

**Snow Avalanche Risk Zoning
For the Remaining Base Areas at
Kicking Horse Mountain Resort
Golden, BC**

**Prepared for:
Kicking Horse Mountain Resort Limited Partnership**

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Executive Summary

This report was prepared at the request of Mr. Steve Paccagnan of Kicking Horse Mountain Resort Limited Partnership. The objective of this report is to provide avalanche risk zoning for the remaining areas at the base of Kicking Horse Mountain Resort and to make recommendations regarding future chair lift alignments within the proposed expanded Controlled Recreation Area. This work completes mapping for the entire base area, including a compilation of previous mapping in the Cabins in the Woods and Terminator areas.

Field investigation of terrain and vegetation was conducted by Alan Jones, P.Eng. on July 15-16, 2008. Air photos dating back to 1953, topographic maps, orthophotos and snow survey data were reviewed. Analyses were conducted to determine long-term avalanche runout distances, speeds and impact pressures using both statistical and dynamic avalanche models. Chris Stethem provided a senior internal review for this report.

The White Zone identified in the attached Figure 3 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). All areas within the proposed residential development are mapped within the White Zone.

The Blue Zone identified in the attached figure could be used for unoccupied structures if permitted by the jurisdiction. This includes two small 50 m to 80 m wide strips of land located immediately downslope of the Red Zone. Construction of occupied structures such as residences is not permitted in this area.

The Red Zone identified in the attached figure is a high-risk area and construction of new buildings in this zone is not normally permitted.

Several new or upgraded lift alignments are proposed. A significant destructive avalanche hazard is apparent on portions of Lifts F, J, K and L. Risk management options discussed in the report include location planning revisions, structural defence and acceptance of risk given the active ski area avalanche control program.

1.0 Introduction

Chris Stethem & Associates Ltd. (CS&A) conducted an investigation of snow avalanche hazards at Kicking Horse Mountain Resort (KHMR) at the request of Mr. Steve Paccagnan of Kicking Horse Mountain Resort Limited Partnership (KHMRLP). The purpose of this study was to identify snow avalanche hazards that could affect the proposed development at the base of KHMR in Golden, British Columbia. This includes the remainder of the development within the proposed expanded Controlled Recreation Area (CRA) that was not previously assessed by CS&A.

A field investigation of terrain and vegetation on and adjacent to the property was conducted on July 15-16, 2008 by Alan Jones of CS&A. Alan Jones was accompanied by Mike Rubenstein of KHMR on July 15 and by Andrew Nelson on July 16, 2008. Air photos dating back to 1953, topographic maps, orthophotos and snow survey data were reviewed. Analyses were conducted to determine long-term avalanche runout distances, speeds and impact pressures using both statistical and dynamic models.

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

1.1 Uncertainty

Although modern methods were applied in this study, there is uncertainty in the runout estimates, impact pressures and return periods due to incomplete knowledge of the behaviour of large snow avalanches and uncertainty in available data.

The potential affects of climate change on the snow avalanche phenomena in the Purcell Mountains are unknown. This analysis relies on the historic effects under the current climate regime.

2.0 Background on Snow Avalanches

2.1 Characteristics of Snow Avalanches

Avalanches may initiate in either *dry* or *wet* snow. Avalanches that start in dry snow may become moist or wet during their descent. Terrain features, including gullies, deflect wet snow avalanches more readily than dry snow avalanches. Consequently, large, fast-flowing dry avalanches may overrun terrain features.

Most large, dry avalanches consist of a *dense component* that flows primarily along the ground, and a less dense *powder component* that travels above and sometimes ahead of the flowing component. In some cases these two components can separate and move independently. The dense-flowing component and the powder component may reach

speeds up to 60 m/s (approximately 200 km/h). However, the impact pressure resulting from the dense-flowing component is much greater than the impact pressure from the powder component due to the higher density of dense flowing snow.

2.2 *Avalanche Path*

An avalanche path consists of a *starting zone*, a *track* and a *runout zone*. Avalanches typically start and accelerate in the starting zone which typically has a slope incline steeper than 30°. The lower limit of incline in rare cases is >25° for dry snow (McClung & Schaerer 2006) and this lower limit can be further reduced in wet snow as the liquid water component of the avalanche is increased. Downslope of the starting zone, most large avalanche paths have a distinct track where the slope angle is typically in the range of 15° to 30°. Large avalanches decelerate and stop in the runout zone where the incline is usually less than 15°. Smaller avalanches may start to decelerate on steeper slopes, typically on inclines less than 24°.

2.3 *Avalanche Frequency*

Frequency is the reciprocal of the avalanche return period and is typically shown as an order of magnitude average ranging from 1:1 (1 in 1) up to 1:300 (1 in 300) years. Each winter, the probability of an avalanche with a specified multi-year return period is constant. For example, if an avalanche with a 100-year return period occurred last winter, the probability of a similar avalanche is the same the following winter. However, over a 1000-year period an average of ten avalanches with a 100-year return period is expected.

Avalanche frequency depends on *snow supply* and *terrain* and *decreases with distance in the track and runout zone*. Snow supply is determined by: 1) frequency of snowfalls and amount of snow; and 2) wind transport of snow into the starting zone of avalanches.

The primary terrain factors in avalanche formation are incline, slope orientation with respect to wind and sun (aspect), slope configuration and size, and ground surface roughness. Slope configuration is important because features such as gullies will often have more frequent and larger avalanches than open slopes. Ground roughness determines the threshold snow depth for slab avalanches to occur. This is particularly important in light snow climates where snow may not exceed threshold depths during some winters.

Obviously snow and weather conditions vary from year to year and the frequency of avalanches is not constant. These averages fall within an actual range of frequency of occurrence; for example 1:30 to 1:300 years in the case of the 1:100 year average.

2.4 *Avalanche Magnitude*

Magnitude relates to the destructive potential of an avalanche and is defined in this report in terms of the Canadian Classification System, which rates avalanches on a scale of 1 to

5. A general description of destructive potential, magnitude and typical path length is provided in Table 1.

Magnitude is often related to frequency - in general, large destructive avalanches occur less frequently, while small ones occur on a regular basis. The magnitude and frequency of effect are also related to location in the overall path. For example, a road located near the toe of an avalanche path will be affected less frequently and by larger avalanches than a site farther upslope in the same path. Both low frequency large avalanches and high frequency small avalanches may affect a road crossing the middle of an avalanche path.

Table 1. Canadian classification system for avalanche size (McClung & Schaerer, 2006)

Size	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 building, or break a few trees.	10 ³	1000	100
4	Could destroy a railway car, large truck, several buildings, or a forest with an area up to 4 ha.	10 ⁴	2000	500
5	Largest snow avalanches known; could destroy a village or a forest of 40 ha.	10 ⁵	3000	1000

2.5 Avalanche Risk Zoning

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 location 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, it has been common practice in recent years to restrict the construction of homes (or permanently occupied structures) where destructive avalanches with a return period of 100 to 300 years are expected. Based on the Canadian guidelines, the White Zone can be considered an area of unrestricted development with respect to snow avalanche hazards.

3.0 Methods

We have determined the location of the avalanche risk zones and associated hazard line using the following methods:

- Field surveys of the terrain and vegetation on July 15-16, 2008;
- Interviews with KHMR snow safety director, Mike Rubenstein;
- Review of topographic maps and orthophotos (1997);
- Review of air photographs dated 1953, 1976, 2001, and oblique photos from 2004;
- Analysis of snow survey data; and
- Review of previous reports, including CS&A report entitled *Golden Peaks Resort Avalanche Hazard to Proposed Access Road and Lifts*, dated 3 August 1999; *Snow Avalanche Risk Zone Mapping for the Cabins in the Woods and Adjacent Development areas, Kicking Horse Mountain Resort*, dated 27 May, 2004; and *Snow Avalanche Risk Zone Mapping for the Southern (Terminator) Portion of the Development Area, Kicking Horse Mountain Resort, Golden, BC*, dated November 24, 2004;
- Statistical and dynamic models of avalanche runout (McClung and Mears, 1991; McClung and others, 1989; Perla and others, 1982; Salm and others, 1990; Perla and others, 1984; and Jones and Jamieson, 2004).

4.0 Snowpack

It is useful to identify winters that likely produced large avalanches to relate to the ground and air photo studies of vegetation damage by large avalanches. Heavy snowpack winters were identified using a threshold of 1100 mm of water equivalent at the Sunbeam Lake Snow Course (2a22) located in the Esplanade Range northwest of Golden (Table 2). It is important to note that some winters with large avalanches are not necessarily associated with deep snowpacks. For example, the winter of 1979 did not have a heavy snowpack but produced large avalanches in parts of the Columbia and Rocky Mountains because a below average, structurally weak snowpack was overloaded by a single major storm event.

Table 2. Heavy snowpack winters near Golden during 1967-2008, Sunbeam Lake Snow Survey Site (2a22), 2010 m (BC Snow Survey, Ministry of Water, Land & Air Protection)

Year	Maximum water equivalent of snow, HSW ₃₀ > 1100 mm
1967	1374
1968	1199
1971	1130
1972	1562
1974	1128
1976	1262
1982	1131
1990	1176
1991	1247
1996	1187
1999	1238
2002	1108
2007	1233

Previous studies by CS&A show that a snowpack height (measured vertically) in starting zone elevations (i.e. > 2000 m) is approximately 3 m with a 30-year return period, and 3.8 m with a 100 year return period. This assumes wind loading of snow into the starting zone. Analysis of the Sunbeam Lake data shows similar results, with a 30-year and 100-year snow depths of 3.5 m and 3.9 m, respectively.

5.0 Vegetation

In previous studies of the Coffee Run avalanche path evidence was found of large, destructive avalanches dating back to approximately 1999, 1996, 1991 and 1982 (or possibly 1979). The oldest trees during that study were dated at approximately 80 years old, which limited the usefulness of vegetation for determining long-term runout distances at that site. Other damage was observed on the air photos, but the specific dates of these events could not be identified. The 1953 air photos (55 years before present) only show an immature forest due to a previous forest fire.

At the southern (Terminator) end of the development there was less frequent evidence of large, destructive avalanches reaching the lower reaches of the runout zones. Evidence was found of large, destructive avalanches in the Terminator and T2 runout zones dating back to approximately 1999 and either 1972 or 1974. There were two other distinct ages of trees in this area including one series dated at approximately 70-80 years old, similar to trees in the Coffee Run path. These trees form a distinctive trimline. Several much older trees were observed that survived the fire that occurred prior to 1953. Several very old trees were dated using core samples, and were anywhere between 125 and 170 years old. These trees can be observed on the 1953 air photo as a distinct patch of vegetation.

During the 2008 field investigation evidence of destructive avalanches was observed dating back to 2002, 1993, 1989-1991, 1978-1980 and the late 1960's. Evidence of

destructive avalanches in the newly surveyed areas was very similar to the previous surveys of the Terminator, Glades and T2 paths.

Many areas of vegetation in the runout zones have been affected by human activities such as logging, ski run and road development. This further complicates the use of vegetation for determining avalanche runout distances in this area.

6.0 Avalanche Hazard Overview

Several large avalanche paths potentially threaten the proposed development within the expanded CRA. Previous reports by CS&A (2004a, 2004b) described the avalanche paths named Terminator, The Glades, T2 and Coffee Run. The remaining avalanche paths affecting the expanded development area are described below and are shown on Figures 1 and 2.

6.1 Terminator Ridge Paths

The southern part of the development area is potentially affected by a complicated, partially overlapping series of ten avalanche paths identified in this report as the *Terminator Ridge Paths*. These paths from south to north are identified as: *T4, T3.3, T3.2, T3.1, T2.5.3, T2.5.2, T2.5.1, T2, The Glades and Terminator*. Some of these are “semi-official” names for the paths, while others were assigned by the authors for identification.

Starting Zones

The starting zones for the Terminator paths are immediately below a prominent ridge feature known as *Terminator Ridge*, which ascends from 2200 m near T4 to approximately 2400 m at T2.5.1. All starting zones face northeast and are subject to extensive loading of wind-transported snow by the predominant southwest winds. Cross loading between gullies is also common in this area. Starting zone inclines are typically in the range of 35-45° with some shallower starting zone areas near 30° in Paths T2.5.1 and T3.1. Starting zones all consist of a mix of steep bedrock and cliffs, talus, and shrubs interspersed with small, immature conifers. Starting zone areas range from approximately 1.5 to 5 Ha for individual avalanche paths.

Tracks

The starting zones transition into the tracks near 1820 to 2040 m elevation. The tracks are mostly unconfined, with several having poorly incised stream gullies that direct the flow of avalanches. Below approximately 1900 m, Paths T3.2 through T2.5.1 become partly confined by a series of narrow tree bands. Paths T4 and T3.3 travel through mostly immature forest and rock bands almost to their runout zones. The remaining areas of the tracks have predominantly alders, shrubs and conifers of varying age class (depending on avalanche frequency). The pre-1953 fire destroyed most of the forest in the lower tracks and runout zones.

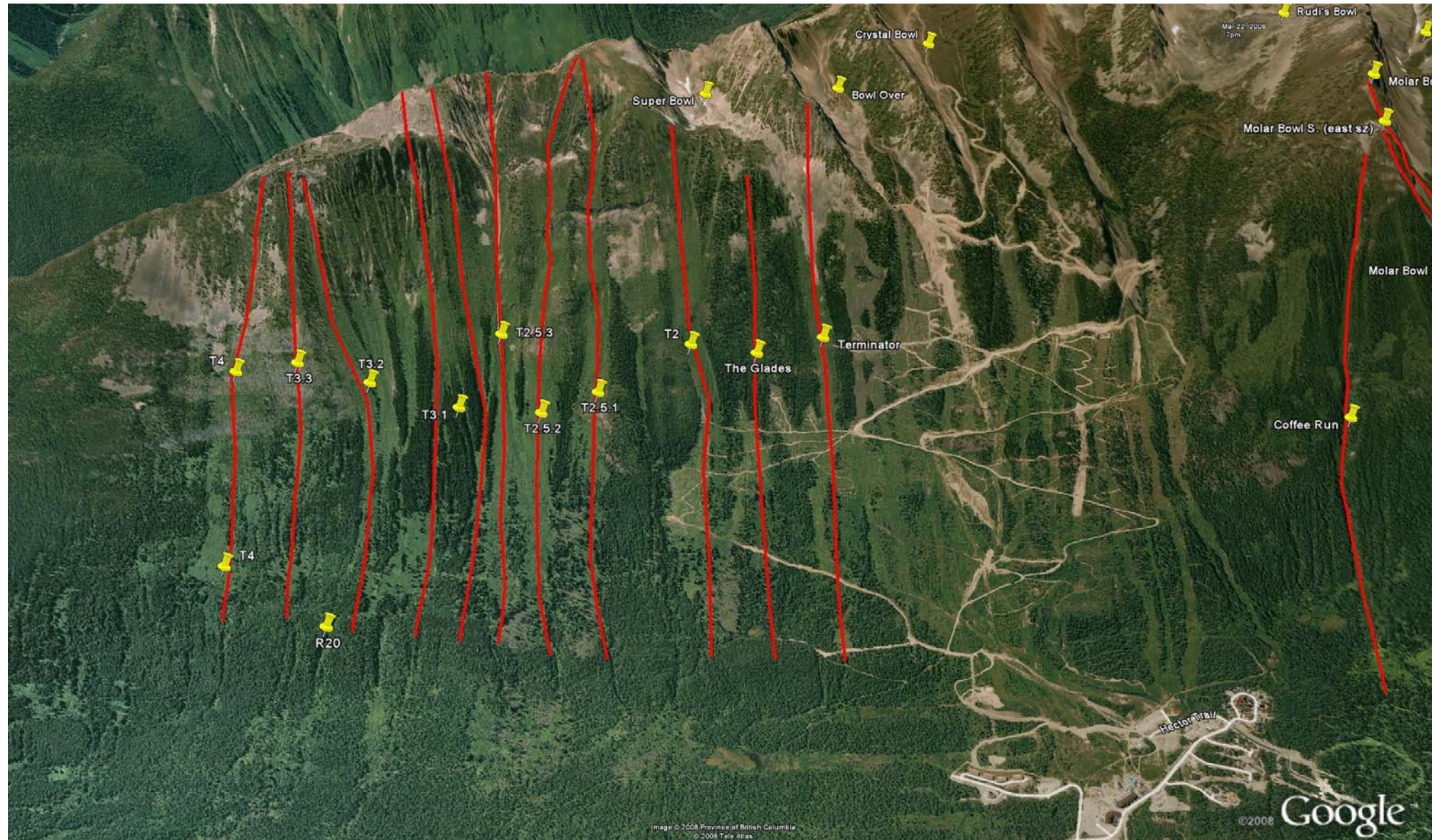


Figure 1. Overview of avalanche paths potentially affecting the southern part of the KHRM CRA.

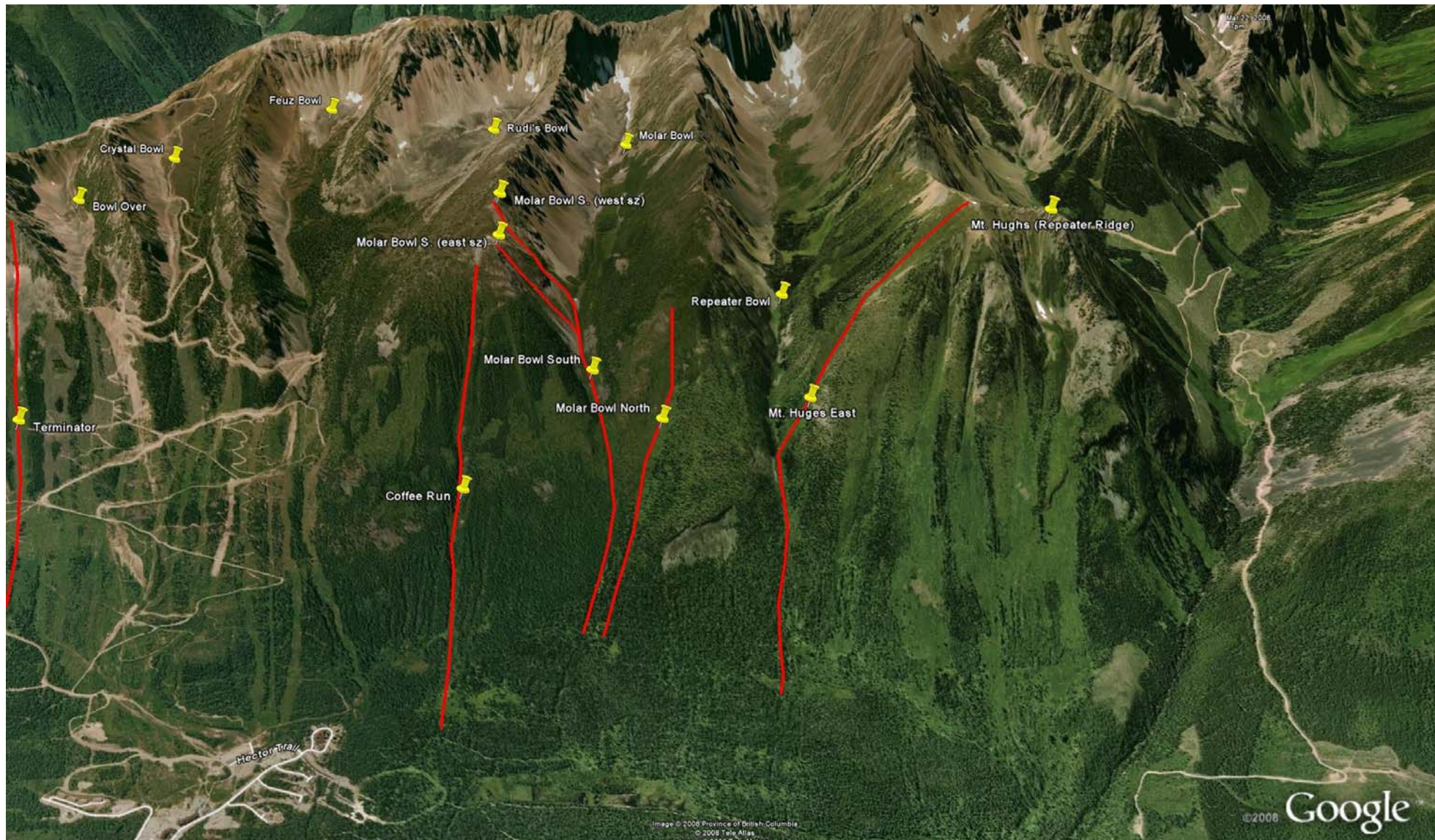


Figure 2. Overview of avalanche paths potentially affecting the northern part of the KHRM CRA.

Slope angles are typically in the range of 15° to 25° with several steep areas of exposed bedrock slabs and cliffs between 1600 and 1900 m. The lower part of the tracks where large, infrequent avalanches start to decelerate is located in the narrow elevation band of 1440-1470 m. This elevation marks the location of a very prominent, gently sloping bench that runs across the entire Terminator area from T4 to the existing ski area.

Frequent (i.e. 1:1 to 1:10) small (Size 1-2) and medium (Size 3) avalanches will stop either in the starting zone or upper track. For most of the paths Size 3 avalanches are expected to stop in the lower track near approximately 1425-1500 m elevation with a frequency of approximately 1:10 to 1:30 years.

Runout Zones

The prominent bench that the majority of large avalanches runout on starts at 1440-1470 m, and continues downslope to 1410-1430 m. Slope angles on the bench range between 5° and 12°. Several areas that look like openings from avalanche damage on the aerial images are actually wet areas that restrict tree growth. Outside of these wet areas vegetation consists of a mix of low shrubs and alders with areas of immature to mature conifer forests of varying age class (e.g. 30-100 years).

Below the lower end of the bench at 1410-1430 m the terrain steepens again to 15°-30° down to an elevation of 1300-1325 m. The streams, which are unconfined on the gentle bench above, generally become confined in shallow gullies on this steep slope.

A second, lower bench is located below the steep slope, starting at 1300-1325 m. Slope angles on the lower bench where the residential development is to be located are less than 10°.

Evidence of large, destructive (Size 3-4) avalanches was observed in all of the paths, reaching down to the lower part of the upper bench near 1425-1430 m. The lowest elevation for observed avalanche impacts was at 1405 m in Path T3.3; this evidence consisted of a single, large powder avalanche that bent mature trees and broke branches (flagging). There was no other evidence of avalanches continuing beyond the upper bench onto the steeper terrain below. Thus, the lower part of this upper bench marks the interpreted location of low frequency (i.e. 1:100 year), large (Size 4) avalanche events.

6.2 Molar Bowl Paths

The current CRA at KHMR approximately follows the ridgeline located on the north side of Molar Bowl. The proposed ski lift and terrain expansion will include Molar Bowl. Although there are numerous avalanche paths located within the bowl only two distinct paths reach the lower part of the valley with potential to affect residential development on the lower bench. These paths are identified as Molar Bowl South (East and West starting zones) and Molar Bowl North.

The steep bedrock and talus area located on the northeast-facing slope between Molar Bowl and Repeater Bowl to the north was also assessed for avalanche hazard. This area is identified as Molar Trees. Due to the large surface roughness of the talus, limited snow supply near 1600 m elevation, and densely forested terrain above and below potential starting zones, this area is incapable of producing large, destructive (i.e. $\geq$ Size 3) avalanches and is not discussed further in this report.

Starting Zones

The Molar Bowl North starting zone ranges in elevation from 2075 m to 1975 m, with an average slope angle of 35°. This area is planar, unconfined and open with sparse trees and shrubs. The starting zone faces southeast so may accumulate snow transported by the predominant southwest winds. The starting zone area is approximately 3.5 Ha.

The Molar Bowl South path consists of two distinct bowls that merge in the main Molar Bowl near 1925 m. Starting zone elevations in these bowls range between 1925 m and 2300 m, with an average slope angle of 33-36°. These starting zones face east and southeast and are subject to extensive wind-loading. Starting zones consist of predominantly rock and talus, interspersed with low shrubs and scattered small conifers. The combined starting zone area for these two bowls is approximately 4 Ha.

Tracks

The Molar Bowl North track is located between 1880 m and 1440 m, with an irregular gradient varying significantly from 14° to 40°. The track becomes confined in a subtle gully feature below 1700 m, which becomes more pronounced and deeply incised at 1640 m. The gully narrows and becomes completely infilled with forest near 1630 m, with the lowest evidence of destructive avalanches observed near 1520 m.

The Molar Bowl South paths merge in their tracks near 1925 m, continuing down to 1445 m with a slope gradient of 17-25°. The common track is confined within a gully infilled with a mix of immature conifers and deciduous trees, with alder and brush. The gully becomes infilled with a more mature forest near 1600 m, with the lowest evidence of destructive avalanches observed near 1540 m.

Runout Zones

The runout zone by definition according to statistical topographic models of avalanche runout (i.e. slope $< 10^\circ$) doesn't begin until 1445 m; however, long (i.e. > 250 m) sections of moderate (e.g. 17-18°) terrain below 1725 m serve to slow down most avalanches well above the start of the runout zone as defined in these models.

The Molar North and South paths parallel each other but don't actually meet until near 1450 m, within densely forested terrain with no evidence of avalanche activity. Medium to large destructive (Size 3-3.5) avalanches are expected to reach 1530 m elevation with a frequency of approximately 1:30 years. The lowest evidence of large (i.e. Size 4) destructive avalanches was observed near 1520 m, corresponding to a return period of approximately 1:100 years.

6.3 Mount Hughes East

The Mount Hughes East path is the northernmost path that could affect the proposed CRA. Mount Hughes is located at the northeastern end of Repeater Ridge, which bounds Repeater Bowl on the north.

Starting Zone

Avalanches initiate approximately between the elevations of 2380 m and 2160 m. The starting zone is a smooth, planar feature with low ground cover (grass, heather, etc.). The average starting zone slope angle is 28°. The starting zone faces east-southeast, so the predominant southwest winds may cross-load this area with wind transported snow. The starting zone has an area of approximately 6 Ha.

Track

The track encompasses terrain from 2160 m down to 1415 m, has an average incline of 23° and a range of 13°-28°. The track is relatively smooth down to approximately 1700 m, which is where it makes a sharp turn to the northeast down the main stream gully. The gully becomes more pronounced and deeply incised (5-10 m) around 1650 m.

Evidence of destructive flowing avalanches was observed as low as 1520 m; powder avalanches were observed to stop higher in the track near 1550 m. Frequent (1:1 to 1:3) avalanches are expected to stop upslope of the prominent bend at 1700 m. Medium (Size 3) avalanches with a frequency of approximately 1:15 years are expected to stop near 1600 m, decreasing to 1:30 near 1550 m. Larger (Size 3.5-4), infrequent (1:100 years) avalanches are expected to terminate near 1520 m.

Runout Zone

The Mount Hughes path is not conventional in that although the infrequent avalanches terminate near 1520 m, gently sloping terrain below 8° is not encountered until below 1415 m. Avalanches terminate higher in this path due to the presence of a long (> 500 m) section of moderate terrain with slope angles of 13-20°. At approximately 1450 m, the gully opens up and becomes completely unconfined.

7.0 Runout Estimates

Estimates for runout distance for the avalanche paths are obtained using a combination of statistical and dynamic models. By using several models, the uncertainty associated with these models due to statistical variation and uncertain input parameters can be reduced.

7.1 Statistical Runout Estimates

The models of McClung and Mears (1991) and Nixon and McClung (1993) use a reference β -point where the slope angle on descent first decreases to 10° which is located between the 1415 m and 1470 m elevation contours for all of the paths studied. This compares favourably with results from previous studies for the Terminator, Glades and T2 paths which had β -points between 1425 and 1435 m. Coffee Run had a slightly lower

β -point located at 1375 m. These results serve to highlight the prominent low-angle bench that crosses the entire base area of the CRA at a consistent elevation.

The angle from the β -point sighted to the top of the starting zone is known as the Beta angle (β), and is shown for paths potentially affecting the development area (Table 3). The α - β model for the Rocky and Purcell Mountains (McClung and Mears, 1991) is used to calculate the α -angle using non-exceedence probabilities (P) of 0.5 and 0.85, as well as the corresponding runout distance (Δx) past the β -point.

Table 3. Statistical estimates of runout using the α-β method						
Path	Location of β -point (elev.) (m)	β -angle (°)	α -angle (°)		Runout distance Δx (m)	
			P=0.5	P=0.85	P=0.5	P=0.85
T4	1442	30.0	27.9	26.2	188	378
T3.3	1450	31.3	29.1	27.4	153	294
T3.2	1470	31.5	29.3	27.6	158	305
T3.1 South	1470	30.0	27.9	26.2	189	373
T3.1 North	1470	28.9	26.9	25.2	183	369
T2.5.3	1460	27.4	25.5	23.8	210	439
T2.5.2	1455	26.9	25.0	23.3	238	500
T2.5.1	1455	27.6	25.7	24.0	239	506
Molar Bowl S.	1445	23.1	21.5	19.8	325	796
Molar Bowl N.	1440	24.1	22.4	20.7	185	419
Mt. Hughes East	1415	24.0	22.3	20.6	281	635
Average	1452	27.7	25.8	24.1	213	456

The Runout Ratio model for the Rocky and Purcell Mountains (McClung and Mears, 1991) is used to provide an additional statistical runout estimate of the runout distance, past the β -point (P = 0.5 and 0.85) (Table 4).

Table 4. Statistical estimates of runout using the Runout Ratio method			
Path	X_{β} (m)	Runout distance, Δx (m)	
		P=0.5	P=0.85
T4	1295	136	267
T3.3	1235	130	254
T3.2	1225	129	252
T3.1 South	1505	158	310
T3.1 North	1575	165	324
T2.5.3	1695	178	349
T2.5.2	1835	193	378
T2.5.1	1790	188	369
Molar Bowl S.	2005	211	413
Molar Bowl N.	1420	149	293
Mt. Hughes East	2170	228	447
Average	1613	170	332

7.2 Dynamic Model Runout Estimates

Estimates of avalanche runout can be obtained from avalanche dynamics models, however, because of the strong dependence of runout on the friction coefficient(s), confidence in the runout estimates is generally lower than for trim lines (boundaries of damaged vegetation) observed in the field or on air photos.

Three avalanche dynamics models were used for estimating runout distances: the PCM model (Perla and others, 1982); the Swiss Model (Salm and others, 1990); and the PLK Model (Perla and others, 1984). These three models are based on different physical models of avalanche motion and require different types of parameter inputs. Runout distance estimates using these three models are shown on Table 5. Assumptions used for the models are included in the Appendix.

Table 5. Comparison of runout distance for model estimates with the field observations

Path	Runout distance past β -point (m)								Average [*]
	PCM	Swiss	PLK	α - β P = 0.5	α - β P = 0.85	Run-out Ratio P = 0.5	Run-out Ratio P = 0.85	Field Observations	
T4	580	95	83	188	378	136	267	95	119
T3.3	578	51	109	153	294	130	254	200	129
T3.2	229	125	259	158	305	129	252	N/A	180
T3.1 S.	222	111	230	189	373	158	310	N/A	182
T3.1 N.	155	49	245	183	369	165	324	N/A	159
T2.5.3	166	61	203	210	439	178	349	180	187
T2.5.2	198	96	198	238	500	193	378	N/A	207
T2.5.1	228	144	233	239	506	188	369	N/A	206
Molar Bowl S.	61	28	53	325	796	211	413	-295	47
Molar Bowl N.	29	-75	54	185	419	149	293	-235	3
Mt. Hughes E.	85	115	791	281	635	228	447	-290	100
Average	230	73	223	214	456	170	332	-58	138
* Values used to determine the average runout distance past β are shown highlighted in dark grey									

7.3 Summary of Runout Estimates

A summary of runout estimates provided by the statistical and dynamics models is provided in Table 5. The location of the extreme runout position where observed in the field is also included in Table 5. The model results shown highlighted in grey were averaged to estimate the extreme runout position for a 100-year (extreme) avalanche. The statistical models using P=0.85 typically provide an overly conservative estimate of runout given the terrain, snow supply and elevation at these sites; consequently these

were not included in the averages. Some of the dynamics models were not applicable to certain paths due to terrain model limitations; these were also left out of the average calculation.

Based on the results shown in Table 5 for Paths T4 to T2.5.1 (southern portion of the CRA), the runout positions for 100-year avalanches are located between the 1410 m and 1445 m elevation contours, upslope of the proposed development. For Molar Bowl South to Mount Hughes East the results indicate the 100-year runout positions are located between the 1395 and 1440 m contours, upslope of the proposed development.

For comparison, the Terminator, Glades and T2 100-year runout positions were located between 1400 m and 1425 m; the Coffee Run 100-year runout position was located at 1350 m. The results for 14 of the 15 paths analysed in the three avalanche zoning projects at KHMR are very consistent; the one anomaly was Coffee Run which had a significantly lower runout position. This is likely due to the fact that it was deeply channelized to a lower elevation (1425 m) than the remainder of the paths.

8.0 Avalanche Risk Map

The objective of this report is to provide avalanche risk zoning for the remaining areas at the base of Kicking Horse Mountain Resort and to make recommendations regarding future chair lift alignments within the newly proposed CRA. This work completes mapping for the entire base area, including a compilation of previous mapping in the Cabins in the Woods and Terminator areas.

The attached avalanche risk map (Figure 3) divides the area into White (low risk), Blue (moderate risk) and Red (high risk) based on the expected avalanche frequency and impact pressure. The risk lines are plotted based on a combination of analyses previously described in this report including: air photo interpretation, vegetation analysis, terrain observations, statistical and dynamic runout models, and experience with similar avalanche paths. Additional statistical methods and expert judgment were used to project the 100-year runout position to a 300-year position, which is required to define the location of the White Zone.

Our results show that for Paths T4 to T2.5.1 (southern portion of the CRA) the extreme runout position for a 300-year avalanche is located between 1360 m and 1420 m. For the Molar Bowl paths and Mount Hughes East path, the 300-year avalanche runout position is located between 1395 and 1440 m. Where present, the transition distance between the Red and Blue risk zones is approximately 50-80 m wide.

The line that joins the risk zone mapping from the current report and the previous Terminator report (CS&A, 2004b) has been modified. Previously, the line dropped downslope south of the T2 path to include an area of relatively steep terrain between the two prominent benches. Given the low snow supply at this lower elevation of 1300-1400 m, this area is incapable of producing destructive (i.e. > Size 2) avalanches even if the trees were removed from this slope. Thus this area is included in the White Zone.

The risk line joining the previous Terminator area mapping to the Cabins in the Woods (Coffee Run) mapping was also modified. The line has been changed to a solid Red zone line that follows the 1600 m contour. There are several areas above this elevation capable of producing small avalanches that the KHMR snow safety team monitors and controls. The lower extent of these avalanche areas is near 1600 m and consequently forms the lower boundary for avalanche terrain in this area.

In the northern part of the development area the risk line continues northwards from the previous end of the Coffee Run risk line. The new risk line in this area is located above 1425 m elevation due to the presence of steep terrain with shallow gullies above. The risk line drops down to 1395 m elevation below the Mount Hughes path and ties into the proposed expanded CRA line.

Based on the location of the risk lines and the proposed residential development at the base area, avalanches will not affect the proposed residential development as currently planned.

9.0 Proposed Ski Lift Alignments

Table 6 lists the typical parameters for ski lift planning for avalanche risk according to the CAA *Guidelines for Snow Avalanche Risk Determination and Mapping* (CAA 2002).

Table 6. Typical parameters for ski area operations				
Land use	Typical threshold return period (years)	Critical avalanche size	Typical planning or action	Typical mapping
Ski lift bases	100	>2	Location; structural protection; closure until the hazard is reduced	Site specific mapping for new lifts
Ski lift towers	30	>2	Location; structural protection based on flow depth and impact pressure	Site specific structures
Ski area terrain	10	>1	Active control plan; ski compaction; worker safety regulations	Avalanche atlas

The existing lifts are not evaluated in the current study. Lift alignments E1, E2, G, M and N are located in the base area and/or lower mountain and not subject to destructive snow avalanche hazards. Comments with respect to the potential avalanche hazards are provided for the extension of Lift D-2 (Pioneer) and new lift alignments including F, H, I, J, K and L.

9.1 Lift D-2 Extension

Alignment D-2 (Pioneer extension) is not affected by destructive snow avalanches. Avalanche terrain which might affect skiers is managed in the existing ski area avalanche control program.

9.2 Lift F

The avalanche hazard to the Stairway to Heaven Lift was assessed by CSA prior to construction (CSA 2002). The proposed top station of Lift F is located in My Blue Heaven Bowl, approximately 150 m SE of the existing Stairway alignment. The alignment then roughly parallels Stairway to pass approximately 45 m SE of the existing base station.

The Lift F top station is located on a knoll in My Blue Heaven Bowl. My Blue Heaven is an easterly aspect bowl subject to lee and cross wind loading during storms. Routine avalanche control is carried out to protect skiers and intensive skier compaction is observed. Avalanches > Size 2 are estimated to occur within the bowl approximately 1 in 10 years and are estimated to have the potential to over-run the top station knoll on the order of 1 in 30 years. Options for avalanche risk management at the top station include terrain modification (grading and/or earthworks) to divert the flow around the station, strengthened design of the structures or acceptance of risk under the existing avalanche control program.

The second area of potential exposure is to the towers along the alignment between the top station and approximately 2150 m elevation. The south-easterly aspect of Redemption Ridge contains several small avalanche starting zones which are subject to cross winds and wind scour. Intensive skier compaction is observed and avalanche control by ski cutting or explosives is carried out when required. Avalanches > Size 2 which could affect lift tower locations are estimated to occur < 1 in 30 years with the ski area avalanche program in place. The individual tower locations should be assessed during design to weigh options including acceptance of risk and/or strengthened design at some locations.

9.3 Lift H

The majority of alignment H is located in the White Zone below 1440 m. The top station is located in the Coffee Run trees approximately 350 m north of the Coffee Run avalanche path. There is no evidence of a destructive avalanche hazard to the lift alignment. Expansion of the ski area avalanche control program should include the hazard to skiers accessing the Coffee Run and adjacent trees.

9.4 Lift I

Lift I ascends the Molar Trees to a bench on the end of Molar Ridge at approximately 1920 m. Between 1920 m and 1665 m the terrain consists of open tree glades with

moderate incline (average approx. 28°). Given the moderate incline and the effect of skier compaction destructive avalanches $> \text{Size } 2$ are not expected in this upper section.

From approximately 1570 - 1665 m the alignment ascends a prominent talus slope (Section 6.2). Given the roughness of the blocky talus and the lower snow supply at this elevation avalanches $> \text{Size } 2$ are not expected. The Molar Trees and talus area should be included in the active avalanche control program for protection of skiers from avalanches $\leq \text{Size } 2$.

9.5 Lift J

The Lift J alignment ascends the broad easterly ridge end between Molar Bowl and Molar Trees to a top station on the Molars Ridge at 2280 m. Between the top station and 2225 m the alignment crosses short slopes on alpine meadows $< 30^{\circ}$ in incline. The alignment then descends a broad ridge to 2150 m. Below this elevation the alignment is located in the forest with no apparent evidence of avalanche damage until the bottom station is reached.

The proposed bottom station of Lift J is located at 1805 m, on a minor ridge approximately 30 m NW of the centreline of the gully track of the Molar Bowl South avalanche path. Avalanches $\geq \text{Size } 3$ are expected to have the potential to reach this location with an estimated frequency of 1 in 10 – 30 years.

The most practical option for avalanche risk management would probably be to move the lift base approximately 80 m to the west to avoid the avalanche runout zone. The exact extent of the relocation depends on the extent to which the avalanche could run-up on the gully side. This should be determined through detailed field investigation and run-up modeling.

Several ski lines exposed to avalanche hazard are accessed by this lift. Significant additions to the ski area snow safety program will be required to manage the risk to skiers.

9.6 Lift K

The proposed Lift K T-Bar alignment on the backside of Eagle Eye is exposed to avalanches from the south-facing open slopes on the backside of the ridge at the head of Crystal Bowl. The avalanche terrain consists of windward, short slopes that rise approximately 150 m from the proposed bottom station to the ridge.

Wind scour from the prevailing south-west wind will usually reduce the snow accumulation in the potential avalanche starting zone and hence the accumulation of a snow supply sufficient to produce an avalanche $> \text{Size } 2$. The estimated frequency of such an event would be on the order of 1 in 30 years.

If this lift were developed, compaction and routine avalanche control would play a significant role in stabilizing the open slopes and preventing a destructive avalanche. The most likely scenario in operation where a potentially destructive avalanche could develop would be the formation of a weak base during early season prior to opening and skier compaction, followed by an extreme snowfall with little wind or an unusual wind from the north quadrant.

This location should be reviewed during the lift design phase to identify the avalanche risk at the base station and the towers along the alignment. Options for avalanche risk management include location planning for the bottom terminal, acceptance of risk combined with ski area avalanche control or reinforced design.

9.7 Lift L

Lift L ascends the Terminator area to the bottom of Super Bowl. The top station at 2170 m is located on the low ridge which forms the boundary between Super Bowl and the terminator Glades. The top station location does not appear to be affected by dense flowing avalanches. The station location is approximately 150 m south of the toe of the steep track of the Super Bowl avalanche paths. Powder snow runout from these paths could reach the top station, however it may not present a significant destructive potential. A detailed site assessment of the design location of the top station is required.

Between approximately 2150 and 1850 m elevation the alignment crosses the Terminator Glades avalanche area. This area will be subject to intensive skier compaction and routine avalanche control. Under this scenario avalanches > Size 2 could occur 1 in 30-100 years. The individual tower locations in this section should be assessed to evaluate the options of active avalanche control and acceptance of risk versus strengthened design for some locations.

Between approximately 1850 and 1600 m elevation the alignment crosses the Terminator avalanche path. The Terminator avalanche starting zone is in the lee of the prevailing wind and it is not subject to skier compaction. Routine avalanche control is completed to protect skiers on the ski run in the avalanche path. Natural or controlled avalanches $\geq$ Size 3 are estimated to reach the 1850 and 1600 m elevation in the 1 in 10 year frequency range. Avalanche risk management for this section could include protection of towers by reinforced design or splitter structures. Reliance on risk reduction by active avalanche control is not advised for this section as either artificially triggered or natural avalanches could threaten the lift.

Below 1600 m the Lift L alignment is within the Red avalanche hazard zone identified for the base area, however acceptance of risk is reasonable option for the lift towers. In the event of an extreme avalanche hazard the lift would remain closed. The lower limit of the zone for tower protection in the Terminator path should be determined in the field during detailed design.

10.0 Conclusions

The White Zone identified in Figure 3 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). This includes all of the areas within the proposed development area identified on Figure 3

The Blue Zone identified in Figure 3 could be used for unoccupied structures if permitted by the jurisdiction. This includes the small strip of land located immediately downslope of the Red Zone, occupying a strip approximately 50-80 m wide. Construction of occupied structures such as residences is not permitted in this area.

The Red Zone identified in Figure 3 is a high risk area and construction of new buildings in this zone is not normally permitted.

Although modern methods were applied in this study, there is uncertainty in the runout estimates, impact pressures and return periods due to incomplete knowledge of the behaviour of large snow avalanches and uncertainty in available data.

Road access to any of the proposed development areas is not addressed in this report, nor are any other activities surrounding these development areas. KHMRLP will be responsible for ensuring policies are in place to protect people doing activities in adjacent areas outside of the occupied structures. This will become particularly important as the ski hill development expands to areas upslope of the residences, whereby the public may be exposed to avalanche hazards outside of occupied structures. These issues are beyond the scope of this report, but may need to be addressed in the future.

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Maps and Air Photographs

- Air photos BC7884 No. 081, 1976; photos from LP Golden files from 1953 and 2001.
- Kicking Horse Orthophoto, Pheidius Project Management Corp. and Alpentec Inc., 1:5000.
- National Topographic System Map NTS 82 NW, 1:500,000, 1978.
- Kicking Horse basemap, Ballast Nedam Canada Limited, 1:5000.
- Oberto Oberti Base Map and Master Plan. File 2320-Jul04-08.dwg.

Appendix 1 - Assumptions for Models

Assumptions for coefficients of the dynamics models:

ξ - turbulence co-efficient
 μ - sliding friction
 d - slab depth in starting zone
 M/D - mass to drag ratio
 ψ - slope angle
 W - average width
 P - control section point
 S - total path length

- | | |
|------------------|---|
| 1. Voellmy-Salm: | ξ – 700-1360 m, $\mu = 0.155-0.25$
d_0 – 1.95
ψ – 28-43°
W – 50-100 m (unconfined),
Hydraulic Radius = 3.2-8.8 (confined)
P – 1442-1470 m |
| 1. PCM | $M/D \sim 0.25$ $S \sim 500-700$
$M = 0.15 - 0.3$ (decreasing from starting zone to runout zone) |
| 2. PLK | $\mu = 0.25-0.38$
$\text{Log}(M/D) = 2.7-2.9$
$R = 0.2$ |

Assumptions for the statistical models:

β - Beta point (usually 10°) and beta angle (beta point to top of path)
 α - alpha angle (top of path to toe of runout)

1. $\Delta x/x\beta = 0.079 + 0.070(-\ln(-\ln(P)))$ (McClung and Mears, 1991)
2. $\alpha = 0.93\beta$ (McClung and Mears, 1991)

Estimates of the coefficients in the dynamic models and the ratios in the statistical 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.

