Snow Avalanche Risk Zone Mapping

for

Gar Creek, Johnsons Landing, British Columbia

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EXECUTIVE SUMMARY

At the request of Doug Nicol, P.Eng. of SNT Engineering Ltd., Dynamic Avalanche Consulting Ltd. (DAC) conducted an investigation of snow avalanche risk for the Gar Creek area where a large landslide occurred located at Johnsons Landing, British Columbia. This work was conducted in accordance with the risk guidelines described in the *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada* (Canadian Avalanche Association [CAA], 2002).

A field investigation of terrain and vegetation was conducted by DAC, and historical air photos and orthophotos were reviewed. Topographic maps and snow survey data were also compiled and reviewed. Statistical and dynamic runout modelling were conducted to determine potential long-term avalanche runout distances, speeds and impact pressures.

Two avalanche hazard scenarios were considered:

1) A temporary bank reinforcement constructed at the first major bend in the Gar Creek gully at 750 m. The bank reinforcement increases the existing gully sidewall height to approximately 10 m; and
2) No bank reinforcement at the first major bend in the Gar Creek gully.

The high risk Red Zone in Scenario 1 is located within the Gar Creek gully. This area overlays portions of Lot L9663 and P9136. In Scenario 2, the Red Zone includes portions of Lot L9663, P9136, and P876.

The moderate risk Blue Zone in Scenario 1 is located on the landslide debris fan at an elevation of 735 m to 760 m. The Blue Zone is the area where avalanche impact loads are greater than 1 kPa with a return period in the range of 30 to 300 years. This area overlays parts of Lots P9136 and P876. Avalanches may reach outside of the Blue Zone, but are expected to have impact pressures of less than 1 kPa or have impact pressures greater than 1 kPa with a return period of greater than 300 years. In Scenario 2 the Blue Zone is located further downslope and includes parts of Lots P9136 and P876.

This report is accompanied by three maps that detail avalanche risk in the project area:

- Johnsons Landing - Gar Creek Avalanche Path Overview; 12-0047-SNT-001,
- Johnsons Landing - Gar Creek Avalanche Risk Zones with a Channel Depth of 10 m; 12-0047-SNT-003,
- Johnsons Landing - Gar Creek Avalanche Risk Zones with a Channel Depth of 0 – 5 m; 12-0047-SNT-006.

1 INTRODUCTION AND SCOPE

At the request of Doug Nicol, P.Eng., of SNT Engineering Ltd., Dynamic Avalanche Consulting Ltd. (DAC) conducted an investigation of snow avalanche hazard and risk for the recent landslide area at Johnsons Landing, BC (Figure 1). The purpose of this project was to determine if the Johnsons Landing landslide increased the snow avalanche risk to private property and residential homes, and to determine avalanche risk zones for locating permanent residential structures.

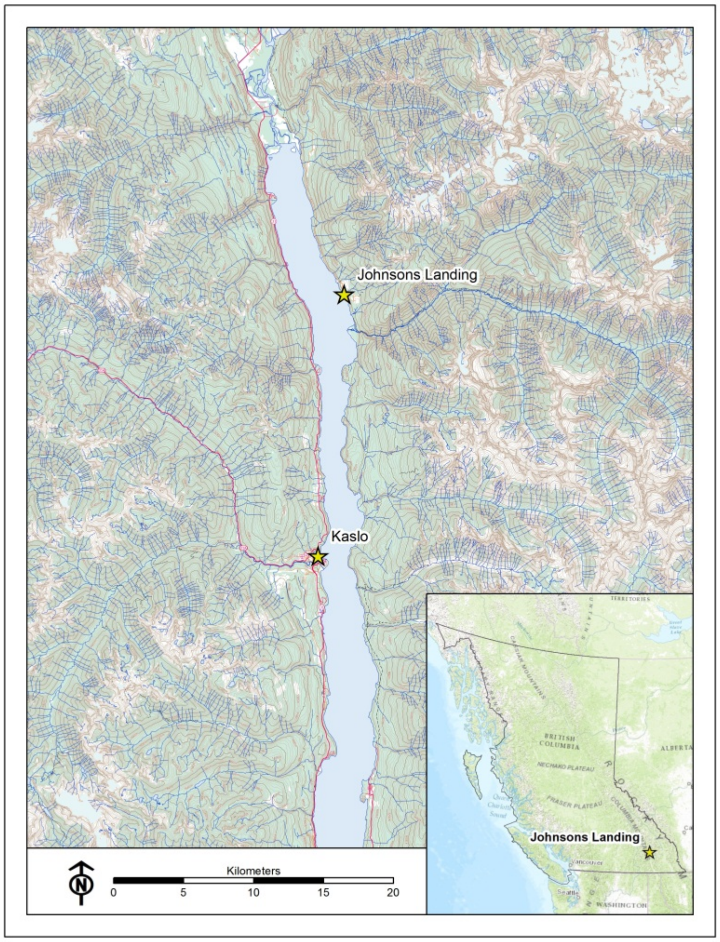

Figure 1. Locator map for Gar Creek, Johnsons Landing, BC.

A field investigation of terrain and vegetation was conducted on October 5, 2012 by Greg Johnson, EIT of DAC. Historical air photos and orthophotos were reviewed. Topographic maps and snow survey data were also reviewed. Statistical and dynamic avalanche runout modelling was conducted to estimate potential long-term runout distances, speeds and impact pressures.

The discussion and recommendations provided in this report follow the guidelines described in the *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada* (Canadian Avalanche Association [CAA], 2002). The deliverables for this project include this report and maps showing the avalanche risk zones for occupied structures, as defined in CAA (2002).

2 BACKGROUND

2.1 Characteristics of Snow Avalanches

A snow avalanche consists of a volume of snow that moves downslope under the effect of gravity. Avalanches also may contain rock, broken trees, soil or ice in addition to snow. There are two general types of snow avalanches:

1) Slab avalanche – involves a cohesive layer of snow that “breaks” away from the underlying snow surface in the starting zone. Slab avalanche initiation results in a distinct fracture line in the starting zone;
2) Loose snow avalanche – involves the release of surface snow with little or no cohesion. As this volume of snow begins to accelerate, it may entrain significant amounts of surface snow as it travels down slope. This is often the case with wet, loose snow avalanches descending in snow covered gullies.

Loose snow avalanches, which may become large in wet snow conditions, are typically smaller and less destructive than slab avalanches. Slab avalanches are typically more dangerous and result in the largest and farthest running avalanche events.

Avalanches can be further characterized as either dry or wet, depending on snow water content. Wet avalanches tend to move slower and may be deflected or channelled by terrain features such as gullies. Large, dry avalanches are more likely to deviate from traditional paths, overrun terrain features, and travel faster, reaching speeds of up to 60 m/s (200 km/h); these are often used as the design avalanche for planning and engineering purposes. Dry snow avalanches that begin at higher elevations may become wet or moist while flowing to lower elevations.

Large, dry avalanches typically have two distinct layers: a dense core that flows along the ground or snow surface, and a low density (powder) layer that flows above and sometimes ahead of the denser layer. These two layers may occasionally separate and flow independently. The dense core has a typical flow depth of 1-3 m while the powder component may reach tens of metres in height. The dense core of an avalanche has a much higher impact pressure than the lower density powder component.

2.2 Avalanche Path

An avalanche path consists of three parts:

1) *Starting zone*: where an avalanche begins and accelerates. The starting zone is typically steeper than 30°, but lower frequency avalanches may start on slopes between 25° and 30°. The lower limit of incline in rare cases is < 25° for dry snow (McClung and Schaerer, 2006). This lower limit can be further reduced in wet snow as liquid water content rises.
2) *Track*: where the avalanche travels between the starting zone and the runout zone. Tracks are broadly characterized as *open slopes* or *channels* (gullies) and have slope angles typically between 15° and 30°.
3) *Runout zone*: is the area located below the track where avalanches decelerate and come to a stop. Slope angles of runout zones are typically less 15° for large avalanches. Small avalanches can decelerate and stop on slopes as steep as 24°. Large avalanches may runout on gentle or flat terrain for long distances.

2.3 Avalanche Magnitude and Frequency

Frequency and magnitude of avalanches depend on snow supply and terrain**.** Snow supply is determined by the frequency and depth of snowfalls and effects of wind transported snow. Important terrain characteristics include slope incline, size, and configuration of avalanche paths. Snowpack structure can also affect magnitude. For example, a weakness buried deeply in the snowpack can result in large avalanches.

Avalanche return period (frequency) is typically given in a range from 1 to 100 years (Table 1). An avalanche occurring every year at a specific location is described as high frequency, whereas one occurrence every 100 years is very low frequency. Annual probability of the avalanche is the reciprocal of the return period (i.e. the annual probability of a 100-year return period is 0.01).

Table 1. Avalanche Frequency.

Average Return Period (events/year)	Frequency Range (events/year)	Frequency Descriptor	Comments
1:1	>1:1 to 1:3	High	Active every winter, or sometimes multiple events per winter.
1:10	1:3 to 1:20	Moderate	Active in some heavy snow winters
1:30	1:20 to 1:50	Low	Long return period avalanches
1:100	1:50 to 1:300	Very Low	Very long return period avalanches

Magnitude is related to frequency in that large destructive avalanches will occur less frequently than smaller ones in a given avalanche path. The frequency of avalanches reaching a specific location in an avalanche path decreases with the location's distance from the starting zone.

Magnitude estimates are described in terms of the Canadian Avalanche Size Classification, which is based on destructive potential or consequence (Table 2). Scaling parameters of typical mass, path length and impact pressure are also included.

The Canadian Snow Avalanche Size Classification is based on potential destructive effect of snow avalanches. The maximum size class (destructive effect) for a given avalanche path relates to the snow supply (depth of avalanches) and terrain (area, length, configuration, and incline of the avalanche path).

A Size 1-2 avalanche will not damage a residential structure. A Size 3 avalanche may damage an unprotected residential structure. A Size 4 and 5 avalanche will destroy unprotected residential structure. Size 5 avalanches are rare but possible in some paths. These types of avalanches usually combine two or more avalanche paths and can redefine the boundaries of known avalanche areas.

In this report, avalanche magnitude and frequency are estimated based on the size, incline, aspect (wind affect), path configuration, and damage to vegetation in the runout zone of an avalanche path. Frequency and magnitude are also estimated based on design snow supply derived from snow climate and elevation data.

Table 2. Canadian Avalanche Size Classification (McClung and Schaerer, 2006).

Size	Description (Destructive Potential)	Typical mass (t)	Typical path length (m)	Typical impact pressure (kPa)
1	Relatively harmless to people.	<10	10	1
2	Could bury, injure or kill a person.	10^2	100	10
3	Could bury a car, destroy a small building (e.g. wood frame house), or break a few trees.	10^3	1000	100
4	Could destroy a railway car, large truck, several buildings or forest with an area up to 4 hectares (ha).	10^4	2000	500
5	Largest snow avalanches known; could destroy a village or forest up to 40 ha.	10^5	3000	1000

Avalanche Risk Guidelines

The recommended zones for land-use planning of occupied structures (CAA, 2002) are:

- *White Zone* (low risk): An area with an estimated avalanche return period of greater than 300 years, or impact pressures less than 1 kPa (comparable to a gale force wind) and a return period greater than 30 years. Construction of new buildings, including permanently occupied structures, normally permitted.
- *Blue Zone* (moderate risk): An area between the Red and White Zones where, for return periods between 30 and 300 years, the product of frequency and impact pressure is less than 0.1 kPa/years and the impact pressure is greater than or equal to 1 kPa. Construction of new buildings, such as industrial plants and temporarily occupied structures, possibly permitted with specified conditions.
- *Red Zone* (high risk): An area where the return period is less than 30 years and/or impact pressures are greater than or equal to 30 kPa, or where the product of impact pressure (kPa) and the reciprocal of the return period (years) exceeds 0.1 for return periods between 30 and 300 years. Construction of new buildings *not* normally permitted.

The line between the White and Red (or Blue where present) Zones represents a boundary that destructive avalanches could reach on the average of once in 300 years. Within the Red Zone, avalanches would be powerful enough to destroy wood frame buildings, break trees and deposit deep snow. Powder avalanches could travel beyond this boundary into the White Zone where they could produce minor damage such as broken tree branches, broken windows and blowing snow inside buildings. Due to the low frequency of powder snow exceeding the hazard line, the risk of such damage is considered acceptable.

For residential developments in Canada, common practice is to restrict the construction of homes (or permanently occupied structures) where destructive avalanches with a return period of 100 to 300 years are expected.

3 METHODS

The location of the avalanche risk zones and associated risk lines were determined using the following methods:

- Field surveys of the terrain and vegetation on October 5, 2012;
- Interviews with local residents and avalanche experts Roger Atkins, Marc Deschenes Kevin Maloney (Ministry of Transportation and Infrastructure);
- Review of topographic maps;
- Review of aerial and orthophotos;
- Analysis of snow survey data; and
- Dynamic (PCM, PLK, LEM, Swiss-Vollemy, RAMMS) and statistical (Alpha-Beta, and Runout Ratio) models of avalanche motion and runout.

4 SNOW CLIMATE STUDY

4.1 Snowpack Height

It is useful to identify winters that likely produced large avalanches to correlate them with ground and air photo studies of vegetation damage by large avalanches. Winters with a heavy snowpack in the area are shown in Table 3. These winters were identified using a threshold of 209 mm of water equivalent of snow at the Duncan Lake (2D07 and 2D07A) snow course, 512 mm at the Gerrard (2D01) snow course, and 1032 mm at the Gray Creek (2D10) snow course (BC Ministry of Environment). These threshold values equal the mean value plus one standard deviation from the mean.

Table 3. Heavy snowpack winters in the Johnson Landing area.

Year	Maximum Water Equivalent of Snowpack, HSW (maximum shown in bold)		
	Duncan Lake Snow Course (2D07 and 2D07A) > 209 mm (Elev. 650 m)	Gerrard Snow Course (2D01) > 512 mm (Elev. 1620 m)	Gray Creek Upper Snow Course (2D10) > 1032 mm (Elev. 2010 m)
1945	n/a	518	n/a
1955	n/a	523	n/a
1966	221	-	n/a
1967	-	**665**	n/a
1969	221	-	-
1971	-	-	1118
1972	234	599	**1300**
1974	-	518	1194
1975	229	-	-
1976	218	-	-
1978	211	-	-
1979	213	-	-
1982	217	n/a	-
1991	-	n/a	1067
1997	**283**	n/a	-
1999	-	n/a	1130
2011	-	n/a	1042
2012	-	n/a	1048

As noted by Fitzharris and Schaerer (1980), winters with large avalanches may not have a heavy snowpack. For example, the winter of 1979 did not have a heavy snowpack but produced large avalanches at Rogers Pass, BC. Since the winters of 1920, 1933, 1935, 1952, 1954, 1972 and 1979 produced large avalanches at Rogers Pass, they may also have produced large avalanches in the Selkirk and Purcell Mountains near of Johnsons Landing.

The Duncan Lake snow course is representative of typical conditions at Johnsons Landing, while the Gray Creek snow course, located at 2010 m elevation 55 km to the south, is representative of upper elevation avalanche starting zones in the Purcell Mountains. Analyses of snowpack heights show that a snowpack of approximately 335 cm can be expected in the starting zones above the property once in 30 years. Snowfall decreases rapidly with decreasing elevation, so one could expect every 30 years approximately 200 cm at 1620 m and approximately 110 cm near 750 m elevation. This does not include the effects of wind which will load additional snow into or scour snow from starting zones. Generally a minimum snow depth of 100 cm is required to produce a smooth snow surface for avalanches to run with little resistance.

4.2 Snowfall

To estimate the possible maximum 24 hour snowfall, historical Environment Canada records were searched for the East Creek station located about 60 km north of the site at an elevation of 2030 m. Records for this station between 1980 and 2011 show a maximum one-day snowfall record of 94 cm (November 10, 1990).

5 VEGETATION AND AIR PHOTO REVIEW

Johnsons Landing, BC is located in the Interior Cedar Hemlock (ICH) bioogeoclimatic zone (BC MOFR 2008). The forest consists primarily of Cedar and Hemlock trees, ranging in age from relatively young 30 year old trees to a maximum of approximately 80-100 year old trees. The transition to a Spruce forest in the Gar Creek drainage occurs above residential areas. Finally, there is a transition to alpine vegetation (alder, shrubs, etc.) in the upper reaches of the Gar Creek drainage just below Kootenay Joe Ridge where large avalanches initiate.

Historical air photos from 1939 show the forest where the landslide debris fan is now located had already been logged. Since then regrowth slowly occurred, with evidence of the clearing still showing in air photos from 2006. Air photos analyzed do not show damage from avalanches running out of the gully directly downhill into the previously cleared area.

Air photos from 1939 show evidence avalanches may have run down the gully into its second significant bend where the gully turns to the west at an elevation of approximately 740 m.

The landslide that occurred in July 2012 completely destroyed all vegetation in the Gar Creek gully and the area where extreme avalanches may occur. This prevented a field investigation of vegetation damage that typically aids in determining previous avalanche activity.

6 AVALANCHE HAZARD OVERVIEW

6.1 Avalanche Path Description

The Gar Creek avalanche path descends from western flank of Kootenay Joe Ridge down a large gully to large, low angle benches in Johnsons Landing. See the Johnsons Landing – Gar Creek Avalanche Overview Map.

The starting zone consists of a series of ribs, gullies, and small cliffs which originate from the western flank of Kootenay Joe Ridge at an elevation of 2300 m. The starting zone is approximately 620 m wide by 150 m long (measured along the slope), with an average incline of 34° with steeper sections. Ground cover in the start zone is mainly rock and talus with some small bushes and trees. The starting zone has two distinct areas separated by a ridge of trees. The largest avalanche events will likely occur when both start zone areas release simultaneously.

The predominant wind direction in southern British Columbia is from the southwest. A large portion of the start zone faces westerly and is likely exposed to wind scouring and cross-loading.

The track has two distinct sections. The upper track is composed of a series of steep gullies that have an average slope angle of 35°. These gullies converge at approximately 1350 m into a large gully that is approximately 30 m wide. Vegetative trim lines between alder and coniferous trees show avalanches run-up on the north side of the gully, indicating large avalanches have high velocities in this area of the track. Where the gullies converge the path turns to the south for a short distance until it reaches the landslide area at 1060 m, where it makes an abrupt turn back to the west meeting Gar Creek.

The lower portion of the track contains the area where the landslide ran down Gar Creek. The landslide heavily scoured the gully removing all vegetation, straightened the creek and widened the gully from about elevations of 910 m to 830 m. The post-landslide ground cover consists of an inconsistent rough soil surface with boulders and wood debris.

The path runout zone starts in the gully at approximately 835 m where the slope angle approaches 10°. The start of the runout is called the β-point (See section 7.1). The β-point is used as a reference point for avalanche runout distances and path features. Similar to the landslide, extreme avalanches will have two runout trajectories. Avalanches will either stay confined to the gully or run in a straight trajectory out of the gully at 750 m elevation and then straight downhill. The ground cover in the runout zone is landslide debris including undulating rough soil, boulders and woody debris.

6.2 Historical Avalanches

There are limited historical observations of avalanches occurring in Gar Creek and the surrounding area. Air photos from 1939 show vegetation damage in the gully to an elevation of 740 m indicating previous avalanches. Records show significant avalanches occurred in 2003 and 2012. Previous residents of Johnsons Landing may have observed avalanches in Gar Creek in the late 1960's and sometime during the 1950's, but these could not be confirmed.

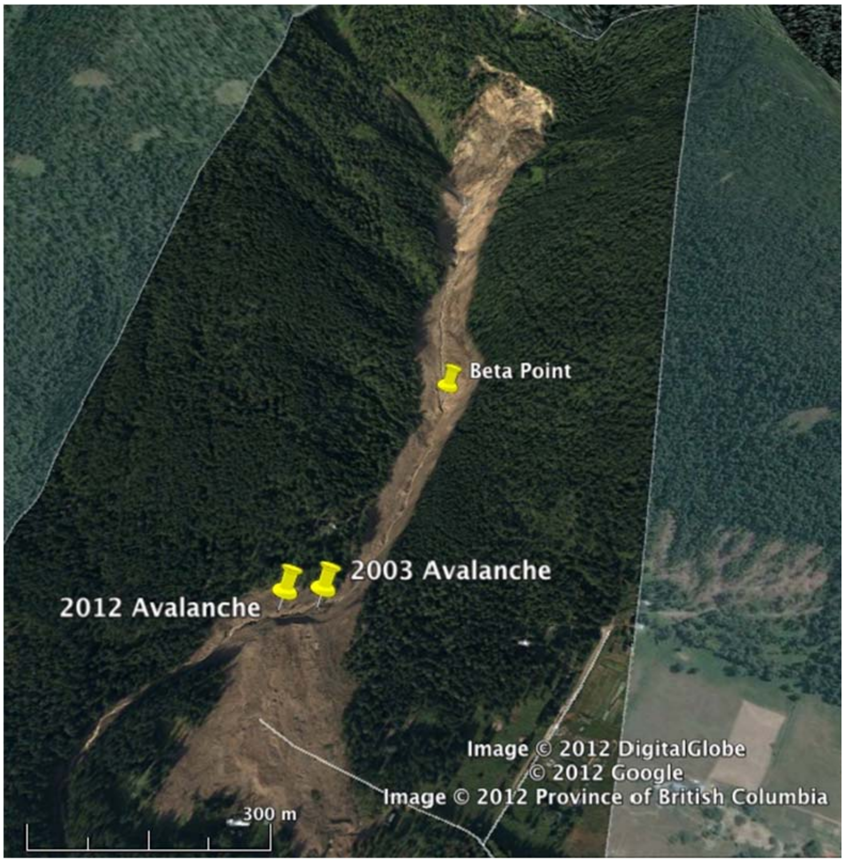

Figure 2. Approximate locations of the 2002 and 2012 Gar Creek avalanches. Table 4 lists the estimated avalanche runout distances for these events.

Figure 3. Avalanche debris that exited out of the Gar Creek gully during the 2012 avalanche event. Photo: Eric Schindler, 2012.

The avalanches that occurred in 2003 and 2012 were similar in size, type, and runout distance. Figure 2 provides an overview image of the approximate locations of their runouts. Both events started just below Kootenay Joe Ridge. Both start zone areas released during the 2003 avalanche. The 2012 avalanche released from the southern starting zone. Each event initiated as a dry snow avalanche. At some point in the gully at lower elevations they entrained moist or wet snow. The avalanche in 2012 destroyed some trees on its descent, likely in the upper portion of the track. The vegetation damage indicates the 2012 event may represent a 30-year return event. For the most part both of these avalanches were confined to the gully, except the 2012 avalanche had one small lobe that ran up the gully wall just exiting the gully (Figure 3).

The runout distances of the 2003 and 2012 avalanches are listed in Table 4 relative to the β-point (Figure 2). The 2003 avalanche stopped at about 745 m elevation, and the 2012 avalanche stopped 60 m further down the gully at 740 m elevation. Both avalanches stopped just beyond the first significant bend in Gar Creek were it turns to the northwest.

Table 4. 2003 and 2012 avalanche runout distance estimates.

Year	2003	2012
Estimates (Δx) past the β-point	510 m	570 m

The avalanche that may have occurred in the late 1960's evidently stopped in a similar location to the 2003 and 2012 avalanches. Record of this avalanche was passed on by word of mouth among Johnsons Landing residents.

The avalanche that occurred in the 1950's reportedly ran out of the gully downhill at the current landslide debris fan a distance of approximately 100 m. Additional details for this avalanche occurrence but could not be verified.

7 RUNOUT ESTIMATES

Avalanche runout distances were estimated using both statistical and dynamic avalanche runout models. Some models are better suited for particular avalanche paths or regions, and by using several methods, the uncertainty associated with these models due to statistical variation and input parameter assumptions can be reduced.

7.1 Statistical Model Runout Estimates

The Alpha-Beta (McClung et al., 1989) and runout ratio (McClung and Mears, 1991) statistical models were used to estimate the horizontal avalanche path runout distance. Both models use the reference β-point where the slopes incline decreases to approximately 10 degrees. The β-point for this path, shown in Figure 2, is located at an elevation of 835 m, part way down the Gar Creek gully. The reference β-angle is the angle measured from the horizontal between the β-point and a point at the top of the starting zone. Assumptions for the models are provided in Appendix A.

The Alpha-Beta model estimates an extreme runout position or α-angle based on the β-angle, and the associated runout distance past the β point is calculated using the observed slope angle within the runout zone (δ) which is 7.9°. The Runout Ratio model estimates the horizontal runout distance (Δx) past the β-point as a function of the horizontal reach X_β, which is the horizontal distance measured from the top of the starting zone to the β-Point.

Both runout ratio and alpha-beta statistical runout estimates were calculated for non-exceedence probabilities (P) of 0.5 and 0.85 using model parameters for the Columbia Mountains (Johnston and others, 2012).

Table 5. Summary of Statistical Model Runout

Estimates (Δx) past the β-point (m)				
	P = 0.5		P = 0.85	
	Alpha-Beta	Runout Ratio	Alpha-Beta	Runout Ratio
Estimate (m)	414	390	792	737

Table 5 presents runout distance estimates for an extreme avalanche. Table 4 (see section 6.2) presents approximate runout distances for the 30-year return avalanche events that occurred in 2003 and 2012, which have runout distances of 510 and 570 m past the β point respectively. The values are greater than model outputs for P = 0.5. In this case both models underestimate the runout distance for dense flow for extreme events. For powder flow (or an extreme dense flow), P = 0.85, both models provide reasonable runout estimates. These values along with dynamic model estimates were used to assist in delineating avalanche risk zone boundaries.

7.2 Dynamic Model Runout Estimates

Avalanche runout was estimated using the PCM Model (Perla and others, 1982), the Swiss Model (Gubler, 1994), the PLK Model (Perla and others, 1984), the Leading Edge Model (LEM, McClung and Mears, 1995), and RAMMS (Christen and others, 2010). These models are based on different physical models of avalanche motion and require different types of input parameters. Each of these input parameters has inherent uncertainty. Monte Carlo simulations were used for the PCM, Swiss, and LEM models to observe different combinations of the input parameters and obtain a higher confidence of model results.

Table 6. Summary of Dynamic Model Runout Estimates (Δx) past the β-point for a 300 yr. event.

Model/ Method	Runout distance past β-point, Δx (m)
PCM	700
Swiss	363*
PLK	718
LEM	715
RAMMS	694
Average	**707**

*Excluded from analysis.

Table 6 presents runout distance estimates for an extreme avalanche using dynamic avalanche models. Assumptions for the models are provided in Appendix A. The model results are generally consistent except the Swiss model which underestimates runout distances. The Swiss model result was excluded from the analysis because it was inconsistent with other estimates. The average of the dynamic model outputs for the runout distance past the β-point is 707 m, which agrees well with the average of 733 m for the two statistical models.

After the landslide, mudflows partially filled the original 10 m deep gully at the first dogleg bend. A temporary earth bank reinforcement was constructed at this location to partially re-establish the natural protection provided by the gully sidewall. If the temporary bank is kept, two avalanche runout trajectories are considered for the 300-year design avalanche. The two trajectories reflect the dynamic flow characteristics of dense and powder components of avalanches. The first trajectory considers the dense component that stays confined to the gully. Dense flow avalanches may be wet and typically they follow terrain features such as gullies and can run for long distances. Model results for the dense flow component are reasonable and reflect the expected distance to runout in the gully.

The second runout trajectory reflects the dynamic flow characteristics of the dry powder avalanche component. Instead of traveling down the gully, the powder component separates from the dense flow and is expected to travel straight at the first bend in Gar Creek at approximately 750 m and onto the landslide debris fan. The extreme runout position of the powder flow is approximately where impact pressures reduce to 0 kPa. These results indicate the powder component may travel up to 707 m past the β-point and 176 m past the bank reinforcement. These results are also reasonable and in line with historical evidence which supports avalanches overtopping the berm during the 2012 and possibly 1950's avalanche events.

The location of the Blue and White risk zone boundary is determined by where avalanche impact loads are greater than 1 kPa and occur at least every 30 years. Avalanche impact loads are a function of avalanche velocity and flow density, and are estimated from the dynamic avalanche models calibrated to the estimated extreme runout position. Model results show the Blue and White zone boundary is determined to be 647 m from the β-point and 116 m past the constructed bank reinforcement. These results are reasonable and consistent with field observations.

If the temporary reinforcement is removed and the existing gully sidewall remains less than 5 m high, avalanches that reach this location will have little natural confinement and they will likely flow straight downhill. In this case, the dense flow and powder flow components of the avalanche will both follow this trajectory instead of separating. The avalanche risk zoning is significantly different in this case because of the increased frequency of avalanches reaching a given point past the bank reinforcement. After removal of the bank reinforcement, the Red Zone is located further downslope, 690 m from the β-point at 738 m elevation. The Blue Zone without the bank reinforcement is located at 730 m from the β-point at 727 m elevation.

8 AVALANCHE RISK ZONING

The objective of this report is to determine which areas have sufficiently low snow avalanche risk for construction of permanently occupied structures according to the Guidelines for Snow Avalanche Risk Determination and Mapping in Canada (CAA, 2002). These guidelines are discussed in Section 2.4 of this report.

This report contains three maps:

- Johnsons Landing - Gar Creek Avalanche Path Overview, 12-0047-SNT-001,
- Johnsons Landing - Gar Creek Avalanche Risk Zone with a Channel Depth of 10 m; 12-0047-SNT-003,,
- Johnsons Landing – Gar Creek Avalanche Risk Zone with a Channel Depth of 0 – 5 m; 12-0047-SNT-006.

The Overview Map provides a boundary of the entire avalanche path, risk zones, and approximate property boundaries. The Risk Zone Maps shows a more detailed view of the avalanche runout zones and property boundaries. Only the Red and Blue zones are delineated; the White zone is considered a low risk avalanche area outside of the limits of these two zones.

The analysis includes consideration of the temporary bank reinforcement constructed after the July 2012 landslide and if no reinforcement is in place. The temporary reinforcement increases the gully sidewall height to approximately 10 m and will help to deflect and stop avalanches. If the reinforcement is removed the residual gully sidewall height of 3 m to 5 m will offer little natural protection and avalanches will be expected to more easily travel out of the gully onto the debris fan.

Avalanche risk zoning affects portions of Lots L9663, P9136, and P876. Lot 9663 includes the Gar Creek gully that contains the high risk Red Zone. A large section of lot P9136 is included in the moderate risk Blue Zone with temporary reinforcement in place and in the Red Zone with no reinforcement. A small section of Lot 876 is included within the moderate risk Blue Zone.

Although modern methods were applied in this study, there is uncertainty in the runout distance estimates due to incomplete knowledge of the behaviour of large snow avalanches and uncertainty in the available data. The uncertainty has been reduced as much as possible by applying a combination of avalanche models, field observations and engineering judgement.

9 CONCLUSIONS AND RECOMMENDATIONS

In accordance with the proposal submitted to SNT Engineering Ltd on September 25, 2012, Dynamic Avalanche Consulting Ltd. completed snow avalanche risk zoning for the landslide area at Johnsons Landing, British Columbia. Key conclusions are summarized below:

- The landslide of July 12, 2012 partially filled in the Gar Creek gully near the first dogleg bend at 750 m. At this location the topography was significantly changed and extreme avalanches are expected to flow out of the once confining gully and straight downhill at this location. Temporary bank reinforcement was constructed after the landslide to re-establish the natural protection of a 10 m high gully wall from future debris flows. If the temporary reinforcement is left in place it will likely provide adequate protection to keep the dense flow component of an extreme avalanche confined to the gully.

- A future wildland fire would have little or no effect on an extreme avalanche event. The avalanche start zone contains sparse trees that do not act as anchors.

- The landslide of July 2012 destroyed trees on the debris fan below the gully. In an extreme avalanche event, prior to the landslide, the trees would have offered little natural resistance and not significantly reduced the runout distance.

- Other than the landslide filling the Gar Creek gully, the landslide did not have a significant effect on avalanche initiation or potential avalanche runout for an extreme (i.e. design) event.

- The avalanche risk zones identified in this report are also within areas destroyed by the landslide. The landslide risk zoning will likely govern and development may be restricted. Due to the anticipated landslide risk restrictions, additional avalanche risk mitigation measures are not recommended.

- The Red Zone shown on the Avalanche Risk Zoning Map is a high risk area where construction of permanently occupied structures is not permitted according to the Guidelines for Snow Avalanche Risk Determination and Mapping (CAA 2002). In the case where temporary bank reinforcement is present the Red Zone includes a portion of the Gar Creek Gully located within Lot L9663 and Lot P9136. In the case where no bank reinforcement is present the Red Zone includes L9663, a significant portion of Lot P9136, and P876.

- The Blue Zone shown on the Avalanche Risk Zoning Map is a moderate risk area where construction of permanently occupied structures is normally not permitted according to the Guidelines for Snow Avalanche Risk Determination and Mapping (CAA 2002). In the scenario where temporary bank reinforcement is present, the Blue Zone includes a significant area within Lot P9136 and a small section of Lot P876. In the case where no bank reinforcement is present the Blue Zone includes larger areas within Lot P9136 and P876.

- The White Zone located outside of the Blue Zone has sufficiently low risk from snow avalanches that it could be used for permanently occupied structures according to the Guidelines for Snow Avalanche Risk Determination and Mapping (CAA 2002).
- The boundary between the low risk White Zone and moderate risk Blue Zone is based on field observations and runout estimates obtained from statistical and dynamic avalanche runout models which represents the expected 300-year return period for a large avalanche.

10 LIMITATIONS AND CLOSURE

This report has been prepared for the exclusive use of SNT Engineering 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 Ltd. 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

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MAPS AND AERIAL PHOTOGRAPHS

MAPS:

- 0.5 m resolution LiDAR DEM. SNT Engineering. July, 2012.

AERIAL PHOTOGRAPHS:

- 2012: Johnson's Landing Landslide
- 2003: Google Earth
- 2006: 30BCC06067:34-35,05-06
- 1940: A7660: 91-92
- 1939: BC173:1-2
- 1939: BC172:104-10

APPENDIX A – ASSUMPTIONS FOR MODELS:

The PCM, LEM, and SWISS models were run using Monte Carlo Simulations. All input parameters were given a range and a statistical distribution. In most cases, the Pert distribution was used that incorporates maximum, minimum and most likely values. Outputs also have a range and distribution.

Ten iterations of the PLK were run. The results were averaged.

Parameters common to the PCM, PLK, LEM, and Swiss Models are:
μ - sliding friction, M/D - mass to drag ratio, R = Random velocity term in PLK, ξ = turbulence

1. PCM
   M/D 950 - 1300 ms^{-1}
   μ = 0.13-0.17 in starting zone, 0.13 - 0.17 in track, 0.22 – 0.27 in runout zone

2. PLK
   μ = 0.25
   Log(M/D) = Log(631) = 3.2
   R = 0.2

3. LEM
   μ = 0.38 -0.42 in track, μ = 0.48 -0.52 in runout
   v_0 = 55 -65 m/s

4. Swiss Model
   1. Starting zone:
      d_0 = 1.6 – 2.0 m
      ψ_0 = 34° - 38°
      530 - 560 m wide x 150 - 225 m long
      ξ = 1100 - 1300 m/s^2
      μ = 0.11 – 0.18
   2. Track:
      Segment is confined
      ξ = 400 - 600 m/s^2
      μ = 0.11 – 0.18
      ψ_t = 24-26°
   3. Segment P:
      Segment is confined.
      ψ_t = 14°
      ξ = 350 - 450 m/s^2
      μ = 0.11 – 0.18
   4. Runout zone:
      ψ_R = 7.5°
      ξ = 500 – 700 m/s^2
      μ = 0.23 – 0.27

Estimates of the coefficients in the dynamic models were based on data obtained from paths various mountain ranges. Because of the uncertainty in choosing model parameters and the statistical variation in results the confidence in each of the runouts from the individual models is low and the runout distances on the zoning map are determined by averaging the results of several models and application of experience. The uncertainty is greater for powder runouts and impact pressure than for flowing avalanches.

MAPS

Johnsons Landing - Gar Creek Avalanche Path Overview

Legend

Avalanche Risk Zoning

- Estimated Avalanche Path Extent
- Red Zone
- Blue Zone

Contour Line - 10 m

- Index Contour
- Intermediate Contour

NOTES:
This map is to be read with the accopanying report Johnsons Landing Gar Creek Avalanche Hazard Zoning.

Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.

Data Sources:
1. Base imagery from Bing Maps

N

Meters

0 250 500 750 1,000

Scale: 1:15,000
Contour Interval 10 m
Coordinate System: NAD 1983 UTM Zone 11N
Unit: Meter

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Drawn by:	Chris Argue, Dipl. T

Johnsons Landing - Gar Creek Avalanche Risk Zones

with a Channel Depth of 10 m

Legend

Avalanche Risk Zones

- Estimated Avalanche Path Extent
- Red Zone
- Blue Zone

Contour Line - 10 m

- Index Contour
- Intermediate Contour

NOTES:
This map is to be read with the accompanying report Johnsons Landing Gar Creek Avalanche Hazard Zoning.

Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.

Data Sources:
1. Cadastral data from GeoBC

N

Meters

0 40 80 120 160

Scale: 1:2,500
Contour Interval 10 m
Coordinate System: NAD 1983 UTM Zone 11N
Unit: Meter

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Johnsons Landing - Gar Creek Avalanche Risk Zones

with a Channel Depth of 0 - 5 m

Legend

Avalanche Risk Zones

- Estimated Avalanche Path Extent
- Red Zone
- Blue Zone

Contour Line - 10 m

- Index Contour
- Intermediate Contour

NOTES:
This map is to be read with the accopanying report Johnsons Landing Gar Creek Avalanche Hazard Zoning.

Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.

Data Sources:
1. Cadastral data from GeoBC

N

Meters
0 40 80 120 160

Scale: 1:2,500
Contour Interval 10 m
Coordinate System: NAD 1983 UTM Zone 11N
Unit: Meter

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