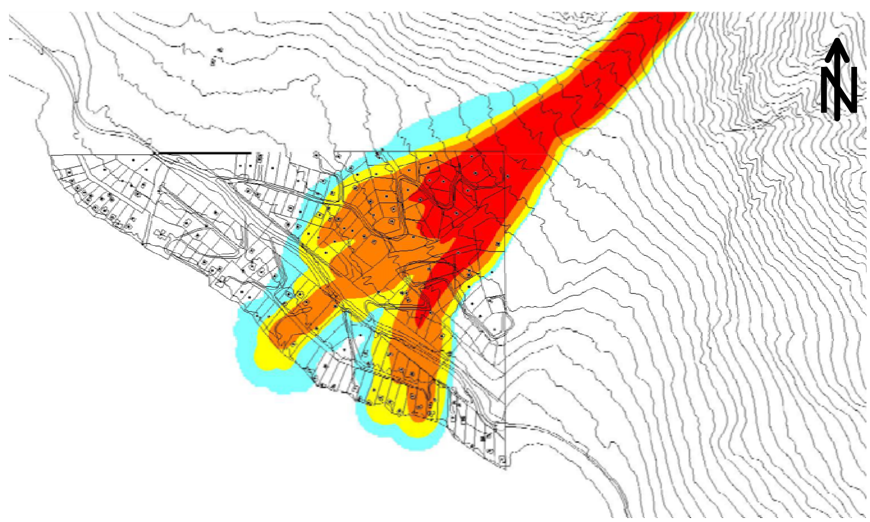


VOLUME: 300,000 m³
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NO FORCED AVULSION

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT: CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT

TITLE: DEBRIS FLOW MODEL OUTPUT 300,000 m³ EVENT SCENARIO - NO FORCED AVULSIONS

CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-7	

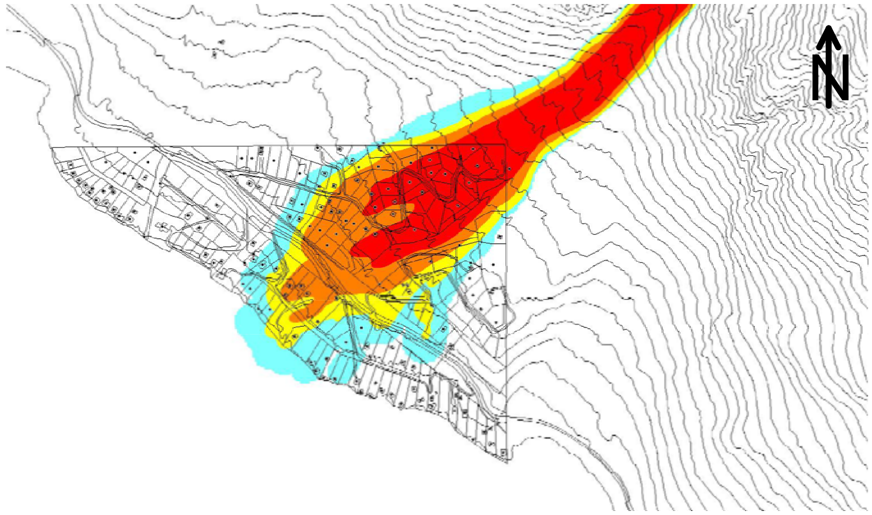
DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

VOLUME: 300,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
NORTH FORCED AVULSION AT A1

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m

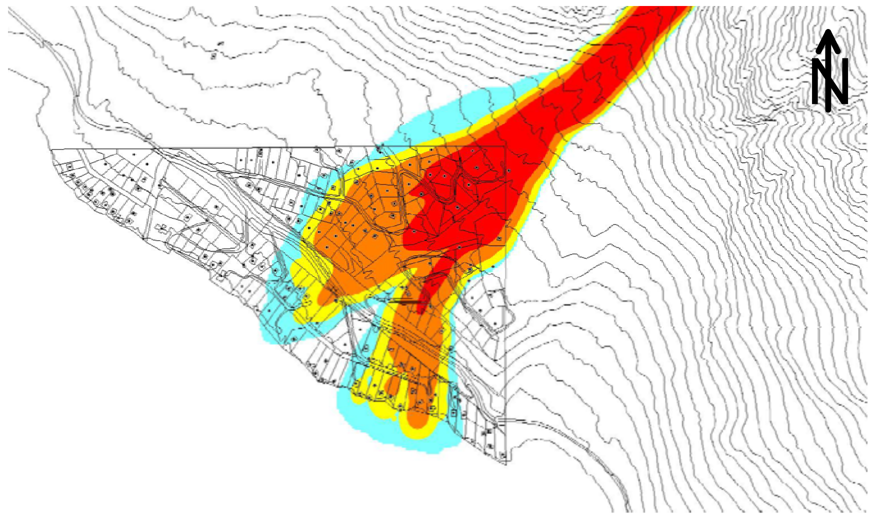


VOLUME: 300,000 m^3
PARAMETER COMBINATION 3
FRICTION COEFFICIENT: 0.20
TURBULENCE PARAMETER: 500 m/s^2
SOUTH FORCED AVULSION AT A2

DEBRIS FLOW
INTENSITY (I_{DF})

100
10
1
0

SCALE 500 m



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DATE:	JAN 2015	CHECKED:	SDM
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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

PROJECT:
CATILINE CREEK DEBRIS
FLOW HAZARD AND RISK ASSESSMENT

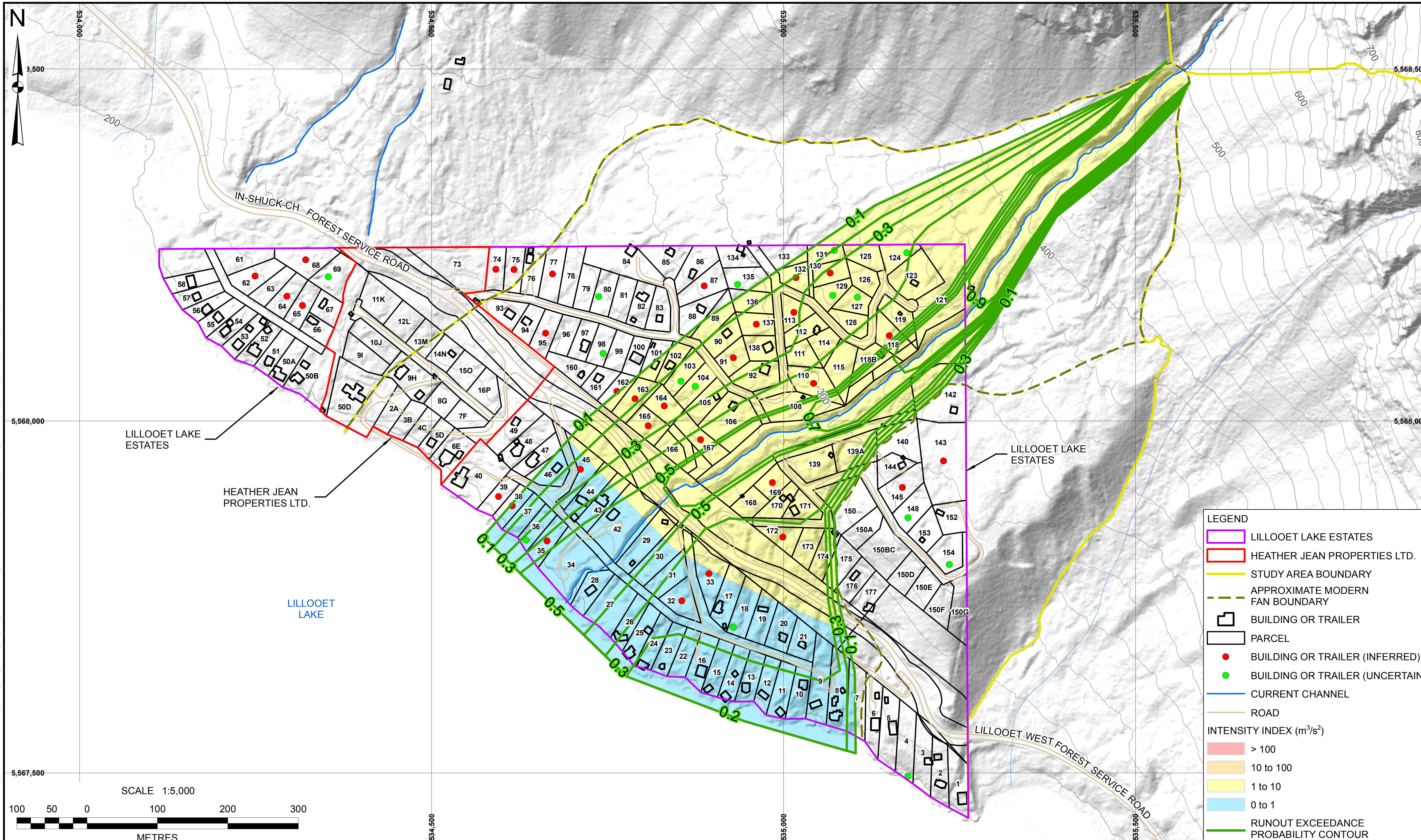
TITLE:
DEBRIS FLOW MODEL OUTPUT
300,000 m^3 EVENT SCENARIO - WITH FORCED AVULSIONS

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT No.:	FIG No.:	REV.:
1358001	F-8	

DWG TO BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 2015.

APPENDIX G
INTERPRETED DEBRIS FLOW MODELLING



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BUILDING OUTLINES AND ROADS PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. IN AREAS OF TREE COVERAGE ONLY PARTIAL BUILDING OUTLINES COULD BE IDENTIFIED.
4. BUILDING POINTS (UNCERTAIN) WERE DIGITIZED BY BGC IN AREAS OF PARTIAL TREE COVERAGE AND SHOULD BE CONSIDERED APPROXIMATE.
5. BUILDING POINTS (INFERRED) WERE PLACED AT THE CENTROID OF THE LOT AND ARE CASES WHERE NO BUILDING WAS IDENTIFIED, BUT BC ASSESSMENT OR RESIDENT INTERVIEW DATA IMPLIED THAT A BUILDING SHOULD EXIST.
6. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 20 m.
7. STUDY AREA BOUNDARY IS ILLUSTRATED BY THE CATILINE CREEK APPROXIMATE MODERN FAN BOUNDARY.
8. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
9. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
10. PROJECTION IS UTM NAD 83 ZONE 10.
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DATE:	JAN 2015
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CHECKED:	SDM
APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

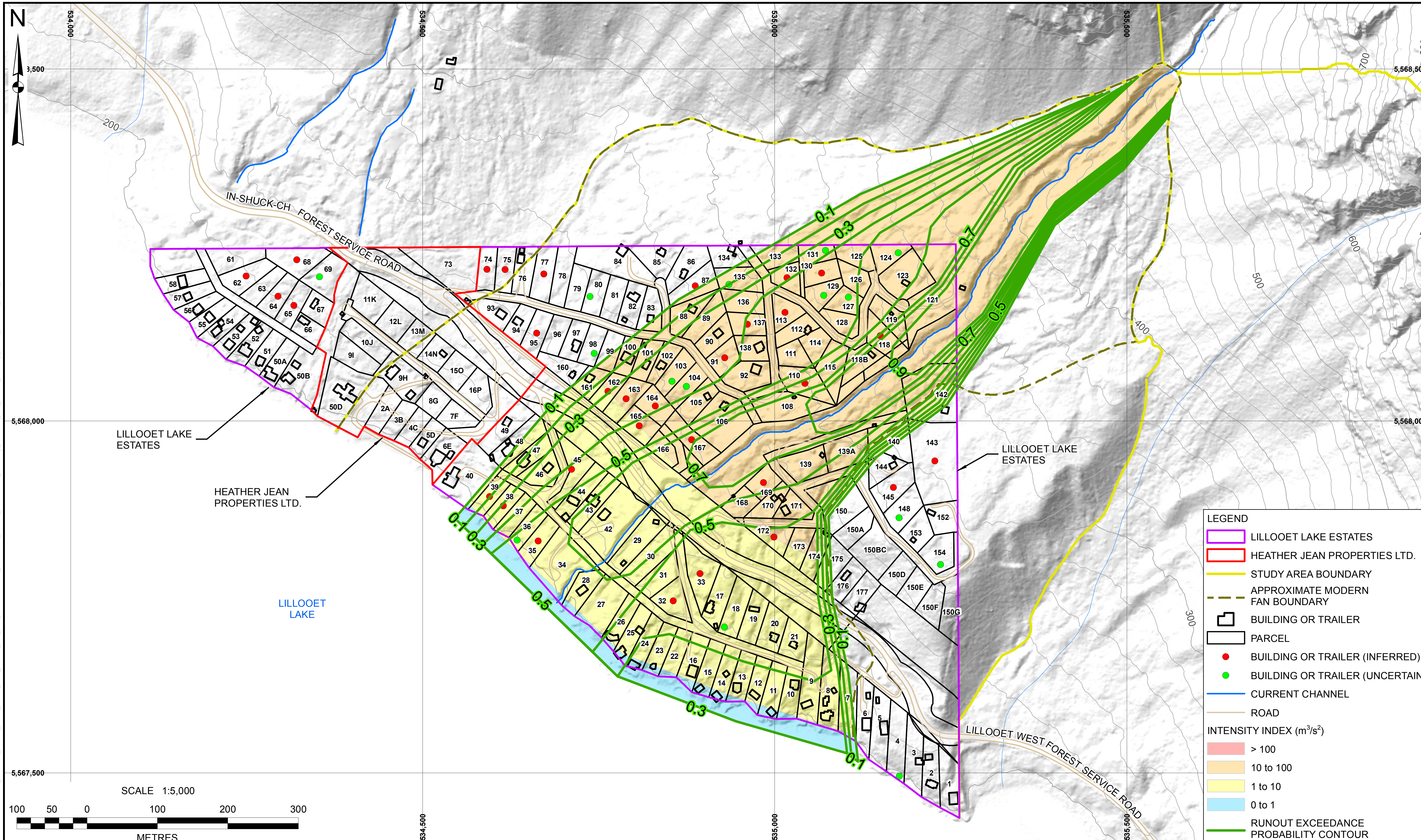
PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
INTERPRETED RUNOUT EXCEEDANCE PROBABILITY CONTOURS AND HAZARD INTENSITY ZONES - 6000 M³ EVENT SCENARIO

PROJECT No.: 1358 001

DWG: G-1

X:\Projects\1358\001\GIS\Production\Report\20140331_REPORT_Catiline_Creek_Debris_Flow_Hazard_and_Risk_Assessment\G1_Interpreted_Runout_Exceedance_Probability_Contours_and_Hazard_Intensity_Zones_6000m3_event_scenario.mxd Date: December 17, 2014 Time: 3:43 PM



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NOTES:

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6. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 20 m.
7. STUDY AREA BOUNDARY IS ILLUSTRATED BY THE CATILINE CREEK APPROXIMATE MODERN FAN BOUNDARY.
8. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
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10. PROJECTION IS UTM NAD 83 ZONE 10.
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DATE:	JAN 2015
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CHECKED:	SDM
APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

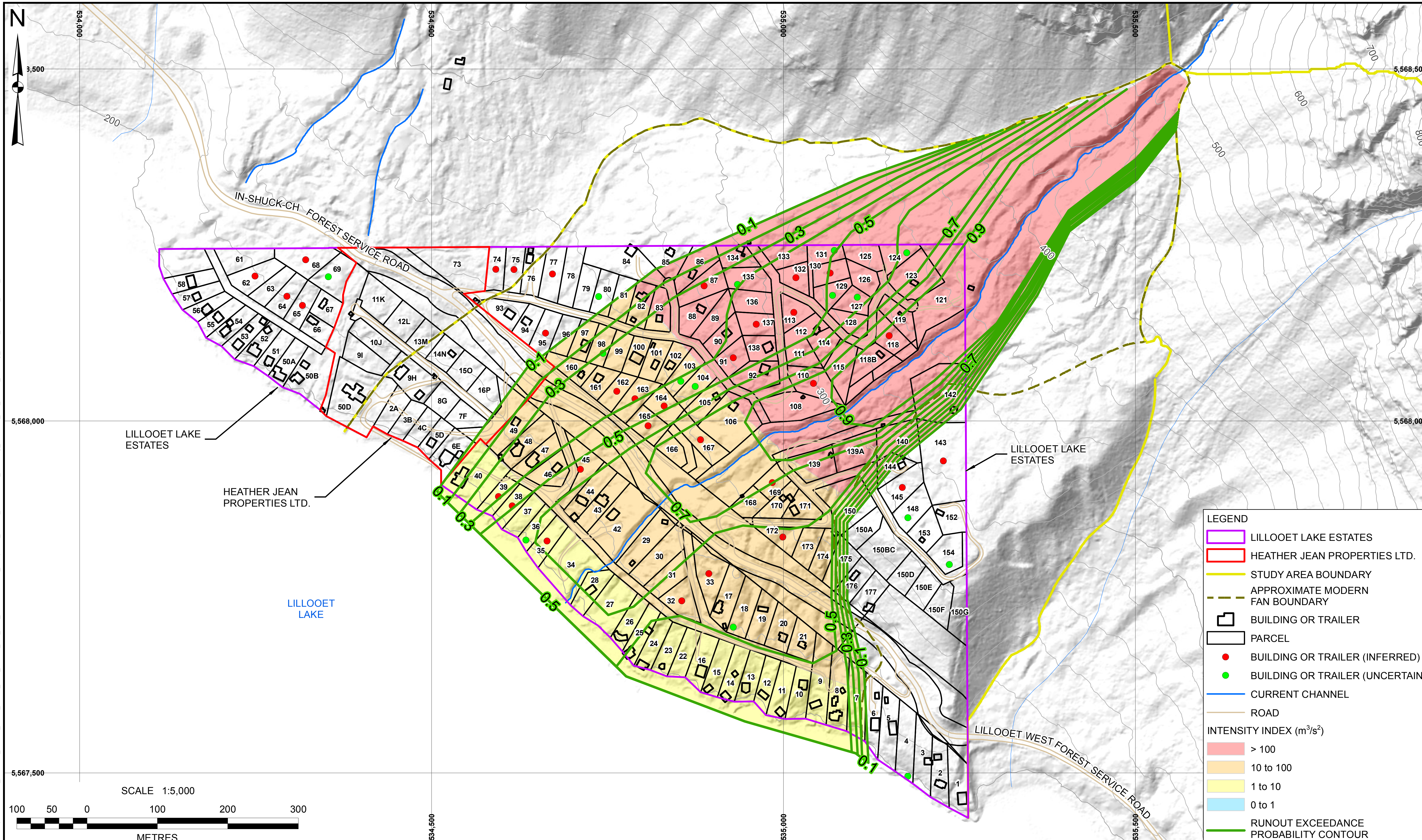
CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
INTERPRETED RUNOUT EXCEEDANCE PROBABILITY CONTOURS AND HAZARD INTENSITY ZONES - 40000 m³ EVENT SCENARIO

PROJECT No.: 1358 001

DWG: G-2



NOTES:

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SCALE:	1:5,000
DATE:	JAN 2015
DRAWN:	LL
CHECKED:	SDM
APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

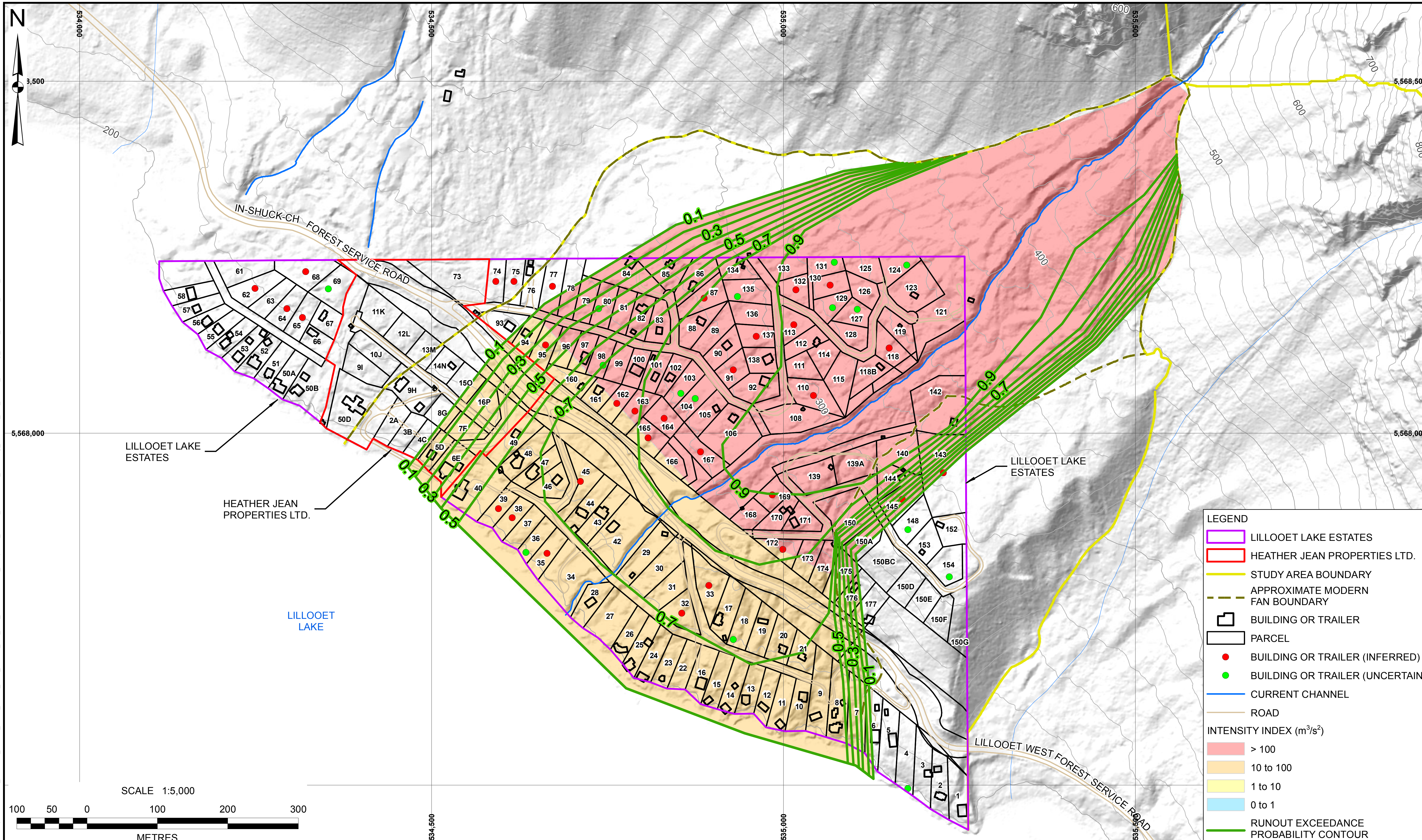
PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: INTERPRETED RUNOUT EXCEEDANCE PROBABILITY CONTOURS AND HAZARD INTENSITY ZONES - 100000 m³ EVENT SCENARIO

PROJECT No.: 1358 001

DWG: G-3

X:\Projects\1358\001\GIS\Production\Report\20140331_REPORT_Catiline_Creek_Debris_Flow_Hazard_and_Risk_Assessment\G3_Interpreted_Runout_Exceedance_Probability_Contours_and_Hazard_Intensity_Zones_100000m3_event_scenario.mxd Date: December 17, 2014 Time: 3:45 PM



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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BUILDING OUTLINES AND ROADS PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. IN AREAS OF TREE COVERAGE ONLY PARTIAL BUILDING OUTLINES COULD BE IDENTIFIED.
4. BUILDING POINTS (UNCERTAIN) WERE DIGITIZED BY BGC IN AREAS OF PARTIAL TREE COVERAGE AND SHOULD BE CONSIDERED APPROXIMATE.
5. BUILDING POINTS (INFERRED) WERE PLACED AT THE CENTROID OF THE LOT AND ARE CASES WHERE NO BUILDING WAS IDENTIFIED, BUT BC ASSESSMENT OR RESIDENT INTERVIEW DATA IMPLIED THAT A BUILDING SHOULD EXIST.
6. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 20 m.
7. STUDY AREA BOUNDARY IS ILLUSTRATED BY THE CATILINE CREEK APPROXIMATE MODERN FAN BOUNDARY.
8. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
9. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
10. PROJECTION IS UTM NAD 83 ZONE 10.
11. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

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APPROVED:	KWH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
INTERPRETED RUNOUT EXCEEDANCE PROBABILITY CONTOURS AND HAZARD INTENSITY ZONES - 300000 m^3 EVENT SCENARIO

PROJECT No.: 1358 001

DWG: G-4

APPENDIX H
COST ESTIMATE TABLES FOR RISK MITIGATION OPTIONS

Table H-1. Conceptual level cost estimate for debris flow risk reduction option 1.

Option 1: Increase Capacity of Existing Channel - Small Upgrade (120 m^2 channel area)

	Item	Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	500	m	$ 60	$ 30,000
3	Clearing, grubbing, & disposal	30,000	m^2	$ 10	$ 300,000
4	Channel excavation	40,000	m^3	$ 20	$ 800,000
5	Fill placement for berm or barrier	40,000	m^3	$ 20	$ 800,000
6	Heavy erosion protection	0	m^2	$ 200	$ -
7	Light erosion protection	0	m^2	$ 100	$ -
8	Barrier outlet structure	0	l.s.	$ -	$ -
9	Bridge construction or replacement (30 m span)	1	l.s.	$ 1,500,000	$ 1,500,000
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 3,500,000**
11	Engineering design & construction support	1	percent	15%	$ 530,000
				ROUNDED TOTAL	**$ 4,000,000**

Option 1: Increase Capacity of Existing Channel - Large Upgrade (300 m^2 channel area)

	Item	Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	500	m	$ 60	$ 30,000
3	Clearing, grubbing, & disposal	50,000	m^2	$ 10	$ 500,000
4	Channel excavation	120,000	m^3	$ 20	$ 2,400,000
5	Fill placement for berm or barrier	120,000	m^3	$ 20	$ 2,400,000
6	Heavy erosion protection	0	m^2	$ 200	$ -
7	Light erosion protection	0	m^2	$ 100	$ -
8	Barrier outlet structure	0	l.s.	$ -	$ -
9	Bridge construction or replacement	1	l.s.	$ 2,500,000	$ 2,500,000
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 7,900,000**
11	Engineering design & construction support	1	percent	15%	$ 1,190,000
				ROUNDED TOTAL	**$ 9,100,000**

Table H-2. Conceptual level cost estimate for debris flow risk reduction option 2.

Option 2: Diversion Structure at Fan Apex - Small Channel (120 m^2 channel area)

	Item	Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	1000	m	$ 60	$ 60,000
3	Clearing, grubbing, & disposal	20,000	m^2	$ 10	$ 200,000
4	Channel excavation	40,000	m^3	$ 20	$ 800,000
5	Fill placement for berm or barrier	40,000	m^3	$ 20	$ 800,000
6	Heavy erosion protection	3,000	m^2	$ 200	$ 600,000
7	Light erosion protection	0	m^2	$ 100	$ -
8	Barrier outlet structure	0	l.s.	$ -	$ -
9	Bridge construction or replacement	1	l.s.	$ 1,500,000	$ 1,500,000
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 4,100,000**
11	Engineering design & construction support	1	percent	15%	$ 620,000
				ROUNDED TOTAL	**$ 4,700,000**

Option 2: Diversion Structure at Fan Apex - Large Channel (300 m^2 channel area)

	Item	Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	1000	m	$ 60	$ 60,000
3	Clearing, grubbing, & disposal	35,000	m^2	$ 10	$ 350,000
4	Channel excavation	80,000	m^3	$ 20	$ 1,600,000
5	Fill placement for berm or barrier	80,000	m^3	$ 20	$ 1,600,000
6	Heavy erosion protection	4,000	m^2	$ 200	$ 800,000
7	Light erosion protection	0	m^2	$ 100	$ -
8	Barrier outlet structure	0	l.s.	$ -	$ -
9	Bridge construction or replacement	1	l.s.	$ 2,500,000	$ 2,500,000
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 7,000,000**
11	Engineering design & construction support	1	percent	15%	$ 1,050,000
				ROUNDED TOTAL	**$ 8,100,000**

Table H-3. Conceptual level cost estimate for debris flow risk reduction option 3.

Option 3: Retention Barrier at Fan Apex - Small Barrier (100,000 m^3 storage volume)					
Item		Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	1000	m	$ 60	$ 60,000
3	Clearing, grubbing, & disposal	50,000	m^2	$ 10	$ 500,000
4	Channel excavation	0	m^3	$ 20	$ -
5	Fill placement for berm or barrier	420,000	m^3	$ 25	$ 10,500,000
6	Heavy erosion protection	5,000	m^2	$ 200	$ 1,000,000
7	Light erosion protection	4,500	m^2	$ 100	$ 450,000
8	Barrier outlet structure	1	l.s.	$ 3,000,000	$ 3,000,000
9	Bridge construction or replacement	0	l.s.	$ -	$ -
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 15,600,000**
11	Engineering design & construction support	1	percent	15%	$ 2,340,000
				ROUNDED TOTAL	**$17,900,000**

Option 3: Retention Barrier at Fan Apex - Large Barrier (300,000 m^3 storage volume)					
Item		Quantity	Unit	Unit Cost	Item Total Cost
1	Mobilization & demobilization	1	l.s.	$ 100,000	$ 100,000
2	Access road construction	1000	m	$ 60	$ 60,000
3	Clearing, grubbing, & disposal	50,000	m^2	$ 10	$ 500,000
4	Channel excavation	0	m^3	$ 20	$ -
5	Fill placement for berm or barrier	720,000	m^3	$ 25	$ 18,000,000
6	Heavy erosion protection	7,500	m^2	$ 200	$ 1,500,000
7	Light erosion protection	9,000	m^2	$ 100	$ 900,000
8	Barrier outlet structure	1	l.s.	$ 6,000,000	$ 6,000,000
9	Bridge construction or replacement	0	l.s.	$ -	$ -
10	Property acquisition	0	each	$ -	$ -
				ROUNDED SUBTOTAL	**$ 27,100,000**
11	Engineering design & construction support	1	percent	15%	$ 4,070,000
				ROUNDED TOTAL	**$31,200,000**

APPENDIX I
RISK TOLERANCE CRITERIA

I.1. Introduction

No legislation currently exists in Canada to define what level of landslide risk should be tolerated by government, except within the District of North Vancouver (DNV), where thresholds for tolerable risk to individuals[1] in existing and proposed new developments were formally adopted in 2009 (DNV 2009).

Instead, land-use decisions in areas with recognized geologic hazards have historically been made by considering hazard frequency only. The decisions have not been based on a consideration of risk, which includes both hazard and consequences.

Porter and Morgenstern (2013) review general principles and approaches of evaluating different measures of landslide risk in Canada, including a summary of published landslide safety criteria. BGC recommends this report as the most complete Canadian reference currently available on this topic. Based on their review, Porter and Morgenstern suggest one or more of the following criteria as appropriate for proposed new residential development:

- <1:10,000 per annum probability for a landslide occurring and reaching the area of proposed development
- <1:100,000 per annum risk of loss of life to individuals most at risk
- group or societal risk of loss of life evaluated on an F-N curve, with the ALARP or broadly acceptable regions as the landslide safety criteria
- tolerable slope deformation under seismic loading = 0.15 m (where it can be demonstrated that soils are not prone to earthquake-triggered liquefaction)
- where appropriate, an allowance for 100 years of predicted toe erosion along river, lake, ocean, or reservoir shorelines.

Porter and Morgenstern also suggest that less stringent criteria, that is, risks up to one order of magnitude higher, may be appropriate for ongoing occupation of, or the approval of minor modifications to, existing residential development. Greater risks may also be tolerable for employees of organizations with infrastructure exposed to known landslides, provided systematic procedures are followed to understand, prioritize and manage the risks.

This appendix provides specific context on risk reduction decision making in British Columbia and Alberta, including summaries of:

- Risk tolerance criteria in the District of North Vancouver
- Risk tolerance criteria in Canmore, Alberta
- Geohazard risk reduction decisions in British Columbia
- Geohazard risk reduction decisions in Alberta.

[1] Individual risk is expressed as the annual probability of death of the individual most exposed within each home.

I.2. Risk Tolerance Criteria by the District of North Vancouver, British Columbia

Following a 2005 fatal landslide in the District of North Vancouver (DNV), a precedent was set in landslide risk management in British Columbia. In this case, recommendation was made by BGC Engineering Inc. (2006) and summarized in Porter et al. (2007) that the thresholds for individual risk for death due to landslide, be set at an annual probability of 10^{-4} for existing development and 10^{-5} for new development. This individual risk tolerance threshold has been formally adopted by the DNV (2009). Since 2009, these standards have formed the risk basis to design risk reduction measures for Mosquito Creek and Mackay Creek, the latter of which is currently ongoing.

DNV has not yet adopted any formal policy for group risk tolerance. However, informal policy for group risk is that development approvals and building permits must demonstrate that natural hazards risks are reduced to As Low as Reasonably Practicable (ALARP) (DNV, 2009b).

I.3. Risk Tolerance Criteria by the Town of Canmore, British Columbia

Following damaging debris floods in June 2013, the Town of Canmore commissioned several debris-flow and debris-flood risk assessments for mountain creeks within the town boundaries (e.g. BGC 2014a). On an interim basis, Canmore adopted the same risk tolerance standards as the District of North Vancouver as well as group risk tolerance standards based on the “As Low as Reasonably Practicable” (ALARP) principal. BGC understands that these criteria may be formally adopted in 2015, subject to approval by Town Council.

I.4. Geohazard Risk Reduction Decisions in British Columbia

Landslide risks exceeding the DNV and Hong Kong risk tolerance thresholds (GEO 1988) have been identified at several locations in BC. However, to BGC’s knowledge, no commitments have been made yet to reduce the risks to specific levels deemed tolerable with the exception of examples in the DNV. For example, individual and group risks exceeding the DNV and Hong Kong risk tolerance thresholds have been estimated for existing homes located on the Cheekye River fan in Squamish (BGC 2008), along the Lillooet River valley near Pemberton (Friele et al. 2008), Johnson’s Landing (Nicol et al. 2013) and at the Village of Lions Bay (BGC 2013).

Within the DNV, individual and group risks exceeding the DNV and Hong Kong risk tolerance thresholds have been estimated for existing homes located on several separate debris flow fans (BGC 2009). The DNV provides background information on their website[2] to help affected homeowners understand and manage their own geohazard risks. A debris-flow net was constructed on Mosquito Creek in 2013 to reduce risks downstream. On another debris-flow fan, the DNV limits the operation of a children’s camp to summer use only, when the likelihood of a debris flow is relatively low. BGC understands that the DNV is currently in the process of prioritizing possible further risk reduction measures throughout the District. These opportunities sometimes arise when the DNV risk tolerance policies are triggered by applications for new building permits, subdivision approval or development approval.

[2] http://www.dnv.org/article.asp?c=1024

Other quantitative debris-flow risk assessments have been completed or are currently in progress in BC and are summarized in the following sections. However, most of the occupied debris flow fans in the province have not yet been studied with the intention of quantifying the risk of loss of life. It is therefore likely that the cases discussed herein represent only a small sample of the number of homeowners in the province currently living with a level of landslide risk comparable to the risks estimated on Catiline Creek fan.

I.7.1 Risk Reduction Decision Cheekye River Squamish, British Columbia

BGC (2008) completed a debris flow risk assessment for Cheekye River fan. The assessment quantified risks to individuals and groups using the DNV/Hong Kong risk tolerance criteria. The Province of BC, the Squamish Nation, and the District of Squamish convened an expert panel to review previous work on the Cheekye River fan and provide and opinion on possible future landslides on the fan. The expert panel recommended a design mitigation event corresponding to the upper uncertainty bound of the estimated 1:10,000-year landslide volume. Furthermore, the expert panel recommended that whether or not there is future development on the fan, existing risk must be mitigated after assessing a range of mitigation alternatives (CRP 2014). While no formal commitments have been made yet to reduce the risks to specific levels deemed tolerable, detailed mitigation design work on behalf of a private developer is ongoing.

I.7.2 Mount Meager, Lillooet River Valley, British Columbia

Friele et al. (2008) quantified the risk from large landslide hazards from the Mount Meager Volcanic Complex located approximately 65 km northwest from Pemberton, British Columbia. The calculated risk to individuals and groups in the Lillooet River valley exceeds risk tolerance thresholds established by DNV/Hong Kong. To BGC's knowledge, no commitments have been made yet to reduce the risks to specific levels deemed tolerable.

I.7.3 Risk Reduction Decision Fairmont Creek, Regional District of East Kootenay, British Columbia

Following a 2012 debris flow on Fairmont Creek fan the Regional District of East Kootenay (RDEK) and the Ministry of Forests Lands and Natural Resource Operations (MFLNRO) commissioned a debris flow hazard and risk assessment. This study did not directly quantify risk on the fan. Rather, the assessment identified zones of high, moderate, and low risk based on the probability of the occurrence and anticipated impacts (Clarke and Golder, 2013). Several debris flow mitigation measures and a 5 phased[3] approach were proposed to reduce the risk to elements at risk on the fan. Phase 1 of the measures was completed and a funding application to the Building Canada Fund Flood for Phase 2 was submitted (RDEK 2014). If successful the Building Canada Fund would fund two thirds of the project cost. In order to fund the remainder of the project and future operations and maintenance costs, the RDEK has proposed a new bylaw that would expand the flood control service areas of Fairmont Creek and Cold Spring Creek and

[3] Phases 1 and 2 include construction works, while Phases 3, 4 and 5 include long-term studies and monitoring.

change the flood control taxation from a flat tax per parcel to a tax rate based on assessed value (RDEK 2014).

I.7.4 Hummingbird Creek, Swansea Point near Sicamous, British Columbia

Following a 1997 debris flow event, a quantitative partial risk analysis[4] was completed including estimation of the probability of debris floods and debris flows and spatial probability (Singh 2004). No known mitigation occurred following this event or publication of the quantitative partial risk analysis.

Following a 2012 high runoff event, the Province of BC committed $3 million for mitigation works, including replacement of the Hummingbird Creek culver with a clear span bridge (Golder 2013).

I.7.5 Johnson's Landing, Regional District of Central Kootenay, British Columbia

Following a 2012 debris flow that resulted in 4 fatalities, the Regional District of Central Kootenay commissioned a landslide hazard and risk assessment for the community of Johnsons Landing. The study included estimation of group and individual risk over a range of return periods up to the 1:10,000 year event. The quantitative risk analysis showed that individual and group risks exceeding the DNV and Hong Kong risk tolerance thresholds exist at Johnson's Landing. Passive and active mitigation options for mitigation were reviewed and a combination of resident education, land use restrictions, maintaining channel depth at a specific location and establishment of a simple landslide monitoring program were recommended. With regards to risk tolerance criteria, Nicol et al. (2013) made the following recommendation: "*Establish uniform and consistent landslide risk tolerance/acceptability criteria to be applied throughout the Regional District for assessment of landslide risk relating to land development, building permitting, and existing residences. The criteria will help avoid potential confusion with respect to what is considered "safe"."* Whether or not these recommendations have been implemented is unknown.

I.7.6 Bayview Creek, Village of Lions Bay, British Columbia

Following identification of a potential debris-flow hazard, BGC carried out a debris flow risk assessment for existing homes on Upper Bayview Road. The assessment identified two properties where individual risk exceeds risk tolerance criteria adopted by the DNV. The group risk plots just inside the tolerable zone when compared with group risk tolerance criteria adopted in Hong Kong BGC (2013). BGC (2013) presented four mitigation options, however the government of BC elected not to pursue risk mitigation work on Upper Bayview Road (BGC 2014).

I.5. Geohazard Risk Reduction Decisions in Alberta

Following the June 2013 flood events in Alberta, the Province of Alberta established a fund to support long-term flood mitigation projects for communities damaged during this event. This followed initial funding to complete emergency repairs and short-term mitigation measures for damaged areas.

[4] A quantitative partial risk analysis does not consider the number of elements at risk (population) or vulnerability.

The Town of Canmore and neighboring Municipal District of Bighorn contain numerous communities affected in 2013. These local jurisdictions commissioned BGC to complete debris-flow and debris-flood risk and mitigation options assessments for approximately 10 communities affected by the 2013 event. The risk assessment framework for these studies was similar to that used to assess Catiline Creek debris-flow risk.

The cost of the assessments was shared between local and provincial jurisdictions, with the provincial government funding most of the cost. In all cases, the studies supported applications to the province to complete design and construction of long-term mitigation measures.

The estimated costs of long-term mitigation for the Canmore and Bighorn studies, which are comparable in scale to Catiline Creek, range from about $15M[5] to $40M. No mitigation work has yet been formally approved.

In addition to the above studies, the Province of Alberta has also commissioned BGC to complete provincial-scale studies to identify and prioritize mountain creek fans that could potentially affect communities and highways in future. These studies may lead to additional detailed assessments on higher priority creeks.

[5] M refers to millions.

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APPENDIX J
LIST OF INDIVIDUAL RISK RESULTS

Table J-1. List of lots exceeding risk tolerance criteria.

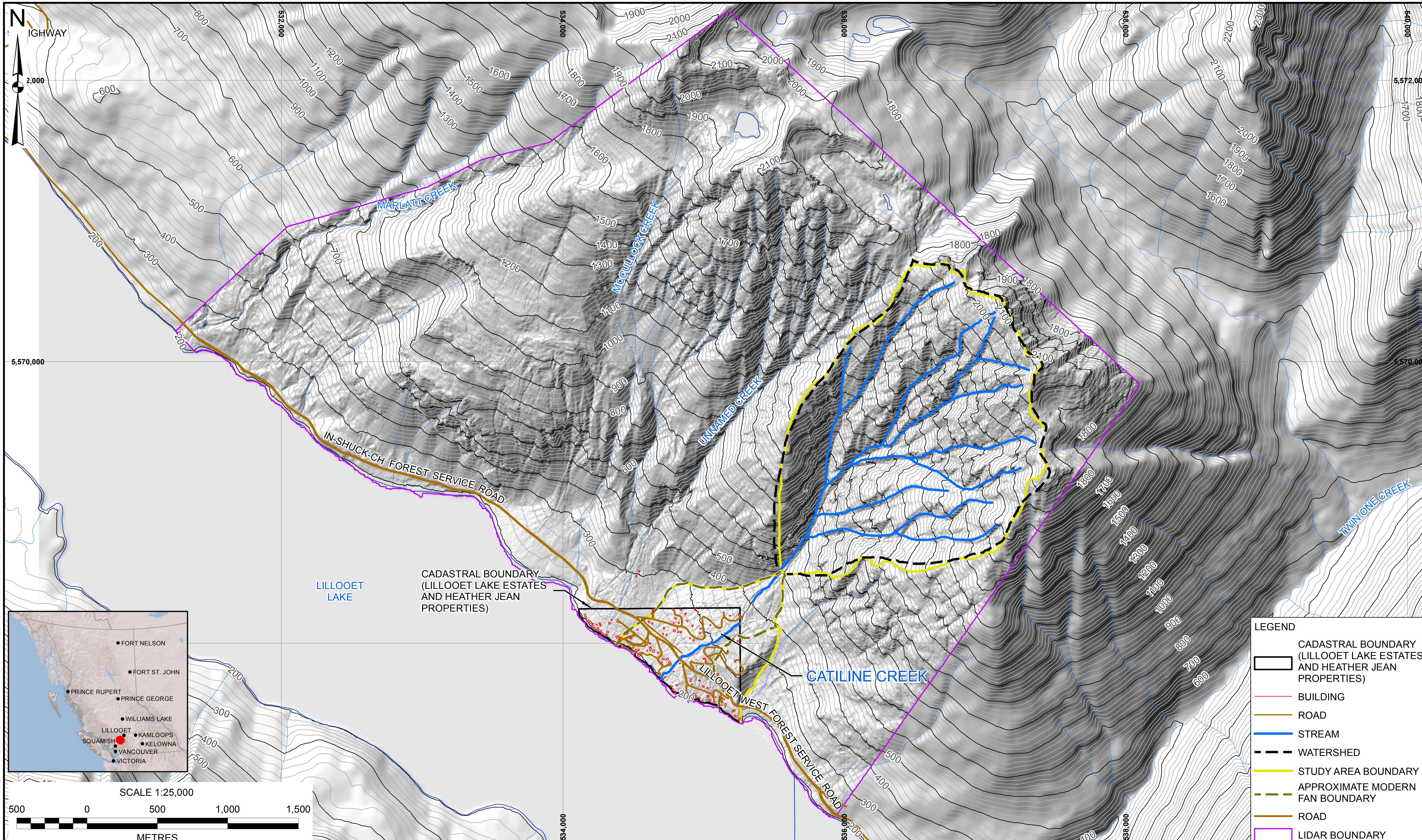
Unique ID	Lot	Lot Type	Occupancy Classification	PDI (Best-Estimate)	PDI Category
0	1	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
1	0	ROAD	NOT OCCUPIED		n/a
2	0	ROAD	NOT OCCUPIED		n/a
3	2	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
4	0	ROAD	NOT OCCUPIED		n/a
5	0	ROAD	NOT OCCUPIED		n/a
6	0	ROAD	NOT OCCUPIED		n/a
7	3	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
8	0	ROAD	NOT OCCUPIED		n/a
9	4	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
10	0	ROAD	NOT OCCUPIED		n/a
11	5	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
12	6	RESIDENTIAL	OCCUPIED	1.4E-05	Annual PDI > 1:100,000
13	7	RESIDENTIAL	NOT OCCUPIED	1.9E-04	Annual PDI > 1:10,000
14	8	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
15	9	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
16	11	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
17	12	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
18	13	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
19	14	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
20	10	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
21	15	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
22	16	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
23	22	RESIDENTIAL	NOT OCCUPIED	2.1E-04	Annual PDI > 1:10,000
24	23	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
25	24	RESIDENTIAL	OCCUPIED	2.1E-04	Annual PDI > 1:10,000
26	25	RESIDENTIAL	OCCUPIED	2.7E-04	Annual PDI > 1:10,000
27	26	RESIDENTIAL	OCCUPIED	2.7E-04	Annual PDI > 1:10,000
28	27	RESIDENTIAL	NOT OCCUPIED	1.1E-03	Annual PDI > 1:1,000
29	28	RESIDENTIAL	OCCUPIED	1.1E-03	Annual PDI > 1:1,000
30	0	ROAD	NOT OCCUPIED		n/a
31	21	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
32	20	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
33	19	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
34	18	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
35	17	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
36	0	ROAD	NOT OCCUPIED		n/a
37	0	ROAD	NOT OCCUPIED		n/a
38	0	ROAD	NOT OCCUPIED		n/a
39	33	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
40	32	RESIDENTIAL	OCCUPIED	3.6E-04	Annual PDI > 1:10,000
41	31	RESIDENTIAL	NOT OCCUPIED	3.6E-04	Annual PDI > 1:10,000
42	30	RESIDENTIAL	NOT OCCUPIED	4.4E-04	Annual PDI > 1:10,000
43	42	RESIDENTIAL	OCCUPIED	1.3E-03	Annual PDI > 1:1,000
44	0	ROAD	NOT OCCUPIED		n/a
45	0	ROAD	NOT OCCUPIED		n/a
46	43	RESIDENTIAL	OCCUPIED	3.8E-04	Annual PDI > 1:10,000
47	0	ROAD	NOT OCCUPIED		n/a
48	44	RESIDENTIAL	OCCUPIED	3.5E-04	Annual PDI > 1:10,000
49	45	RESIDENTIAL	OCCUPIED	2.9E-04	Annual PDI > 1:10,000
50	0	ROAD	NOT OCCUPIED		n/a
51	37	RESIDENTIAL	NOT OCCUPIED	2.0E-04	Annual PDI > 1:10,000
52	36	RESIDENTIAL	OCCUPIED	2.3E-04	Annual PDI > 1:10,000
53	35	RESIDENTIAL	OCCUPIED	2.3E-04	Annual PDI > 1:10,000
54	34	RESIDENTIAL	NOT OCCUPIED	1.1E-03	Annual PDI > 1:1,000
55	38	RESIDENTIAL	OCCUPIED	1.6E-04	Annual PDI > 1:10,000

Unique ID	Lot	Lot Type	Occupancy Classification	PDI (Best-Estimate)	PDI Category
56	39	RESIDENTIAL	OCCUPIED	8.7E-05	Annual PDI > 1:100,000
57	40	RESIDENTIAL	OCCUPIED	7.3E-05	Annual PDI > 1:100,000
58	6E	RESIDENTIAL	OCCUPIED	2.4E-05	Annual PDI > 1:100,000
59	5D	RESIDENTIAL	OCCUPIED	1.0E-05	Annual PDI <= 1:100,000
60	4C	RESIDENTIAL	NOT OCCUPIED	5.0E-06	Annual PDI <= 1:100,000
61	3B	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
62	2A	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
63	50B	RESIDENTIAL	OCCUPIED		Not in Study Area
64	51	RESIDENTIAL	OCCUPIED		Not in Study Area
65	52	RESIDENTIAL	OCCUPIED		Not in Study Area
66	53	RESIDENTIAL	OCCUPIED		Not in Study Area
67	54	RESIDENTIAL	OCCUPIED		Not in Study Area
68	55	RESIDENTIAL	OCCUPIED		Not in Study Area
69	56	RESIDENTIAL	OCCUPIED		Not in Study Area
70	57	RESIDENTIAL	OCCUPIED		Not in Study Area
71	58	RESIDENTIAL	OCCUPIED		Not in Study Area
72	62	RESIDENTIAL	OCCUPIED		Not in Study Area
73	61	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
74	63	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
75	64	RESIDENTIAL	OCCUPIED		Not in Study Area
76	65	RESIDENTIAL	OCCUPIED		Not in Study Area
77	67	RESIDENTIAL	OCCUPIED		Not in Study Area
78	66	RESIDENTIAL	OCCUPIED		Not in Study Area
79	0	ROAD	NOT OCCUPIED		n/a
80	68	RESIDENTIAL	OCCUPIED		Not in Study Area
81	0	ROAD	NOT OCCUPIED		n/a
82	0	ROAD	NOT OCCUPIED		n/a
83	69	RESIDENTIAL	OCCUPIED		Not in Study Area
84	0	R/W	NOT OCCUPIED		n/a
85	0	UNASSIGNED	NOT OCCUPIED		n/a
86	49	RESIDENTIAL	OCCUPIED	7.9E-05	Annual PDI > 1:100,000
87	0	ROAD	NOT OCCUPIED		n/a
88	48	RESIDENTIAL	OCCUPIED	8.4E-05	Annual PDI > 1:100,000
89	47	RESIDENTIAL	OCCUPIED	1.7E-04	Annual PDI > 1:10,000
90	46	RESIDENTIAL	OCCUPIED	2.3E-04	Annual PDI > 1:10,000
91	175	RESIDENTIAL	NOT OCCUPIED	7.2E-04	Annual PDI > 1:10,000
92	176	RESIDENTIAL	OCCUPIED	3.2E-05	Annual PDI > 1:100,000
93	0	ROAD	NOT OCCUPIED		n/a
94	177	RESIDENTIAL	OCCUPIED	5.0E-06	Annual PDI <= 1:100,000
95	0	ROAD	NOT OCCUPIED		n/a
96	174	RESIDENTIAL	OCCUPIED	1.6E-03	Annual PDI > 1:1,000
97	173	RESIDENTIAL	NOT OCCUPIED	1.6E-03	Annual PDI > 1:1,000
98	172	RESIDENTIAL	OCCUPIED	1.6E-03	Annual PDI > 1:1,000
99	150E	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
100	150D	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
101	150F	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
102	150G	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
103	150BC	RESIDENTIAL	NOT OCCUPIED	7.5E-06	Annual PDI <= 1:100,000
104	150A	RESIDENTIAL	NOT OCCUPIED	3.5E-05	Annual PDI > 1:100,000
105	150	RESIDENTIAL	NOT OCCUPIED	2.0E-03	Annual PDI > 1:1,000
106	171	RESIDENTIAL	OCCUPIED	2.0E-03	Annual PDI > 1:1,000
107	170	RESIDENTIAL	OCCUPIED	2.0E-03	Annual PDI > 1:1,000
108	169	RESIDENTIAL	OCCUPIED	2.2E-03	Annual PDI > 1:1,000
109	0	ROAD	NOT OCCUPIED		n/a
110	168	RESIDENTIAL	OCCUPIED	2.0E-03	Annual PDI > 1:1,000
111	154	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
112	153	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios

Unique ID	Lot	Lot Type	Occupancy Classification	PDI (Best-Estimate)	PDI Category
113	152	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
114	148	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
115	0	ROAD	NOT OCCUPIED		n/a
116	139	RESIDENTIAL	OCCUPIED	2.3E-03	Annual PDI > 1:1,000
117	140	RESIDENTIAL	OCCUPIED	2.1E-03	Annual PDI > 1:1,000
118	143	RESIDENTIAL	OCCUPIED	7.8E-05	Annual PDI > 1:100,000
119	144	RESIDENTIAL	OCCUPIED	9.3E-05	Annual PDI > 1:100,000
120	145	RESIDENTIAL	OCCUPIED	7.5E-06	Annual PDI <= 1:100,000
121	0	ROAD	NOT OCCUPIED		n/a
122	139A	RESIDENTIAL	NOT OCCUPIED	2.3E-03	Annual PDI > 1:1,000
123	142	RESIDENTIAL	OCCUPIED	2.7E-03	Annual PDI > 1:1,000
124	0	UNASSIGNED	NOT OCCUPIED		n/a
125	167	RESIDENTIAL	OCCUPIED	1.0E-03	Annual PDI > 1:1,000
126	0	UNASSIGNED	NOT OCCUPIED		n/a
127	106	RESIDENTIAL	OCCUPIED	1.0E-03	Annual PDI > 1:1,000
128	0	GREENBELT	NOT OCCUPIED		n/a
129	0	ROAD	NOT OCCUPIED		n/a
130	166	RESIDENTIAL	NOT OCCUPIED	1.0E-03	Annual PDI > 1:1,000
131	105	RESIDENTIAL	OCCUPIED	6.6E-04	Annual PDI > 1:10,000
132	165	RESIDENTIAL	OCCUPIED	3.8E-04	Annual PDI > 1:10,000
133	164	RESIDENTIAL	OCCUPIED	5.0E-04	Annual PDI > 1:10,000
134	104	RESIDENTIAL	OCCUPIED	5.0E-04	Annual PDI > 1:10,000
135	103	RESIDENTIAL	OCCUPIED	4.8E-04	Annual PDI > 1:10,000
136	163	RESIDENTIAL	OCCUPIED	4.4E-04	Annual PDI > 1:10,000
137	162	RESIDENTIAL	OCCUPIED	2.3E-04	Annual PDI > 1:10,000
138	161	RESIDENTIAL	OCCUPIED	1.5E-04	Annual PDI > 1:10,000
139	160	RESIDENTIAL	OCCUPIED	8.4E-05	Annual PDI > 1:100,000
140	97	RESIDENTIAL	OCCUPIED	6.5E-05	Annual PDI > 1:100,000
141	98	RESIDENTIAL	OCCUPIED	9.9E-05	Annual PDI > 1:100,000
142	99	RESIDENTIAL	NOT OCCUPIED	2.2E-04	Annual PDI > 1:10,000
143	100	RESIDENTIAL	OCCUPIED	2.6E-04	Annual PDI > 1:10,000
144	101	RESIDENTIAL	OCCUPIED	3.5E-04	Annual PDI > 1:10,000
145	102	RESIDENTIAL	OCCUPIED	4.4E-04	Annual PDI > 1:10,000
146	96	RESIDENTIAL	NOT OCCUPIED	4.7E-05	Annual PDI > 1:100,000
147	95	RESIDENTIAL	OCCUPIED	4.2E-05	Annual PDI > 1:100,000
148	94	RESIDENTIAL	OCCUPIED	1.0E-05	Annual PDI <= 1:100,000
149	0	ROAD	NOT OCCUPIED		n/a
150	0	ROAD	NOT OCCUPIED		n/a
151	93	RESIDENTIAL	OCCUPIED	5.0E-06	Annual PDI <= 1:100,000
152	121	RESIDENTIAL	NOT OCCUPIED	1.1E-03	Annual PDI > 1:1,000
153	123	RESIDENTIAL	OCCUPIED	8.9E-04	Annual PDI > 1:10,000
154	119	RESIDENTIAL	OCCUPIED	1.0E-03	Annual PDI > 1:1,000
155	0	GREENBELT	NOT OCCUPIED		n/a
156	0	GREENBELT	NOT OCCUPIED		n/a
157	0	GREENBELT	NOT OCCUPIED		n/a
159	0	GREENBELT	NOT OCCUPIED		n/a
160	115	RESIDENTIAL	NOT OCCUPIED	1.1E-03	Annual PDI > 1:1,000
161	114	RESIDENTIAL	NOT OCCUPIED	7.7E-04	Annual PDI > 1:10,000
162	111	RESIDENTIAL	NOT OCCUPIED	7.3E-04	Annual PDI > 1:10,000
163	110	RESIDENTIAL	OCCUPIED	1.1E-03	Annual PDI > 1:1,000
164	108	RESIDENTIAL	OCCUPIED	1.2E-03	Annual PDI > 1:1,000
165	92	RESIDENTIAL	OCCUPIED	7.2E-04	Annual PDI > 1:10,000
166	138	RESIDENTIAL	OCCUPIED	6.5E-04	Annual PDI > 1:10,000
167	125	RESIDENTIAL	NOT OCCUPIED	7.3E-04	Annual PDI > 1:10,000
168	124	RESIDENTIAL	OCCUPIED	8.2E-04	Annual PDI > 1:10,000
169	126	RESIDENTIAL	NOT OCCUPIED	7.3E-04	Annual PDI > 1:10,000
170	130	RESIDENTIAL	OCCUPIED	7.3E-04	Annual PDI > 1:10,000

Unique ID	Lot	Lot Type	Occupancy Classification	PDI (Best-Estimate)	PDI Category
171	129	RESIDENTIAL	OCCUPIED	7.3E-04	Annual PDI > 1:10,000
172	127	RESIDENTIAL	OCCUPIED	7.3E-04	Annual PDI > 1:10,000
173	0	ROAD	NOT OCCUPIED		n/a
174	128	RESIDENTIAL	NOT OCCUPIED	7.7E-04	Annual PDI > 1:10,000
175	112	RESIDENTIAL	OCCUPIED	6.9E-04	Annual PDI > 1:10,000
176	113	RESIDENTIAL	OCCUPIED	6.6E-04	Annual PDI > 1:10,000
177	132	RESIDENTIAL	OCCUPIED	5.3E-04	Annual PDI > 1:10,000
178	133	RESIDENTIAL	NOT OCCUPIED	4.4E-04	Annual PDI > 1:10,000
179	131	RESIDENTIAL	OCCUPIED	5.3E-04	Annual PDI > 1:10,000
180	85	RESIDENTIAL	OCCUPIED	7.1E-05	Annual PDI > 1:100,000
181	86	RESIDENTIAL	OCCUPIED	8.6E-05	Annual PDI > 1:100,000
182	87	RESIDENTIAL	OCCUPIED	2.6E-04	Annual PDI > 1:10,000
183	88	RESIDENTIAL	OCCUPIED	3.9E-04	Annual PDI > 1:10,000
184	89	RESIDENTIAL	NOT OCCUPIED	4.8E-04	Annual PDI > 1:10,000
185	90	RESIDENTIAL	OCCUPIED	5.2E-04	Annual PDI > 1:10,000
186	91	RESIDENTIAL	OCCUPIED	5.6E-04	Annual PDI > 1:10,000
187	137	RESIDENTIAL	OCCUPIED	6.5E-04	Annual PDI > 1:10,000
188	136	RESIDENTIAL	NOT OCCUPIED	5.3E-04	Annual PDI > 1:10,000
189	135	RESIDENTIAL	OCCUPIED	3.5E-04	Annual PDI > 1:10,000
190	134	RESIDENTIAL	OCCUPIED	2.3E-04	Annual PDI > 1:10,000
191	82	RESIDENTIAL	OCCUPIED	9.9E-05	Annual PDI > 1:100,000
192	81	RESIDENTIAL	NOT OCCUPIED	6.5E-05	Annual PDI > 1:100,000
193	80	RESIDENTIAL	OCCUPIED	5.7E-05	Annual PDI > 1:100,000
194	79	RESIDENTIAL	NOT OCCUPIED	1.5E-05	Annual PDI > 1:100,000
195	78	RESIDENTIAL	NOT OCCUPIED	7.5E-06	Annual PDI <= 1:100,000
196	77	RESIDENTIAL	OCCUPIED	7.5E-06	Annual PDI <= 1:100,000
197	76	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
198	75	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
199	74	RESIDENTIAL	OCCUPIED		Not in Study Area
200	73	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
201	0	ROAD	NOT OCCUPIED		n/a
202	84	RESIDENTIAL	OCCUPIED	4.8E-05	Annual PDI > 1:100,000
203	83	RESIDENTIAL	OCCUPIED	2.6E-04	Annual PDI > 1:10,000
204	50D	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
205	16P	RESIDENTIAL	NOT OCCUPIED	3.7E-05	Annual PDI > 1:100,000
206	7F	RESIDENTIAL	NOT OCCUPIED	3.7E-05	Annual PDI > 1:100,000
207	8G	RESIDENTIAL	NOT OCCUPIED	5.0E-06	Annual PDI <= 1:100,000
208	9I	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
209	10J	RESIDENTIAL	OCCUPIED		Not in Study Area
210	0	ROAD	NOT OCCUPIED		n/a
211	11K	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
212	12L	RESIDENTIAL	NOT OCCUPIED		Not in Study Area
213	13M	RESIDENTIAL	NOT OCCUPIED		Not Impacted By Scenarios
214	14N	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
215	15O	RESIDENTIAL	NOT OCCUPIED	5.0E-06	Annual PDI <= 1:100,000
216	0	ROAD	NOT OCCUPIED		n/a
217	9H	RESIDENTIAL	OCCUPIED		Not Impacted By Scenarios
218	0	COMMONLOT	NOT OCCUPIED		n/a
219	0	GREENBELT	NOT OCCUPIED		n/a
220	50A	RESIDENTIAL	OCCUPIED		Not in Study Area
221	29	RESIDENTIAL	OCCUPIED	1.3E-03	Annual PDI > 1:1,000
222	0	ROAD	NOT OCCUPIED		n/a
223	118	RESIDENTIAL	OCCUPIED	1.3E-03	Annual PDI > 1:1,000

DRAWINGS



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014, AND CANADIAN DIGITAL ELEVATION DATASET FROM GEOBASE.CA. CONTOUR INTERVAL IS 20 m.
4. STUDY AREA BOUNDARY ILLUSTRATED BY CATILINE CREEK WATERSHED AND FAN BOUNDARIES.
5. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
6. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
7. PROJECTION IS UTM NAD 83 ZONE 10.
8. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:25,000
DATE:	JAN 2015
DRAWN:	LL
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: SITE LOCATION MAP

PROJECT No.: 1358001

DWG: 01

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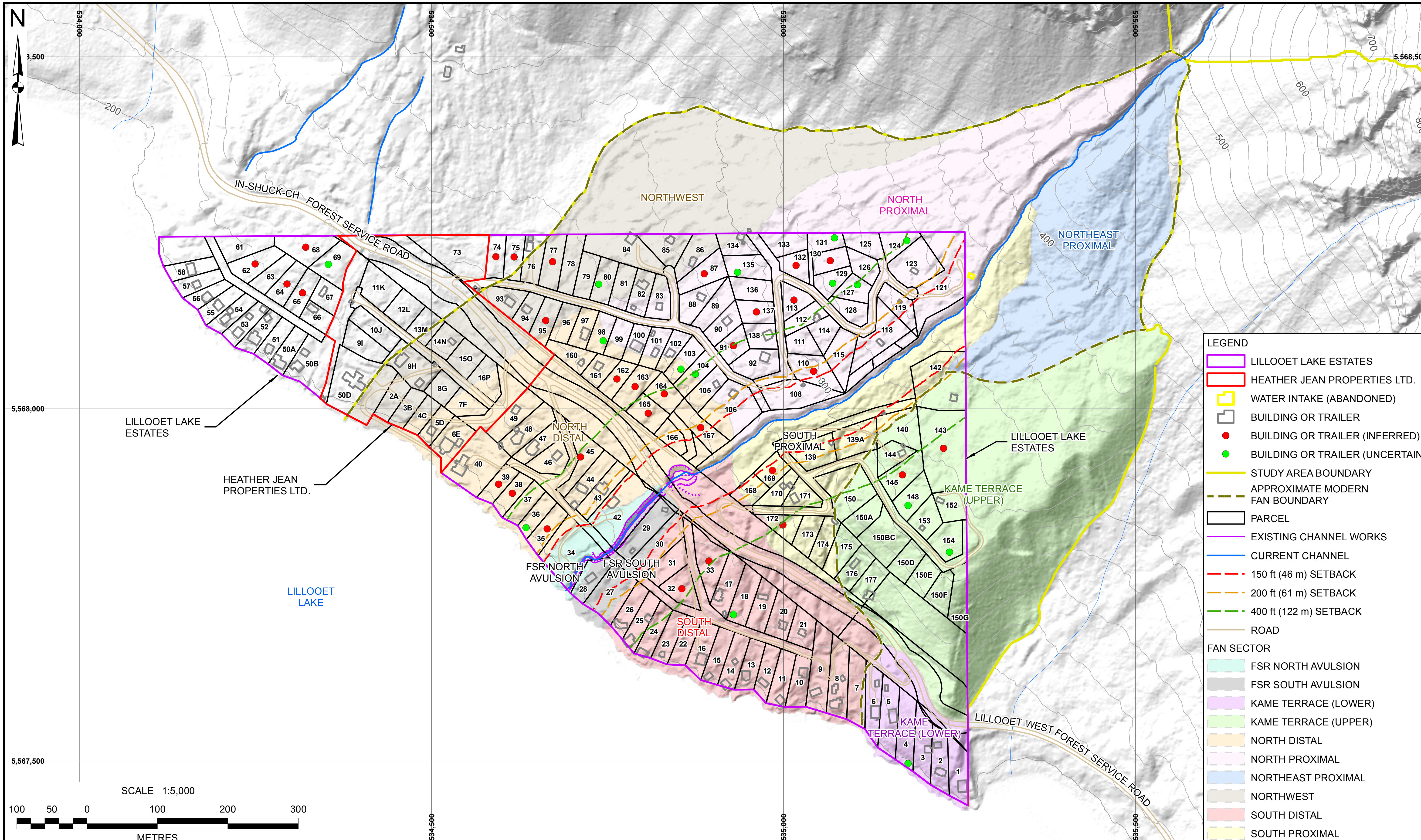

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NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BUILDING OUTLINES AND ROADS PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. IN AREAS OF TREE COVERAGE ONLY PARTIAL BUILDING OUTLINES COULD BE IDENTIFIED.
4. BUILDING POINTS (UNCERTAIN) WERE DIGITIZED BY BGC IN AREAS OF PARTIAL TREE COVERAGE AND SHOULD BE CONSIDERED APPROXIMATE.
5. BUILDING POINTS (INFERRED) WERE PLACED AT THE CENTROID OF THE LOT AND ARE CASES WHERE NO BUILDING WAS IDENTIFIED, BUT BC ASSESSMENT OR RESIDENT INTERVIEW DATA IMPLIED THAT A BUILDING SHOULD EXIST.
6. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 20 m.
7. STUDY AREA BOUNDARY IS ILLUSTRATED BY THE CATILINE CREEK APPROXIMATE MODERN FAN BOUNDARY.
8. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
9. CADASTRAL DATA AND EXISTING CHANNEL WORKS PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
10. SETBACKS SHOWN ON THE MAP WERE CALCULATED FROM THE STREAM CENTRELINE DIGITIZED BY BGC AND MAY DIFFER FROM SETBACKS SHOWN ON PREVIOUS MAPS BY OTHERS.
11. PROJECTION IS UTM NAD 83 ZONE 10.
12. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:5,000
DATE:	JAN 2015
DRAWN:	LL
CHECKED:	SK
APPROVED:	KH

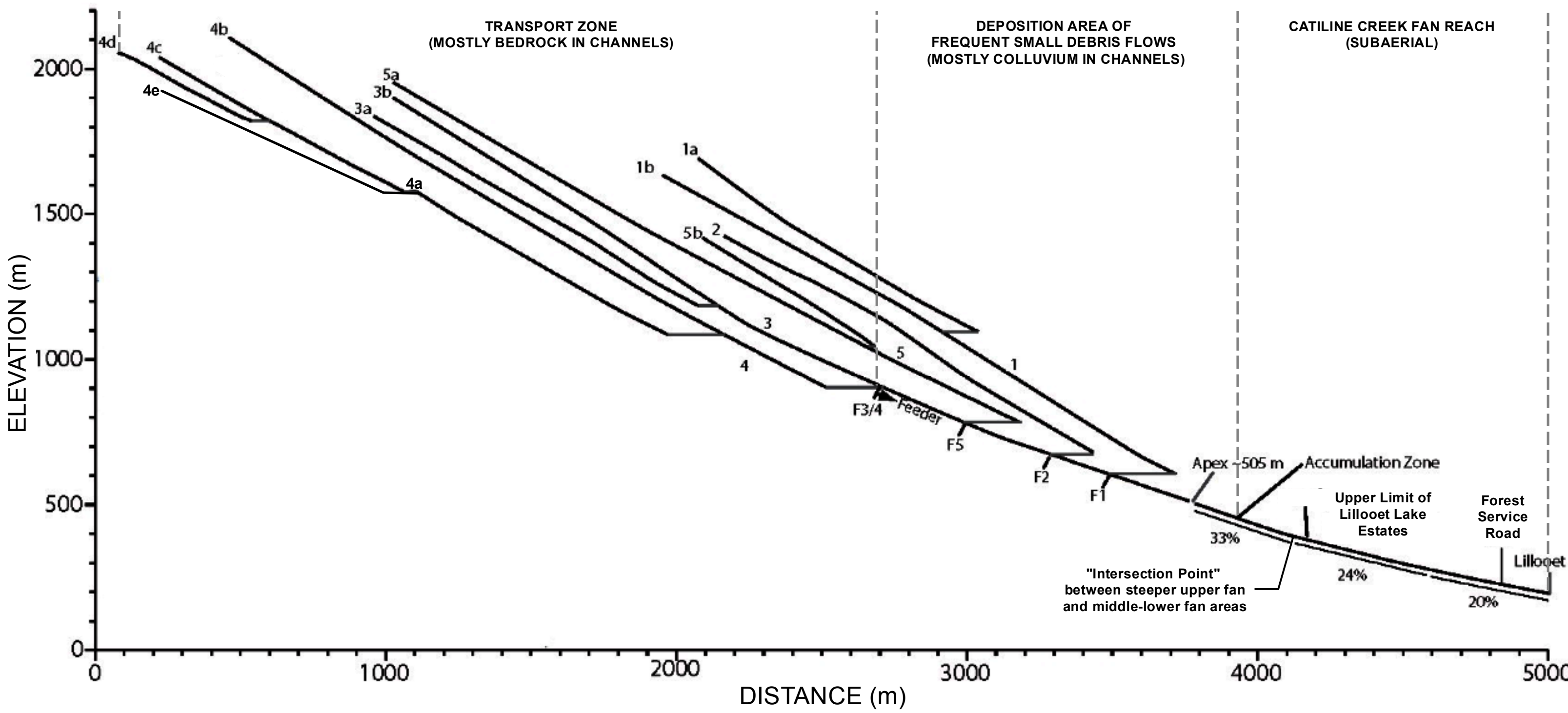
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

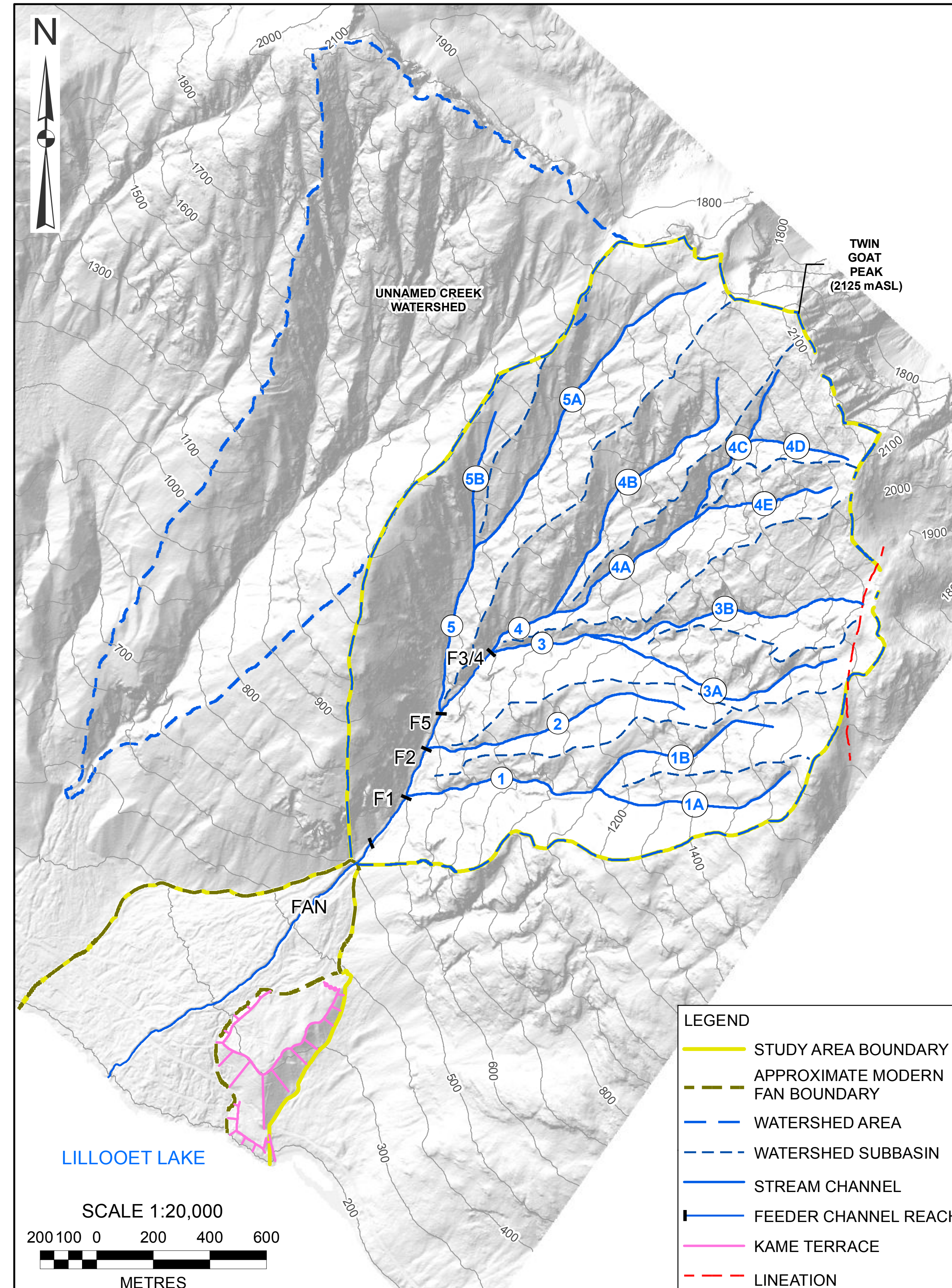
CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
SITE PLAN MAP

PROJECT No.:	DWG:
1358 001	02





NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 100 m.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
5. CHANNEL LABELS ON THE CROSS-SECTION CORRESPOND TO CHANNEL LABELS ON PLAN VIEW MAP.
6. PROJECTION IS UTM NAD 83 ZONE 10.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: 1:20,000	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY	PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT	
DATE: JAN 2015		TITLE: CREEK PROFILES	
DRAWN: PF, LL	CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT	PROJECT No.: 1358 001	03
CHECKED: SK			
APPROVED: KH			

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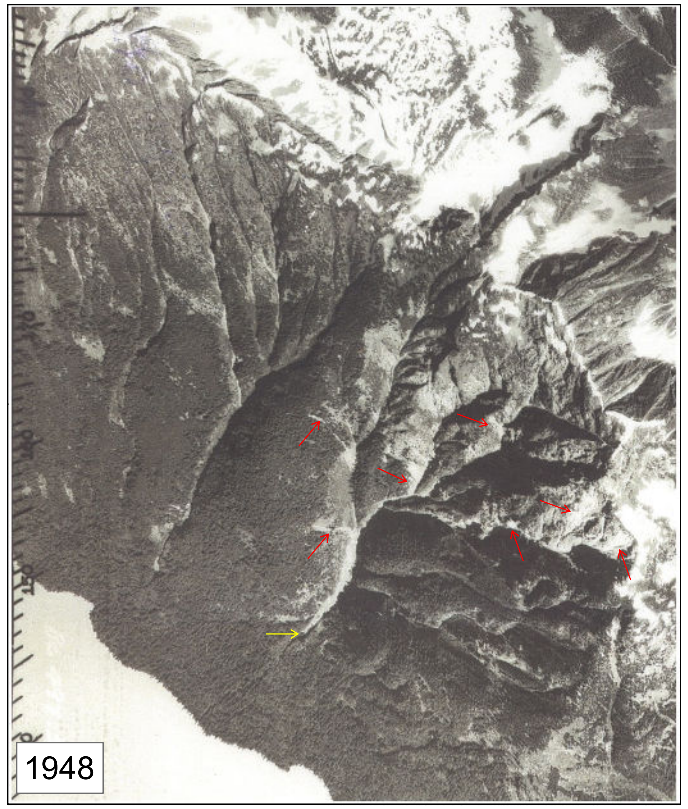

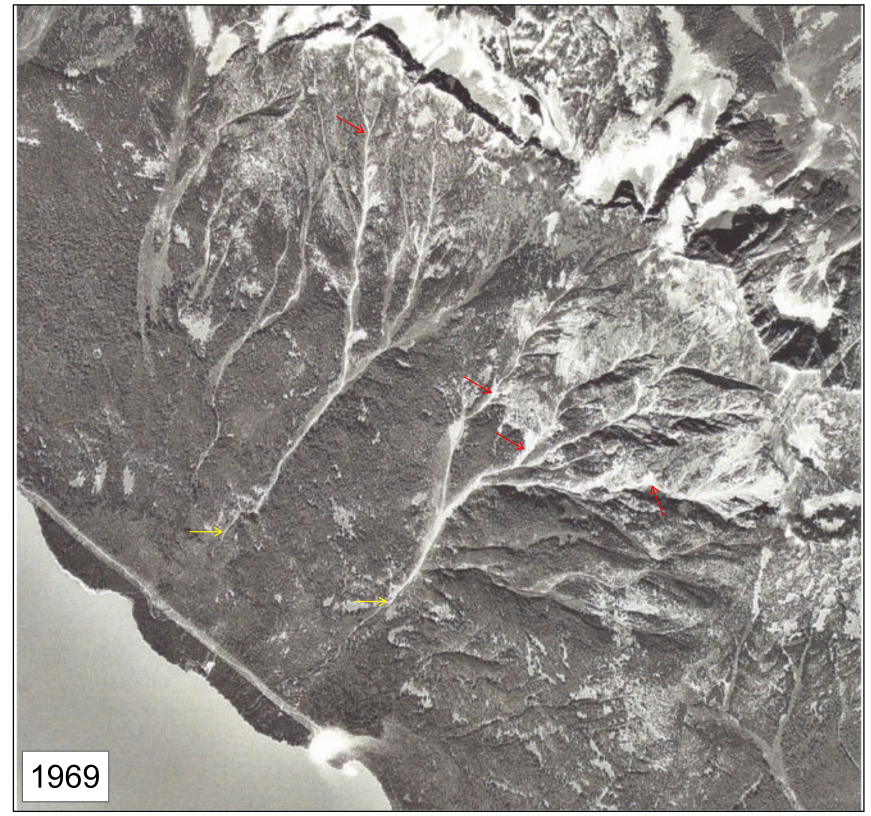

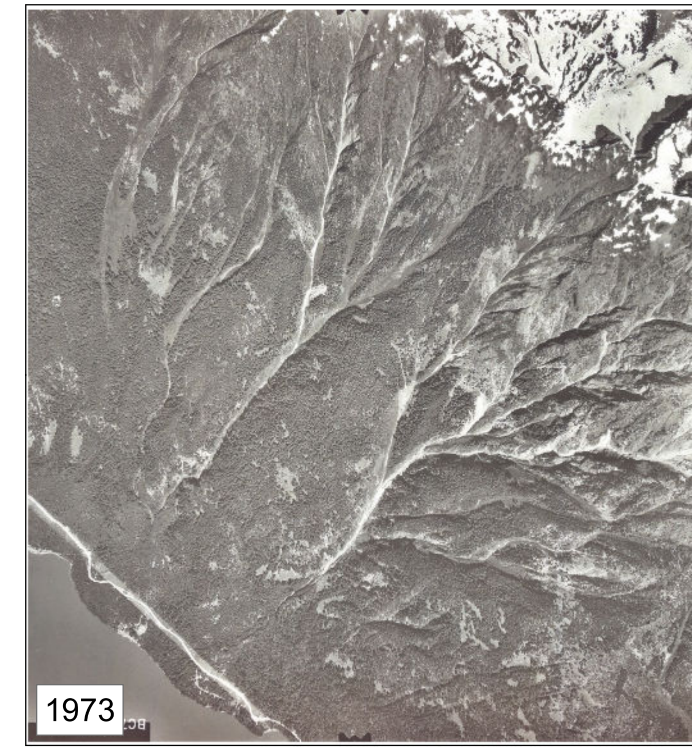

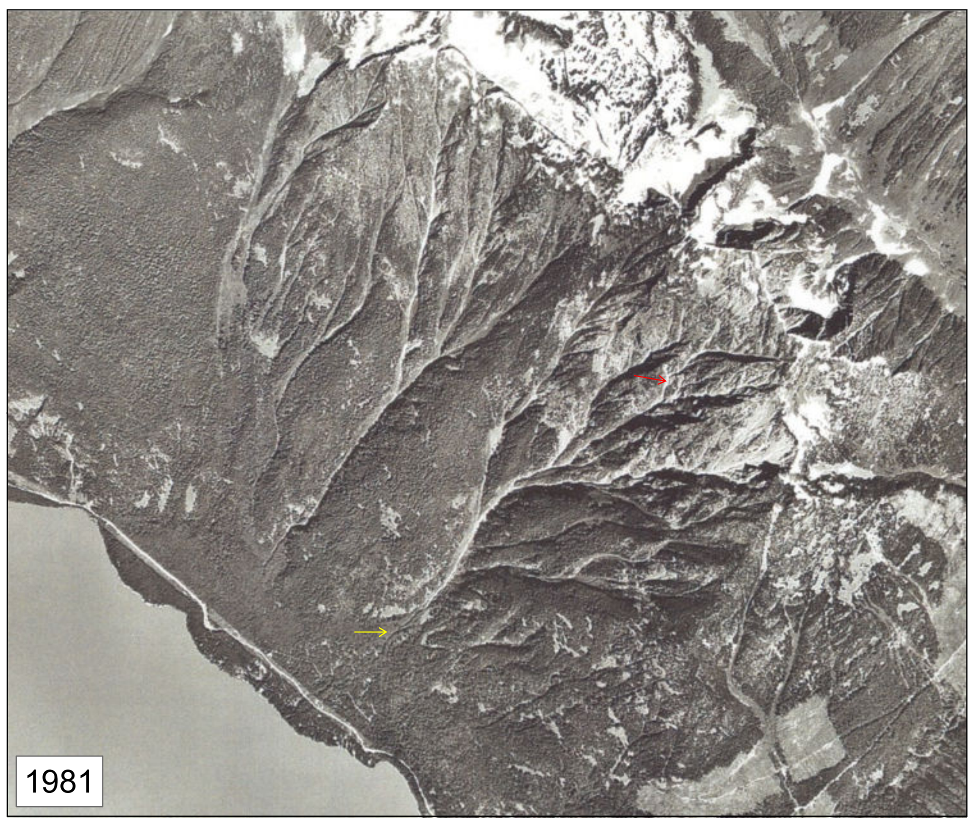

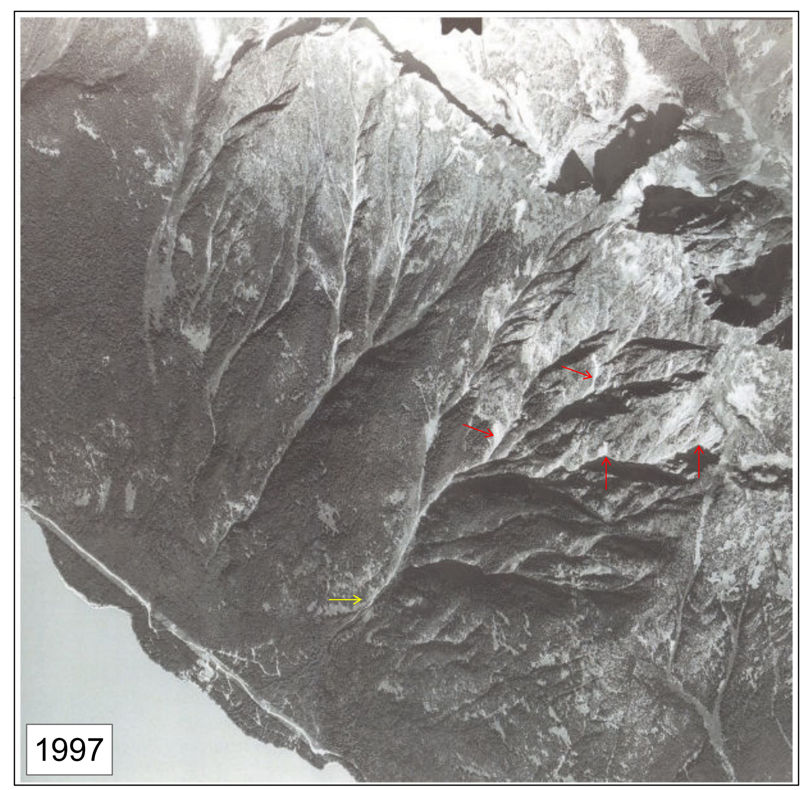

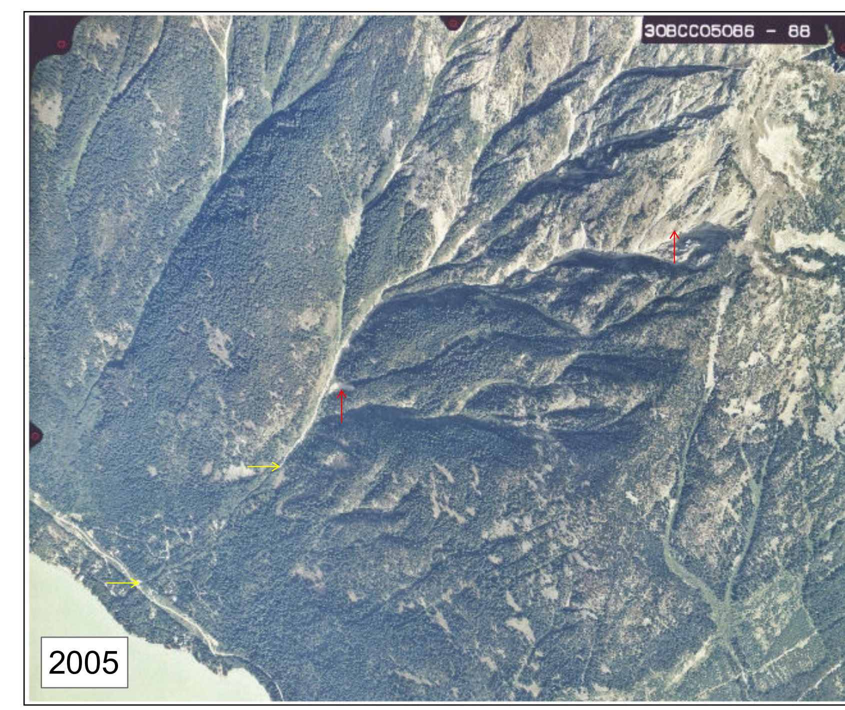

LEGEND

→ INITIATION

→ TOE OF VISIBLE DEPOSITION

NOTES:
1. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
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SCALE:	
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CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
CATILINE CREEK HISTORICAL AIRPHOTO COMPARISON

PROJECT No.:	DWG:
1358001	04

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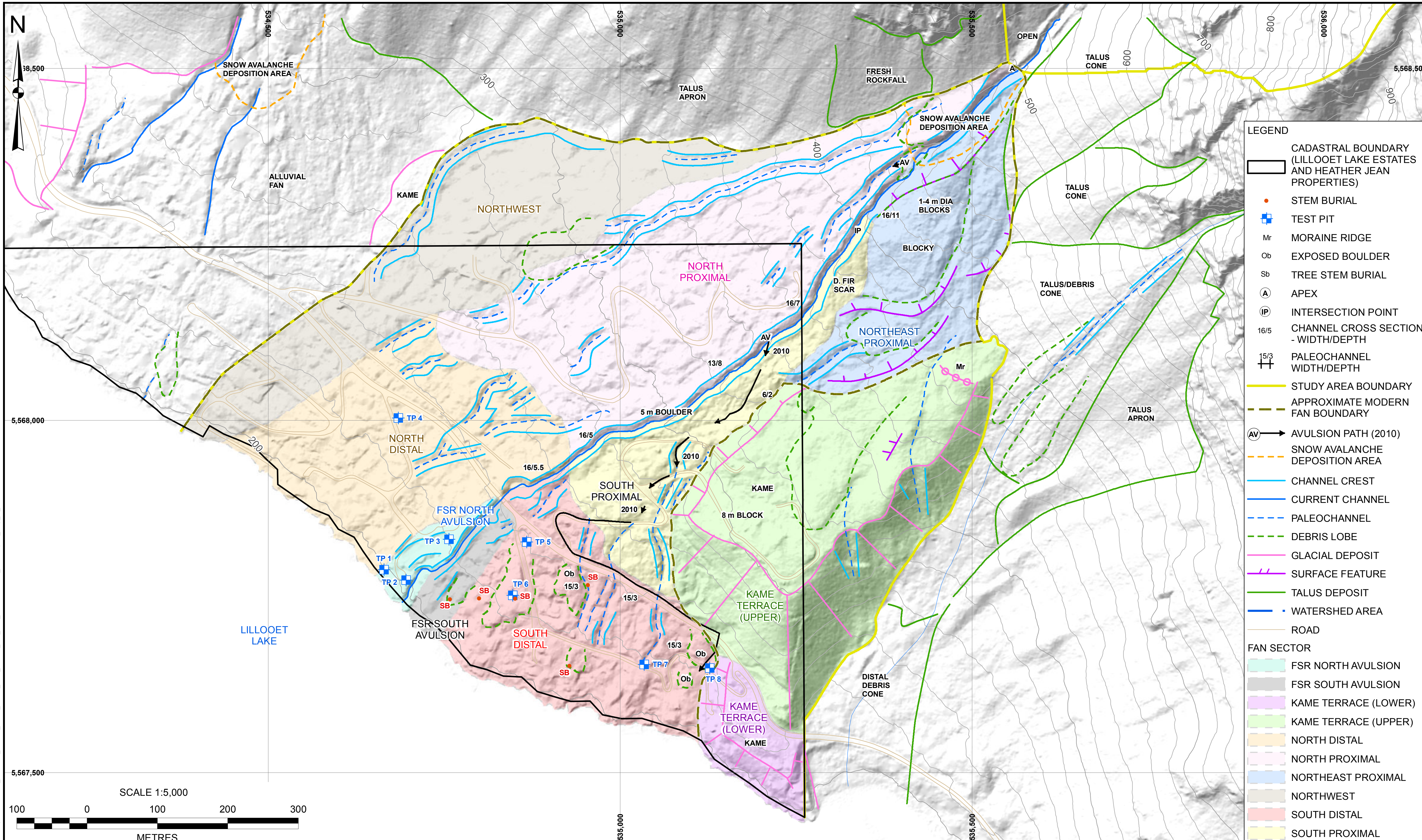

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NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY 2014. CONTOUR INTERVAL IS 20 m.
4. THE STUDY AREA BOUNDARY OF THIS ASSESSMENT ENCOMPASSES CATILINE CREEK BASIN AND FAN. SELECT GEOHAZARDS OUTSIDE THE STUDY AREA ARE SHOWN FOR ILLUSTRATION PURPOSES ONLY AND ARE NOT INCLUDED IN THE ASSESSMENT. ADDITIONAL GEOHAZARDS EXIST OUTSIDE THE STUDY AREA THAT WERE NOT MAPPED. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
5. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
6. PROJECTION IS UTM NAD 83 ZONE 10.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

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DATE:	JAN 2015
DRAWN:	PF, LL
CHECKED:	SK
APPROVED:	KH

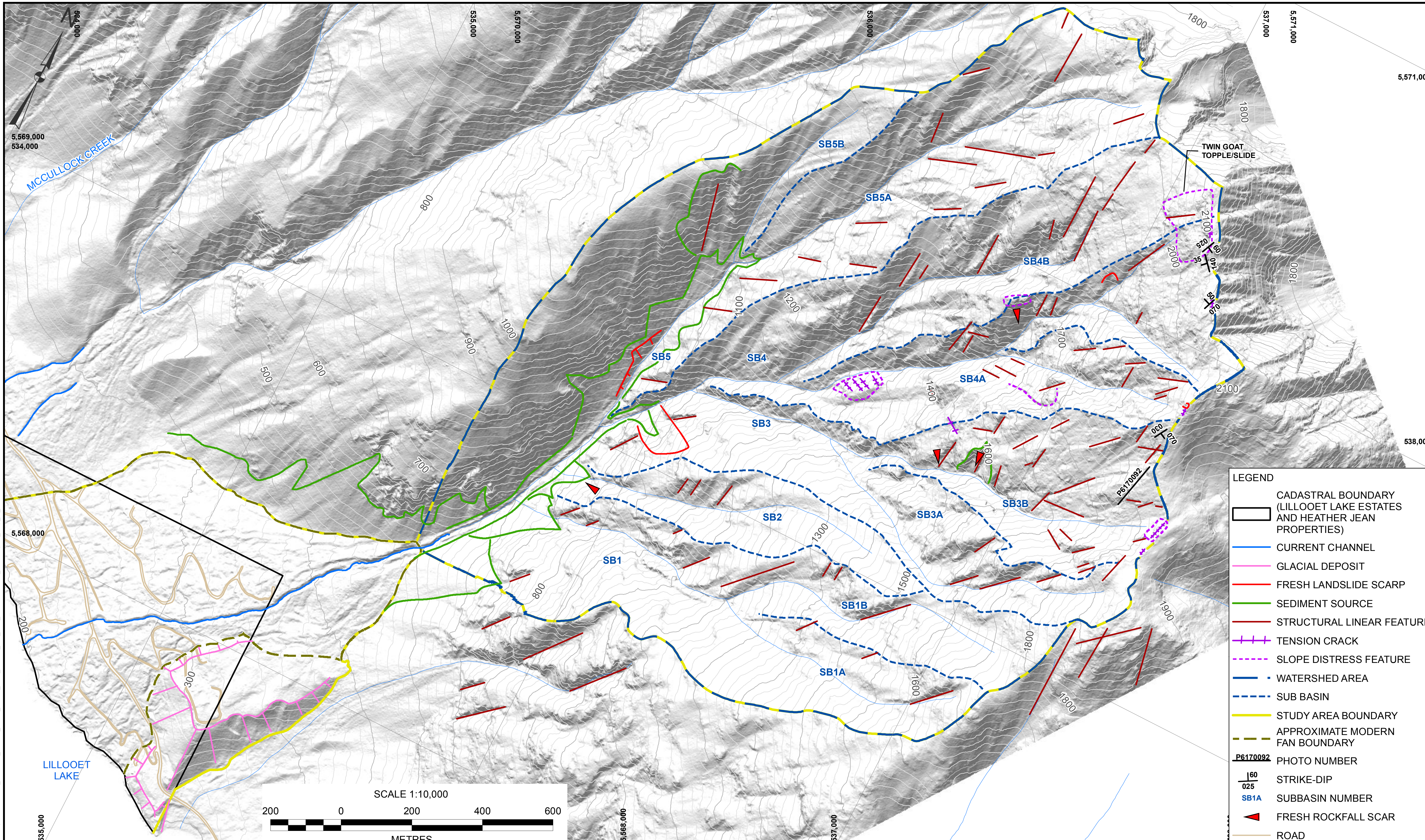
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
GEOMORPHIC MAP OF FAN

PROJECT No.:	DWG:
1358001	05



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3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY 2014. CONTOUR INTERVAL IS 20 m.
4. THE STUDY AREA BOUNDARY OF THIS ASSESSMENT ENCOMPASSES CATILINE CREEK BASIN AND FAN. SELECT GEOHAZARDS OUTSIDE THE STUDY AREA ARE SHOWN FOR ILLUSTRATION PURPOSES ONLY AND ARE NOT INCLUDED IN THE ASSESSMENT. ADDITIONAL GEOHAZARDS EXIST OUTSIDE THE STUDY AREA THAT WERE NOT MAPPED. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
5. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
6. DEBRIS FLOW EVENT DATES AS INFERRED BY DENDROGEOMORPHOLOGY ARE SUBJECT TO UNCERTAINTY AND LIKELY DO NOT INCLUDE ALL THE EVENTS WITHIN THE TIMEFRAME. REFER TO REPORT FOR ADDITIONAL DETAILS.
7. PROJECTION IS UTM NAD 83 ZONE 10.
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CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: GEOMORPHIC MAP OF BASIN

PROJECT No.: 1358001

DWG: 06

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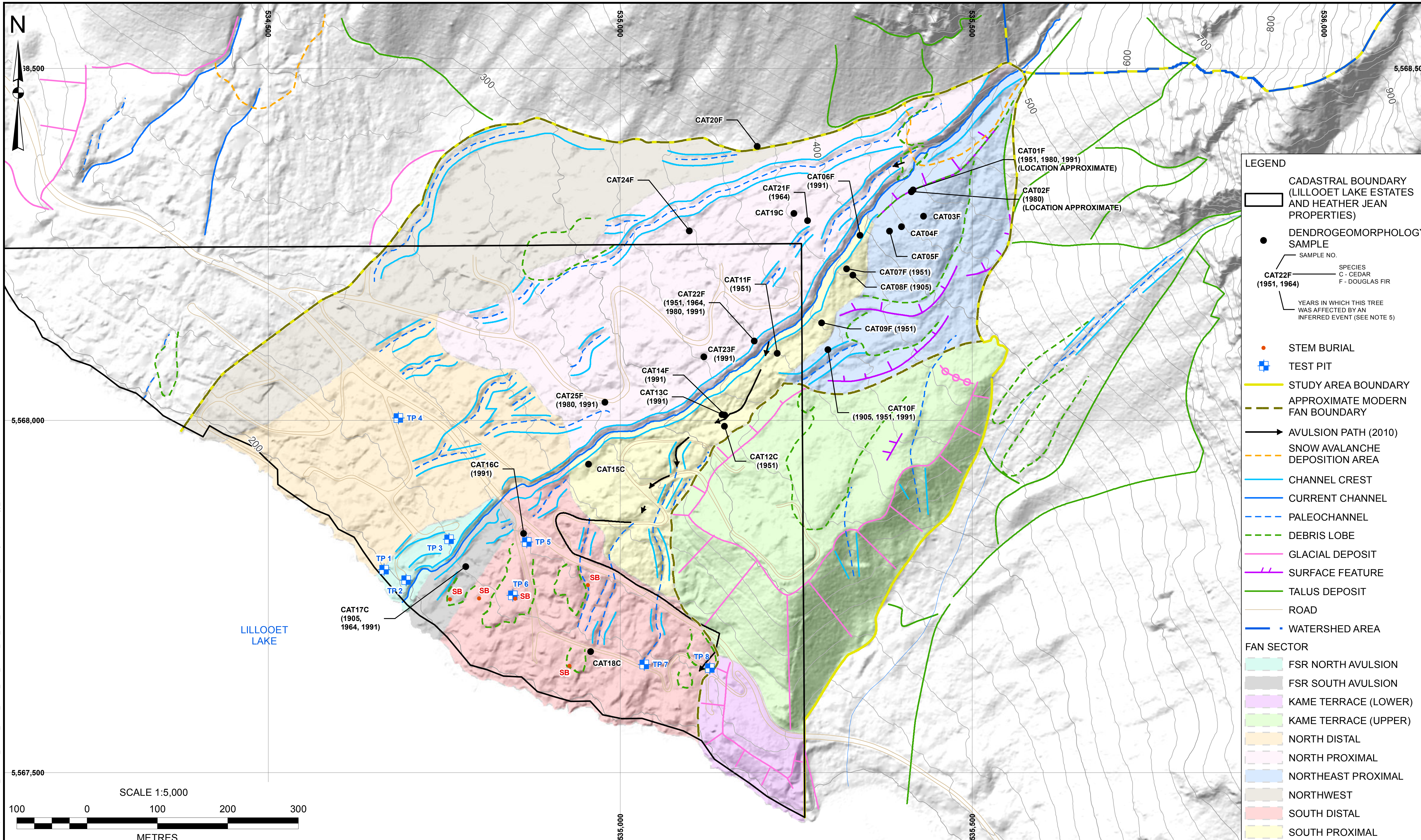

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NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY 2014. CONTOUR INTERVAL IS 20 m.
4. THE STUDY AREA BOUNDARY OF THIS ASSESSMENT ENCOMPASSES CATILINE CREEK BASIN AND FAN. SELECT GEOHAZARDS OUTSIDE THE STUDY AREA ARE SHOWN FOR ILLUSTRATION PURPOSES ONLY AND ARE NOT INCLUDED IN THE ASSESSMENT. ADDITIONAL GEOHAZARDS EXIST OUTSIDE THE STUDY AREA THAT WERE NOT MAPPED.
5. CADASTRAL DATA PROVIDED BY KERR WOOD LEIDAL ON APRIL 1, 2014.
6. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
7. DEBRIS FLOW EVENT DATES AS INFERRED BY DENDROGEOMORPHOLOGY ARE SUBJECT TO UNCERTAINTY AND LIKELY DO NOT INCLUDE ALL THE EVENTS WITHIN THE TIMEFRAME. REFER TO REPORT FOR ADDITIONAL DETAILS.
8. PROJECTION IS UTM NAD 83 ZONE 10.
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CHECKED:	EM
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

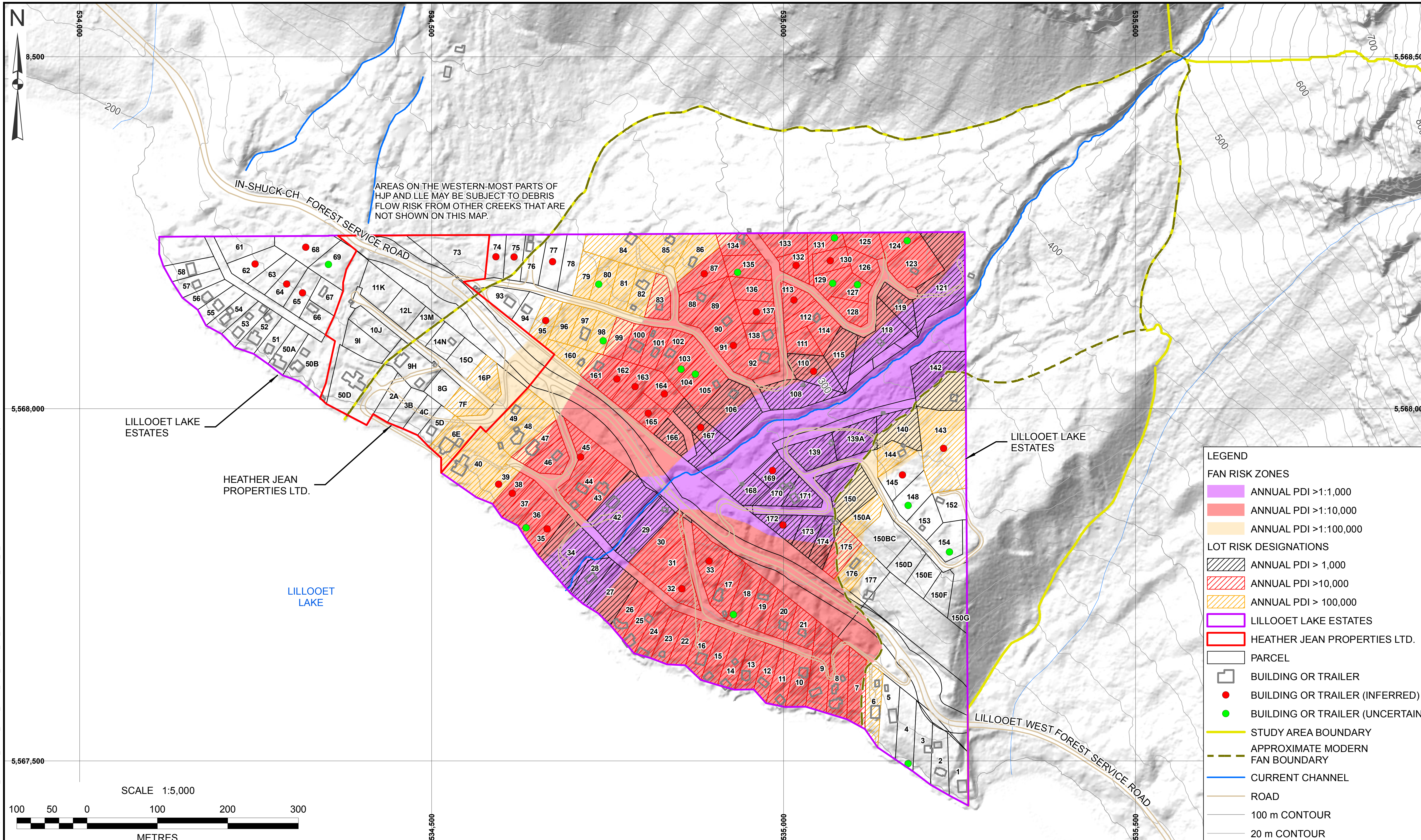
CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: DENDROGEOMORPHOLOGY MAP

PROJECT No.: 1358001

DWG: 07



NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT", AND DATED JANUARY 31, 2015.
3. THIS MAP SHOULD NOT BE USED AT A SCALE LARGER (MORE DETAILED) THAN SHOWN ON THIS MAP.
4. THIS MAP REPRESENTS A SNAPSHOT IN TIME. THE OCCURRENCE OF GEOHAZARD EVENTS OR CHANGES IN DEVELOPMENT MAY WARRANT THE RE-DRAWING OF SOME AREAS.
5. AREAS ON THE WESTERN-MOST PORTION OF CATILINE FAN MAY BE SUBJECT TO ADDITIONAL DEBRIS FLOW RISK THAT IS NOT SHOWN ON THIS MAP.
6. BUILDING OUTLINES AND ROADS PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. IN AREAS OF TREE COVERAGE ONLY PARTIAL BUILDING OUTLINES COULD BE IDENTIFIED.
7. BUILDING POINTS (UNCERTAIN) WERE DIGITIZED BY BGC IN AREAS OF PARTIAL TREE COVERAGE AND SHOULD BE CONSIDERED APPROXIMATE.
8. BUILDING POINTS (INFERRED) WERE PLACED AT THE CENTROID OF THE LOT AND ARE CASES WHERE NO BUILDING WAS IDENTIFIED, BUT BC ASSESSMENT OR RESIDENT INTERVIEW DATA IMPLIED THAT A BUILDING SHOULD EXIST.
9. BASE TOPOGRAPHIC DATA BASED ON LIDAR FROM MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 20 m.
10. STUDY AREA BOUNDARY IS ILLUSTRATED BY THE CATILINE CREEK APPROXIMATE MODERN FAN BOUNDARY.
11. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL DEBRIS-FLOW IMPACT.
12. PROJECTION IS UTM NAD 83 ZONE 10.
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SCALE:	1:5,000
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CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT:
CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE:
RISK TO INDIVIDUALS

PROJECT No.: 1358 001
DWG: 08

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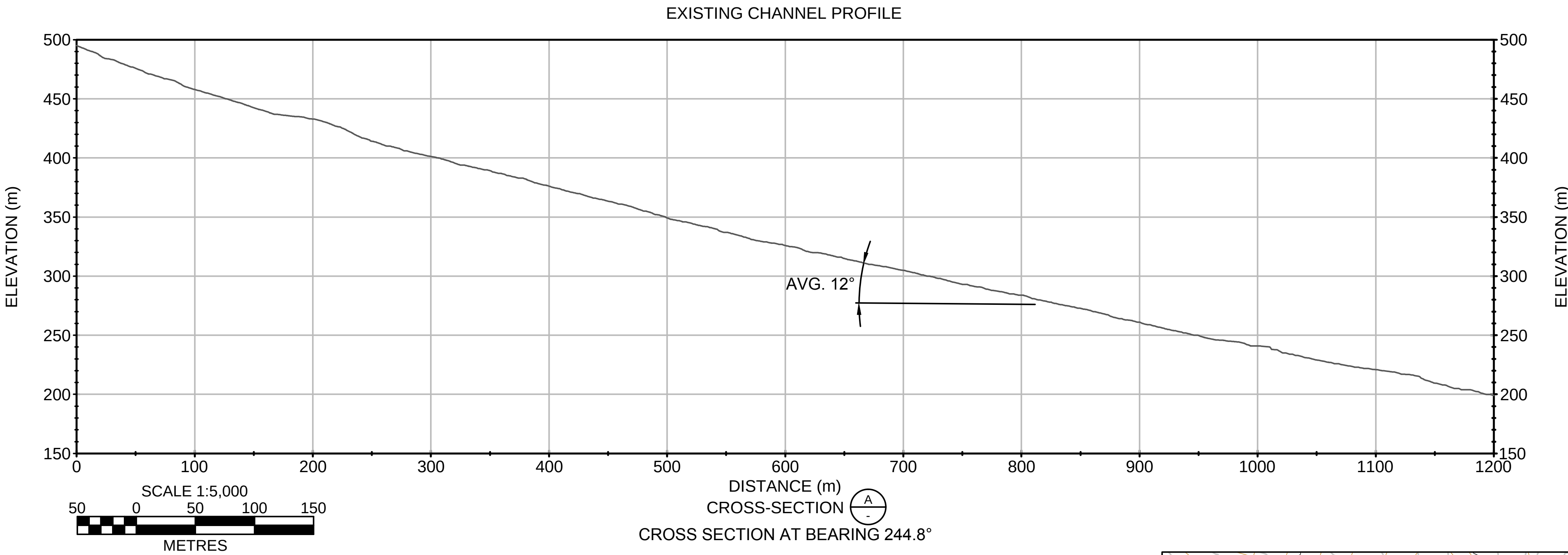

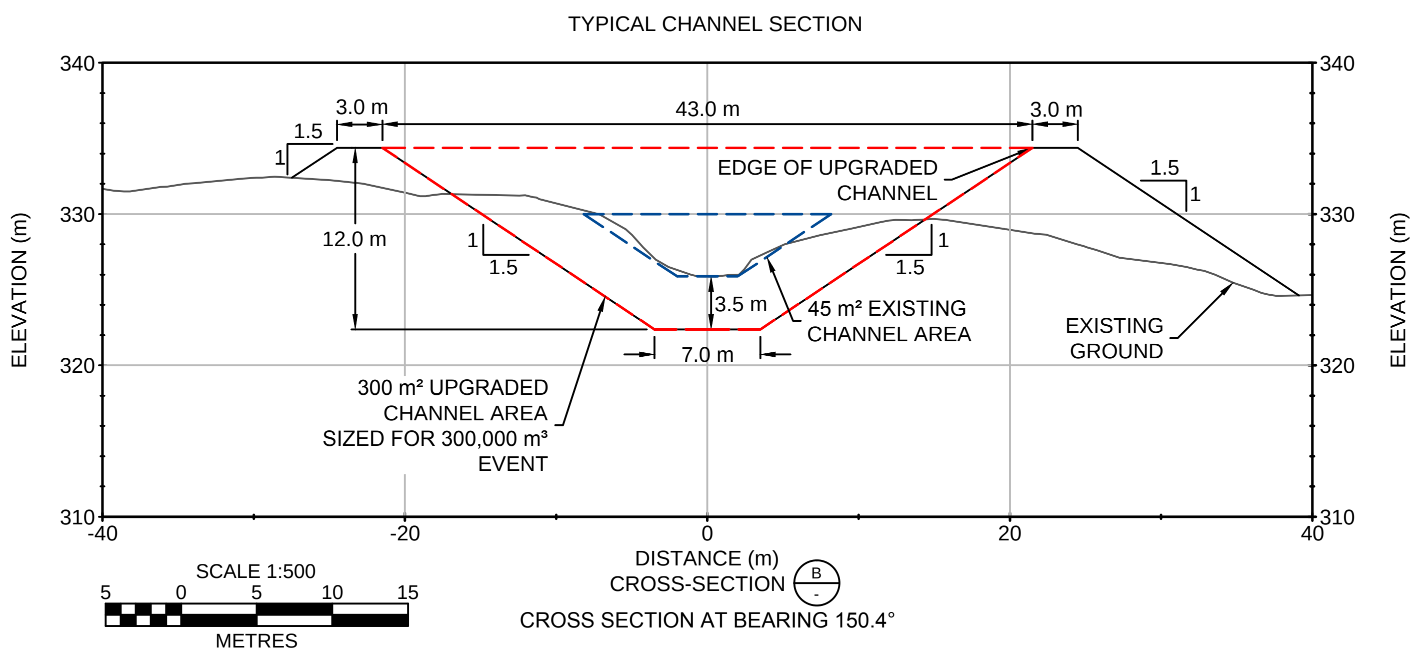

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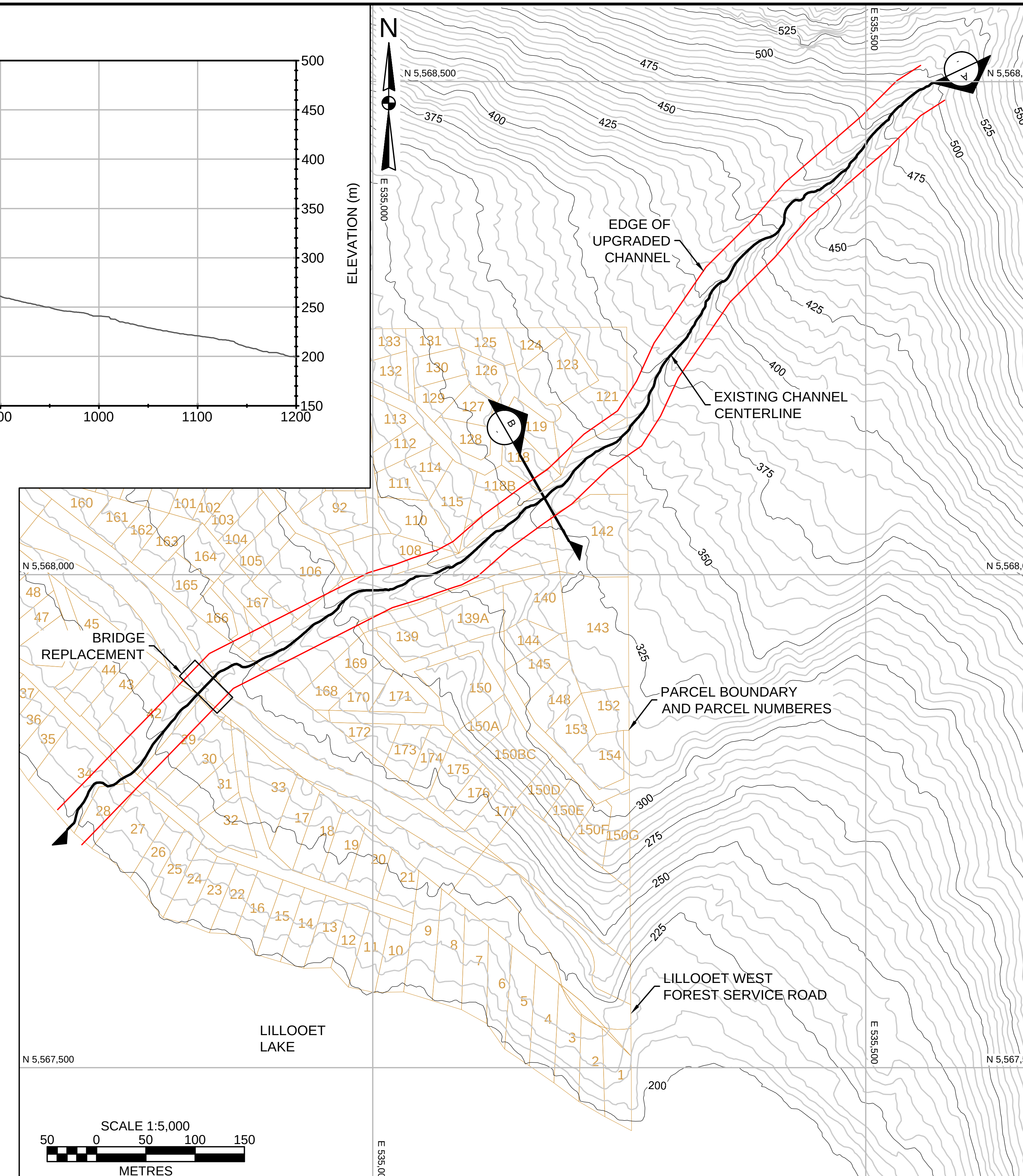

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3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 5.0 m.
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APPROVED:	-

BGC ENGINEERING INC.
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CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: RISK REDUCTION CONCEPT 1 - INCREASE CAPACITY OF CHANNEL

PROJECT No.: 1358001

DWG No.: 09

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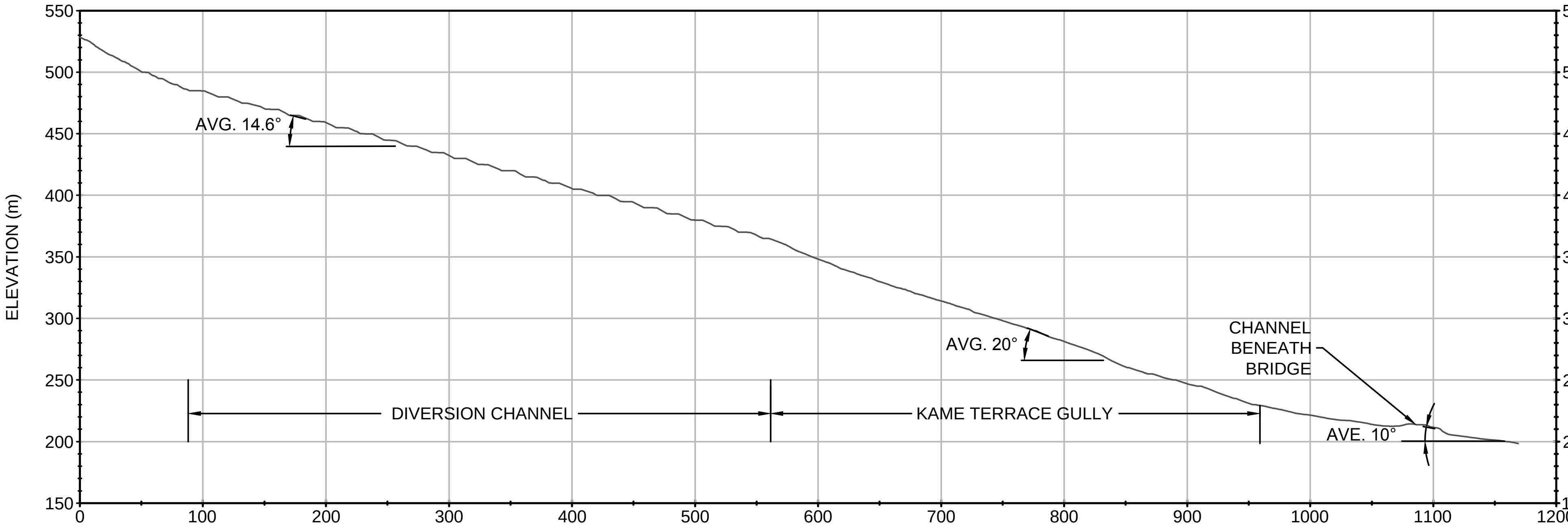
DIVERSION CHANNEL PROFILE

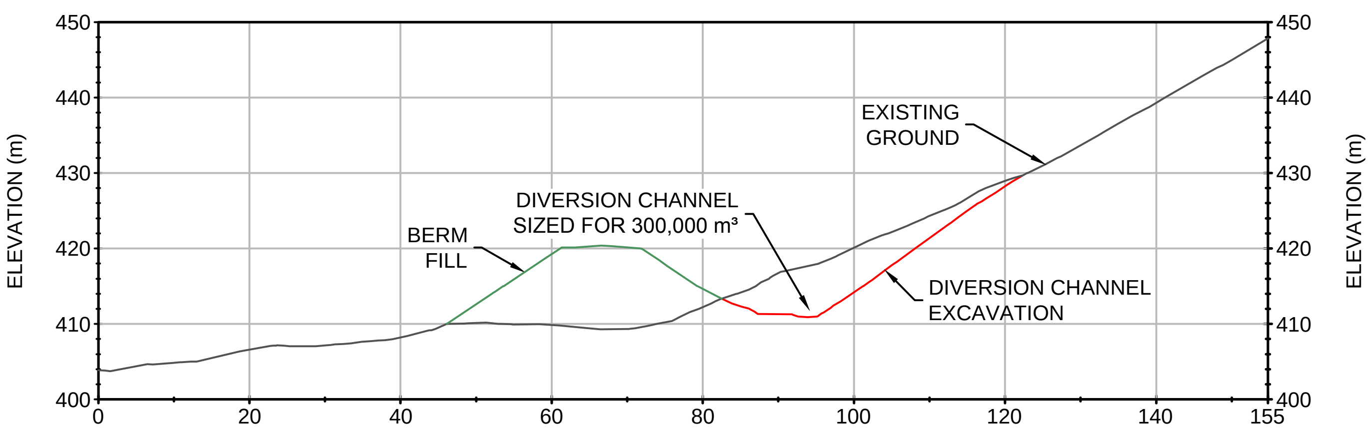


SCALE 1:5,000

CROSS-SECTION C

CROSS SECTION AT BEARING 243.6°

TYPICAL CHANNEL SECTION



SCALE 1:1,000

CROSS-SECTION D

CROSS SECTION AT BEARING 091.3°

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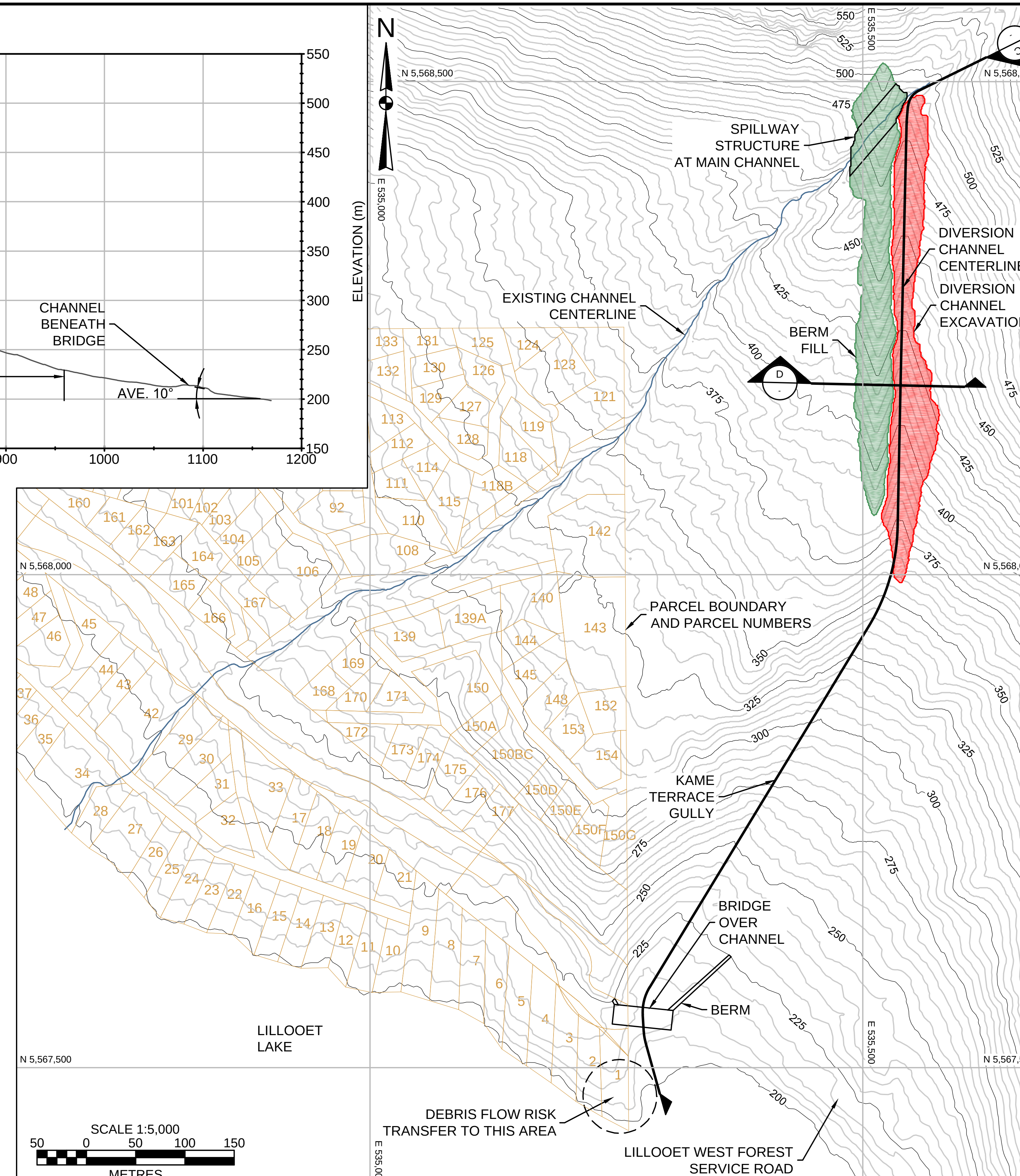

NOTES:

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3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY MCELHANNEY, DATED JULY AND AUGUST 2014. CONTOUR INTERVAL IS 5.0 m.
4. PROJECTION IS NAD 83 UTM ZONE 10N.
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DATE:	JAN 2015
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CHECKED:	CC
APPROVED:	-

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: RISK REDUCTION CONCEPT 2 - DIVERSION CHANNEL

PROJECT No.: 1358001

DWG No.: 10

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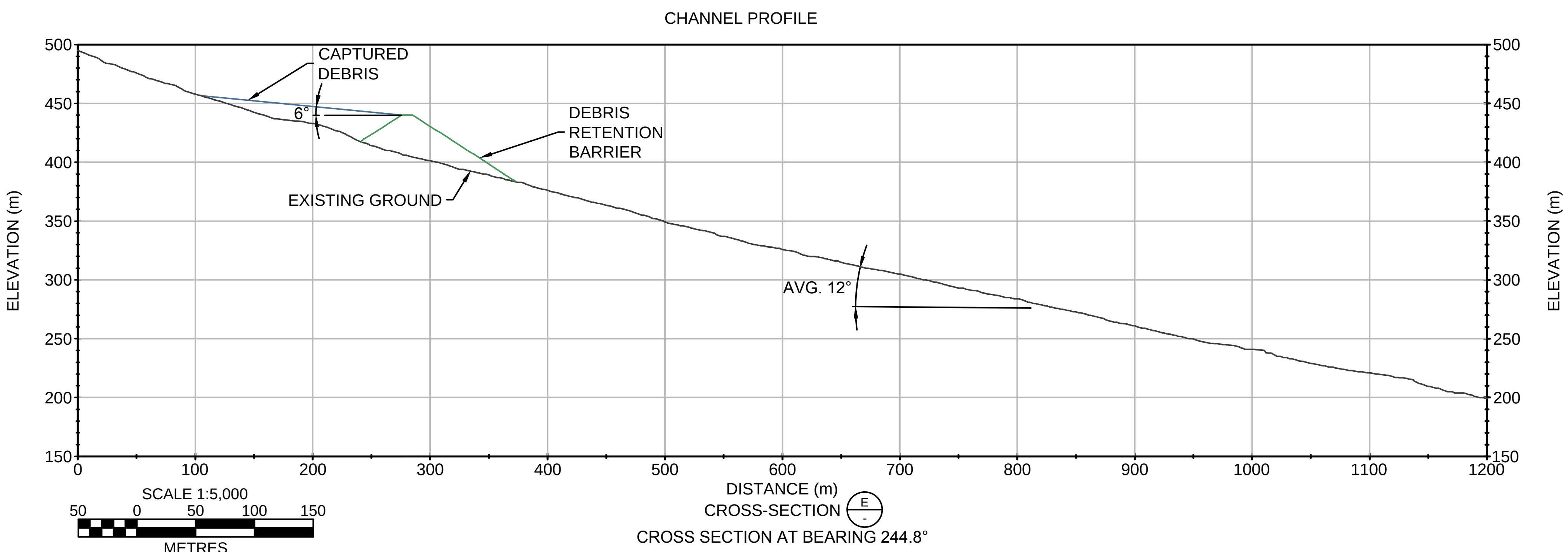

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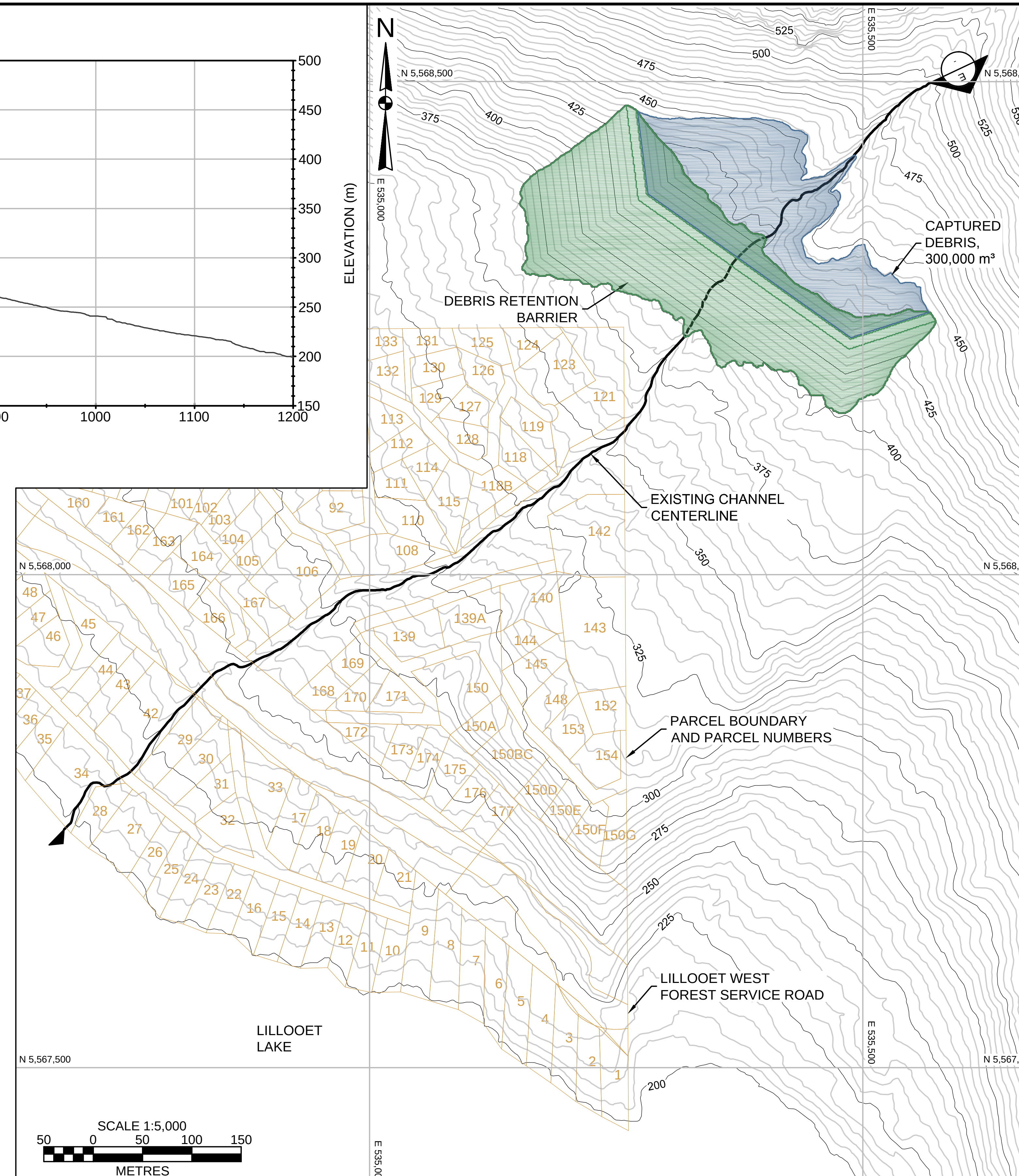

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DATE:	JAN 2015
DRAWN:	CS
CHECKED:	CC
APPROVED:	-

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: SQUAMISH-LILLOOET REGIONAL DISTRICT

PROJECT: CATILINE CREEK DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: RETENTION BARRIER

PROJECT No.: 1358001

DWG No.: 11

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