HEMLOCK VALLEY SNOW AVALANCHE HAZARD ASSESSMENT

FINAL

Prepared for:
Fraser Valley Regional District
45950 Cheam Ave.
Chilliwack, BC
V2P 1N6

Prepared by:
Dynamic Avalanche Consulting Ltd.
Box 2845
Suite 301, 306 1st St. W.
Revelstoke, BC V0E 2S0
250.837.4466

6 October, 2020

Executive Summary

Dynamic Avalanche Consulting Ltd. (DAC) was retained by Fraser Valley Regional District (FVRD) to assess snow avalanche hazard for sections of Mt. Keenan in the Hemlock Valley. The study area included sections of Mt. Keenan that were previously identified as having snow avalanche hazard that could impact residential land parcels along Edelweiss Drive and infrastructure at the sewage lagoons area. The objective of the assessment described in this report was to update previous hazard assessments for these areas, given changes to vegetation and updated topography since the previous assessment in 2012.

DAC combined desktop, field, and analytical methods to assess the snow avalanche hazard. This included interpretation of historical aerial photographs, review of historical reports and observations, analysis of historical snowpack data, a site visit to assess and collect vegetation and terrain data, and application of statistical and dynamic avalanche runout models. The results were compiled to assess frequency and magnitude of snow avalanches with up to 300-year return periods, as recommended by CAA (2016).

The assessment identified seven snow avalanche paths within the vicinity of previously identified paths. More individual paths were identified than previous assessments, as some of the previously defined paths were split into multiple paths. This refinement of the mapping was possible due to the improved topographic base mapping, improved avalanche modelling methods, and detailed field observation. Of the seven paths, three intersect land parcels located along Edelweiss Drive and two paths intersect the sewage lagoons area. Two of the paths do not affect current residential land parcels or FVRD infrastructure.

No current residential land parcels or infrastructure were identified in the Red Zone (high hazard). Hazard areas identified as being within the Blue Zone (moderate hazard) include portions or the entirety of 17 residential land parcels, an approximately 190 m length of Edelweiss Drive, the northern buildings in the sewage lagoons area, and the northwest sewage lagoon.

DAC recommends that FVRD follow the recommendations for occupied and unoccupied structures as outlined by CAA (2016). The current FVRD policy indicates that snow avalanches with a return period of up to 10,000 years should be assessed. The CAA (2016) guidelines recommend consideration of snow avalanches with a return period up to 300 years, which has been followed by most jurisdictions in Canada, and similar classifications are being applied in most U.S. jurisdictions, making this a North America-wide guideline. This guideline is also consistent with hazard map systems in European countries, including Switzerland and Austria.

Hazard boundaries may change in the future due to forest or terrain changes. Hazard boundaries should be updated should substantial changes occur.

To increase confidence and reduce uncertainty in future assessments, FVRD should obtain unedited LiDAR data.

Table of Contents

List of Appendices

List of Drawings

1.0 Introduction

Fraser Valley Regional District (FVRD) requested that Dynamic Avalanche Consulting Ltd. (DAC) reassess snow avalanche hazard for a portion of Mt. Keenan in the Hemlock Valley, on the northern side of the Fraser Valley near Harrison Lake (Figure 1). There are numerous avalanche paths located on Mt. Keenan above sections of Hemlock Valley, including Edelweiss Drive and the sewage treatment plant (sewage lagoons). Residential properties line Edelweiss Drive, and the sewage lagoons area includes two sewage ponds as well as unoccupied maintenance buildings.

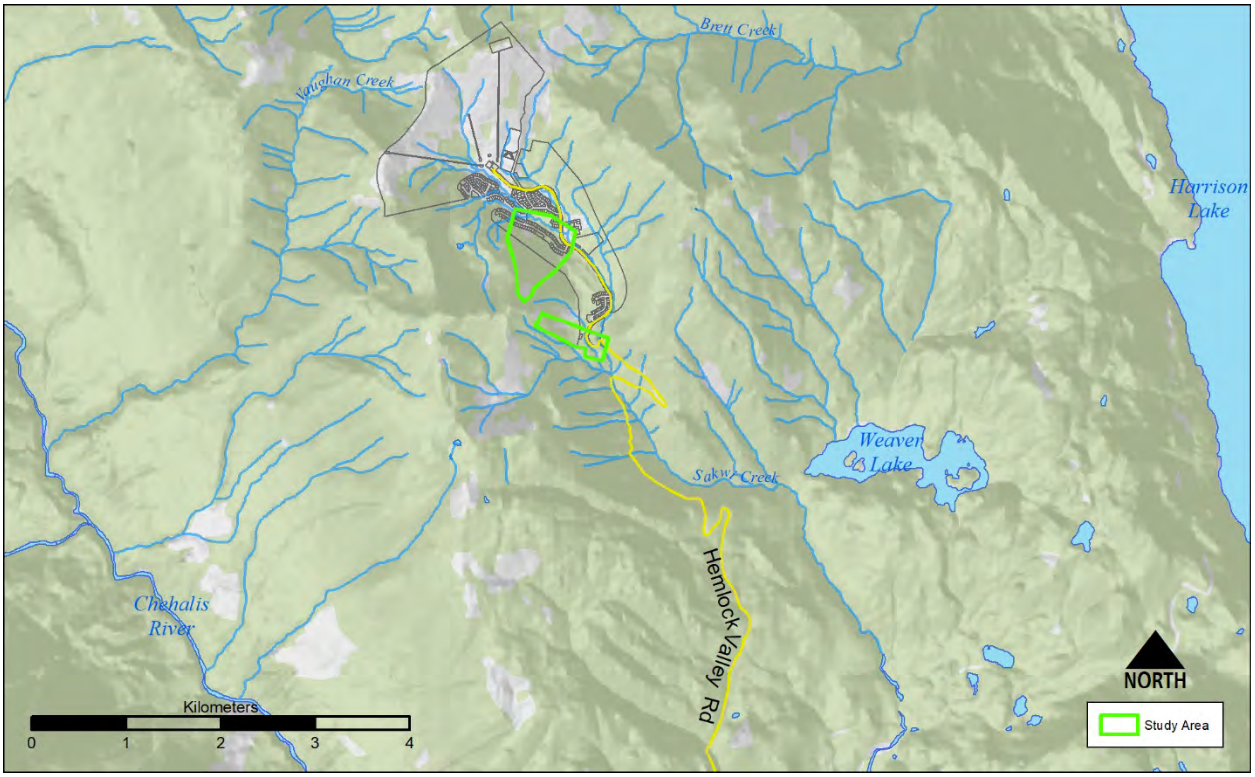


Figure 1. Location map of study area. The northern green polygon shows the Edelweiss Drive development area, and the southern green polygon shows the location of the sewage lagoons.

1.1 Background

Snow avalanche hazards from the slopes of Mt. Keenan were previously identified and documented in the following reports:

- Freer (1981) investigated snow avalanche hazard to Subdivisions 4 (Edelweiss Drive) and 6 (Snowmist Drive near the sewage lagoons) at Hemlock Valley, following the international method of avalanche hazard zoning (up to 300-year return period). Maps outlining Red (high hazard) and Blue (potential hazard) zones were produced. Freer indicated that almost half of the avalanche hazard was due to logging activity above the subdivision.

- Mears (1982) provided avalanche hazard and zoning recommendations for Subdivisions 4 and 6 by assessing a design avalanche with a 1% annual probability (100-year return period). Maps delineating Red (high hazard) and Blue (moderate hazard) zones were produced.
- D&E McClung Enterprises Ltd. (2000) assessed snow avalanche hazard with a return period of about 500 years. Seven sites with avalanche hazard were identified during the assessment, including five sites above Edelweiss Drive, one at Snowmist Place, and one above the sewage lagoons. Maps referenced in their report were not available for inspection for the current (DAC) assessment.
- D&E McClung Enterprises Ltd. (2004) produced a site-specific avalanche hazard report for Plan Number 55972, Lot 53.
- D&E McClung Enterprises Ltd. (2010) completed an assessment of snow avalanche hazards with consideration of occupied structures and facilities, which was to be considered as an updated zoning plan from D&E McClung Enterprises Ltd. (2000). The assessment followed the zoning guidelines prepared by the Canadian Avalanche Association, which analyzed 300-year return period snow avalanches. The report concluded that the sewage lagoons and nearby buildings were in the Blue Zone. Most of the land parcels on the upslope side of Edelweiss Drive were also determined to be located within the Blue Zone.
- D&E McClung Enterprises Ltd. (2012) prepared a risk assessment and suggested mitigation strategies for snow avalanche hazards that may threaten facilities at Hemlock Valley. The findings identified six problem areas, including four along Edelweiss Drive and two above the sewage lagoons. The report mapped snow avalanche hazard with a 500-year return period.

A primary change over the timeframe of the reports is forest cover, which has resulted in changes in avalanche hazard. Most of the trees on the northeast to southeast slopes of Mt. Keenan were logged in the 1960’s. The trees were relatively small during the early avalanche assessments and became substantially taller within a higher density forest canopy during the assessments in the 2000’s. Vegetation cover affects avalanche hazard, by reducing the size of starting zones and preventing the initiation of avalanches by anchoring of the snow, influencing snowfall distribution and weak layer growth in the snowpack, and forests can limit the runout distance of avalanches at the bottom of the paths (i.e., near residential areas).

FVRD was interested in reassessing snow avalanche hazard for the areas identified by D&E McClung Enterprises Ltd. (2012). The reasoning for FVRD’s interest in reassessing the problem areas was due to changes to forest cover, newly available terrain maps and higher resolution digital mapping, and a new site specific geohazard assessment report for the identified areas (FVRD, 2019). The results of the updated assessment are intended to be used by FVRD for development approvals, community planning, hazard management, and emergency management purposes.

1.2 Scope of Work

FVRD requested that DAC perform a snow avalanche zoning assessment of the hazard areas identified by D&E McClung Enterprises Ltd. (2012). The study area includes the sections of Mt. Keenan above Edelweiss Drive and the sewage lagoons area previously identified as being exposed to snow avalanche hazard. Hazard outside of the study area boundaries (Figure 1) were not assessed. Hazard around Snowmist Drive was not analyzed during this assessment, as D&E McClung Enterprises Ltd. (2012) indicated there was adequate forest cover to prevent avalanches from reaching the residences.

The scope of the assessment was based on the Request For Information (RFI) provided by FVRD (2019) and the proposal prepared for FVRD (DAC, 2020a) which provided the following scope of work:

- Project management;
- Site characterization, including review of previous assessments, imagery, snow data, and terrain data;
- Site visit, which was completed on June 10 and 11, 2020, to define snow avalanche path characteristics and collect important data for the assessment;
- Zoning analysis using statistical and dynamic modelling and site visit results to perform frequency and magnitude analysis and estimate approximate velocity and impact pressure to define hazard zones in the study area;
- Forest and climate change analysis, in a qualitative manner;
- Reporting, including a report describing methods and results and plan view maps (this document), as well as Hazard Assurance Statement for Development Approvals for the study area; and,
- A conference call with FVRD staff to discuss the findings of the assessment.

The work was completed under an Agreement for Services dated February, 2020.

2.0 Technical Overview of Snow Avalanche Hazard

A snow avalanche is a rapid flow of snow or ice down a slope. Snow avalanches may release spontaneously, with no obvious trigger, or may be triggered by rapid loading (e.g., human causes, explosives) or mechanical changes to the snowpack brought on by meteorological conditions (e.g., snow, rain, wind, warm air temperature, sun). Snow avalanches can also be triggered by seismic loading.

The two predominant types of snow avalanches include loose avalanches and slab avalanches (McClung and Schaerer, 2006). Loose avalanches occur within snow with low cohesion, where gravitational forces overpower frictional resistance, like sand sliding down a hill. This generally occurs during storms where cohesion of fallen snow is low or on days with substantial warming from air temperature or solar warming, where bonds between snow grains are weakened. Slab avalanches occur when a cohesive block of the snowpack is isolated on all sides and slides downslope due to gravitational forces. Slab avalanches are further categorized based on when they release with respect to storms.

Both loose and slab avalanches can be classified as dry or wet, depending on the water content of the snow involved. Dry avalanches are most common during winter months and wet avalanches are most common in spring and summer months, although they can also occur in the winter during rain events and at low elevations. Fast-flowing dry avalanches may have a powder component, which is a suspended layer of snow, with a height that is often tens of metres above the dense flow. Slab avalanches are typically the most hazardous, as they contain a large amount of snow that can reach the runout zone and be destructive.

A third and much less common type of snow avalanche is a glide avalanche. In this circumstance, the entire snowpack slowly glides downslope because of water flow at the base of the snowpack, possibly opening cracks within the snowpack. The cracks may expand and release a portion of the snowpack downslope, termed a glide avalanche. Such avalanches generally occur in wet snow climates or during the spring in dry snow climates.

This report assumes that the predominant avalanche types in the Hemlock Valley are dry and wet avalanches, and that the design event (i.e., most destructive) within a 300-year return period is a dry slab avalanche.

Snow avalanche hazard may exist anywhere with enough snow accumulation and steep slopes (generally greater than 25°). The terrain feature where a snow avalanche forms, slides, and deposits is referred to as a snow avalanche path. The path includes a starting zone, track, and runout zone. Starting zones are where the snow avalanche initiates and begins to slide, generally on terrain steeper than 30°, but sometimes as low as 25°. Snow avalanches entrain more snow within the track and speed up, usually in terrain with slope angles between 15° and 30°. Snow avalanches then decelerate and stop in the runout zone with slope angles typically less than 15°, leaving a deposit of snow. Larger paths are generally capable of producing avalanches of higher destructive potential, but hazardous snow avalanches may also release and deposit debris on relatively short slopes at any elevation.

2.1 Uncertainty and Limitations

Snow avalanche prediction is complex and subject to high uncertainty. There is uncertainty in snow avalanche runout extent and frequency estimates due to limited historical avalanche observations in the study area, alterations to forest cover from anthropogenic activities, and limitations of statistical and dynamic models. Future alteration of the landscape and vegetation, such as from anthropogenic activities, forest fire, infestation, or other geohazards may alter the frequency and magnitude of snow avalanches and their runout extent and characteristics.

2.2 Frequency and Magnitude

Jamieson (2018) describes frequency as the average number of avalanches that reach or exceed a given location within a specified time period, often a year. The reciprocal of the average annual frequency is the return period. Jamieson (2018) indicates that return period is described as the average time, usually in years, between avalanches that reach or exceed a specified location. For land-use planning, return periods of 3, 10, 30, 100 and 300 years are often used because uncertainty in the data makes it difficult to estimate return periods more accurately. It is possible for two 100-year avalanches to occur within the same year or within consecutive years, although this would be considered a low probability (unlikely) event.

In Canada, snow avalanche magnitudes are classified by size (Table 1). The maximum size of an avalanche depends on snow supply and terrain configuration and therefore will vary for any given path. Within the Hemlock Valley study area, the potential avalanche sizes range from 1 to 3, with Size 3 being the maximum potential design event.

Magnitude is often related to frequency; in general, large destructive avalanches occur less frequently, while small ones occur more frequently. The magnitude and frequency are also related to location in the overall path.

Table 1. Canadian classification system for snow avalanche destructive size (CAA, 2016).

Size	Destructive Potential	Typical Mass	Typical Path Length	Typical Impact Pressure
1	Relatively harmless to people	<10 t	10 m	1 kPa
2	Could bury, injure, or kill a person	102 t	100 m	10 kPa
3	Could bury and destroy a car, damage a truck, destroy a wood framed house, or break a few trees	103 t	1,000 m	100 kPa
4	Could destroy a railway car, large truck, several buildings, or a forest area of approximately 4 hectares	104 t	2,000 m	500 kPa
5	Largest snow avalanche known. Could destroy a village or a forest area of approximately 40 hectares	105 t	3,000 m	1,000 kPa

Note: Size 1 is the minimum size rating. In general, half sizes are not defined, but may be used by experienced practitioners for avalanches which are midway between defined avalanche size classes (i.e., size 2.5).

2.3 Avalanche Hazard Criteria for Occupied and Unoccupied Structures

The CAA guidelines for occupied structures and unoccupied structures are presented in Technical Aspects of Snow Avalanche Risk Management, prepared by the Canadian Avalanche Association (CAA, 2016). The document was prepared to provide snow avalanche professionals resources and guidelines for consistency across the profession. The document describes best practices and was designed to be adopted as the minimum standard throughout Canada for hazard and risk assessment and mitigation, resulting in more consistent decision making and better risk management. DAC (2020b) documents the recommendation of FVRD adopting the CAA (2016) guidelines in place of their hazard acceptability thresholds for snow avalanches (FVRD, 2017). This report assumes that FVRD will accept this recommendation and adopt the CAA (2016) guidelines for snow avalanche hazards.

Occupied structures include industrial, residential, commercial and other structures where people spend portions of the day or night, may gather in or around during a period of avalanche hazard, provide essential services, or otherwise attract people (CAA, 2016). For occupied structures, CAA (2016) recommends that hazard mapping includes the impact-based classification system found in Appendix 1 of this report. CAA (2016) provides further guidance for occupied and unoccupied structures in avalanche terrain (Table 2).

Table 2. Relevant excerpts of Table 9.2 in CAA (2016), captioned "Typical elements at risk for municipal, residential, commercial and industrial areas with avalanche size and return-period thresholds for avalanche planning".

Element at Risk	Typical avalanche size	Typical return period (years)		Typical Planning
Occupied structures	> 1 ≥ 1 kPa	≤ 300	Scale	Path-scale assessment for an exposure time scale of decades.
			Identification and analysis	Path profile mapping (including statistical runout estimation), frequency-magnitude analysis (e.g. vegetation and climate studies, historical and human records)
			Assessment techniques and decision aids	Quantitative procedures (e.g. locally validated numerical runout modeling); impact-based classification
			Supporting map types	Hazard zone map; avalanche path map.
			Mitigation options	Location planning, reinforcement and design of structures, starting zone snowpack support structures and, track and runout zone long-term measures (e.g. splitting wedges). Specification of short-term operational measures (e.g. developing operational risk assessment aids and evacuation plans) where long-term mitigation does not achieve tolerable risk.
Unoccupied structures and other infrastructures	> 2	≤ 30	Scale	Path-scale assessment for an exposure time scale of years to decades.
			Identification and analysis	Frequency-magnitude analysis (e.g. vegetation and climate studies, historical and human records)
			Assessment techniques and decision aids	Qualitative or quantitative procedures; impact-based classification.
			Supporting map types	Hazard zone map.
			Mitigation options	Location planning, reinforcement and design of structures, starting zone snowpack support structures and, track and runout zone long-term measures (e.g. splitting wedges). Specification of short-term operational measures (e.g. developing operational assessment aids).

3.0 Physical Setting and Snow Climate

Hemlock Valley is in the Coast Mountains of BC, which experiences a Maritime snow climate (McClung and Schaerer, 2006) influenced by weather patterns from the Pacific Ocean. Maritime snow climates generally have relatively warm air temperatures and high amounts of precipitation in the form of both snow and rain. This typically results in a relatively deep snowpack, composed of layers of dense snow and melt-freeze crusts from rain events. Loose and slab avalanches generally occur during and within the days after storm events. With storms that deposit large amounts of new snow and wind-transported snow, large and destructive snow avalanches may result. Storm snow generally bonds to the underlying snowpack within a few days following the storm, which generally reduces snow avalanche hazard over time. However, large and destructive slab avalanches can still occur when weak layers are present in the snowpack. Other triggers may also release snow avalanches well after storms, for example where warm air, solar inputs, or rainfall lead to softening and strain in the snowpack.

The freezing level is variable in a maritime snow climate. A deep snowpack may be present in the starting zones when limited or no snow is present in the valley. Hazard from snow avalanches may thus persist in the valley bottom, even when no snow is present at that elevation. This is accentuated in spring months, when snow melts in lower elevations or precipitation falls as rain, whereas a deep snowpack and snowfall may still occur in the starting zones.

4.0 Analysis and Results

This section summarizes the findings of the analyses conducted, as detailed in the scope of work (DAC, 2020a) and recommended by CAA (2016). The analyses included:

- Comparison of historical aerial photographs to observe for changes over time;
- Review of previous reports from the study area to compare techniques and findings and to obtain information about previous avalanche activity;
- Review of historical snowpack data to assess snow supply;
- A site visit, conducted June 10 to 11, 2020, to assess topography, vegetation, and other evidence and measurements to support the overall assessment; and
- Statistical and dynamic avalanche modelling to assess snow avalanche extents and characteristics.

4.1 Historical Aerial Photographs

Aerial photographs were obtained from Digital Air Photos of B.C. and Natural Resources Canada for the years 1930, 1951, 1968, 1983, 2003, and 2016 (Appendix 2). The photographs were georeferenced to allow comparison between each photo year.

The photographs showed trim lines (location of vegetative type and age differences) of preceding snow avalanche events that occurred at least once between the years the air photos were taken. Prominent avalanche related trim lines were observed in the 1930 and 1951 air photos, as they were both taken prior to logging. Trim lines were observed close to Edelweiss Drive in two areas (Figure 2), suggesting large avalanches reached near the road pre-1930. These same trim lines were not apparent in the 2016 photograph, which suggests that avalanche events similar to the pre-1930 events have not occurred since then.

The photograph from 1968 shows the extensive logging conducted around 1963, which removed large amounts of forest cover in the study area (Appendix 2). Trim lines within the forest growth since logging in 1960's were generally similar to pre-logging conditions near the sewage lagoons area (Figure 3), although some areas could not be compared due to road and infrastructure construction since the logging activities. There was no obvious trim line in the 2003 air photo of the reported avalanche that reached the fence of the sewage lagoons in 1999 by D&E McClung Enterprises Ltd. (2010), suggesting that the avalanche debris flowed through the trees without knocking them down. This is not uncommon for a wet flow, which still has destructive potential for structures, despite not destroying the forest.

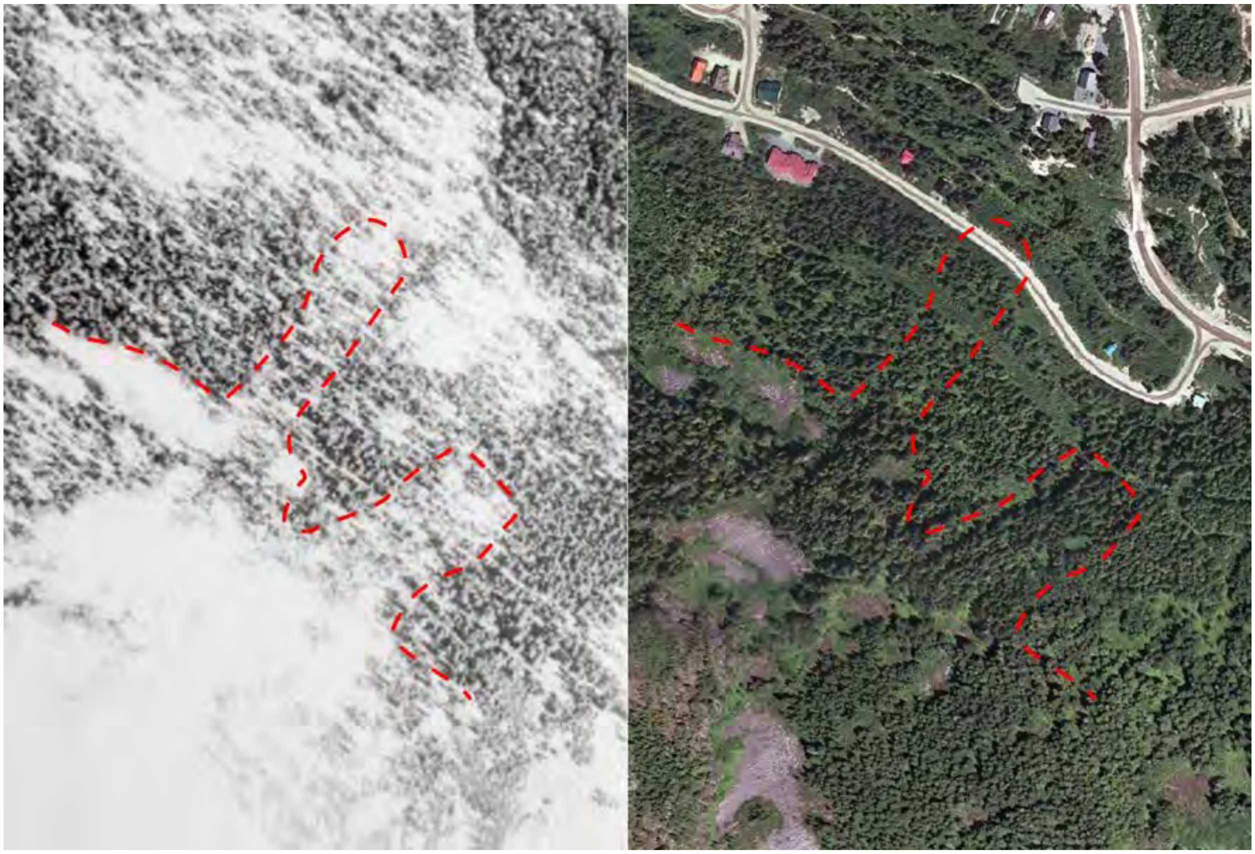


Figure 2. Comparison of aerial photographs from 1930 (left) and 2016 (right) for the Edelweiss Drive area. Red dashed line indicates the approximate location of trim lines observed in 1930 photograph.

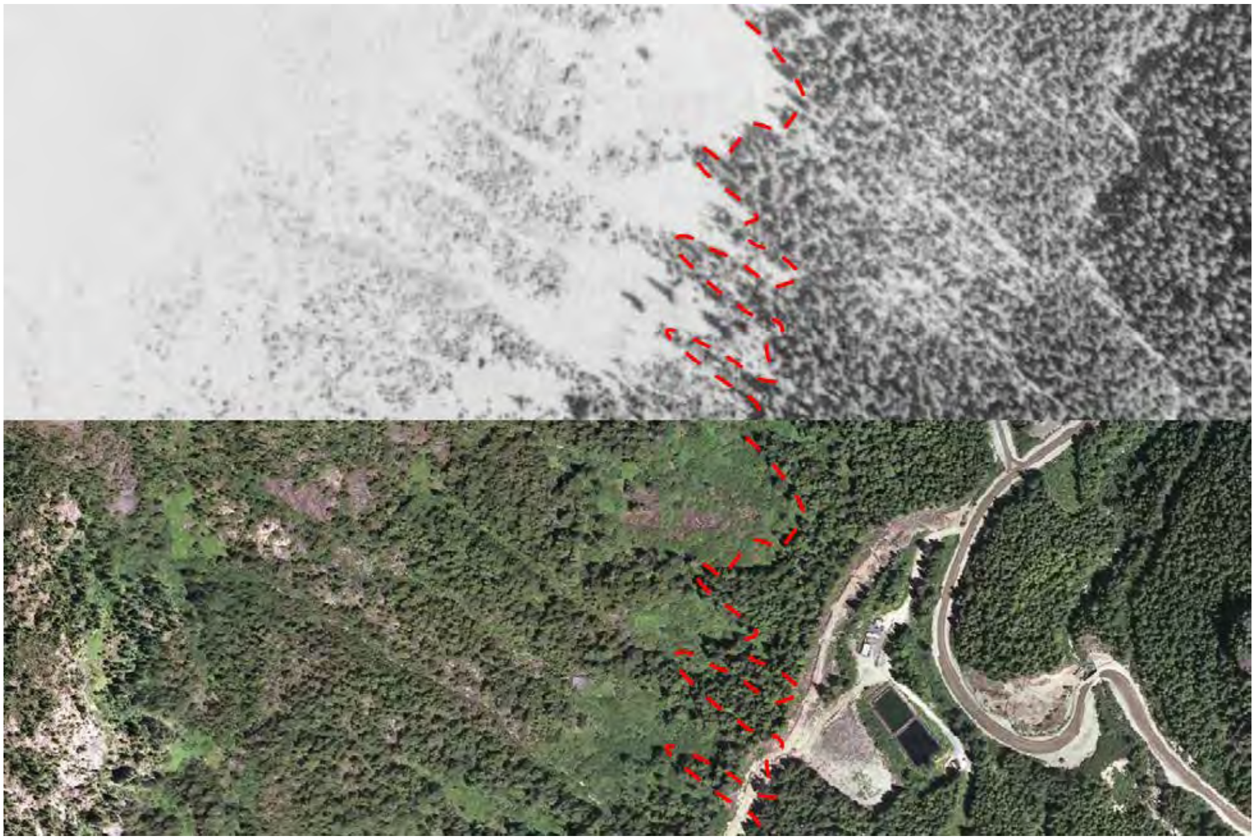


Figure 3. Comparison of aerial photographs from 1930 (top) and 2016 (bottom) for the sewage lagoons area. Red dashed line indicates the approximate location of trim lines observed in 1930 photograph.

4.2 Previous Reports and Observations

The reports described in Section 1.1 were reviewed during completion of our assessment. Previous hazard boundaries were summarized and compared (Appendix 3), and variation of hazard boundaries between the reports was noted. Variations in runout extent is likely due in large part to changes in vegetation. Lateral differences in the boundaries are expected to be largely based on differences in analyses, techniques, and available data. For example, statistical and dimensional dynamic modelling was not available in the early 1980's and multi-dimensional dynamic modelling was not available for the previous reports in the 2000's. Modern mapping techniques with high-resolution topography were also not available for any of the previous reports. These are important methods of defining hazard boundaries with increased confidence in today's state-of-practice, and without them the resulting hazard boundaries typically have greater uncertainty. For example, hazard boundaries for the reports produced in the 1980's included hand-drawn lines and the more recent reports appeared to have used satellite imagery that was approximately 50 m shifted from the coordinate system.

Given the expertise of the consultants that completed the previous hazard assessments, the field observations are expected to be of high quality and reliable. However, in completion of our assessment it was clear that there were issues associated with the transference of this ground information into a reliable, base map format that can reliably be used by the FVRD.

Helpful information from the previous reports include that the slopes of Mt. Keenan were logged around 1963 (D&E McClung Enterprises Ltd., 1999) and that an avalanche reached the fencing around the sewage lagoons in 1999 (D&E McClung Enterprises Ltd., 2010).

Mr. Chris Dyck, a ski patroller at the nearby Sasquatch Mountain Resort with over 10 years of avalanche experience, was interviewed in reference to avalanche activity in Hemlock Valley. Mr. Dyck indicated that most avalanches in the area are direct-action avalanches, i.e., releasing during or shortly after storms. Persistent weak layers have been found in the snowpack, but they are often short-lived due to relatively warm air temperature. The thickest slab avalanche that Mr. Dyck observed was 50 cm thick, but he believes that slabs over 1 m thick may be possible over many years of observations. Mr. Dyck has observed many loose wet avalanches as well, but the destructive size of them were generally small. Mr. Dyck did not have specific observations of avalanche activity for the study area of this assessment but provided useful information on avalanche activity in Hemlock Valley.

4.3 Historical Snowpack Data

Nearby snow course, weather station, and weather plot data were used to assess the potential snow depths and influence on avalanche hazard for the study area. Four stations were used in the analysis, all operated by the province of British Columbia (Table 3). Although the reliability of these data cannot be confirmed, the data were reviewed and appeared representative, and they were generally consistent between nearby stations. Extreme value statistics were used to estimate snow depths for each station for given return periods beyond the length of the data record.

Both linear and exponential regression analyses were conducted on the snow depth data from the stations so that snow depths (cm snow) could be estimated for relevant elevations. Each regression has a coefficient of determination (R^2) greater than 0.96, suggesting good fits. The 10-year, 30-year, and 100-year snow depths for relevant elevations are presented in Figure 4.

A second method used to assess the snow depth was completed using elevation corrections for a single representative station. The Dickson Lake station was used due to its proximity and elevation, as it is located approximately 11 km southwest of the study area and at a similar elevation to the upper portions of the avalanche paths. Elevation corrected snow depths were calculated based on the approaches of Claus et al. (1984) and Liston and Elder (2006).

Averaging all the methods (Table 4), the 100-year snow depth is estimated to be between 6.5 and 7.5 m for the starting zone elevations and 5.0 to 5.5 m for the runout zone elevations.

Snow data from the nearby Sasquatch Mountain Resort's weather plot were also analyzed to assess weather trends. Data from the last three winter seasons were available (2017-2018 season to the 2019-2020 season). Summary statistics of the data are presented in Table 5. Although only three years of data were available, the results suggest that a winter storm has the potential to produce slab avalanches approximately 1.0 to 1.5 m thick.

The snow stations used in this analysis are often in relatively flat and sheltered sites, whereas the snow avalanche starting zones are inclined terrain and exposed to wind and sun. The snowpack depths in the starting zones may be influenced from wind events, solar activity, and from the movement of snow during avalanches over the season. Local-scale snowpack depths may therefore vary across the study area on any given year.

Given the findings, the starting zones of the snow avalanche paths in the study area hold sufficient snow to produce snow avalanches during most winter and spring months.

Table 3. Snow course and weather stations used in the snowpack analysis.

Station Name	Approximate Elevation (m)	Latitude (°)	Longitude (°)	Distance from Study Area (km)	Data Range (From-To)
Dickson Lake	1160	49.32	-122.07	11 km southwest	1991-2020
Spuzzum Creek	1180	49.66	-121.66	37 km northeast	2004-2020
Stave Lake	1250	49.58	-122.31	35 km northwest	1967-2020
Hope	70	49.38	-121.42	40 km east	1966-1981

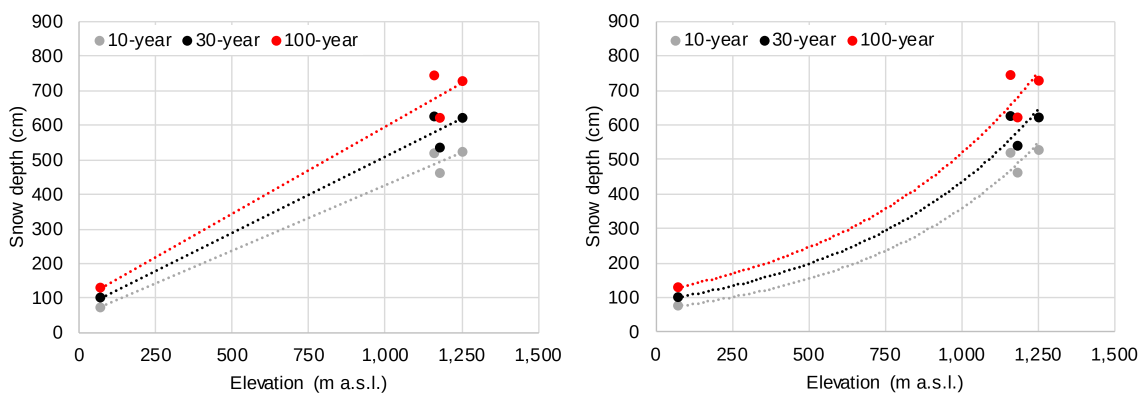


Figure 4. Predicted snow depths for snow course stations near Hemlock Valley, using a linear approach (left) and exponential approach (right).

Table 4. 100-year snow depth derived from various methods. Elevation corrections for the Dickson Lake 100-year snow depth.

Elevation (m)	100-year snow depth (cm)				
	Linear	Exponential	Claus et al. (1984)	Liston and Elder (2006)	Average
1250 (starting zone)	724	758	729	792	751
1100 (starting zone)	648	605	606	713	643
950 (Edelweiss)	573	483	492	642	548
860 (sewage lagoon)	527	422	429	603	495

Table 5. Summary statistics of weather and snowpack data from Sasquatch Mountain Resort weather plot at 1200 m.

Statistic	2017-2018	2018-2019	2019-2020
Temporal length of dataset	Nov 27 to Apr 2	Dec12 to Mar 31	Dec20 to Mar 16
Maximum 24-hour snowfall (cm)	40	55	55
Maximum 3-day snowfall (cm)	94	64	97
Maximum snow accumulation on storm board (cm)	169	95	88
Average winter snowfall density (kg/m^3)	112	114	99
Maximum 24-hour rainfall (mm)	21	74	30
Maximum snow depth (cm)	424	274	326
Month of maximum snow depth	March	March	March
Coldest recorded air temperature (°C)	-17.9	-20.5	-21
Warmest recorded air temperature (°C)	20.4	16	6.2
Seasonal average of minimum daily air temperature (°C)	-3.8	-2.9	-4.5
Seasonal average of maximum daily air temperature (°C)	0.8	0	-2.3

4.4 Site Visit

The site visit was completed on June 10 and 11, 2020. The visit consisted of collecting topographic data and observing terrain and vegetation in the avalanche paths. Photographs from the visit are presented in Appendix 4. The photographs highlight vegetative evidence of avalanche impacts within the paths. Path profiles are presented in Appendix 5.

The avalanche paths identified during the site visit varied enough from previous reports that a new, systematic scheme was used to name the paths. This would avoid any confusion with previously named avalanche paths, which were identified during studies with a less reliable topographic base map and imagery.

For avalanche paths above Edelweiss Drive, the paths are named based on the intersection of the path centerline with the road. For example, path E-475 indicates that the path centerline intersects Edelweiss Drive 475 m from the intersection of Edelweiss Drive and Hemlock Valley Road. A similar scheme was adopted for the sewage lagoons; path SL-105 indicates that the path centerline intersects the road that accesses the sewage lagoons 105 m from the intersection of that road and Hemlock Valley Road. Table 6 summarizes the path names used in this report and their names applied in previous reports.

The sections below describe the findings of the site visit for each path. The paths are described in order from north to south. Other avalanche paths are located on the slopes of Mt. Keenan but were outside of the study area and are not described in this report. Prominent avalanche paths are present between Edelweiss Drive and the sewage lagoons area, as well as further to the south of the sewage lagoons area but they did not intersect the study area.

Table 6. Path names used within this report and compared to naming in previous reports.

Path names in this report	Path names in D&E McClung Enterprises Ltd. (2012)	Path names in Mears (1982)
E-475	Portion of Path 1	Not named
E-450	Portion of Path 1	Not named
E-405	Path 2	Not named
E-300	Path 3	Path 4
E-90	Path 4	Path 3
SL-105	Not identified	Outside of study area
SL-200	Path 5	Outside of study area

4.4.1 Path E-475

The starting zone of Path E-475 is a relatively small opening, approximately 20 m by 30 m, with a ground cover composed of boulder colluvium that inhibits vegetation growth. The starting zone elevation is approximately 1075 m. The path’s starting zone is a small portion of Path 1 from D&E McClung Enterprises Ltd. (2012), and it was separated from E-450 because it can only produce small avalanches that do not contribute to the overall hazard of Path E-450. The path follows a drainage channel to the northeast and is forced into a southerly direction by a topographical ridge to the north. The drainage channel becomes less prominent past the topographical ridge, where the terrain becomes a relatively uniform slope towards Edelweiss Drive. Both sides of the drainage channel were vegetated with approximately 20 m tall trees with no obvious signs of vegetation damage from avalanches, such as flagged trees (missing branches), pistol butts (curved tree trunks), or regrowth of terminal leaders (new vertical tree leader due to a previously damaged one).

4.4.2 Path E-450

The Path E-450 starting zone includes the northern section of an area clear of trees. This opening is clear due to boulder-sized colluvium inhibiting vegetation growth, but patches of short alder are also present that limits further forest growth. The starting zone elevation is approximately 1065 m. The path’s starting zone is part of Path 1 identified by D&E McClung Enterprises Ltd. (2012). The terrain is mostly uniformly sloped towards Edelweiss Drive. The path intersects path E-475 about halfway between the starting zone and Edelweiss Drive, near the edge of the topographical ridge. Below the starting zone clearing, the path is well-vegetated with mature trees but with small (10 m by 10 m) openings. The trees along the path were all approximately 60 years old, consistent with the date of clear-cut logging in the area. There were signs of vegetation damage, including pistol butts and regrowth of terminal leaders, about 40 m upslope of the land parcel boundary, to the south of the Rocky Bluff housing complex. Based on tree age, there may have been an avalanche that reached this area around 20 to 25 years ago.

4.4.3 Path E-405

The starting zone of Path E-405 includes the southern section of an area clear of trees. Much of the opening is clear due to boulder-sized colluvium inhibiting vegetation growth but patches of short alder also exist. The starting zone elevation is approximately 1040 m. The path’s starting zone is in the approximate location of Path 2 identified by D&E McClung Enterprises Ltd. (2012). Mature vegetation below the starting zone were mostly free of vegetation damage, with only minor evidence of flagging of the lower tree limbs. The remainder of the path was well-vegetated with around 20 m tall trees and only a few small areas without vegetation. The topography is relatively uniform, sloping near-perpendicular towards Edelweiss Drive.

4.4.4 Path E-300

The starting zone is a vegetative opening directly beneath rocky cliffs. The rocky cliffs likely frequently shed snow onto the broader starting zone. The starting zone elevation is approximately 1150 m. The path's starting zone is in the approximate location of Path 3 identified by D&E McClung Enterprises Ltd. (2012). The starting zone has likely remained clear of trees due to its composition of boulder-sized colluvium. The path follows a drainage channel with obvious signs of avalanche activity passing through it, such as broken trees and flagging. Vegetative damage was evident within the channel until around the historical logging road about 70 m upslope of Edelweiss Drive.

4.4.5 Path E-90

The starting zone of Path E-90 was covered in snow at the time of the site visit, but it is expected that it has remained free of trees due to a colluvium ground cover, similar to adjacent paths. The starting zone elevation is approximately 1250 m. The path's starting zone is in the approximate location of Path 4 identified by D&E McClung Enterprises Ltd. (2012). This is a prominent avalanche path with historical evidence suggesting that debris has reached near Edelweiss Drive. The starting zone extends further south but was not included in this analysis, as the runout for that section is outside of the study area. The path follows a drainage channel with only sparse mature trees. The trees that exist within the path showed signs of vegetation damage, such as broken trees, flagging, pistol butting, and regrowth of terminal leaders. Many of the trees on either side of the channel were also damaged.

4.4.6 Path SL-105

The starting zone of Path SL-105 is a clearing of vegetation due to colluvium inhibiting vegetation growth. The starting zone elevation is approximately 1000 m. This path was not described by D&E McClung Enterprises Ltd. (2012) but is in the vicinity of the runout of their Path 5. This short path has many anthropogenic activities that have influenced it over the years. Logging in the 1960's removed much of the vegetation in the track and runout of the path, as has the development of logging and access roads. Damage was observed on the trees on the upslope side of the upper road, including damage that appeared to be about 20 to 25 years old (late 1990's or early 2000's). The tree island between the two roads could not be assessed due to potential vegetative damage from road construction and movement of machinery.

4.4.7 Path SL-200

The starting zone of Path SL-200 is a small clearing beneath rocky cliffs, likely due to colluvium inhibiting vegetation growth. The starting zone elevation is approximately 1180 m. This path is in the approximate location of Path 5 described by D&E McClung Enterprises Ltd. (2012); however, the start zone is about 300 m lower than what was identified in the previous report, as topography suggests that snow releasing higher up the slope would flow south and in a direction that would not impact the study area. The starting zone feeds a drainage channel that ends in a vegetative clearing beneath the channel. Given the relatively small starting zone and steep terrain, this path may commonly experience frequent avalanches, which could trigger or entrain additional snow in the vegetative clearing. There is evidence of vegetation damage in the trees below the clearing. An estimation on the path runout length was not possible during the site visit due to vegetative clearing from infrastructure in the sewage lagoons area.

4.5 Statistical and Dynamic Models

Analyses were completed for each path using several statistical and dynamic models. The range of parameters used for each model are summarized in Appendix 6.

Base topography for the models included LiDAR data where it was available for approximately 400 m upslope from Edelweiss Drive and 200 m upslope from the sewage lagoons. LiDAR data was obtained from FVRD via 2 m contours. To utilize the contours for modelling, a triangulated irregular network (TIN) was produced. The resulting TIN had triangles upwards of 10 m in size, suggesting that the LiDAR data was coarse or perhaps filtered prior to the contours being produced. Drainage channels and small-scale terrain features were not visible in the contours and resulting TIN. This limitation affected the accuracy of some of the modelling methods used producing in some areas additional uncertainty with the model results.

Terrain was supplemented by Natural Resource Canada's Canadian Digital Elevation Model (CDEM) for the remainder of Mt. Keenan, which has a spatial resolution of 0.75 arc seconds (NRC, 2013), or approximately 20 m.

For statistical modelling, the Alpha-Beta model (McClung et al., 1989) and Runout Ratio model (McClung and Mears, 1991) were evaluated. These models use a reference position in the runout zone, termed the Beta Point. The Beta Point is the location within the runout zone of the avalanche path where the slope angle first reaches 10°, which is the slope incline that larger, design avalanches typically start to run out and ultimately stop. The Beta Point was determined to be near Edelweiss Drive and the sewage lagoon road for each of the paths, with Beta Point elevations of about 930 to 950 m along Edelweiss Drive and 880 m near the sewage lagoons. The estimated runout distances for the models are presented in Appendix 7.

Four dynamic models were used to estimate snow avalanche velocities as well as assess runout distances of extreme snow avalanches (i.e., approximately 100-year to 300-year return period events). Three one-dimensional models were used, including the PLK model (Perla et al., 1984), PCM model (Perla et al., 1982), and the Leading Edge Model (LEM) (McClung and Mears, 1995). The 2.5-dimensional model RAMMS (Christen et al., 2010) was used. RAMMS is capable of simulating both runout extent and lateral boundaries. The relatively coarse TIN used from the 2 m LiDAR contours increased uncertainty and therefore reduced confidence in the lateral runout extents of the simulations. To increase confidence (or conversely reduce uncertainty) in future assessments, FVRD should obtain unedited LiDAR data.

Each dynamic model requires calibration of one or more input friction parameters (Appendix 6). The modelled avalanche runout distances are presented in Appendix 7.

5.0 Hazard Assessment

The aerial photography, previous reports, site visit, terrain evaluation, and modelling analyses were combined to determine the extents of avalanche runout boundaries for up to 300-year return period snow avalanches. In some cases, especially the field evidence, observations are representative of events with an approximate 100-year return period, which is a limitation of the methods used and available data. Extrapolation of these estimates to the 300-year boundaries was based on calculations, modifying model parameters, and expert judgement. Weighted tables of the results are provided in Appendix 7. Increased weighting was applied for runout extents identified in aerial photographs, the site visit, and previous reporting due to highest confidence in the quality of the data. Less weight was applied for the modelling results due to lower confidence in the data (e.g., coarse LiDAR) and methods (e.g., large range of potential input parameters which are not typically applied to paths like those at Hemlock Valley). Path outlines for the 300-year return period avalanche paths are presented in Drawing 01. Resulting zoning boundaries are presented in Drawing 02.

The assessment did not identify any residential land parcels or infrastructure that are within the Red Zone (high hazard). The interpreted Red Zone is, at minimum, located 10 m upslope of the land parcel boundaries along Edelweiss Drive. The Red Zone intersects a logging road upslope of the sewage lagoons area.

Land Parcels or infrastructure that are located within the interpreted Blue Zone (moderate hazard) include:

- A portion or the entirety of Land Parcels: 20419, 20428, 20429, 20438, 20439, 20449, 20459, 20488, 20489, 20498, 20508, 20518, 20528, 20538, 20559, 20599, 20609.
- Approximately 190 m of Edelweiss Drive over three separate sections.
- Part of the sewage lagoon area, including the northern buildings and northwestern lagoon.

All other areas within the study area are classified as the White Zone (low hazard).

6.0 Forest and Climate Change

6.1 Forest Change

Forest cover is an important factor for assessing snow avalanche hazard. Forest conditions have drastically changed since the 1960's when much of the area was clear-cut. Since then, the forest density on the slopes of Mt. Keenan has increased in most areas.

With continual forest growth and increasing stem density, hazard boundaries are expected to decrease both laterally and with runout extent. Given the colluvium ground conditions in most of the starting zones, forest growth is unlikely to occur in the immediate future in such locations, suggesting that the starting zones will remain open and avalanche activity will continue for many years to come. Should forest density continue to increase in the track and runout zone of the avalanche paths, avalanches that form will experience increased friction, which may result in avalanches stopping higher up the slopes. However, many of the paths follow drainage channels where trees are less likely to grow due to wet soil conditions. As such, it is unlikely that most of the avalanche paths described in this report will disappear until the starting zones are sufficiently vegetated.

Potential methods of forest loss include logging activities, development, infestation, or from geohazards. Logging or development activities should not occur on the slopes of Mt. Keenan upslope of any residential, commercial, or industrial properties or the avalanche hazard boundaries determined in this assessment will likely expand. DAC recommends that such slopes are protected from logging and development activities to inhibit avalanche activity from impacting people and infrastructure. In Europe, these areas are designated as Protection Forests, which are protected by law to mitigate hazard to populated areas.

Other forest changes, such as from infestation or geohazards should be monitored in future years to assess for change. Infestation could increase the size of starting zones or allow for avalanches to travel farther downslope and geohazards (e.g., landslides, debris flows) could progressively form trim lines that could eventually allow for snow avalanches and other geohazards to reach land parcel boundaries.

Should a more detailed analysis be desired on forest change, DAC suggests that a probabilistic approach for forest cover be completed. Such an analysis would provide FVRD with an understanding of the likelihood of substantial forest cover change due to a variety of factors (e.g., fire, pests, logging, recreation) and its effects on the avalanche hazard boundaries.

6.2 Climate Change

It is almost certain that snowpack and avalanche conditions will change over time due to climate change (e.g., IPCC, 2019). With a generally warmer climate in Hemlock Valley, fewer dry snow avalanches may result, as warm air temperature generally promotes bonding within the snowpack and inhibits the growth of persistent weak layers. However, the design event for Hemlock Valley is based on the release of accumulated snowfall amounts over a period of days (e.g., 3-day storm, or longer), which is dependent on short-term winter weather. Although the climate average may change, short-term weather fluctuations are expected to continue. Even with a generally warming climate, it is possible that the design event could become larger, if more extreme snowfall amounts result from long-term climate change.

Given the relatively long timescale of this assessment (up to 300-year return period), conditions that match the design event are expected to periodically occur throughout the period and therefore the findings in this assessment are unlikely to change due to climate change alone. We consider changes in the forest cover to be a more important factor in the Hemlock Valley area than climate change, with respect to long-term avalanche hazard.

7.0 Recommendations

DAC acknowledges that FVRD may rely on this snow avalanche hazard assessment for the issuance of site-specific building permits and development approvals. DAC’s recommendation is to follow the recommendations outlined in CAA (2016), summarized below.

7.1 Occupied Structures

CAA (2016) recommends the following activities based on zone colour:

- White Zone (low hazard): Construction of occupied structures is normally permitted.
- Blue Zone (moderate hazard): Construction of occupied structures may be permitted with specified conditions.
- Red Zone (high hazard): Construction of occupied structures should not be permitted.

Considerations for development in the Blue Zone include number of occupants, timing of occupancy, awareness and acceptance of the risk, the potential implementation of restrictions, and the potential for an effective precautionary evacuation plan. See CAA (2016, Page 63) for additional details regarding these considerations. Development of occupied structures in a Blue Zone could include structural reinforcement to withstand avalanche impact or mitigation measures to modify the avalanche hazard (e.g., deflection dam, snowpack support structures).

For residential land parcels that are partially within the Blue Zone, a restrictive covenant could be placed on the parcel indicating that construction of an occupied structure is permitted in only the portion of the parcel that is in the White Zone. There are precedents in British Columbia for allowing residential development within the portion of a land parcel not affected by avalanches, and limiting the remainder of the property for other uses.

Should development be requested in the Blue Zone, mitigation efforts should be reviewed by FVRD and a qualified Professional Engineer and avalanche professional (or one person that meets both qualifications by virtue of education and experience) prior to approval.

7.2 Unoccupied Structures

The buildings and sewage lagoon do not exceed the criteria outlined in Table 2; i.e., the infrastructure is not exposed to snow avalanche hazard with a return period less than 30 years. Thus, the use of these buildings for industrial (i.e. non-residential) purposes may be considered appropriate, with appropriate risk management measures.

FVRD should assess the importance of the structures in the sewage lagoons area with respect to the identified avalanche hazard. Should it be deemed acceptable that the buildings and other vulnerable infrastructure are damaged or destroyed by a snow avalanche with a return period greater than 30 years, the snow avalanche hazard to personnel could be managed by avoidance or operational safety measures. Avoidance could include no access during winter months and operational measures could include an avalanche hazard assessment by a qualified avalanche professional prior to workers entering the hazard zones. Should the damage or destruction of infrastructure by a snow avalanche result in additional unacceptable consequences (e.g. environmental impacts, disruptive impacts to the community), the structures and area around the sewage lagoons could be protected using engineered structures (e.g., deflection structures) or by a seasonal avalanche safety program including explosive control. The latter may not be an acceptable alternative to engineered structures, depending on the potential consequences to the infrastructure.

New buildings or infrastructure should not be constructed in the Blue Zones without discussion with a qualified Professional Engineer and avalanche professional (or one person that meets both qualifications by virtue of education and experience) about mitigation efforts to protect workers and infrastructure.

7.3 Future Assessments

Hazard boundaries defined in this assessment should be updated should major changes to vegetation and/or terrain occur in the study area, such as to forest cover. Boundaries could also be reviewed if unedited LiDAR data becomes available for the study area.

8.0 Summary

Snow avalanche hazard zone boundaries were prepared for the slopes of Mt. Keenan around Edelweiss Drive and the sewage lagoons area of Hemlock Valley. Red (high hazard), Blue (moderate hazard), and White (low hazard) zone boundaries were prepared to assist FVRD with evaluation and approval of development requests. Boundaries were determined from review of historical photos, reports, snowpack analysis, field surveys of vegetation and terrain, and estimation of runout distances using statistical and dynamic models.

DAC recommends that FVRD follow the recommendations outlined by CAA (2016) for both occupied and unoccupied structures in the study area. Hazard boundaries may change in the future due to forest and/or terrain changes. Zoning boundaries should be updated if substantial changes to the terrain or vegetation cover occur. To increase confidence and reduce uncertainty in future assessments, FVRD should obtain unedited LiDAR data.

9.0 Limitations and Closure

This report has been prepared for the exclusive use of Fraser Valley Regional District for specific application to the subject site. Any use which a third party makes of this report, or any reliance on or decisions made based on this report are the responsibility of such third parties. Dynamic Avalanche Consulting accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

We trust that this report satisfies your present requirements. Should you have any questions, please contact either of the undersigned at your convenience.

Dynamic Avalanche Consulting Ltd.

Report prepared by:

Michael Conlan, P.Eng.

Report reviewed by:

Alan Jones, P.Eng.

References

Canadian Avalanche Association (CAA) (2016). *Technical Aspects of Snow Avalanche Risk Management – Resources and Guidelines for Avalanche Practitioners in Canada*. Prepared by the Canadian Avalanche Association, Revelstoke, BC. 117 pp.

Claus, B.R., Russell, S.O., Schaerer, P. (1984). *Variation of ground snow loads with elevation in Southern British Columbia*. Canadian Journal of Civil Engineering 11(3), 480-493.

Christen, M., Kowalski, J., & Bartelt, P, 2010: *RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain*. Cold Regions Science and Technology 63, 1-14.

Dynamic Avalanche Consulting Ltd. (DAC) (2020a). *Hemlock Valley snow avalanche hazard assessment*. Proposal prepared for Fraser Valley Regional District, dated February 13, 2020.

Dynamic Avalanche Consulting Ltd. (DAC) (2020b). *Snow avalanche zoning recommendation*. Letter prepared for Fraser Valley Regional District, July 2, 2020.

D&E McClung Enterprises Ltd., 2000. *Detailed avalanche map study, Edelweiss Drive: Hemlock Valley, B.C*. Report prepared for Fraser Valley Regional District, January 13, 2000.

D&E McClung Enterprises Ltd., 2004. *Site specific report completed Plan Number 55972, Lot 53*, D&E McClung Enterprises Ltd., August 14, 2004.

D&E McClung Enterprises Ltd., 2010. *Updated snow avalanche report for Hemlock Valley*. Report prepared for Fraser Valley Regional District, October 29, 2010.

D&E McClung Enterprises Ltd., 2012. *Hemlock Valley avalanche study*. Report prepared for Fraser Valley Regional District, March 23, 2012.

Fraser Valley Regional District (FVRD), 2017. *Hazard acceptability thresholds for development approvals*. Prepared by Fraser Valley Regional District, June, 2017.

Fraser Valley Regional District (FVRD), 2019. *Request for information: Hemlock Valley snow avalanche hazard assessment*. Prepared by Fraser Valley Regional District, December 3, 2019.

Freer, G.L., 1981. *Snow avalanche hazard – Hemlock Valley*. Memorandum prepared for Regional Approving Officer, Burnaby, B.C., September 28, 1981.

IPCC (2019). Special Report on the Ocean and Cryosphere in a Changing Climate: Chapter *2: High Mountain Areas*. Report prepared by the International Panel on Climate Change.

Jamieson, B. (ed.) (2017). *Planning Methods for Assessing and Mitigating Snow Avalanche Risk*, (contributions by Jamieson, B., Jones, A., Argue, C., Buhler, R., Campbell, C., Conlan, M., Gauthier, D., Gould, B., Johnson, G., Johnston, K., Jonsson, A., Sinickas, A., Statham, G., Stethem, C., Thumlert, S., Wilbur, C.). Canadian Avalanche Association, Revelstoke, BC. 287 pp.

Jones, A.S.T., Jamieson, J.B., 2004. *Statistical runout estimation for short slopes in Canada*. Annals of Glaciology 38, 363-372.

Liston, G.E., Elder, K. (2006). *A meteorological distribution system for high-resolution terrestrial modeling (MicroMet)*. Journal of Hydrometeorology 7, 217-234.

McClung, D.M. (1999). *The encounter probability for mountain slope hazards*. Canadian Geotechnical Journal 36, 1195-1196.

McClung, D.M. (1999). *The encounter probability for mountain slope hazards*. Canadian Geotechnical Journal 36, 1195-1196.

McClung, D.M., Mears, A.I. (1991). *Extreme value prediction of snow avalanche runout*. Cold Regions Science and Technology 19, 163-175.

McClung, D.M., Mears, A.I. (1995). *Dry-flowing avalanche run-up and run-out*. Journal of Glaciology 41(138), 359-372.

McClung, D.M., Schaerer, P. (2006). *The Avalanche Handbook*. The Mountaineers Books, Seattle. 342 pp.

McClung, D.M., Mears, A.I., Schaerer, P. (1989). *Extreme avalanche runout: data from four mountain ranges*. Annals of Glaciology 13, 180-184.

Mears, A.I., 1982. *Avalanche hazard analysis and land-use recommendations at selected portions of Hemlock Bowl, British Columbia*. Report prepared for Hemlock Valley Recreations Ltd., January 7, 1982.

Natural Resources Canada (NRC), 2013. *Canadian Digital Elevation Model Product Specifications – Edition 1.1.* Report prepared by Natural Resources Canada – Canada Centre for Mapping and Earth Observation, April 1, 2013.

Nixon, D., McClung, D.M. (1993). *Snow avalanche runout from two Canadian Mountain ranges*. Annals of Glaciology 18, 1-6.

Perla, R., Cheng, T.T., McClung, D.M. (1982). *A two-parameter model of snow-avalanche motion*. Journal of Glaciology 26(94), 197-207.

Perla, R.I., Lied, K., Kristensen, K. (1984). *Particle simulation of snow avalanche motion*. Cold Regions Science and Technology 9, 191-202.

APPENDIX 1
ZONING FOR OCCUPIED STRUCTURES, EXCERPT FROM CAA (2016)

Appendix 1: Example of Avalanche Terrain Classification Systems

Impact-based Terrain Classification: Hazard Zones for Occupied Structures

The system of hazard analysis and terrain classification for occupied structures shown in Figure A1.1 and Table A1.1 was developed by the Canadian Avalanche Association after reviewing similar systems in Switzerland and Austria. It applies to all occupied structures. Figure 4.7 (Chapter 4) is an example hazard map based on this classification system. Recommended zoning restrictions for occupied structures in Canada are listed in Section 8.2.2.

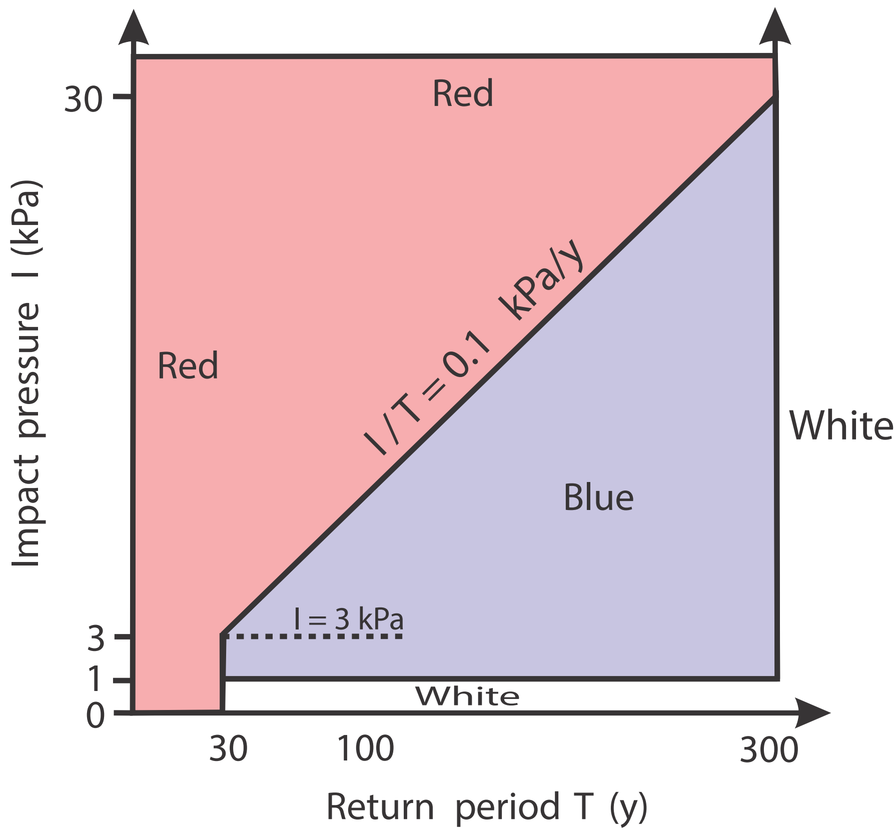


Figure A1.1: *Hazard zones for occupied structures in Canada. Definition for each zone are listed in Table A1.1.*

Table A1.1: *Definitions for the three zones used for occupied structures in Canada as shown Figure A1.1.*

Zone colour	**Definition**
White	An area with an estimated avalanche return period of > 300 years, or impact pressures < 1 kPa with a return period of > 30 years.
Blue	An area which lies between the red and white zones where the impact pressure divided by the return period is < 0.1 kPa/year for return periods between 30 and 300 years, and impact pressures ≥ 3 kPa. The blue zone also includes areas where impact pressures are between 1 and 3 kPa with return periods of > 30 years.
Red	An area where the return period is < 30 years and/or impact pressures are ≥ 30 kPa, or where the impact pressure divided by the return period is > 0.1 kPa/year for return periods between 30 and 300 years.

APPENDIX 2
HISTORICAL AERIAL PHOTOGRAPHS

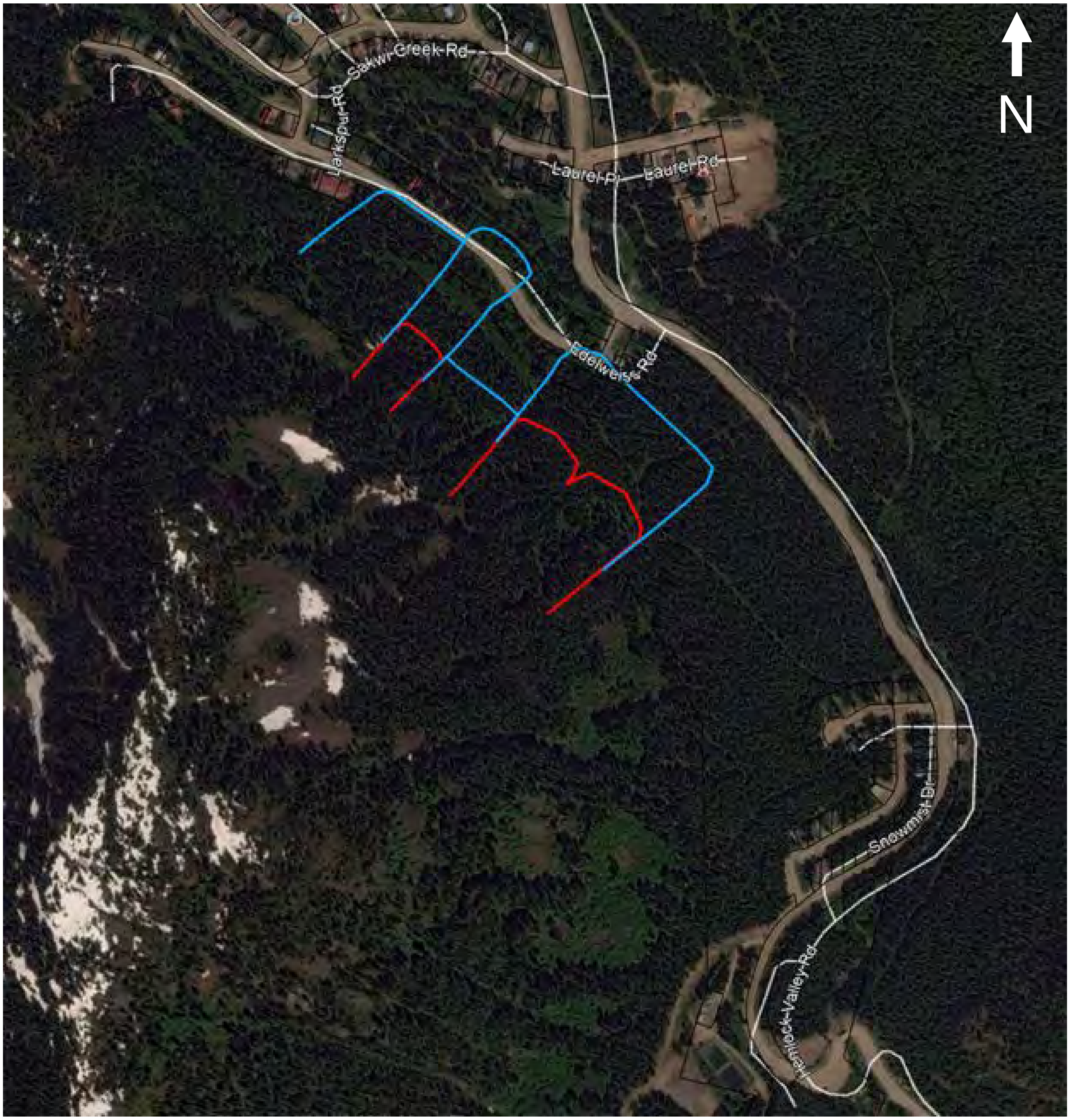
The following aerial photographs were reviewed:

- 1930: A2246/2, obtained from Natural Resources Canada
- 1951: A13245/42, obtained from Natural Resources Canada
- 1968: BC7105/147, obtained from Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Government of British Columbia
- 1983: BC83018/100, obtained from Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Government of British Columbia
- 2002: BCC02030/44, obtained from Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Government of British Columbia
- 2003: georeferenced imagery labelled bc_092h031_xc1m_utm10_2003, obtained from FVRD
- 2016: georeferenced imagery labelled HemlockValley_20160629_30cm, obtained from FVRD

APPENDIX 3
HAZARD BOUNDARIES FROM PREVIOUS REPORTS

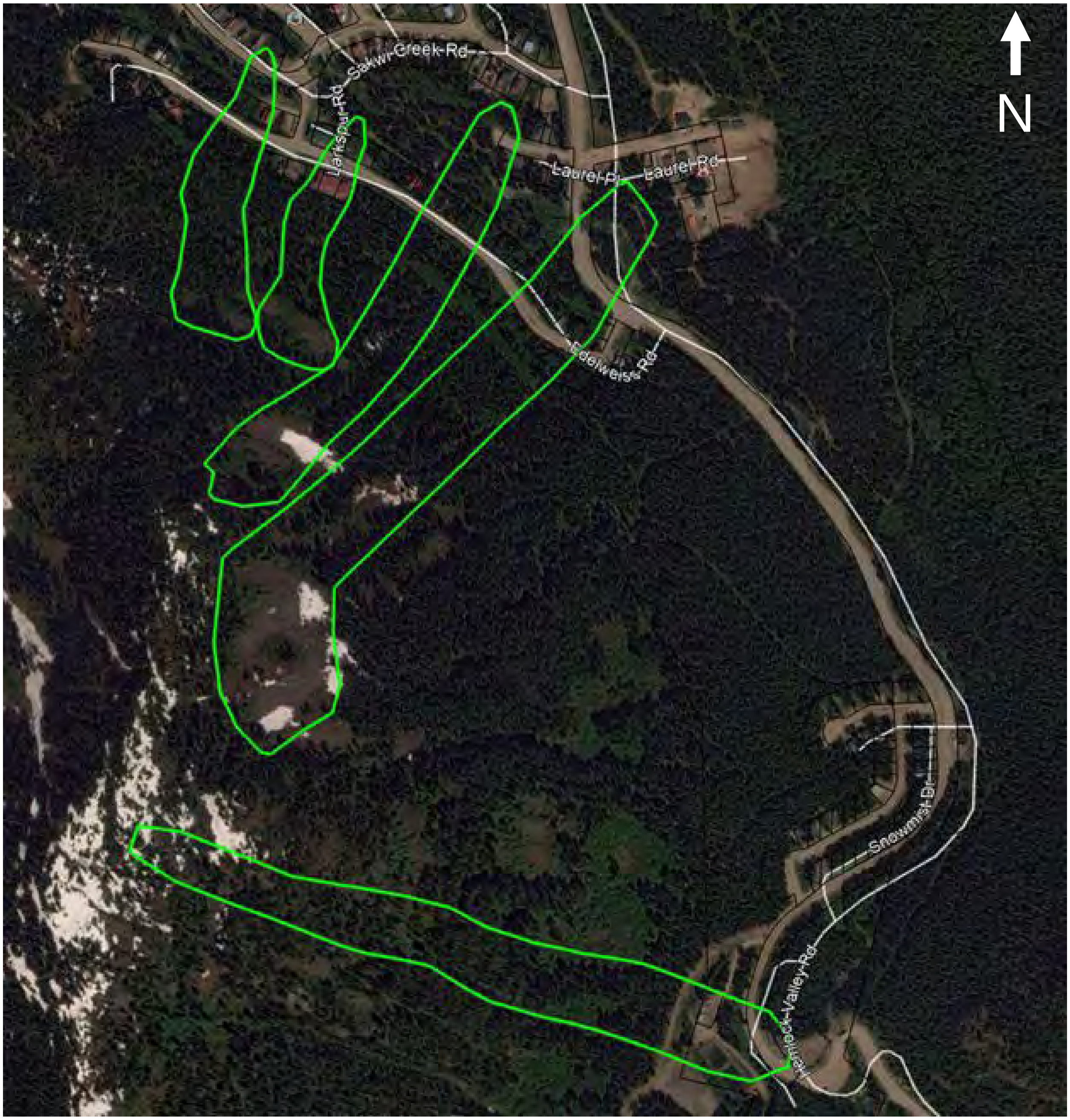
Zoning boundaries from Freer (1981), for 300-year return period snow avalanches. Boundaries are approximate and interpreted by DAC from the original report. Map is not to scale.

Zoning boundaries from Mears (1982), for 100-year return period snow avalanches. Boundaries are approximate and interpreted by DAC from the original report. Map is not to scale.

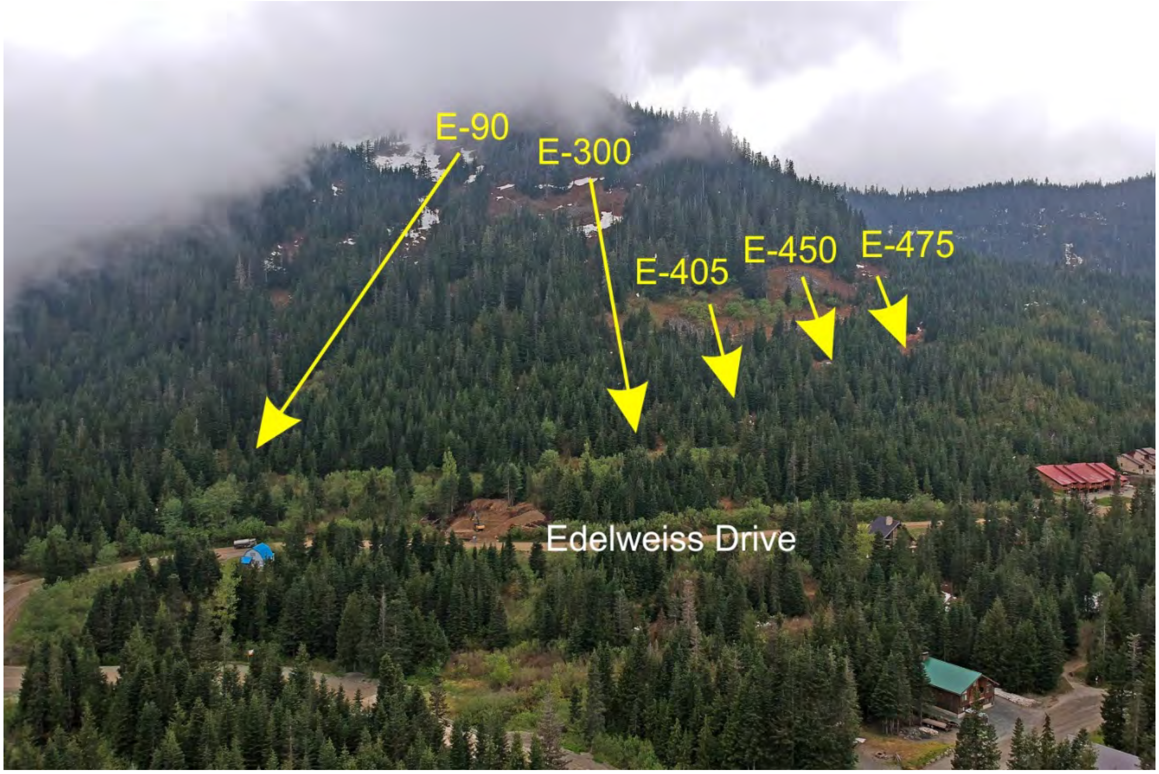


Zoning boundaries from D&E McClung Enterprises Ltd. (2010), for 300-year return period snow avalanches. Boundaries are approximate and interpreted by DAC from the original report. Map is not to scale.

Hazard boundaries from D&E McClung Enterprises Ltd. (2012), for 500-year return period snow avalanches. Boundaries are approximate and interpreted by DAC from the original report. Map is not to scale.

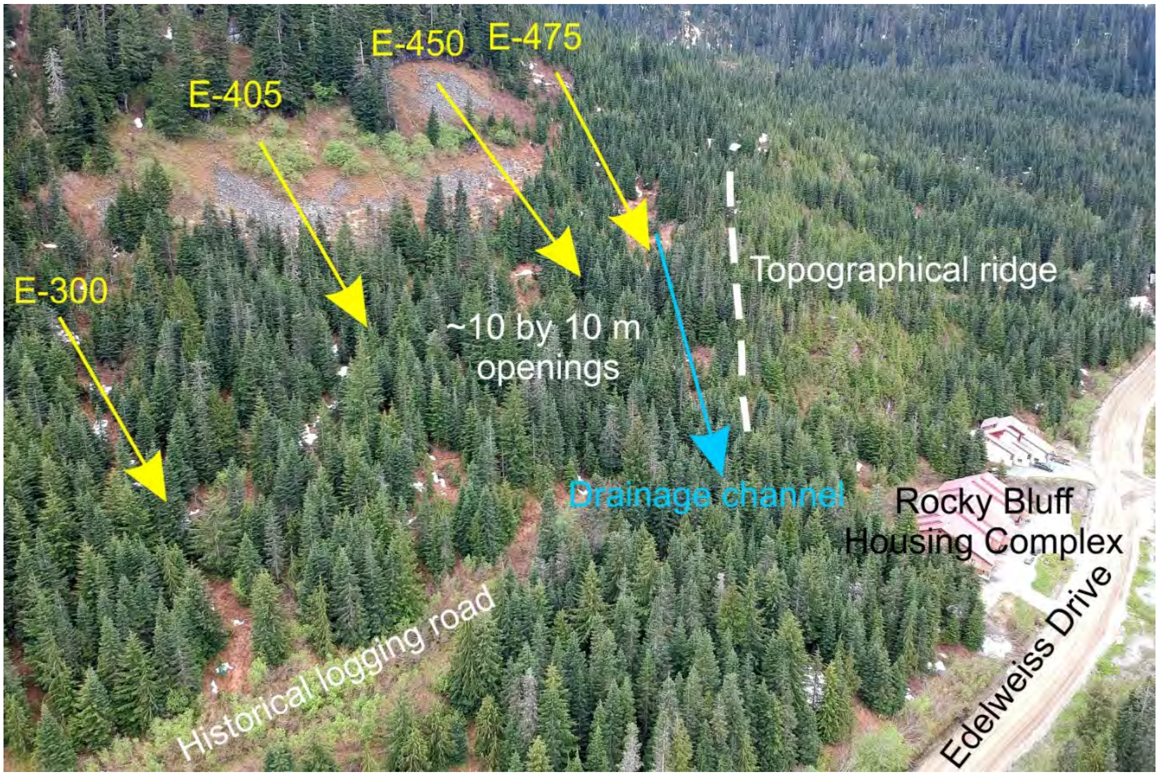


APPENDIX 4
PHOTOGRAPHS FROM SITE VISIT



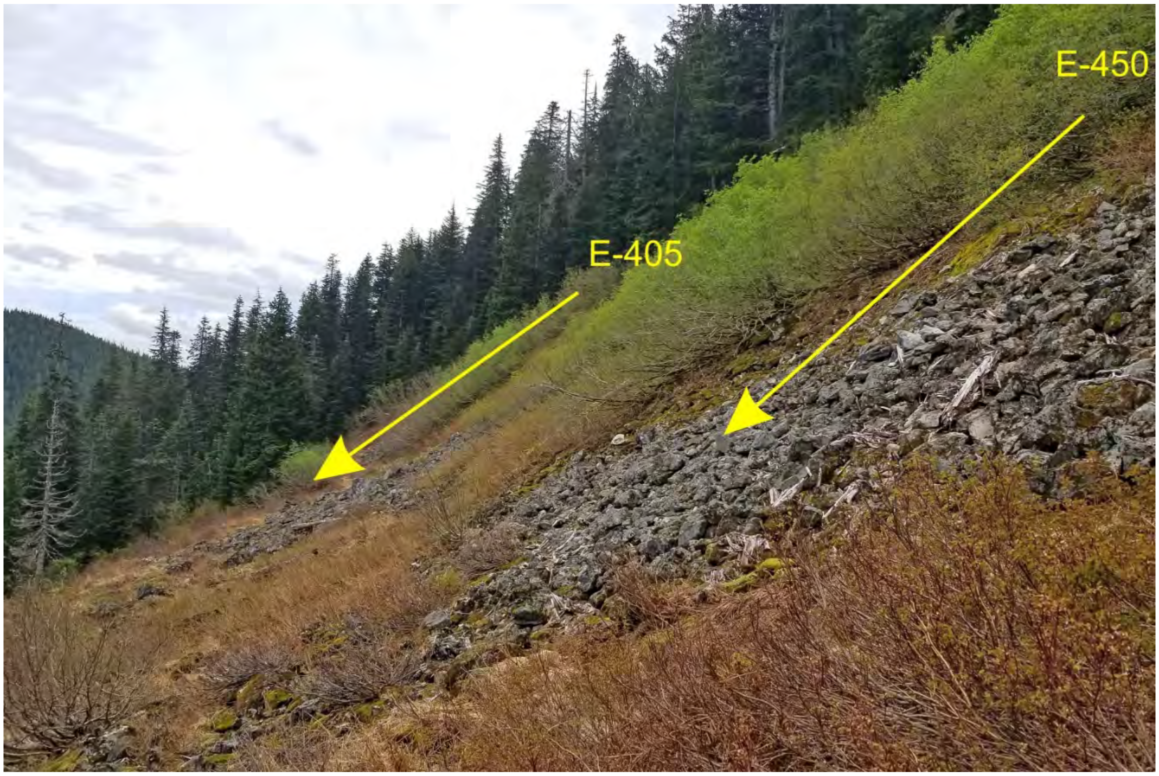
Photograph 1. Looking southwest towards the paths above Edelweiss Drive.

Photograph 2. Looking southwest with black outlines around the starting zones of the paths above Edelweiss Drive.

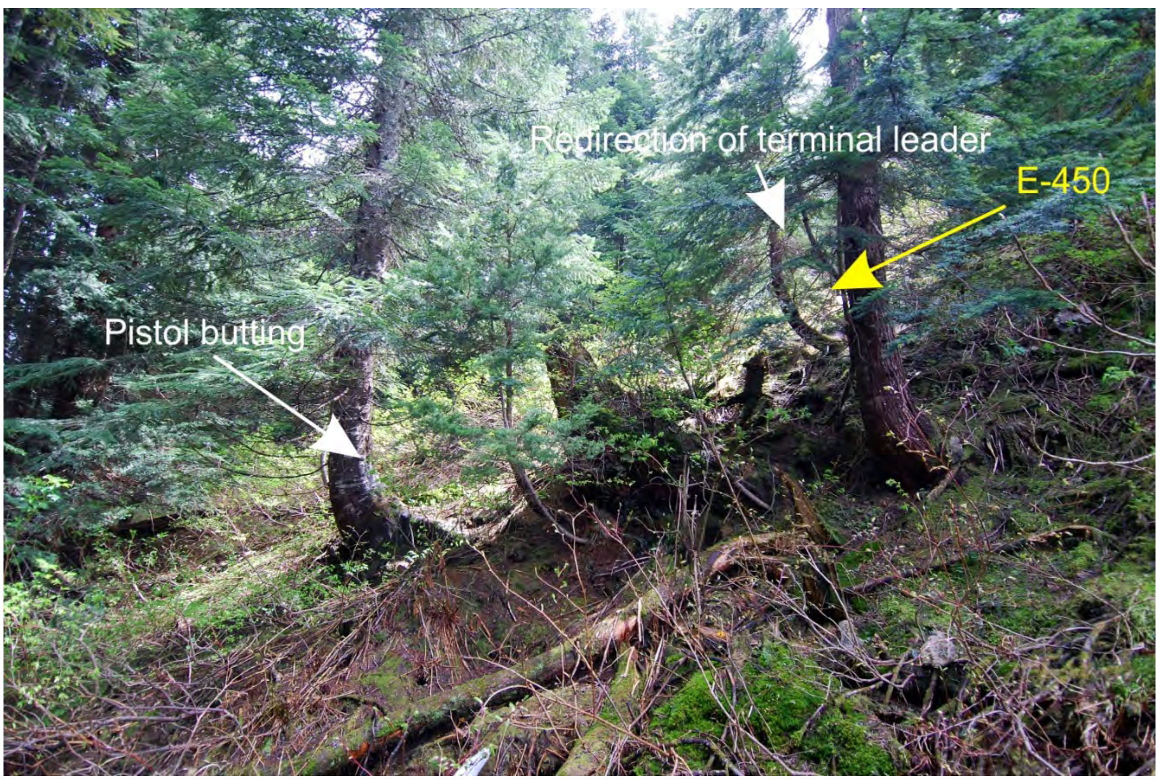


Photograph 3. Looking west towards paths E-475, E-450, E-405, and E-300 above Edelweiss Drive.

Photograph 4. Looking northeast and downslope from near the starting zone of path E-475.

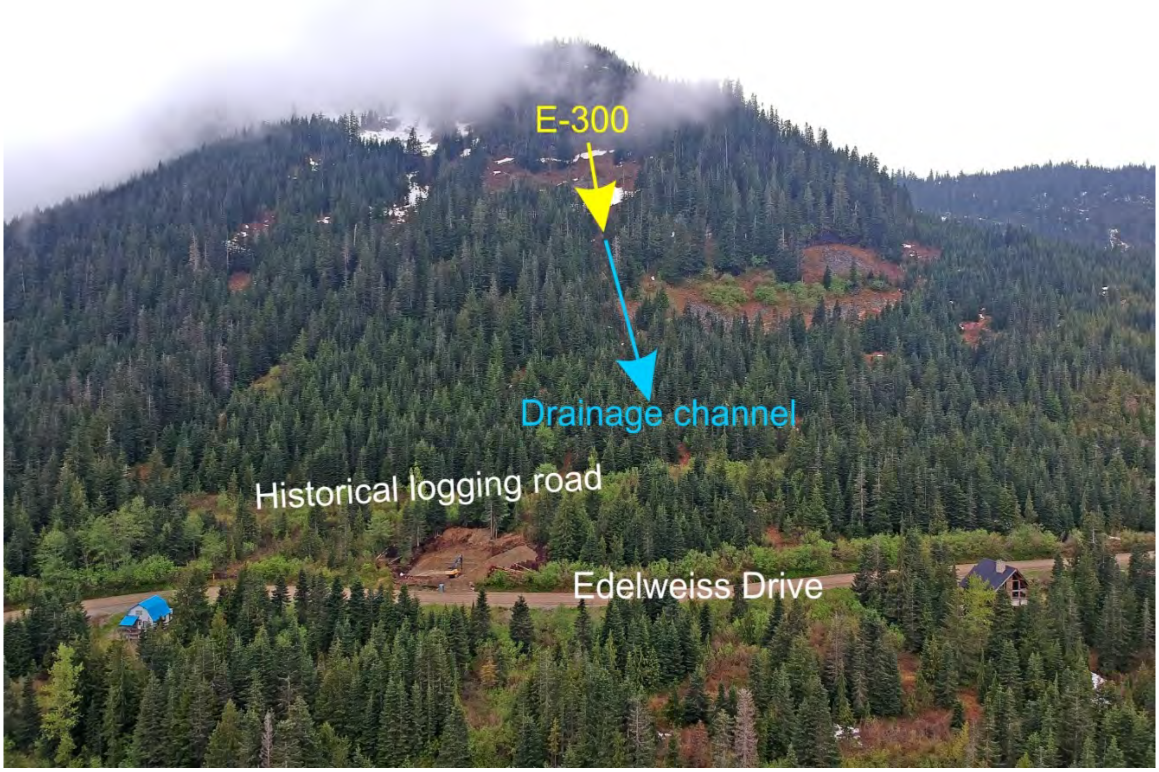


Photograph 5. Looking east towards the starting zones of paths E-450 and E-405.

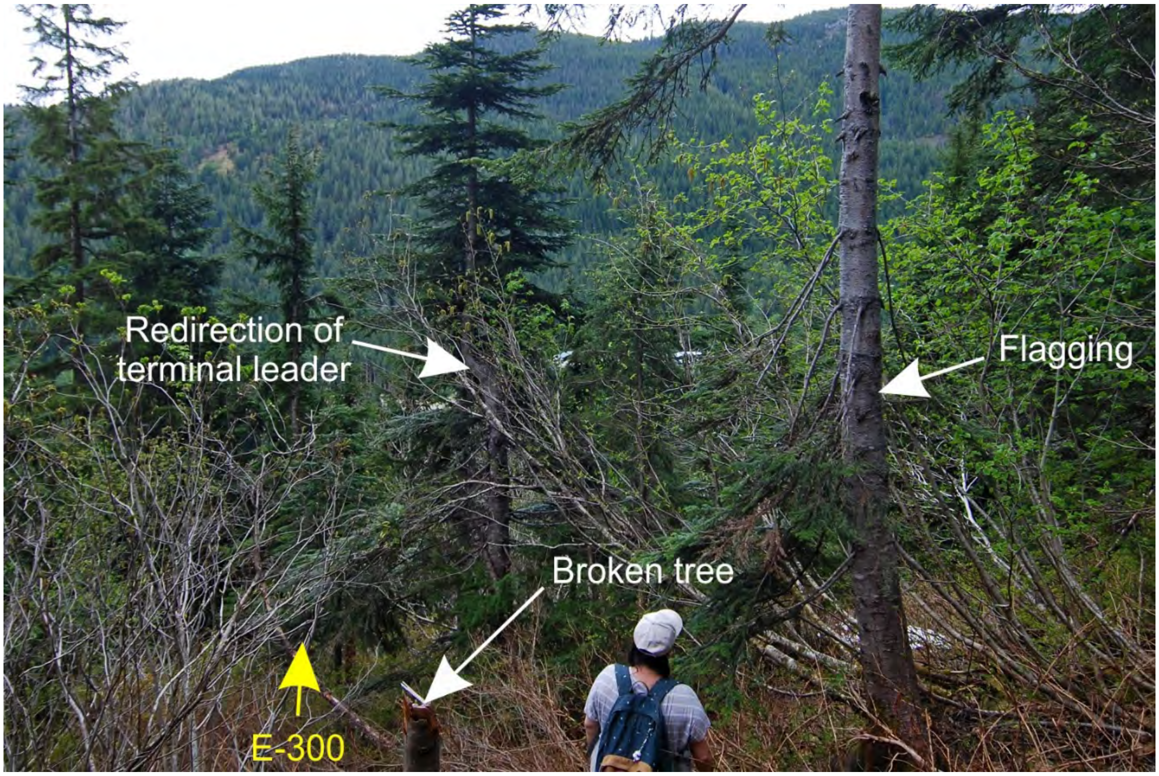


Photograph 6. Looking southeast towards vegetation damage about 90 m upslope of Edelweiss Drive within path E-450.

Photograph 7. Looking south towards the starting zone of paths E-450 and E-405.



Photograph 8. Looking southwest towards path E-300.



Photograph 9. Looking northeast and downslope along path E-300 towards vegetation damage in the track of the path.

Photograph 10. Looking southwest towards path E-90.

Photograph 11. Looking northeast and downslope along path E-90, looking towards vegetative clearing and damage of vegetation within the track.

Photograph 12. Looking west towards paths SL-105 and SL-200 above the sewage lagoons and buildings. Avalanche paths exist adjacent to these paths but do not intersect the study area.

Photograph 13. Looking west towards paths SL-105 and SL-200 above the sewage lagoons buildings.

Photograph 14. Examples of vegetation damage within the runout zones of paths SL-105 and SL-200.

APPENDIX 5
SNOW AVALANCHE PATH PROFILES

Path E-475

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1087	30	Top of starting zone
25	1073	30	Bottom of starting zone
50	1056	33	
75	1040	33	
100	1026	29	
115	1020	24	Channel clear of trees
125	1015	25	
150	1003	26	
175	992	25	
200	981	23	
220	973	22	
225	971	23	
250	962	20	
275	953	20	Land parcel boundary @ 283 m
300	945	17	Beta point @ 300 m
325	944	1	Edelweiss Drive west side @ 325 m
350	939	13	Edelweiss Drive east side @ 345 m

Path E-450

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1071	34	Top of starting zone
25	1054	34	
50	1037	35	Bottom of starting zone
75	1020	34	
100	1007	29	
125	996	24	10 x 10 m openings
150	985	23	
175	975	22	
200	965	22	
225	957	18	
250	950	16	Land parcel boundary @ 245 m
275	946	7	Beta point @ 265 m
300	942	10	Edelweiss Drive west side @ 289 m; Edelweiss Drive east side @ 303 m
325	935	15	

Path E-405

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1048	35	Top of starting zone
25	1030	35	
50	1016	30	Bottom of starting zone
75	1002	29	Dense trees
100	990	27	
125	980	22	
150	971	20	
175	965	13	Historical logging road
200	958	16	
225	951	15	Land parcel boundary @ 219 m
250	946	11	Beta point @ 255 m
275	940	14	Edelweiss Drive west side @ 260 m; Edelweiss Drive east side @ 278 m
300	934	14	

Path E-300

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1189	44	Top of starting zone
25	1164	45	
50	1142	42	
75	1123	36	Bottom of starting zone
100	1106	34	
125	1088	36	
150	1064	44	
175	1040	44	
200	1026	28	Channel with trees showing extensive damage
225	1013	28	
250	1002	25	
275	992	22	
300	981	24	
325	971	21	
350	963	20	
375	956	15	Historical logging road
400	949	16	
425	942	15	Edelweiss Drive west side @ 437 m
450	937	12	Edelweiss Drive east side @ 455 m
475	932	11	Beta point @ 465 m
500	926	14	
525	923	7	
550	923	0	
575	925	5	
600	926	2	
625	925	2	

Path E-90

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1255	42	Top of starting zone
25	1233	42	
50	1210	43	
75	1188	41	Bottom of starting zone
100	1171	35	
125	1152	37	
150	1132	38	
175	1113	38	
200	1098	31	
225	1085	27	Wide channel clear of trees
250	1072	28	
275	1065	16	
300	1042	42	
325	1032	23	
350	1013	37	
375	1002	24	
400	991	23	
425	978	29	End of wide channel clear of trees
450	964	28	
475	953	25	
500	946	14	Historical logging road
525	939	15	Land parcel boundary @ 512 m
550	935	11	Edelweiss Drive west side @ 560 m; Beta point @ 565 m
575	930	10	Edelweiss Drive east side @ 579 m
600	926	10	
625	922	8	
650	920	5	Hemlock Valley Road west side @ 648 m

Path SL-105

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1005	43	Top of starting zone
25	981	43	
50	958	43	Bottom of starting zone
75	940	35	
100	924	34	
125	911	27	
150	898	26	
175	888	22	Trimline @ 190 m
200	881	17	
225	875	13	Beta point @ 235 m; Road @ 238 m
250	871	10	
275	867	8	Sewage building land parcel upslope boundary @ 274 m
300	865	5	Sewage building land parcel upslope boundary @ 298 m

Path SL-200

Horizontal Distance (m)	Elevation (m)	Average slope angle (°)	Comments
0	1184	47	Top of starting zone
25	1157	47	
50	1140	34	Bottom of starting zone
75	1123	35	
100	1107	33	
125	1082	45	
150	1056	47	
175	1032	43	
188	1020	43	
200	1008	43	
225	988	39	
250	968	40	Vegetative clearing
275	947	40	
300	928	37	
325	910	37	Trimline
350	896	28	
375	888	19	
400	882	12	Beta point @ 420 m
425	878	10	Road @ 430 m
450	874	8	Sewage lagoon lot line boundary @ 465 m
475	868	14	Sewage lagoon @ 482 m
500	865	6	
525	862	7	

APPENDIX 6
STATISTICAL AND DYNAMIC MODEL PARAMETERS

Assumptions for Alpha Beta model

$\alpha = 21.11 + 22.41HoY'' - 3.02TP + 0.01Ho$ (Jones and Jamieson, 2004)

Assumptions for Runout Ratio model

u = 0.494 (Jones and Jamieson, 2004)

b = 0.441 (Jones and Jamieson, 2004)

Non-exceedance probability of 0.5

Assumptions for PLK, PCM, LEM, and RAMMS dynamic models.

<table>
<tr><th rowspan="2">Path</th><th colspan="3">PLK</th><th colspan="2">PCM</th><th colspan="2">LEM</th><th colspan="2">RAMMS</th></tr>
<tr><th>μ</th><th>log M/D</th><th>R</th><th>M/D</th><th>μ</th><th>μ</th><th>v_0 (m/s)</th><th>Release depth</th><th>Friction</th></tr>
<tr><td>E-475</td><td rowspan="7">0.3</td><td rowspan="7">2.2</td><td rowspan="7">0.2</td><td rowspan="7">0.8*H</td><td rowspan="7">0.25 for starting zone
0.25 in open track
0.30 in partial trees
0.40 in dense trees
0.35 near road</td><td rowspan="7">0.47 for open trees
0.50 for partial trees
0.53 for dense trees
0.55 for large path</td><td rowspan="7">0</td><td rowspan="7">1.5 m</td><td>Tiny 300-yr</td></tr>
<tr><td>E-450</td><td>Tiny 300-yr</td></tr>
<tr><td>E-405</td><td>Tiny 300-yr</td></tr>
<tr><td>E-300</td><td>Small 300-yr</td></tr>
<tr><td>E-90</td><td>Small 300-yr</td></tr>
<tr><td>SL-105</td><td>Small 300-yr</td></tr>
<tr><td>SL-200</td><td>Tiny 300-yr</td></tr>
</table>

APPENDIX 7
WEIGHTED TABLES OF RUNOUT DISTANCE FOR PATHS

Path E-475

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	40	good	3	fair	220	0.6
	Field survey	125	good	20	good		
Statistical models	Alpha-beta	308	fair	100	good	320	0.2
	Runout Ratio	303	fair	100	good		
Dynamic models	PLK	323	fair	100	fair	305	0.2
	PCM	303	fair	100	fair		
	LEM	223	poor	100	fair		
	RAMMS	268	fair	300	fair		
Weighted average 300-year dense flow runout						**257**	**1**

Path E-450

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	75	good	10	fair	290	0.6
	Field survey	205	good	30	fair		
Statistical models	Alpha-beta	270	fair	100	good	300	0.2
	Runout Ratio	180	fair	100	good		
Dynamic models	PLK	274	fair	100	fair	305	0.2
	PCM	262	fair	100	fair		
	LEM	270	poor	100	fair		
	RAMMS	290	fair	300	fair		
Weighted average 300-year dense flow runout						**295**	**1**

Path E-405

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	58	good	10	fair	115	0.6
	Field survey	58	good	10	fair		
Statistical models	Alpha-beta	225	fair	100	good	220	0.2
	Runout Ratio	170	fair	100	good		
Dynamic models	PLK	236	fair	100	fair	225	0.2
	PCM	185	fair	100	fair		
	LEM	178	poor	100	fair		
	RAMMS	212	fair	300	fair		
Weighted average 300-year dense flow runout						**158**	**1**

Path E-300

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	480	good	100	fair	495	0.6
	Field survey	360	good	30	good		
Statistical models	Alpha-beta	495	fair	100	good	510	0.2
	Runout Ratio	484	fair	100	good		
Dynamic models	PLK	436	fair	100	fair	495	0.2
	PCM	445	fair	100	fair		
	LEM	489	poor	100	fair		
	RAMMS	440	fair	300	fair		
Weighted average 300-year dense flow runout						**498**	**1**

Path E-90

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	495	good	100	fair	565	0.6
	Field survey	435	good	30	good		
Statistical models	Alpha-beta	640	fair	100	good	640	0.2
	Runout Ratio	595	fair	100	good		
Dynamic models	PLK	565	fair	100	fair	630	0.2
	PCM	592	fair	100	fair		
	LEM	583	poor	100	fair		
	RAMMS	560	fair	300	fair		
Weighted average 300-year dense flow runout						**593**	**1**

Path SL-105

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	~	none	~	none	~	0
Forest damage	Air photos	192	good	10	fair	280	0.6
	Field survey	205	good	20	good		
Statistical models	Alpha-beta	239	fair	100	good	290	0.2
	Runout Ratio	260	fair	100	good		
Dynamic models	PLK	265	fair	100	fair	305	0.2
	PCM	254	fair	100	fair		
	LEM	280	poor	100	fair		
	RAMMS	295	fair	300	fair		
Weighted average 300-year dense flow runout						**287**	**1**

Path SL-200

Estimation method		Horizontal distance along path (m)	Confidence in runout	Return period of time elapsed (years)	Confidence in time scale	Horizontal distance along path for 300-yr (m)	Weight w_i
Historical records	Reports	480	poor	100	fair	520	0.2
Forest damage	Air photos	440	good	80	fair	510	0.4
	Field survey	350	good	20	good		
Statistical models	Alpha-beta	415	fair	100	good	520	0.2
	Runout Ratio	585	fair	100	good		
Dynamic models	PLK	463	fair	100	fair	520	0.2
	PCM	514	fair	100	fair		
	LEM	577	poor	100	fair		
	RAMMS	415	fair	300	fair		
Weighted average 300-year dense flow runout						**516**	**1**

DRAWINGS

Hemlock Valley Snow Avalanche Hazard Assessment

Avalanche Path Map

Fraser Valley Regional District

- Study Area
- Blue Zone
- Red Zone
- Avalanche Path
- Roads
- Streams
- Land Parcel

Contour Line

- Index Contour
- Intermediate Contour

NOTES:
1. Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.
2. Coarse contour interval 20 m. Fine contour interval 2 m.
3. Avalanche hazard was not assessed outside of the study area boundaries. Unmarked avalanche hazards may exist within the study area boundary, for example upslope of defined avalanche paths, but are of insufficient scale to affect residential land parcels.

Data Sources:
1. Base imagery and LiDAR from FVRD
2. 20 m topographic data contains information licensed under the Open Government License - Canada.

N

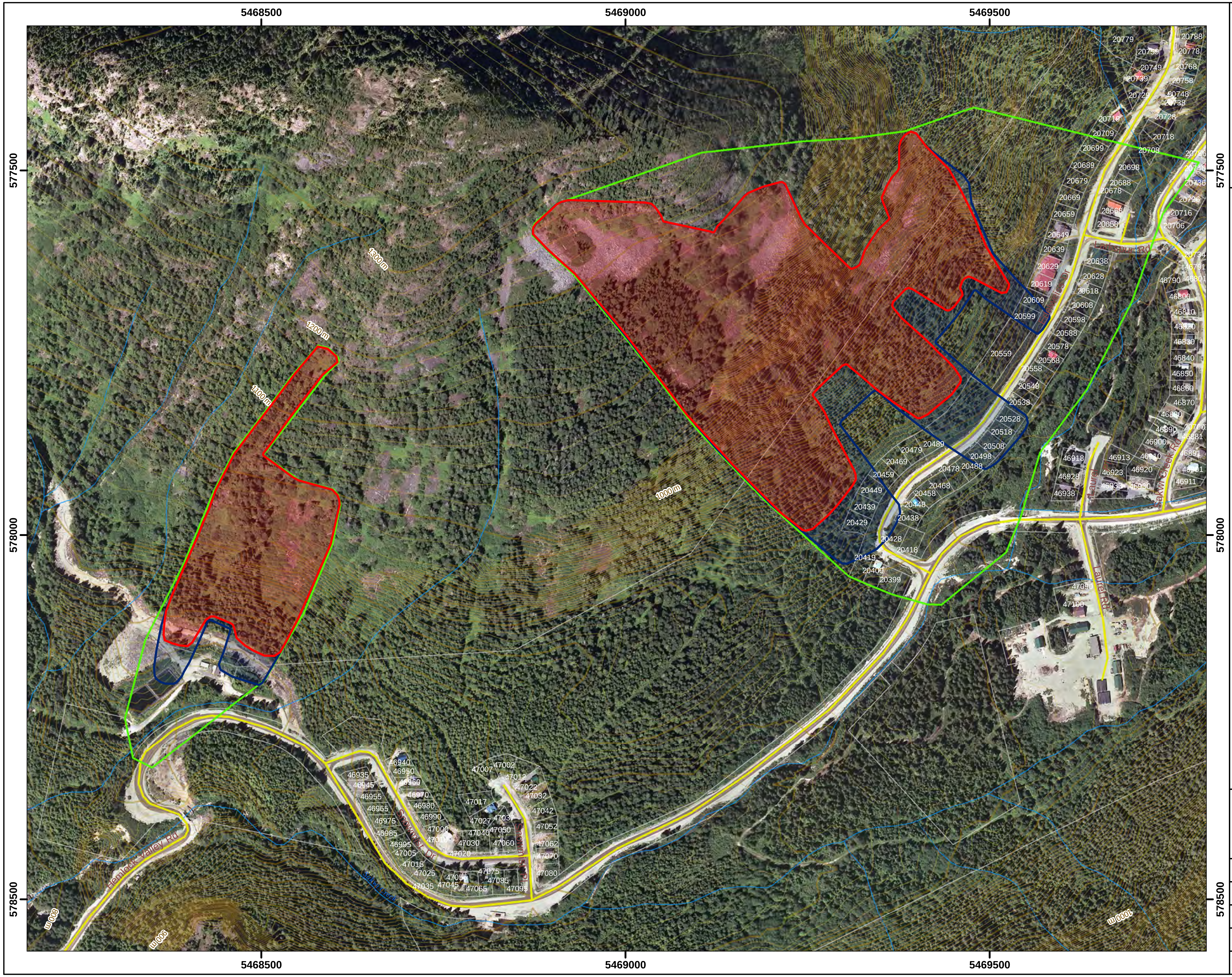
Meters

0 50 100 150 200

Scale: 1:5,000
Coordinate System: NAD 1983 UTM Zone 10N
Unit: Meter

DYNAMIC
AVALANCHE CONSULTING LTD
Box 2845 Revelstoke, BC, Canada V0E 2S0
Ph: (250) 837-4466 dynamicavalanche.com

Drawing Number:	20-0009-FVR-001
Date:	2020-09-29
Designed by:	Mike Conlan, P.Eng
Reviewed by:	Alan Jones, P. Eng
Drawn by:	Dan Rohn, EIT



Hemlock Valley Snow Avalanche Hazard Assessment

Avalanche Hazard Map

Fraser Valley Regional District

- Study Area
- Blue Zone
- Red Zone
- Avalanche Path
- Roads
- Streams
- Land Parcel

Contour Line

- Index Contour
- Intermediate Contour

NOTES:
1. Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.
2. Coarse contour interval 20 m. Fine contour interval 2 m.
3. Avalanche hazard was not assessed outside of the study area boundaries. Unmarked avalanche hazards may exist within the study area boundary, for example upslope of defined avalanche paths, but are of insufficient scale to affect residential land parcels.

Data Sources:
1. Base imagery and LiDAR from FVRD
2. 20 m topographic data contains information licensed under the Open Government License - Canada.

N

Meters

0 50 100 150 200

Scale: 1:5,000
Coordinate System: NAD 1983 UTM Zone 10N
Unit: Meter

DYNAMIC
AVALANCHE CONSULTING LTD
Box 2845 Revelstoke, BC, Canada V0E 2S0
Ph: (250) 837-4466 dynamicavalanche.com

Drawing Number:	20-0009-FVR-002
Date:	2020-09-29
Designed by:	Mike Conlan, P.Eng
Reviewed by:	Alan Jones, P. Eng
Drawn by:	Dan Rohn, EIT